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Arcform

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Abstract. Arcform is a notation for expressing diverse thoughts using nodes and arcs in a new graph-like network structure. The structure differs from directed graphs by including arcs that point from or to other arcs, and *semi* arcs where one end points from or to itself. This supports a new generative statement composition structure which allows expressive statements to be read as grammatically normal sentences while integrated into maps containing multiple statements. This paper describes this compositional structure with a special focus on a few patterns for assigning meaning to nodes and arcs that preserve the above characteristics while ensuring an even tighter integration of diverse statements into networks. A few additional features are considered before raising some far reaching questions about how it can support thought work.

Keywords: Network Notation, Generative Composition, Controlled Language.

1 Introduction

In prior work [1], arcform has been introduced as a new network notation using a new statement composition structure, requiring a new graph-like network structure. Furthermore, in that work, the compositional structure was compared to that of a range of other notations and various hypothetical ways of using triples and enclosures, the ease of using the compositional structures was tested on potential users and the expressiveness of the compositional structure was tested while capturing a text corpus in the notation.

Arcform has since been used in research projects in processes of untangling stakeholder relations and beliefs from interview data [2, 3], including one project that used the compositional structure with a language other than English [4]. It has also been considered as a foundation for an e-learning platform [5].

This paper presents the compositional structure in more detail than provided elsewhere. In the process it also presents a more specific, or regular pattern for how meaning can be captured in the compositional structure. This allows us to both explore and extend a small number of central characteristics of arcform. This version of arcform also differentiates between statement compositions (thought compositions) and object description compositions, and provides a new pattern for using the latter. Finally, a few possible implications are discussed.

2 Objects and Thoughts

The current presentation of arcform assumes an important distinction in our thinking between objects of thought (objects) and thoughts. Objects include physical objects, imaginary physical objects, collections of objects, events, ideas, beliefs and more. In general, an object is anything that can be represented by the subject or object part of speech of normal sentences. In arcform an object is always represented by a node and labels are the simplest way of identifying an object as shown in **Fig. 1**. It is important to note that a thought cannot be used directly as an object.

Fig. 1. An object represented by a node with associated labels.

At least as important as objects are thoughts about these objects. They are also very divers and may for example include imaginings about the physical world, the experiential world or fictional words. In general, a thought in arcform is approximately anything that can be represented by a normal declarative sentence. In arcform a thought is always represented by an arc, normally with a single word label. There are many different types of thoughts in arcform, let us explore some of the most common of these.

3 First Order Thoughts

All first order thoughts are arcs pointing from an object and labeled with a present tense third person verb (written with brackets to accommodate two possible endings). One variation of a first order thought is an ordinary arc pointing to another object to express the same as a simple transitive sentence as shown in **Fig. 2**.

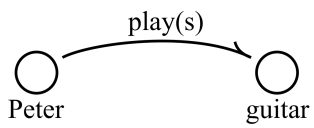

Fig. 2. The thought 'Peter plays guitar' represented by an arc labeled "play(s)".

The other variation of a first order thought uses a different type of arc, a semi arc that points from an object, but instead of pointing to another object, points to itself. It expresses the same as a simple intransitive sentence as shown in **Fig. 3**.

Fig. 3. The thought 'Jane sings' represented by a semi arc labeled "sing(s)".

4 Higher Order Thoughts

Arcform can use an arc pointing from or to another arc to represent thoughts with greater context. They are called higher order thoughts because they involve at least one other thought (a thought they point from or to). One variation of these are arcs labeled with a preposition (e.g. "for") as shown in **Fig. 4**.

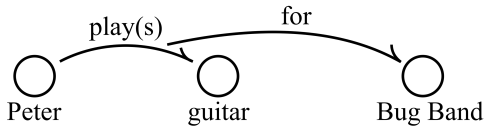

Fig. 4. The thought 'Peter plays guitar for Bug Band' represented by an arc labeled "for".

Two other variations of higher order thoughts are arcs labelled with a subordinating conjunction (e.g. "because") and arcs labeled with an adverb (e.g. "beautifully"). Higher order thoughts can also point from first order thoughts that are semi arcs as shown in **Fig. 5**.

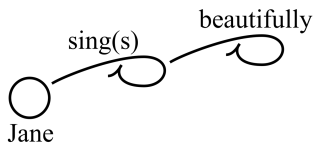

Fig. 5. The thought 'Jane sings beautifully' represented by an arc labeled "beautifully".

Another variation of higher order thoughts is labeled with modality phrases (e.g. "do(es) not") and point from an object to another thought as shown in **Fig. 6**.

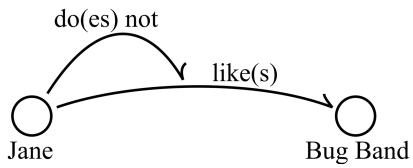

Fig. 6. The thought 'Jane does not like Bug Band' represented by the arc labeled "do(es) not".

A central part of higher order thoughts is that they can be involved by other higher order thoughts to express new thoughts as shown in **Fig. 7**.

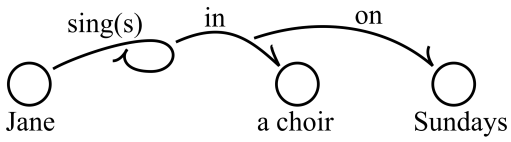

Fig. 7. The thought 'Jane sings in a choir on Sundays' involving the thought 'Jane sings in a choir', which involves the thought 'Jane sings'.

This nesting of higher order thoughts within other higher order thoughts can continue indefinitely to express thoughts with greater and greater context. The possibility to do this using arcs pointing from or to other arcs differentiates arcform from all notations relying on a directed graph structure and specifically concept maps where longer expressions are created only by attaching arcs to nodes [6]. Because of this, it is worth clarifying some conventions for talking about arcform expressions:

- *Thought arcs.* Each of the displayed arcs represent a thought. For reasons that will become apparent, we can most often simply refer to these arcs as thoughts.
- *Thought compositions.* Each thought spans the tokens that it points from or to, and the tokens that these point from or to, and so on, down to include all the involved objects. We call this structure the thought composition.
- *Composition sentences.* When compositions are arranged as they are above with all thoughts pointing from left to right the labels of all the tokens can be sequenced into what we call the composition sentence.

5 Natural-Language-Like

Arcform is not, like a descriptive grammar, an attempt to represent how natural language syntax works (the compositional structure serves other purposes). It is also a controlled language [7] in that both the compositional structure and restrictions on how the tokens are labeled (e.g. verbs are always active present tense verbs) exclude many natural language composition sentences. However, it is meaningful to think of it as natural-language-like.

Most significantly, it has been designed to allow composition sentences to be read as grammatically normal sentences by reading the labels in sequence from left to right. Thus in **Fig. 7** we put together the labels “Jane”, “sing(s)”, “in”, “a choir”, “on”, “Sundays” to read the sentence: “Jane sings in a choir on Sundays”. This exploits our familiarity with a natural language vocabulary and word ordering when interpreting thought compositions.

Furthermore, arcform seems to be expressive in the way a natural language is. Like natural languages, arcform uses a generative composition structure supporting indefinitely many compositions. Although arcform excludes many natural language sentences, different natural languages support different redundant ways of sharing the same information [8]. As long as arcform provides natural language alternatives to the excluded sentences (e.g. by using higher order thoughts to specify when something happens rather than using past tense or future tense verbs), then it maintains this expressiveness.

6 Arcform Maps

Above we saw that the labels of tokens could be read in sequence from left to right as normal sentences. However, this sequence is fully determined by how arcs point from

and to other tokens. We can change the layout of the thought structure significantly as shown in **Fig. 8** and still determine the reading order of the labels.

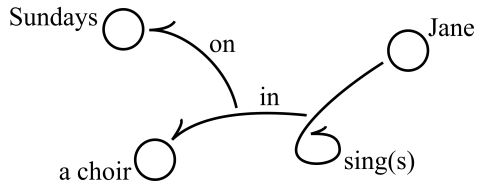

Fig. 8. The composition of the thought 'Jane sings in a choir on Sundays' with an arbitrary layout.

The obvious advantage to spreading out compositions on the plane is that multiple compositions can reuse the same tokens. This allows us to create maps integrating these compositions in networks as shown in **Fig. 9**. As before, every arc represents a thought, its composition is identified by the nested thoughts and objects that it involves and its composition sentence is determined by sequencing the token labels as if all arcs in the composition pointed from left to right.

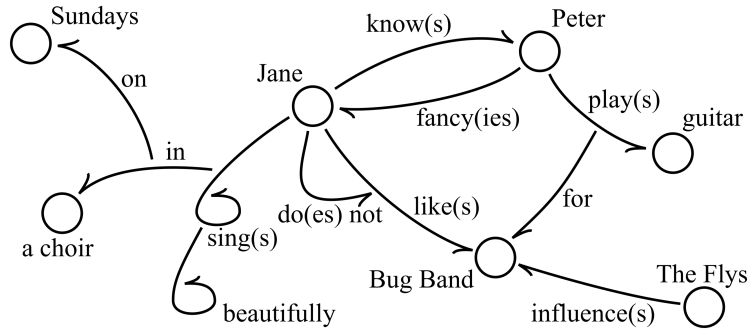

Fig. 9. An arcform map including multiple compositions.

7 Unitokenality

Prior work on arcform [1] introduced the concept of unitokenality for representations. It specifies that one meaning gets one token, no matter how many times that meaning is used in a representation. Unitokenality was seen as a requirement for a representation to be map-like. Consider how the city Edinburgh only needs to appear once in a geographical map of the world. Then contrast this to how a paragraph of natural language text may need to include multiple references to the city. Now there appear to be three increasing levels in which representations can be unitokenal with respect to our mental objects and thoughts.

1. All objects get their own token. This was the original motivation for arcform: to simply give all subjects and objects of non-trivial grammatically normal sentences their own node for reuse.
2. Some thoughts get their own token. This is seen in all prior versions of arcform. Consider how the thought 'Jane sings' is reused without repeating in two other thoughts in **Fig. 9** above.
3. All thoughts get their own token. This requires that involved meanings in our thinking are not subsumed in other thoughts tokens.

The current version of arcform attempts to achieve the third level of unitokenality with its patterns for labels on arcs. Thought arcs do not just point from or to other meanings, but point from or to the most encompassing involved meanings. Consider how the thought 'Jane sings in a choir' cannot, in this version, be labeled "sings in" and point directly from the object 'Jane' and how this would skip giving the involved thought 'Jane sings' its own token. The current version of arcform ensures that 'Jane sings' is represented once and can be reused without repeating. This pattern is intended to apply to the composition of any involved meanings in our thinking.

8 Additional Features

There are also many design features of arcform that cannot be described in detail here, but strengthen the notation within the characteristics of natural-language-likeness and unitokenality, or are otherwise important to know about. An important sampling of these are: *object descriptions*, *thoughts in objects*, *conjunctions*, and *short-handing*.

Object descriptions are nodes or arcs that are neither objects or thoughts. They are a unitokenal alternatives to using labels (e.g. "a rock band" shown in **Fig. 1**) to describe objects. Like thoughts, descriptions also span the tokens that they points from or to and all the tokens that these point from or to and so on down. When a description composition is arranged with all its arcs pointing from left to right the labels of the tokens can be read as a grammatically normal description phrase. **Fig. 10** shows a description composition 'a rock band' with its tokens drawn with a different shade to make them easily distinguishable from objects or thoughts.

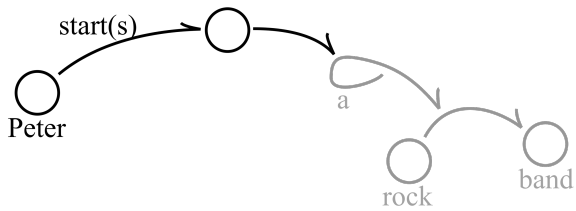

Fig. 10. A thought with an object linked to a description compositions.

Objects are connected to their descriptions using a *linking* thought which does not have a label, but is sometimes read as if it has the label "is" or "are". **Fig. 10** shows two thoughts 'Peter starts something' and 'something is a rock band', which can be

read simply as “Peter starts a rock band”. In a map the same object can have multiple descriptions and the same description can describe multiple objects.

Description composition may also involve non description tokens. For example the description ‘the king of Spain’ involves the object ‘Spain’. Likewise a description composition can also involve a thought. In **Fig. 11** we can read “Peter believes that Jane likes Bug Band” where the belief is an object linked to the description ‘that Jane likes Bug Band”. The description token labelled “that” creates a description out of a thought. This pattern is important if we want to discuss claims or beliefs within arcform while allowing the involved meanings in those claims or beliefs to be unitokenally represented and reused.

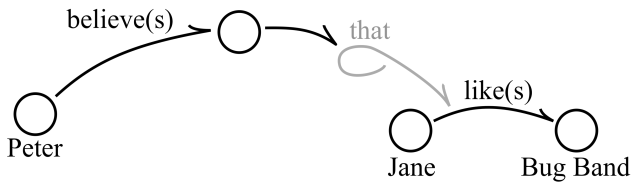

Fig. 11. A thought with an object described using another thought.

Finally it should be noted that arcform maps will include shapes that are not discussed here. For example there is a way of joining objects into conjunction or disjunction collections that can themselves be used as objects. There are also many ways of drawing pars of a composition in *shorthand* to hide tokens that do not at the time need to be reused. For example, in **Fig. 11**, we could draw a single shorthand arc labeled “believes that” from the node labeled “Peter” to the arc labeled “like(s)” when we do not need to reuse the belief ‘that Jane likes Peter’. This and many other kinds of short handing can greatly simplify many maps.

9 Discussion

Arcform’s design and especially its focus on expressivity, grammatically normal sentences and a high-level of unitokenality raises some interesting question about how it can support thought work. Through its seeming expressiveness we should be able to create maps on any topic, but can it go beyond simply giving a map-like experience of what would otherwise be expressed as a paragraph of text?

It seems that two maps can always be merged, here identical objects, thoughts or descriptions in the two maps become one in a new map while unique objects, thoughts or descriptions of the two maps coexist in the new map, but how far can this be taken?

Through nesting thoughts in (indefinite orders of) more contextualized thoughts, the contextualized thoughts should become less and less dependent on a containing map for their interpretation. Will these thought compositions be interpreted correctly by arcform users regardless of which other thoughts they are displayed next to? At the same time the pattern of thoughts pointing from or to the most encompassing involved meaning should allow many more opportunities for thought compositions to reuse

involved thoughts. Can the combination of these support a tighter integration of more diverse thoughts then seen before? Could we in principle integrate our thoughts into one big network?

Of course, such a network of meaning would in practice require a digital implementation; at the very least to avoid the shear crowdedness of drawing it on paper. Would the composition and assignment of meaning make the expression of ideas more predictable and retrievable with structured queries? Would filtering and layout algorithms allow the dynamic and ad hoc generation of new perspectives on existing information?

Assuming the above, would the grammatically normal composition sentences make such a network more accessible for general use by non-programmers than existing knowledge base schemas? What would be the benefits of users sharing and reusing thoughts in such a network? Could it allow beliefs to be more closely connected to their counter beliefs? Could it support a new type of online social rating, not of amorphous containers of meaning like posts or pictures, but of individual thoughts?

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