From Creativity toward Origination:
Dreaming, Mental Imagery and Computational Creativity

Comprehensive Examination Question 2:

Present, discuss and contrast two current models of dreaming and two current models of mental imagery and/or imagination. For each of the four models, discuss their relevance to computational creativity (the field concerned with using computers as creative means).

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1 Introduction

Dreams may be one of the fundamental experiences of human life. Their nearly ubiquitous nature indicates they have a function significant enough to offset their metabolic cost. This paper provides a continuum of theory, starting with dreams, leading through mental imagery and ending with computational implementation. A short survey on the qualities of dreams (sourced from reviews covering content analysis), and a discussion of bottom-up (dreams as perception) and top-down (dreams as imagination) conceptions of dreaming will be discussed in Section 2. In Section 3, a leading theory of mental imagination is discussed, as well as a computational model of mental imagery that integrates multiple theories. The relevance of these theories to computational creativity is discussed in Section 4. In particular, the system that allows perceptual experiences to trigger conceptual[1] activations, and vice versa, is relevant for the construction image-making machines. Specific areas where cultural theory, neuroscience and computational creativity can mutually contribute is the notion of dream as cinematic narrative, which is common in content analysis. The degree to which dreams are remembered or synthesized begs the question: what are the atoms of synthesized experience? This relation between recall and synthesis is highly relevant to computational creativity, in which synthesis is emphasized over recall, and systems rarely make use of perceptual material in their creative processes.

[1] The terms *concept* and *conceptual* are used loosely and refer to a class-like abstraction of perceptual information.

2 Dreaming

The examination of the qualities and meaning of dreams has a long cultural history. An introductory summary of dream qualities is presented later in this section, which focuses on the explication of two apparently opposing conceptions of dreams. Hobson [11] proposes that dreams are the result of our brains making sense of random activations originating in the pontine brain-stem (bottom-up). These random activations result in raw sensory experiences that are organized into a structure by higher level brain functions. Although random, Hobson believes that dreams have a functional role in the development of the "protoconsciousness", and in memory maintenance. Nir and Tononi [21] propose that dreams are the result of high level concepts generating dream imagery (top-down). Whereas Hobson proposes that dreams are like perception, Nir and Tononi consider dreams a result of the mechanisms that enable mental imagery, where sensory representations are generated by high level functions.

First, a little background: Sleep is divided by a number of objectively observable stages that reflect the degree of activation of the brain [18]. Slow Wave Sleep (Stage III and IV) is characterized by high amplitude and low frequency electroencephalogram (EEG) signals, while REM sleep (Emergent Stage I) is characterized by low amplitude and high frequency EEG signals. Most dreaming occurs during REM sleep, but dreams also occur during Non-REM (NREM, Stages II to IV) sleep, although they have different qualities than REM dreams, to be discussed later.

Dreams have a number of characteristics that differ from waking consciousness. Hobson [9] makes a distinction between primary and secondary consciousness: primary consciousness involves only perception and emotion, while secondary consciousness involves self-reflective awareness, abstract thinking, volition and meta-thinking, and is dependent on language. Dreams are not strongly associated with the features of secondary consciousness, but are associated with primary consciousness. The following selection of dream features are sourced from Hobson [9, Supplementary information S1] and Nir et al. [21]:

Sensation: Dreams often involve the perception of vision and movement and an increased emotionality: anxiety, elation, anger, joy, surprise and fear are common, while sadness, guilt and depression are rare. Lucid dreamers report a lack of fine detail in dream images.

Recall vs. Synthesis: Residue of waking life is incorporated in 50% of dreams. 20% of dream experiences are recognizable from memory while 80% are "synthesized de novo" [9].

Cognition: There is a reduced degree of voluntary control and self-awareness in dreams. Single-mindedness, a willingness to accept contradiction and the impossible are common. Dream *plot* is often incongurent. Dreamers report a gradual change of orientation within *scenes* and radical changes between scenes. Transitions between scenes lack continuity. Dreams may contain chimeric *characters* (characters that are the fusion of multiple people). In some cases, dreamers can recognize the internal mental states of other dream characters. The network of associations in dreams is looser than in waking. Dreams may involve both rational and irrational thinking. Nir and Tononi [21] consider waking and dreaming as graded phenomena.

Child vs. Adult Dreams: For adults dreams are "...vivid sensorimotor hallucinatory experiences that follow a *narrative*[2] structure" [21]. The dreams of preschoolers are rare during REM sleep and are plain and static—for example, thinking about an animal, or eating. Between 5–7 years dreams become longer, though not more frequent, and may involve sequences of events with characters that interact, but narratives are not developed. At around 7 years[3] dreams become longer and more frequent, contain thoughts and feelings, and the child's self becomes a dream participant. Dreams also acquire narrative structure, like adult dreams, and "reflect autobiographic, [and] episodic memories" [21].

NREM Dreams: NREM dream reports are seven times shorter then REM reports. The sensation of movement is more common in REM than NREM dreams. These dreams tend to be "...short, thought-like, less vivid, less visual and more conceptual, less motorically animated, under greater volitional control, more plausible, more concerned with current issues, less emotional and less pleasant" [21]. NREM dreams tend to have a higher number of known characters than unknown characters.

2.1 Activation, Input/Output Gating, and Modulation (AIM) (Hobson)

Hobson's AIM model [9] is a successor to the "activation-synthesis" theory [10], and are both neurologically oriented accounts of dreaming. The AIM model is associated with a theory of protoconsciousness in which dreams provide a "...virtual reality model of the world that is of functional use to the development and maintenance of waking consciousness" [9]. This "virtual reality" both reactivates neural pathways, and provides a simulator in which the protoconsciousness can develop. Empirical evidence indicates that fetuses exhibit REM-like states before waking-like states develop. REM sleep is at its peak in the third trimester of gestation and "...plummets after birth, as waking time and cognitive capability increase." These REM states allow the development of the "protoself" which "...is instantiated, at first to account for and later...to take responsibility for what begin as entirely automatic acts." These "automatic acts" are the results of the random activation of brain regions during REM. The persistence of REM sleep in adults testifies to a function beyond the development of the protoself.

The model describes the essential neurological aspects of dreaming, which are composed of three dimensions that operate in parallel: (1) *Activation*: During waking and REM sleep, the brain is highly activated while during NREM sleep it is highly inactive. Activation during REM sleep is self-regulating and not driven by external stimulus. (2) *Input-output gating*: During REM, the reticular activating system disconnects the body from the brain, resulting in temporary paralysis. Once the brain is disconnected from the body, the random PGO waves begin, initiating REM. These signals have been measured in the pontine brain-stem (P), the lateral geniculate nucleus (G), and in the occipital cortex (O), but also "...occur in sensori-motor systems in the forebrain." These signals originate in the brain-stem and cause activation of the sensory systems, in particular vision. This process may also contribute to sensori-motor integration, as those systems are active during REM. (3) *Modulation* involves changes to neurotransmitter levels during sleep: During REM, aminergic neurons are inhibited which leads to memory impoverishment, while cholinergic neurons are activated. Acetylcholine and dopamine are activated, while serotonin, noradrenaline and histamine are diminished during REM. The dimensions of the AIM model constitute a

[2]The word "narrative" is not emphasized in the original text.

[3]Hobson [9] puts the age at which children begin adult-like dreams at approximately 5 years.

state-space that "…enables the mapping of exceptional mental states such as lucid dreaming and abnormal conditions such as coma and minimally conscious states." Each of these conditions is reflected in a location in the AIM state-space.

2.1.1 Discussion

In "untiled iterations" [1] I muse that consciousness is the ability to construct / perceive structure from nothing but randomness. According to Hobson's proposal, high-level brain functions transform a random flow of sense-data into a cohesive, and even narrative, subjective experience. Hobson provides no discussion of the structure of these PGO waves. The visual system is multi-layered and topographically structured, which begs the question: exactly where in the visual system are these random signals introduced? Watching white noise on a TV screen presumably involves a similar activation of low level sensory neurons. Why does that stimulus not lead to dream-like hallucinatory narratives? Hobson may argue that the modulation of neurotransmitters during REM sleep facilitate the narrative interpretation of these random sensory impressions. Perhaps PGO signals interact with the visual system at a higher level—but that would seem to undercut the argument that dreams are initiated "from the motor side up" [9].

2.2 Dreams as Mental Imagery (Nir and Tononi)

Nir and Tononi [21] provide an alternative account of dreaming that is rooted in a criticism of Hobson's theory. Hobson himself describes this inconsistency: "An important caveat is that although the distinctive features of dream consciousness…are maximally correlated with REM sleep, they are also found — to a limited degree — in nREM sleep…" [9]. Hobson's theory is highly correlated with the kinds of dreams that occur in REM sleep, and does not explain, and in fact is weakened by, the notion of dreams in NREM sleep. Hobson correlates dreams with PGO waves [2], and yet dreams occur in NREM sleep where PGO waves do not. The qualities of the dreams that occur in REM and NREM sleep are different (as discussed above), but Hobson does not explain how NREM dreams could occur in the absence of PGO waves.

Additionally, Nir and Tononi's interpretation of Hobson's model (according to "Dreaming and the brain: Toward a cognitive neuroscience of conscious states" [11]) involves a change in the directionality of signal propagation, suppressing feed-back (top-down) and enhancing feed-forward (bottom-up) connections: "High levels of acetylcholine in the absence of aminergic neuromodulation might enhance feed-forward transmission and suppress back-propagation" [21]. They cite lesion studies that "…suggest that dreaming is more closely related to imagination than it is to perception." These studies indicate that dreaming depends more on the fore-brain than the "brain-stem REM generator". A area of particular interest is Broadman's area 40, which "…supports various cognitive processes that are essential for mental imagery." Damage to this area often leads to the total cessation of dreams and subjects may also show deficits in visual-spatial abilities. Damage to the ventromedial prefrontal cortex, for example due to lobotomy, lead to total cessation of dreams in 70–90% of subjects, who also exhibited a "…lack of initiative, curiosity and fantasy in waking life." In general, damage to perceptual areas leads to deficits in both perception and dreaming: "…lesions leading to impairments in waking have parallel deficits in dreaming."

Evidence for the link between imagination and dreaming is also made on the basis of an analysis of children's dreaming. The development of dreams in infants appears to correlate with the development of mental imagery, and not linguistic nor memory ability. Analysis of the content of children's dreams shows that the younger the child the more simplistic the dream experiences. This is not due to a lack of linguistic ability: "...although children of age 2–5 years can see and speak of everyday people, objects and events, they apparently cannot dream of them." The dreams of children of this age are further characterized by having "no characters that move, no social interactions, little feeling, and they do not include the dreamer as an active character. There are also no autobiographic, [or] episodic memories..." Children under 7 years report dreams when awakened from REM sleep only 20% of the time, when compared to 80–90% in adults. Nir and Tononi provide a compelling argument that dreaming may in fact be more closely related to imagination than perception, and that neural mechanisms used in mental imagery are in play in the case of dreaming.

2.2.1 Discussion

Nir and Tononi do not provide any citations that make the direct connection between abilities on mental imagery tests, for example the Block Design Test [33], and the content of children's dreams. Indeed a significant difficulty with this argument is the childrens' reporting ability. If there is such a correlation, it implies that the conceptual system that allows both mental imagery and dreams is different than the conceptual system that leads to linguistic ability. If there was a single conceptual system, why would there be a difference between linguistic and mental imagery abilities? The authors note that there is at least one significant difference between dreaming and mental imagery: "...while imagining, one is aware that the images are internally generated (preserved reflective thought)." The lack of reflective thought in dreams could be explained by the modulation of neurotransmitters during sleep according to the AIM model. The lesion studies cited are particularly problematic for a bottom-up theory of dreaming.

A significant issue with Nir and Tononi's account is: what *causes* the activation of fore-brain structures that result in the mental images that occur in dreams? Hobson neatly solves this problem with PGO waves. Both theories appear to be overly concerned with brain directionality (bottom-up vs. top-down). Studies in attention make the case that high level brain function effects lower-level perception [31], and the opposite is obviously the case. Perhaps there is little difference between these two options. On one hand, random PGO waves effect perceptual systems and lead to conceptual activation, and on the other hand, the unknown activation of conceptual structures that result in perceptual experiences. In both cases perceptual and conceptual systems are activated, and causality is notoriously difficult to determine. What is missing is the mechanism by which concepts are causally linked to perceptual experiences (if they are at all).

3 Mental Imagery

While Hobson, Nir and Tononi discuss the particulars of how dreams may occur, and their characteristics, the notion of the system that connects high level concepts and low-level sensory impressions is left unexplained. "Perceptual Anticipation Theory" [16] is a leading theory of mental imagery proposed by Kosslyn. It holds that mental imagination involves mechanisms shared with visual perception. This section closes with a description of Sima's "Attention-Based Quantification Theory" [28], a computational model of mental imagery.

3.1 Perceptual Anticipation Theory (Kosslyn)

In "When Is Early Visual Cortex Activated During Visual Mental Imagery?" [17], Kosslyn describes the "Perceptual Anticipation Theory" where mental imagery depends on the early visual system: ". . . mental images arise when one anticipates perceiving an object or scene so strongly that a depictive representation of the stimulus is created in [the] early visual cortex." The act of imagining an object involves the construction of a sensory impression of that object.

The patterns that define these mental images (visual long-term memory) are not stored in the visual cortex, but are encoded, using "population coding" [29, 34], in the inferior temporal lobes. In population coding, a pattern is not reflected in the firing of a particular neuron, but in the firing of a group of neurons. Unlike the arrangement of the visual cortex, these representations are non-topographical. The long-term memory representations of images in the inferior temporal lobes are implicit because of this encoding. They can only be made explicit through the constructive activation of the topographically oriented early visual system: ". . . image generation is not simply 'playing backward' stored information, but rather is necessarily a constructive activity" [17]. These representations do not include spatial information, which is encoded elsewhere.[4]

Once the images in long-term memory are reconstructed in the visual cortex, they are perceivable using the same mechanisms as normal visual perception. These imagined reconstructions can be used to further conceptualize images propositionally or linguistically: ". . . reconstructing the shape in topographically organized early cortex affords an opportunity to reinterpret the pattern." According to this theory, activation in the visual cortex is expected to occur when the task requires (1) a higher resolution representation than is afforded by the linguistic system, (2) a specific example of such an object, not a prototype of a class and (3) the inspection of object-centric properties—not spatial relations. Perceptual Anticipation Theory proposes that mental images are explicitly represented in the topographically oriented regions of the early visual cortex and are perceived by similar mechanisms that allow the perception of external images.

3.1.1 Discussion

Since the 80's Kosslyn [13, 14, 15, 16] and Pylyshyn [23, 24, 25, 26] have been engaged in a long standing debate on the nature of mental images. Pylyshyn's "propositional" theory contends that mental images are not images, but are symbolic / propositional descriptions of visual properties that do not make use of the visual system. Rather than being rooted in visual experience, these representations are composed of the same kinds of abstract symbolic codes used in language. According to Pylyshyn's theory, any activation in the early visual system during mental imagery is spurious and nonfunctional. Dominic Gregory [7] attempts to resolve these two views through a philosophical framework in which the intrinsically visual *content* of mental images are at the forefront, and that the underlying *format*, or encoding, contributes to impasse.

Kosslyn is specifically focused on the early visual system, which may be problematic as the complexity of mental images may involve higher level processes. Kosslyn's account depends on the notion that the inferior temporal lobe is correlated with the long-term storage of memory. The role of the inferior and medial temporal lobes in perception and memory is questioned by the "Emergent Memory Account" (EMA) as proposed by Graham, Barense and Lee [6]. According to the EMA, the medial

[4] For more views regarding the processing of object and spatial information see [5, 19, 20].

temporal lobe is not simply a storehouse for memory, but is specialized for high level visual representations that are used in both memory and perception. If the EMA is correct, then mental imagination would involve much of the ventral stream and not only the early visual system. The function and relation between the inferior and medial temporal lobes are complex and not yet well understood. Presumably, the temporal lobe is also where Pylyshyn's non-visual representations are stored. If Kosslyn and Pylyshyn agree on the location and the *content*, but disagree on the *format*, imaging and lesion studies may not shed much light on this debate.

3.2 Attention-Based Quantification Theory (Sima)

Sima [28] proposes a computational integration of existing theories of mental imagery. The argument is that no single theory easily explains all of the available empirical evidence, and that a combination of theories will exhibit greater explanatory power. Sima cites three major theories of mental imagery: (1) Kosslyn's "Quasi-pictorial" theory, which was discussed in Section 3.1, proposes that mental images are imprinted on the early visual system. (2) Pylyshyn's "descriptive" theory, also briefly introduced in that section, proposes that mental images are "simulations" resulting from tacit knowledge and constructed from concepts related to the symbolic / linguistic system, which are independent of visual processing. (3) The "enactive" theory, described by Thomas [30], rejects all notions of representation in mental images. According to this theory the experience of mental images is the reenactment of sensori-motor processes:

> Enactive theory assumes that we have sets of inspection processes, commonly called schemata, that are associated with seeing or imagining concepts. For example, we go through the execution of a sequence of schemata that identify the concept "cat" whenever we look at and recognize a cat. The reenactment of these perceptual processes during the absence of a cat is what the theory claims to cause the experience of mentally imagining a cat. [28]

Sima focuses on three families of experiments that have been used to support particular theories and refute others. A summary of these experiments, and the theories they support, are summarized in Table 1. "Mental scanning" experiments show a correlation between the time between fixation events during the mental scanning of a memorized map and the physical distance between the corresponding map points. "Mental reinterpretation" experiments show that, unlike in perceptual images, it is difficult to attend to particular details in ambiguous mental images. Experiments have shown that in some situations the eyes move in accordance with the imagined fixation in mental images.

	Quasi-Pictorial	Descriptive	Enactive
Mental Scanning	Strong	Weak	Strong
Mental Reinterpretation	Weak	Strong	Weak
Eye Movement	Strong	Weak	Strong

Table 1: The degree to which each family of experiments supports the various theories of mental imagery. For simplicity, support is only presented as weak or strong. The reader is encouraged to refer to original sources in [28] for details.

Attention-Based Quantification Theory integrates elements from these theories in an effort to develop a model that explains all the cited experimental data. The model was developed computationally because "... a computational cognitive model can be an instrumental source to drive further empirical research as it allows to pin-point open questions and offer concrete assumptions and predictions." The model has three major properties that differ from any one of the existing theories: (1) Non-trivial images are constructed from conceptual/descriptive data. (2) The system has no "quasi-pictorial" aspect, no images are constructed in the visual system. (3) Mental scanning time and eye movements are explained by an attentional module.

The model is composed of two working memory structures: (1) the *Qualitative Spatial Representation* (QSR) "represents concepts, parts, and their spatial relations on a qualitative level" [28], and (2) the Visuo-Spatial Attention Window (VSAW) reflects the focus of "internal attention". The VSAW is the quantitative counterpart to the QSR, and allows attentional focus on particular areas of the QSR. Two types of information are assumed to be stored in long-term memory (LTM): (1) Spatial information that reflects the configuration of complex objects and scenes. These are encoded in terms of "qualitative relations" and populate a graph structure. (2) Visual information is encoded as a set of feature vectors that define "shape information". Both the QSR and VSAW have independent access to both types of information in LTM.

The QSR contains the "minimal necessary information to generate a mental image." The fidelity of the QSR representation is extended, and reduced, on demand to match the task at hand. For example a house may initially be represented as a single atom with a location and no further detail but can be extended to include sub-components, for example walls, roof and chimney. The QSR guides the movement of the VSAW, which temporarily adds quantitative spatial information, for example coordinates, distances, etc., to the QSR, which initially contains only qualitative information.

The VSAW selects a region of interest (ROI) under the guidance of the QSR. This ROI has both a position in the QSR, and a size. The size of the window is proportional to the resolution of the region of interest—the higher the resolution, the smaller the window. Attention can shift within the window (covert attention), and the entire window can also shift (overt attention). The model assumes that the mechanism that drives the shifting window is shared with the sensori-motor systems that are responsible for saccades. The VSAW serves two main functions: (1) It quantifies the qualitative spatial relations in the QSR, using attentional shifts as a measuring tool. (2) It infers spatial or shape information from LTM, which impacts the QSR representation. Both of these functions occur at "scene level", where the arrangement of objects are quantified, and at "shape level" where the details of the shape of an object are quantified.

The integration of these theories into a unified, although incomplete, model resolves their inconsistent empirical support. Mental scanning and eye-movements are explained by the movement of the VSAW. The difficulty of Kosslyn's theory to explain differences in the reinterpretation of mental images is resolved by the lack of a quasi-pictorial representation of mental images.

3.2.1 Discussion

This computational theory of mental imagery concerns reasoning through image-like mechanisms, and gives little insight into the construction of images. There are a number of systems that model visual reasoning that purport to be models of mental imagery, for example [12, 32, 35]. None of these models is able to construct an image from a conceptual structure.

The notion of non-visual mental images is suspect from a phenomenological point of view. It is difficult to accept that mental images could be illusionary, and that the process of imagining an image is simply a process of visual reasoning. This difficulty is at the core of the argument between Kosslyn and Pylyshyn. This work notwithstanding, the existence of images on the visual cortex during mental imagery is certainly not disproved. If we refer back to Table 1, the only empirical data that is cited against Kosslyn's theory is that of mental reinterpretation.

If we accept that dreaming and mental imagery depend on shared mechanisms, then evidence from dream research could be relevant to the subject of mental images. Studies of lucid dreamers indicate a lack of fidelity in dream images compared to perceptual images. This lack of fidelity is reasonable, considering that these images are reconstructed from conceptual abstractions. The lack of fidelity in dreams could explain the difficulty in reinterpreting mental images. There is another area where dream research could impact mental imagery. If we accept the descriptive theory, then the construction of mental images is a thought process. Do the changes in brain chemistry during dreaming support this type of thinking? Both of these points depend on a connection between dreaming and mental images that is not proven, but perhaps an integrative consideration of mental images and dreams could bare light on both areas.

4 Relevance for Computational Creativity

Colton et al. [4] define computational creativity as "... the study of building software that exhibits behavior that would be deemed creative in humans." Human's exhibit creativity in many different ways, ranging from the invention of scientific theories, to visual explorations in the context of cultural practise. The construction of a *creative machine* is a lofty goal, and comes down to the the methodology that determines what is "deemed creative"—*evaluation*. My very interest in dreams and imagination is an attempt to skirt this issue. I am much more interested in *origination* than creativity. These two terms are often conflated in computational creativity, but the simple fact that evaluation requires something to evaluate describes the order of dependence sufficiently. I believe that in order to make a contribution in computational creativity, we must begin with origination. Despite not being explicitly or consciously evaluated, dreams are some of the most original, and perhaps creative, generations of the human mind.

Directly related to computational creativity is Hobson's notion of a dream process: Dream images result from randomly generated perceptual data that is made sense of by high level brain functions. In dreams, the evaluation mechanism is implicit and unconscious, if it even exists, and yet dreams appear, according to Hobson, to transmute randomness into narrative structure. Often "creative" computational systems follow a similar architecture: a pool of random variation is explicitly evaluated by fitness criteria. It appears obvious that the generation of variation is the easy part, the difficulty lies in evaluation—in particular unsupervised evaluation. Hobson is clear about the constructive, and creative powers required by his theory: "... our brains are as much creative artists as they are copy editors." The system that makes sense of random sense data is no less magical than creativity itself (perhaps more so). This sets the problem of computer image synthesis in a different light: The brain makes sense of random patterns in the visual cortex in a similar way as it makes sense of external visual stimulus. The way in which dreams become meaningful and cohesive is enabled by the same processes that make the world meaningful and cohesive. This was understood by Cohen [3], who relates perceptual (image-reading) and generative (image-making) cognition: "... all image-making and all image-reading is mediated by cognitive processes of a rather low-level kind, presumably processes by means of which we are able to cope also with the real world." The link between constructing images, perceiving images, and perceiving the world may all be enabled by a shared set of cognitive processes.

There are two key aspects of dream content analysis that are relevant to computational creativity: the dependence on cinematic and narrative language, and more importantly, the relation between constructed and remembered dream components. The jargon of dream content research depends significantly on narrative terms. Hobson himself describes aspects of dream cognition in terms of "plot incongruity" or "scene transition", without providing any explanation or definition of them. It may be because the ubiquity of cinema causes dreamers and researchers to use these terms without reflection. It could also be because we experience our dreams as if they *are* cinematic narratives. This is a largely unexplored area where computational creativity, cinema theory and generative art can contribute. This contribution could come in two major forms: (1) the use of cultural, narrative and cinema theory in the analysis of dream content and (2) the construction of systems that generate narrative and cinematic sequences, as informed by (1). Systems that attempt to bridge cinema, narrative and dream theory have been developed, for example the "Visual Daydreamer" [22] developed by Pérez. Unfortunately, theories of narrative and dreaming are reduced to highly simplistic terms in this work. The neuroscientist's dependence on cinematic and narrative terms signals a opportunity for interdisciplinary collaboration.

According to dream content analysis 20% of dream components are remembered, and 80% are "synthesized". This begs the question: what are the atoms of conceptually reconstructed experience? It is presumed that the brain learns patterns from the world and reconstructs those in mental imagery and dreams, but what is the extent of conceptual atoms used to generate mental images and dreams? If they were single features of a particular retinal cells, then why don't we dream of images like abstract field paintings, devoid of edges? The atoms must be larger, perhaps corresponding to whole objects (whatever these are in neurological terms). This would not explain chimeric characters and locations that are fusions of multiple places, therefore the answer likely lies somewhere in between, or perhaps they have no constant size. An analysis of dream content emphasizing the search for the atoms from which mental images and dreams are constructed could contribute to an understanding of the system that generates perceptual experiences from concepts, or concepts from perceptual experiences. Knowledge of such a system could be directly applied in a computational system that synthesizes images from conceptual abstractions.

Kosslyn's neurological explanation of mental imagery is focused on how concepts relate to mental images. This model does not provide a great deal of detail regarding the structure of a system that generates images from conceptual abstractions, nor do the computational models cited in this paper. There are hierarchical systems that both learn from and reconstruct input patterns, such as Deep Boltzmann Machines [27], or DRASiW / WiSARD [8], but these systems are not rooted in neurological or cognitive science. On one hand we have cognitive models that explain the objective aspects of mental images (empirical data) but provide little knowledge regarding how to synthesize images. On the other hand are complex mathematical systems that learn patterns and regenerate them, but only in highly restrictive contexts.

Sima's computational model brings to the forefront a significant schism in the theory of mental images, best represented by the theories of Kosslyn and Pylyshyn. In both cases the purpose of mental images is visual reasoning, the ability to think in images. As clearly pointed out by Pylyshyn and illustrated by Sima, the explicit construction of images, which are perceived using mechanisms shared with external perception, are not required for this kind of visual thinking. While Sima's theory has great explanatory power in terms of empirical evidence it has little to say regarding the construction of images, and only proposes a framework in which visual thinking can operate, without images no less.

Philosophers, computer scientists and neurologists have all tried to explain the mechanisms of human reason, which is inherently dependent on the the structure of concepts in the mind-brain, and how those structures are grown, partly from experience, and partly from genetic determination. What concepts are, let alone how they are structured and constructed, is an open area. Our imaginative abilities can (re)produce images ranging from total abstraction to near photographic realism. An understanding of this ability may allow machines to transcend the limitations of their particular styles, and to contribute to an understanding of how knowledge of visual images is structured in the mind-brain.

5 Conclusion

Dreams have likely inspired artists and creative practitioners since the origins of our culture, perhaps our species. They embody the central core of creativity, the ability to originate images and thoughts with unparallelled flexibility. Even the most irrational thinker may be hard-pressed to rival the originative powers of dreams. Evidence suggests that dreams and mental images are correlated, and perhaps make use of shared mechanisms. It has also been argued that mental images share mechanisms with visual perception. This trinity of mechanisms, from perception, through mental imagery to dreams, highlights the importance of the relation between lived experience and origination. Perhaps the only way for machines to attain a human level of creative, originative or image-making abilities is for them to engage in a lived experience that rivals the duration and richness of a human's.

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