# Expecting space

*an enactive and active inference approach to transitions*

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# EXPECTING SPACE

## AN ENACTIVE AND ACTIVE INFERENCE APPROACH TO TRANSITIONS

**BY**
**ZAKARIA DJEBBARA**

DISSERTATION SUBMITTED 2020

AALBORG UNIVERSITY
DENMARK

# EXPECTING SPACE

## AN ENACTIVE AND ACTIVE INFERENCE APPROACH TO TRANSITIONS

*PhD Thesis*
*by*
*Zakaria Djebbara*

AALBORG UNIVERSITY
DENMARK

Aalborg University
Department of Arcitecture, Design, Media and Technology
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*A clash of doctrines is not a disaster, it is an opportunity.*
A. N. Whitehead

*L'avenir, ce n'est pas ce qui va nous arriver, mais ce que nous allons faire.*
Henri Bergson

*Do not abuse Time, for it is Allah (swt) Who is the Time.*
Islamic Hadith, Sahih Muslim (Book 27, Hadith 5584)

| | |
|---|---|
| *For* | *À* |
| *my mother,* | *ma mère,* |
| *my mother,* | *ma mère,* |
| *my mother,* | *ma mère,* |
| *and my father* | *et mon père* |

# English Summary

The following thesis is an interdisciplinary investigation of architectural transitions cast as a composite of space and experience in time. Dispersed between philosophy, architecture and cognitive neuroscience, the thesis also attempts to provide an empirically plausible neuroscientific framework that best explains the human experience of architectural transitions. Accordingly, the thesis is neither a pure study of space nor of the human, but instead, an investigation of the dynamics that emerge between the body and space during transitions. To this end, a falsifiable hypothesis is derived from the framework and tested to assess the quality of the framework.

Throughout thousands of years, architectural transitions have been shaped by human beings for various reasons—this makes this transhistorical both architecturally and biologically attractive. Transitions extend in time and space and depend heavily on the human body's capabilities to propel itself through space. For this reason, the emerging experience caused by transitions is analysed as a composite of space and time, which biologically translates to an investigation of action-perception. A phenomenological approach to the emergence of perception over time establishes conditions for an empirically plausible neuroscientific framework, which in turn provides a meaningful explanation of the dynamics between human experience and architectural transitions. Indeed, the following thesis is an attempt to synthesise phenomenological arguments with a prominent theory of brain activity. Active inference, as a computational approach to cognition and cortical activity, is attempted bridged with enactivism, which is a phenomenological and sensorimotor account of experience, to demonstrate how the environment emerges as an experience *in* the dynamics themselves. Essentially, transitions in the human experience, as a structure of change, are argued to be the genesis of experience itself—transitions become both the question and the answer, albeit, on different terms.

The phenomenological framework is heavily based on the temporal nature in human experience and its characterisation as inherently bodily, i.e. the world emerges through an active experience through enactive sensory systems. If the dynamics of enactive biological systems are affected by architectural design, it implies that architectural design can affect the human experience through short-term processes, on which the long-term processes, e.g. the psychological expectation of space, are based.

The free energy principle, i.e. active inference, is an application of Bayes' theorem to investigate biological systems through computational models. Portraying the human body as a dynamic system that must resist environmental disorder through homeostasis, fundamental processes as action-perception can be described as the consequential outcome of minimising uncertainty about the environment. On a cellular level, the process of emergence is the outcome of dynamic self-organising systems, which is the very foundation of action-perception.

By providing a thorough analysis of the computational process, it is revealed

that *knowing how* is inherently different from *knowing that*, which indeed makes the computational approach more appealing as it aligns with the philosophical and enactive account of human experience. Active inference is essentially demonstrated to fit an embodied, embedded, enactive and extended account of cognition, rather than a traditional sandwich-model account to cognition.

In sum, the thesis may be taken as (1) an account of how architectural research may go beyond traditional methods and address questions that are currently not in the vocabulary of architects, (2) a computational neurophenomenological account of experience that provides a meaningful explanation of the emergence of architectural experience and (3) an answer to how do architecture impact experience and body on a sensory-level, from how the world is perceived.

# Danish Summary

Sammenfattende kan denne afhandling betragtes som (1) en redegørelse for, hvordan arkitekturforskning kan gå ud over traditionelle metoder og adressere spørgsmål, der i øjeblikket ikke er i arkitekternes ordforråd, (2) en beregningsvenlig tilgang til hjernen og fænomenologien der giver en meningsfuld forklaring på arkitektonisk oplevelse og (3) et svar på, hvordan arkitektur påvirker oplevelse og krop på et sensorisk niveau, hvorfra verden opfattes.

Afhandlingen er således en tværfaglig undersøgelse hvor oplevelsen af arkitektur forståes som et fænomenologiske og neurobiologisk fænomen med arkitektoniske overgange som case, og dermed også af de rent neurofysiologiske/kropslige aspekter af oplevelsen af kontrollerede arkitektoniske/rumlige konfigurationer.

Denne afhandling skal derfor ses som en tværdisciplinær undersøgelse arkitektoniske overgange set som en bevægelse i tid og rum, der inddrager såvel filosofi og arkitektur som kognitiv videnskab for herigennem at tilvejebringe en empirisk testbar model baseret på neurobiologi, der kan forklare oplevelsen af arkitektoniske overgange som fænomen.

Således er afhandlingen hverken et absolut studie af rummet eller af mennesket, men i stedet en undersøgelse af den dynamik der opstår mellem kroppen og rummet under overgange. Til dette formål er en falsificerende hypotese afledt fra den teoretiske model og testet empirisk for at vurdere teoriens validitet.

Overgange udgør arkitekturhistorisk et transhistorisk element der gennem tusinder af år er blevet brugt som arkitektonisk element med forskellige såvel verdslige som religiøse formål, hvilket som udgangspunkt må tages som et tegn på, at i hvert fald dette arkitektoniske virkemiddel har et distinkt emotionelt påvirkning. At forstå arkitektoniske overganges oplevelsesmæssige og dermed mulige neurologiske og biologiske konsekvenser kan dermed blive en indgang til en dybere forståelse af oplevelsen af arkitektur som sådan. Overgange strækker sig i tid og rum og er afhængige af menneskets evner til at bevæge sig gennem rum. Af denne grund analyseres den oplevelse der forårsages af overgange, som en sammensætning af rum og tid, der biologisk oversættes til en undersøgelse af aktion og perception. En fænomenologisk tilgang til fremkomsten af opfattelse over tid etablerer betingelser for en empirisk plausibel neurovidenskabelig ramme, som igen giver en meningsfuld forklaring af dynamikken mellem menneskelig oplevelse og arkitektoniske overgange. Således er den følgende afhandling et forsøg på at syntetisere fænomenologiske argumenter med en fremtrædende teori om hjerneaktivitet. *Active inference*, som er en beregningsmæssig tilgang til kognition og hjerne aktivitet, der sammenholdes med *enactivism*, som er en fænomenologisk og sensorimotorisk teori om oplevelse, for at demonstrere, hvordan oplevelsen opstår som en oplevelse *i* selve dynamikken. Der argumenteres for at selve overgangen i den menneskelige oplevelse er selve oplevelsen. Overgangen bliver både spørgsmålet og svaret, omend på forskellige vilkår.

Den fænomenologiske ramme er stærkt baseret på den tidsmæssige natur i menneskelig oplevelse og dens karakterisering som kropslig, dvs. verden opstår

gennem en aktiv oplevelse gennem aktive sansesystemer. Hvis dynamikken i aktive biologiske systemer påvirkes af arkitektonisk design, indebærer det, at arkitektonisk design kan påvirke den menneskelige oplevelse gennem kortvarige processer, som de langsigtede processer, f.eks. den psykologiske forventning om rum, er baseret på.

Gennem anvendelse af *Free energy principle*, dvs. *active inference*, kan en matematisk model baseret på Bayes' formel formuleres til at undersøge biologiske systemer gennem computermodeller. På celleniveau fremkommer aktion-perception som et resultatet af dynamiske selvorganiserende systemer. Ved at fremstille menneskekroppen som et dynamisk system der skal modstå miljøforstyrrelser gennem opretholdelse af den homeostatiske balance, her forstået som *Free energy principle*, kan aktion-perception fremstilles som en konsekvens af at minimere usikkerhed/entropi omkring adfærd i rum/miljø.

Ved at demonstrere en grundig analyse af beregningsprocessen afsløres det, *at vide hvordan*, der i sagens natur adskiller sig fra, *at vide at*, gør at den beregningsmæssige tilgang stemmer overens med den filosofiske og aktive funktion af menneskelig oplevelse. Det demonstreres at *active inference* passer til en kropslig, situeret, aktiv og udvidet beretning om kognition snarere end en traditionel sandwich-model af kognition.

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The following thesis is the result of a wealth of love, motivation and sacrifices.

I want to start by thanking the Department of Architecture, Design, Media and Technology, Aalborg University for funding the project and for their trust in me as a researcher. I also want to thank all the secretaries fo their relentless work and for being patient with me. I am thankful for the opportunity to do research in such a lovely department and to have had the chance to meet each and every one.

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Laura Petrini has been my co-supervisor throughout my master thesis and now PhD. I am fortunate to have had your opinions and feedback when most needed. Your vast knowledge in neuropsychology and environment has been incredibly helpful. I highly appreciate your support and motivation already at the master-level to pursue this project. Indeed, the comments and feedback by Antje Gimmler of my presentations have certainly coloured many decisions; I am deeply thankful.

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As part of the PhD project, I spent 6 months abroad in FG Biopsychologie und Neuroergonomie, TU Berlin, where Professor Klaus Gramann took me in without hesitation and entrusted me with responsibility beyond my expectations. He took the time out his busy agenda to talk patiently with me, an architect, about cognitive neuroscience and even sophisticated analyses methods. The work-ethic in his lab was an eye-opening experience—it makes you want to study and do research. Besides supervising my experiment and analyses, Professor Klaus Gramann taught me to find the balance between work and social life, that life as a researcher is so much more. I am deeply grateful for all the conversations and experiences we have shared. I also want to thank the whole BeMoBIL-team for their patience and support throughout my stay. The whole BeMoBIL-team greeted me with care and trust beyond my imagination. I am deeply grateful for

all the help, all the social events and all the amazing moments we have shared. I also want to thank Juliet King for her exceptionally motivating talks; I am grateful.

Lukas Gehrke, Anna Wunderlich and especially Marius Klug sacrificed enormous amounts of time to talk and discuss scientific ideas with me and even spent hours after working hours to talk Virtual Reality and coding techniques. I could not have analysed nor processed the data without the immense amount of time and support from them. I have the most profound respect for your mathematical and programming skills—thank you for teaching me as much as possible.

Besides the process of analysis, I was lucky to have an amazing companion, namely Federica Nenna, who was a master student in the lab at that time. Federica and I supported one another with programming the virtual reality environments, conducting the EEG experiments (a total of ~50 participants in a month), analysing the data and sustain a healthy life in busy Berlin. The experience of going abroad would have been nothing without your constant support and motivating talks about philosophy and life in general. Our many conversations highly influence the structure of my thoughts—thank you for being patient with me and always sharing your thoughts.

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Elias Sabbah, my dearest friend, dedicated endless nights to philosophical and architectural discussions long before this thesis existed. The vastness of his knowledge and lifestyle has indeed marked my very persona. Elias Sabbah has inspired me to take the power of the body serious. Thank you for your unwavering support.

My mother, father, and my siblings, Amar, Dadi and Ilies, have all contributed to the thesis in each their own way. My mother and father for their moral support and having faith in me. Amar for his thought-provoking ideas and inspirational programming skills—the many talks we have shared over days and nights have been critical to my thinking. Dadi for always questioning my approach and reminding me, by way of my nephew Ibrahim, that life is more than research. Ilies for his constant curiosity in life and critical questions in science in general. You have my deepest gratitude.

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*Zakaria Djebbara,*
*January 2020*

## Motivation

My first encounter with architecture as a study was in 2011—until then, the environment was just my apparent environment. During the first years of the study, I realised that an architect draws ideas into the world convinced that the design is used and experienced in such and such manners. Architecture has to do with designing the world that others live in and experience. To become a good architect, one must, to some degree, possess the ability to imagine the experience of the designed space. Here, architecture becomes increasingly complicated, because since architecture has to do with drawing for someone else, the architect must take wild guesses about the users' experience. How can I know what others will experience? Are there generalities of experience that translate to spatial design?

Two years before graduating, everything I knew about architecture and experienced space changed. Lars Brorson Fich's lecture on the impact of architectural design on bodily stress-level immediately captured my interest. It was mainly the anti-dualistic philosophy that Fich presented that was captivating. He suggested that mind and body were in fact not distinct but an interrelated outcome of neurophysiological and other biological processes relative to homeostasis. With this in mind, some spatial configurations, it turns out, facilitates some experiences better than others. For instance, Fich's experiment showed that stressing people in enclosed spaces resulted in significantly higher levels of cortisol (stress as measured from saliva) as compared to open spaces. What I found interesting here, is that Fich never tries to explain their experience of the space, but tries to understand the underlying biological process by varying the architecture.

I spent the next half-year, researching how architecture impacts the body and experience for my master thesis, instead of working as an architect-intern. In my pursuit, it was clear that no architectural method was tailored for such an examination. Indeed, like Fich, it was time to turn to other disciplines that were better suited for such questions. At this crucial time, I stumbled across Pavlov and his dogs. The dogs learned that every time the bell rang, food was about to be served. By using environmental cues like the bell, biological processes, such as drooling, reflected the anticipation of his dogs, although there was no perceivable food to initiate the drooling. In my attempt to translate this to architecture, I could not help but imagine that perhaps, the experience of a space is not based on that single space alone, but the complete narrative consisting of expectations until that space is reached. Perhaps, the architectural experience was the outcome of Pavlovian conditioning using sequences of spaces before that space, instead of sequences of bells before eating. This initiated a range of new questions; does that not imply that we experience what is expected? How can architecture enter a learning-process? The bells and dog-food were presented as auditory-visual integration, what about other senses?

Continuing the research, I found that it was possible to synthesise Pavlovian conditioning with the placebo effect, which is the effect that we experience and act according to personal expectations, and synesthesia to allow learning between senses. At this point, an architectural placebo effect would unfold as a sequence of spaces, where the expectation would depend on the changes between spaces. In other words, architecture became to me a question of a learning-process through sensory anticipation. This thought was central to my research; it changed from a spatial and discrete understanding of experience to a more fluent and temporal appreciation. Instead of questioning the experience of space, I could address the changes between spaces, i.e. the dynamics, and argue the differences as central to the architectural experience. In other words, the architectural variability that Fich introduced could be conceived as a sequence of spaces. Reading modern neuroscientists, e.g. Chris Frith, Karl Friston and Ramachandran, and philosophers, e.g. Andy Clark, Shaun Gallagher and Evan Thompson, I was confirmed that perception is largely based on expectations. The question thus became, how can expectations enter the realm of architectural design?

By looking into architectural history, I discovered that transitions could be found throughout the history of architecture, e.g. ancient Egyptian and Babylonian architecture to Greek and Roman architecture, as well as modern examples like the architecture of Le Corbusier, Louis Kahn and Tadao Ando. For instance, Le Corbusier builds his *promenade architecturale* on the idea that the structure of thoughts was the outcome of bodily impact from the environment. His promenade dictates that architecture facilitates the process of continuously modulating the sequence of thoughts. That is why architectural transitions are so attractive. Thinking it through, transitions are perhaps the most fundamental architectural element ever to exist. As soon as you create a space, you inherently also create a transition from the inside to the outside—and thereby, create an expectation of what can be found inside or outside.

Transitions in architecture are inescapable precisely because they constitute the flow of experience. In other words, the structure of the environment compared to the *structure of experience*, which in turn is reflected in biological processes. In order for me to design expectations, I needed to analyse the biological processes relevant to transitions. To this end, homeostasis is central and can be described mathematically through the *free energy principle*—and by using a rework of the principle, i.e. *active inference*, it was possible to demonstrate how expectations are generated from acting and perceiving in space. Here, mathematics and philosophy merge and elucidate architecture.

I hope to be able to highlight the immense impact the designed environment has on body and brain—thus, cognition. By arguing that architecture has a direct influence on the body and brain, I argue that architecture no longer can be thought of as *nice to have* but urge to think of it as *need to have*. It turns out, the environment is not just my apparent environment—it is a fundamental part of *how* I am.

# List of publications

## Journal/Book chapter:

Djebbara, Z. (2018) 'Architectural, transition and cognition: an electrophysiological approach to action, perception and architectural transitions', in *Design Research Epistemologies III*. Aalborg, Denmark: Aalborg University Press, pp. 51–66. [Parts used in Chapter 2]

Djebbara, Z. *et al.* (2019) 'Sensorimotor brain dynamics reflect architectural affordances.', *Proceedings of the National Academy of Sciences of the United States of America*. National Academy of Sciences, 116(29), pp. 14769–14778. doi: 10.1073/pnas.1900648116. [Chapter 12]

Djebbara, Z., Fich, L. B. and Gramann, K. (2019) 'Understanding Perceptual Experience of Art Using Mobile Brain/Body Imaging', in Nijholt, A. (ed.) *Brain Art: Brain-Computer Interfaces for Artistic Expression*. 1st ed. Cham: Springer International Publishing, pp. 265–282. doi: 10.1007/978-3-030-14323-7_9. [Parts of Chapter 9 and Appendix B]

## Conferences:

Djebbara, AZ, Fich, LB, Petrini, L & Gramann, K 2018, Incentive architecture: Investigating spatial affordances in architecture using MoBI and VR. in *Conference Proceedings of the 3rd International Mobile Brain/Body Imaging Conference*. s. 106-107, Conference Proceedings of the 3rd International Mobile Brain/Body Imaging Conference, 12/07/2018. https://doi.org/10.14279/depositonce-7236

Djebbara, AZ, Fich, LB, Petrini, L & Gramann, K 2018, Incentive Architecture: Neural Correlates of Spatial Affordances During Transition in Architectural Settings, in *Academy of Neuroscience for Architecture: Shared Behavioral Outcomes*. Academy of Neuroscience for Architecture, s. 52-53, Academy of Neuroscience for Architecture 2018 Conference, La Jolla, USA, 20/09/2018.

# Table of Figures

All 68 figures are own illustrations.

# OUTLINE

## PART I

PART II

## PART III

# Reading guide

## General:

It is highly advised to read the appendices as they are referred to in the main text. Concepts, systems and terms become elucidated through the appendices.

Throughout the thesis, a high-school level knowledge in mathematics and statistics is presumed. Therefore, some concepts are unpacked accordingly either throughout the respective chapter or in the related appendix.

All quotes, important terms for the theory and book titles are written in cursive. Added emphasis is the regular font: *"This is quoted, while* this is emphasised.*"*

An *experiencing agent* is the notion used about the human experiencer. It is a compound of machine learning and philosophical terms, i.e. an open system that dynamically interacts with the environment.

Footnotes, equation numbers and figure numbers are all reset for each chapter.

## Mathematical notations:

*Approximating posterior probability* refers to *expectation propagation*, which is an iterative Bayesian method that approximates a target probability distribution.

Probability distributions are written as: $P(x)$. Reward probabilites are written as: $R(x)$. If conditioned by another probability $z$ it is written as: $P(x|z)$.

The expectation of a function $f(x, y)$ of a variable $x$ is written as: $E_x[ f(x,y) ]$. If conditioned by another variable $z$, the exptectation is written as: $E_x[f(x)|z]$.

*Shannon entropy*, which refers to the amount of information/content, of a probability distribution $P$ is written as: $H(P) = E_{P(x)}[ -\log P(x) ]$.

# Abbreviations

| | |
|---|---|
| **FEP** | Free Energy Principle |
| **KL-D** | Kullback-Leibler Divergence |
| **BU** | Bottom-Up |
| **TD** | Top-Down |
| **PEs** | Prediction-Errors |
| **DST** | Dynamic Systems Theory |
| **DH** | Dynamical Hypothesis |
| **ERP** | Event-Related Potential |
| **PINV** | Post-Imperative Negative Variation |
| **C-C** | Coupling-Constitution fallacy |
| **HAC** | Hierarchical Affordance Competition |
| **SMC** | Sensorimotor Contingency |

# Outline

## AN INTROUDCTION AND PHILOSOPHY OF SCIENCE

## CHAPTER 1

# Introduction:

an outline of the thesis

*"* [Thresholds] *provide a preface to perception of architectural space. They live in the sequence of what lies in the past, present and future. This means: threshold spaces also live in the expectation of what is to come."*
*(Boettger, 2014, p. 10)*

**Summary.** This brief introduction describes the transhistorical value in transitions, which makes them suitable for a thesis with the current theme. They are the most fundamental architectural element ever to exist, making them an ancient element. This is followed by an outline, aim, scope and initial questions of the thesis. The overarching structure of the thesis is introduced as a merging of philosophy and empirical science, which enables the research question to address a more profound understanding. Thus, the research question unfolds as the arguments accumulate throughout the thesis. The content of each chapter is also brought forward to portray the line of argumentation.

### 1.1 Transhistorical element

Transitions are omnipresent in various forms. They exist both *in* human beings and *outside* in space. Those within human beings coexist with those outside. Transitions outside serve to delineate space for varying purposes. By delineating spaces, they ambiguously provide entrance and exit; they act separating while connecting. Not only does transition exist as different kinds of transitions, but it also serves contradictory functions—indeed, transitions are mysterious and phenomenal.

Transitions in architecture are ancient, and so is the idea to approach them from a scientific and mathematical aspect. The ancient architecture was about transitions—although, they were not explicitly referred to as transitions but rather as studies of mathematical proportions and relations. Undoubtedly, transitions are the very first architectural element ever to exist—a mere wall would effectively create a transition and so would a roof, a staircase, a window or a cave. Transitions are consequences of spatial delineations—which are necessary for survival, e.g. a threshold between inside and outside.

Transitions create narrations. The passing through a threshold, i.e. a spatial delineation, creates a sequence of spaces, which occur in a specific temporal order; a narrative emerges. By organising space in sequences, transitions transcend their spatial anchor by emancipating into a temporal continuity. Transitions are indeed a complicated element that is fundamental to architecture, which is what makes transitions a transhistorical element. Cultures from around the world all encountered the architectural problem of designing a transition. There are different solutions; what made them different?

The historical element of transitions is a critical argument for a biological investigation; insofar, we assume that biological systems adjust to any change, or expected change, in the environment. Their role on an evolutionary level may have been essential in the development of the contemporary human being, which in turn may be enlightening for health and experiential reasons. The fact that space has an impact on the human experience is apparent when moving into a new space or making changes in the existing space. A new space, which brings with it new routines, new gestures and new habits, may be experienced as a reason for a complete change in self-conception.

One might wonder whether architects always have been aware of the effect caused by transitions. Similar to Zeki's opinion on artists throughout history, it is believed that architects may have been "[…] *neurologists, studying the brain with techniques that are unique to them and reaching interesting but unspecified conclusions about the organization of the brain. Or, rather, that they are exploiting the characteristics of the parallel processing-perceptual systems of the brain to create their works, sometimes even restricting themselves largely or wholly to one system, as in kinetic art*" (Zeki, 1998, p. 77).

Transitions and spatial configurations are intertwined. The object belongs to space and quantity, while the subject is temporal and qualitative, yet, they are evidently coupled. Questioning the very threshold between object and subject one discovers the primacy of the body. By using architecture as the study of space, philosophy as the study of time and biology to elucidate their relations, it may be possible to fill in the gap. This thesis investigates, through a study of transitions in architecture, a truly embodied aspect of an experience.

## 1.2 The outset

The following approach reaches beyond body-inspired proportions as a scientific approach to architectural transitions by synthesising arguments from fields as probability theory, dynamic systems theory, self-organisation, phenomenology, ecological psychology and cognitive neuroscience. As described above, the inspiration of natural proportions in the Western world came to determine the transitions between spaces, i.e. the dimensional relation within and between spaces. For instance, using geometric proportions, the initial space relates to the next by scaling up the initial space ratio by the geometric mean. Ultimately, the use of proportions paved the way for quantification of experience, however, proportions also reduce the complex nature of architectural transitions, e.g. promenade architecturale, to the respective proportional rule and constrain it to be mathematical and conceptual contemplations, with no direct anchor in human perception nor experience. The proportions are rooted in the Platonic idea of cosmological order causing proper behaviour instead of the relation between human being and space. Proportions in that sense provide more about those natural relations than about the complex spatiotemporal nature of transitions.

The primary philosophical arguments of the following thesis rest on educated mathematicians that either got into philosophy or remained in the field of mathematics; for instance, Henri Bergson, Edmund Husserl, Henri Poincaré, Bernhard Riemann and Karl Popper, among others. The following thesis proposes a synthesis across doctrines to answer questions that go beyond architectural research. Nevertheless, the approach is not much different from earlier architectural theorists; it is not the first time an architect has asked questions that other disciplines are better suited to answer. As the opening quote from Whitehead suggests, the crossing of doctrines is here taken as an advantage and an opportunity to synthesise fields relevant to experience and architecture.

The span of disciplines is rather extensive. Bringing in interdisciplinary arguments may appear challenging to grasp at first hand—therefore, the developed appendices are critical—but it is unthinkable to discuss transitions in the absence of philosophical consideration of space and time because they are core components. Transitions are in their nature experienced as extended in time and only possible by the unfolding of action that, in turn, depends on space. It turns out, precisely these parameters, i.e. time/action/space, are essential for understanding the underlying process within the human brain and body and its relation to a spatial environment. Transitions are certainly a matter of bodily and experiential adaption, not only so that the body is not surprised by a change in the environment, but also so that there is a continuity in perception, i.e. how the body adapts to and anticipates its environment is a continuous biological process, making it an important aspect to include. Indeed, it was the final research question, the aim and the scope that determined the necessary disciplines to involve.

## 1.3 Main aim and scope

There are two overarching aims. One is to develop a framework of computational neurophenomenology of architectural experience and thereby elucidate experience by meaningful explanation. From this framework, it is the aim to be able to derive numerous hypotheses for experimentation so that the theoretical framework undergoes adjustments that strengthen it. The second aim is to address the immediate event and the underlying mechanisms of expecting space. It is aimed to identify the fundamental mechanisms involved in creating an expectation of space.

Regarding the theoretical development, it is primarily intended to answer an architectural question concerning transitions. Because the complexity of the question involves other fields, it is intended to provide a synthesis regarding human experience as discovered during an architectural experience of transition. To avoid confusion between doctrines, a philosophical analysis of the human experience is provided by establishing an ontology and related definitions. Hereafter, an analysis of an empirical account in line with the established ontology and definitions is provided. This is a necessary strategy given the thesis aims to answer an architectural question through interdisciplinary methods. Ultimately, the phenomenological account of experience provides a link between a philosophically sound position of experience to mathematical models.

Architecturally, the aim is not to provide architects with cookbook-like principles concerning how to design; there is no fitness. It is not about optimising parameters, nor to provide general design principles. Instead, this investigation sets out to properly understand the influences of the environment on the animate human being. It is not within the scope of this thesis to unravel the biological underpinnings of a full-blown architectural experience, nor is it to develop mathematical models that simulate such experiences. However, it is within the scope to elucidate phenomenological conditions of experience through mathematical models and to describe the relation between architectural settings and the human experience.

## 1.4 A rolling research question

The research question of departure is vaguely stated because determining the question will immediately determine the answer. *"The truth is that in philosophy and even elsewhere it is a question of finding the problem and consequently of* positing *it, even more than of solving it"* (Bergson as cited in Deleuze, 1988, p. 15; original emphasis). In stating the problem, a range of terms and conditions are set up, in which the answers must adhere. "[…] *the problem always has the solution it deserves, in terms of the way in which it is stated (i.e., the condition under which it is determined as problem), and of the means and terms at our disposal for stating it"* (Deleuze, 1988, p. 16). Setting up the problem will thus determine the point of departure for the answer, meaning the question must adhere to a set of limits and reductions to truly pose the question of interest. Constructing the question becomes the initial steps of constructing a sufficient answer.

Therefore, instead of immediately constructing a detailed question, it is allowed to be a vague rolling research question that is actively articulated throughout the thesis; it becomes a continuously evolving parameter of the thesis, changing and articulating it throughout various chapters. When the research question reaches a level of sophistication and depth sufficient to pose it as a falsifiable hypothesis, it is then subjected to experimentation.

Architectural experience of transitions are complex spatiotemporal phenomena by nature, which makes it challenging to investigate holistically and entirely—however, it is the impact that sequences of space on the human experience and body relative to the environment that is of interest. It is a question of interaction. Indeed, the development of the theory becomes an analysis and argumentation for the necessary reduction in the final research question. It is inevitable to arrive at a reduced answer based on the set of limits that match the research question—therefore, the final research question is the outcome of several comprehensive and strategic analyses and argumentations.

### 1.4.1 Initial questions

The initial questions serve to portray a vague impression of where the question is directed. As the aim is to develop a computational neurophenomenological framework, addressing experience in architectural transitions is appropriate:

- What is a threshold between spaces, and what is the role of passing it in the narrative?
- How does a transition shape human experience?
- What are the capabilities of a spatial threshold on the human experience?
- How does a transition of experience unfold?
- What is the relation between the narrative and the human experience?
- How does the expectation of space interfere with the experience of space?
- What does it mean to expect a space?
- How does spatial expectation emerge, and what is its role in experience?

Indeed, these questions are vague, hardly pointing in a single direction—this is the advantage of not commencing by posing a clear research question. Instead, the question becomes more articulate before posing a final research question throughout the thesis; it suggests an iterative and recursive nature, where the accumulated theory informs the question.

Eventually, the research question becomes more specific and is finally addressed through an empirical experiment. The current research question is the following:

**Can architecture impact the human experience of a transition—if so, is it possible to provide a meaningful explanation by identifying the underlying mechanisms empirically?**

Although this question is immensely broad and begs a plethora of related questions, it addresses the relation between environment and experience and questions the relevant mechanisms.

## 1.5 General structure of the thesis

Ahead lays a highly interdisciplinary thesis. Indeed, the nature of experience enters numerous doctrines that outrun each of a meaningful explanation alone. Instead of restricting architectural research to methods of architects, it is expanded and pursued in its true complex nature. To this end, the general approach can be summarised as a blending between metaphysics and science, deeply inspired by Bergson:

> *"Scientific hypothesis and metaphysical thesis are constantly combined in Bergson in the reconstitution of complete experience."* (Deleuze, 1988, p. 118)

By dividing the thesis into a philosophical and scientific part, the central arguments and positions are traced in the philosophy of experience and applied as conditions for an empirical account thereof. Needless to state that the philosophical conditions shape the kind of reduction in the experience, which in turn later reflect an appropriately reduced answer. Using conditions from philosophy allow commencing from a non-reduced position, namely experience itself. Indeed, this approach of using conditions from one discipline and applying them to another rests on a coherent epistemological stance. Consider here a brief outline of the epistemological stance and a brief outline of the chapters[1].

**Chapter 2**, therefore, inquires: *What is the epistemological position of the thesis?* It is the first step to argue the process of scientific findings and to refine the interdisciplinary approach. By discussing logical reasonings and discussing the fitness of Peircean reasoning, Popperian falsification, Hackian foundherentism, the approach can ultimately be compiled as an abductive-Bayesian programme for the doctoral thesis.

### 1.5.1 Part I

**Chapter 3** discusses: *What defines a transition?* By dissecting transition into a spatial and temporal concept, two new terms are introduced, namely, an *architectural transition,* which is inherently spatial, and an *experiential transition,* which is the temporal transition from moment to moment. A definition of the reconciliation of the two kinds of transitions forms the unified and central topic, namely the *architectural experience of transition.* To illustrate how the architectural experience of transition can be inquired, a quandary, which involves an experiencing agent moving from one space to another, is provided to guide the development of the thesis.

It is clear that action cannot be eliminated from such transition, therefore, **Chapter 4** addresses the question: *What is the role of action in space and time?* Bergson is invoked at this stage to provide a vocabulary to discuss and review the differences between space and time, i.e. a difference in *degree* and *kind*, respectively. Inspired by Riemann's *multiplicity,* Bergson uses the concept to explain the possibility and distinction of virtuality and reality. At this stage, experience is reduced to involve the immediate experience exclusively—thus, not addressing the reflected experience. Bergson's framework of time and space is prolonged and concretised by Husserl in an explicitly phenomenological manner.

*How do Bergson and Husserl comply in their philosophy, and how is Husserl relevant to*

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[1] The following brief outline of the chapter content merely demonstrate the coherency between chapters.

*the research question?* **Chapter 5** provides explicit parallels between the two and illustrates how Husserl's development of action and perception build on similar concepts as Bergson. Their understanding of time is complementary, although expressed differently. Bergson uses *duration,* while Husserl refers to a *temporality.* Their account of action is directly linked to their account of temporal development, which leads to the next chapter.

**Chapter 6** seeks to establish: *How can one describe the relation between experience and time?* By elaborating on the temporal structure of experience, conditions of experience emerge. Critical to both Husserl and Bergson is their account of perception being the possibility of movement, which according to Husserl involves a *horizonal intentionality*, whereas Bergson suggests *virtual actions.* The concepts essentially describe the same underlying ideas, which amount to the list of conditions that *Part II* must account for to argue an investigation of experience.

### 1.5.2 Part II

Commencing in biological science, **Chapter 7** attempt to answer: *What is the point of departure of experience in biological science?* This chapter provides a discussion on a cellular level of the relation between homeostatic balance and dynamic systems theory that guides the adjustments that a living organism must undergo to survive the environmental changes. The organisation of the body becomes a critical question. The genesis and organisation in the body are argued to be rooted in self-organising principles, which essentially situate the primary feature of action-perception as paramount for any experience of the world. This chapter further provides a crucial discussion on the bidirectionality in the nervous systems and organisation thereof, situating the brain and body as essential for experiencing the world.

To this end, it becomes urgent to ask: *How do the brain and body relate to the environment?* **Chapter 8** provides first a link on a neuronal level by reviewing whether environmental stimuli are reflected in cortical activity, and second a link on a philosophical and psychological level, where the limitations of cognition are discussed. Central arguments from *the extended mind hypothesis* are explicitly discussed and defended. This provides the theoretical framework with empirical and philosophical reason to pursue cognition as coupled to the environment.

**Chapter 9** questions: *What are the roles of action and perception in experience and cognition, and are these internally represented?* As the previous chapter commenced an empirical approximation, this chapter remains on a philosophical level and targets experience of architecture from a cognitive perspective. A sensorimotor contingency (SMC) is introduced as a non-representational account of experience in action-perception, which suggests that internal representations of the environment are unnecessary as the experience emerges from causal coupling *in* the transition of time instead. This further indicates what to look for empirically.

Before questioning what do look for, **Chapter 10** questions: *How does the actual process of action-perception unfold?* This chapter is profoundly computational as it links with SMC by approaching cognition through predictive Bayesian statistics. The central theoretical framework is Free Energy Principle, which becomes *active* *inference* when reworking the equations. It attributes a predictive power in virtuality and affordance in the transitional feature of time, which in turn cause action. Actions, therefore, become a matter of long- and short-term predictions. Central terms in this chapter include Hidden Markov Models, generative model, Jensen's inequality, Kullback-Leibler Divergence and action policies.

Diving into the physiology of body and brain, **Chapter 11** addresses: *What implications—on a physiological and neuronal level—does the unfolding of action-perception have on human experience?* A temporal scale is here provided to map the cascade of prediction in sensorimotor integration so that the physiological reactions and cognitive functions are expressed through a coupled interactive relation between brain, body and environment. Since the architectural transitions are experienced from a perspective and the experience depends on the unfolding of immediate predictions and action, which at this point are hypothesised to be reflected in neuronal activity, a falsifiable hypothesis can be established.

**Chapter 12** tests the following hypothesis: *If an enactive account of perception, action, and cognition is correct, then it is expected to find differences in cortical responses to* resonate *as a function of affordances over sensory and motor areas—can this be tested?* By measuring the cortical activity of participants transitioning from one space to another using a mobile brain/body imaging technique, the hypothesis is attempted to be falsified. Surprisingly, the empirical data complements the theoretical framework as the neuronal activity reflects the architectural affordances.

**Chapter 13** summarises, concludes and suggests the future directions that this computational neurophenomenological framework can take. For future research, the invented term *architectural cognition* is suggested to encompass the impact that architectural design has on cognitive processes.

### 1.5.3 Part III

The third part of the thesis is dedicated to crucial appendices, ranging from **(A)** the theory behind imaginary numbers that link to *multiplicity*, **(B)** a brief introduction to neurons, the nervous systems and the workings of an electroencephalogram, **(C)** the functional integration and segregation in the brain, **(D)** Bayes' rule, Hidden Markov Models and the darkroom problem, **(E)** a walkthrough of active inference, **(F)** supplementary information to the experiment, and finally the references.

## 1.6 Final note

It is believed that quantifying architectural impact through proportions is misleading. Instead, the philosophical and mathematical approach is reconsidered and reconnected to provide a novel approach. It is exceedingly important to note that the following approach seeks to unify philosophy and cognitive neuroscience, which are fields each with their methods. To this end, the next chapter is dedicated to establishing a philosophy of science.

# CHAPTER 2

## Philosophy of science:
## epistemology between architecture and brain sciences

*"The rules of deduction may seem to impose a dynamic of belief, such that we should believe whatever follows deductively from what we already believe, but this is an illusion, since we may always turn the argument around by rejecting a consequence and restoring consistency by also revising some of our previous beliefs."*
*(Lipton, 2004, p. 106)*

**Summary.** *What is the epistemological position of the thesis?* An epistemological stance is taken to argue the process of scientific findings. This chapter reviews the limitations of deduction and induction in the context of scientific discovery. Their insufficiencies in generating new knowledge due to their point of departure are solved by a Peircean abductive logic that is supported by a Popperian approach to theory and hypothesis. Furthermore, this chapter provides integration of foundationalism and coherentism, i.e. foundherentism, to form the strategic programme of the doctoral thesis as a whole. These positions synthesised can eventually be summed as an abductive-Bayesian approach to the epistemological position of science, which is significantly beneficial for an interdisciplinary case of architecture, philosophy and cognitive neuroscience.

### 2.1 Introduction

The vigour of science is the ability to increase, or decrease, the certainty of a theory. Indeed, a critical attitude towards the theory is necessary to understand the weakness, strength and limitation of that theory. Logical reasoning usually takes two forms, either deductive or inductive—however, parallel to the establishment of pragmatism, abductive reasoning, which was concerned with the explanatory power and heuristic nature of the discovery of a hypothesis, reinvented the logic of scientific discovery (Bacon, 2012, chap. 1). A combination of abductive reasoning and critical rationalism from Popper (2007, chap. 4) and even further a foundherentist system (Haack, 1993) integrated with a Bayesian probability approach to explanatory considerations (Okasha, 2000; Lipton, 2004, chap. 7) form the epistemology of the current doctoral thesis. Why is epistemology a vital topic to discuss? The purpose of scientific research in academia, led by research questions and methodologies, is ordinarily to produce new knowledge. At least two questions must be addressed to succeed in this herculean task; what is knowledge, and how is new knowledge produced. These questions are critical and essential in epistemology, and given the ambition of producing new knowledge, they are worth discussing.

There is no single *right* epistemological approach—instead, different approaches are serving different purposes, which emphasises the importance of being familiar with the purpose of the research, i.e. knowing the research questions, and the consequential limitations. Moreover, because architecture as a discipline is typically concern planning, drawing, projecting and building, it operates differently from, e.g. philosophy and cognitive neuroscience. To this end, it is found necessary to establish an epistemological approach that embraces interdisciplinary research questions that stretch from humanistic concerns of human experience to natural scientific concerns of human experience.

This chapter argues that an abductive form of reasoning entails both deductive and inductive forms and that only abductive inference may contribute with knowledge that was not already known. In principle, abductive reasoning seeks to *explain the case* rather than *infer a result or premise*, which means that it takes seriously the explanatory aspect of reasoning instead of the premise or result. Abductive reasoning is further extended by the integration of Popper's critical rationalism in testing hypotheses that are falsifiable in order to advance the theory. Essentially, knowledge, given by a rule or a hypothesis, never reaches absolute truth, but rather an approximation of the truth. For this reason, the Bayesian dynamics in reasoning, integrated with an explanatory consideration that is retrieved from abductive inference, yields an epistemology suitable for interdisciplinary research question stretching from philosophy and architecture to cognitive neuroscience.

It is important to note that *environment*, as referred to in psychological, cognitive and neuroscientific circles, concerns any external stimuli beyond the brain and body, i.e. any stimulation of the exteroceptive senses. Quite similarly, architecture is rather inclusive than exclusive (see Quintal, 2016 for 121 definitions of architecture) regarding a definition. To create a delineation, the environment that is referred to onward is a *composed spatial structure*, which consequently excludes other people, temperature, humidity, light conditions, haptic dimension and any other non-visual property. Such reduction of architecture is necessary to conduct systematic experimentation, where the variables are as controlled as possible.

## 2.2 Logical inference

To *infer* is to conclude on a case reached through the logical composition of reasoning or evidence and plays an essential role in scientific research and epistemology. Logical reasoning is the elimination of any doubt so that the conclusion necessarily follows. When the purpose is to create new knowledge, the approach must sustain such an objective, and for this reason, the logical inference is necessary to discuss. Aristotle was the first to investigate systematically the principles of reasoning from which his deductive, syllogistic, reasoning emerged (Aristotle, 1989, pp. 1–6). Logical syllogisms consist of mainly three components, namely a premise, a case and a result. At least two properties are essential to the type of logic. First, the logical validity of the inference, i.e. whether at all the inference is logically sound, and second, the reasoning of the result.

### 2.2.1 Deductive logic

The premise, also known as a *major premise* (Aristotle, 1989, chap. 1), is a conditional statement that must be true (Aristotle, 1989, p. 1). It may be a negation, as long as the premise is true in itself. A classical instance:

1. All men are mortal. (Premise)
2. Aristotle is a man. (Case)
3. Thus, Aristotle is mortal. (Result)

*The case* is the observed state relative to the premise and is also known as a *minor premise*. Both the premise and the case must necessarily be true to deduce the result. Otherwise, the deduction is incomplete: *"I call it incomplete if it still needs either one or several additional things which are necessary because of the terms assumed, but yet were not taken by means of premises"* (Aristotle, 1989, p. 2). Finally, the result is the deduction itself. A deduction is a discourse where premises necessarily gives rise to the result without any knowledge outside the premises—hence, a deduction can be distilled to a logical inference where if both the premise and case are correct, the result necessarily follows.

In light of the generation of new knowledge, it is clear that every valid deductive proposition, i.e. premise and case, the result necessarily follow. Consequently, if the results already exist in the arguments, one may question the degree of novelty of the inference. Concisely: *"If in an inference the conclusion is not* contained *in the premise, it cannot be valid; and if the conclusion is not different from the premises, it is useless; but the conclusion cannot be contained in the premises and also possess* novelty*; hence inferences cannot be both valid and useful"* (Cohen and Nagel, 1968, p. 173; emphasis added). This problem of inferring new knowledge from existing knowledge is referred to as *the problem of deduction*. The question at hand is whether deductive inference qualifies as a method of reasoning to produce new knowledge. Following Cohen and Nagel (1968), a brief review of *novelty* and *contained* elucidates the alleged problem of deduction.

Regarding the novelty of deduction, the conclusion/result of an argument is not readily apparent upon inspecting the premise—especially when the chain of inference is of considerable size. Being able to immediately infer the rearrangements of a particular mathematical formula—without the stepwise calculations—then one does not need a widened demonstration of that particular theorem. Indeed, there is no logical novelty in the conclusion of a deductive argument, but the psychological novelty may seem unexpected and lead to new ideas (Cohen and Nagel, 1968, p. 174). At any rate, the logical novelty in the conclusion bears with it no new knowledge if the argument must be valid. In other words, the premise that the argument is based on *contains* already the conclusion, which naturally makes one wonder, how was the premise at all established to be true. When the conclusion is said to be contained in the premise, it is not readily there to be unpacked, but rather to be discovered and said to be inferred.

> *"Propositions imply one another, and our inferences are valid in virtue of such objective relations of implication. We may make inferences; we do not make, but only discover, implications.* Which *of the propositions implied by a set of assumptions we do infer, is of course not logically determined. That depends upon our extralogical interests and our intellectual skill." (Cohen and Nagel, 1968, p. 175; original emphasis)*

Mainly, concerning the creation of new knowledge, it can be stated about the deduction that the new knowledge that seems to emerge from the conclusion/result is already discoverable in the premise, making the premise of higher interest. Although deductive reasoning may bring forward new psychological insight (see also Popper, 2007, pp. 7–9), it continues to suffer from an initiation problem, i.e. an infinite regress in questioning the validity of the major premise, e.g. can one deductively infer that all men are mortal? Furthermore, even after initiating the deductive argument, going from premise to the case to the result depends on extralogical interests and intellectual skills, which is hardly defined. According to Popper, a deduction-activist, *"there is no such thing as a logical method of having new ideas, or a logical reconstruction of the process.* [...] *every discovery contains 'an irrational element', or 'a creative intuition', in Bergson's sense"* (Popper, 2007, p. 8).

Concluding a deductive argument thus rests on the creative and intellectual skills of an individual, that which Bergson named *creative intuition.* Indeed, the logical inference in deduction is a logically valid top-down argumentation, but the kind of inferred insight depends on the creative and intellectual skills.

### 2.2.2 Inductive logic

Turning to inductive inference, it reverses the direction of the logical inference so that it concludes on a premise starting from an observation. This approach may be said to take a bottom-up approach. Induction rests on observations and universal truths based on experience, i.e. knowledge by experience. The classical instance:

1. This swan is white. (Result)
2. This swan is from the world. (Case)
3. Thus, all swans in the world are white. (Premise)

Inductive reasoning advances a databased premise, and by doing so creates absolute truths, i.e. uniformity about nature. From a particular observation of a white swan and the case that it is from the world, inductive reasoning allows inferring that all the swans in the world are white. In other words, induction is the inference of the premise by way of the case and the result. The inductive inference can never be logically justified because one has not seen all swans and thus do not eliminate doubt.

*The problem of induction* that has been addressed by philosophers such as Karl Popper (2007, pp. 313–316) and David Hume (2007) has roots in Hume's critique regarding that the past experience is able to predict the future experience. The problem concerns the generalisation of a single observation to a class of objects assuming uniformity in nature. Hume states that "[…] *there can be no demonstrative arguments to prove, that those instances, of which we have had no experience, resemble those, of which we have had experience*" (1958, p. 89). To Hume, an accumulation of observation $A$ cannot change the probability for $A$ to happen in the future. Indeed, the problem of induction is essentially one of time and space, because Hume criticises precisely the uniformity and continuity of time in space[1] through a critique of experiencing cause and effect. Hume denied the ability to experience causal relationships, e.g. observing "*one billiard ball striking another,* […] *we cannot see one cause the other to move, but only one movement followed by another*" (Bacon, 2012, p. 36). For the same reason, Hume can logically be sceptical towards the proposition, *the sun will rise tomorrow,* because it is equally intelligible as its refutation, *the sun will not rise tomorrow* (Hume, 2007, p. 25).

The assumption that the sun will rise tomorrow is based on the principle of uniformity of nature—hence, if no result is reliable, then the reliability is presumed. It may not be apparent, but this forms a circular argument. If, for instance, one states that inductive inference is valid to utilise in the future due to its effectiveness in the past, the argument enters a circular argumentation, i.e. validating the past observations of induction is to validate the future observation of induction, ipso facto. To give a less radical example, consider a bag of beans (Peirce, 1933, para. 2.622). Despite how many black beans one may stepwise take out of the bag; it will never be a logically valid conclusion to state that all the beans in the bag are black. The spectacular property of inductive reasoning is precisely that although it is logically invalid, it is probably right, despite entering a circular argumentation.

Can inductive reasoning create new knowledge, is the argumentation logically sound, and how does the conclusion emerge? The novelty was stated to be logical independence of the prior, which is the *premise* in deduction and the *result* in induction. Because inductive reasoning is based on observations, which in turn may be provided *a priori*, it may for the same reason as deductive reasoning fail to bring new knowledge, i.e. the conclusion is already in the *result.* The novelty that is brought forward is merely psychological, i.e. defining the observation differently,

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[1] A critique of the blending of space and time is provided in Chapter 4 and 5.

which once again seem to dwell on creative and intellectual skills. Inductive reasoning is a bottom-up argumentation that, despite being an invalid logical inference, reaches an apparent truth through its circular argumentation, i.e. uniformity of nature. Although the conclusion is based on mere observation, the novelty once again depends on creative and intellectual skills.

### 2.2.3 Deduction and induction

The primary concern in deduction is the validity of the result based on the premise and the case, i.e. it dictates whether the result necessarily follows or not, whereas the primary concern of inductive reasoning is to establish premises of what is apparently, but not necessarily, true. Deduction thus serves to infer the result logically when given the premise and case, whereas induction serves to infer the premise given the case and result. The consequence is that no new knowledge can emerge from either inference.

In both deduction and induction, the production of new knowledge is bound to the creative and intellectual skills of the operator/researcher. To this end, it is vital to acknowledge the fact that deduction is only logically valid because there is no epistemic uncertainty when all parts necessary to conclude are apparent, whereas this is not true for induction. Instead, induction is concerned with making statements that appear true, rather than necessarily true. Nevertheless, both inferences rest precisely on their potential production of *knowing that*, which is a type of knowledge that is arguable different from *knowing how, knowing why, knowing who* (Wang, 2015). It is a static propositional approach to the topic of *knowing,* which obscures the importance of the process of how *knowing that* came about in the first place. It is an important note because the process of realising *how* is indeed related to the creative and intellectual skills that both logical inferences seem to rest upon.

To sum up, the issues with deduction are:

- The initiation problem.
- Infinite regress in the major premise.
- Not capable of producing new knowledge.

While the issues with induction are:

- The initiation problem.
- Circular validity.
- Not capable of producing new knowledge.

Peirce's abductive logic is precisely a logical inference that embraces the progression of science, i.e. production of new knowledge, by taking the process of creative and intellectual skills seriously (Fann, 1970). Perhaps the structure of the logical inference may depend on the creative and intellectual skills of a researcher by introducing a feedback-feedforward circulation, where the strength of the argument is in its circularity, i.e. the coherence of the argument is a strength. Foundationalism and coherentism are returned to.

### 2.2.4 Abductive logic

Inspired by hermeneutics and pragmatism, the abductive logical inference seems to be a qualified candidate for producing new knowledge. Instead of propositionally *knowing that* it becomes a question of practically *knowing how,* i.e. the process of approaching a practical truth is according to Peirce the only logical operation that *may* yield any new knowledge. Abductive reasoning, then, "[…] *is the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea; for induction does nothing but determine a value, and deduction merely evolves the necessary consequences of a pure hypothesis"* (Peirce, 1933, para. 5.171).

The structure of abductive logic does not differ much from deduction and induction—in fact, it may be conceived as a combination of both. Deduction and induction infer either the premise or the result—at any rate, the case is given in both logical inferences. Abductive inference suggests that one may form a hypothesis by taking a qualified guess, which essentially means that the inference is based on the creative and intellectual skill exclusively (Peirce, 1933, para. 2.623):

1. All the beans from this bag are white. (Premise)
2. These beans are white. (Result)
3. Thus, these beans are from this bag. (Case/Hypothesis)

The genius manoeuvre behind abductive reasoning is that it merely forms suggestions, i.e. hypothesis that something may be true, which through a combination of deduction and induction can be tested. Because abductive reasoning only offers suggestions, it does not matter how it came about. This kind of liberty in reasoning ultimately ends the initiation problem discovered in deduction and induction, because abductive reasoning is not a static form of reasoning, but a "rolling" kind. It is a form of inference to the best explanation (Lipton, 2004). The hypothesis that is generated is considered currently correct insofar that it accounts for the premise and result. Peirce puts the logical inference as following:

> *"The surprising fact, C, is observed* [unexpected result]*; But if A* [new hypothesis based on unexpected result] *were true, C would be a matter of course; Hence, there is reason to suspect that A is true." (Peirce, 1933, para. 5.189)*

This explanation demonstrates how the observed result would have come about if the new, creative hypothesis were true (Fann, 1970, p. 43)—it is reasoning through the process. This is a clear example of the abductive reasoning taking advantage of being able to go both top-down and bottom-up. The deduction would have dismissed the logic without suggesting a further direction, and inductive reasoning may not at all form an argument, however, abductive reasoning has the liberty to move between and improve the validity of the premise; the new hypothesis becomes the new premise in a new test. The hypothesis yesterday could be the premise today.

How does the abductive reasoning precisely solve the initiation problem? If a researcher came across a phenomenon, how does the researcher know that his particular phenomena have nothing to do with the position of the planets, or perhaps the colour of the researcher's shirt? *"Think of what trillions of trillions of hypotheses might be made of which one only is true; and yet after two or three or at the very most a dozen guesses, the physicist hits pretty nearly on the correct hypothesis"* (Peirce, 1933, para. 5.172). No matter how well one may investigate the logical problem of the production of a hypothesis, it will never succeed. The reasoning in the process of creating a hypothesis transcends the logical reasoning, and thus, as Popper mentioned, may rest on creative and intellectual skills. In brief, the abductive reasoning solves the initiation problem by assuming that a created hypothesis is true, but must undergo a test to withhold the title of being the closest hypothesis to the truth. In agreement with Popper, Peirce makes the point regarding the instinctive generation of a hypothesis clear: *"If you ask an investigator why he does not try this or that wild theory, he will say, 'It does not seem* reasonable.*' It is curious that we seldom use this word where the strict logic of our procedure is clearly seen. We do [not] say that a mathematical error is not reasonable. We call that opinion reasonable whose only support is instinct"* (Peirce, 1933, para. 5.174; original emphasis).

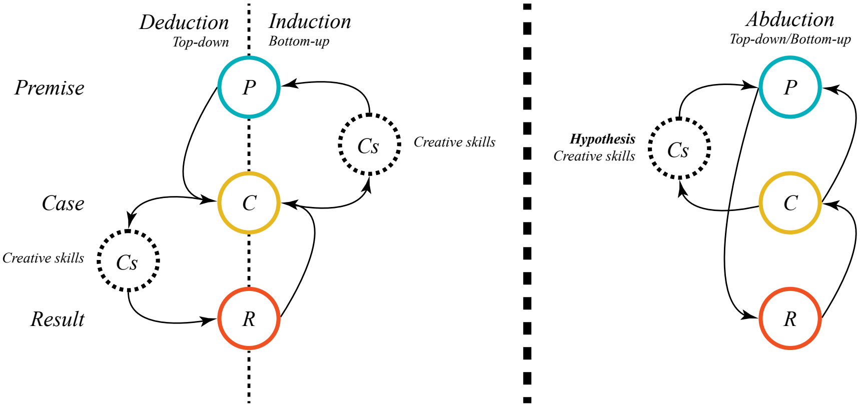

*Figure 2.1—The three kinds of logical inferences. The blue circle, P, designates the premise. The yellow circle, C, designates the case. The red circle, R, designates the result. The black dashed circle, Cs, designates the creative skills in the case of deduction and induction, but also the process of generating a hypothesis in abductive inference. A deduction is a top-down inference that starts from a premise, then observing a case to infer a result. Induction operates the other way, namely bottom-up. It starts from having a result and a case from which it makes the generalised premise. Both inferences share the fact that the case is a given. Abductive logic is concerned with generating what the case might be, given that it may be hidden knowledge if only the result and the alleged premise are given. Starting from the premise, and observing a result, one may creatively form a hypothesis from the case, which in turn can be stated as a premise to test the validity.*

In sum, the abductive inference consists of the following stages (Fann, 1970, pp. 31–32) (Fig. 2.1):

- When observing that a prediction is falsified by experimentation, a *"[…] hypothesis then, has to be adopted, which is likely in itself, and renders the facts likely. This step of adopting a hypothesis as being suggested by the facts, is what I call* abduction*"* (Peirce, 1933, para. 7.202; original emphasis).
- *"[…] the first thing that will be done, as soon as a hypothesis has been adopted, will be to trace out its necessary and probable experiential consequences. This step is* deduction.*"* (Peirce, 1933, para. 7.203; original emphasis)
- *"Having, then, by means of deduction, drawn from a hypothesis predictions as to what the results of experiment will be, we proceed to test the hypothesis by making the experiments and comparing those predictions with the actual results of the experiment.* […] *This sort of inference it is, from experiments testing predictions based on a hypothesis, that is alone properly entitled to be called* induction.*"* (Peirce, 1933, para. 7.206; original emphasis)

In sum, the abductive logic *may* produce new knowledge, that is, if there is incongruence between results and hypothesis. Nevertheless, although the novelty is essentially based on the creative process, the abductive inference is by nature a critical rational approach to scientific discovery, because it describes the process of discovering heuristically the *knowing how* and *knowing why* instead of the static logical proposition of *knowing that.* The fundamental difference between *knowing that* and *knowing how* compares to the difference between a claim and an explanation. The abductive inference is inference to the best explanation through a heuristic process where Bayes' theorem may explain the dynamics[2] (see further; Okasha, 2000; Lipton, 2004, chap. 7). This also makes the initiation problem obsolete as the hypothesis must anyhow undergo experimentation.

Abductive inference, similar to induction, enters a circular—but coherent—argumentation of its validity. If the hypothesis cannot be proven false, it may be accepted as the best explanation until further experimentation, which means that as long as there is no incongruence of belief in theory and no experiment has been able to falsify the hypothesis, it is assumed the best explanation hitherto. The validity of future observation is based on prior experiences, which are also valid because they can be successfully predicted. The genius manoeuvre is that abduction does not form a closed system, but an internally coherent and consistent system, which welcomes any new knowledge. This is surprisingly well in line with foundherentism.

## 2.3 Foundherentism

Epistemologically, the justification of a belief within a theory according to

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[2] Bayes' theorem plays a critical role in this thesis for its explanatory power when integrated with abductive reasoning, i.e. *knowing how.*

coherentists rests on how well that belief coheres with other beliefs in the total system of beliefs, i.e. the theory. A theory qualifies as coherentist if it is held that a belief is justified iff[3] it belongs to a coherent set of beliefs (Haack, 1993, p. 17). Susan Haack, a British philosopher, believes that "*experience and reasons are both elements in justification, and an adequate theory of justification must show how they work together*" (Bacon, 2012, p. 149), which is in stark contrast to foundationalism. Foundationalism casts the validity of a belief within a theory as necessarily independent of the support of any other belief (Haack, 1993, p. 14). The apparent contrast is that one builds its validity of a belief on precisely the coherency between the beliefs, whereas the other on its independency of other beliefs.

Their nature of organising the beliefs may distinguish the two epistemological philosophies, i.e. foundationalists have a serial form whereas the coherentists hold a circular form. According to coherentists, one may safely enter a circular system of beliefs, if the system is coherent to a sufficiently high degree. If a belief contributes to the holistic system by, for instance, creating subsets without internal inconsistencies, then it is not a false belief—au contraire, the belief system is justified precisely because of its holistic non-linear sense of coherency (BonJour, 1985). Consequently, coherentism holds that there are no basic beliefs that can be justified because the justification emerges only from the coherency of the system rather than of its parts. Foundationalists hold instead that basic beliefs require no justification by other beliefs—hence, *basic*—and that these basic beliefs serve as the foundation for non-basic and more complex derived beliefs (Bacon, 2012, p. 149). Such a system naturally takes the form of one-directional knowledge where the basic beliefs never receive justification from complex beliefs, ultimately casting the validity of a theory as parts that form a whole.

Deduction and induction both could not resolve the issue with an infinite regress, which provides the current discussion with a point of interest, i.e. how do coherentism and foundationalism solve the infinite regress argument?

The infinite regress argument questions the premise's premise ad infinitum. Foundationalism holds that the infinite regress is finite and has an end, which is precisely the foundation for that argument. Foundationalism is typically linked to empiricism because it bases the final premise on experience, that is, justification is granted based on experiential beliefs. The limitations of foundationalism are the fact that it is organised in a series of beliefs and that basic beliefs can be justified by experience. For instance, looking out the window and observing that it is raining justifies that outside is wet, but it is not necessary to experience the wet-ness outside to justify such a belief. Coherentists do not justify beliefs on experience but rather on the extended pattern of relations, which means that to justify that it is raining outside other beliefs regarding that belief must be met. In turn, it is easy to demonstrate the limitations of coherentism. It fails to establish a critical form of justification because *"that a set of beliefs is consistent and large is no more a guarantee, or indication, of its truth than that it is, simply, consistent"* (Haack, 1993,

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[3] Iff translates to "if, and only if".

p. 26). This translates to a gathering of drunken sailors supporting one another by leaning back to back, which is a criticism bound on the enclosure of the coherent system, i.e. coherentism gives no role to experience or world in justifying a belief since the justification depends on the coherence (Haack, 1993, p. 27). A coherence view regarding justification finds its strength in the circular argument, essentially stating that the infinite regress discovered in deduction and induction is finite, but has no apparent end. The justification for a proposition is not another proposition, but a holistic justification of a process.

Susan Haack suggests a double-aspect theory integrating both inadequate philosophies into an adequate *foundherentist theory*, amounting to abductive-like reasoning, where testing of the belief, relative to the system as a whole and the evidence, is necessary to evaluate the quality of that belief. Foundherentism accepts that sensory experience takes a role in justifying a belief (foundationalist), while simultaneously stating that there is no privileged class of basic beliefs (coherentist), eventually taking the matter of mutual support among beliefs above the one-directional organisation of justification seriously. To this end, to justify a belief is a matter of reasoning stemming from well-evidenced and mutually supporting beliefs (Bacon, 2012, p. 150).

> *"How reasonable one's confidence is that a certain entry in a crossword puzzle is correct depends on: how much support is given to this entry by the clue and any intersecting entries that have already been filled in; how reasonable, independently of the entry in question, one's confidence is that those other already filled-in entries are correct; and how many of the intersecting entries have been filled in." (Haack, 1993, p. 82)*

Recall that abductive logic is an inference to the best explanation. Foundherentism, quite similarly, holds that the quality of the conclusion depends on how well a belief supports the evidence and how well each belief coheres with other beliefs, i.e. the system as a whole. When applying foundherentism to the current discussion, the belief within a system can be translated to a hypothesis while the system of beliefs is a theory. In this light, foundherentism suggests that the quality of a hypothesis depends on its coherence with the system of a whole, but must also enter a pragmatic turn of event to be considered justified. Such an approach may take advantage of Karl Popper's approach to fallible hypotheses.

### 2.3.1 A Popperian approach

In foundherentism, a belief is understood as a hypothesis from a more extensive theory, where its quality, i.e. validity, is determined by the apparent evidence and holistic coherence. It is essential to note the fallible argument in foundationalism, namely the end-premise being an experience since such a thesis leads foundationalism into the arms of positivism; that valid knowledge is based on *a posterior* knowledge, i.e. observable, empirical and measurable evidence. This consequently makes science a study of knowledge that stems from positive affirmations of theories.

An absolute critic of positivism and the inductive reasoning is Karl Popper. *The Logic of Scientific Discovery* (2007) was entirely dedicated to criticising positivism and advance a hypothetico-deductive approach to science. A primary argument in his criticism is that positivists verify hypotheses through induction by seeking for a logical justification of universal statements, although such reasoning is not logically valid. Indeed, a deduction is preferred over induction due to the lack of logical validity in the latter.

Consider here the steps in deductive testing of theories as suggested by Popper (2007, pp. 9–10). The first step in the Popperian approach is to test for coherency of the theory or hypothesis, where it was famously stated that a theory needs no logical structure to be initiated—however, a criterion of internal coherence and non-contradictive axioms must with established before testing (Popper, 2007, pp. 7–8). At any rate, the question of how a new idea occurs is irrelevant for the logical analysis of scientific knowledge. Second, one must determine whether the theory holds an empirical or scientific character, i.e. whether it has to do with human experience or mathematically deducing a formula. Third, it must be considered whether the generated hypothesis would constitute a scientific advancement given that it would survive a series of critical tests, which constitutes the fourth step, namely, the testing.

Popper's hypothetico-deductive suggestion for scientific discoveries can be framed as a series of critical reasonings starting by what can be as abstract as imagination. Should the hypothesis hold true subsequent to experimentation, then it has for the time being passed, but is not a logically necessary truth, for it may be so that another test in the future may bring it down. To believe that a verification yields universal truth is the pitfall of inductive reasoning. Popper's approach puts forward that scientific reasoning is a dynamic relation among (1) theory, (2) logical prediction and (3) observational evidence, as opposed to positivists and empiricism that cast science as a discipline derived from experience, i.e. sense data.

The hypothetico-deductive approach does not exclude experience as a method—the experience is central to the approach. Empirical science intends to demonstrate only *one real world*, of which there theoretically could be a plethora. To do so, it must firstly demonstrate that the world is a possible world, i.e. non-contradictive, secondly, it must also be a world of experience, i.e. non-metaphysical, and finally, *"it must be a system distinguished in some way from other such systems as the one which represents* our *world of experience"* (Popper, 2007, p. 17; original emphasis). In this sense, the experience becomes a distinctive method between different worlds that must be submitted to tests in order to evaluate the validity of the system, i.e. that world. Despite naming the approach deductive testing of hypothesis, Popper advances an approach that approximates the abductive form of reasoning.

> *"A scientist, whether theorist or experimenter, puts forward statements, or systems of statements, and test them step by step. In the field of the empirical sciences, more particularly, he constructs hypotheses, or systems of theories, and tests them against experience by observation and experiment." (Popper, 2007, p. 3)*

From a new idea that may emerge from induction and has not yet been justified in any way, i.e. a hypothesis or theory, conclusions are only drawn by deduction that hereafter is compared to other conclusions to discover potential logical relations (Popper, 2007, p. 9). The critical rationalism in this line of thinking stems from Popper insisting that a theory cannot be verified simply because a hypothesis was not falsified.

### 2.3.2 Falsifiability of hypothesis

Verification is not possible, which is expressed in one of Popper's most important insights in scientific discovery, namely the falsifiable hypothesis. It builds on the fact that a hypothesis must be conclusive, i.e. one-sided decidable between two or more theories. The fact that a hypothesis is verified does not verify the theory as a whole, because verification of a statement has nothing to do with the system as a whole. It merely shows that at the time being, the hypothesis survived a test. Therefore, when generating a hypothesis, it must be formulated such that it may be falsified precisely because falsification alone brings new knowledge to science. If a hypothesis is verified, then the conclusion was already in the premise. In brief, one should attempt to falsify a theory firstly because it brings new knowledge, and secondly because falsification has the ability of one-sided decidability between two hypotheses. By using a falsifiable hypothesis, it strengthens the theory by ruling out more than before (Popper, 2007, pp. 17–19, 62, 66).

In a nutshell, Popper states that a hypothesis can never be verified; it can only be falsified. If one states that a hypothesis can be verified, one makes the mistake of induction, i.e. to generalise from a single occurrence, which is precisely Popper's critique of the positivistic atmosphere in science.

This position ultimately suggests that knowledge can never be truly known and that any verified hypothesis is but tentative until a test might bring it down. If brought down, the theory from which it was derived, needs to be adjusted to fit the experimental results. Indeed, due to technological instruments and poor experimental procedure, an experiment might suffer from non-reproducible results. Such non-reproducible results have no impact on science, meaning that anyone should be able to falsify the very same hypothesis using the very same procedure. Popper's approach is admirable in the sense that it holds genuine and human respect towards what can be known in nature so that any theory is merely the most probable one. Any theory is the most probable tentative theory until a better explanation appears.

## 2.4 Abductive-Bayesian approach

A most probable tentative theory is addressed particularly by Bayesian[4] abduction. Bayesians and explanationists (abductive inference) converge in numerous

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[4] Both Thomas Bayes and Pierre-Simon Laplace independently formulated how prior probability given new evidence update posterior probability. Bayes formulated this in *An Essay towards solving a Problem in the Doctrine of Chances* (1763) and Laplace in *Théorie analytique des probabilités* (1812).

ways (Okasha, 2000; Lipton, 2004, chap. 7). Bayesians hold that belief is probable and subject to change over time while accumulating new evidence, where the dynamics can be accounted for via Bayes' theorem:

$$P(H_n|E) = \frac{P(H_n)\, P(E|H_n)}{P(H_n)\, P(E|H_n) + P(\neg H_n)\, P(E|\neg H_n)} \tag{2.1}$$ [5]

Eq. 2.1 translates to:

$$posterior = \frac{prior \cdot likelihood}{evidence} \tag{2.2}$$

The product of the probability of particular evidence given a hypothesis (likelihood) and the probability of the hypothesis alone (prior probability) over the probability of the evidence, can define the probability of that hypothesis given that evidence (posterior). Bayes' theorem plays a critical role in the following thesis in explaining the neuronal dynamics and human behaviour. It is because the combination of explanationism and Bayesianism subsume into an extraordinary explanatory model of inference (Lipton, 2004, pp. 103–104). The claim here is that Bayesian dynamics integrated with explanatory considerations from abductive inference and Popper's falsifying hypothesis serve as an extraordinary strong philosophy of science, mainly because it takes seriously the explanation over the claim. Recall that the aim of abductive inference *"is to not to infer the most probable claim, but rather the most probable of competing explanations"* (Lipton, 2004, p. 110).

Given competing hypotheses, if one hypothesis' posterior is less than the prior, it is stating that the new evidence that comes in heuristically is more surprising than before, which eventually disconfirms the hypothesis, i.e. validity is certainty while surprise is an uncertainty. If the posterior is greater than the prior of one hypothesis, then that hypothesis is a more probable explanation to a phenomenon compared to the other. However, how to know the other probabilities like probabilities of the evidence and the hypotheses?

Lipton (2004) suggests that if one accepts that explanatory consideration, of which the abductive inference speaks of, are more accessible than probabilistic principles, then an explanationists approach to prior probability and likelihood serve as a useful surrogate. Essentially, *"[...] the resulting transition of probabilities in the face of new evidence might well be just as the Bayesian says, but the process that actually brings about the change is explanationist"* (Lipton, 2004, p. 114). The upshot in this Bayesian abductive integration is the compliance between the heuristic nature in abductive inference suggested by Peirce and Popperian philosophy of accepting that a theory is merely the most probable at the given time and that scientific advance must entail a falsifiable hypothesis. Furthermore, the integration operates on explanations rather than statements and claims.

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[5] The posterior probability is read as: the probability of the hypothesis $H_n$ given evidence $E$. Similarly, the likelihood is read as: the probability of the evidence $E$ given the hypothesis $H_n$.

## 2.5 Conclusion

In the following thesis, a Bayesian abductive inferential model of scientific discovery is applied, keeping in mind the level of interdisciplinarity. Foundherentism played out the systematic strategy where the system may be based on experience as long as the system is internally coherent. This is firstly ensured by having both a top-down and bottom-up approach to the research question, i.e. from experience to theory, and from a cellular level to the human experience. Based on the above, a theoretical framework of experience is necessary, thus introducing phenomenology. Some conditions are generated in *Part I* that *Part II* must adhere. The use of central conditions of experience thus ensures coherency. Secondly, the nature of the thesis is both empirical and mathematical, in the sense that the mathematical construct seeks to predict the empirical measures. Thirdly, the aim is to formulate the theory/hypothesis as a mathematical model enabling it to produce predictions that are comparable and thus clearly falsifiable with an experimentally produced dataset.

In sum, the *Part I* (Chapter 3-6) must generate some conditions which *Part II* (Chapter 7-11) must adhere—and if so, the end of *Part II* must form a falsifiable hypothesis, which then is submitted to a test (Chapter 12). If the hypothesis survives the test, the established theory survives this experiment and serves as a probable explanation, from which over time more hypotheses must be derived and submitted to more experimentation.

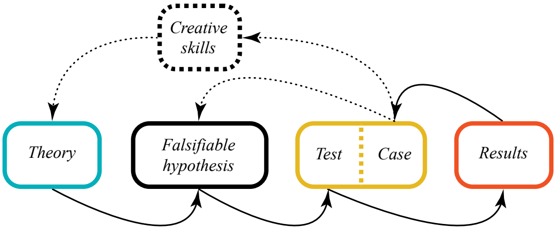

*Figure 2.2—The proposed epistemological approach. The theory informs the falsifiable hypothesis, which then is submitted to experimentation. Eventually, this yields some results from which an explanation is inferred. The explanation is linked to the hypothesis if it turns out that it could not be falsified—however, if the hypothesis is falsified, one may infer another explanation that in turn suggests an update of the theory.*

# Part I

## A PHENOMENOLOGICAL FRAMEWORK

## CHAPTER 3

# On the nature of transition in space and experience

*"The river where you set your foot just now is gone*
*— those waters giving way to this, now this"*
*Heraclitus*

**Summary**. *What defines a transition?* This short chapter serves to investigate the nature of a transition itself and to highlight the fundamental issues that emerge in space and time. It also serves to set the stage through meditation on transitions and their underlying mechanisms. Philosophically, it is possible to distinguish between an *architectural transition* and an *experiential transition*. This dissection serves to clarify the differences only to reassemble them into an *architectural experience of transition*. An architectural transition can be defined as a sequence of space delineated by an observable threshold, whereas an experiential transition does not start nor stop, but is a continuous unfolding of events that a conscious being experiences. Further, this chapter questions the relation between world and experience by constructing a quandary of architectural and experiential transition, which further guide the upcoming questions.

### 3.1 Distinguishing transitions

What does transition mean in architecture? The answer to the question of transition proves more complicated than one might expect. Although transitions are transhistorical elements, one finds different definitions when investigating the ontology of transition. Linguistics and philosophy are briefly brought forward to reveal an important aspect of the nature and definition of transition. In linguistics (Allan, 1980) and philosophy (Quine, 1960), nouns can be characterised at least by two distinct properties, namely *count noun* and *mass noun*, depending on their meaning in a sentence. Although the word *transition* often takes form as a countable noun, it exhibits mass properties. It is arguably subject to both types, yielding different meanings. Mass nouns are defined by their ability to be counted, e.g. *car, dog, idea* and *giraffe*, whereas count nouns can be pluralised and occur with quantifiers, such as *each* and *every*. Mass nouns, e.g. *sugar, garbage, advice* and *knowledge*, are singular and uncountable, accompanied by measure terms, such as *most, much* and *some*. Nouns can be both *mass* and *count*, living a dual-life serving both purposes (Kiss *et al.*, 2017). Roughly put, mass nouns serve to describe a qualitative aspect of the given word, whereas the count noun quantifies it, allowing a physical counting (Krifka, 1989). Relative to architecture, using transition as a count noun refers to an *architectural transition*, whereas using it as a mass noun refers to an *experiential transition*. For instance:

Count noun: Each transition in this building is captivating.
Mass noun: Some transitions are processes of confusion.

Regarding transition as a count noun, it refers to the spatial, built environment that facilitates a transition from one space to another, e.g. *staircase, door, port* and *corner*. This transition is countable, in the sense that it is possible to compare two buildings and state which of these includes most transitions. Mass noun is the experiential process where the quality within a given period is essential. It is non-spatial although the transition might be of physical matter, e.g. *the transition from girl to a woman*—and yet, the word transition is temporal, rather than spatial. Note the ambiguity and difference in meaning in stating *there is a transition in architecture*. The statement makes sense both as a mass noun and as a count noun, because it may refer to historical events concerning a change of architectural preferences, or merely that architecture offers built transitions. The statement refers to both the temporal/experiential and the spatial/physical property of transition.

The justification of having a transition as a mass noun is the impossibility of being able to divide transitions from one another—this is because a transition is intrinsically related to the verb of the word, which is an action that extends continuously over time and action turns out to be indivisible. The mass noun and the verb are closely related, i.e. the quantification of the verb corresponds to the mass noun. Transitions thus contain more than a single rationale, which proves essential for understanding its proper nature. One is the built environment, which provides no qualitative content of transition, but serves instead as a physical definition that facilitates a given agent to experience a transition. *Architectural transition* henceforth invokes this physical environment. This is distinct from the interval experienced from one moment to another. *Experiential transition* henceforth invokes the temporal/qualitative experience of transitions that belongs to the experiencing agent. This distinction proves to be important as the thesis unfolds. The aim of the distinction is twofold; firstly, the distinction enables and animates a discussion on transitions, which is a method used by Bergson (his philosophical dualisms) to investigate the apparent nature of a phenomenon. Secondly, to show that they are inseparable because they are embedded in one another.

Despite their differences, the two kinds of transitions share the fact that they are transitions. What constitutes a transition? Taken in its broadest, it is a complex term grounded in time, space and change, and can be found in the most diverse building cultures and on various social dimensions and scales (Giedion, 1959; Gennep, 1960). Consider architectural transitions, they serve multiple purposes but primarily introduced when the urge to divide arise, be they spatial or functional. Not only does transitions entertain liminality between other spaces, but it is further linked to the idea of bidirectional crossing, transformation and change of place (Ferrier *et al.*, 2018, p. 7). *Change* is the keyword for transitions. For instance, the literal definition of the mass noun in Oxford Dictionaries reads: "*The* process *or a period* of changing *from one state or condition to another*" (OED, 2018; emphasis added). This demonstrates the precedence of change and time. Being a process or period, transitions contain temporal breadth where change occurs, ultimately serving to separate one state or condition from another. The change itself holds an essential role for any transition and can occur in different manners, proving the phenomenon of change to be exceedingly complicated in defining the extent of transitions.

## 3.2 Short-term, long-term and events

The experiential transition can be dissected to numerous smaller short-term processes that make the long-term transitioning possible, e.g. walking through a passage consists of first being in a space, then passing a threshold, which may be an extended passage or an abrupt doorway, and finally reach another space. Even these processes may be dissected into smaller processes, namely of firstly perceiving the transitional element (extended passage or doorway), then planning how to move the body to propel the body through space successfully. Indeed, a range of short-term processes constitutes the long-term processes—however, long-term processes also exerts context for the short-term processes (Klein, 2014), e.g. walking down a narrow passage is experienced differently if one is in Aalborg's many alleys compared to the sacred passage in Temple of Apollo in Didyma; although both constitute the experience of a narrow passage, they are experienced differently. The long-term processes bring context to the small-term processes, which are always at work. The more one dissects these processes; the more one realises that the body is at constant change, i.e. a constant temporal transition.

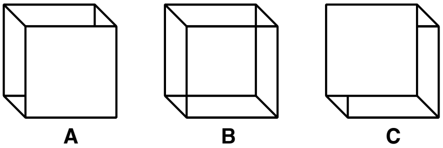

*Figure 3.1—Kaniszą's cube is a bistable figure that allows one to experience a change in perception without a change in the world, which is an important note considering transition. Despite being a two-dimensional drawing, it is experienced in three-dimensions in two different ways, namely A or C.*

The change itself, regarding the built environment, necessarily integrates with an experiential change because architecture itself cannot move about and transit, but merely facilitate it. The equivalent with Kanisza's cube would be to state that the cube changes over time. When architects state that a specific space is a transition, they mean it serves the experiential transition—however, what kind of architecture serves not experiential transition? This critical note suggests that space have a different nature than time. Architecture is not driven by anything as it merely occupies space, whereas a moving body over time causing change drive the experiential transition. Nevertheless, it is possible to speak of a transition in architecture, as if the temporal transition was the same as the spatial transition.

As the term *transition* has been dissected and has shown to consist of a spatial/quantitative and a temporal/qualitative component, it is vital to establish the relation between the two, i.e. to establish whether they are in fact two inseparable aspects of the same concept or can be seen as separable concepts. In order to enable an investigation of their relation, they are separated and discussed as separate entities. Indeed, the issue in question is the relation between short- and long-term processes in *architectural experience of transition*, e.g. an event of a change in space that correlates with an experiential change. The relation between space and experience may be revealed at the event of the short-term change—thus, it is important to define what is meant when speaking of the transition as an *event*.

For the transition as an event to occur, there must be an initial space and a subsequent space, interlinked with a transition (Fig. 3.2). The physical transition must have a starting threshold and an ending threshold, forming together an event that the experiencing agent recognises as a transition. Although transitions may come in various kinds, the event functions as a temporal span and spatial delineation between two spaces, and this is what an architectural transition must fulfil conceptually before one says to have experienced a transition in architecture[1]. The link between experiential transition and architectural transition comes to depend on movement. One can propel the body through experiential and architectural transition so that the temporal span and spatial delineation are experienced through movement. Although the transition event could be a corner, a staircase, a ramp—it must succeed in facilitating a change from one space to another to be considered an architectural transition.

The situation of transitioning from one space to another entails many short-term layers, e.g. the approach, the actual trespassing, the intellectual reflection (realisation) that the transition might have had. Although they may seem as separate short-term processes, they are highly interrelated. How to approach a door-opening depends on the shape of the opening, the physical shape of the body, the intention for passing through in the first place, and other processes. Indeed, the short-term layers are not separable from one another—instead, they form long-term processes. Regarding experience, it is the experienced temporal synthesis

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[1] Notably, this serious reduction of what may be considered a transition in architecture is necessary to isolate the effect that transitions have on human experience as caused by spatial variability.

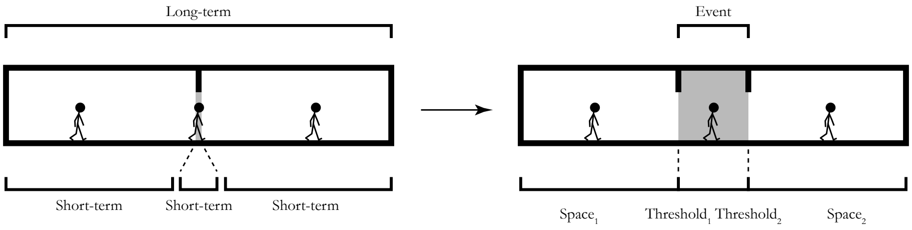

*Figure 3.2—The conceptual definition of the event of a transition. It is conceptual because this is what it must be able to facilitate to be considered a transition. The event is the transition itself, which consists of a starting threshold and an ending threshold, delineating two spaces temporally and spatially.*

relative to architectural change, which is of interest[2].

## 3.3 Transition in the environment

Two spaces delineated by a threshold defines an architectural transition. One may question what qualifies as a spatial threshold, let alone when does a space start and end? These complex matters are avoided by questioning not their content, as in what they consist of, but rather their origin. Seeking the origin, instead of the content, can reveal more about interrelations and position in other processes, i.e. the short-term processes in long-term processes. Relating this idea to architectural transition, the process of changing from one space to another then depends on *how* the observer perceives the environment, and *how* the experiential transition unfolds. Determining an architectural transition necessarily needs someone to have moved between two spaces before deciding that it was experienced as a transition. The decision thus rests on how perception emerges during the process of change. Explaining the *architectural experience of transition* is to explain the agent rather than the architecture. The agent experiences the architectural and experiential transition through movement; movement is what causes the change in perception of space, even if only an eye saccade. Tentatively, it seems that through a moving body, one is able, during a continual synthesis of experience, to make sense of perception.

## 3.4 Research Question: quandary of architectural transition

The general research question regards the relation between architectural transition and experiential transition, now termed the *architectural experience of transition*. Architectural transitions can consist of abstract delineations. For instance, a rectangular space, with a kitchen in one end and a living room in the other. The transition is evident in functionality, yet not in space. Likewise, change in colour, lights and purpose, all function as possible thresholds; even subtle changes in a

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[2] Once again, architecture has been reduced to mere spatial configurations, excluding thermal properties, lighting conditions, materiality etc. This is another necessary reduction to enable a discussion on architecture solely as a spatial entity.

room or floor height can function as an architectural threshold. To decrease the complexity of transitions, a reduced understanding of space is used, namely that of forms and shapes. Following definition of architectural transitions is proposed: *architecturally, transitions consist of a sequence of spaces, delineated by an experienced threshold.*

To address the critical aspect of the architectural experience of transitions, a quandary has been proposed because it provides a grip onto the relation between space and time, as well as architecture and experience (Fig. 3.3). The quandary entails three space where *space A, B* and *C* are different in their spatial configuration. Since the architectural transitions *A* → *B* and *C* → *B* both amounts to *space B*, there is good reason to believe that *space B* is experientially the same space approaching from either direction. Is the experience of *space B*, arriving from *space*

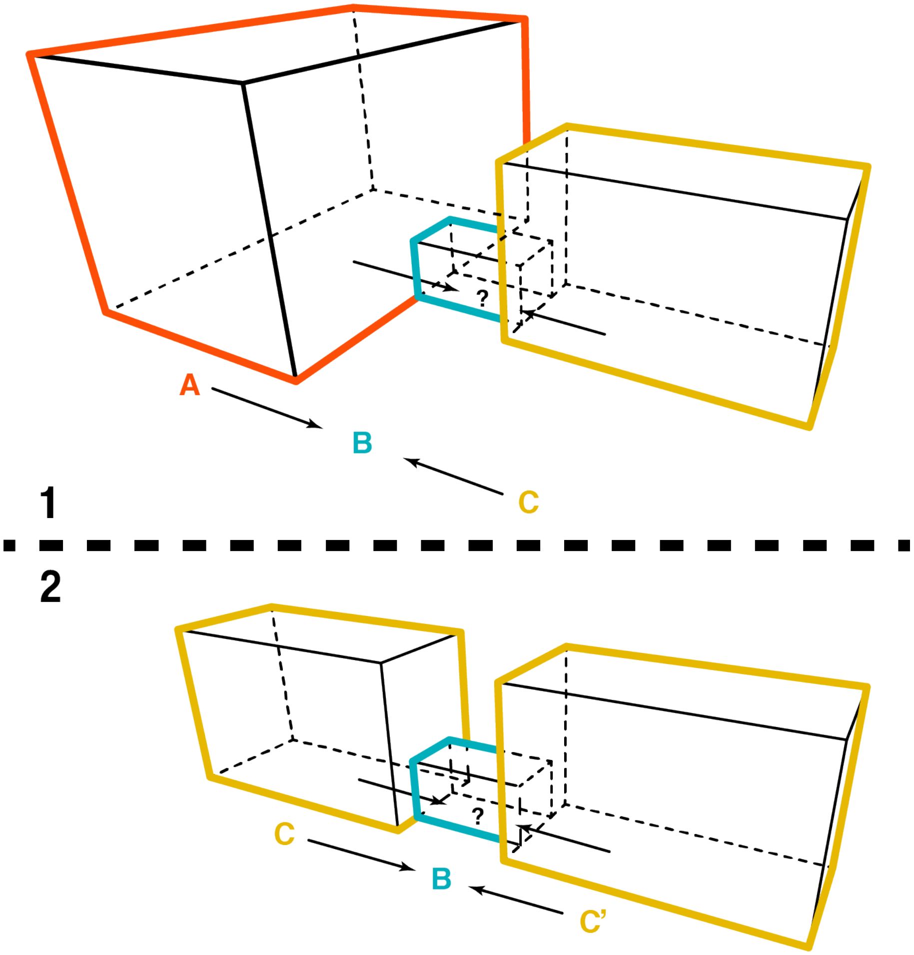

*Figure 3.3*— **1.** *Space A to space B, compared to space C to space B. Architecturally similar, experientially different.* **2.** *Space C to space B, compared to space C to space B. Architecturally similar, experientially different.*

*A*, identical to the experience if arriving from *space C*? This question is not the research question itself, but assists in articulating the idea behind. One may state since the prior space is different, *space B* may not be experienced identically. For instance, in a second quandary, given the transition from *C* → *B* is compared to the transition from *C'* → *B*.

It is reasonable to believe that, if space is experienced separately and discretely, the current experience is independent of the prior space because one is experiencing that specific space immediately. However, if time is conceived as a continuous duration, it is impossible to divide the experience of the prior space from the immediate space, because (as elaborated in Chapter 4) the immediate experience retains that of the past and anticipates that of the near future. A reasonable topic to investigate is thus the temporal structure and internal relations of experience.

It is fallible to assume that certain spaces can infinitely re-position an agent in identical experiences. Such an assumption absorbs the spatio-temporal relation between subject and object, experience and space, which is subject to investigation. It is not within the scope of this thesis to resolve the relationship between time and space in human experience, but rather to form a framework that enables to investigate questions relative to space/architecture and time/experience. Indeed, architectural research relative to experiential impact must inevitably develop a framework that enables investigating space relative to time.

Transitions concern an experiencing agent who must move the whole body, and by doing so changing the perception of space, to successfully transit from one space to another. The movement itself cause a range of perceivable changes of space, which supports the idea that the experience of *space B* cannot be similar coming from *space A* or *space C*, i.e. the order of spaces composes the narrative of the experiencing agent, which affects the immediate experience of the final space.

### 3.5 Precedence of time in experience and movement

Given events as transition, and considering the examples above, they occupy both a spatial and temporal dimension, meaning one cannot grasp it in its entirety at an instant. *"[...] given that events are changes, they must have a temporal span. Thus, at any one instant in time it is impossible to see an event in its entirety"* (Schwartz, 2008, p. 58). Time is a sophisticated ribbon of events. Any account of experience is an unfolding of a specific temporal structure, so that temporality can reveal aspects of the relation between subject and object, experience and environment. In fact, questions relative to subject and object ought to be investigated as a function of time rather than space. By questioning the origin, one enforces a temporal approach rather than a spatial approach, ultimately obtaining insights into the development and relation rather than what they are.

In brief, there cannot be change without time, and without time, no movement. Similarly, without movement, there cannot be a change to cause the architectural experience of transition, i.e. there is an apparent circularity to the structure of time. To fully grasp architectural experience of transitions, a theoretical framework of interrelation between time, change and movement is paramount.

## 3.6 Conclusion

Space and time have been dissected into architecture and experience, respectively, to enable an investigation of transitions as events. Furthermore, since space differs in its nature from time, it enables discussing the spatio-temporal relation between architecture and experience. Eventually, both space and time are part of the human experience of architectural transition, i.e. *architectural experience of transition*, when stating that one has experienced a transition. The event of a transition was shown to depend on the experience of the architecture. Short-term processes constitute the long-term process of a transition, but also vice versa, which suggests that selecting short-term processes in order to answer the long-term process of architectural experience of transition is one of two possible approaches.

It turns out that even the definition of the architectural transition depends on the experiential transition, which in turn poses a quandary. The constructed quandary serves to guide the research question towards a theoretical framework that provides an answer. The main point is that the experience is in question; the answer must make explicit how space and time are interrelated and form experience. In fact, it must be able to answer firstly, how space relates to experience, secondly, the role of the temporal order on experience, and thirdly, how the unfolding of space during movement, causing changes in perception, relate to experience. Indeed, it is essential to address the underlying processes of the perceiving human and temporal unfolding of experience. Perception and the temporal structure of experience during transition in space might provide a unique insight to the origin and inner workings of the relation between object and subject during transitions in space.

It is conjectured insofar that the environmental transition has an impact on the experiential transition. Yet, to wholesomely grasp this potential impact, the relationship between movement and experiential transition must also be accounted for, as it is this relation that is conjectured to reveal how architecture may affect the experience. The underlying argument is that since everything is subject to the constant force of time, everything changes accordingly.

## CHAPTER 4

# Indivisible time, multiplicity and experience

*"Metaphysics will then become experience itself; and duration will be revealed as it really is, —unceasing creation, the uninterrupted up-surge of novelty"*
*Henri Bergson (2007, p. 7)*

**Summary.** *What is the role of action in space and time?* It was suggested in the prior chapter that space and time differ in kind, i.e. their respective nature. Therefore, an approach to managing differences in kind is presented with a specific focus on experience as it unfolds. By invoking Bergson, with various examples and paradoxes, a range of concepts are introduced to guide the relationship between space and time, as in *matter* and *duration,* respectively. To this end, only certain aspects of Bergson's philosophy are presented, i.e. those of ontological value. It is firstly demonstrated, through discrete and continuous composites, how time and space are different kinds, where space within itself only differs in degree, while time, differs in kind. Secondly, emphasising the process of change and differentiation amounts to the Bergsonian concept *multiplicity* that initially was developed by mathematician Riemann. Multiplicity guides the unity of durations into a single universal duration. Ultimately, it is argued that this temporal unity of multiplicities addresses the immediate experience.

### 4.1 Henri Bergson

Henri Bergson (1859-1941), trained as a mathematician, was a professor of philosophy who reached popularity close to a cult during his active years (Guerlac, 2006, pp. 9–13, 42). He is conceived as a philosopher of process due to his belief that everything is undergoing a constant change (Mullarkey, 2000, p. 4). His first work, *Essai sur les Donnés Immédiates de la Conscience* (Time and Free Will), was his doctoral dissertation written from 1883 to 1887, a period in history with limited knowledge of the inner human workings, where he argued for a free agency. It took approximately 100 years to understand him better and the importance of his concepts that are recently being acknowledged in modern times (Deleuze, 1988; Morris, 2005; Winkler, 2006; Moulard-Leonard, 2008).

Notably, for Bergson, there are two kinds of consciousness, namely the reflective and the immediate consciousness—hence the name of his dissertation. Reflective consciousness is separated from immediate consciousness, as it objectifies experiences through the act of the intellect. It treats experience similar to how it considers objects in space, whereas immediate consciousness is the way something feels directly. It precedes any involvement of trying to communicate or represent through tools as language, logic, mathematics or other symbols (Guerlac, 2006, p. 62). Here, the term and concept *duration* become quite complicated. Duration can only be lived and this is precisely what Bergson attempts to reach by introducing intuition as a method. It is an attempt to bring up what reflective consciousness suppress because it is structurally inaccessible to *post hoc* intellect. In a nutshell, by duration, Bergson attempts to describe the immediate experience of the radical force of the time in becoming.

Due to the complexity in his articulation, quotes of Bergson are at times given in full length. Since Bergson's philosophy has been criticised for being difficult to grasp, it here approached by direct readings, where quotes of his work follow statements and alleged claims. This chapter is confined to the following concepts:

- *False problems* and *composites*,
- *duration* and *multiplicity*,
- *hetero-* and *homogeneity*, which closely relates to continuous and discrete changes and
- *virtual* and *real action* as the relation between action/perception and time/space.

Although all the central principles of Bergson have been described elsewhere (Lacey, 1999), and are thus not reiterated here, the presented concepts pave the way for his doctrine of space and time. Bergson's doctrine, philosophy of mind and concurrent conclusions prove extraordinarily essential to grasp the temporal nature of inner experience relative to space—particularly because he sought not to provide a causal explanation of inner human experience, but an explanatory principle in general for all life sciences. He was concerned with meaningful explanations over causal explanations (Mullarkey, 2008).

## 4.2 Bergson's concepts

### 4.2.1 False problems

By way of intuition, Bergson stated that some problems were false problems, due to their blending of *more* and *less* (intensity on a scale) regarding entities that do not differ in degree, but in kind (Deleuze, 1988, p. 14). Using his famous dualistic division of composites to enable a discussion, he was able to differentiate between a range of kinds, e.g. space and time. The resemblance of Peirce's abductive logical reasoning in Bergsonian intuition is palpable; certainly, intuition is a way of reasoning about the world.

False problems are rooted in the way they are posited. In philosophy, the question of finding the problem and positing is more important than solving it, because a speculative problem is solved the moment it is appropriately stated (Bergson, 2007, pp. 36–37). The solution exists and merely needs to be uncovered by stating the problem appropriately. However, stating the problem is not to uncover or discover; it is to invent and to invent consist most often in creating the appropriate terms in which the problem will be stated. Posing a problem and solving it appears close to equivalent. According to Deleuze, false problems can be defined as the following:

> *"False problems are of two sorts,*
> [1] *'nonexistent problems,' defined as problems whose very terms contain a confusion of the 'more' and the 'less';*
> [2] *and 'badly stated' questions, so defined because their terms represent badly analyzed composites" (Deleuze, 1988, p. 17)*

It is through a vital critique of negation that Bergson demonstrates the problematics of stating a false problem, so that there is not *less*, but *more* in *nonbeing* compared to *being*. Similarly, there is more in *disorder* than in *order*, so that there is more in that which is conceived as lacking (Deleuze, 1988, pp. 17–18). In the concept of *nonbeing*, there is (1) the idea of being, (2) the logical operation of negation and (3) the psychological motive. This fact approximates that there is more in the *possible* than in the *real*. Inquiring why there is, rather than why there is not, one is mistaking the more for the less. As if *being* came to coordinate *nonbeing*. That which is not actualised is a multiplicity of its kind, as compared to the actualised unity. This human arrangement of considering things as *more* or *less*, as intensities, proves to be what is deceiving; they lead to wrongly stated problems.

The second type of false problems is the confusion between *degree* and *kind*. Poorly analysed composites are arbitrarily grouped despite being different in kind. Note how intensities presume a single scale as if sharing the same unit in measurement. As Bergson states in his analysis of joy, sorrow and grace:

> *"The aesthetic feelings offer us a still more striking example of this progressive stepping in of new elements, which can be detected in the fundamental emotion and which seem to increase its magnitude, although in reality they do nothing more than alter its nature" (Bergson, 2001, p. 11).*

It is to confuse quantity with quality to address the intensity of a sensation or affective state. They are not a matter of increasing or decreasing an intensity—they differ in kind, not in degree. Perhaps even more clearly, consider happiness in pleasure. Is happiness a succession of pleasure? In defining the words, one might find that the words have nothing in common other than being desirable states by man; "*humanity will have classified these very different things in one genus because it found them of the same practical interest and reacted toward all of them the same way*" (Bergson, 2007, p. 37). Neither pleasure nor happiness are psychological facts that take up certain space in the body as they grow in intensity precisely because they are not intensities—they are qualitative alterations of the whole psychic state. They do not differ in degree, but in kind, because they involve different qualitative changes yielding a difference in their natural articulation (Bergson, 2001, pp. 10–11; Guerlac, 2006, p. 46). Arguably, the difference between mental states is based on experiencing change between the different kinds of qualitative states, which in duration is qualitative progress. Thinking in *more* and *less* when there are differences in kind obscures the actual problem by substituting the true nature of the question, and thus is subject to producing false solutions to false problems.

| | | |
|---:|:---:|:---|
| *Duration* | ↔ | *Space* |
| *Quality* | ↔ | *Quantity* |
| *Heterogeneous* | ↔ | *Homogeneous* |
| *Continuous* | ↔ | *Discontinuous* |
| *Difference in kind* | ↔ | *Difference in degree* |
| *Virtual* | ↔ | *Actual/Real* |
| *Instinct* | ↔ | *Intellect* |

*Table 4.1—Bergsonian dualistic division for composite analyses that differ in their natural articulation (Deleuze, 1988, p. 23). Bergson has other divisions, such as that of multiplicity, which is modus of understanding the composites, i.e. "continuous multiplicity", "quantitative multiplicity".*

Accurately stating a problem, must instead be posited in terms of well-analysed composites. Bergson's method involves analysing dualities before uniting them (see e.g. Table 4.1). Composites consist of natural articulations that differ in kind; for instance, because *pure intellect* is spatial, whereas *pure instinct* is duration[1], these terms form a composite (Bergson, 2007, p. 19). The intellect obscures the difference in kind and mistakes it for a degree so that this tendency towards intellect will state false problems unless unravelled by intuition. Intellect operates merely upon the phantom of intuition as a *post hoc* operation. What is particularly incongruent between composites is the process of change. To consider this aspect, Bergson introduces the concept of *multiplicity,* as initially developed by Riemann, into continuous and discontinues changes (Deleuze, 1988, p. 40).

### 4.2.2 Continuity and discontinuity

Because numbers have both a temporal and spatial dimension, they form a unique case in elucidating the relation between composites. By applying the

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[1] Note that Bergson's notion of pure is his restoration of the difference in kind and tendencies, and that which differs in kind is said to be pure (Deleuze, 1988, p. 22), i.e. pure duration, pure discontinuity, pure intellect.

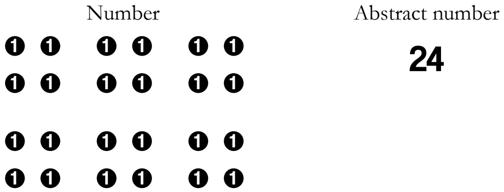

*Figure 4.1—Counting numbers that share the same irreducible unit (in this case 1), differs from the abstract number that is constituted by the figure of the number.*

composite analysis from above onto how numbers change and what makes a numeric unit, it is demonstrated how time differs from space by being indivisible and divisible, respectively. Counting sheep demonstrates the case.

Disregarding the individual difference between the sheep, they form a flock of identical sheep that are countable, i.e. they share the same unit in measurement, so they differ in degree. Accordingly, the process of counting should be entirely spatial. When the shepherd counts the sheep, it unfolds by either including them all into the same image or by counting them one-by-one, repeating unique sheep 24 times in succession. Does this not make the process of counting temporal, i.e. counting in duration? By no means. Even by repeating them, for the number to increase, the succession is a question of spatially juxtaposing them in an ideal space, because counting them separately is always to count a single sheep at the time—thus, not increasing (Bergson, 2001, pp. 76–77). Counting material objects is to count in space, but is this also the case regarding the abstraction of numbers?

Bergson defines abstract numbers by their numeric figure (Fig. 4.1), e.g. 24, which is not the same as counting twenty-four or representing twenty-four (Bergson, 2001, p. 79). It is unnecessary to count to 12 two times, to find out that 24 is double, and 24 is conceivable without counting to 1, 24 times. The figure of the abstract number seems intuitively known—however, as soon as the number (as in Fig. 4.1) must be thought of, it is necessarily spatialised. Counting to 24 necessarily acknowledges that the successive numbers contain their preceding one, i.e. the previous numbers must be held onto for enabling a successful counting. This is precisely only possible because the numbers are fixed to a position in space, e.g. the number 5 contains the numbers from 1 to 4, and after 4 always comes 5. The numbers are divisible by unit 1. This is not possible in time, because "[…] *when we add to the present moment those which have preceded it, as is the case when we are adding up units, we are not dealing with these moments themselves, since they have vanished for ever, but with the lasting traces which they seem to have left in space on their passage through it"* (Bergson, 2001, p. 79).

One can consider any number of its own as an indivisible unity itself, e.g. the number 5 is precisely, indivisibly 5 despite being a collection of similar units. What does it mean that a number is a collection of similar units? There are two kinds of *unit*[2]. One is ultimate, where numbers are formed by continuous addition, and

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[2] Unit is the fixed amount in sudden equi-distanced jerks. Conventional counting use unity of 1: [1, 2, 3 … ].

the other is provisional, where "*the number so formed* […] *is multiple in itself, and owes its unity to the simplicity of the act by which the mind perceives it*" (Bergson, 2001, p. 80). In other words, any number is constituted by other numbers, while also constituting other numbers.

This act of mind to conceive a number as indivisible because one thinks of its unity alone is opposed by the ability to objectify it in space and conceive it as infinitely divisible, i.e. the sum of fractional quantities. The act of mind implies uniqueness in a discontinuous number. Discontinuity is the discrete change and the lack of interval, in the sense that it is by sudden equally distanced jerks that one can advance from one unique number to another. As soon as the indivisible number escapes the (dividing) extension into space, it becomes once again fully continuous. The vital argument is thus: one must distinguish between the unity in which one thinks and the unity in which one sets it out as object after having thought of it. In the immediate consciousness, as the number is being built, the number is discontinuous, "*but as soon as we consider number in its finished state, we objectify it, and it then appears to be divisible to an unlimited extent*" (Bergson, 2001, p. 83). In other words, during the subjective process of constructing the number, it appears indivisible, but as soon as it is objectified by space, it appears infinitely divisible (Bergson, 2001, p. 83).

> "[…] *there is no doubt that, when we picture the units which make up number, we believe that we are thinking of indivisible components: this belief has a great deal to do with the idea that it is possible to conceive number independently of space. Nevertheless, by looking more closely into the matter, we shall see that all unity is the unity of a simple act of the mind, and that, as this is an act of unification,* there must be some multiplicity for it to unify.*" (Bergson, 2001, p. 80; emphasis added)*

### 4.2.3 Hetero- and homogeneity

Duration is understood as a continuous transition that differs in kind; "*Pure duration offers us a succession that is purely internal, without exteriority; space, an exteriority without succession*" (Deleuze, 1988, p. 37). Keep in mind that only duration offers a succession (interpenetration) of states, whereas space offer juxtaposition of states. As soon as duration combines with space, which metaphysically is a process of compressing the *virtual* so it becomes *real*, the immediate experience will be spatialised and intellectualised by the reflective consciousness. This is precisely what was described above in counting numbers. There are two kinds of realities, namely heterogeneous and homogeneous; one which is sensitive to qualities, the other a faculty of space and abstraction, enabling clean-cut distinctions as in numbers (Bergson, 2001, p. 97).

Consequently, the homogenous milieu is a reality without apparent quality. Time can enter this milieu—in fact, it does so as soon as one speaks or manifest anything else in space; it becomes a ghost of space haunting the reflective consciousness (Bergson, 2001, p. 99). The significant difference between the inherent heterogeneity and the outer homogeneity is their nature of change, in the sense that inner states interpenetrate one another making them indivisible, whereas spatial change is a matter of juxtaposition making it infinitely divisible. On one hand, heterogeneity does not accept instants because the successive nature of interpenetration cannot be divided into independent instants—it is only conceived as lived duration. On the other hand, homogeneity accepts only abstract instants that are subject to infinite divisibility.

> *"Pure duration is the form which the succession of our conscious states assumes when our ego lets itself* live*, when it refrains from separating its present state from its former states." (Bergson, 2001, p. 100; original emphasis)*

It is palpable to answer the established quandary given the citation above. Pure duration is a succession of qualitative changes that permeate one another, without distinct outlines or any tendency to externalise themselves from any other, i.e. pure heterogeneity. In short, homogeneous space juxtaposes terms, while heterogeneous duration merges states. Hetero- and homogeneity are reoccurring concepts that take increasingly precise shape throughout Bergson's philosophy. However, it is precisely this temporal synthesis that the immediate experience is found according to Bergson's model of time and space, and thus we shall return to this issue (Chapter 5). As mentioned, Bergson was criticised for being too vague to grasp—however, the essential terms in his philosophy have been introduced. They are worth introducing as his analysis is an important kind. It elucidates the heterogeneous nature of time and the homogenous nature of space.

## 4.3 Multiplicity

In itself, the term *multiplicity* is among the most complicated terms in Bergson's philosophy perhaps due to its origin in mathematics, set theory and physics (see Appendix A for short introduction to Riemann surfaces; see e.g. Smith, 2003 for a review of Badiou and Deleuze on multiplicity). In the current context of *qualitative multiplicity*, take for instance Bergson's example: four candles lighting up a piece of paper. As the first, the second and third candle is put out one might be inclined to state that the paper remains white, despite the paper looks nothing like the paper from when all four candles were lit. As the candles were blown out, we tend to state that the colour white decreases in intensity. It becomes less white, less bright, because there is less light, however "[…] *what you really perceive is not a diminished illumination of white surface, it is a layer of shadow passing over this surface at the moment the candle is extinguished*" (Bergson, 2001, p. 53). Black is just as real to consciousness as white is, and so does not by nature depict void, absence or omission. It is a quality of its own, already acknowledged by the fact that the illumination will not appear to change if it did not bring with it, or produce, a new quality. In other words, when the light source changes sufficiently, a new quality is perceived—thus, it is a question of *kind* rather than *degree* in perception, i.e. a continuous qualitative nuance. This is the qualitative multiplicity; that inner states have a sense of multiplicity of different qualities relative to the objective. It is this sense of qualitative multiplicity that Bergson attributes to the inner experiences of consciousness (Guerlac, 2006, p. 56). The sensation is, therefore, not a physical measure but acts as an auxiliary to introduce a relation between the subjective experience and the objective measure.

Likewise, there also exists a quantitative discrete multiplicity, which differs in degree rather than kind. From the example of the numbers above, the following can be said about qualitative and quantitative division: the term *subjective* is applied for that which is already known, while the term *objective* for that which is known by increasingly many impressions. The subjective is not merely indivisible, akin the experienced shift in colours —*"rather, it is that which is divided only by changing in kind, that which was susceptible to measurement only by varying its metrical principle at the stage of the division"* (Deleuze, 1988, p. 40). In contrast, the objective[3] is that which do not change in kind when divided—as it remains in the same unit but is divided; there is *more* of the matter.

Quantitative multiplicity is multiplicity in space similar to numerical multiplicity, as mentioned above. Optical illusions serve as excellent examples. Aristotle (2006a, chap. 8) and Gestalt psychology (see Wagemans *et al.*, 2012 for an excellent review) conveyed a similar message as Bergson regarding perception: the whole is greater than the sum of its parts. However, Bergson's notion is different from the tradition of such claim. *Parts*, in this sense, are in space, whereas the *whole* is in duration, that which is continuously changing. The immobile parts of space are mobilised in duration, thus given a whole (Smith, 2012, p. 264). For instance, reconsider how the experience in Fig. 4.2, where Cube B contains both Cube A and C, can be moved from one stable state to another.

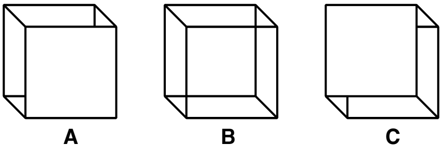

*Figure 4.2—Kaniszạ's Cube, also introduced in Fig. 3.1, introduces an ambiguity in perception, demonstrating how a stable object introduces qualitative multiplicity. One can perceive Cube B as either Cube A or C, and so containing a multiplicity beyond its objective actuality.*

The difference between the two multiplicities were already implied when examining continuous and discontinuous changes. It was stated that any object situated in space is infinitely divisible. In this sense, any quantitative multiplicity is conceived of as virtually possible in principle. The possible changes are already visible to consciousness upon perceiving it although not necessarily actualised, i.e. the possible percepts of Kaniza's cube are already virtually available to the

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[3] The objective is that which hold no virtuality because it has already been actualised. There can only be more in matter, but not anything of a different kind. It denotes that which do not, in dividing, change in kind. It is a numerical, discrete, quantitative multiplicity. The multiplicity is rooted in its more and less unit (Deleuze, 1988, p. 41).

perceiver, even before changing between the percept to actualise any of them. Bergson mean by objectivity precisely that it is *"this actual, not merely virtual, apperception of subdivisions in the undivided* [...]*"* (Bergson, 2001, p. 84). Objectivity holds nothing virtual—it is actual; it is that which is actualised from the virtual. The properties of space are instantaneous; they are actualised. Any change in quantitative multiplicity is a matter of degree, and not in kind: *"This is the same as saying that number has only differences in degree, or that its differences, whether realised* or not*, are always actual in it"* (Deleuze, 1988, p. 41; original emphasis). This is the strict opposite of duration, i.e. the subjective qualitative multiplicity, which designates the multiplicity of the virtual.

### 4.4 Movement and duration

How then do these concepts apply to the experience of transition in architecture? Duration is to think intuitively. The intellect operates in the static, homogenous, spatial reality where movement is retrospective and a matter of juxtaposing immobile and fixed points in space; nothing is ever created and nothing is ever lost (Bergson, 2007, p. 22). In contrast, intuition conceives movement as immediate reality itself. Change is essential:

> *"Intuition, bound up to a duration which is growth, perceives in it an uninterrupted continuity of unforeseeable novelty; it sees, it knows that the mind draws from itself more than it has, that spirituality consists in just that, and that reality, impregnated with spirit, is creation." (Bergson, 2007, p. 22)*

In the process of becoming actualised, intuition is inseparable from the movement of its actualisation; movement actualises the virtual. If an experiencing agent moves through the proposed quandary, the process of moving can be understood as a composite itself. For one, the space traversed in the process of moving forms an infinitely divisible, yet immobile, multiplicity, where all parts are actualised and differ in degree and only understood so by intelligence. Intelligence retains only the positions in space, i.e. the inanimate trajectory in hindsight so that movement can be understood as definite positions in space. It seeks out fixity, refusing interpenetrated transitions so that between two fixed points, there are more fixed points and so on ad infinitum. On the other hand, if one skips the intelligent representation of movement, the immediate movement is just as indivisible as duration, forming a qualitative multiplicity and changes qualitatively for each division (Deleuze, 1988, p. 47). Movement is mobility itself, and yet always understood as a series of fixed, immobile points in space by intelligence in hindsight.

> *"But as a certain space will have been crossed, our intelligence, which seeks fixity everywhere, assumes after the event that movement has been* exactly fitted *on to this space (as though it, movement, could coincide with immobility!) and that the mobile exists in turn in each of the points of the line it is moving along." (Bergson, 2007, p. 5; original emphasis)*

As movements differ in kind, no two movements are the same. Raising the hand to vote is different from raising the hand to greet. Although the trajectory and space traversed are similar, the *intention* of the movement colours the experience differently. Upon analysing motion in mechanistic terms, it is precisely the mechanistic similarity in the spatial trajectory that functions as a common denominator allowing comparison of movements (Mullarkey, 2000, p. 13). This comparison reduces movement to mere spatial homogeneity differing in degree rather than kind—however, when considering the *origin* of the movement, it cannot be homogenous. It must instead be cast as heterogeneous, unique throughout its process of becoming precisely due to the flow of duration—it is the process of reality unfolding itself, which makes the trajectory nothing but a shadow of a living anti-mechanistic process (Fig. 4.3).

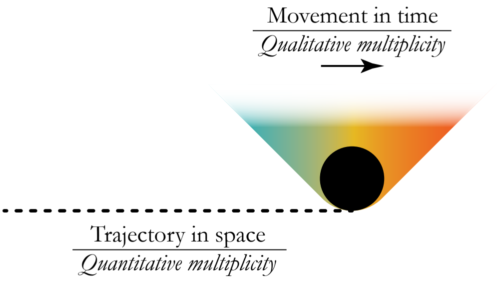

*Figure 4.3—An abstract illustration of how the creative qualitative multiplicity in movement becomes objective in space. The black circle depict the movement, which depends on the process of duration. It leaves behind it actualised points in space from the multiplicity of virtuality that theoretical contains all possible realities—hence the fading of colours upwards. Here, the colours, which the circle is embedded in, depicts the temporal process, where the blue can be considered as past, the yellow as the immediate moment and the red as the future. As illustrated, these cannot be divided from one another without containing one another; thus, qualitative multiplicity is considered indivisible. The trajectory in space that is left is infinitely divisible; a quantitative multiplicity, and reflect nothing but the shadow of the creative process in motion.*

This point is the radical claim in Bergson's philosophy of movement. Movement is immediate in actualising novelty, and not predefined points in space as if one knew the movement before it had been actualised. Movement is precisely the process of becoming, i.e. duration and perception, and must be grasped within its dynamic nature. It is not simple snapshots fixed side-by-side; quite contrary, it is the continuity of transition within the flux of duration, forming an indivisible change. The body is the main medium between subject and object, between duration and space; thus, it belongs to enduring individuals and spatial situations. In brief, Bergson is calling for a dynamic understanding of movement and perception, rather than a static conception because it generalises movement stripping it of any uniqueness.

What about movements that are intuitive, e.g. walking during mind wandering, which is usually the case during transitioning from one space to another? Are these movements generalisable?

> *"There is no such thing as a general type of movement; there may be a more or less individual movement, but none that can be perfectly general. Such actions that are less individual form the basis for the more homogenised levels at which we most often communicate and otherwise publicly interact with each other." (Mullarkey, 2000, p. 26)*

*Pure* movement is a transference of a state, e.g. experiential transition, rather than of a thing, e.g. the body (Mullarkey, 2000, p. 14). To highlight the individuality and the becoming in movement, as in experiential transition, consider two of Zeno's paradoxes, where it is found that movement is indivisible, conforming to duration and that instants or spatial points in time does not reveal the process of movement, but merely the current coordinate.

### 4.4.1 Zeno's paradoxes

Zeno of Elea (495-425 BC), a pre-Socratic philosopher, described one of the Eleatic paradoxes; Achilles and the tortoise. His paradoxes have been heavily debated and proven soluble, and insoluble, a plethora of times. Zeno's paradoxes of space, time, and motion concern the very idea of the divisibility of space and time. Before presenting three solutions, including that of Bergson, consider the paradox as described by Zeno.

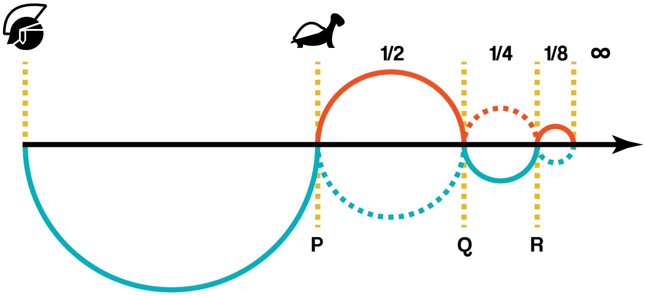

*Figure 4.4— Achilles overtaking the tortoise would mean for Achilles to reach the point where the tortoise started, however, since the tortoise is half as fast, it already has travelled half the covered distance. Following this logic, Achilles will never be able to overtake the tortoise, but merely approximate it.*

Imagine a race between Achilles and a tortoise (Fig. 4.4). The tortoise gets a head start of 100 metres because Achilles is twice as fast as the tortoise. Instinctively, Achilles would soon overtake the tortoise—however, here, Zeno raises the paradox. For Achilles to overtake the tortoise, he must at some point reach the starting point of the tortoise, *point P*. At this time, the tortoise has already travelled half the covered distance, *point Q*, given it is half as fast as Achilles, and thus Achilles must now reach *point Q* to have a chance at overtaking the tortoise.

Once again, whenever Achilles reaches *point Q*, the tortoise is then at *point* R, and so on ad infinitum. Although their distance is minimised, Achilles never passes the tortoise, but merely approximates it (Ray, 1991, p. 7). Mathematically, this is expressible as a geometric series, namely:

$$\sum_{n=1}^{\infty}\left(\frac{1}{2}\right)^{n}=\frac{1}{2}+\frac{1}{4}+\frac{1}{8}+\frac{1}{16}\ldots \tag{4.1}$$

The real problem is the mixing of space and time, i.e. degree and kind and thus posing a false problem. Zeno informs that, spatially, when Achilles reaches halfway of his next position, so must the tortoise to his next position. Is not this a pure mix of space and time? If this information is correct, then the tortoise has either increasing speed or Achilles a decreasing one. It is not a question of location in space, but an ideal location in time, which is only possible because they have initially been mixed. Achilles is never halfway in space when the tortoise is halfway in space—however, he is in time (Fig. 4.5A). It is assumed that the time it takes for Achilles to take a step is similar to that of the tortoise so that their relative interval remains constant, namely double, as Achilles is twice as fast. Zeno thus geometrically divides Achilles' movement as explained by the tortoise' movement, ultimately defining their relative spatial position to be synchronous, like that of two parallel lines. In short, by dividing an actor's spatial position as a movement relative to that of another actor, a mixing of indivisible action that differs in kind rather than in degree is at stake; Achilles actions are then defined and regulated by the actions of the tortoise. The err is evident when considering the *"movement in relation to the actions articulating it rather than the one form of homogeneous and immobile spatiality subtending it"* (Mullarkey, 1995, p. 247). Then, the fact that Achilles never overtakes the tortoise is the mathematical outcome of approximating two different embedded actions; they can never be the same. Hence, Bergson states:

> "[The] *mistake of the Eleatics arises from their identification of this series of acts, each of which is of* a definite *kind and* indivisible, *with the homogeneous space which underlies them. As this space can be divided and put together again according to any law whatever, they think they are justified in reconstructing Achilles' kind of step, but with the tortoise's kind: in place of Achilles pursuing the tortoise they really put two tortoises, regulated by each other, two tortoises which agree to make the same kind of steps or simultaneous acts, so as to never catch one another." (Bergson, 2001, p. 113; emphasis added)*

Two related issues are urgent: (1) the division of movements of different actors due to (2) the belief that movement consists of immobile positions. Following Zeno's information would amount to Achilles' steps being a matter of dividing his steps, or action, into tortoise-time, as if reconstruction of actions of one actor is identical with that of another. Each of Achilles' steps is believed to be infinitely divisible, as they are carried out in space—however, this amounts to believing that Achilles' movement must consist of a range of immobile positions in space; thus, an illusory understanding of movement stems from coinciding mobility with immobile points. *"To tell the truth, there never is real immobility, if we understand by that an absence of movement"* (Bergson, 2007, p. 119). Movement precisely changes, and change is constant, so there cannot be real immobility. Movement is unique to the individual and situation, whereas immobility presumes fixity. Ultimately, each of Achilles' steps is incomparable to those of the tortoise.

To emphasise the issue of dividing movement, examine the paradox by dividing their positions in space. One will soon find that Achilles overtakes the tortoise, and this reveals nothing regarding their movements, but merely their positions in space.

> *"But one body is faster than another, not because it takes less time than the slower to cover the same distance, but because it covers a greater distance than the slower in the same interval of time." (Paul Weiss as cited in Chappell, 1962, p. 200)*

If understood as a practical problem of positions in space, given a finite interval of time where movement consists of a succession of immobile positions, the paradox becomes soluble. Consider the actual positions during movement of Achilles, where the velocity is defined as the finite distance covered given a finite interval of time. Achilles must necessarily cover more than one position in space to move. In the process of moving into the next position in space, the velocity of the former position must be withheld, although the current position may measure a different covered distance, and thus by definition a different velocity. Ultimately, velocity consists of variable motion. Such an account fails to encompass the fallacy of Zeno's division, namely that an immobile instant can be at motion; movement is recovered as a question of change, a process, and not immobile positions[4]. It is then true that Achilles never overtakes the tortoise, simply because the movement is not a question of position in space, but as their action causes them to change position in space—reducing the paradox to a spatial problem—one can understand their spatial relation and not duration (Fig. 4.5B).

The fallacy of an immobile instant at motion is demonstrated in another paradox, namely Zeno's Flying Arrow Paradox. As described by Aristotle in his *Physics:*

> *"*[Zeno] *says that if everything when it occupies an equal space is at rest, and if that which is in locomotion is always occupying such a space at any moment, the flying arrow is therefore motionless." (Aristotle, 2006b, p. 91 Book VI, Part 9)*

At any rate, being motionless is being at rest, referring not to the fact that the arrow must continuously remain at rest in successive instants, but the fact that an instant is a motionless immobile point in space (Fig. 4.6A). Anything at an instant

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[4] Such an account is similar to the Bergsonian argument that Lynds (2003) brought forward relative to quantum mechanics.

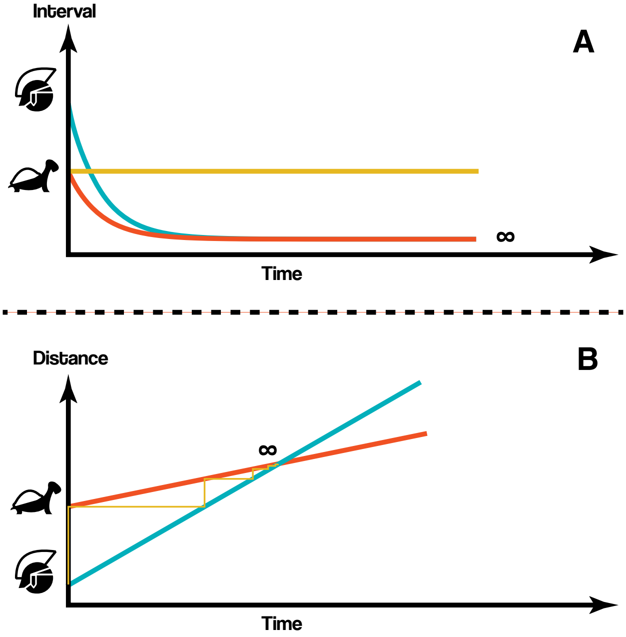

*Figure 4.5*— **A.** *Dividing the duration as a function of the spatial position relative to each other ultimately leads to a geometric series only approaching a finite number. Achilles (blue line) is thus never able to overtake the tortoise (red line). Achilles can be expressed as:* $f(t) = 1/2^t$, *and since the tortoise is half as fast:* $g(t) = \frac{f(t)}{2}$. *Consequently, their relative distance remains constant:* $h(t) = \frac{f(t)}{g(t)}$, *(yellow line).* **B.** *Considering instead their spatial position, instead of their relative interval (yellow lines), Achilles (blue line) soon overtakes the tortoise (red line). The yellow line designates the geometric series, which is infinitely divisible.*

is motionless; this is the property of an instant, it immobilises. It is true that for the arrow to move, it must occupy two successive positions in space, but at any given moment, the arrow only occupies a single position and thus must remain at rest (Fig. 4.6B)—hence, the paradox states external motion as impossible. Consider the internal movement; for any given movement, the qualitative multiplicity is always a reality, prohibiting any clear division, thus containing a mobile duration. Because the qualitative multiplicity is precisely the outcome of duration, motion becomes possible again; this demonstrates how duration solves movement.

Real action can be divided into instant points in neither time nor space—instead, it follows the nature of duration. Zeno's paradoxes make explicit the individuality, multiplicity and continuity of each action, which are all necessary to comprehend to investigate the experiential transition emerging from the movement from one space to another. The role of action in space and time is clear; one must distinguish between action as occupying immobile, fixed points in space from mobile, free and continuous actions. Nevertheless, are these not all merely metaphysical meditations on the action, i.e. an action that is evident in all parts of nature?

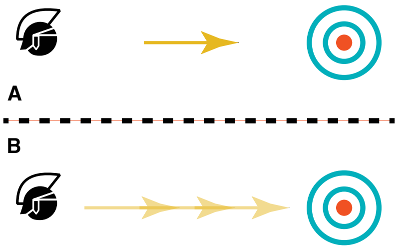

*Figure 4.6—* **A.** *Taking a snapshot of the flying arrow, the arrow necessarily only occupies a limited amount of space.* **B.** *Any motion must occupy more than a single instant in time, for it to move.*

### 4.4.2 Virtual to Real action

There does not exist immobility, if we understand by it the absence of movement, Bergson asserted above. Going beyond metaphysics and into biology, examine the emergence of a colour, e.g. green. The colour green presents itself through the medium of light, which holds all the frequencies of any other colour, i.e. all possible frequencies are everywhere and always real. The question is that despite there being movement everywhere, here as light-frequencies, why is green picked up; why is any picked up? This is the virtual action—*"it is this virtual action which extracts from matter our real perceptions* [...] *condensations within an instant of our duration of thousands, millions, trillions of event taking place in the enormously less drawn-out duration of things"* (Bergson, 2007, p. 44).

Even when considering the biological point of departure regarding movement, it is bound upon duration. Primitive organisms carry out actions upon immediate contact with the environment, enabling a proper reaction to either seize their prey or escape danger. For various organisms, including human beings, tactile perception is rarely much different from organs of movement, so that *"the more immediate the reaction is compelled to be, the more must perception resemble a mere contact"* (Bergson, 2004, p. 22). However, not all sensory perceptions depend on necessary contact, e.g. visual, auditory, olfactory senses are all examples of sensory of distance integrated with perception. As the distance increase providing an extended possibility of a reaction, the measure of determination and certainty decreases, as one is less confident of the external world. In this sense, any perception is merely an eventual action, which the indeterminate human may act upon and so actualise. The actuality of perception is in the activity of movement so that all present are ideo-motor (Bergson, 2004, p. 74).

Consequently, perception is not up to intellectual contemplation or speculation and added to the rendering of the real, as if reconstructed from sensory or idea—instead, it is lived, touched and penetrated. Regardless of how rapid one may suppose perceptual processes to be, they must endure and take up more than an instant, as prior experiences are already at work in emerging any perceptual experience (Bergson, 2004, p. 76). Thus, perception is a master of space in the exact measure in which action is a master of time (Bergson, 2004, p. 23). This relation between action and perception is revived in Chapter 7 and 8.

The radical statement insofar is that perception is not knowledge, but eventual action; virtual actions[5]. These may, or may not, be actualised. This opposes both idealism and realism who believe that perception is empirical knowledge about the world in one way or another. For Bergson, the experienced perception is a mixture, hence the indeterminate position of the body and consciousness; the real task of the body and consciousness is resolving uncertainty about the world. Note that highlighting idealism and realism additionally sheds light upon the body-mind problem as explicated by René Descartes (1596-1650). Idealists hold that the world, at least the representation of it, is entirely within the mind, whereas realists hold that our perception occurs as a function of our brains, based on reactions from the sensible and empirical world (Guerlac, 2006, p. 107).

> "[…] *for realist as for idealism, perceptions are 'veridical hallucinations', state of the subject, projected outside himself; and the two doctrines differ mere in this: that in the one these state constitute reality, in the other they are sent forth to unite with it." (Bergson, 2004, p. 73)*

There are various accounts of realists (see for instance; McDowell, 1996; Strawson, 2008; Searle, 2015), and idealists (see for instance; Hegel, 1979; Gottlieb Fichte, 1998). Given the intuitive approach of using composites, Bergson's strategy is evident. Instead of narrowing the problem to separate entities of mind and body, there is a third leg, which is the relation between the two. To Bergson, the human is always at an indeterminate state, and as demonstrated with his structure of composites, the lived nature is always a mixture rather than a pure; the pure is only theoretical and principal to enable investigations. By stating that a human body is a centre of indeterminacy, the position is neither realist nor idealist, because both idealists and realists hold that perception occurs in the service of truth. That propositional knowledge dissolves by approaching it with indeterminacy, i.e. resolving uncertainty about the world by acting in it. Essentially, the apparent state of the world is only relational so that neither mind nor body monopolise the apparent state—instead, the state is constructed dynamically in the interaction between prior experiences and body. In other words, the indeterminate body does not rely on absolute truths, but on prior experiences from interaction with the environment; perception serves action—not knowledge. In other words, any change in the motor activity must necessarily be resolved as changes in perception.

> *"Let us no longer say, then, that our perceptions depend simply upon the molecular movements of the cerebral mass. We must say rather that they vary* with them*, but that these movements themselves remain inseparably bound up with the rest of the material world." (Bergson, 2004, p. 12; original emphasis)*

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[5] Chapter 5 elaborates on the nature of virtual actions. It is evoked here to distance Bergson's philosophy from that of realists and idealists; Bergson is concerned with the creative process in lived experience, which is arguably practical.

There exists a variable relation between the experiencing agent and the surrounding world, where the variations reflect, as a function, the level of uncertainty and indeterminate state. The process of becoming certain, as reflected in perception, is shaped by virtual actions.

J. J. Gibson (1904-1979) advanced an ecological approach that is reminiscent of Bergson's account of action and perception (see for instance; Gibson, 1966, 1972, 1977, 1986). The underlying theory is that the world contains *"something more than, but not something different from, that which is actually given"* (Bergson, 2004, p. 78); what is perceivable is only that which is of interest to the body and actions. Gibson refers to this as *affordances.*

> *"The perceiving of an affordance is not a process of perceiving a value-free physical object to which meaning is somehow added in a way that no one has been able to agree upon; it is a process of perceiving a value-rich ecological object. Any substance, any surface, any layout has some affordance for benefit or injury to someone." (Gibson, 1986, p. 140)*

As compared to virtual action:

> *"Perception, understood as we understand it, measure our possible action upon things, and thereby, inversely, the possible action of things upon us." (Bergson, 2004, p. 57)*

Although there are fundamental differences in the manner each term is articulated by its respective author, they share the ideology of perception serving action. Besides virtual action and affordances, Bergson and Gibson share another range of arguments, for instance space, also for Gibson, is homogenous (Gibson, 1986, p. 18), and affordances, just as virtual actions, are between subject and environment (object) (Gibson, 1986, p. 127).

The common denominator for both concepts is their base on what one *can* do; actions that might unfold, directed towards the multiplicity of the virtual—however, only a single action is unfolded. This is where the two terms differ in their nature; Gibson held a Darwinist account of affordances so that the affordances of food were related to the content and not the shape of the food, e.g. the affordances of a plastic carrot are not the same as the vegetable. Affordances seem to be biased by a semi-psychological factor that alters the perception depending on the animal species: *"Depending on the animal species, some afford nutrition and some do not. A few are toxic. Fruits and berries, for example, have more food value when they are ripe, and this is specified by the color of the surface"* (Gibson, 1986, p. 131). Chapter eight is entirely dedicated to these evolutionary perspectives of affordance and environment (Gibson, 1986, chap. 8). Instead, Bergson addresses the interaction as an action-reaction that depend on the physical structure of the object and the body. Virtual actions are formed as virtual worlds; nothing prevents other worlds, corresponding to another choice, from existing with the current world in the same place and time (Bergson, 2007, p. 45). The weight of the term is on the physical activity relative to an object rather than a semi-psychological factor altering action-decisions. The difference between affordance and virtual action[6] is elaborated later (Chapter 11).

The process of virtual action is inspired by the principles in thermodynamics' second law, which to Bergson is *"the most metaphysical of the laws of physics since it points out without interposed symbols, without artificial devices of measurements, the direction in which the world is going"* (Bergson, 1944, p. 265). The second law is that of entropy; the definition of entropy was shown by Boltzmann to be equivalent to that of statistical entropy that designates the level of uncertainty. Bergson must have acknowledged similarities to the idea of the indeterminate state of human nature. According to thermodynamics, systems that spontaneously evolve towards equilibrium does so through a process that entails releasing free energy, which reflects the available energy given certain constraints in its current state—thus, the equilibrium emerges from quite similar principles as virtual actions increase certainty of the indeterminate body. Notably, such an account urges the importance of the process of selecting from the richness of multiplicities evident in the immediate perception; that which is intuitive and free of intellectual processing.

> *"[…] from the immensely vast field of our virtual knowledge, we have selected, in order to make it into actual knowledge, everything which concerns our action upon things; we have neglected the rest. The brain seems to have been constructed with a view to this work of selection." (Bergson, 2007, p. 114)*

## 4.5 Bergson's principles/conditions

Several vital points from Bergson's philosophy have proven valuable to the current research question. With an outset in human intuition, the philosophy of Bergson serves as a departure in understanding the relationship between architectural and experiential transitions. Based on mere intuition and logically valid axioms, the Bergsonian approach generates several conditions and remarks that must be accounted for in any empirical framework. Notably, a Bergsonian project would involve a scientific understanding of metaphysical ideas, e.g. traces, lines, dynamism, leaps, linking and re-linking in thought (Deleuze, 1988, p. 117). Particular established Bergsonian principles are inevitable and must be covered if to shed any light upon experience:

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[6] Virtual actions are not comparable to possible actions. If virtual actions were possible actions, they would already exist before the real, and so the agent would simply have to choose from a given range. Only by the act of the mind does the possible become the real. The possible is given in retrospect once enacted, although there never were any existing conscious acts considering the possibilities. It is only in light of the real that the possible exists, despite the intellect presenting in retrospect that the possible was always not-impossible, and thus existed before the real. (Bergson, 2007, pp. 81–83). Actions unfold from virtual actions, which are continuously generated in a creative process depending on the actual situation. The real only makes itself possible in retrospect as a consequence of the intellect, so that the possible does not become the real, but from the real the possible is generated. It is only the virtual that can become the real (Bergson, 2007, p. 85).

1. **Heterogeneity of duration**; is the principle of immediacy, continuity and flow in duration as a constant change beyond discrete instants. Duration springs from the multiplicity put available by the physical structure of the body. Temporally, everything interpenetrates and occupies positions for both immediate-past and immediate-future.

2. **Indeterminate state of human**; reflects the thermodynamic concept of equilibrium. This principle functions as the anchoring of the body in the upcoming discussions to not fall victim to the representational approach to cognition. The indeterminate body only becomes more determinate about the external world through the creative process of action-perception.

3. **Dynamic relations**; refers to the temporal focus in bodily processes, including predicting virtual actions and retaining immediate experiences. It casts the emergence of becoming through experience as a dynamic system.

It is crucial to continuously highlight the principles as the investigation unfolds—however, this is not to state that other introduced concepts are to be left and forgotten. Bergson's principle of, for instance, the difference in kind and degree proves to be an essential tool in investigating the nature of a term.

Notice that all three principles resonate—they are interrelated, supporting one another as a complex system. These principles serve to guide the threshold between strictly a strictly scientific approach and a philosophical, e.g. any proper investigation of experience must account for the heterogeneity of duration.

### 4.6 Conclusion

Perception is how the body virtually interacts with the environment, and considering the posed quandary, a transition is only graspable by situating an individual, i.e. an experiencing agent with a particular body, restricting and allowing specific manners of interaction with the environment. The physical structure of architectural space becomes a critical feature because the interaction between perception and action, as a development from virtual to real action, determines the process of experiential transition. It can be concluded that the bodily functions, as an enduring system of creative movements, is precisely the way the indeterminate human becomes more determinate and experiences the world; therefore, there can be no answer to the quandary unless the real problem of action-perception is appropriately posited.

It is here clear: the process of action-perception necessarily emphasises the possible influences the object can inflict the subject, so that the experience of the environment, thus architecture, is a temporal relation as it becomes a question of the process of virtual action between subject and object.

It might still not be clear why linking architecture and Bergson's conception of space and time is useful. Bergson's conception of numbers and their status as spatialised time proves helpful to the process of delineating spaces so that the homogeneity of space is different from the heterogeneous duration, i.e. experience. Since space merely offers a difference in degree, a juxtaposing of elements stripped of no virtuality, there is entirely discrete division. There are no reasons to believe that there exist other transitions than the experiential transition. Architectural transitions, as defined in the prior chapter, are an illusion, always created in retrospect by the intellect, to justify a sufficient change in experience, similar to that of a blowing out candles or acknowledge a different colour. What is meant by retrospect is not only post-experience but also intellectual predictions; some spatial configurations, e.g. a door, may attract an intuition of an architectural experience of transition. Such a spatial configuration may be termed *a transistor* and can be recognised before passing.

Most importantly, not confusing space with time suggests that *space A* is never directly related to a *time A*, that is, an *experience A*, as if time and experience can reoccur as perceptions. Confusing space and time result in a tendency, when given a qualitative heterogeneity, to interpret it through a homogenous, objective medium. This tendency is a reaction towards the heterogeneity that anchors experience (Mullarkey, 1995, p. 234). It would thus be an error to believe that specific spaces can evoke certain emotions, as an automaton, but instead one should understand the process of change, the transition of spaces as formed by the action-related restrictions and perception so that retention, i.e. that which remains, and virtual actions ultimately shape the foundation of experience.

Regarding the importance of time relative to space, the difference between past and present is more important for the experiencing agent than the difference between spaces (Guerlac, 2006, pp. 106–107). Bergson suggests understanding the relation between processes rather than the outcome. This is the true Bergsonian embodiment; bodily processes are always in reciprocal coupling to its environment with content that is unique to the experiencer, and thus inaccessible to others. One should not attribute much value to the content and representation itself, but instead to the underlying processes, shedding light upon how one might influence it, which ultimately is the underlying temporal approach; to understand the heterogeneous transition rather than the homogenised content. Therefore, according to Bergson, architecture, since it involves indivisible successions of movement animating space, is an *art of experience*, rather than an *art of object*. For this particular reason, Bergson stated that: *"Questions relating to subject and object, to their distinction and their union, should be put in terms of time rather than space"* (Bergson, 2004, p. 77).

Despite Bergson's rigorous study of time, a clear structure of the immediate experience was not offered—instead, Bergson provided a framework for understanding the nature of space and time. Indeed, this chapter suggests that to understand the structure of the immediate experiential transition, a framework of action, perception and unfolding of time is necessary.

## CHAPTER 5

# Bergson and Husserl meet:

## unpacking Bergsonian ideas using Husserl

*"We are the true Bergsonians"*
*Edmund Husserl at a conference of phenomenology*
*(Spiegelberg, 1994, p. 428)*

**Summary.** *How do Bergson and Husserl comply in their philosophy, and how is Husserl relevant to the research question?* In search of the structure of duration and experience as portrayed by Bergson, his theoretical framework proved to be insufficient to analyse the structure of the immediate unfolding of experience. However, he did demonstrate that there could not be a discrete or instantaneous point of experience since experience belongs to duration. By tracing parallels between Husserlian *temporality* and Bergsonian *duration*, an account of temporal development concerning intention and virtual actions, outline a framework suitable for empirical investigations of transitions. In this respect, a phenomenological account of perception and experience are given and compared with a Bergsonian account. It is argued that Husserlian intentionality differs marginally from Bergsonian virtual action, serving a similar purpose in terms of time, space and experience. Given the remarkable similarities, the developed Bergsonian principles are extended and unpacked by Husserl's phenomenological account, functioning as support to Bergson's principles.

### 5.1 Manifold of multiplicities

During the uprising of phenomenology in France, there was yet a Bergsonian dominance, and although Bergson and Husserl never met, their philosophies had obvious parallels (Spiegelberg, 1994, chap. VIII). Amongst the many similarities, consider the most fundamental one, namely that of multiplicities[1]. Both philosophers derived their concept of multiplicities from the notion of *manifold* as coined and defined by Riemann in his *Habilitationsschrift* from 1854 (Winkler, 2006, p. 94). It is interesting due to Riemann's twofold-position in philosophy and mathematics since his mathematics can be understood as *conceptual mathematics*. Such entails thinking of space as a concept with complex structure, rather than as Euclidean geometry and sets of points (see Appendix A for elaboration). In this regard, geometry concerns the measure and scale of space, whereas topology, which is what Riemann essentially argues for, only concerns the structure of space and the shape of figures, understood as complex structures and concepts. Riemann aimed to develop a multidimensional notion of magnitude, from which he managed to distinguish *continuous* from *discrete* manifold. This led him to state that:

> *"The concepts of magnitude are only possible where there is an antecedent general concept which admits of different specialisations. According as there exists among these specialisations a continuous path from one to another or not, they form a* continuous *or* discrete *manifoldness [Mannigfeltikeit]; the individual specialisations are called in the first case points, in the second case elements, of the manifoldness." (as cited in Plotnitsky, 2006, p. 193; original emphasis)*

As stated in the previous chapter, Bergson was largely inspired by Riemann's approach to space due to his disregard of points in space and insistence of understanding mathematical objects as concepts. In this sense, concepts have each a continuous or discrete manifold whose elements or points are related through a given determination, a complex structure. Riemann's notion of manifold paves way for structurally conceptual mathematics, which goes beyond the algorithmic and formulae approaches, making continuous and discrete manifolds different concepts, where the former measures a number of elements in a manifold, and the latter the relations that act upon it (Plotnitsky, 2006, p. 194; Winkler, 2006, p. 95).

Admittedly, despite both Bergson and Husserl taking Riemann's multiplicity serious, their respective philosophies had different purpose and motives, making their comparison difficult and limited. Bergson was occupied with *durée* (duration), which he discovered through a rigorous investigation of change and process as inner continuity (Bergson, 2007, pp. 3–5), whereas Husserl focused on investigating *experience* through a descriptive method devoid of presuppositions about the world (Zahavi, 2003, pp. 66–68). Both purposes were further developed and changed as they kept on writing, e.g. Bergson explicitly stated that his philosophy was just as subject to the change of time as any other spatio-temporal object. Because it will continuously develop, change and expand, Bergson positioned himself as a *process philosopher*, or *philosopher of change* (Mullarkey, 2000, p. 5). Husserl can arguably be understood as an early-Husserl, developing on his significant contribution of *intentionality,* and a later-Husserl, where he enters transcendental

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[1] E.g. intuition as method, philosophy as rigorous science and theory of multiplicity (Deleuze, 1988, p. 117).

philosophy investigating the structure of experience through intersubjectivity, intentionality and time (Zahavi, 2003). Nevertheless, the philosophers are argued to share sufficient axioms in their theories so to understand Husserl as a possible extension of Bergson, at least in their understanding of inner experience through a theory of time.

In his paper, Winkler (2006) argues that Husserl and Bergson make use of the manifolds in each their system, amounting to a very similar position. To repeat, for Bergson, elements in space are countable and thus juxtaposed, forming infinitesimal divisions differing only in degree and not in kind; the manifold of space is that of juxtaposed elements differing in degree. In contrast, time is a continuous manifold where elements are not external to one another but interpenetrate by interconnecting in succession. For each position or point in this manifold, there are traces of another, creating an indivisible and indissoluble continuity.

Although Husserl and Bergson shared a remarkably similar philosophy on numbers, unity and multiplicity (see e.g. Husserl, 1887), Husserl had a different approach. Starting in senses, Husserl notices the double relation in the unity of perception, namely that of seeing the environment in its forms and motions, its colours and sounds, its structure and size, and that of seeing the anger appearing in the eyes of another, the joy in a smile, the happiness in a gait (Husserl, 1997, pp. 8–9). In perceiving an object there belongs a manifold of discrete appearance, which Bergson coined *quantitative multiplicity*—however, in the unity of appearance, there is a manifold of continuous manifolds, which Bergson referred to as *qualitative multiplicity*. Husserl thus, similar to Bergson, outline perception as a continuous experience, bringing with it both manifolds of continuous relations and discrete appearances, and not merely a linear deciphering of sensory datum.

Departing from the manifold, both Bergson and Husserl hold that perception is a passage. Husserl holds that the manifolds consist of possible perception, understood as anticipated perceptions (Husserl, 1997, p. 252), whereas Bergson holds that manifolds consist of virtual states which pass into the actual. Within their theories, the virtual and the anticipated both take point of departure in the past, which, to this end, is the critical point. For both Bergson and Husserl, a fundamental principle of experience is the synthesis, or actualisation, into a unity of the indeterminate manifolds resulting in a synthesis of real experience. The anticipated perception and virtual actions are based on prior experiences, meaning the past is present even before the present—this will be clarified later. Further, both for Husserl and Bergson, dissociating time from space marks the fundamental difference between consciousness and reality (Winkler, 2006, p. 98). Given their apparent convergence, Husserl's concept of temporality and intentionality provide new principles to the established list in the prior chapter. The following four points of convergence will be highlighted:

- The *relation* between action and perception
- *Intentionality* and *virtual action*
- *Constitution* and *unity* of experience
- *Indivisibility* of time

Elemental attitudes in Husserlian phenomenology concerns; what is meant by perception is phenomenology, what constitutes it and how is it related to intentionality? By addressing these questions, the emerging answers naturally synthesise with Bergsonian philosophy.

## 5.2 Primacy of perception

### 5.2.1 Perception in phenomenology

*"We must go back to the 'things themselves'"* Husserl wrote in his *Logical Investigations* (2001, p. 168), properly situating the role of perception in phenomenology. *The primacy of perception* by Merleau-Ponty (1964) follows suit. Generally, phenomenologists hold that the relation with the world is original and practical, as well as direct and rich, as opposed to those who argue perception is intellectual knowledge of the world, e.g. early empiricism. The role and purpose of perception is an essential discussion in the given architectural context since perception may be misconceived as driven by intellectual knowledge, which would lead to a reductionist concept-driven mechanism of perception interrelated with symbolic and linguistic abilities (Fodor, 1979, 1987). In this sense, the perception of architecture would depend solely on the intellect and ability to recognise signs and symbols (Jencks, 1978). Phenomenology instead takes serious the situated and embodied encounter with the world, guided by practical concerns based on first-person and second-person perspectives, suggesting that perceiving architecture depends on the body, perspective and intentions of the situated experiencing agent. To perceive the world is not akin to that of a thinker to an object of thought. It is not comparable to a proposition, because no types of intellectual interpretation, deciphering or the like are performed. Instead, perception is experienced in action, intuitively, rather than explicitly knowing.

To Merleau-Ponty, the relation between subject and the world involves the contradiction in transcendence and immanence, an aspect relatively similar to Husserl's position (Merleau-Ponty and Edie, 1964, p. 13). Merleau-Ponty sometimes refers to the contradiction as a paradox, because two seemingly different features in perception co-exist (Merleau-Ponty and Edie, 1964, p. 16)—henceforth, it is referred to as *asymmetry in perception.* To illustrate the contradiction in perception, consider this example from Merleau-Ponty:

> *"If we consider an object which we perceive but one of whose sides we do not see, or if we consider objects which are not within our visual field at this moment* [...]*—how should we describe the existence of these absent objects or the nonvisible parts of present objects?* [...] *Should we say* [...] *that I* represent *to myself the sides of this lamp which are not seen? If I say these sides are representations, I imply that they are not grasped as actually existing; because what is represented is not here before us, I do not actually perceive it. It is only a possible. But since the unseen sides of this lamp are not imaginary, but only hidden from view (to see them it suffices to move the lamp a little bit), I cannot say that they are representations." (Merleau-Ponty and Edie, 1964, pp. 13–14; original emphasis)*

It is important to emphasise that transitions are similarly a question of understanding what is not currently available to the visual field, and must instead be anticipated, i.e. the process of anticipation is inherent in perception. Anticipation becomes a mere supposition, a possible perception, only refutable if one moves according to the structure of the object, and not by intellectual inference akin to geometric reasoning. In that sense, perception is of practical matter as a practical synthesis rather than intellectual synthesis. Perception is not divisible to simple sensory events or parts but must be grasped in its entirety, the whole setting and given context because perception is not given separately from what they signify. It is immediate and pregnant with its form, devoid of deciphering and intermediate inferences of what each sign may signify, which would otherwise be necessary given the gap between signifying sense data and the signified concept (Merleau-Ponty and Edie, 1964, pp. 14–16). To illustrate the importance of the whole setting in perception, see Figure 5.1A, where the central line is equally wide in both arrows. Besides the fact that it is close to impossible to perceive truly the central lines as equally wide, they also offer different ways of practical interacting. Suppose these were physical structures, affording to be picked up and practically investigated. If so, the structures are different from one another in perception as in their practical syntheses, e.g. they are picked up differently. Suppose the central rods were dissected from their arrows; then, the rods would be similar in their physical structure, namely plain rods of equal length. They afford to be practically investigated in the same manner. In Figure 5.1B, if the perception was a matter of intellectual synthesis, the two blue central circles, which share the same size, ought to be perceived as equal size. However, this is not the case—they are in fact perceived as different in size, mainly due to their context (Gallagher and Zahavi, 2012, pp. 106–107). The black squares in Figure 5.1C are equal in size and quadratic. The horizontal lines dividing the row of squares are all strictly linear, horizontal and parallel. If perception were an intellectual process that deciphers parts from a whole, each square would have been conceived as strictly quadratic and the lines as strictly linear. Instead, what is perceived is curved lines, almost crossing one another with eschewed squares. Opposite to immanence, perceiving more than the sum of the parts is a feature of transcendence in perception, and hence, it can be established that intellectual synthesis is different from perceptual synthesis.

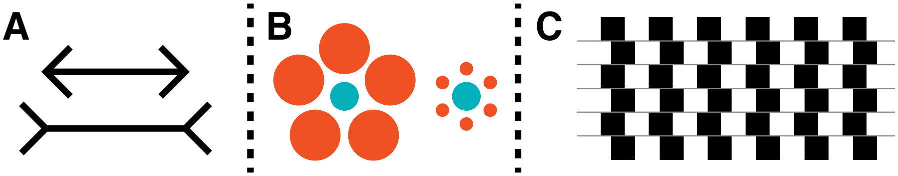

*Figure 5.1*— **A.** *Müller-Lyer illusion. The central line is of equal width in both cases. The perception that one is short/longer than the other is due to their practical use afforded by the arrows.* **B.** *Ebbinghaus-illusion. The two blue central circles in each group share the same size. Yet, one is perceived larger/smaller than the other, due to their whole setting.* **C.** *Café wall-illusion. The black squares are all quadratic, with all linear lines running strictly horizontally, although they appear to be eschewed lines and non-quadratic black squares.*

The intellectual synthesis is later resumed—however, in order to progress, it is necessary to grasp how this transcendence in perceptual synthesis is at all possible.

### 5.2.2 Transcendence in perception

Perceptual consciousness, i.e. consciousness of what is perceived, persistently transcends the perspectival profile to understand the object itself. This is what characterises the transcendental feature of perception; although the object escapes the immanent perception, there is a transcendental consciousness of the object itself. For this reason, it is said that immanence is in mind, while transcendence is outside it, i.e. the constructed impression of an appearance that is not currently immanent in mind is a transcendental feature (Brough, 2008).

In Husserl's concept of *horizonal intentionality,* one anticipates the unseen side of the lamp from another standpoint given immanently. Transcendence in this sense is anticipatory [*Vorgriff*] entering the perception as something co-intended with the actual and immanent, bringing them into *appresentation*; a kind of making co-present (Husserl, 1999, p. 146). The nature of horizonal intentionality is precisely the anticipatory process in perception, as it allows the experiencing agent to see more than she sees, and less than she sees (Gallagher and Zahavi, 2012, p. 108). She sees more in the sense that perception fulfils the objects in their entirety by anticipating them as a whole, a form of transcendence in perception, whereas she sees less in the sense that although most of the peripheral vision seems colourful, it is, in fact, colourless (Johnson, 1986). Although much of the environment seems given, it is difficult to read this page by looking at it once, closing the eyes, and read it from some mental representation. Indeed, there is no representation [*Vergegenwärtigung*] of the world within the subject. Husserl holds an anti-representational account of perception, with no intermediary between the embodied agent and the world, hence the *primacy of perception*. Instead, the world is directly perceived by acting in it and anticipating within the perceptual synthesis, devoid of intellect, so that the act of perception precedes the intellect. In this sense, there are no relevant differences between a perception and a hallucination, since both situations offer the intentional object as presented in an intuitive givenness.

The relation between intellectual and perceptual synthesis can be demonstrated through an analogy of propositional reasoning and abductive reasoning. Although the *Pythagorean Theorem* is true now and later and although the later progress in knowledge cannot disprove the theorem, it can, however, change how one perceives the theorem. Further developments of the theorem may make the first theorem a mere draft, changing the perception of it—yet, it remains true. If once proven true, it cannot be proven untrue; this is the condition of numbers and mathematical logic. The perceptual truth of Pythagorean Theorem is not timeless, whereas its ideal truth is. The ideal and perceptual truth is precisely what the intellectual and perceptual syntheses share; they appear to themselves as temporal, with a future and a past, and a future-directed openness holding the power of correcting what now appears false (Merleau-Ponty and Edie, 1964, pp. 20–21); indeed, this is an abductive form of reasoning. It holds true for both kinds of syntheses that *"what is given is a route, an experience which gradually clarifies itself, which gradually rectifies itself and proceeds by dialogue with itself and with others"* (Merleau-Ponty and Edie, 1964, p. 21). Given the syntheses share the truth-adjusting feature, both syntheses seem to qualify as answers to the question of perception; but is perception a question of truth-value? As the route unfolds over time, what role does perception take relative to the intellect? Does one intellectually infer spatial forms through several deciphering processes of the mental image, or, is it given through perceptual syntheses that transcend by anticipatory feature? Based on our prior experiences, we can foresee a transistor; is this part of the anticipatory intuitive feature in transcendence or is it an intellectual inference?

Consider now the intuitive aspect of immediate perception. The temporal aspect of perception in the following quote from Merleau-Ponty's conclusion on the nature of perception provides a hint:

> *"By these words, the 'primacy of perception', we mean that the experience of perception is our presence at the moment when things, truths, values are constituted for us; that perception is nascent* logos; that it teaches us, outside all dogmatism, the true conditions of objectivity itself*; that it summons us to the tasks of knowledge and action." (Merleau-Ponty and Edie, 1964, p. 25; emphasis added)*

A theorem is first perceived before it is known; perception is presence, which precedes the intellect. Perception emerges intuitively from the paradox, asymmetry in perception. The asymmetry consists of a misfit between the transcendent (subjectively anticipative) and immanent (objectively material) perspective of the world. Because the asymmetry requires an anticipative feature, which is absent from the present immanent perspective, a pseudo-paradox emerges. It is a pseudo-paradox because it is not a real paradox, but only resembles a paradox[2]. It begs the question: if the transcendence of an object is co-present with the immanence of the object, how is it possible to hold more than a single perspective in mind? Does this not attain to hold two perspectives of the world simultaneously? Husserl's account of intentionality provides excellent clues to these questions of co-presence.

### 5.2.3 What is intentionality?

In any given situation, any one person is constantly phenomenally conscious of something, as in having a conscious experience. In phenomenology, being conscious of something is precisely the intentionality of consciousness (Gallagher and Zahavi, 2012, p. 123), i.e. the intention to represent the world precisely like *this*, rather than *that*; as Nagel put is: *"something that it is like to* be *that organism—something it is like* for *the organism"* (1974, p. 436; original emphasis). Contemporary philosophy address intentionality most often as *qualia*, which is conscious experience.

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[2] Note this pseudo-paradox as it will in this chapter only be dealt with philosophically but readdressed in cognitive neuroscientific terms in Chapter 8.

Before Husserl, other philosophers, e.g. Aristotle, Aquinas and Brentano, spoke of intentionality as the capacity to hold in mind something as a mental state or as a representation. David Chalmers, whom coined qualia as the *hard problem of consciousness*, argued that any problems relating to the causal processes of mind are easy problems, whereas those that deal with the content of the intentional, i.e. qualia, and the first-person experienced inner life address the hard problem of consciousness (Chalmers, 1996, pp. xi–xii). Chalmers questions how it is possible for a physical structure, such as the body and brain, to give rise to phenomenal experience. He then also questions the phenomenal experience itself, which is the specific character of conscious experience; why a particular colour is experienced as *this* rather than *that* (Chalmers, 1996, p. 5). This is a critical aspect to raise relative to the pseudo-paradox because it addresses the core of how experience emerges from physical structures such as the sensory organs. Chalmers' questions are located at the very threshold of transcendence and immanence, a position that is critical to a naturalisation of phenomenology, which is not a direct goal of the thesis, but an important step to address given the empirical nature of the research question.

Throughout history, it has been challenging to dissociate intentionality and mental representation, which are often used interchangeably (Brower and Brower-Toland, 2008). To this end, the dominant debate concerns whether intentionality is reducible to qualia, or vice versa (see e.g. Dennett, 2015). Fodor (1987, p. 97), defending a representational account of mind, expressed that in naturalising intentionality and being a realist, it is hard not also to be reductionist; can one exclude the first-person experience in investigating intentionality, by reducing it to mere psychophysics, so that the differences in experiencing the colour red are not qualitative differences (differences in kind) but differences in quantity (differences in degree)? If so, all experiential qualities are a matter of physical measurement, i.e. light intensity upon the eyes. These broad questions are not sought to be answered directly—however, giving a Husserlian account of intentionality, and comparing to Bergsonian virtual actions, reveals a general agreement on an alternative approach to qualia. Although qualia are not of main interest, it holds nonetheless an essential position in perception, and since architectural transitions operates through perception, it is necessary to investigate the nature of qualia and mental representation. Furthermore, intentionality and virtual action will reveal how it is possible to simultaneously co-present objects and experience space.

Intentionality in phenomenology studies the meaning in mental states, not to be confused with having a purpose in mind when acting; this is merely one aspect of it (Gallagher and Zahavi, 2012, p. 126). Unique to Husserl's theory of intention is the *existence-independency,* which means that the intended is independent of its actual existence. Brentano, for instance, approached instead a form of *immanentism*, where the intended held an ontological reality in mind, i.e. an actual representation. Husserl's existence-independent intention is the essence of the anticipatory feature situated at the asymmetry because it allows anticipation to form as an intention without the actual perceived. To be more concise, different from his other contemporaries, Husserl had a relationally structured approach to intentionality, so that it is impossible to understand the mind without its objective correlate, which is the perceived. For instance, if *A* causally influences *B*, then *A* and *B* must exist, however, if *A* intends *B*, only *A* must exist.

Similarly, it is impossible to understand the intentional object without its subjective correlate so that intentionality and perception are interrelated (Gallagher and Zahavi, 2012, p. 129). This approach is different in the sense that in dealing with imagined objects, any intentional object must refer to, or be about, something, i.e. *a referent*. Even if the referent does not exist, the intentional state has a reference as it retains certain conditions fulfilling the imagination. If it is true that the person reading this doctoral thesis is holding it in the hands, then both the person and the thesis exists. If it is true that the reader intends the doctoral thesis, then the doctoral thesis does not need to exist (Zahavi, 2003, pp. 20–21). The intentional, that which is retained in mental states, is not an object (Zahavi, 2003, p. 17), but an answer to the question of what a certain mental state is about:

> *"If the answer refers to some non-existing object, the intentional object does not exist. If the answer refers to some existent thing, then the intentional object is that real thing. So if I look at my fountain pen, then it is this real pen which is my intentional object, and not some mental picture, copy, or representation of the pen." (Gallagher and Zahavi, 2012, p. 131)*

By further exploring intentionality, the anticipative feature, which is of high interest, becomes clearer. Currently, Husserl suggests that the anticipative feature does not need to exist to be intended. To put it in architectural terms, to anticipate the subsequent space in architectural transition is intuitive, and nothing more. The intended space, which is arguably comparable to qualia, does not need to exist in space, but merely as intuitive anticipation for the experiencing agent. However, the anticipative feature in transcendence is not the full story. As Merleau-Ponty pointed out above, it takes nothing but a simple action to bring forth whether the intentional object meets the immanence in perception—if not, an asymmetry calls for adjusting the perception. Action, it seems, resolves the question posed in perception and intentionality.

### 5.2.4 Embodiment

Husserl has arguably written less on the role of the body in perception, as compared to Merleau-Ponty. However, having dedicated half the lectures given in 1907 (Husserl, 1997) to kinaesthetic and oculomotor changes in perception reflects their importance in his philosophy of perception. Over time, Husserl provided extensive investigations of the body as he came to realise its central position between subjectivity and the world. The body anchors perception to a certain point of view, from which all that enters perception is understood only in its part, so that perception is a reference to the whole. It is not an act of the intellect, but a totality open to a horizon of perspectives that merge and define the object in question. For instance, one cannot conceive a perceptible place where oneself is not present providing a point of view (Merleau-Ponty and Edie, 1964, p. 16). There is no pure point of view, i.e. a view from nowhere. Any perception of the environment is thus from a spatial orientation, as it is always from here or there that the environment appears to the perceiver. Husserl develops in his theory of perception the concept of orientation, which is precisely that anything is given from a situated and embodied point of view, where the body continuously utilise self-experience as an indexical *here* concerning what appears in the environment (Zahavi and Overgaard, 2012, p. 285). *"Hence the discreteness of spatial perspectives. And hence also the transcendence of objects of outer perception, for, again, on perceiving the object from the front side its backside cannot be perceived ... So, given an infinite number of spatial orientations the object will always be 'more' than what is perceived of it from any side"* (Winkler, 2006, p. 98).

The early Husserl was preoccupied with the orientation provided by the body, whereas the later Husserl realise the body's role for constituting a perceptual reality, and thus turn to the mobility of the body. Husserl investigates the process of change in perception, given a mobile body (Husserl, 1997, p. 133; Zahavi, 2003, p. 99)—quite similar to Bergson. Here, he immediately observes the importance of time in movement, since the body seems to perform continuously double functions in order to make sense of the perceived because, during action, perception is continuously under perspectival change. The co-functioning is firstly expressed with a kinetic experience of the body itself, which amounts to a form of bodily self-awareness, putting the body as both a subject and an object, and secondly with a continuous transition from one perception to the other (Husserl, 1997, pp. 131–132; Zahavi, 2003, pp. 99–100). If these two conditions are not met, one is presented with two separable objects. Once again, a co-intentional[3] process is evident in Husserl's philosophy, one that is yet to be elaborated on. Consider the following practical example:

> *"Whereas the actually given front of the wardrobe is correlated with a particular bodily position, the horizon of the* cointended *but momentarily absent profiles of the wardrobe (its backside, bottom, and so on) is* correlated *with my kinaesthetic horizon, that is, with* my capacity for possible movement. *The absent profiles are linked to an intentional if-then connection. If I move in this way, then this profile will become visually or tactually accessible. The absent backside of the wardrobe is only the backside of the same wardrobe I am currently perceiving because it can become present through a specific bodily movement." (Zahavi, 2003, p. 100; emphasis added)*

In this sense, the kinetic synthesis is a practical synthesis, so that one is not perceiving movement, but anticipating it in co-intention. Recall Bergson's principles, namely the importance of interacting with the environment to reduce the indeterminate state of the body. Furthermore, the unified process of action and

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[3] Perhaps even "co-conditional".

perception construct an individual world. For Husserl, at any given moment, perception is both correlated with a position of the body and with co-intended perceptions; this is precisely the aforementioned double function that credits the body a constitutive role in perception.

Husserl realised that the body could provide answers for questions regarding the relation between subject and world, mainly because the body could be perceived as a subject and as an object, i.e. at the threshold of the asymmetry. Consider the tactile sensation when sweeping the fingers over a table. One may sense the table itself and its properties, but one may similarly change attention towards the sensing hand so that one becomes aware of the movement and pressure, that are not part of the object, but the experiencing hand. From this example, one may differentiate between the *sensing,* as the hardness and smoothness of the table, and the *sensed,* as part of the embodied subject (Zahavi, 2003, pp. 102–103). Another example; the right-hand touching the left one. Sweeping the right-hand over the left-hand one senses the surface of the left hand; however, similarly, the left-hand senses being touched. The touching hand is not touching an object, or an insensible hand, since the touched senses the touch itself. This ambiguous double-sensation is precisely the sense of self-awareness; one is experiencing oneself in a way that anticipates how others might experience the sensed. One enters a loop of self-evidencing so that the touch must come by one's own since the touch correlates with both experiences—again, co-intentional. Within the experienced reciprocity, Husserl refers to an agreement and simultaneity between *objectivating* and *subjectivating* the experiences (Husserl, 1997, p. 137). There is an agreement of both experiences that is experienced by changing attention, which in turn explains the role of the body as an indexical *here*, since over time, the body correlates with any given experience situating the experiencing agent precisely *there*. In this sense, the body is not given and subsequently one investigates the world—au contraire—the world is provided as bodily investigated. It is in the interaction between body and world that the subject becomes aware (Zahavi, 2003, pp. 103–105). In short, bodily actions causes a perception, which in turn causes the action.

Insofar, it is established that:

- One perceives the whole rather than the parts.
- The intention is independent of direct perception enabling co-intention in perception by possible action.
- Experience is constituted by simultaneity in perception and active bodily functions.
- There is a self-evidenced awareness of the body through double-sensation, where the reciprocity enables a co-intention to take place at the same time.

It must be emphasised that these points require parallel processes of consciousness and can only be valid if the experience itself is temporally widespread, in the sense that it does not occupy a single moment, but rather a duration. With this established, we are now better equipped to investigate the temporal problem of co-intention, the double perception of the world and how the asymmetry between transcendence and immanence unfold.

## 5.3 Intentionality and experience

### 5.3.1 Intentional fulfilment

As stated above, the relation between experience and world—a responsibility that is ascribed to intentionality—reveals the asymmetry between transcendence and immanence. To clarify this relation, the nature of intention must be explored. When intending an object, there are three distinctive alternatives; *signitive (linguistic), imaginative (pictorial)* and *perceptual (direct)* (Zahavi, 2003, p. 29). The lowest level an object may be intended is in the signitive act. In a conversation about a lost cat, one can refer to their specific cat, without the cat being present nor any other appearance of her. Indeed, the cat, although merely a linguistic referent, becomes an intentional object, devoid of any intuitive content. If, for instance, a picture of the cat accompanies the talk, then an appearance of the cat becomes the intentional object, perceiving her now indirectly. Imaginative intention bears a certain resemblance to the cat as seen from the perspective offered by the picture. Only perceptual intention offers a direct type of intentionality which presents us with the object itself, *in propria persona*, that is, to perceive the cat herself (Gallagher and Zahavi, 2012, p. 100). The signitive act is of interest because this intentional act designates the existence-independent intentionality, which paved the way for the anticipatory feature in perception. In fact, through a process of signitive intentionality and the fulfilment of it, one has acquired justified knowledge about the world. The cat is instantiated as a mere intention, but when found, the synthesis of coincidence functions as a double fulfilment. The cat differs in its givenness, as it is given as an intentional object and as an intuitively present object. This is not to be confused with two separate ontological truths, but merely a synthesis of coincidence between two intentions. The directedness in intentionality reflects the primacy of perception, the direct relation to the world, devoid of intermediate mental representations—the world and its properties are not experienced as re-presented as much as presented; experience is presentational of the world and its relative properties.

When the lost cat is found and directly perceived, the direct perception of the cat fulfils the intention. *"Whereas at first I had a mere signitive intention, it is now being fulfilled by a new intention, where the same object is given* intuitively*"* (Zahavi, 2003, p. 30; original emphasis). The cat was merely intended or held in mind, but when met with *itself,* it attained an intuitive fulfilment of the cat. To this end, Husserl reflects his Bergsonian influence, namely in that any intentional experience consists of more than a single moment, making it inseparable because it necessarily consists of an intention that is not yet met. In other words, there is an *intentional quality* and *intentional matter* of the experience. The former refers to the kind of experience in perceiving, hoping and judging, whereas the latter refers to whatever the intention is directed at, e.g. a cat, a book or this doctoral thesis. In this sense, intentional quality is the heterogeneous dimension, whereas the intentional matter is the homogeneous dimension of Bergsonian philosophy. When the cat was found, the direct perception fulfilled the intention with quality and matter, and this is the essence of the asymmetry between transcendence and immanence in Husserlian philosophy; how the mind and world relate through fulfilments of intentions, or the failure to do so. The inseparability is addressed in the temporality of experience.

Notably, although a signitive intention is fulfilled, it is rarely fulfilled perfectly as intended. In fact, it is the asymmetry, the lack of coincidence, between the given and the intended that characterise the acquired knowledge about the object. No object is perceived as intended, because of the bodily and perspectival constraints; because only perspectival profiles of the object are given. When intending the physical book of this doctoral thesis, one is not intending the perspectival given surfaces, but one transcends the given and understands the book itself from virtually any perspective. There will always remain perspectives that are not given and instead anticipated in intention. Epistemologically, the intuition is irrelevant; *"It is only when the intuition serves the function of fulfilling a signitive intention that we acquire knowledge"* (Zahavi, 2003, p. 33).

Does Husserl, then, state that perception is knowledge? Not a bit. The anticipatory feature of intentionality supports a future-directed perceptual truth so that perception is pragmatically anticipatory. i.e. if one moves through a transistor, i.e. a spatial delineation between one space to another, what might one expect to see, touch, feel? If Husserl meant to link propositional knowledge to perception, there are no reasons to argue for the different types of evidence, emphasising that intuition is variational certainty regarding the evidence about the world. It depends on the relation between intention and the sensory that is meeting the intention (Zahavi, 2003, pp. 33–35).

If the intention was considered knowledge, then it naturally leads to an *idealist trap,* i.e. the intention becomes epistemologically sufficient to declare knowledge about the world. Indeed, the signitive intentionality is existence-independent—however, it is fulfilled in various degrees by direct perception, where the perspectival givenness of the object is based on the asymmetry. The intended object does not exist mind-independently but is intuitively given so that the *object* of knowledge is different from the *act* of knowledge.

In his criticism of psychologism, as presented in *Logical investigations,* Husserl claimed that psychologism failed to recognise the fundamental difference in the *object* of knowledge and the *act* of knowing—a critique that draws parallels to Bergson's general critique of psychophysics and the abductive form of reasoning (Bergson, 2001; Zahavi, 2003, pp. 7–10). Mathematical truths hold their validity regardless of the world so that 2 + 1 = 3 is true independently of the world with actual things. It refers not to a subjective experience with a temporal duration, but an ideal atemporal truth. Nevertheless: *"Although the principles are grasped and known by consciousness, we remain conscious of something* ideal *that is irreducible and utterly different from the* real *psychical act of knowing"* (Zahavi, 2003, p. 9; original emphasis). In discovering a paradox between real and ideal, i.e. that objective truth is known in subjective acts of knowing, Husserl suggests that an answer may be offered in the investigation of experiential givenness, hence his intuitive/transcendental approach. This argument has often been given through the observation that it is possible to imagine a *worldless* subject, whereas it is not possible to imagine a *subjectless* world.

> *"The world, and more generally, every type of* transcendence*, is relative insofar as the condition for the appearance lies outside itself, namely, in the subject. In contrast the subject, the* immanence*, is absolute and autonomous since its manifestation only depends upon itself" (Zahavi, 2003, p. 48; original emphasis).*

Acknowledging no difference in kind between object and act of knowledge leads any such questions towards false problems and, more profoundly, false solutions. In this regard, there is an undeniable similarity in the elemental philosophy between Husserl and Bergson. Their similarities strengthen when comparing their understanding of representation using *virtual action* and *intentionality.*

### 5.3.2 Virtual action and transcendental idealism

In *Matter and memory,* Bergson explicitly refers to an aggregate of continuous inner images as fundamental for representing the world. Bergson's use of the word, *representation,* is used in the French sense, meaning a mental picture often understood as perception (Bergson, 2004, p. 3). The apparent obstacle in this context is that Bergson seems to be a representationalist, whereas Husserl an anti, thus obscuring their resemblance particularly regarding representation. Both take the origin of representation and perception seriously, leading them to an investigation of the relation between subject and world. If one can see past the choice of words, given both philosophers are translated from non-English, and inspect their postulations about the inner relations in perceptual systems concerning representation instead, one finds that virtual action is fundamentally not much different from transcendental idealism. It is rather facile to show that Bergson was not a representationalist, but held a position approximating Husserl.

As shown, Bergson believes that both idealists and realists confuse the role of perception for being absolute truth, either ideal or empirical. He held that the body was at an indeterminate state, using action to investigate the world, and once investigated, the world is given as investigated through virtual actions. Perception is thus not truths about the world, but rather a matter of virtual action—or to use Gibson's term, *affordances* (Gibson, 1986, p. 140).

> *"Our representation of matter is the measure of our possible action upon bodies: it results from the discarding of what has no interest for our needs, or more generally for our functions.* [...] *The whole difficulty of the problem that occupies us comes from the fact that we imagine perception to be a kind of photographic view of things, taken from a fixed point by that special apparatus which is called an organ of perception—a photograph which would then be developed in the brain-matter by some unknown chemical*

> *and psychical process of elaboration. But is it not obvious that the photograph, if photograph there be, is already taken, already developed in the very heart of things and at all the points of space?" (Bergson, 2004, pp. 30–31)*

Bergson criticises the idea of photography preceding that which is given a priori and intuitively. He rejects any absolute truth in representation about the world given through perception, simply because this is not the purpose of perception. World and its objects, according to Bergson, are represented by their virtual action, i.e. how one might immediately act upon it, drawing deep parallels to Husserlian practical synthesis, and not by a photographic representation produced by perception organs. The temporal dimension of the anticipatory feature in virtual actions must once again be emphasised; it is the ability to immediately, and practically, *foresee* that brings about the perception, which in turn makes the foreseeing uncertain rather than absolute, i.e. a truth-value as in realism and idealism[4].

Correspondingly, Husserl rejects both isms through a similar argument, namely by targeting the role of representation and perception. For Husserl, there is a strict distinction between appearance as intentional or a complex of sensations (Husserl, 2001, pp. 89–91). In transcendental idealism, which he insists is different from any idealism at that time, transcendent objects are not objects of consciousness and are not reducible to the experience of them. *"It is to speak of object that might always surprise us, that is, objects* showing themselves *differently than we expected"* (Zahavi, 2003, p. 70; original emphasis). The transcendental object is transcendental for the experiencing agent, given from a particular perspective with a particular appearance. Its existence is linked to its possibility of appearance, and not its appearance itself so that the experience of it is embedded in a horizon of experience (Zahavi, 2003, pp. 69–70). To be more concise, Husserl uses *reell* to signify anything that is immanent in consciousness, as opposed to something that is intentionally present. An act of perception is a real event, but whatever is perceived is not *reell* in consciousness. In external space, the perceived has its reality, but the intentional content is *irreal* as it is perceived by consciousness but is not immanent (Gallagher, 1998, p. 44).

The distinction amounts to an essential notion in Husserl's intentionality, namely *intentional relation*[5]. Intentional relation is not a duplication of the external environment but explains the relation between sensed and intended. By stating that intentionality goes directly to the thing, Husserl avoids creating, and so duplicating, perceptual objects as a mental phenomenon. To this end, Husserl approximates Bergson's philosophy regarding perception by stating that perception is not mental representation understood as an absolute truth about the environment, but instead is a practical *meaning* so that one perceives something *as* something.

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[4] To believe that one may interact with spatial objects in a certain way is itself a prediction ahead of the present—one foresees that possible interaction.

[5] Recall the existence-independent feature of an intention. The intentional relation is an elaboration of that term.

To put it differently, how one perceives transcendent objects is tightly linked to how virtual actions bring about perception; they depend on bodily actions. Virtual actions are not intellectual acts that generate a finite number of *possible* actions, but is rather acts of intuition, generating embedded and embodied virtual actions that are not necessarily foreseeable, e.g. some virtual actions may be acquired by watching others or through intellectual information. In this sense, any perception depends on how one intuitively and practically might gain more knowledge about the perceived, from which there are theoretically an infinite amount of ways.

In Husserl's transcendental analysis of kinetic synthesis, he designates immense attention to the role of belief-positing, which, once again, is a matter of fulfilling an intention, so that the *reell* content in perception is a matter of establishing phenomenological evidence (Husserl, 1997, p. 14). For instance, the fixity of space as one move is constituted by the succession of appearances that are reinforced and validated through the unity of belief, i.e. we expect the space to behave in a certain way as we simultaneously move in a certain way, making the sensed and intended correlate. The fulfilment of the interpenetrating beliefs, or signitive intents, are anticipative, starting within the *phantasy*, making the unity of experience not only a continuity of appearances but a presupposed fulfilment (Husserl, 1997, pp. 125–128).

With Husserl's rejection of idealism and realism through variational certainty in the asymmetry and intentional fulfilment, where does his philosophy situate him? His transcendental approach ultimately leads his form of idealism to a position alike Bergson, which is being neither a realist nor an idealist, but instead in a melange of the two. One could have foreseen this coincidence already by their acknowledgement and agreement upon the body as an indeterminate state of being, which must necessarily interact, through a self-evidencing loop of action and perception, with its environment to firmly grasp the world. This is a temporal question of consciousness, in the sense that to understand the world, one must attempt a practical prediction of the perception in question.

### 5.3.3 A question of anticipation

Transcendence cannot be reduced to a mere range of anticipatory process—however, it is undeniably an intrinsic part of its nature to be able to encompass more than a single *if-then*-perception of any transcendent object at once. The asymmetry between transcendence and immanence emerges here; phenomenology understands perception and the relation between subject and world by inquiring the possibility of transcendent intention and validity in the sphere of immanence. A continuous perceptual belief about the world is presupposed, which is either met with conflicting or fulfilling immanence, and this is precisely the paradox of the co-existence of transcendence and immanence, i.e. immanence ensures the perceived is not foreign, while transcendence contains more than what is given. The virtual action is thus comparable to the unfulfilled intention that occupies the transcendental realm, waiting to be validated with phenomenological evidence. The world is perceived from an embedded and embodied perspective, restricting the perceptual accessibilities, and yet the world is experienced transcendentally offering more than what is given. This independent-dependent relation between consciousness and the world is a central feature of transcendental idealism (Winkler, 2006, p. 102). From Husserl's 1907 lectures:

> *"How then further will we come to understand perceptual beliefs, which relate to the actual Being of the perceived object and which now are 'confirmed' and now 'conflict,' now get determined more precisely and now possibly are determined in a completely novel way through new perceptions which bring the object to 'ever more complete' givenness and show in ever new directions 'what the object is in actuality'?" (Husserl, 1997, p. 16)*

Presupposing perceptual belief is arguably a concept in favour of idealism. Husserl introduces the validity of the directedness in a real-world, which is not mediated by any intra-mental objects. Idealism and realism seem to co-exist in a self-evidencing loop using a presupposed perceptual belief that is based on normality to resolve uncertainties about the world. Thus, Husserl's transcendental idealism is a melange of both, celebrating the statement of Bergson regarding his use of composites situating realism in one end and idealism in the other.

> *"From this indetermination, accepted as a fact, we have been able to infer the necessity of a perception, that is to say, of a* variable *relation between the living being and the more or less distant influence of the objects which interest it." (Bergson, 2004, p. 24; original emphasis)*

Similar to Bergson, Husserl hold that objectivity is constituted in lived experience, meaning that only at the constitution, which is at the conflict of transcendence and immanence, does objectivity take place (Husserl, 1997, p. 16).

> *"We have argued that in perception as such a perceived object stands there as believed and in the flesh, that in uni-fold perception, as we could name it (versus mani-fold perception), the object indeed stands there as given, but only from 'one side,' and in the mani-fold perception as given from many sides, and that in every uni-fold perception (whether for itself or as a phase of a mani-fold and continuously mani-fold perception) a distinction is to be made between presentational contents and the moment of apprehension, on which are founded, in a changing way, the intentions and act-characters of a higher stratum, including belief." (Husserl, 1997, p. 119)*

To further explore what happens at the heart of the asymmetry, the concept of *constituting* in Husserl's philosophy is inevitable. If one follows the temporal unfolding and structure of experience, where does the constitution of lived experience take place?

### 5.3.4 Constituted lived experience

It is understood that Husserl insists that *being* and *consciousness* unite in transcendental subjectivity. It must first be emphasised that the *constituting* is a process that permits appearance, unfolding and articulation, and so is not merely an epistemic relation between subject and object, as between experience and world. Such an account would credit *constituting* a spatial character when instead, it is a matter of process and time. It precisely constitutes by intertwining the transcendental subject with the immanent material space, so that subject and the world cannot be grasped separate from one another (Zahavi, 2003, pp. 72–76).

To Bergson, change is what is real, and change is what constitutes experienced reality. If so, then change consequently makes the past and future essential to the experience. How can the past survive in the present? It cannot be an instant, because it was shown in the previous chapter that an immobile, numerical point is an abstraction of real existence. In other words, two fixed abstract points that touch are the same point; they are necessarily juxtaposed—thus, to construct time through instants and points will yield no progress, no increase, but real existence has a duration. Indeed: *"The distinction we make between our present and past is therefore, if not arbitrary, at least relative to the extent of* the field which our attention to life can embrace. *The 'present' occupies exactly as much space as this effort"* (Bergson, 2007, pp. 125–126, 130; emphasis added). In other words, the edge-like experience of presence is a unity of past and future constituted by the effort of the extent that attention to life can embrace. Bergson argues that *unity* is multiplicity united into an immediate consciousness, which is a temporal argument of the possibility for experience.

Is this in line with Husserl's constitution? Is *constituting* the unfolding and uniting process between subject and world due to time? To this end, Husserl provides a hint:

> *"This parallel problem* [correlation of Ego and the surrounding world] *is offered by the temporal environment and by the constitution of the one time in which temporality of the thing resides and into which its duration is integrated, just as is the duration of all things and thingly processes belonging to the environing things. Into this same time the Ego is integrated as well, not only as an Ego-Body but also according to its 'psychic lived experiences.' The time that pertains to every thing is its own time, and yet we have only one time." (Husserl, 1997, p. 69)*

The constitution is a temporal intersubjective process, i.e. a process where the subject is inseparable from the world and drawn into the *constituting*. Constituted experience is the simultaneity of the internal and external world where perception is the master of space (homogenous and objective) while action is the master of time (heterogeneous and subjective). By now, it should be clear that the experience spoken of is one that precedes any intellectual act; it is instead at the intuitive stage, where experience is immediate.

### 5.3.5 Is the content important at all?

Given both the architectural context and the portrayed importance of time and process, one might come to question whether the (spatial) content of experience is at all important. Chalmers famously addressed the qualia issue in spatial terms, however, he failed to see the temporal aspect, or at least, proper attention was not offered. There is a difference between inquiring the *content* of the experience and the *origin* of the experience, i.e. the structure of the process. Is it necessary to naturalise the content or character of any experienced inner life/qualia, to give an empirically plausible model of the process of experience? Insofar, the concern is not to understand *what* a transistor is like for someone, as much as understand *how* it influences the experience. A description of an experienced inner life is unique to the experiencing agent, so that another experiencing agent may disagree—to what extent is *what a transistor is like* useful for architects?

Unless the description holds a meaningful explanation on how something came to be experienced like *that*, then it seems unessential. There are no apparent reasons to believe that experience of spaces are generalisable or universal; this is the hard problem of qualia. Even when restricting architecture to geometrical configurations, it is far more informing for architects to understand the internal relations in an animated narrative. The causal and correlated are of interest, as it may shed light upon *how* space might have influenced the experience. Only if the experiencing agent gives an intuitive outline with outset in their own duration can the architect benefit from such descriptions.

Undoubtedly, describing the animate experience as it unfolds affords a different description compared to the reflected description, i.e. the one in hindsight. It is unessential to discuss and compare the redness or form in the experience, despite it being enlightening on a phenomenological level. The content of what is intended is a crucial aspect and indeed, a *hard problem*. However, questioning *how* to influence it, instead of *what* it is, resolves various kinds of design questions.

Though Chalmers may define processes as the easy problem, and qualia as the hard problem, it must be emphasised that the easy problem solves highly essential questions relative to the temporal structure, whereas the hard problem solves in this context meaningless and irrelevant questions. In terms of design, it is irrelevant to understand whether one experiences red alike another, whereas *how* the experience of red may be influenced offers a potential design-tool. In a nutshell, the argument is not to inquire the content of the experience, but instead, the general structure of experience making it at all possible in the first place. Even the question of what a new utopian material feels like is a question of how the mixture of sensations are constructed, e.g. the blending of visual and haptic sensations.

With the overarching approach, which is to link an empirical framework to phenomenology, in mind; could it be that the experience should be approached strictly from a temporal dimension, i.e. an approach that investigates the dynamics of experience rather than the content of experience?

## 5.4 Conclusion

In sharing the same starting point, i.e. Riemannian multiplicity, their philosophies naturally synthesise and converge in several concepts. Both rejected the truth-value in perception and built instead a framework of perception around the bodily perspectival, i.e. the embodied and embedded, constraints so that perception depends on the kinds of actions the body can bring. Consequently, perception becomes rooted in action, i.e. knowing via a process of act. Their similarities function firstly as an argument of extending Bergsonian distinction of space and time into Husserlian phenomenology, and secondly as a Husserlian unpacking of Bergsonian philosophy of time. Husserl elaborates on the Bergsonian *virtual* by a rigorous analysis of the intended, portraying the process from virtual to real action as to the asymmetry of the transcendental and immanent, i.e. both the virtual and the intended are existence-independent and forms perception as a question rather than an answer. *"The transcendental conditions of experience are no longer abstract conditions of possible experience, they are virtual conditions of real experience"* (Moulard-Leonard, 2008, p. 7). Concisely, the Bergsonian virtual approximates the Husserlian horizonal intentionality as an anticipation feature in practical synthesis belonging to intuition rather than intellect.

With Husserl and Bergson, a framework of the immediate constituted experience of the world is provided. There exists an asymmetry, a paradox, a parallel co-conditional feature between the subject and object. The homogeneous space is scattered in its relation to the heterogeneous duration, spanning from past to future while held in the present. Distinguishing ideal from the perceptual, i.e. intellectual and intuitive, the practical synthesis was demonstrate to govern the *act*—rather than the *object* of— of knowing. It is not surprising that both ultimately explain subjectivity and time as self-temporalising and dynamic in their nature.

The next chapter elaborates on the duration/spanning through diagrams pinning down time-related concepts e.g. horizonal intentionality, appresentation and retention that are later important features in comparing the phenomenological conditions with the empirical framework.

## CHAPTER 6

# Model of temporality:
## the structure of temporal unfolding in experience

*"Life can only be understood backwards;*
*but it must be lived forward"*
*Søren Kierkegaard*

**Summary.** *How can one describe the relation between experience and time?* This short chapter seeks to clarify the critical topic of the concrete structure of time in the constitution of experience. Husserl and Bergson shared the interest in the temporal unfolding of experience, which leads them to similar structures of time—ironically, over time both Husserl and Bergson continuously realised issues with their diagrammatic structures of time leading them to several numbers of revisions. It is here attempted to put forward a framework of time and experience, which will lay the foundation and conditions for the empirical theory in the second part of the doctoral thesis. The objective is thus to expand further and unpack the theoretical framework of temporality and add Husserlian points to the existing list of conditions for a proper investigation of experience.

### 6.1 Type of time

#### 6.1.1 Cognitive paradox

At the very heart of time, there is movement; there is change. Describing the change in consciousness as a *stream* is different from a *succession*[1]. William James (1842-1907) famously described consciousness as a stream, where the *now* had a

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[1] Succession here must not be understood as Bergsonian duration where time interpenetrates, but rather as a juxtaposition of points in space, i.e. Bergsonian homogenised space.

width rather than being a knife-edge. Indeed, time moves, but the integration of past, present and future has been debated at least since the Numidian philosopher and bishop, St. Augustine of Hippo's (354-430) *Confessions* from year 400. The core issue has been presented in numerous ways but can be approximately summed as *the cognitive paradox* (Gallagher, 1998, pp. 6–7). It is named the cognitive paradox because it is a matter of resolving the integration and relation between memory as the past, perception as the present and expectation as the future. How can past be represented as past by an impression that is present? How does a stream of consciousness represent more than a single time simultaneously? Is change not that which it was not? The cognitive paradox is primarily an issue concerning the simultaneous occurrence of cognitive functions. Although the specious present has puzzled Aristotle, St. Augustine, Locke, Lotze, William James, and many others, only the approach by Bergson and Husserl are here considered.

Nowhere else was Bergson's understanding of the duration in the present more concisely expressed than in the second lecture of *Perception of Change:*

> *"Thanks to philosophy, all things acquire depth,—more than depth, something like a fourth dimension which permits* anterior perceptions to remain bound up with present perceptions*, and* the immediate future itself to become partly outlined in the present. *Reality no longer appears then in the static state, in its manner of being; it affirms itself* dynamically*, in the continuity and* variability *of its tendency." (Bergson, 2007, p. 131; emphasis added)*

This description of the present is strikingly similar to Husserl's structure of temporality, which also is their solution to the cognitive paradox; Husserl's intentionality avoids the problem of the cognitive paradox by his notion of intentional relation and by describing the temporal flux through his concepts of *retention, primal impression* and *protention*, which are neither *memory*, *the now* nor *an expectation*, respectively.

Before diving into Husserlian temporality and unpacking the mentioned concepts, consider first the direction of time. Bergson and Husserl understand time as a flux, a dynamic and continuous process that is indivisible. This may seem quite natural to many, but this does not reach universal acceptance among philosophers. McTaggart (1866-1925), a Scottish philosopher of time, distinguished between A-series and B-series, which designate different approaches to time and came to define two common philosophical descriptions of time (see also presentism and eternalism in; Buonomano, 2017). Philosophers belonging to A-series believe that time flows from the future to the present, to the past as a dynamic process; a stream. Such an account makes events move from and presumes that the present is not fixed and unchanging, but variable and changing.

In contrast, philosophers who belong to B-series, believe that time is a physical substratum, where the flux is merely an illusion of the mind (Fig. 6.1). For them, terms as *past, present* and *future,* are irrelevant and instead pays attention to *being earlier than* and *being later than* relative to each other. Time is an objective measure;

thus, nothing will ever subjectively change due to the passage of time. One event comes after another, chronologically and objectively; a succession (McTaggart, 1908, pp. 457–459; Gallagher, 1998, p. 87; Mullarkey, 2000, p. 12). Coarsely, A-series philosophers cast time as subjective, whereas B-series philosophers cast it as objective.

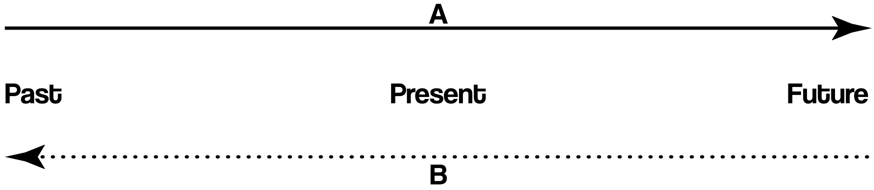

*Figure 6.1*— **A.** *The solid continuous line designates the structure of experience according to Bergson and Husserl. One starts from the past, using prior experiences to accurately perceive the environment and to intuitively generate virtual actions, moving into the future through experience.* **B.** *The juxtaposed dots forming a line designates the structure of events. The present is always the present; it never changes. Time is objective in this sense.*

Bergson's critique of the spatialised time is precisely a critique of the B-series philosophers, who do not attribute continuous change value nor importance to the conception of time. Duration seems more in agreement with A-series philosophers regarding the movement of time, so that time moves with the condition that the future is based on the past: *"In any case, the Bergsonian revolution is clear: We do not move* from the present to the past, *from perception to recollection, but* from the past to the present, *from recollection to perception"* (Deleuze, 1988, p. 63; emphasis added). Vital for the upcoming structure of time is that the direction of time flows from past to future according to Bergson; thus, the present depends on earlier encounters. A closer look reveals that already at this assumption of direction of time presumes the present to be constituted by more than given. Diving into hyle data[2], Husserl reveals that in the sensory content itself, there is no more than given, but that the apprehension mechanism is increasingly complex (Gallagher, 1998, pp. 46–47). This necessarily problematises the temporal explanation, because then one may have sense contents that have not yet reached the perception organ. How is it possible to sense something that is not currently apparent?

### 6.1.2 Husserl extending Bergson

The issue at hand is to explain how temporality allows the possibility to have *reell* sense-contents to be both now and not-now. Deleuze interprets Bergson's use of *recollection* as preserved in itself, i.e. *in* duration, so that the recollection belongs to the intuition of time, and not (working-) memory as contemporarily defined (Deleuze, 1988, p. 54). For Bergson, the past and present coexist, i.e.

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[2] Hyle data is Husserl's expression of sensory content, which is understood as the current sensory response, e.g. the current light onto the eyes, the current sound in hearing and the current temperature in a space. It is the non-representational and immanent in consciousness (Williford, 2013).

the recollection is intuitive and serves as the foundation of the present. In other words, to believe that the past is no longer is to confuse *Being* with *being-present.*

> "[...] *Bergson invokes metaphysics to show how a memory is not constituted after present perception, but is strictly contemporaneous with is, since* at each instant duration divides into two simultaneous tendencies, one of which goes toward the future and the other falls back into the past." *(Deleuze, 1988, p. 118; emphasis added)*

Presence *is* not—instead, it is *becoming.* While the present passes, the past preserves itself in itself as a whole integral past, making all past contemporaneous with the present (Deleuze, 1988, pp. 58–59). Bergson turns to the concrete structure of apprehended time and Being to *psychologise* time by embodying it (Deleuze, 1988, p. 57). It is the embodying and concretising that Husserl excels at, and so extends Bergson's ideas involving tendencies going towards the future and falling back into the past.

Husserl, agreeing that the present is a duration, introduces not intellectual acts of consciousness, but performances belonging to consciousness, such as *retention*: *"The retentional tone is not a present tone but precisely a tone 'primarily remembered' in the now"* (Husserl, 1991, p. 33). Husserl exemplifies retention by referring to musical tones so that one holds a tone in retention even when it has just-passed and another tone is *reell.* The retention must not be confused with the intellectual act of recollection or reflection, because it is part of the *immediate* consciousness:

> *"But it surely does belong to the essence of the intuition of time that in each point of its duration (which we can make into an object reflectively) it is consciousness* of what has just been *and not merely consciousness of the now-point of the object that appears as enduring" (Husserl, 1991, pp. 33–34; original emphasis).*

Husserl elaborates on the retention and the now:

> *"When a primal datum, a new phase, emerges,* the preceding phase does not vanish but is 'kept in grip' *(that is to say, precisely 'retained'); and thanks to this retention, a looking-back at what has elapsed is possible. The retention itself is not a looking-back that makes the elapsed phase into an object; while I have the elapsed phase in my grip, I live through the present phase, take it—thanks to retention—'in addition' to the, elapsed phase;* and I am directed towards what is coming (in a pretention)." *(Husserl, 1991, p. 122; emphasis added)*

In this sense, retention performs as *direct intentionality*, allowing continuity of itself as a just-passed referent by transcending itself and posit *something* as being just-passed, without *something* being *reell.* This is the mastery of intentionality and the solution posed by Husserl for the coexistence of past and present; it is an intended just-passed, which is structurally part of the present. The very same idea

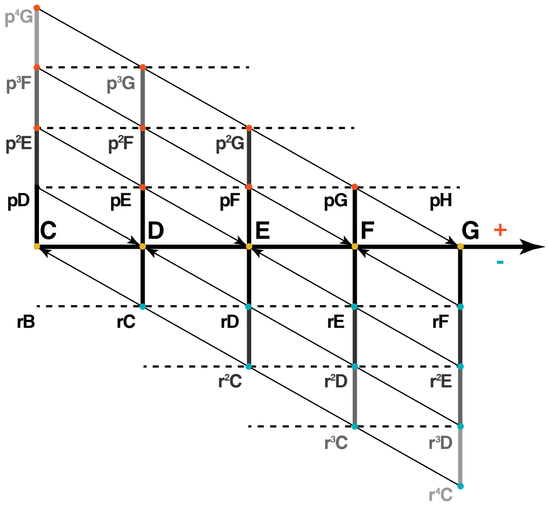

*Figure 6.2—Husserl's diagram of time, based on drawings from the Bernauer Manuskripte (Husserl, 2001b, pp. 20–22). The solid horizontal line, CDEFG, designates the flow of events. Each phase contains retention, primal impression and protention. The retentions are designated by blue dots below the horizontal lines, whereas the protentions are red dots above the horizontal line. The vertical lines illustrate retention, protention and primal impressions at the crossing. For instance, at the phase of D, there is more certain protention of the upcoming phase, pE, compared to the further phases $p^2F$ and $p^3G$. There is also retention of prior phase, rC, which similarly is more certain than the further phases $r^2B$ and presumably $r^3A$. As everything is pushed into retention, time can be conceived as an ever-growing retentional train (Gallagher and Zahavi, 2012, p. 84). It is worth noting that one neither move backwards nor forward, but somewhat sideways, through time, i.e. facing the future above and the past beneath while moving to the right.*

applies to the future, i.e. the protention as mentioned above. Note that both retention and protention perform as uncountable nouns, i.e. mass nouns.

Throughout his investigations, Husserl developed different diagrams of temporality that are expressed in the famous *Bernauer Manuskripte* (Husserl, 2001b, pp. 20–22), from which also his diagram lays point of departure in Fig. 6.2.

At each phase, illustrated as a vertical line[3], an enduring act of consciousness contains retention of the just-passed, a *reell* primal impression and a protention of the about-to. Within the phases, both retention and protention stretch far into their respective directions, so that one hold a less certain conscious intention of the just-just-passed compared to just-passed, and mutatis mutandis for protention (Gallagher, 1998, pp. 50–52). The intelligible manoeuvre that Husserl exhibits in his model is two-fold. First, neither retention nor protention contains anything *reell*, but are instead intentions with references—not representation. Such account

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[3] As mentioned by both Bergson and Husserl; the moment the structure of time is spatialised through a drawing, it becomes obsolete. The contemporaneous property of time becomes juxtaposed rather than interpenetrating. For this reason, both struggled with their development of diagrams of time—however, Husserl's proposal seems adequate to make the points.

allows for more than a single static understanding of the world, as retention and protention do not hold any representational status—that is, one does not experience more than one world by having retention and protention. Instead, the experience of the world is precisely co-intentional, which in turn makes the flow indivisible; at each instant of time, the protention and retention change in kind. Second, by intentionality, each phase contains another phase without being *reell,* consequently stretching the now-phase by an intentional self-temporalising present[4], ultimately bringing an alternative to the cognitive paradox. Husserl's co-intentionality necessarily produces a Bergsonian interpenetration of time, making it indivisible into separate wholes. It always stretches in time, as *durée*. Husserl thus solves both (1) the possibility for an indivisible horizontal flow of duration by interpenetrating past and future into the present, and (2) vertical co-intentional simultaneity of past and future, i.e. retention and protention, in the present. It must be emphasised that neither retention nor protention is a function of memory or intellectual anticipation, but a constant feature of consciousness, intuitively widening the present with an intentionally constituted duration (Gallagher, 1998, p. 51).

The primary reason for Husserl's diagrammatic readjustments of the temporal synthesis, as evident throughout *Bernauer Manuskripte* (Husserl, 2001b), is the cognitive paradox—he could not make sense of the primal impression as a flux in the diagram. Perhaps, this is the reason for Bergson rarely drawing diagrams of the unfolding of time. Translating time to a diagram is to necessarily change its nature to that of space, which consequently becomes infinitely divisible. For instance, the primal impression in Fig. 6.2 can be understood as a point and can thus be divided continuously, which might have brought Husserl to the drawing desk time and again.

How does the structure of time fit with the practical synthesis, the horizonal intentionality and the asymmetry between transcendent and immanent? The relation between protention and retention is a structure of fulfilment of protentional directedness, necessarily situating protention in a guiding role of experience. In contrast to retention, protention is unfulfilled intentionality, providing a virtual horizon of perception. *"In general, protention indicates the mode of givenness of an immanent object-point that is directed toward a future mode of givenness in which this object-point will be given in its maximum fullness"* (Kortooms, 2002, p. 166). In this sense, protention as a horizonal intentionality approximates Bergsonian virtual actions because protention is an immediate performance of consciousness with intentionality that has yet to be fulfilled. Given the interest in immediate experience of transition, the structure of immediate fulfilment is essential.

### 6.1.3 Synthesis

Fulfilment can be split into passive and active levels, so that the former, in

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[4] The present becomes self-temporalising in the sense that the stream of pretention moves towards becoming retention. This stream temporalise the now-phase.

contrast to the latter, occurs without intellectual acts of the Ego[5]. Roughly put, passive synthesis, as elaborated in Husserl's *Analyses Concerning Passive and Active Synthesis* (2001a)*,* is an unconscious synthesis with manifold of lived experiences of a transcendent that believes it needs fulfilment (Husserl, 2001a, p. 148). The radical claim Husserl puts forward is that experience is guided by, and thus depend on, passive anticipations of normality, which is established by prior experiences. In other words, the current and upcoming experiences depend on prior experiences. Protentions are thus not mere unfulfilled intentions, but an immediate expectation of normality that the retention must adhere—however, if the current experience mismatches the prior experiences, an experience of *anormality* emerges, adjusting future anticipations (Zahavi, 2003, p. 133). Only the negation, which is expressed in different ways, is of relevance.

> *"First, an original negation here essentially presupposes the normal, original constitution of the object* [...]. *The constitution of the object must be there in order for it to be modified originally. Negation is a modification of consciousness that shows up as such in accordance with its own essence. Secondly, the original constitution of a perceptual object is carried out in intentions (where external perception is concerned, in apperceptive apprehensions); these intentions, according to their essence, can undergo a modification at any time through the disappointment of protentional, expectational belief." (Husserl, 2001a, p. 71)*

> *"The being of the world is only apparently stable, while, in reality, it is a* construction of normality*, which in principle can collapse" (Husserl as cited in Zahavi, 2003, p. 139; original emphasis).*

It thus follows that there is no stagnant, invariable world, but a relation between normality and *anormality*. To this end, it is at this level of the passive synthesis in the immediate experience that concerns the architectural experience of transitions. Notably, the attentive and affective dimensions in passive synthesis elucidate the felt experience and its bridging to active synthesis. For instance, during the nagging experience of a staircase having too big steps, there is a peculiar affective pull from an object given to consciousness, and then to the attentive of the Ego (Husserl, 2001a, p. 196). The fact that the stairs are too big is not given by conscious inferences, or active synthesis, but by unconscious inferences, or passive synthesis, based on prior experiences and a proper understanding of the bodily physical structure. This very process of intuitively constituting the world is reflected in the horizonal intentionality, e.g. upon encountering staircases, one constitutes that these are stairs and not fallen roof or broken floor. This constitution is independent of any conscious intervening, but based on passive immanent connections, and brings forward with it the affective similarities. Upon the

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[5] The Ego translates to the intellectual act of consciousness. Active synthesis is the involvement of the Ego, while passice synthesis occurs at the level of intuition, i.e. in absence of the intellect.

constitution of the staircase, an affective pull is *felt*, which tends towards previously experienced affective pull (Husserl, 2001a, chap. 2).

Given the possibility of adjusting in cases of asymmetry in normality, the role of the passive synthesis is to perform inference to the best explanation. In other words, passive synthesis performs abductive reasoning, i.e. tending self-evidencing reasoning, to grasp affectively and practically the environment. In the act of transitioning, prior experiences aid the experiencing agent to generate protentions of the upcoming space—not by first perceiving, then relating to prior experience and then connect the perception to the prior experience. In this sense, the world would be dissociated from meaning, so that one first encounters a world, and then adds meaning to it. Instead, within the act of perception, retention and protentions are already within the horizonal intentionality endowed with meaning, referring to the primacy of perception. It is always a meaningful world one encounters.

The following aesthetic passage of Bergson observing the clock describes the relation between passive synthesis and duration:

> "[…] *four o'clock strikes… each stroke, each disturbance or excitation, is logically independent of the other, mens momentanea. However, quite apart from any memory or distinct calculation, we contract these into an internal qualitative impression within this living present or passive synthesis which is duration. Then we restore them in an auxiliary space, a derived time in which we may reproduce them, reflect on them or count them like so many quantifiable external-impressions." (Deleuze, 2004, p. 92)*

### 6.1.4 Points of convergence

Although there seem to be several points of agreement, there are also several disagreements. For instance, Bergson refrained from drawing models of time, as opposed to Husserl, because the models are necessarily externalised by using an infinitely divisible line that spatialises time. However, the first point of concrete agreement is the nature of time. This argument amount to the Bergsonian argument of time, namely that it is indivisible into separate wholes that are independent of one another. If one attempts to divide time, one will not have differences in degree, i.e. moments that share the same unit of measure as mathematicians consider $t$, but differences in kind where each moment must be considered separately with a different unit of measure. Therefore, time is theoretically separable, but when separated, the moments differ in kind, not degree. Another point, among others, is that Husserl addresses the performance of immediate consciousness to hold experience in retention, while Bergson is preoccupied with the fact that all present are based on the past. Both positions hold that at any given now-point, an immediate past, or merely past, interferes with the apprehension of a constituted present. Husserl extends this idea to also pretention being part of the now—that which Bergson approached as virtual action. Bergson's account in this sense has paved the way for Husserl's temporality, where the past and the future coexists with the present.

It appears Bergson and Husserl agree upon:

- **Duration in any given moment**, making time indivisible as it contains retention and protention that differs in kind, not in degree.
- **Embodied perception**, which depends on the action, situating the experiencing agent in a practical world through a bodily physical structure.
- **Temporalisation proposes a change that proposes an action** that is guided by virtual actions and protention, which thus are comparable.
- **Passive abductive reasoning** occurs in the absence of the intellect, i.e. the possibility of logical operations by the unconscious to perform abductive reasoning, so it adjusts the world through experience.
- **Neither a pure realist nor idealist position** can account for experiencing the world. Perception does not serve truths. Instead, the experience is a mixture where protention is expected to be fulfilled and adjusted accordingly if any asymmetry occurs relative to retention.

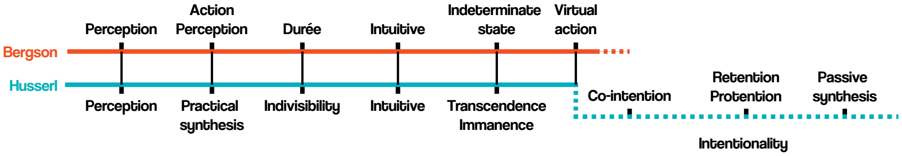

*Figure 6.3—Converging points between Bergson and Husserl that illustrates in which fashion Husserl functions as an extension to Bergson. The outset for both philosophers is human perception, which depends on a situated acting body, which practically perceives. Any experience endures, otherwise one is not able to fulfil the primary conditions for knowledge, which in turn is believed to belong to intuition, or the transcendental in Husserlian terms so that the multiplicity is given beyond what is perceived immanently. The asymmetry between the transcendent and immanent illustrates an indeterminate state of the body, only resolved through dynamic processes between protention and retention, where unfulfilled intentions are either rejected or fulfilled in retention. This allows a co-intentionality to take place already at the stage of intuition, hence the name 'passive synthesis'. Virtual action covers the exclusively detailed descriptions of intentionality offered by Husserl, and it is precisely his detailed descriptions that are necessary to understand the temporal structure of experience.*

These points reflect the agreements between the philosophers—not the conditions for a proper investigation of experience. Interestingly, as Husserl comply with Bergson to this level, and given that Husserl went on further in his philosophy of experience than Bergson, taking Husserl's points seriously can illuminate the immediate experience of architectural experience transitions (Fig. 6.3).

## 6.2 Temporalising nature and naturalising time

By now, it is clear that time and experience are inseparable and interlinked notions, so that speaking of temporalising nature and naturalising time is a topic relative to the nature of experience; it is a relation between the intended and the given. Analysing Bergson and Husserl helps bridge the seemingly unbridgeable gap between biology and experience, i.e. the earlier mentioned *hard problem*. However, both philosophers have positioned themselves as critics of purely natural sciences, believing the agenda of natural science alone does not comply with each philosopher's respective agenda. Consider Bergson's critique of Fechner for instance. In *Time and Free Will*, Bergson provides a rigorous critique of the detrimental reduction of sensation in psychophysics to understand what it means to experience. Bergson stated that Fechner confused measuring sensation with determining the exact moment at which an increase of stimulus produces a change in the sensation (Bergson, 2001, p. 61). The quantitative intensity was confused with qualitative phenomena. Bergson held that quality is private, inaccessible by others—how it arises; we shall never understand (Bergson, 2004, p. 39). There are traces of a similar line of argument in his critique of idealism and realism. The service of perception is not to provide absolute truths about the world, and so their relation is not one-to-one. The sensation is not a matter of intensity and should not be confused with the qualitative aspect of experience. There is not much chance for naturalising experience through science alone according to Bergson.

Instead of naturalising experience, he was primarily occupied by a temporalised nature, finding in the mobility of time much more about the qualitative human nature of the action, body and experience and their complex dynamic interrelations. Temporalising experience is a necessary step to naturalise experience; this is evident in Husserl's general approach and development of phenomenology. Although, for Husserl, the central issue in naturalising phenomenology is the different agendas. Phenomenology is not only concerned with a psychological description of an experience, which approximates what Husserl termed phenomenological psychology but also phenomenology as a transcendental philosophy concerned with the possibilities of knowledge and the general conception of *a priori*, i.e. subjectivity in transcendental phenomenology. Importantly, according to Husserl, empirical and transcendental subjectivity are not two different subjectivities, but two aspects of the same subjectivity. The fundamental difference between the psychology and the philosophy is their aim, so that phenomenological psychology concerns descriptions of first-person perspective and intentionality, while transcendental phenomenology concerns the possibility for knowledge, i.e. consciousness as a condition for meaning and appearance. Insofar, transcendental phenomenology is a matter of an indeterminate body that can, due to its temporalising nature, make use of action and perception to resolve the asymmetry between the transcendental and immanent. This issue has been well-discussed by Zahavi (2004), who suggest at least four potential ways a naturalising phenomenology can go:

- Empirical sciences continue, regardless of phenomenology.
- Phenomenology must constrain empirical science, situating phenomenology over empirical science in one-way communication, meaning that phenomenology sets the agenda of experience.
- Distinguish between the transcendental and psychological phenomenology, investigating the psychological aspect alone, so that the transcendental dimension remains untouched. Such an approach amounts partly to

an investigation of the (retrospective) intellectually processed experience.
- Allow an inter-manipulative relation between empirical science and transcendental phenomenology, informing on another and thereby changing continuously their definitions, including what might be understood by *nature*, i.e. a reciprocal dynamic approach.

The approach suggested by Bergson proves supportive of naturalising phenomenology without reducing its transcendental character. Given the transcendental dimension, phenomenology is not explicitly concerned with the content of experience, i.e. the hard problem, but rather with the possibility of knowing a colour, a taste, a smell or other qualitative experiences. The proper nature of transcendental phenomenology is temporal. It is a question of how it unfolds over time as an experience, revealing the pure structure and possibility of experience. Time is not strange to empirical sciences, and can with metaphysical conditions generate better knowledge applicable to both science and philosophy. Recall that:

> *"Scientific hypothesis and metaphysical thesis are constantly combined in Bergson in the reconstitution of complete experience." (Deleuze, 1988, p. 118)*

Therefore, the fourth suggestion is precisely what must be attempted in the current context—namely, to establish a list of conditions by Bergson and Husserl to ensure a proper investigation of the structure of experience during architectural transitions. In this sense, investigating the immediate, embodied and lived experience serves the purpose of naturalising specific aspects of the experience. As suggested in the last point of Zahavi's (2004) list, the two can join a fruitful exchange of findings, suggesting progressive thinking without an ontological duality in sight.

The inevitable question becomes; how does the body become more determinate and confident about a world? The variational certainty is revealed in action and perception, so both in time and space. The twist added to the current approach is that, to paraphrase Zahavi (2004, p. 336), the general assumption has often been that a better understanding of physical space brings a better understanding of time, perhaps due to the general confusion of mixing them—however, the assumption here is that a better understanding of time provides a better understanding of space and its relation back to time.

### 6.3 Immediate experience

With three distinct models of time, protention hardly played any role until the last model (Kortooms, 2002, p. 158). Protention is highly underestimated in Husserl's accounts of time. Indeed, protention is comparable to virtual actions, revealing virtual perception of the space, i.e. specific perceptions that could emerge from specific actions. Bergson asserts that the virtual is more than the actual numerous times. In the passive pre-reflective synthesis, the *a priori* to experience is precisely the protention of the immediate experience—it is protention before becoming retention. Passive synthesis is thus capable of explaining the dynamics of how experience is temporalised and constituted before the active intellect intervenes.

It would be to misunderstand Husserl's model of time to believe that the primal impression is constituting experience if by *constitution* is understood a stable unity of experience. Keep in mind that the transcendental is that which has a role in the constitution of a world (Kant, 2000, p. 23), which mean that if the primal impression constituted experience, it must itself hold retention and protention, and admittedly fall into a regressive fallacy[6].

What is then the role of primal impression in constituting a world? The primal impression is *when* the effect of the constitution takes place rather than the cause. Husserl solves this issue by suggesting that the continuous progression of the flow is not analogous, but as "[…] *shocking (when not initially even absurd) as it may seem to say that* the flow of consciousness constitutes its own unity*, it is nonetheless the case that it does"* (Husserl, 1991, p. 84; emphasis added). It was already stated that subjectivity is self-temporalising (Zahavi, 2003, p. 90), so this is hardly a surprise. The important note here is that the self-temporalisation is the genesis of experience emerging from the asymmetry between protention and retention—it is not the primal impression, retention or protention alone that are the genesis of experience, but their dynamics.

> *"Further, the phenomenon gives itself as a genesis, with the one term* [protention] *as awakening, the other* [retention] *as awakened. The reproduction of the latter gives itself as aroused through the awakening" (Husserl, 2001a, p. 166)*

The emergence from the asymmetry between retention and protention is precisely what gives the possibility for experience, i.e. lived experience is made up of a continuous stream of retention and protention, so that it is brought forward through a vast anticipative construction (Berthoz and Petit, 2008, p. 70).

## 6.4 Conclusion

Husserl has proven helpful in extending and unpacking Bergson's contemplations regarding time. In broad terms, what Bergson termed *intuition* approximates Husserl's *passive synthesis*, since both happen before the functioning of the active ego or intellect. Both hold time is indivisible because it is interpenetrated by retention and protention, which is how the self-temporalised subjectivity makes sense of the asymmetry between the transcendental and the immanent. In other words, the asymmetry is an intuitive process, i. .e a passive synthesis, of comparing protentions that are based on prior experiences with the immanent hyle data that are evident in the primal impression and held in retention. The immediate experience becomes a river of intentionality that is either fulfilled or met with obstruction based on normality. Intentionality, including virtual actions, all depend on the body's

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[6] If the primal impression (*pi*) is constitutive, it holds retention (*r*) and protention (*p*)—but if one strip, once again, the *r* and *p* from the new *pi*, there emerges a new *r* and *p*—and so on, ad infinitum.

physical structure and capabilities to investigate and generate apperceptions.

The strategic manoeuvre by Husserl was to not assign *reell* status to retention and protention, so that the theory offers an alternative to understanding the immediate experience as stretched into the past and future as a co-intentional structure. Co-intention in perception is the outcome of this manoeuvre, i.e. being able to co-present perception due to retention and protention.

Following points can be considered as Husserl's unpacking and extending of Bergson's conditions for a proper investigation of experience:

1. **Heterogeneity of duration** is unpacked and extended as **the indivisibility of time**. Husserl unpacks the indivisibility by casting any given moment as constituted by retention and protention so that the stream of consciousness is eventually self-temporalised. The extension is in the co-intentionality giving the retention and protention non-*reell* status, moving beyond the cognitive paradox.

2. **Indeterminate state of the human** is unpacked as the **asymmetry of the transcendental and the immanent**. By holding an embodied anchor in the empirical framework, the indeterminate state is unpacked as incongruence between idealist and realist, which is resolved only through action/perception.

3. **Dynamic relations** are unpacked as **the primacy of intuition.** It refers to what Husserl named *passive synthesis*, which is the phase of immediate retention and protention. By operating at the level of intuition, the investigation remains at the threshold of dynamic self-temporalisation.

At the very threshold between the transcendental and the immanent is this peculiar performance of self-temporalising. It functions as a cornerstone in the phenomenological account of experience and temporality, yet it seems obscure and vague. What does it mean to self-temporalise? How does intuition self-temporalise? How many of these constructed metaphysical terms are empirically determined? Which terms are dissociable processes and not the outcome of intermingled processes? These are some of the questions that *Part II* must pursue to answer—and it does so by questioning firstly, what does it mean to *emerge* in biology?

# PART I

# Specifying the research question

The question, from the architectural quandary in Chapter 3, was whether the experience of *space B*, arriving from *space A*, is identical to the experience if arriving from *space C*—keeping in mind that architectural transitions are reduced to shapes and forms. In the current context, the affective experience is never questioned because that belongs to the psychological description rather than the transcendental. Instead, it is held that to understand transitions, we must understand under which measures and conditions they emerge in perception. It is the possibility of creating a meaning of the world; not the psychological effect, but the transcendental cause.

It was argued that equating specific spatial configurations with specific experiences is to confuse space with time. Instead, one should acknowledge that the body is embedded in space so that the experience of space is always from a specific point of perspective, which means that space is never grasped as a whole space, but only as what is available to the organs of perception. The experience unfolds over time, where dynamics of retention, primal impression and protention constitute experience. Necessarily, the experience of *space B* as approached from *space A* is distinct from the experience of *space B* as approached from *space C*, because the retention differs, which in turn cause other protentions. Architecture differs in degree since it is in space, whereas the experience of it is continuous and dynamic, i.e. indivisible, differing in kind just as the motion that propels the body through space.

Husserl unpacks and extends Bergson's concepts and philosophy of time, which brings with it the strategic manoeuvre of co-intentionality. Although the perceptual organs do not present one with the backside of a cup or the upcoming space behind a transistor, there is an *a priori* practical understanding of the potential interaction with the cup or the transistor. Husserl named this the *practical synthesis,* which is enacted by a dynamic relation between retention and protention, on which the co-intentional feature in perception is based. Retention and protention describe the temporal phase of the practical synthesis so that potential interactions are situated as virtual actions in the protention, whereas the prior experiences to construct the current state of the world are situated in the retention. This analysis reveals that the *architectural experience of transition* is a question of the dynamics of immediate prediction and prior experiences.

In sum, according to Bergson and Husserl, space can influence experience as it is involved in forming the perception and the potential action in the environment. This observation emphasises the action-perception process of experience, which articulates the research question in the direction of the process of actively moving between two spaces delineated by a spatial threshold. At the temporal scale, the research questions address the immediate experience, i.e. the experience that anchors the experiencing agent to the world. At the spatial scale, it is the unfolding of animate space as one transit from one space to another. The overarching research question is thus:

**How does experiential transition unfold through action and perception relative to architectural transition?**

It is worth noting that the nature of the research question in the thesis is a rolling one, i.e. it changes as more knowledge is acquired throughout the thesis. The forthcoming chapters must indeed be conceived as an attempt to naturalise phenomenology and aspects of experience, involving complex dynamic systems that share the same foundations as the philosophical outset. This is precisely the reason for initiating the research question from philosophical grounds, i.e. phenomenology sets conditions for a proper investigation of experience. The following conditions must be met in an empirical account of the experience:

1. **Heterogeneity of duration as an indivisibility of time**, i.e. continuity in the stream of consciousness by interpenetrating moments of time.
2. **Indeterminate state of the human as the asymmetry of the transcendental and the immanent**, i.e. reducing indeterminacy about the world through embodied and embedded action/perception.
3. **Dynamic relations as primacy of intuition**, i.e. the immediacy of the given and the process of self-temporalising.

# Part II

## AN EMPIRICAL AND COMPUTATIONAL FRAMEWORK

## CHAPTER 7

# Self-organising dynamical systems:
## embodied emergence of cognition

*"The term dynamics refers to phenomena that produce time-changing patterns, the characteristics of the pattern at one time being interrelated with those at other times. The term is nearly synonymous with time-evolution or pattern of change. It refers to the unfolding of events in a continuous evolutionary process."*
*(Luenberger, 1979, p. 1)*

**Summary.** *What is the point of departure of experience in biological science?* In order to build a model that enables empirical testing of a hypothesis, it is essential to shape an understanding of the interplay between environment, body and brain relatively detailed. Thus, this chapter marks a change in the scientific discipline. Directing attention towards a naturalised theory will form the point of departure for this second part. The naturalised approach must fulfil the conditions from *Part I* to argue an investigation of the human experience. This chapter provides an overview of cognitive function relative to the anatomical organisation of the brain and body with an emphasis on the neuronal relations. To this end, this chapter anchors the theory in certain positions in cognitive neuroscience, e.g. a minimally decomposable system. For now, there is no consensus regarding the underlying biological processes describing the relation between body and brain, and therefore the following is not an absolute theory, but a prominent account. A dualism between global (including body) patterns and local components enables a discussion of causations between the body, brain and the environment. It is argued that to maintain the homeostatic balance, which is necessary to stay alive, the brain is embodied via biologically self-organised dynamical systems that regulate the homeostatic balance. In this sense, the body and brain entertain a circular causal relation, where the brain is influenced by, and influence, the body. Self-organisation and circular causality are dynamically indivisible systems because

components of the systems cannot maintain themselves, which addresses the condition on the indivisibility of time. The take-home message is that action-perception of the world emerges *in* time via the dynamics between predictions and sensory. This chapter seeks to address:

- *Why is investigating the brain and neuronal activity an advantage during architectural experience and transitions?*
- *Is it expectable to establish linear-models of brain functions during architectural experience and transitions?*
- *Is it reasonable to search for architectural experience-dedicated brain region(s)?*
- *How do experiential transitions relate to global and local patterns?*

### 7.1 Basic minds

It is by now clear that the research question addresses transcendental cause that are fundamentals of existence, i.e. a matter of basic human functions, comparable to the task for a living creature to remain alive in its environment—in other words, the maintenance of homeostatic balance. To succeed in this task, any living organism must interact with its environment in a manner that optimises chances of survival. Therefore, by first investigating the elementary processes of staying alive as a human organism, it is intended to highlight the indeterminate nature of the human body embedded in an environment that needs to be understood dynamically. A look into the biological perspective of the most basic types of life sheds light upon the question: what are the most basic functions of a living creature?

According to Antonio Damasio, the mechanics of life management—including procuring nutrition, consuming and digesting it, finding the energy products, placing them in the body, disposing of waste—are crucial for living cells to stay alive (Damasio, 2010, p. 41). Any deviation of the acceptable narrow range results in discomfort experienced in the organism. To stay alive, the cell goes through homeostasis, so the internal milieu fits the external milieu in a sense that maximises potential to stay alive. What does this mean? Maintaining homeostasis is not simple. It requires the cell to maintain a collection of parameters dynamically in its internal milieu within an acceptable narrow range from an always chaotic external milieu. These parameters include tracking levels of oxygen and carbon dioxide, converting energy to ATP, regulate temperature, relocate nutrition and much more. Damasio (2010, p. 44) argues that actions within the internal milieu are guided by what now comes to flourish as emotions in complex human beings, making emotions more basic than earlier anticipated. Although Damasio claims homeostasis to be able to do the magic for life to happen, he does not believe that simply correcting *after* any imbalances will keep the cells alive. Instead, Damasio suggests that evolution "[…] *took care of this problem by introducing devices that allow organisms to* anticipate imbalances *and that motivate them to explore environments likely to offer solutions"* (Damasio, 2010, p. 44; emphasis added). From being able to anticipate, which applies equally to an amoeba as to a human being, *biological values* emerge. This concept describes the values assigned to external milieu concerning the anticipated implications of homeostasis. By interoceptive and exteroceptive sensing, the organism can predict the biological value according to the particular regulation required to maintain the homeostatic balance (Damasio, 2010, p. 49).

At the threshold between a living organism, performing homeostasis to stay alive, and a chaotic external milieu, the organism through exteroceptive sensory actively interacts with its environment, and even assigns biological values to some of the features that it anticipates will improve the current balance. Damasio emphasises multiple times that these regulating and predicting processes are non-conscious processes (2010, pp. 42, 49). At this threshold, we find the origin of perception, i.e. how a living system responds to its environment.

Responding to an environment is perhaps the most important feature for survival, precisely because a response involves movement. To paraphrase Damasio, plants can have tropisms, but they cannot uproot themselves and cross the garden where there is currently a better environment (Damasio, 2010, p. 50). The given example is limited in the sense that before the plant decides to uproot itself, it needs to sense that there is a better environment across the garden. This emphasises the relation between movement and intero-/exteroceptive sensory, namely that sensing changes can lead to movement. Interoceptive senses came to include internal pH-levels, temperature, muscle tension and other molecular tracking, whereas exteroceptive senses came to include smell, taste, touch, hearing and seeing, without going into details (Damasio, 2010, pp. 50–51). To move and respond to the environment does not require a complex brain or a mind (formal subject); plants, eukaryotic cells and bacteria express these capabilities. It is easy to see how the basic feature, i.e. action-perception, co-evolved into a complex reciprocal system that is essential to understand given the nature of the research question. The unfolding of action and perception depend on the environment, but the direction of the unfolding is, according to Damasio, a matter of responding to environmental incentives (2010, pp. 51–54). These incentives, independent from conscious deliberation, serve to guide behaviour in favour of biologically economic outsets through rewards and punishments. Incentives came to be because of brains able to measure the degree of need for correction. For such measurement, the brain needs to have an impression of the current state, desired state and the comparison of these. Damasio explains briefly how this process takes place:

> *"The agents involved in orchestrating these tissue states are known as hormones and neuromodulators and were already very much present in simple organisms with only one cell. We know how these molecules operate. For example, in organisms with a brain, when a given tissue is risking its health due to a dangerously low level of nutrients, the brain detects the change and grades the need and the urgency with which the change must be corrected.* […] [A] *corrective chain of responses is engaged, in chemical and neural terms, helped by molecules that speed up the process." (Damasio, 2010, p. 53)*

Brain activity, through hormones and neuromodulators, in this sense, reflects the degree of need for correction (see Appendix B for a brief introduction to neuron and nerve systems). Keep in mind that the brain must understand internal and external milieus, and thus responses to both milieus are implicitly reflected in cortical activity (this topic is returned to in Chapter 10. On a molecular level, the brain would begin to release dopamine and oxytocin for rewarding, whereas it releases cortisol and prolactin for punishing. In return, these releases optimise behaviour and prediction in the sense that *"they would differentiate the coming of an expected item and an unexpected one by degrees of neuron firing and the corresponding degree of release of a molecule (e.g. dopamine)"* (Damasio, 2010, p. 54). The upshot is that responses improve by predictions, which further anchors total bodily states as emotions, drives and motivations.

It becomes apparent to see how a living organism can respond and automatically adjust to events in the environment—however, a continuous preparation for what might be coming next, requires pre-emptive action and not mere reactive actions, i.e. an active agent rather than a passive agent. The organism must predict multiple contingencies and have strategies for dealing with potential events. *Allostasis* designates such a predictive self-adjustment (Sterling, 2012). Allostasis is a process that allows for strategical planning and prediction to override ideal homeostatic balance because it is concerned with adapting to change to achieve stability (Sterling, 2004). By having a predictive attitude towards regulation, allostasis respects the homeostatic balance by satisfying the internal and external needs before they arise, making prediction a most basic feature of natural biology and life. The term *basic feature* has appeared twice, that is, once relative to action and perception and once relative to predictions in organisms. As it turns out, these features may not be as distant as seemingly so.

However, it remains difficult to see precisely how the process of an organism making sense of the external milieu with regard to its internal milieu unfolds. The body and brain make sense of the environment through exteroceptive sensory organs, which are constantly active, but always uncertain of the signals. Aranyosi (2013) has extensively researched the relation between philosophy of mind and the peripheral nervous system (PNS) because the PNS is the apparent outermost distinction between the human body and environment. The sensitive parts of the PNS serve to make sure that exteroceptive stimulus, through nerve cells, finds a way to the central nervous system (CNS), which then enters awareness (Aranyosi, 2013, pp. 1–2). The brain is anatomically a centre of nervous systems, co-construed in a manner that fits the beholder's body. The uncertainty about the environment has an immense influence on the internal states, e.g. believing that a ball is coming at one's face is going to put one in either a nervous state or a courageous state—either way, it is felt throughout the body. Precisely the question of *how* the brain and body make sense of the environment is essential to the research question. Dynamics systems theory (DST) provide a perspective that suggests how an organismic system may organise itself and respond to the environment to settle the indeterminate state of the body into a more certain state.

## 7.2 Dynamic systems theory

### 7.2.1 Non-linear dynamics

Before introducing DST, the importance of parallel processing in even the most basic biological creatures retaining a brain must be considered. From simple studies of the nematode *C. elegans*, which has 302 neurons and thus can be considered to hold a very basic brain, it can be observed how not only touch, but different kinds of touch will affect the worm in its exploration of the environment (Li *et al.*, 2011). Besides managing tactile sensations in the environment, the worm is further able to set out strategies for when to consume food and how by way of smells (Hart and Chao, 2009). For instance, by use of olfactory cues, the worm explores its environment and decides whether to feed alone, which it usually does when given a quiet environment, or if to come in groups, given a particular odour that indicates threat (Damasio, 2010, pp. 56–57). Despite holding a very basic brain, the worm exhibits complex behaviour that is not too far from human behaviour. The worm does not know what is really going on but is instead guided by environmental cues that its eight dopaminergic neurons responds and adjusts to while providing action possibilities (Kindt *et al.*, 2007; Vidal-Gadea and Pierce-Shimomura, 2012). In this sense, the body only has control of itself, and by being in an indeterminate state constantly, exploring the potentially harmful environment is the only hope for survival. The pressing question is then, how to manage in parallel the bodily system given all available environmental cues?

DST offers an explanation, and it has to do with temporal relations in systems. The forerunner of DST, *cybernetics*, embodies the underlying ideas in DST. *"The most fundamental concept in cybernetics is that of 'difference', either that two things are recognisably different or that one thing has changed with time"* (Ashby, 2015, p. 9). By these words, Ross Ashby understands the minimal requirement for a transition. Cyberneticists were occupied with building mechanical structures that could maintain themselves internally by retrieving information about the external environment. Ashby explicitly retrieves inspiration for such a mechanical system from biological systems, ultimately building a mechanical machine that can maintain its homeostatic balance, i.e. *The Homeostat* (Ashby, 2015).

In DST, as the opening quote suggests, the term *dynamic* refers to time-changing patterns, where a pattern at one time is interrelated with that at another time. In other words, *"it refers to the unfolding in a continuing evolutionary process"* (Luenberger, 1979, p. 1). Time is the essence in DST, dealing in particular with the transitional pattern involved in a given system, explaining why DST is presented mathematically as differential or difference equations, i.e. they represent the temporal linkage between variables. The term *system* refers to the recognition that a meaningful investigation of phenomena can only be achieved by considering the entirety, including its environment. In this sense, one should expect complex interrelations with several components in the system of the body, where meaningful analysis can only emerge if taking into account the entire system and relations among its components (Luenberger, 1979, p. 2). Systems involving a large number of interrelated variables are named *multivariable systems,* where the change of the output is not proportional to that of the input, i.e. a non-linear system. Linking the mind in science with DST can be traced back to cybernetics (Ashby, 2015) and synergetics (Haken, 1983)—however, their link has not been posited as explicit as Van Gelder's (1998) *Dynamical Hypothesis* (DH)[1]. Van Gelder explicitly states that action, perception and cognition can be better understood by way of a DST approach as opposed to the dominant computationalist approach. DST introduces advantages over non-dynamic (digital) systems in, for instance, the von Neumann bottleneck problem[2].

DST provides a way around the Neumann problem, which is the limitation of throughput given the computer architecture, that is, by the use of symbols in processing, a sequential rule is inevitable, making parallel processing difficult or impossible. The paradigm that designates this approach is usually referred to as the *input-process-output system*, which is precisely what DST avoids. By disregarding symbolic processing, which is *localised*, meaning that any malfunction will result in a severe malfunction of the system as a whole, DST instead makes use of distributed operations, making the system more robust to single malfunctions (Varela, Thompson and Rosch, 2016, p. 86).

The issue of any non-dynamic approach to cognition is that of prioritising *state* over *time*. Instead of inquiring the precise state of a system, DST attempts to establish how the state changes, i.e. the transitions between states. This makes DST a prominent theoretical approach to understanding the human experience in transitions. To give an example beyond computer science, consider the classic example of the solar system. The system consists of various components, i.e. the planets, the moons and the sun. The DST approach aims to describe the system's behaviour over time by modelling the change mathematically. To this end, DST is a mathematical model of system behaviour (Thompson, 2007, p. 39). To contrast DST and computationalists (non-dynamic approaches), consider here their characteristics (Port and Van Gelder, 1995; Van Gelder, 1998, pp. 38–43; Thompson, 2007):

- **Change/State**: dynamicists prioritises how things change over time, where the medium is the state, which is of little interest. Computationalists focus on the state so that change is merely the bridge between states.
- **Geometry/Structure**: dynamicists understand a state by its relative position in the system as a whole, so what constitutes the state is of little interest. Computationalists focus on the internal structure to explain how combining pieces form a structured whole.

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[1] DH refers to a DST approach, casting the organisation of the brain as maintaining a dynamic system.

[2] von Neumann's bottleneck problem refers to the computational limit due to its architecture, i.e. between processors and memory storage, where running programs are held in memory, there is an inevitable latency when running a program (data transfer rate). Because processors have become increasingly faster, while the memory processing has not, the processor spends a lot of time idle. Despite the velocity of a processor, the bottleneck problem regarding the data transfer rate cannot be overcome.

- **Timing/Order**: dynamicists are interested in when states change, rather than what the states are, as opposed to computationalists. In light of human nature, dynamicists are interested in how behaviour happens in time, in contrast to what the behaviour is.
- **Parallel/Serial**: dynamicists hold that processes operate in parallel interdependently given their complexity in relations, whereas computationalists hold that processes change in series. Dynamicists hold that processes unfold continuously and simultaneously.
- **Continuous/Discrete**: dynamicists do not consider inputs as the initiation of the system nor outputs as the goal or result, as computationalists do. Instead, dynamicists hold that the system is a continuous model of its environment, maintaining appropriate change.
- **Coupling/State-setting**: interaction is a matter of influences on the shape of change. In contrast to computationalists, who hold that interaction is a matter of state changes, dynamicists hold that interaction is a matter of continuous changes coupling systems reciprocally.
- **Antirepresentation/Representation**: dynamicists hold that there is no use of symbols or representations in systems, as opposed to computationalists, but instead parameters that hold no other purpose but to influence its environment, e.g. a specific parameter as viewed from one aspect of the system, may seem different from another aspect.

These points outline the main differences between DST and non-dynamic approaches, which generally can be distinguished as centralised (non-dynamic) and decentralised (dynamic) accounts of neuronal and cognitive functions. DH, being the link between algorithmic processes of DST to biological and cognitive processes, explicitly states that the body of cognitive agents are dynamic systems, where cognition, action and perception do not happen *over* time, but rather *in* time. Recall the example of the solar system. The system behaviour was initially thought to be predictable by way of differential equations so that when given the initial conditions, all future states are calculable (Thompson, 2007, p. 39)—however, differential equations depend on initial conditions, e.g. the velocity of all particles that exhibits non-linear behaviour, which makes calculating all possible future state in principle impossible. Instead, Henri Poincaré provided a novel approach in a series of papers starting from 1881 where he simultaneously initiated the early days of DST. Poincaré introduced the *qualitative* study of differential equations. *"Rather than seeking a formula for each solution as a function of time, he proposed to study the collection of all solutions, thought of as curves or trajectories in state space, for all time and all initial conditions at once"* (Norton, 1995, p. 46). In this geometric understanding of equations, topological/geometric techniques were a clear choice. To consider all possible solutions collectively is achievable by using *phase space*[3] (Fig. 7.1). The notion of process and time in complex systems seem to have led both Riemann

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[3] Phase space refers in DST to a space where all possible solutions are traced, i.e. the full trajectory of a planet.

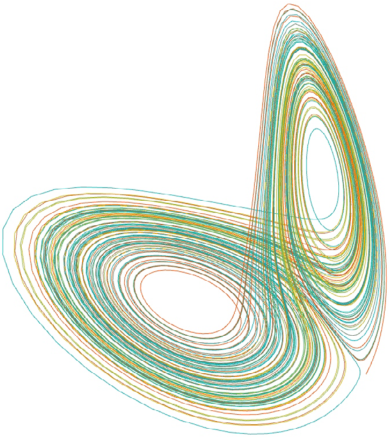

*Figure 7.1—This trajectory is known as the Lorenz attractor. Here illustrating all the possible states (within discrete time) of three simplified non-linear Navier-Stokes equations from fluid dynamics. When plotting all possible states in phase space, a complex ordered system emerges, known as a strange attractor. Characteristic of strange attractors is that they never close on themselves, and thus never repeat the same motion, as long as the state remains on the attractor. The attractor can be considered the global pattern, which emerges from local rules directed by dynamics equations.*

and Poincaré to a topological understanding of systems (see Poincaré's epic publication *Analysis Situs*). This approach, instead of seeking the exact values of states, seek to understand the character of the system's long-term behaviour. In contrast to computationalists, the symbol processing is here replaced by the topology of the system and its components, so its functions are directly dependent on their physical realisation.

Why is it important to understand the underlying principles of DST given a research question on architecture and transitions? The architectural experience of transition depends on the embedded body from which action and perception emerge. The basic feature, i.e. action and perception, was shown to be temporally extended and involve retention and protention. Insofar, Husserl, Bergson and now Damasio emphasise the importance of anticipative behaviour in basic cognition, e.g. action and perception. This approach does not solve the puzzle of anticipative ability—however, DST does shed new light upon how cognitive processes relative to the body and environment might be understood, and it certainly involves predictive behaviour, i.e. long-term behaviour. To this end, DST is an approach that focuses on the pattern of change that admits to a parallel reciprocal system that can reach an immensely complex structure.

Nevertheless, this is not to say that the whole body interconnects directly, as this would bring forth an ineffective network. Ashby (1960, p. 219) rightfully argues that there are occasions where an increase in the number of connections can be harmful. Considering neuronal networks, Ashby radically states that coordination between parts in the brain can take place in the environment, *"communication within the nervous system is not always necessary"* (p. 222).

> *"The anatomist may be excused for thinking that communication between part and part in the brain can take place only through some anatomically or histologically demonstrable tract or fibres.* The student of function will, however, be aware that channels are also possible through the environment.*" (Ashby, 1960, p. 220; emphasis added)*

This radical claim has direct implications for architecture begging the question; how does the brain make use of the environment, if at all? This question is addressed later (Chapter 8). Insofar it has been established that operating with DST; the whole system changes if a single state change, which makes the implications of change *global*, as opposed to *local*, i.e. any change, is a change at the global level of the system. It is worth noting that global in this sense refers to the body as a whole—hence, *embodied* cognition. This approach may seem chaotic in the sense that, if a human brain consists of 86 billion neurons where 16 billion are in the cerebral cortex (Herculano-Houzel, 2009) and a single neural state changes, then it will have an effect on the system as a whole. However, DST favours a network theory of cognition, which emerges from neuronal reciprocity and anatomical connections that are necessary (Sporns, 2011, p. 184). If the role of the environment in the cerebral function is a question of dynamical linking the biological body with its environment, it is necessary to dive into the very threshold of how such systems emerge. This inevitably leads to a brief discussion on the biological origin of cellular and neuronal activity.

### 7.2.2 Biological emergence

To specify a system accurately, organisational behaviour, i.e. a set of relations, is necessary. In *The Organizational Behavior* (Hebb, 2002) Donald Hebb famously introduced the idea that *neurons that fire together, wire together*, implicating that the connection between two neurons that fire simultaneously, strengthen their connectivity as an abstract form of learning. This has often been referred to as *learning by correlation* (Hebb, 2002, p. 158). From this theory on cellular assembly (Hebb's rule) flourished the idea of neural networks, forming the connectionist approach to neuronal activity. In this sense, the history of neurons is inseparable from its connectivity since stronger connectivity indicates prior compliance. Hebb's rule, therefore, holds that neuronal activity is intrinsically related to that neuron's particular history, which exhibits adaptive behaviour. This is quite a powerful statement. Assuming Hebb's rule to be accurate, neural networks respect a DST approach since such a strategy would prioritise the network rather than a given independent neuron. The system, in this manner, takes part of a higher complex system, which, when presented by a pattern, goes through a learning phase and then creates strong or weak links that ultimately can fall into an internal configuration that reflects the learned item (Varela, Thompson and Rosch, 2016, p. 88).

In the science of non-linear dynamical systems, which ranges from chaos theory, complexity studies and connectionist modelling, these biological systems are known as *autonomous systems*. In this biological view, autonomy can ultimately be viewed as a self-maintaining organisational system that enables living creatures to manage their interactions with the world using their own capacities. Consequently, such a system must self-regulate to maintain itself (Vernon *et al.*, 2015, p. 3), which complies with Damasio's account of homeostasis as a primary balance for life.

*Autonomy* closely links to *self-organisation* and *emergence*, and although these are not interchangeable concepts, they are indefinable without one another. At least since the symposium *The Notion of Emergence* in 1926 by the Aristotelian Society, various types of things have been characterised as emergent, e.g. laws, effects, events, entities, and properties (Stephan, 1992, pp. 25–26). In the context of biological systems, a definition of self-organisation goes:

> *"Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern." (Camazine et al., 2001, p. 8)*

This definition emphasises the lower-levels of the system as predominant for the emergent pattern, i.e. local-to-global—however, emergence also refers to processes that involve interacting components in a system stemming from a global pattern, i.e. global-to-local. Due to the interacting components *"there is a global cooperation that spontaneously emerges when the states of all participating 'neurons' reach a mutually satisfactory state. In such a system, then, there is no need for a central processing unit to guide the entire operation"* (Varela, Thompson and Rosch, 2016, p. 88)—hence, a decentralised approach. In emergence, the self-organisation amounts to an apparent behaviour through either a local-to-global pattern or a global-to-local pattern; each with their characteristics. Local-to-global is constrained by local interactions, whereas global-to-local constrains the local interaction through its interaction with the system environment (Thompson and Varela, 2001; Vernon *et al.*, 2015). As noted by Vernon and colleagues, the link between autonomy, self-organisation and emergence is that self-organisation results from the intrinsic character of the system rather than by some external force, i.e. emergent self-organisation is autonomous similar to how autonomous systems involve emergent self-organisation (Vernon *et al.*, 2015).

To give an example of self-organisation, consider, for instance, *cellular automata*, where interaction between elements amounts to spontaneous global patterns. What makes it indeed a self-organised system, is the fact that there is no centre holding information on how to form and organise itself—instead, it happens from simple interactions, devoid of any pre-informed code or program, e.g. John Horton Conway's *Game of Life,* or other mathematical games, which Martin Gardner published in a series of articles in *Scientific American.* By straightforward Boolean rules regarding each cell's environment, a global pattern emerges due to cellular interaction.

The critical lessons in the context of neurons concern the characteristics of emergence:

- First, an autonomous system, as an emergent process, acknowledges a **reciprocal relationship** between neurons (Maturana and Varela, 1992).
- Second, the whole system (neuronal network) is **non-reducible to its parts** (neurons) (Thompson and Varela, 2001), similar to how only the fusion of hydrogen and oxygen displays an emergent behaviour, where the properties of the parts cannot explain the behaviour of water.
- Third, autonomous systems exhibit self-organising capacities where global pattern, which stem from interacting elements in the system, also has **downward causation** (Varela *et al.*, 2001).

On a biochemical level in cellular systems, *autopoiesis* refers to a particular form of self-producing self-organisation. Autopoiesis is essential in this context because it provides biological evidence for cellular closure that is continuously coupled to its environment while being self-sustained. An autopoietic organisation within the cell admits to a recurrent circular dynamic where molecular components determine bounded systems. The molecular components then generate metabolic reactions that, in turn, produces molecular components. When extending autopoiesis to autonomous systems, it is usually referred to as either *organisational* closure or *operational* closure (Maturana and Varela, 1992), but it certainly brings closure to the system. *Organisational* closure refers to its self-referential and recursive network that defines the system as a unity, whereas *operational* closure refers to the recurrent dynamics within the system.

Critical for autopoietic systems is the ability to self-produce their own topological boundaries. It can be determined whether a system is self-organised if it is true that (1) the system is defined by a semipermeable boundary, (2) the components are being produced by reaction of an internal network, and (3) the produced boundary is produced by the internal network while the network is regenerated due to the boundary (Thompson, 2007, pp. 45, 103). Such circular causality and autonomy enable emergent processes. Thompson coined the term *dynamic co-emergence,* which embodies the temporal dilemma of over-determination (Chapter 8) (Thompson, 2007, pp. 60–65). According to dynamic co-emergence and autopoiesis, the causal changes on a local level are synchronous with those at a global level; they are temporally interdependent. This naturally leads to an over-determinate supervened position of the system, where "who is in charge" seems to be under-played (Kim, 2001, pp. 13–14). Questioning "who is in charge" is an example of redundantly questioning the control-centre in decentralised systems—yet, this question is an essential kind because it is addressing the direction of evolution of time. The question could be rephrased: is it the global or the local patterns that decide the direction, or is it the interaction that unfolds in time? How does the global pattern constrain the local patterns, while simultaneously local patterns emerge as global patterns? A detailed review of how the three characteristics of emergence apply to the neurons and brain offers a hint.

#### 7.2.2.1 Setting up the brain mesh

The characteristics of emergence are essential to understand in detail, since they ultimately concern the link between brain and body, linking further to the environment. It is difficult to discuss the three characteristics independently of each other since they are based on similar grounds.

The first characteristic states that the emergent process stems from the interdependency of elements. Unidirectional relations behave differently from bidirectional relations because the causal link is only dependent in one direction, as opposed to the interdependent relation where *x* may influence *y* just as vice versa. In bidirectional relations *x* and *y* causally couple. In unidirectional relations, one necessarily causes the other, so that the other cannot occur without the occurrence of the first. In other words, *x* cause *y* (Fig. 7.2). Dynamic systems differ from computational symbol processing precisely in this regard. Computationalists hold that neuronal processes occur separately and in series that resolve one issue at the time, whereas a DST approach supports reciprocal causation, i.e. coupling, which allows for multiple processes to occur in different tempos from different sources.

The second characteristic entails the non-reducibility of an emergent process. Reducing a process or a system is a topic well-discussed in philosophy. According to Silberstein and McGeever (1999), there are two kinds of emergence relative to emergent properties. Emergent properties are properties of a system that exert a causal influence down on the parts of the system consistent with the causal capacities of the parts themselves. If the emergent property is understood as the global pattern, then this is downward causation, which leads to the third characteristic.

The first kind of emergence is epistemological, i.e. *epistemological emergence*, where a property is considered emergent "[…] *if the property is* reducible to *or determined by* the intrinsic properties *of the ultimate constituents of the object or system, while at the same time it is very difficult for us to explain, predict or derive the property on the basis of the ultimate constituents*" (Silberstein and McGeever, 1999, p. 186; emphasis added). In this sense, trying to understand the behaviour of a system as a whole by tracking individual part or process will be inconclusive. Instead, as DST suggests, one must try to grasp the qualitative behaviour of the system by grouping various systems with different underlying causal substrata (Silberstein and McGeever, 1999, p. 185).

The other kind of emergence is ontological, i.e. *ontological emergence*, by which

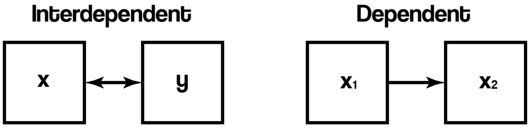

*Figure 7.2—Interdependent relations have bidirectional relations so that y may influence x, as well as x, may influence y. Dependent relations have unidirectional relations so that x2 can only occur if x1 takes place. In this sense, x2 is dependent on x1, or put differently, x1 cause x2. For dependent relations, the state goes from x1 to x2 because the linear relations indicates that x2 can be conceived of as an extension of x1, that is necessarily part of the same system. For interdependent relations, the two states may influence one another, so that one state cannot be conceived of as an extension of the other. In other words, x could be y2, while y could be x2—both would be true.*

they mean a system that holds causal capacities that are non-reducible to any of its intrinsic parts. Ontological emergence holds that the relations between parts of the system are all determined without remainder by the intrinsic properties (Silberstein and McGeever, 1999, p. 186; Thompson, 2007, p. 417). The causal features in ontologically emergent features are thus not reducible to more basic features, e.g. the intrinsic causal capacities of the parts.

In this context, the dispute regarding kinds of emergence concerns whether the brain's cognitive organisational system is decomposable to the intrinsic properties of its subsystems, which closely links to the debate regarding structural localisation of specific cognitive functions (see Appendix C for a discussion on the integration and segregation of anatomical and cognitive structures). Approaching the brain as a decomposable system allows to address each operation of a subsystem independent from other subsystems. Such an approach posits a modular organisational system of the brain, where the level of modularity depends on the strength of the reciprocal connections. If one holds at all the brain to be decomposable, then if the connections are weak, the system is *nearly decomposable,* because the causal interaction *within* the subsystem takes a stronger role in determining the operation *of* the subsystem. Instead, if the subsystem has strong connections, which refers to *minimally decomposable* system, then the causal interaction between subsystems take a more significant role than the those within the subsystem (Thompson, 2007, pp. 420–421, 2014). It is generally a matter of whether the environment of the subsystem governs a more significant role in determining the operation as compared to the intrinsic properties of the subsystem itself. Besides *nearly* and *minimally decomposable* systems[4], there is also *strictly decomposable* system, where specific brain areas can be conceived of as intrinsically specialised, and thus independently responsible for specific cognitive functions. This stands in high contrast to *non-decomposable* systems, which are systems where the connectivity and relations themselves between the components that give rise to global patterns so that the components are no longer clearly separable. Compared to Silberstein and McGeever's account of different kinds of emergence, only the non-decomposable system is an ontological emergence, because the behaviour of the system cannot be reduced to non-linear dynamics between components. This came to be known as a form of *relational holism* due to inexplicable states in quantum mechanics, where the underlying state of a system occurs in a holistic sense (Morganti, 2009).

Considering DST and DH, the emergent processes favour a *minimally decomposable* approach, i.e. the brain reflects a complex non-linear dynamic system, where ongoing global activity collides with non-linear dynamics of the local components, amounting to large-scale networks (Chapter 8 and 10 discusses neuronal responses). As illustrated in a study by Anderson and colleagues (2013), analysing

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[4] The decomposability of the systems can be conceived as the degree of decomposition before causing a turn from stability to chaos. A strictly decomposable system will continue staying stable even after removing great junks, whereas the non-decomposable system suggests that chaos reigns in removing any parts of either large- or small-scale networks.

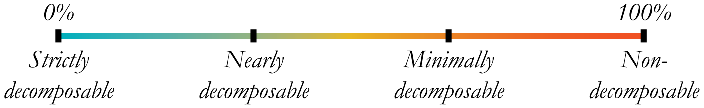

*Figure 7.3—Decomposability of a system. The degree of decomposability can be illustrated on a spectrum—the spectrum goes from 0% to 100% on the dependence of interaction between large- and small-scale networks to function. Applying these systems to the organisation of the brain, then the strictly decomposable system designates a modulatory view where removing parts is equivalent to removing functions. A nearly decomposable system favours the interaction of local component (small-scale) over large-scale networks, whereas the minimally decomposable system suggests that the large-scales of the brain exerts authority over small-scale networks. Finally, the non-decomposable system states that the function of the brain rests on its entire organisation, from small-scale to large-scale.*

accumulated neuroscientific data demonstrates that the brain operates using emerging networks that exhibit strong assortativity[5], whereas other networks consist of relatively heterogeneous parts. Accordingly, the networks that display strong assortativity are dominant modes (Corbetta, Patel and Shulman, 2008), which in future terms can be characterised by functional fingerprints (Anderson, Kinnison and Pessoa, 2013). The global pattern in this sense is not constrained to the activity of a single recognisable network but to the emerging pattern as a whole, including other brain regions and areas. That some networks appear as more dominant in certain functional tasks is precisely what is understood by a minimally decomposable system, as compared to the view of strictly decomposable system. Consequently, nearly decomposable systems are insufficient to illustrate strong assortativity, *ipso facto,* if it consists of weak connections, so that one might still falsely hold that *"the phenomenon of interest is due to component operations discretely localized in component parts of a mechanism"* (Bechtel and Richardson, 2010, p. xxx). Thus, in agreement with Pessoa (2014b):

> *"[…] decomposition of the brain network in terms of meaningful clusters of regions, such as the ones generated by community-finding algorithms, does not by itself reveal 'true' subnetworks. Given the hierarchical and multi-relational relationship between regions, multiple decompositions will offer different 'slices' of a broader landscape of networks within the brain." (Pessoa, 2014b)*

The structure-function mapping, i.e. specific parts of the brain are assigned specific tasks, of the brain, thus become obsolete, precisely because, at the level of brain regions, the area itself is not a meaningful unit of function as compared to the network that is distributed onto several brain regions. To quote Pessoa (2014a; original emphasis): *"The* network *is the unit, not the brain region."*

The embodiment in this context emerges from the fact that interoceptive signals are inherently bodily. For instance, a critical part of regulating homeostatic balance is to estimate positions of limbs for action, blood-sugar levels, filtering of blood and extracting nutrients from food in the intestines, all of which provide

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[5] Assortativity refers to a preference for a network's nodes to attach to others

the brain with signals about the internal milieu. The brain is indisputably bodily. As the next chapter will reassure, cognitive processes are not skull-bound so, as *the student of function* would argue, the networks go beyond brain regions. For now, the chapter deals with cognition from the brain perspective.

#### 7.2.2.2 Reciprocal causality

The current position is that the brain is minimally decomposable because the emerging features stem from a non-linear dynamic system, which leads to the third characteristic of an emergent process, namely that the global pattern also has an upper hand on local systems. Global patterns designate the state of the system as a whole, meaning it often constrain the behaviour of their local parts, known as downward, or top-down (TD), causation. On the other hand, local patterns designate the state of the parts of a system, meaning it partially determines the state of the system as a whole, known as upward, or bottom-up (BU), causation. Most do not find BU causation mysterious because intrinsic properties of a component usually constitute the system as a whole, e.g. components of a computer constitute the computer as a whole, e.g. if the RAM dysfunctions, the computer as the whole dysfunctions. However, it seems puzzling to many how TD states can have the upper hand on local parts (Bechtel, 2017). To be sure, upward and downward causations are not a matter of whether the systems hold a unilateral direction so that exclusively global or local patterns govern one another, but instead a matter of which pattern dominates the other, i.e. it is a reciprocal link, so the domination is both TD and BU. In line with DST, the emergent process establishes large ensembles of networks across brain regions, where their arising and disappearance is tightly linked with their context. TD-states concern the ongoing endogenous activity originating from bodily states, in contrast to BU signals that concern ongoing exogenous activity anchored in the external milieu (neuronal response to endo- and exogenous activity is returned to in Chapter 8). Regarding reciprocal causation, once again, the problem with global patterns governing lower levels is that such a feature may seem logically overdetermined.

Consider BU causality in sensory signals, so that the local activity in clusters of neurons in sensory regions, have the upper hand on the global pattern of the brain. On a neuronal level, in bilateral relations any local dysfunction will influence the global state, it means that dysfunction in specific clusters of neurons can cause a disruption, or a spread of disruption, in the emergent process of the global pattern. If, for instance, a single cell misbehaves in some cellular automata, it is impossible to reach a similar global pattern as if the cell was not dysfunctional. On the other hand, TD causation can be understood as the irreducibility of a system to its parts, so the most basic state is that of the whole. In such TD causation, the global pattern has the capacity to constrain local activity, which means, on a neuronal level, that its local functional environment influences the dysfunctional neuronal cluster. Thus, there will be very little, if any at all, disruptions on a global level of the brain state. In other words, the global pattern constrains the local pattern so that disruptions on a local level have less impact on the global outcome.

In light of DST, large-scale functional networks of the brain operate through TD causation in the sense that TD causation is a matter of a collection of interconnected brain areas that interact to perform circumscribed functions (Thompson and Varela, 2001; Varela *et al.*, 2001; Bressler and Menon, 2010). The issue with overdetermination is that there seems to be conformity between TD and BU patterns before they take place—as if the global and local patterns predict one another perfectly. Is there a form of neuronal emergence based on internal prediction?

Recall the first characteristic; the relations are reciprocal. This cooperativeness within various brain regions was realised when the prefrontal cortex required reinterpretation (Nauta, 1971; Goldman-Rakic, 1988). In investigating the visual cortex, Zeki states:

> *"The picture that one obtains from studying the visual cortex is one of* multiple areas *and of* parallel pathways *leading to them. It is a picture that shows* a deep division of labour*, the evidence for which is best when obtained from the* pathologic human brain*" (Zeki, 1993, p. 295; emphasis added).*

Zeki suggests that vision emerges from multiple areas that are parallel connected, and thus divides labour. Importantly, Zeki emphasises the pathological (anatomical) importance in understanding cortical processes: "Nothing *in that integrated visual image suggests that different visual attributes are processed in* physically separate parts *of our cortex*" (Zeki, 1993, p. 295; emphasis added). As the influential paper by Varela and Singer (1987) indicate, the visual pathway seems to hold a significantly higher amount of connections from the cortex to the lateral geniculate nucleus (LGN) than from the eyes themselves. This intuitively rejects the sequential understanding of vision, because, as they suggest, a transient mismatch between ongoing cortical activation and newly arriving retinal activity should alter the activity pattern of the feedback projection (Varela and Singer, 1987, p. 11; Varela, Thompson and Rosch, 2016, p. 95).

In brief, reciprocal relations are thus essential for TD causation, which in turn is essential to explain large-scale networks, constituting global patterns. Emerging from reciprocal relations, the network dynamics depend on their particular topology and closure so that TD causation concerns constraining local patterns through global interrelations, whereas BU causation concerns cellular metabolic reactions and molecular components initiated by external stimuli, offering different topological constraints on global patterns.

In this regard, the agent's life is constituted by TD predictions that are matched with BU signals, essentially anchoring and situating the agent in a body and environment. The predictive behaviour that Damasio, Sterling, Husserl and Bergson refer to are all different from one another. Bergson referred to virtual actions, i.e. the interaction depending on physical structure, whereas Husserl referred to protention in temporality, i.e. the immediate prediction as part of a present. In both Damasio's and Sterling's terms, this predictions in neuronal activity during adjustments is vital to life in general (Damasio, 2010; Sterling, 2012).

Furthermore, on a topological level, how the mechanism restricts the behaviour of its parts differs from how the parts are affected by an external stimulus (Bechtel, 2017). It becomes clear here that the brain operates in a dynamic fashion, where interdependent relations constitute neuronal activity. From such internal relations, specialised and complex networks emerge, satisfying in parallel exogenous and endogenous signals here expressed as BU and TD, respectively. Insofar, the nervous system and the brain are argued to be coupled on various levels, detaching cognition from the skull and rightfully linking it back to more than internal neural states—however, can cognition be considered released from a skull-bound theory, and onto an embodied and environmentally situated process? Such an account has serious implications for interpretations of cortical activity and functional networks.

### 7.2.3 Bergson and Husserl coming to light

Numerous claims regarding cortical organisation have been put forward and, yet, there remain unsolved issues. Examining these claims relative to the established phenomenological principles seem reasonable.

*Dynamic co-emergence* had difficulties explaining how two independent components could bilaterally comply and thus co-create one another, i.e. the issue of over-determination. Dynamic co-emergence is an essential feature for circular causality in explaining brain organisation as self-organising and autonomous. Surprisingly, an answer to the problem was already within Damasio's account on how primitive cells adjust—they need to be anticipative so that the homeostatic balance is not disrupted. If the process of homeostasis is interrupted, it is arguably too late for the organism, which was the critical argument of allostasis (Sterling, 2004, 2012; Vernon *et al.*, 2015). Such jeopardising is evitable with predictive features already at the cellular level. For components within a cell, to predict is a powerful feature that requires an action by the component towards the other component(s). Bergson foreshadowed this feature in his concept of the virtual. Needless to state that the DST approach complies with the very core of Bergson's philosophy because the cortical activity is not restricted to spatial matters, but rather to dynamics and time, i.e. cognition emerges in the process of interaction. Bergson's principle of indivisibility of time due to the interpenetration of any given moment onto the next one, which Husserl complies with by stretching the present into retention and protention, extends to this cellular micro-level of life as the predictive behaviour. The components at any given moment already hold a prediction of how the other components will act, based on the retained history of itself and its relations, thus acting accordingly. In this sense, emergence sheds light upon the possibility of prediction on a cellular level up to a global cognitive level. The local patterns have a BU influence on the global stage, which in turn may have a TD influence on local patterns.

If to predict is no longer conceived only as a long-term psychological process, but also as a short-term transcendental act, it becomes clear how intuitive prediction is part of the present, immediate experience.

This relation sheds light upon the process of resolving uncertainty about the world that consequently settles the body in a more determined state. Consider pure TD dominance on local patterns. In such cases, which is comparable to a purely mental world that is devoid of any BU sensory signals, an ideal world is established. The exact opposite—so that local BU modulations entirely govern global states—is comparable to a realist's account of the world. Bergson and Husserl disregarded both idealist and realist approaches to cognition. According to Bergson, their most significant mistake entails the value of *truth*, so that any change is linearly describable. For instance, external stimulus *x* will always yield precisely cortical activity *y*, where a dynamic approach suggests that the cortical activity is non-linear, e.g. neuronally resolved through a network. In both the idealist and realist approach, the neuronal response from internal and external stimulus, respectively, will always direct global or local patterns, which would be incompatible with both the cortical anatomy and with DST because DST is based on non-linear reciprocity between multiple variables. In other words, the idealist holds that the world is a projection of internal changes, e.g. nihilism, whereas the realist holds that the world is directly sensed and constructed based on sensory signals, e.g. empiricism.

DST allows for coupling so that two systems interacting can shape each other's change. Ultimately, akin Husserl and Bergson, systems are governed in part by an idealist and in part by a realist that come together to resolve uncertainty about the world using sensory signals and global predictions. Chapter 9 will discuss these matters explicitly.

### 7.3 Conclusion

Insofar, there has been a great number of claims, begging an overview. First, Damasio argued that in order to maintain life, a homeostatic balance must be respected. During the process of homeostasis, the living organism must regulate the internal milieu in accordance with the external milieu since the living organism only holds control of its own milieu. This regulation depends on interoceptive and exteroceptive sensory, from which a model of the world emerges internally as externally. By observing merely internal regulations, it is theoretically possible to tell whether an organism is in an environment that is cold or hot, hungry or full, decaying or thriving, dying or living. More importantly, for a more complex organism such as human beings, when experiencing a threat, the human can move and improve its chances for survival. According to Damasio, an act of improvement is rewarded, while a damaging act is punished, so that these incentives guide the organism as a whole. Essentially, for any of these processes to be successful, the organism must successfully construct a model of itself and thereby its environment well before disrupting the homeostatic balance; this is the anticipative behaviour emphasised in allostasis and the principles of *Part I*. Time becomes the essence.

Given the temporal priority, DST proved to be a qualified approach to the biology of the human body as compared to computationalists because the importance is in the potential of change and interaction rather than the current state. By illustrating how neurons anatomically interact on both a local and global pattern and their interdependent relations, it is shown that DST favours a network approach to cognition over a location determined approach. The relation between networks is argued to be minimally decomposable so that local hubs can exhibit specialised behaviour governing global patterns. For instance, autonomous systems have organisational closure, which is not a matter of a single cell maintaining its own homeostatic balance, but a constant exchange of matter and energy with its local environment. This further illustrates the interdependent coupling between different levels (levels of the spectrum of TD and BU) throughout the brain and body. In this sense, cells and neurons are always structurally coupled to their local environment, meaning the history of dynamic interactions leads to a structural congruence. Prediction based on cellular history is a form of practical primitive operation, where a decision of how to act is necessary[6]. The process of how this primitive kind of learning takes place will reveal how the brain organises itself.

Husserl refers to this logical operation as a passive synthesis, because it happens on an intuitive level that is constrained by bodily functions without any interaction from the intellectual self. Further, from the enactment of the logical operation, it necessarily ensues that a form of synthesis is constructed, which within itself hold new prediction of actions.

The discussion serves as an anatomical and functional outset for investigating the human brain through architecture. By unpacking the underlying processes of cognition in the brain, including the anatomical landscape, the implications of architecture on brain responses are clearer. Furthermore, the outset for interpretation of neuronal data is better anchored. Returning here to the anticipated questions:

**Why is investigating the brain and neuronal activity an advantage during architectural experience and transitions?**

- The brain contains neurons that reflect internal and external interactions between body and environment via the peripheral and central nervous system. Neuronal behaviour can reveal causal interactions stemming from both environmental features and bodily states.

**Is it expectable to establish linear-models of brain functions during architectural experience and transitions?**

- As attractive as it may seem to establish linearly predictable models of how the environment affects the brain, the cortical systems function as non-linear dynamic systems so that the complexity of the brain as a whole exceeds such possibility. A linear model assumes a unique, stable, functional organisation—instead, the brain contains many interrelated networks that are minimally decomposable, where some may confine to linear models.

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[6] There is here no distinction between cellular action and bodily action.

**Is it reasonable to search for architectural experience-dedicated brain region(s)?**

- Given the dynamics systems fundament, it is not reasonable to attempt to localise or assign regions to cognitive functions.

**How do experiential transitions relate to global and local patterns?**

- During the continuous unfolding of experiential transitions, global patterns reflect the predicted state, whereas the local pattern the continuously incoming sensory. Experiential transitions thus relate to global and local patterns through the dynamics of mismatch between predicted and incoming sensory.

# CHAPTER 8

# Coupling architecture to brain and body

*"The brain neither generates its neural activity in a completely passive way as driven by the external stimuli nor in an exclusively active way, that is, entirely driven by its spontaneous activity. Instead, based on empirical evidence, we need to accept a model of brain that undermines the passive/active dichotomy and integrates both in a spectrum that allows for categorizing different forms of neural activity according to the degree of the brain's participation in generating that activity." (Northoff, 2018, p. 5)*

*"The principal activities of brains are making changes in themselves."*
*(Minsky, 1988, p. 288)*

**Summary.** *How do the brain and body relate to the environment?* The previous chapter established a biological framework from a cellular level and neuronal activity to large-scale networks in the brain. This chapter intends to link the environment to brain and body firstly on a neuronal level and secondly on a philosophical and psychological level. The emergence approach in biology depends heavily on the interdependent coupling so that patterns and systems emerge from bidirectional influences that couple the body and brain. The coupling argument reaches into the environment well-beyond the body and brain. This chapter provides an overview of the origin of neuronal responses by reviewing passive and active models of the brain and emphasises the relation between environment and body-brain by discussing a critique of central arguments in *the extended mind hypothesis*. In defence of the environmental coupling, three objections have been established. Taken together, there are empirical and philosophical reasons to pursue cognition as coupled to the environment.

## 8.1 On a neuronal level

Body and brain have not been separated from one another insofar—and rightfully so. When considering the neuronal activity, it originates from different sources. It is argued that two such sources are the body and environment. The cortical synaptic activity reflects message-passing between neurons through neurotransmitters (see Appendix B), but what are neurons communicating and how is this related to either body or environment? The task here is to discuss two different kinds of models of the brain, as brought forward by Northoff (2018, chap. 1), to empirically identify the origin of synaptic activity. Eventually, it is shown that architecture, as external stimuli, is supposedly reflected in neuronal activity but intertwined with endogenous activity.

An early model of the brain and spinal cord proposed that these are reflexive in nature so that the brain reacts automatically to external stimuli. The implications are that all external stimuli are reflected in brain activity, i.e. any external stimuli encountering the spinal cord, e.g. touch, will exclusively define the immediate brain activity—hence, *passive model* of the brain. It is passive in the sense that it awaits stimuli from external sources before generating activity. Such a model assumes Humean views (Chapter 3).

A different model suggests that external stimuli do not exclusively sustain brain activity, but that spontaneous activity emanates from within the spinal cord and the brain themselves. Hans Berger (1873-1941), the inventor of electroencephalogram (EEG; elucidates brain waves from the synaptic activity), proposed that the brain is constantly busy. That the brain is restless and generates its own activity is famously known as *resting-state activity*[1] (Raichle, 2011, 2015), which lately has been hypothesised to be involved in certain conscious features, such as day-dreaming, mind-wandering and retrieval of autobiographical pieces (Buckner, Andrews-Hanna and Schacter, 2008). The resting-state activity is characterised by the absence of and any external stimuli, i.e. the body and brain simply rest. The critical question is thus; what is the origin of the neuronal activity?

### 8.1.1 Exogenous approach: passive brain

The reason both the passive and active models of the brain are of interest is to define the boundaries of the potential impact of architectural experience. Architecture is here considered an external stimulus, i.e. the built environment. If the brain is active in the sense that it generates its own activity, then cortical measures will reveal nothing about the impact of architecture, simply because the brain reflects its own activity exclusively. If the brain is passive in the sense that its activity depends on external stimulus, then cortical measures will reflect only the impact of external stimulus, e.g. architecture. For this reason, this issue needs to be resolved; a strong, moderate and weak model of both passive and active model of the brain are reviewed.

A strong passive model of the brain suggests that there is no neuronal activity

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[1] Resting-state activity, spontaneous activity and endogenous activity are used interchangeably.

unless there are external stimuli. This argument is objected by several empirical findings, particularly in the topic of metabolism and neuronal activity (Northoff, 2018, p. 9). According to this model, the metabolic activity (measured by the rates of glucose or oxygen in the brain) is not reflected in neuronal activity (measured by the cycles between glutamate and glutamine; see Appendix B) (Hyder *et al.*, 2006; Shulman, Hyder and Rothman, 2014; Northoff, 2018, pp. 8–9). However, it has been shown that there is, in fact, a close coupling between metabolic activity and neuronal activity, i.e. the cerebral metabolic rate of oxygen consumption and the rate of firing in neurons (Shulman, Hyder and Rothman, 2014). Because the process of metabolism (e.g. the energy consumption for converting food to building blocks for proteins) is in fact reflected in neuronal activity, this strong passive model of the brain in inconceivable.

Consider a moderate passive model of the brain, which suggests that spontaneous activity and stimuli-induced activity co-exist with no interaction, i.e. neuronal activity resulting from endogenous sources have no impact on neuronal activity stemming from an external stimulus (Northoff, 2018, pp. 10–12). A series of studies led by Hesselmann and Kleinschmidt show that resting-state activity just before the auditory stimulus was able to predict the successful and unsuccessful trials (Sadaghiani, Hesselmann and Kleinschmidt, 2009). An inclined resting-state activity predicted successful trials. In another study, they were further able to predict whether the participants would visually perceive a vase or a face in an ambiguous figure, again using the resting-state activity as a marker (Hesselmann *et al.*, 2008). Various other studies show that resting-state activity has an impact on the behavioural outcome (Andrews *et al.*, 2002; Hesselmann, Kell and Kleinschmidt, 2008; Sadaghiani, 2010). Thus, ongoing resting-state neuronal activity cannot be segregated from the neuronal activity stemming from external stimulus—in fact, the empirical data suggests an integrative position—which makes the moderate passive model inconceivable as well.

Between resting-state activity and stimulus-induced activity, a weak passive model of the brain proposes that only external stimulus influence the apparent stimuli-induced activity, which means that no matter the level of the resting-state activity, the external stimulus alone can explain the stimulus-induced activity. In a study by Qin et al. (2013), they took advantage of the Berger waves[2] in the continuous activity of the brain when the eyes are closed, as compared to when the eyes are opened. Thus, setting eyes-closed and eyes-open as the two states of the participants yielded two different resting-state activities. The fMRI-study revealed that during eyes-open, there was no difference in neuronal response when the participants heard either their own name, friend's names or unknown names. However, during eyes-closed when the participants heard their own name, as compared to friend's names and unknown names, there was a significant difference in auditory cortex, indicating that the resting-state activity does have a causal impact

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[2] The inventor of EEG, Hans Berger, discovered that when closing the eyes, there is a natural increase of alpha frequency (8 Hz to 12 Hz) in the continuous electrocortical activity.

on stimuli-induced activity. This study is limited to self-specific stimuli but offers, nonetheless, insights into the dependency of resting-state activity in the stimuli-induced activity. It is important to note that there were no significant differences in all variables; hence, it cannot be said that the resting-state activity has an exclusive influence on stimuli-induced activity. Instead, it can be said that self-specific stimuli are reflected differently in the brain when the resting-state activity is high.

Taken together, there is evidence that the brain is not a passive bystander driven by external stimuli—instead, it contributes the ongoing activity to its own neuronal activity. However, spontaneous activity does not appear to exclusively account for neuronal activity (Northoff, 2018, chap. 1).

### 8.1.2 Endogeneous approach: active brain

If the brain is exclusively contributing to its own neuronal activity, which may be named a strong active model of the brain, then the neuronal activity is effectively self-evidencing. If this is the natural behaviour of the brain, it brings with it many philosophical issues as it tends towards a nihilistic perspective of life. If the brain is exclusively self-evidencing, then when was any impression of the world ever given in the first place? There is an apparent bootstrap problem. Such an account assumes no difference in neuronal activity between spontaneous activity and stimuli-induced activity. It was clearly shown above that this is not the case—thus, this model is empirically inconceivable.

It is worth noting that the resting-state activity is not restricted to specific locations in the brain, which was hypothesised to be the default-mode network (Raichle *et al.*, 2001; Raichle and Snyder, 2007; Raichle, 2011), but put back down again by Klein (2014). The spontaneous activity does not operate within limited regions but is evident throughout the whole brain in every region. It is also worth noting that the firing rate of neuronal activity, i.e. the temporal dimension, of resting-state activity suggests that low- and high-frequencies modulate each other through phase-coupling from slow to fast frequencies (Buzsáki, Logothetis and Singer, 2013; Northoff, 2018, p. 18). This means that phase-locking in one region can modulate frequencies of different regions. The fact that all neuronal activity behaves in different spatiotemporal dimensions suggests that resting-state activity is a rather dynamic and wide-spread activity. Thus, even a moderate model of an active brain is difficult to defend since it holds that stimulus-induced activity does not interact with the spatiotemporal structure of spontaneous activity (Northoff, 2018, p. 20). The weak model of an active brain states that the neuronal activity of external stimulus is exclusively explicable by resting-state activity, but this was resolved with Qin et al.'s (2013) experiment above. In sum, the brain cannot be accounted for generating its own neuronal activity, that is, neither radically, moderately nor in a weak sense.

### 8.1.3 The spectral model

In line with Bergson and Husserl, Northoff (2018) suggests that one must go beyond the mere dichotomy of active/passive and introduce instead a scale in which both extremes are present (Fig. 8.1). Eventually, the concepts of active and passive models of the brain displays the degree of involvement of the brain to its neuronal activity, where the extreme passive end is no involvement of spontaneous activity, whereas the extreme active end of the spectre is exclusively self-generated activity independent of any external stimuli (Northoff, 2018, p. 7). This account amounts to the Bergsonian and Husserlian criticism of pure realism and idealism as unpacked in Chapter 4 and 5. According to Northoff (2018, chap. 4), *the spectral model* of the brain is the model that best explains the unfolding of neuronal activity, where none of the extremes occurs in healthy people:

> "[…] *the spectrum model of the brain suggested here is about the balance between the contributions of resting-state activity and external stimuli to the brain's neural activity. Since various constellations in the balance between the resting state and external stimuli are possible, the brain's neural activity can best be captured by a spectrum model that has room for configurations between purely active and purely passive models* […]" *(Northoff, 2018, p. 21)*

Neither the endogenous nor the exogenous stimuli determine the neuronal activity alone—instead, it is a mixture of both signals. Although the spectral model provides an empirically plausible model on the source of neuronal activity, it must be emphasised that it does not encompass a unifying theory of the brain as it does not explain how external stimuli, i.e. architecture, is directly related to neuronal activity, e.g. through TD and BU signals. For now, the spectral model served the purpose of linking body/brain to the environment on a neuronal level, bringing to light the fact that external stimuli, e.g. architecture, are reflected in neuronal activity.

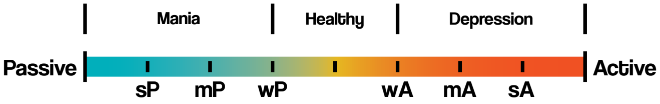

*Figure 8.1—The spectral model, as suggested by Northoff (2018). The spectral model holds that the norm operates within the yellow-range (mid) of the spectre, displaying no extreme cases of active or passive brains. Northoff suggests instead that extreme cases can be found in psychiatric disorders, where the balance tends one or the other extreme, e.g. active as depression and passive as mania (Northoff, 2018, p. 22). Strong passive model is here designated as sP, moderate passive as mP and weak passive as wP. Similarly, for active models of the brain, the weak model is designated by wA, the moderate active as mA and strong active as sA. It is unfortunate that the taxonomy of the models that best describe the general population, thus proposing strong models of the brain, are termed the weak models of the brain.*

## 8.2 On a philosophical and psychological level

It is clear that external stimuli have an impact on neuronal activity—however, to move beyond the neuronal level, one must question how do the brain and body interact with the environment beyond neuronal activity? Or to paraphrase Clark and Chalmers (1998); where does the mind stop and environment start?

This next part intends to argue that external features are actively exploited to improve cognitive organisation. The underlying argument is that self-organisation on cellular and neuronal level extends beyond bodily barrier by dynamically externalise features relevant to cognitive processes into the environment. In other words, the same manner in which the cells and neurons act upon the active brain beyond their barrier, the brain acts upon the body through CNS and the body acts upon the environment. Cognition is ubiquitously present through all the stages. Although this is not entirely in line with the extended cognition hypothesis (Clark and Chalmers, 1998), it does share the fact that cognition goes beyond body and brain. This has been met with criticism, which is here reviewed and answered as a defence of the externalisation of cognitive relevant features.

### 8.2.1 Coupling-constitution fallacy

How does the brain make use of the environment, if at all? In setting up the brain mesh (Chapter 7), it was argued that a necessary outcome of a DST approach means that the brain operates through interdependent rather than unidirectional dependent relations. While the brain and body are interdependently coupled, it is here argued that the environment enters a similar coupling with brain and body, so that the brain, body and environment are dynamically coupled constituting a system as a whole. The coupling to the environment is cast as extra-neuronal in the sense that cognitive processes make use of external interaction to succeed in a given task. A common critique of this position is the coupling-constitution (C-C) fallacy by Adams and Aizawa (2009), which states that "coupling-arguments" to the environment are confusing *causality* with *constitution* (Aizawa, 2010). In turn, Adams and Aizawa promote a symbol-processing account for cognition so that semantic content is necessary for meaning (Adams and Aizawa, 2001).

Regarding the C-C fallacy, put in their own words:

> *"The fallacious pattern is to draw attention to cases, real or imagined, in which some object or process is coupled in some fashion to some cognitive agent. From this, one slides to the conclusion* that the object or process constitutes part of the agent's cognitive apparatus or cognitive processing.*" (Adams and Aizawa, 2010, p. 68; emphasis added)*

What does this mean? To put it in an example, the C-C fallacy opposes that a frequently used notebook constitutes part of the memory because the notebook is not *part of* the cognitive process but instead *causing* a cognitive process (Adams and Aizawa, 2010). The fallacy was a reaction to two *students of function*, namely Clark and Chalmers and their active externalist *Parity Principle* that states:

> *"If, as we confront some task, a part of the world functions as a process which,* were it done in the head*, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process. Cognitive processes ain't (all) in the head!" (Clark and Chalmers, 1998, p. 8; original emphasis)*

The issue at hand concerns whether coupling is constitutional or causal. If the environment takes part in a cognitive process, e.g. a notebook, do the environment compose that cognitive process, or is it causally coupled? To answer such a question, it is necessary to consider the difference between *coupling (causality)* and *constitution*. Coupling is a causal relation. A relation is coupled between two events or states if one produces the other. Pushing a button to turn on a screen is a causal relation, i.e. the pushing of the button caused the screen to turn on. However, constitution is a compositional relation. A relation is compositional if one event makes up another type. An example of compositional relation is that of water and $H_2O$, i.e. the substance water is composed of $H_2O$. Can it be said that $H_2O$ *cause* water, and can it be said that the pushing of the button *composes* the turning on of the screen? According to the C-C fallacy, coupling should not be confused with constitution so that the coupling of *X* with *Y* cause a cognitive process, does not mean that *X* and *Y* compose that cognitive process. The form of C-C fallacy can be unpacked as following (Aizawa, 2010):

1. *C* is a cognitive process.
2. *E* causally couple to *C*.
3. *E* is part of a cognitive process.

The reason for this critique is that causation and constitution are independent relations, where one does not tell us anything about the other. At the core of the fallacy lays a question on whether coupling includes composing. To answer this, Adams and Aizawa (2010, p. 68) propose that it is necessary to define a *mark of the cognitive*, because the nature of cognition will reveal whether causal relations also compose cognition. In other words, they are inquiring; when is something cognitive?

#### 8.2.1.1 Objection 1: the mark of the cognitive

Recall the characteristics of emergence, the dynamic approach and the minimally decomposable networks to see an initial objection. Any internal mark of cognition seeks to reduce behavioural operations such as reasoning, memory, learning, concept formation, to the internal relations within the brain so that a process involving a plethora of variables can be fully decomposed. The C-C fallacy and the desire for a cognitive marker are rooted in the spatial dimension of cognition so that the process itself is less important compared to where it occurs. This is particularly clear when directly asking *"Which parts of the brain are doing cognitive processing?"* (Adams, 2010, p. 330). If acknowledging that *decomposing* is a spatial operation, it is easy to illustrate the difficulty of classifying a process because it is purely dynamical. Going backwards can be helpful, i.e. what can one remove from the process before it ceases to serve the cognitive purpose? Minsky's quote comprises the difficulty in decomposing a process:

> *"Why are processes so hard to classify? In earlier times, we could usually judge machines and processes by how they transformed raw materials into finished products. But it makes no sense to speak of brains as though they manufacture thoughts the way factories make cars. The difference is that* brains use processes that change themselves—and this means we cannot separate such processes from the products they produce. *In particular, brains make memories, which change the ways we'll subsequently think.* The principal activities of brains are making changes in themselves.*" (Minsky, 1988, p. 288; emphasis added)*

Neuronal processes are dynamic, influencing and being influenced by multiple external and internal variables, producing what that today is generally accepted as cognitive behaviour, namely reasoning, memory, learning, language processing, and concept formation, which are difficult to separate. The need for a mark of the cognitive is vaguely comparable to determining the mark of the ringing of a clock; is it the arm of the bell, the cave of the bell, the environment the bell is in or the auditory process? There is no ringing without the arm, neither without the cave of the bell nor the environment. The reducibility of a process to its parts to determine a mark misguides the understanding of that particular process.

According to Ross and Ladyman (2010), investigating water by applying the C-C fallacy brings with it an important observation:

> *"The usual philosophical identity claim 'water is $H_2O$' ignores a rich and subtle scientific account that is still not complete. What is important in this context is that the causal–constitutive distinction dissolves because the kind water is an emergent feature of a complex dynamical system. It makes no sense to imagine it having its familiar properties synchronically. Rather, the water's wetness, conductivity, and so on all arise because of equilibria in the dynamics of processes happening over short but nonnegligible time scales at the atomic scale. From the point of view of any attempted reductive explanation, the kind water is not held by physicists to be 'constituted' as opposed to 'caused,' because it is not a 'substance' in the classical metaphysical sense of that term. Instead, it is a kind of process explained as the result of emergent features of the interaction of atomic properties" (Ross and Ladyman, 2010, p. 160)*

If the world is made of small bricks that are fully able to explain anything the bricks put together, then emerging properties remains a phenomenon. Water is wet, which is a property that emerges from the causal linkage between hydrogen and oxygen forming dihydrogen monoxide (water). Surely, in this sense, dihydrogen monoxide *composes* the wet water similar to the fact that dihydrogen monoxide *causes* it, despite the wetness is not an intrinsic property of neither hydrogen nor oxygen. The modern scientific account of water is not a matter made of smaller matters, but an emerging process particularly rooted in the emergent properties of hydrogen and oxygen. These dynamics are overlooked and goes by unacknowledged, which is precisely what the second objection concerns.

#### 8.2.1.2 Objection 2: disregard of the temporal dimension

This objection builds on Kirchhoff's argument stating that *synchronic* constitution cannot account for *diachronic* processes in dynamic patterns (Kirchhoff, 2015). When analysing the temporal aspect in analytical metaphysics, it becomes clear that a cognitive process is not a decomposable material that can clearly be marked, but rather a system that develops over different temporal frequencies linking reciprocally to other systems, which further entail inter- and intra-level dependent relations that operate at the level of local and global patterns. Instead of considering (1) *C* a cognitive process where an external entity couple to it, i.e. *E* does to *C* in (2), then the dynamic approach suggests that the reciprocal coupling of *E* and *C* constitute the cognitive mark *Z*. As Menary puts it:

> *"The aim is not to show that artifacts get to be part of cognition just because they are causally coupled to a pre-existing cognitive agent, but to explain why X* [E] *and Y* [C] *are so coordinated that they together function as Z, which causes further behaviour." (2006, p. 334)*

This critique by Menary (2006) illustrates the static and synchronous understanding of cognition presented by Adams and Aizawa (2001, 2009, 2010) versus the dynamically diachronous processes of cognition. It is easy to demonstrate how diachronic processes can constitute cognitive processes, having already established the biological background in emergentism and integrated a DST perspective. In the synchronic constitution, time is subject to a form of reduction so that processes occur in a series of snapshots that synchronically attempts to initiate a process. On the other hand, diachronic constitutions are embedded in a dynamic system where time is continuous so that slowing any processes yields a change in either the lower-level processes or the higher-level phenomenon (Kirchhoff, 2015, p. 325). Only when considering time as continuous and constitution as diachronic is it possible to establish a form of causal constitution as advocated by DST—which explains why cognitivists, computationalists and others who consider cognition as static, may run into, what Bergson would name, *false problems.* Because any change in either the environment, brain or body will cause a change in the cognitive process, it is not possible to speak of a specific mark of cognition. Cognition is not a matter of difference in the *degree* of a boundary—it is a matter of different *kinds* of systems. As Bergson discussed in Chapter 4 and 5, discussing differences in degrees yields false problems. Given that *Z* itself unfolds dynamically, while being composed by process that unfold over different frequencies, the cognitive process changes in kind over time. For instance, the cognitive act of remembering the exact address of Museum of Modern Art (Clark and Chalmers, 1998) at time *t* is a different kind of cognitive process of remembering at time *t+1*.

By having a causally constitutive coupling, any change to the parts of the system will have an influence on the system as a whole—and thus, cognition, referring here to the process as a whole, is influenced by the environment of the brain and body, just as the brain and body influence environment. Accepting this temporal dimension, a definition for their mark of cognition could be: *anything with an influence on brain, body or environment may partake in cognitive processes.* Gallagher reaches a similar conclusion, i.e. cognition depend on the instantiation of certain dynamical couplings so that a specific kind of cognition would not arise were it not for the causal interaction that defines the system (2017, p. 10). Material understanding of constitution underplay time to a degree where it simply cannot account for dynamic systems giving rise to cognitive processes:

> *"If the notion of 'time' in synchronic accounts of material constitution entails that temporality itself is not essential to the constitutive nature of constituted entities, then the explanatory language of material constitution will be inappropriate for describing and explaining dynamical systems, and the way in which such systems give rise to distributed cognitive processes, that are temporal in their very essence." (Kirchhoff, 2015, p. 325)*

Kirchhoff further emphasises the importance of time in emergent processes:

> *"In emergence, if the relation between lower-level processes, Xs, and the higher-level emergent feature, Y, is diachronic (ontologically), then the relation of emergence is not ontologically synchronic—that is, it is not present in its entirety within a single time slice. In cases of diachronic emergence, the relata are commonly processes; and for processes to be what they are, they depend on spatiotemporal or causal continuity." (Kirchhoff, 2014, p. 92)*

#### 8.2.1.3 Objection 3: the butterfly objection

The butterfly objection pursues to emphasise the level of global impact from local changes. Changes in local systems may cause severe changes in global systems, e.g. epileptic discharges that may cause a chain of reactions throughout the brain (see for instance; de Curtis and Avoli, 2010). Chaotic structures underline the difficulty in clearly delimiting natural complex processes, i.e. the wind produced by the wingbeat of a butterfly may cause a storm elsewhere. Delineating a complex process is what makes the butterfly objection relevant to cognition. Adams (2010) suggest that the C-C fallacy needs a mark of the cognitive to state whether a process is a cognitive or non-cognitive process, thus Adams question whether something is cognitive because it takes place within, or couple to, a cognitive system. What is at stake when insisting on defining what is not yet fully comprehended is the risk of reducing the phenomenon to simple, and potentially misguiding, semantic concepts. Consider the following two examples for why letting semantics guide cognition might be misleading.

First, although colours can be perceived as discrete, they are far from being so. For instance, in a rainbow, the colours do not form discrete limits but smooth and continuous changes in wavelengths, and yet, they are experienced as discrete stripes of different colours in the sky. Colours seem to be intellectually categorised mental concepts that might have been dissociated for practical purposes, e.g. colours of plants and fruits guide potential human interaction (Barrett, 2017, pp. 84–85). Also, facial expressions are intellectually categorised mental concepts that share no universal distinction across cultures. This thesis has been brought forward multiple times by various affectivity researchers (Gendron *et al.*, 2014; Barrett, 2017). Realising the complexity of natural processes, or at least understanding the limitations whenever suggesting a semantic concept to define a natural process, leads to a fuller understanding that eventually is more practical than reducing a process to a culturally anchored concept. Reductionism is not wrong in science; it is necessary. However, one must understand the limits of the reduction and not erroneously insist that the reduced concept may explain a full-blown natural process. In a nutshell, given the complexity of dynamic systems, it seems inappropriate to determine when cognitive processes start and end, and even misleading to define the start/end by a semantic concept, i.e. a mark of the cognitive.

Second, Adams (2010, p. 325) argue that the fact that cognition has been investigated for so long without a precise definition is not an indication that cognition need no precise definition, but simply that science of *X* can arise before a consensus on what *X* exactly is. To Adams' surprise, there "[…] *seemed to be a wealth of opinion that one doesn't need a mark of the medical to practice medicine, or a mark of the biological to do biology, or a mark of the psychological to do psychology* […]" (2010, p. 325). Adams believes there is a need for a mark that makes the field so that cognition is confined to the brain and body. It is difficult to follow this line of thought because e.g. plants do exhibit cognitive abilities, and yet plants are not a mark of the psychological (Gagliano, Abramson and Depczynski, 2018). However, it is clear that reductionism in science is necessary to investigate a particular process—yet, it must be accepted that a medical doctor and a plant do not belong to two separable worlds that are mutually exclusive. In other words, one may distinguish between a gardener and a cognitive scientist, but a plant still seems to share with a human being comparable fundamental cognitive abilities as simple movement, i.e. geotropism, phototropism, chemotropism, and hydrotropism. The ability may be informative to cognitive scientists after all, as it may apply to human beings as well, thus questioning why cognition need to be confined to brain and body (Alpi *et al.*, 2007; Garzón, 2007). As tempting as it may seem to centralise and force practical categorisation onto complex natural processes, it is not always the case that these concepts reflect delimited processes. It is precisely because they may be decentralised and more practical if delimited in multiple ways. The consequence might be, that results reflect the chosen categorisation just as much as the topic under investigation, and thus leads to circularity.

Ultimately, given the dynamic approach to the intricate natural process, one may question; can something be part of a process without being involved in composing it? It does not make sense to pose that elements, which may influence the system causally, do not constitute that system. If dynamic emergentism as a biological framework is accepted, then it is clear that the nature of cognition depends on the instantiation of dynamical (causal) coupling between brain, body and environment (Gallagher, 2017, p. 10).

#### 8.2.1.4 Is the C-C fallacy a threat?

It is important to recall the main difference between DST and computationalists. The former handles cognition as relevant to time, while the latter handles cognition as symbol and information processing. When approaching cognition from DST, capacities such as reasoning, memory, language processing and concept formation are not a matter of *degree* of complexity, so that phototropism either does or does not, make the cut for *a cognitive mark*. Instead, cognition is a matter of different *kinds*. The complexity of dynamic networks cannot be equated with linear laws where external stimuli produce identical network activity—however, some tendencies form over time, which is precisely why the networks can only be considered *minimally* decomposable. Instead of reducing cognition to a set of marks, where a process that "[…] *rises to the level of the cognitive*" (Adams, 2010, p. 330) can be considered cognitive, then DST suggests that cognition belongs to the discussion of relative interaction and emergent properties (Fig. 8.2). In this sense, the C-C fallacy is ontologically not valid yielding no threat to the argument that cognition emerges from the interaction between brain, body and environment.

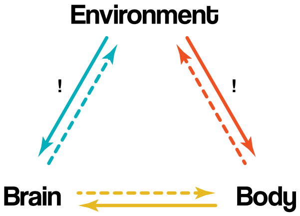

*Figure 8.2—The triad describes how cognition emerges through the interaction between body, brain and environment. Physiological and perceptual investigations address body/brain-to-environment relations (dotted blue/dotted red)—however, the environment-to-body/brain impact remains largely understudied. The exclamation marks designate the links that are necessary to address to answer the research question, namely the link to the environment.*

### 8.2.2 Learning from Tetris

When using an abacus for arithmetic, is one not outsourcing cognitive loads, and by doing so, externalising the cognitive process into the environment? One of the most convincing studies is the task of mentally versus physically rotating a zoid during Tetris (Kirsh and Maglio, 1992). According to Kirsh and Maglio, *epistemic action* can be distinguished from *pragmatic action* (Kirsh and Maglio, 1994). Their infamous experiment displayed how it took significantly more time to reach a solution when mentally rotating the zoid coming down to an existing environment of zoids, as compared to physically rotating it (Fig. 8.3). Kirsh and Maglio argue that epistemic actions are performed to uncover information that are difficult to represent mentally, whereas pragmatic actions are performed to bring one physically closer to a goal (1994, p. 513). Translated to their experiment, the epistemic action is the rotation while the pragmatic action is to land the zoid in the organised environment. Experts in Tetris make excessive use of epistemic actions by externalising the rotation, i.e. physically rotating it. This kind of action

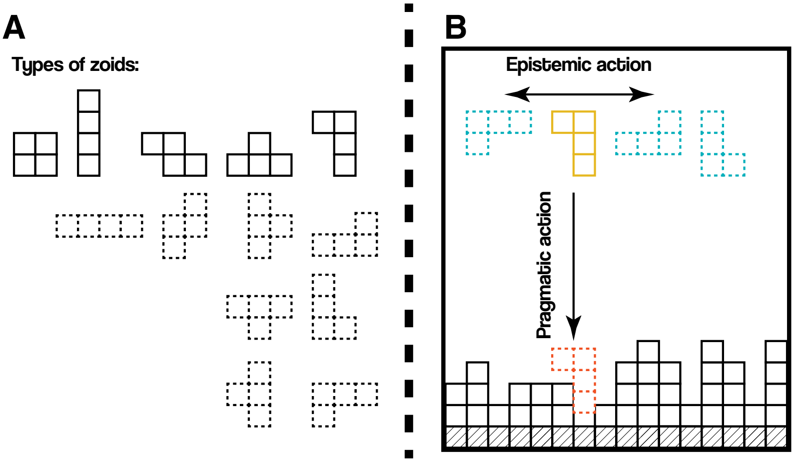

*Figure 8.3*— **A.** *The zoids on top are the shapes that need to be rotated, where the dashed zoids represent the rotated possibilities.* **B.** *This is how the game unfolds. Tetris consists of continuously falling zoids that show up one at a time, which the operator must rotate and fit into an environment at the bottom of already landed and organised zoids. The goal of the game is to organise the zoids so that a continuous horizontal line, from wall to wall, is established. The shaded bottom line is a full horizontal line, which then goes on to diminish.*

serves to change the world (perception of the world) to facilitate a task, i.e. the world is actively changed to guide perception. Many movements involve epistemic extension on different levels throughout an average day, e.g. writing down a phone number or an address are basic epistemic actions, whereas sketching before painting, making a draft of a doctoral thesis, or the gestures used for warming up before a physical exercise are all advanced epistemic actions utilised to facilitate a pragmatic action.

Considering architectural transitions, are there epistemic or pragmatic actions? There certainly are pragmatic actions, as one practically moves through the transition—however, there are rarely epistemic actions. If, for instance, one wakes up during the night to go to the bathroom, and it is too dark, epistemic actions through a tactile and auditory sensory act as an exploration that inform the agent about the environment (Gehrke *et al.*, 2018). These are touches that aid the pragmatic action—however, there is a feature that precedes the epistemic action, namely the virtual action. Virtual actions are the possible interactions, given a physical structure, one may have with an environment, without necessarily unfolding the actions, hence *virtual.* An example of how virtual actions interact with epistemic actions is the active use of the desk at the office, where unread articles are stacked on the left and read articles on the right. Virtually, all papers could be stacked on top of each other, but then the researcher must remember all the unread and read articles, which significantly increase the difficulty of the task. The epistemic act of organising the articles, using left and right, aids off-loading the cognitive process. When reorganising an apartment, the virtual actions encompass the possible scenarios the apartment could take, but the unfolding the physically organising the apartment is the epistemic action. Virtual actions operate at the level of intention serving the epistemic action of placing something in a certain way in space to reduce expenses of neuronal currency. How does this relate to architectural transitions?

The body of the zoid and the affordances of the zoid-environment, which the zoid is embedded in, determines the process during the slow fall. In the human case, while approaching a door, the process of unfolding bodily actions approximates a bodily posture that fits the door. It is clear that the process of externalising cognitive features to offload the cognitive process is fundamentally a process of action-perception, i.e. one changes what the world is perceived like by acting upon it to improve the conditions for the cognitive results according to the intentions. The process of action-perception originates in the virtual actions, unfolds as epistemic actions to fulfil pragmatic actions. In other words, the process of experiential transition (temporal) in architectural transition (spatial) is highly dependent on the interaction between action and perception and reflects the mechanics of externalising cognition furthermore. Although human beings have here been reduced to zoids and the architectural environment to a two-dimensional environment, it will be shown onward how action-perception is essentially how cognitive processes operate. It was shown here that the externalisation of virtual actions is essentially how the brain, body and environment couple on a psychological and philosophical level.

### 8.3 Conclusion

This chapter set out to link environment to brain and body first on a neuronal level and then on a philosophical and psychological level. The nature of the neuronal activity was shown to stem from an intertwining of spontaneous and stimulus-induced activity. This eventually yielded the spectral model of the brain, which suggests that the balance of endogenous, i.e. self-generated, and stimuli-induced, i.e. built environment, activity reveals the psychiatric position of the brain in question. This approach ensures an empirically possible investigation of architecture as an external environment may be reflected in neuronal activity.

The psychological and philosophical linkage of the environment to body/brain unfolded through a defence of the parity-argument in *the extended mind hypothesis* by Clark and Chalmers (1998). It was shown that the C-C fallacy is invalid with a dynamic and emergentist approach to cognition because there is necessarily a temporal and diachronic dimension that dissolves the causal/constitutive relation. It seems that the process of cognition goes beyond the spatial character. Interestingly, it appears that the link between brain/body and environment unfolds through the basic feature of action-perception, which was precisely dictated by Bergson, Husserl, Damasio and Varela. There are good reasons to believe that the way the environment enters the process of cognition is through the process of action-perception.

With that said, when revisiting the research question of the thesis, two dimensions need to be addressed, namely the architectural transition and the experiential transition. The issue at hand becomes how architectural transition, as an external stimulus, has an impact on the experience. Keeping in mind that neuronal activity itself has not been stated to reflect experience; in fact, such would amount to unfortunate radical epiphenomenalism. It is for this reason that the phenomenological conditions were set up; to attempt to establish an empirical framework that does not reduce the phenomenological nature of experience. Instead, the next challenge is to understand how the experience of the environment enters the action-perception process. How is the environment experienced? How does the environment imprint itself in cognition via action-perception? It is unknown to which *degree* architecture can influence neuronal activity and even more critical; it is unknown what *kind* of influence architecture can have on neurophysiological balances.

## CHAPTER 9

# Sensorimotor contingency and representations in the brain

*"Seeing is directed to the world, not the brain."*
*(O'Regan and Noë, 2001, p. 962)*

*"We go wherever we are looking."*
*(Berthoz and Petit, 2008, p. 67)*

**Summary.** *What are the roles of action and perception in experience and cognition, and are these internally represented?* It was shown in the prior chapter that the environment as an external stimulus is reflected in neuronal response and that cognitive processes externalise elements relevant to cognitive operations. This chapter remains on a philosophical level and targets experience of architecture from a cognition perspective. In this chapter, the notion *experience* in architectural experience is addressed via an enactive account, i.e. sensorimotor contingency (SMC), to introduce SMC and to investigate whether SMC is a representational or non-representational account of basic cognition. Eventually, this will guide the direction of the empirical framework. It is found that SMC casts perceptual experience as emerging from the active structure of change in the sensory signals. SMC dictates that cognition emerges from the coupling of brain, body and environment, where the link to the environment is critical. Earlier accounts of the coupling have argued the interaction to be based on internal representations of the world. However, through action-perception, an internal representation of the environment is unnecessary, suggesting a non-representational account of the causal coupling instead.

### 9.1 On action and internal representation

As the contemporary debate on mental representation is complex, the prevalent implications are sorted out and used to generate a list of conditions that a representation must fulfil to be considered a representation at all. The kind of representation that is addressed is only relative to action-perception, i.e. whether action needs representation in an action-perception approach to the coupling to the environment. In phenomenological words, whether the protention prior to action, or the potential action itself, is representational. Since it was established in Chapter 7 and 8 that the process of action-perception could be considered very basic, the task at hand is to investigate whether a representation is necessary for basic cognition[1].

What is meant by mental representation in action? Because there is no agreement on what mental representation is, various philosophers generate different conditions for a representation. Whether there is any mental representation when asked to reproduce the route from the office to the café mentally, is beyond this discussion. In the present discussion, the immediate action-related experience is of concern. Similar to intentionality and representation is their concern of physical and mental contents, e.g. qualia. They are also thought to be related not only because they hold the feature of *pointing*, so that the world is pointed to through internal mediators, but also because they are *about* a variety of things, e.g. properties, abstractions and relations. Any form of representation includes a series of complex processes to make the content to be internally represented. As Ramsey (2007, p. 16) states: *"My belief that Columbus is the capital of Ohio is about Ohio, its seat of government, the city of Columbus, and the relation between these things."* For instance, the complexity of *belief* in representationalism; it is a complex operation that refers to logical propositions, i.e. to *believe* in having learned that architecture is a crucial discipline to understand cognition is a fact that is stored in memory, from which it is then retrieved, accessed or recalled when necessary—in other words, a belief is a propositional knowledge that holds a truth-value, in contrast to pragmatic knowledge. Believing is not an immediate operation at the level of action-perception, and it is precisely the immediacy of action-perception that makes it such a basic feature of cognition. Although belief can be used in various contexts, it is yet one thing that a particular space appears marine-blue and another thing that one deduces the colour, i.e. one is immediately given while the other takes a

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[1] Only representation relative to action-perception are discussed, any approach involving cognition and representations, such as Fodor's representational theory of mind (Fodor, 1987) or Marr's approach (Marr, 1982) are not considered. Such approaches have been sorted out during the discussion of DST, decomposability and global-to-local effects, as incompatible with biological brain and body structures. This is not to deny that the mental does not involve language and symbols operations, but that language and symbols are helpful only on a highly advanced class of high cognitive processes. This investigation concerns the complexity of pre-linguistic organization of experience, which is arguably devoid of language and symbols, and instead organized and driven by action and perception. Believing that language and symbols are necessary to understand the world, is stating that language and symbols precede action; that one could talk before acting. Berthoz and Petit name these approaches crypto-dualism. In space, things happen outside, and mental representations inside. In time, stimulus comes first, then the percept. In causal order, first come cause, e.g. an event, then comes effect, e.g. visual representation (Berthoz and Petit, 2008, p. 15).

logical propositional attitude. Both the protention and virtual action are *knowing how* and take part in immediate consciousness, making it difficult to declare either one as representational.

Why is representationalism a critical subject for the current research question? Recall the quandary introduced in Chapter 3. If the brain constructs the world through representation, our investigation must necessarily take a representation-related turn, including locating the content in perception such as qualia, which consequently impose a computational-approach neglecting the dynamic nature of cellular organisation and cognition (Chapter 7 and 8). It would include locating perception as a *re-reality* in the brain. Even if there is no re-reality representation in the brain, but instead states that are semantically evaluable (Adams, 2010), the brain still faces a loci-oriented approach that is criticised hitherto—however, by taking a DST approach and attempt to understand the sensorimotor[2] relations to cognitive processes, it may be shown that there is no representation in the brain neither in action nor in basic cognition.

Many have found it necessary to solve representation through action, giving rise to *motor representations* as the link between action and the outcome of that action (Butterfill, 2014). This approach still serves the claim that the only objective of mental states is to represent, i.e. mental states only exists as representations. An example is action-oriented representation as described by Clark (1997, p. 49): *"representations that simultaneously describe aspects of the world and prescribe possible actions, and are poised between pure control structures and passive representations of external reality."* These action-representations display the idea in question addressed in the next parts. Exactly how does the environment emerge from action-perception, or more precisely, how does an architectural transition emerge from action-perception?

Recall that architectural transitions are reduced to their properties of forms and shapes, where, e.g. colours, lights, texture, are not considered. To simplify even further, only the visual contribution to perception is taken into account. Seeing the colour *dark green* is different from seeing the colour *red,* but not too different from *light green*. Why is that? It may be tempting to say that the green colours are close in wavelengths stimulating similar neuronal processes and thus giving rise to similar percepts, but since there is no a priori reason for why neuronal activity should generate experiences, this cannot be regarded as a valid answer. Is experience reducible to the little space between neurons, namely the synapses (Appendix B), as LeDoux (2003) suggested? Even if assuming that different neurotransmitters give rise to different experiences, there is the question of why and how these neurotransmitters give rise to precisely those experiences.

To reassure, representation in perceptual experience refers to the hard problem of qualia (Chalmers, 1996). Quale is usually exemplified as a phenomenal, qualitative and subjective experience of colour—however, does quale include shape and form? The hard problem of form is rarely mentioned as part of quale. Analysing form as a function of time, Robbins manages to encapsulate the essence

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[2] Refers to the cortical process of the integration of the sensory and motor systems.

of inquiring temporal questions, rather than spatial, relative to quale (2007, p. 24). Although Robbins argues for a holographic theory of perception, the strategic approach is admirable. Robbins introduces an experiment, namely a rotating cube with varying speeds. When the speed is strobed in phase with its symmetry period, it is perceived as a rigid cube. When it is strobed out-of-phase breaking the temporal constraint that the perceptual system is constrained to, the cube is perceived as wobbly (Robbins, 2007, pp. 5–6). The example is comparable to the reverse-rotation effect, i.e. when a wheel spins at a specific frequency, it is perceived as rotating backwards. Form and shape can undoubtedly be considered as phenomenal, qualitative and subjective experiences equivalent to the notion qualia.

In architecture, form has indubitably a significant role. The nature of form emerges from any edge-like perceptual behaviour that is subject to the figure-ground organisation in perceptual grouping, e.g. colour differences, lines and general geometric forms. Shapes emerge from differences in patterns during any change in perspective causing a sense of shape and form appropriate to the perceptual apparatus. Shape and form cannot emerge from their simple occurrence. Thus, from these observations, the claim is that the qualitative character of experience is not a matter of static states of something, but directly a consequence of the action-perception process. Experience is an active, qualitative feature, leaving nothing to a static spatial character, such as a colour or a shape. As put forward by O'Regan and Noë:

> *"Qualia are meant to be properties of experiential states or events. But experiences, we have argued, are not states. They are ways of acting. They are things we do. There is no introspectibly available property determining the character of one's experiential states, for there are no such states. Hence, there are, in this sense at least, no (visual) qualia. Qualia are an illusion, and the explanatory gap is no real gap at all […] Our claim, rather, is that it is confused to think of the qualitative character of experience in terms of the* occurrence *of something (whether in the mind or brain). Experience is something we do and its qualitative features are aspects of this activity." (2001, p. 960; original emphasis).*

Since there are no states in experience but only dynamics, the explanatory gap[3], thus, does not exist. Experience has a qualitative character that depends on the forms of activity, which relate to environment-involving interactions, but there is no explanatory gap equivalent to qualia as described; this is a false problem (Hutto and Myin, 2013, p. 169). The *feeling* of what something is like (Nagel, 1974) is here argued to stem from the activity in the dynamics of the sensorimotor integration. This hardly seems as a novel idea since the practical synthesis in

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[3] *"One of the central philosophical debates surrounding qualia concerns the question whether qualia can be studied by means of traditional biological and cognitive science. It has been suggested on this point that there is an unbridgeable 'explanatory gap,' that it is not possible to explain the subjective, felt aspects of experience in behavioral, physical, or functional terms." (O'Regan and Noë, 2001, p. 960)*

Husserlian phenomenology is a forerunner to this idea. Before drawing the parallels to Husserl, the conditions of a representation is here taken into account.

### 9.1.1 Conditions of representation

As it turns out, several definitions of representation in action explain the relation between body, brain and environment. Instead of focussing on a set of definitions by a single author, the recurrent conditions by numerous authors are examined to get a holistic aspect of the issue. The conditions closely follow Gallagher's (2017, chap. 5) outset of representations of Rowlands (2006, pp. 5–10), Wheeler (2005, chap. 8.2), Orlandi (2014, p. 9), Hutto and Myin (2013, chap. 1) and Clark (1997, pp. 47–49). The various definitions range from representations being exclusively internal, discrete, content bearing with reference for something else, requiring interpretation and decouplability from the context. Recall that the representation in question is related to action.

The following definition of representation stems from carefully reading the mentioned authors to include the recurrent/chronic principles. First, there is consensus about representation *standing in* informationally for something else, taking a mediator role within a system. This has been referred to as the representational constraint, that is, to be representational it must carry information about something other than itself. Consequently, the representation calls for interpretation as in symbols and signs, which necessarily calls for propositional knowledge. In the context of action, this means that the chains of reactions are not causal but communicative, i.e. the body schematic process when walking through an architectural transition is a process of a moment to moment interpretation of actions to understand the limb positions in space.

Second, besides interpretation, a representation must be teleological; that is, it must track or hold a specific function towards the represented, similar to how a thermometer tracks the temperature of a space. To this end, the thermostat can be said to represent the temperature of the space. This constraint sets forth the frozen static and discrete ontology of representation. In the context of action, a discrete view suggests that the just-passed (retention) is processed independently of the about-to (protention) in the sense that these two moments are *communicative* rather than *causal*.

Finally, if something is representational, it is decouplable from that something, so that something can be represented even in the absence of that something. In the context of action, decouplability is the argument that an action can be detached from perceptual and proprioceptive input. This constraint sets forth the need for decouplability in representation (Gallagher, 2017, p. 99). In sum[4]:

1. Informational mediator.
2. Discrete duration.
3. Decouplability.

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[4] The points further resemble those summed up by Gallagher (2017, p. 99).

All points are interrelated given they follow a computationalists approach to cognition. This is necessarily in conflict with the hitherto established dynamic nature of the biological properties. In the next part, Husserl's practical synthesis is linked with a sensorimotor perspective of enactivism inference and hereafter compared to these three conditions for representation in action.

### 9.1.2 Husserl's practical synthesis

Husserl argued that perception is practical, making it irreducible to sensory events or parts. Instead, it must be grasped in its entirety since perception is not given in separated forms (Chapter 5). It is immediate and pregnant with its form, devoid of intellectual processes as in deciphering and intermediate inferences of what each sign may signify. The immediacy covers the transcendental dimension of perception, namely that one perceives more than given. It was concluded in Chapter 5 and 6 that this was due to the anticipatory process of visual perception involving fulfilment of intention as action unfolds. The predictive feature of perception is arguably the root of the impression of seeing every detail in visual perception as if one can read this page from a mental representation.

The counter-intuitive trait of transcendental and non-representational perception is the feeling of being able to see it all, even without a picture-like internal representation. According to Husserl, it is tempting to believe that at first glance one can see all the details of the visual scene, but this is explicable as a practical synthesis.

> *"As you look at a visual scene, you can interrogate yourself about different aspects of the scene. As soon as you do so, each thing you ask yourself about springs into awareness, and is perceived—not because it enters into a cortical representation, but because knowledge is now available about how sensations will change when you move your eyes, or move the object" (O'Regan and Noë, 2001, p. 946).*

The visual scene is readily there for the observing agent, who, with a healthy pair of eyes, knows how to actively generate saccades or movement and see what is of interest, and thus *bringing* that detail to visual perception.

The appearance that one perceives all is similar to the investigation of fridge-light; is it always on? When opening the refrigerator, the light is on—even after closing it, then opening it again, the light is yet on. If one wants to see if the light is on, one simply opens the fridge. Analogically, "[…] *the visual field seems to be continually present, because the slightest flick of the eye, or of attention, renders it visible"* (O'Regan and Noë, 2001, p. 947). Interestingly, bringing a visual detail to attention is a practical task as it involves eye saccades.

Nevertheless, beyond eye saccades, the transcendental dimension of perception holds also for other sensory organs:

> *"Let's return again to simple examples. You hold a bottle in your hand. You feel the whole bottle. But you only make contact with isolated parts of its surface with isolated parts of the surface of your hands. But don't you feel the whole bottle as present? That is, phenomenologically speaking, the feeling of presence of the bottle is not a conjecture or an inference.* The feeling you have is the knowledge that movements of the hand open up and reveal new aspects of bottle surface. *It feels to you as if there's stuff there to be touched by movement of the hands. That's what the feeling of the presence of the bottle consists in.* But the basis of the feeling, then, is not something occurring now. The basis rather is one's knowledge now as to what one can do.*" (O'Regan and Noë, 2001, p. 963; emphasis added)*

The sense of touch, and getting a full haptic grasp of the bottle, is guided by the visual sense as it continues to extend beyond the currently given interaction with the bottle. The feeling of fully grasping the bottle is not due to being in full haptic contact with the bottle, but because the visual sense assures that if the agent wishes to interact with other parts, it is readily there. The interaction gives rise to a feeling of transcendence in perception, which is precisely the phenomenon necessary to understand in architectural transitions because it seems sensory predicts the environment using prior experiences during movement. Recall the architectural quandary, i.e. whether *space B* is experienced in the same way when approached from *space A* compared to *space C*. In this sense, the point of departure in the approaching of the experiencing agent is different environments that give rise to different predictions. Not because the environments are represented differently in the brain, but because the predictions in the practical synthesis are different; one has the knowledge about which bodily parts to move to modify the sensory input bringing one closer to the next space. In other words, the continuous perception of transitioning in space is strictly a matter of how the body schema and future actions in that space, i.e. *knowing how*.

This is not different from other observations insofar, e.g. Bergson introduced virtual actions*,* Husserl introduced practical synthesis and horizonal intentionality*,* whereas the DST/DH approach offered an action-perception process encouraging a radical embodied cognitive science, and finally, epistemic actions were introduced as a type of action, which extends mental operations into the environment. Beyond the sensorimotor system as the integration of sensory and motor system, which unfolds in the brain, the claim is as summed in Berthoz and Petit: *"We are going to claim that* the brain is essentially an organ for action*, whereas others hold that on the contrary,* the brain is an organ of representation. *Many have concluded that the basic division is between those who hold the view of* representation for action*, and those who hold the contrary view, of* action for representation" (Berthoz and Petit, 2008, p. 1; emphasis added). In Bergsonian spirit; the division between representationalists and non-representationalists can be set out as the difference between those who hold the brain is a master of representation or a master of action. Enactivism casts the body and brain as masters of action and taking a non-representational position that emphasises the importance of action-perception for cognitive processes.

## 9.2 What is enactivism?

Enactivism was coined the first time in 1991 by Varela, Thompson and Rosch (2016, p. 173), suggesting the origin of cognition to be in the action-perception process so that cognition ultimately emerges from sensorimotor patterns that enacts a world. Put briefly, the world is understood through senses and the specific laws that govern that specific sensory modality, which differ in characteristic structure from modality to modality, e.g. visual to auditory. Similar to all senses is their dynamics of being enacted in the sense that BU sensory signals are met by TD predictions that are based on the history of the structural coupling. Varela and colleague's early enactivism introduce the idea of sensorimotor dependencies (2016, p. 172). Interestingly, they go on to dismiss the (discrete) truth-ness of idealism and realism, because they take the notion of representation to reflect truth-value. This rejection is precisely like that of Bergson and Husserl; the lines of arguments add up. Perception holds no truth-value but depends strictly on the dynamics of the sensorimotor contingency pattern that may be taken as perceptual experience (O'Regan and Noë, 2001). Enactivism has ever since grown considerably and developed into 4E-cognition (Newen, De Bruin and Gallagher, 2018). The ism itself is not of interest, but the principles covering the coupling[5] of experience between the world and body are of major importance towards an empirical theory.

To demonstrate how perception is interlinked to action, take perception and action independently into regard[6]. The emerging *problem of perception* is that since the brain does not have direct access to causes of the sensation, it must infer the origin. For instance, the visual sensory signal of *white* may be caused by staring into the wall at Kiasma Museum of Contemporary Art by Steven Holl, or facing another wall in Kunsten Museum of Modern Art by Alvar Aalto, but indeed not a Rothko painting. Each of these examples attenuates experience in each their way when acting in the respective environment—thus the experiences of whiteness (or non-whiteness) are not comparable. In other words, the perception problem is to infer the source of the sensory signal.

The *problem of action* refers to being able to infer causes of sensation and the consequences of actions from only operating with sensory signals. In enactivism, the basic feature of perception and action linking in a manner where they hardly can be separated may be termed basic cognition. Basic cognition is constituted by and understood in terms of concrete patterns of environmental situated organismic activity relative to action and perception (Hutto and Myin, 2013, p. 11). Both problems highlight the same issue but from different points of view. They are arguably identical. One problem forms the solution of the other, and this is

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[5] The coupling is the action-perception process that deeply integrates one with the other so that they are inseparable, and essentially, separating two philosophies of science, namely intellectualists and dynamicists.

[6] The problem of perception and the problem of action are two extremely important notions for the upcoming chapter, which seek to resolve firstly the problem of perception by setting an inferential model of the world, and hereafter apply an "update" of the inference by resolving the problem of action.

precisely what O'Regan and Noë advocates in the sensorimotor coupling.

### 9.2.1 Sensorimotor coupling > Representation

In their seminal paper, O'Regan and Noë present a general framework to visual consciousness (2001). The problem they address is related to qualia, that is, the hard problem of experience relative to neural activity. O'Regan and Noë argue that although the brain maps the spatial position of the body through place-cells (O'Keefe and Nadel, 1979; Moser, Kropff and Moser, 2008), the neural activity cannot explain the quality of the experience of being somewhere. This is an important statement relative to architecture and the research question. The central thesis in O'Regan and Noë's proposal is *a sensorimotor contingency* (SMC) approach, which is ultimately an approach that is based on DST focusing on the change of pattern instead of the state of the pattern itself. Vision in SMC becomes an active exploration of the world through sensorimotor contingencies, thus usually referred to as an actionist approach.

> *"Actionism is committed to the idea that perception is active, but not in the sense that it requires that one move. What is required is that one understand the relevance of movement to action, and that one knows what would happen if one were to move. Perception is active, according to the actionist, in the same way that thought is active. We exercise our sensorimotor understanding when we see." (Noë, 2010, p. 247)*

Consider the first condition for a representational account, namely that of internal representation as propositional knowledge, i.e. informational mediator. To properly unpack SMC against this condition, it is necessary to evoke Ryle (1945) and the difference between propositional knowledge (intellectual) and practical knowledge (intuitive). Ryle distinguished between *knowing-that* and *knowing-how,* and states that *knowing-how* necessarily precedes *knowing-that* because *knowing-how* cannot be defined in terms of *knowing-that*, but only vice versa. That is, the intuitive knowledge is logically prior to the intellectual (Ryle, 1945, pp. 4–5).

> *"Knowing a rule of inference is not possessing a bit of extra information but being able to perform an intelligent operation.* Knowing a rule is knowing how. It is realised in performances which conform to the rule, not in theoretical citations of it.*" (Ryle, 1945, p. 7; emphasis added).*

According to O'Regan and Noë, the kind of knowledge in SMC is not propositional, but practical, in the sense that the perceiver knows how to interact with the percept; it is a skilful deployment of specialised practical knowledge relative to the sensory organ. It is knowing *"the ways in which stimulation in a certain sense modality changes, contingent upon movements or actions of the organism"* (Hutto and Myin, 2013, p. 25). SMC's account of action-perception does not comply with the first condition for representation.

SMC does not comply with the second condition either, namely that of discrete duration. This can be shown by drawing parallels from Husserlian passive synthesis, and the fulfilling of intention in experience and perception to SMC, i.e. retention and protention are necessarily respected in SMC. The physiologist Alain Berthoz comments on action and intention in a manner that complies with Husserl's initial account:

> *"What is brought into play in the preliminary phases of the micro-genesis of the action is not just an accumulation of energy awaiting the moment of release but rather* the formation of an intention before the occurrence of the movement*; that is, of a sense content that would make of this movement something more than simply a movement: a motor behaviour,* but precisely an 'action' directed towards a goal.*" (Berthoz and Petit, 2008, p. 62; emphasis added)*

In other words, the protention becomes the immediate prediction in action necessarily linking any continuous action dynamically. There cannot be any action before the forming of an intention to act which extends dynamically over time, i.e. it naturally streams towards the retention that forms the prior experiences, which in turn adjust normality used to form future protentions. This is how the passive synthesis forms a practical abductive loop.

On a neuronal level, anticipative activity has been measured at least since the discovery of the readiness-potential (Libet *et al.*, 1983), that is, cortical activity before action. The difference on a neuronal level between the representational and non-representational account of cognition in action is that the connections in the sophisticated connectivity of the brain are affected causally by chemical processes, as opposed to representational communicative processes (Gallagher, 2017, p. 101). *"The dynamical process* […] *does not require the idea that one discrete part of the mechanism interprets in isolation (or off-line) the information presented by another part. Rather, the protentional/anticipatory aspect that characterizes action itself, on the dynamical model, functions only in relation to the ongoing, online, project-determined coupling with the environment"* (Gallagher, 2017, p. 102). Given the dynamic and self-organising continuous causation in the temporal structure, there cannot be static/frozen moments during action/perception[7]. In fact, actions can be fallible precisely because perception can be misenacted, e.g. the step was a bit taller, the door was not that wide or the space was lighter than anticipated.

Regarding the third condition on decouplability, there is a misconception of the feature with regards to action. Re-enacting an action, i.e. to remember or simulate the action of walking through a transition, may require representation—but this says nothing about representation in the immediate and intuitive action (Gallagher, 2017, p. 91). Any immediate action preparation is not only physically linked to the current environment but also to the current body schema and

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[7] Needless to state that Bergson built the very fundament of his philosophical framework precisely on the impossibility of movement in spatialised time, which is precisely the founding idea of static time-evolution in cognition.

current task. The criticism of the second condition elucidates the continuity in action so that any immediate action is not decouplable from neither the current environment nor the retained or protentive properties of that action. The perceptual and proprioceptive inputs are part of the unfolding of the continuous action. Therefore, SMC does not comply with the third condition either.

### 9.2.2 Perceptual experience in architectural experience

The SMC approach to experience helps de-mystifying experience, so the gap between natural sciences and social sciences is reduced, allowing a reach from one to another. For architecture, closing the gap is to extend architectural research from pure phenomenological descriptions to experimenting and constructing theoretical frameworks that embrace the complexity in architecture. If one continues to restrict architectural experience to quale one is failing to accept the non-existence of qualitative properties. This is not to say that subjective experiences are illusory; the *perceptual experience* of red is explicable through SMC, but the phenomenological *subjective experience* is not accessible by others. The subjective experience is confined to the experiencer alone. Nonetheless, architectural experience occurs over time and space: "[…] *experience is shaped by a heterogeneous environment, as a perspectival deformation that is continuously synthesized in temporal transitions—the fundament of architectural experience is that of a continuously heterogeneous environment."* (Djebbara, Fich and Gramann, 2019, p. 271)

The perceptual experiences have insofar been (methodologically) restricted to phenomenological descriptions on a personal level. SMC offers a novel way of understanding the perceptual experience, namely through action, which in itself is a phenomenological turn:

> "[Phenomenology] *demonstrates the wide-ranging features of experience through reflections on the experience itself, by not restricting experience to representation and perception. In fact, phenomenology teaches an important lesson on human experience by emphasizing time as a necessity for experience (Gallagher and Zahavi, 2012, chap. 4). Merleau-Ponty et al. (1968, p. 29) underlines that from feeling and vision will be retained only what animates and sustains them, meaning that perceptual experience is what enables a continuity, a passage from one moment to another. Experience as such does not become a matter of 'knowing' and rationally untangling the depth of perception. Rather, experience develops from perception as 'in action' and thereby, attributing perception a primacy due to its bodily relation (Merleau-Ponty and Edie, 1964, pp. 12–13)." (Djebbara, Fich and Gramann, 2019, p. 266)*

The idea of quale holds back architecture from natural sciences—thus, if SMC holds true, architectural research may encounter a wave of novel research that is based on sensorimotor dynamics enlightening the perceptual experiences of architectural settings. The temporal approach to experience disregards the spatial character of experience, shifting the focus towards dynamics. Instead of spatial character (quale), the rules of change in action become the perceptual experiences that are free of any representation. If actions entailed representations then to answer the research question, the approach necessarily needs to be representation-oriented, which entails investigating the brain as a centre of representation instead of action. Hitherto, it seems that action entails no representation but operates through a dynamic (causal) relation with perception. In sum, SMC provides a non-representational approach that rearranges how an experience should be conceived and determines the direction of the empirical framework.

## 9.3 Conclusion

The radical argument in SMC is that the dynamics, or the law governing the sensory apparatus, *is* the experience. O'Regan and Noë refer to the dynamics that give rise to experience as the *structure of changes* (2001), highlighting the importance of the temporal structure in an experience. SMC offers not only an account of the action-perception process as non-representational dynamic coupling but also a philosophically and physiologically bound theory, paving the way for a range of serious investigations in the mysterious field of human experience. In many ways, it seems that perception can almost be entirely summed, as the possibility for the brain to extract from the environment information relevant to action. To use Bergson's term; to perceive is to anticipate the virtual interaction. Not only does SMC fit perfectly into the DST/DH approach, but it also complies with Bergsonian and Husserlian principles on immediacy and dynamicism, and the relation between action and perception. In brief, Bergson, Husserl, Damasio, Thompson and Varela all suggest that action and perception are so intimately interwoven, they cannot be fully separated; they depend on one another in a circular causal manner. Bergson directly suggests *"[…] the truth is that perception is no more in the sensory centres than in the motor centres"* (2004, p. 43), while Husserl suggests that kinesthetic synthesis and fulfilling an intention make up a system of action and perception over time (Chapter 5 and 6).

However, SMC has not been able to offer a detailed structure of practical knowledge in the relation between action and perception. A representationalist may rightfully criticise SMC for not being able to bring an appropriately detailed description of the practical knowledge and how it links over time. Undoubtedly, the dynamic coupling is describable as above, but what is needed is an explicit and direct description of the practical inferential link that governs the action-perception system—otherwise, SMC offers an ideal/abstract and inefficient solution to action-perception. As such, SMC is meaningless with regards to the construction of an empirical framework. To properly amount to an empirical framework, the *problem of perception* and the *problem of action* must be grabbed by their horns and handled. The question is; how does the active inference of action-perception unfold? This was recently answered in a methodological paper by Djebbara, Fich and Gramann: *"The non-radical claim is that investigations in action-perception are able to provide a better understanding of how architecture affects and shapes our experiences. We thus set out to understand the advancement of movements, through active inferences and affordances"* (Djebbara, Fich and Gramann, 2019, p. 269).

## CHAPTER 10

# A Bayesian cognitive neuroscience:
## Active Inference

*"Probability theory is nothing*
*but common sense reduced to calculation."*
*Pierre-Simon Laplace (1749-1827)*

**Summary.** *How does the actual process of action-perception unfold?* SMC claimed to provide a non-representational account of the action-perception process but lacked an explicit and direct description of the practical inferential link that governs the process. How the active inference of action-perception unfolds is surprisingly well described in Bayesian cognitive science. Unbeknownst among architects, Bayesian cognitive science has recently proven outstanding in terms of describing cortical responses and human behaviour. This chapter goes beyond philosophy and takes a deep dive into computational neuroscience. Applying Friston's active inference to action and perception highlights the dynamics in the practical inferential link between experiencing agent and environment. Furthermore, the links between enactivism, Bergsonian virtual action, Husserlian temporality, and active inference are highlighted to demonstrate the similarities and thus compliances. This chapter suggests that Bayesian cognitive science may pave the way for a new field of architectural research, namely a form of architectural cognition where cognition is enacted by virtual actions that are offered in a designed environment. Important terms that will be unpacked include Hidden Markov Models, generative model, Jensen's formal description of inequality (variational free energy), Kullback-Leibler Divergence and action policies (virtual actions).

## 10.1 Generation *Predictive Mind*

Throughout the recent years, a trend towards a predictive mind has emerged from both philosophy and cognitive neuroscience. It was recently revived as a model for visual perception under the name *Predictive Coding* (Rao and Ballard, 1999), where hierarchical layers couple through top-down (TD) and bottom-up (BU) signals, encoding prediction and prediction-errors (PEs) and further weighted by their precision. However, the predictive and hypothesis-testing approach to the brain has been hypothesised for many years using different terms (von Helmholtz and Southall, 1962; Gregory, 1980; Frith, 2009). Generally, the Bayesian approach to modelling holds that cognitive processes depend on predictions that are based on inferential models. Since *Predictive Coding*, various kinds of Bayesian inferential models have been developed, for instance, predictive processing (Clark, 2015), predictive mind (Hohwy, 2013) and active inference (Friston, 2010). Their common denominator is the generative[1] Bayesian model, which can be briefly summed up as the probability of an event to take place based on prior knowledge regarding conditions relative to the event (for a brief walk-through of Bayes' theorem see Appendix D). This chapter deals specifically with active inference, which is a rewriting of the free energy principle as applied to action-perception.

## 10.2 Framework of Free Energy Principle (FEP)

This chapter builds around the problem in perception (inferring the sensory outcome) and in action (planning which actions are appropriate to solve the perception problem). Both problems were pointed out in Chapter 9. The outline of this subsection is to provide an overview of the theoretical ground by firstly resolving the problem of perception, i.e. how perception emerges from a process of minimising free energy, by giving a walk-through of how one may apply Bayes theorem to infer sensory signals. FEP displays ingenuity in the resolving of the intractable problem of too many hidden states—FEP suggests that free energy can be used as an approximation. Second, a resolving of how the action policies[2] emerge parallel to perception is added to the equation—here, the links to enactivism, non-representationalism, Bergson and Husserl become explicit. Finally, in the next subsection, an instance is given to demonstrate how this may be applied to action-perception situations in architecture.

### 10.2.1 FEP in words

FEP, a prominent framework in Bayesian cognitive science, dictates that the brain functions as a predictive organ that continuously guesses the incoming

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[1] A generative model can be contrasted with a discriminative model. Their main difference is that the generative model learns the joint probability distribution, i.e. P(o, s), for categorising, e.g. signals, whereas the discriminative model learns the conditional distribution, i.e. P(o | s), for categorising. Generative models can be said to address the question regarding which category generates a signal, whereas the discriminative models are not concerned about the signal, but on how to best categorise given the data—thus, conditional.

[2] The set of possible actions.

sensory signals using prior experiences (Friston, 2005, 2010). Such a brain constructs a probable model of the world by acting in the world *"in ways appropriate to the combinations of bodily and environmental causes that (it estimates) make the current sensory data most likely"* (Clark, 2015, p. 7), enforcing a constant prediction of incoming sensory signals (Friston, 2005; Friston, Kilner and Harrison, 2006). It is worth noting that the model that is referred to is the world and not a representation of the world (Friston, Thornton and Clark, 2012). More specifically, FEP states that the brain models a hierarchical generative model with bidirectional links for TD predictions and BU sensory signals, where the PEs serve to correct the generative model. In line with homeostasis (Damasio, 2010) and allostasis (Sterling, 2012), any living organism seeks to avoid surprises, which is here quantified by the PEs, to maximise chances of staying within the homeostatic balance—therefore, according to FEP, living organisms need to predict the external (and internal) events correctly. One may minimise entropy (uncertainty) about the predictions through a range of specific actions. In other words, predictions are improved by actions that best minimise PEs.

The characteristics of Bayesian cognitive science is that the approach suggests only two states need to be inferred, namely (1) the state of the world and (2) the uncertainty about the state (Friston *et al.*, 2012, p. 2). The state of the world refers to the *true state*[3], which is not how the world is perceived (R(s, o) in Fig. 10.1), but how it *is* as objectively as the perceptual organs can portray it. Since the body and brain have no direct access to true states of the world through other modalities than sensory, perception is based on these available sensory observations, where uncertainty about the inferred state further needs to be inferred.

The mathematical framework in the context of modelling FEP is dynamic programming, i.e. Markov decision process (Bellman, 1957, 2010). Importantly, FEP is not a magical theorem from which the world magically emerges, unravelling consciousness. It is an ingenious probabilistic approach to the nature of how the brain makes qualified guesses, and particularly a highly plausible description of neurophysiological responses (Friston *et al.*, 2012). It is surprisingly in line with basic principles found in Damasio's homeostasis principle (Damasio, 2010), Varela's radical embodiment and emergence approach (Thompson and Varela, 2001; Varela, Thompson and Rosch, 2016), dynamic systems theory (Van Gelder, 1998), Bergsonian (Bergson, 2001) and Husserlian (Husserl, 1997) temporality and phenomenology. As the author of FEP refers to the framework, it is a *unified* brain theory (Friston, 2010).

Recall the two different transitions, namely architectural and experiential transition. The term *generative process* is the equivalent of the environment, i.e. the architectural transition, while the *generative model* is the constructed world that demands an observer, i.e. the experiential transition.

Eventually, the FEP can be rewritten into active inference so that perception,

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[3] A true state in FEP lingo is the best approximation possible—not an absolute truth-value of the world that must be pursued.

i.e. the generative model, and action, i.e. the action policies, coexist through a Bergsonian and Husserlian understanding of time. Instead of static, frozen moments, active inference suggests that any given moment interpenetrates so that t–1 and t+1 are integrated into the minimal formulation of FEP. The continuous function of free energy can be expressed (Friston, Kilner and Harrison, 2006, p. 73):

$$F = \int Q(\vartheta) \ln\left(\frac{P(y,\vartheta)}{Q(\vartheta)}\right) d\vartheta \tag{10.1}$$

Here, $\vartheta$ designates environmental parameters and $y$ designates sensory inputs. It is not yet clear from Eq. 10.1 how a probabilistic model of the environment using action and perception may emerge. This is because action has not yet been introduced to the equation. Applying Bayes theorem is already to have the sensory data, and then generating a model that approximates the sensory the best—however, this is only possible with a known number of hidden states. When dealing with an infinite amount of hidden states, the brain must model an approximated model that through action-generated PEs pulls in closer on the evidence model. The term *active inference*[4] refers to the minimisation of free energy through action and perception and is a rearranged form of FEP (Parr and Friston, 2018a).

The Bayesian pattern is not only applicable to cognitive neuroscience but various sciences. In fact, FEP has been suggested to explain the dynamics of living systems and their ability to adapt to an ever-changing environment (Ramstead, Badcock and Friston, 2018), bringing FEP to an equivalent of natural selection. In a nutshell, FEP is a Bayes optimisation according to PEs that further depend

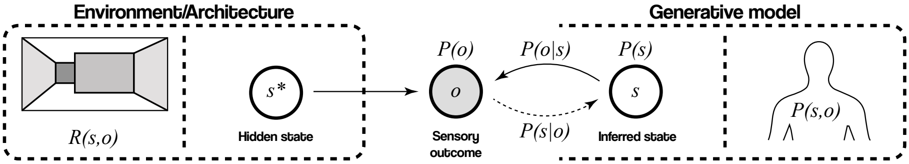

*Figure 10.1—Architecture functions as a hidden state that the brain must infer to perceive. The hidden state generates a sensory outcome, which in turn enters a Bayes inferential loop that infers the cause of the sensory outcome resulting in an inferred state about the hidden state. S* designates the true state, opposite to the inferred state, which is s without asterisk (Solopchuk, 2018).*

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[4] In the generative model, there are a number of matrices that correspond to steps, e.g. the **A matrix** corresponds to the likelihood, **B matrix** corresponds to the transition causing an action, **C matrix** corresponds to the prior preferences as probability distributions over observations (that it "feels good" to not be hungry), **D matrix** corresponds to the prior beliefs before any sensory observation, **E matrix** corresponds to the action policy prior, **F function** corresponds to the variational free energy, **G function** corresponds to the expected free energy and **H matrix** corresponds to the entropy of likelihood (Parr and Friston, 2019). In this chapter, however, the focus rests on action and perception, which include matrices and functions **A, B, E, F and G**.

on predictions and shreds of evidence. This is the generality of FEP that is applied to widen the understanding of architectural and experiential transition in the upcoming subsections (for discussion on the darkroom problem, see Appendix D). There might seem a lot to take in at first glance, but a simplified and systematic description of active inference will highlight the internal structure of FEP.

### 10.2.2 Applying Bayes to perception

While providing a statistical background for PEs, remark how Friston's FEP theorem synchronise with enactivism and DST through active inference and how representation also here is unnecessary when considering the action-perception system. Much of the following evaluation of active inference is built on existing papers and blog-posts (Friston, 2005, 2009; Friston and Stephan, 2007; Friston *et al.*, 2010, 2017; Parr and Friston, 2018b; Solopchuk, 2018).

The problem in perception is that for the body and brain, the world is presented through sensory signals without details on causes of sensation—the world and architectural spaces are thus referred to as *hidden states* (s) that generate *sensory outcome* (o). As the sensory outcomes are the only access the embodied brain has to the environment, hidden states are inferred through the Bayesian model:

$$P(s|o) = \frac{P(s)\,P(o|s)}{P(o)} \leftrightarrow P(o) = \frac{P(s)\,P(o|s)}{P(s|o)} \tag{10.2}$$

What is important in using Bayes' theorem is to quantify the probability of a hidden state given an observation. The probability of an observation, P(o), will itself function as a quantity that represents the quality of the model.

The embodied brain must infer the evidence, earlier referred to as P(B) but now as P(o), which is usually an intractable issue since there may exist infinite causes with various probability for each sensory signal, leaving P(s | o), the posterior probability, without results (Friston, 2010; Ramstead, Kirchhoff and Friston, 2019). P(o) is named *model evidence* because it quantifies how well the model is predicting the real observations. It is also known as *marginal likelihood* because it is the sum of all possible hidden states given a sensory signal (it marginalises the hidden state, *s*), here put as the joint probability:

$$P(o) = \sum P(s, o) = \sum P(s)\,P(o|s) \tag{10.3}$$

If calculating an exact posterior probability is an intractable issue, how then does the embodied brain generate it? Recall the DST principle involving not calculating a single exact outcome, but rather all potential outcomes (Poincaré in Chapter 7). One way of making an inference is to find the state that best maximises the likelihood, P(o = s | o), of the sensory input. Assuming a binomial distribution of the data, one must look to maximise the likelihood by estimating the distributions of the hidden state (Fig. 10.2). Maximising likelihood is the equivalent of

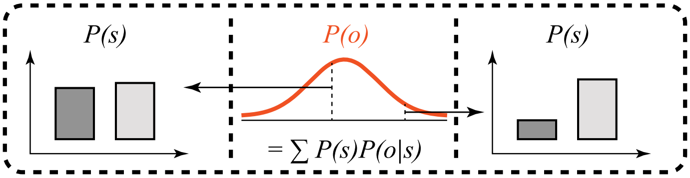

*Figure 10.2—Compare two models with different estimated distributions of the true posterior, which is 50/50 of two measures (e.g. number of times people chose the right door compared to the left door). The closer to the mean of the true posterior, the higher the likelihood estimation. The model on the left shows a distribution close to 50/50, whereas the model on the right shows a distribution of 70/30, which is off. Notice the estimated distribution (Solopchuk, 2018).*

minimising surprise, which is the negative log of the evidence (Eq. 10.4). The rationale is that low probability equals high surprise, while high probability equals low surprise. From Eq. 10.3, the evidence can be written as the sum of the joint probability; therefore, the surprise can be written[5]:

$$-\log P(o) = -\log \sum P(s, o) \tag{10.4}$$

By introducing an approximation, it is possible to get around the intractable issue of estimating all possible values of hidden states. For the embodied brain to estimate the cause of the sensory, it instead performs an approximate Bayesian inference, involving an inversion, as if the embodied brain had access to the evidence. As shown above, the generative model can instead be written as the product of the likelihood function of the sensory signal given the hidden states and the prior probability of these hidden states. Now, the inversion entails a statistical mapping from observable consequences to hidden causes. In order to allow for such inversion, a belief updating, which is usually referred to as *variational densities,* is necessary. However, first, let *Q* designate the *"approximate posterior probability distribution or Bayesian belief that constitutes the organism's 'best guess' about what is causing its sensory states (including the consequences of its own actions)"* (Ramstead, Kirchhoff and Friston, 2019, p. 3) so that *Q* approximates P(s | o):

$$Q(s) \approx P(s|o) \tag{10.5}$$

Before diving into the operations of belief update, consider how the discrete description of active inference (Eq. 10.1) emerges when approximating the model evidence by adding the approximation *Q*(s) and applying Jensen's formal

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[5] Using the logarithm has different advantages. First, multiplying a plethora of very small numbers yields numbers that are too small to be computed, whereas representing the numbers by log means they should be added rather than multiplied, i.e. log(a · b) = log(a) + log(b). Second, due to the nature of log, optimising the log-likelihood is the same as minimising the negative log-likelihood. The approximation probability, *Q*, is always above the negative log of the model evidence, and by minimising the free energy, it approximates the negative log of the model evidence, P(o).

description of inequality[6] in Eq. 10.7. The Bayesian minimisation involves the minimisation of an upper bound (quantity approaching from above) on the evidence model, and this is known as the *variational free energy*. The strategic manoeuvre by Friston in the approximation method originates from Feynman's (1972) variational free energy that represents a bound on the log-evidence, which is precisely where Jensen's inequality guarantees that the free energy functions as an upper bound.

In brief, given the maximum likelihood estimate, which was pursued by minimising surprise, and then $Q$(s) was added as an approximate Bayesian inference. This can be expressed:

$$-\log \sum Q(s) \, \frac{P(o,s)}{Q(s)} \;\le\; -\sum Q(s) \log \frac{P(o,s)}{Q(s)} \qquad (10.6)$$

$$F = \sum Q(s) \log \frac{Q(s)}{P(o,s)} \qquad (10.7)^{7}$$

Eq. 10.7 is the famous formulation of active inference usually read in active inference papers (Friston and Stephan, 2007; Friston, 2013; Bogacz, 2017; Parr and Friston, 2018a, 2018b).

Returning to belief updating, to optimise the belief, one must minimise the variational free energy, which can be shown to be the difference between expectation and true posterior observation. In other words, the difference between expectation and true posterior observation reflects the generalised PE that needs to be minimised. For this purpose, it is necessary to provide a detailed introduction of Kullback-Leibler Divergence (KL) because, as demonstrated, the minimisation of variational free energy leads to minimising the difference between two probability distributions. KL is a measure of how two different probability distributions are different from one another. By minimising the difference, one is approximating the other. The minimisation has been argued to hold a representational feature, as KL represents the difference of internal states introducing decouplability (Kiefer and Hohwy, 2018). The difference that KL offers can be interpreted in multiple ways, e.g. simply the divergence of P from $Q$, the relative entropy of P to $Q$, the surprise in seeing P expecting $Q$. KL always yields a non-negative because if the two probability densities are similar, KL yields 0. For probability measures that are continuous KL is generally defined as:

$$KL[p(x) \,\|\, q(x)] = \sum p(x) \log \frac{p(x)}{q(x)} \qquad (10.8)$$

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[6] Jensen inequality ensures that the right side is always greater than or equal to the left side due to the convexity of the function. With this in mind, we keep the free energy as an upper bound of the negative log, minimising it until equilibrated.

[7] Keep in mind that –log(A) = log(1/A), hence the switch in denominator from Eq. 10.6 to Eq. 10.7.

KL measures the anticipated number of extra bits required to code samples from p(x) when using an approximation q(x)—thus, KL is not a direct measure of difference in distance (Bishop, 2006, p. 55), but rather an indirect measure of uncertainty reflecting how surprising a set of sensory outcomes are on average. With some rewriting of the denominator, Eq. 10.7 can be written as:

$$F = \sum Q(s) \, \frac{Q(s)}{P(s|o)\, P(o)} \tag{10.9}$$

$$KL[Q(s) \,||\, P(s|o)] = -\log P(o) \tag{10.10}$$

Following Ramstead, Kirchhoff and Friston (2019), variational free energy is the equivalent of the relative entropy between *Q*(s), the approximated posterior probability distribution, and P(s | o), the true posterior distribution[8]. Now, the central aim is to minimise PEs by minimising the divergence between the approximated and the true posterior, so that:

$$Q(s) = \arg\min_{s} F \Rightarrow Q(s) \approx P(s|o) \Rightarrow KL[Q(s) \,||\, P(s|o)] \approx 0 \tag{10.11}$$

Eq. 10.11 is stating that the minimisation of free energy is the equivalent of minimising the relative entropy between the approximation and the true posterior. However, the equation can be rewritten more effectively, so that the divergence is not between *Q*(s) and P(s | o), but instead between the approximated probability and the probability of the sensory, P(s):

$$KL[Q(s) \,||\, P(s)] - \sum Q(s) \log P(o|s) \tag{10.12}$$

$$\underbrace{KL[Q(s) \,||\, P(s)]}_{complexity} - \underbrace{E_Q[\ln P(o|s)]}_{accuracy} \tag{10.13}$$

Eq. 10.13 is a rewritten form of the variational free energy (Eq. 10.9), now expressing the *complexity*, which displays the anticipated number of extra bits required to code samples from P(s) when using an approximation *Q*(s) and the *accuracy* that displays a score of the expected outcome.

These rewritings do not solve how action should aid perception becoming more certain about its model of the world, and this is because *“beliefs about* [action] *policies rest* on outcomes in the future*, because these beliefs determine action and action determines subsequent outcomes.* This means that policies should, a priori, minimise the free energy of beliefs about the future*”* (Friston *et al.*, 2016; emphasis added). Insofar, the temporal structure has not been considered at all—instead, the theoretical

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[8] Keep in mind that: log(A/B) = log A – log B, and that: $KL[p(x) \,||\, q(x)] = \sum p(x) \log \frac{p(x)}{q(x)}$

background of how free energy is minimised is reviewed. The outcomes in the future, which is named *expected free energy,* is only possible by adding action into the equations. Before doing so, it is necessary to show that the perception (model of the world), established is a non-representational one, to ensure that it fits with enactivism and the phenomenological conditions. Ultimately, when adding action into the equation, the best option is to cast predictions as the expected free energy, which we shall turn to later. For now, consider representation in KL.

#### 10.2.2.1 (Non-)Representation in KL

Regarding representationalism, Kiefer and Hohwy (2018) argue that precisely because the divergence and the posterior are not identical, i.e. $\text{KL}\ [Q(\text{s})\ ||\ \text{P}(\text{s}\,|\,\text{o})] \neq 0$, the inferred state is a misrepresentation, making room for a representational account of FEP by casting the KL as a decouplable feature (Chapter 9; 3rd condition for representationalism) in active inference. A strong objection is that KL is only a measure of internal densities, whereas a true measure of relative entropy would compare the difference between internal and environmental dynamics (Kirchhoff and Robertson, 2018). As KL obey neither internal representation through signs or symbols between internal and external states (1st condition), discrete duration (2nd condition) nor decouplability (3rd condition), there is no reason to suspect representational content in KL.

When variational free energy has been minimised so that KL equals 0, it can be said that free energy is equal to surprise, which, as put earlier (Eq. 10.4), equals $-\log \text{P}(\text{o})$. In words, minimising free energy yields approximating the *predicted* posterior probability model to the *true* posterior probability model, which in turn means that one is avoiding surprise and thus obeying a homeostatic balance. According to active inference, this is how perception emerges without considering any form of action.

#### 10.2.2.2 Hidden states and Markov Blankets

Insofar, this particular walkthrough of active inference is a case of a single observation—however, over time, the generative process must dynamically model time series. Hidden Markov Models (HMMs) are widely used to model time series where a true state is not directly observable. Instead, HMMs are used to infer the hidden state through observations, so it is necessary to introduce how HMMs may help resolve hidden states. HMMs are a particular kind of dynamic Bayesian network, which forms a (graphical) representation of the conditional interdependencies of random variables, specifically well-suited for modelling time series (Jordan *et al.*, 1999; Ghahramani, 2001). Such systems may take advantage of the *Markov property*[9], which is that the next state depends mathematically only

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[9] Keep in mind that the prior state referred to here is not the prior state of a single variable, but the prior state of the Markov blanket as a whole. Furthermore, the philosophical counter-argument to the Markov property is that the state would not have been considered in the first place was it not for the prior states, which means—ipso facto—all their priors necessarily already define any current state.

on the current state—the prior state is obsolete, thus the method is frequently referred to as memoryless (Clark, 2017).

In Fig. 10.3, the prior states do not enter the probability of the current state, i.e. the state V does not depend on S, but on Z (and U), but Z would not be considered in the first place if not for the state, S. However, the next step depends not on the prior. The Markov blankets serve precisely to disambiguate the boundaries of one specific state by considering a number of pre-set rules of hierarchy, i.e. the *Markov boundary,* which is more feasible after introducing the graphical layout.

To understand the graphical representation properly, basic notations from graph theory, which is essential in connectionism and network theory, are here introduced. In Fig. 10.3, *nodes* represent random variables and *edges* represent the dependencies in the Bayesian network revealing the *parent-child* relation—parents influence children, which in turn may influence their children (children's children). An essential advantage of using graph theory is to make obvious the Markov blankets, which is defined for a given variable as its parents, children, and the parents of its children (Pearl, 1988). It has been suggested that nature in general, including human consciousness, experience and any living organism, is composed by millions of blankets within blankets and thus explicable by adequately understanding the relation between these (Hohwy, 2013; Clark, 2017; Kirchhoff *et al.*, 2018; Parr and Friston, 2018b; Ramstead, Badcock and Friston, 2018). In turn, the nested Markov blankets give rise to a hierarchy in the generative model.

Given that Markov blankets and the graphical representation are purely functional, one may suspect that a physical boundary for any living organism is difficult to put down by absolute. For this purpose, Pearl (1988) coined the term *Markov boundary*, which designates *"when a Markov blanket for a node has no proper subset that is also a Markov blanket for that node"* (Clark, 2017). With Markov blankets, systems can be outlined graphically and statistically, which has significant implications for how to understand the structure of, e.g. the brain. Although neurons are intermeshed in various directions, seemingly with no boundary, Markov blanket may aid how the brain can still be viewed as a minimally decomposable entity because systems

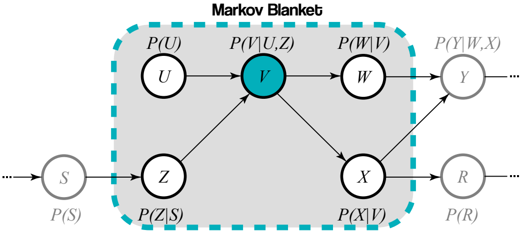

*Figure 10.3—An example of a Markov blanket, Bayesian network and the basics of graph theory. The circular shapes represent single nodes. The arrows represent their parent-child relation. In the example, the Markov blanket for node V is the dashed area, which entails the parents, children and the parents of its children. In terms of the Bayesian network, its parent gives the probability for each node, so that the node V depends on U and Z, and both W and X depend on V, which takes the form of the Markov blanket. A single node may correspond to a neuron, where the blanket describes the Markov blanket relevant to that neuron, explaining the minimal decomposability. Keep in mind the direction of the stated probabilities are only given for one direction.*

emerge from the parent-child relations between neuronal hubs. Interestingly, this offers a statistical perspective of the anatomical functions of the brain, i.e. a connectionist aspect. It is worth noting that Markov blankets have been used to explain how the biological self-organisation (see Chapter 7) distinguishes itself from its immediate environment, e.g. organelles within cells, within tissues, within organs (Kirchhoff *et al.*, 2018; Palacios *et al.*, 2020).

### 10.2.3 Adding action to active inference

Adding the action to active inference, note that observations depend only upon the current state, opposite to state transitions that depend on action policy (a sequence of actions; π) (Friston *et al.*, 2015, 2016). When introducing time to the equations, observations become necessarily dependent on the action policy that currently unfolds, as the new observations that are generated depend on the action. In active inference, action (u) can be understood as an operation that minimises the expected KL between outcomes predicted at the next time step and the outcome after each act. Formally[10]:

$$u_t = \arg\min_{\mathrm{u}} E_Q[\, KL[P(o_{t+1}|s_{t+1}) \parallel R(o_{t+1}|s_t, u)]\,] \qquad (10.14)$$

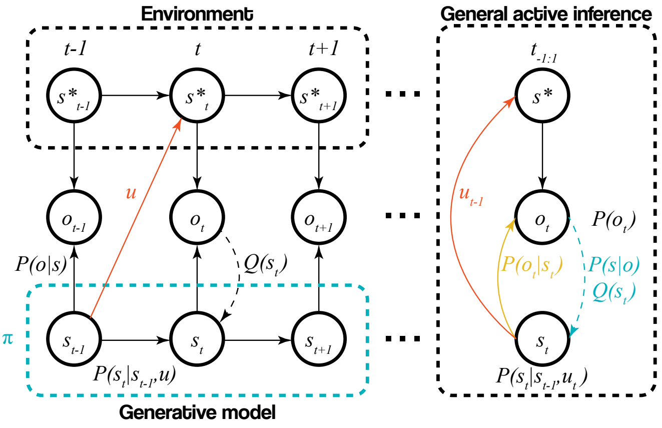

*Figure 10.4—This figure serves to illustrate how time integrate into active inference (Solopchuk, 2018). With time comes the possibility for action, and in this particular case, there is only a single action policy (π). Fig. 10.1 illustrated how active inference models the world passively—however, in time, it can be shown how action and perception are interrelated (this figure is heavily based on Appendix D). The minimisation of free energy entails changing parameters serving to minimise the KL, and thus optimising perception. The transitioning needed to improve the parameters of the model is action! The true state of the environment, therefore, depends on the prior true state and the prior action. The approximated distribution is still in play, informing which action policies may improve perception. The terms -1:1 designates the range of integers from -1 to 1 including 0, which designates not-past and not-future.*

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[10] E refers to the expected outcome of what is within the brackets—in this case, the KL between outcomes predicted and outcomes subsequent to actions. R refers to probability.

The action is minimising the expected outcome while simultaneously realising the expected outcome (Fig. 10.4). Almost tautologically, action is causing perception, which in turn makes the inference active. To put it in perspective, the coupling suggested in enactivism, i.e. SMC, suggests that perception is active, and that exercising sensorimotor skills is to understand perception practically. The exercise itself is inherently dependent on predictive mechanisms that display practical knowledge relative to the sensory organ. Eq. 10.14 expresses how the generative model makes sense of action relative to perception—although, in line with SMC, there are many possible actions one may take, causing various models (see Appendix D for discussion on selection among models). In SMC, the model is driven by a practical intention to investigate or interact with the world from which action sequences, i.e. *action policies*, emerge (Fig. 10.5). Once again, recall that this approach is a dynamic (Poincaré) approach; thus, all possible competing action policies are considered at the same time in parallel. It is worth noting that the action policies are very reminiscent of Gibson's affordances, but in fact, they do not correspond. This discussion is critical because it clarifies what is meant by action policies in active inference given the enactive approach, which leans considerably on ecological psychology (Gibson's theory of perception using affordances).

In this context, it is argued that Bergson's term *virtual action* describes much better the underlying process as compared to Gibson's term *affordances.* There are two major differences between the terms in the current context. Firstly, an affordance is inconceivable without an intention of an agent. On the one hand, affordances arguably describe potential interaction relative to an intention, i.e. it is task-oriented. On the other hand, virtual actions describe the potential interaction in the absence of an intention. Secondly, the manner affordances link to intention encompasses a complex feature of human perception involving values and meanings that surpass the concept of a range of unrealised actions. Affordance *"*[…] *is not a process of perceiving a value-free physical object to which meaning is somehow added in a way that no one has been able to agree upon; it is a process of perceiving a value-rich ecological object"* (Gibson, 1986, p. 140). Furthermore, affordance is *"something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment"* (Gibson, 1986, p. 127). It is clear that affordance refers to the complex relation between the perceiver and the perceived, where the genesis of unrealised actions is part of the relation. To make explicit the difference between the two terms, virtual actions operate exclusively at the level of the intuitive (practical) with no influence from the intellect, whereas affordances can be highly influenced by the intellect, which forms the intention[11]. This is not to say that the affordances do not influence the execution of the inferred action; indeed, the emotional and bodily state will have a direct influence on the performance of the selected virtual action. It is more appropriate to refer to action policies as virtual actions refer to the range of unrealised actions. To paraphrase Bergson, action policy refers to a set of action sequences that differ

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[11] Intention is here used as in the will to act rather than as intentionality, which is inherently intuitive.

in *kind*. Actions that differ in kind delimits the sequences so that taking a step up a staircase can only differ in *degree* when not proprioceptively placing the foot the exact same way, but cannot differ in kind since the action brings you up a step. This discussion is further unpacked in Chapter 11.

Returning to action policies, these competing virtual actions depend on the goal behaviour (intention) of the agent, but architecture is seldom explicitly experienced. The majority interacts with their architecture on a basic level, where it is implicitly part of everyday routines. It can thus be assumed that the case of transitioning from one space to another is, for the most part, a question of passing with minimal effort in the sense of less effort. These actions are skilful actions mastered by the experiencing agent, and so need no explicit attention, but rather unfolds implicitly (Rietveld and Kiverstein, 2014). The action sequences, bodily trajectory or virtual actions that are offered by the environment refer to the same underlying process in the action-perception loop; namely, π.

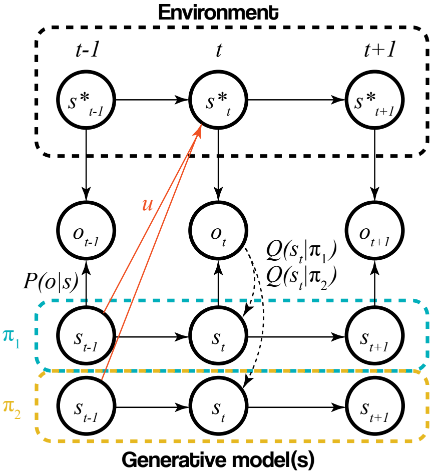

*Figure 10.5—With multiple action policies, they are all considered in parallel at the same time (Poincaré).*

Recall that expected variational free energy required predictions, which now can be described through action. Thus, the *expected* free energy, *G*, can be rewritten from Eq. 10.7 as follows:

$$\sum Q(s_t|\pi) \log \frac{Q(s_t|\pi)}{P(o_t, s_t|\pi)} \tag{10.15}$$

$$= \sum_s Q(s_t|\pi) \sum_o P(o_t, s_t|\pi) \frac{Q(s_t|\pi)}{P(o_t, s_t|\pi)} \tag{10.16}$$

Notice that time has been added to the equation and the substitution of action (u) in Eq. 10.14 for action policy (π).

While action unfolds in the generative process, the virtual action becomes an intrinsic part of the generative model. Although not all virtual actions are actively unfolded; they are tied to the body as possible outcomes with different probabilities depending on their expected free energy. When an action policy is outlived, the virtual action manifests itself in time (because it unfolds as a bodily trajectory at that given moment bringing with it new action policies on the go) and in space because the virtual action is transcending the generative *model* towards the generative *process* to, in turn, improve the *model*; this makes the generative model and process inseparable.

Taking the next steps in active inference, with numerous rearrangements using rules of arithmetic and by adding of *prior preference on future outcomes,* namely P(o), then the free energy equation reaches a practical form as explained by Solopchuk (2018) and equation 6 in Friston et al. (2016):

$$G(\pi, t) = \underbrace{KL[Q(o_t|\pi) \mid\mid P(o_t)]}_{\textit{expected cost}} + \underbrace{E_Q[\ H[\ P(o_t|s_t)]\ ]}_{\textit{expected ambiguity}} \qquad (10.17)$$

Active inference is attractive because it not only infers states of the world by maximising model evidence P(o), but it also infers the policies that should be pursued in terms of maximising the evidence expected (Kaplan and Friston, 2018). Recall the two primary states that need to be inferred from earlier, namely the state of the world and the uncertainty about that state. That is precisely what Eq. 10.17 expresses; the expected cost informs the free energy minimisation and thus the best guess of the current state of the world, while the ambiguity literally scores the uncertainty about the best guess. In brief, the generative model considers the expected cost, which is the divergence between the expected observation under the virtual action and the prior preferences, and the expected ambiguity that denotes the expected uncertainty about the environment. Eq. 10.17 demonstrates that the expected ambiguity does not depend directly on virtual action, $\pi$, but is instead a question of quantifying the mutual information between sensory outcome and input, which in turn is informed by action.

In summary, active inference is a matter of minimising surprise while sampling an environment through a single function, namely variational free energy. The free energy functions as an upper bound on surprise, so that minimising free energy is the equivalent to minimising uncertainty. Since the embodied brain has no access to the hidden states, given they are hidden from direct observation, it generates an approximate posterior density, namely *Q*(s), over the hidden states and infers their state through qualified action. What makes active inference appealing is the integration of action and virtual action into the modelling of the environment—or in other words, the integration of action that is selected from posterior beliefs about a particular virtual action in perception, and vice versa.

More importantly, Bayes' rule, HMMs and active inference all depend on the transition matrix, which, in other words, can be said to be the *structure of change.* This is precisely the reasoning behind this particular approach to experiential transition; namely it foreshadows both the perceptual experience and architectural space not only at the same time but also *in* time. In sum, because the approach makes use of non-representational processes, interpenetrating temporal states, coupled systems and focuses mainly on transitions, i.e. in the spirit of DST, it qualifies as an overarching empirical framework, from which the research question may emanate.

### 10.3 Simulacrum

The statistician Box (1976) coined the general idea and limits of using statistics to explain natural phenomena when he stated that: *"All models are wrong, but some are useful"*. Active inference is a statistical model of the world inferring its hidden states. This begs the question of limitation in neurobiological measures. Friston (2006; 2010; 2011) stated that the world is a model, i.e. a generative model, that *reflects* all neurobiological parameters—however, how should active inference be interpreted (given its computational nature) in a strictly non-computational, non-representational framework? Active inference is able to describe the underlying operation of qualified guessing, using Bayes theorem, which seems to appear in numerous systems in the body.

Active inference is per principle a statistical model that approximates human processes, using nothing but arithmetic manipulations that are free of representational content (Kirchhoff and Robertson, 2018). Indeed, active inference reflects the exact mechanisms or biological operations that take place in the body, brain and environment (Howard *et al.*, 2017; Haarsma *et al.*, 2019). Albeit, the embodied brain has no particular knowledge on Solomon Kullback/Richard Leibler and their probability distribution divergence—nor do the embodied brain know Karl Friston, active inference or FEP. Nevertheless, these terms and mathematical models serve to simulate the rationale behind the dynamics between brain and body serving action, perception and cognition to give science a predictive upper hand, which is essential in theorising. In fact, prediction errors (Schultz, 1998; Friston, Mattout and Kilner, 2011), Bayesian learning (Friston, 2003; Friston *et al.*, 2016), TD and BU signals (Cupchik *et al.*, 2009; Adams, Shipp and Friston, 2013) are all empirically measurable and consistent with active inference. Whether a model can comprise cognition comes down to the complexity of the particular model that is simulated, and as stated by Conant and Ashby: *"Every good regulator of a system must be a model of that system"* (1970).

Recall the initial quote from Laplace: *"Probability theory is nothing but common sense reduced to calculation."* The keyword in this sentence is that probability theory is a *reduction* of common sense to calculation; indeed, it is not a direct equivalence fully explaining a natural phenomenon, but offers rather particular aspects of interest. If the interest is of increasing complexity, so must the probability model increase in complexity to be a better predictor of that natural process.

As for architecture, why is it essential to consider active inference if it is merely a simulacrum? Architecture is the equivalent of the environment in the triad of cognition (brain, body and environment), and this poses a serious approach to causal physiological relations. For too long has architectural research been restricted to pure speculations or behavioural experimentation, which traditionally is executed in psychology (Arnheim, 1977), philosophy (Böhme and Engels-Schwarzpaul, 2017), sociology (Jensen, 2014), anthropology (Amerlinck, 2001) and other social sciences. Approaching a human-centred research programme in architecture becomes immensely important to understand general physiological consequences of space. As stated by Solupchuk (2018): "*However, the scheme* [active inference] *is rather intended as a proof of principle, and is sufficient to be useful in computational psychiatry. For example, precision is believed to reflect the function of dopamine, meaning that inability to infer the optimal precision would have adverse psychopathological implications.*"[12]

### 10.4 Phenomenology and inference in sensorimotor

At the level of sensorimotor measurements of the brain, the selection between virtual actions operates in a predictive manner by inferring policy-dependent outcomes, as shown in Appendix E (Pezzulo, Rigoli and Friston, 2018). Action in terms of PEs is a question of proprioceptive PEs; the PE minimisation relative to action is affected by proprioceptive PEs at the sensory level[13] (Friston *et al.*, 2012, p. 3). What may one expect to measure on a sensorimotor level given varying virtual actions? Keep in mind that according to active inference[14], predictions function as TD signals (Friston, 2005), which is precisely how virtual actions manifest as proprioceptive PEs. TD refers to the local expectation in single neurons, which can be hierarchically scaled up when concerning clusters of neurons so that it becomes the expectation of cortical areas. Between the layers of the hierarchy, a process of backpropagation takes place, enforcing a learning sequence on a chemical level in neurons (Parr and Friston, 2018b). It is here argued that features of *global-to-local* (Chapter 7) and TD are interlinked so that global patterns can emerge from a general conformity of prediction (minimal PEs) in greater cortical areas. If multiple brain areas and regions conform to the TD-signalled predictions, a global pattern emerges from such prediction.

Active inference genially establishes a principle for such dynamics, namely that states are actively inferred from the smallest scale and onward. Indeed, the very core of active inference reflects both Husserlian temporality and Bergsonian interpenetration of time—thus, making active inference a qualified theoretical and practical approach to experimenting with human experience, brain structures and architecture as a phenomenological framework.

One obvious issue with Bayesian cognitive science as a phenomenological framework is the seeming incompatibility of a computational approach compared to the dynamic approach. Computation was related to an intellectualist approach

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[12] A neurophysiological perspective is provided in the next chapter.

[13] This is a topic covered in the Chapter 11.

[14] Note that the current inference cannot be free of past and future; in other words, any current experience cannot be free of retention and protention. G, which is literally a prediction, takes part of the current inference F, which in turn bases probabilities on prior experiences.

to cognition, which was disproven earlier in the advantage of intuition. One such problem is the discrete stages in Markov decision process, e.g. belief updating in inference and belief propagation in learning (Friston, Adams and Montague, 2012; Friston, Parr and de Vries, 2017). Is it possible to update belief without being an intellectualist, but rather a dynamicist? Without further unpacking the implications of intellectualist and intuitionist (Chapter 7), if one acknowledges that neurons respond relative to their history, there must be an inference at this cellular level, i.e. Hebb's law (cell assembly theory). Consequently, active inference is not an intellectual operation but operates at the level of intuition, i.e. on a cellular level. This is precisely where active inference as a statistical simulacrum of a natural process is clear; it holds an explanatory function of neurobiological responses instead of stages performing a KL operation. Instead, the neurobiological responses approximate an active inference process of cognition (Friston, 2005, 2010) particularly—and this, in turn, poses the strategy that it may be better to ask not what cognition tells about the nature of active inference but what the nature of active inference tells about cognition. Since active inference approximates neurobiological responses, it may be an advantage to turn the table and understand cognition from the relations in the approximated model.

Following active inference, one should not expect sensorimotor PEs in scenarios that are predictable in practical terms—however, one should instead expect an emerging sensorimotor pattern culminating in a practical experience relative to that perception and that predicted action. For instance, as mentioned in Chapter 9, the case of feeling a bottle: *"It feels to you as if there's stuff there to be touched by movement of the hands. That's what the feeling of the presence of the bottle consists in. But the basis of the feeling, then, is not something occurring now. The basis rather is one's knowledge now as to what one can do"* (O'Regan and Noë, 2001, p. 963). The present feeling is not present; it is predicted. Following active inference, the outset for a prediction is a transition matrix, or put in SMC terms; a structure of change, which is caused by a hidden state, e.g. the form of space (O'Regan and Noë, 2001, p. 952). According to SMC, the experience of the hidden state depends on the structure of change, which is defined by the virtual action that best minimises free energy, meaning that there is good reason to believe the human experience of space depends on the experiential transition through action-perception features in that space. Indeed, a physiology of anticipation is necessary to the experiment, and since any given moment must be understood in its temporal context, at the level of intuition (retention and protention), the experiment must be designed with cautious regard to time. The world is not construed linearly, but dynamically through so immediate predictions that they cannot be separated from the current moment.

> *"In fact, constitution is not just the attribution of properties to a pre-constituted object but an originary constitution of the latter, and without which the latter could not support such properties:* a pre-configuration of the analysis that the brain is going to make of the world and not just a mental representation, which always comes on the scene after the event. *The decisive step in neurophysiology is*

*therefore the transition from a bottom-up neurophysiology to a top-down neurophysiology,* a physiology of anticipation." *(Berthoz and Petit, 2008, p. 130; emphasis added)*

## 10.5 Conclusion

It was demonstrated how FEP, as a hybrid of a hierarchical and heterarchical system[15] (Turvey, 2007), is useful in predicting action-perception related questions. With sufficient rearrangements, FEP is an active inference, sharing the fundamentals of enactivism and predicting perception by selecting a virtual action that best minimises free energy. *"Active inference can be seen as an embodied (enactivist) form of predictive coding, in which perception minimises exteroceptive prediction errors and action minimises proprioceptive prediction errors"* (Friston *et al.*, 2012, p. 1). It serves as a simulacrum that might develop into a full-blown experiential simulation of the human action-perception cycle that excels at predicting the transitional matrix (experience) given a certain space and task.

The structure of active inference can be generalised to the usage of Bayes' theorem to predict the effect virtual actions has on the posterior probability and selecting the virtual action that best minimises the expected free energy. Nonetheless, the term *free energy* emphasises the general approach, namely that the approximation unfolds by using free energy as an upper bound on surprise, i.e. $-\log P(o)$, and by selecting the virtual action that minimises the expected free energy, the model pulls in closer and closer on the true posterior.

However, FEP, as a normative theory similar to natural selection in evolution, cannot itself be falsified, as it is a self-evident truism. Instead, a range of falsifiable hypotheses can be generated from FEP so that it functions as a framework instead of a natural true law, i.e. a tautological self-evident truism (Allen, 2018). FEP explains, through DST, how organisms survive by respecting homeostasis (Damasio, 2010) what arguably is a process of allostasis (Sterling, 2012), by acting (perception), adapting (minimise expected free energy), adjusting (correcting PEs) and anticipating (generate predictions).

Yet, FEP stays within the phenomenological conditions. As stated in SMC, while respecting the phenomenological and temporal principles of Bergson, Husserl, DST and active inference, experience *is* the transitional pattern itself. This conclusion is evident given the Bergsonian time, Husserlian temporality, the dynamically embodied brain and now a theory of active inference structurally coupling environment and the embodied brain through action and perception. Put in other words, perceptual experience is to predict the structure of the transition correctly through change by acting. Although active inference cannot account for a fully naturalised phenomenology of experience, it has a promising take on some of the most fundamental aspects of experience, e.g. the relation between action and perception. Instead of falsifying FEP, the next chapter generates a falsifiable

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[15] A hierarchical system refers to the flow of control from higher positions to lower positions, whereas the heterarchical system refers to a reciprocal system. A hierarchical architecture: A ⟶ B ⟶ C.
A heterarchical architecture: A↔B, C↔A, C↔B (Turvey, 2007).

hypothesis using active inference in action-perception loop. Critical for the argument is that the process of estimating which virtual action to proceed with is the capability of the brain and body to process in parallel, i.e. dynamically. Chapter 11 elaborates on this subject.

# CHAPTER 11

# Virtual action, affordances and active inference

> *"If this is the best of possible worlds,*
> *what then are the others?"*
> *Voltaire (1694-1778)*

**Summary.** *What implications—on a physiological and neuronal level—does the unfolding of action-perception have on human experience?* By identifying the underlying cortical activity for the intuitive process of selecting amongst virtual actions using their affordances, a testable and falsifiable hypothesis is derived using principles from active inference and enactivism. A temporal scale of neuronal activity serves to map the cascade of bidirectional predictions and to enlighten the importance of the time-domain in sensorimotor integration. Furthermore, an aspect of the role of neuromodulators emphasises the anchor of embodied underpinnings in behaviour. Ultimately, because brain, body and environment are dynamically coupled, it is argued that designed environment is neither governing nor governed by the brain and body, but instead non-linear dynamic relation. This suggests responsibility for architects because the environment, through virtual actions and affordances, may systematically favour specific brain structures.

## 11.1 What to look for?

### 11.1.1 Neuronal activity

In approaching an experimental setup to address experience in architectural transition, it becomes urgent to know what to look for. Since the framework insofar has narrowed the journey to a cognitive neuroscientific approach, the question is what to look for in the brain. It was previously argued that the brain does not form internal representations of the world—perception instead emerges from the dynamics of the embodied brain integrating physical action. In the framework of active inference, the process of action-selection, i.e. selecting virtual actions by their affordances, is a bidirectional cascade of TD and BU predictions and probabilities operating in different time-scales. According to recent Bayesian cognitive neuroscience, the brain describes these predictions and probabilities physiologically through a range of neuromodulators that in turn may be measured electro-cortically (Doya, 2002; Yu and Dayan, 2005). Electro-cortical responses reflect the embodied brain's attempt at minimising free energy by acting (Friston, 2005). In other words, the typically analysed endogenous components of evoked cortical responses in electrophysiology reflect PE minimisation stemming from TD/BU error-correction. Particularly the nature of the synaptic behaviour is here investigated to form what to expect in an electrophysiological experiment.

Synaptic activity behaves in frequencies so that populations of neurons fire at specific rates, such as delta (~0.5-3 Hz), theta (~4-7 Hz), alpha (~8-12 Hz), beta (~16-31 Hz) and gamma (~32-100 Hz). The classic evidence is the clear increase of alpha waves when closing the eyes (Gloor, 1969; see Appendix B). The time-domain of neuronal activity may reveal much about the nature of synapses relative to behaviour. Take for instance the sense of time. There seem to be an understanding of it at the neuronal (microcircuits) level of in-vitro brain-slices of rats (Goel and Buonomano, 2016). In Johnson, Goel and Buonomano's (2010) experiment, auditory neurons were electrically stimulated with intervals of 100 ms, 250 ms and 500 ms for a couple of hours, to simulate what the brain stimulates typically by sensory organs. The neurons have no contact with the outside world. When stimulating the same microcircuits in the dish, they found that: *"Naïve slices often respond to a brief electrical pulse with a burst of network activity that lasts up to a few hundred milliseconds. This occurs because the neurons directly activated by the shock will activate other neurons, which in turn might further activate others—the activity 'reverberates' for a few hundred milliseconds until the activity dies out"* (Buonomano, 2017, p. 97). This signature reverberation depends on how the neuronal microcircuit was encultured before situated in the dish, which was either by intervals of 100 ms, 250 ms or 500 ms.

It is an important discovery because it indicates that neurons, despite being completely decoupled from a living body, reflect an encultured pattern that exclusively depends on the surrounding synapses, which the sensing body ordinarily constitutes. What the neurons undergo in terms of electric stimulation depends on the respective sensory organ, which in turn makes the neurons reverberate a specific behaviour. In other words, neuronal activity on a sensory level reflects a reactive behaviour bound on the activity of a sensory organ, which in their study was auditory. More importantly, as Buonomano (2017, p. 97) asserts, the neuronal activity reflects not a specialised computation per se, but an intrinsic property of neuronal circuits that is relative to the sensory organs—thus, the body. The unfolding of a particular behaviour induced by an electric charge is not stored computation that is electrically activated, but an ingrained, congenital property of living neuronal microcircuits. Indeed, as indicated above, neuronal behaviour is a complex topic that is not well understood yet, and it is not the purpose here to expand on this scientific topic. However, the task of this chapter is to identify the relation between action-selection and neuronal activity by firstly reviewing selected previous studies, then pinpointing the temporal scale and order of active inference and finally unpack the character of virtual actions and affordances in neuronal activity. Furthermore, a note on neuromodulators enlightens the importance of the designed environment.

### 11.1.2 Previous studies

Questioning whether neuronal activity describes the decision-making between multiple actions has been posited before in simple motor-related reaching tasks using single-unit recordings (an invasive measure of action potential in a neuron) in primates (Cisek and Kalaska, 2005). Recording from microelectrodes on the arm area of the dorsal premotor cortex (PMd), Cisek and Kalaska designed a reaching task that involved choosing between two or one circle(s) when presented with eight circles (Fig. 11.1). Their study presented their primates with a centre-hold on a screen, which is simply a yellow circle with a cross in it at the centre of the screen (500 ms), followed by a spatial-cue (1000 ms) that would reveal the position of two (red and blue), or one (red), circle(s) on the radially distributed circles. The spatial-cue was followed by a second centre-hold stimulus (500-1500 ms). A colour-cue (1500-2000 ms) would then indicate which of the two circles to select when presented with the total eight circles. Finally, a Go-cue that presented all possible eight circles again from which the primate had to select the circle with the colour presented in the colour-cue. During the 2-target task, the primate needed to remember the location of both circles and the colour-cue to plan its actions correctly.

Their study report that when given the possibility of choosing between two different actions, neuronal population activity increase equally and immediately after being presented with the location—the virtual actions—of the circles. After the colour-cue, there was a strong bias in population activity in favour of the indicated colour. The population activity reveals where the stimuli will show up in the Go-cue. Between these cues, population activity described neuronal competition between two actions, before a decision. This translates to a competition between two possible actions, where the highest neuronal activity wins the competition.

Interestingly, their results demonstrate that a preference, reflected in population activity, was present immediately after the colour-cue. In a matter of ~50 ms, the competition seems almost settled. As they conclude, their results indicate "[...] *the dynamics of the competition that determines decisions are dependent on spatial variables. These are irrelevant for the abstract economics of cognition, but are important for the motor system, which selects between physical actions where geometrical relationships matter*" (Pastor-Bernier and Cisek, 2011). This is an important conclusion about the action-perception process since the neuronal activity reflects the decision-making already at the level of sensorimotor, independent from higher cognitive regions. They continue: "[...] *although decisions between actions are influenced by variables supplied* *by higher cognitive regions, they are determined by a competition which takes place within sensorimotor circuits"* (Pastor-Bernier and Cisek, 2011). Their results further suggest that competing actions are considered in parallel, dynamically, complementing the enactive inference framework. Regarding the neuronal populations, the two population activities (n=100) demonstrated dissociable activity patterns relative to the two possible actions.

An increasing neuronal activity before action is not a novel discovery in cognitive neuroscience. Increasing activity prior to action is reflected in a well-established component in contemporary electrophysiology, namely the contingent negative variation (CNV). Its discovery by Walter (1967) led to a wave of CNV studies, which led to the discovery of more components (see Brunia, 2003 for a discussion on anticipative behaviour and electro-cortical components). The novelty in the study by Cisek and Kalaska is that they were able to differentiate between two neuronal populations, each describing differentiable action clearly displaying the action-selection. However, did their study locate where to look for physiological descriptions of predictions and probabilities relative to virtual actions? The limitations of this study are many—keep in mind that the critique is approached from a critical architecture experimental perspective. First, the study was performed on a primate, making the results (although minimally) translational neuroscience. Second, the experimentation itself was performed on a two-dimensional platform (a screen), choosing between different circles that were placed radially. The restrained spatial dimension limits the interpretation of architectural design since architecture is embedded in the real-world three-dimensional environment. More fundamentally, the task does not correspond to navigating *in* space directly—although it has to do with action-selection. Third, the results may describe the neuronal activity of *selective attention* (sharing characteristics with the Posner paradigm) rather than of virtual actions and affordances. Recall that virtual actions determine the transition matrix in active inference, informing the experiencing agent how to minimise best expected free energy. This process is much more immediate than >1000 ms of planning and bringing the virtual actions to awareness—they are so immediate that they are part of early perceptual processes. The experimental setup demonstrated the *planning* of action and navigation, which is much in line with how grid cells map locations in space.

How does this relate to action-perception as described in active inference? In the 'Go-cue', the eight circles describe the virtual actions, i.e. *"which actions does this particular situation induce me to pursue"* (Fig 11.1). The affordances of the virtual actions would depend on the 'Spatial-cue', i.e. which one I should choose. When the virtual action of interest is denoted, affordances change and consequently select (attract) a virtual action. In active inference, sensorimotor constructs have both sensory and proprioceptive consequences. *"These constructs are maintained by bottom-up prediction errors in both modalities and reciprocate top-down (proprioceptive) predictions to the peripheral motor system that drive classical motor reflexes; while top-down predictions to sensory systems play the role of corollary discharge and suppress (exteroceptive) prediction errors"* (Friston *et al.*, 2012, p. 3). The BU PEs reciprocate the TD predictions in

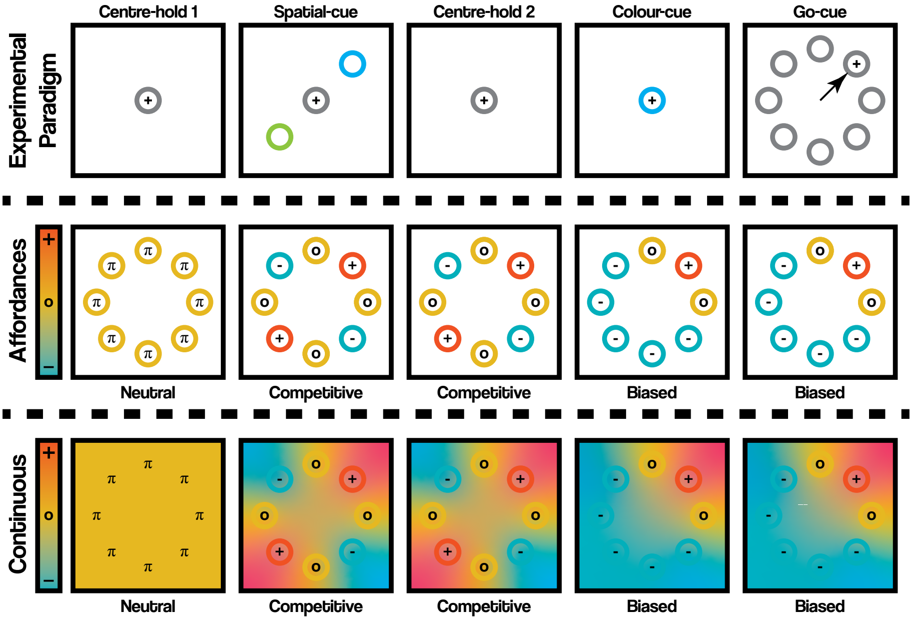

*Figure 11.1*— **Experimental paradigm**. *Reproduced procedure from Cisek and Kalaska (2005). The 'Centre-hold 1' instructs the perceiver to focus attention to the centre, which yields equal values (denoted by 'o') of affordances for all virtual actions (denoted by 'π'). The 'Spatial-cue' instructs the perceiver about two colours in each their location. This changes the affordances to attract (denoted by '+') two virtual actions that are now competing, which consequently makes other virtual actions less affordable (denoted by '-'). The 'Centre-hold 2' functions as a brake, which yields no differences from the prior scene. The 'Color-cue' reveals which virtual action that yields a congruent trial, which in turn biases the affordance competition.* **Affordances**. *The affordances corresponding to each stage are given through coloured precision.* **Continuous**. *The last line, 'Continuous', illustrates the continuous development of precision also through coloured precision.*

their experiment by adjusting the affordances according to the sensory, which in the example of Fig. 11.1 is the blue circle (northeast), and therefore they were able to measure the competition in the motor system. Operating at the level of sensorimotor, cascades of PEs in active inference also takes place on a much faster temporal scale as compared to the unfolding of behaviour, which the 'Go-cue' allowed. The time-scale at which active inference operates needs elaboration.

## 11.2 Time-scales in active inference

According to active inference, lower sensorimotor inferences are faster than higher cognitive features. In fact, the "hierarchical" in *hierarchical model* refers to the nonlinear coupling between anatomical layers of the brain that operate in different time-scales. At the lower levels, i.e. primary sensory areas, neuronal states describe the course of short/fast environmental causes, whereas higher levels describe the context where lower levels unfold (Kiebel, Daunizeau and Friston, 2008). This couples the distinct areas in a diachronic manner precisely due to the asymmetric temporal unfolding in each hierarchical level (Chapter 8). This is an

| Cortical area | Description | Time-scale |
|---|---|---|
| Sensory and association cortex | Sensory processing | Milliseconds → Centi-seconds |
| Primary motor and premotor cortex | Serve the prediction of sensory consequences of action | Centi-seconds → Seconds |
| Rostral anterior cingulate cortex | Hierarchical, contextual influence on action prediction | Deci-seconds → Longer period |
| Lateral prefrontal cortex | Hierarchically ordered 'cognitive control' system | Deci-seconds → Longer period |
| Orbitofrontal cortex | Most stable environmental states | Very long period |

*Table 11.1—Reproduced as presented by Kiebel et al. (2008) and their supplementary review.*

essential feature since the behaviour of an adaptive agent should not depend on equally slow processes, but rather on faster processes from which the adjustability may emerge. It has been reflected in Zajonc's (1980) argument that intellect is slower than intuition, so that affect is faster than reflective cognition. The affective dimension of Zajonc's argument corresponds here to TD predictions that stem from separate endogenous compartments, which culminates as emotional, or affective, experience (Barrett and Bar, 2009; Barrett and Simmons, 2015; Barrett, 2017).

Kiebel and colleagues (2008) list an order of brain systems that form levels in an anatomical-temporal hierarchy. The following table (Table 11.1) is based on their supplementary review (specifically their Table 1).

Their proposal respects both the established *minimally decomposable* attitude to the brain and cognitive functions, and cortico-cortical long-range coupling across time-scales, referring here to global-to-local effects mentioned in Chapter 5. Note that although sensory processing is faster than the higher processes of the orbitofrontal cortex, an active inference approach still makes possible for the higher levels to bias, by TD precision in prediction, a BU sensory signal. For instance, it has been shown that visual object recognition initiates TD processes projected from orbitofrontal to the visual cortex (Bar *et al.*, 2006). The biasing depends on precision weighting during err, which (as will be presented) is an essential feature in the relation between virtual actions and affordances. In total, Kiebel and colleague's (2008) proposal adds a temporal dimension to several established concepts:

- the current framework of cortical responses (Friston, 2005),
- diachronic hierarchical generative model (Kirchhoff and Robertson, 2018)
- and minimally decomposable brain areas relative to function (Pessoa, 2014), and thereby provide a consistent and integrated theory of an embodied brain.

Active inference supports the concept of fast, lower sensorimotor processes contributing to a hierarchical and dynamic model of the world. This means that how one might act upon the environment is an ongoing process of selecting virtual actions taking place as early as perceptual processes, contributing to resolving navigation and affordances, fitting the presented phenomenological and enactive framework.

## 11.3 Virtual action, active inference and neuromodulators

### 11.3.1 Precision weight in virtual action

The idea of continuously resolving affordances has been hypothesised by Pezzulo and Cisek (2016) and coined hierarchical affordance competition (HAC). HAC aligns closely with the current framework. Generating a set of virtual actions is a much faster process than the complex behaviour in navigating affordances, because generating virtual actions takes place at the level of sensorimotor processes, whereas affordances is a selection among virtual actions with different densities, i.e. an affordance describes the probability of selecting (attracting) a virtual action. HAC emphasises the action selection, i.e. affordance density. For instance, during transitioning to another space, HAC suggests the higher levels bias the lower level competitions, which operate at the level of action itself, through a cascade of expected affordances. Given the lower levels are fast, a continuous process of selecting amongst virtual actions that best satisfy expected affordances unfolds.

Recall the Tetris example from Chapter 8, where pragmatic action differ from epistemic action (Kirsh and Maglio, 1994). Affordances, in active inference, are

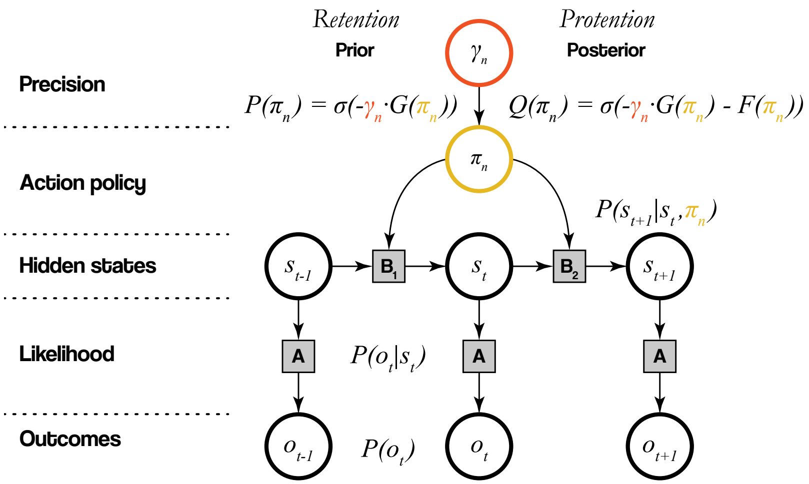

*Figure 11.2—This Forney factor graph/diagram designates a probabilistic generative model. The hidden states (s) generate sensory observations (o) using the likelihood matrix (A). The transition from prior to posterior depends on the transition matrix (B), which further depends on the action policy. In other words, how to change observations depends on the selected kind of action, which in turn depends on the degree of prior precision. The probability of a virtual action depends on the expected free energy and precision, which is given by the softmax function of the expected free energy. $\gamma$ designates the precision of the expected free energy under the specific policy, $\pi$. There are many policies ($\pi n$) considered at the same time, yielding different precisions ($\gamma_n$).*

defined as the *epistemic* and *pragmatic* values, in terms of the posterior predictive distribution over outcomes, of a virtual action. In other words, *"minimizing expected free energy minimizes the divergence between predicted and preferred outcomes* [...] *and any uncertainty afforded by observations* [...]. *Heuristically, this ensures observations are informative. For example, an agent who wants to avoid bright light will move to the shade, as opposed to closing its eyes"* (Friston *et al.*, 2015, pp. 193–194). The pragmatic value describes the predicted reward relative to behaviour, whereas the epistemic describes the salience relative to ambiguity-resolving (Friston *et al.*, 2016).

Virtual actions, on the other hand, is the set of possible motor trajectories as sequences of action, usually referred to as *policy* in active inference papers, that emerge along with the unfolding of action-perception. Naturally, the unfolded action sequences are precisely behaviour; thus, virtual action corresponds to potential behaviour (Fig. 11.2). The value of these virtual actions corresponds to affordances so that affordances becomes an attribute determining the certainty of the state; this is precisely why the value (affordance) of a virtual action is determined by the epistemic value and pragmatic value (Friston, 2018).

To briefly sum up and use the taxonomy of active inference; prior beliefs and sensory observations inform the updating of the states of the world, which in turn is continuously updated by action policies (virtual actions) that are valued by their epistemic and pragmatic estimates (affordances). Ultimately, this process accumulates—using a softmax function[1]—to a precision of beliefs given specific policies (virtual actions). This precision weighing has been pointed out on different occasions (Fig. 11.2, Chapter 10 and Appendix E, Eq. E.4).

$$\sum_{n} \sigma(-\gamma_n \cdot G(\pi_n)) = 1 \tag{11.1}$$

The σ designates the softmax function, π designates the virtual action, γ designates the precision weight and *G* designates the expected free energy. In the vast number of virtual actions, the selected attractor, which depend on the precision of sensory PEs that has yet to be unpacked, defines the current sequence of action that is unfolding. The number of virtual actions is equal to the number of possible ways the future can unfold, that is an infinite number. Whenever $P(\pi) = 0$ there are no changes in sequential actions, so the selected virtual action is continuously selected.

In the process of unpacking, the PEs can either persuade or annihilate higher-level metastable attractors that best explain the sensory input. This process of selecting an attractor corresponds to selecting an attractor with an affordance that best explains sensory input (Friston *et al.*, 2012; Pezzulo and Cisek, 2016). In active inference, the precision weighing is hypothesised to be described by the dopaminergic activity, so that dopaminergic rewards reflect familiarity of sensory

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[1] The softmax functions is method to normalise (make probabilities to sum 1), so that vectors that do not sum to 1 and might hold negative numbers are remapped/normalised so that the numbers are between [0 1] and sum to 1 making them readable as probabilities.

states (Friston *et al.*, 2012; Eshel and Tian, 2014; Shea, 2014). If true, the salience is a question of precision, which was denoted γ (see e.g. Hickey, Chelazzi and Theeuwes, 2010). Dopamine, in this sense, can bias the sensorimotor integration and action selection, because it controls ongoing competition on higher levels through adjusting the precision in the selection of proprioceptive and exteroceptive signals. Fig. 11.3 attempts to illustrate the complex relation between virtual action, precision and selected virtual actions (attractors).

The importance of a neuro-electrophysiological marker, e.g. dopamine, is that it makes the virtual actions and affordance measurable; what can one expect, on a neuronal level, by systematically manipulating virtual actions and affordances?

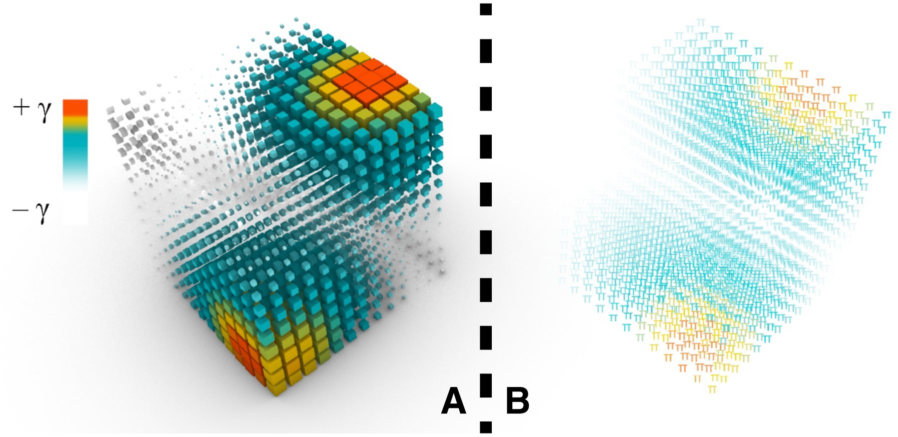

*Figure 11.3—An abstract diagrammatic state-space illustration of increasing precision in attractors in a field of virtual actions, π. This abstraction serves merely to visualise the general idea—under no circumstances does the brain or mind produce such representation.* **A.** *Each voxel describes a virtual action, which is theoretically not directly dissociable but maintains a fluid and continuous nature. The size and colour describe certainty. Each virtual action is a sequence of actions that can be biased by the ascending proprioceptive and exteroceptive PEs. In this example, due to high precision around two competing virtual actions, two attractors naturally emerge from the range of virtual actions.* **B.** *Using here the taxonomy of active inference, the voxels are replaced by π with its respective precision-value.*

Recall the Tetris example from Chapter 8. Virtual actions and affordances belong to epistemic and pragmatic actions, in the sense that virtual actions and affordances are continuously unpacked, even during pragmatic action. However, virtual actions only bring the kind of action necessary to change the perception to the generative model, whereas the affordance (precision weight) depends on (1) the environment, (2) the physical structure of the current zoid and (3) the intention of the agent. Architectural transition is very much like a three-dimensional game of Tetris—with extra steps. The separation of virtual action from affordance makes clear the difference between the necessary actions to perceive (practical perception) versus actively selecting what one wants to improve the perception thereof. There is an intention in affordance, whereas virtual action is the practical knowledge that if the urge to improve the perception of this particular environment, it can be done so and so.

To exemplify the differences further, consider a dinner situation. The affordances of a fork not only depend on what is for dinner but also what one intends to do with the fork in general, i.e. chopsticks may be the agent's preference given a specific kind of dinner. The virtual actions of the fork do not vary according to the intention. The fork is perceivably the same physical structure because the virtual actions remain the same, whereas the attracted set of actions (Fig. 11.3) depend on the intention and vary accordingly. Affordances of the fork depend on what is for dinner, while virtual actions depend on the physical structure of the fork.

### 11.3.2 Electrophysiological response

Concerning the biological underpinnings, FEP corresponds to a computational formulation of homeostasis, where the objective is to resist a tendency to disorder and thereby keeping the organism alive. FEP does so by minimising PEs and keep the organism within an acceptable bound. The synaptic gain of neurons, which is the magnitude of the neuronal synaptic response, is directly related to adjustments relevant to homeostasis (Burrone and Murthy, 2003). In fact, this is one of the essential novelties FEP (Friston, 2005) brought forward arguing that the predicted states of the world are described through synaptic activity. Synaptic gains in the cortical system reflects different kinds of precisions through neuromodulators, e.g. cholinergic system is hypothesised to reflect the precision of *expected* uncertainty, whereas noradrenergic system reflect the precision of state transitions, i.e. *unexpected* uncertainty, and finally the dopaminergic system reflects the precision of action selection, i.e. precision of beliefs about policies[2] (Parr and Friston, 2017).

According to the outlined framework, an increasing uncertainty of the sensorimotor integration will build up a synaptic gain that is hypothetically caused by inter alia dopaminergic activity because it directly relates to action selection, i.e. goal-directed behaviour (Phillips *et al.*, 2003; Montague *et al.*, 2004; Montague, Hyman and Cohen, 2004; Thurley, Senn and Lüscher, 2008). PEs may elicit different kinds of behaviours, e.g. positive PEs elicit approach behaviour that conceivably brings along a range of positive emotions and is approached, whereas negative PEs elicit avoidance behaviour, which is more likely to be hated and avoided. Despite the negative PEs not being rewarding per se, they do describe (negative) reward (Matsumoto *et al.*, 2016) as opposed to fully predictable rewards; these naturally do not produce any PEs (Montague, Hyman and Cohen, 2004). The negative

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[2] Neuromodulation is the chemical process throughout the body and brain that regulate various populations of neurons in different timescales and locations in the brain. The major systems include dopaminergic, noradrenergic, serotoninergic and cholinergic system. These have different signatures and different characteristics in terms of point of origin, neural targets and bodily effect. For instance, the noradrenergic system, which is also known as norepinephrine system, originates in the lateral tegmental field, targets the hypothalamus and effects the arousal (reactivity/selective attention, see e.g. De Martino, Strange and Dolan, 2008). See Appendix B for a description of neurotransmitters and neuromodulators.

reward reflects a physical intensity rather than a negative value; dopaminergic responses in macaques indicate an increase with intensifying physical impact, while bitterness in liquid solution reduced the activity (Fiorillo, Song and Yun, 2013).

Dopamine and other neuromodulators are of particular interest because they are known to alter behaviour, which is ultimately the outcome of action-selection. According to the current framework, different environments may elicit different behaviours (Elliot, 2006; Doya, 2008); including addiction, anxiety, depression, schizophrenia and PTSD. The reason for different emerging behaviour is conjectured to be rooted in affordances and virtual actions. This is partially supported by the architectural, psychosocial and physiological study by Fich and colleagues (2014). By systematic architectural variations during psychosocial stress (Trier-Social-Stress-Test), where participants delivered saliva-test samples every ten minutes, their results show that open spaces induce significantly less stress as compared to enclosed spaces. The stress was induced psychosocially by asking the participants to count backwards in steps of 13 from 1687 and to prepare a speech for a highly attractive job-interview. Cortisol was measured in the saliva as a measure of stress, which conveniently—relative to FEP—partially describes disturbances in the homeostatic balance (Herman *et al.*, 2016). Their results are in line with the hypothesis that restrictions on virtual actions may cause avoidance behaviour, which in turn is directly related to the dopaminergic activity. As stated early on by Schultz, there is evidence for *"the involvement of dopamine neurons in central processes determining the behavioural reactivity of the subject to important environmental events"* (Schultz, 1992). Indeed, concurrent dopaminergic activity during different behavioural processes emphasises its role in motoric activities.

To briefly sum up, it is suggested firstly that the cholinergic, noradrenergic and dopaminergic systems describe certainties relevant to maintaining homeostasis, i.e. minimising free energy. Secondly, it is suggested that the amplitude in neuronal responses reflects the PEs relative to disturbances in the homeostatic balance. Increasing uncertainty in the sensorimotor integration, which is preferably avoided as it decreases chances to survive, has a primary effect on synaptic transmission, i.e. neuromodulatory gain control. Thirdly, because environment restricts actions, it naturally restricts behaviour, i.e. one cannot merely storm out a prison cell or transit into the next room without a door. There are no affordances because firstly the virtual actions do not exist.

The relation between behaviour and precision is dynamic in the sense that behaviour can both be modulated continuously by fast BU sensory precision, or by TD proprioceptive (behavioural) predictions. Neuromodulators alter/modulate the precisions of the virtual actions yielding the probability they will be enacted (Friston *et al.*, 2012). Because a new update brings with it new expected free energy of a policy, affordances and virtual actions are continuously renewed and internally competing in a winnerless competition. In other words, the generative model may bring with it new virtual actions and precision values that directly influence the attraction/selection of action sequences, so that a specific virtual action is only an exciting action if it holds a high precision, i.e. useful affordances. For instance, as mentioned, if the sun is blinding, one goes to the shade, and not merely close the eyes (Friston *et al.*, 2015, pp. 193–194). This is simply because the affordances of the virtual action better minimise the expected free energy by moving to the shade as opposed to closing the eyes, and essentially, the affordances attract that particular policy. *"The precision updates are effectively driven by the difference between the expected free energy over policies, relative to the equivalent expected free energy prior to observing outcomes"* (Kaplan and Friston, 2018, p. 328).

## 11.4 Hypothesis

Active inference builds on the coupling between body, brain and environment by suggesting that action and perception are inseparable, making cognition the outcome of a dynamic triangulation between (1) what the environment has to offer, (2) an acting body with proactive sensory organs and (3) a hierarchical generative model of the world. Cognition, being inherently temporal, is to reason a coherent spatial world continuously by acting and perceiving. For this reason, the following testable, falsifiable hypothesis is established:

> *"If an enactive account of perception, action, and cognition is correct, then affordances are intimately related to higher hierarchical levels through low-level perceptual cues. Such an account would situate the processing of affordances at a similar stage as early perceptual processes and should reveal differences in sensory and motor-related ERPs associated with the perceived affordance of an environment.* […] [It is] *expected to find differences in cortical responses to covary* [resonate] *as a function of affordances over sensory and motor areas. In addition,* [it is] *expected to see differences in MRCPs as a function of the environmental affordances* […]*." (Djebbara et al., 2019)*

## 11.5 Conclusion

Given the architectural conundrum of transiting from one space to another, the experiencing agent generates a TD prediction that meets a BU sensory signal where their incongruence generates PEs. This complex cascade unfolds in different time-scales, where the sensorimotor integration is the lowest, thus the fastest, as opposed to higher cognitive processes. This is in line with active inference and HAC (Pezzulo and Cisek, 2016; Parr and Friston, 2017). Neuroanatomically, one can at least expect to measure the generated PEs as endogenous components in the sensorimotor areas. Note that such a measure does not describe the decision-making of virtual actions in architectural transition, but the free energy minimisation of a selected virtual action. In particular, the measure reflects the incongruity between a specific virtual action, e.g. $\pi_1$, and a specific visual observation of a transition, e.g. $o_1$.

The relation between virtual actions (policies) and affordances (precisions) have been elaborated. Affordances according to Gibson (1986) describe the practical interaction-relation between subject and object—one that relates to the form of an acting body and the form of an object/environment—so that object and environments may have good, or bad, affordances. The context in which Gibson refers to good affordances is in evolutionary terms, i.e. terrain features, shelters, water, object (Gibson, 1986, pp. 18–19, 36–42), e.g. good affordances in the environment are spaces that allow for flight in stressful situations (Fich *et al.*, 2014). By adding the layer of virtual actions, the term affordances may expand to encompass the intention of the experiencing agent, so that what determines whether an object/environment has good affordances is already in the intended interaction with that object/environment. Recall Chapter 5 and 6, where Husserl investigated intentionality in experience, which was a prolongation of Bergson's early phenomenology and a forerunner to the predictive mind framework. Husserl's and Bergson's temporal approach to experience emphasises the role of action, ultimately relating to the afforded interaction of a living body and its immediate environment under a specific intention. Fich and colleague's (2014) experiment elicited an implicit intention, i.e. the fight/flight mechanism, based on evolutionary terms, which may explain why cortisol levels in open spaces (flight) were significantly lower as compared to enclosed spaces (fight). However, according to the framework of virtual actions and affordances, the value of affordances depend directly on the intention of the experiencing agent—and furthermore, is the very fundament of the emerging cognitive process.

## PART II

# Specifying the research question

**Conditions of Part One**

The overall strategy was to establish phenomenological conditions regarding experience using Bergson and Husserl for an empirical framework to ensure that it addresses experience. These conditions are compared to emergence, enactivism and active inference (FEP). The conditions are here recited:

1. **Heterogeneity of duration as an indivisibility of time**, i.e. continuity in the stream of consciousness by interpenetrating moments of time.
2. **Indeterminate state of the human as the asymmetry of the transcendental and the immanent**, i.e. reducing indeterminacy about the world through embodied and embedded action/perception.
3. **Dynamic relations as primacy of intuition**, i.e. the immediacy of the given and the process of self-temporalising.

**1.** The heterogeneity of time characterises the view that time is continuous and interpenetrated by past and future—thus, it is indivisible to separate distinguishable parts. Active inference is essentially the core of this principle because it builds on the continuity, i.e. the transition states, of a current state. Indeed, this is due to the predictive brain outset. Emphasising the predictive nature of the brain by using the prior experience, which essentially is a Bayes optimal generative model, proposes that the brain is operating on the upcoming experience, i.e. protention, using prior experiences, i.e. retention, to generate qualified guesses. The specious present serves as the unity of retention and protention—a phenomenon in time where it is neither protention nor retention alone that reigns, but a comparison through unity, which active inference refers to as PEs. Despite the apparent congruence regarding indivisibility of time in the condition and the empirical framework, active inference as an inferential generative model struggles to make up for continuous-time[1]. Active inference currently operates in discrete state-space, which makes the continuity divisible in theory—yet, each given moment, even when divided, is constituted by the prior moment and the prediction. In brief, this means that the unfolding of time in the simulation is divisible, but the simulated agent still depends on prior experience and predictions of expected free energy.

The closer an empirical theory is coming to experience, the more it seems that time has been misunderstood. Perhaps because mathematics and statistics always reduce it to a static frame-count. This seems not to be the natural behaviour of time—instead, it seems that time is heterogeneous, involving manifolds beyond the known two-dimensional number system (Appendix A). This turn of events in the theory is akin to that of Poincaré in mathematics; that is, the introduction of movement and time in the equations is the origin of dynamic systems theory. For Poincaré, all possible points were drawn, or in other words, the virtual actions of the behaviour are drawn, and these determine *that* particular system.

**2.** The key argument to make up for the indeterminate state of the human is the self-organising process in emergence, i.e. a process where the whole is greater than the sum of its parts. There is no hurricane in water nor in the wind, similar to how there is no financial collapse in a dollar bill. These things emerge from local components and their interplay. According to Damasio (2010), homeostasis is the process that enabled basic reflexes and metabolic regulations through incentives that guide and drive the living creature. This would eventually lead to emotional states anchored in the body, describing a cognitive architecture that places the affective dimension equally with more conventional processes (Vernon *et al.*, 2015). To avoid straining the homeostatic balance, allostasis was suggested to function as a predictive self-regulation during perturbation stemming from interactions with the environment, requiring adjustments before actual events (Sterling, 2012). This complex biological behaviour rest on the ability to predict on a cellular level, which is where DST demonstrate how the body functions as a dynamic system using patterns of change over time instead of symbolic processing. Given the DST approach, the argument took a biological turn towards autopoiesis and self-organising principles demonstrating how organisational and operational closure maintains a system through visceral top-down signals that compete with sensory signals of the environment. Furthermore, DST demonstrates how networks of the interconnected brain cannot fully decompose to its component parts to explain cortical functionality. Instead, the brain uses the global network as a whole with minimally decomposability of local patterns in the brain to enact cognition.

Concerning the asymmetry of the transcendental and immanent, active inference wholly encapsulates the Husserlian concept of transcendental perception,

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[1] This is not referring to the rewriting of an expression from summation to integral.

i.e. horizonal intentionality. The anticipated perception [Vorgriff] is precisely the prediction in active inference and SMC, so that the perception that one anticipates to perceive depends on the action than one selects—this is essentially the core of proactive sensory. The asymmetry thus refers to the comparison by unity in the specious present, which in active inference is a prediction error.

**3.** The last condition concerns the immediacy of the given and how that partakes in self-temporalising. The link between DST and emergence is the dependency of dynamic causality. By arguing that a living organism operates through reciprocal causality, it becomes clear that the organism and environment couple structurally, which further yields an embodied congruence between system and environment. Dynamic co-emergence is an expression for this diachronic co-determined coupling between an organisms system and its environment—thus, architecture takes an essential position in the structure of cognition. If the environment is coupled to brain and body, it seems natural to investigate how designed environment partake in the complexity of this dynamic system.

Furthermore, DST links to Bergson's continuity and heterogeneity of time, not through the fact that DST can account for continuous time-series, but through the fact that dynamic systems do not target the state in a given system—instead, DST aims to understand the transition, the change of pattern over time. Similar to DST, the Hidden Markov Model is certainly also Bergsonian in its approach inference and time. In these models, the environment is held to be hidden states, i.e. an environment that the architects usually design. They are hidden states for the observing agent, but not for the all-seeing architect who designed the environment. The hidden states that the actively inferring agent must infer are essentially *designed* hidden states that influence the unfolding of the inference Markov chain. Any inferences at the lowest scale (prediction) of the hidden states are predictions about the designed environment that refer to action. These predictions unpack at the level of intuition. Active inference as a framework of explaining experience through virtual actions links perfectly well with SMC, DST, enactivism and phenomenology.

### Specifying the research question

The early distinction between architectural and experiential transition (Chapter 3) has guided the research question more than expected. Architectural (physical) transition is interrelated with the (metaphysical) transition in time since cognition is anchored in body, brain and environment. If the function of the brain is to predict potential movements instead of resolving representations of an external world, it seems that architecture may hold a much greater privilege on cognition than anticipated. The research question may thus go from:

**How does experiential transition unfold through action and perception relative to architectural transition?**

To:

## Can an embodied neuroscientific framework, based on phenomenology, experimentally answer how the experiential transition relates to the cognitive process of action-perception with regard to architectural transition?

The question is two-fold. It questions whether it is possible to derive an empirical framework from phenomenological conditions, and it questions whether the framework can answer how experience relates to action-perception and the environment. The answer to the latter will also determine the answer of the former.

To be sure, active inference only makes up a specific aspect of a phenomenological understanding of experience—in no way can active inference correspond directly to a phenomenological dimension of human experience. The novelty proposed here is the integration of the argument in SMC, namely that experience depends on the structure of change in the perceptual organs (O'Regan and Noë, 2001), with active inference, because the structure of change corresponds to the transition matrix. Furthermore, the transition matrix is inherently dependent on the action policy (virtual action) and precision (affordance). Comparing the conditions for phenomenology to active inference essentially states that active inference offers a computational cognitive neuroscientific approach to understand how the environment appears as it does—not that active inference can correspond to a full-blown experience with intentionality/quale. In practice, how the environment appears, is deeply seated in neurophysiological processes, which reveals how important it is to understand the underlying processes of human homeostasis and basic cognition, i.e. action-perception, since psychiatric and psychological conditions emerge from disturbances in precisely neurophysiological processes (see e.g. Grant and Adams, 2009). As mentioned before, this poses the strategy that it may be better to ask not what cognition tells about the nature of active inference but what the nature of active inference tells about cognition.

# CHAPTER 12

# Sensorimotor brain dynamics reflect architectural affordances

*This chapter is an extended version of the thesis-related publication Sensorimotor brain dynamics reflects architectural affordances in Proceedings of the National Academy of Sciences of the United States of America by the author (Djebbara et al., 2019).*

**Summary.** *If an enactive account of perception, action, and cognition is correct, then it is expected to find differences in cortical responses to* resonate *as a function of affordances over sensory and motor areas—can this be tested?* This chapter concerns the experimental setup to test the established hypothesis. The utilised method is a mobile brain/body imaging approach recording brain activity synchronised to head-mounted displays. Participants perceived and acted upon virtual transitions ranging from non-passable to easily passable. It was found that early sensory brain activity, on revealing the environment and before actual movement, differed as a function of virtual actions. In addition, movement through transitions was preceded by a motor-related negative component that also depended on affordances. Surprisingly, the empirical data are in line with the hypothesis, complementing the empirical framework as a whole.

## 12.1 The hypothesis

> *"If an enactive account of perception, action, and cognition is correct, then affordances are intimately related to higher hierarchical levels through low-level perceptual cues. Such an account would situate the processing of affordances at a similar stage as early perceptual processes and should reveal differences in sensory and motor-related ERPs associated with the perceived affordance of an environment.* […] [It is] *expected to find differences in cortical responses to covary* [resonate] *as a function of affordances over*

> *sensory and motor areas. In addition,* [it is] *expected to see differences in MRCPs as a function of the environmental affordances* […].*" (Djebbara et al., 2019)*

### 12.1.1 Phenomenology, SMC and active inference

Phenomenologically, the hypothesis questions the immediacy of the experiential transition concerning the architectural transition. According to the framework insofar, the continuity of experience is a constant integration of sensorimotor activity, so that action and perception cannot be distinguished to separate wholes. Consequently, phenomenology situates the perception of the environment at the intuitive level, meaning the virtual actions and affordances should not be considered intellectual outcomes, but rather intuitive givens, i.e. the early and fast cortical processes that are linked to sensory processing must resonate with the virtual actions and affordances of the environment. However, this is not to say that a full-blown experience is captured in these early, fast processes of the brain, but that experience emerges from those operations, i.e. the following experiences are further based on these.

Sensorimotor activity, according to SMC, reflects the perceptual experience in perception where that pattern of change in a sensory activity constitutes the experience. The pattern of change depends on one part on the actions of the agent, but since the perceptual organs are proactive, there is a continuous practical feed of structural change over time in the sensory activity. An agent cannot reduce actual uncertainty about what is not perceivable without physically moving the body—however, the proactive perceptual organs contribute to the stable (non-acting) perception of the world. From the perspective of SMC, the hypothesis is that since the perceptual experience originates in the structure of change over time, which in turn depends on the action policies, the sensorimotor activity resonates with the environmental affordances, if the agent intends to interact with the environment.

Regarding active inference, the environment is equivalent to the generative process. Motor systems suppress errors through a dynamic interchange of prediction and action so that there are two ways to minimise prediction errors. One may adjust predictions to fit the current sensory input, or one may adapt the unfolding of movement to make predictions come true (Chapter 10). Action is thus both perceived by and caused by perception (Friston, 2003), which means that action, perception and cognition coordinate to move in ways that conform to a transitional set of expectations (Clark, 2013). The set of action policies constitute the transition matrix in active inference, where they are considered in parallel to alter the generative process according to the intention of the agent.

## 12.2 Event-Related Potential brain components

Previous neuroscientific experiments addressing this issue contributes to discussions centred on how human beings relate to the world. Enactivists have stated the reciprocal dependency of the living organism, as a self-organised living system, and the embedded body in a world for cognition (Maturana and Varela, 1992; Thompson, 2007; Varela, Thompson and Rosch, 2016). Enactivism shares roots with phenomenology (Jelić *et al.*, 2016; Gallagher, 2017), similar to prominent architectural theorists, who put body, action, and cognition central to experience. The link between active inference and enactivism rests on the critical concept that one acts to perceive, and vice versa. Such a thesis rests on a hierarchical and dynamic model of the world, which temporally dissociates lower sensorimotor inferences from higher motivated goals, as fast and slow, respectively (Chapter 11; Kiebel, Daunizeau and Friston, 2008). Fast, lower sensorimotor inferences depict processes related to virtual actions and affordances, which thereby must be present in early stages of perception. HAC takes the temporal aspect of affordances much further, by suggesting that cortical activity relates to the immediate decision of action selection, which occurs fluently during movement (Pezzulo and Cisek, 2016). Such an account of temporally extended affordance is in accordance with active inferences, SMC and phenomenology.

The Mobile Brain/Body Imaging approach (Makeig *et al.*, 2009; Gramann *et al.*, 2011, 2014) allows recording brain activity with EEG, synchronised to movement recordings and head-mounted virtual reality (VR) to investigate the impact of environmental affordances on early sensory processing in acting humans. This approach allows for investigating brain dynamics of participants perceiving an environment and the transitions contained therein as well as brain dynamics during the transitions themselves. Previous studies investigating event-related potential (ERP) activity in stationary participants demonstrated slow cortical potentials to indicate anticipative motor behaviour (for an overview see Luck and Kappenman, 2011, chap. 8). Known motor-related cortical components (MRCPs) are the readiness potential (RP; Kornhuber and Deecke, 2016), contingent negative variation (CNV), and the stimulus-preceding negativity (SPN; Brunia, 2003), which can be seen as indicators of predictive behaviour (Di Russo *et al.*, 2017). MRCPs are negative-going waveforms preceding an actual, or imagined, motor execution. However, these negative components are associated with multiple processes including sensory, cognitive, and motor systems. Bozzacchi et al. (2012) attempted to measure affordances of a physical object by evaluating whether the anticipated consequence of action itself influences the brain activity preceding a self-paced action. The authors compared MRCPs of situations where it was possible to reach out and grasp a cup, versus situations where it was impossible to grasp the cup, by tying the hands of the participants. A motor execution was forced at all times. In situations where it was impossible to grasp the cup, the authors reported an absence of early activity over the parietal cortex and found instead increased activity over the prefrontal cortex. The results were interpreted as reflecting an awareness of the inability to execute a goal-oriented action. Closely related to the MRCPs is the post-imperative negative variation (PINV), a negative-going waveform that is present following an imperative stimulus. It reflects the immediate motor execution related to the onset of an imperative stimulus and is observed during experiments investigating learned helplessness or loss of control (Elbert *et al.*, 1982; Diener *et al.*, 2009). The PINV thus allows linking motor-related potentials to the readiness to act (Casement *et al.*, 2008).

## 12.3 Method [1]

### 12.3.1 Participants

Twenty participants, of which nine were females and none with a history of neurological pathologies, were recruited from a participant pool of the Technical University of Berlin, Germany. All participants needed to read and sign the written informed consent, which was approved by The Ethics Committee of Technical University of Berlin, about the experimental protocol. Participants received either monetary compensation (10€/hour) or accredited course hours. The mean age was 28.1 years ($\sigma = 6.2$ years), all participants had normal or corrected to normal vision, and none had a specific background in architecture (no architects or architectural students). A single participant was excluded due to technical issues during the experimental setup.

### 12.3.2 Paradigm

The experiment took place in the Berlin Mobile Brain/Body Imaging Laboratories (BeMoBIL) with one of the experimental rooms providing a space of 160 m$^2$. The size of the virtual space was 9 m × 5 m with a room size of 4.5 m × 5 m for the first room and a room size of 4.5 m × 5 m for the second room. Participants performed a forewarned (S1-S2) *Go/NoGo* paradigm (pseudorandomised 50/50) in the VR environment that required them to walk from one virtual room to a second virtual room, akin to the architectural conundrum (Chapter 3). Doors of different width ranging from unpassable (20 cm, *Narrow*) to passable (100 cm, *Mid*) to easily passible (1500 cm, *Wide*) manipulated the transition affordance between rooms. The experiment consisted of a 3 × 2 repeated measures design, including the factors door width (*Narrow*, *Mid*, *Wide*; pseudorandomised) and movement instruction (*Go*, *NoGo*). A total of 240 trials per participant were collected with 40 trials for each of the factor levels. One trial consisted of a participant starting in a dark environment on a predefined starting square (Fig. 12.1). The "lights" would go on after a random intertrial interval (mean = 3 s, $\sigma = 1$ s), and participants faced a room with a closed door. They were instructed to wait (mean = 6 s, $\sigma = 1$ s) for a colour change of the door with a change to green indicating a *Go* trial and a change to red indicating a *NoGo* trial. In the case of a green door, the participant walked toward the door, which would slide aside. Upon entering the subsequent space, participants were instructed to find and virtually touch, using the controller, a red rotating circle. The circle would inform the participant to have earned another 0.1€ to their basic reimbursement of 10 Euro per hour. After each trial, participants had to give an emotional rating of their state irrespective of whether they transitioned through the door (*Go* condition) or whether they remained in the same room (*NoGo* condition) without transition. To this end, participants were instructed to go back to the starting square to fill in a virtual Self-Assessment Manikin (SAM) questionnaire, using a laser pointer from the controller, and subsequently to pull the response button located at the

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[1] This subchapter is heavily based on the writing in (Djebbara et al., 2019)

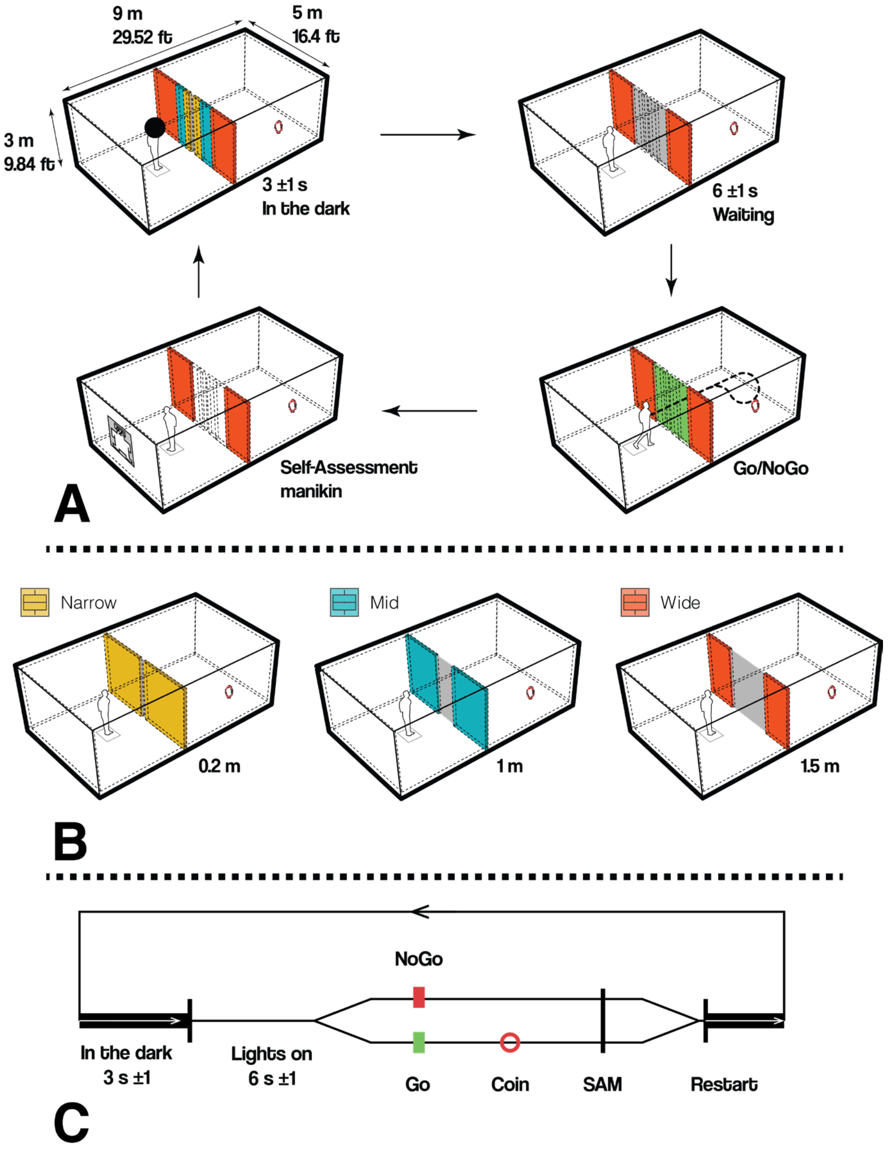

*Figure 12.1*— **A.** *Participants were instructed to stand in the start square. A black sphere would restrict their vision to pure black for 3 seconds, σ = 1 second. The moment the black sphere disappears, participants perceive the door they have to pass. They wait for the imperative stimulus, either a green door (Go) or a red door (NoGo), for 6 seconds, σ = 1 second. In the case of Go, participants were instructed to pass the opening, virtually touch the red circle, which in turn would release a monetary bonus, return to the start square and answer the virtual SAM questionnaire. In the case of NoGo, participants were instructed to turn around and answer the virtual SAM.* **B.** *The three different doors were dimensioned as follows: Narrow 0.2 meter, Mid 1 meter, and Wide 1.5 meters. Note the colour code for each door as they are used throughout the paper.* **C.** *The diagrammatic timeline depicts the sequences of events for a single trial in a conceptual manner. Illustration from Djebbara et al. (2019).*

pointer finger to turn the "lights off." The lights would go back on automatically to start the next trial.

In *Go* trials, participants were instructed to walk toward the door and into the second room even in cases where the door was too narrow to pass. This ensures control for motor execution in the *Go* condition while allowing movement toward the goal irrespective of the affordance (passable vs unpassable). A narrow opening was thus different from a *NoGo* trial, in the sense that a *NoGo* trial did not require any movement toward the door, whereas a *Go* trial always required approaching the door. Upon touching the surrounding walls, the walls would turn red and inform the participants that they have failed to pass, and thus must return to the start square, fill in the virtual SAM, and start the next trial. Participants would quickly notice that the narrow door (20 cm) was impossible to pass without producing the warning feedback that they have failed to pass, and yet they were required to try passing. All participants had a training phase to get accustomed to the VR environment and the different conditions. The experimenter observed the participants from a control room, separated from the experimental space, using two cameras and a mirrored display of the virtual environment to reduce interactions to a minimum during the experiments.

### 12.3.3 Subjective and behavioural

The subjective experience of the task was investigated by introducing the participants to a virtual SAM questionnaire after each trial. The SAM is a pictorial assessment of pleasure, arousal, and dominance on a 5-point Likert scale (Bradley and Lang, 1994). The manikin display ranges from smiling to frowning (*pleasure*), from a dot in the stomach to an explosion (*arousal*), and from being very small to massive (*dominance*). Participants were asked to self-assess their current state after each trial. Furthermore, regarding behavioural measures, the reaction time was recorded from the onset of the *Go*-stimulus (door colour change) to reaching the opening-threshold itself, to assess the behaviour. The data were analysed using analysis of variance (ANOVA) with the width of the doors as repeated measures factor. In the case of violation of normality and homogeneity, corrected p-values are reported. For post hoc analysis, the data were contrasted using Tukey HSD.

### 12.3.4 EEG recording and data analysis

All data streams were recorded and synchronised using LabStreamingLayer (LSL; 37). Participants wore a backpack, which held a high-performance gaming computer to render the VR environment (Zotac, PC Partner Limited, Hong Kong, China) attached to two batteries and an EEG amplifier system. The technological combination consisted of a Windows Mixed Reality (WMR; 2.89″, 2880 × 1440 resolution, update rate at 90 Hz, 100-degree field of view with a weight of 440 grams, linked to the Zotac computer through HDMI) headset and one controller by Acer to display and interact with the virtual environment based on Unity (Fig. 12.2). Events for recordings of performance and physiological data were triggered by the position of the participant in the tracking space or by the respective

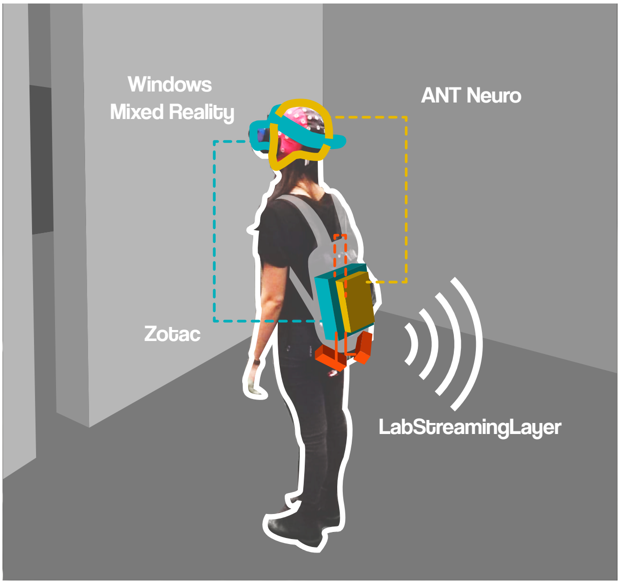

*Figure 12.2—Mobile Brain/Body Imaging setup. The participants wore a backpack, carrying a high-performance gaming computer (Zotac, Cyan colour), powered by two batteries (Red colour). An EEG amplifier (ANT eegoSports, Yellow colour) was attached to the backpack and connected to the computer. The participants wore a VR head-mounted display (Windows mixed reality) on top of a 64-channel cap. This setup allowed participants to move freely around while recording data. Illustration from Djebbara et al. (2019).*

response buttons of the remote control. Specific events, such as touching the wall, all button presses, transitioning through the door, answering the questionnaire, and all cases of "lights on" (and off), were synchronised with the recorded brain activity and the presented VR environment through LSL.

EEG data were acquired continuously with a 64-channel EEG system (eegoSports, ANT Neuro, Enschede, Netherlands), sampled at 500 Hz. Impedances were kept below 10 kΩ. The computational delay generated by the interaction of ANT Neuro software, Windows Mixed Reality, and Unity was measured to be 20 ms ($\sigma = 4$ ms), which was taken into account during the analysis by subtracting the average delay from each event latency. With a jitter of 4 ms, the delay was considered to have little to no impact on the ERPs. Offline analysis was conducted using MATLAB (MathWorks, Natick, MA, USA) and the EEGLAB toolbox (Delorme and Makeig, 2004). The raw data were band-pass filtered between 1 Hz and 100 Hz and down-sampled to 250 Hz. Channels with more than five standard deviations from the joint probability of the recorded electrodes were removed and subsequently interpolated. The datasets were then re-referenced to an average reference, and adaptive mixture independent component analysis (AMICA; Palmer, Kreutz-Delgado and Makeig, 2011) was computed on the remaining rank of the data using one model with online artefact rejection in five iterations. The resultant ICA spheres and weights matrices were transferred to the raw dataset that was preprocessed using the identical preprocessing parameters like the ICA dataset, except the filtering, which used a band-pass filter from 0.2 Hz to 40 Hz. Subsequently, independent components (ICs) reflecting eye movements (blinks and horizontal movements) were removed manually based on their topography, their spectrum, and their temporal characteristics.

Epochs were created time-locked to the onset of the room including the closed door ("Lights on") from –500 ms before to 1500 ms after stimulus onset for *Narrow*, *Mid*, and *Wide* door trials. Similarly, another set of epochs was time-locked to the second stimulus *Go/NoGo* from –500 ms before to 1000 ms after the onset of the stimulus for *Narrow*, *Mid*, and *Wide* door trials. On average, 15% ($\sigma$ = 10.8) of all epochs were automatically rejected when they deviated more than five standard deviations from the joint probability and distribution of the activity of all recorded electrodes.

The visual-evoked potentials, as well as MRCPs, were analysed at central midline electrodes (*Fz*, *FCz*, *Cz*, *Pz*, *POz*, and *Oz*) covering all relevant locations including the visual and the motor cortex as reported in previous studies (Bozzacchi *et al.*, 2012, 2015). Because stimuli were distributed across the entire visual field and participants walked through the virtual spaces, any lateralisation of ERPs were not expected. All channels were analysed, however, only three channels (*FCz*, *Pz*, and *Oz*) are reported and discussed in-text according to reported results by Bozzacchi et al. (2012). The analysis results of all six channels can be found in Appendix F. For peak analysis of the P1-N1 complex, the grand-average peaks were estimated, and individual peaks were defined as the maximum positive and negative peak in the time window surrounding the grand-average P1 and N1 peaks (±10 ms from the peak), respectively. An automatic peak-detection algorithm detected the peaks in the averaged epochs for each participant. Multiple peaks were detected and systematically weighted depending on the magnitude, the distance to the grand-average peak latency that was determined by visual inspection of grand-average ERP, and the polarity. For anterior N140 and posterior P140, by visual inspection of the grand-average ERPs, the grand-average latency was estimated to be 140 ms with a search window for individual peaks ranging from 50 to 200 ms. For the anterior P215 and posterior N215, the grand-average peak latency was estimated to 215 ms with a search window for individual peaks ranging from 140 to 290 ms.

Mean peak amplitudes were analysed using a 3 × 3 repeated-measures ANOVA using the door width (*Narrow*, *Mid*, *Wide*) and electrode as repeated measures. The results descriptions focus on the visual-evoked P140 component at posterior electrodes (*Pz*, *POz*, and *Oz*) and the N140 component at frontal leads (*Fz*, *FCz*, and *Cz*) based on separate ANOVAs. For the N215 and P215 components at posterior electrodes (*Pz*, *POz*, and *Oz*) and frontal leads (*Fz*, *FCz*, and *Cz*), separate ANOVAs were computed in the time range of 140 to 290 ms. For the later motor-related potentials, an ANOVA was computed for the mean amplitude in the time range from 600 to 800 ms. The data were analysed using a 2 × 3 × 6 factorial repeated-measures ANOVA with the factors imperative stimulus (*Go* and *NoGo*), door width (*Narrow*, *Mid*, and *Wide*), and electrode location (*Fz*,

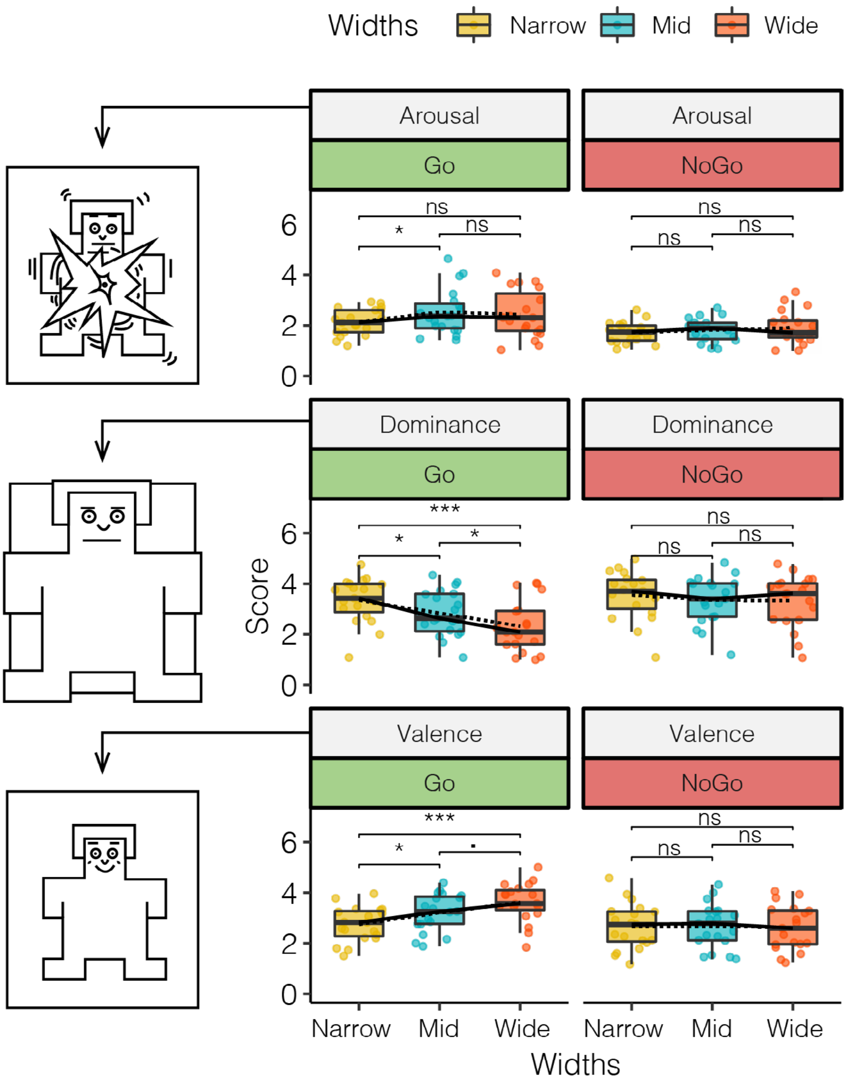

*Figure 12.3—Box plot of the SAM questionnaire results for the three different SAM scales (Arousal, Dominance, and Valence) as a function of the door width (Narrow, Mid, Wide). The left column displays a pictorial representation of the SAM manikin for the highest value of each condition presented. The middle column displays the SAM ratings for the Go condition. The right column displays the SAM ratings for the NoGo condition. Means are indicated by a dashed line, while medians are a solid line. Illustration from (Djebbara et al., 2019).*

*FCz, Cz, Pz, POz*, and *Oz*) within the time window (600–800 ms). For post hoc analysis, the data were contrasted using Tukey HSD. In the case of violations of the sphericity, corrected p-values are reported. All ANOVAs were computed as linear mixed models.

## 12.4 Results [2]

### 12.4.1 Subjective data: SAM

The SAM questionnaire was answered regardless of *Go* or *NoGo*, and for all door conditions. A 2 × 3 factorial repeated measures ANOVA with the factors imperative stimulus (*Go* and *NoGo)* and door width (*Narrow*, *Mid*, and *Wide*) for each emotional dimension of the SAM questionnaire revealed differences in the main effect for width in *Arousal* ($F_{2, 90} = 3.35, p = 0.0393, \eta^2 = 0.048$), *Dominance* ($F_{2, 90} = 10.03, p < 0.0001, \eta^2 = 0.138$), and *Valence* ($F_{2, 90} = 5.31, p = 0.0065, \eta^2 = 0.073$). For the imperative stimulus, differences were found for *Arousal* ($F_{1, 90} = 36.81, p < 0.0001, \eta^2 = 0.266$), *Dominance* ($F_{1, 90} = 25.26, p < 0.0001, \eta^2 = 0.173$), and *Valence* ($F_{1, 90} = 28.59, p < 0.0001, \eta^2 = 0.196$). Interaction effects revealed significant difference for *Dominance* ($F_{2, 90} = 4.14, p = 0.0189, \eta^2 = 0.056$) and *Valence* ($F_{2, 90} = 7.04, p = 0.0014, \eta^2 = 0.096$), however only tendencies for *Arousal* ($F_{2, 90} = 0.92, p = 0.4000, \eta^2 = 0.0134$). Post hoc contrasts using Tukey HSD (Fig. 12.3) showed no significant differences for *NoGo* in *Arousal*, however, significant differences were identified for *Go* between *Narrow* × *Mid* ($p = 0.0386$). For *NoGo* in *Dominance*, no significant differences were revealed as opposed to *Go* for *Narrow* × *Wide* ($p < 0.0001$), *Mid* × *Wide* ($p = 0.0335$), and *Narrow* × *Mid* ($p < 0.0345$). Similarly for *Valence*, significant differences were only revealed in *Go* for *Narrow* × *Mid* ($p = 0.0326$), *Narrow* × *Wide* ($p < 0.0001$), and a tendency for *Mid* × *Wide* ($p = 0.0625$).

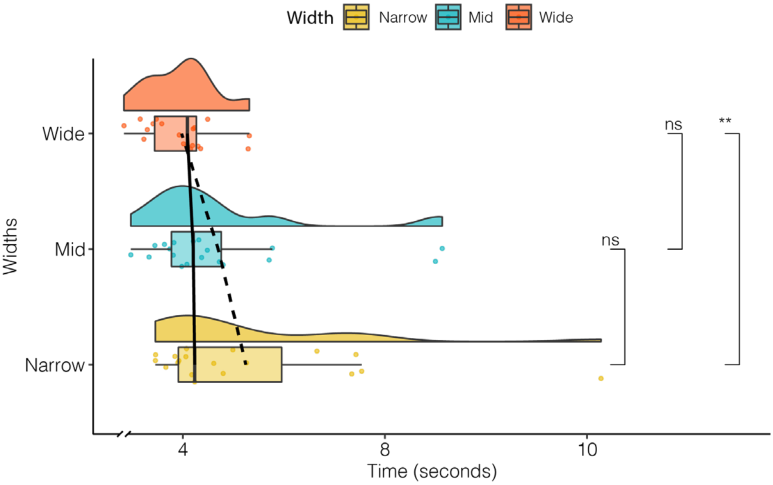

*Figure 12.4—Rain-cloud plot of approach times for each door width condition. Post hoc comparisons using Tukey HSD test. Means are indicated by a dashed line, while medians are displayed as solid lines. Illustration from (Djebbara et al., 2019).*

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[2] This subchapter is heavily based on the writing in (Djebbara et al., 2019)

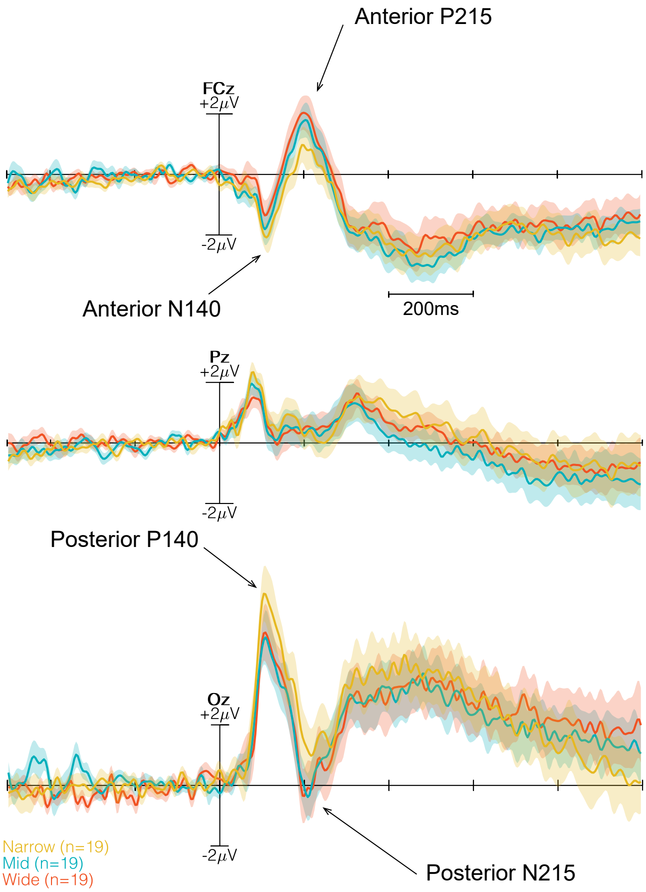
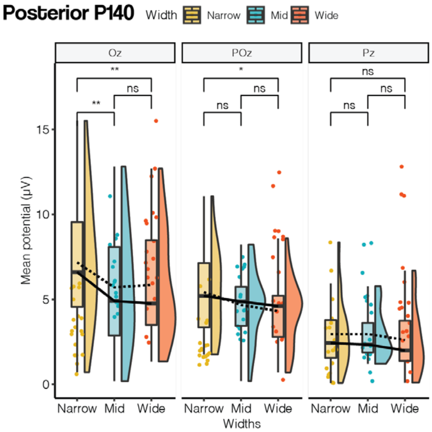
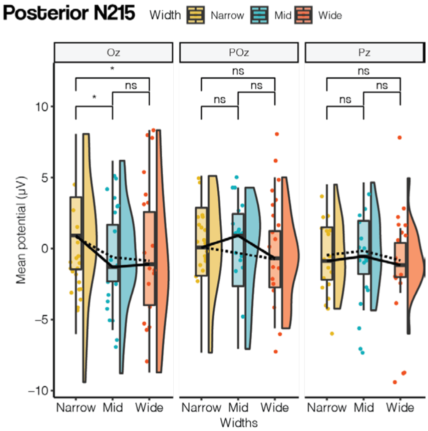


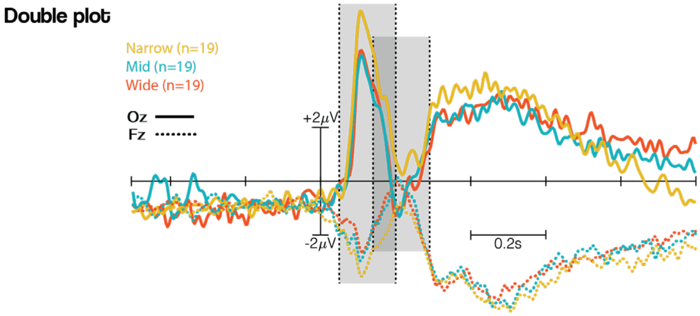
*Figure 12.5—Three time-locked ERPs (FCz, Pz, and Oz) at the onset of "Lights On" event. Narrow condition in yellow, Mid condition in blue, and Wide condition in red. Two time-windows are indicated with dashed lines and grey transparent box. The first time window (50–200 ms) marks the anterior N140 and posterior P140, while the second window (140–290 ms) marks the anterior P215 and posterior N215. The components are marked with arrows. Illustration from (Djebbara et al., 2019).*

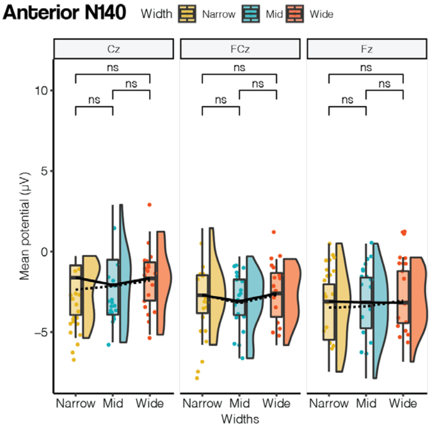
### 12.4.2 Behavioural data: approaching-time

This analysis is only possible for *Go* trials, as it required actually approaching the door. To investigate the time it took participants from the *Go*-stimulus to pass the door, a one-way ANOVA with repeated measures for different door widths was computed revealing a significant difference for the factor door widths ($F_{2, 36} = 6.07$, $p < 0.0053$, $\eta^2 = 0.232$; Fig. 12.4). Post hoc comparison (Tukey HSD) showed no significant differences in behaviour when approaching the *Narrow* compared to *Mid* doors ($p = 0.3073$), approaching a tendency to be slower when approaching *Mid* as compared with *Wide* doors ($p = 0.1312$), and a significant difference between approaching *Narrow* as compared with *Wide* door ($p = 0.0038$) with significantly faster approach times for the *Wide* door condition.


Posterior P140
Width
Narrow
Mid
Wide
Oz
POz
Pz
**
**
ns
*
ns
ns
ns
ns
ns
Mean potential (μV)
0
5
10
15
Narrow
Mid
Wide
Widths


Posterior N215
Width
Narrow
Mid
Wide
Oz
POz
Pz
*
*
ns
ns
ns
ns
ns
ns
ns
Mean potential (μV)
−10
−5
0
5
10
Narrow
Mid
Wide
Widths


Double plot
Narrow (n=19)
Mid (n=19)
Wide (n=19)
Oz
Fz
+2μV
-2μV
0.2s


Anterior N140
Width
Narrow
Mid
Wide
Cz
FCz
Fz
ns
ns
ns
ns
ns
ns
ns
ns
ns
Mean potential (μV)
−5
0
5
10
Narrow
Mid
Wide
Widths

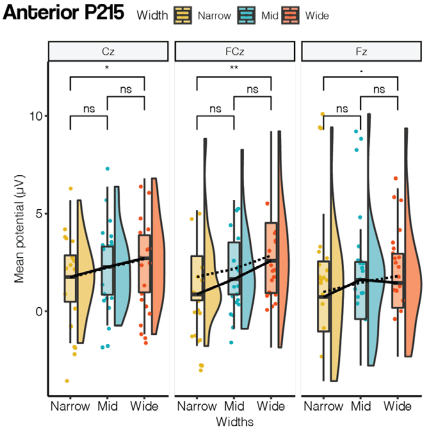

Anterior P215
Width
Narrow
Mid
Wide
Cz
FCz
Fz
*
ns
ns
**
ns
ns
.
ns
ns
Mean potential (μV)
0
5
10
Narrow
Mid
Wide
Widths

*Figure 12.6—* **Posterior P140.** *Rain-cloud plot of detected mean amplitude of the positive peak in the time-locked event "Lights on" in the time range of 50 to 200 ms for Pz, POz, and Oz. Means are indicated by a dashed line, while medians are a solid line. The significance is calculated using Tukey HSD. Significant differences were observed for Oz between Narrow × Mid ($p = 0.0021$) and Narrow × Wide ($p = 0.0065$), while POz in Narrow × Wide revealed a significant difference ($p = 0.028$); however, no significant differences were observed in other electrodes and other contrasts.* **Posterior N215.** *Rain-cloud plot of detected mean amplitude of the negative peak in the time-locked event "Lights on" in the time range of 140 to 290 ms for Pz, POz, and Oz. Significant differences were observed only for Oz in Narrow × Mid ($p = 0.0113$) and Narrow × Wide ($p = 0.0372$).* **Anterior N140.** *Rain-cloud plot of detected mean amplitude of the negative peak in the time-locked event "Lights on" in the time range of 50 to 200 ms for Fz, FCz, and Cz No significant differences were observed for any electrode.* **Anterior P215.** *Rain-cloud plot of detected mean amplitude of negative peak in time-locked event "Lights on" in the time range of 140 to 290 ms for Fz, FCz, and Cz Significant differences were observed in all channels in Narrow × Wide, except for only a tendency in Fz ($p = 0.0717$), FCz ($p = 0.0071$), and Cz ($p = 0.0214$).* **Double plot.** *Frontal (dashed line) and posterior (solid line) time-locked ERPs (Fz and Oz) at the onset of "Lights On" event. Narrow condition in yellow, Mid condition in blue, and Wide condition in red. Two time-windows are indicated with dashed lines and grey transparent box. The first time window (50–200 ms) marks the anterior N140 and posterior P140, while the second window (140–290 ms) marks the anterior P215 and posterior N215. Illustration from (Djebbara et al., 2019).*

### 12.4.3 Electrophysiology: Event-Related Potentials

#### 12.4.3.1 Posterior P140

With onset of the lights that allowed participants to see the room including the door ("Lights on"), the ERPs demonstrated a clear P1-N1 complex most pronounced over the occipital midline electrode with a first positive component around 140 ms, followed by a negative peak around 210 ms (Fig. 12.5 and see Fig. F.1 in Appendix F for full six channels). At the frontal midline electrode, this pattern was inverted, and a negative component around 140 ms was followed by a positive peak observed around 215 ms. The 3 × 3 repeated measures ANOVA on P140 amplitudes for posterior channels revealed significant main effects for both the factors door width ($F_{2, 108} = 8.163, p = 0.005, \eta^2 = 0.096$) and channel ($F_{2, 36} = 15.868, p < 0.0001, \eta^2 = 0.187$). The interaction effect was not significant ($F_{4, 108} = 1.669, p = 0.1624$). Post hoc comparisons using Tukey HSD revealed significant differences in peak amplitudes at channel *Oz* between *Narrow* and *Mid* transitions ($p = 0.0021$) and between *Narrow* and *Wide* transitions ($p = 0.0065$) and at *POz* comparing *Narrow* and *Wide* transitions ($p = 0.028$).

#### 12.4.3.2 Posterior N215

The 3 × 3 repeated measure ANOVA on N215 amplitudes for posterior channels revealed a significant main effect for the factor door width ($F_{2, 108} = 4.348$, $p = 0.0153$, $\eta^2 = 0.066$) and no significant impact for the factor channels ($F_{2, 36} = 0.0893, p = 0.9147, \eta^2 = 0.001$). Post hoc Tukey HSD contrasts revealed no significant differences for *Pz* and *POz*. However, similar to posterior P140, significant differences at *Oz* for the comparison of *Narrow* and *Mid* transitions ($p = 0.0113$) and for the comparison of *Narrow* and *Wide* transitions ($p = 0.0372$) were found (Fig. 12.6).

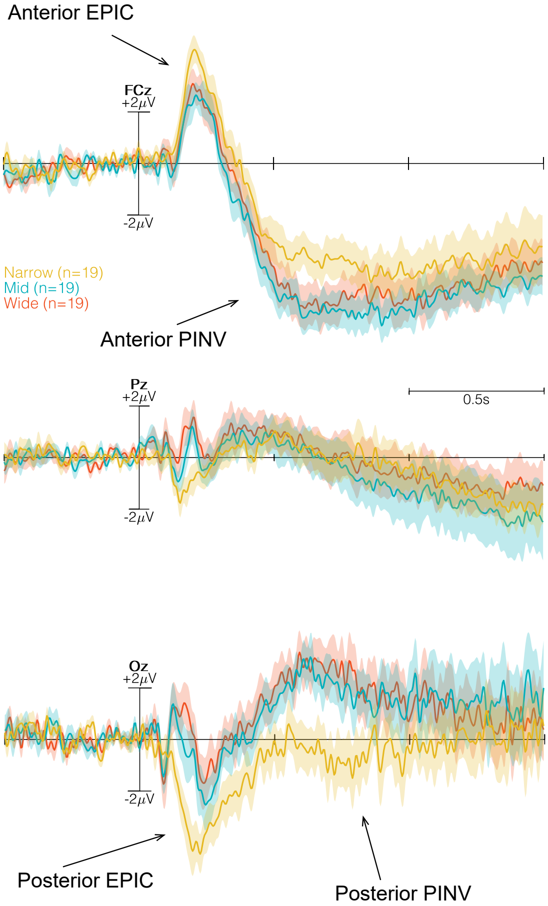


*Figure 12.7—Three time-locked ERPs (FCz, Pz, and Oz) at the onset of Go/NoGo. Narrow condition in yellow, Mid condition in blue, and Wide condition in red. The time window, indicated with dashed lines and grey transparent box, illustrates the selected time window to analyse the MRCP by a global 2 × 3 × 6 factorial repeated-measures ANOVA. Anterior and posterior PINV are marked with arrows. Illustration from (Djebbara et al., 2019).*

### 12.4.3.3 Anterior N140

The 3 × 3 repeated measures ANOVA on N140 amplitudes for anterior channels revealed no significant main effect for the factor door width ($F_{2,108} = 1.823, p = 0.1663, \eta^2 = 0.024$). In contrast, the main effect of channels reached significance ($F_{2,108} = 8.109, p = 0.0012, \eta^2 = 0.107$). The interaction did not reach significance.

### 12.4.3.4 Anterior P215

An inverse pattern was observed for amplitudes over anterior leads with a main effect of door width that differed depending on the affordances ($F_{2,108} = 11.071, p$

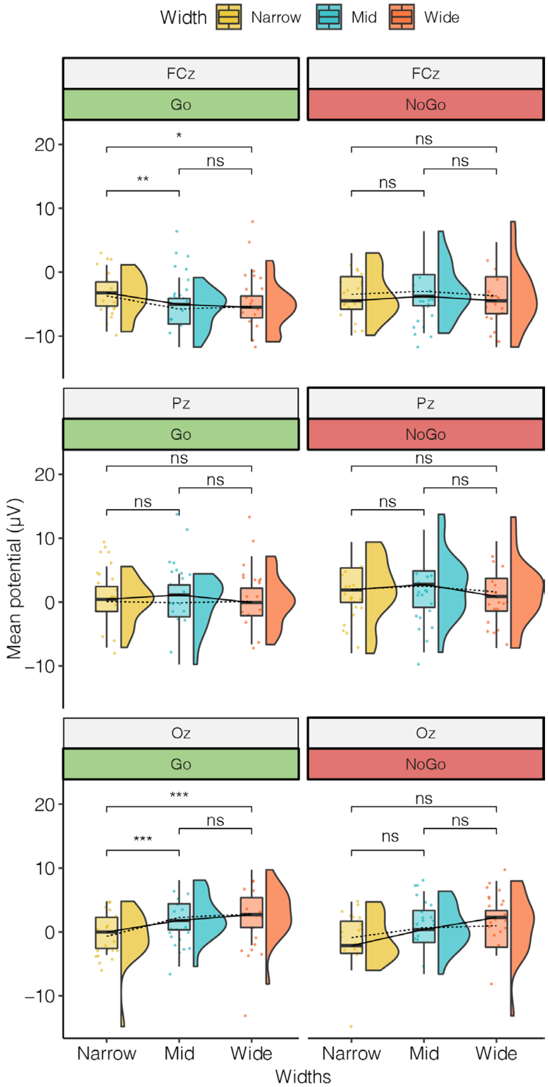


*Figure 12.8—Rain-cloud plots of the mean amplitude of negative development in the time-locked event of Go/NoGo in the time range of 600 to 800 ms for FCz, Pz, and Oz. Means are indicated by dashed lines, while medians are solid lines. The Tukey HSD contrast revealed differences only in FCz and Oz, and between Narrow × Mid for FCz ($p = 0.0059$) and for Oz ($p < 0.0001$), and between Narrow × Wide for FCz ($p = 0.0323$) and for Oz ($p < 0.0001$). No differences were observed for NoGo. Illustration from (Djebbara et al., 2019).*

$< 0.0001$, $\eta^2 = 0.139$). The main effect of channels also reached significance ($F_{2,36} = 5.3627$, $p = 0.0092$, $\eta^2 = 0.067$). Tukey HSD contrasts revealed significant differences only between *Narrow* and *Wide* transitions for *FCz* ($p = 0.0071$) and *Cz* ($p = 0.0214$), and a tendency at *Fz* ($p = 0.0717$). The interaction was not significant.

### 12.4.4 Motor-related processes

#### 12.4.4.1 Anterior EPIC

A 2 × 3 × 3 repeated measures ANOVA revealed significant difference in the main effect for widths ($F_{2,270} = 4.21, p = 0.0157, \eta^2 = 0.025$), imperative stimulus ($F_{1,270} = 23.66, p < 0.0001, \eta^2 = 0.071$), and for channel ($F_{2,36} = 6.70, p = 0.0033, \eta^2 = 0.040$). No interaction effect was observed. The post hoc Tukey HSD revealed no significant differences between the transition widths for different channels or imperative stimuli.

#### 12.4.4.2 Posterior EPIC

The identical ANOVA for the posterior potentials of the EPIC revealed no significant impact of transition width ($F_{2,270} = 2.001, p = 0.1371, \eta^2 = 0.013$) nor imperative stimulus ($F_{1,270} = 2.30, p = 0.1298, \eta^2 = 0.007$). Significant differences in EPIC amplitudes were observed for the factor channel ($F_{2,36} = 5.45, p = 0.0085, \eta^2 = 0.035$). Because topographical differences were not the focus of this study, no further post hoc contrasts were computed. No interaction was significant.

#### 12.4.4.3 PINV

In the preparation time before the onset of the door colour change, indicating either to walk through the door or to remain in the same room, no systematic negative-going waveform was observed as reported in previous studies (Brunia, 2003; van Boxtel and Böcker, 2004). However, after the onset of the colour change, a pronounced positivity, the EPIC, followed by a long-lasting negative waveform over frontocentral locations was observed in the ERP (Fig. 12.7 and see Fig. F.2 in Appendix F for all six channels). This negative waveform resembled a PINV as described in previous studies (Klein *et al.*, 1996; Casement *et al.*, 2008; Diener *et al.*, 2009). The PINV component was observed 600–800 ms after the imperative stimulus (colour change of the door) and varied as a function of the affordance of the environment (door width). A global 2 × 3 × 6 factorial repeated measures ANOVA was computed to analyse the MRCPs using *Go/NoGo*, *Width*, and *Channel* as repeated measures. The ANOVA revealed significant differences in the main effect for *Go/NoGo* ($F_{1,540} = 19.54, p < 0.0001, \eta^2 = 0.039$) and for *Channel* ($F_{5,90} = 16.69, p < 0.0001, \eta^2 = 0.112$). Significant differences were reported for the interaction effect of *Go/NoGo* × *Channel* ($F_{5,540} = 5.25, p = 0.0001, \eta^2 = 0.035$) and for *Width* × *Channel* ($F_{10,540} = 2.61, p = 0.0042, \eta^2 = 0.035$). A tendency was observed for the interaction of the factors *Go/NoGo* × *Width* ($F_{2,540} = 2.33, p = 0.0975, \eta^2 = 0.006$).

Post hoc contrasts, using Tukey HSD, revealed significant differences only for the *Go* condition, as opposed to the *NoGo* condition (Fig 12.8). Similar to the early evoked potentials, differences were only observed at frontal and occipital sites and between *Narrow* and *Mid* door widths over *FCz* ($p = 0.0059$) and *Oz* ($p < 0.0001$), as well as between *Narrow* and *Wide* doors at *FCz* ($p = 0.0323$) and *Oz* ($p < 0.0001$). No differences were observed between the *Mid* and *Wide* doors (Fig. F.3 in Appendix F for all six channels).

## 12.5 Discussion [3]

### 12.5.1 SAM and approaching-time

The analysis of subjective ratings revealed significant differences between different *Go* trials, but no differences for *NoGo* trials regarding all ratings. Notably, in cases of *NoGo*, all participants perceived a similar scene standing in front of a red (*NoGo*) door, turning around, and answering the virtual SAM. Varying door sizes for *Go* trials yielded differences for *Dominance*, reporting that *Narrow* doors were more dominating than *Mid* and even more for *Wide doors*. The increase in *Dominance* for *Narrow* doors is inversely reflected in *Valence* because increasing values were observed with increasing door widths. Regarding *Arousal*, participants reported less arousal for *Narrow* doors compared with *Mid* and *Wide*. Furthermore, it is noteworthy that *Dominance* for *NoGo* is relatively high in value, compared with *NoGo* in *Arousal* and *Valence*, which score a low and central value, respectively. Taken together, the findings indicate that subjective reports differ significantly depending on whether participants received a *Go* actively moved through the rooms or not implying an impact of action affective ratings of an environment. The results, however, should be considered with caution as the subjective ratings might have been influenced by several factors beyond affordance, including monetary reward, different trial durations, physical activity, and different skills of subjective/introspective emotional evaluation.

Performance data might thus provide a better basis for interpreting the impact of affordances on behaviour. The time it took participants to reach the door after the onset of the imperative colour change varied according to the environmental affordance. Participants approached the *Wide* doors either with a tendency to a significance or significantly faster than the *Mid* and *Narrow* doors, respectively, while there was no significant difference for *Mid* and *Narrow* transitions. While the *Wide* door clearly offered a passage without greater demands regarding the motor plan and execution, the *Mid* door width, being ambiguously wide/narrow, might have triggered motor processes simulating a transition to estimate whether the door was passable or not. In this sense, the *Mid* and *Narrow* doors, causing uncertainty, might have delayed approach times due to increased processing demands. Admittedly, results derived from the approach time are limited, partly due to the caused fatigue of operating a physically demanding task for a relatively long time period, and partly due to passing a door that is seemingly impossible to pass. This led participants to develop different approach strategies, e.g., twisting their bodies, peeking inside from different angles or walking directly into the virtual wall to trigger a failed attempt, causing different delays. Given no participant was told beforehand that one opening is impassable, the enthusiasm and creativity decreased over the course of trials when they learned it was the narrow door. However, the fact that participants, in general, spent significantly more time approaching the *Narrow* doors compared with *Wide* doors provides sufficient guidance for the analyses of cortical measures associated with these differences.

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[3] This subchapter is heavily based on the writing in (Djebbara et al., 2019)

### 12.5.2 Early evoked potentials

As an initial insight into the association of affordances and cortical potentials, the early visual-evoked potentials were analysed. It was expected to find differences in the stimulus-locked ERP at occipital channels reflecting differences in sensory processing of affordance-related aspects of the transition. Based on the assumption of fast sensorimotor active inferences that should be reflected in action-directed stimulus processing influencing not only sensory but also motor-related activity, it was also hypothesised to find differences in the ERP over motor areas in the same time window as sensory potentials (i.e., between 50 and 200 ms). As illustrated in the analysis, significant differences were found in amplitudes of the visually evoked P140 component over the central occipital electrode varying with the affordance of the transition. In addition, and in line with the hypothesis, a difference over frontocentral leads starting around 50 ms and lasting until 200 ms after onset of the doors display was found. Taken together, no significant differences in peak amplitudes were found when comparing the passable *Mid* and *Wide* doors while peak amplitudes associated with both door widths significantly differed from impassable *Narrow* doors. Note that the visual scene of the three doors was comparable as they contained the same physical contrasts in the *Go* and the *NoGo* condition. Also, being merely introduced to the environmental setting, participants did not know whether they would have to attempt to pass, or not. These results indicate that impassable doors with poor affordances produce significantly different early evoked potentials compared with passable doors, particularly at the frontocentral and occipital sites. Thus, environmental affordances, in terms of being able to program a trajectory to transit spaces, yield a significantly measurable effect on early cortical potentials best pronounced over frontal and occipital sites at approximately 200 ms after the first view of the environment.

Considering the affordance-specific pattern observed for the early P1-N1-complex, prior studies have shown this visual-evoked potential complex to reflect attentional processes associated with spatial or feature-based aspects of stimuli (Posner and Dehaene, 1994; Hillyard and Anllo-Vento, 1998; Mangun, Hopfinger and Heinze, 1998; Gramann *et al.*, 2007; Gramann, Töllner and Müller, 2010). Attended stimuli elicit larger P1-N1 amplitudes than unattended ones. Based on these findings, the results suggest that passable transitions were associated with increased attentional processing. Keeping this in mind, viewing the affordance-specific pattern of P1-N1-complex in light of active inferences (Friston *et al.*, 2012), the difference confirms the assumption that perceptual processes covary with environmental affordances. In this sense, the amplitude difference might be credited to the process of actively inferring whether the body can move and transit at all, implying that visual attention is also guided by action-related properties of the environment. Similar to HAC (Pezzulo and Cisek, 2016) and active inference (Kiebel, Daunizeau and Friston, 2008; Friston, 2013), these findings are in line with parallel cortical processes integrating sensory information to specify currently available affordances. How one might act upon the environment is an ongoing process of resolving affordances, taking place as early as perceptual processes, and which situates actions in an intimate position with perception. Such early processes are deeply involved in the conception and articulation of the environment for an agent, pointing toward the importance of movement in cognition, and of how an agent continuously enacts the world.

### 12.5.3 Motor-related potentials

Although the ERP plots indicated an affordance-trend of the EPIC, statistical tests revealed no significant differences. However, the *Narrow* door width elicited the greatest amplitude, both in case of anterior positivity and posterior negativity. The increased amplitude associated with *Narrow* transitions can be interpreted as a reflection of the body simply not fitting, producing a prediction error because one is forced to interact with the transition. The nature of the PINV component is not as well investigated as other ERP components, limiting the reliability of an interpretation. Some studies treat this component as modality-unspecific "*electrocortical correlate of a cognitive state*" (Rockstroh *et al.*, 1997). The study by Gauthier and Gottesmann (1977) hypothesised the PINV, similar to affordances, to act as a marker of change in the psychophysiological state. Ever since, the PINV has been used to investigate depression, schizophrenia, learned helplessness, and loss of control (Elbert *et al.*, 1982; Kathmann, Jonitz and Engel, 1990; Klepeis *et al.*, 2001; Casement *et al.*, 2008; Diener *et al.*, 2009). Results show depressive and schizophrenic participants to exhibit an increased PINV that is explained as an increased vulnerability for loss of control, as well as increased anticipation for future events (Klein *et al.*, 1996; Casement *et al.*, 2008; Diener *et al.*, 2009). It must be emphasised that affordances reflect actions directed toward the future. If an increased PINV reflects increased vulnerability for future events, as observed for impassable doors, then the component might shed new light on the intentionality in affordances. Given the intention to pass, yet deprived of doing so, seems to be reflected in the PINV. Casement and colleagues (2008) suggested the PINV depended on lack of control as the state of having no influence; depriving the potential to act. This could explain the difference in the *Narrow* condition, as participants were instructed to attempt to pass at all times until failure, even for impassable openings, leading to a sense of loss of control.

A difference in the PINV component was only observed in cases of *Go*, which varied with the environmental affordances. Amplitudes of the component for *Narrow* doors were significantly different from *Mid* and *Wide* doors, while the passable conditions did not differ from one another. Further, there were no significant differences in the PINV component in cases of *NoGo*, emphasising the importance of the motor execution itself to evoke the PINV component. These results point toward the PINV component as an expression of the readiness to interact with the designed environment, i.e., less negative for passable doors and more negative for impassable doors, thus serving as a potential marker for the readiness to act given environmental affordances. The presented results are further consistent with the observed increase in activity over frontocentral sites by Bozzacchi et al. (2012). Bozzacchi and colleagues concluded that the meaning of the action and awareness of being able to act—affordances—affect action preparation, which is here understood as the motor-related potential before movement onset. One may argue that the PINV component might reflect a readiness aspect of affordances. This would mean that the PINV is not modulated by the perception (that the door is different visual information) but reveals something about the readiness to act. For this reason, significant differences in cases of *Go*, but not in *NoGo*, are found, and further for passable compared with impassable.

In light of HAC (Pezzulo and Cisek, 2016), a potential explanation for the absence of differences in the *NoGo* trials is related to the immediate action selection, which in all cases (*Narrow*, *Mid*, and *Wide*) is a simple turn to answer the questionnaire, and thus the task presents the participant with identical affordances. When instead given a *Go*, cortical processes require an action selection related to the anticipated motor trajectory, which differs according to the affordances of the door width. HAC suggests the higher levels bias the lower level competitions, which operate at the level of the action itself, through a cascade of expected next affordances. The lower levels have a continuous competition of how to satisfy the higher expectations. Action selection, executed while continuously unfolding the planned movements, depends on the expectation of next affordances.

Notably, regarding architectural experience, because the PINV component was only expressed in the *Go* condition (forced interaction with the environment), these findings support the importance of movement for architectural experience, in a sense that action or even only the perception of action possibilities alters brain activity. Visually guiding and propelling the body in space dramatically influences the continuous emerging of affordances, which in turn affect the human experience. Differences in frontocentral and occipital areas, prior to movement through space with the post-imperative negative-going waveform most pronounced over *FCz* indicated an involvement of the supplementary motor area (SMA) as reported by Bozzacchi et al. (2012). Earlier studies showed the involvement of the SMA in visually guided actions (Picard and Strick, 2003), which is the essence of active inferences. The PINV can be generated independently from the re-afferent signal, which is, in terms of active inference, understood as ascending (bottom-up) proprioceptive prediction errors (Adams, Shipp and Friston, 2013). This suggests the PINV component might reflect descending (top-down) predictions, rendering SMA as an essential area of the action-perception loop, and thus crucial for processing continuous affordances. This account might resolve the finding of frontocentral differences in *Go* trials only. The SMA is anatomically bridging the frontal cortex with motor cortex—perhaps also functionally as argued by Adams et al. (2013) because this anatomical nature fits with the proposed hierarchical characteristics of forward and backward projections in active inferences.

Using VR to investigate cortical processes has its natural limitations, for instance, the absence of a physical body. Regarding the sense of body, which is at stake in the current study, it is suggested that VR "*may offer new embodied ways for assessing the functioning of the brain by directly targeting the processes behind real-world behaviors*" (Riva, Wiederhold and Mantovani, 2019), which is remarkably valid for the current study. Riva and colleagues (Riva, Wiederhold and Mantovani, 2019) argue that the brain's predictive capability immerses the body, and thus related processes if the visual perception is in line with the body's actions, for instance by head movements and wandering. Through the process of trial and error, the brain and body adjust to VR. Furthermore, in terms of architecture, VR as a head-mounted display (Pasqualini, Llobera and Blanke, 2013) and as a CAVE system (Vecchiato *et al.*, 2015) has been integrated into studies with bodily and environmental interests yielding comparable results. However, VR in combination with neuroscientific methods, is still a novel method and thus must be utilised with care. It must be emphasised that the purpose of VR, in the current experimental setup, was to isolate and control the factor of interest. Future studies will have to use MoBI in real-world environments to investigate whether the results from VR can be generalised to the real world.

## 12.6 Conclusion [4]

The present study provides strong evidence for affordances to be processed as early as perceptual processes, linking action and perception in a similar manner to active inference. The results point toward a conception of the brain that seems to deal with "how can I act" while in parallel processes referring to "what do I perceive" take place. The results thus support the assumption that perception of the environment is influenced by affordances and action itself—hence, affordances and action can influence the experience of an environment. Because of the importance of affordances and action for brain dynamics, this further emphasises and qualifies the general idea of enactivism as a holistic approach to investigate cognition. It is important to emphasise that these results do not claim that architectural affordances are directly represented as a specific ERP component; however, the current study provides evidence for an action-perception account of cognition, which systematically differentiates according to the definition of affordances.

As a note for the architects: the fact that human beings are mobile and predictive beings suggests that architects should take the temporal aspect as seriously as the spatial, given that the predictive process of unfolding bodily movement can alter the perception of space. Moving and transitioning in space is to construct continuously a prediction of a world, a world that one perceives dependent on the action potentials, which informs the brain, body, and mind. By altering perception, it would ultimately lead spaces to have a potential physiological impact on users. Much remains to be uncovered in architectural cognition.

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[4] This subchapter is heavily based on the writing in (Djebbara et al., 2019)

## CHAPTER 13

# Conclusion and future research:

## architectural cognition

**Summary.** *What can be concluded insofar?* Although each chapter provided unique conclusions, this chapter offers an overarching conclusion by addressing the architectural quandary and introducing the scope of architectural cognition for future research. Furthermore, a discussion on limitations and criticisms, as well as further research and speculations regarding the position of architectural cognition is offered.

### 13.1 Brief outline

The research question was developed throughout *Part I* and *Part II*, starting from a philosophical point of departure and ending in a cognitive neuroscientific research question. Before commencing the phenomenological framework, a philosophy of science was put forth to frame the overarching strategy. Mainly, a synthesis of Peircean abductive reasoning, Popperian falsifiability and Hackian foundherentism—framed as an abductive-Bayesian approach—was proposed as the epistemological position. Such an approach allows rationally critical reasoning to adjust the currently best explanation of a phenomenon. In the current context, the research question forms the phenomena, whereas the experimentation seeks to falsify the hypothesis derived from the theoretical arrangement.

By creating a dualism of time and space, Chapter 3 demonstrated the different natures of the two concepts—mainly, a spatial approach and a temporal approach to transitions. An architectural transition was defined as a sequence of space delineated by an observable threshold, i.e. a transistor, whereas an experiential transition does not start nor stop, but is a continuous unfolding of events that a conscious being experiences. Their relation was summed through a quandary of comparing the experience of transitions.

Bergson is invoked to tackle the relation between space and time and provides that space is infinitely divisible and time as indivisible. Duration is introduced as a concept of temporal, experiential transitions in contrast to space and matter; duration differs in kind while the matter in degree. A multiplicity of both composites is henceforth provided, which in turn develops into virtuality and reality, i.e. duration and matter, respectively. The multiplicity of inner experience is a creative process of becoming in time, whereas space offered mere quantity.

Such a thesis further encouraged pursuing the temporal nature of inner human experience through a Husserlian phenomenological scope, which primarily was a prolongation of Bergsonian conception of experience and time. Both characterise time and experience as indivisible in the sense that each moment interpenetrates the other. However, Husserl investigates the quality of experience, a transcendental phenomenology, far further than Bergson, providing a window into the condition of experience. This necessarily yielded a discussion on the relation between action-perception and multiplicity.

Ultimately, *Part I* constituted three conditions which any empirical framework must entertain to argue an investigation of the immediate experience. Such an approach yielded the following research question:

**How does experiential transition unfold through action and perception relative to architectural transition?**

*Part II* sought to establish an empirical framework that fit under the phenomenological framework and to rework the research question to become a point of departure for a testable hypothesis. A biological framework rooted in the philosophical thought, namely emergence*,* and homeostasis initiated *Part II* by arguing that bodily and cortical dynamics depend on the homeostatic balance. This essentially argues that the brain is embodied so that the body and brain entertain a circular causal relation via a biologically self-organised dynamical system, i.e. the body and brain function as dynamical systems. The environment thus emerges *in* time through interaction, which appropriates Bergson's creative process of becoming—becoming is the operation of self-organisation.

Such a position suggested investigating how the relationship between body/brain and environment appears on a neuronal level. By discussing active and passive brain models, it was found that the brain and nervous systems are organised according to the primary mechanism of action-perception so that the brain and body couple to the environment through a bidirectional relation, i.e. prediction about the action influence perception and vice versa. Cognition emerges from the bidirectional interaction between body, brain and environment.

Extending this conception was supported by sensorimotor-contingency (SMC, which argues for an enactive (4E; embodied, enactive, embedded and extended) programme of cognition. Perceptual experience is best explained as a structure of change in the organs of perception that is free of representations. SMC suggested to approach the action-perception loop through dynamics of perception and action as they unfold in the body—however, enactivism and SMC were found to be limited in the sense that they were not able to formulate a concrete approach to cognition. Thus, it was supported by Friston's Free Energy Principle (FEP), which when reformulated yielded active inference.

Active inference is a Bayes-optimal generative model of action-perception that concretely describes the predictive process of action-perception so that it may be testable, and ultimately brings back aspects of Bergson's virtual action and Husserl's temporality. Furthermore, although active inference was formulated in computational neuroscientific terms, it translates to neurophysiological parameters, e.g. dopamine as the precision of action policy (virtual action), which proved to be adequate to rework the first research question:

**Can an embodied neuroscientific framework, based on phenomenology, experimentally answer how the experiential transition relates to the cognitive process of action-perception with regard to architectural transition?**

A neuroscientific experiment was carried out to answer the research question by generating virtual spaces that human participants had to walk through. The environment formed a transition in the form of door-like openings that challenged the bodily posture depending on the size of the doors. The research question was addressed through the following hypothesis:

> *"If an enactive account of perception, action, and cognition is correct, then affordances are intimately related to higher hierarchical levels through low-level perceptual cues. Such an account would situate the processing of affordances at a similar stage as early perceptual processes and should reveal differences in sensory and motor-related ERPs associated with the perceived affordance of an environment.* […] [It is] *expected to find differences in cortical responses to covary* [resonate] *as a function of affordances over sensory and motor areas. In addition,* [it is] *expected to see differences in MRCPs as a function of the environmental affordances* […]*." (Djebbara et al., 2019)*

## 13.2 Conclusion and critique thereof

Expecting the upcoming space during an architectural transition is a long-term process that is modulated by short-term processes on the sensory-level. Instead of approaching the psychological expectation of space, the thesis argues that whatever psychological concepts that may be conceptualised, such process build on a world constructed by the senses, which are demonstrated to be biased by the affordances and virtual actions provided by the environment. Consequently, by addressing the intuitive rather than the intellect, the architectural impact can go beyond the long-term psychological outcome—in fact, it affects the fundamental process of constructing the world through sensory signals.

Irrespective of which long-term processes that are initiated during architectural transitions, their genesis and commencement are in the basic feature of action-perception—albeit, long-term processes may also impact short-term processes. Indeed, future research must consider this conclusion before interpreting the psychological impact of the environment. Otherwise, the interpretation may lead to erroneous conclusions, e.g. radical biophilic design.

### 13.2.1 The conditions

It has been necessary to synthesise theories from different fields than architectural research to answer the research question. In turn, it has provided an empirical framework on the experience of architecture, which is beneficial for the architectural research community. Evident in both the research question and conditions, the question of whether a neuroscientific framework is at all compatible with the phenomenological framework is essential to review. The question supposes that a phenomenological account is empirically testable. It was attempted to ensure a phenomenological account by establishing three conditions rooted in Bergson and Husserl. The problem is thus; how well did the neuroscientific framework comply?

#### 13.2.1.1 First condition

The first condition constrains the empirical theory by the heterogeneity of duration as an indivisibility of time, which is to respect the interpenetration of experience. Experience is a construct over time, according to both Bergson and Husserl, that is experienced as a continuity, i.e. there are no abrupt experiences. The theoretical process commenced in dynamic systems theory (DST) to ensure the property of indivisibility in the outcome. Indeed, DST alone merely suggests the kind of framework that must be composed and not a concrete model of that interpenetrates time—instead, this task was solved by the architecture of active inference as a stochastic Markov decision process. Although the Markov property suggests that the future state only depends on the present state, and not the chain of events that preceded it, it was shown in Appendix D that the preceding states highly influence the probability of the completion of virtual states as it forms the point of departure. This was also expressed diagrammatically in Fig. 11.2 as a probabilistic generative model. Active inference certainly fits well within the basic principles of temporality and the emergence of experience. Active inference arguably translates to a computational phenomenology, where the complexity is reduced according to the carefully selected parameters. A full-blown human experience of space is not the task of computational phenomenology, but instead takes the role of a tool in architectural cognition, whose objective is to investigate the relation between brain-environment and body-environment.

#### 13.2.1.2 Limitations

Whether the first condition was respected comes down to how *interpenetration* is defined. Interdependent relations were defined in Chapter 7 as a bidirectional influence, which in this context translates to both how the retention project forward in time and how protention project backwards in time so that they constitute a moment where both are present. Active inference suggests that a single moment is not a single state at time t, but a range where a prediction and a prior contribute in defining the current state. The interpenetration thus only occurs in the process of unfolding the Markov model, which makes the current state of the model questionable.

On the one hand, the fact that active inference divides states into discrete states, suggesting a serial-like process instead, is a counter-argument of interpenetration. On the other hand, it could be argued that the interpenetration occurs *in* time, which means that the current state is dependent on how the prior becomes that current state, i.e. the pattern of change because only over time can the interpenetration occur.

#### 13.2.1.3 Second condition

The second condition refers to the indeterminate state of the human as an asymmetric relation between transcendence and immanence, which translates to an asymmetric relation between the experience beyond the given and the given, respectively. According to the phenomenological approach, the indetermination is reduced by acting and perceiving in the world. Keep in mind that experience was approached from a Bergsonian temporal perspective, where Riemann's concept, the manifold, was central because it allowed time to become virtuality that does not necessarily unfold in space, hence multiplicity. The virtuality, according to Bergson's phenomenology, is temporal and bound to the body through action that has not necessarily been unfolded. Virtuality and time were drawn as intuitive, escaping the retroactive nature of the intellect, which, according to both Husserl and Bergson, is not necessary for perception. Husserl picked up the line of thinking where the action plays a critical role in defining the relation between transcendence and immanence, expressed as *horizonal intentionality* in his theoretical work. There are virtual actions in horizonal intentionality as they both describe a multiplicity of possible actions—perceiving beyond what is present is then rooted in the ability to move and predict while moving.

The indeterminate body was expressed through homeostatic and allostatic processes in the equivalent neuroscientific theory. According to emergence and self-organising dynamical systems, the body and brain constantly readjust according to the environment. Perception and action are basic mechanisms that are developed to increase certainty about the body and the environment, which in turn improve the chance of surviving. The theoretical argument for action and perception being the same process is the bidirectional modulation of top-down predictions from the brain, and bottom-up signals picked up from sensory organs. The prediction-errors occurring at the sensory level are much faster than higher-cognitive prediction-errors, e.g. complex mathematical reasoning, explaining the fast neuronal response of the action-perception process. The action to unfold depends on the environment, and the action of passable transitions do not vary, as they are passable—however, for the impassable transitions, the selected action is a different kind. The results from the experiment suggest that the continuous interaction with the environment is a relation of prediction and prediction-errors. In other words, the brain seems to deal with "how can I act" while in parallel processing "what do I perceive".

#### 13.2.1.4 Limitations

Action-perception cycle is the effect of *knowing how* rather than *knowing that*, as elaborated in Chapter 2. SMC suggests that perception is rooted in the active inference of possible perceptions, i.e. knowing how to act to cause a specific percept. The limits of the experimental setup are that affordances, as defined by Gibson (1977, 1986), differs from virtual actions, as defined by Bergson (2001, 2004), by being known *a priori*. Recall the example of having dinner; the affordances of a spoon depend on what is for dinner, i.e. how to interact with the spoon depends on whether the dinner consists of soup or beef, whereas this is not the case of virtual actions. Instead, the possible ways one may interact with the spoon are defined by the physical structure of the fingers/hand and the spoon—not the intentions. The process of action-perception thus develop by first knowing, *a priori,* that one can interact with the spoon in such and such ways, then intuitively select an action depending on intentions. In the case of transitions, the agent must have known *a priori* which possible actions to choose amongst, and 50-250 ms after perceiving the door width, a set of actions that fit accordingly have been selected—this is expressed in active inference as precision ($\gamma$) of action policy. One limitation of the action-perception cycle is thus the unknown intentions of an agent that may change dynamically irrespective of task. Translated to the experimental setup, it is not possible to *know* whether the participants had other intentions during the experiment, which might have influenced the acquired neuronal data[1].

#### 13.2.1.5 Third condition

The final condition guides the empirical theory towards a primacy of intuition. According to Bergson, the "immediacy of conscious data" belongs to the intuitive knowledge, which is a practical knowledge emerging from the structural coupling[2] between brain, body and environment—and the virtual. The virtual is the creativity rooted in the continuity within the structural coupling so that human decision depends on the duration and multiplicity, i.e. the human organism is duration (Fig. 13.1).

The hierarchical architecture of active inference suggests that higher-order cognitive processes hold a long-term nature that is reciprocally related to short-term processes. Indeed, considering the experiment, deciding which set of actions to unfold takes place at the sensorimotor time-scale (Chapter 11) with influence

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[1] The hard question thus becomes whether neuronal activity reflects intentions, and if so, how, e.g. large- or small-scale network, transient activity, frequency-related?

[2] The structural coupling provides causal relations between body, brain and environment over time.

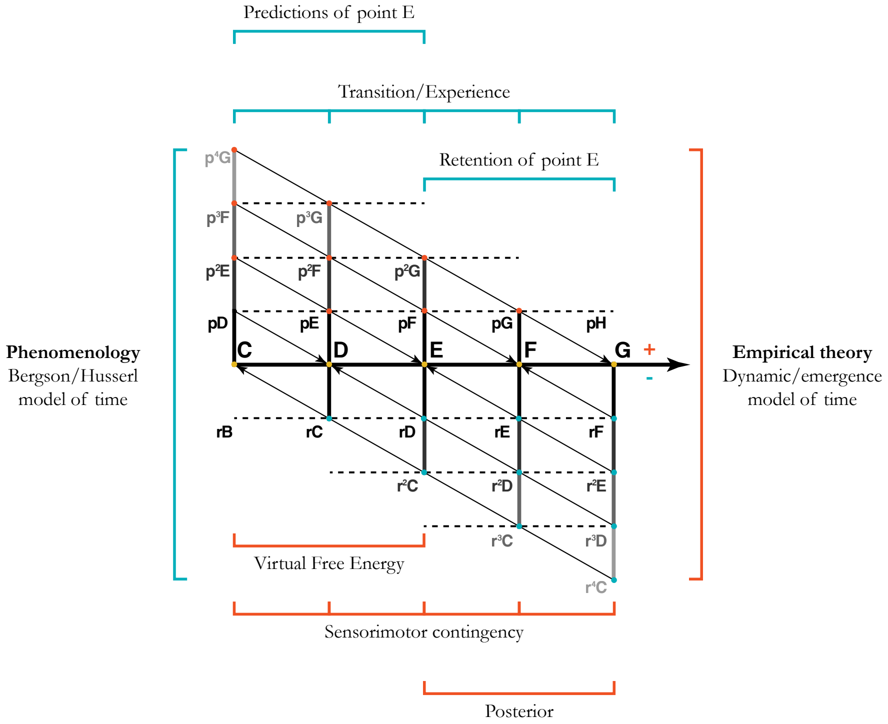

*Figure 13.1—This diagram serves to illustrate how the different stages of experience have been investigated and applied in the empirical approach. Philosophy contributed with a model of time that interpenetrates that the empirical theory must adhere. It does so by approach time and experience through dynamic systems theory and the property of emergence. In the model, the protention of a current experience corresponds to the expected free energy, which quantifies the probability of action over a precision. The retention corresponds to the adjusted model of the world, namely the posterior—and so experience continues to unroll itself overtime; any posterior today is tomorrow's prior. The transition between each moment is a pattern of structural change, which according to SMC, may be the key to understanding the content of experience, i.e. qualia.*

from bottom-up signals and top-down predictions, i.e. small-term and long-term processes. Both active inference and Bergson suggest that between stimulus and response lays a key-component to understand the nature of intuition, which consist of bidirectional influences. To state that intuition is a problem of super-position is to have misunderstood the non-Cartesian monism at play. Emergence is precisely the counter-argument of dualism as it takes seriously the temporal decentred subject, i.e. the development of action is the product of two forces dynamically forming one another. It is a hybrid of a hierarchical and heterarchical system that couple reciprocally and structurally to the environment, body and brain with different priors and likelihoods. Although active inference refers to the nature of intuition as a process of action-perception, Bergson's approach might be termed action-*reaction*, because it emphasises that it occurs between stimulus and response. Here, the virtual belongs to the stage of intuitive predictions before the action.

#### 13.2.1.6 Limitations

By suggesting a hierarchical/heterarchical generative model of the brain, body and environment, it may be argued that the problem of experience is merely relocated to complex relations in temporal systems. The intuitive process of action selection and the generation of action policies have different durations and order. Active inference, as a theory, is not capable of locating the intuitively available sets of actions upon perceiving the environment, i.e. selecting among different actions, the sets of actions must emerge as a form of *knowing how*. Virtual actions are intuitively present, but not all virtual actions are considered. Sometimes, intuition may present one with new virtual actions. How does active inference resolve the generation of action policies? The experiment suggested that the functional relationships in the process of selecting action policies are expressed in neuronal activity as prediction-errors[3]. In the equations, the generation of action policies remains hard-coded in the prior and likelihood matrices, which, since the posterior today is the prior of tomorrow, means that both the prior and likelihood arrays rest on previous priors (for more on hyper-priors; Clark, 2015, pp. 174–175). However, the debate on hyper-priors in active inference can be lead to an evolutionary scale of priors (Ramstead, Badcock and Friston, 2018).

### 13.2.2 Experiential and architectural transition in action-perception

The second part of the research question considers the relation between experiential transition and architectural transition via action-perception—the central argument of the thesis. Discovering a similarity between Bergsonian/Husserlian phenomenology and emergence/enactivism/SMC provided an embedded approach to cognition and experience. The radical claim is that the human experience is the integration of retention and protention in the pattern of change during the action, which is precisely how the human organism *is duration* in Bergsonian terms. Since exteroceptive sensory is a matter of change over time, it means precisely that time is the best measure of space. Removing time from the experience of space would theoretical yield no experience since sensory is simply not able to change; action is not possible, thus causing no perception. Consequently, human experience is equated with action-perception as a small-term cognitive process.

Given the organisation of the brain (Chapter 7 and 8), the dependencies of neuronal activity (Chapter 9, 10 and 11) and the empirical results (Chapter 10), the sensorimotor processing is the fastest network in the hierarchy, suggesting that any architectural investigation through neuroscience is firstly an investigation of action-perception. As argued throughout the thesis, the hierarchy is interconnected

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[3] Indeed, the suggested model of cognition is based on prediction-errors, as opposed to a two-factor theory of cognition (Corlett, 2018, 2019). A two-factor theory of cognition suggests that delusions, for instance, needs at least two neuropsychological impairments, in perception and in the belief evaluation. Prediction-error theory of cognition suggests instead that a one-factor theory of cognition is more appropriate, so that delusions are the product of a process on one level modulating the hierarchical structure.

with bidirectional influences—therefore, the elaborated and sophisticated question hereof is how architectural design, through sensorimotor processing, impact other networks and other systems in the body. In the current context, the empirical results provide evidence for an action-perception account of cognition and that neuronal activity depends on architectural affordances.

The transcendental experience of perceiving more than apparent is the outcome of the prediction in action-perception, i.e. the *knowing how* to make that which is not apparent, apparent. Bergson referred to this mechanism of perception as *virtual action* because one is virtually acting upon the space to generate predictions of perception. SMC suggest precisely the same operation in perception, but extend it to be able to explain qualia. Such approaches are rooted in *knowing how* (practical) rather than *knowing that* (propositional) as proposed in Chapter 2. Providing a bigger picture, SMC matches the active inference framework without compromising its central arguments. Primarily, it is suggested that the pattern of change translates to the B matrix (transition matrix) in active inference, making experience dependent on the virtual actions and expected free energy. A full model of the temporal unfolding, as Husserl's model of temporality, is the generative model provided by active inference. Active inference, as a linking framework to phenomenology, qualifies as an answer to the question regarding the relationship between architectural and experiential transition. Figure 13.1 provides an overview of the corresponding philosophical terms in the empirical framework.

### 13.2.3 The quandary

#### 13.2.3.1 An answer

Is the experience of *space B*, arriving from *space A*, identical to the experience if arriving from *space C*? According to the established framework, considering both the philosophical and empirical measures, the apparent answer is *no*—however, it arguably depends on the bounds of the experience of *space B,* i.e. when does the experience start and end. Recall that a transition consists of small-term processes, e.g. action-perception, and large-term processes, e.g. consciously reflecting or retrieving/recalling the experience. Although the conscious introspective retrieval of the experience is highly appealing, it may paint an inaccurate picture of the immediate experience, which, after all, is the primary concern. The experiment investigated both the short-term process before entering a subsequent space and the emotional state returning to the prior space, which is arguably the emotional outcome of a long-term process. The experience of *space B* was never directly assessed by for instance posing the question "what was the subsequent space like?" Instead, electro-cortical measures and a questionnaire assessed the sensorimotor cortex activity prior transition and the emotional state of the participant post transition, respectively. An answer to the quandary takes shape from these measures.

Given three different door sizes, the experiencing agent had three different prior spaces. According to the established framework, the immediate experience consists of retentional features and a multiplicity of protentional virtual actions. At the threshold of the transition, the experiencing agent is positioned between two spaces[4] that shape the gesture of the body. The gesture of the body is already shaped before reaching the threshold-position in the first place and influencing the planned motor-trajectory onward. Accordingly, both the sensorimotor dynamics and the emotional self-report reflected the affordances of the transition. Therefore, the experience of the subsequent space depends on the virtual actions in the transition from the prior space.

The results may be criticised by arguing that the experience of *space B* is the conscious recognition of that space, i.e. the immediate recollection and introspection of the experiencing agent. If the measure was an immediate self-report of the experiencing agent, the experience of *space B* may consistently (across many trials) be recognised as *space B,* and thus infer that the experiences are identical irrespectively of the prior space. Such an account argues that the experience of *space B* does not depend on the prior space, but merely on the space itself.

It is worth noting that such an account of experience is intellectualised into a long-term process that may be affected by various personal beliefs, for instance confusing that recognising a space is identical to the experience of that space[5]. In other words, it is an account that attempts to detach the bodily nuances and provide a representational account of the space, e.g. the bedroom is always experienced as the bedroom, because it merely is the bedroom—however, as abstract a concept one may be considering *space B,* it cannot be a disembodied account. Neither can it be detached from the current environment, which means that the current space most likely biases the immediate self-report that the experiencing agent delivers. It has been argued that cognitive processes that involve abstractions, language, fantasy or more profound thoughts are disembodied cognitive processes (Chatterjee, 2010). Because these processes are seemingly stimulus-absent, they are thought of as disembodied and detached from the environment. Following Sims (2019), taking a radical example as mental imagery, it can be shown to be stimulus-sensitive, so that the current stimulus an agent experiences can affect the current mental imagery. The fact that bodily sensory from the environment affects is sufficient for a process to qualify as being embodied and coupled to the environment. Therefore, to state that the experience of the subsequent space is independent of the prior space is to suggest the possibility of disembodied cognitive processes, and fall prey to the illusion that mental-life is detached from the body and immediate environment.

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[4] An architectural transition can be defined as a sequence of space delineated by an observable threshold.

[5] It seems that philosophers and neuroscientists that cast the brain as containing representations, rest their arguments on purely inductive or deductive argumentations. It was shown in Chapter 2 that the abductive reasoning, which contain both induction and deduction, is a valid approach of reasoning. Abductive reasoning invokes time to adjust the reasoning, which essentially means that the current truth is not necessarily true later—over time, one may have learned more. The meaningful explanation is more than the propositional truth-value; there is an inherent difference in kind and degree. Perhaps the discussions on decomposability and representations in the brain all rest on poorly stated problems, as Bergson and Deleuze would have stated it.

## 13.3 Future research

### 13.3.1 Architectural cognition

In recent literature, many cognition suffixes are emerging, e.g. embodied cognition, natural cognition and quantum cognition. Why is it necessary to introduce architectural cognition? As a research discipline, it is suggested that architectural cognition addresses how architecture affects cognitive processes. Smart architectural designs can ignite novel interactions causing a spark in creativity, e.g. multifunctional transitional spaces. The question then becomes what is *smart*. Encompassing both small- and large-term processes, cognition is arguably an embodied process that is constantly situated in an environment of which the processes makes use. The term *natural cognition* is not opposing an unnatural cognition, but advocating a methodology that takes movement in cognition seriously (Gramann, Ferris, *et al.*, 2014; Gramann, Jung, *et al.*, 2014; Jungnickel and Gramann, 2016). Methodologies of brain imaging that restrict everyday mobility in solving tasks may be considered to measure a restricted form of behaviour and cognition, i.e. a physically detached human cognition. Particularly in architectural research, it is difficult to imagine a high level of spatial immersion while in a noisy fMRI depriving any three-dimensional spatial interaction—nonetheless, there must be some level of immersion. Indeed, architectural cognition belongs to a natural, embodied cognition that integrates movement. The relation can be seen as:

Cognition
↪Natural cognition
↪ Embodied cognition
↪ Architectural cognition

As argued in Chapter 8 and 9, the reciprocal coupling to the environment is critical to cognition. The mind does not *extend* into the environment because the environment was always part of cognition. Instead, operations can be externalised to off-load cognitive ballast. It is worth noting that the cognitive ballast that is off-loaded is necessarily situated in space, e.g. unread books to the left, dirty clothes in the basket, two steps heighten the bedroom. Architectural cognition involves unpacking the reciprocal relation between short- and long-term processes usually expressed through a spatial organisation.

The reciprocity is an essential argument for the whole framework because it allows downward causation. Take, for instance, placing the book that one is currently reading on the leftmost side on the shelf. The necessity in systematically placing it is evidence of a long-term process (off-loading memory) that affects a short-term process (action-perception) through expecting to find the correct book on the shelf when needed. In active inference lingo, the action needed to bring forward the perception of the correct book is to reach actively for the leftmost side book. The prediction is then either met or updated. It may be updated because upon perceiving the correct book one is reminded which book is the current one and thus concluding the prediction as wrong. The benefit is that one relates to the world through actions and perceptual predictions instead of perceptual recollection, i.e. it is the action of reaching to the leftmost book that determines which book one is currently reading—not the perceptual recollection, which may be flawed. In spatial design, the organisation of the spaces shape the action sequences necessary to bring forward the desired perception. For instance, before leaving home, the action sequences sometimes unfold almost ritually; leave the office, go to the bathroom, and go to the entré before leaving. Arguably, architects modulate how cognition unfolds, because architects design the action sequences that are necessary to bring forward the desired perception. This upward and downward causation is precisely the nature of cognition. In other words, space offers a set of virtual actions, $[\pi_1 ... \pi_n]$, that form the cognitive process while the cognitive process forms the virtual actions.

> *"Humans often represent and reason about unrealized possible actions – the vast infinity of things that were not (or have not yet been) chosen. This capacity is central to the most impressive of human abilities: causal reasoning, planning, linguistic communication, moral judgment, etc. Nevertheless, how do we select possible actions that are worth considering from the infinity of unrealized actions that are better left ignored?" (Phillips, Morris and Cushman, 2019)*

The radical claim that needs further research is that architects design cortical activity. If so, one may suspect that architects have not only affected by their designs our everyday environment but also the autobiographical narrative and unfolding of thoughts—assuming here cognitive processes influence thought.

### 13.3.2 Architecture and human systems

The phenomenological and empirical framework approached experience without critical incongruence. Indeed, terms like *representation* and *belief* are debatable—however, the general architecture and organisation of the body, brain and environment do not indicate theoretical inconsistency. Since the embodied cognition approach comprises all physical systems within the body, it means that cognition, as a process, can be investigated from any empirical experimentation of such systems. The systems follow according to FEP an active inference process, thus providing a hypothesis generator, i.e. their activity can be simulated by modelling an environment and provide a task. Concisely, the future research of architectural cognition is to systematically investigate the essential systems of the human body and introduce systematic architectural variability (Fig. 13.2).

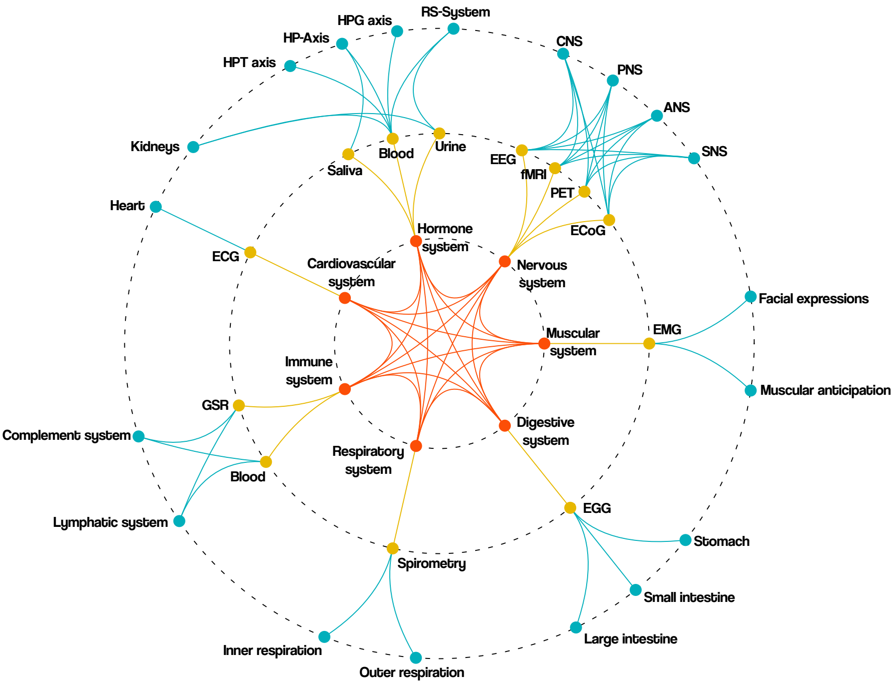

*Figure 13.2—A diagram of possible ways of investigating architectural cognition. The central (red) web addresses the interrelated physical human system. The central web (yellow) addresses the method of measure. The outermost circle (blue) addresses the related organs and systems. The diagram merely illustrates potential measures where systematic architectural variability may cause a difference.*

# Part III

## APPENDICES AND REFERENCES

## APPENDIX A

# Riemann surfaces and complex numbers:
## numbers' second dimension and imaginary numbers

### A.1 Introduction

Philosophy of mathematics is a critical discourse for the establishment of Bergsonian and Husserlian philosophy. This appendix utilises mathematical examples and reasoning to put forward the line of thinking in *manifolds*. For this purpose, it is vital to understand the similarities between Riemann's manifold/surfaces and the nature of complex numbers. The mathematical steps are shortened to an absolute minimum to avoid misunderstandings. Riemann surface is a complex single-dimensional surface that defines holomorphic functions between other Riemann surfaces. Riemann surfaces originate from the analysis of multi-valued functions. Concisely, a multi-valued function is a holomorphic function operating with complex numbers in complex planes. The phenomenon of holomorphic function is that the analytical continuation of the function along different paths leads to different branches of that function (Forster, 1981, p. 1). In other words, the unfolding of a holomorphic function yields different trajectories—Riemann explains this behaviour through the notion of *complex planes,* i.e. Riemann surface. An example is provided to ensure that the above makes sense. A short description of how imaginary numbers function is the most useful explanation of the term *complex* and Riemann surface.

### A.2 Imaginary numbers

The fundamental theorem of algebra was put forward by Carl Friederich Gauss (1777-1855) in 1799 (see for instance; Derksen, 2003). It stated that any polynomial equation of degree $n$ has $n$ roots or solutions. Consider the following polynomial:

$$f(x) = x^2 + 1 \tag{A.1}$$

According to Gauss, Eq. A.1 has two solutions—however, Fig. A.1 indicates that this is not the case. A solution, or root, is the point where the function yields zero, which in graphical terms is where the functions cross the x-axis. To solve this problem, it is essential to summon the imaginary numbers (see e.g. WelchLabs, 2015). The regular number line of natural numbers (also referred to as *real* numbers, i.e. ℝ) is a one-dimensional system of numbers, encompassing fractions, zero and negative numbers, but this system omits the imaginary numbers. Numbers are practical in the sense that they can be used to track sequences of anything in reality; it anchors mathematics in reality—however, what happens when *abstraction* in mathematics proves to hold a solution to a practical problem, e.g. negative numbers? This is precisely the case of imaginary numbers.

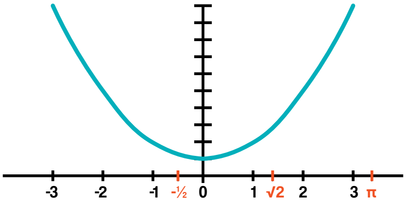

*Figure A.1—Graphical illustration of Eq. A.1 in blue. Red numbers are examples of fractions on the number line.*

Take for instance the infamous case of $\sqrt{-1}$; the square root of a negative number. The square root of a number is the number that is multiplied by itself, e.g. $\sqrt{9} = 3 \leftrightarrow 3^2 = 9$ What can result in a negative number when multiplied by itself? Upon immediate sight, there seems to be no solution—however, there is indeed a solution. The solution was initially worked out in 1572 by Rafael Bombelli in *L'Algebra*, which also laid the foundation to what is known today as the imaginary numbers. Bombelli suggested that $\sqrt{-1}$ is a new kind of number, one with a different nature than the one-dimensional that is going only and always in one direction. Instead, it is an imaginary number that holds a different property than natural numbers, but it is not merely an invention—it is a discovery because imaginary numbers follow the established rules of algebra and arithmetics. The nature of imaginary numbers is arguably peculiar. Bombelli held that if one accepts that:

$$\sqrt{-1} = -1 \tag{A.2}$$

Then one can still show that this new kind of number behaves within the established rules, for instance:

$$\sqrt{-25} = \sqrt{25} \cdot \sqrt{-1} = 5\sqrt{-1} \tag{A.3}$$

$$2\sqrt{-1} + 3\sqrt{-1} = 5\sqrt{-1} \tag{A.4}$$

Taking the thought even further, Leonhard Euler introduced the notation *i* for imaginary numbers more than a century later, so that:

$$\sqrt{-1} = i \tag{A.5}$$

This enabled to construct complex numbers, namely a combination of both natural numbers and imaginary numbers, for instance:

$$\overbrace{\underbrace{x}_{\text{natural}} + \underbrace{y \cdot i}_{\text{imaginary}}}^{\text{complex number}} \tag{A.6}$$

This eventually established the second dimension of numbers. The number line of natural numbers is a one-dimensional line, e.g. the x-axis in Fig. A.1, but when investigating the nature of *i*, there emerges a new system, a new direction. When multiplying positive natural numbers, e.g. $2^2$, the results remain in the positive direction—when multiplying a negative natural number with a positive number, the direction flips 180 degrees, e.g. $2 \cdot (-3) = -6$. Multiplying negative natural numbers, the direction flips once again 180 degrees and becomes positive, e.g. $-3^2 = 9$. The 180 degrees flip in the system of natural numbers is a consequence of the single dimension. Turning to imaginary numbers, the peculiar nature of *i* is that it has a repetitive pattern in polarity when it is increasingly squared. The pattern repeats every four increments, i.e. $i^1$, $i^2$, $i^3$, $i^4$. This behaviour is indeed different from natural numbers. When multiplying with *i* the rotation is no longer 180 degrees, but instead 90 degrees (Fig. A.2.1). This suggests that the natural number line has a perpendicular dimension where the imaginary numbers exist as a natural extension.

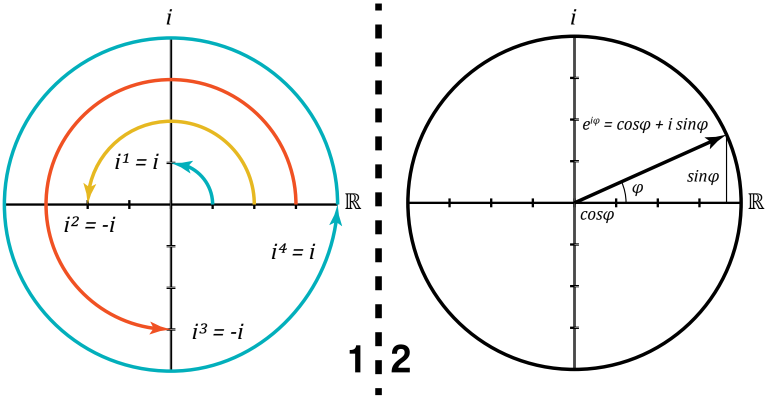

*Figure A.2—* **1.** *The horizontal line designates the natural number line, whereas the vertical line designates the imaginary dimension. When multiplying with* i *the rotation is no longer 180 degrees, but a mere 90 degree. The geometric plane of the new dimension functions as an extention of the natural number line, known as the complex plane.* **2.** *As an example of how imaginary numbers may be applied. Euler applied the geometric system of imaginary numbers to show that* $e^{i\varphi} = \cos\varphi + i \cdot \sin\varphi$ *. Eventually, Euler's statement is only derivable in the complex plane, which is an important contribution to complex analysis.*

## A.3 Complex plane

Although it may seem this mathematical turn is irrelevant to Bergson and Husserl, it is, in fact, essential to their line of thinking regarding time. In many ways, time is equally one-dimensional going only and always in one direction. Nevertheless, the number line is shown to have a natural extension, namely the imaginary numbers, which further provides the advancement of the complex plane. After reading *Part I*, it is hopefully apparent why it is necessary to show that a single number in space can hold more than a single value, imaginarily[1]. One is inclined to question the nature of time as well.

The short introduction to imaginary and complex numbers is necessary to advance the complex plane (Fig. A.2). The complex plane should not be confused with a conventional coordinate system (XY plane), because the complex plane operates with complex numbers, Eq. A.6, whereas the XY plane operates with XY coordinates. Addition in the complex plane are similar to vector additions, but multiplication is different:

$$\begin{aligned} (2 \cdot 3i)\,(3 + 2i) &= \\ 6 + 4i + 9i + 6i^2 &= \\ 3 + 13i + (6 \cdot (-1)) &= \\ -3 + 13i & \end{aligned} \tag{A.7}$$

Translating complex multiplication to the complex plane can be done by adding the angles relative to the real number dimension, and multiplying the magnitude of the complex numbers. Eq. A.7 is an example of algebraic (rectangular form) solving, whereas Fig. A.3 is an example of the geometric (polar form) solving, based on Fig. A.2.

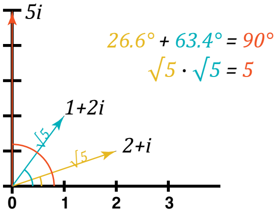

*Figure A.3—Multiplying complex numbers can be done by adding the angles relative to the natural number dimension and multiplying the magnitude of the complex numbers.*

When moving beyond complex multiplication to complex functions, which is usually described in a two-dimensional plane, something philosophically interesting emerges. Functions are engaging in this relationship because they describe a systematic trajectory—eventually, how this applies to the complex plane will explain the idea of movement and time in Bergson and Husserl. Functions have

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[1] The key-word is co-intentionality; retention and protention.

an input, usually a continuous range of numbers, and output, which is a systematic rearrangement of the input caused by the function. Complex functions are geometrically challenging to visualise because it takes complex numbers as inputs and equally outputs are given as complex numbers, where both operate in complex planes. Such an operation amounts eventually to a four-dimensional plane, which is impossible to visualise in a single coordinate system. For this reason, two complex planes are illustrated; one for input and the other for output. The complex function that is dealt with is Eq. A.1.

Complex functions consist of a real number and an imaginary part. Thus, writing Eq. A.1 as a complex function amounts to changing the variable input, i.e. $x$, to a complex number (Eq. A.6):

$$f(x) = x^2 + 1 \tag{A.8}$$

$$f(x) = \left(\overbrace{\underbrace{x}_{natural} + \underbrace{y\cdot i}_{imaginary}}^{complex\ number}\right)^2 + 1 \tag{A.9}$$

$$\overbrace{\underbrace{u}_{natural} + \underbrace{vi}_{imaginary}}^{complex\ number} = (x + yi)^2 + 1 \tag{A.10}$$

$$\underbrace{w}_{complex} = u + vi \tag{A.11}$$

$$\underbrace{z}_{complex} = x + yi \tag{A.12}$$

$$\underbrace{w = z^2 + 1}_{complex\ function} \tag{A.13}$$

The output is also necessarily a complex number, so the natural number of the input, i.e. $x$, is the equivalent output $u$, whereas the imaginary number of the input, i.e. $yi$, is output as $vi$.The natural numbers in the function are thus $u$ and $x$, and the imaginary numbers $v$ and $y$. To simplify the matters, the output can be written as Eq. A.11, the input as Eq. A.12, hence the function in Eq. A.13. The variables of the input can be tracked on one coordinate system, while the variables of the output can be tracked on another coordinate system (Fig. A.4). The translation from one complex plane to another with the input $1 + i$ unfolds as follows:

$$\begin{aligned} w &= \\ (1 + i)^2 + 1 &= \\ (1 + i)(1 + i) + 1 &= \\ 1 + 2i + i^2 + 1 &= \\ 1 + 2i& \end{aligned} \tag{A.14}$$

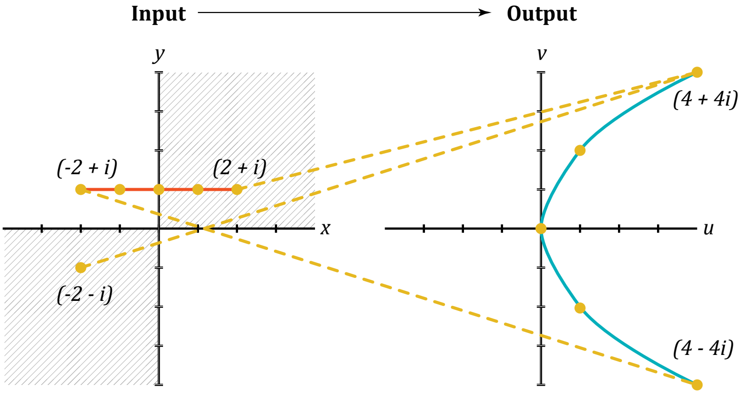

*Figure A.4—The complex plane on the left represents the input values, whereas the plane on the right represents the output values. The red trajectory emerging from the yellow dots drawn in the input is nothing alike the output. The complex function not only completely remaps the trajectory; it even suggests that some different input values are remapped to the same output value. Given Fig. A.2 and A.3 the direction, magnitude and scaling adds up, however, this makes the complex function a multivalued function, as opposed to an ordinary function, which may be called a single-valued function.*

## A.4 Multi-valued function/holographic function

There are two important points to note. First, the input trajectory is a straight line, while the output is a curve. This interesting behaviour is revisited later. Second, one may quickly discover that inputs on the hatched areas amount to the same output, which makes the complex function a multi-valued function. Multi-valued functions were referred to as holomorphic functions in the introduction. This is not similar to the ordinary single-valued function that is known in algebra. One approach to multi-value functions is to inverse the remapping, so that one rather approaches the input through the output than vice versa. The order is inversed. This allows understanding how two different inputs can amount to the same output.

To simplify even further, the formula is reduced to:

$$w = z^2 \tag{A.15}$$

The inverse of the function is thus:

$$z = f^{-1}(w) = \pm\sqrt{w} \tag{A.16}$$

To solve the multi-valued output, Bernhard Riemann (1826-1866) brought forward that it is necessary to visualise more than two complex planes, i.e. one for input and one for output. Instead, three complex planes are needed to resolve the bistable outputs. One complex plane for the input, and two for the outputs. The complex plane of the input is thus divided into two halves, where the positive range of the x-axis of the input is output in the $w_1$ *plance* and the negative range is output in the $w_2$ *plane*.

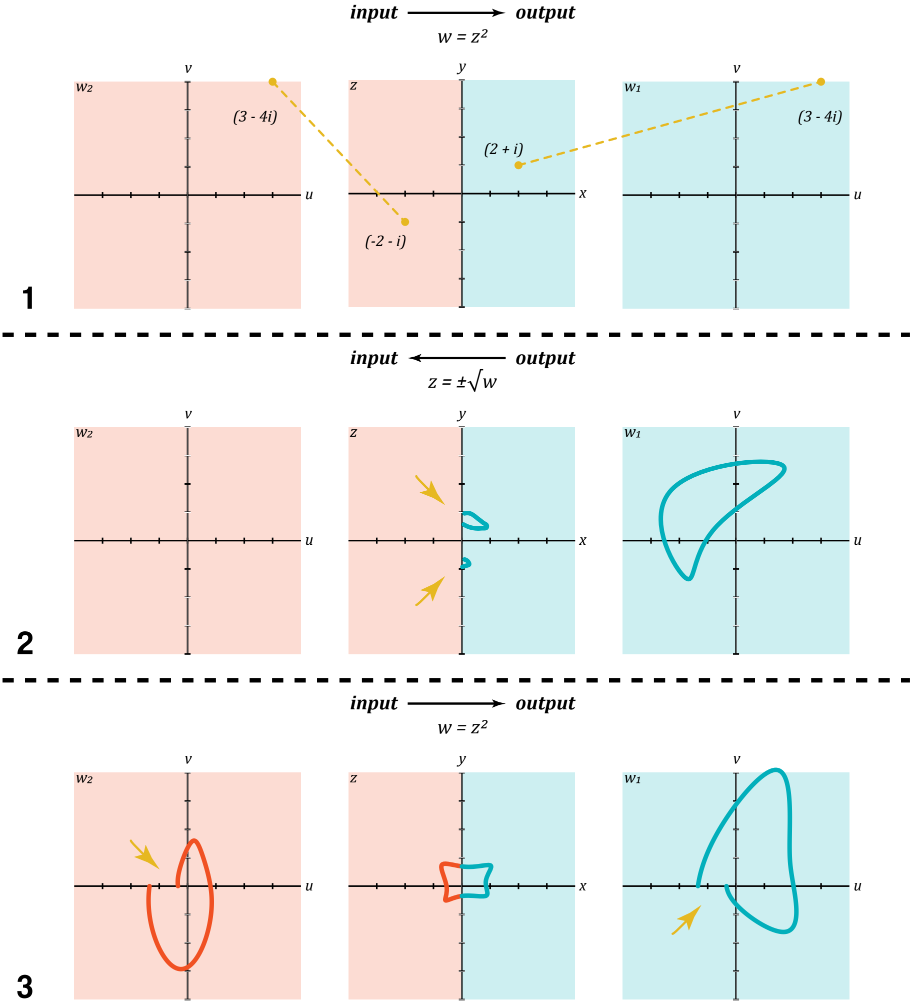

*Figure A.5*— **1.** *The complex output plane in Fig. A.4 can be split into so-called branches. This is an important operation to understand the behaviour of a path in complex functions. The advantage is that the points that referred to the same outputs are now remapped to different complex planes, consequently resolving the ambiguity of an output.* **2.** *Notice the change in direction, going from output to input (inverse function). When remapping a path in the inverse function, an abrupt discontinuity occurs, which is explained by Riemann as an invisible switch in the manifold in the two-dimensional coordinate system.* **3.** *When remapping a closed path in the forward model again (notice the change in direction, going from input to output again), there is a characteristic behaviour of complex functions. The remapping is not enclosed because it does not continue in the same manifold—there is a switch.*

When splitting the complex plane of the input (Fig. A.5) into two branches, the output is easily tracked. The ambiguity of a point can thus be resolved. However, when going the inverse direction, i.e. from branch to input, a characteristic behaviour of complex functions emerge; there is a discontinuity in the input trajectory when going backwards! This causes severe mathematical issues because one cannot calculate the derivative or integral of the function. Riemann solved this peculiar issue when going back to the forward model, and drawing a fully closed trajectory on the input function, which mapped back again to the branches in discontinuity. He then explained that this behaviour is due to the limitation of the two-dimensional coordinate system, which can only be improved to a natural limit, given the human experience of geometry is limited to three dimensions. To Riemann, it was evident that the points where the trajectory ends in $w_1$ are the points where the trajectory starts in $w_2$, which meant that the continuity happened on another dimension, which is not visible on a two dimensional coordinate system! Therefore, Riemann suggested merging the two complex planes. The complex plane $w_1$ utilise already two dimensions, which means the third dimension can be occupied by one of the dimensions of $w_2$, either the natural number or the imaginary numbers. For the sake of simplicity, the third dimension is attributed the natural number. The final dimension cannot be illustrated as an axis; thus colours are used to display the intensity of the imaginary number.

From simple observations of the Fig. A.5.3, it is visible that the negative axis of the real number line (x-axis) there is a shift/portal to another dimension. The self-intersection cause a switch in the manifold so that the trajectory changes plane/branch. One way of explaining the complexity of holographic functions is the analogy of shadows. The shadow of two pens crossing produces a figure of a cross where the two pens actually across and not two separate pens. The shadow corresponds to the self-intersecting axis that also displays the portal to the other branch.

The emerging Riemann surface (Fig. A.6):

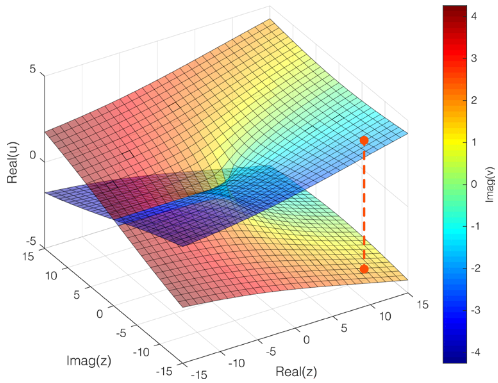

*Figure A.6—The emerging Riemann surface reveals that when a path crosses the apparent self-intersection, which is not self-intersecting but a mere shadow of another dimension, it switches branches and continues the path. The colour-map on the right illustrates the imaginary part of the surface, i.e. the fourth dimension. The surface also reveals that the multi-valued function is in fact distributed between two branches.*

By using colours to display the change of branch, the path can be drawn as fully enclosed in a two-dimensional coordinate system with a bit of imagination.

Returning here to Fig. A.1 and the question of how Eq. A.1 could have two solutions, it turns out that the solutions are taking place in another dimension that is not visible on the two-dimensional coordinate system. By introducing the imaginary axis in the z-axis, it is easily shown that the function Eq. A.1, has, as predicted by Gauss, two roots (Fig. A.8).

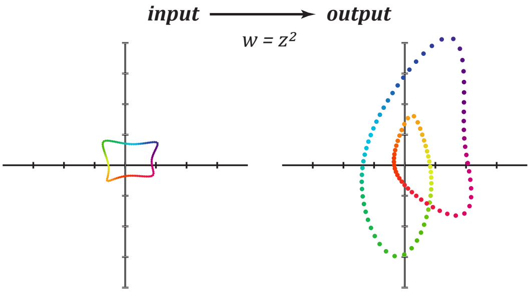

*Figure A.7—The path drawn in Figure A.5.3 can be fully enclosed using the colours to illustrate the positon on the manifold. With a bit of imagination, it is possible to see how the path wraps around in the Riemann surface. The colours of the inputs correspond to the colours of the output.*

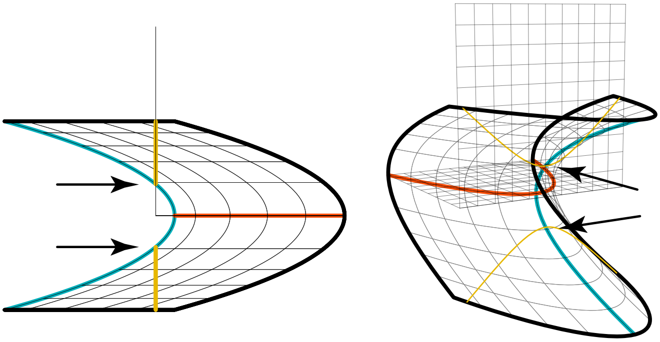

*Figure A.8—The blue function in Fig. A.1 is represented as the red curve. The curve is but a single dimension of a surface—one that emerges from the collision with the conventional coordinate system. When investigating the surface as a whole, the two solutions appear to collide with zero (the yellow curves). Finally, it turns out that Eq. A.1 has two roots that hid in the imaginary dimension of the function.*

### A.5 Conclusion

How did Bergson and Husserl benefit from these mathematical approaches to geometry at the threshold of human perception? Recall that both Bergson and Husserl were trained mathematicians before becoming philosophers, so the fact that the very same trajectory of a function can lead to different planes became a source of inspiration for Bergson and Husserl. These contemplations brought Riemannian geometry into philosophy.

Numbers represent the time in many respects, e.g. calendars and clocks. This may be due to the singular dimensionality of experienced time as if time is the process of an existing and predictive future; indeed, after 1 o'clock comes 2 o'clock. The singular dimensionality is challenged here by imaginary numbers, holographic functions and Riemann surfaces. It turns out that the medium utilised for tracking time is itself not single-valued as anticipated, but there exists a natural extension of that medium, namely the imaginary numbers. Does this mean that there exists imaginary time?

Bergson builds around the idea of virtuality, which may be hypothesised to stem from imaginary time. There are clear trails of Bergsonian multiplicity and imaginary numbers in the concept of multi-valued functions, so the unfolding of a trajectory may not be as straightforward as first anticipated. Bergson holds a respect for the unpredictability of time in the same sense that the trajectory drawn on a holographic function may be wholly misconceived.

Indeed, Husserl continuous the idea of multiplicity in temporality, but Husserl was more interested in the continuity, which Riemann solved through strategic manoeuvres. Because the multi-valued function yielded the same output for different inputs, Riemann split the input into two separates that operate on each their branch. Husserl may have been inspired by this ingenious manoeuvre when writing on the possibility of co-intentionality, which ultimately brought Husserl closer to a final model of temporality.

Riemann surfaces and complex numbers are shreds of evidence that nature is more complicated than seemingly so. Nature operates in dimensions that are obscure to human experience, and as time may be considered a natural phenomenon, i.e. non-invented, Bergson and Husserl reasoned that time might operate in manifolds that escape the human experience. Neither Bergson nor Husserl ever stated that time holds a specific function, translatable to Riemann surface, but emphasised the fact that time unfolds in more complex manners than anticipated by the mathematical $t$ in ordinary functions. They suggest that time is not as linear as the intellect may want to project it, but it may seem linear given the retrospective nature of the intellect, i.e. wise in hindsight.

## APPENDIX B

# Neurons, the nervous systems and electroencephalogram:

## a brief introduction

### B.1 Introduction

Much of the second part of the thesis assumes basic knowledge of neurons and human biology. To ensure this assumption, this appendix is dedicated to a basic introduction of the central nervous system (CNS), the peripheral nervous system (PNS) and neurons. In this appendix, it is intended to answer why it is crucial to consider the brain when questioning the environment by embedding a human into an environment. Note that the appendix is based on acknowledged textbooks in neuroscience, namely Eric Kandel's *Principles of Neural Science (5th ed.)* (Kandel, 2013), in human physiology, namely Cindy Stanfield's *Principles of Human Physiology (5th ed.)* (Stanfield, 2013), and electrophysiology, namely Steven Luck's *An introduction to the event-related potential technique (2nd ed.)* (Luck, 2005). Furthermore, this appendix serves to introduce electroencephalography (EEG) and a Mobile Brain/Body Imaging approach to EEG.

### B.2 The nervous systems

In the human body, the nervous systems can generally be divided into two parts, namely the PNS and the CNS (Fig. B.1):

1. The CNS comprises the brain, the cerebellum and the spinal cord.
2. The PNS generally comprises sensory neurons (input to CNS from outside the CNS) and motor neurons (output from CNS from within the CNS). However, the PNS can further be divided into two subsystems:
    - The somatic nervous system (SNS) is the system that is

responsible for bringing back and forth sensory and motor information through the spinal cord and is generally linked with skin and voluntary movements (the outermost part of the body).

- The autonomic nervous system is the system that is responsible for internal regulations of bodily functions, e.g. blood flow, breathing, the beating of the heart, and is generally linked with involuntary movements (internal part of the body).

Generally, the role of PNS is to link the CNS with the body, i.e. organs and muscles. By being extended to the outermost areas, the PNS serves to bring information upwards from sensory neurons regarding, e.g. pain, temperature, touch and downwards from the motor neurons. Both types of neurons are part of the SNS. The upward motion is termed *afferent*—thus, the sensory neurons are afferent neurons, i.e. they serve to bring the information into the spinal cord and the brain. The downward motion is termed *efferent*—thus, the motor neurons are efferent neurons, i.e. they bring down commands of voluntary actions from the brain to the muscle fibres. The nerves that make up the PNS are in fact the bundles of axons stemming from the neuronal cell body in the cortex. It is through the interaction of CNS and PNS that one sense and acts upon the world. The SNS is by far the greatest in size of the nervous systems, taking up the whole body, and leaving merely the brain and the spinal cord for the CNS (Stanfield, 2013, chaps 9, 10, 11).

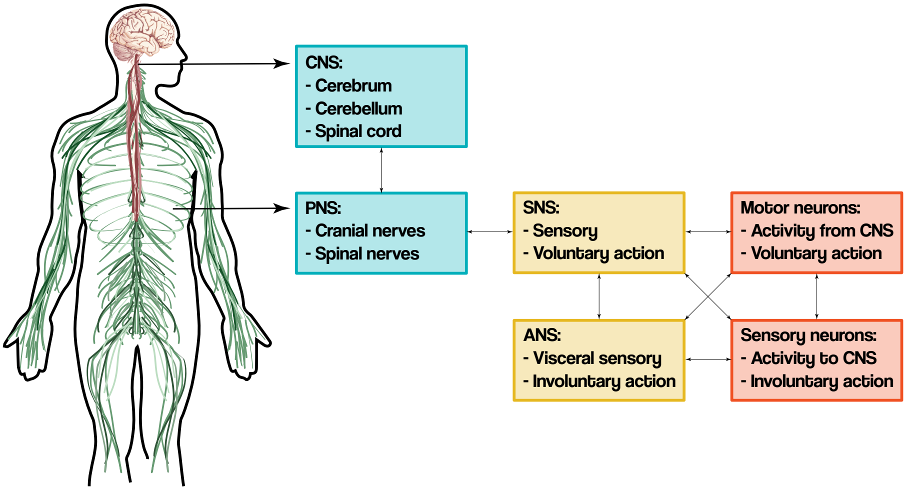

*Figure B.1—The brain, the brainstem and the spinal cord constitute the CNS (brain and red nerves). The CNS consists mainly of interneurons. The PNS (green nerves) comprises the 12 cranial nerves (e.g. olfactory, optic, abducens nerves) and spinal nerves that carry the motor-related activity. The PNS consists of the SNS and the autonomic nervous system, which further is composed of efferent motor neurons and afferent sensory neurons.*

## B.3 Cerebral cortex

The brain consists of two hemispheres where each hemisphere is primarily concerned with sensory and motor processes on the contralateral side of the body, i.e. the right side of the brain operates mainly on the left side of the body, and vice versa. The cerebral cortex is structurally formed with intelligent evolutionary folds (sulcus are the folds inwards and gyrus are the ridges), from which five lobes across the hemispheres can be categorised: the cerebellum, occipital, parietal, frontal and temporal lobe. The outermost part of the brain is the grey matter, whereas internally before the subcortical structures, i.e. basal ganglia, is the white matter. The grey matter, which is approximately 2-4 mm thin, is where some of the cell bodies of the interneurons reside. The white matter is composed of the axonal projections, e.g. the corpus callosum that holds 2-300 million axonal projections. Even deeper into the brain are the subcortical structures that also contain neurons, e.g. the basal ganglia. The cerebrum, cerebellum, diencephalon, midbrain, pons, medulla and the spinal cord together compose the CNS.

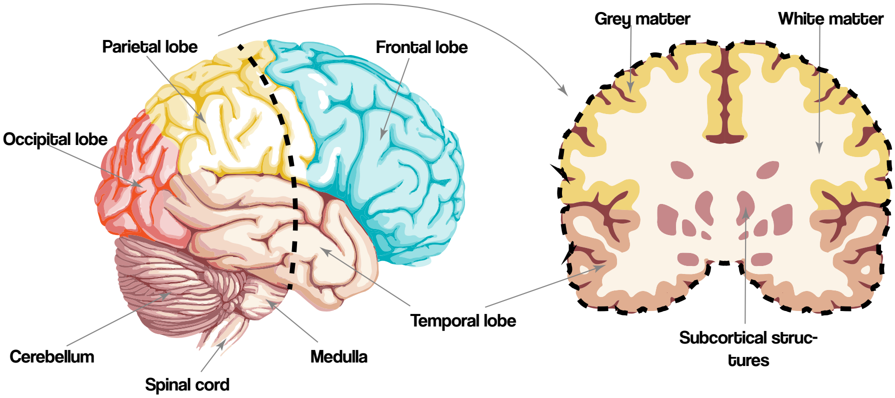

*Figure B.2—The brain can coarsely be divided into five-part: cerebellum, occipital, parietal, frontal and temporal lobe. The dashed line designates the section-cut, which is illustrated on the right side. The outermost part of the brain is the grey matter, usually referred to as the cortex, which holds the cell bodies of the neurons. The internal part of the brain is the white matter, usually referred to as the subcortex, which holds all the axons of the neurons.*

## B.4 Neurons

The nervous system has three classes of neuronal cells: the sensory neurons, the motor neurons and the interneurons (Kandel, 2013, chap. 8). The motor and sensory neurons were briefly described above. The interneurons exclusively reside in the CNS, throughout the brain and the spinal cord. They connect one neuron with another, e.g. interneurons in the spinal cord receive activity from the afferent sensory neurons (or other interneurons) and then transmit activity to motor neurons (or other interneurons). For instance, walking into Tadao Ando’s Chichu Art Museum in Japan, there are corners and transitions in the architecture that are naturally picked up by the senses. These senses communicate the intriguing corners and transitions to the interneurons, which immediately activates motor neurons to approach the beautiful transitions and spaces.

### B.4.1 Anatomy of neurons

Interneurons are composed of mainly three parts, namely the soma (cell body), dendrites and axons (Fig. B.3). The soma consists of the same cellular parts as other body cells, so it is here the nucleus and other cell structures reside. An essential purpose of the soma is to produce the protein necessary to construct the other parts of the whole neuron, i.e. dendrites and axons. From the soma, both dendrites and axons emanate with different purposes and structures. Neurons transmit and receive their signals through the dendrites and axons. These have different purposes.

#### B.4.1.1 Dendrites

Dendrites are responsible for receiving and process the incoming signals, so that it either makes the neuron behave excitatory, i.e. make the neuron fire, or inhibitory, i.e. resist the neuron from firing. Because a single neuron may have hundreds of dendrites (dendritic tree), it is the sum of the excitatory and inhibitory signals that is finally responsible for the potential firing of an action potential. Excitatory post-synaptic potential (ESPS) and inhibitory post-synaptic potential (ISPS) are additive, so the summation must surpass a threshold before it makes the receiving neuron fire an action potential. ESPS and ISPS can also cancel one another out, given that one is positively charged and the other negative. This is a remarkably important note relative to electroencephalogram (EEG) because it is precisely the summation of post-synaptic potentials that are measured in EEG.

In theory, the first electric activity of a neuron is the action potential (sometimes referred to as input spike, as opposed to output spikes in ESPS/ISPS), but as will be presented, this kind of activity is difficult to measure non-invasively. If the action potential is initiated, the signal is transmitted to the axons, which is linked to numerous other areas.

#### B.4.1.2 Axons

The axons are mainly responsible for conveying the neuronal signal to various areas. Unique to the axon is the myelination of the nerve, which improves the rapidity of the conveying, i.e. conductivity improvement. Axon terminals, located at the end of the axons, link to target cells through synapses. In the case of interneurons, the axons are linked to other cell bodies, and since axon is composed of numerous branches, the impulse can be distributed to several cells. At the axon terminals, the axon that conveys the signal is termed the pre-synaptic cell, whereas the dendrite that receives the signal is termed the post-synaptic cell. It is worth noting that the interneurons are mainly multipolar neurons, which means there is only a single (outgoing) axon extruded from the soma but it has multiple (incoming) dendrites. This allows for a high degree of integration from other neurons

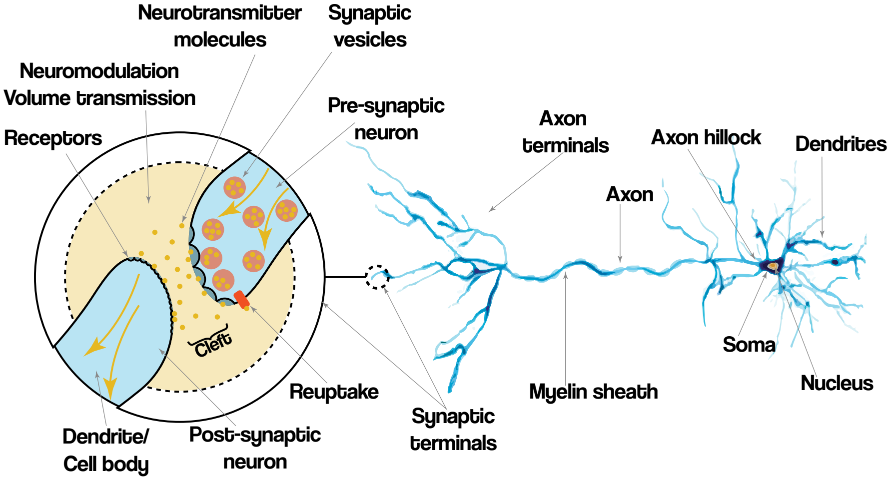

*Figure B.3—The anatomy of a neuron. The neuron is illustrated on the right, where the nucleus in the soma is designated by a yellow form. Dendrites emanate from the soma and are connected to other neuronal axons. If the dendritic process sums to excitatory behaviour, the action potential impulse is reflected in axons terminals as synapses. During synaptic transmission, different kinds of neurotransmitter can be released and picked up itself as a control of the neurotransmitter level and by the target cell, which may be a cell body or a dendrite. Neurotransmitter molecules are also picked up enzymes and thereby degraded. Molecules that are not pick up act as neuromodulators by volume transmission and alters the activity of a group of neurons.*

before transmitting a signal itself. In brief, when an action potential that stems from the processes in the dendrites initiates a neuronal firing, it is conveyed through the axon terminals that in turn triggers a chemical neurotransmitter, which must fill the gap between the pre-synaptic and post-synaptic cells.

### B.4.2 Neurotransmitter

Between the pre-synaptic and post-synaptic cells, the electrical synapse triggers a chemical neurotransmitter where ions and other molecules cross the synapse between the two cells as a transmission (Kandel, 2013, chaps 12–13). In turn, this connection to the post-synaptic cell initiates either excitatory or inhibitory signal in the receiving cell—hence the convenient name, neurotransmitter. Their purpose is precisely to transmit. It is worth noting that the advantage of using electrical signalling is the rapidity of response, as compared to the endocrine system (associated with homeostatic balance), which uses hormones as the chemical signalling. Electrical signals are fast whereas hormones are slow but long-lasting.

Neurotransmitters also have a longer-lasting influence on neurons, but only through the modulatory effect. Whether a neuron responds excitatory or inhibitory depends on the target dendrites—however, a neurotransmitter may also have a third class of influence, namely modulatory. These are not restricted to the gap between a pre-synaptic and post-synaptic cell but instead, they affect a large number of neurons ultimately regulating a whole population of neurons. The process of regulation is slower than the excitatory and inhibitory responses.

There are different kinds of neurotransmitters with each of their characteristics. Here, some of them are very briefly characterised:

- **Glutamate** is by far the most widespread neurotransmitter in the brain and is characterised by its *excitatory property* on neurons.
- **GABA** (gamma-amino-butyric acid) is an amino acid that is mainly characterised by its *inhibitory property* on neurons (for more on glutamate's and GABA's role in the brain, see: LeDoux, 2003, chap. 3).
- **Oxytocin** is both a hormone and a peptide neurotransmitter. It plays an essential role in social bonding.
- **Norepinephrine**, a monoamine neurotransmitter, reflects the level of alertness in the body and is typically related to fight/flight responses, which links it further to mobilising the body and to regulations of stress levels.
- **Dopamine**, which is also a monoamine neurotransmitter, plays an essential role in bodily movement, reward circuits and motivation levels. For this reason, it involved in a wide range of research, e.g. addiction, Parkinson's and decision making.
- **Serotonin** is a powerful monoamine neurotransmitter involved in mood, anxiety, sleep and appetite. Serotonin reuptake inhibitors usually treat depression.
- **Acetylcholine** is involved with motor neurons and muscular movements, and for this reason, plays a fundamental role in cognitive functions. As it is the only neurotransmitter found in the somatic nervous system of the brain, it holds a unique position regarding cognition—given that cognition depends on action (see Chapter 9).

There are generally three main ways in which neurotransmitters are eliminated: reuptake by the pre-synaptic cell, enzymatic degradation and diffusion. In the synaptic process, there are neurotransmitter molecules released and picked up by receptors in the target cell. While the neurotransmitters are picked up, some are reabsorbed by the pre-synaptic cell as a type of regulation. This process is named reuptake. Reuptake is essential in regulating the level of neurotransmitter that is currently present. It can be considered a way of controlling the release amount. Besides the reuptake, enzymes in the cleft function as eliminating the neurotransmitter by breaking it down. This is named enzymatic degradation. Furthermore, when the pre-synaptic cell detaches from the target cell, drifting neurotransmitter molecules are absorbed by glia cells and thus eliminating the neurotransmitter by diffusion. Diffusion also functions as a volume transmission to other areas of the brain, which is how neuromodulation emerges.

### B.4.3 Neuromodulators

When neuromodulators influence a population of neurons, the process is initiated by volume transmission where the neurotransmitter molecules are diffused. This process is also known as volume transmission, which due to lack of rapid degradation and reuptake, the neurotransmitters modulate the neurons over a longer time. This is the main difference between modulators and synaptic transmitters, i.e. the effect duration, where synaptic transmitters last for a short time as opposed to modulators that have a long-lasting effect. The purpose of the neuromodulator is to alter the activity of a group of other neurons by entering the field of post-synaptic receptors from a long distance.

## B.5 Electroencephalogram

This subchapter briefly introduces the electroencephalogram (EEG). When millions of synapses are excited at the same time, they are measurable from the scalp using an EEG (Luck, 2005). Hans Berger (1873-1941), a German psychiatrist, first discovered this in 1924 (Gloor, 1969) by placing an electrode on the scalp, then amplifying the signal and plotting the changes in volt over time. Demonstrating that it is possible to measure the electrical activity of the human brain revolutionised brain sciences because it enabled in vivo human experimentations. For instance, Berger famously discovered the alpha oscillations (8-12 Hz) that increase upon closing the eyes and decrease immediately upon opening them, which today is a paradigm in experimenting the influence of external stimulus on spontaneous brain activity (Northoff, Qin and Nakao, 2010). Berger observed the alpha waves without a digitalised EEG, which is the norm today.

A modern EEG consists of various electrodes and different types of amplifiers with different recording tempo. A high-density EEG-recording is typically considered from 64 channels (electrodes) and upwards (256 channels), whereas a low-density is below 64 channels, typically 32 channels. Amplifiers today can easily sample data at 1 kHz, which means that it records 1000 points of voltage changes per second. The temporal resolution is the key-advantage of the EEG as a non-invasive technique for measuring cortical activity. Spatially, the EEG provides coarse measures where the raw data cannot be used to elucidate specific neuronal signals. First, the EEG signals reflect any voltage in the electrode's environment, e.g. a computer screen or the subway system. Thus, raw EEG signals are considered highly noisy—however, this is solved by processing the raw data in ways that reduce the noise. Second, each channel reflects a mixing of neuronal sources of activity that stem from various cognitive processes. This is typically referred to as a *cocktail party problem*, because during a cocktail party, many open conversations add up to the noise, but each a distinct, and hopefully meaningful, conversation. This problem can be solved through algorithmic modifications of the data, e.g. an adaptive mixture of independent component analysis (Palmer, Kreutz-Delgado and Makeig, 2011). The technology behind an EEG is increasingly complex but has been simplified for the sake of description. What does the EEG then measure?

### B.5.1 What is potential? Ohm's law

The origin of EEG signals stems from the pyramidal cells (neurons) that are always oriented perpendicular to the cortical surface. The electrical nature of neurons that is measured is the voltage, which is typically referred to as *potential* because it describes the potential pressure for electrical current to move. Ohm's law can sum the relation between voltage, current and resistance. Ohm's law dictates:

$$\textit{voltage} = \textit{current} \cdot \textit{resistance} \;\leftrightarrow\; V = I \cdot R \tag{B.1}$$

A textbook example of their relation is the water hose analogy. Current, denoted by *I,* is the flow of electricity. A measure of current is a measure of the number of electrons or protons through a given point at a specific time. The unit of the measure is ampere. The critical point of current is that it flows from negative to positive, i.e. it has a direction. In the context of the water hose, the current is the pressure of the flow of water through the hose, i.e. the actual vehicle.

Resistance describes the ability to keep charged particles from passing. Opposite to resistance is the conductance, which facilitates the passing of particles. This property is tightly related to the composition of the substance, e.g. copper, silver and gold are good conductors, but also the length and the diameter of the substance contribute to the resistance. The unit of measure is ohm. Using the water hose analogy, a 50 metre-long water hose with a diameter of merely 1 centimetre, will resist the flow of water as compared to a 1 metre-long water hose with a diameter of 5 centimetres will allow less resistance, and thus increase the current.

Voltage, which is the unit that EEG measures in, describes the potential for the current to flow. Even if the current is not flowing in any direction, the potential to do so exists. Voltage can be considered the electrical pressure that enables current to flow, which analogous to the water hose example, means that there can be a lot of water pressure in a hose even if the end is closed off. The moment the hose is opened, the water starts to flow—that is, if there is sufficient pressure, i.e. no electric current can flow without the electrical potential to apply pressure.

### B.5.2 Post-synaptic potentials and dipoles

Excitatory neurons produce an action potential along the axons to reach the axon terminals, where neurotransmitters are released. When the neurotransmitters bind to a receptor on a post-synaptic cell, it causes a change in voltage that typically last tens or hundreds of milliseconds. Action potentials last only about a millisecond, so any measured potential 20 milliseconds after stimulus onset most probably reflects post-synaptic potentials.

The physical structure of the brain is an important topic in EEG, because it describes both which neurons are measured but also what kind of electrical activity in neurons. If the current flowing in an action potential flow parallel to another axon until they reach an axon terminal their voltage summate and increase chances for measuring action potential through the scalp using EEG. However, if the

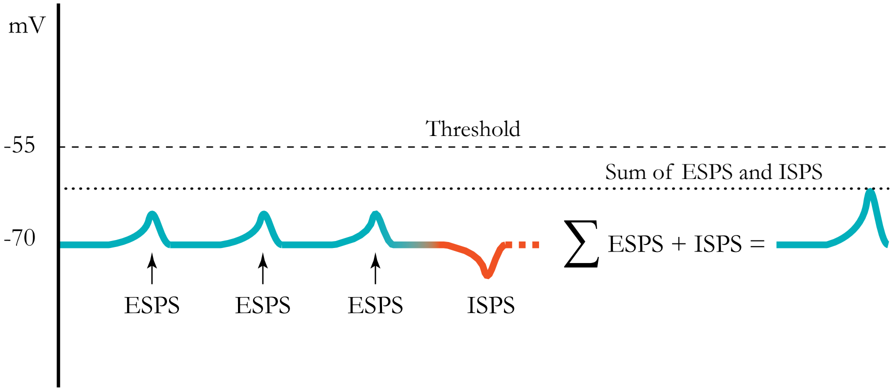

*Figure B.4—An example of the summation between ESPS and ISPS. This process is largely confined to dendrites, where the decision whether to excite the neuron, or not, takes place. The dashed line represents the threshold to excite a neuron, while the dotted line represents the summation of the ESPSs and ISPSs. In this example, there are three ESPSs and a single ISPS, which amounts to one ESPS cancelling out. This is a highly simplified demonstration of the process, as the temporal summation has not been considered (Stanfield, 2013, p. 204).*

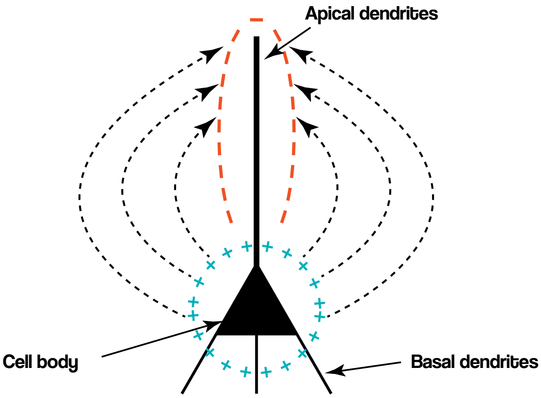

*Figure B.5—An example of how the dipole emerges from the polarities in a pyramidal cell. In this example the cell is excitatory, which means the cell body is positively charged. The positively charged ion in the dendrites causes a negative charge forming a dipole altogether with the cell body.*

action potentials are just slightly asynchronous, then as the action potential is flowing into one axon, it may be flowing out other axons, which results in the signals cancelling out. By far, axons do not fire at the same rate; thus, action potentials are considered close to impossible to measure from the scalp (Luck, 2005, p. 39).

Particularly the summation of post-synaptic potentials allows the EEG to measure distinct and deep areas of the brain be they either excitatory or inhibitory (Fig. B.4). Because of the physical position of pyramidal cells, i.e. perpendicular to the cortical surface, the apical dendrite is always pointing outwards (cortical surface) while the dendrites are pointing towards the white matter. This physical structure allows inferring the direction of the current flow. For instance, when an excitatory neurotransmitter is released around the dendrite, the positively charged ions will flow into the cell body and change the polarity around the dendrite regions. This flow of current creates a small area of positive and negative charges, and that is precisely what a single *dipole* is; these are important for the processing of EEG data (Fig. B.5). In the case of an inhibitory post-synaptic potential, the polarities are inverted (Luck, 2005, p. 40) (To localise the dipoles, one needs to solve the forward problem, which is a statistical problem that is not touched upon here).

When thousands or millions of neurons form dipoles at the same time, they summate and become measurable from the scalp. The issue then is the folding of the brain, because the dipoles might be oriented such that they cancel each other out (Fig. B.6). The orientation is exceedingly important to infer the origin of measured EEG data, and the organisation of pyramidal cells makes it more likely to be the source, merely because they are not randomly organised. Neurons in basal ganglia are increasingly random in their orientation, which makes it highly difficult to measure activity in that area from the scalp. Luck (2005, p. 42) following conditions for measurable signals from the scalp:

- Simultaneous activation of a large number of neurons.
- Similar orientation of individual neurons.
- The source of the post-synaptic potential must be similar, i.e. apical dendrites or cell body.
- The majority of neurons must have the same direction of current flow.

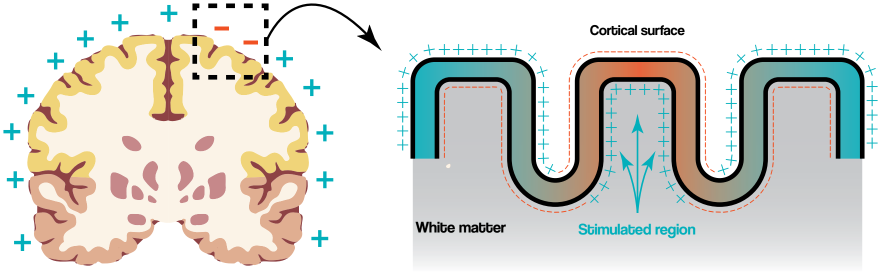

*Figure B.6—The folds of the brain complicate the estimation of neuronal origin because the electrical charges may be additive in one sense, while possibly cancelling out in another sense. Beyond self-cancellation, the potential needs to be strong enough to be measured through the skull.*

### B.5.3 Processing

Recording meaningful EEG data requires a range of devices. A typical setup of using EEG consists of:

1. Device for presenting the stimulus, e.g. monitors, Virtual Reality, headphones.
2. Cap with electrodes:
    - The number of channels defines the density of the EEG recording.
    - A reference electrode and a ground electrode. The measured potential of a single channel is always relative to the reference and ground electrodes.
    - Conductive gel to improve signal-to-noise ratio.
3. EEG amplifier to synchronise the measured potentials and the events of the external stimulus at a fixed rate. Amplifiers also contain filters.
4. Computer to digitise the signals.

How the data is pre-processed depends entirely on the hypothesis and the paradigm of the experiment. However, the operations are usually entails down-sampling the data, assign channel locations, filtering, rejection bad channels for each participant and eventually interpolate the bad channels using the approximate channels, referencing the channels and running an independent component analysis (ICA), which essentially attempts to solve the cocktail party problem.

The brain is continuously processing for various reasons, which means that several processes overlap in the channel recordings. The ICA attempts to segregate the reasons into separate components, where the sum of the components naturally yields the EEG data (see for instance Palmer, Kreutz-Delgado and Makeig, 2011). Such an analysis allows identifying interfering activity measured from movements from the eyes or the neck muscles. Processing the data attempts to suppress noise in the data cautiously, without interfering with "true" cortical activity; down-sampling and filtering may cause artificial oscillations or distort temporal positions of stimulus onset. At any rate, un-cleaned and noisy EEG data cannot answer questions of cortical activity—thus, applying filters and ICA are essential steps in processing EEG data. For instance, muscles contribute to the noise in the EEG signal and obscure "true" cortical activity. However, a technique named Mobile Brain/Body Imaging (MoBI) has excelled in treating EEG data with minimal distortions to the cortical data.

### B.5.4 Mobile Brain/Body Imaging technique [1]

The MoBI approach (Makeig *et al.*, 2009; Gramann *et al.*, 2011, 2014) allows recording activity of the human brain in actively moving participants using mobile brain imaging devices like electroencephalography (EEG) or functional

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[1] This subchapter is heavily based on the thesis-related publication: (Djebbara, Fich and Gramann, 2019)

near-infrared spectroscopy (fNIRS) synchronised to motion capture and other data streams. Head-mounted virtual reality systems can be coupled to the setup to allow full control over visual and auditory stimulation while human participants move through and interact with virtual worlds. The method was developed to allow investigation of the relationship of action, cognition, and brain activity and aims at overcoming the limitations of traditional brain imaging modalities that restrict active movement of participants to avoid artefacts originating from movement—thus, MoBI excels at investigating neuronal and functional principles of enactivism and active inference while acting in virtual architectural environments. MoBI is the method of choice to investigate the brain dynamics underlying the impact of architecture on perception and action in freely behaving humans. By synchronising recordings of brain activity with motion capture, MoBI allows us to investigate the interplay of sensation, perceptual experiences, and action, while recording the accompanying brain dynamics. This contrasts MoBI studies from mobile EEG studies that do not record specific aspects of participants' behaviour but rather compare brain activity in different movement conditions like sitting as compared to walking (Jungnickel and Gramann, 2018). Using data driven analyses approaches with the help of information from movement recordings to advance the signal decomposition, i.e. ICA, MoBI allows separation of brain and non-brain activity for further analyses.

Early MoBI studies mainly focused on demonstrating the feasibility of the approach using treadmills that allowed movement of participants without necessitating large physical spaces. These studies demonstrated that it is possible to investigate human brain dynamics accompanying cognitive processes including attention to relevant rare stimuli during active behaviours like walking (Gramann *et al.*, 2010). In the study by Gramann and colleagues (2010), participants were standing or walking with different speed on a treadmill while, at the same time, responding to rare target stimuli in a visual oddball task presented on a screen in front of them. Using ICA and subsequent clustering of ICs, the authors demonstrated that the P300 component, a positive deflection in the event-related potential, could be reconstructed for target stimuli irrespective of the behavioural state.

## B.6 Closure

This appendix ranged from introducing nervous systems to neurons and the process of excited neurons, including neurotransmitters and the electrophysiological underpinnings of neuronal activity. Ultimately, a method of measuring the voltage generated by pyramidal cells was introduced along with an advanced method of analysing cortical activity. The brain is indeed a complex organ that is exceedingly difficult to grasp and, despite the many discoveries of its organisation and functions, continuous to be a mysterious organ.

# APPENDIX C

# Functional segregation and integration

## C.1 Introduction

Additional to the discussion on the decomposability of the brain and its functions, is the debate regarding functional segregation and integration in cognitive processes. This debate is highly dependent on the brains' ability to bring together two spatially distinct processes that occur in parallel. To this end, it is necessary to briefly review how neuronal processes are observed to be linked and two different theories of how distinct areas may be interrelated. Both convergence-divergence-zones and phase synchrony are reviewed and supported by revisiting Hebb's rule through excitatory post-synaptic potentials. Essentially, integration and segregation of cognitive processes rely heavily on the neuronal ability to strengthen and weaken connectivity.

## C.2 Segregation and integration

Semir Zeki, a neuroscientist, captures the essence of the discussion regarding segregation and integration as organisational principles of the brain in his book *A Vision of the Brain:*

> *"For that experience is one of wholeness, of a unitary visual image, in which all the visual attributes take their correct place, in which one can register the precise position, shape and colour as well as the direction and speed of motion of a bus simultaneously and instantaneously, as if all the information coming from that bus had been analyzed in one place, in a fraction of a second. Nothing in that integrated visual image suggests that different visual attributes are processed in physically separate parts of our cortex.*

> *The task, then, is to enquire into how the brain puts the separate attributes together." (Zeki, 1993, p. 295)*

Integration, as understood in this context, is the ability of the brain and body to integrate all necessary attributes of sensory into a meaningful percept. Phenomenology suggests that the integration is evident in behaviour and transcendental states, i.e. one acts according to a multisensory world and experiences an integrated world. The paradox in this debate is that some neuronal responses are stimulus-specific and tend to form specialised hubs in the brain, and by doing so favours a localisation-oriented brain, but the meaningful percept is phenomenologically evident to be an integration of the whole. Eventually, such a position states that functions of the brain emerge from their specific locations, whereas a dynamic systems theory (DST) approach suggests that the brain operates as a whole in spite of its anatomical structure. The debate can be distilled to a question of modulatory structures of cortex with a subdivision of labour, versus, a widespread distribution of labour that depend on the ability of large-scale integration.

The concept of segregation in the cortex ranges from specialised neurons to neuronal hubs and cortical regions. It builds on the strategy that anatomical connections shape the structure of separate cortical areas, so that information passed between these areas form a coherent and meaningful percept (Zeki and Shipp, 1988). Importantly, segregation does not correspond to the radical localisation theory of mental functions, i.e. Broca's theory of area-specific functions in the brain, but refers instead to a statistical distinction between neuronal responses, i.e. specialised hubs (Sporns, 2011, p. 185). This is an important note because the debate on segregation and integration is not the same as localisation versus anti-localisation theories of cortical organisation, i.e. the structure-function dilemma (Sporns, 2011, chap. 4). Instead, segregation and integration address how separate areas of the brain integrates to a phenomenologically whole percept. There are at least two ways the integration may unfold, and once again, *time* is of the essence. Damasio suggests functional integration through convergence (Damasio, 1989; Meyer and Damasio, 2009), while Varela suggests distant phase locking or synchronisation without convergence (Varela, 1995; Varela *et al.*, 2001).

### C.2.1 Convergence-divergence-zone framework

Damasio's idea is that integration by convergence creates more specialised hubs by a conjunction of other less specialised hubs (Damasio, 1989). At any rate, convergence can *"generate neurons whose activity encodes high-level attributes of their respective input space, increase the functional segregation and specialization of the architecture"* (Sporns, 2011, p. 185). Damasio is suggesting a hierarchical structure to the cortical organisation and cognitive function, where segregation and integration can hardly be separated processes because it makes extensive use of feedback and feedforward modulations (Meyer and Damasio, 2009).

The framework casts neuronal architecture as ensembles in early sensorimotor cortices and neuron ensembles located downstream the sensorimotor in higher-order cortices—the architecture operates through convergence-divergence-zones (CDZs). Upon receiving convergent projections, CDZs send back divergent projections to the same sites and hold in retention the combinatorial arrangement so that it is shaped by experience (Fig. C.1). Despite the separate sites, the influenced areas are temporally coincident in their activity and therefore modify the connectivity pattern within a shared CDZ downstream, which eventually associates their activity. The downstream is equivalent to top-down (TD) signalling. The connectivity principle takes place at all levels of the hierarchy, i.e. feedback and feedforward signals that allow for *feature detectors* (Meyer and Damasio, 2009; Sporns, 2011, p. 186).

Different from traditional accounts of sensory perception is that CDZ register linkages among fragments, i.e. the combinatorial arrangement of the multi-site activities, whereas the traditional accounts hold that information is transferred and projected to single anatomical sites to enable an apprehension further. As Chapter

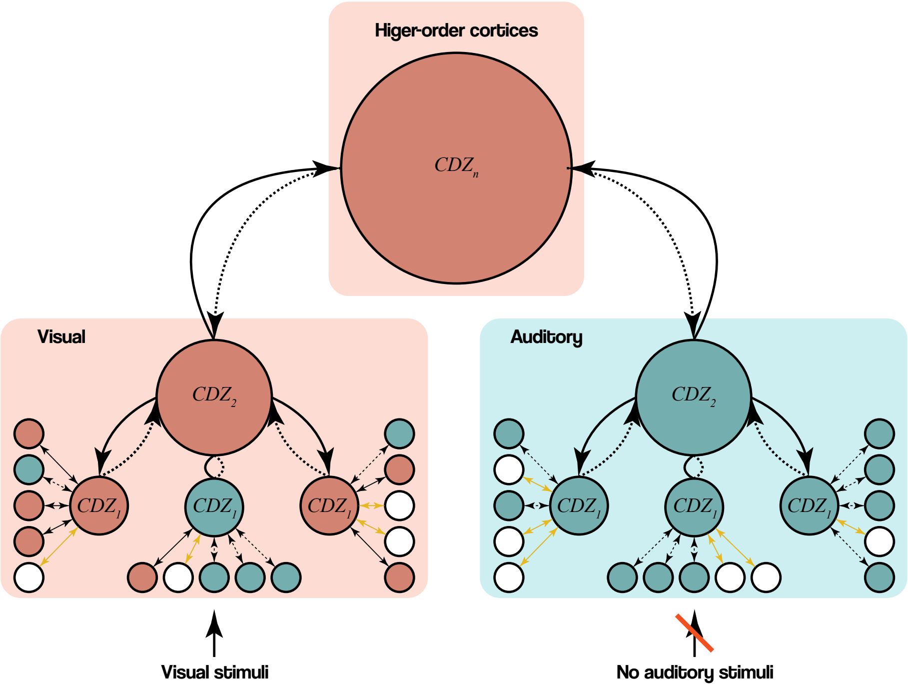

*Figure C.1*— **Convergent-divergent-zones**. *A schematic overview of visual apprehension of lip movement without auditory stimuli. CDZ consists of a multi-level hierarchy where response patterns retro-activate various CDZs. By visually observing a lip movement, the visual stimuli activate specialised visual hubs of neurons due to convergent forward projections (solid arrows). However, the divergent projections lead to retro-activations (dashed arrows) in both the visual and auditory areas. This is due to the connectivity established during activation of the pattern when the visual-auditory activity was previously experienced together. Parts of the specialised hubs remain inactive (yellow arrows). The blue areas are retroactively enabled, while the red areas are the neuronal hubs activated by forward projections. Illustration inspired by (Meyer and Damasio, 2009).*

10 and Appendix D and E will elaborate on, the linkage can be seen as probabilities that need to be improved, i.e. decrease the uncertainty, through interaction with the environment to enhance the grip of the percept. The CDZ trigger and synchronise neuronal patterns through the projections but cannot be the locus of integration themselves (Sporns, 2011, p. 186). Instead, the framework casts CDZ as hubs that are distributed throughout the cortical architecture and ensures functional integration through coordinated activity, i.e. synchrony.

To give an example of how CDZ synchronise auditory and visual sensory, consider an observation of a lip movement. Because the auditory sensory repeatedly co-occurs with the visual sensory of a lip movement, the two events modulate connectivity in early sensorimotor areas. Consequently, the visual event of a lip movement will not only elicit visual activity alone but the activity pattern, given the modulate connectivity, will retro-activate (i.e. by backward projection) early auditory area despite the absence of the accompanying sound in the environment (Meyer and Damasio, 2009).

> *"According to the CDZ framework, the meaning of a lip movement includes the sound typically associated with it, and the auditory map of that sound, therefore, has become an integral part of the lip movement's neural representation."* (Meyer and Damasio, 2009, p. 378)

### C.2.2 Phase-synchronisation

Integration has also been posed without convergence but instead through dynamic links, i.e. through phase-locking of distinct neuronal populations. Singer and colleagues have provided, through a series of experiments, evidence for stimulus-dependent neuronal synchrony within and between cortical areas (Gray and Singer, 1989; Gray *et al.*, 1990; Singer, 1999). This is an important discovery because it suggests that the brain integrates various sensory through phase-synchronisation of gamma-oscillations (~20-80 Hz) (Buzsáki, 2006). The role of coherent phase-synchronisation in large-scale networks is to facilitate the mutual communication and to modulate the strength of connectivity (Fries, 2015).

Varela and colleagues provided evidence that large-scale networks are evident during meaningful perception as opposed to meaningless percepts (Rodriguez *et al.*, 1999). Their experimental paradigm was to present their participants with either meaningful (*Mooney*) faces or meaningless shapes and to analyse the phase-synchronisation in the measured EEG-data. Their analyses consisted of functional connectivity on a channel-level, i.e. phase-synchronisation amongst the EEG electrodes, and of time-frequency transforms. Their results indicate that during meaningless perception, there is close to none phase-synchronisation among different areas of the brain, whereas dring meaningful perception, a highly significant increased number of areas start to synchronise from distinct and distanced areas of the brain.

Varela suggests that the brain consists of reciprocal relations throughout the whole brain, which, through large-scale networks, allows distinct areas of the brain to communicate and integrate. This theory strongly suggests that large-scale integration unfolding through phase-synchronisation is a dynamic process paramount for cognitive and perceptual processes (Varela *et al.*, 2001). However, the linear measures of functional connectivity is a static measure of large-scale networks, because it does not consider temporal evolution.

Large-scale networks that emerge from phase-synchronisation are immediate networks—but networks that evoke other regions over time cannot be elucidated within that type of *functional* analysis (Friston, 2011). Instead, the *effective* connectivity must be taken into account by analysing, for instance, the Granger causality between two neuronal hubs. Such analysis yields whether the activity of one neuronal hub Granger-causes the activity of another.

### C.3 Spike Timing Dependent Plasticity

Recall from Appendix B that a presynaptic neuron sends a signal while a post-synaptic neuron receives the signal. This means that over time, one should be able to measure one spike one moment, and the next moment measure another spike from the post-synaptic neuron if it chooses to fire. As explained in Chapter 7 (2.3), Hebb's rule clarifies the mechanism underlying synaptic firing. The rule can be distilled to *neurons that fire together, wire together*—however, for the brain, it is not only a matter of which neurons connect, but also about the strength of the connection. It is not always that a post-synaptic neuron fires. Hebb emphasised that *"when an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased"* (Hebb as cited in Caporale and Dan, 2008). Hebb's rule foreshadowed the process that adjusts the strength in connectivity named Spike Timing Dependent Plasticity (STDP) where causation is an important aspect. The temporal order of neuronal spikes may reveal a great deal regarding their connectivity relations, e.g. strength.

Buonomano (2017, pp. 29–31) provide an excellent example that illustrates the asymmetry of cause and effect in neuronal activity. For the sake of the example, consider two neurons in a baby Zoe's brain (Fig. C.2). Neuron A is linked to neuron B, and vice versa, thus, there are two synapses. Neuron A is excited by the sound of the letter *Z* and neuron B of the sound of the letter *O*. Whenever Zoe hears her name, neuron A fires 25 milliseconds before neuron B. Here, the objective of the synaptic rule is to strengthen, or weaken, the synapses according to the pattern of activity. In this case, neuron A to neuron B is strengthened, while neuron B to neuron A is weakened. At any rate, that neuron A fires before neuron B makes it likely that neuron A contributed to the firing of B. This simple rule allows the brain to learn cause-and-effect regarding neurons that are responsible for the stimulus-specific activity, i.e. external events in the world, like architecture. This biological process ensures that Zoe responds to the sequence of Z-O-E instead of O-Z-E, where O is before Z.

## C.4 Closure

In brief, segregation and integration are inevitable processes in cognition and behaviour that may be obscured by the reciprocal relations in the brain. Indeed, the dynamics of the brain are essential for cognitive and perceptual processes, because such processes require functional integration from distinct neuronal hubs that are distributed throughout the brain. Evident from the discussion above, the brain is inclined to be hierarchically structured with forward and backward projections, operating through large-scale networks. This is indeed in line with a DST approach, and even further with a free energy principle (FEP) approach, which is presented in Chapter 10, Appendix D and E. In fact, the CDZ framework is an excellent biological forerunner to FEP and active inference as it is easier to understand the structure of CDZ—however, they are very reminiscent.

STPD magnified the process of connectivity to a neuronal level and revisited Hebb's rule to document the potential of neuronal wiring in strength, which is essential in both phase-synchrony and the CDZ framework.

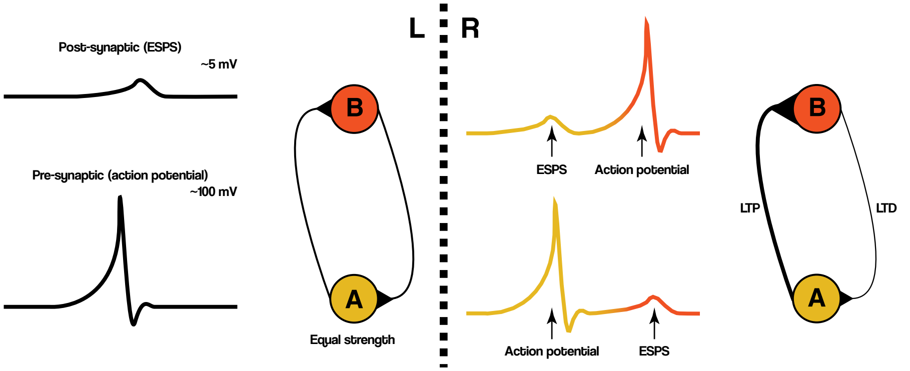

*Figure C.2—* **Left.** *Spike Timing Dependent Plasticity (STDP) is electrically measured in neurons. A pre-synaptic neuron can link to a post-synaptic neuron through its axons and the post-synaptic neuron's dendrites (Appendix B). An excitatory post-synaptic potential's (ESPS) role is to either initiate or inhibit excitatory behaviour in a neuron (the inhibitory version of ESPS is the ISPS). If a neuron is excited, it fires a considerably stronger action potential. However, the ESPS have an additive effect, which is what is measurable using EEG.* **Right.** *If the neuron A fires an action potential consistently before the ESPS, then the connection will get stronger (long-term potentiation; LTP)—however, if the output spike (ESPS) occurs prior to the input spike (action potential), then the connection will get weaker (long-term depression; LTD).*

## APPENDIX D

# Bayes' rule, Hidden Markov Models and the darkroom

### D.1 Introduction

This appendix serves to introduce Bayes' rule, Hidden Markov Models (HMMs) and discuss the darkroom problem. To this end, simplification of an experiential transition using architectural transition is demonstrated, using both Bayes' rule and HMMs. Bayes' theorem is the inverse probability that naturally leads to the process of inferring hidden states (Stone, 2013, pp. 27–28), which is how Bayes' theorem links with HMMs. It is worth noting that this appendix is statistical and assumes basic probability theory and mathematical skills.

Furthermore, it is based on textbooks of machine learning (Jordan *et al.*, 1999; Ghahramani, 2001; Jebara, 2004). The concepts to be discussed relative to Bayes' rule are prior probability, likelihood function, marginal likelihood and posterior probability. For HMMs, it is transition probabilities, emission probabilities, maximum likelihood estimation and Viterbi's algorithm.

The idea here is to demonstrate how a combination of Bayes' rule and HMMs can form intellectually informed guesses—however, the purpose of this demonstration is to apply the same underlying concepts not to the intellect, but to the practical knowledge as it appears through action-perception. The process of inferring hidden states as modelled by HMMs is applicable to sensory states inferring the world. It is precisely an attractive method due to the SMC hypothesis regarding the structure of change in experience. Although the following example is not applied on a sensory level (Chapter 10), the same underlying concepts can be transferred to the action-perception process.

## D.2 Bayes' rule

Recall the architectural conundrum from Chapter 3. This time, the experiencing agent starts in *space A* walks through *space B* to finally reach *space C*. These three spaces could be any other three seemingly separate spaces, such as [outdoors, entré and living room] or [living room, hallway and home office] etc., but for the sake of simplicity, the example sticks to [outdoors, entré and living room]. Coming home early from work, e.g. 2 pm, and observing that the lights are turned on inside, Bayes' theorem can aid deciding the probability that your significant other (SO) is in the living room. The architectural transition is here composed of three spaces, where the task is to predict whether the SO is in the last space, which means that one can pick up sensory cues from *space A* to strengthen the guess regarding *space C* from *space B*. According to Bayes theorem (Eq. 1), sensory cues picked up in the current context, i.e. outside, evaluate prior experiences that are used to expect the next space.

To add some numbers to the chances, say, what is the probability that the SO is home in general? Prior experiences indicate that the SO is home two out of five times at 2 pm—but only home five out of eight times when the lights are on. Besides, how often are the lights just randomly on? The kids might have come in earlier from school and turned the lights on, or the last person leaving forgot to turn them off. There are endless reasons that the lights could be on randomly—assume that out of twenty observations, the lights are on eight. Given these probabilities, it is possible to process the probability of whether the SO is home when the lights are on using Bayes theorem while still being outdoors:

$$P(A|B) = \frac{P(A) \cdot P(B|A)}{P(B)} \leftrightarrow posterior = \frac{prior \cdot likelihood}{marginal\ likelihood} \qquad \text{(D.1)}$$

In Bayesian probability, the P(A) stands for *prior probability,* which is the probability that functions as a weight to the *likelihood function*, namely P(B | A). Note that the likelihood is a conditional probability so that it depends on a variable. The standard convention is that the probability of which is sought is named the *parameter* while the evidence is named the *variable.* The P(A | B), which is what the current example concerns, is referred to as the *posterior probability.* The posterior is the product of the likelihood and the prior. The P(B) is referred to as *marginal likelihood* and is often disregarded because a different value would change all competing posterior probabilities by the same proportion. It simply does not affect the relative probability (Jebara, 2004, pp. 23–24; Stone, 2013, p. 15). Essentially, Bayes' rule combines prior experience with observed data to generate a qualified guess, i.e. Bayesian inference. This approach is the best way of forming an informed guess using prior experiences. It has many applications in decision-making, e.g. deciding between whether someone said "four candles" or "fork handles", or a simple hypothesis comparing that the hypothesis is true versus false.

Applying Bayes' theorem to the current example unfolds like this:

$$\frac{P(SO) \cdot P(Light|SO)}{P(Light)} = \frac{\frac{2}{5} \cdot \frac{5}{8}}{\frac{8}{20}} \approx 63\% \tag{D.2}$$

Before transitioning from outdoors to the entré and exclusively using light as a cue, yields a 63% probability that the SO is home—however, this probability is subject to change as the sensory cues update as one acts towards, and eventually enters, the entré. The new information that is gathered continuously either increase or decrease the probability, e.g. in the entré one might *not* find the SO's shoes, which severely decrease the probability for the SO to be present. Indeed, there is no computation of this kind explicitly happening in the brain or the body—yet, Bayes theorem seems to describe best (simulate) rational decision making in human behaviour.

Using Bayes theorem in architectural transitions, there is an expectation regarding what to find in space or put in other words; an expectation to space. In the described example, there is a 63% expectation to find the SO at home, which brings with it a range of new expectations relative to the SO as one approach, e.g. loud music, the smell of dinner or cut grass. Indeed, it is not as static and discrete as in the example but instead takes form as a continuous and dynamic updating. Calculating the precise probability is close to impossible because there are in theory an infinite amount of hidden states that needs to be inferred, but as shall be presented there is a solution to this otherwise intractable problem (Chapter 10).

To rehearse Bergson and Husserl; according to their phenomenology, the current moment is interpenetrated by retention and protention, so that any given moment is already constituted by past and future. On an intellectual level, the example of the SO and the light is likely to develop precisely as described, i.e. as a conscious contemplation—however, for architectural spaces, if not an architect, these expectations happen on a basic and intuitive level never reaching full conscious contemplation. It is comparable to background noise until there is a relative prediction error. Rarely does one have to bring to mind how to transit from one space to another; one transits with a task in mind that caused the transit in the first place. In Chapter 11 it is argued that space is much more significant than background noise because space takes the role as the platform and foundation for experience, and if this foundation of experience is mispredicted, it may cause significant physiological reactions.

### D.3 Hidden Markov Models (HMMs)

The strength of HMMs is that it guesses patterns when given observed states and transitional information. In other words, an HMM *"is a tool for representing probability distributions over sequences of observations"* (Ghahramani, 2001, p. 2). Sequences can be considered deterministic and indeterministic, i.e. the seasons form a deterministic system. Every time, after winter, comes spring, then summer, then autumn and finally back to winter. The states, i.e. seasons, are easily inferred from the current state, i.e. season. Architectural transitions are undetermined, and HMMs are powerful in the context of the research question as it seeks to resolve undetermined sequences, which was stated in Chapter 4, 5 and 6 to be a characteristic of experiential transition. This is a critical notion relative to the example above as it aids guiding the sequences in experiential transitions, i.e. as one approaches the next space, new perceptual cues are informing the expectation regarding the next space. To demonstrate how a combination of Bayes' rule and HMMs can be powerful, consider there the same example, first with a different approach and then an immediate approach.

How were the probabilities found? The probabilities are based on prior knowledge about how often the SO is home at 2 pm (Fig. D.1). For the sake of simplicity, coming home early at 2 pm has happened twenty times, from what is recallable. Out of these, the SO was home eight times. It is important to emphasise that these probabilities only inform that if the current state is positive (the SO is home), then the probability for a positive next time one comes home early is eight out of twenty (two out of five). The HMM model is based on transition probabilities so that the transition from one state to either itself or another is what is important. From the observations in Fig. D.1, it can be shown that if the SO is home, there is a 25% (two out of a total of eight) chance for another positive next time one gets off early, but 75% chance for a negative. However, if the SO is currently

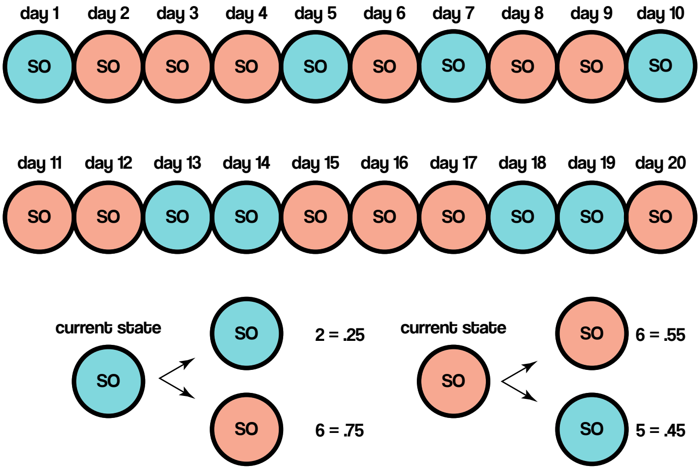

*Figure D.1—The blue nodes designate when the SO is home (positive), while the red nodes designate when the SO is not home (negative). Out of twenty days where one has come home earlier, the SO has been home eight times. Each of these designates a single state; thus, the transition from one to another can be counted to establish transition probabilities. The number of transitions sum to the total number of observations minus 1, whereas the percentages must sum to 1 in each state. It can be shown that if the current state is positive, there is a 25% chance that it stays positive, while 75% that it turns negative. If the current state is negative, there is a 55% chance that it stays negative, while 45% that it turns positive.*

not home, there is a 55% chance for another negative the next time, while a 45% chance for a positive. These are the *transition probabilities*, i.e. the probability for a transition (Fig. D.1).

The transition probabilities belong not to the observations per se, but to the HMM in the sense that the lights have not entered the model yet. The observation of the light condition at home relates to the HMM through conditional probability. The condition of the light is the observation, while the state of the SO, being home or not, is the hidden state that needs to be inferred—therefore, it is vital to know a priori the *emission probability* that refers to the emitted states, namely whether the

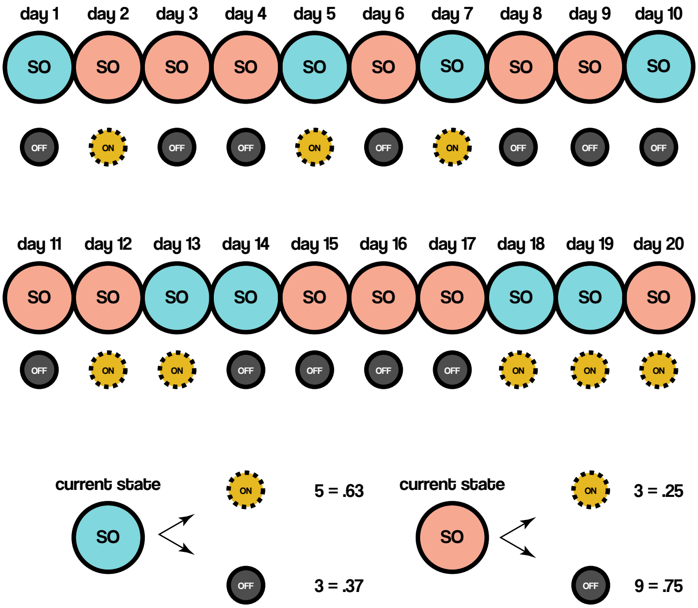

*Figure D.2—The emission probabilities are found by calculating the distribution of when the lights were on, or off, given a specific state. When the SO was home, the lights were on five out of eight times, where when the SO was not home the lights were still on one out of fourth. The lights were off while the SO was home three out of eight times, while they were off three out of four time while the SO was not there.*

lights were on or off (Fig. D.2), and as this is an observation it can also be gathered from the data, i.e. prior experiences. To be clear, the transition probabilities refer to the transition of the state in the HMM, while the emission probability refers to the probability, given a state, a specific outcome is emitted.

When combining the transition probabilities and the emission probabilities, the total HMM emerges (Fig. D.3). From here, different expectations can be derived. For one, consider the question from the example above; standing outside, and the lights are on, what is the probability that the SO is, and is not, in the living room? It was demonstrated above that Bayes’ rule can estimate that probability, but it can also be shown using HMM. In the case of estimating the probability of a single day, the transition probabilities can be disregarded, leaving only the emission probabilities. The prior probabilities are known, namely 2/5 (0.4), for when the SO was home, and 3/5 (0.6) for when the SO was not home. For a positive, there was a 63% chance of the lights being on, while only 37% being off. For a negative, there was a 25% chance of the lights being on, while 75% being off. To calculate the probability that the SO is home given the lights are on:

$$\frac{P(SO) \cdot P(Light|SO)}{P(Light)} = \frac{0.4 \cdot 0.63}{0.4} = 63\% \tag{D.3}$$

$$\frac{P(\cancel{SO}) \cdot P(Light|\cancel{SO})}{P(Light)} = \frac{0.6 \cdot 0.25}{0.6} = 25\% \tag{D.4}$$

The SO is home 2/5, and when the SO is home, it was shown that 63% of the time, the lights were on and finally the probability that the lights were randomly on was 2/5. In sum, there is a 63% chance that the SO is home when the lights are on. In the case of the lights being on, but the SO not being home, there is a 25%, using the same reasoning. Therefore, the HMM is inherently using Bayes' theorem to infer the hidden state, which is precisely why HMMs are considered dynamic Bayesian networks.

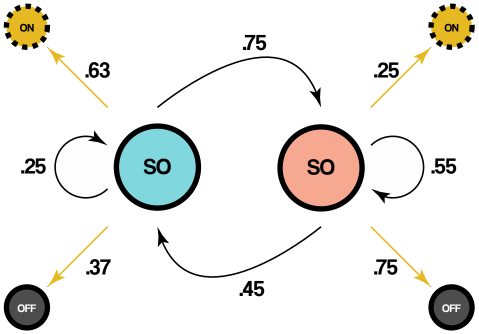

*Figure D.3—The total HMM, including emission and transition probabilities.*

As mentioned in the example, the probabilities change as one approaches the entrance because there are tons of perceptual cues available, revealing the hidden states better. In cases of transitions, there are by definition not a static calculation but rather a sequence of calculations and these can also be cast through HMM. As one is approaching the entrance, it is no longer the condition of the light alone, which informs the experiencing agent. Instead, several new perceptual cues can provide information, e.g. shoes outside the door, trash outside the door, jacket hanging in the entrance, keys on the table in the entrance and a workbag in the entrance. These cues are exemplified here through the Viterbi algorithm, which is a dynamic form of programming where likelihoods are not calculated to the end but where the maximum likelihood is estimated on the go—hence, *maximum likelihood estimate.*

To infer the sequence of the hidden states, it is necessary to estimate the likelihood of the transitions. As there are many transitions in this particular model, consider a single example of a transition (Fig. D.4). As it has been demonstrated how priors are found, so for simplicity, the new priors are mere assumptions to enable the example. In theory, the observation of lights being on followed by no shoes outside the door, which decreases the probability of the SO being home, can be sequences of [positive, positive], [positive, negative], [negative, positive] and [negative, negative], that is, a total of four different sequences of inferred hidden states. For the sake of the example, Fig. D.4 illustrates the probability of the sequences, where the model selected is the model that is most likely to make the observations happen—once again, maximum likelihood estimation. The model selected in Fig. D.4 states that the observation that the lights were on followed by the observation of missing shoes outside the door yield the sequence of believing the SO is home, then not believing it.

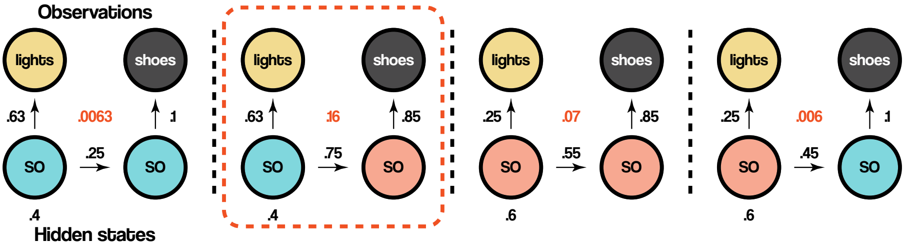

*Figure D.4—Notice that all observations are the same and that the HMM attempts to infer the sequence of the hidden states. Four different possibilities are considered where the model with the highest likelihood is selected—hence, maximum likelihood estimation. Note that the probabilities for the missing shoes are assumed and not introduced until this diagram. The red numbers in the centre of the sequences are the products of the models, i.e. the likelihood.*

The sequence (chain) of the hidden states can be considered virtual sequence as they are all just as real as one any other, but only a single model is selected, namely the one with the highest likelihood from which a path appears. In Viterbi's algorithm, the likelihood estimation is dynamic in the sense that the model is selected on the go. Examine the sequence of observing that the lights are on, the shoes are missing and so is the trash outside, and as one enters, the jacket is not there either, but the keys and the workbag are there. The HMM can aid the unfolding of inference of the hidden states as one transits from one space and expecting the next one (Fig. D.5).

The chain unfolds so that the initiate state is either that the SO is home, or not. In case of a positive, the transition from positive to positive continues but competes with the case that if the initiation was negative. Ultimately, the chains have two competing models as new cues accumulate, where the model with the highest likelihood is always continuing. Eventually, choosing the highest likelihood yields a path (Fig. D.6), or sequence of beliefs that may describe the experiential transition. According to the HMM, observing that the lights are on, there is good reason to hold a positive belief, but the missing shoes tilt the belief towards a negative, and so does the missing trash and jacket. However, the keys on the table and the workbag in the entrance reassure that the SO is in fact home from work, but perhaps not in currently in the living room. This is how HMM can be applied to expect spaces.

In the case of active inference, the hidden state is the environment and the observations are all the sensory observations. The approach in the case of active inference is based on the free energy, i.e. the approximation of the posterior, and collects new evidence by informed actions, i.e. affordances, and given the current research question, this is precisely why active inference is attractive. Nonetheless, Viterbi's approach and active inference are both Bayes' optimal behaviour, which is criticisable for casting human behaviour as absolute rational at all times.

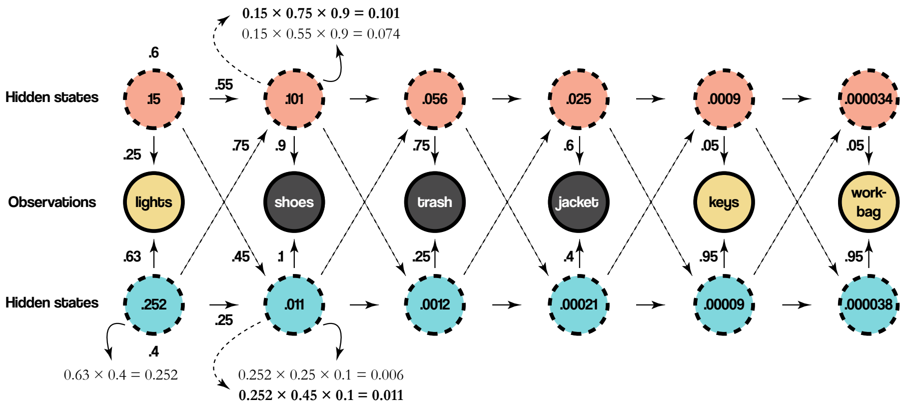

*Figure D.5—The black nodes designates the fact that the object is missing. The dotted diagonal line would be the competing models, i.e. if the prior state was different. The numbers inside the hidden states are the maximum likelihood probabilities for each observation. The chain is initiated by the product of the P(SO) × P(SO | Light), which is the same as 0.4 × 0.63. The probability for the next state to be positive depends on the next observation, which in this case is the missing shoes that yields a mere 10% chance to continue believing that the SO is home. The probability for another positive is thus the product of the selected model, the 25% known from Fig. D.3, and the new 10%. This model would compete against if the initial state were negative.*

## D.4 Darkroom problem

The darkroom problem refers to the criticism directed against a Bayes-optimal behaviour in human beings (Friston, Thornton and Clark, 2012). Applying Bayes' theorem to the process of action-perception yields a system of inferences that are informed by affordances and virtual actions—however, these have neuronal and cellular costs, particularly if the environment is challenging the homeostatic balance. According to the Bayes-optimal framework on behaviour, whose objective is to minimise surprise over the states and outcomes, why should a human being not constrain its environment to a dark room, which is always perfectly predictable? A series of objections can be raised.

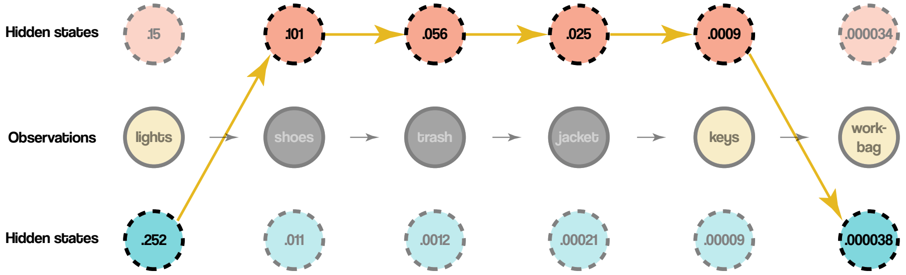

*Figure D.6—The final path emerges when choosing the states with highest likelihood.*

Firstly, if the visual perception matters to the minimisation of expected free energy, then why does one not just close the eyes? This issue frames perfectly the darkroom problem in FEP. Although in the current context, FEP is utilised to describe intuitive processes rather than intellectual ones, it is clear that closing the eyes will not yield any minimisation of expected free energy—one might argue the opposite. The fact that one does not know what is going on in the world is a terrible position of the experiencing agent. Closing the eyes does not reduce uncertainty, but increase it.

> *"More formally, there is a fundamental difference between the intuitive meaning of 'surprise' in terms of unpredictable sensory input and surprise (in information theoretic terms) under a particular model of the world. Finding ourselves in a dark room (and being subject to a surprising sense of starvation and sensory deprivation) is a highly surprising state, even though it represents an environment with maximally predictable sensory input." (Schwartenbeck et al., 2013)*

Bayes-optimal behaviour is limited. To predict the intellect by Bayes' theorem, is arguably difficult, as the Bayes' theorem supposes the individual to execute strictly action that minimises free energy, i.e. improve chances of living. However, it does not take much time to observe in the real world the number of people using their cell phones while driving despite knowing it increases chances for an accident. People behave irrationally regularly. In the example above, the rational estimation of the sequences of beliefs are estimated using HMM, but in reality, the sequence of beliefs could have unfolded in another virtual sequence due to picking up other perceptual cues that were not integrated into the HMM. Indeed, regarding intellectual processes, the Bayes-optimal estimation is criticisable—however, when applying it to the intuitive, practical processes, i.e. action-perception, it is reasonable to assume that the world is attempted at all times to be constructed with the lowest uncertainty. No matter how hard one attempt (intellectually) to construct the sensory observations of Bergson in person, he will not show up, except when having an illusory experience (Chapter 11).

Secondly, the darkroom is not a predictable room—a light one is. The behaviour is naturally to seek how to turn on the lights, and once the lights have been turned on, one is situated in a more certain world. This should arguably reduce uncertainty about the world. Nevertheless, as one is then situated in the world, space offers affordances and virtual actions that need to be considered. The process of actively inferring the hidden states of the world is thus immediately initiated.

Thirdly, the absolute limit of FEP is the intention-barrier, i.e. it is not possible to simulate free will or intention. FEP attempts to predict the intentions by predicting action but is usually guided by a task that becomes the intention. For instance, if an individual completes a task, it may be assumed that the task is within the intention of that individual. This issue is particularly visible in the discussion of adjusting virtual action and affordances. One offers all the virtual interaction that might take place, but the affordances reflect the goals of the agent that are generated by a will, an intention to act. The virtual actions may be easily given, but the affordances depend on the intention. To overcome this barrier is to design a brain and body beyond homeostatic balance. According to FEP, it may be hypothesised that the issue can be overcome with sufficient Markov blankets to initiate the emergent property of an intention, which in turn is based on prior experiences. For now, this is considered an intractable problem of consciousness.

# APPENDIX E

# A walkthrough of active inference

## E.1 Introduction

This appendix provides a walkthrough of active inference as described in the free energy principle. The example demonstrates how action is inherently related to perception so that the prediction in perception is based on *expected free energy* stemming from the virtual actions. Once again, this appendix is highly statistical and assumes basic probability theory and mathematical skills. The equations used are based on Chapter 10 and several of Friston's papers (Friston, 2010; Friston *et al.*, 2010, 2015, 2016; Bogacz, 2017)

## E.2 Walkthrough of active inference

Appendix D demonstrates how HMMs function on an intellectual level—however, it is here attempted to transfer the concepts to active inference and demonstrate how action-perception emerges on an intuitive level. Virtual actions are here ideal to discuss first because they guide perception relative to practical knowledge. When introducing the continuity of action as it immediately unfolds, it results in new ranges of virtual actions that interpenetrate temporally, so that each action generates a continuous range of new informing actions. In other words, pragmatic action as a whole sequence is a set of infinitesimal epistemic actions. This continuous development of virtual action has been approximated by Cisek (2007) as a hierarchical affordance competition (HAC), where TD sensorimotor trajectories inform the upcoming signals continuously as a sequence, or a set, of proprioceptive predictions. For instance, to perceive what is in the next room, one walks towards it without much effort in planning each step. These intuitive steps, which continuously follow one another, constitute a single virtual action and is based on prior beliefs. Thus, virtual action is the equivalent of proprioceptive predictions packing motor trajectory, which in turn is an action policy, namely $\pi$. It is important to note that in the upcoming example, it is not a matter of a single action, but of a sequence of action understood as an action policy, which is continuously subject to change from moment to moment, e.g. given an unforeseen step one is able to adjust to the new encounter. During active inference, a number of virtual actions continuously compete forming a metastable dynamic system involving varying attractors. This has been coined as a *winnerless competition* (Afraimovich, Rabinovich and Varona, 2004; Afraimovich *et al.*, 2008) where the attractors (the competing virtual actions) are used to generate new predictions as time goes (theoretically) to infinity. The path between virtual actions is thus subject to change dynamically. Consider the example below.

### E.2.1 Virtual actions in active inference

While $F$ refers to *current* free energy (Eq. 10.10 and 10.11 in Chapter 10), $G$ refers to the *expected* free energy (Eq. 10.1), which is the about-to-become $F$. Tautologically, by selecting a virtual action that best minimises $G$ means to have a minimised $F$ in the next moment. First, the example illustrates how perception minimises $F$, and as perception minimise $F$, action and virtual action minimise the expected $F$, namely $G$.

For simplicity, consider the conundrum posed in Chapter 3, and assume that the experiencing agent believes the environment can only have three environmental states for a transition from *space A* to *space B*, namely a wide, a mid-sized and narrow door width. Further, it is assumed the agent expects to be easily able to transit, i.e. higher priors of wide and mid-sized doors. $P(s)$ designates these prior beliefs based on earlier experiences (Fig. E.1—and see Appendix D). The likelihood, $P(o \mid s)$, designates the *probability* of observations given a state, e.g. either in state wide/mid/narrow, and the *likelihood* given an observation, i.e. how likely the observation is given a state. Once the agent observes the door width, the likelihood $P(o \mid s)$ updates the prior $P(s)$—this is expressed by multiplication, namely as the joint probability $P(s, o)$. The value of model evidence, $P(o)$, reflects how likely the current observation is under this model, and as one keeps modelling the environment, using models instead of hidden states, one would eventually end up with priors over models generating posterior beliefs over models given the observation. This would be the ideal scenario (blue part of Fig. E.1)—however, because there may be an infinite amount of hidden states, active inference suggests that through inference one can approximate the joint probability by minimising a measure of divergence, namely free energy $F$ (Eq. 10.8 in Chapter 10).

The approximation evaluates first the virtual actions as the predictions depend on the probabilities of all the virtual actions, $P(\pi)$. Given three different types of door transitions, the agent has three different virtual actions where—when given a policy—yields three different approximate priors. Selecting, for instance, the second virtual action, the variational free energy includes the new priors the virtual

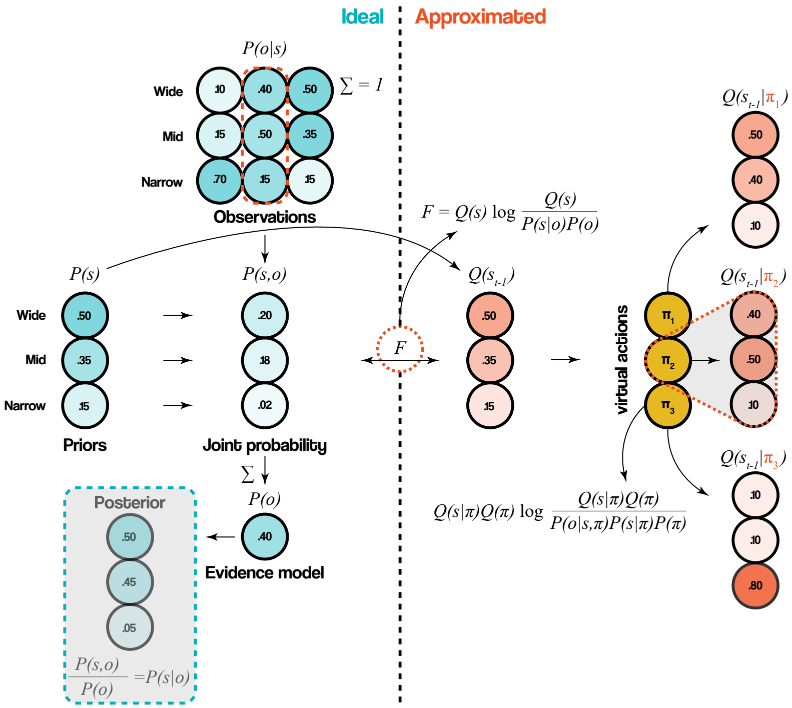

*Figure E.1—A practical example of active inference and the generation of virtual actions. Given a hidden state, Matrix A constitutes the parameters of the likelihood and probability of an outcome (probability sums to 1 of all possible outcomes). In an ideal scenario, the number of hidden states is known (as shown in the dashed box labelled 'Posterior')—however, this is not the case in the real world. Instead, the approximation is used as a point of departure for an upper bound on the surprise (free energy). The matrix B specifies the probabilistic transition among hidden states functioning as virtual actions (action sequences/action policies). Adding the virtual action to the joint probability and the approximated posterior in the nominator integrates the virtual action into the free energy. Ultimately, this process yields a prior probability that an outcome will be observed.*

action offer (Fig. E.2) and further unpacks the posterior. As mentioned several times, in action there is sensory prediction, despite the sensory not being observed yet. Therefore, during t-1 (t minus one), the approximated probability considers a virtual action, so to minimise the expected free energy $G$ through action. The prediction is the approximated priors multiplied with the transition matrix, which is usually referred to as *matrix B* in active inference papers (Bogacz, 2017). The transition matrix allows predicting the upcoming time step depending on the virtual actions' minimisation of expected free energy. Note, one chooses not one single virtual action exclusively, but it is instead a looping process of a winnerless competition, offering multiple virtual actions on the roll, so that one may adapt to an unexpected event (such as that of an unexpected doorstep or unexpected space after a transition). Both action and perception are continuously updated with improved precision as the virtual actions compete against one another. Once a virtual action is not minimising free energy, it increases uncertainty and thus lowering precision and lowering the probability of being enacted.

The product of the approximated prior (given a chosen virtual action) and the likelihood yields a new matrix A, namely the joint probability for each observation and state. Normalising the joint probability generates the evidence model, which in turn determines the posterior beliefs. The process of active inference is not self-erasing in the sense that any loop in active inference demands one to forget the link between posterior and prior; in fact, that is precisely what active inference does not. Prior preferences, P(o), is established over time as a mechanism of survival and adaptation since the experiencing agent must have done sufficiently right to be in time where the agent is. Prior preferences are coloured by what is known (experienced earlier) to have been beneficial in a similar situation. Therefore, prior preferences are multiplied with the posterior beliefs, yielding now a joint probability of the future (expected free energy, or simply, *G*, i.e. Eq. E.1). This happens for each action policy, where the selection depends on which action policy best minimise the difference of what is expected to be perceived and the ambiguity of what one is to perceive if unfolding the action, i.e. the KL-D.

$$G(\pi, t) = KL[Q(o_t|\pi) \,||\, P(o_t)] + \sum_{t} Q(s_t|\pi)\, H\, [P(o_t \,|\, s_t)] \qquad \text{(E.1)}$$

As the virtual action become real action, a continuous loop of active inference and winnerless competition is on a roll, adjusting precision of predictions and minimising free energy (Eq. E.4) while acquiring sensory observations (Friston, Mattout and Kilner, 2011, sec. 3).

Using the model evidence that is based on deeply subjective preferences, it can be seen that the outcome suggests a possible ambiguity between a mid-sized door and a wide door, where, at the current time, a narrow door is out of the question. The mid-sized door and wide door closely compete as one acts towards the door until precision increases or uncertainty decreases.

### E.2.2 Precision, expected free energy and virtual action

Given Eq. 2 and Fig. E.2, while perception optimises predictions, then action minimises prediction errors, and this adds to the argument that action and perception are hardly separable. They are moulded, intertwined and integrated into the very same process. Their sophisticated relation witnesses their contribution to the dynamic system inherently evident in the brain and body. Although rearrangements of the equations may be helpful, it is essential to note that active inference holds a particular philosophy of self-evidencing (Fig. E.3), namely internal states are never directly in contact with the environment, but their relation is describable through inferences of hidden states. When translated to the research question, the architectural transition is the hidden state of the experiential transition, which is inferred using virtual action the architectural transition has to offer and prior experiences.

It comes down to minimising expected free energy through the selection of

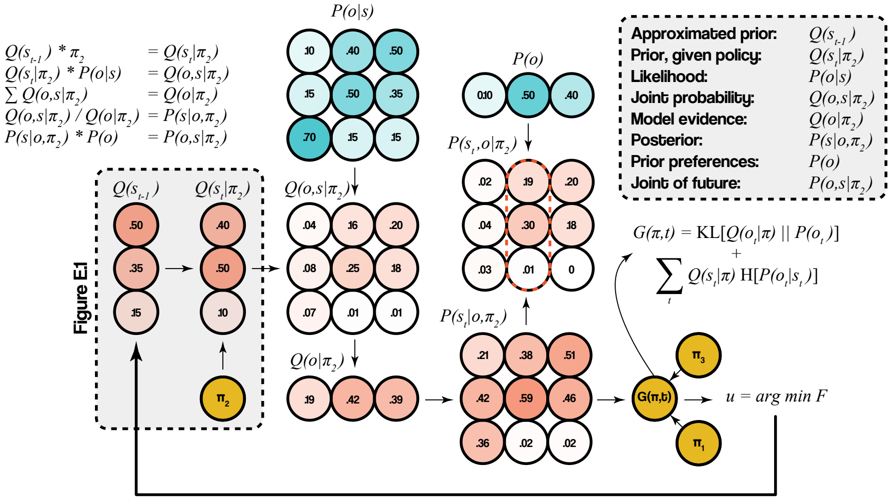

*Figure E.2—This is the continuation of Fig. E., where the priors are approximated using a virtual action. The process is then identical to the ideal case in Fig. E.1 (the blue part), i.e. multiplied with the likelihood of observations. The sum of the joint probability represents the model evidence, which is used to find the posterior beliefs given a virtual action. Prior preferences take the role of the history of the experiencing agent and are deeply subjective. The joint probability of the expected free energy, G, will help ensure a lowered free energy, F, in the process. This is precisely how action guide perception and/or action manipulates perception, namely, through the selection process of virtual action relative to efficiency in minimising expected free energy. The dashed red line shows what* $\pi_2$ *suggests to be observed based on deeply subjective preferences.*

virtual actions to uncover the architectural transition. In turn, the selection of virtual actions depends entirely on the expected free energy. A virtual action can thus be defined:

$$\pi = \arg\min_{\pi} G(\pi) \tag{E.2}$$

$$Q(s,\pi) = Q(\pi_n)\prod_{t}^{n} Q(s_t|\pi_n) \tag{E.3}$$

Eq. E.3 states that the approximated probability of the hidden states considers all action policies, achieved by averaging states over policies using the softmax function. Because active inference treats selection among virtual actions ($\pi$) as a Bayes model selection problem, which is basically to select the virtual action that best minimises the expected free energy, $G$, one may apply a softmax function to convert $G$ into a probability distribution and multiply it with a precision factor. This eventually yields:

$$P(\pi) = \sigma(-\gamma \cdot G(\pi)) \tag{E.4}$$

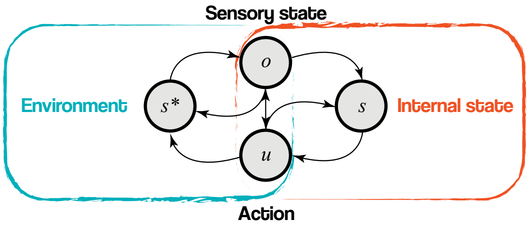

*Figure E.3—The environment (s*) has a reciprocal relation with the sensory outcome (o), which in turn informs internal states (s). The internal states then guide action (u), or is manipulated by action by changing the observable environment. This is the general self-evidencing strategy for active inference.*

Eq. E.4 describes the prior belief over a specific policy where gamma, $\gamma$, designates the precision, i.e. the confidence of the expected free energy under a specific policy, and sigma, $\sigma$, designates the softmax function (Parr and Friston, 2017). The precision holds a critical role in the selection among virtual actions because it comes to take the role of an intention, i.e. practical intention. Thus, the precision may be changed depending on how the agent seeks to interact with the environment. Although the precision under a virtual action becomes the affordance-value, it is worth noting that it is based on epistemic and pragmatic values in the expected free energy (Fig. E.4). The precision is an important character to evaluate in neurobiological terms, and thus a topic that is discussed in Chapter 11. It is important to remember that active inference always involves distributions that can be displayed. Fig. E.4 display how the different virtual actions may affect the posterior.

The tautological, self-evidencing loop between internal states and the environment is a natural pattern that inevitably emerges from human nature. However, the limitations of active inference must equally be understood; active inference neatly

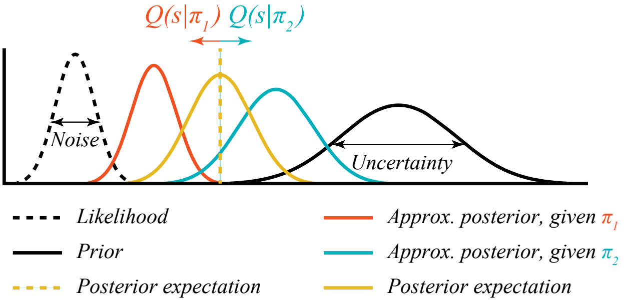

*Figure E.4—The dashed black distribution designates the likelihood of sensory evidence of a hidden state, and the solid black distribution designates prior beliefs relative to the hidden state. Regarding the coloured lines; the dashed yellow vertical line designates the approximated posterior expectation. The width designates the dispersion, which is the inverse of precision. The precision can determine whether the posterior belief is biased towards the prior (solid line) or the sensory evidence (dashed line). The density of the approximated distribution is what refers to the affordances of an action, whereas the set of competing actions refer to the virtual actions. The approximated posterior in red ($\pi_1$) designates an example of a bias towards priors, whereas the posterior in blue ($\pi_2$) designates a bias towards sensory evidence.*

describes neurobiological mechanisms and exercise a correspondence between variational Bayes optimal models and biological processes. Nevertheless, active inference must not be thought of as an explicit process theory unfolding in the brain, as if the brain and body were literally constituted by Kullback-Leibler divergence and softmax functions. Instead, active inference describes a statistical framework yielding a variational Bayes optimal model describing human cognitive processes.

# APPENDIX F

# Supplementary Information to Chapter 12:

## Sensorimotor brain dynamics reflect architectural affordances

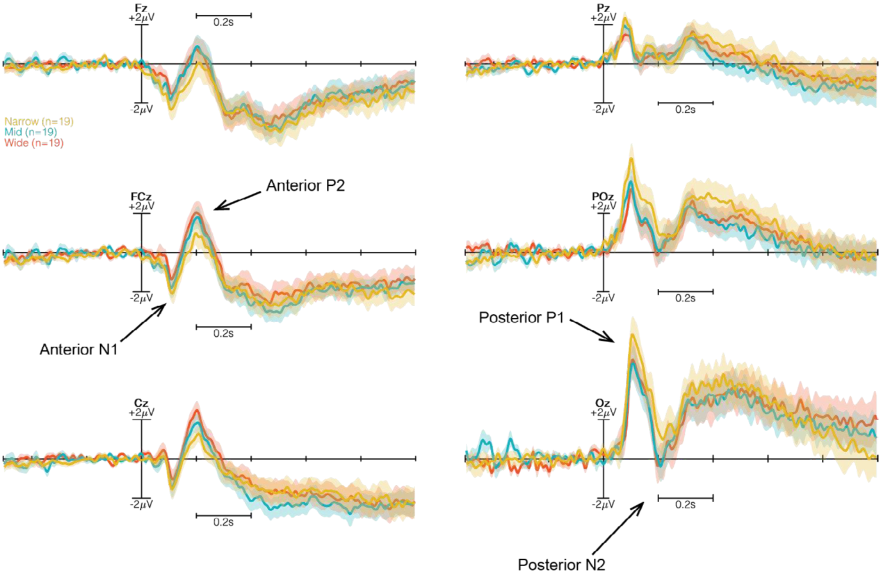

*Figure F.1—ERP plots of "Lights On" stimulus for all six channels (Fz, FCz, Cz, Pz, POz, and Oz). Narrow condition in yellow, Mid condition in blue, and Wide condition in red. N1-P1-complex are marked with arrows.*

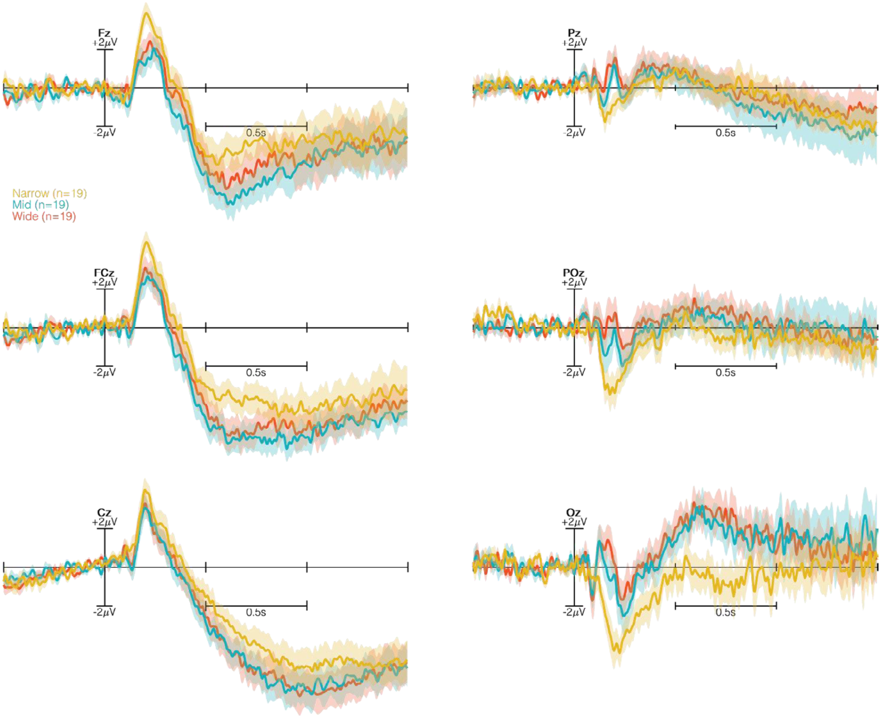

*Figure F.2—ERP plots of the total six channels only for Go trials. ANOVA with repeated measures of time-locked ERP, where the increasing darkness behind the plots indicates the increasing level of significance. The repeated measures ANOVA revealed Fz (F2, 36 = 4.546, p = 0.0174), FCz (F2, 36 = 7.116, p = 0.0025), Cz (F2, 36 = 4.116, p = 0.0236), Pz (F2, 36 = 0.089, p = 0.915), POz (F2, 36 = 1.708, p = 0.196), and Oz (F2, 36 = 14.39, p < 0.0001). We observed no difference for NoGo—however, we observed a difference within fronto-central and occipital sites for Go trials.*

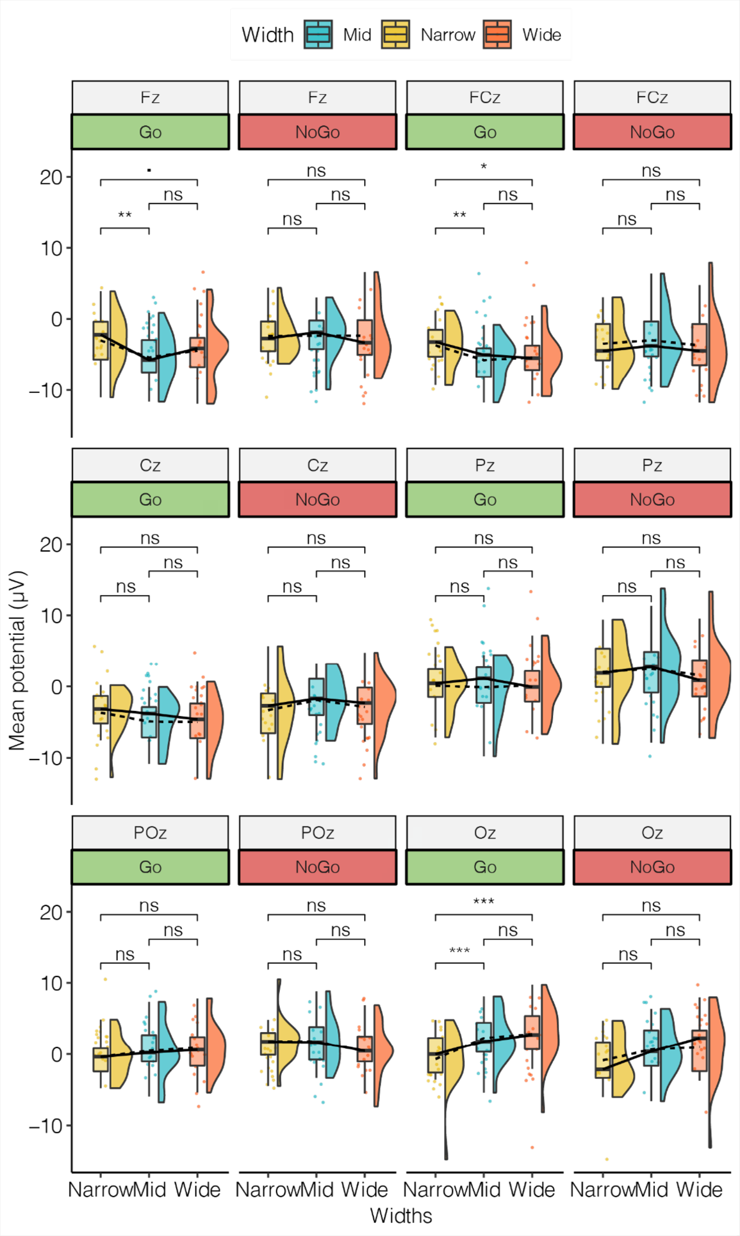

*Figure F.3—Rain-cloud plot of the mean amplitude of selected six channels between 600 and 800 ms post-imperative stimulus – PINV component. Means are indicated by dashed line, while medians are a solid line. We compared (Tukey HSD) the Width within Go and NoGo conditions, and observed only significant differences for the Go condition. We observed differences within fronto-central and occipital sites.*

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