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Analogical Reasoning, Models of Development

Analogical reasoning involves a structured comparison, or mapping, between one situation (source) and another (target). Analogy is a powerful means for people to learn about new situations based on their prior understanding of the world. While central in adult cognition, analogy is also important for children's capacity to transfer learning across domains and for schema abstraction. While there is general agreement that analogy is important for cognitive development, there is considerable disagreement on the mechanisms underlying children's development of mature, adult-like analogical reasoning. In this entry we briefly survey the dominant theories of the development of analogy and then discuss computational models attempting to test these theories.

Developmental Change in Analogy

While older children frequently use relational similarity in the service of solving problems, young children typically favor concrete, less relationally complex analogies based on featural similarity. Hypotheses for explaining these differences have centered on changes in relational knowledge and maturation of executive functions.

Relational Knowledge

Usha Goswami has argued that children are able to map relations in a rudimentary manner from early infancy, but their later analogical reasoning skills build on prerequisite content knowledge. Thus children's analogical reasoning becomes more and more adult-like on a domain by domain basis as knowledge develops.

Similarly, Dedre Gentner and colleagues hypothesized a "relational shift" during cognitive development such that as children build knowledge in a domain, they move from attending to similarity based on object features to relational similarity. These authors postulate this process is not an age-related phenomenon, but rather is tied to knowledge acquisition. Robert Morrison and colleagues have alternatively argued that the relational shift can be understood as a deficit in inhibitory control in working memory, one aspect of executive functions.

Executive Functions

Even when young children can demonstrate relational knowledge in a domain they frequently have difficulty using analogies requiring integration of multiple relations. Graeme Halford has proposed a theory of *relational complexity* to categorize relations by the number of sources of variation that must be processed in parallel. Halford suggested that on average, children's working-memory capacity is such that after age two, children can process binary relations, and after age five they can process ternary relations. Thus, children of age two could perform very simple analogy problems, but not problems that require integrating multiple relations.

Computational Models of Analogy

Over the last forty years there have been many computational models of analogical reasoning. In spite of this there have been relatively few attempts to use these models to describe the development of analogy. Efforts to do this can essentially be divided into two branches: 1) efforts to model how children develop relational representations of knowledge, and secondly, efforts to model how children use those representations in the service of analogy.

Building Relational Representations

All successful models of analogical reasoning operate on structured representations in long-term memory; however, until recently, no explanation existed for how these structured representations might arise. The lack of an account of where relational representations come from has lead Robert Leech and colleagues to postulate that analogy might not rely on structured representations but rather simple associations. However, these approaches have failed to provide an explanation of how children can process progressively more relationally complex analogies or exhibit the flexibility in relational thinking characteristic of adults. A more viable option is that humans can learn structured relational representations from unstructured examples. These representations could then be used in traditional symbolic or symbolic-connectionist models to perform analogical reasoning. Leonidas Doumas and colleagues have recently described one such approach that uses comparison to bootstrap learning structured relational representations starting with simple distributed representations of objects as feature vectors.

Developing Analogical Reasoning

Assuming a mechanism to learn relational knowledge, a computational model of the development of analogical reasoning must account for why children show a relational shift, why the relational shift is domain specific, and why children initially have difficulty processing relationally complex analogies. In an effort to capture the relational shift, Gentner and colleagues hand-coded different relational representations in the Structure-Mapping Engine (SME). SME showed a mapping advantage for the representation containing the higher-order relation similar to that observed in older vs. younger children.

An alternative solution to this problem, involves assuming that the development of analogy is at least partly tied to maturation of brain systems, particularly areas of the prefrontal cortex known to develop well into adolescence. Previous neuropsychological and neuroimaging analogy studies in both children and adults have shown these areas of the brain to be critical for analogy performance. Working under this assumption, Morrison and colleagues used Hummel and Holyoak's LISA (Learning and Inference with Schemas and Analogies), a symbolic connectionist model of analogy, to successfully simulate both the relational shift as well as relational complexity effects in children from the age of 3 to 13. All that was necessary to capture these phenomena was a change in LISA's inhibition parameter, a parameter closely tied to one likely role of the prefrontal cortex. Importantly, this approach can also benefit from domain specific changes in representation, when relational representations are chunked presumably as a result of knowledge accretion or expertise. Thus, as relational knowledge develops in a domain, processing can become easier for LISA. This approach provides an explanation for both quick changes in analogy performance as a result of learning and also slower maturational changes as a result of changes in biology.

Robert G. Morrison

see also: Analogical Reasoning: Analogical Mapping and Reasoning; Analogical Reasoning: Computational Perspectives; Reasoning: Development of Reasoning, Reasoning: Developmental Models of.

Further Reading

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