General Situated Cognition

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1 Introduction

I develop a theory of General Situated Cognition. The project has several goals: (1) to unify existing foundational approaches to cognition; (2) to characterize the function of cognition in autonomous systems and suggest a general (meta-)framework for cognitive architecture; (3) to provide sufficiency conditions and a classification of representation mechanisms in natural and artificial cognitive systems.

2 Unembedded Approaches

2.1 The Symbolic Approach

In this section I investigate the Classical AI approach to cognition as formulated by Newell and Simon in terms of the physical symbol system hypothesis. I examine both the sufficiency and the necessity claims of the hypothesis and various criticisms of the approach. With respect to sufficiency, I examine the Fodor and Dreyfus style criticisms of the approach focusing on the “frame problem” and the problem of relevance. While the criticisms are serious, doubting the plausibility of some more naive architectures based on symbols systems, I find the criticisms inconclusive. However, they place a serious burden on the narrow version of the classical approach. I also conclude that a more serious problem with the approach comes from the assumption that cognition (and intelligence) can be described by ignoring embedding.

The question of necessity of symbolic processing raises different problems all together. Originally the claim of necessity was meant to cover human-like intelligence. If the question is raised about simpler cognitive systems, necessity seems highly implausible. The interesting question is: Are there non-exotic, truly useful cognitive capacities that require some form of symbolic processing. I examine some of the arguments offered by Fodor and Pylyshyn — insisting that compositional representations requires symbolic, propositional representations — and some replies offered by (e.g.) Stitch, etc. As Clark argues however, “symbol” and “compositionality” are process dependent notions, thus the precise scope of the claims is unclear. Nevertheless, whether or not symbolic processing is absolutely necessary, it seems extremely important. Even if a cognitive architecture is not, in its base, symbolic, a capacity for symbolic processing must be implemented to allow for some of the most successful aspects of human-like cognition. Symbolic processing allows incredible representational flexibility, although this comes at a cost of inefficiency.

2.2 Connectionism

I examine the proposal that the connectionist (PDP) network architecture offers a better alternative to symbolic processing. While connectionist networks offer a truly interesting alternative to symbolic processing, offering performance characteristics that are unlike what is seen in classical AI, the strong position offered by e.g. Churchland is rejected as unsupported, and ultimately unproductive. In many respects, my verdict about connectionism is similar to my verdict about symbolic processing. Both offer possible architectures that are useful in some cases and inappropriate in others. In both cases the demand of universality is unwarranted, and without universality many of the philosophical debates disappear. Like with symbolic
processing, the most serious challenge to the connectionist approach is that cognition is regarded as an unembedded phenomenon.

3 Embedded Approaches

3.1 Dynamicism and Situated Robotics

I discuss the dynamicist program as endorsed in different ways and degrees by e.g., van Gelder, Thelen & Smith, Chamero, Wheeler, etc. I reject the strong thesis of the program, but I endorse the insights that: (1) dynamical interactions between agent and environment play a central role for understanding the structure of cognition; and (2) dynamical system theoretic models are important for explanation of cognitive and related phenomena.

3.2 Distributed Cognition

I examine the pioneering work of Edwin Hutchins in the program of distributed cognition. I am not as interested in the possibility of cognition in social/technological groups. Rather, I am interested in what the proposal can teach us about cognition in general, including human cognition. Hutchins’ approach to cognitive systems is partly influential for my own proposal discussed in Chapter 6.

3.3 Biological and A-Life cognition

I explore the approach to cognition that claims that cognition is fundamentally related to life, and that the proper theoretical framework for cognition is not the theory of computation, but the theory of A-life. I explore Wheeler’s analysis of the distinction between the A-life approach and the traditional AI approach. I also explore a particular proposal for a theory of cognition due to Maturana and Varela. (Further discussion exist in 5.2)

4 Information for Cognition

4.1 Between Dynamics and Cognition

In this section I introduce some of the central concepts related to the notion(s) of information. I have two goals: to acquaint the reader with the different approaches/aspects of information; and, to isolate what approach is needed to develop a general theory of cognition.

First, I discuss quantitative theories of information — Shannon’s communication theory and Kolmogorov/Solomonoff algorithmic theory. I investigate the conditions under which the theories apply as well as shortcomings with the theories. Some hold that quantitative theories exhaust the concept of information; I hold that a more general, qualitative account of information is needed to ground cognition.

Second, I introduce accounts of physical information. I explain the connection between thermodynamic entropy and information, the negentropy principle of information, and the connection between information and order.

Third, I explore semantic theories of information. I question whether notions such as data, meaning and truthfulness can be defined in isolation in the most general cases of information. I also discuss other important distinctions within semantic theories — (e.g.) the distinction between factual and instructional information. I conclude that theories of semantic information do not provide the needed generality for pre-cognitive information.

Fourth, I turn to pragmatic theories of information. I consider the discussion of informational content due to MacKay, who argues that the meaning of the message is the way the message sets the “conditional-probability matrix” of the receiver’s dispositions. The most systematic account of pragmatic information is developed by Deo de Nauta, who insists that information is at its core (and in its most general form) a semiotic notion, i.e. information proper exists only within the process of semiosis. I adopt many of Nauta’s ideas.

Finally, I argue that the proper notion of information for a theory of cognition must be based on dynamics: Informational processes need to be viewed as special kinds of dynamical processes. They are such because the organization of the dynamical system, induced by the constraints on it, provides the correct dynamical regularities that implement informational transformations and control relationships. The central question
becomes: how the structure in the world allows the emergence of the kinds of dynamical relations in the interactions of systems with other systems that facilitate the kinds of semantic relations that are found in cognitive systems. Dynamic information must be viewed as providing a level of abstraction between the underlying dynamics of a system, and its cybernetic/semiotic behavior.

4.2 Potential Information from Dynamics

I examine in more detail the alleged connection between the Maxwell's Demon thought experiment and information. This leads me to a discussion of the negentropy principle of information, as proposed by Brillouin, connecting the reduction of entropy in an open system to increase of information (from which it follows that every increase of information must be accompanied by increase of entropy somewhere else). Brillouin distinguishes between physical information (information implemented in a physical system) and free information (which is abstract and is given an epistemic spin). He insist that the negentropy principle extends to free information. I argue that Brillouin is attracted to the term “information” because of his intuitions about free information, yet only physical “information” is properly connected to entropy.

Any hope to recover an epistemically interesting notion of information must look at the conditions under which a system can have lower entropy. One suggestion is to connect information to “order”, where order is defined as the difference (or ratio) between the maximal entropy of a system and its actual entropy. We need to move beyond a statistical measure of order however. One observation, going back to Weaver, but also emphasized by Collier, is that not all systems are equally susceptible to effective description with statistical techniques. We can delimit systems according to a measure of complexity and according to a measure of order. Of particular interest are the systems that have both relatively high complexity and relatively high order (organization) — these are the complex organized systems. These systems are not effectively described with the machinery of statistical physics, nor with the analytical tools of dynamical systems theory. Yet, these are the systems where deviation from equilibrium can lead to an interesting notion of information.

A useful notion for understanding the nature of complex organized systems is the notion of dynamical constraint. A dynamical constraint is a constraint that limits the available states of a system. Order can be decomposed into ordered free energy (exergy) and ordered constraints. Statistical mechanics allows us to deal with free energy but not easily with dynamically changing ordered constraints. An important connection exist between the notions of free energy and constraints and the notion of work. Constrains can be generated by work from free energy channeled by other constraints. This suggests a mechanism for spontaneous generation of order.

If we consider systems with dynamical constraints we may be interested in conditions for the appearance of stable subsystems organized by the constraints. The dynamical notion of cohesion may be defined. Important aspect of the physical notion of information is related to the emergence of such organized sets of constraints. Cohesive systems and the interaction that they have with their environment allow for processes that may be described as involving semantic information. It is best if we do not use the term “information” to describe the phenomenon of order. Instead we should use the term “potential information”, and preserve the term “information” for the case of semantic, or the more genera semiotic information. Potential information gives us dynamical conditions for the existence of the processes facilitating informational transformation and flow.

4.3 Informational Coupling and Control

Information is relevant in cases where two or more systems interact and one of the systems can be regarded as a user of information from the other system(s). Particularly, information is relevant when the systems enter some coordination relation, they become dynamically coupled. Such systems can coordinate some of their structure, whereby some structure in one can play the role of information carrier about the other.

Not all structure correlations are interesting, however. For the notion of information one wants the emergence of some control relation between the systems, where the correlation facilitates change in the behavior of one of the systems because of the other. The control relation, the resultant change of behavior, the effect of that behavior on the environment and particularly on the controlling system, provides the basic conditions for the emergence of semiosis. It is in virtue of this that the interaction can usefully be described as informational.

The coupled dynamics of semiosis is more basic than the description of the systems as “communicating” in terms of data. In the most general case, the informational states of the systems, for which Shannon style
quantitative measures may apply, emerge from the process of semiosis as stable patterns within the coupled
dynamics.

Only once a sufficiently organized information dynamics exist can we ask the question about meaning
(third person meaning, not meaning for the system). The question of meaning is a question about an isolated
sub-process within the larger process of semiosis — it is a question about the nature of the correlation between
the informational states of the two systems.

5 The Cognitive Agent?

5.1 Setting the problem of cognition

I ask what the function of cognition for an organism is, in a way one can ask a similar question about
the function of metabolism, or the immune system, or the reproductive system. I distinguish between the
systemic function of cognition — related to the role cognition plays in the interaction of the organism and
the environment — and the organizational function of cognition — related to what internal role cognitive
mechanisms play for the organization of the system. I am interested in the organizational function of
cognition.

I argue that a good strategy for understanding the function of cognition is to adopt a design stands, and
ask what general problem cognition solves in a system. Ideally, a good characterization of cognition will be
a characterization of the most restricted naturally definable class of systems that is faithful to the practice of
cognitive science. In other words, I want to describe the most restricted class of systems that captures the
full generality of skills and capacities that are important to cognitive science. It is very difficult to prove
that such a class has been defined. Instead, I settle for finding an abstract characterization of cognition that
naturally encompasses typical capacities that cognitive science studies: learning, memory, feature detection,
representation, reasoning, etc.

5.2 Functional and Minimal Approaches to Cognition

I look at various proposals for characterizing/defining cognition (elaborating on some of the discussion in Ch.
3) either following a top-down functional approach or a bottom-up minimalist approach. On the functional
side I investigate a proposal by Mark Rowlands. I like the informational approach of Rowlands, but I find
that the proposal is not general enough. On the minimalist side I investigate the proposal of Maturana
and Varela who claim that the property of auto-poiesis is sufficient to account for cognition. I also look at
some criticisms of the suggestion: I investigate extensions of the proposal due to Bourgine and Stewart,
who continue to insist that cognition is related to metabolisms, but to a special adaptive metabolism, and
due to Bitbol and Luisi. I conclude that the proposals are incomplete because they rely too heavily on the
under-characterized notion of adaptivity. Surely, cognitive systems are adaptive systems, but this does not
say much.

5.3 Autonomous Agents and Informational Limits

Notions such as auto-poiesis do not prove sufficient for cognition, but they describe a first step towards
cognition. Autopoietic systems are the simplest autonomous systems — these are the systems for which the
capacity of cognition becomes useful. I describe a sequence of nested design problems that leads to isolating
the problem that cognition solves. The first design problem is maintaining viability. All autonomous systems
can be viewed as providing a solution to this problem. A way of improving a solution to this problem is
for the system to systematically produce beneficial actions. A second problem is: *How can an autonomous
system act in a way to improve its chances of survival?* A way to improve a design for the second problem is
to make the actions dependent on information from the environment. I call an agent to be a highly organized
complex system which has intrinsic goals (in its minimal sense, persistence within viability boundary) and
whose dynamical organization supports an informational description. A third design problem is: *How can an
autonomous agent utilize more and better (more relevant) information about the environment?* Every
agent is informationally deprived because of the large complexity of the relevant environment and the relative
simplicity of the information channels (perception) and internal informational resources. This deprivation
raises a forth design problem: *How can the organization of the agent be such that it can begin to overcome
this informational limitation?* I claim that cognition is the general strategy for resolving this design problem.
5.4 The Function of Cognition

The communication model of Shannon’s theory gives us a way of thinking about the problem of informational limitation. Saying that an agent is informationally deprived can be interpreted within communication theory by saying that the agent is receiving signals from the environment through a low capacity channel. Overcoming informational limitation is described as lowering conditional information entropy between the agent and the environment. The conditional entropy of a source of information on a receiver is lower if the pre-communication correlation between the informational states of the two systems is larger (i.e. the receiver “knows” about the source.) The entropy can also be lowered if the agent “focuses” on more selective features of the source (if it picks the right abstraction for organizing the world). Using these insights I characterize cognition as follows:

The cognitive system is the set of organizational constraints (mechanisms) of an autonomous agent that: (1) allow increase of the correlation and integration between the environment and the control structure of the agent, i.e. allow lowering of the conditional information entropy of selected important informational sources in the environment on the control structure of the agent, (2) so that the agent can improve the selection of actions to produce successful behavior in light of its informational limitations.

I show how the cognitive capacities: learning, memory, feature detection, representation, and reasoning, can be viewed as strategies for lowering of the conditional information entropy. I do not claim that this is all that these capacities do, nor do I claim that this is all that need be said about cognition — this is only a minimal account of cognition, this is the least that must be said.

6 The Informational Network Architecture

6.1 Lessons from Distributed Cognition

I go back to the discussion of distributed cognition, as formulated by Hutchins, and look at the idea that a cognitive system may be implemented by networking different representational devices that have unique, limited sets of properties which together allow an agent to navigate its environment. My goal is to generalize these ideas to a general (meta-)architecture for cognition.

6.2 Informational Media

I define the notion of informational medium:

An informational medium is a triple $\mathcal{M} = (\mathcal{D}, \mathcal{IC}, \mathcal{F})$ where $\mathcal{D}$ is a dynamical system, $\mathcal{IC}$ is a collection of disjoint sets of states of $\mathcal{D}$, where we think of the sets as being the different information-carrying states, and the states in each set as the possible dynamical states that depict the same information-carrying state. $\mathcal{F}$ is a collection of functions from $\mathcal{D}$ to $\mathcal{D}$ that respect the information-carrying states—i.e. $\forall f \in \mathcal{F}$, if $I, J \in \mathcal{IC}$ and $x, y \in I$ and $f(x) \in J$, then $f(y) \in J$—and we think of the functions in $\mathcal{F}$ as information-preserving transformations.

An informational medium network is a set of informational media with a set of information management operations among the media, and a set of information processing operations associated with each medium.

An informational medium has a dual nature: it is a dynamical system that participates in the dynamical/causal structure of the world; and, it is an informational system entering informational relations with other informational systems. The dual nature is central for the claim that informational networks can be used as a (meta-)architecture for situated cognition.

The dual nature of informational media and the roles they can play in an informational network provide several dimensions of characterization of the media. A medium can be evaluated according to: (1) its ability to enter in an appropriate and sufficiently rich informational connection with a source; (2) its ability to have desirable causal consequences; (3) its ability to contain detailed information; (4) its ability to process the information appropriately; (5) its ability to enter in appropriate management operations (5a) from it, and (5b) to it.
6.3 Cognitive Systems as informational medium networks

All cognitive agents are informational networks whose organization and dynamical interaction with the environment facilitates various informational media to be coordinated with some informational sources in the environment. Viewing a cognitive system as an informational network puts upfront the idea that cognition is achieved by careful integration of dynamical systems with various skills. Historically, theoretical approaches to cognition have attempted to propose unified, single medium architectural frameworks. The information network approach instead allows for many distinct, multi-skilled media. Instead of searching for the one super job candidate to implement all cognitive capacities, it searches for a carefully tuned collection of limited skill candidates that can work together. A significant part of the approach consists of characterizing the various general job descriptions that media may need to fill in the network of an active cognitive agent.

I describe the significance of different general measures for informational media: informational connection with a source, information processing skills, information management skills, informational-causal coordination. I discuss self-modifying networks where the information controlled causal effects of media within the network may modify the network itself. This is especially important for advanced forms of cognition. I also discuss virtual media, where informational states define a dynamical system on which further informational states can be defined. Such media are very important in human cognition, especially involving language.

6.4 The Significance of Network Topology

Unembedded architectures — symbolic processing and connectionism — can be modeled as degenerate cases of information networks, where only a single medium is present. These architectures fail to appreciate explicitly the role network topology may have for cognition. I discuss aspects of network topology, such as hierarchical organization, the density of connectivity, etc. I show, for example, that it is possible to distinguish between strongly distributed architectures and modular architectures. At one end, distributed architectures rely more on information management operations among simple media, while at the other end modular architectures rely on complex media connected by scarce management operations. Many other topology driven distinctions can be made.

7 Building Representational Systems

In this chapter I plan to explore the emergence of representational systems within cognition. I explore naturalistic accounts of representation due to Millikan, Dretske, Haugland, Wheeler, Floridi, as well as enactive theories of content. I suggest that we need a bootstrapping theory of representation, where we need the presence of a representational systems tightly connected with their content — enactive theories are important here. I suggest that one of the most important conditions for the emergence of informational media that act as representational systems is the existence of informational-causal feedback loops between the system and its content. Once such a representational system emerges, it is possible within an informational network to connect them with other representational systems which derive their content through the first.

We want to move towards symbolic representational systems. Important for this is the emergence of representational grammar — the emergence within the informational network of media (or sub-media) whose states can be given representational significance within the system in virtue purely of the structural properties of the states. Also important is the existence within the system of the capacity to control the representational connections of some media to others. The extreme case is a medium that can be both content flexible (any state or token can mean anything) and effect flexible (any state can have every available control function). Symbolic media, such as language, have these two kinds of flexibility. Interestingly, it is possible to define intermediate representational systems as well.

These notions allow me to provide a solution to the symbol grounding problem, a solution that generalizes the proposal in Floridi & Taddeo. It also allows us to make positive progress towards making sense of the distinction between third person representation and representation for the system, which is crucial for a naturalistic account of “intentionality”.

8 Conclusion

I explore further avenues of research and the way the theory developed in the dissertation helps in the process.