Towards a cognitive model of conceptual blending

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Abstract

We outline a way to use Goguen's (2006) account of conceptual blending in the cognitive architecture ACT-R. Despite recent advances in linguistics and general accounts of conceptual blending (for example, Fauconnier and Turner 2002, 2008) it has received scant attention in cognitive modelling, which is partly due to the fact that there are hardly any computational accounts of this phenomenon, Goguen's being one of them.

Keywords: conceptual blending; metaphor; analogy; linguistics; conceptualisation; scientific creativity; ACT-R; Theory of Institutions.

Analogy, metaphor, conceptual blending

A major factor for the power and flexibility of the human cognitive system is its ability to create new concepts, in particular by combining existing ones. It is both central in creating new scientific ideas as well as for 'everyday' thinking. We are particularly interested in the role of this mental machinery in the creation of new mathematical concepts (Guhe, Smaill and Pease 2009). Most current accounts of scientific creativity emphasise the role of analogy (Gentner & Markman, 1997) or metaphor (Lakoff & Núñez, 2000). Here, we outline the more general process of conceptual blending, its role in creating new concepts, and how it can be integrated into the cognitive architecture ACT-R (Anderson, 2007).

Analogy and metaphor, which we take to be essentially the same, are cognitive processes that (1) establish mappings between parts of a cognitive system's knowledge representations (usually called *domains*) and that (2) can transfer knowledge between domains for which a mapping was established. For example, in the extensively studied metaphor TIME IS SPACE, the expression *Christmas is two days away* recasts an event (*Christmas*) as a location with respect to the speaker's current location in time by specifying a temporal interval (*two days*) as a distance.

According to Fauconnier and Turner (2002) metaphors and analogies are only special cases of conceptual blending. A metaphor is simply a 'cross space mapping' (Goguen, 2006, p. 8). The TIME IS SPACE metaphor, for example, not only provides the basic mapping, but allows reconceptualisations as well as the integration of knowledge from other domains. A common reconceptualisation of the TIME IS SPACE conceptual blend is, for example, a change in perspective, where time is conceptualised as passing a static observer, e.g. in the expression *Time passes slowly* (Fauconnier and Turner 2008). It is important to note that a metaphorical or analogical mapping alone cannot account for this additional mental flexibility.

Goguen's approach

Fauconnier and Turner's account of concept blending is not directly suited for computational cognitive modelling, because it remains purely descriptive. Goguen (2006) outlines a computational account of conceptual blending – based on Fauconnier and Turner – using the theory of *Institutions*, a theory similar to *Information Flow*, which we used earlier (Guhe, Smaill, & Pease, 2009).

We cannot go into much detail here, so we will restrict ourselves to one of Goguen's (2006) motivating examples of a conceptual blend between the concepts HOUSE and BOAT, resulting in the conceptual blends HOUSEBOAT and BOATHOUSE, cf. Figure 1 for a depiction of the HOUSEBOAT blend. A base domain (shown at the bottom) provides the 'glue' needed for mapping two domains (in the middle, left and right) and creating a conceptual blend (at the top). The most important mapping here is the one of *live-in* and *ride*, which provides the reconceptualisation of a BOAT as an OBJECT in which a person can not only RIDE but also LIVE.

Goguen restricts the many possible conceptual blends by specifying sortal frames, which must match in order for a mapping between domains to succeed. Sortal restrictions are

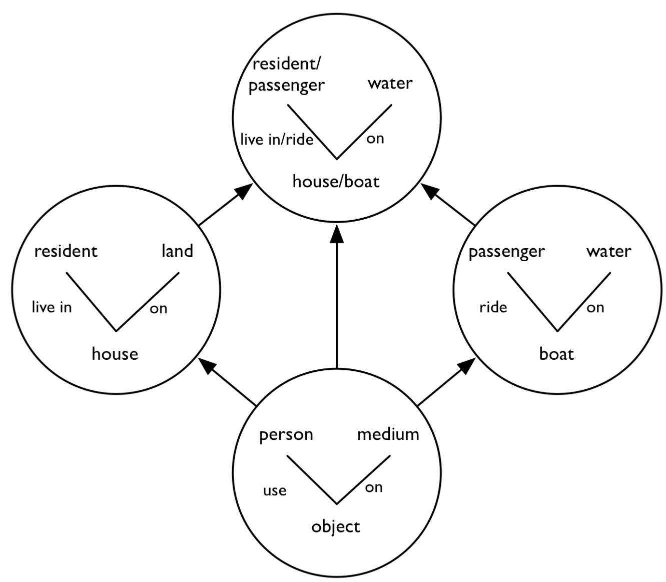

Figure 1: HOUSEBOAT conceptual blend

specified in a signature, for example for the HOUSEBOAT case Goguen defines the following sortal frames:

resident: → Person	*passenger : → Person*
house : → Object	*boat : → Object*
land, water: → Medium	*land, water: →Medium*
livein : Person Object → Bool	*ride : Person Object → Bool*
on: Object Medium → Bool	*on: Object Medium → Bool*
livein(resident, house)	*ride(passenger, boat)*
on(house, land)	*on(boat, water)*

Transfer to ACT-R

The translation of Goguen's proposal to ACT-R (Anderson, 2007) is rather straightforward. In our prototypical implementation, facts are represented as chunks and the matching and transfer operations are realised with production rules. The one major problem is that ACT-R does not have a sortal mechanism comparable to Goguen's. Although ACT-R uses sorts (in the form of chunk types), it does not automatically check for super-/subsort relations like in Goguen's conception. This means, for example, that WATER is not automatically understood to match frames specifying MEDIUM. Thus, the mapping of *on(house, land)* to *on(boat, water)* fails, because these facts cannot be linked via the base domain (by using *on(object, medium)*). We outline two basic solutions below. Which one provides a better model of the cognitive mechanisms will have to be established experimentally.

Solution 1 – Explicit sortal checks

The first solution is to explicitly perform sortal checks with a set of production rules. For such a model we coded information about subsorts as chunks of type

```
(chunk-type is-subsort sort1 sort2)
```

The production rules performing the sortal checks keep the information about the two facts that are being compared in the imaginal buffer while the information about the sortal hierarchy is retrieved from the declarative memory.

A variant for faster processing is to include sortal information with the facts, e.g. for predicates:

```
(chunk-type predicate name result-sort
            par1 sort1 par2 sort2)
```

The major disadvantage of this solution is that the representations contain much redundancy and do not provide the usual generalisations, e.g. that WATER is a subsort of MEDIUM.

Solution 2 – Amending the declarative module

An alternative solution is to change ACT-R on the architectural level, i.e. to amend the declarative module. A rather mild extension is to provide the declarative module with sortal information (e.g. a lattice of sorts) and let it consider not only chunks that directly match the sort of the chunk (i.e., that match in the `isa` slot) but also chunks that have a supersort of the chunk being requested.

A more severe alteration is to check all slot values that a chunk specifies and match not only the values themselves but check for values higher up in the sortal hierarchy. For example, if a request to the declarative module specifies a chunk with a slot–value pair like

```
retrieval>
   isa predicate
   name on
   par1 house …
```

the `par1` slot would also match for chunks like:

```
retrieval>
  isa predicate
  name on
  par1 object …
```

Solution 2 predicts much faster processing than solution 1, because all checks are performed within one memory retrieval. Thus, it neither requires firing multiple productions nor multiple retrievals from declarative memory.

Conclusion

Conceptual blending is a central, powerful and productive aspect of human cognition, allowing, for example, to conceptualise time in terms of space. However, cognitive modelling has not yet seriously addressed this issue. We outlined in broad terms a way to transfer Goguen's notion of conceptual blending into the cognitive architecture ACT-R as a first step to include conceptual blending in cognitive models of scientific creativity, in particular mathematical thinking. Whether a modification of ACT-R's declarative module will provide better cognitive adequacy will have to be decided on the basis of empirical data.

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