

Higher-order Abstraction: An Analogy-generation Mechanism?

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An important vehicle for representation-change, analogy is often treated as a special case, distinct from the conceptual operations of generalization and abstraction. But analysis of conceptual-structuring possibilities reveals that abstraction is capable of *mediating* analogy where the context is a conceptual structure of sufficient depth. The talk will demonstrate the effect and examine some of the questions raised about the theoretical relationship between analogy and abstraction.

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Hard to find analysis focusing *exclusively* on this issue.

Easy to find theories of *concepts* which have implications for it, or make assumptions about it.

These range from 'minimal' (each concept has its constituents and that's it) to 'permissive' (*any* structure of *any* complexity is possible)

Who assumes what?

Smith and Medin (1981) note 'conceptual combination' is responsible for 'enlarging the taxonomy by combining existing concepts into novel ones'.

Open to the possibility of arbitrary hierarchical (i.e., taxonomy-like) structure?

Rosch et al. (1976) contrast the 'basic' conceptual level with the superordinate and subordinate level.

Thinking of a specifically three-level system?

Prinz (2002) talks about concept combination via 'alignintegration' and 'feature pooling'

Assuming arbitrarily deep hierarchical combination but subject to constraints (e.g., 'relation linking')?

Similarly with concept-combination theory (Ward, Smith, Finke, 



Which way?

A natural approach is to try to (a) determine the general nature of concepts and then (b) identify implications for conceptual structure.

Alternative is to try to (a) determine the general form of conceptual structure and then (b) identify the implications for concepts.

Step 1: basic cases

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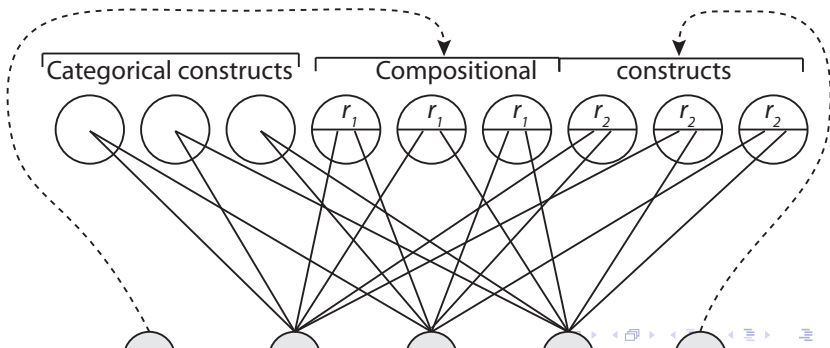
Complete combination is thus what happens in generalization, abstraction, is-a construction and category/class formation. I'll be calling it *categorical construction*.

Incomplete combination is what happens in model formation, schema acquisition, 'part-of' construction etc. I'll call it *compositional construction*.

Step 2: enumeration

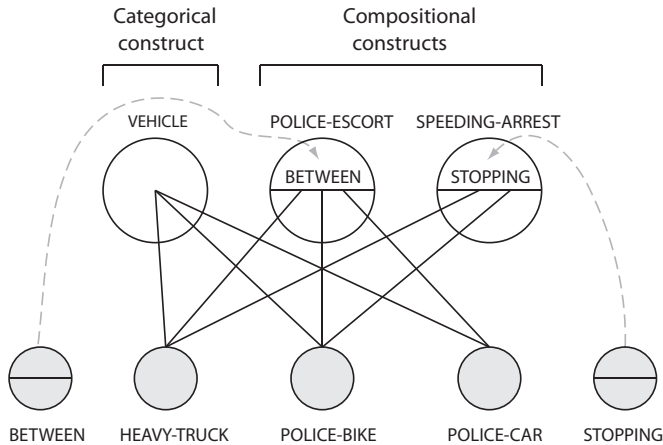
Enumeration of possible constructs derivable from some given concepts is straightforward.

Each combination of given concepts enables one categorical construct and n compositional ones, where n is the number of available/applicable ensemble definitions (i.e., relational concepts).

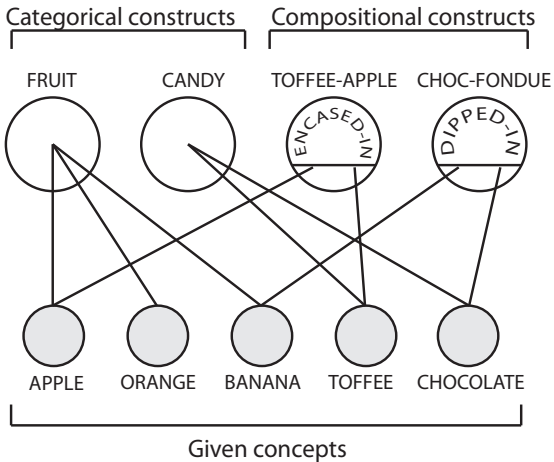


Vehicles example

Putting labels on the concepts illustrates how constructs implement 'generalization' and 'schema-acquisition'.



Food example



Step 3: completeness

Categorical/compositional distinction is exclusive and exhaustive.

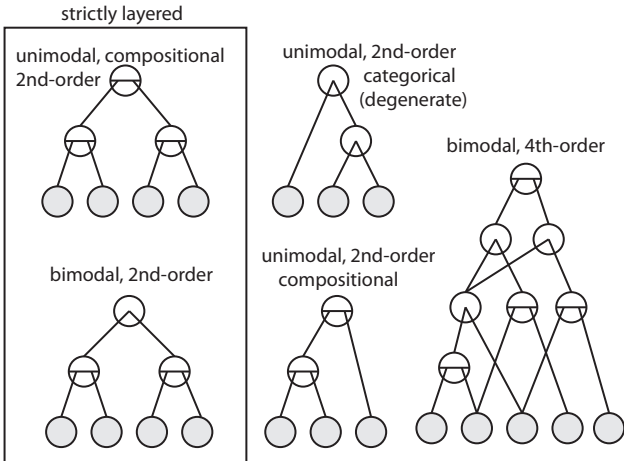
Every act of concept-combination must be complete or incomplete.

No concept can be constructed from a combination of constituents without it being either a categorical or a compositional construct of those constituents.

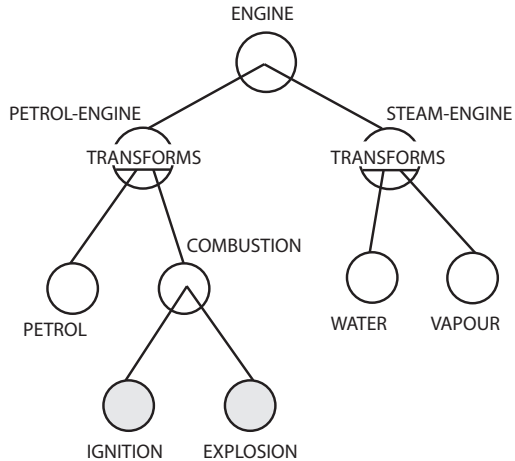
Enumeration in terms of categorical/compositional constructs is therefore exhaustive.

Step 4: Hierarchical forms

Combining some concepts to form a new concept produces a new entity which can be used in further combinations.



Bimodal ENGINE



Step 5: general form

The general form of conceptual structure is hierarchical but *not* taxonomy-like and *not* homogenous.

It's bimodal in general and divided into specific orders.

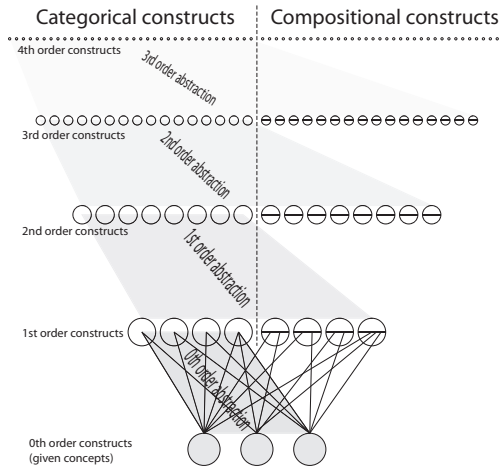
$$C_i \rightarrow \dot{C}_i | \overline{C}_i$$

$$\dot{C}_i \rightarrow \{C_{j:0..i-1}^*\}$$

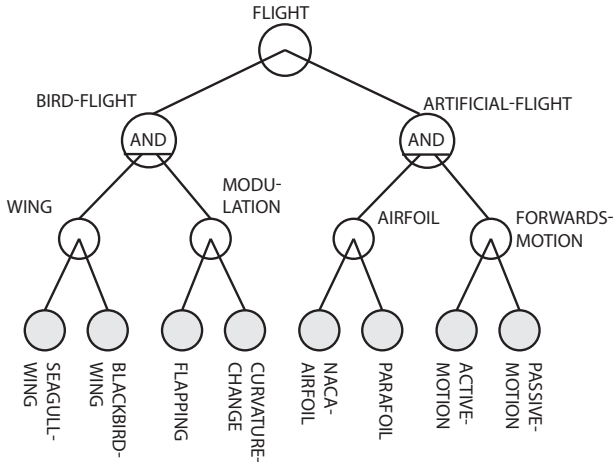
$$\overline{C}_i \rightarrow \langle \overline{C}_0, C_{j:0..i-1}^* \rangle$$

Because categorical degeneracy 'blocks' vertical development in one modality at every level, it also exhibits a **staircase** structure.

Abstraction staircase

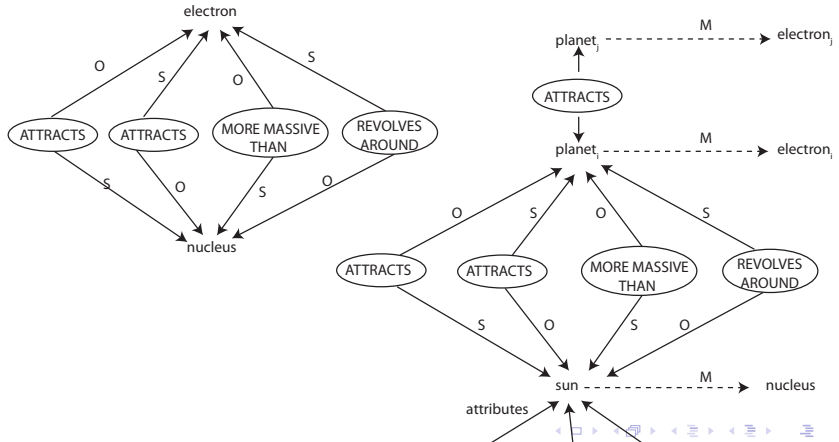


Higher-order FLIGHT

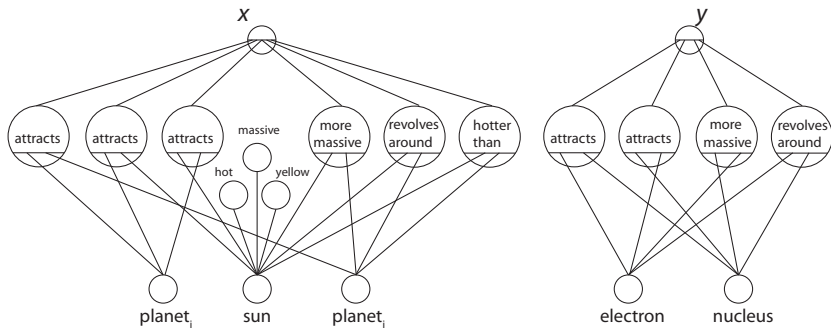


Analogy by structure-mapping

In structure-mapping theory, e.g., (Gentner 1983), the strength of an analogy depends on 'systematicity' — the degree to which 'systems of relations' are carried across from 'base' to 'target'.



Same analogy, different view



Systematicity or redundancy?

In structure-mapping, the systematicity bias is grafted onto the analogy-forming agent.

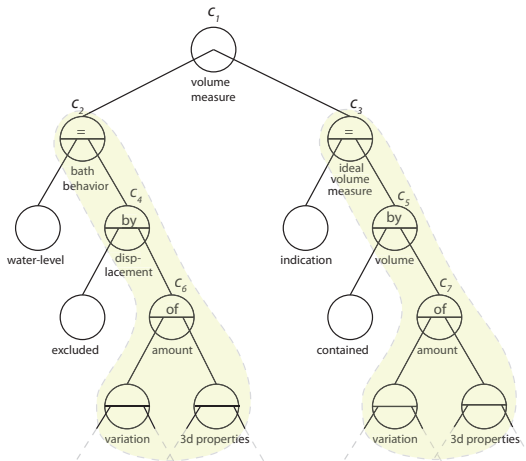
The agent is taken to be actively directed towards relational correspondences.

Viewing analogy-formation as higher-order abstraction, we can cash this out as a more general preference for elimination of conceptual redundancy.

May also save having to treat schema-acquisition as an added extra.

(This is particularly noticeable in LISA: 'augmented with a basis for intersection discovery, the inference algorithm becomes an algorithm for schema induction' (Hummel Holyoak, 2003, p 230).)

Archimedes example

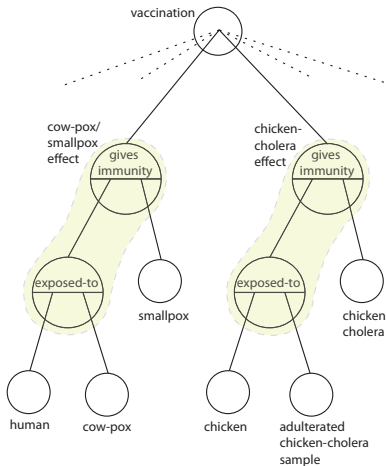


Exploitation of analogy, similarity or redundancy?

Gentner and Kurz (2006) note 'considerable' support for the claim



Vaccination example



Analysis can identify the general form of conceptual structure without assuming anything specific about concepts.

Rather than a homogenous 'taxonomy', it's really a bimodal 'staircase' of distinct levels, encapsulating an interplay between categorization and composition.

Distinctions which prioritize specific 'depths' or 'levels' (e.g., concept v feature v property, and basic v superordinate v subordinate) will not show up at the structural level.

Higher-order abstraction can be viewed as mediating analogy.

Systematicity bias may reduce to a more general preference for elimination of conceptual redundancy.

Bits and pieces left out of the talk (e.g., bootstrapping issue, and implementation of redundancy-based systematicity bias) covered in a paper at www.christhornton.eu/papers/gainful-analogies.

Fauconnier, G. (2002). Conceptual blending and analogy. In D. Gentner, K.J. Holyoak and B.N. Kokinov (Eds.), *THE ANALOGICAL MIND: PERSPECTIVES FROM COGNITIVE SCIENCE* (pp. 255-285). London: The MIT Press.

Gentner, D. (1983). Structure-mapping: a theoretical framework for analogy. *COGNITIVE SCIENCE*, 7 (pp. 155-170).

Gentner, D. and Kurtz, K. (2006). Relations, objects, and the composition of analogies. *COGNITIVE SCIENCE*, 30 (pp. 609-642).

Holyoak, K. and Hummel, J. (2002). Understanding analogy within a biological symbol system. In D. Gentner, K.J. Holyoak