Analogical Reasoning: A Core of Cognition

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Analogies have always been considered to be a central part of human intelligence and cognition. This survey offers an overview of analogical reasoning and its applications, showing that analogies are an important element of various cognitive abilities like memory access, adaptation, learning, reasoning, and creativity. Therefore, analogies can provide a basis for integrated large-scale cognitive systems.

1 Introduction

Analogy research has a long history and was subject of investigation on various levels: Ancient Greek philosophy examined analogy as a proportional relation between objects. In belletristic texts, metaphors use analogy implicitly to describe objects in a figurative way. In natural sciences, analogy is an indispensable tool for scientific progress [18].

While classical research on analogy mainly deals with higher-level intelligent behavior, the focus in cognitive science has shifted to the examination of more basic cognitive abilities, relevant for agents interacting with their environment. Many of these abilities seem to rely on analogy as well and thereby give an explanation for the analogical capacity on the higher-level. Therefore, it is not astonishing that analogy plays a central role in cognitive science research.

2 What is Analogy?

Analogy making is a highly sophisticated cognitive process in which two conceptualizations - a source and a target - are analyzed for common structural patterns [6]. In analogies, source and target are typically of different domains (for metaphors this is even essential). The purpose of analogies is to adapt knowledge available about the source conceptualization such that it can be applied to the target in a way that new analogous inferences can be drawn. Analogy making requires intelligence since analogous patterns and transfers often are not obvious and depend on a certain conceptualization of the domains.

Metaphors and analogies occur in a large variety of domains, as well as in quite different forms. In order to classify certain aspects and properties of analogies, three types of analogies are often distinguished[1] [14, 22]: First, proportional analogies have the general form $(A : B) :: (C : X)$. Proportional analogies can be *in domain* which means that A, B, C are expressions from the same domain. This type is characteristic for intelligence test where the subjects have to continue a sequence of geometric figures [4] or numbers and strings [12]. Proportional analogies can also be *cross domain*. In this case, A and B establish a relation in the source domain which should be applied to a concept C of the target domain to get the result X in the target domain.

Proportional analogies have a nice counterpart in metaphoric expressions. For example, a statement like *Gills are the lungs of fish* can be analyzed as the solution to the following analogy: *mammals : lungs :: fish : X*. Here the word *gills* refers to whatever the analogical relation constructs for X. What is mentioned in the surface structure of the metaphoric expression is typically a cross domain role relation meaning *X* plays the role of *lungs* to fish, while the reference to the counterpart of *fish* (*mammals*) is assumed to be derivable by background knowledge.

A second type of analogies are predictive analogies. They describe a new domain (target) not only by specifying structural commonalities with a given domain (source), but also by transferring information and explanations from the source to the target [5, 13]. Besides the classical domain of metaphoric expressions, complex conceptualizations of correlations between seemingly different physical domains are good examples for such analogies. They relate physical domains which are hardly accessible by our direct experience to domains which have perceivable properties. The importance of analogies becomes evident in cases where such working analogies are not available. Why is relativity theory or quantum mechanics so hard to conceive by humans? The main reason is, because the analogical transfer to a domain which is accessible to our direct experience essentially fails. There are many other examples in modern physics where no good analogies are available or strange metaphors are used which do not explain very much: consider for example the wave-particle dualism, exchange forces (based on photons, gravitons etc.), or string theory.

The third type of analogy, analogical problem solving, can be used to solve a problem by transferring a solution from a well-known domain to an unknown domain. Case-based reasoning [16] formalizes approaches of this type. Other examples are the famous tumor-fortress problem [8] or the usage of program code for developing new programs by abstraction [23].

Another aspect connected to analogies is the re-conceptualization of known domains (called rendition). This may occur if an obvious analogy fails. A classical example is the conceptualization of a paintbrush as a tool to transfer paint to a canvas by pumping paint in contrast to smearing it [14]. In general, verifying hypotheses about allegedly known (real world) situation (source) by experiments in a

[1] We do not claim that the following classification of analogies is complete, nor that it is the only possible one. Rather such a classification can be useful to specify different properties of analogies.

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