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SCALING UP WITH RADICALLY EMBODIED COGNITION

by

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Abstract

Radically embodied cognitive science (REC) is typically concerned with basic cognition such as perception and action. However, complex cognition or higher-order cognition is difficult to explain for REC, as these theories eschew traditional representational explanations. This leaves REC with a scaling-up problem.

In this dissertation I will explore options for REC to fix its scaling-up problem. I am specifically interested in autonoetic cognition, which is the ability to remember and imagine object and events in the way they would be experienced if they were immediately present to be perceived. I contend that a simulationist account provides many of the necessary conceptual tools for understanding autonoetic consciousness from a REC perspective. Furthermore, simulationist accounts are generally useful, as they are suggestive of a way to understand the observed neural activity and can be used to make empirical predictions. I will examine different simulationist theories in order to determine whether or not they can cohere with REC and help solve the scaling-up problem. Eventually I will argue that the REC commitment to reject representations makes the scaling up problem insurmountable at this time.

TABLE OF CONTENTS

Chapter 1: The Scaling Up Problem

Introduction

Radically Embodied Cognitive Science (REC) has a scaling-up problem. Using non-representational approaches, REC has had success in explaining basic cognition such as perception and action. However, it is unclear how such non-representational approaches can deal with more complex forms of cognition, such as the cognitive processes involved in remembering, imagining, solving problems, telling narratives, and reflecting and evaluating our actions (see e.g., Clowes & Mendonca, 2016; Fogalia & Grush, 2011). These are said to be 'representation-hungry' capacities (Clark & Toribio, 1994). Accordingly, Chemero (2009) suggests it's important to 'scale up' dynamic systems approaches from the analysis of action and perception to more complex cognitive performance, while, at the same time, admitting that it, "is still an open-question how far beyond minimally cognitive behaviors radical embodied cognitive science can get" (p. 43).

There are many different forms of complex cognition, but for this dissertation I will focus on what I'll call, following a terminology suggested by Tulving (2005), *autonoetic cognition* (AC). AC includes things like episodic memory and imagination. As Tulving puts it, "Autonoesis refers to the kind of conscious awareness that characterizes conscious recollection of personal happenings" (2005, p. 7). I am not specifically interested in the consciousness part of AC (i.e., the hard problem), but I will rather focus on the more general cognitive ability colloquially known as "mental time (and space) travel", which involves sensory imagination and episodic memory. My goal in this dissertation is to explore possible solutions to REC's scaling-up problem. I will discuss different ways that REC may explain the different manifestations of autonoetic cognition.

In this dissertation I will investigate theories of cognition that make use of neural simulation in their explanations for complex cognition. These simulationist accounts (SA) are embodied theories to varying degrees. I will make the case that they provide REC the tools for scaling up, but only if REC is willing to give up certain core commitments.

In this first chapter I will lay the groundwork for my project. I am interested in AC, which is often taken to be a complex or higher-order cognitive ability. According to Clark (1997) and others, AC cannot be explained without reference to representation.

> [Representation-hungry] cases include thoughts about temporally or spatially distant events and thoughts about the potential outcomes of imagined actions. In such cases, it is hard to avoid the conclusion that successful reasoning involves creating some kind of prior and identifiable stand-ins for the absent phenomena – inner surrogates that make possible appropriate behavioral coordination without the guidance provided by constant external input. (p. 167)

This is problematic because REC theories reject representationalism for a number of reasons. It is unclear how REC theories could scale up their explanations of basic cognition to also encompass complex cognition like AC.

In the second chapter I turn to neural simulation accounts. Simulation involves the re-use of perceptual and motoric neural resources while 'offline' in order to achieve cognition. I discuss the grounded cognition theories that are unified in their commitment to simulation explanations. Grounded cognition makes use of concepts from classical cognitivism that have been modified in order to fit into a SA framework. I will discuss concepts central to this approach and provide a broad overview of the grounded cognition movement.

In the third and fourth chapters I discuss, respectively, two theories that utilize simulation-style explanations, perceptual symbol systems (PSS) and predictive processing (PP). PSS is a SA that attempts to explain complex cognitive acts directly and, in so doing, provide a way of understanding how AC is achieved. PP is primarily concerned with basic cognition that is involves in perceiving and acting. PP explanations make use of an understanding of neural activity that is simulationist, and proponents of PP claim that the explanations therein can scale up to complex forms of cognition like AC.

Finally, in the fifth chapter I will evaluate the SAs discussed in the previous chapters. They will be assessed according to their potential coherence with REC theories. Eventually I will argue that PP is a better fit for REC, and I will discuss a REC theory that attempts to remove the representational gloss on PP, predictive engagement (PE). While PE is a better way to understand the brain-organism-environment system, I will ultimately conclude that a non-representational approach may not be able to explain AC satisfactorily.

Autonoetic Cognition

In the cognitive sciences there is a common distinction between the kind of cognition that allows organisms to perceive and act upon their worlds and the kind of cognition that allows especially intelligent organisms to perform impressive feats such as planning for the future, discovering new scientific facts about the world, building a complex society, etc. In this dissertation I am primarily concerned about the latter, more complex forms of cognition. Basic cognition is an interesting topic in its own right that has been dealt with in a number of different REC theories already.

Basic cognition involves motor coordination and the perception of threats as well as possibilities for action in the world around us. Reaching and grasping, tracking objects with our eyes, and walking and running without bumping into things all require basic cognition. REC theories have found success in explaining basic cognition, while classical cognitivist explanations have fallen short. Conversely, cognitivism does provide a framework for understanding some aspects of more complex cognitive abilities.

For my project I am interested in autonoetic cognition (AC). Tulving describes autonoetic consciousness as a "medium" through which we perform episodic memories or imagine situations that have not occurred. It is the kind of awareness that occurs when imagining absent objects or events. Noë (2012) describes it as "presence as absence". You become, in a sense, "aware" of some entity or event that is not present, and this awareness includes the sense that the event or entity in question is not actually present (i.e., you do not mistake this kind of awareness with normal perceptual consciousness).

At least two "higher-order" cognitive abilities seem to depend upon autonoetic consciousness: episodic memory and sensory imaginings. Episodic memory is the ability to remember a previously witnessed event, or to "re-experience" a past event. During explicit recollections we become autonoetically (or self-reflectively) aware of the memory as an experience that is not currently happening. Sensory imaginings also involve autonoetic awareness. We can autonoetically imagine events that have not occurred or even fantastic and unlikely events. Autonoetic cognition thus enables a person to self-reflectively re-examine past events and even counterfactually plan for the future. Together, episodic memory and sensory imaginings are colloquially referred to as "mental time travel" (Tulving, 1983). All of the theories that I will be covering in detail in my dissertation will assume that episodic memory and sensory imaginings are closely related.

According to Tulving (2005), episodic memory is an evolutionary adaptation that itself has been exapted for sensory imagination. The function of this adaptation was originally to extend our memory of experienced events beyond the immediate present, but it has since been exapted to allow us to autonoetically experience imaginary situations.

> Episodic memory emerged, presumably gradually, in the course of human evolution. It may have grown out of a gradual extension of the human mental reach farther and farther back into subjectively apprehended past, perhaps as a sort of temporal stretching of the duration of the subjectively experienced here and now… Along with such an expansion of the subjective time horizon toward the past in remembering occurred a similar, even if possibly more muted, expansion toward the future. Once the brain "discovered" the trick of representing subjective time and making access to it available to the evolving self, through similarly evolving autonoetic consciousness, our distant forbears came to live with the capacity of awareness of subjective time in which they and their group existed, their ancestors had existed, and their children were going to exist. (p. 20)

He goes on to argue that this ability is probably unique to humans. AC is truly a "higher order" cognitive act in the sense that only creatures like us have access to it. Other animals can be empirically shown to have episodic-like memory, but, unfortunately, experiments cannot ever show that the animal is actually having AC without a verbal report. Furthermore, Tulving's understanding of episodic memory is that language is required in order to "navigate" the AC medium in the first place. AC is an evolutionary add-on to the semantic memory system that allows for episodic memory and only exists in more complicated animals.

It is not clear how the complex cognition involved in AC is related to the basic cognition of moving and perceiving. One might think that the two forms of cognition are entirely distinct from one another and require very different theories. Tulving's account of AC does not apparently scale down to basic cognition. Furthermore, his account provides very few details about how the organism achieves AC. He states only that episodic memory is "dependent on prefrontal cortex and other neocortical regions in a way that other systems are not" (2005, p. 11).

Tulving's theory of AC shares a number of commitments and problems with classical cognitivism. For my project I will explore other, more embodied, alternatives. As we shall see, many REC theories have problems with complex cognition like AC because they reject representational explanations. They instead take a more dynamic and holistic approach to understanding the whole organism-environment system. While this approach has success with basic cognition, it seems to lack the tools to deal with complex cognition.

In this dissertation I will review embodied theories that make use of neural simulations in their explanations of AC. These SAs assume that the same neural "resources" involved in basic perception and action can be re-used in neural simulations, which sometimes involves or causes AC. I contend that simulationist explanations will be necessary for REC theories to deal with complex higher-order cognition such as AC.

Cognitivism and AC

Tulving's theory of episodic memory is influenced by cognitivism. Cognitivists understand the mind as a type of computer that processes information. There are many different versions of cognitivism that utilize different concepts and commitments. Fodor (1983), for example, identified cognitivism with a number of interlocking theories about the mind, which include computationalism, representationalism, adaptationism, and the modular mind.

A typical cognitivist explanation for abilities such as AC involves the notion of symbolic mental representation. Symbolic representations are believed to "stand-in" for features of the external world in our minds while we are thinking, much like physical pictures represent the objects in the pictures. According to this view, information is transduced into sentence-like propositions that function as the content of amodal symbolic representations that logically describe the world. Representations are said to be combinatorial, which allows for the invention of new representations that lack a real world referent (Fodor, 1983; Pinker, 1997).

Cognitivism typically does not have a substantial account of precisely how activity in the brain is involved in cognition. Our cognitive capabilities are conceived as software that is supported by hardware of the brain. Obviously the hardware on a computer is important and necessary for the system to run, but the really interesting work done on a computer is performed through various software programs that could be instantiated on a number of different types of computers each with their own hardware. Classical cognitivism offers a functionalist account that is sparse on the neural details. Cognitivists reason that neurons function as binary symbols; they either fire or they do not fire. Such binary computations somehow result in representations of the external world stored and accessed inside the head (Flanagan, 1984).

The Embodied Turn in the Cognitive Sciences

Unlike the cognitivist accounts, embodied explanations put the whole organism center-stage. They focus not just on brain and body, but also on how the organism is coupled to the environment. "[Embodiment means] that cognition depends upon the kinds of experience that comes from having a body with various sensorimotor capacities, and these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological, and cultural context" (Varela, Thompson, & Rosch, 1991, pp. 172-173). Like any healthy school of thought, embodied cognitive science is not homogenous. There are a number of competing variations that share some commitments while differing sharply in other areas.

While many embodied theories build upon cognitivism and adopt its terminology and assumptions, REC theories attempt to break away from cognitivism as much as is possible. In making this break, REC reject ideas and assumptions that have been central to the entire cognitive science project as traditionally conceived such as representationalism, computationalism, modularity, and even information-processing (Hutto & Myin, 2013; Varela, et. al., 1991). In contrast to REC theories, less radically embodied theories, such as the SAs we will cover in the following chapters, often retain cognitivist ideas and attempt to fit them into their embodied framework.

REC theories provide non-representational explanations for basic cognition. For example, ecological psychology is radically embodied insofar as it rejects internalist and representational explanations for basic cognition. According to ecological psychology, the anatomy of organisms and their history of interactions with the world cause some features of the environment to stand out as foreground and other features to fade to background. Those foreground objects are determined by their invariant features (e.g., shape, size, etc.), which are physically relevant to the observer because of his or her motoric possibilities (Gibson, 1979). Foregrounded objects *afford* motor activities to the perceiver. An affordance is, “a specific combination of the properties of its substance and its surfaces taken with reference to an animal” (Gibson, 1977, p. 67). For example, when a human looks around an office he or she notices all of the chairs as “sittable” because they appear soft and of a particular height that affords sitting. A mouse in the same office wouldn’t notice the chairs as such. Instead the mouse would notice the dark spaces and small openings that afford escaping. On these accounts, perception and action are connected in such a way that no mental calculations are necessary. Importantly, perception of an affordance is direct and unmediated by non-perceptual cognition; it does not require an extra inferential step.

Sensorimotor enactivism is another radically embodied theory that also provides non-representational explanations for basic cognition. According to this view, organisms learn sensorimotor contingencies throughout their lives. A sensorimotor contingency is a regular and expected relationship between some bodily movement and changes in perceptual experience. For example, there is a direct relationship between turning one's head and experiencing the field of vision as pivoting when it occurs. This is a very basic sensorimotor contingency. We can also develop sensorimotor contingencies for irregular behaviors such as driving a car in reverse using mirrors. The relationship between our bodily movements and the image in the mirror is opposite to the sensorimotor contingency that we are used to while driving forward. Driving backwards using mirrors requires that the driver learn new sensorimotor contingencies, which can be improved through practice. If sensorimotor enactivism is true then we do not need mental models of our surroundings in order to navigate, as the world is its own best model (O'Regan & Noe, 2001).

REC principles of basic cognition have been applied in the field of situated robotics. Rather than attempting to recreate human cognition with cognitivist principles, researchers in situated robotics focus on the basic motoric activity of the whole organism. The most famous example is the subsumption architecture developed by Brooks (1986) in his Mobots. In this design there is no central processor that provides commands in a top-down manner. Instead, the robot carries a number of simple systems composed of a few sensors and actuators connected to very basic devices. Each system has a single task that it performs such as avoiding collisions or following walls. The devices only operate in the domain of their subsystem's task. In this design, the information from the different subsystems is never pooled together in one central computer. Instead the sensory functions are directly coupled to action functions, and so the classic division between sensory and motor functions is removed. Researchers found that by distributing the processing around the subsystems, the robot is able to act in a very life-like manner and easily perform the tasks that other robots built on cognitivist principles cannot.

The success of subsumption architecture in reproducing life-like behavior in robots is taken as an indicator that biological minds are constructed in a similar fashion. Perhaps we do not calculate the effects of our movements algorithmically; instead, perhaps our perceptual and motor systems are such that we directly perceive opportunities for actions based upon our motor possibilities. Unfortunately, these insights lead us to the scaling-up problem. It is unclear how a mobot that can manage its immediate environment could ever be made to do things like plan for the future or learn from the past.

REC and AC

REC theories are primarily concerned with basic cognition, which is surprisingly difficult to explain, or to achieve in robotics, using only cognitivist principles. Activities that a child can easily perform such as walking on two legs are difficult for a system following algorithmic computations. Conversely, complex cognitive abilities such as AC are difficult to explain with REC. It is unclear how the shape of our bodies and our history of interactions could explain the vivid imaginings of non-existent creatures that any toddler can perform. Sensorimotor explanations do not seem to be in-themselves enough for REC to solve the scaling-up problem

Those REC theorists brave enough to attempt to grapple with the scaling-up problem have warily appropriated findings from neuroscience that entail the importance of neural simulation processes. For example, when discussing mental imagery Thompson explicitly states views that are consistent with simulation theory, "[We] could say that to visualize X is to mentally re-present X by subjectively simulating or emulating a neutralized perceptual experience of X" (p. 292). Hutto (2015) arrives at the same conclusion after considering the evidence from neuroscience, "The simulation idea gains support from its fit with the general finding that the brain often re-uses neural apparatus' to do various distinct kinds of cognitive work." In both explanations, AC is achieved in part by re-creating neural states in the parts of the brain concerned with perception and action.

Nevertheless, both Hutto and Thompson make great pains to hedge their support for using a SA to explain AC. REC traditionally eschews representationalist approaches to understanding the coupling of organisms with their environments. Conversely, SAs seek to understand which neural systems are involved in AC and how the interactions between these systems give rise to it. SAs are typically reductionist and internalist. If REC and SA are to be compatible then one must make concessions to the other.

According to REC theories, the extensiveness of the mind makes focusing on the brain alone impossible, and we must take a holistic approach instead. While a holistic understanding of the mind is certainly helpful in guiding our thoughts, it does little to help understand exactly what is going on during AC. Neuroscience has made great progress over the past few decades, and we are in a position to understand the workings of the brain during normal coupling behavior. A rapport between REC and SA may benefit both. SA may be helpful to REC by providing a way of understanding what is occurring in the brain during cognition. REC may be helpful to SA providing a holistic understanding of the brain-body-world relationship that can help guide further research in neuroscience.

Conclusion

My project in this dissertation is to help REC with its scaling-up problem, specifically to explain the ability to mentally place ourselves in the past or imagine the future, that is, AC. I contend that theories that involve neural simulation, SAs, are the best candidates for providing REC an understanding of the neural mechanisms that are involved in AC. However, SAs involve concepts from classical cognitivism such as representation and mental modularity that are problematic for REC.

In this chapter I have introduced REC's scaling-up problem. I indicated that I am specifically interested in AC, which allows humans to mentally time travel. After discussing AC I summarized the classical cognitivist view. Finally, I turned to embodied cognition theories and discussed how the more radically embodied theories deal with representation-hungry cognition like AC.

In the next chapter I discuss neural simulation and the notion of grounded cognition. Some grounded theories attempt to explain basic cognition while others attempt to explain more complex cognition. Typically grounded theories utilize various concepts from classical cognitivism, and I will spend much of the chapter differentiating them.

After introducing neural simulation, I will turn to two specific SAs in the subsequent chapters. In the third chapter I will describe Perceptual Symbol Systems theory, which attempts to explain representation-hungry cognition directly. In the fourth chapter I will describe Predictive Processing theory, which was formulated to explain basic cognition, but which may be able to scale up to representation-hungry cognition. Finally in the fifth chapter I will review the SA *solutions vis a* vis enactivism and its scaling-up problem. I'll introduce a third, REC-inspired SA, namely Predictive Engagement. This theory attempts to take predictive processing theories in a radically embodied direction. As we shall see, it is ultimately unclear how predictive engagement can provide REC an account of AC.

Chapter 2: Simulation accounts

Introduction

Simulation accounts (SAs) have been offered for a number of different problems in the cognitive sciences. A neural simulation consists of reactivations in perceptual and motor areas of the brain that are not coupled in a direct and apparent way to the ongoing sensory array. These multimodal and decoupled reactivations may occur when we remember or imagine something that is not present, and are isomorphic with or analogous to neural activations that would occur if that stimulus were present. Put another way, cognizing something involves the reactivation of some of the perceptual and motoric neural states that originally occurred in the presence of the target of the cognizing.

Barsalou (2008) describes simulation in the following way:

> Simulation is the reenactment of perceptual, motor, and introspective states acquired during experience with the world, body, and mind. As an experience occurs (e.g., easing into a chair), the brain captures states across the modalities and integrates them with multimodal representations stored in memory (e.g., how a chair looks and feels, the action of sitting, introspections of comfort and relaxation). Later when knowledge is needed to represent a category (e.g., chair) multimodal representations captured during experience with its instances are reactivated to simulate how the brain represented the perception, action, and introspection associated with it. (pp. 618-619)

In this chapter I will provide an overview of some of the different simulation accounts. I will start with a generalized account of the grounded cognition movement in the cognitive sciences. Grounded cognition is a collection of theories that share a commitment to some form of neural simulation. The various grounded theories are often problematic for Radically Embodied Cognitive Science (REC) because they include many appropriate operative concepts from cognitivism such as mental modularity and representationalism. The types of SAs that I am interested in fall into three broad categories: social simulation theories, cognitive simulation theories, and situated action theories.

Grounded Cognition

Barsalou categorizes all of the theories that make use of neural simulation into one unified program, "Grounded Cognition." While the theories do share a focus on the activities of the brain, each is also substantially different from the others. Furthermore, it is not clear any of the neural activity being described in these theories is an instance of simulation as traditionally defined in the simulation theory of social cognition. As Gallagher (2007) points out, there are two aspects involved in the traditional definition of simulation in the social cognition context. A simulation is a counterfeit version of a real thing that is deliberately done. This is the aspect of pretense. A simulation is also a model of something else that we use in order to help understand the real thing that is being modeled. This is the instrumental aspect. Notably, none of the SAs satisfy this definition of simulation.

Rather than attempting to understand the concept of neural simulation found in SA in line with any of the various definitions of the word 'simulation', I will stipulate upfront that simulation occurs when the brain activates in a similar way to a previous relevant activation while the stimulus that caused the original activation is absent. Simulations are the reactivation of the previous neural states that originally became associated together during some worldly event. These reactivations somehow allow the organism to perform cognitive acts such as remembering, planning for the future, considering options, and even imagining novel events and entities. Perhaps using a different, more precise, term for it rather than coopting the term ‘simulation’ for yet another meaning would be better. However, this terminological debate is not particularly interesting so I will follow with the terminology that has already been established.

Grounded theories share a commitment to rejecting the significance (and in some cases the very existence) of amodal symbolic representations. They attempt to ground knowledge in the brain’s sensory, motoric, and introspective modalities through appeals to neural simulation. This approach can be contrasted with traditional cognitivist theories of knowledge wherein multimodal information is transduced into amodal representations (e.g., feature lists, schemata, frames, predicate calculus expressions, etc.). Grounded cognition shares a negative claim with enactive theories. Both schools of thought seek to reject amodal symbolic representations in their explanations.

Representation in Grounded Cognition

Most grounded theories still make use of cognitivist ideas such as representation. They understand representations to be multimodal states of neural activity that track occurrences in the environment of the organism. This understanding of representations is substantially different from the classical understanding provided by cognitivism. The neural representations of SA are physically embodied processes. As such they are influenced by the idiosyncrasies of the system as well as the physiological state of the whole organism.

Representations in classical cognitivism are propositional and amodal. Amodal symbolic representations as posited by classical cognitivism have a number of problems, however. The most obvious problem is a lack of direct evidence for their existence. Researchers in cognitive psychology have worked on this problem for decades, but reviews of the work seem to indicate that these supposedly amodal symbols do in fact have a perceptual (i.e., modal) character (Glaser, 1992). Furthermore, it's difficult to understand how amodal symbols could implement some computational functions such as spatio-temporal knowledge. If spatio-temporal knowledge is represented by amodal representations then the computational systems that result are incredibly complex and computationally intractable (Clark, 1997).

There is also a lack of evidence for amodal symbolic representations in neuroscience. It has been established that categorical knowledge involves the sensorimotor areas of the brain. When sensorimotor parts of the brain are damaged we observe impairment in the ability of the subject to categorize particular objects depending upon how that object is normally processed by the brain (Damasio, 1989; Pulvermüller, 1999). This result is difficult to explain with amodal representations, but it is an expected result with multimodal representations.

Another serious problem concerns transduction. According to amodal theories, incoming sensory information becomes amodal symbolic representations through the process of transduction. However, no details have ever been provided about transduction, and there is no evidence for this process in the brain. The transduction problem has two facets: How do modal sensory stimuli become amodal, and how do we map amodal symbols back upon the world (Searle, 1980; Harnad, 1990)? A solution is to claim that there are perceptual representations that are associated with amodal representations and guide their work (Neisser, 1967; Harnad, 1987). However, if this is true then the perceptual representations are doing all of the real work and amodal symbols become redundant.

A final objection is that amodal symbols are too powerful. Any result can be explained through *post hoc* modifications. Amodal systems are unfalisfiable, and they do not make strong predictions (Anderson, 1978). Amodal symbolic representations are an explanatory fiction that functions as a kind of placeholder in our theories. If we are able to discard them then we probably should do so.

Grounded cognition theories attempt to appropriate the concept of representation from cognitivism. Although most grounded cognition theories still attempt to use their understanding of representations in a cognitivist framework, their alternative understanding of representation is substantially different from the original. Multimodal representations can still be symbolic and, therefore, usable in mental computations. It remains to be seen whether or not these multimodal representations cohere better with some variant of cognitivism or with embodied theories.

Modularity in Grounded Cognition

Another core supporting commitment in mainstream classical cognitivism is mental modularity. This is the idea that the mind is composed of a number of different modules, and each module has its own tasks to perform. Prinz (2006) identifies nine characteristics that modules typically possess: Modules are (1) mandatory, (2) fast, (3) shallow, (4) localized, (5) subject to characteristic breakdowns, (6) domain specific, (7) cognitively impenetrable, and (8) informationally encapsulated, and they follow (9) distinctive patterns during development.

Cognitivists argue that the mind can only be a computational engine if it is also modular. A non-modular system attempting to perform mental computations would encounter a combinatorial explosion of possibilities. As Carruthers (2006) puts it,

> If a processing system can look at any arbitrary item of information in the course of its processing, then the algorithms will have to specify, in respect of each item of information that it could access, what step should be taken next – presumably different for each such item of information, if the system is to be a context-sensitive one. So the more items of information a program can look at while processing, the more complex its algorithms will need to be. So conversely, if a

> system's algorithms are to be computationally tractable, limits will need to be placed on the set of items of information they can look at. (p. 184)

A modular mind would solve this problem, as it would be able to limit the amount of information that the system can consider. Hence the nine requirements listed above. Requirements (1) – (3) describe the nature of the processing; it happens automatically, quickly, and the output does not require further processing. Requirements (4), (5) and (9) refer to the neural correlates to the modules; they are localized into one neural structure, damage to those structures has predictable consequences, and they develop in roughly the same way for different individuals. Requirements (6) – (8) are concerned with the nature of the modules that makes them suitable for this job; they each have their own area of concern, they cannot be interfered with by higher-level cognitive processes, and they cannot draw upon beliefs that interfere with the processing.

The modular explanation for cognition is as follows. Information-carrying light strikes the retina and is (somehow) transduced into an amodal symbolic representation. As discussed above, there is no detail regarding how the transduction process occurs. The content of that representation is assessed (presumably by a specialized module for incoming information). Depending upon the content, the representation is passed on to another module that specializes in that content. That module can only draw upon information in its domain so it can process the incoming representation quickly. The output is sent to other specialized modules and the process continues.

Modularity is considered to be a necessary condition in order for traditional understandings of computationalism to be viable. However, modularity exists in direct competition with multimodal theories of knowledge. If the multimodal view is correct then modules cannot be (4) localized, (6) domain specific, or (8) informationally encapsulated in the traditional sense. Despite the fact that sensory systems are taken as paradigmatic examples of modules in cognitivism, in grounded theories they are parts of a wider multimodal system with almost universal applications in the mind.

Grounded cognition theories reject the modular mind thesis. This is a significant break with one of the core commitments of classical cognitivism as well as many cognitivist theories inspired by it. However, grounded cognition theories typically do not deviate from classical cognitivism beyond their revisionist conceptions of representation and modularity. Explanations of complex cognitive abilities such as Autonoetic Cognition (AC) in grounded cognition theories are still influenced by cognitivist assumptions. REC has much work to do.

Frames

Some grounded theories also use the cognitivist notion of frames. Frames are structured representations that are necessary for mental computations and are therefore important for theories that make use of them. Barsalou and Hale (1993) identify four basic properties of frames; they are characterized by (1) structural invariants or predicates, (2) attribute-value bindings, (3) constraints, and (4) recursion.

In the context of representation, a structural invariant is a kind of normal and expected relation between the features of an object or event. For example, regardless of the type of chair in question, the legs of the chair support the seat. The legs and seat have an invariant relation between them that is also found in other instances of chair. Similarly, the frame for "feeding my dog" invariably involves my fixing the food before the dog can eat it. In order for a representation to be used successfully in computation, the relationship between its features must be specified (Barsalou, 1992).

An attribute is a property that members of a category share, and a value is the specific details of the property for some individual member of a category. Frames structure representations so that attributes have values. For example, in all instances of the "feeding my dog" frame I must give her dog food. Dog food is an attribute for the frame, while the flavor of the food is the value of that attribute.

Constraints are similar to structural invariants in that they involve background knowledge, but instead of describing constant relations between attributes, they describe relations between the values of these attributes in specific examples (Barsalou, 1993). For example, the frame for "ski vacation" includes attributes for *activity* (e.g., boating) and *location* (e.g., maritime) that are structurally invariant. However, different values for those attributes will constrain one another. For example, if the value for *activity* is boating then the value for *location* cannot be a desert or mountain. Finally, recursion is the ability to organize symbols within the frame hierarchically. Representations can be decomposed into smaller parts or set within larger representations.

While frames play an important role in classical cognitivism, they are not relevant to most of REC. In classical cognitivism, frames are structured representations for events that can function as symbols in mental computations. In REC, the mind is not engaging in algorithmic computations, so frames are unnecessary. This is one conflict between REC and grounded cognition theory. For my project, frames are important in order to understand Perceptual Symbol Systems, which will be covered in detail in the next chapter.

Cognitive Simulation Theories

Grounded theories can be subdivided into three categories: cognitive simulation theories, theories of situated action, and social simulation theories. All three categories share a commitment to neural simulation as an explanation for cognitive behavior. The remainder of this chapter will provide a general overview of the three categories. Influential theories of cognitive simulation and situated action will be treated with more detail in subsequent chapters. Social simulation will be dealt with below.

There is empirical evidence that many aspects of cognition involve neural simulation in the motoric and sensory modalities. Cognitive simulation theories attempt to provide a framework for understanding the evidence in behavioral psychology, clinical psychology, and neuroscience. For example, studies have shown that motoric simulations in the brain aid in recognizing objects. Subjects verbally identify tools faster if they are simultaneously performing actions that relate to the use of that tool (Helbig, Graf, & Kiefer, 2006). Witt et. al. (2010) had subjects squeeze a rubber ball in one hand while naming pictures of tools and animals. Subjects' performance was impaired when the picture of the tool was oriented toward the hand already engaged in squeezing the rubber ball. They hypothesized that the act of squeezing the ball engaged the motor areas necessary to simulate grasping and interfered with simulation of grasping tools. This interference inhibited recognition because motor simulations play a role in identifying tools. In other words, in order to recognize a tool the brain will simulate acting upon it, and when the brain cannot perform these simulations, because the neural resources are tied up in a similar action, it slows recognition time.

Physical reasoning in visuospatial tasks has also been hypothesized to make use of motor simulations (Hegarty, 2004). For example, people simulate the movement of gears in order to infer the direction in which a target gear will turn. Evidence for this has been found in chronometric tasks where the time to draw the inference is correlated with the duration of the physical event (Schwartz & Black, 1996). When subjects carry out associated actions such as tracing the path it improves the inference (Schwartz, 1999). Complimentary research by Sims and Hegarty (1997) show that the inferences in these tasks are visuospatial (and therefore utilize multimodal simulation) rather than verbal or propositional inference. They performed similar experiments while also having the subject keep either visuospatial or verbal information in working memory. They found that the performance of the subjects suffered when working memory was occupied with visuospatial information rather than when it was occupied with verbal information. These results were taken to indicate that the task was indeed a visuospatial task that required multimodal simulation.

There is also evidence that mental simulations are involved in memory. Wheeler et al. (2000) used a word retrieval task to show that the brain utilizes multimodal simulations in forms of memory. If the subject studied a word visually then the visual areas of the subject's brains became activated in the word retrieval task, and if it was studied auditorally then the auditory areas became activated. A number of grounded theories have emerged to explain this evidence. For my project, I will focus on a theory that I would argue is paradigmatic of grounded cognition: Perceptual symbol systems theory.

Barsalou (1999) originally proposed perceptual symbol systems (PSS). According to this theory, features of the neural activations that occur in the perceptual and motoric systems during normal experience can be "captured" or "recorded" as multimodal associations or "perceptual symbols." These perceptual symbols can be recombined later in order to recollect or even cognize novel events. Barsalou posits that perceptual symbols can create representations that can be used in traditional computations. Thus, PSS is compatible with some variations of cognitivism as well as some embodied cognition theories. PSS is also compatible with neo-empiricism, which is a theory of the format of knowledge wherein knowledge is stored and represented in its original multimodal format rather than an amodal symbolic format (Prinz J. , 2002).

PSS is described as “a high-level functional account of how the brain could implement a conceptual system using sensory-motor mechanisms… [that] does not specify the features of perception, or why attention focuses on some features but not others… [nor] how the cognitive system divides the world into categories, or how abstraction processes establish categorical knowledge… [Nor] does it explain how the fit between one representation and another is computed, or how constraints control the combination of concepts” (Barsalou, 1999, p. 582). This theory offers possible explanations for AC. On this view, mental time travel is achieved through the manipulation of perceptual symbols in neural simulations. I will provide a detailed account of PSS in the next chapter.

Theories of Situated Action

Neural simulations are also involved in ongoing perception and action. Perception of stimuli in one’s environment has been shown to prompt automatic and covert mental simulations in the perceptual and motoric areas of the brain in the perceiver. A number of different phenomena have been identified and explained through the simulationist framework. However, until recently there were few accounts that could explain the different forms of perception and action simulation observed and integrate them with SAs more broadly. I will briefly describe some of these simulations, as they are understood by grounded cognition.

Upon perceiving an object in our environment, the brain undergoes simulations in the motor areas that are isomorphic to appropriate actions for manipulating the object. This is motor resonance, and it is believed to involve the same neural resources that are involved with the actual performance of actions upon the stimuli. In other words, when you see an object your brain automatically activates areas of your motor system associated with actions that you can perform upon that object (Prinz W. , 1997; Grezes & Decety, 2002; Zwaan & Taylor, 2006; Schutz-Bosbach & Prinz, 2007).

It has been hypothesized that motor resonance simulations play a role in preparing the body for situated action (Barsalou, 2008). When we see an object our brain automatically undergoes neural simulations of possible relevant actions that we can perform upon the object as a means of preparing us for our next move. The action simulated is relevant to the context in which the perception of the object is occurring (Bub, Masson, & Cree, 2007). For example, in a study by Tucker and Ellis (2001), subjects produced different motor simulations relative to the different grips required by the object being viewed. When the subjects viewed a grape their brains activated for a precision grip, but when the subjects viewed a hammer their brains activated a simulation for a power grip instead. Additional research has shown that these simulations are influenced by the orientation of the object (Symes, Ellis, & Tucker, 2007), its size (Glover, Rosenbaum, Graham, & Dixon, 2004), and its perceived weight (Bosbach, Cole, & Prinz, 2005).[1]

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[1] Additionally, motor resonance has been hypothesized to play a role in a number of important features of cognition such as perceptual inference of motion (Stevens, Fonlupt, Shiffrar, & Decety, 2000) and the perception of space (Longo & Laurenco, 2007).

Perceptual inferences are simulations that seem to occur immediately before the sensory activations as a means of anticipating what will be perceived. During perception we generate an anticipation of the movement of objects. If we see an object flying through the air then our brains will anticipate and simulate its path ahead of its actual position. In experimental situations the object can be artificially stopped midflight upon which a perceptual simulation of the continuation of the flight can be observed. This simulation is influenced by the speed of the object so that the simulation for a fast moving object is different from a slow moving object (Reed & Vinson, 1996). Interestingly, simulations can cause the person to falsely remember seeing the movement completed (Freyd, 1987). Perceptual inferences may explain common misperceptions as our brain preemptively fills in the expected ongoing sensory array.

It is also hypothesized that there are online motoric simulations, which make difficult motor tasks possible. For example, skilled reaching involves an ongoing coordination between sensory feedback and motor commands so that the reach can be subtly adjusted in real time. Proprioceptive feedback takes too long for it to be useful in skilled reaching, however. Clark (1997) and others postulate that the brain must make use of an emulator (forward-model) system of some kind. Emulator devices in robotics are internal chips that send mock (simulated) feedback signals immediately prior to the sensory feedback, which allow for robots to successfully perform difficult motor tasks.

Motor emulation involves a simulation of the predicted sensory feedback signal immediately prior to an action's actual sensory (i.e., proprioceptive and visual) feedback; it delivers a rapid prediction about anticipated changes. The emulation compares an efferent signal with the action intention, prior to and predictive of the afferent feedback signal that will issue from the action. "The output of the emulator is thus… a quick prediction of the future proprioceptive feedback" (Clark & Grush, 1999, p. 6). This allows for smooth online feedback before the action is performed since a mismatch (i.e., prediction error) between the two signals can be corrected much faster than waiting for the feedback and responding to that alone. In normal situations, motor emulation is important for motor control. It allows for fine-grain adjustments to our actions because proprioception and sensory feedback alone are not fast enough to handle rapid yet smooth motor commands such as skilled reaching and eye saccades.

> [Motor emulation] allows the system to exploit mock feedback signals available ahead of the real-world feedback, and hence allows rapid error-correction and control. It can support reasonably sensible behavior in the total absence of real-world feedback. And it can allow the improvement of motor skills to continue off-line – the agent can practice using the emulator model without engaging the real world system at all. (p. 6)

It is unclear how theories of situated action, which cover explanations of basic cognition, could scale up to cognitive simulation theories, which offer explanations of representation-hungry cognition. However, both of these simulation accounts (cognitive simulation and situated action theories) utilize simulationist explanations, and a unified account may be possible. Furthermore, theories of situated action are interesting from an embodied cognition perspective. They are similar to REC theories insofar as both seek to explain basic cognition and pragmatic, enactive perception. They differ in that REC theories reject concepts that are still important to theories of situated action, such as representation. However, it may be the case that both approaches could benefit from one another. A theory that respects REC intuitions and goals but that utilizes SA methodologies and concepts may be better than either theory by itself. Theories of situated action may be the bridge between REC and SA, and SA may be the most embodied account of AC on hand.

In the fourth chapter I will discuss a theory that makes use of predictive mechanisms that are similar to the emulators discussed above, predictive processing (PP). This theory may provide a comprehensive understanding of the mind that can explain both basic and complex cognition while respecting REC intuitions.

Social Simulation Theories

In this section I will provide a brief overview of social simulation theories; specifically, the theory posited by Goldman (2006). For this section, I will make use of nomenclature from social cognition; social cognition theories that involve neural simulation are together known as simulation theory (ST), which is in contrast to the "theory theory" of social cognition. Many of the ideas in other SAs originated in social simulation theories, and social simulation theories provide an account for some aspects of AC.

ST is one of many social cognition theories that assumes that people mentalize or mindread one another during social interactions. "Mentalizing or mindreading is a second-order activity: It is mind thinking about minds. It is the activity of conceptualizing other creatures (and oneself) as loci of mental life" (Goldman, 2006, p. 3). In ST, this is done through neural simulations of the target's bodily states. In other words, while interacting with another person our brain initiates neural activations in the motoric areas that in some ways mimic the movements, gestures, and expressions of the person we are observing.

According to ST, the primary method for understanding the minds of others that people employ is simply to place themselves "in the mental shoes" of the other[2]. It is an attractively intuitive idea that involves three steps (Goldman, 2005):

1. The creation of pretend states to match those of the target.
2. The processing of those pretend states by the same mechanisms that the attributor uses to understand his own mental states.
3. The assignment or "projection" of those states onto the target.

While this process was originally considered to be a purely conscious or introspective feat that was initiated and performed voluntarily by the observer (i.e., explicit ST), recent discoveries in neuroscience have created an alternative account.[3] Experiments on macaque monkeys have revealed the existence of sensorimotor neurons in the motor cortex of both macaques and humans. These "mirror neurons" have prompted a storm of controversy in the cognitive sciences.

A mirror neuron is a type of neuron that possesses both perceptual and motor properties. These sensorimotor neurons are interesting because they fire both when an action is performed and when an individual that is observed performs that action. What is even more interesting is that they only fire when observing goal directed movements of others (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; Rizzolatti & Craighero, 2004; Gallese, 2009). In other words, these neurons "mirror" actions performed by conspecifics, and in

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[2] This simple interpretation has existed since long before the cognitive sciences, and we can see it explicitly in the words of Adam Smith (1982[1759])

> By the imagination we place ourselves in his situation, we conceive ourselves enduring all the same torments, we enter as it were into his body, and become in some measure the same person with him, and thence form the same idea of his sensations, and even feel something that, though weaker in degree, is not altogether unlike them. (p. 12)

[3] Explicit ST is still defended by some theorists, see Currie & Ravenscroft, 2003.

this respect they are said to allow a certain form of understanding to occur. Simulationists have seized upon this finding to support an implicit version of ST, and some have claimed that mirror neurons form the basis of all social cognition. Gallese (2009), for example, claims that the "resonance" that occurs in the observer while viewing a target is what informs the observer that the target is also minded like the observer. Most theorists, however, have taken a more conservative, or hybrid, route by claiming that mirror neuron activity is a low-level process that allows for a higher-level explicit form of simulation to occur (Gallese & Goldman, 1998; Jeannerod & Pacherie, 2004; Goldman, 2006).

There are a number of different accounts of ST, each of which relies heavily upon the activity of mirror neurons. Arguably the consensus view is a hybrid account called the "direct matching" hypothesis. According to this theory, mirror neurons actually "mirror" the state of the target in the observer. This mirroring elicits a similar emotion or intention in the observer, which is then implicitly or explicitly projected upon the target. The observer then infers the meaning or intention of the target using this information (Gallese, Keysers, & Rizzolatti, 2004; Decety & Grezes, 2006). Goldman, for example, distinguishes between low-level mindreading that occurs in the brain and body automatically and without our conscious awareness, and high-level introspective mindreading that is explicitly performed by the mindreader and attributed to the target. Low-level mindreading involves automatic neural activations in the motor areas of the brain that attempt to mimic the observed motor behavior of the mindreading target. This suggests a possible source of our ability to empathize or even to have some aspects of gut-level intuition.

Implicit or low-level mentalizing does not involve AC as it is accomplished subconsciously; however for high-level mindreading abilities such as AC may play a role. Goldman's account of high-level mindreading involves what he calls "enactive imagination" (E-imagination), which is clearly a form of AC. He marshals empirical evidence from a number of different fields to argue that visual imagery of the sort used in E-imagination, involves the mental mechanisms of vision itself (p. 153). For example Spivy et al. (2000) found that while imagining a scene, subjects initiated spontaneous eye saccades that are similar to the spontaneous eye saccades that occur while actually viewing the scene. Additional evidence from clinical psychology found that neglect patients displayed the same impairment while simply imagining a visual scene (Bisiach & Luzzatti, 1978).

Social cognition itself is not clearly relevant to my project, and I will not say much more about it, even though ST does provide interesting suggestions for explaining AC. However, ST has been criticized by REC (Gallagher, 2007), and in regard specifically to the higher-order, explicit simulation process, primarily on the basis of phenomenology. If the typical way for an observer to understands others is to *consciously* employ E-imagination to create a matching state, guess what that state means, and then attribute that state to the target, then there would be some kind of evidence of this process in phenomenological experience. However, evidence of this kind is not readily apparent in (most of) our social-cognitive experience. Placing ourselves in the "mental shoes" of others does not actually occur except in exceptional third-person encounters that are not typical to our day-to-day interactions (Gallagher, 2007). In normal interactions, REC claims we do not read minds but rather we respond and interact with the target, and, in some cases, we use narrative to understand what the other person intends, without the need for any step-wise simulation.

Conclusion

My project is to identify a SA that can help REC with its scaling-up problem. I contend that it’s possible for SA to help REC by providing an understanding of the neural events that are involved in representation-hungry activities such as AC. There are a number of different SAs that are unified under the grounded cognition movement. In the following chapters I will discuss specific grounded cognition theories and evaluate their compatibility with REC.

In this chapter I discussed neural simulation, which is the reactivation of neural states in the perceptual and motoric modalities. Some forms of cognition, including AC, seem to involve neural simulations of an object or event that are in many ways similar to the activations involved in actual perception of the object or event.

I also discussed the differences between simulation accounts and classical cognitivism. Simulation accounts are embodied theories that make use of cognitivist ideas. In order to appropriate these ideas, simulationists must reimagine cognitivist notions like representation and modularity. This will be important in future chapters because both PSS in the next chapter and PP in the fourth chapter utilize versions of these concepts. Another cognitivist notion, frames, was also described because they are required by PSS, as discussed in chapter three.

In the next chapter I turn to a particular grounded cognition theory, PSS. This cognitive simulation theory purports to provide a way of understanding many representation-hungry cognitive abilities, possibly including AC. In chapter four I discuss PP, which, I argue, is a SA, and which I believe is interesting for REC as it can scale up its explanations for basic cognition in order to explain representation-hungry cognition such as AC. Finally, in the fifth chapter I will evaluate the SAs on whether they can properly cohere with REC.

Chapter 3: Perceptual Symbol Systems

Introduction

Perceptual symbol systems (PSS) is a cognitive simulation theory. According to these theories, cognition is achieved by neural "simulations" that occur in the sensory and motoric areas in the brain. Information is somehow "stored" in the original multimodal neural format, and cognition involves the reuse of these multimodal activations in the brain. PSS is a simulationist account (SA) that aims to explain features of the mind like autonoetic cognition (AC).

> PSS assumes that a single, multimodal representation system in the brain supports diverse forms of simulation across different cognitive processes, including high-level perception, implicit memory, working memory, long-term memory, and conceptual knowledge. According to PSS, differences between these cognitive processes reflect differences in the mechanisms that capture multimodal states and simulate them later. (Barsalou, 2008, p. 622)

In this chapter I will provide a detailed overview of PSS. Barsalou (1999) posits that PSS has six primary properties and four additional properties that can be derived from the primary properties. These properties collectively constitute a conceptual system capable of computational functions. I will treat each property in turn before discussing possible ways that PSS could be implemented in the brain.

Barsalou is explicit in his alignment with cognitivism. He intends for grounded cognition to provide a less functionalist basis for mental computations by providing an account of the basic neural processes. "This formulation of the theory should be viewed as a high-level functional account of how the brain could implement a conceptual system using sensory-motor mechanisms. Once the possibility of [a high level functional account like PSS] has been established, later work can develop computation implementations and ground them more precisely in neural system" (1999, p. 582).

My project is to examine PSS in order to determine whether some portions of the theory are amenable to radically embodied cognitive science (REC). If they do cohere in some way then it may provide a REC-friendly explanation for AC. Ultimately I will argue that PSS is not an effective direction for understanding representation-hungry cognition, but other SAs may provide a better alternative while still being REC friendly.

Core Properties of Conceptual System

Barsalou's stated goal in PSS is to formulate a basic conceptual system that exhibits all of the important properties required for mental computations. He lists six core properties of the system that collectively implements a basic conceptual system: (1) Perceptual symbols are neural representations in sensorimotor areas of the brain. (2) They are multimodal and include perception, action, and introspective elements. (3) They represent schematic components of experience. (4) They are organized by frames in the simulator. (5) They integrate with related symbols to form simulators that can generate limitless simulations. (6) They are controlled by language. Four additional derived properties are also listed, which are to allow for a fully functional conceptual system. I'll consider each of these in turn.

Neural representations exist in the sensorimotor systems: The first core property of PSS deals with the format and location of perceptual symbols. A perceptual symbol is a neural state constituted by the combined activity of associated neurons in sensory, motoric, and introspective parts of the brain. We learn perceptual symbols over time and through repeat exposure to whatever is being represented. Perceptual symbols reside at the neural level, as the specific configuration of neural activations that is correlated with an experience is what is stored as a perceptual symbol rather than the conscious experience itself. In fact, it is possible for a perceptual symbol to form for an experience that was not originally processed consciously.

> A perceptual state can contain two components: an unconscious neural representation of physical input and an optional conscious experience. Once a perceptual state arises, a subset of it is extracted via selective attention and stored permanently in long-term memory. On later retrievals, this perceptual memory can function symbolically, standing for referents in the world and entering into symbol manipulation. As collections of perceptual symbols develop, they constitute the representations that underlie cognition. (Barsalou, 1999, pp. 577-588)

Multimodal perceptual symbols: A second related core property of PSS is that any one symbol includes components from multiple modalities. Simultaneous activations in different modalities become associated with one another. Furthermore, some concepts are represented primarily in other modalities than perceptual modalities. For example, conceptual tasks involving animals (e.g., imagining a giraffe) involve visual areas of the brain while conceptual tasks involving tools (e.g., imagining a hammer) involve motoric and somatosensory areas (Pulvermüller, 1999).

Schematic perceptual symbols: The third core property of PSS is that perceptual symbols are schematic aspects of experience rather than holistic recordings of the entire scene. Rather than developing a perceptual symbol for holistic experience, we instead focus on components of the experience that represents a coherent aspect of the neural state. According to this view, selective attention plays the role of determining which aspects of an experience are stored as a perceptual symbol. Attention first isolates information in perception and then stores the isolated information in long-term memory. For example, selective attention may focus on the shape of the object and store the neural representation of the object’s shape without also storing the color or size of the object despite the fact that those additional features were present in the original experience.

The schematic nature of perceptual symbols allows for greater flexibility in representation. Rather than entire scenes being recorded holistically, selective attention focuses and records only parts of the scene. Later when the scene is recalled, it is reconstructed piecemeal much like it was recorded. Furthermore, this property allows perceptual symbols to represent something as indeterminate. This can be achieved consciously through the process just described if selective attention doesn’t record every component. It can also be achieved unconsciously through qualitatively oriented neurons, which I will return to below.

Frames: The fourth core property of PSS is the creation of frames, which function as a kind of background concept for an entity or event. I discussed frames in detail in the previous chapter. Frames are important for PSS because they are structured representations that are necessary for mental computations. They organize separate perceptual symbols into a unified network of associated features that together constitute “understanding” the entity or event. Later, the structure of the representation allows for the generation of a simulation that is relevant to the situation.

Frames are constructed for an entity after repeated exposure to specific instances of the entity, and they allow the cognitive system to construct specific simulations. Each time we experience a dog, for example, selective attention focuses on different aspects of the experience, which are stored in long-term memory and added to the existing frame for dogs. The different aspects come from any combination of relevant modalities involved.

Frames can also be constructed for events. Perceptual symbols are associated by physical similarity, shared context, and temporal proximity. When two perceptual symbols are associated by temporal proximity it can form an event sequence frame. For example, first I mix the dog food before I put it in a bowl. I then watch my dog eat, and finally I put the bowl away. Each of those subevents is stored in perceptual symbols, and the different subevents are all associated together temporally. Collectively they create the frame for "feeding my dog", which is a daily event[1].

Simulators and simulations: The fifth core property of PSS is the production of high-level simulators over repeat exposure to a category instance, which can later be used to simulate specific instances. Barsalou explicitly identifies simulators with concepts. "It is the knowledge and accompanying processes that allow an individual to represent some kind of entity or event adequately" (1999, p. 587). If this is correct then human learning can be accurately described as the formation of simulators for events and entities. What it means to know something is to be able to simulate it to a culturally acceptable degree, which is identical to understanding it. Knowledge is the mastery of simulators such that individualized and appropriate simulations can be generated for the entity or event depending upon the context.

A simulator is composed of an underlying frame that combines perceptual symbols after repeat exposure and the myriad of possible simulations that could be constructed by that frame. Simulators are built over time for various events and objects that we encounter. Later, while thinking about an event or object that has been previously experienced, the simulator becomes active and generates relevant simulations depending upon the frame and context of the situation.

Simulators are essentially concepts, and, as a consequence, categorization is a different process than it is traditionally conceived. Rather than using amodal structures such as definitions and prototypes to determine category membership, simulators just appeal to associative

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[1] See chapter 2 for more on frames.

principles such as temporal proximity, shared context, and physical similarity. If the entity in question is correctly a member of some category then the simulator for that category should be able to simulate the entity as a member of that category.

> Each successful categorization stores a simulation of the entity categorized. If the same entity or a highly similar one is encountered later, it is assigned to the category because the perception of it matches an existing simulation in memory. Alternatively, if a novel entity is encountered that fails to match an existing simulation, constructing a novel simulation that matches the entity can establish membership. (Barsalou, 1999, p. 587)

For example, "chair" can be a category and a tree stump can be the entity in question. The frame for chair includes motoric symbols for sitting down as well as perceptual symbols for objects of a certain height and shape. The tree stump's perceptual symbols can be integrated into the simulator for chairs, so that tree stump can be included in the "chair" category. This is important because the ability to categorize allows for category inferences, wherein an entity is assumed to have some feature based upon its membership in a category of entities with the assumed feature.

Linguistic indexing and control: The sixth core property of PSS is that language can be used to initiate and specify simulations. Importantly, linguistic symbols are not amodal; rather they are perceptual symbols for hearing or speaking a spoken word or seeing or writing a written word. Selective attention focuses on these noises, marks, and motions and adds the perceptual symbols to simulators. Later, merely reactivating the linguistic symbol is enough to trigger the simulator to produce a simulation. This allows for control over the simulation activity. "Once simulators for words become linked to simulators for concepts, they can control simulations" (Barsalou, 1999, p. 592).

Those six core properties of PSS provide a generalized understanding of the theory. (1) Neural representations take place in sensorimotor areas of the brain and (2) each representation is composed of perceptual, motoric, and introspective parts acting together. (3) As we go about our lives we are constantly selecting aspects of perceptual experience with attention, which are then added to long-term memory as perceptual symbols. (4) Repeated exposure to an entity or event will form a generalized frame from the associated perceptual symbols. (5) The frames and the simulations they produce together form concepts or simulators, which allow for categorization. (6) Linguistic symbols such as spoken or written words are multimodal perceptual symbols that allow for conscious control of simulations.

Derived Properties of a Conceptual System

A fully functioning conceptual system can represent both types and tokens, it produces categorical inferences, it combines symbols productively to produce limitless conceptual structures, it produces propositions by binding types to tokens, and it represents abstract concepts. Four additional properties can be derived from the six primary properties and are required in order to achieve this end: (1) Simulators can be combined to implement productivity. (2) Simulators can become bound to individuals to implement propositions. (3) Complex simulations can produce abstract thought. (4) Perceptual symbols are neural states so they implement variable embodiment rather than functionalism.

Productivity: This is the ability to create complex representations out of simple symbols using combinatorial and recursive mechanisms. Productivity is possible in PSS because perceptual symbols are formed schematically. While building simulators, much of the information is filtered out and only the selected aspects become symbols. This process can run in reverse in order to implement productivity. Frames contain unspecified information about the structural invariances and constraints of an entity or object. While specifying the details of the particular target in the simulation, new perceptual symbols can be added as different values for attributes. For example, the frame for “feeding my dog” has different attributes that are not given values until a specific simulation is initiated. The simulation for the event could give *chicken* as the value for the *flavor* attribute, but the value could also be *beef* instead even if I had never used that flavor dog food before.

Propositions: Traditionally, propositions are considered amodal structures. They are often described as sentence-like, but they can also take other amodal forms. Fully functioning conceptual systems require propositions because they are necessary to describe and interpret situations in different ways (Pylyshyn, 1973). They also allow for different concepts to be brought to bear on the same aspect of the situation.

Importantly, propositions give the content of representations the important features they must have in order to be used in traditional algorithmic computations. This is important for Barsalou’s stated intention that PSS be compatible with cognitivism. They can be combined in order to form complex hierarchical representations and can establish type-token bindings that allow for categorical inferences. They can also do things like indicate negative states and acquire a truth-value. “Propositions involve bringing knowledge to bear on perception, establishing type-token relations between concepts in knowledge and individuals in the perceived world” (Barsalou, 1999, p. 595).

Type-token mappings allow for a system to implement computations. This is the ability to recognize an individual (i.e., token) as a member of a category (i.e., type). This ability follows naturally from the process of simulator construction. As an example, imagine perceiving a car on the street. Multimodal information is gathered about the individual car. The car simulator becomes activated if its frame includes that individual car or if it can produce simulations that fit well with the individual (e.g., it has a steering wheel that allows it to be driven, it has the same shape, etc.). When a simulator becomes bound to an individual through a simulation it is type-token mapping.

Categorical inferences are determinations that can be made based upon the features of a category. For example, the category for “cars” has a number of attributes that all members of the category share. For ease, “all cars are made out of plastic, metal, and glass” is a categorical statement. From this I can infer that any random car that I might perceive will be made out of those materials rather than wood or cardboard.

A system that is able to implement categorical inferences has the capacity to determine truth-values of its propositions and to preserve truth across multiple operations. If a simulator cannot bind to a perceived individual then that is a false proposition. For example, the statement, “Mt. Everest is inside my living room” has the truth-value of false. When I attempt to comprehend the sentence, the frame for “Mt. Everest” and the frame for “my living room” and the frame for “inside” become active due to the perceptual symbols for the sounds of the words. There is an obvious constraint here that larger objects cannot be inside of smaller objects, and there are also the simulations for my living room that do not include Mt. Everest. Thus representations in PSS have the important truth-bearing properties of contentful states, which allow them to be used in traditional computations.

Abstract concepts: One of the greatest challenges for SAs like PSS is explaining abstract concepts. If knowledge is stored and accessed in its original multimodal format then how are we able to access concepts that have no perceptual components? PSS provides two solutions to this problem.

Embodied semantics is a theory from cognitive linguistics, which famously postulated that the grounding of abstract concepts occurs through embodied metaphors (Lakoff & Johnson, 1999; Gibbs, 1994). With this framework we can also understand abstract concepts such as justice, time, and love that have no physical correlate. In these instances we make use of our bodily possibilities in order to metaphorically understand the concepts. For example, *justice*: in our daily lives we do understand the physical experience of balancing wherein two sides must be relatively equal in weight in order to maintain their relationship with one another (e.g., a child's seesaw). There may also be a biological underpinning to balance as it relates to fairness in interpersonal interactions as there is evidence that animals such as dogs are averse to inequity (Range, Horn, Viranyi, & Huber, 2008; Brosnan, 2006).

According to this explanation for abstract concepts, we use our bodily experiences "metaphorically" and in this way understand these abstract concepts. Justice can be understood in a very bodily way as having to do with a balance of two sides and the feeling of fairness (or aversion to being cheated). Similarly, we have the bodily experience of having a front and back and the movement of things away from us into the distance. Time is typically understood by spatial metaphors that describe the future as forward and the past as behind us. Love can be similarly described in terms of devouring, or possessing, or being involuntarily trapped. In each example, we understand these manifestly abstract ideas through references to relatively mundane bodily experience.

This idea dovetails nicely with research showing conceptual processing involves motoric and sensory neural activations that are relevant to the concept being processed. For example, when performing conceptual tasks involving animals the visual areas of the brain become highly active, but when performing conceptual tasks involving tools the motoric areas of the brain become damaged. Furthermore, damage to different areas of the brain is correlated with the impairment of conceptual processing for certain words depending upon what part of the brain is damaged (See Pulvermüller, 1999).

Studies in psycholinguistics seem to complicate this hypothesis, however. For example, Cacciari et al. (2011) found that the motor system becomes activated during the production of action sentences to different degrees depending upon the way the verb is used. Literal and metaphorical action verb sentences evoke higher motor evoked potentials than idioms and non-action verb sentences (See also Rüschemeyer, Brass, & Friederici, 2007 for similar results). This indicates that there must be more to the account of abstract verbs, as idioms and non-action verbs are at least partially processed in other ways besides motoric activations. Furthermore, other studies have found that there is no necessary overlap or match between the neural areas involved in language tasks and the neural activiations for performing those actions (See Postle et al. 2008, Willems, Hagoort, & Casasanto, 2009, and Bedny & Caramazza, 2011).

Another option is to represent the abstract concept directly with perceptual symbols. This is possible due to the properties listed above. Abstract concepts require frames that allow for recursion, schematic perceptual symbol formation, and introspective perceptual symbols. The process for generating abstract concepts is straightforward. First, the abstract concept is framed against the background of a simulated event sequence. This temporal extended event allows for the abstract concept to be framed in the context of a larger body of knowledge. Next, selective attention captures the relevant features of the event and adds them to the simulator that is being developed for the abstract concept (Langacker, 1986). Finally, perceptual symbols from the introspection modality are critical for capturing the concept.

Perceptual symbols for interoceptions such as homeostatic and proprioceptive sensations have characteristic phenomenological experiences, which may make them viable as perceptual symbols. Introspective perceptual symbols are not limited to these kinds of direct experiences, however. Recursion allows for the formation of perceptual symbols for features of the mind such as representation and propositional construal. A metacognitive simulator for *mental representation* can be formed, which contains primarily introspective perceptual symbols.

> First, identify an event sequence that frames the abstract concept. Second categorize the multimodal symbols that represent not only the physical events in the sequence, but also the introspective and proprioceptive events. Third, identify the focal elements of the simulation that constitute the core representations of the abstract concept against the event background. Finally, repeat the above process for any other event sequences that may be relevant to representing the concept. (Barsalou, 1999, pp. 600-601)

Variable embodiment: This is the idea that a symbol's meaning reflects the physical system that represents it (Damasio, 1994; Clark, 1997). Activations for perceptual symbols occur in the sensorimotor systems so they are influenced by the idiosyncrasies of each system. Variable embodiment follows naturally from the schematic nature of perceptual symbols. Simulators are constructed piecemeal through selective attention. Later, when a simulation is generated there is a reconstruction process as the frame is filled in with details from long-term memory. No two simulations ever need be identical even when they are simulating the same target.

Furthermore, perceptual symbols have semantic implications for their referents that amodal symbols do not. If the perceptual symbols for *dog* are upside down or shrunken in size then it says something about the dog: it is upside down or far away. In contrast, amodal symbols are abstracted away from the idiosyncrasies of the systems. For example, an amodal symbol for *dogs* is the written word, “dog”. It doesn’t matter if the size of the word increases or if it is flipped upside down, the amodal symbol for *dog* has an arbitrary relation to actual dogs.

PSS on AC

According to PSS, during perceptual experience the brain in some sense captures elements of the neural activations to use as perceptual symbols. This is a possible explanation for AC. Conceptual processing occurs using perceptual symbols in the sensory and motor areas of the brain, and this processing can somehow be made conscious and accessible. Barsalou (1999) only addresses this one time directly.

> Pylyshyn (1999) concludes that cognition only produces top-down effects indirectly through attention and decision-making – it does not affect the content of vision directly. Contrary to this conclusion, however, much evidence indicates that cognition does affect the content of sensory-motor systems directly. The neuroscience literature on mental imagery demonstrates clearly that cognition establishes content in the sensory-motor systems in the absence of physical input. (p. 588)

Other cognitive simulation theories deal with memory directly. For example, Rubin’s (2006) Basic Systems Theory and Conway’s (2009) memory theories utilize the simulationist framework provided in PSS. According to these theories memories contains many multimodal components and that retrieving memories involves simulating those components together. Some memory is autonoetic because it is achieved using activity in the sensory and motor areas of the brain, which can be made to be phenomenally experienced. All of this dovetails nicely with Goldman’s (2006) concept of “e-imagination” discussed in the previous chapter.

PSS is also suggestive of an account of the familiar phenomena of internal speech. According to PSS, written and spoken words can be added to simulators. The sounds, sights, and feelings of both speaking/writing and hearing/reading words can be associated with concepts.

Furthermore, Barsalou claims that this ability to harness language into perceptual symbols allows us to control and direct our simulations. If this is correct then it stands to reason that in some cases the manipulation of linguistic symbols is experienced autonoetically as a kind of inner voice.

Neural Implementation of PSS

The explication given in the previous sections is the high-level functional account of PSS. However, Barsalou explicitly rejects the idea that PSS is merely a functionalist account. In his view, it could not be implemented on a computer because multimodal perceptual symbols are instantiated within a physical biological brain. This puts pressure on Barsalou to specify the neural mechanisms that achieve simulation. “One [of the] strengths of grounded cognition is its natural fit with the brain. Because grounded cognition rests in the modalities, knowledge of how the brain implements the modalities inform grounded cognition” (Barsalou, 2008, p. 635). In this section I will formulate an account of what is occurring in the brain during cognition according to PSS. My intention is not to delve into technical details but instead to provide a generalized description of how these structures are supposed to work and what they are supposed to accomplish.

Neural simulation is a complicated activity that involves a number of associations between different modalities. Neural structures must exist that can capture these associations and then redeploy them later during simulations. The neural control hypothesis is that the brain contains structures that are responsible for modulating other brain structures, “Neural control structures… are any neural circuits, structures, or processes whose primary role is to modulate the activity of other neural circuits, structures or processes – that is to say, any items or processes whose role is to control the inner economy rather than to track external states of affairs or directly control bodily activity" (Clark, 1997, p. 136).

Convergence/divergence zones (CDZs) are neural control structures that are hypothesized to play a central role in PSS (Barsalou, 1999; 2008). CDZs are specialized groups of neurons that "capture" patterns of neural activity in the sensory modalities. They exist downstream from the sensory modalities in association cortices. When the sensory modalities become activated they send signals to these association cortices. The signals from the various modalities converge on the CDZ in temporal proximity with one another, which causes an association between these signals. Later, activations in the sensory modalities send signals to the CDZs again. If the incoming signals are similar to previous patterns then the associated neurons in the CDZ will become active again through a pattern completion process (Barsalou, 2009). The CDZ will then send diverging signals back to the sensory cortices to reactivate them (Damasio & Damasio, 1994).

CDZs are also hierarchical. Low-level CDZs capture associations for basic knowledge such as entity categories, while high-level CDZs can associate more complex combinations by associating low-level CDZs with one another. This allows high-level CDZs to easily initiate widespread low-level activity. If this is correct then low-level CDZs handle very generalized information while high-level CDZs are required in order to retrieve unique entities and events. The different levels form a nested hierarchy because activation of higher-level CDZs involves activations in the lower-level CDZs that compose them.

The CDZ architecture is very powerful because it is a plausible account of how association is achieved by the brain. Low-level CDZs instantiate basic perceptual symbols, which are organized by medium-level CDZs into frames. Whenever a general simulation is generated, the medium-level CDZs activate higher-level CDZs that can access other frames and perceptual symbols and that can organize them into the simulation. Finally, a simulation of an individual requires an even higher-level CDZ. Concepts are identified with simulators and all of the various simulations that they can produce. As such, concepts are organized by very high-level CDZs, but involve activations at every level of the hierarchy.

> The architecture is constituted by two crucial elements: (i) neuron ensembles in early sensory and motor cortices, which represent separate knowledge fragments about a given object; and (ii) neuron ensembles located downstream from the former in association cortices, which operate as convergence-divergence zones (CDZs). CDZs receive convergent projections from the early sensorimotor sites and send back divergent projections to the same sites. CDZs contain records of the combinatorial arrangement of the knowledge fragments coded in the early cortices, that is, they hold information about how those fragments must be combined to represent an object comprehensively. CDZ records are shaped by experience. When the organism interacts with an object t, several aspects of the interaction are mapped simultaneously at separate sites in early sensorimotor cortices. The temporally coincident activity at the separate sites modifies the connectivity patterns to, from and within a shared CDZ downstream, with the result that various fragments of information about the object become associated. (Damasio & Meyer, 2009, pp. 376-377)

Damasio et al. (Damasio, 1989; Damasio & Damasio, 1994; Damasio & Meyer, 2009) argue that CDZs are the right kinds of mechanisms for explaining recognition and memory. Upon first perceiving an entity, various CDZs are formed that associate the perceptual elements of that entity. The next time a similar shape is perceived it activates the CDZ, which then sends signals to the other associated modalities. The collective multimodal activations in sensory modalities play a role in recognizing that entity as familiar. Obviously, this fits well with SAs such as PSS because it seems to suggest that knowledge is represented by multimodal neural activations.

Another neural control structure that is hypothesized to play a role in the conceptual simulation of abstract concepts is the “cog.” When thinking in the abstract about a seemingly ungrounded concept like *time* we have neural simulations in the areas of our brain involved in forward and backward motions as well as spatial perception. However, there must be more to the story, as abstract concepts seem to require highly specified simulations. It seems that some other neural control structure must be involved that applies filters to the neural simulations so that they only involve particular aspects of experiences rather than being full-blown reactivations of an entire experience.

"Cogs [are] structuring circuits in the sensorimotor system, which normally function as part of the sensorimotor operations, but whose neural connections to specific details can be inhibited, allowing them to provide inferential structure to "abstract" concepts. If all of this is correct then abstract reasoning in general *exploits* the sensorimotor system" (Gallese & Lakoff, 2005, p. 19). The inhibitory function of cogs allow for generalization (e.g., from "poodle" to "dog" to "animal") as well as for abstraction (e.g., time, love, morality, etc.) and for novel thought (e.g., physical reasoning, artistic creativity, etc.). Unfortunately, the physical correlates for cogs have yet to be discovered.

The last neural control hypothesis I will discuss is the somatic marker hypotheses (SMH). In many ways, somatic markers are very similar to CDZs in that they allow for association between different forms of experience. However, instead of establishing associations between the sensory and motoric modalities, somatic markers establish associations between multimodal activations and marker signals that arise in bioregulatory processing (e.g., emotions, feelings, motivations, homeostatic urges, etc.). In other words, somatic markers associate affective experience with sensorimotor experience.

According to SMH, when a multimodal experience engenders an emotional state the two become associated with one another in the ventromedial prefrontal cortex (Damasio, 1994).

Later, when that multimodal experience is encountered again it causes a reactivation of the emotional state as well. Damasio calls the association a "factual-emotional set", but his understanding of the format of knowledge is very similar to grounded theories so "facts" are stored and represented in the sensorimotor modalities (Bechara, Damasio, & Damasio, 2000).

The reactivation of the prior emotional state can occur in the body itself, which is experienced as the original emotional experience. This is the "body loop" wherein we use our own bodies as the vehicle of simulation. Alternatively, there is an "as-if body loop" that does not involve a full reactivation of the entire emotional state. Instead, the reactivation signals are sent to the somatosensory structures in the brain, which can then take an appropriate pattern.

Somatic markers are hypothesized to play a role in decision-making by facilitating appropriate memories very rapidly. When we experience a situation that previously elicited a strong emotional reaction somatic markers partially re-activate that state[2]. The associated partially reactivated emotional state functions as a kind of gut impulse that immediately suggests a response or at the very least narrows down the possible options.

> [Somatic markers] force attention on the negative outcome to which a given action may lead, and functions as an automated alarm signal... The signal may lead you to reject *immediately*, the negative course of action and thus make you choose among other alternatives… There is still room for using a cost/benefit analysis and proper deductive competence, but only after the automated step drastically reduces the number of options… Somatic markers probably increase the accuracy and efficiency of the decision process. (Damasio, 1994, p. 173)

Barsalou does not include somatic markers in PSS, despite the fact that they seem to be amenable to the rest of the theory. This is probably due to a few related factors. First, it is unclear that an emotional state can become a perceptual symbol. This seems odd because introspection is

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[2] Damasio characterizes the linkages as "dispositional" to indicate that they are not realizations of the actual state but rather they have the potential to reactivate it.

identified with cognitive operations and emotions; however, nowhere does Barsalou include an affective state as a perceptual symbol in any of his examples or discussions. This seems to be a generalized problem with the modalities: they are confusing and underspecified.

Another related problem is that perceptual symbols are gathered schematically but it is unclear how this could occur with affective states. This is complicated by the fact that there are so many theories of emotion on offer. For example, if one adopts a James-Lange theory of emotion, as Prinz (2002) seems to do, then affective experience is constituted by the conscious experience of bodily viscera as it reacts to the environment. In that case, the perceptual symbols for emotions are interoceptions in the sensory modalities rather than being elements of the introspection modality. The emotion itself is an abstraction[3].

Finally, this could be caused by a general tendency in Barsalou to eschew searching for basic elements of the mind (i.e., psychological primitives). This can be seen most clearly in his work on frames. He argues that frames go “all the way down” and that the recursive nature of frames means that they can always be further specified (1992).

Prinz (2002) does approach this topic while formulating his similar neo-empiricist view. He attempts to provide a definition for the senses, which can presumably be applied to the

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[3] Alternatively, if one adopts the conceptual act theory of emotion as Barsalou seems to in Wilson-Mendenhall, Barrett, Simmons, & Barsalou, 2011 then there might be some combinations of core affect that are phenomenologically distinct enough to become perceptual symbols. However, Barrett (2006) is not always clear about whether core affective states are noticeable in experience or are simply embodied dispositions. If they are embodied dispositions then the problem of perceptual symbol formation that the James-Langue theory faced is also true for the conceptual act theory. Either way, Barsalou never attempts to settle this topic.

modalities. Senses are dedicated input systems. Affective states have the same problem here, however, because different theories of emotion disagree on whether or not they are actually an input system. According to the James-Lange theory, emotions are perceptions of bodily states, which would make them legitimate sense modalities. However, if this is correct then the same problem applies as above: emotions are actually abstractions that draw their perceptual symbols from traditional sense modalities such as proprioception. Either way, Prinz's neo-empiricism does utilize somatic markers as elements of simulation.

Earlier I mentioned qualitative neurons. Qualitative neurons are high-level neurons that correlate with qualitative information. These neurons fire for the mere presence of a feature independently of that feature's specific details. For example, some qualitative neurons fire for the presence of a line. It doesn't matter if the line is short or long, and it doesn't matter if it is red or blue. Simulations formed using qualitative neurons can be indeterminate and generic.

> Consider the representation of *triangle*. Imagine that certain neurons represent the presence of lines independently of their length, position, and orientation. Further imagine that other neurons represent the vertices between pairs of lines independently of the angle between them. Three qualitative detectors for lines, coupled spatially with three qualitative detectors for vertices that join them, could represent a generic triangle. Because these detectors are qualitative, the lengths of the lines and the angles between them do not matter; they represent all instances of *triangle* simultaneously. (Barsalou, 1999, p. 585)

If PSS theory is more than just a high level functional account, it needs to specify the neural underpinnings of cognition, and, in this section I have explicated some possible mechanisms for instantiating PSS in the brain. To summarize, during normal perceptual experience, appropriate sensory modalities become activated in the brain as we see, hear, smell, etc. As we attend to specific features of the perceptual experience it causes the sensory modalities involved to send signals to special association areas in the brain called CDZs. These low-level associations are called perceptual symbols. As we experience objects and events, we generate frames for those objects and events by combining perceptual symbols in higher-level CDZs. Later, when we attempt to conceptualize the object or event the frame generates a partial neural reenactment of the perceptual states. Detailed knowledge of the object or event requires additional neural reenactments as perceptual symbols are added to the frame to provide detail. Complex understandings and knowledge of individuals requires even higher-level CDZs to organize all of the CDZs beneath them.

These simulations in sensorimotor areas of the brain achieve typical cognition. Simulations for general knowledge are less complex than simulations for individuals; this allows for productivity because novel perceptual symbols can be added to frames in order to represent new information. Abstraction is achieved by the simulation of embodied metaphors and involves neural mechanisms such as cogs that actively inhibit parts of simulations and qualitative neurons that only fire for qualitative features. Finally, somatic markers may play a role in the associative processes as well because they associate affective states with perceptual experience.

Obviously, this account of brain activity could be improved. Much of the account as it stands remains functionalist. It doesn't explain the causal process in PSS that performs mental computations, and a number of neural mechanisms are still missing to explain how some of these activities could occur in a brain. However, it does provide some specification on a general picture of how the activities in the brain are related to cognition.

PSS is an embodied theory that attempts to synthesize empirical research with cognitivism. It shares many commitments to cognitivism that are rejected by REC. As such, it is unclear that PSS could cohere with REC. Alternative SAs that are much more embodied are available. In the next chapter I will discuss predictive processing, which may provide a REC-friendly SA for AC.

Conclusion

My project is to identify a SA that can help REC with its scaling-up problem. I am specifically interested in how these theories can explain AC. SAs like PSS attempt to explain representation-hungry cognition like AC directly through reference to neural simulation. As I'll show in Chapter 5, however, PSS and related theories utilize cognitivist concepts that are rejected by REC. Other SAs may provide explanations that better cohere with REC.

In this chapter I have reviewed PSS in detail. This theory attempts to formulate a basic conceptual system that has the properties necessary for mental computations. Following Barsalou, I described the six core properties and four derived properties of a conceptual system that utilizes neural simulations. Collectively they are able to provide the kind of system necessary to implement some traditional computational operations. I then discussed the neural implementation of PSS. A number of hypothesized neural control structures could be involved including CDZs, somatic markers, and cogs.

PSS does provide explanations of AC. According to the theory, perceptual symbols can sometimes be experienced autonoetically during processing. This can also explain other autonoetic phenomena such as inner speech. Barsalou's account can be augmented by memory theories offered independently by Conway (2009) and Rubin (2006). By these accounts, episodic memory involves the creation of frames for the event and neural simulation in the sensory, motor, and introspective modalities.

In the next chapter I turn to another theory, predictive processing, which also makes use of simulation-like neural activity. Like REC theories, predictive processing is primarily concerned with basic cognition such as movement and perception. However, proponents of the theory (Clark, 2016; Hohwy, 2013) claim that it can scale up to explain representation hungry activity, including AC. In the fifth chapter I return to PSS and evaluate it in relation to REC.

Chapter 4: Predictive Processing

Introduction

In this chapter I turn to predictive processing (PP) for a possible alternative explanation for autonoetic cognition (AC). While basic cognition is the primary focus of PP, it claims to be able to encompass representation-hungry cognition in its explanations. If PP can scale up its explanations for basic cognition in order to explain AC then those explanations may be useful to radically embodied cognition (REC), which is also primarily concerned with basic cognition. As we shall see, PP and REC have many of the same goals and approaches. If the theories could be reconciled then REC may have the tools to solve the scaling-up problem. PP is a very powerful theory that seeks to encompass almost every aspect of cognition under its framework for understanding the mind. Clark (2016) claims that PP or a similar account has the potential "to tackle a wide range of issues, illuminating perception, action, reason, emotion, experience, understanding other agents, and the nature and origins of various pathologies and breakdowns" (p. 10). For my project I am concerned with AC

Clark's PP theory closely follows the prediction error minimization (PEM) framework offered by Hohwy (2013), and which ultimately derives from predictive models developed in engineering and neuroscience by theorists such as Karl Friston. That Clark and Hohwy agree on so many specific issues is surprising considering that they have radically different conclusions. In fact, it is quite possible to read both accounts as complementary to one another. De Bruin and Michael (2016) have taken pains to determine exactly where Hohwy and Clark diverge. They are able to discover only five substantial disagreements between Hohwy and Clark. Furthermore, the most substantial disagreements revolve around interpretations of what PP seems to imply about the embodiedness and extensiveness of the mind. “While Hohwy is primarily concerned with the constraints PEM places on Embodied Cognition, Clark thinks that Embodied Cognition plays an important role when it comes to the actual implementation and development of the PEM framework” (p. 3). Clark takes a decentralized and externalist perspective wherein the process of PEM is best understood as including aspects of the environment such as tools and conspecifics. He argues that PP is compatible with the extended mind hypothesis. Hohwy, on the other hand, has an internalist interpretation. He argues that the mind never makes direct contact with the environment and must make inferences about what is out there. Despite these dramatic differences in final interpretations, Clark and Hohwy agree on the fundamentals regarding how to understand the observed activity and what mechanisms are required. Note that the PEM framework offered by Hohwy (2013) slightly predates Clark’s (2016) account of PP. I will make note whenever the two accounts diverge in important ways.

PP is not directly related to the grounded cognition movement, but, as we shall see, in order for the system to work there must be simulation-like activities. Indeed, Clark goes so far as to describe the neural activity as being “simulations” (pp. 159-160; see quote below). According to PP, the brain initiates activity at the lowest levels of the sensory cortices in order to better anticipate changes in the sensory flow. For my project I will treat PP as a (predictive) simulation account (SA), at least with regards to AC.

In this chapter I will provide a concise description of PP as presented by Hohwy and Clark. The theory is incredibly powerful and has far-reaching implications in a number of different areas of research. As such, it is impossible to cover all or even most of the details.

Instead, I will approach PP using Hohwy's understanding of the core elements involved in the process, which Clark follows. Hohwy lists perceptual inference, expected precision, active inference, and complexity reduction as essential elements of PP. I'll cover these topics shortly. First, however, I will cover some of the basics.

Predictive Coding

Predictive coding is a data compression strategy originally developed in the field of signal processing. The challenge was to develop a strategy to save on bandwidth and increase efficiency. In predictive coding it is assumed that for any given piece of information, a number of other pieces of information can be reliably predicted. If some information occurs that is not well predicted then the prediction error which results will receive further processing while all of the successfully predicted information will be ignored or passed over. This strategy saves time and bandwidth by ignoring the well-predicted information and only reporting the prediction errors.

> Consider a basic task such as image transmission. In most images, the value of one pixel regularly predicts the value of its nearest neighbors, with differences marking important features such as the boundaries between objects. That means the code for a rich image can be compressed (for a properly informed receiver) by encoding only the 'unexpected' variations: the cases where the actual value departs from the predicted one… As long as there is detectable regularity, prediction (and this form of data compression) is possible. It is the deviations from what is predicted that carry the 'news', quantified as the difference (the 'prediction error') between the actual current signal and the predicted one. This affords major savings on bandwidth… (Clark, 2016, p. 26)

According to PP and related (predictive) SAs, the brain also makes use of predictive coding in its processing. Messages sent between different areas of the brain are simplified to include only unexpected information. PP builds on predictive coding accounts but deviates in some details regarding how and when the predictive coding occurs. It is "not simply the use of the data compression strategy known as predictive coding. Rather it is the use of that strategy in the very special context of hierarchical (i.e., multilevel) systems deploying probabilistic generative models" (Clark, 2016, pp. 25-26).

PP is considered a 'Bayesian' theory of the brain. Bayes rule is a theorem of probability theory. "This rule tells us to update the probability of a given hypothesis, given some evidence by considering the product of the likelihood and the prior probability of the hypothesis… The best inference is then the hypothesis with the highest probability" (Hohwy, 2013, p. 17). Bayesian brain theories assume that the brain engages in inference using something like Bayes rule. That is, the brain makes hypotheses about the source of incoming sensory signals. The organism's history of interactions determines the prior probability of the hypothesis, and this prior probability is updated through evidence.

> [Bayes rule] allows us to adjust the impact of some incoming sensory data according to background information about (1) the chances of getting that sensory data if the world is, indeed, in such-and-such a state… and (2) the prior probability of the hypothesis… Crunching all that together in the right way yields the correct estimation (given what you know) of the revised probability of the hypothesis given the new sensory evidence. (Clark, 2016, pp. 301-302)

According to Bayesian brain views, the brain sends a top-down signal that contains probabilistic predictions about the source of the incoming sensory signals. These probabilistic predictions are based upon what the organism knows about the world from previous experience and based upon what it knows about the reliability of its own operations depending upon the context.

As noted above, a major difference between the above accounts and many other predictive coding accounts is the use of hierarchical generative mental models. "A generative model, in this quite specific sense, aims to capture the statistical structure of some set of observed inputs by inferring a causal matrix able to give rise to that very structure" (Clark, 2016, p. 21). In other words, generative models are internal mental models that are filled in through probabilistically governed guesswork. Throughout previous sensory experience we develop expectations that specific kinds of sensory stimuli will be caused by certain sources. During normal perception and action, we form and update our generative model of the surrounding environment that includes which objects are present and which events are occurring at that time. Generative models are hypotheses about the world around us that are based on what we have learned to be the most statistically probable sources of the sensory information we experience.

PP features a number of different levels of generative models in the brain that are organized hierarchically. There are high-level models and low-level models that interact with other models at higher, lower, and lateral levels. The level of the model is determined by the spatial sizes and temporal spans involved. Higher-level models deal with large spaces and long time spans. Conversely, lower-level models deal with small spaces and short time spans. Clark interprets the notion of generative model layers or levels as functional and does not attempt to settle on a current theory for their neuronal implementation (2016, p. 313 note 4).

Hohwy (2013) is willing to offer some speculative details about the neuronal implementation of generative models. Generative models are formed through experiences of interactions in the distal world. They aim to discover regularities in the sensory flow such as correspond to the day-night cycle or the noises created by certain events. Different models capture regularities at different temporal and spatial scales. "Regularities come at different time scales, ranging from tens of milliseconds to hundreds, to seconds, minutes, and upwards towards regularities or rules that are stable over weeks, months, and years" (p. 27). For example, fast (i.e., low-level) time scale regularities are things like the shifting profile of a face during speech production. Slower time scale regularities might be visually tracking a feather caught in the wind. Slower still might be high-level regularities that take place over long times such as the idiosyncrasies of interacting with certain individuals or even very long time span regularities that must be learned indirectly such as how *El Nino* influences the normal weather patterns every few years.

> Fast regularities are processed early in the sensory processing stream (for visual perception this happens in area V1 at the back of the brain) and then increasing time scales are processed as the sensory signal works its way up through the primary sensory areas and into higher areas… The hierarchy also has a spatial dimension… The fast time scale regularities represented in low levels of the hierarchy (such as V1) have small, detail-focused receptive fields of only a couple degrees whereas later areas of processing have wider receptive fields (e.g., 20-50 degrees) in the temporal cortex. (p. 28)

Generative models pass messages to the levels immediately above, below, and lateral to one another. The interplay between levels includes back-and-forth interactions that modify the contents of each level. Each level of the hierarchy is nested within other levels and provides details of the causal structure of the world. "A complete hierarchy would reveal the causal structure and depth of the world – the way causes interact and nest with each other across spatiotemporal scales" (p. 28).

Interactions between levels take different forms depending upon the direction of the message. "Low level, fast scale regularities help choosing among hypotheses higher up and higher-level hypotheses about slower regularities work as control parameters on low-level regularities" (p. 31). In other words, higher-level models send expectations about the distal causes of various stimuli downward to lower levels. These expectations modify the content of the lower-level models to better drive the PEM behavior. A high level generative model may include information about the absent or distal cause of the stimuli, which provides the necessary context for perceptual exploration at lower levels. In contrast, generative models only send error signals upwards in the hierarchy. That is, the higher-level models provide the framework for organizing PEM behavior, and the lower level models organize the immediate bodily actions required to achieve PEM behavior. When a prediction is found to be in error then the model must be incorrect and an error signal is generated. This error signal is sent up the hierarchy to modify the incorrect generative models. The error signal will propagate upwards and modify the models until the system settles on a new prediction that includes the recently discovered information.

Clark (2016) provides a description of the interaction between levels while discussing the work of Rao and Ballard (1999), which I will quote at length,

> [Sensory] signals are… processed via a multilevel cascade in which each level attempts to predict the activity at the level below it via backwards connections. The backwards connections allow the activity at one stage of the processing to return as another input at the previous stage. So long as this successfully predicts the lower level activity, all is well, and no further action needs to ensue. But where there is a mismatch, 'prediction error' occurs and the ensuing (error-indicating) activity is propagated laterally and to the higher level. This automatically recruits new probabilistic representations at the higher level so that the top-down predictions do better at cancelling the prediction errors at the lower level (yielding rapid perceptual inference). At the same time, prediction error is used to adjust the longer-term structure of the model so as to reduce any discrepancy next time around (yielding slower timescale perceptual learning). Forward connections between levels thus carry only the 'residual errors' (Rao & Ballard, 1999, p. 79) separating the predictions from the actual lower level activity, while backwards and lateral connections (conveying the generative model) carry the predictions themselves. Changing predictions corresponds to changing or tuning your hypothesis about the hidden causes of the lower level activity. In the context of an embodied active animal, this means it corresponds to changing or tuning your grip on what to do about the world, given the current sensory barrage. The concurrent running of this kind of prediction error calculation within a bidirectional hierarchy of cortical areas allows information pertaining to regularities at different spatial and temporal scales to settle into a mutually consistent whole in which each such 'hypothesis' is used to help tune the rest. (pp. 30-31)

Generative models exist in a hierarchy wherein talk of different models refers to models corresponding to differing scales of time and space. They can communicate with higher and lower level models, but Clark takes great pains to state that they can also communicate with lateral models. Unfortunately, he never goes into detail about the number of models that exist at each level. A few different interpretations are available. He may be suggesting that these other lateral models come from different sensory modalities, as this seems to be the position implied by Hohwy in the quote above. Hohwy clearly identifies the low level models as being neuronally implemented by activity in the early sensory cortices (V1 in the example), which to me implies that activity in the early sensory cortices of other modalities may also produce low level models. If this were true then it probably follows that each exteroceptive channel produces its own generative model (and possibly the interoceptive channels as well).

This interpretation has problems, however. Clark (2016) clearly thinks that at least some models are multimodal. For example, his understanding of emotions is that they are a special kind of multimodal perceptual inference. “These interoceptive, proprioceptive, and exteroceptive predictions are construed differently in different contexts, and each provides ongoing guidance to the other. A single inferential process here integrates all these sources of information, generating a context-reflecting amalgam that is experienced as emotion” (p. 234). It may be the case that the number of models per level is determined by the ‘rank’ of the level in the hierarchy. Low levels deal with very specific sensory information from a single modality while higher levels work by integrating the modalities together. He seems to suggest this while discussing hyperpriors, “For example, we may see and hear an approaching car: In such cases, the two sources of sensory input need [to be integrated]… Such integration depends both upon specific (sub-personal) expectations concerning the sight and sound of typical cars and also upon more general expectations such as the expectation (a systematic hyperprior) that whenever auditory and visual estimations of the spatial location of a signal source are reasonably close, the best overall hypothesis is that there is a single source – in this case a rapidly moving car" (p. 64). It seems necessary that hyperpriors are multimodal. If they are playing this important role in the formation of generative models then the models themselves (at least these high level models) should be understood as being multimodal as well. I will discuss hyperpriors later in this chapter.

Alternatively, different models at the same level may be different hypotheses in competition with one another. Hohwy (2013) seems to suggest this when he states that, "It is likely that lateral connections within the same hierarchical level serve to decorrelate prediction units such that when a particular hypothesis begins to emerge as having the highest posterior probability other units are progressively prevented from influencing inference" (p. 61). According to this interpretation, ambiguous sensory information can create multiple possible models. The system then engages in PEM behavior in order to determine which model is correct. This interpretation works, but it does multiply the number generative models that are involved in cognition. Generative models are already suspiciously similar to kind of internal representational states that REC rejects, a point of contention that I will return to in the final chapter.[1]

Much more can be said in general about predictive coding accounts, as they are remarkably powerful theories. However, these preliminaries should suffice for dealing with the

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[1] To be fair, Clark takes a very functionalist stance toward the talk of levels (p. 313 note 4) and generative models in general. If Clark is not a realist about these things then it is unclear why talk of "lateral communications between models at the same level" should track actual levels that could be identified in a physical brain. It may instead be shorthand designed to track theoretical distinctions that do not track distinctions in nature.

four elements of the PEM mechanism offered by Hohwy and expanded upon by Clark in his account of PP: perceptual inference, expected precision, active inference, and complexity reduction. I will deal with each in turn before discussing ways that PP is implemented in the brain. As we shall see, Clark endeavors to situate PP as very close to REC in its outlook. In the final chapter I will determine if this is truly possible.

Perceptual Inference

Perceptual inference is part of the process of normal perceptual experience that occurs constantly in every exteroceptive modality. Exteroceptions are perceptions originating from sensory organs targeting the external environment. These are the traditional senses of vision, audition, taste, touch, and olfaction. Other perceptual inputs that are sometimes included in the list of our senses, such as kinesthesia and proprioception, are examples of interoceptions. Interoceptions are important for PP explanations of self-generated motion, affective consciousness, and emotional experiences. I will be touching on interoceptions in later sections while discussing active inference.

During perceptual inference the brain engages in a kind of preemptive ‘filling-in’ of perceptual experience. The brain generates a mock feedback signal immediately before the actual feedback signal from perceptual experience is fully activated. This mock signal is generated by the higher-level models (based on prior experience and the just prior sensory input) and is sent from the top downward where it meets the driving bottom-up sensory signal. If all is well then the two signals will match and the rest of the neural activation will develop while the system moves on to the next task. If the two signals do not match then an error signal is sent upwards to adjust the models and reduce further prediction error. That is, the brain is able to self-generate activity in the early sensory cortices in advance of sensory feedback, which speeds up the processing of perception by guiding perceptual explorations and initiating the activations in the sensory cortices ahead of time. "[The] system is trying to generate (at multiple spatial and temporal scales) the incoming sensory signal for itself. When this succeeds, and a match is established, we experience a structured visual scene" (Clark, 2016, p. 14). The upshot is that perception is directly influenced by our expectations. If the PP story is on track then it gives us leverage on perceptual illusions, confirmation bias, placebo effects, and other strange phenomena.

In the case of confirmation bias, placebos, and psychosomatic illness, PP suggests that the problem is occurring in the sensory experience itself rather than in the judgment made about the sensory experience. Illusions are also explicable as a combination of perceptual inference, misleading hyperpriors, and Bayes optimal mistakes. That is, in an illusion such as ventriloquism there is a systematic hyperprior that is normally correct but that is misleading in this particular instance. Clark provided an example I already quoted, "[Whenever] auditory and visual estimations of the spatial location of a signal source are reasonably close, the best overall hypothesis is that there is a single source" (p. 64). This hyperprior is Bayes optimal as it is the most probable hypothesis based upon the evidence and prior experience. The hyperprior influences the generative models such that perceptual inference occurs and we may seem to 'hear' the voice coming from the moving mouth of a puppet.

Perception is a back-and-forth process between generative models at different temporal and spatial scales. The context that the organism finds itself in provides an early generative model of expectations about what will be perceived. These expectations meet the sensory signal and actively modify it. Error signals cause revisions in the generative models, which leads to further perceptual inference as the new models now subtly modify the sensory signal. Clark (2016) again provides us with an account of how top-down and bottom-up influences can together create perceptual experience.

> During early stages of processing, a PP system will avoid committing itself to any single interpretation, and so there will often be an initial flurry of error signals… as competing 'beliefs' propagate up and down the system. This is typically followed by rapid convergence upon a dominant theme (such as "animals in a natural scene") with further details ("several tigers sitting quietly under the shade of a large tree") subsequently negotiated. The setup thus favors a kind of recurring 'gist-at-a-glance' model, where we first identify the general scene followed by the details. This affords a kind of 'forest first, trees later' approach (Friston 2005; Hochstein and Ahissar, 2002). These early emerging gist elements may be identified on the basis of rapidly processed (low spatial frequency) cues, as suggested by Bar, Kassa, et al. (2006). Such coarse cues may indicate whether we confront (for example) a cityscape, a natural scene, or an underwater scene, and they may also be accompanied by early emerging affective gist – do we like what we are seeing? (See Barrett and Bar 2009) (pp. 41-42)

Expected Precision

If PP is on track about perceptual experience then there are instances where our expectations influence our experiences from the top-down. An immediate concern to be raised is how much this should undermine our trust in the senses. If top-down influences can alter perceptual experiences then how can we trust things in cases of ambiguous perception or even eyewitness testimony?

There must be a balance between top-down expectations and bottom-up sensory signals. Take a cocktail party as an example. The general din of the party can make a conversation impossible. Fortunately, we do not rely upon the noise-filled sensory signal alone. Instead we use the context and certain clues in order to "guess" what is being said. Perceptual inference makes it such that these "guesses" show up in experience as if you had actually heard what you guessed. This is similar to what has been observed by Merckelback and van de Ven (2001) in their research on sine-wave speech. Understanding sine wave speech is almost impossible until you hear the sentence spoken normally. After you know what is being said then suddenly top-down influences make the same sine-wave speech sound intelligible to you. Top-down modulation is important to perception because it allows the listener to better detect the actual signal from the obscuring noise

The cocktail party example also highlights the changing ratio of bottom-up to top-down influence on experience. That is, the system will make greater use of top-down signals in some circumstances and bottom-up signals in others. Over time we learn the optimal circumstances to use both approaches and we seamlessly modify our behavior accordingly. Clark (2016) uses the example of driving at night where there are patches of dense fog intermittent with clear spaces. In this situation the driver must switch between primarily top-down and primarily bottom-up strategies. “Visual input, in the fog, will be estimated to offer a noisy and unreliable guide to the state of the distal realm” (p. 57). While in the fog, the driver is better served prioritizing top-down expectations, especially on a familiar road. During clear patches of road the driver can switch to bottom-up perceiving where the road itself guides the driver. Generative models are formed for “driving without fog”, “driving in fog”, and “driving through intermittent patches of fog”. Each generative model suggests a different strategy on the ratio of top-down and bottom-up influence in perception.

Expected precision is the ‘weight’ given to a sensory signal based upon the context and history of interactions of the organism. In some situations the sensory signal is expected to be highly precise or reliable. On a clear day with plenty of light we can generally trust our eyes and we place much weight on the bottom-up signal coming from them. During a chaotic or noisy situation the signal is unreliable. At night or in fog there are visual effects like moving shadows and hazy obscuration. In these situations we switch to relying on the top-down expectations from our generative models to guide our movements.

Expected precision is, “a kind of second order perceptual inference because it is inference about perceptual inference” (Hohwy, 2013, p. 65). Another way to understand expected precision is as a confidence rating in the sensory signal. Signals that we feel more confident about will have greater influence over the generative model. For example, on a clear day the visual sensory signal will be rated as highly precise and the organism will have confidence in what it sees. If it does not visually perceive what it expected to perceive then the sensory signal would send highly weighted prediction error signals up the hierarchy. These highly weighted error signals force the models to be updated. During the cocktail party conversation mentioned above we may have the opposite occurrence. The ambient noise can interfere with the auditory signal, so the auditory signal is rated as low precision. If the listener hears something unexpected then it still generates error signals. However, the error signals are lowly weighted and therefore may only require small modifications to the generative models. With such little confidence in what is heard, agents typically switch to contextually driven partial listening.

One upshot of this understanding of expected precision is that it gives us leverage on explaining or at least better understanding some pathology. Expected precision is a second order statistic, but there is no additional third order statistic with which to judge our judgments of expected precision. This means that problems with expected precision can seriously impair an otherwise healthy person. A number of pathologies are suggested to have their root cause in problems with the expected precision mechanism, but two pathologies are particularly interesting because they have been so difficult to understand in the past. Hohwy and Clark posit that certain symptoms of schizophrenia and autism are explicable from the predictive coding perspective.

Schizophrenia occurs when an individual cannot successfully make use of bottom-up information; autism, on the other hand, occurs when an individual cannot successfully make use of top-down information.

According to this view, schizophrenic individuals are unable to feel confidence in the bottom-up sensory signal. For these people, highly weighted (i.e., high precision) prediction error signals are (incorrectly) generated by typical experiences. This creates much confusion, as high-precision signals are rated as very trustworthy by the system and will demand an explanation at higher and higher levels of the hierarchy. This leads to dramatic revisions in the world model of the afflicted person in order to explain the bizarre experience. The experience of "salient strangeness" that is reported by schizophrenic individuals is understandable through this framework as the experience of highly weighted prediction errors being generated by banal environmental stimulus. The bottom-up signal of the innocent object is in some way 'infused' with a sense that there is more to the object than is immediately apparent (i.e., highly weighted error signals). Something is wrong and the individual cannot identify the source of the problem. These (false) error signals will propagate all the way up the system to the highest levels of the hierarchy and can force deep revisions to the generative model. Suddenly, improbable and seemingly irrational explanations (e.g., alien abduction, telepathy, etc.) become the best explanations from the perspective of the afflicted. This then conditions top-down expectations in such a way that allows for false perceptions, which allows for a self-reinforcing cycle. All of this fits the profile for positive symptoms of schizophrenia.

> The basic idea is that [delusions and hallucinations] might flow from a single underlying cause: falsely generated and highly weighted (high-precision) waves of prediction error. The key disturbance is thus a disturbance in metacognition – for it is the weighting (precision) assigned to these error signals that makes them so functionally potent, positioning them to drive the system into plasticity and

> learning, forming and recruiting increasingly bizarre hypotheses so as to accommodate unrelenting waves of (apparently) reliable and salient yet persistently unexplained information. The resulting higher-level hypothesis (such as telepathy and alien control) appear bizarre and unfounded to the external observer, yet from within now constitute the best, because the only, explanation available… Once such higher-level stories take hold, new low-level sensory stimulation may be interpreted falsely… False inferences supply false percepts that lend spurious support to the theories that gave rise to them, and the whole cycle becomes perniciously self-confirming. (Clark, 2016, pp. 206-207)

On the other hand, autistic individuals cannot successfully make use of the top-down signal. In this case, however, the problem seems to involve lower weighting of the top-down signal. In other words, the individual cannot use prior knowledge (i.e., top-down signals) that normally contextualizes experience and guides sensory exploration of the scene. Without top-down influences, the individual will spend much more effort and time on processing inconsequential information and will be easily confused by small changes. For example, a person with this problem may have difficulty recognizing an object under different lighting conditions as shadows can drastically alter the visual profile of an object. Top-down inference allows neurotypical people to abstract away from visual details like changing shadows, and problems with top-down influence can lead to impairments in this ability. This could have severe emotional costs that contribute to a variety of behaviors typical of people on the autism disorder spectrum. In an attempt to protect herself by simplifying overly chaotic sensory experience, a number of strategies can be employed such as repetition, insulation, and single-mindedness.

> [Autism involves] a disturbance to systemic abilities to deal with sensory uncertainty due to an attenuated influence of prior knowledge. The upshot of such weakened influence is a positive capacity to treat more incoming stuff as signal and less as noise… But this means in turn that huge amounts of incoming information are treated as salient and worthy of attention, thus increasing effortful processing and incurring significant emotional costs. (Clark, 2016, p. 225)

Expected precision is a mechanism to better evaluate the available signal, but there is no additional mechanism to evaluate expected precision. When the individual suffers from impairment in the neural mechanism that achieves expected precision (which I will discuss toward the end of the chapter) then the consequent confusion could be very difficult to correct. A vicious circular feedback will occur when, for example, the schizophrenic person generates sensory information from the top-down and then trusts only that top-down sensory information to guide further investigations. The top-down expectations will cause the unfortunate individual to attend to certain features of the environment and then to find confirmation of these expectations with the aid of perceptual inference. This can cause the individual to completely lose touch with reality.

If the PP story is on track then it also gives us new insight into the familiar phenomenon of attention. Attention is a manifestation of expected precision insofar as we direct our bodies toward (i.e., attend to) features of the environment that we expect to carry highly precise signals. Attention, in the PP story, is a kind of a high-precision spotlight that we direct toward aspects of the environment expected to be relevant to the situation. By this understanding, attention is a whole-body prediction error minimization behavior (active sampling is performed by moving one's body, directing one's eyes, for example) that yields highly weighted signals.

> The familiar idea of 'attention' now falls into place as naming the various ways in which predictions of precision tune and impact sensory sampling, allowing us (when things are working as they should) to be driven by the signal while ignoring the noise. By actively sampling where we expect (relative to some task) the best signal to noise ratio, we ensure that the information upon which we perceive and act is fit for purpose. (Clark, 2016, p. 59)

Much more can and will be said about expected precision. As we shall see, this element of the predictive coding story is crucially important to PP's explanation of self-generated motion and for my project of complex cognition. In fact, from a big picture perspective, expected precision is the most important element of the PP story! I will be returning to it throughout this chapter. In the next section I will move to the third element of PP: active inference.

Active Inference

There are two ways to reduce prediction error signals. Thus far we have encountered the more straightforward approach of changing what is predicted. When high precision prediction error signals make their way up through the hierarchy it forces a number of revisions in the generative models at different levels. The alternative way to reduce prediction error signals is to change the signal itself in order to match the prediction. In other words, move various parts of the body so as to confirm or disconfirm the predictions. This is referred to as active inference. As we shall see, while active inference has a number of parallels to perceptual inference, it is also a very different process that requires a rethinking of how we understand the role of movement and the functioning of the motor cortex.

According to PP, the motor cortex is much more similar to the various sensory cortices than is traditionally conceived. For example, the visual cortex, by the PP account, is primarily concerned with generating perceptual predictions at different timescales. These predictions meet with the driving bottom-up signal in V1 to create visual experience. Similarly, much of the motor cortex is primarily concerned with generating predictions of sensory stimulus. In this case, the sensory stimuli being predicted are proprioceptive. "The primary motor cortex is no more or less a motor cortical area than the striate (visual) cortex. The only difference between the motor cortex and the visual cortex is that one predicts retinotopic input while the other predicts proprioceptive input from the motor plant" (Friston, Lawson, & Kilner, 2011, p. 138). This understanding of the motor cortex is radically different from traditional accounts wherein the various motor areas are involved in the production of movement. Instead of producing movement, the higher motor areas are predicting proprioceptive signals in perception-action simulations.

Active inference "names the combined mechanism by which perceptual and motor systems conspire to reduce prediction error using the twin strategies of altering predictions to fit the world and altering the world to fit predictions. This general schema may also be labeled 'action oriented predictive processing" (Clark, 2016, p. 122). The details of active inference will be familiar as they are similar to the perceptual inference story. There is a hierarchy of levels based upon temporal span and spatial size. These levels communicate to one another in the same manner that was described above for perceptual inference. The difference between perceptual and active inference can be (somewhat misleadingly) identified in terms of what is being predicted. In perceptual inference you are attempting to predict what you perceive in the surrounding environment. In active inference you are attempting to predict how you will move.

> Perception and action here follow the same deep logic and are implemented using versions of the same computational strategy. In each case, the systemic imperative remains the same: the reduction of ongoing prediction error. In perception, this occurs when a top-down cascade successfully matches the incoming sensory data. In action, it occurs when physical motion cancels out prediction errors by producing the trajectory that yields some predicted sequence of proprioceptive states. (pp. 123-124)

Active inference brings action back into the picture through action oriented predictive processing. According to PP, we use a combination of perceptual and active inference constantly in order to navigate our world. Active inference is important in the process because it is a means of testing the hypotheses from perceptual inference.

> Perceptual inference allows the system to minimize prediction error and thus favor one hypothesis. On the basis of this hypothesis the system can predict how sensory input would change, were the hypothesis correct. That is, it can test the veracity of the hypothesis by testing through agency whether the input really changes in the predicted ways. The way to do this is to stop updating the hypothesis for a while, and instead wait for action to make the input fit the hypothesis. If this fails to happen, then the system must reconsider and eventually adopt a different or revised hypothesis. (Hohwy, 2013, p. 79)

Active and perceptual inferences play asymmetrical roles in the process. While both processes deliver predictions of sensory signals, the function of active inference is to better test the perceptual inferences. Active inference involves more than just the brain and motor cortex. It involves the entire body that is being moved about in order to reduce prediction error.

Active inference involves the use of forward models of the motor system, which are similar to the emulator mechanisms discussed in chapter two. These are thought to be in some way isomorphic with soon-to-be-achieved bodily movements. Forward models are deployed ahead of the action and generate the estimated sensory feedback immediately before the actual feedback. This allows for fine-grained adjustments to be made without wasting energy. Forward models are important because sensory experience is often temporally fragmented. In an important sense, we live in the past, as there are delays in the processing time depending upon the sensory organs involved and the context. Forward models allow us to live in the present by streamlining ongoing experience (Franklin & Wolpert, 2011).

The predictive coding accounts of both Hohwy and Clark depart from traditional theories of motor control. PP does not require additional posits such as efference copies, corollary discharges, and inverse models of the motor system. Instead, action is directly caused by expectations about trajectories of motion. This is similar to the ideomotor view of action[2]: the

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[2] Also see James, 1890

idea of moving causes the movement directly. According to this, when we think of the future it includes all of the motor behaviors that lead into our plans. Those motor behaviors are unpacked and specified according to the context and history of worldly interactions. The mere thought/prediction of movement will cause the body to move.

> In the ideomotor view, in a sense, causality, as present in the real world, is reversed in the inner world. A mental representation of the intended effect of an action is the cause of the action: here it is not the action that produces the effect, but the (internal representation of the) effect that produces the action. (Pezzulo, Baldassarre, Butz, Castelfranchi, & Hoffman, 2007, p. 75)

Self-generated movement involves the expected precision assessment of proprioceptive signals. According to PP, agents first plan (actually, predict) their movements (or, more accurately, the proprioceptive responses to those movements). These predictions create prediction error, as the proprioceptive feedback of the body before it moves does not match the prediction of the moved body. These predictions are highly weighted and can only be reduced through movement. The body moves in order to reach a position where the prediction error is minimized, which puts it into the predicted position. “Action thus emerges as a kind of self-fulfilling prophecy in which neural circuitry predicts the sensory consequences of the selected action. Those consequences do not immediately obtain, however, so prediction error ensues: error that is then quashed by moving the body so as to bring about the predicted sequence of sensations” (Clark, 2016, p. 124).

The ideomotor view of action will be important for PP’s explanation of AC. PEM systems create high level models in order to predict the best course of action for achieving some end. These high level models are unpacked at lower levels where they ultimately entrain basic movements that move us toward our goals. In other words, we predict desired states in high-level models, when then send downward signals to lower levels. These signals are cashed out at each subsequent lower level until they organize motor actions at the lowest levels. According to PP, during AC the system is doing something very similar.

Complexity Reduction

The final element of PP is complexity reduction, which is the way in which generative models are created and refined. As we have seen, generative models can become revised by high precision sensory information. When attempting to reconcile high-level models with lower models, the system will opt for a compromise that can explain away the high precision error signals in the easiest way. It looks for ways to make sense of the incoming complex manifold of sensory information in the overarching context in which it finds itself. In order to create efficient models the system has the means to reduce the complexity of incoming signals. “A generative model that is rich enough to maintain an organismic grip upon the regularities important for selecting behavior, but that does so using minimal energetic or representational resources is efficient in this sense” (Clark, 2016, p. 271).

A way that efficiency of processing can be improved by a reduction in complexity is through general parameters that can guide prediction. These can come about through acquired hyperpriors or they can be the result of the shape of our bodies. As discussed above, a hyperprior is a generalized principle such as, “When multiple sensory signals seem to be temporally coordinated then assume they originate in a common source.” These are generally Bayes optimal assumptions that help produce more efficient models. “Hyperpriors are essentially ‘priors upon priors’ embodying systemic expectations concerning very abstract (at times almost ‘Kantian’) features of the world” (Clark, 2016, p. 174). Hyperpriors also give us leverage on understanding well-known illusions such as the rubber hand or the concave face illusions. For example, as discussed above, ventriloquists exploit the hyperprior by synchronizing the speech sounds with the movement of the doll's mouth.

It is important to reduce the complexity of generative models in order to deal with the surplus of stimuli in the sensory array. The system prefers hypothesis about the world that are more likely and, hence, more simple in an important sense. Generative models that can explain the sensory array without positing unlikely overly complicated circumstances are less complex as they require less model revision at higher levels.

Complexity reduction may be involved in cognitive phenomena that involve a "feeling of knowing". For example, we often feel as though we know a word or name but cannot verbalize it, the tip-of-the-tongue phenomena. Other times we may experience a situation (such as a complex argument) as being problematic without being able to immediately verbalize the reason (sometimes this is called "intuition"[3]). For PP, these phenomena are the result of the complexity reduction element of the PEM system.

Generative models in the PEM system cannot be overly complex, and the system is hypothesized to take active steps in reducing overly complex models by strengthening some neural connections and weakening others (possibly through synaptic pruning). In other words, the system strives to make the model such that it can explain as many different error signals as possible. The different "feeling of knowing" phenomena mentioned may be understood as the consequences of this complexity reduction. Tip-of-the-tongue phenomena occur when some critical proportion of connections have been pruned or reduced in such a way that some aspects cannot be easily recalled. The other "feeling of knowing" phenomena mentioned above may also

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[3] "Intuition" has a number of disparate meanings that I will not distinguish. For my project I mean simply a source of relevant knowledge that is acquired without verbal reasoning or explicit awareness.

be explicable as the result of complexity reduction. Aspects of the sensory array that cannot be explicitly identified may cause model revisions that seem inexplicable to the person experiencing them. In other words, intuition and eureka moments may occur because model revision can happen without conscious awareness. During intuition this may give the impression of knowing something without having explicit verbal "thoughts" about it. Eureka moments may occur when a (correct) high level model is formed without explicit awareness that is then "discovered" through explicit reasoning.

Representation-hungry Cognition in PP

While PP is primarily concerned with basic cognition like perception and self-generated movement, it also gives us some leverage on explaining AC. According to Clark (2016), capacity for AC involves the same mechanisms used in basic cognition.

> PP offers an attractive 'cognitive package deal' in which perception, understanding, dreaming, memory, and imagination may all emerge as variant expressions of the same underlying mechanistic ploy… At the heart of the package lies the ability to use downward connections to self-generate perception-like states. The very same 'perceptual' machinery… accounts for imagery and dreaming, and may pave the way for 'mental time-travel' as we assemble cues and contexts able to reconstruct the past and preconstruct the future. It also paves the way for more deliberative forms of reasoning. (p. 107)

The account of AC in PP depends upon the gating effect produced by the precision weighting of prediction errors. Recall that expected precision is a kind of weighting given to bottom up signals that causes them to have either more or less influence in generative model revision. During AC the system generates activity at low-level sensory cortices that are isomorphic with the sensory activations that would be active should whatever is being imaged actually be present. This self-generated activity (in effect, a simulation) is given a very low precision weighting and, as such, will not demand revision of the generative models concerned with the immediate environment of the agent. These lowly weighted self-generated activities are experienced as a kind of perceptual input that is somehow not entirely relevant to the situation at hand. The objects of imagined perceptions are, in some strange sense, consciously present to the agent while at the same time being physically absent.

> [In motor planning the system will] lower the weighting on (selected aspects of) the proprioceptive motor signal, while simultaneously entering a high-level neural state whose rough-and-ready folk-psychological gloss might be something like 'the cup is grasped'. Motor action is entrained by high-precision proprioceptive expectations and cannot here ensue. But here too, all the other intertwined elements of the generative model remain poised to act in the usual way. The result should be a 'mental simulation' of the reach and an appreciation of its most likely consequences. *Such mental simulations provide an appealing way of smoothing the path from basic forms of embodied response to abilities of planning, deliberation, and 'offline reflection'*" (pp. 159-160; Italics added).

AC is possible because the system will self-generate neural states at the sensory cortices in mental simulations. It achieves these simulations through the gating effects of the precision-weighting mechanism. This explanation also includes an account of inner speech. Spoken words, according to PP, are a kind of created external symbol that the system can use as a high-precision sensory signal. In internal speech, the 'thought-constituting words' are generated in the auditory cortices much like other self-generated perceptual experience. These auditory simulations then modify the system accordingly. "[We] take a 'first-order' cognitive product… clothe it in public symbols… and launch it into the world so that it can re-enter our own cognitive system, and the cognitive systems of other agents, as a new kind of concrete perceptible – the percept of a written or spoken sentence. Those new perceptibles bear highly informative statistical relations to other such linguaform perceptibles" (pp. 277-278). Internalized speech involves neural activations in the auditory cortex that are generated as part of the ongoing sensory array (much like visual perceptual inferences). As such, inner speech has no privileged information about the content of the generative models and is itself a kind of PEM "behavior".

Neural Implementation of PP

Now that the basic overview of the primary elements of a PEM system as described by Hohwy and Clark is complete, we can turn to the neural details of how PP is instantiated by the brain. PP does not disappoint in this area as Clark describes the theory as "mid-level", which fits well with Barsalou's description of PSS as a "high-level functional account". Appropriately, the details of PP are less broadly functional than PSS's details and include more specific posits.

Understanding the brain in PP requires first that we recognize and acknowledge the excessive amount of activity that is always occurring in the brain. Research on the brain has always been hampered by our inability to distinguish the relevant activations from the background 'noise' of ongoing activations that seem to play no role in the activity being performed. For PP, the overactive brain is in the constant process of model generation at different scales. There are no isolated cognitive acts, but rather every cognitive act emerges from the ongoing contextualized dynamics of neural activity. "According to [this] account, such spontaneous activity is not 'mere neural noise'. Instead it reflects a creature's overall model of the world. Evoked activity (the activity resulting from a specific external stimulus) then reflects that model as it is applied to a specific sensory input" (Clark, 2016, p. 273). Similarly, the 'default network' is a collection of neural regions that are most active when the organism is not engaged in attention-involving tasks and instead underpin abilities to mentally wander or daydream. Clark hypothesizes that this network is involved in constructing an overall world model that includes our agent-specific set of homeostatic demands as well as our attitudes and desires.

Furthermore, the system is thought to operate according to a gist-at-a-glance process whereby the system almost instantly picks up the general gist of the perceived scene. The gist is a partial high-level model that organizes predictions at lower levels in order to refine the perception into a recognizable event in the overarching context. Research by Barrett and Bar (2009) shows that the brain automatically enters into an overall state of activation according to subtle clues of affective import. This early state establishes an interpretive context for the agent during perceptual processing. “Putting all this together we arrive at a picture of the brain that is never passive, not even before the arrival of the coarse cues that drive ultra-rapid gist recognition” (Clark, 2016, p. 166).

Another initial observation about the brain in PP concerns the existence of “mental modules.” The neural architecture of PP features functional differentiation and functional integration. Functional differentiation is when local neural assemblies acquire ‘response profiles’ (similar to neural correlates) that reflect local cortical biases (native functions), the history of interactions, and dynamics of other coupled neural areas. These functionally differentiated neural assembles are dynamically coupled to other assemblies in functional integration, which allows for temporary and spontaneous task-specific processing regimes to emerge as contextual effects repeatedly reconfigure the flow of information and influence.

The upshot of functional differentiation and integration is that we once again have mental modules. However, these mental modules are temporary and best understood as ‘transient assemblies’. “[They] act in some ways like modules or components. But they are formed and reformed ‘on the fly’, and their functional contributions vary according to their location within larger webs of processing" (Clark, 2016, p. 150; also see Cocchi, Zalesky, Fornito, & Mattingley, 2013). In other words, the complexity-bordering-on-chaos that characterizes the brain's activity in general is understood by PP to be the thoroughly embedded brain's ongoing coupling with the environment through downward flowing predictions and upward flowing errors.

Finally, according to PP, in both exteroceptive and interoceptive channels only the lowest level cortices are involved in the incoming signal. The higher-level cortices are primarily concerned with generating predictions for the lower levels. This is especially interesting with regards to proprioception or interoception because it defies the received wisdom of motor control wherein higher motor cortices are involved in the generation of movement. In PP, higher-level motor cortices are instead generating proprioceptive predictions much like the exteroceptive cortices. Self-generated action occurs when the upward proprioceptive input is weighted low and downward proprioceptive predictions of movement are weighted high, which entrains movement from the body.

A functional mechanism required in PP is some kind of novelty filter. Recall that the processing in predictive coding involves skipping over the well-predicted sensory input. If a perception is predicted then the system does not bother to process it. Instead, error signals are only generated when the system encounters an unexpected stimulus. In order for this to work, there must be a mechanism that allows the brain to be especially sensitive to changes and difference.

Novelty filters function as a kind of anti-Hebbian learning mechanism. Contrary to the typical Hebbian truism, "neurons that fire together wire together", there must also be anti-Hebbian effects so that cells can learn to stop firing together or even inhibit one another. This allows for the system to ignore the expected stimulus and attend to novel or unexpected signals. "Anti-Hebbian feedforward learning, in which correlated activity across units leads to inhibition rather than activation (see Kohonen, 1989), enables the creation of so-called 'novelty-filters' that learn to become insensitive to the most [familiar] features of the input" (Clark, 2016, p. 29).

Following the work of Hosoya et al. (2005), Clark identifies amacrine cell synapses as neuronally plausible ways to implement novelty filters. Activity at these synapses can mediate plastic inhibitory connections that then alter the receptive fields of retinal ganglion cells. This will suppress the predicted components and "strip from the visual stream predictable and therefore less newsworthy signals" (Hosoya, Baccus, & Meister, 2005, p. 76). Interestingly, these experiments were performed on salamanders and rabbits, which is indicative that non-human animals utilize PEM systems as well, at least at the level of basic perception.

Clark (2016) also provides a candidate for the physical correlates of complexity reduction, synaptic pruning. This is the natural process by which our brain eliminates weak or redundant connections, which allows for better models as it improves the generalizability of what you know to a wide range of superficially distinct yet functionally similar instances. "Synaptic pruning provides an endogenous means of improving our grip upon the world. It enables us to improve the grip of our models and strategies by eliminating spurious information and associations, and thus avoiding – or at least repairing – the kind of 'overfitting' that occurs when a system uses valuable resources to track accidental or unimportant features… [it] is best seen as a mechanism for improving the models that we already, in a rough sense, command" (pp. 272-273). Synaptic pruning is hypothesized to occur during sleep.

A final mechanism I will mention is the gating mechanism of expected precision. According to PP, AC involves neural simulations that allow for virtual exploration. As described above, the same mechanisms that handle normal perceptual experience also perform simulated perceptual experience. In order for this to work, there must be some kind of gating mechanism that prevents the system from performing the predicted movements or being fooled by simulated perceptual experience. The gating mechanism is believed to involve the expected precision element of PP. Downward flowing predictions cause the brain to generate sensory information at the bottom cortices. These simulations are weighted in such a way that they do not entrain action.

> Within the PP framework, gating is principally achieved by the manipulation of the precision-weighting assigned to specific prediction errors. The primary effect of this is to systematically vary the relative influence of top-down versus bottom-up information by increasing the gain ('volume') on selected error units. (Clark, 2016, p. 148)

Clark provides two possible ways the brain may implement gating: neurotransmitters and oscillation frequencies. Slow neuromodulators like serotonin, dopamine, noredrenalin, and acetylcholine can control the amount of post-synaptic gain and, hence, the relationship between top down predictions and bottom up error signals (Friston, 2009). Another way to implement gating is through the frequency of oscillations. When activity in different neural regions becomes synchronized, it can have an influence on post-synaptic gain. "Gamma oscillations can control gain by affording synchronized neural discharges a greater influence on the firing rate of downstream neurons" (Feldman & Friston, 2010, p. 2).

To summarize, we are constantly creating and refining generative models of the world at different timescales. The seemingly overactive brain is actually engaged in the ongoing creation of these generative models at different scales. Generative models generate activity at the bottom sensory cortices that predicts immediately incoming perceptual experience. The self-generated activity uses much of the same neural equipment as activity caused by environmental stimuli. The system is able to tell the two apart and prevent self-generated motion through a gating mechanism that is implemented through slow neuromodulators and synchronization of the neural oscillations of different parts of the brain. The self-generated activity allows for the system to get ahead of the incoming sensory array. Predictive coding allows the system to save its processing power for the unpredicted sensory stimuli. Sensory signals that are well predicted by the top down models are passed over and ignored. This is made possible by novelty filters. Clark mentions amarcine cell synapses as a way to implement novelty filters in vision.

Furthermore, the framework provided in PP can encompass the hypothesized neural mechanisms in both PSS and Goldman's simulation theory. For example, convergence zones are, "hubs in which many feedback and feedforward loops converge allowing for the simultaneous activation of separate neural regions" (Clark, 2016, p. 148). PP takes a deflationary view of mirror neurons wherein neurons can become "multiply tuned, responding both to execution and passive observation" as a direct result of processes of associative learning (pp. 154-156).

Conclusion

My project is to identify a SA that can help REC scale up its explanations in order to explain AC. PP is a theory that utilizes neural simulation to explain basic cognition, but this theory may also scale up to representation-hungry cognition. Clark makes explicit overtures to REC when formulating PP, and this theory may provide direction for REC's future.

In this chapter I have provided a detailed overview of PP. This theory attempts to formulate a PEM system that utilizes hierarchical generative models. Following Hohwy, I describe the four elements of a PEM system that can achieve basic cognition and that also may be able to scale up to explain AC. I then discussed the neural implementation of PP. A number of neural mechanisms to achieve the elements of the system have been suggested.

PP provides an explanation for AC. According to the theory, downward flowing predictions initiate simulation-like neural activity at the sensory cortices during perceptual inference. This is typically used as a predictive process during movement and perception, but it can also be uses to create autonoetic experiences. Simulations can be experienced autonoetically depending upon the weighting that downward flowing signal receives. During AC, we are "predicting" a possible future state, which involves lowly weighted and downward flowing signals.

In the final chapter I evaluate PP, as well as perceptual symbol systems theory from the previous chapter. The explanations for AC that both theories provide will be evaluated according to their fit with REC. Unfortunately; both theories maintain cognitivist concepts that are problematic to REC. I will then turn to a REC theory formulated by Gallagher and Allen (2016) that follows PP.

Chapter 5: Solving the Scaling-up Problem

Introduction

The scaling-up problem has proven to be very difficult for radically embodied cognitive science to contend with thus far. In the previous chapters, I introduced two theories that utilize neural simulation in order to deal with CC: perceptual symbol systems theory (PSS) as proposed by Barsalou (1999) and predictive processing theory (PP) as proposed by Hohwy (2013) and especially Clark (2016). Barsalou approaches representation-hungry directly with his cognitive simulation theory, PSS. Clark's theory is a broader interpretation of the minded organism that focuses on explaining basic cognition but then can scale up to CC.

In this chapter I will assess PSS and PP according to their coherence with REC. Can a simulationist account (SA) help REC with the scaling up problem? I will start by quickly discussing the two theories side by side before turning to them individually. As we shall see, PP is compatible with most aspects of REC, and REC theories that make use of the (predictive) SA framework (in some way) have already been introduced. Finally, one such REC theory, Predictive Engagement (PE) will be briefly described.

PP and PSS

Clark describes self-generated perceptual activity as being a form of simulation. If this is correct then both PP and PSS involve the same broad neural architecture in that both utilize neural simulation activations for autonoetic cognition (AC). It is tempting to simply graft PSS and PP together as they seem to compliment one another. An easy interpretation might be that PP is true in basic cognition and PSS describes how those same processes are implemented for representation-hungry cognition. If we accept that the neural simulation in PP is a genuine kind of simulation then we need only to explain how this form of simulation can scale-up to the form of neural simulation in PSS. Is it the same mechanism in both instances or have the mechanisms for one form of simulation been repurposed and exapted for the other?

It may be premature to ask these questions, however. Before we can work out the possible continuity between PP and PSS, it is important to note the significant differences. The two SAs diverge in their understandings of the mind. While they may generally agree that neural simulations are involved in cognition, they disagree with respect to how to understand these neural simulations.

Barsalou is explicit in his intentions that PSS be more-or-less consistent with cognitivism. PSS understands the mind to be a hidden locus of agency that determines goals and directs cognitive activities. During AC, the mind in some sense orders or directs the brain to conceptualize various relevant objects and events through neural simulations. There is no discussion of basic cognition, and it is unclear how it could fit into this framework.

On the other hand, Clark's interpretation of PP comes from the embodied tradition of cognitive science. Minds are conceived of as situated within and extending to an environment that includes other organisms and even cultural artifacts. During AC, we are updating our higher-level generative models of the world by testing predictions virtually using self-generated neural activity at the sensory cortices in neural simulations. Similarly, basic cognition involves updating lower level models by testing predictions virtually using perception-and-action simulations. In other words, during basic cognition the system attempts to generate the incoming sensory signal ahead of the actual signal, which then allows it to focus on only the prediction errors. Similarly, during AC the system attempts to generate desired sensory signals except at a larger and more abstract scale. This allows us to create complex predictions about the future and explore those predictions virtually in AC.

Perhaps some insights from PSS could be appropriate when trying to understand this self-generated activity in PP. Such rapprochement between the two theories is beyond the scope of my project. However, it is clear that the bulk of theory revision would need to take place in PSS in order to fit the two views together. PP, as stated above, is a more radical departure from classical cognitivism. As we shall see, there are a number of problematic terms and understandings that limit the coherency between REC and PSS.

The REC Evaluation of PSS

In a previous chapter I provided a detailed overview of PSS. According to PSS, complex cognition involves activations of neural circuits in the perceptual, motoric, and introspective areas of the brain. These activations in some sense recreate or mimic or simulate the activations that occur from perceiving or interacting with objects in our environments. In other words, while thinking about absent objects our brains activate as if they perceive the objects, and while thinking about performing actions our brains activate as if they are performing the actions.

This suggests a way of understanding what is occurring in AC While imagining an absent event or object our brains are activating in ways that are similar to the way they would act if we were experiencing the imagined event or object. Both remembering and imagining are the same basic process of neural simulations in the modalities. Activations in the modalities can sometimes be accompanied by phenomenal experience. This doesn't explain why some are conscious while others are not, but it is consistent with neo-empiricist style theories.

Furthermore, spoken and written words are perceptual inputs that can be simulated absent of the stimulus. The first-person experience of "talking to yourself" may be an accurate interpretation of what is occurring as you think. Motoric areas of the brain are activating *as-if* you are speaking, and auditory areas of the brain are activating *as-if* you are hearing a voice. Language is able to control the simulations that occur, which explains our uniquely human capabilities.

Barsalou also provides some detail about how PSS can be implemented in the brain. However, this account is still heavily functionalist and seeks to cohere with the computationalist framework. PSS promises a more satisfying neural account in the future, but it may not help if it still holds questionable cognitivist assumptions. Research in neuroscience is ongoing, but it may all be for naught without the correct theoretical framework for understanding the empirical discoveries.

What are enactivists to make of PSS? It is certainly an embodied theory in the trivial sense that such a system could not exist as a program on a computer. More importantly, it replaces amodal symbolic representations that have questionable neural correlates with multimodal symbolic representations that occur as identifiable neural events. In the process it calls into question the modular mind thesis, which has conceptual problems on its own (Prinz J. , 2006).

However, PSS proponents like Barsalou indicate throughout that they intend for PSS to be compatible with the classical interpretation of the mind found in cognitivism. According to this view, the mind is like a filing cabinet that stores explicit knowledge for retrieval using algorithmic processes. This can be seen most clearly in Barsalou's discussion of simulators and frames.

A simulator for an event or object consists of the frame as well as the multitude of possible simulations that can be initiated. Frames are built over time when selective attention focuses on elements of perception and adds them to long-term memory as perceptual symbols. Later simulations are constructed from the previously stored perceptual symbols in order to perform cognitive operations. Concepts are identical with simulators as they are the frame for an event or object as well as the possible instantiations that can be simulated. Concepts in PSS are similar to a database of information in long-term memory (Prinz J. , 2002). The attention system methodologically adds new perceptual symbols to existing concepts. Hence, concepts are created over time and in some sense stored in the head even when not being put to use.

Furthermore, Barsalou attempts to infuse his neural representations with content-bearing properties, which would presumably allow them to be used in traditionally understood computations. He explicitly includes explanations for how PSS can implement truth-preserving operations such as implication and comparison. For example, neural representations can form propositions with truth-values. PSS attempts to be compatible with classical cognitivism, but classical cognitivism is incompatible with REC.

If Barsalou does intend for PSS to cleave very closely to classical cognitivism then his account has problems. Neural representations are different than amodal representations in a number of ways. If this is true of the representations in PSS then it is unclear how they might function correctly in traditional computational models. Unfortunately, this is an area where Barsalou provides no detail, although we might think that a connectionist account in terms of neural networks is possible.

Alternatively, Barsalou could adopt much more liberal definitions of representation and computation. Representation is an especially controversial topic that has already been discussed at length in a number of other places[1]. There seems to be as many different definitions for representation as there are theorists writing about them. I do not wish to adjudicate the disagreement here. However, I will point out that most criticisms of representation are directed toward the classical interpretation wherein they are involved in algorithmic computations.

A very liberal definition of representation could be as broad as any mediating state between perception and action that plays a causal role in the economy of the system. Barsalou's understanding of representation is obviously somewhere between these two extreme views, but it is difficult to pin down his exact position. On the one hand, he considers multimodal representations to be contentful states that can be used in mental computations. On the other hand, he seems to indicate that representations are just an abstraction when he claims that a multimodal representation has "no existence separate from the process, but is instead embedded in, distributed across, and is thus inseparable from real time processes. From this perspective, there is not a fixed and separate representation of anything" (Barsalou, Breazeal, & Smith, 2007, p. 80).

A liberal definition of computation is a mechanistically governed transition between representations in order to transform information. While this definition obviously applies to PSS, Barsalou goes further and attempts to retain properties in PSS that allow for the classical computations such as categorical inference and truth-values for propositions. However, he avoids giving any details about the computation that takes place in PSS.

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[1] See Chemero (2009) and Hutto & Myin (2013) for discussion on this topic from an enactive perspective.

If Barsalou uses classical cognitivist understandings of representation and computation then PSS necessarily involves a poor fit with REC. If Barsalou uses the liberal understandings of these concepts then PSS may have less of a problem. Despite his explicit attempts to retain properties of representations that allow them to be utilized in computations, it is obvious that he is aware of this tension. Perhaps he is only keeping his theory unspecified in these details in order to situate himself in the literature as it stands while leaving room for the more radical interpretations from others.

If we approach PSS with this generous spirit then some aspects of the theory are amenable to REC. By adopting liberal understandings of problematic terms the two theories are almost compatible. However, the overall conception of the mind that is implicit in PSS is still problematic for REC. The mind is still like a filing cabinet that somehow stores information in the head. In other words, the internalist computer metaphor is resilient!

In PSS, frames for objects and events are constantly being constructed and improved. Barsalou treats frames as packages of information that are stored together much like folders store sets of files on a computer. He seems to conceive of frames as whole knowledge structures that continue to exist in a relatively stable way even when not in use. If this is the correct interpretation of PSS then a REC-inspired revision of the theory should begin here.

A typical move in REC is to adopt the dynamical stance. The problematic notion of frames is an example where the dynamical stance might provide a non-trivial change in our understanding of the problem. Rather than conceiving of frames as stable knowledge structures that exist independent of their use, they could be conceived as attractors in a state space for multimodal neural activations. Our history of worldly interactions sets these attractors through associative mechanisms, and during neural activations the system will settle on them depending upon the context. If this interpretation is correct then frames are emergent features of the complex interactions of associated neural structures rather than stable and explicit stores of information kept within our heads.

Barsalou (1999) already provides a similar description for the generation of specific and detailed simulations from the generic frames.

> In any given subregion, the specialization having the highest association with the subregion, with other active regions, and with other active specializations becomes active. Because this process occurs for each subregion simultaneously, it is highly interactive. The simulation that emerges reflects the strongest attractor in the frame's state space. If context "clamps" certain aspects of the simulation initially, the constraint satisfaction process may diverge from the frame's strongest attractor toward a weaker one. If an event is being simulated, subregions and their specializations may change over time as the constraint satisfaction process evolves recurrently. (p. 591)

Dynamical descriptions of the neural activations take into account the fact that simulations develop over time. They help us to identify the features of simulation that are emergent rather than concrete components in the system. And they better describe the complex and massively interactive character of these activations. Perhaps if PSS went this direction it might be coherent with REC.

The REC Evaluation of PP

In the previous chapter I provided a detailed overview of PP. According to PP, AC involves self-generated neural states at the sensory cortices (i.e., simulations). These simulations are given a low weight by the precision weighting gating, which allows them to be in some sense experienced without being confused for actual sensory input.

> Take some animal that commands a rich and powerful generative model enabling it to predict the sensory signal across many temporal and spatial scales. Such an animal already seems well-placed to use that model 'offline' (See Grush, 2004) so

> as to engage in mental time travel imagining future unfoldings and selecting an action accordingly. (Clark, 2016, p. 159)

The experience of the inner monologue is also a kind of simulation in the sensory (i.e., auditory) cortices that is weighted in such a way to not be confused with actual voices. Spoken and written words are bits of perceptual stimulation that can be reactivated or simulated later. Furthermore, language allows PEM behavior to occur between different people.

> Among human subjects already possessing significant shared understanding, language thus provides a kind of cheap, readily available 'top-top' route for the control of action. Looping linguaform interactions can thus help create what Hasson et al. (Hasson, Ghazanfar, Galantucci, Barrod, & Keysers, 2012, p. 114) describe as systems of 'brain-to-brain coupling' in which 'the perceptual system of one brain [is] coupled to the motor system of another' in ways that enable the emergence of new forms of joint behavior. (Clark, 2016, p. 287)

PP may also give us insight into more elusive and difficult to describe elements of cognition, such as feelings of knowledge, intuition, or maybe gut-reactions. Generative models are always revised in such a way that favors less complexity. They attempt to provide the most likely and straightforward explanation or description of the world. "Bayes optimal agents seek both to maximize the accuracy of their predictions and minimize the complexity of the models they use to generate those predictions" (FitzGerald, Dolan, & Friston, 2014, p. 1). During this process, some information is lost in such a way that is difficult but not impossible to recover. Perhaps after the system reduces its internal complexity by strengthening some connections and weakening others, it leaves some kind of trace that the agent can later use to recall the information. More research needs to be done on this topic from the perspective of PP.

According to PP, AC should be understood within the larger PEM framework. The same PEM process that explains self-generated movement also explains aspects of AC. All cognitions, whether basic or complex, are performed in order to better predict the changing sensory array.

This account is more complete and attractive than the PSS account. As mentioned above, the framework provided in PP can encompass the hypothesized neural mechanisms in both PSS and Goldman's simulation theory.

What are enactivists to make of PP? It is, without doubt, a major departure from classical cognitivist orthodoxy. The classical understandings of representation, computation, and modularity have been reinvented and repurposed to do explanatory work in this more embodied framework. However, it is not without it's own problems as certain commitments and interpretations seem to conflict with enactive thought. In the following sections, I turn to some of these conflicts between REC and PP.

PP proponents place themselves in the embodied cognition camp. However, the two most visible champions of PP have different opinions about the relationship between REC and PP. Hohwy considers PP antithetical to enactivism because of the supposed inferential barrier between the agent (or, specifically, it's brain) and the environment. In his interpretation of PP, the brain is almost completely cut off from the world. Perception is a process that is heavily mediated by inference and expectation. As such, there is much room for radical skepticism about the external world. Predictive agents are vulnerable to illusions and pathologies such as schizophrenia and autism that interfere with successful prediction. "Though most of us get most things right most of the time, it does not seem to take much to disrupt the entire system in profound ways that make it veer off' (Hohwy, 2013, p. 169). We are frail creatures who are only indirectly connected to our world.

This is bad news for embodied cognition,

> The embodied and externalist aspects of [the embodied cognition camp] are much less attractive from the point of view of prediction error minimization… the starting point for the prediction error account… is one of indirectness: from inside

> the skull the brain has to infer the hidden causes of its sensory input, which crucially depends on interaction with the creatures' body…. The inferential process is essentially indirect. As such it is difficult to free it from [skeptical worries about how knowledge of the world is possible]. (p. 220)

Clark has a very different interpretation of PP. He finds it compatible with embodied cognition and ecological psychology. For Clark (2016), Hohwy's skeptical worry is misleading and somewhat irrelevant to the issue at hand. It is a 'red herring'. "[The] mere possibility [of being in the Matrix/of being a brain in a vat] in no way casts doubt upon the key claims associated with work in embodied cognitive science" (p. 193). In order for an evil scientist to manipulate our perceptions, she would need to control the brain in such a way as to recreate movement and self-generated action. Skeptical worries about the external world are an entirely separate issue.

Furthermore, Clark makes explicit overtures towards REC with the intention of finding common ground. Unlike Hohwy, Clark's (2016) vision of PP is thoroughly embodied and embedded in the world. For example, he recognizes the enactive problems with representation. While Clark uses representation in his theory, which will be discussed in the following section, he rejects the classical interpretation of representations, namely, that they provide a kind of passive 'mirroring' of a pregiven external world. He also respects the enactive intuition that organisms are fundamentally coupling with their worlds.

> [PP] plausibly represents the last step in this retreat from a passive, input-dominated view of the flow of neural processing. According to this emerging [view], naturally intelligent systems do not passively await sensory stimulation. Instead they are constantly active, trying to predict (and actively elicit) the streams of sensory stimulation before they arrive. (p. 52)

Where Clark's PP departs from REC is in REC's complete rejection of representations. "PP deals extensively in internal models – rich, frugal, and all points in-between – whose role is to control action by predicting complex plays of sensory data" (p. 291). However, Clark does not feel that this disagreement is a serious issue. Inner models and representations in PP "seek to *engage* the world rather than to depict it in some action-neutral fashion" (p. 291). For Clark this understanding of representations respects the enactivist intuition about internal states. An inner model in PP is "the result of self-organizing dynamics operating at multiple temporal scales, and functions selectively to expose the agent to the patterns of stimulation that it predicts. The generative model thus functions – just as an enactivist might insist – to enable and maintain structural couplings that serve our needs and keep us viable" (p. 293).

Clark intends for PP to be mostly compatible with enactivism whereas Hohwy believes that PP refutes the more radically embodied theories like enactivism. What do the enactivists think about PP? Enactivists have already begun attempting to bridge the gap between the two theories, and below I briefly discuss their progress. Before that, however, I will turn to the problematic terminology of PP.

In determining the acceptability of PP to REC, it is important to first notice that PP is a radical departure from classical cognitivism in almost every way. Representation and modularity are pillars of cognitivism that have either been removed or repurposed for use in PP. The function of representations is not to preserve truth through mental computations. As quoted above, PP representations are not action-neutral and are akin to the pushmi-pullyu representations championed by Millikan (1996). These representations are both descriptive and imperative at the same time. They tell you about the world by telling you what to do in the world.

Obviously, representations in PP need to be understood very liberally. They are internal cognitive states that play a causal role in the economy of the system. Unfortunately, it is difficult to say much more about representations in PP as the descriptions are multiple and confusing. Are generative models themselves representations or are the predictions or error signals the representations? Are representations ever conscious in this framework, do they remain subpersonal, or are representations a kind of statistical veil that governs our PEM? Clark (2016) recognizes the confusing nature of representation in his theory. The representation-involving activity is complex because it loops between predictions and precision estimates, internally and externally, and from higher to lower models. “Such looping complexities will make it hard (perhaps impossible) to adequately capture the contents or the cognitive roles of many key inner states and processes using the terms and vocabulary of ordinary speech” (p. 292).

The closest we get to a full description of representations is as follows,

> The probabilistic generative model is designed to engage the world in rolling uncertainty-modulated cycles of perception and action. The representations thus constructed are ‘not actual re-presentations or duplicates of objects in the world but… incomplete abstract code that makes predictions about the world and revises its predictions on the basis of interaction with the world’ (Lauwereyns, 2012 p 74). Within PP, high level states (of the generative model) target large-scale, increasingly invariant patterns in space and time. Such states help us to keep track of specific individuals, properties, and events despite large moment-by-moment variations in the stream of sensory stimulation. Unpacked via cascades of descending prediction, such higher-level states simultaneously inform both perception and action, locking them into continuous circular causal flows. Instead of simply describing ‘how the world is’, these models – even when considered at the ‘higher more abstract levels – are geared to engaging those aspects of the world that matter to us. They are delivering a grip on the *patterns that matter* for the *interactions that matter*. (p. 291)

Clark sees this understanding of representation as a way to ‘make peace’ with the enactivists. He even considers the possibility of PP without representation, but ultimately finds it impossible. I will once again quote Clark at length,

> For it is surely that very depiction [using representational terminology] that allows us to understand how it is that these looping dynamical regimes arise and enable such spectacular results. The regimes arise and succeed because the system

> self-organizes so as to capture patterns in the (partially self-created) input stream. These patterns specify bodily and worldly causes operating at varying scales of space and time. *Subtract this guiding vision and what remains is just a picture of complex looping dynamics spanning brain, body, and world. Such a vision is surely correct, as far as it goes. But it does not explain the emergence of a structured meaningful realm apt for perception, thought, imagination, and action.* (p. 293; my italics)

Modularity in PP is also substantially different. In PP, modules consist of transient assemblies of neural regions that are first functionally differentiated and then functionally integrated. They are soft-assembled, which is a far cry from the classical Fodorian modules of the last century. "Beliefs" were a staple in cognitivist theory. In PP a belief consists of "probabilistic densities… associated with intermediate levels of the hierarchical model" (Clark, 2016, p. 317).

Finally, the notion of inference is used heavily in both versions of PP. Following Hemholtz, both Clark and Hohwy conceive of perception as being an inferential process. There seems to be something undeniable between causes (i.e., sensory stimulations) and effects (i.e., percepts). Recall, this was the source of Hohwy's skeptical concerns. However, Clark does not see this as being a very intellectualist understanding of inference, despite the influence our expectations play on the contents of our perceptions. I will quote Clark (2016) at length one more time for his response to this concern.

> I think we should resist the claim that what we perceive is best understood as a kind of hypothesis, model, fantasy, or virtual reality. The temptation to think so, it seems to me, rests on two mistakes. The first mistake is to conceive of inference-based routes to adaptive response as introducing a kind of representational veil between the agent and the world. Instead, it is only the structured probabilistic know-how distilled from prediction-driven learning that enables us to *see through the veil of surface statistics* to the world of distal interacting causes itself. The second mistake is a failure to take sufficient account of the role of action, and of organism-specific action repertoires, in both selecting and constantly testing the ongoing stream of prediction itself. Rather than aiming to reveal some kind of action-neutral image of an objective realm, prediction-driven learning delivers a

> grip upon *affordances*: the possibilities for action and intervention that the environment makes available to a given agent. Taken together, these points suggest that the probabilistic inference engine in the brain does not constitute a *barrier* between agent and world. Rather, it provides a unique tool for encountering a world of significance, populated by human affordances. (pp. 170-171)

On such an account, PP does not seem fundamentally opposed to REC style theories. With respect to REC, PP certainly coheres better than PSS. Additionally, it has a more attractive explanation for AC. PP may be exactly what REC requires to solve the scaling-up problem. However, many enactivists still have concerns with the account. In the next section, I will turn to Gallagher and Allen (2016), who formulated a REC theory of predictive engagement that takes (predictive) SAs like PP into account.

Predictive Engagement

Predictive Engagement (PE) is a REC theory that makes use of the framework provided by predictive SAs like PP. Gallagher and Allen (2016) provides an explicit contrast between PP and PE. They claim that both Hohwy and Clark make the same mistake in understanding action and the role of the brain. For both versions of PP, the role of action is ultimately to test or sample the neural predictions. Enactivists find this problematic because it places the action and perceptual capabilities of the body in service to what gets understood as the truly interesting and important part of the system, the brain. "For PP, active inference is part of a process that produces sensory experiences that confirm or *test* my expectations (p. 7; italics in original)

PE is an enactive alternative to PP. It is derived from the Free Energy Principle, according to which we should understand the drive toward successful prediction as an attempt "to minimize an information-theoretic isomorph of thermodynamic free energy in a system's exchanges with the environment…" (Clark, 2016, p. 305). In doing so a biological system is able to avoid death because it "[avoids] unexpected states [and] maintains [its] dynamical integrity (minimizes surprise)" (Gallagher & Allen, 2016, p. 8). As such, the system is performing analogously to autopoietic cellular processes as discussed in Varela et. al. (1974). From this perspective, we should understand the minimization of surprise as involving more than just the brain, but also including the body and world. "The brain is not located at the center, conducting tests along the radiuses; it's on the circumference, one station amongst other stations involved in the loop that also navigates through the body and environment and forms a whole" (Gallagher & Allen, 2016, p. 8).

In PE, the predictive model is autopoietic and embodied due to the capacity for active inference. That is, generative models are concerned first and foremost with survival and operate "by accurately predicting worldly states (which entails their contextualization by an organism's possibilities for action), or by acting in the world such as to render it unsurprising (which entails the sensitivity of action to the states of the organism)" (p. 9). In other words, generative models are concerned with maintaining viability in the organism and do so through world-engaging action. Rather than internal models that reflect the world in some way, they are attempts by the brain to discover patterns of neural activation most appropriate for dealing with the ongoing sensory array. The brain is not creating internal models of the world and using motoric actions to test them. Instead both the brain and body are constantly engaged in seeking perceptual states that minimize surprise. Negative homeostatic interoceptions (e.g., hunger, thirst, etc.) are surprising in this sense and the system is concerned primarily with exploring the environment in such a way that minimizes that surprise.

> In this scheme, sensory-motor coupling is always a slave to the internal, embodied (homeostatic) dynamics, which the system must maintain to survive. Any action or perception is constrained by this need to maintain autopoietic integrity.

> Heuristically, this can be thought of as the system always seeking to maximize evidence for the hypothesis that it is alive. (p. 9)

Taken together, this is substantially different than what is presented in PP wherein action is in service of testing perceptual hypotheses and affectation is a background condition. For PE, perception, action, and affectation engage in a kind of circular causality where each reciprocally determines the others. This dovetails nicely with the affective prediction hypothesis forwarded by Barrett & Bar (2009) mentioned above. According to this view, the body undergoes muscular and hormonal changes during the earliest stages of visual processing. This suggests that, "conscious percepts are indeed intrinsically infused with affective value, so that the affective salience or significance of an object is not computed after the fact" (p. 1328).

> This suggests that priors, which include affect, are not just in the brain, but involve whole body dispositions and adjustments – 'anatomically informed priors' (Freund et al. 2016; also see Seth 2013; and Seth et al. 2012). In perception bodily affective changes are integrated with sensory-motor processing so that before we fully recognize an object or other person for what it or he or she is, our bodies are already configured into overall peripheral and autonomic patterns shaped by prior associations. (Gallagher & Allen, 2016, p. 10)

PE offers an embodied and engaged account of the processes described in PP. It is unclear how PE deals with AC, however. Recall that previous REC theorists are already positing simulation-style understandings of AC. They are worth quoting again,

> [We] could say that to visualize X is to mentally re-present X by subjectively simulating or emulating a neutralized perceptual experience of X. (Thompson, 2007, p. 292).
> The simulation idea gains support from its fit with the general finding that the brain often re-uses neural apparatus' to do various distinct kinds of cognitive work. (Hutto, 2015, p. 72)

This description of simulation is closer to PSS than it is to PP. The mind picks a target and simulates the various features of it in sensory and motoric modalities. There is no overarching understanding of how the process fits into the larger framework of the whole organism/environment system, and there is no attempt to describe how these simulations may take place.

PE offers a different way of understanding AC in the context of the whole organism. However, it is not clear that the PE account offers anything in the way of detail regarding how AC is achieved. That is, the understanding of AC in PP is that high-level generative models are sending downward signals that activate the sensory cortices in self-generated sensory experiences that are such that they are not confused with bottom up signals from actual perception. The high level model will send a signal that predicts something relevant in the world, and the lower level models execute the signal by producing the activation at the sensory cortices. During AC, the sensory activations initiated from high-level models create a kind of virtual experience wherein we can predict various counterfactual situations.

PE can argue that we should understand the signals as the dual processing of perception and active inference, and we should understand the models as being a pattern of neural activation that best engages the system in its project of survival. Furthermore, they can say that AC is a surprise minimizing capacity that biological systems with bodies like ours may possess. This description (while probably correct) does not provide a way to isolate specific cognitive phenomenon for explanation nor does it offer a manner to even approach an account of how it is implemented by brain.

The benefit of taking a representational approach like PP is that it breaks the process into parts and provides easier targets for empirical work. The PE description erases the distinctions between representation-hungry cognition and any other activity. Everything the organism does can be understood as the system seeking a pattern of neural activation that accommodates the sensory array. Furthermore, a neuroscientist or psychologist can use PP as a framework by which to understand observations and direct further study. For example, generative models are described as existing in a hierarchy of sorts in terms of scope with higher-level models dealing with long time spans and large spaces (and probably "big" ideas). Presumably this tracks something about the neural dynamics that reflects this hierarchy. Perhaps the hierarchy reflects entirely different neural areas. Alternatively, the hierarchy may be truly nested in which case the levels are similar to settings or gears that use the same neural resources in different ways depending upon the level of the model. The concept of signals communicating between levels is also useful. Without this concept it is very difficult to track interactions between different parts of the brain.

PE is a relatively new theory, and, as such, a number of details have yet to be worked out. Currently, PP has more to offer regarding detailed explanations of AC than PE. However, PE provides a much better description of the organism as it engages with its world. More work will be required before AC can be satisfyingly dealt with by REC, but REC theories using the (predictive) SA framework may be a step in the right direction.

The Future of REC

The goal of my project was to solve the scaling up problem for REC. I examined SAs that I suspected could satisfy REC intuitions in doing so. PP seems to be an ideal candidate, but the represenational approach that it entails runs directly counter to a core commitment of REC. PE is a REC theory that attempts to radicalize PP. However, the description of the organism in PE is too holistic to deal with specific cognitive processes in much detail. It appears that PE will need to either restrict itself to holistic descriptions of representation-hungry cognition and basic cognition or it will need to adopt some componential elements. I will briefly discuss both options.

Explanatory pluralism is the idea that there need not be a "framework debate" in the cognitive science. There is no single framework that can accommodate all cognitive processes. Instead we ought see how different theories at different levels of explanation can work together in the context of investigation. Even theories that are at the same level and that don't neatly cohere with each other may be able to provide useful insight to one another.

> This is not to say that there cannot be a genuine competition between different theories in similar levels or situations. It does suggest the possibility of theoretical integration that cuts across contexts rather than an endless wrestling match. Theoretical assumptions and "commitments" thus need not function as fundamental pillars to be upheld inviolately, but rather serve to define explanatory boundary conditions. (Dale, Dietrich, & Chemero, 2009, p. 2)

If REC takes this route then there is no competition between PP and PE. The two theories are just at different levels of description. However, if this is the case then the best solution for AC available for REC is simply PP. Clark is working from an understanding of the organism/environment system that he explicitly states is radically embodied. PP is just what PE looks like at the level of explanation that includes representational-hungry cognition. By this interpretation, PE is simply talking about something different than PP.

Synthesis between the two theories may be another possible solution. Perhaps PE could adopt important elements of PP in order to deal with specific cognitive processes. Once again, however, it is unclear how this could add anything to the explanation of AC in PP. By adopting the representational approach, PE just collapses into PP.

Innovation is a possible final solution. If it were possible to develop an empirical program for cognitive phenomenon that avoids representationalism then it may allow PE to offer entirely different accounts of AC that are in many ways superior to the accounts in PP. Unfortunately, innovation is not something that can be simply generated or even entirely directed towards a specific goal. However, if REC could develop a methodology that is externalist and not representationalist then perhaps representation-hungry cognition could be better described.

One way of developing this program would be to identify experimental paradigms and topics from different fields in biology and cognitive science that are shown to be reliable and that provide meaningful insight into these aspects of cognition. These methods can serve as reliable empirical "markers", and we can use them to formulate a kind of interdisciplinary "profile" for representation-hungry cognitions (or at least the behaviors associated with it). For example, behavioral psychology has an expectation violation or "surprise" paradigm wherein gaze allocation is observed during surprising events. This is considered to have a number of methodological advantages (See Reisenzein, Wulf-Uwe, & Schutzwohl, 1996). Endococrinology provides reliable empirical marker, as there are concrete observations about the hormonal changes that take place with certain behaviors. Also, in behavioral neuroscience we can make fairly confident claims about how the brain relates to some behavior. Perhaps by identifying these empirical markers we can somehow describe AC in a satisfying way.

The last solution is the most exciting, but it may be less attractive upon consideration. This approach could rightly be described as interdisciplinary behaviorism (albeit one that includes phenomenology, considerations of the situatedness of organisms, and a neural account). Perhaps a dynamical methodology could be applied to this form of behaviorism, and the behavior of the organism could be described in differential equations instead. A similar approach has been attempted in research on affordances, but, while it has had success in explaining basic cognition, it has little to say about representational-hungry cognition. As in behaviorism, the inner life of the organism is ignored and instead the external movements of the organism are tracked and described mathmatically.

Accusations of behaviorism aside, a dynamical approach may be able to provide a way to synthesize the empirical evidence from the different experimental paradigm markers. Perhaps with the right kinds of descriptive equations from these different paradigms it is possible to discover relationships between observations. This may lead to useful components defined by their regularly observable physical interactions rather than their proposed functions. While such a methodology is desirable, it is beyond the scope of my project .

After consideration, it is my opinion that REC may need to simply concede that it cannot deal with AC. Perhaps the criticisms from PE will improve PP from a holistic perspective, while the aspects of PP that are important for explaining AC are preserved. The ideal solution is that REC develops a methodology that avoids functionalism altogether while still allowing for specific processes to be identified and, in important ways, isolated. A dynamical approach that synthesizes concepts between different disciplines may be able to solve the problem directly, but, at least for now, it seems that REC is without a solution to the scaling-up problem.

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