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Toward an information theoretic ontology of risk, resilience and sustainability and a blueprint for education - part II

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ABSTRACT
The concept of risk as the theoretical and methodological basis forinformation- consistent ranking of decision alternatives is centralto safe, sustainable and resilient societal developments. However, due to significant disparities in the understanding of the concept ofrisk in academia, and in its application in governance and industry,we argue that a new paradigm for risk must be established. In asequence of three papers (Part I, Part II and Part III) we take upthis challenge, with the leading objective of providing a coherentfoundation for the further development and transfer of the generalbody of knowledge relevant to governance of risk, resilience and sustainability – through research and education. Part II (the presentpaper) provides a logic for the structuring of the knowledge domainin terms of a domain ontology of the concepts relevant for anintegrated science of risk, resilience and sustainability.

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Risk; resilience; sustainability; risk governance; domain ontology; embodied cognition; philosophy of education; learning design

1. Introduction

Societies at local and global scales are facing major challenges in the pursuit of welfare, safety, security, and even existence. Global trends of population growth, urbanization, depletion of non-renewable resources, and anthropologically induced climate change severely challenge sustainable developments. These trends, together with a host of natural and anthropological hazards, well represented by the recent outbreak of the Covid19, call for a disruptive improvement in governance at all levels of societal decision making.

The concept of risk stands in the middle of this challenge. It is well appreciated that risk forms the basis for optimal decision ranking when the outcomes of decisions are associated with uncertainty. However, risk has not been established as a knowledge domain in itself until now, and for this reason, there is substantial variability in how the concept of risk is understood across sciences and application domains. Conceptual knowledge underlying the knowledge tradition of risk is unsystematic and disorganized. It stems from a spectrum of disciplines and application areas spanning engineered, social and environmental systems, but despite the generic structure of the procedures, concepts and terms are poorly, if at all, defined, and definitions are widely divergent across applications. The growing acknowledgement of the generic characteristics of the concept of risk, and risk-based analysis as the only legitimate form of evidence in support of ranking of individual and collective decision and actions, however, supports the perspective that the subject matter of risk might be seen as a science in its own right rather than a specialization within established, individual disciplines.

The integration of risk, resilience and sustainability considerations into a common conceptual and operational framework is at the vanguard of research. It is now at this early stage of integrating these knowledge traditions that a common conceptual classification system needs to be established, that is generic and captures the theoretical foundations upon which knowledge of risk, resilience and sustainability can build on.

We here endeavor to take a first step in establishing a more formal basis for the continuously evolving knowledge domain of risk in the context of societal governance for resilient and sustainable developments.

To this end, in a triad of papers (Part I – Part III[1]) we:

(i) Outline an approach and a methodical basis for representing the knowledge domain of risk, resilience and sustainability science (Part I);
(ii) Establish an ontology for the integrated knowledge domain of risk, resilience and sustainability (Part II) and;
(iii) Identify educational requirements, and together with the results of Part I and Part II, finally provide an blueprint for the design of educational offers (Part III).

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The overall structure and contents of the triad of papers is illustrated in Figure 1.

The present paper, i.e. Part II, is organized as follows: In Section 2 we compare and contrast alternative structures for knowledge organization. We contrast the present best practice of compiling glossaries of terms as structured or unstructured lists with the advantages of more sophisticated structures, such as taxonomies and ontologies. We explain, in non-technical terms, differences between taxonomies and ontologies as well as genealogical, radial and mereological hierarchies. Further, we provide background on relevant theoretical concepts from embodied cognition that we use as anchors for the classification choices we have made in designing the ontology: family resemblance, prototype effects, and basic level categories. In Section 3 we present the ontology and briefly discuss the themes covered by its four dimensions. In Section 4 we give an overview of the sources and methods for selecting concepts for the ontology. In Section 5 we discuss what it means to know a concept and what a definition is. Subsequently, we provide an overview of the paradigmatic framework of embodied cognition, which we have used as a structuring principle of the ontology and key terms such as image schema and conceptual metaphor are introduced and explained. In Section 6 we discuss the image schemas and conceptual metaphors that correspond to the categorical pairs in the ontology and how selection of the source domain of metaphors affects the boundaries of concept and system definitions. Section 7 attempts to establish a basis for a shared inter-cultural language between Western and Eastern conceptual systems. Finally, Section 8 offers a summary and reflections on the extent to which the ontology may provide direction toward a unified theory of risk, resilience and sustainability and a shared language among disciplines and cultures. A vision of this new science as a holistic life science is outlined, together with how the ontology can be used in the design of education.

2 Alternative structures for organizing conceptual knowledge informing design choices in the ontology

A knowledge domain can be organized to form very different structures, resting on different logical foundations, such as lists, glossaries and hierarchies, of which the latter type form the basis for the design of taxonomies and ontologies. In this section, we explain briefly, and in non-technical terms, how taxonomies and ontologies differ, and how different kinds of hierarchical structures affect design choices for building domain ontologies.

When items are classified through child-parent-grandparent relations, typically the structure is called a taxonomy and it resembles a genealogical tree. The function of a taxonomy is to classify an individual entity into a category of ascending (parent/more general) or descending (child/more specific) order. From Aristotle's system of categories to Darwin's theory of evolution via the Linnaean taxonomic system, classification of biodiversity in evolutionary biology has historically been based on the hierarchical tree structure. The system is an arrangement of morphological attributes by means of which plants, animals and minerals can be classified and identified through classes, orders, families, genera, and species. More recently, classification based on advances in molecular biology, uses genetic and molecular sequencing to structure variety. The concept of 'horizontal gene transfer' (Ouzounis, 2005), which describes the process of an organism incorporating genetic material from without (i.e. from another organism) rather than inheriting it from within (an ancestor), has uprooted the genealogical tree metaphor and replaced it with another structural metaphor – the network. The vertical hierarchy, whether top-down from general to particular or bottom-up from particular to general, has over the past two decades been replaced by the phylogenetic tree, whose horizontal hierarchy has been used to theorize structural arrangements as 'flat hierarchies' in multiple domains.[2] Both the tree and the network are

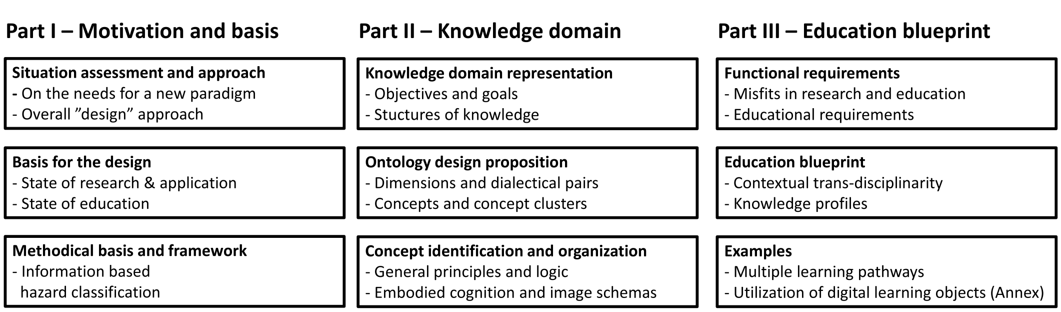

Figure 1. Overview of the structure and contents of the triad of papers presenting the information-theoretic ontology of risk, resilience and sustainability and a blueprint for education.

hierarchies in the sense that they classify relations among objects. However, while the tree has an internal structure of inherited relations, the network has a radial structure of family relations. By 'family', it should be understood any grouping, cluster or category where elements interact not on the basis of inherent shared properties but on the basis of functional relations. 'Family resemblance' is a notion introduced by mathematical philosopher Ludwig Wittgenstein to describe how concepts can be united in a common category without the pre-condition that they all share a common collection of properties; rather, in a family-like manner, some properties are shared by different members (Wittgenstein, 2009). The implication of Wittgenstein's observation is that category boundaries are not fixed but stipulated and that the only possible definition of a concept is ostensive. Both implications are of central importance to the design of the ontology presented in the present Part II and the education blueprint presented in Part III of this triad of papers. In the ontology, we choose not to provide definitions of the concepts, but to present the semantic range of a concept by means of displaying family-related concepts in a given concept cluster.

In the following, we explain how prototype theory of categorization can be used to structure categories radially by having basic level categories at the center of the hierarchy, with superordinate categories branching upward and subordinate level categories – downward. We discuss implications for this arrangement in terms of the role basic level categories play in the metaphorical transfer of meaning between image schemas and our design choice to visualize the ontology as a radial structure. The notion of basic level categories is, in fact, closely connected to the notion of family resemblance. It would be impossible to differentiate levels in a category if all category members shared the same common properties. Wittgenstein's demonstration that some members of a category are better examples is the foundational basis for Rosch's (1975) prototype theory and basic level categorization in experimental psychology. According to the latter, some members of a category are perceived and judged as being more representative of a category than others, resulting in asymmetries (technically called 'prototype effects') between members rated as more or less representative, with the most representative members referred to as 'prototypes'. These prototypes function as anchors or 'cognitive reference points' of inference Rosch (1975). However, unlike Wittgenstein's radial structure of family resemblance, which has no center or core, Rosch's experiments reveal that the middle level (i.e. the level of genus) is the primary level of organizing information, which is why categories at this level are called basic level categories:

Superordinate level – ANIMAL
Basic level – BIRD
Subordinate level – SWAN

Lakoff (2008) summarizes four characteristics of the basic level of categorization based on the empirical studies of Berlin et al. (1974/2013) and Mervis and Rosch (1981):

(i) Perception: Overall perceived shape; single mental image; fast identification
(ii) Function: The level at which a person uses similar motor actions to interact with category members
(iii) Communication: Shortest, most commonly used, contextually neutral words; first learned by children
(iv) Knowledge organization: The level where most attributes of category members are stored.

Basic level categorization is applied to the structure of the ontology presented in this paper (Figure 2).

The ontology's three levels: concept, concept cluster and dimension correspond to the subordinate, basic, superordinate levels from cognitive linguistics experimental and theoretical studies of Rosch, Lakoff and Johnson. This structuring enables a radial rather than genealogical hierarchy. The notion of family resemblance underlies the choice to not give prominence to any prototypical members of a concept cluster in order to avoid disciplinary bias. Prototype effects are instead treated in the context of their relation to image schemas (explained in Section 5.4), which govern the superimposed structural level of dimensional pairs, visualized symbolically as an ouroboros that groups the four dimensions into two complementary pairs. The ouroboros layer should be seen as the interface for a shared language between theoretical and cultural traditions. The 'core' of the ontology is thus the middle ring of concept clusters. The level of concreteness contracts inwards toward the subordinate scale of individual concepts, while the level of abstractness expands outwards toward the superordinate scale of dimension.

A major shortcoming of the genealogical hierarchy structure is that it cannot be used to represent a knowledge system, in which concepts may have more than one categorization. Furthermore, a category can fall into more than one branch. An ontology, in contrast with a taxonomy, is a more flexible structure in that its function, in addition to classification, is specification. In a seminal paper by Gruber (1993), an ontology is defined as 'an explicit specification of

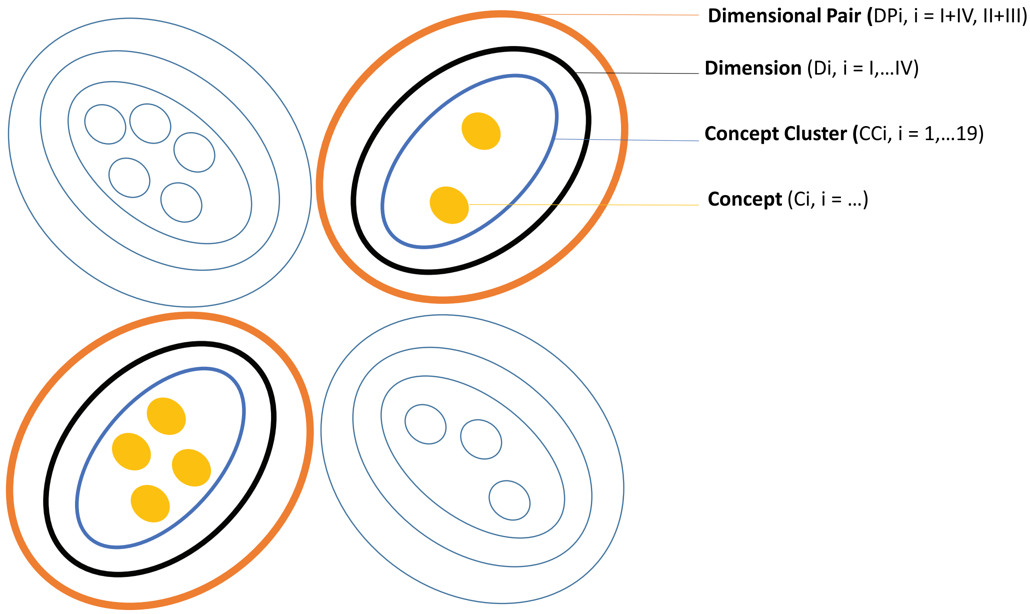

Figure 2. Skeleton of the ontology.

a conceptualization' and a formal ontology as 'the statement of a logical theory'. Writing in the context of artificial intelligence, Gruber's definition of ontology intuitively touches upon a significant difference in the subject matter of a taxonomy and an ontology. A taxonomy is typically used to organize physical (material) entities, whose existence is not questioned (see discussion on natural kinds in Section 5.3) and is accepted as a given. The data of taxonomies is thus typically plants, animals, materials, and artifacts. Ontology, as a branch of philosophy, is first and foremost interested in defining what exists, how it exists and how we can know that it exists. An ontology thus starts by defining what an entity is and only subsequently, how entities are organized in relation to one another. For example, when organizing entities x, y, z, a taxonomist's assumption is that there are 3 entities. An ontologist's first consideration is to arrive at a logic that proves that given x, y, z there are 3 entities or whether the combinations of these entities, in turn form new entities (e.g. x + y, x + z, y + z, x + y + z), or in other words, when a collection of entities forms an entity. The data of ontologies are con-cepts, information clusters, which derive from the physical realm of per-cepts. Taxonomies and ontologies have a dependency relation since ultimately the question of how many entities there are or exist only makes sense after a classification or sorting scheme has been assumed. This dependency underlies the position of pragmatic realism outlined in Putnam (1981, p. 1990).

Pragmatically, the function of an ontology is to facilitate a shared language among a variety of users with different knowledge bases (Gruber, 1993). In the context of our design, a shared language among disciplines and culturally different conceptual systems is an explicit functional requirement. The design of the ontology is then a precondition for fulfilling this requirement. An ontology, unlike a taxonomy, is a designed structure. A taxonomy is organized data. An ontology is not the data itself but the rules that define the organization. In the present paper, the rules for the proposed ontology are qualitatively described. In Part III of the triad, we discuss the possibility for formalizing these rules for the design of a repository of digital learning objects.

One further example needs to be made with regard to the choice of hierarchical structure. When an ontology is structured as an aggregate of individual forms (things, objects), the designed system is atomistic. The individuals are so-to-speak chiseled out of the undifferentiated matter (content). Such structures tend to be visualized as horizontally or vertically branching trees. When a taxonomy or ontology is structured as an aggregate of functions, the designed system is mereological and individual instances (spatio-temporal events) are subsumed by a nested set of containers. Such structures tend to be visualized as regions of bounded space. The difference between taxonomic and mereological classification is not straightforward due to a common cognitive tendency to confuse kinds and parts. Mereology (in philosophy and mathematics) is the study of parts and wholes. Figure 3 provides an explanatory illustration.

A taxonomic classification has ontological commitment to objects. An instance of a category is a kind of that category. It is differentiated from other instances in the category on the basis of form and its membership in the category depends on shared attributes of form with the other instances in the category. A swan is a kind of bird, not a part of bird. A tsunami is a kind of natural hazard, not a part of natural hazard.

A mereological classification has ontological commitment to events. Here the instance of a category is not a kind, but a functional part. Hence, tusk is a part of elephant, not a kind of elephant. Trust is part of social cohesion, not a kind of social cohesion.

In embodied cognition, PART-WHOLE is a basic image schema for organization of information based on human-environment interaction that is said to occur at precisely the basic level described in Rosch's theory of basic level categories. This claim is supported by experimental evidence from Tversky and Hemenway (1984), which shows that part-whole relations structure cognitive processes both with respect to objects and to events. First, with regard to objects, part-whole structures provide understanding of functions. Lakoff (2008) points out that we learn and reason about functions based on our sensorimotor interaction with the parts of objects. In the words of Tversky and Hemenway (1984): 'We sit on the *seat* of a chair and lean against the *back*, we remove the *peel* of a banana and eat the *pulp*.' The same embodied cognitive process is at the core of Gibson's (1977) theory of affordances that underlies the principles of form-function design as well as the ecological concept 'niche'. Second, with regard to events, part-whole interactions with the world also capture basic level actions, static states and dynamic processes.

3. Presentation of the ontology

Figure 4 provides a visual illustration of the ontology as a nested hierarchy, comprised of the elements concept, concept cluster, dimension, and dimensional pair. The color scheme is based on Opponent Process Theory of Color Vision (Hering, 1964). Visualization is a significant part of both the ontology and blueprint design. The use of color is not arbitrary and it aims to convey some of the logical principles of the design to potential end-users. In Nielsen (Nielsen & Faber, 2020) the principles and rules of visualization for the purpose of communicating design choices in the ontology and blueprint are discussed in terms of a visualization grammar that explains the choices for graphical elements (marks and symbols) and categorical and relational attributes (color hue, color saturation, and part-whole containment).

In the remainder of this section we briefly discuss the content of each dimension, while in Section 6, we present the conceptual structuring of the dimensions in terms of embodied image schemas.

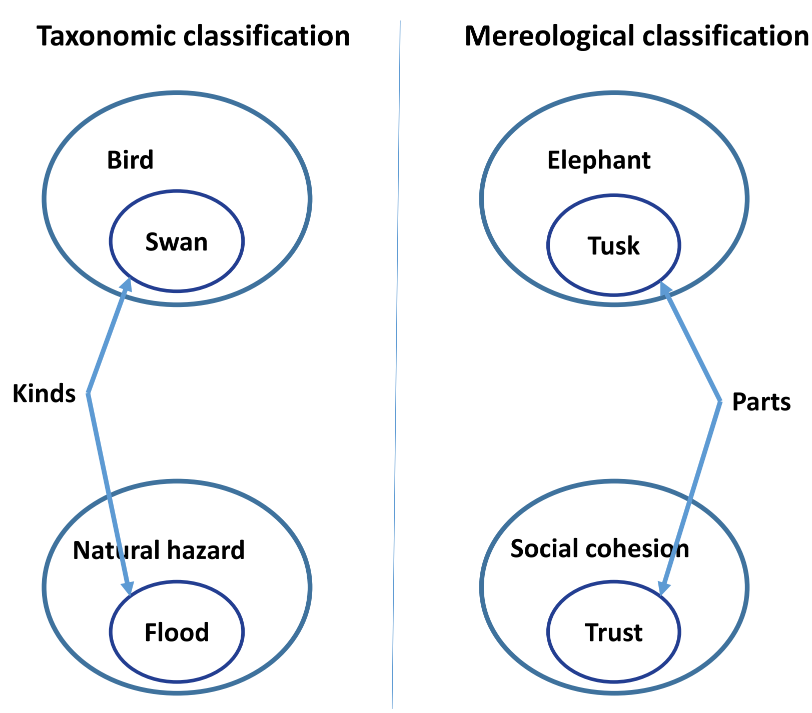

Figure 3. Illustration of the principal differences between taxonomic and mereological classification.

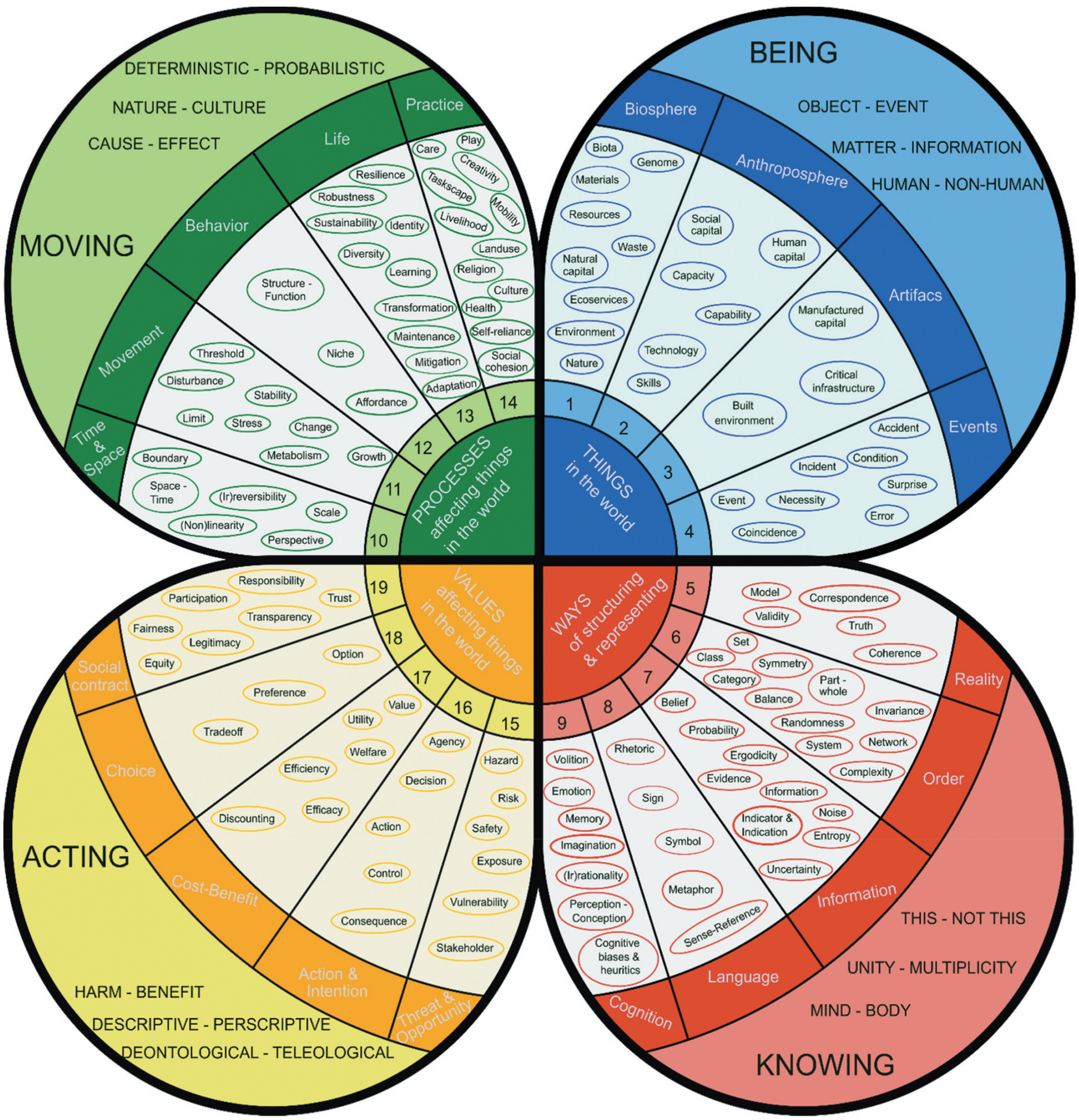

Figure 4. Ontology of the knowledge domain of risk, resilience and sustainability.

3.1. Dimension I – things in the world

This dimension deals with the ontological question of Being, or what the integrated knowledge domain of risk, resilience and sustainability is composed of, namely concepts denoting organisms, artifacts, resources, and events. Three additional categorical pairs overlay this dimension: object – event, matter – information and human – non-human. The first pair deals with the problem of whether the concepts denoting what exists refer to objects or to events. Do objects and events have the same ontological status? Is the difference between them one of kind or one of degree? What are the implications for acting in the world if we adopt a materialist object view of reality or an immaterialist informational view? While we have chosen to give equal ontological status to objects and events, the new hazard classification system based on information type places hazards in the event category (concept cluster 4) rather than listing individual hazards as separate objects.

3.2. Dimension IV – values affecting things in the world

This dimension deals with the axiological notion of Acting. In the context of risk analysis, action overlaps with decision. Axiology (from Gk *axios*, 'worthy') is the branch of philosophy that studies values – ethical and aesthetic.

The reason for pairing Dimension I with Dimension IV is that which hazards we select for consideration and how we define the boundaries of a system (choices made in Dimension I) has significant implications for the normative framework chosen to treat risk (choices made in Dimension IV). Three additional categorical pairs overlay Dimension IV: deontological – teleological, descriptive – prescriptive and nature – culture. In the following, we briefly explain how these relate to human actions.

Decision Theory is the inter-disciplinary science of action. Descriptive decision theory aims to describe how humans actually make decisions in reality. It has strong empirical roots in psychology and behavioral sciences. Normative decision theory is prescriptive. It is about how we ought to make decisions.

The purpose of risk management and governance is clearly normative. While descriptive decision theory can and does help to better calibrate models, the principles upon which normative decisions about risk must be made are based on considerations of utility.

3.3. Dimension II – ways of structuring and representing

Dimension II is about order and our perception of it. Philosophically, it relates to epistemology. Mathematically, it relates to set theory, statistics, probability theory, and information theory. Linguistically, it relates to semantics and semiotics. Empirically, it relates to embodied theories of cognition and affect theories. Each of these conceptual schemes is represented in the ontology through the respective clusters 'Reality' (5), 'Order' and 'Information' (6 and 7), 'Language' (8), and 'Cognition' (9). D II is about sense making: perceiving, orienting, learning, and knowing in the world and about the world. In developing this dimension as well as the ontology as a whole, our underlining assumption is that our only access to physical reality is by means of some kind of model. The choices we make in building our models define our reality. By defining a spatial and temporal boundary around a set of elements, we define a system. The boundary we draw influences our subsequent choices of which consequences and causal relations we take in consideration of the predictions we make about the behavior of a system. There are no systems in the physical reality. Systems are the structures defined by our models.[3] An assumption underlying the entire triad of papers is then the postulate that no matter what physical reality may be, our only access to it as humans is through perception. We concur with Wittgenstein that there are no systems out there independent of how we perceive and conceive them. Thus, we argue that systems – engineered, ecological, social, hybrid, etc. -are constructs of our embodied mind in interaction with an environment, a synonym for which in the present paper is 'a context'. This does not mean that systems are purely subjective constructs, for if they were, we would lack a means for interaction, a shared language. There are subjective elements to the choices we make in drawing a system's boundaries, but these choices are not arbitrary. They follow rules of structure – information rules. This underlies our choice to call the proposed ontology 'information theoretic ontology' and base its design on the information principle of matter-form-function.

The three additional categorical pairs of DII, mind – body, this – not this, unity – multiplicity underlie the choice of model free structuring and representation of reality.

3.4. Dimension III – processes affecting things in the world

Dimension III is about change and process – the dynamics of biophysical and human systems. The three additional categorical pairs cause – effect, deterministic – probabilistic and nature – culture are based on a number of embodied image schemas for movement and interaction of forces. A fundamental goal of risk management is to distinguish between hazards with trivial and non-trivial consequences for the integrity of a given system, where integrity is to be understood through the family-related concepts identity, robustness, resilience, and sustainability (concept cluster 13). Despite best practice methods for consequence modeling and rigorous scientific frameworks for assessing indicators and metrics (e.g. Planetary Boundaries framework, LCA methods, etc.), there is no such rigor when it comes to the rather more fundamental task of distinguishing the trivial from the non-trivial and the relevant from the irrelevant information. The concepts in concept cluster 10 (time, space, boundary, scale, perspective, etc.) are precisely those that provide information for orientation in space and time for us as moving observers in an evolving environment (context).

4. Matter

4.1. Where do concepts in the ontology come from?

The material basis for the ontology is a corpus of 0.5 million peer-reviewed articles indexed in the Web of Science for the domains of risk, resilience and sustainability for the period 1990–2017. Based on statistical data mining of this corpus, a finite set of 2634 terms (concepts) clustered according to a term's co-occurrence and link strength with other terms was derived and 26 cluster maps of the knowledge domain established (Nielsen & Faber, 2019).

Using cluster analysis as an objective and transparent method of concept selection is tempting indeed. It is clear to see in a cluster map which concepts have high occurrences and form stronger links, so they would be 'natural' candidates to be selected as the most important concepts in the domain. Such concepts, however, tend to be loaded with ideological content and disciplinary bias. Since our goal is to establish a generic representation of the concepts of relevance to the study of risk, resilience and sustainability regardless the application domain of such knowledge, the statistical data mining was complemented with a qualitative hermeneutic method of text interpretation to establish criteria for the selection of a term as a concept in the ontology. The criteria are established such that the logical consistency of selection and order is also coherent with functions and purposes of the ontology. These criteria are outlined in the following:

Criteria 1: MODULARITY

(i) Avoid, whenever possible compound concepts
(ii) Refrain from concepts referring to particular organisms, hazards or activities, so that concepts may be applicable across systems

In complex categorization, a set theoretical treatment of adjective-noun phrases is based on the operation of intersection. The clustering procedure in our bibliometric analysis is based on the co-occurrence strength of noun-noun phrases, which is syntactically the same as adjective-noun phrases. In the linguistic domain of semantics, the inadequacy of this method is demonstrated by a plethora of examples where the complex or compound concept is not an intersection of sets. Osherson and Smith (1981) provide some clear examples – 'small galaxy', 'electrical engineer', 'past president', etc., where the intersection, or in other words, the categorically common feature, of the set of e.g. small things and galaxies, electrical things and engineers forms a logical inconsistency. In our context, compound concepts such as 'circular economy', 'inclusive wealth', 'ecological resilience', 'engineering resilience', 'risk assessment', 'risk management', 'risk communication, etc. are excluded from the ontology even though in the statistical analysis they appear as central concepts. Typically, this means excluding noun phrases (noun + noun or adjective + noun) as they tend to particularize or instantiate a thing or phenomenon by discipline or by application area. For example, we have selected 'growth' but not 'inclusive growth', 'population growth'. We have, however, made an exception in the case of capital, and included natural, human and social capital as separate entities. This was done in order to comply with (ii) above to stay when possible at the level of genus rather than species.

Criteria 2: SYNONYMS

When faced with synonyms, we have chosen the one that most looks like a lay term. A lay term tends to coincides with the prototype (best or salient example) of a category, according to Rosch's prototype theory. For example, of the trio 'consequence', 'impact' and 'effect', we have chosen 'consequence' as we believe it is the term most likely to evoke association with the superordinate level concept 'causality', of which it is an instance. Furthermore, 'consequence' tends to appear in wider contexts, hence its perceived neutrality of usage in comparison with the other two terms. 'Impact' tends to be used in research dominated by social and political science, while 'effect' is the preferred term in the environmental sciences. There is also a tendency for 'impact' to be found in the context of human activities causing consequences while 'effect', in the context of natural counterforce.

Criteria 3: MISSING CONCEPTS

Given our academic and professional experience in the knowledge domain, we felt justified to introduce concepts in the ontology, which were not captured, or were not captured prominently, by the statistical analysis. In taking the freedom to include these concepts, our considerations focus on the instrumental purpose of the ontology as a basis for the subsequent development of the education blueprint.

Table 1 lists the concepts that were selected from the bibliometric study and the concepts that were added by the authors, organized in alphabetic order according to the dimension where they were allocated. Some of the selected concepts appear as members of a concept cluster; others designate a concept cluster.

The selection of concepts and their organization into particular clusters and dimensions has been highly iterative. Once a more or less stable form of the ontology emerged and was color-coded into the four dimensions (D I Things in the world, D II Ways of structuring and representing, D III Processes affecting things in the world, and D IV Values affecting things in the world), we applied the rules of the designed ontology to the full data set of the bibliometric study, classifying each term in the data set according to the new ontology. Figure 5 shows the distribution of concepts in the ontology before and after terms were selected from the bibliometric study.

Table 1. Ontology concepts derived from the bibliometric study and concepts added by the authors.

D I Things	D II Ways	D III Processes	D IV Values
Selected	Selected	Selected	Selected
Accident	Balance	Adaptation	Action
Biota	Complexity	Behavior	Agency
Capability	Evidence	Boundary	Benefit
Capacity	Indicator	Care	Choice
Condition	Information	Change	Consequence
Critical infrastructure	Language	Culture	Control
Ecosystem service	Model	Disturbance	Cost
Environment	Network	Diversity	Decision
Error	Noise	Emergence	Efficacy
Human capital	Order	Growth	Efficiency
Material	Perception	Health	Equity
Natural capital	Probability	Identity	Exposure
Nature	Sense	Land use	Hazard
Resource	System	Learning	Legitimacy
Social capital	Uncertainty	Life	Opportunity
Skills		Limit	Option
		Livelihood	Participation
		Maintenance	Preference
		Metabolism	Responsibility
		Mitigation	Risk
		Mobility	Safety
		Movement	Self-reliance
		Practice	Stakeholder
		Sustainability	Threat
		Resilience	Tradeoff
		Robustness	Transparency
		Scale	Trust
		Space	Utility
		Stability	Value
		Stress	Vulnerability
		Threshold	Welfare
		Time	
		Transformation	
Added	Added	Added	Added
Coincidence	Belief	(Ir)reversibility	Discounting
Event	Category	(Non)linearity	Fairness
Genome	Class	Perspective	Participation
Incident	Cognitive Biases & Heuristics	Structure-function relations	Self-reliance
Manufactured capital	Constants & Variables	Affordance	
Necessity	Coherence	Niche	
Surprise	Correspondence	Lifeworld	
Technology	Emotion	Play	
Waste	Embodied Cognition	Creativity	
	Ergodicity	Religion	
	Indication	Social Cohesion	
	Imagination	Taskscape	
	Invariance		
	(Ir)rationality		
	Memory		
	Metaphor		
	Part-Whole		
	Randomness		
	Reference, added to Sense as Sense-Reference		
	Relation		
	Rhetoric		
	Set		
	Sign		
	Symbol Volition		
	Symmetry		
	Truth		
	Validity		

This difference is informative of the extent to which the ontology presented in this paper is 'designed' vs the taxonomic kind of classification of the cluster mapping.

When we look at the research domain encompassing risk, resilience and sustainability over the past 30 years through the lens of our ontology, we see that research focusing on conceptual schemes related to values (D IV)

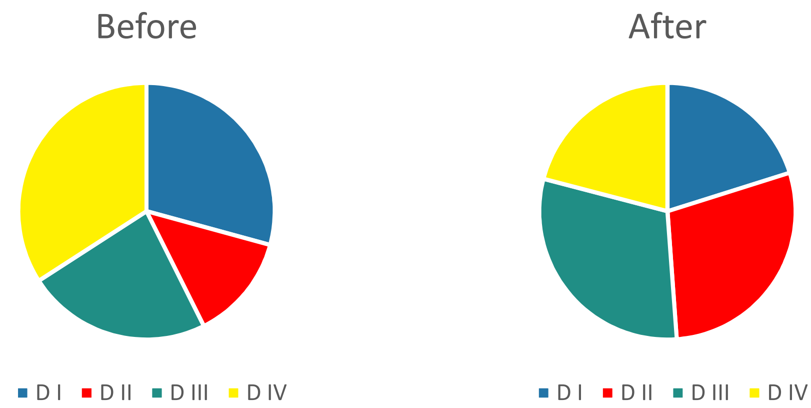

Figure 5. State of research in risk-resilience-sustainability domain 1990–2017 according to the classification of the new ontology.

Figure 6. State of research in risk-resilience-sustainability domain 1990–2017 according to the dialectical pairing in the new ontology.

is double that of research on conceptual schemes related to information (D II). D I has a sizable chunk due to the fact that according to the current practice of classifying hazards by their source, concepts here are mostly instances of every possible source of hazard: fire, flood, earthquake, greenhouse gasses, terrorism, e-coli, etc. The processes dimension, D III has a fairly large representation due to the significant increase in research over the 30-year period in environmental sciences and ecology.

As in a later iteration of the design process, we decided to add the dimensional pairs, so that D I and D IV formed a pair and D II and D III formed a pair, we could see that the balance in the research domain was tipped on the side of pair D I and D IV (Figure 6).

Figure 7 shows that much of past and current research in risk, resilience and sustainability is driven by value-related conceptual schemes, while the only area where information theoretical concepts are to be found is in the area showing research on robustness that stems exclusively from engineering disciplines. Since we argue that the concept of 'information' is the common denominator that integrates the knowledge traditions of risk, resilience and sustainability, we have designed both the ontology and the education blueprint such as to distribute the balance of forces in a way that brings 'information' out of the engineering closet. Figure 5 (before scheme) corresponds to Figure 7 in terms of percentages. Concepts which we have associated to

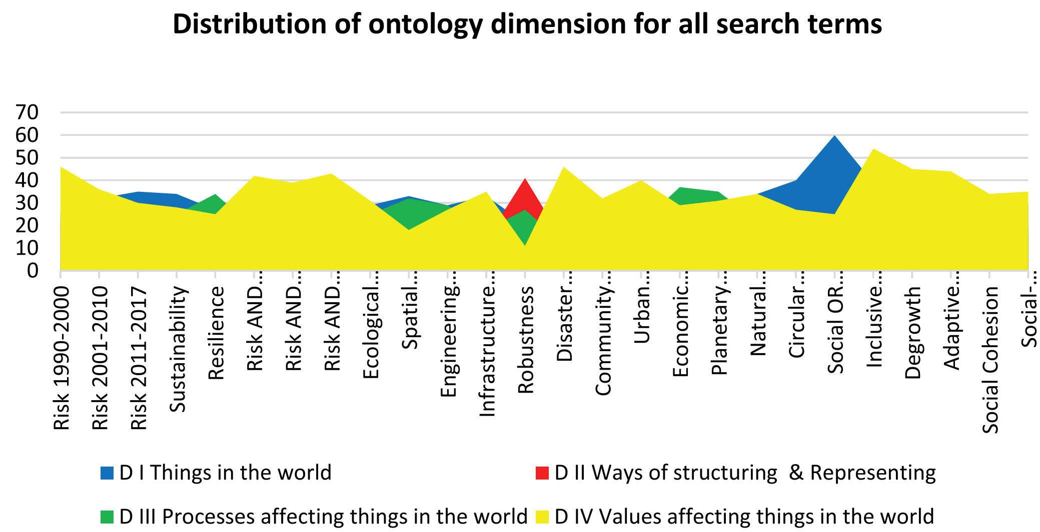

Figure 7. Research domain dominated by value-driven conceptual schemes.

DIV in the present state-of-the art dominate the concepts we have assigned to the other 3 dimensions in the ontology.

The knowledge domain of risk builds predominantly on engineering, economics and behavioral psychology disciplines. The knowledge domain of resilience builds on knowledge predominantly from ecology and environmental management as well as the newly revived discipline of ecological economics. The knowledge domain of sustainability builds on knowledge predominantly from environmental science, economics, political science, and sociology.

Of the three, risk has the longest history of research and the widest geographic distribution of produced research. Sustainability has the second longest history of research. The geographic distribution of the research in the formative period of the domain (1970–2000) is confined to Western Anglo-Saxon countries but has expanded to China over the past two decades. Resilience is the youngest of the three domains. It is limited in geographic scope of production of research to several hubs in the Commonwealth and Scandinavian countries, and the U.S. It has, however, the most articulate and cohesive conceptual structure, which it has succeeded to transfer across a large number of external domains.

An integration of the knowledge bases of the three domains requires thus more than a synchronization of terminology. It requires a common conceptual basis that is of generic application to all disciplines and practices that inform these knowledge bases. This begs the questions, what then is a concept, and where do concepts really come from if not from the statistical data mining of the corpus? We take up these questions in the remainder of this paper.

5. Form

5.1. *Where do concepts really come from? Disembodied vs embodied concepts*

There is a voluminous literature that deals with defining what a concept is, concept types, what counts as conceptual knowledge etc. (see e.g. Margolis and Laurence (2019) for a comprehensive overview). Despite multiple differences across the knowledge traditions of philosophy, psychology, cognitive, and learning sciences, a common function of concepts recognized across individual academic domains is that a concept is an abstraction, a compressed bundle of information that allows us to act and re-act in a context. Through the senses, information about particular instances in the physical environment enters the mind. The mind performs an operation of abstraction whereby particulars are grouped, sorted and classified into a higher-level generalization – a kind, class, type, or category. The particulars then become members of a shared property.

5.2. *What does it mean to know a concept? What is a definition?*

Contrary to Frege's understanding of concepts as the sense constituents of propositions, i.e. abstract objects in the mind (see e.g. (Textor, 2010)), our understanding of concepts is based on the assumption that meaning is generated in practice and evolves concurrent with practice. Concepts do not have fixed identities – neither in the Platonic realm of rational, objective scientific definitions, nor in the social conventions of codes, regulations and domain taxonomies. In our design to 'know' a concept is to have knowledge of the concept's range of possible usages. To know a concept, one must therefore know many concepts; not a definition.

Ontologies, as the chief product of Western metaphysics, are logical systems aiming at the description of true reality. Methodologically, this involves the dissecting of reality into its components, which is done by cutting out categories of distinct elements. Ontologies are then assemblages of things, where definitions are paramount because for an item to be included in an ontology it must exist distinctly. Definitions are properties of logical systems, rather than physical systems, i.e. definitions are of the mind rather than the world.

5.3. Categorization principles based on embodied cognition

Embodied cognition is a theoretical and methodological framework stemming from cognitive science research on how thought processes involved in human understanding and behavior involve blending physical perception and mental conception. Instead of treating reason, perception and bodily movement as three autonomous systems (neurological, sensory and motor), the basic tenet of embodied cognition is that the body's capacity for perception and movement shapes our reasoning about what is real as well as if and how we can know it.

At the core of the embodied cognition framework is a theory of categorization based on experience and interaction with the world rather than on a logical system of analytic a-priori. As a methodology, it presents an alternative to classical empiricism (e.g. Hume, Berkeley) and logical positivism (e.g. Carnap) on the one hand and rationalism (e.g. Descartes, Kant) on the other. According to the former, because all concepts are derived from experience, those that cannot be verified based on observation are not of legitimate scientific concern. According to the latter, concepts are a-priori in the mind. The role of perception in experience is to reveal the a-priori in our pragmatic engagement with the physical world.

In the tradition of embodied cognition, largely developed by Lakoff and Johnson through the 1980s and 1990s, perception is both biological and philosophical. A-priori conceptual structures come to be known in experience through the possibilities allowed or constrained by virtue of having a body. Categories are neither analytic nor synthetic a-priori, but structures for differentiated experiences. Similarly, concepts are not generalized abstractions but dynamic neural structures that generate our categories. Furthermore, concepts are not internal (mental) representations of external reality, but are in-formed by our sensorimotor system. This renders the distinction between percepts (external sensory input) and concepts (internally processed information), empirically invalid. In contrast to Western philosophical and scientific traditions based on the mind-body divide, embodied cognition offers a phenomenological, empirically validated framework for conceptualization and categorization that is neither based on categories of natural kinds and a correspondence theory of truth nor on purely subjective categories (see Sapir-Whorf Hypothesis of cultural relativism, (Sapir, 1929)) and a coherence view of truth.

In a position known as essentialism, there are two kinds of properties: essential and accidental. The former capture those things without which a thing would not be that kind of thing. They are, in other words, the necessary and sufficient conditions for a thing to be that kind of thing. Natural kinds then are the objective categories of the entities existing in the world. Being purely objective, they are independent of perception and linked in a system of logical relations. Truth (meaning) in correspondence theory is determined either based on Fregean sense-reference functions (Frege, 1892) or on Kripke-Putnam's causal theory of pointing and naming (Kripke (1972), Putnam (1975)), both of which depend on the assumption of correspondence between symbols in a natural or formal language and a physical world that is independent of any perception. Categorization relies on a set-theoretic methodology whereby an item is classified as a member of a set (a category) based on the inherent shared properties of members of the set and in accordance with binary logic. Everything that exists is either in the particular set or outside it.

The correspondence theory of truth relies on isomorphism between model and reality. This isomorphism is the basis for associating 'scientific facts' with evidence of truth. In contrast, truth in the coherence view is understood in terms of conditional beliefs about the relations between physical phenomena. Truth is then 'justified belief'. To base the development of the ontology as we do here on the mechanisms of embodied cognition, not only underlines the inevitability of subjectivism, but also aims to reduce the subjectivism to its core constituents – namely what individuals can perceive and conceive; rather than what societal processes of consensus and marketing have identified as being objectively subjective at a given time and place.

In the embodied cognition paradigm, the correspondence and the coherence schools form a synthesis. Embodied image schemas function as enduring structures of meaning based on experiential and interactive properties whereby items are categorized on the basis of prototypes (typical cases) and in terms of their roles in different kinds of experience. A definition is not given in terms of an isolated binary differentiation of inherent properties, but pragmatically, in a relational context, such that the function of definition is to provide a general scheme for understanding a concept and how it fits and evolves within a larger conceptual system.

5.4. Image schemas, conceptual metaphors, source and target domains of conceptual metaphors

To address the possibility of a shared language among disciplinary traditions within the Western conceptual system, the research tradition of embodied cognition provides an empirically tested model of image schemas as dynamic structures for categorizing experience (Lakoff & Johnson, 1999). Biologically in-formed but undetermined, image schemas interact with the context (sensory, cultural, spatio-temporal) in producing meaning, not in a symbolic sense-reference manner but in action. Image schemas are thus used to unravel the perceptions that in-form the con-ceptions included in the ontology (Part II, Sections 5–6) and to show the possible ranges of definitions of risk, resilience and sustainability.

Furthermore, there is empirical evidence that image schemas similarly underlie inferential processes within the Chinese conceptual system (Jia, 2008). The use we make of image schemas as a structuring principle of the ontology enables thus a shared conceptual language not only among disciplinary traditions in the West, but a common ground for the conceptual development of a risk, resilience and sustainability science which is not based on a purely Western perceptions and methods for organizing experience. Regardless of how concepts per se relate to the phenomenal world, at the very least, the image schemas provide a structure for relating concepts to each other, i.e. to other concepts – within a single culture as well as across multiple cultures.

In embodied cognition, conceptual metaphors function as conduits between perception and conception. Unlike the traditional view of metaphor as a poetic figure of speech that identifies one object or experience in terms of a set of similar properties shared with another object or experience, metaphor is a relational property of concepts, not of particular words. The relation is usually not one of similarity but of difference. The function of metaphor is foremost pragmatic understanding; its aesthetic use is secondary. Technically speaking, a metaphor is the mapping and understanding of one conceptual schema in terms of another. A minimal unit of a conceptual schema is referred to as an image schema.

In Johnson (1990, 2013) an image schema is defined as a ‘recurrent pattern, shape, and regularity in or of . . . ongoing activities.’ These patterns are not static containers such as templates, scripts or blueprints, but dynamic – in the sense that they engender meaningful structures through interaction and manipulation of objects in moving through space. Image schemas thus partially order human experiences while at the same time are also partially ordered and modified because of their embodiment in concrete experiences. Table 2 provides a selection of the most important basic image schemas.

It can be seen from this chart that some of the image schemas refer to positioning in space, while others to the integrity of objects and events. The former are called orientational image schemas; the latter – ontological. (Kovecses (2010) uses ‘orientational and ontological metaphor’.)

Orientational image schemas (Table 3) are spatially organized systems of concepts and have primarily an evaluative function (Kovecses, 2010). They are grounded in our bodily existence in the world. It is by virtue of having the bodies that we do that we distinguish ‘up’ from ‘down’, ‘front’ from ‘back’, ‘on’ from ‘off’, ‘deep’ from ‘shallow’, etc.

Table 2. Selection of basic image schemas after Johnson (1990) and Johnson (2013).

CONTAINER	BALANCE	COMPULSION
BLOCKAGE	COUNTERFORCE	RESTRAINT REMOVAL
ENABLEMENT	ATTRACTION	MASS-COUNT
PATH	LINK	CENTER-PERIPHERY
CYCLE	NEAR-FAR	SCALE
PART-WHOLE	MERGING	SPLITTING
FULL-EMPTY	MATCHING	SUPERIMPOSITION
ITERATION	CONTACT	PROCESS
SURFACE	OBJECT	COLLECTION

Table 3. Examples of basic orientational image schemas.

Space	UP-DOWN, LEFT-RIGHT, FRONT-BACK, CONTACT, CENTER-PERIPHERY, NEAR-FAR, PATH, ROTATION, SCALE
Attribute	BIG-SMALL, DARK-BRIGHT, HEAVY-LIGHT, STRAIGHT, STRONG-WEAK, WARM-COLD
Containment	CONTAINER, CONTENT, FULL-EMPTY, IN-OUT, SURFACE

Table 4. Semantic transfer range for UP-DOWN with respect to concepts AMOUNT, VALUE, SCALE (Johnson 1990, 2013).

UP	DOWN
Happy	Sad
Conscious	Unconscious
Health	Sickness
Life	Death
Having control/force	Being subject to control/force
More	Less
High status	Low status
Good	Bad
Virtue	Depravity

Table 5. Examples of ontological schemas by function.

Qualitative identity	OBJECT (events, actions), SUBSTANCE (activities), CONTAINER OBJECT/CONTAINER SUBSTANCE (states)
Quantity/Multiplicity	COLLECTION, COUNT-MASS, LINKAGE, MATCHING, MERGING, SPLITTING, PART-WHOLE

Orientational schemas are based on physical and cultural experiences but are not arbitrarily determined. Which ones are chosen depends on the role of a given schema within the coherence of the overall conceptual system. If we consider, for example, UP-DOWN as a source domain for targets such as AMOUNT, VALUE or SCALE, the semantic transfer from source to target would constitute the following range of meanings, determined both physically and socially (Table 4).

Such semantic transfer from source to target is technically referred to as the metaphorical extension of an image schema. What image schema ends up in the definition of a target abstraction such as RISK, SAFETY, GROWTH, EQUITY, RESPONSIBILITY, RESILIENCE, SUSTAINABILITY, and so on is a product of our being in the world physically and culturally.

Ontological schemas provide the basis for distinguishing entities and substances as individual things and consequently lay the rules for qualitative classification in categories, quantification, and ultimately inductive reasoning. Ontological schemas are frames for understanding objects, events, actions, activities, and states. In Table 5 ontological metaphors are presented according to their functions to conceptualize (i) qualitative identity and (ii) quantity.

Because our bodies define us as discrete entities, our experience of ourselves in the world is that of a container whose boundary marks what is on the inside and on the outside (Johnson, 1990, 2013). This experience is projected on objects we perceive in the visual field. When clear boundaries are not directly perceived, often we draw a mental boundary such that the perceived becomes conceived as container objects, composed of various substances. This applies not only to tangible objects but to abstract entities. We believe we recognize 'love', 'altruism', 'happiness', 'social cohesion', and so on when we see them. Once their existence has been established, we can measure them, analyze their composition, compare their attributes, and classify them into higher order abstractions. Through this metaphoric operation, the embodied mind gives birth to the concept of 'category'. A category is a metaphoric container. It is thus by means of the CONTAINER image schema that we reason, i.e. make inferences about things in the world.

Johnson (1990, 2013) argues that it is our experience with containers and bounded spaces which provides the inferential patterns for rules of classical logic such as transitivity of set membership, the logic of negation as based on the law of the 'Excluded Middle', and the equivalence of double negation (tautology). Following Johnson, Lakoff and Nuňez (Lakoff & Núñez, 2000) have demonstrated the metaphoric process of mapping container schema inferences onto category inferences for Boolean logic, illustrating the primacy of embodied spatial reasoning over the abstract logic of categories in set theory.

5.5. Metaphoric transfer from source to target domains

Technically, conceptual schemas from which we draw metaphors are called 'source domain', while the resulting conceptual schemas that structure our understood experience are called 'target domain'. Structural metaphors are mappings of a source domain onto a target domain. They enable the understanding of a more abstract concept in terms of another, simpler one. The function of structural metaphors is to frame a given perception into a specific conception. Table 6 lists typical source and target domains. Typical source domains include basic entities such as physical objects and substances and their experienced qualities (shape, color, weight, positive/negative, desirable/non-desirable, etc.). The source domain is the physical domain of humans, animals, biological organisms, artefacts, and the physical forces that govern their movements. In contrast, the typical target domains include abstract mental states, collectives and processes.

In the case of highly abstract concepts such as sustainability, resilience, risk, the metaphoric transfer occurs from one abstract source to another abstract target domain. In the ontology we present, we aim to get to the image schema level of how these abstract concepts are formulated.

Which source domain is mapped onto a target domain determines the contextual boundaries of the concept and the range of interactions in a conceptually coherent system. To account for the multiplicity of inputs into highly abstract target domains, Fauconnier and Turner (2002)'s theory of conceptual integration networks (also known as 'conceptual blends') provides an explanation for how new concepts 'emerge' in a manner that cannot be predicted from the input of the source domain(s). Kimmel (2013) explores cultural factors as determinants for the selection of a source domain. Culture can be viewed as a collection of cognitive patterns at a collective level. In Kimmel (2013) the ethnographic view of culture is thus contrasted with embodied cultural learning. The former is comparative and phenomenological; the latter is generic and cognitive.

In the proposed ontology, the source domain corresponds principally to Dimension I. Dimension I is the phenomenal world of physical experience comprised of objects and events. The target domain corresponds principally to Dimensions III and IV. Dimension II is the conduit by means of which basic source domain entities are mapped onto abstract target domain concepts. Dimension II is the domain of mind, models and cognition, juxtaposed to the phenomenal world of Dimension I.

It might be interesting to note that the image schemas and the general concept of embodied cognition, which we take benefit from in the structuring of the ontology, have a resemblance with the concept of likelihoods from Bayesian reasoning. The image schemas offer an analogy for the mapping of our prior understanding (prior knowledge) together with what we perceive in a given context (embodied cognition) into what we conceive (posterior knowledge). As in the case of Bayesian reasoning, the strength of the image schemas (likelihoods) depends and varies with context (more discussion of this is provided in Section 2 of Part I of this trilogy).

6. Image schemas and conceptual metaphors in the domain ontology

Figure 8 shows how the different image schemas have been allocated to the categorical pairs and the 4 dimensions of the ontology. For purposes of illustration, we present and discuss the image schemas only for Dimension I of the ontology, and refer the interested

Table 6. Typical source and target domains (as listed in kövecses (Kovecses, 2010)).

Typical Source Domains	Typical Target Domains
Human body	Emotion
Health and Illness	Desire
Animals	Morality
Plants	Thought
Buildings and Construction	Society/Nation
Machines and Tools	Politics
Games and Sport	Economy
Money and Economic Transactions	Human Relationships
Cooking and Food	Communication
Heat and Cold	Time
Light and Darkness	Life and Death
Forces	Religion
Movement and Direction	Events and Actions (change, cause, purpose, means)

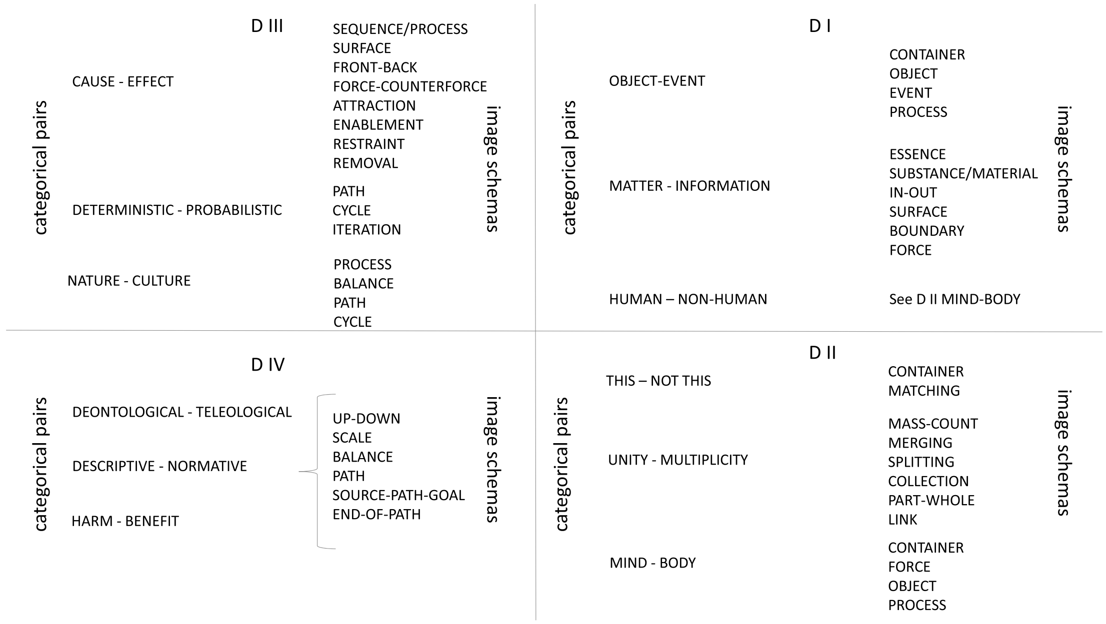

Figure 8. Image schemas corresponding to the dialectical pairs in the ontology.

reader to Nielsen (2021 forthcoming) for a full presentation and discussion of the image schemas for all 4 Dimensions.

6.1. Image schemas for dimension i

The distinction between objects and events has a very long history in the Western conceptual system, resulting in a cascade of categorical pairs such as atomistic-relational, material-immaterial, etc. In embodied cognition research, the battle between object and event continues among proponents of OBJECT as the primary building block of conception and proponents of spatio-temporal EVENT schemas as primary in cognitive development. Since our design is pragmatically oriented, we disregard the question of origin and grant

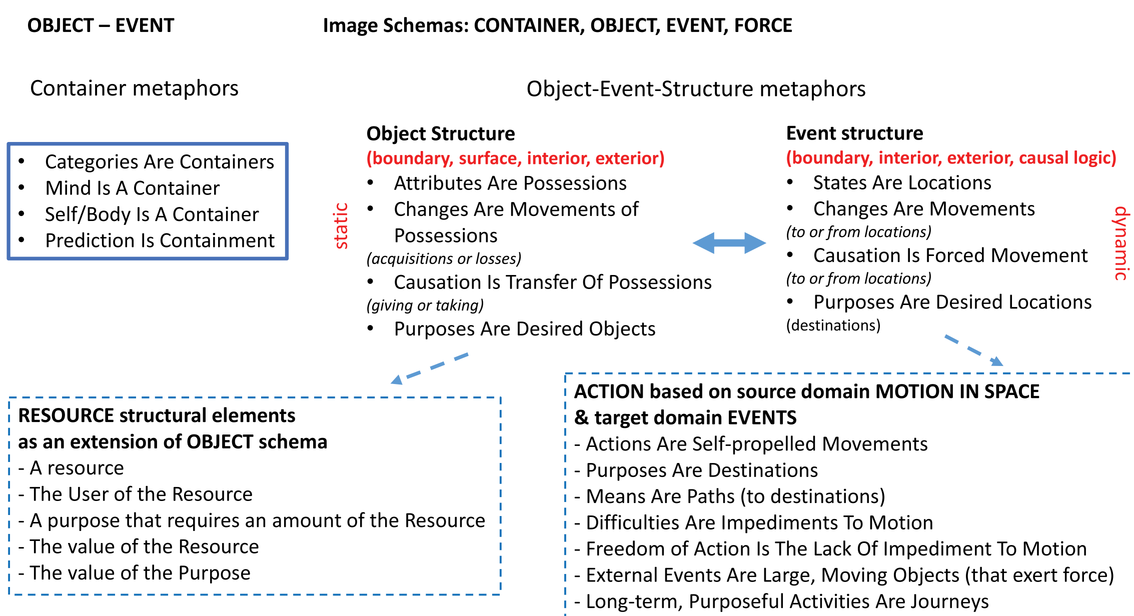

Figure 9. Image schemas and conceptual metaphors for categorical pair OBJECT-EVENT. image schemas and conceptual metaphors based on selection from johnson (1990) and johnson (2013), .Lakoff and Johnson (1999) and Lakoff (2008).

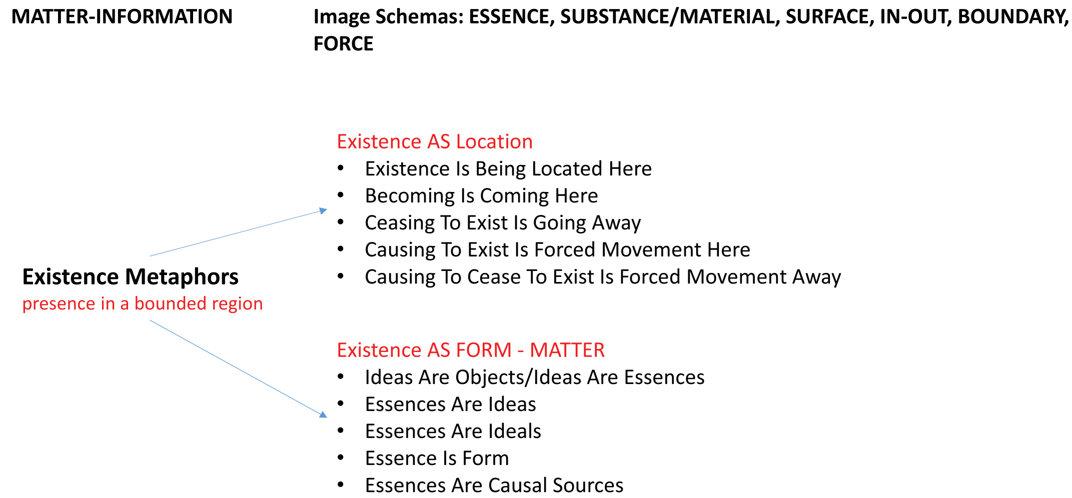

Figure 10. Image schemas and conceptual metaphors for categorical pair MATTER – INFORMATION. Image schemas and conceptual metaphors based on selection from Johnson (1990, 2013), .Lakoff and Johnson (1999) and Lakoff (2008).

objects and events equal ontological status in D I. However, objects and events do not exist equally, in that whether an object or an event schema is chosen to conceptualize an experience, the consequences of this choice are not trivial for the modeling of risk, resilience and sustainability.

In Figure 9, it can be seen that the underlying cognitive structures for OBJECT and EVENT mirror each other, with the exception that the OBJECT schema is static, while the EVENT schema is dynamic. A possible metaphoric extension of the OBJECT schema is shown for the concept RESOURCE. It can be seen how a resource comes to be defined as an object relative to another object in terms of function. In the Western conceptual cognition system this metaphoric transfer creates a family resemblance among the concepts {resource – expenditure – scarcity – efficiency – waste – time – savings – worthiness – sustainability – efficacy – resilience} located in different dimensions of the ontology. This illustrates how although the image schemas constrain the choice of arbitrary interpretations for what a resource is, they are not universal. They are, instead, embedded in a socio-cultural context. But while there might be a widely divergent understanding across cultures and social groups about what defines a single concept such as waste, resource or time, the cluster of concepts sharing a common image schema, affords a pragmatic understanding of the context in which a given concept is used. In other words, the choice of any image schema has implications on the semantic range, i.e. the boundaries of categorical groupings. It is the OBJECT schema that makes the grouping of {resource – expenditure – scarcity – efficiency – waste – time – savings – worthiness – sustainability – efficacy – resilience} possible. When applied to the context of risk analysis, this general structuring principle comes to be responsible for how a system is defined and a decision context framed, depending on what elements can be associated to a frame bounded by a particular image schema.

The CONTAINER schema is the source domain of inferences about categories. Inferential logic, which is typically considered the epitome of conceptual reasoning in mathematics is actually spatial logic, i.e. it is embodied by virtue of our perception of objects in space as the metaphor Categories Are Containers demonstrates. CONTAINER schema inferences structure the logical concepts of 'excluded middle', 'modus ponens', 'hypothetical syllogism', and 'modus tollens', which is also the basic structure of Boolean logic, set theory, and probability theory. (see Lakoff and Nuňez, Lakoff & Núñez, 2000).

The second categorical pair of Dimension I deals with the material vs informational essence of reality. Figure 10 shows the image schemas and metaphors on which the distinction between the material and immaterial rests.

7. Quasi-universal shared language: image schema and *xiang*

If the knowledge domains of risk, resilience and sustainability converge at the global scale, an ontology must make sense outside the conceptual traditions of the West. Our introduction of dimensional and categorical pairs complementary to the individual dimensions and concept members is an attempt to raise awareness of this problem and is by no means a comprehensive or sufficiently systematic effort.

In Julliene (Jullien, 2002) the Western concept of 'category' is contrasted with the Chinese use of pairs of items that form a 'tension'. In this view, reality is not composed of metaphysical object-concepts, but rather of physical events. Contradiction, which the Western system of logic uses to validate the truth-value of propositions, is in Chinese thought not something to be avoided as a logical fallacy, but adhered to as a physical law – a creative, engendering principle upon which the processual physical reality rests.

Hansen (1985) postulates that classical Chinese thinking is structured on the basis of a mereological classification because Chinese nouns are uncountable. A conceptual system, in which number is understood as a degree of quality (a more or less of something) rather than as a distinct amount can thus be said to be a mereological ontology.

In Ma and Brakel (Ma & Van Brakel, 2016) the notion of a quasi-universal is introduced as that something by virtue of which a comparison of concepts is made possible. The context of their investigation is translation of Western – Chinese conceptual schemas, which they base on Wittgenstein's notion of 'family resemblance' and a theory of meaning grounded in pragmatic experience as opposed to symbolic sense-reference correspondence. The quasi-universal is thus part of a shared experiential mode of being in the world, which provides a meta-structure for comparing one concept with another across cultures. For example, what enables the translation of the Greek concept of ἀρετή (usually translated into English as 'excellence') with the Chinese concept of *de* 德 is a shared experience in the perceptual and conceptual systems of Greece and China of the quasi-universal experience of (moral) excellence (Ma and Brakel, Ma & Van Brakel, 2016)).

Meaning as a shared experience is a pragmatic notion. It refers to behavior, practices and ways of acting. As such, meaning is constructed subjectively unlike the analytic notion of sense-reference, according to which meaning exists objectively, outside the realm of perception. It is important to underline that in the theory of embodied cognition and in comparative linguistics and philosophy grounded in 'family resemblance' (FR), the perceptual world of experience is not a relativistic Humpty Dumpty realm of meaning, but is constrained and structured through quasi-universal embodied cognitive gestalts. These cognitive gestalts are quasi-universal image schemas that function as cross-cultural FR concepts.

The categorical pairs we introduce in the ontology that help to define and structure the four dimensions are precisely such FR concepts based on quasi-universal image schemas (Figure 11). The cluster of categorical pairs in D I provides a conceptual scheme for the metaphysical dimension of the ontology, which is a catalogue of the things that exist (i) in the physical world and (ii) in the conceptual domain of risk, resilience and sustainability. In D I OBJECT – EVENT is a quasi-universal pair used in both Western and Eastern traditions in consideration of metaphysical questions. Within the Western tradition Putnam (Putnam, 1992a) points out that 'entity', 'object', 'event', 'situation', 'fact', and 'property' have not one fixed use but an expanding family of uses. Heidegger's 'thing', Russel and Whitehead's 'event', Ortega y Gasset's 'situation', Harmann's 'object' are in the context of metaphysics, FR concepts. Similarly, in the Chines tradition *wu* 物 is used to denote a thing, a kind of thing, an event, or an organism. Ma Lin (2015) explains that in classical Chinese animals are moving *wu*, i.e. *dongwu* **动物**; humans are *renwu* 人物; plants are *zhiwu* 植物; and inorganic things (e.g., rivers, mountains, landscape) are *jingwu* 景物 .

In the Western tradition the semantic ranges of D I-D II form a compatible pair. The teleological end of metaphysics is epistemology. Knowledge has intrinsic value. Indeed, the instrumental use of knowledge to achieve other purposes than knowledge itself is perceived as ethically suspect. The ideal of science is objectivity that bears no relation to utilitarian purposes. D III – D IV also forms a natural pair through the FR concepts cluster 'law-regulation-choice-control' as there can be no values without the concept of change, which can simply be defined as observed invariance.

In the Chinese tradition, metaphysics is not pursued for epistemic purposes, but for the moral purpose of right living. The pairing of D I with D IV is grounded in the neo-Confucian notion of '*daoxue*' 道學. In our ontology, we have paired D I with D IV instead of D III with D IV as we wish to re-frame the deterministic perspective arising from pairing D III process – be that laws of nature or laws of culture and convention – with D IV values. In our ontology thus the taxonomic kinds of D I and the normative values of D IV do not form natural kinds or predetermined laws, but are instead the result of choice that embodied cognition enables in the process of our classification of experiences through interaction with the things in the phenomenal world. The choices made in D I to frame what exists affects what values are chosen for their measurement. What values we choose to measure affects where we draw the boundaries around what matters.

D II and D III form a further compatible pair through another classical Chinese notion – *li* 理. We understand *li* is an abstract category for information in the sense

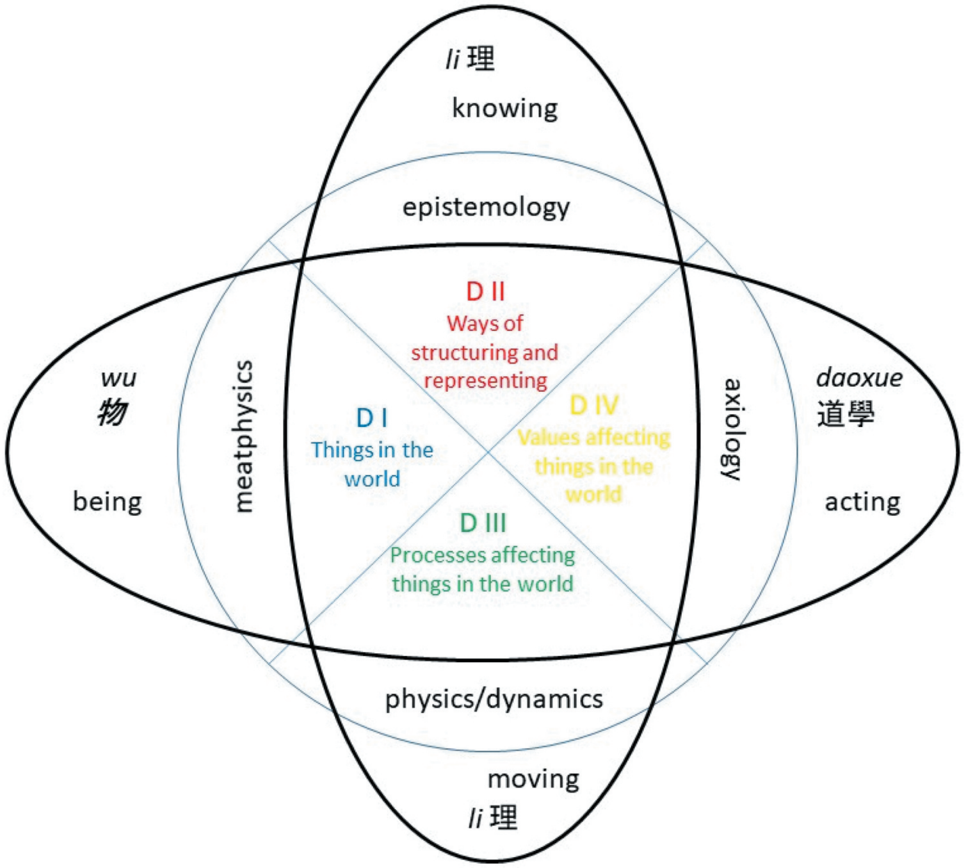

Figure 11. Dimensional pairs with corresponding Western branches of philosophy and Chinese concepts.

that it is used in descriptions of ordering and structuring the form and function of both organic and non-organic things in the world.

In Qiao Qingju (2006) a thesis is put forth that Western metaphysical concepts (matter, time, space) and epistemological concepts (perception, rationality, regularity, understanding) have entered the modern Chinese lexicon as neologisms that are used to describe these concepts as individual categories rather than as the all-encompassing classical Chinese FR concept of *li* 理, which is used as a descriptor for all of the above. A modern Chinese dictionary defines *li* as ‘Laws and regularities of matter, natural criteria, regularities pertaining to ethical categories and motion of matter, fundamental principles of the universe, the arche of the universe, the form of matter, ethics and morals, the differences in matter and so forth.’ The Chinese concept of *li* captures both what in the West is understood as a ‘pattern’ and the dynamic organizing principle that creates the pattern.

The analytic definition imports the alien to Chinese experience Western practice of pairing concepts from our ontology’s D I (metaphysics) and D II (epistemology). The classical Chinese concept of *li* is made more comprehensible in the pairing of D II (epistemology) and D III (process). This latter pairing (D II-D III) enables a comprehension of *li* as the structuring principle of both perceived and conceived reality. *Li* is the matter that forms and is in-formed. The classical Chinese concept of *li* is, in other words, our concept of ‘information’. It is a good approximation to the range of meanings we attach to our notion ‘information-theoretic ontology’.

The Chinese concepts *wu, li* and *daoxue* thus offer a possibility for establishing a shared West-East ontology:

- D I – the phenomenal lifeworld of objects and events, characterized by multiplicity of forms/patterns;
- D II – the cognitive-affective ability of humans (i.e. the heart-mind/embodied mind) to discern and conjure patterns;
- D III – the unitary principle of in-formation, i.e. the ceaseless reproduction of forms/endless creativity/process;
- D IV – when D II properly actualized through the pursuit of self-cultivation and empirical inquiry

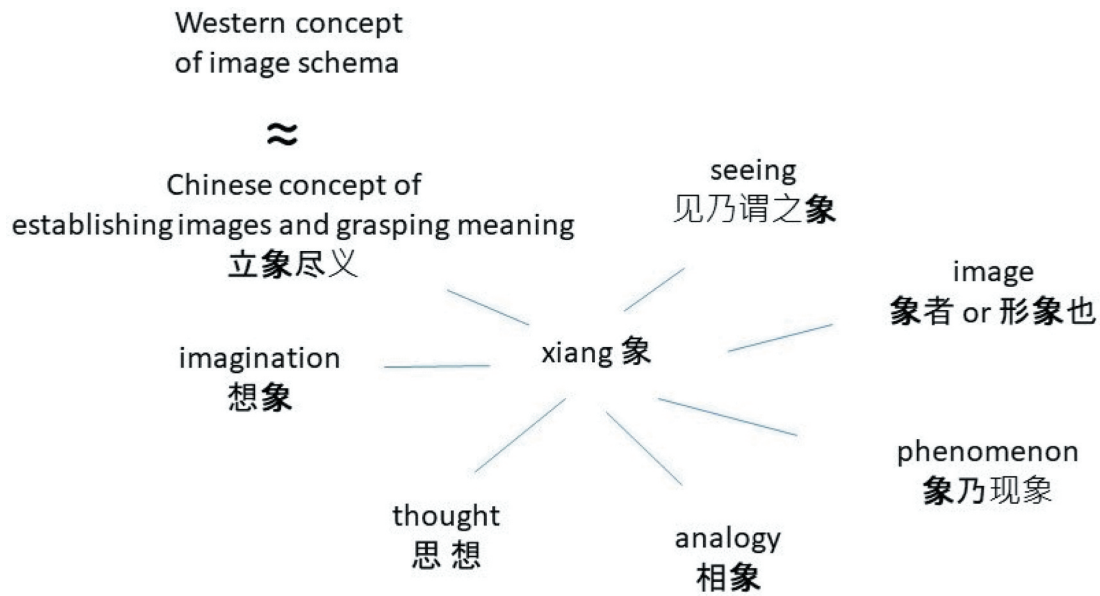

Figure 12. Semantic range of the Chinese concept *xiang* as an approximation to embodied cognition concept of image schema. Based on translation from Jia (2008).

leads to good governance (virtuous action) based on the unitary principle of informed-choice; a meeting point for the Socratic definition of knowledge as virtuous action and the Chinese cosmological axiology summarized in the notion of *daoxue*.

The concept of 'information' is a quasi-universal we use to establish meaningful communication between West and East also with respect to the notion of image schema. In a linguistics study of the Chinese character system Jia (2008) examines the embodied conceptual system of Chinese thought as a product of metaphorical mappings of image schemas. He demonstrates how the concept of *xiang* (image), expressed by the two cognate homophonic characters 象 and 相, underlies the process of analogical inferential logic, which structures Chinese perception, understanding and reasoning about phenomena in the world as well as acting in the world. The semantic range of *xiang* clearly shows the family resemblance between visual perception, classification of experiential input, inferential information processing, and not least, understanding as a faculty of imagination rather than disembodied pure reason.

In Figure 12 we show a radial semantic range for the concept of *xiang*, illustrating the close correspondence between the Western notion of cognition based on embodied image schemas and the Chinese mode of visual perception-conception.

In this context, the structure-function relation can be thought as a quasi-universal that facilitates a comparison between Western and Chinese ways of conceptualizing cognitive processes. *Xiang* 象 is a pictographic depiction of a dead elephant's bones (Jia, 2008). Far from a symbolic sense-reference representation of a ghostly natural kind, the Chinese elephant is a probabilistic statement of a degree of belief. Just as in the inferential image schematic reasoning, perception is grounded in the concrete visual experience of a form and metaphorically transferred to the abstract domain of conception. The conduit of this metaphoric transfer, which we may call learning or grasping meaning, is imagination. Knowledge priors are image structures stored in the *xin* 心 (heart-mind); on call for re-call, potentially pliant. Figure 13 presents an illustration of this process from the Chinese perspective of how meaning (function) is generated from image (form).

8. Summary

The present paper is the second in a triad of papers in pursuit of establishing a formal basis for the representation of knowledge and for designing education in risk, resilience and sustainability science. In this paper we focus on the representation of the knowledge domain.

To this end we assess different options for structuring of conceptual knowledge in terms of different hierarchical structures: taxonomies and ontologies. On this basis, we propose a structure of the knowledge domain of risk, resilience and sustainability through what might be termed a mereological ontology (in philosophy) or a nested hierarchy (in computer science), consisting of

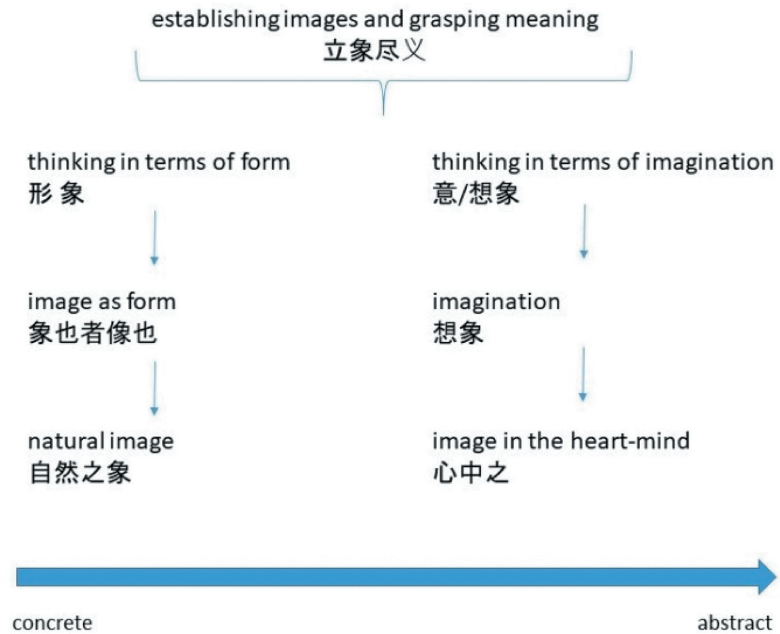

Figure 13. Image schematic process of chinese sense making based on structure-function relations. examples and translation from .Jia (2008)

128 concepts, 19 concept clusters, 4 dimensions, and 2 dimensional pairs. The theoretical and methodical basis for the proposed ontology is provided only in summary. Moreover, we include a mere minimum of formalism in this presentation such as to support the readers in the domain of risk, resilience and sustainability who might not be familiar with the formal philosophical basis for structuring knowledge.

As we strive for a knowledge representation in a context of governance at in principle any geographical scale, we finally address and describe the differences and the similarities between the traditional Western and Eastern lines of logical reasoning. To this end, taking basis in the fundamental concepts *wu, daoxue* and *li* from classical Chinese philosophy as a representative of Eastern lines of logical reasoning, we discuss and relate the dimensions, the clusters and the categorical pairs from our proposed ontology.

We fully appreciate that our proposal might be improved, not least with respect to inclusion/exclusion of concepts – the choices of which underlie significant subjectivity and which, moreover as such will change meaning in the course of time. However, our proposition for the structuring of the knowledge domain of risk, resilience and sustainability offers a new paradigm for education and governance that integrates risk, resilience and sustainability considerations into a single theoretical and methodological framework. It establishes thus for the first time a conceptual baseline for the synthesis of the three knowledge traditions of risk, resilience and sustainability, which until present have evolved and been pursued independently. The baseline is the common domain ontology that allows their further development as a new life science. A unique strong point of our proposition is that it holistically and neutrally integrates relevant concepts from both the natural, social, human and technical sciences and across cultures, in a manner that is balanced in the context. Using the metaphor of construction as we have been applying this to illustrate and explain the design of the ontology – our ontology may be seen as a building, a container and organization of relevant knowledge – profiling the fallacies of present developments in Western societies where the 'space' for the human and social sciences rhetorically and financially is shrinking.

In the last part of this triad – Part III – we use the developed knowledge representation to establish a blueprint for the design of education offers in risk, resilience and sustainability science as an instrument for achieving informed preferences, decisions and actions across scales.

Notes

1. For ease of syntax, in the following we refer to Part I and Part III of the triad without specification of authors and year, however these are always the same and may be found in the list of references under (Nielsen & Faber, 2020).

2. Prominent examples include actor network theory (Latour, 2013) and object oriented ontology (Harman, 2018).
3. 'Can you say where the boundaries are? No. You can *draw* some; for there aren't any drawn yet. . .To repeat, we can draw a boundary – for a special purpose.' Wittgenstein, Philosophical Investigations 68–69.

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No potential conflict of interest was reported by the author(s).

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