

Automated Scientific Discovery and Hofstadter's Fluid Concepts Model

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Abstract

In this talk we present the Fluid Concepts cognitive model, developed by Douglas Hofstadter and his students over the last 30 years. Models in the Fluid Concepts tradition aim to provide a psychologically plausible description of perception and analogy-making, incorporating the parallel processing of bottom-up, data-driven percepts and top-down, expectation-driven hypotheses. We discuss these models' implications for scientific discovery.

Introduction

In this work we discuss the fluid concepts architecture, developed by Douglas Hofstadter and his Ph.D. students over the last 30 years, and the implications of this work for cognitive models of scientific discovery.

At the end of Hofstadter's book *Gödel Escher Bach* (1979) there is a set of problems Hofstadter considered to be incredibly far from the capacities of then-current models of artificial intelligence and cognitive science. They were called "Bongard problems", for the name of their creator, the late cybernetics researcher Dr. Michail M. Bongard from the Soviet Union. Each problem displays two sets of figures, asking the solver to identify a feature distinguishing elements on the left from elements on the right. Figure 1 displays two Bongard problems.

The reader should not have the impression that these problems have a trivial solution or that being situated in the microdomain of Bongard problems keeps them distant from the requirements of cognition. These problems were highly influential in the development of Hofstadter's subsequent microdomains, such as the number sequences of *Seek Whence* or the letter-strings of *Copycat* (see Hofstadter 1985, Hofstadter and FARG 1995). The programs operating in these microdomains include a number of features that Hofstadter saw as essential for modeling the human mind:

- (i) **Active symbols:** in most symbolic systems of traditional AI, symbols are simply data manipulated through procedures; in an active symbols system, the moment that a symbol (say, "triangle") becomes active, it influences

the direction of future processing. (It might, for instance, attempt to find other triangles, or spread activation to related concepts, such as "angle");

- (ii) **Top-down (hypothesis-driven) and bottom-up (data-driven) computation:** both types of processes operate simultaneously. It is impossible to separate perception from concepts; i.e., there can be no perception module on a cognitive system;
- (iii) **Analogy at the core of cognition:** the basic idea here is that, for instance, in vision, the same set of photons will never reach the retina in the exact same way. Analogy lets us handle abstract similarities. Figure 2 shows how analogy plays a crucial part in the game of chess (Linhares 2005, Linhares and Brum 2007).

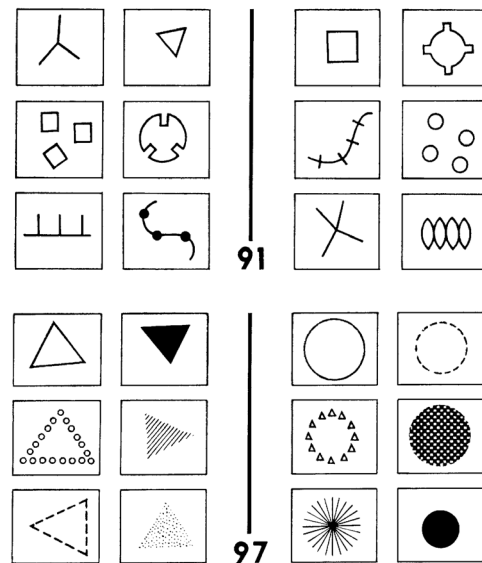
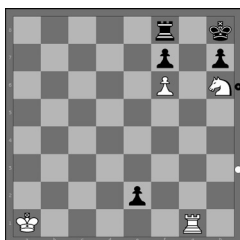


Figure 1. Bongard problems #91 and #97. The number of potential characteristics to distinguish the groups is enormous. Foundalis (2006), for instance, showed that even abstract notions of the real world, such as time, motion, gravity, three-dimensionality, etc., may play a part in the solution of a Bongard problem. Linhares (2000) showed how people could come with inconsistent,

incompatible interpretations in a given problem, yet feel that there was no inconsistency involved (for example, in problem #91, people respond “three objects versus four objects”, without realizing that, in so doing, they have carved the squares on the left as single objects, and the square on the right as four independent objects—“consistent” interpretations would lead to “12 line segments versus 4”, or “three squares versus one”. This shows that top-down, contextual pressures, can alter the perception of each object.

8:



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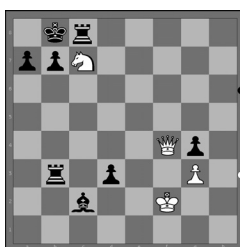


Figure 2. Positions 8 and 20 used in Linhares and Brum (2007). White to move. For readers unfamiliar with chess, the solutions are: In position 8, white moves rook to g8 check, black rook captures white rook, white knight captures black pawn at f7 checkmate. In position 20 white moves knight to a6 check (by knight and by queen), black king escapes to a8, white moves queen to b8 check, black rook captures white queen, white knight returns to c7 checkmate. These variations of “Philidor’s mate” display high strategic similarity and no similarity at a surface appearance level.

Implications

Given this brief introduction, what are the implications of Hofstadter’s studies to the field of cognitive modeling of scientific discovery? What features should architectures that model automated scientific discovery have? We suggest that models of human-like scientific discovery should incorporate the following ideas:

- (i) A deep intermingling of bottom-up, data-driven perception processes with top-down, expectation-driven hypothesis. Perhaps here lies the greatest contribution from Fluid Concepts to automated scientific discovery. Take for example, classification sciences

such as taxonomy (prior to DNA). Classification problems are extremely close to Bongard problems in their cognitive demands. Understanding that sharks and dolphins are extremely different requires more than bottom-up perception data, which may lead to error (in fact, Linnaeus himself initially classified dolphins as fish). It also requires that one holds in mind the expectations of what constitutes a mammal and what constitutes a fish, and hence perceiving, in disguised polymorphic forms, a mammal in a dolphin.

- (ii) Analogy at the core of knowledge expansion. From the model of the atom to the idea of superstrings, to viewing DNA as a staircase, analogies play a crucial part of scientific discovery. In Hofstadter’s models, there is a semantic network called the slipnet. A crucial feature of this associative network is that concepts are allowed to “slip”, changing their distances to other concepts as new ideas are brought up. This type of model facilitates the perception of DNA as a zipper (in a cell biology scenario), of DNA as a computer program (in a cell development scenario), or of DNA as a fingerprint (in a crime scene). The fact that we can use concepts as semantically apart as those to describe and understand a molecule tells us a lot about the power of analogy-making in scientific discovery.

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