Scientific progression -

# COGNITIVE SCIENCE IN THE CONTEXT OF KUHN'S MODEL OF PARADIGMS


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## *Introduction*

Since the dawn of scientific inquiry itself, the philosophy of science and the nature of its progressions have been pondered. Scientific fact and theory are not categorically separable, and it is critical for any scientific field to recognise and acknowledge its current position and progression, in order to predict the direction of the field.

On the premise that this paper is written to discuss scientific philosophy, I find it necessary to briefly define the broad spectrum of science itself. Science can be defined as comprising the intellectual and practical systematic study of phenomena that occur within the physical and natural world. Science encompasses a series of techniques and standards for investigating phenomena through formulating, testing and modelling hypotheses (The Editors of Encyclopedia Britannica, 2017). Despite the aim of objectivity, science has a culture and philosophical approaches that one must always take into account when observing the practices of scientists in their field.

There are multiple perspectives in the philosophy of science regarding what constitutes and triggers change and development. Much of this has been discussed under the demarcation problem, the philosophical question of when fields classify as science, and when they do not (Hansson, 2017). Approaches include logical positivism and falsificationism. Logical positivism emphasises science as a paradigm of knowledge, grounding itself in empirical testing (Bechtel, 1988). Opposing the hypothetico-deductive method is Karl Popper, who introduced falsificationism. Popper claims it is never possible to prove a general statement as true, and can only truly claim was can be falsified (Bechtel, 1988). Popper received much criticism for his demarcation criteria, often deemed too harsh and hindering towards anomalies. Allchin (1999) views anomalies as an indication of "an incomplete recipe" (p. 303), rather than the inability to achieve positive results or findings of value.

Thomas Kuhn voices an alternative approach to scientific progress, believing the historical and social contexts of sciences catalyse radical change, also known as paradigm shifts. The phases and progressions that Kuhn describes have been generalised to be known as the Kuhnian Cycle, which includes pre-science, normal science, and revolutionary science (Kuhn, 1970).

Cognitive science is a relatively new field of study that investigates into the workings of the mind, unified by the computational perspective (Friedenberg & Silverman, 2006). Like all sciences, cognitive science operates according to the scientific method and under certain paradigms which establish the premises for theoretical speculation and empirical investigation. Despite a unified perspective, cognitive science struggles particularly hard to demarcate its position due to its dynamic nature, an implication of its interdisciplinary approach to studying the mind. Cognitive science confronts issues that cannot be solved within the paradigm. As it is such a dynamic discipline, it must remain vigilant to not exclude potentially vital knowledge that appear as anomalies. Throughout this essay I will investigate and argue for the position of cognitive science from the perspective of Kuhn's theory. I contend that cognitive science is currently experiencing a *drift,* the beginnings of the scientific revolution phase in Kuhn's cycle.

### *Outline*

In this essay I will elaborate on Kuhn's model of paradigms, and outline the cycle of paradigm change. After describing cognitive science, I will present arguments for why I believe cognitive science to be in the drift stage of revolutionary science. Firstly, I will argue that cognitive science is not in the pre-scientific stage. I will then review the paradigm that cognitive science has formed a normal science from, computationalism. Lastly, I will review the evidence for a paradigmatic drift, overviewing competing paradigms and the influences of sub-disciplines. Throughout the essay, I will elaborate on definitions that are of importance to this discussion, to allow for a better formulation and understanding of the arguments presented.

## *Kuhn's Model of Paradigms*

It is important to understand the perspective from which we are pondering cognitive science's progression, Kuhn's model of paradigm change. In his highly influential challenge to the prominent culture that regarded development in science as a steady progression of new ideas and knowledge, *The Structure of Scientific Revolutions* (Kuhn, 1970) argues for a much less linear advancement. Taking social and historical context to the forefront of scientific progression, Kuhn (1970) instead outlines the advancement of science through intermediate revolutionary bursts, triggered by a new and powerful movement of thought. Competition between segments of the scientific community often results in the rejection of one previously accepted theory. These new, dominant frameworks of thought are known as Kuhnian paradigms, and the process of changing over is a paradigm shift or change (Kuhn, 1970). It should be made explicit that in this essay that unless otherwise stated, the term paradigm will mean Kuhnian paradigm.

Kuhn's model further highlights the truly difficult nature of successes in science. Whilst the culture of science would believe additional research to correlate in a linear progression with additional knowledge, it actually makes this type of progress harder. Increases in research and discoveries makes it more difficult for paradigms in science to incorporate them, resulting in an ironic paradox.

### *Paradigm*

An important acknowledgement in scientific philosophy is that observations rarely exist in a vacuum, they are observed within a context and for a community. Kuhn (1970) himself coined the term paradigms as " universally recognised scientific achievements that for a time provide model problems and solutions to a community of practitioners," (p. viii). A paradigm establishes the parameters from which a community of scientists select; the questions they address, what phenomena they observe and investigate, and the standards from which they interpret their findings (Kuhn, 1970). Despite the limitations of paradigms themselves, when they are successful it provides progression once never thought possible. A classic example of a paradigm shift described by Kuhn is within the field of physics, when classical Newtonian physics was replaced by quantum physics due to the discovery of wave-particle duality, revolutionising this science (Kuhn, 1970). Contra to experimental paradigms, a Kuhnian paradigm is rarely replicated, but rather "an object for further articulation and specification under new or more stringent conditions" (p. 19).

## *The Kuhnian Cycle*

### *The Phases*

*Pre-science* is when the actions of scientific inquiry are carried out without the presence of an overarching paradigm, and is instead characterised by casual fact gathering of a non-critical nature. However, there is normally an externally supplied paradigm (Kuhn, 1970). The actual acquisition of a paradigm moves pre-science into the normal science stage.

*Normal science (paradigmatic science)* is described by Kuhn (1970) as the activity in which scientists practice within their field on the assumption that their worldview accurately explains the phenomena they investigate. It is the actualisation of the theories and knowledge of that worldview into the articulation of the paradigm itself. In normal science there is generally a unified consensus over the paradigm, and it will historically be defended against anomalies by its proponents. Normal science is often characterised by textbooks, journals on the discipline and a place in the curriculum (Kuhn, 1970).

*The model drift stage* was not specifically termed in Kuhn's writings, but it has since previously been added to some interpretations for clarity and accommodation of the indistinguishable, intermediate phase between a normal science and scientific crisis (Thwink.org, n.d). It has been speculated that many sciences actually spend more time than the community presumes in this drift stage, as there is the tendency to suppress fundamental novelties (Thwink.org, n.d). This could be due to that a crisis in a science is traumatic to that scientific community, as it invalidates much of the work and progress established. I find the inclusion of this phase compelling, and will incorporate it in the discussion of this essay.

*Revolutionary science* is marked by the phases of drift, crisis and paradigm change. Revolutionary science occurs when the shared paradigm breaks down to competing paradigms, eventually giving way to a new framework for inquiry. Paradigms shifts are characterised by achievements that share the two characteristics of changing normal science through being unprecedented enough to attract supporters and open ended enough to problems to resolve.

## *The Cycle*

The Kuhnian cycle (see Appendix 1) can be concisely described in the analogy of a vase. One can visualise the paradigm as a vase, which stands as a structure in which the observations for the normal science are held. However, there can be phenomena that do not 'fit' into the vase. Whilst the occasional discrepancy to the paradigm is generally accepted, if a certain threshold of such issues is reach, the paradigm begins to move into a drift phase. If too many anomalies continue to fall outside the vase, the current vase must be shattered (Radke, 2009). The process of revolution is eloquently described by Kuhn (1970) as "…the extraordinary investigations that lead the profession at last to a new set of commitments, a new basis for the practice of science" (p. 6). This shattering of the vase is the mark of reaching the crisis phase of the cycle, and continuing to the model change phase. The vase is then replaced by a bigger vase, and the process continues again (Radke, 2009).

The bigger vase can assist in visualising how the next paradigm is generally more broad and encompassing. Kuhn (1970) notes that new paradigms often incorporate aspects of the old one. For example, aspects of behaviourism are still incorporated in much psychological and cognitive science, despite it no longer being the dominating paradigm in the field. Paradigm shifts are rarely incremental, they are generally a reconstruction of prior theories and re-evaluations of previous fact. As Kuhn (1970) himself notes, "Out-of-date theories are not in principle unscientific because they have been discarded" (pp. 2-3).

## *Cognitive Science*

Cognitive science can broadly be described as the "scientific interdisciplinary study of the mind" (Friedenberg & Silverman, 2006, p. 2). The first major institutions of cognitive science emerged in the 1970's, propelled by the likes of Miller, Newel, Simon and Chomsky, to form this multidisciplinary endeavour (Bechtel, Abrahamsen & Graham, 1998). Cognitive science incorporates an array of fields, typically; philosophy, psychology, linguistics, artificial intelligence, robotics, and neuroscience, all aiming to understand the mind (Friedenberg & Silverman, 2006). The interdisciplinary nature of cognitive science is its hallmark as well as its advantage in attempting to investigate a phenomenon as vast and complex as the mind. It is important to recognise that cognitive science is the collaboration of the convergence and intersection of these various disciplines in addressing the mind. Bechtel, Abrahamsen and Graham (1998) acknowledge that whilst cognitive science is by no means unique in its endeavour to understand the mind, it is distinctive in its perspective that cognitive processes are computations, thus using the theoretical framework of computationalism to investigate the mind.

## *Computationalism*

The classical computational theory of mind emerged in the 1960's in wake of Turing's proposal of computation, which has been integral to cognitive science. Computationalism likens the functioning of the mind to that of an information processor (originally a Turing machine) and views core mental processes, such as attention, perception and memory as computation (Rescorla, 2017). Therefore, the mind can be abstracted to be a metaphor for software, and the brain as a computer. This paradigm revolutionised psychological science from its previously behaviouristic paradigm, and catalysed the development of cognitive science (Miller, 2003). Computationalism is exemplified by Friedenberg and Silverman (2006), "Cognitive scientists view the mind as an information processor. That is, a mind, according to this perspective, must incorporate some form of mental representation and processes that act on and manipulate that information" (p. 3).

The computational perspective in cognitive science has allowed for more direct comparisons of natural versus artificial intelligence, yielding a more formal and empirical methodology for analysis (Bechtel, Abrahamsen & Graham, 1998). From computationalism there have been attempts to explain the computational functions and limitations in human minds, how computational algorithms are instantiated in the brain, and develop computational models.

## *Arguments*

In the following section I will provide arguments with the intention of revealing how cognitive science is experiencing a drift.

### ***Cognitive Science is not Pre-science***

It is understandable that some will view cognitive science as a pre-science, when Kuhn (1970) casts doubts that "…it remains an open question what parts of social science have yet acquired such paradigm at all" (p. 15). However, I will argue that cognitive science is a science, both in the sense of the definition of science, and from the Kuhnian perspective. Whilst cognitive science does include non-scientific disciplines, "Its primary methodology is the scientific method, although as we will see, many other methodologies also contribute" (Friedenberg & Silverman, 2006, p. 2).

Kuhn himself states that a pre-science is characterised by scientists within a field "confronting the same range of phenomena, but not usually all the same particular phenomena, describe and interpret them in different ways". (Kuhn, 1970, p. 17). In the context of the Kuhnian cycle, cognitive science has a clear scientific paradigm of computationalism, and thus cannot classify as pre-science. Evidence for computationalism as a paradigm is clear in computational models incorporated in cognitive science. Treisman's (1964) attenuation model of auditory attention incorporates computational theories, describing the model as "defined in the language of channels, information, filtering processes and storage" (pp. 15), aligning with a computational approach.

Cognitive science also indicates its attainment of the normal science phase through obtaining the characteristic elements Kuhn ascribes to this phase. Cognitive science has an established society, which connects "together researchers from around the world who hold a common goal: understanding the nature of the human mind" (The Society, n.d, para. 1). Furthermore, there is an array of textbooks available, such as Friedenberg & Silverman's *Cognitive Science - An Introduction to the Study of Mind* (2006). Computationalist ideas have clearly been the framework from which cognitive science has functioned. I argue computationalism meets the definition that Kuhn sets for a paradigm; it created a shift in the problems available and the standards by which practices are accepted.

## *The Drift Phase*

So, it leaves to question whether cognitive science is currently in a normal science or a revolutionary science phase. Here I will discuss some evidence and issues which I believe to be indications that cognitive science is experiencing a drift. Whilst I argue for a drift, it is important to remain critical over the model Kuhn provides, which may not be the optimal model for addressing progressions of cognitive science. As cognitive science contains multiple disciplines with their own progressions, I do not necessarily believe it to be the best model to account for its scientific developments. Cognitive science is in constant flux, and it is my personal belief that it will always classify as being in a drift stage, due to the progressions and updates in all the sub-disciplines. However, in the context of Kuhn's model, I still hold by my contention that it is in a drift, and will investigate into evidence indicating this.

## *Evidence of a Drift*

### *The Replicability Crisis*

The replicability crisis was brought about by the findings of the Open Science Collaboration in their paper *Estimating the reproducibility of psychological science* (2015). Focusing on psychological science, this report found that of 100 reports, only 36% were found to be significant when replicated, and the effect sizes were approximately halved. This was attributed to selective reporting, biased analysis and insufficient specification of the conditions necessary to obtain results (Open Science Collaboration, 2015). As replicability is a foundational characteristic of science, this report 'rocked the boat' in the psychological world, and put to question the standards and framework from which it is practiced by its scientists. Whilst it is important to allow for innovation to achieve optimal progress, it exposes the culture of publication bias in science (Open Science Collaboration, 2015).

Since paradigms set the foundations and standards from which scientists practice in a field, the replication crisis is a clear sign we have a paradigm that struggles to account for all of our findings, and puts the methodology to question. Whether this is a crisis in the paradigm of our statistical methods, standards, or a theoretical downfall, is for further questioning. Some may doubt the relevance of this replication crisis for cognitive science, as psychology is merely a sub-discipline. A sub-discipline it may be, yet psychology is a cornerstone discipline of cognitive science. Therefore, it would be ignorant to deny the consequences this crisis has for cognitive science.

## *Competing Paradigms*

According to Kuhn's theory, there can only be one dominant overarching paradigm in a normal science at a time. Currently, cognitive science is experiencing a phase in which there are multiple paradigms. This is evident in the progression from computationalism to connectionism, and embodiment's increased influence. In accordance to Kuhn's theory, this is a clear indication that cognitive science is currently in a drift. Here I will review two of the main competing paradigms.

The two paradigms I will discuss stem from some core drawbacks in computationalism. The symbol grounding problem summates these issues, and is iconised through Searle's (1990) classical critique of computationalism, the Chinese Room Argument. In this thought experiment, Searle describes a situation in which a monolingual English speaking man is situated in a room, and given a batch of script and matching rules. This man is passed slips of Chinese script, in which he then consolidates his set of rules, and returns the corresponding answer. Thus he communicates effectively in Chinese, despite not actually understanding the semantics of the language (Searle, 1990). Opposing Turing's theory of the Turing Test, Searle shows formal symbol processing cannot be made intrinsic to the computer system. Without a mind to 'ground' the symbol in consciousness and meaning, the symbol has no meaning to them and their referents (Searle, 1990). This is a challenge to the way computationalism views cognition and reveals the conflict in computationalism between semantics and multiple realisation. Possible theories attempt to address the symbol grounding problem. One is connectionist, which is to make a system that is functionally identical to cognitive systems. The other is an embodied, to create a system functionally and structurally identical to cognitive systems.

### *Connectionism*

A paradigm which both challenges and complements the computational theory of mind is connectionism. Emerging in the 1980's, connectionism began to gain attention in cognitive science and has been viewed as a "prominent rival to classical computationalism", and a conflict which cognitive science must address (Rescorla, 2017, para. 4; Friedenberg & Silverman, 2006). Yet, others view connectionism as a progression of computationalism, emphasising complementary alignment. Connectionism is a theory of cognition that models it as the interaction of simple neuron like structures, interconnected to each other through neural networks, which are of great difference to Turing models (Schneider, 1987). Connectionism assumes processing occurs in populations of simple units, in which knowledge is stored in connectionist weights between them (Schneider, 1987). Connectionism has been important in addressing two drawbacks of computationalism; it increases efficiency by incorporating parallel processing, and its distributed operations make it comparatively robust (Froese, 2007). A way in which this theory of neural networks has been adapted into models in cognitive science is exemplified in the Adaptive Control of Thought Theory (Anderson, 2015). In this model, memory is theories to be a result of activations in a neural network of associations with input weights, association strengths and baseline activations, all characterised in the connectionist paradigm (Anderson, 2015) (See Appendix 2).

There are several fundamental differences between connectionism and classical computationalism, including the way in which they represent knowledge and processing style (Friedenberg & Silverman, 2006). Furthermore, computationalism is implementation independent, whereas connectionism isn't. Whilst they differ in approaches, connectionism can also be viewed as a development complementary to classical computationalism. Some argue both connectionism and computationalism are paradigms of symbol-manipulation systems, and both have grounding in the work of McCulloh and Pitts (Rescorla, 2017). Furthermore, a neural network can be implemented in a classical model, and a classical model into a neural network (Rescorla, 2017). Some may argue that connectionism has replaced computationalism as the new and accepted paradigm. This is difficult to discern, as Kuhn (1970) acknowledges that paradigms do develop in face of new evidence and anomalies. Since both computationalism and connectionism are grounded in the assumption that the mind is computable, I conclude they are not incommensurable. Thus, connectionism is not a paradigm which has pushed cognitive science to a revolutionary crisis and paradigm change, but it has provided some challenges that indicate a drift.

### *Embodiment*

A paradigm that outright challenges computationalism is the paradigm of embodied cognition. Embodied cognition "means that it arises from bodily interactions with the world and is continually meshed with them… therefore, cognition depends on the kinds of experiences that come from having a body with particular perceptual and motor capabilities that are inseparably linked" (Thelen, 2000, p. 5). This approach emphasises the role of the body of an agent in the workings of their brain, contrary to the otherwise dominant view that the body is a mere periphery in understanding cognition (Wilson & Foglia, 2017).

Examples of embodied cognition have been extensively researched, some include;

- *Mirror neurons* have been a significant finding supporting the embodiment paradigm. Discovered in the motor cortex of monkies, these neurons are activated when the monkey perform an action, but also when they see someone else perform that same action. This connection between the percpetual and motor modalities reveals how we can relate ourselves to the actions of others (Anderson, 2015).

- *Gesturing* when communicating has been found to facilitate not just the actual communicating, but also the processing of the language (McNeil, 1992). This is in line with the findings of Glenberg and Gallese (2012), who contends that understanding of language can be facilitated by covertly acting the descriptions of verbs.
- Barsalou's (1999) *percpetual symbol hypothesis* describes abstract concepts to be grounded in a combination of physical and introspective events. Developments of such hypotheses indicate the growing emphasis on embodiment.

Embodiment maintains the connectionist focus on the self-organising dynamic system, yet it also adds that cognition is a situated activity which covers a totality consisting of an agent's brain, body and environment (Froese, 2007). Embodiment challenges the computational and representational theories of mind, in turn challenging the very core of the current paradigm cognitive science is built upon. Yet, instead of rejecting embodiment, cognitive science has already begun to be adopt it into its discipline, despite the challenges it poses, noting it "is a serious alternative to the investigation of cognitive phenomena" (Wilson & Foglia, 2017, para. 1). A body of researchers within cognitive science approach this field with an embodied approach, critiquing and replacing the traditional approached (Wilson & Foglia, 2017). This is a clear indication of a paradigm shift and drift phase, as computationalism clearly cannot accommodate for theoretical difference in this approach.

### *The Influence of Disciplines on the Paradigm*

As previously noted, cognitive science is characterised by its interdisciplinary nature. The two-way flow of collaboration naturally results in that changes of direction in sub-disciplines also impact the focus of cognitive science. These 'trends' influence what questions are asked, and thus have implications for the paradigm at the time. Some include;

Artificial intelligence (AI) has had a clear influence on the shift of focus to embodiment, Froese (2007) contends that experimental results generated in AI research catalyses the "ongoing shift from orthodox to embodied-embedded cognitive science" (p. 2). The adoption of the embodied approach, and the even more extreme shift towards enactivism, has inspired

AI to develop increasingly organismically inspired robots. This push has spilled over to the cognitive sciences and the ideas of cognition as computation is being challenged by the paradigm of embodiment (Froese, 2007; Wilson & Foglia, 2017).

Additionally, we are also moving towards a more theoretical neuroscientific perspective, which, whilst coherent with computational-representational paradigm, requires expansions and revisions of old ideas (Thagard, 2011). This is due to the new views of the nature of representation and computation it presents. Furthermore, Bayesian statistics and modelling continues to gain prominence and explore modalities such as vision and language. Social dimensions have gained prominence in psychology and therefore cognitive science, further propelled by the inclusion of anthropology as a sub-discipline. The implications of social interactions have gained more attention, and bring about new questions which could potentially challenge the paradigm (Thagard, 2011).

***What are we progressing towards?***

***- A Conclusion***

From the arguments presented, it is apparent that cognitive science is experiencing a drift towards revolution in the Kuhnian cycle. Despite the clear evidence that cognitive science is experiencing a drift, it is very difficult to discern the direction in which cognitive science is going. Will we hit a crisis? Or will we expand our paradigm to incorporate competing theories and stabilise? Only time can tell. Kuhn (1970) acknowledges that instability does not always result in a crisis, so a crisis is not necessarily inevitable. It is my intuition that embodiment will continue to gain credence in the cognitive science community, but we are a long way from shaking off our computational roots. Perhaps a collaboration between the two is possible, as shown in the field of AI. For now, however, we must accept our lack of foresight, and remain aware that cognitive science is currently and perhaps indefinitely in the drift phase of the Kuhnian cycle.

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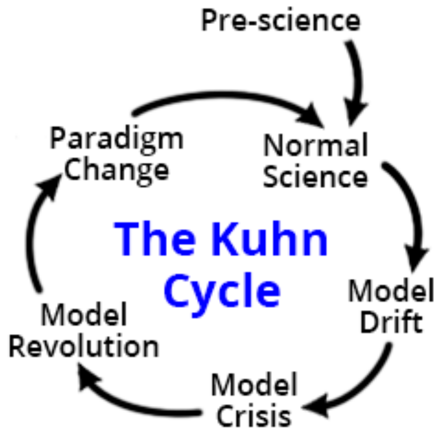
## Appendix 1

Kuhnian Paradigm Cycle – visual example



## Appendix 2

Anderson's Adaptive Control of Thought Theory – visual example.

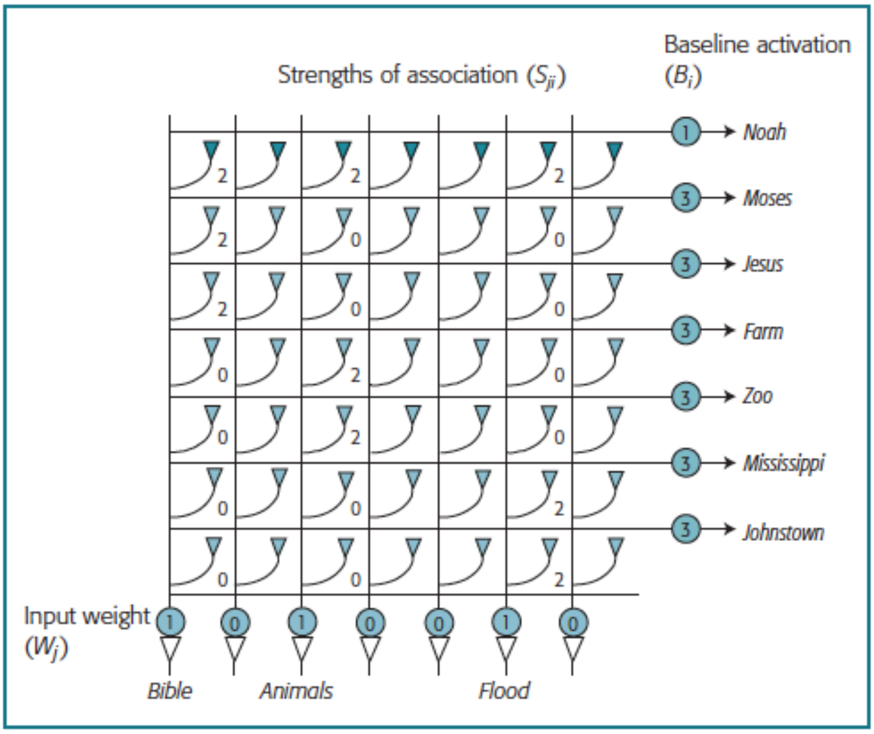



**FIGURE 6.11** A representation of how activation accumulates in a neural network such as that assumed in the ACT theory. Activation coming from various stimulus words—such as *Bible*, *animals*, and *flood*—spreads activation to associated concepts, such as *Noah*, *Moses*, and *farm*.