Understanding Diagrammatic Reasoning through Predictive Processing

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1 Introduction

The thesis I want to support is that the *Predictive Processing* (PP) [4] approach on cognition should be considered as especially suitable to describe how humans understand and work with diagrams, given the particular definition of diagrams brought forward in [8]. The need for this model stems from the incompatibility of some of the most prominent cognitive features of diagrammatic reasoning (e.g. transparency-loss, the need for self-shaping and interaction, aspect-seeing, etc) with other recent approaches on cognition. Predictive Processing presents no such incompatibilities. I develop this thesis in three steps: firstly I select some of the characterising features of mathematical diagrams, as described by V. Giardino and colleagues [8–10]; secondly I briefly describe how a variety of epistemological stances on cognition (cognitive internalism, extension and enculturation, [1][2][12][14][15]) fail to describe diagrammatic reasoning; finally I show how Predictive Processing overcomes some of these difficulties. I then point out what new research directions this understanding of diagrammatic reasoning leads to.

2 Salient cognitive features of diagrammatic reasoning

According to [8], mathematical diagrams can be described as two-dimentional representations which have three identifying features: (1) they are accompanied by a textual caption; (2) they have to be understood as kinaesthetic objects; (3) they function as they do because of their hybrid cognitive status. The need for captions stems from two factors: firstly, interpreting diagrams requires expertise and captions guide this process; secondly, captions distinguish diagrams from mere *sketches*. Since a reader needs to take into account visual, dimensional and textual information when interpreting a diagram, the diagram becomes more than a mere visual stimulus and is only understandable by using different cognitive mechanisms.

The idea behind this description is that diagrams have an inherent interactive component, which renders them objects of epistemic actions ([13]) carried out by agents with a variety of different skill-sets. Being the objects of epistemic actions, diagrams defy the need for *informational* and *procedural transparency* [12]. A representation is informationally transparent if it immediately displays its meaning, in the same way the meaning of English words is transparent to native speakers. It is procedurally transparent if it is a resource that can be accessed by the agent without the need for pragmatic effort. Since diagrams, being epistemic objects, are better understood by agents with a certain degree of expertise, they can be neither informationally nor procedurally transparent. At the same time, this interactive nature of diagrams calls for a certain degree of self-shaping within the cognitive architecture of the agent: by performing epistemic actions on them the agent both builds symbolic scaffoldings in the environment ([16]) and shapes the cognitive structure of her own mind [14]. Finally, the ability to shift from seeing some aspects of a diagram to others, known as "*aspect-seeing*" [10], is intrinsic in our understanding them: it allows for a dynamic relationship with them.

3 General approach and completed work

Given these features of diagrammatic reasoning, I have confronted the different cognitive approaches which could be employed to describe this phenomenon, concentrating mainly on: cognitive internalism, cognitive embodiment, cognitive extension and enculturation.

I argue that cognitive internalism ([1]) is objectionable because it considers diagrams as superfluous copies of internal representation, thus failing to capture their active role within the process of abstract understanding. From the point of view of embodied and extended approaches, on the other hand, the most promising is the *extended mind* framework [3][6], as it posits that cognitive agents incorporate external elements (in this case diagrams) as constitutive of their own cognition. Diagrams are, then, cognitive tools in their own right. This is captured by Clark's and Chalmers' well known parity principle, according to which "[i]f, as we confront some task, a part of the world functions as a process which, were it to go on in the head, we would have no hesitation in accepting as part of the cognitive process, then that part of the world is (for that time) part of the cognitive process" [2]. However, even though this approach gives diagrams a fundamental role, it treats them as external representations that are immediately accessible, and that do not need to be transformed and manipulated.

Philosophically, this is a consequence of adopting the notion of *knowledge* as epistemologically fundamental. What is problematic is not the notion of knowledge per se, but rather its characterisation as *justified true belief* (JTB)[7][5]. This description of knowledge presupposes the following: agents only have knowledge of propositions (beliefs), and not of visual information such as diagrams; knowledge can only be based on truth (i.e. truth-dependence of knowledge); there needs to be a *justification* to knowledge, i.e. true information that has been obtained improperly cannot be considered knowledge. Studying diagrammatic reasoning in an epistemological framework of this kind would have a variety of negative consequences:

- the visual component of diagrams and the dynamic relationship between agent and diagram would not be captured (as diagrams would be reduced to static propositions rather than kinaesthetic objects).
- there would be a demand for truth and justification that is not generally present in diagrammatic reasoning: when carrying out epistemic actions and when manipulating and interpreting a diagram the focus of the cognitive agent is on the effects of the manipulation rather that on truth and justification, as shown in [3][4].
- a framework of this kind would not explain why diagrams do not present themselves transparently and immediately as the products of knowledge usually do. Therefore, there would be no way to account for the expertise that is needed when interpreting a diagram, which is described in [8].

To remedy these problems, I argue that it is necessary to turn to the model of PP, which replaces the notion of knowledge with that of *understanding* [5][11] (an agent understands something when her cognitive architecture is composed of a network of information that is structurally and epistemically linked together). According to this point of view, agents are continuously trying to anticipate the incoming stimuli of the environment they are in, in order to reach some sort of equilibrium in a sea of uncertainty. These predictions are carried out by application of bayesian priors through a constant top-down involvement of brain areas. Since bayesian models are approximate and imperfect, the agent is also constantly active in a process of correction of the prediction errors. I have found that PP is well fitted to describe all the features of our understanding of diagrams that I have described:

1. the loss of transparency and the element of aspect-seeing emerge because the agent identifies the diagram immediately, but needs further epistemic steps to hone in on the exact meaning of its sections.

2. the accuracy of the bayesian priors depend on the level of expertise of the agent
3. diagrams can be fully understood only through interaction with them. This is completely compatible with the notion of action-based cognition that is structurally linked to PP: action is brought about as a means of correction of the prediction error. The necessity to enact the relationship with the diagram can be explained in these terms.

I, thus, conclude that, in the process of diagram-understanding, the agent and the diagram have to be described as a coupling centered on the need to find an epistemic and semantic equilibrium. Predictive Processing certainly allows this description.

4 Further research and philosophical impact

The main consequences of this work are that it allows to shift the research from *knowledge-based* approaches to *understanding-based* ones and that it makes sense of the different observations on diagrammatic reasoning in a unified and strong framework. This allows further research directions, including: understanding how the neurological structuring of Predictive Processing describes diagrammatic reasoning; describing how diagrammatic reasoning can be thought of in a epistemological framework which can include false information and ignorance; showing how inaccurate bayesian priors influence the understanding of a diagram.

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