A Machine that Dreams: An Artistic Enquiry Leading to an Integrative Theory and Computational Artwork

by

Benjamin David Robert Bogart

M.Sc., Simon Fraser University, 2008

B.F.A. (Hons.), Ryerson University, 2003

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APPROVAL

Name: Benjamin David Robert Bogart

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Title of Dissertation: A Machine that Dreams: An Artistic Enquiry Leading to an Integrative Theory and Computational Artwork

Examining Committee: Dr. Carman Neustaedter, Assistant Professor
Chair

Dr. Philippe Pasquier, Associate Professor
Senior Supervisor

Dr. Thecla Schiphorst, Professor
Supervisor

Dr. Steven J. Barnes, Instructor I
Supervisor
Department of Psychology, University of British Columbia

Dr. Steve DiPaola, Associate Professor
Internal Examiner

Alan Dunning, Adjunct Professor
External Examiner
Department of Art, University of Calgary

Date Approved: September 9th, 2014

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Abstract

What is a dream? What is the relationship between dreaming, mind wandering and external perception? These questions are at the core of this artistic enquiry. In this art-as-research practice, both arts and sciences are defined as practices that construct culturally relevant representations that function as tools exploited in our attempt to make sense of the world and ourselves. Through this research, novel contributions are made to both artistic practices and cognitive science where both are manifest in a computational system that serves as both a generative and site-specific artwork and as a computational model of dreaming — the *Dreaming Machine.*

Visual mentation is the experience of visual images in the mind and includes visual aspects of perception, mental imagery, mind wandering and dreaming. The Integrative Theory of visual mentation unifies biopsychological theories of perception, dreaming and mental imagery and makes three major hypotheses: Visual mentation (1) involves the activation of perceptual representations, (2) is experienced phenomenologically due to the activation of these representations, and (3) depends on shared mechanisms of simulation that exploit these representations. The Integrative Theory is the theoretical foundation of the model and artwork that generates dream imagery.

The *Dreaming Machine* is an image-making agent that uses clustering and machine learning methods to make sense of live images captured in the context of installation. Visual images are generated during external perception, mind wandering and dreaming, and are constructed from shared perceptual representations learned during waking. The difference between these processes of visual mentation are varying degrees of activation from external stimuli (exogenous) and feedback in a predictive model of the world (endogenous). As an artwork, the generative methods manifesting biopsychological processes create a rich diversity of imagery that ranges from abstract collage to photo-realism. The artwork is meant to facilitate the viewer's sense of his/her own fabricated perceptions and consider the relationships between computation, cognitive models and scientific conceptions of mind and dreaming.

Keywords: Dreaming; Mind Wandering; Generative Art; Site-specific Art; Art-as-research; Cognitive Science

For Mom.

SAL 9000:	*Will I dream?*
Dr. Chandra:	*Of course you will. All intelligent creatures dream—but no one knows why.*

2010: Odyssey Two, Arthur C. Clarke (1982)

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I would like to thank my committee, Philippe Pasquier, Thecla Schiphorst and Steven Barnes, for providing support and critique. In particular, Steven Barnes has been invaluable in developing the biopsychological aspects of this work, and providing the guidance needed to learn the jargon and methods required to understand the literature on biopsychological mechanisms of dreaming. Philippe Pasquier's assistance in the development of the Integrative Theory, and the computational formalization, have significantly improved the quality of this work.

I would like to thank my peers in the Metacreation, Agents and Multi-Agent Systems lab who have engaged in much discussion regarding the project. In particular, I would like to thank Graeme McCaig, with whom discussions about the research have been insightful and valuable. Thanks to those who have assisted with technical aspects of the computational model, specifically Matthieu Macret and Matthew Gingold.

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Chapter 1

Introduction

From Aristotle through Descartes and Freud to contemporary brain scientists and artists, dreams have captured our wonder and attention. The worlds we enter when we dream have been interpreted as parallel universes, as gateways into our unconscious, and even as meaningless randomness. Dreams can be short and banal, or they can be long and potentially bizarre experiences that combine impossible elements: transitions of space and scale and even characters who appear to be one person, and yet the dreamer knows to be another. Dreams are so captivating that their representations permeate visual culture. The "dream sequence" is practically a cinematic cliché. Surrealist painters like Salvador Dalí have saturated culture with the notion of dreams as bizarre and impossible juxtapositions of diverse elements. Breton (1924) defines Surrealism as a process in "which one proposes to express…the actual functioning of thought." In order to examine thought as independent of intentional control, many Surrealist methods involve removing rational, aesthetic and moral concerns from the process. Surrealism, like this research, emphasizes the thought present in dreams (and mind wandering) over the rational and task-oriented thought that pervades day-to-day life. There does seem to be a relation between the way we conceptualize and make sense of our dreams and the visual culture we find ourselves in. It was even thought for a time — coinciding with the peak of black and white cinema and television — that dreams were primarily black and white.[1] This implies that the relation between our experiences (or at least our descriptions thereof) and cultural representations are highly intertwined. Through all the diversity and incongruency of these conceptions of dreaming, researchers have yet to reach consensus on the exact function or mechanisms of dreaming.

The conclusion reached, through the research described in this thesis, is that dreams are simulations of reality constructed from representations of perceptual information that exploit a predictive model of the world. Both the perceptual information and the predictive model are learned through

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[1] For an analysis of dreams as black and white, see Schwitzgebel (2002).

an agent's embodied sensory experience. These simulations are valuable and meaningful because they manifest implicit relations between significant sensory experiences we learn through waking perception. Simulation is of functional use to external perception because knowing what to expect optimizes attention to ignore that which is routine, and emphasize that which is a surprise. Simulation is a central aspect of cognition and occurs in both dream sleep and waking perception. Shared mechanisms of simulation lead to the notion of contiguity between dreaming and external perception where both exploit shared perceptual representations. These conclusions constitute a portion of the Integrative Theory of visual mentation (perception, mental imagery, mind wandering and dreaming) which is a central contribution of the research described herein.

This research is centrally concerned with the development of a site-specific generative art installation titled *Dreaming Machine #3*. The work is situated in a series of generative artworks, titled *Context Machines* (Bogart & Pasquier, 2011, 2013a, Chapter 2), which all involve generative processes of image-making that transform photographic images of a particular site using computational and machine learning methods. The research into the biopsychological mechanisms of dreaming and the development of the Integrative Theory form the conceptual framework for the development of the artwork. As a computational system, the artwork is considered a model and situated agent that manifests the Integrative Theory. The realization of the theory in a computational model facilitates reflection and analysis of the theory at a formal level of description. The images produced by the artwork/system are then visualizations of the system's internal generative mechanisms of simulation, and documentation of the artwork's generative behaviour. In Bogart (2008), the material of the art practice is considered "the structure in which the artist does their work of creation", which at that time was the software implementation of the artwork. During this research, the notion of material has shifted even more ephemerally, where much of the work was done through scholarship — reading, discussions, thought and writing — rather than implementation. This signals the shift from artist to artist-theorist, as described in Chapter 3. The primary material of the artwork is the set of ideas that constitutes the notion of a *Dreaming Machine* as formalized in the Integrative Theory. This theory, the computational model and the aesthetics of the resulting images, are considered a conceptually cohesive whole, where the theory is the central core that informs all aspects of the work. The quality of the images produced by the system are not a separate line of artistic enquiry, but a means to manifest the theory, which is both an artistic and scientific proposition.

The genesis of this research project began with the intuition that there is a natural affinity between dreaming and visual generative art. In generative art, the aim is to construct complex formal systems whose behaviour is diverse and, to some degree, a surprise to the artist. Previous *Context Machines*, such as *Memory Association Machine* (Bogart, 2008), were explicitly contextualized in terms of metacreation[2] — a discipline devoted to the construction of machines that exhibit creative

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[2] For a overview of metacreation in relation to generative art, see Whitelaw (2004).

behaviour. The interest in dreams arose from an interest in generative aspects of creativity independent of the evaluative mechanisms common in metacreative systems, which mirrors the Surrealist position. Rather than engaging in an artistic process where my creativity is the result of reducing evaluative mechanisms, my interest is in developing a system whose behaviour lacks explicit evaluation. Despite the lack of deliberate volition in dreams, to be discussed later, significant creativity and insight has been attributed to them. Frankenstein resulted from a 'waking dream', while the structure of benzine was apparently inspired by Kekulé's day-dream of a snake consuming its own tail. Surrealist artworks could all stand as highly creative and involve reduced explicit evaluation. Not only can dreams be insightful, but there is little doubt to the impressive diversity of experiences dreams could include. An enquiry of the diverse and flexible mechanisms of dreaming leads to novel image-making methods that are of value to generative arts. As this research involves the development of a formal system of generative processes, the scope is centred on the biopsychological mechanisms of visual dreaming, as dreams are most understood at the biopsychological level of description.

An examination of the literature on the biopsychological mechanisms of dreaming indicates that it is unclear how mechanisms of dreaming result in the visual phenomenology of dreams. In the process of synthesizing the literature, theorization is key in the integration of diverse theories and empirical results concerning dreaming, mental imagery, mind wandering and perception. The goal at the start of this project was not to develop an integrative theory of visual mentation; the Integrative Theory arose as a necessity in the development of a cohesive conception of the literature in sufficient detail as to allow computational realization. While the Integrative Theory is developed in the context of this art-as-research enquiry, the hope is that the work inspires future empirical validation and research and thus contributes both to cognitive science and artistic practice.

The Integrative Theory is both a biopsychological argument and an artistic concept. Generative arts are considered a close relation to the conceptual arts of the 1960s, in particular the instruction works where the artist provides a set of rules which are carried out by the viewer to complete the work.[3] In the 1960s, these rules where often instructions typed on paper and presented in a gallery context, along with the required implements. In computational generative arts, the artist is similarly engaged in a process of writing instructions, except those instructions are carried out by the computer, rather than by the viewer. Where the artwork is located in conceptual art depends on the artist's approach. Artists may consider the artwork the result of the execution of the instructions, the instructions themselves, or the very concept. The position taken up in this research is that the artwork is the concept (the Integrative Theory) which is manifest in a system of relations including the implementation of the computational model, the images it produces and even extends to written descriptions, artist-talks and conversations. This emphasis on the cohesion of the concept, over the aesthetics of the representations, facilitates the hybrid framing of this work between art and science.

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[3] See Tamblyn (1990); Cramer (2002); Bogart (2008) for further elaboration on computer software as conceptual art.

Chapter 3 is an articulation of the relation between arts and sciences focused on *representation* as a key concept of both arts and sciences, and extends the methodological approach described in Bogart (2008, Chapter 6). Chapter 3 is written from an artistic perspective for a practice-oriented art audience and describes the approach to art-making that informs this research, including: (a) the emphasis of exploration over expression in art-making, (b) the definition of arts and sciences as practices that construct culturally relevant representations that function as tools exploited in our attempt to make sense of the world and ourselves, and (c) a speculative extension of the Integrative Theory that frames cognition as a hierarchy of dynamic simulators.

This text includes papers describing two formulations of the Integrative Theory: (a) The associative conception, published in Bogart et al. (2013, Chapter 4), and (b) the predictive conception, submitted for publication in Cognitive Science and included in Chapter 5. These two formulations differ in terms of their definition of simulation but describe the same central hypotheses: (1) Visual mentation involves the activation of perceptual representations, (2) the phenomenological experience of visual mentation is due to activity of these perceptual representations, and (3) visual mentation is the simulation of perceptual information exploiting perceptual representations and modulated by internal and external activation. The predictive formulation is a more fully developed and articulated refinement of the associative formulation. Creativity, specifically Dietrich's (2004) conception of *spontaneous* creativity, is integrated in the associative conception but is excised from the predictive formulation. The details of the shift from the associative to the predictive formulations is discussed in Chapter 6.

The associative formulation (Bogart et al., 2013, Chapter 4) holds that dreams are simulations constructed from perceptual information, where dream content is the result of unconscious associations between visual representations based on the similarity of their features. This activity occurs in brain regions supporting perception and long-term memory. These associations are based on the similarity of various memory components and occur constantly during waking — although not integrated into consciousness. In dreaming, these associations become the content of dream consciousness. These unconscious associations are considered a generator of spontaneous creative insight (the *spontaneous processing mode*) by Dietrich (2004) where the associative process leads to thoughts that are *random, unfiltered, and bizarre* and are unconstrained by consciousness. Dietrich (2004) proposes that these associative processes are not only the basis of spontaneous creativity, but also the basis of dream content: "...dreaming might be regarded as the most extreme form of the spontaneous processing mode and can give rise to insights that are difficult to come by during normal waking consciousness." Under the associative formulation, the mechanisms that generate spontaneous creative insights are the same mechanisms that lead to dream content. Dreams can lead to creative insight because the lack of deliberate control allows weak associations to be experienced, which also explains the apparent bizarreness of dreams.

The predictive formulation of the Integrative Theory (Chapter 5) also holds that dreams are simulations constructed from perceptual representations. In this formulation, simulations are generated by endogenous activity in a predictive model of the world, rather than the result of associations between memories according to their perceptual features. The predictive model is learned through exposure to external stimuli, and functions to tune perceptual mechanisms (in particular attention) to surprising events. Thus, the predictive model is exploited in both perception and in dreaming. In the predictive formulation, there is no role for association between memories based on the similarity of features — only associations that result from shared contexts. This emphasis on prediction shifts away from associations according to particular visual features and towards contextual associations. According to the predictive formulation, the narrative and sequential quality of dreams is due to their dependence on a predictive model. The apparent bizarreness of dreams is due to errors that accumulate when predictions are not anchored in plausible reality by sensory information.

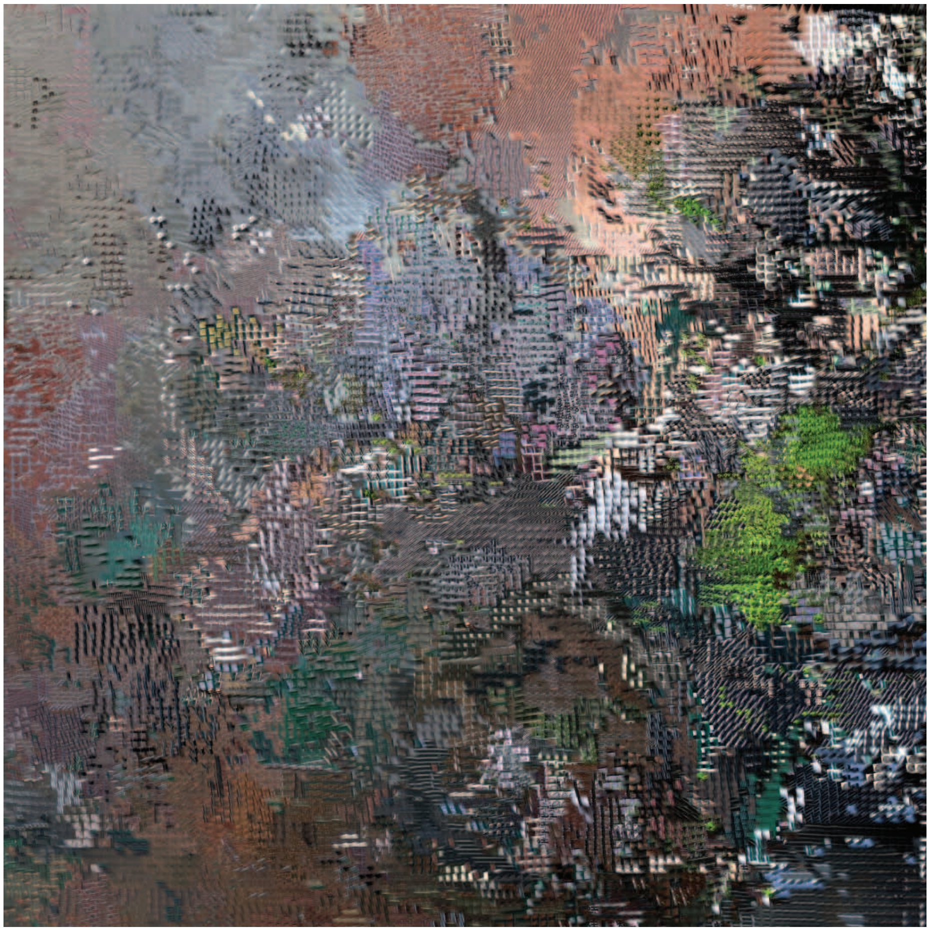
During the development and research processes, works-in-progress leading to *Dreaming Machine #3* have been exhibited internationally in artistic (New Forms Festival 2012) and academic (Bogart & Pasquier, 2013b) contexts. A selection of the images produced, and a discussion of their properties, are included in Chapter 6. The first exhibition is titled *An Artist in Process: A Computational Sketch of Dreaming Machine #3* and was shown at the New Forms Festival in 2012. The installation consisted of a work-space where the author developed software to (a) explore the aesthetic potential of an early version of the system's perceptual system, and (b) create associative sequences (dreams) from data collected during the residency. *Dreaming Machine #3 (Landscape)* has been accepted for exhibition at the International Symposium of Electronic Art (ISEA) 2014, in Dubai. This will be the first exhibition of the completed system and is described in detail in Chapter 6. In addition, Chapter 6 includes current progress on a spin-off project titled *Watching and Dreaming*, where the system is fed frames from films rather than live images from a site of installation.

The following chapters articulate the series of artworks — *Context Machines* — of which this work is a situated (Chapter 2) and the methodological approach that informs the interdisciplinary scope of this art-as-research (Chapter 3). The associative and predictive formulations of the Integrative Theory are described in Chapters 4 and 5. Following these chapters, the relation between these two formulations and documentation of three artistic realizations of the system are described (Chapter 6). The thesis concludes with future directions of research and final summary remarks (Chapter 7).

Chapter 2

Context Machines: A Series of Situated and Self-Organizing Artworks

As published in Leonardo, 46(2): 114–122, 2013a.



ARTISTS' ARTICLE

Context Machines: A Series of Situated and Self-Organizing Artworks

Benjamin David Robert Bogart
with Philippe Pasquier

ABSTRACT

The authors discuss the development of self-organizing artworks. *Context Machines* are a family of site-specific, conceptual and generative artworks that capture photographic images from their environment in the construction of creative compositions. *Resurfacing* produces interactive temporal landscapes from images captured over time. *Memory Association Machine's* free-associative process, modeled after Gabora's theory of creativity, traverses a self-organized map of images collected from the environment. In the *Dreaming Machine* installations, these free associations are framed as dreams. The self-organizing map is applied to thousands of images in *Self-Organized Landscapes*—high-resolution collages intended for print reproduction. *Context Machines* invite us to reconsider what is essentially human and to look at ourselves, and our world, anew.

1. INTRODUCTION

Context Machines are generative artworks, whose design is inspired by models of memory and creativity drawn from cognitive sciences. In a traditional artistic context, the artist works directly in the material that is presented to the audience. In generative art, the artist manifests the concept in a system whose output is presented to the audience. This is a process of metacreation: the building of systems that create media artifacts. Our development of *Context Machines* is manifest computationally and informed by cognitive models and theory, which are rarely exploited in generative art.

Our initial motivation leading to *Context Machines* is that their output be, to some degree, a surprise to us. Computational theories of complexity, emergence and nondeterminism contribute to processes that enable surprising results. The creative behavior of *Context Machines* is manifest in the generative representation presented to the audience. *Context Machines* are image-makers—but the process by which they generate images is more significant than the images themselves. Cohen describes the significance of cognitive processes in image-making:

> An image is a reference to some aspect of the world which contains within its own structure and in terms of its own structure a reference to the act of cognition which generated it. It must say, not that the world is like this, but that it was recognized to have been like this by the image-maker, who leaves behind this record: not of the world, but of the act [1].

Context Machines (presented chronologically in Fig. 1) share a number of core features: They all involve a computer-controlled camera, used to collect images of their visual context, and use computational methods to generate novel representations. *Resurfacing* [2] (see Section 3), developed by Bogart and Vakalis, is a precursor to the cognitively inspired *Context Machines* we have developed since. We discuss it to illustrate the transition between the overtly interactive artworks Bogart produced before 2006—where the viewer's behavior is integral to the work—and the emphasis on autonomy that informs our current cognitively oriented *Context Machines*.

Memory Association Machine [3] (Section 4) is an explicit application of self-organizing maps [4] (Section 2.4) and a simplification of Gabora's theory of creativity [5] (Section 2.3). In tandem, these processes provide a simplified "mind" for this machine, and our later projects depend on this central contribution. *Dreaming Machine #1* [6] and *Dreaming Machine #2* [7] (Section 5) use the same mechanism as *Memory Association Machine* in the construction of sequences of images that are framed as machine dreams. During the day, associations are initiated by images in the world, while at night they are randomly activated. *Self-Organized Landscapes* [8] (Section 6) are large and high-resolution print [9] collages that complement the *Dreaming Machine* installations. *Self-Organized Landscapes* far exceed screen resolution, and their structure reflects the self-organizing map's organization of thousands of pre-recorded images.

2. BACKGROUND AND RELATED WORK

Context Machines are characterized by features consistent with conceptual, site-specific and generative art practices. The genesis of *Context Machines* is the result of motivational elements that initiate, and are transformed by, our production process. They also inform the use of Gabora's theory and self-organizing maps.

2.1. Artistic Practices

In conceptual art, the *idea* is of equal or greater importance compared with the *object*. For LeWitt, "Ideas can be works of art; they are in a chain of development that may eventually find some form. All ideas need not be made physical" [10]. Both conceptual and generative art have a strong emphasis on process over object. Conceptual art includes "instructional" works, in which the artist provides a recipe for the construction of an artwork rather than a finished piece. These works are highly analogous to generative artworks, wherein the artistic concept is encoded in software instructions and executed by

Benjamin David Robert Bogart (artist), 250 13450 102nd Avenue, Surrey, Canada. E-mail: <bbogart@sfu.ca>.

Philippe Pasquier (teacher, artist), 250 13450 102nd Avenue, Surrey, Canada. E-mail: <pasquier@sfu.ca>.

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Article Frontispiece. ***Self-Organized Landscape #32 (Millstream Courtyard, University of Limerick: Study From Video),*** **Hong Kong, 2011. (© Benjamin David Robert Bogart)**

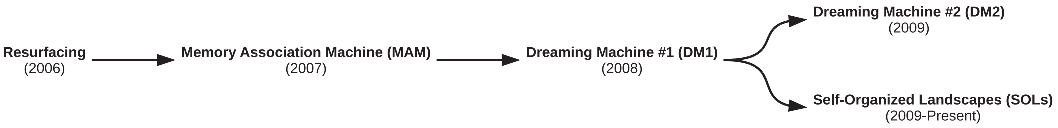


Fig. 1. The trajectory of *Context Machines* produced to date. (© Benjamin David Robert Bogart)

the computer. Site-specific art locates the meaning of an artwork in a specific social, historical or physical environment. For Kwon, a site-specific artwork gives "itself up to its environmental context, being formally determined or directed by it" [11]. *Context Machines* automate this task by literally capturing images of the environment and using them as raw material from which to generate their own representations. Generative art is a niche within the broader context of electronic media art, a contemporary art practice at the intersection of technology and cultural production. For Whitelaw, "New media art self-consciously reworks technology into culture, and rereads technology as culture." In his typology of a-life works, *Context Machines* can be considered hybrids of "Hardware" (where the importance of the physical world reflects the "movement of focus from inner to outer worlds") [12] and "Abstract Machines" (where there appears a "heightened attentiveness to form in itself and to processes of growth and transformation") [13]. The following motivational elements intersect with these artistic practices to varying degrees.

2.2. Motivation

Our development of *Context Machines* was the result of a practice that is both driven and constrained by three primary motivational elements: (1) Our central drive in building *Context Machines* is an emphasis on autonomy—we expect some degree of surprise in their output. (2) The situated nature of *Context Machines* reflects an interest in embodiment, where internal processes are causally linked to the physical world. (3) Scientific models are used to enrich the meaning of the work through a rigorous linkage between the technical and the conceptual. These elements define a territory of enquiry we refine as the works are developed.

2.2.1. Autonomy

The artwork should relate itself to its context, without that relation being predetermined by the artist.

This is our central motivation and informs *Memory Association Machine*'s production and remains in the background of all *Context Machines*. The use of an "intentional stance" frames the work as an autonomous entity that is capable of forming a relation to its context, which includes the audience. In order to form such a relation, the artwork must be embodied—albeit in a simplistic sense: The world impacts the system through the images collected by the machine, while the artwork impacts the world through the subtle effect of its representation on the viewer. For example, a rich and complex representation may encourage viewers to approach the work, which would increase the number of images of people collected by the system. In addition is the aspect of surprise, where the machine's representation should, to some degree, appear independent of the intention of the artist. This interest in surprise is analogous to the interest in erasing the "artist's hand" [14] in traditional art. In illusionistic painting, the lack of visible brush strokes gives the viewer the impression that the work is magical and disconnected from the artist while simultaneously testifying to her skill. The creative behavior of the *Context Machines* provides a similar magical quality: "The signs of the will of a creator are sometimes less palpable in these objects than a manifestation of a 'will' of their own" [15].

2.2.2. Embodiment

The artwork is a "transforming mirror" [16] *that takes input from the world, processes it, and reflects it back into the world.*

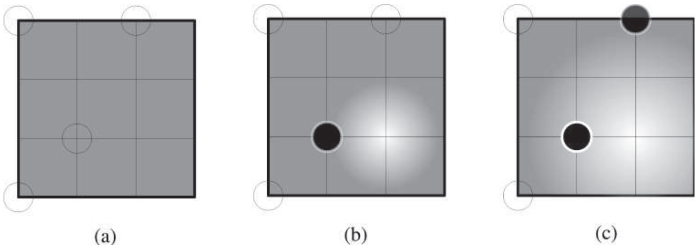
The outward-looking nature of the *Context Machines* qualifies them as "transforming mirrors." In interactive artwork, the system's sensors are typically directed at the viewer. The "transforming mirror" reflects the viewer back at him- or herself. The output of the system provides an abstracted *portrait*—a transformed representation of the viewer's behavior. In contrast, the cameras used in the *Context Machines* do not focus on the viewer but reflect the whole visual context of the work back onto itself. The visual appearance of the work is then a *landscape*—a representation of place in space and time.

2.2.3 Modeling

The artist is more interested in the concrete process of doing rather than the abstract notion of representing.

This motivational element reflects a conception of computation as a link between concept and object. It presents a naïve dichotomy between doing and representing that has been questioned both historically and through our practice. From a materialist perspective, the act of representation is no less physical than any other process. The root of this dichotomy originates in the potential lack of continuity between material reality and artistic concept. The interest in *doing* is a desire for a rigorous integration of concept and material. This is consistent with the practice of Expressive AI [17]

Fig. 2. Differing degrees of activation of memory components resulting from a query: The open circles are locations where a memory component is stored, the radial gradient represents the query, and the opacity of the filled circles reflects their degree of activation. (© Benjamin David Robert Bogart)



and is the foundation of the use of computational methods in our work, where the concept is encoded in software. In our current work, this interest in rigor leads to modeling, which bridges physicality and representation, and explains our interest in cognitive models. With the exception of *Resurfacing*, creative behavior is enabled by the explicit application of models from cognitive science and neurology. We have chosen models the properties of which align with our philosophical and artistic conception of the project and are appropriate for computational realization.

2.3. Cognitive Mechanisms Underlying the Creative Process

Gabora's conception of human creativity [18] is a core theoretical foundation of *Memory Association Machine* and *Dreaming Machines*. Gabora's theory focuses on the *generation* of creative ideas rather than their evaluation [19]. In essence, Gabora considers creative thinking a form of highly controlled association between memory components. These components are "micro-features" that define the qualities of memory. A creative thought process is composed of numerous cascades of these associations: A chain of many small, and perhaps obvious, associations can lead to extremely surprising and creative results.

The theory depends on three primary features: Human memory is content-addressable, distributed and sparse. These are features of the "conceptual space" (Fig. 2a)—a topologically organized space (gray plane) in which memory components (open circles) are situated. Memory components are content-addressable because they can be retrieved using their features rather than an arbitrary index.

A query, defined by the features of the item being searched for, is manifest in the activation of a location in the conceptual space (Fig. 2b). Memory components are activated inversely proportional to their distance from the query. The spread of activation allows the activation of multiple components that do not exactly match the features queried (Fig. 2c). The size and shape of the activation is controlled by conscious will. For Gabora, this is the cognitive manifestation of analytic and associative modes of thought. In analytic thinking, the activation function is small and tightly constrained in certain directions, allowing linear and rational links. Associative thinking results from a broader activation that spreads in multiple directions.

Memory components are not uni-

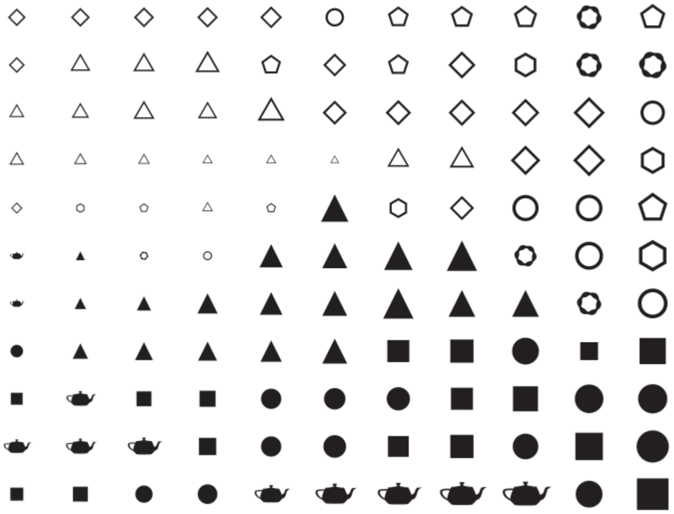
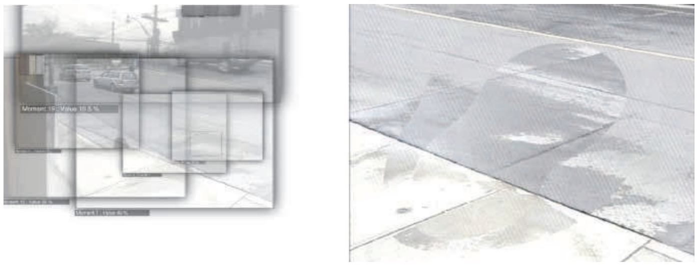


Fig. 3. A self-organizing map "feature-map" trained on images of black-and-white shapes. Note the clear boundary between filled and unfilled shapes. (© Benjamin David Robert Bogart)

Fig. 4. *Resurfacing* installation at the InterAccess Electronic Media Arts Centre in Toronto, 2006. (left) The screens and facade. (right) Interaction with the installation. (© Benjamin David Robert Bogart)

Fig. 5. Screen-grab details of *Resurfacing*. The interactive touchscreen is pictured on the right, while the collage is pictured on the left. (© Benjamin David Robert Bogart)



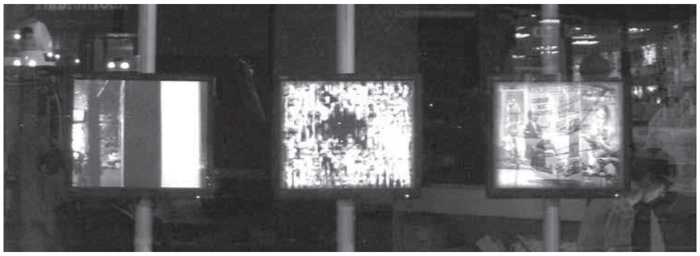


Fig. 6. Installation of *Memory Association Machine* at the Pure Data Convention in Montréal, 2007 (photographed during the night). (© Benjamin David Robert Bogart)

Fig. 7. *Memory Association Machine* photographed during the day. (© Benjamin David Robert Bogart)

formly distributed across the conceptual space, but form a sparse collection of islands of similarity where components can be associated using small activation functions. Islands can be bridged by large activation functions and correspond to "Eureka" moments.

2.4. Self-Organization

The ability of *Context Machines* to organize diverse visual images is enabled by the self-organizing map [20], which models a topological and content-addressable memory field analogous to Gabora's "conceptual space." The self-organizing map is an AI technique inspired by neurophysiology, composed of many simple units that work together to organize input patterns by similarity.

The result of a trained self-organizing map is a content-addressable "feature-map" that reflects the topology of the set of input patterns. The feature-map reflects the self-organizing map's structure—it is composed of a fixed number of units and often arranged in a two-dimensional grid. The feature-map associates input patterns with self-organizing map units such that similar patterns are associated with nearby units.

The self-organizing map is unsupervised—it does not require an external teacher but organizes input patterns based on the structure of those patterns alone. An example feature-map resulting from a set of images of various shapes at different scales is pictured in Fig. 3. The details of the self-organizing map, as it is implemented in *Memory Association Machine*, is discussed by Bogart [21].

2.5. Related Work

Context Machines are not unique in their use of computer-controlled cameras to capture images of the environment. A number of other art projects do so in order to create their own unique representations. David Rokeby's *Sorting Daemon* [22] and *Gathering* [23] are the most similar and use computer-controlled pan/tilt cameras to collect images of people. These images are sorted and scaled using a variety of algorithms to construct collages. These works are generative but do not make explicit use of cognitive models.

Byers et al. have constructed a "Robot Photographer" [24], a mobile robot that navigates through social gatherings in order to document participants via photographic snapshots. This project is meant to be overtly interactive: The viewer is expected to engage with the robot as if it were a human photographer. This project is technically similar to *Dreaming Machines,* as both use computer-controlled digital still cameras. While the Robot Photographer is oriented toward portrait photography, *Context Machines* use a multiplicity of images to create landscapes of various forms.

3. *RESURFACING*

Resurfacing [25] integrates both generative and interactive components and was produced before the cognitively oriented *Context Machines*. The artwork autonomously explores its visual context and collects images, which are stored in a navigable structure. The installation (Fig. 4) is composed of two screens housed in an architectural façade and a computer-controllable video camera mounted to collect images from outside the gallery. The system is initiated with 20 manually selected camera positions, indexed by the pan, tilt and zoom of the camera. Over the course of the installation, the camera continuously captures images as it cycles through these positions. The right screen (Fig. 5, right) shows a live video feed from the camera, while the left screen (Fig. 5, left) presents a collage of frames. The camera position (pan/tilt/zoom) is mapped to on-screen parameters (x/y/scale), resulting in an image that provides a slightly wider view that approximates, due to lens distortion and a lack of precision, the spatial relations between frames in the physical context. As the camera position changes, the collage is adjusted to match.

Sustained touch on the right screen results in a hole opening at the contact point that reveals corresponding images from earlier in time. As the viewer runs her fingers over the display, up to five layers of images, from the increasingly distant past, are shown. Each moment is annotated with a "value," calculated during each touch event, that reflects the relative number of contact events that occur while the moment is on screen. Each time a moment appears, its value is compared with a threshold. If the value is below the threshold, then a new random camera position will take its place during the next cycle. The value system is meant to rank moments by how much contact they receive, in order to replace low-value moments with new and potentially interesting ones.

Resurfacing aims to facilitate the viewer's examination of aspects of the world

Fig. 8. Sample of a feature-map generated by *Memory Association Machine.* (© Benjamin David Robert Bogart)

to which she may be habituated. The machine's gaze is strikingly different from that of a human. It tends to focus on visual items that are often ignored, providing a representational surface through which to encourage curiosity and exploration of the world.

4. *MEMORY ASSOCIATION MACHINE*

Memory Association Machine [26,27] (Figs 6 and 7) consists of three screens and a computer-controllable video camera. The left screen shows a live video feed from the camera, corresponding to the current stimulus. The middle screen (Fig. 8) presents the system's memory field [28]—the feature-map that results from the self-organizing map. The right screen presents *Memory Association Machine*'s associative sequence through collected images. Each screen presents one of the three processes that define *Memory Association Machine*'s behavior:

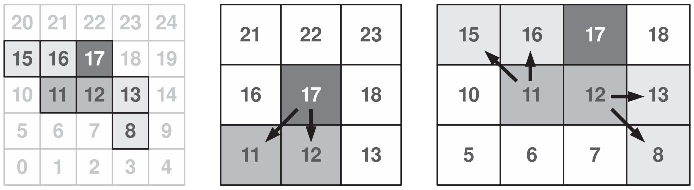
1. The *perception* process captures images from the visual context. The camera's gaze is driven by random pan/tilt values. For each associative sequence, the camera moves to a random position, and one image is captured. Each image is subsampled to 40×30 pixels and fed to the integration process as a vector of RGB values.
2. The *integration* process organizes captured images into the memory field, as enabled by the self-organizing map. The middle screen shows the memory field, where each node is represented by its corresponding image. To emphasize the content of the images—and de-emphasize their arrangement—Gaussianoid alpha channels are used (Fig. 8). The self-organizing map is continuously training as it attempts to learn the structure of the world. Due to the finite number of memory locations, and the complexity of the visual context, the self-organizing map will never converge at a stable topological representation that perfectly reflects the structure of the world.
3. The *association* process sequences images from memory and is enabled by an independent network of units that mirror the arrangement of units in the self-organizing map such that each unit is linked to a corresponding image in the memory field. When a new input stimulus is presented to the self-organizing map, the most similar image from memory is activated (presented on the right screen) and becomes the basis of a new associative sequence. The activation of an association unit results in the propagation of that activation to its neighbors to a lesser degree and after a random delay.

Figure 9a illustrates the overall pattern of activation: In Fig. 9b unit 17 is activated, to a degree represented by its shading. Two random directions are chosen, and the activation is propagated to neighbors between those two directions (units 11 and 12), to a lesser extent. Each of those units continues to propagate activation to an even lesser degree, as illustrated in Fig. 9c.

Each image is presented on screen with an opacity—and for a duration—proportional to the degree of activation. Every 12 seconds the camera chooses a new random direction, and a new image initiates another associative sequence. The length of these sequences is an emergent result of the interaction between the current image and the memory field. Reactivation is restricted by an inhibitory model that prevents already activated memories from being selected. Insufficient nighttime light restricts the duration for which *Memory Association Machine* is active. In order to continue to engage the audience, association units are randomly activated. This corresponds to the random activation of brain regions during dreaming, according to Hobson's model [29].

Memory Association Machine uses a novel combination of a self-organizing map and Gabora's theory of creativity to generate associative sequences of images. These images are collected from the visual context and represent the sum of the

Fig. 9. Propagation of activation signals resulting from associative sequences. (© Benjamin David Robert Bogart)



(a) (b) (c)

Fig. 10. ***Dreaming Machine #2*** **installation at Cinémathèque québécoise during the Elektra Festival, Montréal, 5–9 May 2010. (© Benjamin David Robert Bogart)**

Fig. 11. ***Self-Organized Landscape #12 (View from Overpass: Study from Video)*****, Hong Kong, 2009. (© Benjamin David Robert Bogart)**

system's experience. *Memory Association Machine*'s random nighttime associations inspired us to create *Dreaming Machines*, in which sequences are framed as machine dreams.

5. *DREAMING MACHINES #1* AND *#2*

In *Dreaming Machine #1* [30] and *Dreaming Machine #2* [31] (Fig. 10) we refined the associative process initiated in *Memory Association Machine*. *Dreaming Machine #1* is a prototype and uses the same video camera as in *Memory Association Machine* installations. In *Dreaming Machine #2*, the video camera is replaced with a digital still camera on a computer-controllable pan/tilt mount. Both *Dreaming Machines* use a single screen that presents a fusion of the memory field and the associative sequence (Fig. 11). Both *Dreaming Machines* manifest the same process and differ only in hardware and installation details.

In an installation of *Dreaming Machine #2* for the Elektra festival [32], the camera was mounted on the second floor and looked over the street below (Fig. 10, right). The associative sequence was projected on a large display in the lobby (Fig. 10, left). The display shows the current activated memory in the center of the screen, surrounded by its eight immediate neighbors, all masked with Gaussianoid alpha channels and overlapping 50 percent (see Color Plate C No. 2).

Whereas the camera in *Memory Association Machine* was driven by random pan/tilt positions, the *Dreaming Machines* use a random walk to trace the camera over the visual field. In the *Dreaming Machines,* images are not sub-sampled and fed directly to the self-organizing map, but are abstracted into color histograms. The use of histograms simplifies the task of organizing images. As demonstrated in the *Self-Organized Landscapes* (Section 6), the histogram is sufficient when used on unconstrained real-world images.

In *Memory Association Machine,* memory activation is similar to dropping a pebble in a pond—energy is propagated in multiple directions. This results in an extremely dense and complex network of associations. In the *Dreaming Machines,* an activated memory propagates only to its most similar neighbor. The strength of the activation, manifested in opacity, decays inversely proportional to the degree of similarity between memories. The more similar the memories, the less the signal decays and the shorter the duration they are visible. The temporal inhibition used in *Memory Association Machine* is replaced with memory-specific inhibition: A memory will be activated only if its referent is not in a ring-buffer that stores previously activated memories. These refinements result in sequences that progress smoothly through individual associations [33].

The *Dreaming Machines* complete the contribution made in *Memory Association Machine* through a more faithful application of Gabora's theory. An aesthetic weakness in *Memory Association Machine*

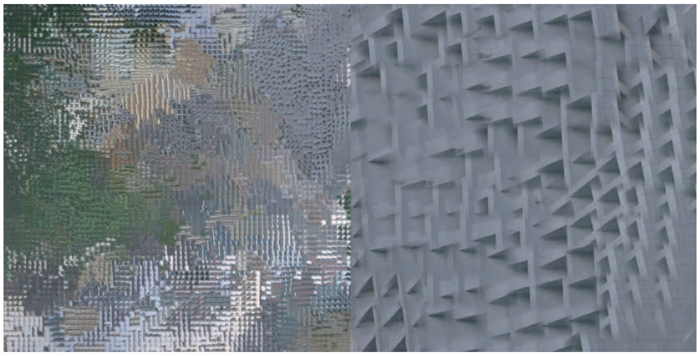


Fig. 12. (left) *Self-Organized Landscape #6B (Self-Motivated Study)*, Vancouver, 2009; (right) detail. (© Benjamin David Robert Bogart)

and the *Dreaming Machines* is that the self-organizing maps never achieve a topological representation of the world.

6. *SELF-ORGANIZED LANDSCAPES*

In the series *Self-Organized Landscapes*, we applied the self-organizing map to a finite number of images, which allows *Self-Organized Landscapes* to more closely reflect the topology of input images. *Self-Organized Landscapes* have inherited many of the processes we used in the other projects discussed here, but in *Self-Organized Landscapes* they are applied in the creation of high-resolution print collages (Article Frontispiece, Figs 11 and 12).

Self-Organized Landscapes can be grouped into two categories: One uses the same computer-controlled digital still camera we used in *Dreaming Machine #2*, and the other uses frames captured on a hand-held high definition video camera. A 150×150 unit feature-map trained on approximately 10,000 images, captured using the still camera, is pictured in Fig. 12 [34]. *Self-Organized Landscapes* in this category are "self-motivated," in that an algorithm is used to generate pan/tilt instructions. The next position of the camera is determined from an analysis of five regions—the left, right, top and bottom edges and the middle—of the current image. A histogram of each edge region is compared to the middle histogram. If the difference between the middle and left histograms is greater than the difference between the middle and right, then the camera pans left, to a degree proportional to the difference. The same process is repeated for the tilt axis. This mechanism is meant to steer the camera toward areas that differ from the previous image.

A *Self-Organized Landscape* constructed from video frames is pictured in Fig. 11. The set of images tends to have less variance than those captured with the still camera because of the short duration required for capturing images (10,000 images can be captured in ~5 minutes of video, while the same number of images takes the still camera ~8 hours). The difference in variance leads to divergent aesthetics in the resulting landscapes. Video studies tend to have clearer cluster boundaries and appear more organic. In the *Self-Organized Landscapes* we have directly applied knowledge attained through the development of previous installations.

7. FUTURE WORK AND CONCLUSION

Our current research is focused on *Dreaming Machine #3*, which explicitly implements interrelated cognitive models of perception, memory and dreaming. *Self-Organized Landscapes* are large, topologically correct representations and are ideal "memory fields" for the associative process used in *Dreaming Machine #2,* resulting in *Dreams of Self-Organized Landscapes.*

Context Machines are artworks whose generative representational processes are inspired by images captured from their installation contexts. We have found few examples of generative artworks that are informed by cognitive models of creativity and create images from visual material collected from the contexts of their installation. These works encourage us to see the world anew through a reconsideration of art, perception, memory, creativity and dreams. The artwork is meant to be a public discursive interface for questions such as: What are crucial aspects of creativity and dreaming? Can these extend to non-human animals and machines? What aspects of mind are not represented in AI systems and cognitive models? What is lost if we accept strict scientific conceptions of mind? A machine that creates and dreams is a reflection of our (perhaps misguided) conceptions of ourselves.

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References and Notes

Unedited references as provided by the authors.

1. H. Cohen. "What Is an Image?" in *Proceedings of the International Joint Conference Artificial Intelligence,* p. 24 (1979), <http://www.aaronshome.com/aaron/publications/whatisanimage.pdf>.

2. B. Bogart and D.M. Vakalis. "Resurfacing," in Philip Beesley et al., *Responsive Architectures, Subtle Technologies* (Riverside Architectural Press, 2006) pp. 182–183, <www.ekran.org/ben/wp/2007/07/06/resurfacing-2006/>.

3. B.D.R. Bogart, "Memory Association Machine: An Account of the Realization and Interpretation of an Autonomous Responsive Site-Specific Artwork," Master's Thesis, School of Interactive Art and Technology, Simon Fraser University (2008), <http://summit.sfu.ca/item/8969>.

4. T. Kohonen. *Self-Organizing Maps* (Springer, 2001).

5. L. Gabora. "The Beer Can Theory of Creativity," in *Creative evolutionary systems* (Morgan Kaufmann, 2002) pp. 147–162.

6. B.D.R. Bogart, *Dreaming Machine #1* (2008), <www.ekran.org/ben/wp/2008/dm1/>.

7. B.D.R. Bogart. *Dreaming Machine #2* (2009), <www.ekran.org/ben/wp/2009/dm2/>.

8. B.D.R. Bogart. *Self-Organized Landscapes*, 2009/2010, <www.ekran.org/ben/wp/?cat=13>.

9. Print is the ideal reproduction method for *Self-Organized Landscapes* due to their high resolution (approximately 30,000×30,000 pixels).

10. S. LeWitt. "Sentences on Conceptual Art." *Art-Language,* Vol. 1, pp. 11–13 (1969).

11. M. Kwon. *One Place after Another: Site-Specific Art and Locational Identity* (MIT Press, 2004) p. 11.

12. M. Whitelaw. *Metacreation: Art and Artificial Life* (MIT Press, 2004) p. 103.

13. Whitelaw [12] p. 148.

14. For a discussion on the erasure of the "artist's hand," see J.D. Bolter and R. Grusin. "Remediation: Understanding new media." *Journal of the American Society for Information Science,* Vol. 50, No. 8, pp. 730–732 (1999).

15. Whitelaw [12].

16. D. Rokeby. *Transforming mirrors: Subjectivity and control in interactive media,* Chapter 7 (SUNY Press, 1995) pp. 133–158.

17. M. Mateas, "Expressive AI: A Hybrid Art and Science Practice," *Leonardo* **34**, No. 2, 147–153 (2001).

18. Gabora [5].

19. For more information on the role of evaluation in creativity see M.A. Boden, *The Creative Mind: Myths and Mechanisms,* 2nd Ed. (London: Routledge (2004).

20. Kohonen [4].

21. Bogart [3].

22. D. Rokeby. *Sorting Daemon* (2003), <http://www.davidrokeby.com/sorting.html>.

23. D. Rokeby. *Gathering* (2004), <http://www.davidrokeby.com/gathering.html>.

24. Z. Byers, M. Dixon, W.D Smart and C.M. Grimm. "Say cheese! Experiences with a robot photographer." *AI magazine,* Vol. 25, No. 3, p. 37 (2004).

25. B.D.R. Bogart. "Self-Other Organizing Structure 1: Seizures, Blindness & Short-Term Memory," in Andrew Brouse, ed., *Proceedings of the Second International Pure Data Conference,* Montréal; 21–26 August 2007. Pure Data Conference 2007 (2007). <http://artengine.ca/~catalogue-pd/9-Bogart.pdf>.

26. B.D.R. Bogart and D.M. Vakalis [2].

27. *Memory Association Machine* was originally titled *Self-Other Organizing Structure #1.*

28. This memory field results from a test installation and is composed of 12×12, rather than 20×20, units.

29. J.A. Hobson. "REM sleep and dreaming: Towards a theory of protoconsciousness," *Nature Reviews Neuroscience,* Vol. 10, No. 11, pp. 803–813 (2009).

30. Bogart [6].

31. Bogart [7].

32. <http://elektrafestival.ca/>

33. See dream samples in supplementary material. A selection of dreams, exhibited at Transmediale: <http://www.ekran.org/ben/video/DM2-Dream Selection.mpg>.

34. The same image may appear in multiple locations in the collage.

Chapter 3

Imagination, Art and Reality

As submitted as book chapter to Techne Technique Technology (tentative title) edited by Camille Baker and Kate Sicchio (September 2013). This chapter is written from a first person artistic perspective, intended for a non-academic art audience and is speculative in nature.

I must admit, I am somewhat of a contrarian. One of the greatest motivations for me is to refute some dominant idea. At worst, a contrarian could be considered someone who cares not about ideas themselves, but only their cultural dominance. I prefer to consider this proclivity as providing a valuable service: by being critical of the dominant, I provide greater balance and diversity in the world of thought. As an artist, I believe my role in cultural production is the exploration of what art is and could be. Art is, at least partially, a process of articulating and transforming what art is.

This paper is an articulation of the key themes that structure and inform my art-as-research (Busch, 2009) practice: (1) the framing of art as exploratory, rather than expressive, (2) an explicit articulation of knowledge-making at the intersection of science and art, and (3) an emphasis on processes of representation and meaning — how a representation holds *content* — which is considered philosophically and cognitively. These themes have been developed through art productions, collaborations and discussions and are informed by readings in philosophy, cultural theory, psychology and neurobiology. The influence of these themes expand beyond the artistic practice itself and permeate my life and world-view. This paper is but a snapshot in the life of these ideas; they are continually refined as my practice develops. This paper could be considered a signpost marking a shift of emphasis from artist to artist-theorist.

I hope this text, just like my artworks, beg more questions than provide answers. I strive to challenge us all to question the dominance of particular systems knowledge and what they say about us and our culture. In this paper, I endeavour to express my state of thought, as it currently stands, as genuinely as possible. I do so without the constraints and need for validation emphasized in academia, or even without acceptance in contemporary or electronic media art (Bogart, 2008). Whether you accept these notions or not, my only hope is that they stand to enrich your perspective, in either agreement or opposition.

3.1 Art as Exploration

I am not very interested in art objects in themselves. The significance of objects is not in their form, but in their meaning. Objects are important in how they structure and constrain human behaviour and also inspire interpretations different from those intended by the object's creator. The objects of art are articulations, demonstrations, realizations and documentation of the process of art-making. In my Masters thesis (Bogart, 2008), I described the effect of an artwork on a viewer as a "perturbation", borrowed from creativity researcher Liane Gabora (2000b). I consider the viewer's mind as a pool of experiences and knowledge. The sensory experience of an artwork is like a pebble being dropped into that pool. It is not that the artwork produces a message that is received by the viewer, but that an artwork initiates a cascade of activations that extend far beyond the pebble's initial impact. Our minds are not still pools; they are constantly active with some neurons firing due to external stimuli, and others firing due to internal activation. In fact, it is very difficult to follow causation in brains. When we talk about representation in art we are really talking about how the experience of a shared world, mediated by a shared culture, can allow one person to produce an arrangement of material (artwork, symbols, etc.) that causes a somewhat predictable set of associations and interpretations in the viewer/reader. This predictability depends on the shared cultural knowledge which itself is dependent on the stability and constraint provided by a shared physical world in which we live, without which there would be no grounded meaning.

Artists are also engaged in a similar process of perturbation. When an artist manifests their will in material, they become a viewer. The artistic idea is no longer a thought in their mind, but a sensory reality before them. The tension between what they expected and what occurred could either (a) facilitate an optimization process where differences between intention and reality are reduced, or (b) inspire a novel interpretation that shifts the intention of the artist, and thereby the direction of the project. The resulting optimization, or shift in intention, informs future choices made by the artist. The artist continuously makes choices and evaluates those choices in what I describe as the realization→interpretation loop (Bogart, 2008, Chapter 6). The interpretation of a work is a key aspect of artistic production, and thus the viewer and the artist are engaged in very similar processes of finding meaning in objects through the cascade of activations resulting from the objects presence.

Let us consider artistic practice as a continuum between exploration and expression. Expression is an emphasis on arranging material to elicit particular patterns of perturbation in the minds of the viewers for the purpose of communicating particular notions. Exploration is an examination of the relation between culture and objects in the shared physical world. The focus is on the mechanisms of the interaction between the world and ourselves that leads to perception, recognition, representation and even prediction. My practice emphatically emphasizes the exploration side of this continuum. This interest leads my practice to a strong emphasis on systems, causality and the rigorous scientific processes that produce rich and deep meaning about the physical world, and ourselves. These interests are currently manifest in the contextualization of my work in (1) technology, in particular approaches to artificial intelligence, machine learning and machine creativity and (2) brain science, in particular cognitive, psychological and neurobiological conceptions of mind and brain.

Knowledge from these disciplines is considered in a critical and culturally-centric context where they are expected to contribute to the design of a generative site-specific electronic media artwork, a *Dreaming Machine.* This artwork has seen multiple revisions and re-conceptualizations, manifested in different contexts and exhibited under multiple titles.[1] My focus on mechanisms and processes means that these various realizations are manifestations of the same conceptual framework. My practice has always been an artistic examination of the relation between those technologies we build and ourselves. *Dreaming Machine #3* is the current incarnation of the project, developed during my doctoral studies, and follows from a series of generative site-specific installations called *Context Machines* (Bogart & Pasquier, 2013a).

3.2 Art and Science

There is a complex and long historical relationship between arts and sciences that is out of the scope of this paper. Instead, I aim to provide a set of conceptions that have helped me carve out a space between the two in my current practice. Arts and sciences are practices that construct culturally relevant representations that function as tools exploited in our attempt to make sense of the world and ourselves. In arts, these representations are often artworks themselves, be them music, sculpture, dance, or even ideas or complex information patterns contained in a computer. Often these artworks make reference to the history of art, the world, or simply to pure sensual experiences. In sciences, these representations are the figures, texts and mathematical models used to describe the object of study. The *object of study* may be physical or conceptual and may refer to a process or even an experience. It is not the media that defines these disciplines, as both artists and scientists exploit any available media in the service of their practice. The artist may be just as capable of writing a text as a scientist, while a scientist may be just as capable of drawing a figure. An artwork can be described by a set of equations just as an image can describe

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[1] *Self-Organizing Structure #1*, *Memory Association Machine*, *Dreaming Machine #1*, *Dreaming Machine #2*.

a neurobiological theory.

The difference between arts and sciences is more a question of emphasis than a hard distinction. The strict parlance and methods used in sciences are used to constrain the number of possible interpretations that can be read into a scientific work (model or theory). Science favours causal, rational and objective ways of thinking. If a scientist is to embark on purely theoretical work, then the purpose is to inspire future empirical study to support or refute that theory. The primary value of scientific research is in the model or theory's power to explain or predict the structure or behaviour of the object of study. The process of validation is the mechanism by which we can evaluate the value of the results of scientific research. In the case of prediction, this is done by creating experiments that compare measurements of the model with measurements of the actual object of study. The results of these experiments are then used to transform the theory. This transformation can be as harsh as to abandon the theory entirely,[2] or as benign as to simply refine it. What is important to note here is that the empirical work done in scientific research is situated in a context of knowledge and theory that is constantly refined and tested.

There is a clear definition of the object of study in science because such strictness is required for the explanation and prediction of the object's properties. These definitions constrain the creative process of designing experiments. It has been noted by Kuhn (1962) that revolutionary discoveries in science are (by definition) at odds with the dominant knowledge of the day. These may even involve a change of the definition of the object of study — constructing a novel perspective. It is possible that by encouraging more broad conceptions and definitions of the objects of study, we inspire more broadly ranging empirical work — pushing research into less explored territories. Thus, we can consider two processes in play in scientific research: (a) *validating* — the rational and objective process of testing implications and predictive power of theories and (b) *theorizing* — the creative and generative process of developing theories and alternative definitions meant to inspire future empirical work.

In representational arts, the object of study is quite clear, it is that which the artwork is a representation of. The artwork itself is analogous to the scientific theory produced in a context of existing knowledge and theory. The artist validates his or her theory continuously as the artwork is constructed. Each time she considers the relationship between the realization and interpretation of the work, she is engaged in a process of validation. As in science, there is much latitude as to what could constitute an appropriate object of study. Representational arts then are most closely aligned with the scientific process of *validating* a representation against reality.

In non-representational arts, things become quite a bit more muddy. The object of artistic study could be any experience, process or idea. Being non-representational, the object of study is anything except for a physical object out in the shared world. In the natural sciences, the object of study is physical because knowledge can only be objectively validated against physical properties

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[2] We must keep in mind that failed experiments have significant value in contributing to theory development.

that can be independently measured. Indeed, the notion of a non-representational natural science is nonsensical because the purpose of natural science is the description, explanation and prediction of reality. Non-representational arts engage in *theorizing* in order to encourage novel perspectives that are meant to inspire future artworks and ideas.

In the case of natural sciences, *validating* and *theorizing* are rarely considered in isolation because the predictive and explanatory power of scientific theories are only deemed valid if supported by empirical study. In the case of arts, representational and non-representational modes could be considered almost independent disciplines. All this assumes that representational arts and scientific objectivity both have a privileged perspective on reality. In the arts, it is trivial to imagine an artwork that is simultaneously representational and non-representational. A single image could have differing degrees of realism where one part is clearly representational and another slides into abstraction as to become totally ambiguous. I think of representation and non-representational arts as being two sides of a continuum. On one end of the continuum we have *validation* where we strictly match the representation with external reality such that the representation encapsulates the essence of the object of study. On the other end we have *theorizing* where representations refer to other representations (stories, histories, ideas) and strict validation is not possible because the representation is increasingly abstracted from that which is represented. This describes a continuum of abstraction where *validating* involves a decreasing amount of abstraction and *theorizing* involves an increasing amount. As abstraction increases — and we loose the ability to validate against reality — we begin to consider the form of the abstraction itself. In art, we concern ourselves with formal properties such as composition, colour, line, et cetera. This formal evaluation is not limited to arts but also surfaces in the evaluation of science where Occam's razor is concerned with the elegance of a theory.

Lets take a concrete example: Imagine a prehistorical artist drawing in charcoal on a cave wall with the intention of representing a human figure. Either another human is present to serve as a model, or the artist works from memory. The task of translating the sight, or memory, of a figure into a charcoal representation is extremely complex because of the lack of fidelity of the media (charcoal on rock), and thus the artist must make many compromises in the representation. Only the strongest and most essential features of the figure are manifest in the drawing. While the drawing is validated against reality, the properties of the media itself interfere with the fidelity of the representation. The stability of the media and the object of study leads to stability in the representations. Eventually, the figure that roughly resembles a human being becomes a signifier for a human, and future drawings need no longer to be validated against reality. The repetition of drawing and redrawing the figure over time begins a process of optimization — where the symbolic value is retained while the form itself continues to evolve. It could eventually transform so significantly that it bares no resemblance to the original cave drawing. The form could even be distorted to the point of being non-representational where it lends itself to any number of contradictory interpretations. At this point, the representation becomes a total abstraction — a form whose representational content is ambiguous. The point here is twofold: (1) there is a continuum of increasing abstraction between *validating* and *theorizing*, and (2) that the process of validation is mediated. The utility of an abstract representation is in its lack of resemblance to reality because it allows the greatest flexibility in its use. If all representations were highly accurate they would have little practical value because the representation would be just as awkward as reality. Imagine carrying around a life-size sculpture of a dear friend, presented every time you wanted to refer to that individual. As we allow increasing transformations of the representation (e.g. from a life-size sculpture to a photograph) their fidelity decreases, but their flexibility increases. We end up with total abstractions such as the words on this very page whose utility is nearly infinite because of the ease with which they can be deployed, which is a direct result of their lack of resemblance to reality. The symbolic meaning of abstract representations then depends on their context. Without an understanding of context, it would be nearly impossible to narrow the field of possible interpretations to that which the author or artist intended. Thus, with increasing abstraction representations gain flexibility, descriptive power, and greater context dependence.

Let us return to natural science. When we speak of the validation of a theory — by comparing what the theory indicates with reality — we are required to make measurements of the world. The eyes and perceptual abilities of the representational painter provide an analogous apparatus for the measurement of the object of study. Measurements are, by their nature, probes. These subsets of the world are abstractions from the very start because (1) they are extracted from their contexts in reality and (2) because the media (the measuring device) interferes with the representation, i.e. a measurement has a limited granularity at which point differences are no longer measurable. A scientific theory can only be validated insofar as the measurement apparatus used in the experiments allow. Theorization, as the use of abstraction in generating representations of the world, is not only an important component of arts and sciences, but is intrinsic to general cognition.

3.3 Cognition

When sighted and hearing infants learn the labels that represent objects out in the world, they are learning an association between the sound of the word and the objects the infant can visually perceive. On the first presentation of the object and the word, an infant could be associating any number of visually present objects with the word. It is through the ongoing presentation of the word and the object in different contexts, and the infant's shared attention with her care-giver, that a specific association can be made.

Lets return to the pool analogy introduced earlier in this text. We can consider both the audible word "dog" and the visual appearance of the dog as two pebbles simultaneously falling into the pool. Many parts of the mind can be simultaneously activated, even when we are only consciously aware of a small subset of that activation. Unlike a pool, some parts of the mind are more connected than others, and thus the activation propagates unevenly. The ripples are not concentric circles, but complex asymmetrical loops.

When we learn correlations between words (e.g. "dog") and objects (e.g. dog) we are making it easier for the pebble's energy (activation) to pass from one part of the pool to another. Our minds are able to constrain and reinforce certain connections in certain contexts, both consciously and unconsciously. We can attend by directing the pebbles activation in differing directions. We cannot limit our conception of perception to a simple causal interaction between the pebble and the pool because perception cannot be reduced to the sensory processing of the eye. Perception is a perturbation of the viewer: a consideration of sensory experience (pebble) in the context of all the resulting associations (the state of the whole pool).

Numerous psychological experiments (e.g. Davenport & Potter, 2004; Yi et al., 2008; Diekhof et al., 2011) have confirmed that our intention and expectations have great influence on our perception of the world — particularly in cases when sensory information is ambiguous (e.g. Meeter & Olivers, 2006). Perception is not the inactive reception of information from the world, but an act that directs activation in the mind. We may interpret the same object as one thing in one context and another thing in another context (Oliva & Torralba, 2007). This is because the context changes the activity of the pool, and therefore changes how subsequent activation is propagated within it. Many of our expectations are implicitly learned, and thus the patterns of propagation are modulated by unconscious processes.

Let us put this in the context of a concrete example: A person sees a familiar dog on their way to a meeting for which they are late. The sensory impression of that dog causes a pebble to activate the pool. Previous experience of this dog leads to the activation of a simulator that corresponds to this particular dog. Activation propagates more deeply into the pool, recruiting increasingly abstract simulators, including those for this particular breed, dogs in general, and extending all the way down to the simulator that has learned the concept of an animate object. The activation of these simulators prime the pool with potentially relevant information. The result is that the surface will process some information more quickly because it is primed and expected to occur, including dog's name, the feeling of his fur, a wet nose and an image of the last time the person saw this particular dog. The fact that the person is late for a meeting is not forgotten; this strong task-oriented drive is still modulating the surface of the pool. This modulation emphasizes the motor actions required to get to the meeting over the primed motor actions to pet the dog. After the person has finished the meeting, she walks back along the same route. She walks past the location where the dog was seen earlier and begins to day-dream. This sensory context causes an activation in the pool's surface, resulting in the activation of a simulator for that location in space, which recruits the simulator for that particular dog because it was recently experienced. She proceeds to pet the dog in her imagination, which is manifest in the recruitment of a number of simulators including the motor movements of petting the dog, the sensation of the fur, and so on.

When we recollect an image in our minds, the same part of our brains are activated as when we initially experienced the stimulus (Graham et al., 2010). Remembering is like arranging the pool of our minds in a particular state that resembles the state in which we stored the memory. When we remember, imagine or dream, a specific part of the pool is put into a particular state. We can consider memories and mental images as the result of instructions that specify how to arrange a particular part of a pool to resemble the memory or image. To extend the pool analogy, the surface of the pool is concerned with sensory information, while the water beneath the surface contains the instructions and mechanisms that are able to constrain and manipulate the activity of the water's surface. The instructions are simulators organized in hierarchies, and the memories are simulations. The state of a particular part of the surface (simulation) is a function of the simulator immediately below it. These hierarchies of simulators extend deep into the pool and those closest to the surface are the most concrete and correspond to the *validating* end of the continuum described above. As we delve deeper into the pool, these simulators are increasingly abstract, leading to the *theorizing* end of the continuum. The deeper the simulator, the greater the influence over larger regions of the water's surface. The simulators change the activity of the pool's surface to emphasize particular associations over others and constrain the propagation of activation from external stimuli.

Our perceptions are the result of simulators in our minds interacting with external sensory information in the construction of mental images. When we recognize an object out in the world it is not a pebble simply causing a cascade of activations. Perception requires an interaction between the sensation and the simulation such that they form a reinforcing state. When we are exposed to an ambiguous stimulus, our simulators use the available sensory information and fill in details not seen by our eyes.

This process resembles the process of both artistic and scientific enquiry. Our sensory organs and technologies provide probing measurements of the physical world which lead to theories (ideas, concepts, correlations and artworks) that are refined through an ongoing process of continuous measurement and simulation. Theories constrain the impact of measurement and sensation, changing what aspects of the world deserve emphasis. Simultaneously, measurement and sensation support and ground theories in reality. The notion that art is more about an act of cognition than creating forms was noted by the early pioneer of computer and generative art, Harold Cohen (1979), who stated:

> An image is a reference to some aspect of the world which contains within its own structure and in terms of its own structure a reference to the act of cognition which generated it. It must say, not that the world is like this, but that it was recognized to have been like this by the image-maker, who leaves behind this record: not of the world, but of the act.

3.4 A Machine That Dreams

A Machine That Dreams is the title of the art-as-research project that constitutes my doctoral work. The interest in dreaming came about as a result of my previous enquiry into machine creativity. This examination of machine autonomy and creativity is manifest in the series of artworks titled *Context Machines* (Bogart & Pasquier, 2013a), that all use generative processes to transform raw material collected from their environment into novel representations.

The idea of a machine that is more than a sum of its parts could be considered the central tenant of my art-as-research practice. This work is not only an enquiry into the limits of our machines (Wilson, 1995), but also in those representational processes we use to make sense of the world and ourselves. It is easy enough to consider a causal notion of meaning, where external stimulus drives mechanistic processes that result in the "illusions" of agency and consciousness that pervade our experiences. These conceptions beg the question whether there is any difference between the causal processes in play in geology or fluid dynamics and those that constitute animate life.

In machine creativity, it is common to think of a dualistic process of generation and evaluation. Some generator is able to create nearly limitless variations in ideas and form, but most of that variation will have no social or functional value. A secondary process intentionally drives, constrains and filters the results of these generative processes. Selecting only those with the potential to become socially acceptable or functional. My interest in dreams arose from a dissatisfaction with thinking about creativity in this way. Dreams contain great variation and flexibility, and yet present a somewhat cohesive world still containing characters, locations and social interactions. Dreams are creative because they generate novelty contextualized in the concerns and experience of the dreamer. It is certainly thought, thanks to Freud and Jung, that dreams reflect meaningful insights into ourselves, insights of which we may not be consciously aware. Dreams sit at the very interesting intersection of simulation and reality, where they are known to contain elements learned from waking experience, and at the same time are capable of generating impossible juxtapositions.

The default state of mind is generative, rather than reactive. We imagine the world, not in purely subjective isolation, but in the context of the very real sensory information that we receive from it. We don't create the world but we do complete it, read into it, and transform it. Our simulations of reality are not copies, they are ongoing collaborations between ourselves (explicit and implicit, conscious and unconscious) and the world. Our dreams show the flexibility of our systems of imagination, and I think could be key in understanding cognition in relation to the world.

I am not interested in the content of dreams, but rather the mechanisms that generate that content. This interest in mechanism is what lead me to neurobiological conceptions of dreaming. At first it was the notion of agency that interested me. Taking Merleau-Ponty's phenomenology (1968) as a starting point, I've ever since been attempting to resolve the hard objective argument that we are nothing but cascades of mechanistic causal processes and our apparent will, consciousness and agency are illusions. While I concede that none of these things is quite the same as we experience them, that does not mean that there is no causal role of consciousness in the world.

The artworks in the *Dreaming Machine* series began as an attempt to take the mechanistic conception of mind as far as I could take it. The hope is that the productions of the machine are a surprise to myself. The system's processes take the sensory information from out in the world and actively constructs images that resemble perception, mind wandering and dreaming. These images are not perfect mirror reflections of the external world, but collages produced by the system's attempt to make sense of and predict the complexity of reality.

The work conceptually folds in on itself. Our minds make sense of the world and we generate our own internal structures that reflect our knowledge of it. Then the scientists, philosophers and artists among us, take this process as an object of study and generate representations, studies and models that attempt to make sense of how we make sense of the world. Then there are those who build simulations, systems of representation that dynamically act. They are representations, but representations that participate in the causal flow of the world. These simulations, of which the *Dreaming Machines* are an example, take the abstraction an additional step further and enact the knowledge encoded in models. When these systems are presented as artworks, the loop is completed. While the system is being perturbed by our presence, we are being perturbed by its presence. We attempt to glean meaning from the images produced by the system, while those very images are the result of the system attempting to glean meaning from us. When we gaze into the machine, we see ourselves reflected back. We don't see ourselves only in the images in which we recognize ourselves, but also in the system's mechanism: We see a system that manifests those neurobiological conceptions of mind, perception and dreaming that we use to understand ourselves — even if we don't recognize it.

My motivation is not to produce a model validated by scientific standards, but to facilitate, inspire and enrich the discussion around those systems of knowledge through which we know ourselves and how they are constructed. Just as our simulations of the world are tools that have utility in the context of our experience, so too are the models produced in sciences and the artworks produced by artists. Perhaps they don't actually tell us all that much about the world itself, perhaps their true value is in how they stand as records of our own processes of making sense of the world. When we peer out into the complexity of the world and we recognize, we are recognizing as mediated by our concepts, by our simulations that tell us what we should expect to see. What we perceive is as much us as it is the reality beyond us. When we peer into the depths of space and into the microcosm of the infinitesimal, we are looking into ourselves — into those very processes that allow us to make sense of anything, those processes that make us who we are.

Chapter 4

An Integrative Theory of Visual Mentation and Spontaneous Creativity

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An Integrative Theory of Visual Mentation and Spontaneous Creativity

Benjamin D. R. Bogart / Philippe Pasquier
School of Interactive Art and Technology
Faculty of Communication, Art and Technology
Simon Fraser University
250 - 13450 - 102nd Avenue, Surrey, BC, Canada
bbogart@sfu.ca / pasquier@sfu.ca

Steven J. Barnes
University of British Columbia
2329 West Mall, Vancouver, BC Canada
sjb@nervouscreation.com

ABSTRACT

It has been suggested that creativity can be functionally segregated into two processes: spontaneous and deliberate. In this paper, we propose that the spontaneous aspect of creativity is enabled by the same neural simulation mechanisms that have been implicated in visual mentation (e.g. visual perception, mental imagery, mind-wandering and dreaming). This proposal is developed into an Integrative Theory that serves as the foundation for a computational model of dreaming and site-specific artwork: *A Machine that Dreams*.

Author Keywords

Dreaming; Creativity; Mental Imagery; Mind-Wandering; Perception; Default Mode Network; Generative; Simulation; Art; Neuroscience; Biopsychology

ACM Classification Keywords

J.5 [Arts And Humanities]: Fine arts; I.2.0 [Artificial Intelligence]: Cognitive simulation

INTRODUCTION

Perception does not produce a perfect replica of the world: Percepts are an amalgam of sensory information and our expectations [28]. Indeed, the visual perceptual system has often been described as a *creative process* (e.g., [13]). In this view, visual perception is the result of the construction of highly detailed impressions of our external reality that are not reducible to either the world, or the agent's expectations. The existence of constructive mechanisms in visual perception indicates that certain aspects of creativity may be rooted in ordinary mental processes (see [30]). While perception is constrained by external sensory information, mental imagery involves the construction of images in the absense of, or in conflict with, sensory information.

Dreams are meaningful simulations, however abstract, of a somewhat familiar world and may even have functional value. Dreams can be as simple as banal thoughts or images, or as complex as long recurring melodramas. They are often thought of as bizarre, and may include chimeric elements — fusions of multiple places or people. There are two popular biopsychological conceptions of dreaming: Dreams result from our perceptual system's attempt to make sense of random activation in sensory regions of the brain, or dreams are akin to mental imagery and are largely independent of the sensory systems. Mind-wandering (day-dreaming) and dreaming overlap in their content and involve similar modulations of cognition — e.g. the lack of self-reflective awareness. Perception is highly constrained by external stimuli while dreams occur in the absense of external stimuli. Mind-wandering is a diversion away from external stimulus toward internally generated imagery.

It has been established that creativity involves, at least, the generation of ideas or artifacts that are both novel and valuable [26, 4]. This definition of creativity is concerned with the products of a creative process, rather than the characteristics of the process itself. Both novelty and value are evaluations of ideas or artifacts in the context of their production and use. The scope of such evaluations can be relative to the life-time of the individual (*Psychological-Creativity*) or to the whole of human history (*Historical-Creativity*) [4]. The difficulty with the evaluation of both novelty and value is their context dependence; an artifact considered creative in one culture, domain or time-frame may not be in another. The importance of context makes automated evaluation in computational creativity challenging. In this work we segregate generative and evaluative modes and focus on the former.

The contributions of the present work are twofold: First, we propose an Integrative Theory of perception, dreaming, mental imagery, mind-wandering, and spontaneous creativity wherein all of these phenomena exploit overlapping mechanisms of simulation**.** These mechanisms are enabled by a common set of perceptually-oriented associative representations. Second, our theoretical proposal serves as the foundation of a computational model and artwork that constructs images from sensory components through creative processes manifest during each of three states: (1) perception, (2) mind-wandering and (3) dreaming.

Our computational model, the *Dreaming Machine*, serves three major purposes in itself. First, it formalizes the Integrative Theory and provides a site for the evaluation and refinement of that theory. Second, it is also an artwork contextualized in a series of generative site-specific installations [6]. Thirdly, the manifestation of the theory in an artwork broad-

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ens discourse on creativity and visual mentation beyond traditional scientific contexts.

BACKGROUND

Visual aspects of perception, mental imagery, mind-wandering and dreaming are all modes of thought that are experienced visually. Accordingly, in the present paper, we will refer to these modes, collectively, as *visual mentation*. This section of the paper discuss biopsychological theories of both visual mentation and spontaneous creativity. It will be shown that these theories all share certain characteristics that serve as the basis of the Integrative Theory, to be presented in a later section. In terms of creativity, we discuss Dietrich's [8] proposal for a neurobiological basis of creativity. In terms of dreaming, we describe two major theories: (1) Hobson's [11] proposal that dream experiences are the result of random activations of sensory and perceptual regions of the brain, and (2) Nir and Tononi's [20] proposal that dreams are more closely related to mental imagery than perception. Kosslyn's [16] theory of mental imagery compliments Nir and Tononi's proposal. Finally, we present Domhoff's [9] proposal that dreaming and mind-wandering recruit overlapping components of the *default mode network* (DMN).

Two Creative Processes

Dietrich [8] proposes a neurocognitive framework where creativity is considered *integral* [8] to the study of cognition, is a *fundamental* [8] aspect of human activity and is grounded in ordinary mental processes. The consideration of creativity as a general aspect of cognition implies that the study of creativity may provide insights into other mental processes, such as dreaming and mind-wandering, and vice versa.

As illustrated in Figure 1, Dietrich's framework divides the brain into two major functional regions: (1) The temporal, occipital and parietal lobes of the cortex (TOP), shaded in grey in Figure 1, hold high-level and long-term representations of sensory information and enable spontaneous creativity. (2) The prefrontal cortex (PFC) accesses these representations during deliberate creativity and is implicated in executive functions such as self-awareness, planning, decision making, working memory and attention. In Dietrich's framework, the PFC provides the evaluative mechanisms that shape and/or filter novel thoughts, thereby deeming them creative or not. In particular, working memory, which involves the PFC, is important for creative cognition as it provides a facility for the manipulation of representations — required for flexible shifts in cognition and access to the TOP.

Dietrich proposes two major modes of creative insight: (1) *a spontaneous* mode, which results from associative activity within the TOP, and (2) *a deliberate* mode, which results from goal-oriented manipulation and refinement of ideas in the PFC. These modes are not meant to be exclusive; creative practises involve both.

The spontaneous mode generates insights that may be *random, unfiltered, and bizarre* [8] and are promoted to the PFC for evaluation. This mode is enabled by cognitive processes that are unconscious and therefore unconstrained by the bottleneck of conscious thought. Dietrich considers spontaneous creativity as only a *starting point* because "[i]nnumerous insights turn out to be incorrect, incomplete, or trivial, so judging which insights to pursue and which to discard requires prefrontal cortex integration" [8]. For an idea to be considered creative, it must undergo evaluation in terms of novelty and value. If it is lacking in either area, then it is refined through prefrontal interactions with other brain regions.

The generation of ideas is not limited to the spontaneous mode, but can also occur in the deliberate mode where insights are "structured, rational, and conform. . . to internalized values and belief systems" and are limited to established conceptual structures *(preconceived mental paradigms* [8]). An individual engaged in the spontaneous mode requires only a diverse sensory experience to generate novelty, but knowledge and skill, developed over years, are required for fruitful creativity in the deliberate mode. Creativity requires a balance between both deliberate and spontaneous modes, and yet "[s]ome of the most brilliant ideas in the history of science. . . " [8] appear to arise from the spontaneous mode.

The mechanisms of creativity described in this section highlight a division of labour in creative thinking. The spontaneous mode is education independent, unconscious, and has extreme generative potential. Unfortunately, this mode may generate insights that cannot be considered creative, due to their lack of utility or novelty. The deliberate mode is conscious, reasoned, systematic, and pulls information from TOP as well as being fed the results of the spontaneous mode. The deliberate mode depends on a body of skill and knowledge to determine utility and novelty.

Spontaneous Creativity and Dreaming

Dietrich makes an explicit connection between the attributes of the spontaneous mode and dreaming. He notes that during REM sleep the PFC is less active, leading to a deficit in self-reflection, awareness of time, volition, abstract thinking, active decision making, and focused attention. These deficits are also characteristic of many dreams, as will be discussed later. Dietrich's proposal that spontaneous creativity results from associative activation within TOP is a key component of the Integrative Theory. His assertion that dreaming and spontaneous creativity show a lack of prefrontal activity supports a possible overlap of constituent mechanisms. Dietrich even suggests that dreams could be an ultimate form of spontaneous creativity: ". . . dreaming might be regarded as the most extreme form of the spontaneous processing mode and can give rise to insights that are difficult to come by during normal waking consciousness" [8].

Sleep, Dreaming and Mental Imagery

A description of dreaming is incomplete without an overview of sleep, a behavioural state displayed by many mammals and birds [23] that is modulated by a circadian clock entrained by any one of many zeitgebers (e.g. visual brightness and social interaction) [19]. Sleep is usually divided into stages. Sleep begins with *descending stage 1*, which is quite similar to waking, in terms of the electroencephalogram (EEG), and is characterized by high frequency and low amplitude EEG. Sleep then descends through increasing stages (2 to 4). Each subsequent stage is characterized by an EEG with greater amplitude and lower frequency, with stage 4 being characterized by the lowest frequency and the highest amplitude waves (delta waves). Once a sleeping individual has progressed through sleep stages 1 to 4, the progression reverses back through the stages. An entire cycle typically lasts approximately 90 minutes. The sleeper spends the rest of the night oscillating between sleep stages. However, an important change occurs as a typical night of sleep unfolds: The first half of a night's sleep contains much more *slow-wave sleep* (SWS; stages 3 and 4), whereas the second half contains much more stages 1 and 2 sleep.

The initial stage 1 episode is relatively uneventful, but thereafter each stage 1 (*emergent stage 1*) tends to be accompanied by a variety of other physiological changes including loss of muscle tone and *rapid eye movements* (REMs). Accordingly, emergent stage 1 is more commonly known as *REM sleep* [1], and the other sleep stages are commonly referred to as *Non-REM (NREM) sleep*.

Dreaming can occur during any stage of sleep. Nevertheless, there are some general conclusions that can be made about the distribution of dream content over a typical night of sleep. Early on in the night, narrative dreams are more likely to be reported when awaking subjects during REM sleep. By contrast, waking a subject from NREM sleep early in the night dreams are more likely to be reported as "…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" [20]. As the night progresses, narrative dreams are more likely to be reported, irrespective of the stage from which they are woken.

In this section, we describe two popular biospychological theories of dreaming, as well as their links to perception and creativity. First, Hobson's *Activation, Input/Output Gating, and Modulation* (AIM) [11] theory proposes that dreams are the result of high-level cognitive processes attempting to make sense of random activations of early sensory regions. The resulting perceptual experience is a functional *simulation* of reality. Second, Nir and Tononi [20] propose that dreams are more similar to mental imagery than to perception, and are not dependent on the random activation of early sensory regions.

Activation, Input/Output Gating, and Modulation

Hobson's AIM model [11] is the successor to the *activation-synthesis* theory [12]. AIM proposes that, during early development, dreams are important for the emergence of the *protoself* (a precursor to the sense of self); dreams provide a "…virtual reality model of the world that is of functional use to the development and maintenance of waking consciousness" [11]. This *virtual reality* is a free-running simulator of possible sensory and motor scenarios. The protoself develops to *account* for and *take responsibility* for unconscious cognitive operations that respond to both external (during waking) and internal (during dreaming) stimuli. It is presumed that the protoself develops through the incremental growth of attentional and control mechanisms in the PFC that structure reflex and associative activity in TOP. AIM constitutes a state-space of three dimensions of dream properties:

Activation: During waking and REM sleep, the whole brain is highly activated and during NREM sleep it is minimally activated. Activation during REM sleep is due to waveforms (PGO waves) that originate in the pontine brainstem and cause activation of the various sensory systems, in particular vision; thus, this activation is not driven by external stimuli. This activation is then interpreted by the same mechanisms as external perception, pictured by the top black arrow in Figure 1 (left).

Input-output gating: During REM sleep, PGO waves begin and the reticular activating system disconnects the body from the brain, resulting in temporary paralysis (output) and a loss of most sensory afferents (input).

Modulation refers to the change of neurotransmitter levels: During REM sleep, aminergic neurons are inhibited and cholinergic neurons are activated. This results in an attenuated influence of the PFC, which accounts for the poor recall of dream material and a lack of self-awareness.

According to Hobson's proposal, perceptual functions transform relatively random brain activity into a cohesive, and even narrative, subjective experience. According to this conception, a dream is the output of our sensory and perceptual functions. Hobson [11] provides no discussion of the structure of these PGO waves, nor exactly what is meant by 'randomness.' Hobson's theory also depends on a strong correlation between REM sleep and dreaming, yet this correlation is weaker than was once believed [24]. Hobson himself acknowledges this inconsistency: "[a]n 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…" [11]. Aspects of Hobson's theory that are relevant to computational modelling include the degree to which external stimuli effect sensory regions (*gating*), as well as the degree of *activation.*

Dreams as Mental Imagery

Nir and Tononi [20] provide an alternate account of dreaming that is rooted in a criticism of Hobson's theory. Central to their criticism, as mentioned above, is the fact that Hobson's theory depends on a correlation between REM sleep and dreams.

In contrast to Hobson, Nir and Tononi consider dreams as comparable to mental imagery [20]; that is, in their conception, dreaming depends more on the forebrain rather than on the brainstem-created PGO waves. Central to their argument is the observation that damage to portions of the PFC (as occurred to victims of prefrontal lobotomy), led to total cessation of dreaming in 70–90% of subjects. Those same individuals also exhibited a "…lack of initiative, curiosity and fantasy in waking life" [20]. In general, it seems that damage to perceptual areas leads to deficits in both mental imagery and dreaming.

Analysis of children's dreams shows that the younger the child, the more simplistic the dream content. Their dream reports contain "…no characters that move, no social interactions, little feeling, and…do not include the dreamer as an active character. There are also no autobiographic, [or] episodic memories…" [20]. Nir and Tononi provide a compelling argument that dreaming may in fact be more closely related to mental imagery than perception, and therefore that the neural mechanisms implicated in mental imagery are also in play during dreaming.

Nir and Tononi 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)" [20]. The lack of comparable reflective thought in dreams could be explained by the relative lack of activation in the PFC during sleep.

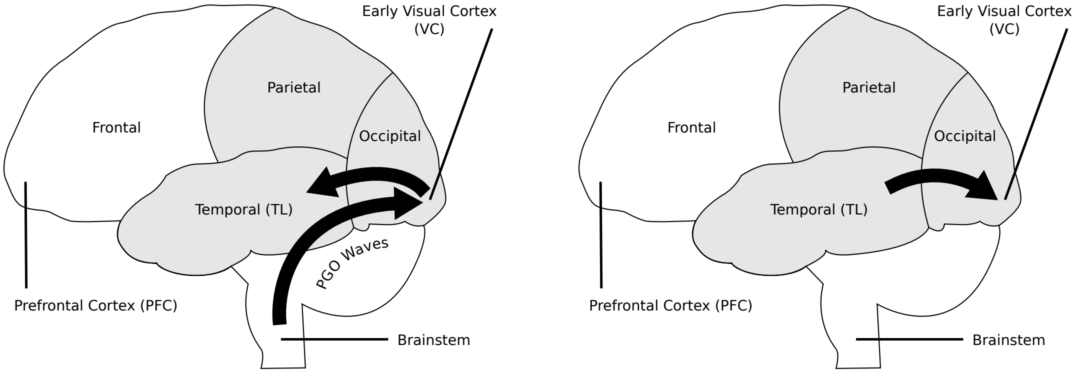

Figure 1. Information flow during: (1) dreaming, according to Hobson (left), and (2) mental imagery, according to Kosslyn (right).

What Causes Activation During Dreaming?

A significant issue with Nir and Tononi's account is the absence of a specified cause of the activation during dreaming. Hobson neatly solves this problem with PGO waves. According to Nir and Tononi, activation could be due to intentional prefrontal control during REM sleep, but where self-awareness is inhibited — dreams are the same as mental images except they are not recognized as being intentional. Alternatively, the activation is not due to the PFC but is rather due to endogenous associative activations of TOP — those same mechanisms implicated in Dietrich's conception of spontaneous creativity [8]. Nir and Tononi also make reference to a possible role of the DMN, due to the partial overlap of brain activity during REM and DMN structures. This latter proposal will be returned to later.

Whether dreams are similar to perception or mental imagery, there appears to be a consensus that dreams are the result of activation of high-level perceptual representations (presumably in TOP). However, two things are in dispute: (1) whether there is intentional control and (2) whether there is functional role for the early sensory regions. Still, the most relevant aspects of Nir and Tononi's theory include the consideration of a possible role of the DMN, and the idea that dreams as enabled by the same mechanisms as mental imagery.

Perceptual Anticipation Theory

Kosslyn's [16] *Perceptual Anticipation Theory* of mental imagery proposes a functional role of 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" [16]. According to Kosslyn, the patterns that define these mental images are long-term visual representations encoded in the temporal lobe (TL). Unlike the retinotopic arrangement of the visual cortex (VC), where adjacent cortical columns tend to correspond to adjacent patches of the contralateral visual field, these representations are non-topographical. They can only be decoded through constructive activation: "…image generation is not simply 'playing backward' stored information, but rather is necessarily a constructive activity" [16]. This constructive activation is pictured as a black arrow in Figure 1 (right).

Once the images are decoded they are are perceived using the same mechanisms as external perception, not pictured in Figure 1 (right). These imagined reconstructions can be used to further conceptualize images propositionally or linguistically. Activation of the VC 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 (eg. colour and size) — not spatial relations (eg. position).

Shared Representations in Perception and Imagery

Kosslyn's account is specifically focused on the early visual system and assumes that long term visual memory is located in the TL. According to the *Emergent Memory Account* (EMA) of Graham et al. [10], the TL is not simply a storehouse for memory, but is specialized for high-level visual representations that are used in both memory and perception. Under this conception, visual mental imagery may involve much of the TL and would not depend on the early visual system. If the TL is activated in memory and perception, and stores high-level representations of perceptual information, then a functional role of the early VC during imagery is unclear. Kosslyn supports the stance that mental images are decoded in the early VC through studies that directly relate mental images and visual external perception. These studies have assumed that the similar constraints in mental imagery and perception are due to shared involvement of the early VC.

Summary of Sleep, Dreaming and Mental Imagery

Hobson theorizes that dreams involve mechanisms similar to external perception, while Nir and Tononi consider that dreams involve mechanisms that more closely overlap with those of mental imagery. Both theories posit a key role for high-level perceptual representations. Kosslyn proposes that mental imagery exploits the same functions as external perception. Thus we can consider dreaming, mental imagery and external perception as highly related and that they may share neural mechanisms, including a role for TL-based perceptual representations. The mechanisms that cause the activation of these TL-based representations is, as yet, unclear. However, consideration of the DMN may resolve the activation source.

The Default Mode Network and Dreaming

As noted by Domhoff [9], current research on dreaming certainly emphasizes a continuity between dreaming and waking cognition. Although notions of dreams as bizarre narratives have captured our collective imagination for a significant period, even early dream content studies from the 1970s indicated that *bizarre* dreams are exceptional; most dream reports are "…clear, coherent, and detailed account[s] of a realistic situation involving the dreamer and other people caught up in very ordinary activities…" (Domhoff [9] citing Snyder [25]). A consideration of dream content as *ordinary* and the inclusion of terms describing meta-awareness (eg. *contemplate*, *decide*, *realize*, *ponder*, etc.) in dream reports supports a continuity between dreaming and waking consciousness. Studies of relaxed waking (such as mind-wandering) in laboratory settings have shown that these states can be "…as fragmented or unusual as dreams" [9]. Physical impossibilities and disconnected thoughts are present in both dreaming and in mind-wandering.

The DMN is a set of neural structures that are highly active when the subject is resting (during mind-wandering) and are inhibited during goal-oriented activity. Domhoff [9] proposes that dreams result from an activation of a subset of the DMN that "…is active when the mind is wandering, daydreaming, or simulating past or future events." Regions that are associated with the DMN include the "…medial prefrontal cortex, the anterior cingulate cortex, and the temporoparietel junction…", which are also implicated in dreaming. Not all neural structures implicated in the DMN are highly active during REM and NREM sleep. Domhoff proposes this lack of activation during dreaming is because sensation, locomotion and executive functions are *not necessary* during dreaming.

Domhoff proposes that DMN activity serves as a bridge between waking and dreaming consciousness: Just before the onset of sleep, the DMN is likely to be active due to a relaxed state. The shift from waking relaxed thought to sleep is rapid and DMN activity continues into NREM. The central component of Domhoff's proposal [9] is the correlation between dreams and the DMN, which provides a link to mind-wandering. This link is compelling as the characteristics of mind-wandering (in particular the lack of volition and self-reflection, and the presence of associative thought) resemble those of both dreaming and spontaneous creativity, as proposed by Dietrich [8].

Domhoff's argument that the DMN may be implicated in dreaming, and therefore that mind-wandering and dreaming may be enabled by shared mechanisms, is compelling. It resolves the colloquial relation between dreaming and daydreaming (mind-wandering) with biospychological evidence. If it is accepted, then "…dreams can be seen as a unique and more fully developed form of mind wandering, and therefore as the *quintessential cognitive simulation* [emphasis added]" [9]. The key aspects of Domhoff's proposal are that dreams and mind-wandering may easily transition from one to the other, and are enabled by overlapping components of the DMN.

Dreaming, Mind-wandering and Prediction

The general overlap of activity during dreaming and mind-wandering indicates a possible overlap in function. Both Hobson [11] and Schooler [22] describe dreams and mind-wandering as having a predictive function. In both cases, our attention shifts inward, and we show impairments in executive function. For example, during mind-wandering the DMN is most active when subjects are not aware of their mind wandering (e.g. a lack of meta-awareness) [7]. The DMN is also active when people engage in "personal planning concerning the future" [9], supporting the notion that simulation is common to both dreams and mind-wandering.

Summary of Theories

This section covered significant territory, so we will summarize the key aspects of the reviewed theories:

1. Dietrich proposes that creativity can be functionally segregated into two modes: (1) *Deliberate* creativity results from intentional creative effort and is correlated with prefrontal activity, while *spontaneous* creativity results from associative activations in the TOP that are promoted to PFC for evaluation and refinement.
2. Hobson proposes that dreams are the result of our perceptual mechanisms attempting to make sense of the random activation of sensory regions during REM sleep. REM sleep is characterized by: a similar degree of activation to waking, a disconnection of the brain from the rest of the body, and a suppression of feed-back mechanisms. Dreams are considered functional simulations.
3. Nir and Tononi propose that dreaming is less like perception and more like mental imagery.
4. Kosslyn proposes that mental images and external perception are subject to similar constraints. Encoded representations in the TL are rendered in early VC and perceived by the same mechanisms as external perception.
5. Domhoff proposes that dreams are enabled by the same mechanisms that support mind-wandering, specifically a subset of the DMN. Dreams result from the activation of perceptual information and provide the *quintessential* mechanism of simulation, thus extending the function and phenomenology of mind-wandering.

The following two sections describe the details of the contributions of this research. First, the Integrative Theory is described, after which its companion computational and artistic realization is summarized.

INTEGRATIVE THEORY

The previous sections include discussions and a selection of key points of theory regarding possible relations between visual aspects of external perception, mental imagery, mind-wandering, dreaming (visual mentation) and spontaneous creativity. This section unifies theoretical points made in the previous section into a proposal for an Integrative Theory that serves to inform the computational model. Three central hypotheses are made, whose support is described in the following paragraphs:

1. Visual mentation and spontaneous creativity involve the activation of high-level TL representations of sensory information [11, 20, 16, 10].

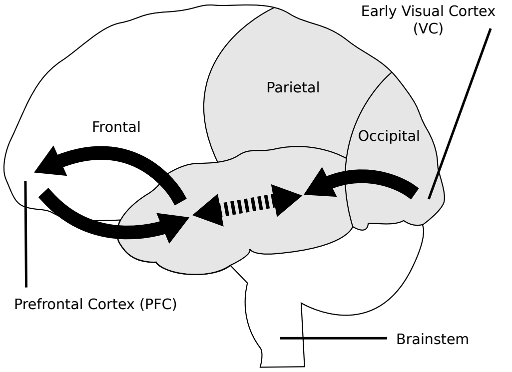

Figure 2. The Integrative Theory unifies external perception, mental imagery, mind-wandering, dreaming and spontaneous creativity.

2. The phenomenological experience of visual mentation is due to activity within the TL [18, 17, 3].
3. Simulation is a key attribute of visual mentation and spontaneous creativity [22, 11, 9].

There is a fairly clear consensus regarding Hypothesis 1, as all theories predict some functional role of representations in the TL — be they encoded or explicit, conceptual or perceptual. For Dietrich, cortical representations in the TL are constantly being activated through associative mechanisms that are unconstrained by evaluation. These representations are promoted to prefrontal systems for constraint and evaluation. Hobson [11] notes that TL epileptics experience seizures commonly characterized as *dreamy states.* He also contends that dreams are perceived using the same mechanisms as external perception, which implies a degree of TL processing. Nir and Tononi [20] link dreaming with mental imagery as the activation of representations implicated in mental imagery. For Kosslyn [16], the TL is the storehouse for visual representations, and overlaps with Hobson in proposing a functional role of early VC. Graham et al. [10] link perception and memory and propose that TL damage leads to deficits in memory recall and perception. The representations implied in mental imagery are shared with external perception, and therefore presumably also in dreams. Domhoff [9] and Nir and Tononi [20] cite studies that show that damage to the TL, in particular at the temporo-occipito-parieto junction, leads to deficit in *initiative, curiosity and fantasy,* and even the total cessation of dreaming.

While Hypothesis 1 is fairly well established, the cause of the activation of TL representations is disputed. In order to arrive at a cohesive conception, some aspects of the discussed theories must be rejected. We identify three explanations: TL activation results from (1) early VC activation, as in external perception (Hobson, Kosslyn), (2) endogenous (self-regulating) TL activation (Dietrich), or (3) prefrontal control (Domhoff, Nir and Tononi).

The functional role of early VC in mental imagery and dreaming is key to the theories proposed by Hobson and Kosslyn. The relation between mental imagery and external perception has been a topic of study since the 1970s and often conflate image recall (the recall of a particular visual memory), imagery of a memorized image (mental imagery of a learned visual image) and novel imagery (the construction of a new mental image not in memory nor perception). In 1978 it was shown by Podgorny [21] that mental images and perceptual images could be directly compared. The experiment involved the registration of a perceptual grid with a mental image such that the subject reported whether a particular perceptual cell was occupied by a portion of the mental image. This study, and others like it, have shown that perception and mental imagery share similar constraints, including field of view [18], scan time [14] and resolution [15].

In Marzi et al.'s study [18], a subject with damage to the early VC had no perceptual ability in one visual quadrant but was able to construct whole mental images. Most interestingly, perceptual constraints in the blind quadrant (reaction time effects dependent on location of stimulus in the field of view) did not apply to mental images as in normal subjects. This indicates that the early VC modulates mental images but is not functionally required. Recent fMRI decoding studies have allowed a more detailed examination of the role of the early VC in mental imagery.

Decoding studies have attempted to correlate patterns of brain activity with particular visual stimuli. An analysis of brain activity can predict which visual stimulus a subject is currently viewing. Lee et al. [17] demonstrated that activity in the VC and TL could predict an image either seen or imagined (after memorization) by a subject. During imagery, they found a high degree of correlated activation relevant to the memorized stimulus in the TL, and low stimulus-correlated activity in the VC. During perception, they found the opposite pattern, greater stimulus-correlated activation in the VC and less stimulus-correlated activation in the TL. As suggested by Lee [17], visual mental imagery and visual perception are different network dynamics of the same system of temporal representations. The relatively low activity in the VC during imagery has been repeated in other studies (e.g. [3]). These studies indicate that the activation of representations in the TL are due to dynamics independent of early VC.

As dreams occur in the absence of PGO waves, we can conclude that the experience of images in the mind is likely due to activity in the TL (Hypothesis 2) that is independent of the early VC. We are then left with two possibilities: activation of representations is due to intentional control from the PFC, or it is due to endogenous activation of the TL. The intentional control of representations in the TL is analogous to Dietrich's [8] notion of *deliberate* creativity, while endogenous TL activation resembles *spontaneous* creativity. These two options need not be resolved due to the diversity of phenomena in the proposed Integrative Theory: mental imagery results from intentional functions of the PFC, external perception is highly dependent on external stimuli impacting the early VC, and mind-wandering, dreaming and spontaneous creativity are the result of associative endogenous activation.

Figure 2 depicts the causal patterns of three modes of visual mentation: External perception is the result of exogenous activation of early VC which in turn causes the activation of TL representations. Mental imagery is the result of PFC control mechanisms causing activations of TL representations, which result in the experience of mental images. Visual aspects of spontaneous creativity, dreaming and mind-wandering are all the result of endogenous activation (the dashed line) within the TL, which is modulated by varying degrees of control initiated by the PFC.

The exploitation of shared TL representations in visual mentation and spontaneous creativity means that one cognitive process (e.g. dreaming) could be impacted by and impact another (e.g. external perception). For example, it has been shown that waking perception in the hours before sleep has a significant effect on dream content [27]. Antti Revonsuo describes the continuity of perception and dreaming: "We are dreaming all the time, its just that our dreams are shaped by our perceptions when awake, and therefore constrained" [29]. We can then consider the differences between the various modes of visual mentation and spontaneous creativity as due to the same mechanisms except with differing dynamics.

Hypothesis 3 states that a key functional attribute shared between visual mentation and spontaneous creativity is simulation. Considering the constructive aspects of external perception, we can conceive of our experience of the world as a simulation that is highly constrained by sensory information. By contrast, mental imagery is a simulation relatively unconstrained by external stimuli, but intentionally controlled and constrained by task demands. Dreaming and mind-wandering result from these same mechanisms of simulation, but operating independently of task demands or sensory-oriented controls. These free-running simulations may have diverse functions, for example "... autobiographical predictions necessary to successfully navigate the complex social world" [22], and the development of self [11]. The particular brain systems that enable all of these simulations are possibly a subset of the DMN; which has been implicated in dreaming and mind-wandering. Domhoff characterizes dreams as the *quintessential cognitive simulation* [9] because they are a *more fully developed form of mind wandering.* We can then consider dreams as a free-running manifestation of those very same mechanisms that enable spontaneous creativity.

In summary, the Integrative Theory proposes that visual mentation and spontaneous creativity are a set of closely related phenomena that all exploit the same mechanisms of representation and simulation. The next section discusses the computational model that arises from the Integrative Theory.

COMPUTATIONAL MODEL: A MACHINE THAT DREAMS

The Integrative Theory is the foundation for the computational model and artwork *Dreaming Machine*. While the Integrative Theory includes a role for evaluative mechanisms, the computational model formalizes a subset of the theory, centrally focused on generative mechanisms corresponding to spontaneous creativity. The model is summarized here and further details of the system are available in a companion paper [5]. The key features of the proposed theory manifested in the computational model include: representations shared by perception, mind-wandering and dreaming, and the explicit continuity of those three states. The work follows in a series of site-specific artworks (*Context Machines* [6]) that collect visual material from their contexts of installation in the service of generative image-making processes.

Computational modelling provides a compelling framework for the theorization and critique of biopsychological conceptions. The implementation of these ideas in formal language requires sufficient detail as to force the specification of tacit aspects. The computational model is a working system that learns from its visual perceptual experience during the day and generates hypothetical (simulated) images constructed from collected perceptual material while 'dreaming' at night — all in the absence of evaluative functions associated with the PFC. As an artwork, the model is meant for long-term installation in a public setting in order to be exposed to as much variety of visual material as possible.

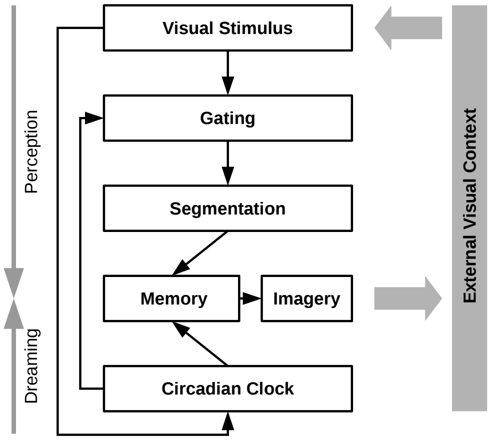

Figure 3. Overview of the Computational Model — Dreaming Machine

The system manifests three modes of visual mentation where images are constructed from associative memory representations of visual information, as pictured in Figure 4: (1) Perception is the construction of perceptual images as constrained by external visual stimulus. (2) Dreaming is the result of spontaneous creativity where generated images are the result of activations of memory representations which are initiated by recent waking perception. The propagation of associative activation results in hypothetical images. (3) Mind-wandering is a fusion of perception and dreaming modes where a static perceptual image (habituated stimulus) emphasizes the associative (dream-like) propagation of activation, resulting in images that are both perceptual and dream-like. In all three modes, associative activation is propagated and modulation causes shifts between the exogenous and endogenous activation of percepts. The system's habituation to the external environment, and a circadian clock, cause the transition between these contiguous modes. The spontaneous mode of creativity, as manifest in dreaming and mind-wandering modes, is the result of associations based on simple features, and therefore lacks the richness and complexity of human spontaneous creativity. The dreams and mind-wanderings of the system are meant to appear similar to those of children and perhaps non-human animals. The design of the computational model manifests the following key attributes informed by the theories described in previous sections:

- The degree to which perceptual content is activated by external stimuli is controlled by a gating system [11].
- Dreaming and mind-wandering are enabled by the associative activation of shared representations (percepts) constructed by perceptual processes [8].
- External perception, mind-wandering and dreaming are contiguous processes modulated by varying degrees of influence from exogenous stimuli and endogenous activation. That degree of influence is controlled by a circadian clock entrained by the luminosity of the external environment [11].
- The system is a partial artificial agent that contains no analogue of the PFC, nor the limbic system and therefore lacks executive control or emotional tone.

Modules

The relations between modules are depicted in Figure 3. For a more detailed technical overview of the system see [5].

VISUAL STIMULUS provides 1920×1080 pixel video images (captured by an immobile camera) to SEGMENTATION via GATING. The neurobiological analogue of the visual stimulus is the retina-geniculate-striate system, which includes the VC. The mean luminosity of images entrains the CIRCADIAN CLOCK.

GATING controls the degree to which VISUAL STIMULUS causes activations in MEMORY, which is determined by the state of the CIRCADIAN CLOCK. The neurobiological analogue of the gating function are the brainstem nuclei in the reticular activating system and the thalamus.

SEGMENTATION separates the foreground from the background and further breaks the background into contiguous colour regions. These regions are used by MEMORY to generate percepts of the external world. The neurobiological analog of this function are processes in the TL.

MEMORY is the core of the system, and corresponds to the TOP in biological terms. It is the structure that holds the associative representations used in spontaneous creativity. MEMORY clusters segmented regions such that an object seen in subsequent frames is stored as a single representation. Percepts are atoms of long-term visual memory (analogous to the TL representations discussed in the Integrative Theory) and are the material that are the basis of external perception, dreaming and mind-wandering. All percepts are ordinally sorted according to their features — position in frame, position in time, area, and mean colour. For each dimension of each feature (the position in frame is an $x\,y$ pair, while colour is represented by the three CIE Luv channels) there is a graphical model that represents associative links. These FEATURE LISTS correspond to the associative structure of representations in the TL.

Each percept may propagate its activation (initiated by clustering) to its two most similar neighbours. This propagation corresponds to associative activation and the resulting pattern manifests unconstrained simulation (the construction of images that resemble sensory information). For each propagation, the degree of activation decays or is amplified, depending on the state of the CIRCADIAN CLOCK, which represents the day-night cycle. During perception, activation decays for each propagation. During dreaming and mind-wandering, propagations oscillate between decay and amplification where activated percepts decrease or increase the activation of their neighbours. When propagation reaches the ends of the FEATURE LISTS, or the activating percept is reactivated by its nearest neighbour, activation is propagated to the nearest neighbour in another FEATURE LIST (along another dimention). This shift in dimension supports continuous endogenous associative activation. The selection of which dimension to propagate is determined by the PROMINENT FEATURE of the activating percept. The PROMINENT FEATURE of percept A is the feature that makes A stand out most from other percepts. These associative propagations are the basis of external perception, mind-wandering and dreaming modes, which will be discussed in the next section.

The system also exhibits habituation, as percepts that have been activated are subsequently more difficult to activate — the greater the repetition of a stimulus, the weaker the response. This allows percepts in VISUAL STIMULUS that are constant over time to fade from IMAGERY. While a percept is not being activated, its degree of habituation gradually recovers.

CIRCADIAN CLOCK is an oscillator whose period is entrained by the day-night cycle of light in the environment, manifested in the luminosity of VISUAL STIMULUS. The clock registers the onset of day and night and modulates GATING and the propagation of activation in MEMORY. The neurobiological analogue of this circadian clock is the suprachiasmatic nucleus of the hypothalamus.

IMAGERY presents those percepts in MEMORY with sufficient activation on a 1920×1080 display. The degree of activation determines the degree of opacity of the presented percept. IMAGERY is a window into the current state of activation of MEMORY. What is seen in IMAGERY is analogous to what insights would be promoted into working memory in the PFC, according to Dietrich's framework [8].

Cognitive Modes

The particular mode of the system is determined by the CIRCADIAN CLOCK that both modulates the degree of GATING and the propagation of activation in MEMORY.

During PERCEPTION, associative activations decay with each propagation. The strongest activations are those initial activations caused by perceptual clustering. As percepts corresponding to the current stimulus are most active, IMAGERY is composed of percepts that correspond to the current stimulus and therefore resembles the image captured by the camera — a simulation of perceptual information. With a lack of habituation, this image would appear similar to the camera image, as pictured in Figure 4 (far left). It is presumed that the majority of VISUAL STIMULUS surface area will remain static (background) and will therefore become increasingly habituated to. This would result in the greater activation of novel percepts that would be presented with greater opacity in IMAGERY, as pictured in Figure 4 (middle left). Associative propagations are constant, but due to the decay of activation and continuous external stimuli, these weaker activations are drowned out, and not promoted to IMAGERY. This corresponds to Dietrich's conception that spontaneous and associative activations in TOP happen continuously, but are not always promoted to conscious awareness.

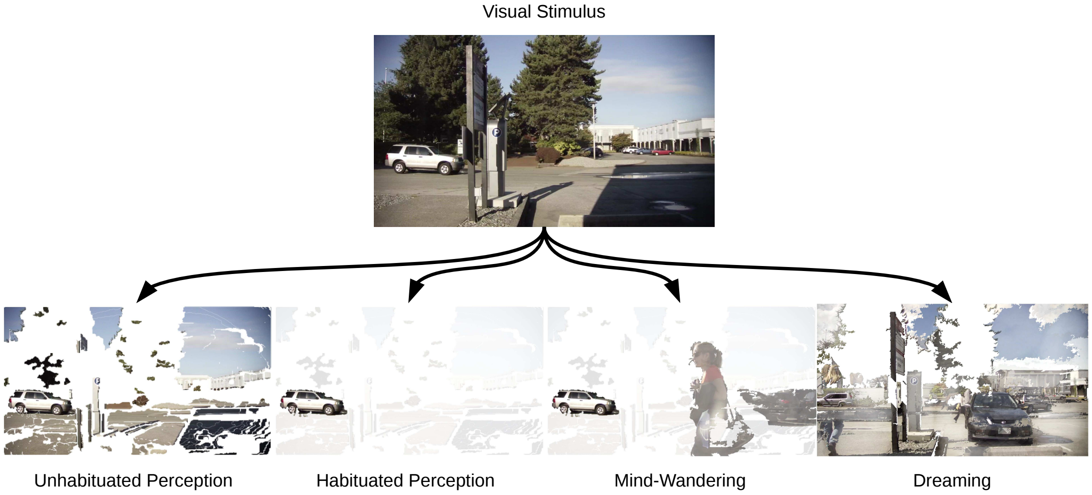

Figure 4. Depiction of Visual Stimulus and corresponding Imagery in external perception, mind-wandering and dreaming modes. These images were produced during an exhibition of a prototype of *Dreaming Machine #3*. © Benjamin D. R. Bogart

Dreaming occurs when the latent activation from perception initiates further propagation, while exogenous activations are reduced via Gating. A dream sequence begins during in a state of habituated perception. The Circadian Clock modulates the propagation of activation such that weak activations are initially amplified, rather than decayed, as in external perception. Once the sum activation of all percepts crosses an upper threshold, then propagations once again decay. The ebb and flow of activation resembles the shifts between REM and NREM sleep. During the REM-like state, many percepts are activated to a high degree — resulting in the Imagery being dense with percepts, as in Figure 4 (far right). During the NREM-like state, the low activation results in few percepts presented on Imagery, or presented at extremely low opacity.

Mind-Wandering results when highly static external stimuli lead to a high degree of habituation and therefore little activation, the same perceptual state that occurs before a dream is initiated. Mind-wandering is a fusion of perception and dreaming where Gating is open, but activation propagates as during dreaming where activations are amplified during propagation. The result is that percepts are activated both exogenously and endogenously and both internally and externally generated imagery appear, as pictured in Figure 4 (middle right).

FUTURE WORK AND CONCLUSION

The current computational model of simulation is limited to the construction of visual images, but the mechanisms outlined here could be applied in other modalities. Future development will emphasize the simulation aspect of dreams over the associative mechanisms described in this paper. Under the view of generation as simulation, perceptual priming is due to the prediction that a particular percept will occur next. Predictions are learned from perceptual experience and exploited in visual mentation and creativity. Dreams would still be the result of an unconstrained simulator, but images would result from a predictor that unfolds learned causal chains of perceptual information. Additionally, we will examine Barsalou's theory of Perceptual symbol systems [2], which describes concepts as simulators that recruit perceptually oriented representations on the fly, for the purpose of integrating it with the Integrative Theory proposed in this paper.

Theories of visual mentation provide compelling frameworks for the consideration of cognitive mechanisms that are implicated in creativity. The Integrative Theory considers perception, mental imagery, mind-wandering, dreams and spontaneous creativity as enabled by the same unconscious associative processes of simulation that are correlated with a subset of the DMN. Dreaming and mind-wandering are mechanisms of simulation that are capable of a wide range of variation in their constructive capacity. Spontaneous creativity manifested in dreams and mind-wandering is a simulator run amok in the absence of sensory information to constrain it. Dreams and creativity have the potential to manifest some of the deepest nuances of how we conceptualize and remember the world. Dreams make explicit and conscious the unconscious processes of simulation and association that are the substrate of spontaneous creativity and, perhaps, general cognition.

REFERENCES

1. Aserinsky, E., and Kleitman, N. Regularly occurring periods of eye motility, and concomitant phenomena during sleep. *Science 118* (1953), 273–274.
2. Barsalou, L. Perceptual symbol systems. *Behavioral and brain sciences 22*, 04 (1999), 577–660.
3. Bartolomeo, P. The neural correlates of visual mental imagery: An ongoing debate. *Cortex 44*, 2 (Feb. 2008), 107–108.

4. Boden, M. A. *The Creative Mind: Myths and Mechanisms*, 2nd ed. Routledge; London, 2004.
5. Bogart, B. D. R., and Pasquier, P. A machine that dreams: A generative system informed by biopsychological conceptions of dreaming. Tech. rep., Simon Fraser University, 2012. Forthcoming.
6. Bogart, B. D. R., and Pasquier, P. Context machines: A series of situated and self-organizing artworks. *Leonardo 46*, 2 (2013).
7. Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., and Schooler, J. W. Experience sampling during fmri reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences 106*, 21 (2009), 8719–8724.
8. Dietrich, A. The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review 11* (2004), 1011–1026. 10.3758/BF03196731.
9. Domhoff, G. W. The neural substrate for dreaming: Is it a subsystem of the default network? *Consciousness and Cognition 20*, 4 (2011), 1163–1174.
10. Graham, K. S., Barense, M. D., and Lee, A. C. H. Going beyond LTM in the MTL: A synthesis of neuropsychological and neuroimaging findings on the role of the medial temporal lobe in memory and perception. *Neuropsychologia 48*, 4 (2010), 831–853.
11. Hobson, J. A. REM sleep and dreaming: towards a theory of protoconsciousness. *Nature Reviews Neuroscience 10*, 11 (2009), 803–813.
12. Hobson, J. A., and McCarley, R. W. The brain as a dream state generator: an activation-synthesis hypothesis of the dream process. *American Journal of Psychiatry 134*, 12 (1977), 1335–1348.
13. Kandel, E., and Wurtz, R. Constructing the visual image. *Principles of neural science 4* (2000), 492–506.
14. Kosslyn, S. Scanning visual images:Some structural implications. *Attention, Perception, & Psychophysics 14*, 1 (Feb. 1973), 90–94.
15. Kosslyn, S. Can imagery be distinguished from other forms of internal representation? evidence from studies of information retrieval times. *Memory & Cognition 4*, 3 (May 1976), 291–297.
16. Kosslyn, S. M., and Thompson, W. L. When is early visual cortex activated during visual mental imagery? *Psychological Bulletin 129*, 5 (2003), 723–746.
17. Lee, S., Kravitz, D. J., and Baker, C. I. Disentangling visual imagery and perception of real-world objects. *NeuroImage 59*, 4 (Feb. 2012), 4064–4073.
18. Marzi, C., Mancini, F., Metitieri, T., and Savazzi, S. Retinal eccentricity effects on reaction time to imagined stimuli. *Neuropsychologia 44*, 8 (2006), 1489–1495.
19. Morin, L., and Allen, C. The circadian visual system, 2005. *Brain Research Reviews 51*, 1 (2006), 1–60.
20. Nir, Y., and Tononi, G. Dreaming and the brain: from phenomenology to neurophysiology. *Trends in cognitive sciences 14*, 2 (2010), 88–100.
21. Podgorny, P., and Shepard, R. N. Functional representations common to visual perception and imagination. *Journal of Experimental Psychology: Human Perception and Performance 4*, 1 (1978), 21–35.
22. Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., and Sayette, M. A. Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences 15*, 7 (2011), 319–326.
23. Siegel, J. M. Do all animals sleep? *Trends in Neurosciences 31*, 4 (2008), 208–213.
24. Siegel, J. M. Rem sleep: A biological and psychological paradox. *Sleep Medicine Reviews 15* (2011), 129–142.
25. Snyder, F. *The Psychodynamic implications of the physiological studies on dreams*. Thomas, 1970, ch. The phenomenology of dreaming, 124–151.
26. Sternberg, R., and Lubart, T. The concept of creativity: Prospects and paradigms. *Handbook of creativity 1* (1999), 3–15.
27. Stickgold, R., Malia, A., Maguire, D., Roddenberry, D., and O'Connor, M. Replaying the game: Hypnagogic images in normals and amnesics. *Science 290*, 5490 (2000), 350–353.
28. Triesch, J., Ballard, D. H., Hayhoe, M. M., and Sullivan, B. T. What you see is what you need. *Journal of Vision 3*, 1 (2003), 86–94.
29. Tucker, L., Thompson, A., Smith, J., Cohen, A., Clark, M., and Barrett, M. Why do we dream? Documentary Television Program, Feburary 2009. BBC Horizon Documentary.
30. Weisberg, R. W. *Creativity: Understanding Innovation in Problem Solving, Science, Invention, and the Arts*. John Wiley & Sons, June 2006.

Chapter 5

An Integrative Theory and Computational Model of Visual Mentation

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An Integrative Theory and Computational Model of Visual Mentation

Benjamin David Robert Bogart
School of Interactive Art and Technology, Simon Fraser University
Philippe Pasquier
School of Interactive Art and Technology, Simon Fraser University
Steven J. Barnes
Department of Psychology, University of British Columbia

Abstract

Visual mentation is the experience of visual images in the mind and includes visual aspects of perception, mental imagery, mind wandering and dreaming. We propose an Integrative Theory of visual mentation (VM) that unifies biopsychological theories perception, dreaming and mental imagery. Under the theory, we make three major hypotheses where VM (1) involves the activation of perceptual representations in the temporal lobe, (2) is experienced phenomenologically due to the activation of these representations, and (3) depends on shared mechanisms of simulation — dependent on a subset of the Default Network — that exploit these perceptual representations. The resulting Integrative Theory informs the development of a computational model — and generative site-specific artwork — that generates visual images from perceptual, mind wandering and dreaming processes. These images are composed of shared perceptual representations learned during waking. Perception, mind wandering and dreaming are contiguous simulations of sensory reality modulated by varying degrees of exogenous and endogenous activation impacting a predictive model.

Introduction

Perception does not produce a perfect replica of the world: Percepts are the results of sampled sensory information that is integrated and extended according to expectations occurring at multiple levels of abstraction and in relation to task demands (Triesch et al., 2003). Indeed, the visual perceptual system has often been described as a *creative process* — e.g. Kandel & Wurtz (2000). Under this conception, visual perception is the result of the construction of highly detailed impressions of our external reality that are not reducible to either the world, or the organism's expectations. While perception is constrained by external sensory information, mental imagery involves the construction of images experienced by the mind occurring in the absence of, or despite, available sensory information. Through a review of a number of theories of dreaming and mental imagery, the authors conclude that the mechanisms that allow constructive perception are the same as those that allow mental imagery (Borst & Kosslyn, 2012), and are exploited in dreaming and mind-wandering.

Dreams are meaningful simulations, however abstract, of a somewhat familiar world. These simulations are sequences of events whose order is determined by feedback in a predictive model of the world. Dreams can be as simple as banal thoughts or images, or as complex as long recurring melodramas. They are often thought of as bizarre, and may include chimeric elements — fusions of multiple places or people. In this review, we focus on two popular and conflicting biopsychological conceptions of dreaming: Dreams result from our perceptual system's attempt to make sense of activation in sensory regions of the brain, or dreams are akin to mental imagery and are largely independent of the early sensory systems. Visual mentation is the phenomenological experience of images in the mind, be them self-generated (in the case of dreaming, mind-wandering and mental imagery) or the result of external stimuli (perception). Mind wandering (day-dreaming) and dreaming overlap in their content and involve similar modulations of cognition (Domhoff, 2011; Fox et al., 2013) — e.g. lack of self-reflective awareness. Perception is highly constrained and anchored by external stimuli while dreams occur largely in the absence thereof. Mind-wandering is a shift of attention away from external stimuli toward internally generated imagery.

The contributions of the present work are threefold: First, we review biopsychological mechanisms of visual mentation, in particular perception, mental imagery, mind-wandering and dreaming. Second, we propose an Integrative Theory of visual mentation where constituent phenomena exploit overlapping mechanisms of simulation**.** These mechanisms are enabled by a common set of perceptually-oriented cortical representations which are contextualized by a predictive model. Third, our theoretical proposal serves as the foundation of a computational model (situated agent) and artwork that constructs images from sensory components through generative processes manifest during each of three cognitive processes: (1) perception, (2) mind wandering and (3) dreaming. It is assumed that the dreams and mind wanderings of the system will appear similar to those of children, and perhaps non-human animals, and not human adults.

Our computational model serves three major purposes in itself. First, it formalizes the Integrative Theory and provides a site for the evaluation and refinement of that theory. Second, it is also an artwork, titled *Dreaming Machine #3*, contextualized in a series of generative site-specific computational installations (Bogart & Pasquier, 2013). Thirdly, the manifestation of the theory in an artwork broadens discourse regarding visual mentation beyond traditional scientific contexts. The interdisciplinary nature of this work is expected to be mutually beneficial: (a) an artistic perspective and critique of biopsychological theories of dreaming is expected to broaden and generalize existing theory and (b) a rigorous analysis of biopsychological theories enriches and deepens the artwork.

Background

This section of the paper reviews a number of biopsychological theories of visual mentation. It will be shown that these theories all share particular characteristics that serve as the basis of the Integrative Theory, to be presented in a later section. We describe two major theories of dreaming: (1) According to Hobson's Activation-Synthesis (2000) and AIM (2009) theories, dream experiences are the result of high-level perceptual processes making sense of activations of early sensory regions of the brain, and (2) Nir and Tononi's (2010) proposal that dreams are more closely related to mental imagery than perception. Kosslyn and Thompson's (2003) theory of mental imagery compliments Nir and Tononi's proposal. Additionally, we present Domhoff's (2011) proposal that dreaming and mind-wandering recruit overlapping components of the *default mode network* (DMN).

Visual Mental Representation

In the introduction, it was stated that visual mentation is dependent on a common set of *perceptually-oriented* cortical representations, learned from perceptual experience. Additionally, they are characterized by being high-level and abstract. By *high-level* we mean that these representations are highly invariant to shifts in scale, orientation and lighting. This invariance results from increasing cortical processing in the ventral stream. These representations are *abstract* because increasing cortical processing causes them to decreasingly resemble the patterns of light projected upon the retina. These representations are diffusely encoded in the medial temporal lobe (Graham et al., 2010), in particular the perirhinal cortex, and active during visual mentation. At a cognitive level of description, these representations can be considered percepts that correspond to concrete concepts, such as table, ball, sky, et cetera. Through the remainder of this paper, we will refer to these representations as *perceptual representations*.

Sleep, Dreaming and Mental Imagery

A description of dreaming is incomplete without an overview of sleep, a behavioral state displayed by many mammals and birds (Siegel, 2008) that is modulated by a circadian clock entrained by zeitgebers — e.g. visual brightness and social interaction (Morin & Allen, 2006). Sleep is usually divided into four stages: *Rapid eye movement* sleep, REM Sleep (Aserinsky & Kleitman, 1953), and non-rapid eye movement sleep, NREM stages 1 through 3. Sleep begins with NREM stage 1, which is quite similar to waking, in terms of the electroencephalogram (EEG), and is characterized by high frequency and low amplitude EEG. Sleep then descends through increasing NREM stages (2 to 3). Each subsequent stage is characterized by an EEG with greater amplitude and lower frequency, with stage 3 being associated with the lowest frequency and the highest amplitude waves, and also known as *slow-wave sleep* (SWS). Once a sleeping individual has progressed through NREM stages 1 to 3, the progression reverses back through the stages where REM sleep may occur after NREM stage 1. In addition to rapid eye movements, REM sleep also tends to be accompanied by a variety of other physiological changes (e.g. the loss of muscle tone). An entire cycle typically lasts approximately 90 minutes. The sleeper spends the remainder of the night repeating these cycles and oscillating between sleep stages. However, an important change occurs as a typical night of sleep unfolds: The first half of a night's sleep contains much more NREM stage 3 sleep, whereas the second half contains much more NREM stage 1 and 2, and REM sleep.

Dreaming can occur during any stage of sleep (Nielsen, 2000). Nevertheless, there are some general conclusions that can be made about the distribution of dream content over a typical night of sleep. Early on in the night, narrative dreams are more likely to be reported when awaking subjects during REM sleep. By contrast, when waking a subject from NREM sleep early in the night, their dreams are more likely to be reported as "...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" (Nir & Tononi, 2010). Later in the night, dreams are reported as being "considerably longer and more hallucinatory", (Nir et al., 2013) irrespective of the stage from which a subject is woken.

In this section, we describe two popular biopsychological theories of dreaming, as well as their relation to perception. First, Hobson's *Activation, Input/Output Gating, and Modulation*

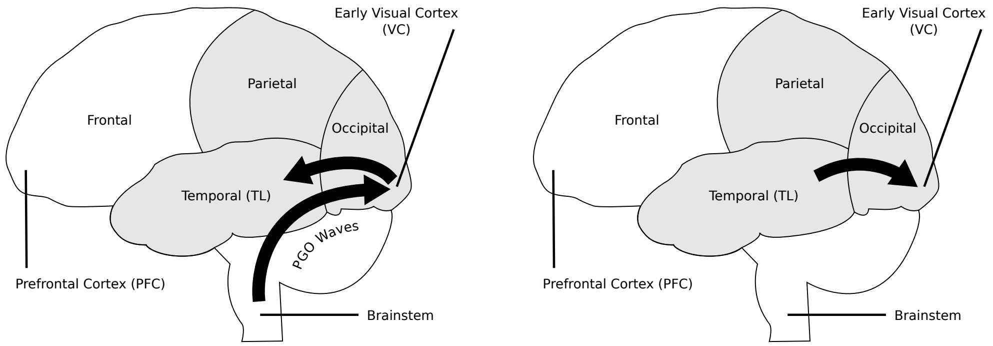

Figure 1. : Information flow during: (1) dreaming as perception, initiated by PGO waves originating in the brainstem, according to Hobson (left) and (2) dreaming as imagination, according to Nir and Tononi (right).

(AIM) (J. A. Hobson, 2009) theory proposes that dreams are the result of high-level cognitive processes that shape activations of early sensory regions into narrative sequences. The resulting perceptual experience is a functional *simulation* of reality. Second, Nir and Tononi (2010; 2013) propose that dreams are more similar to mental imagery than to perception, and are not dependent on the activation of early sensory regions.

Dreams as Perception. Hobson's Activation, Input/Output Gating and Modulation (AIM) model (2009) is the successor to the *activation-synthesis* theory (J. A. Hobson & McCarley, 1977). AIM proposes that, during early development, dreams are important for the emergence of the *protoself* (a precursor to the sense of self); dreams provide a "...virtual reality model of the world that is of functional use to the development and maintenance of waking consciousness" (J. A. Hobson, 2009). This *virtual reality* is a free-running simulator of possible sensory and motor scenarios which is initiated by the activation of early sensory regions. The protoself develops to *account,* and *take responsibility,* for unconscious cognitive operations that respond to both external (during waking) and internal (during dreaming) stimuli. It is presumed that the protoself develops through the incremental growth of executive mechanisms (e.g. working memory, attention and planning) in the prefrontal cortex (PFC) that structure and contextualize automatic and predictive activity in the temporal, occipital and parietal cortices. AIM constitutes a three dimensional state-space of neurological properties:

Activation: During waking and REM sleep, the whole brain is highly activated and during NREM sleep it is minimally activated. Activation during REM sleep is due to PGO waves (Callaway et al., 1987), so named because they have been measured in the pontine brain-stem (P), the lateral geniculate nucleus (G), and in the occipital cortex (O), and originate in the pontine brainstem. PGO waves have also been shown to "...occur in sensori-motor systems in the forebrain" (J. A. Hobson, 2009) and cause activation of the various sensory systems, in particular vision, "...from the motor side up." (J. A. Hobson, 2009) This activation is not driven by external (exogenous) stimuli. The PGO waves "...encode saccadic eye movement directions that are commanded by the oculomotor brainstem network" and cause the early sensory regions to generate imagery in the absence of sensory information from the eyes. Thus, PGO waves drive eye movements during REM sleep that also result in activation of early sensory regions. This activity is then interpreted by the same mechanisms as external perception, pictured by the top black arrow in Figure 1 (left) which shows the ventral stream of visual processing.

Input-output gating: During REM sleep, PGO waves begin and the reticular activating system (in the brainstem) disconnects the body from the brain, resulting in temporary paralysis (motor output) and a loss of most sensory afferents (sensory input).

Modulation refers to the change of neurotransmitter levels: During REM sleep, aminergic neurons are inhibited and cholinergic neurons are activated. This results in an attenuated influence of the PFC, which accounts for the poor recall of dream material and a lack of self-awareness.

By plotting the degree of activation, gating and neurotransmitter modulation in the AIM state space, it is possible to contextualize exceptional conscious states: In lucid dreaming the balance between aminergic and cholinergic neurons is even, gating is partial, and activation is as high as during waking. States of conscious deficit, such as coma, include a lack of aminergic activation, a wide range of degrees of gating, and a low degree of activation.

According to Hobson's proposal, perceptual functions transform activity in early sensory regions into a cohesive, and even narrative, subjective experience that is an exploitation of the organisms model of the world. According to this conception, a dream is the output of our sensory and perceptual functions, which are necessarily intertwined with the learning and exploitation of the predictive model. Hobson (2009) provides little discussion of the structure of PGO waves beyond their relation to saccadic eye movements. It is unclear how these saccadic control signals could cause early sensory activations that would lead to the complexity and narrative qualities of many dreams. Hobson's theory depends on a strong correlation between REM sleep and dreaming, yet this correlation is weaker than was once believed (Siegel, 2011). Hobson himself acknowledges this inconsistency: "[a]n 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. . . " (J. A. Hobson, 2009). So if PGO waves cause the narrative qualities of dream experience, then what causes the dream-like qualities of phenomenological experience during NREM sleep?

AIM and Free Energy Minimization J. Hobson & Friston (2012) have developed an alternate conception that links the existing AIM theory and free energy minimization. The free-energy formulation posits that biological systems resist disorder by minimizing *surprise* (Ashby, 1947). Friston (2010) defines surprise as the improbability of sensations given a model of the world, i.e. surprising sensations are those that have not been predicted. Since an organism can't control the environment, surprise cannot be directly minimized; The minimization of free energy improves the organisms ability to predict: ". . . free energy is always greater than surprise, which means that minimizing free energy implicitly minimizes surprise. . . " (J. Hobson & Friston, 2012). Free energy is a way of looking at an organisms ability to stabilize itself in opposition to changing environmental factors (homoeostasis); For example, a warm-blooded mammal's ability to keep a constant internal temperature despite the changing temperature of the environment.

According to the free energy formulation of AIM, predictions are learned during waking consciousness and contribute to the organisms "virtual reality model" of the world. The model is optimized during REM sleep through the reduction of its complexity. The function of sleep (and in particular REM sleep dreaming) is to refine and compress the predictive model of the world on which the organism depends. The most significant contribution of the free energy formulation is that the aspect of prediction is central, and dreaming is described functionally as the optimization of the predictive model. The AIM proposal is that the early sensory regions, in particular vision, cause activation of higher level perceptual systems, which entails the simulation of a “virtual reality” learned from external stimulus, but experienced phenomenologically in the absence of external stimuli.

Dreams as Mental Imagery. Nir and Tononi (2010) provide an alternative account, rooted in a criticism of Hobson’s theory, that proposes that dreams are more similar to mental imagery than perception. Hobson’s theory depends on a correlation between REM sleep and dreams, and does not explain, and in fact is weakened by, the notion of dreams in NREM sleep. The qualities of the dreams that occur in REM and NREM sleep have been reported as having different characteristics, see Nir & Tononi (2010, page 94), but Hobson does not explain how NREM dream-like mentation could occur in the absence of PGO waves and saccadic eye movements.

Additionally, Hobson’s model, according to Nir and Tononi’s interpretation of J. A. Hobson et al. (2000), involves a change in the directionality of signal propagation, suppressing feedback and enhancing feed-forward connections: “High levels of acetylcholine in the absence of aminergic neuromodulation might enhance feed-forward transmission and suppress back-propagation.” (Nir & Tononi, 2010) This change in directionality could also explain the weakened activity in parts of the PFC during REM sleep, and high inhibition during NREM sleep (Muzur et al., 2002). Nir and Tononi 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 forebrain than the “brain-stem REM generator” (PGO waves). In many cases, damage to the temporo-parieto-occipital junction also leads to total cessation of dreaming (Solms, 2000), and “. . . supports various cognitive processes that are essential for mental imagery.” Damage to the prefrontal cortex, for example due to leucotomy, leads to total cessation of dreams in 70–90% of subjects, who also exhibited a “. . . lack of initiative, curiosity and fantasy in waking life.” (Nir & Tononi, 2010) 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.” (Nir & Tononi, 2010)

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.” (Nir & Tononi, 2010) 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. . . ” (Nir & Tononi, 2010). Children under 7 years report dreams when awakened from 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 mental imagery (top-down) than perception (bottom-up), and therefore that neural mechanisms used in mental imagery are in play in the case of dreaming.

Nir and Tononi do not provide citations that make the direct connection between abilities on mental imagery tests — e.g. the Block Design Test (Wechsler, 1967) — and the content of children’s dreams. Indeed, a significant difficulty with their argument is the childrens’ reporting ability: How could a child understand the concept of a dream without experiencing one? If there is a correlation between dreams and mental imagery but not linguistic ability, it implies that the system that allows both mental imagery and dreams is different (in terms of connections, access or network dynamics) than the system that leads to linguistic ability. Nir & Tononi (2010) 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 comparable reflective thought in dreams could be explained by the relative lack of activation in the PFC during non-lucid dream sleep.

What Causes Activation During Dreaming? A significant issue with Nir and Tononi’s account is the absence of a specified cause of the activation during dreaming. Hobson locates the cause of dreaming in PGO waves. According to Nir & Tononi (2010), activation could be due to intentional prefrontal control during dreaming, but where self-awareness is inhibited — dreams are the same as mental images except they are not recognized as being intentional. This is interesting to consider in relation to the lack of self-reflective thought in (non-lucid) dreaming, and the role of the temporo-parieto-occipital junction in both mental imagery and dreaming. Nir & Tononi (2010) also make reference to a possible role of the DMN, due to the partial overlap of associated brain regions active during dreaming and the DMN structures, in particular the PFC and temporo-parieto-occipital junction. Possible links between dreaming and the default network will be discussed later. Visual imagination and mental imagery are used interchangeably by Nir & Tononi (2010), and are not explicitly defined. It is clear that they consider perception as being “bottom-up”, where sensory information is processed by increasingly high-level perceptual processes, and mental imagery as “top-down”, where processing happening in higher level abstract brain areas (presumably along the ventral visual stream) causes the experience of visual images in the mind.

Whether dreams are similar to perception or mental imagery, there appears to be a consensus that dreams are the result of the activation of high-level perceptual representations in the medial temporal cortex, including the hippocampus, parahippocampus, entorhinal, and perirhinal areas. Hobson, Nir and Tononi’s 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 low-level perception (Triesch et al., 2003), and the opposite is obviously the case. Perhaps there is little difference between these two options: (a) PGO waves activate early sensory regions and lead to perceptual activation (J. A. Hobson, 2009), and (b) the activation of perceptual representations leads to the activation of early sensory regions (Nir & Tononi, 2010). In both cases, perceptual and sensory systems are activated, and causality is difficult to disentangle. While there is a lack of an explicit definition of mental imagery, Nir & Tononi (2010) cite S. M. Kosslyn (1994), who proposes a theoretical account for the presence of mental images in the mind functionally dependent on the early visual cortex and explains their resemblance to perception. However, it is disputed whether there is a functional role for the early sensory regions in dreaming and metal imagery.

Perceptual Anticipation Theory. Kosslyn (2003; 2006) proposes the *Perceptual Anticipation Theory* of mental imagery which proposes a functional role of 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” (S. M. Kosslyn & Thompson, 2003). The act of imagining an object involves the construction of a sensory impression of that object in sensory cortex.

The patterns that define these mental images (visual long-term memory) are not stored in the visual cortex (VC), but are encoded, using “population coding” (Stokes et al., 2009; Young & Yamane, 1992), in the temporal lobe (TL). 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 VC, these representations are non-topographical and therefore implicit. 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" (S. M. Kosslyn & Thompson, 2003). These representations do not include spatial information, which is encoded elsewhere.[1] The constructive activation of early VC from TL representations is analogous to that pictured as a black arrow in Figure 1 (right).

Once the TL representations are decoded into the VC, they are perceived using the same mechanisms as external visual perception, not pictured in Figure 1 (right). Kosslyn's proposal that the early VC is functionally required in mental imagery is due to the overlapping constraints between mental imagery and perception, in particular the results of visual scanning experiments (S. Kosslyn, 1973; S. M. Kosslyn et al., 1978; Pinker & Kosslyn, 1978; Pinker, 1980), to be discussed in later. In many of these studies it is noted that those subjects most adept at imagining images, as measured by the *Vividness of Visual Imagery Questionnaire* (Marks, 1973), showed the smallest differences between perceptual and mental imagery constraints.

Reconstructed mental images 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." (S. M. Kosslyn & Thompson, 2003) Activation in the early VC 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 (e.g. color and size) — not spatial relations (e.g. position).

Are Mental Images Visual or Propositional? Since the 80's Kosslyn (1979; 1980; 1981; 2003) and Pylyshyn (1981; 2002; 2003a; 2003b) 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 symbolic / propositional descriptions of visual properties that do not depend on 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, any activation in the early visual system during mental imagery is spurious and nonfunctional. Dominic Gregory (2010) 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 an impasse in resolving imagistic and propositional conceptions.

Shared Representations in Perception and Imagery Kosslyn's account is specifically focused on the early visual system and assumes that long term visual memory is located in the inferior TL. The role of the inferior and medial TL in perception and memory is questioned by the *Emergent Memory Account* (EMA) as proposed by Graham et al. (2010). According to the EMA, the medial temporal lobe is not simply a storehouse for memory, but is specialized for perceptual representations that are used in *both* memory and perception. If the EMA is correct, then visual mental imagery would involve much of the medial temporal lobe (MTL) and may not even depend on the early visual system. Under the EMA hypothesis, perceptual information leads to the activation of perceptual representations in the MTL. This account is incompatible with Kosslyn's theory that predicts a functional role of the early VC following the overlapping constraints in visual perception and mental imagery, to be discussed in detail later.

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[1] For more information regarding the processing of object and spatial information see Mishkin et al. (1983); Goodale & Westwood (2004); Murray et al. (2007).

Summary of Sleep, Dreaming and Mental Imagery

Hobson theorizes that dreams involve mechanisms similar to external perception, while Nir and Tononi consider that dreams involve mechanisms that more closely overlap with those of mental imagery. Both theories posit a key role for perceptual representations in long term memory. Kosslyn proposes that mental imagery exploits the same functions as external perception, and mental images are decoded into early visual cortex from encoded TL representations. Thus we can consider dreaming, mental imagery and external perception as highly related and that they may share neural mechanisms, including a role for perceptual representations situated in the TL. The mechanisms that cause the activation of these representations is, as yet, unclear. The default network, which is active in both dreaming and mind wandering, may explain the source of activation of perceptual representations in dreaming.

The Default Mode Network and Dreaming

As noted by Domhoff (2011), current research on dreaming certainly emphasizes a continuity between dreaming and waking cognition. Although notions of dreams as bizarre narratives have captured our collective imagination for a significant period, even early dream content studies from the 1970s indicated that *bizarre* dreams are exceptional; most dream reports are "...clear, coherent, and detailed account[s] of a realistic situation involving the dreamer and other people caught up in very ordinary activities..." (Domhoff (2011) citing Snyder (1970)). A consideration of dream content as *ordinary* and the inclusion of terms describing meta-awareness (e.g. *contemplate*, *decide*, *realize*, *ponder*, etc.) in dream reports supports a continuity between dreaming and waking consciousness. Studies of relaxed waking (such as mind-wandering) in laboratory settings have shown that these states can be "...as fragmented or unusual as dreams" (Domhoff, 2011). Physical impossibilities and disconnected thoughts can be present in both dreaming and in mind-wandering.

The DMN is a set of neural structures that are highly active when the subject is resting (during mind-wandering) and are inhibited during goal-oriented activity. Domhoff (2011) proposes that dreams result from an activation of a subset of the DMN that "...is active when the mind is wandering, daydreaming, or simulating past or future events." Regions that are associated with the DMN include the "...medial prefrontal cortex, the anterior cingulate cortex, and the temporoparietel junction...", which are also implicated in dreaming. Not all neural structures implicated in the DMN are highly active during REM and NREM sleep. Domhoff proposes this lack of activation during dreaming is because sensation, locomotion and executive functions are *not necessary* during dreaming.

Domhoff proposes that DMN activity serves as a bridge between waking and dreaming consciousness: Just before the onset of sleep, the DMN is likely to be active due to a relaxed state. The shift from waking relaxed thought to sleep is rapid and DMN activity continues into NREM. The central component of Domhoff's proposal (2011) is the correlation between dreams and the DMN, which provides a link to mind-wandering. This link is compelling as the characteristics of mind-wandering (in particular the lack of volition and self-reflection) resemble those of dreaming.

The proposal that dreams and mind-wandering have common mechanisms is also supported by a recent meta-study by Fox et al. (2013), which concludes that there are "...large overlaps in activation patterns of cortical regions..." in REM sleep, mind-wandering and DMN activity. Areas associated with the DMN that are activated during mind-wandering and dreaming include medial PFC, posterior cingulate, hippocampus, parahippocampus and entorhinal cortex (the latter three being constituents of the medial TL). Note that the temporo-parieto-occipital junction (inferior parietal lobule) was not found to be active during REM sleep in this meta-study. This is difficult to resolve with evidence that damage to this area often leads to a cessation of dreaming according to Solms (2000). The association between mind-wandering and dreaming is not limited to neuroimaging studies, but also supported by first-person reports where the phenomenology of both include an emphasis on visual and auditory information, the inclusion 'bizarre' and implausible events, an emphasis on "ongoing waking concerns", the inclusion of social interactions, and a lack of meta-awareness (the awareness of being aware).

The implication of the DMN in dreaming proposed by Domhoff (2011) and extended by Fox et al. (2013), and therefore that mind-wandering and dreaming may be enabled by shared mechanisms, is compelling. It resolves the colloquial relation between dreaming and day-dreaming (mind-wandering) with empirical evidence. If it is accepted, then "... dreams can be seen as a unique and more fully developed form of mind-wandering, and therefore as the *quintessential cognitive simulation.* [emphasis added]" (Domhoff, 2011). It is important to note that the overlap between dreaming and the default network reported by Fox et al. (2013) is tied specifically to REM sleep: "... the observed overlap with the DMN is not common to all sleep stages, but specific to REM sleep—*the only sleep stage truly reliably associated with dream mentation*.[emphasis added]" (Fox et al., 2013). Thus the link between the DMN and dreaming becomes muddy in NREM sleep. Still, a role of the DMN network, in particular the associated PFC regions, at least partially answers the open question as to what causes the activation of TL representations if we consider dreaming as mental imagery. Additionally, Domhoff (2011) notes that the activity of the DMN through relaxed waking into sleep indicates a continuity of mind-wandering, and dreaming where the difference is due to network dynamics and not independent mechanisms.

Dreaming, Mind-wandering and Simulation Simulation and prediction have being considered as frameworks for the organization of general cognition (Hesslow, 2002). Both J. A. Hobson (2009) and Schooler et al. (2011) describe dreams and mind-wandering, respectively, as having predictive functions informed by learned models of sensory reality, which is supported by overlapping activity during dreaming and mind wandering. It has been proposed that subsets of the DMN function as simulators: "the default network thus comprises at least two distinct interacting subsystems — one subsystem functions to provide information from memory; the second participates to *derive self-relevant mental simulations*.[emphasis added]" (Buckner et al., 2008) The former system being correlated with the TL and the latter the PFC. Together, these sub-systems of the DMN use components of long-term memory in the construction of simulations. Such simulations are not only valuable for the rehearsal of social interactions (Schooler et al., 2011) and threat response (Revonsuo, 2000),[2] but could also contribute to waking perception. The combination of sensory information and a simulation, informed by a predictive model of the world, facilitates the ability to anticipate changes in the environment and thus have obvious adaptive value. The predictions learned through waking perception that form the basis of these simulations also allow the unconscious modulation of attention for particular scenarios, as evidenced by priming experiments, e.g. (Davenport & Potter, 2004).

In both dreaming and mind-wandering, our attention shifts to internal images where external stimuli is largely ignored and we show impairments in executive functions. For example, during mind-wandering the DMN is most active when subjects are not aware of their mind-wandering (e.g. a lack of meta-awareness) (Christoff et al., 2009). The DMN is also active when people engage in

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[2] Revonsuo (2000) proposes the *threat simulation hypothesis* where dreaming provides an adaptive function by allowing the practice of threat perception and avoidance in the absence of real danger.

"personal planning concerning the future" Domhoff (2011). When we dream and let our minds wander, we enter the simulated worlds of our imaginations.

Summary of Theories

This section covered significant territory, so we will summarize the key aspects of the reviewed theories:

1. Hobson (2009; 2012) proposes that dreams are the result of our perceptual mechanisms attempting to make sense of the PGO activation of sensory regions during REM sleep. REM sleep is characterized by: a similar degree of activation to waking, a disconnection of the brain from the rest of the body, and a suppression of feed-back mechanisms. Dreams are considered functional simulations.
2. Nir and Tononi (2010; 2013) propose that dreaming is less like perception and more like mental imagery.
3. Kosslyn (2003; 2006) proposes that mental images and external perception are subject to similar constraints. During mental imagery, encoded representations in the TL are rendered in early VC and perceived by the same mechanisms as external perception.
4. Domhoff (2011) proposes that dreams are enabled by the same mechanisms that support mind-wandering, specifically a subset of the DMN, a position which is also supported by Fox et al. (2013). Dreams result from the activation of perceptual information and provide the *quintessential* mechanism of simulation, thus extending the function and phenomenology of mind-wandering.

The following two sections detail the contributions of the research presented in this paper. First, the Integrative Theory is described, after which its companion computational and artistic realization is summarized.

Integrative Theory

The previous sections include discussions and a selection of key points of theory regarding possible relations between visual aspects of external perception, mental imagery, mind-wandering and dreaming (visual mentation). This section unifies theoretical points made in the previous sections into the Integrative Theory where three central hypotheses are made:

1. Visual mentation involves the activation of perceptual representations located in the TL.
2. The phenomenological experience of visual mentation is due to activity of perceptual representations within the TL.
3. Visual mentation is the simulation of perceptual information exploiting perceptual representations and modulated by varying degrees of exogenous activation.

All theories discussed above predict some functional role of perceptual representations in the TL — be they encoded or explicit, conceptual or perceptual, and thus support Hypothesis 1:

1. J. A. Hobson (2009) notes that TL epileptics experience seizures commonly characterized as *dreamy states.* He also contends that dreams are perceived using the same mechanisms as external perception, which implies a degree of TL processing.
2. Nir & Tononi (2010) link dreaming with mental imagery as the activation of representations implicated in mental imagery.
3. For S. M. Kosslyn & Thompson (2003), the TL is the storehouse for visual representations, and overlaps with Hobson in proposing a functional role of early VC.

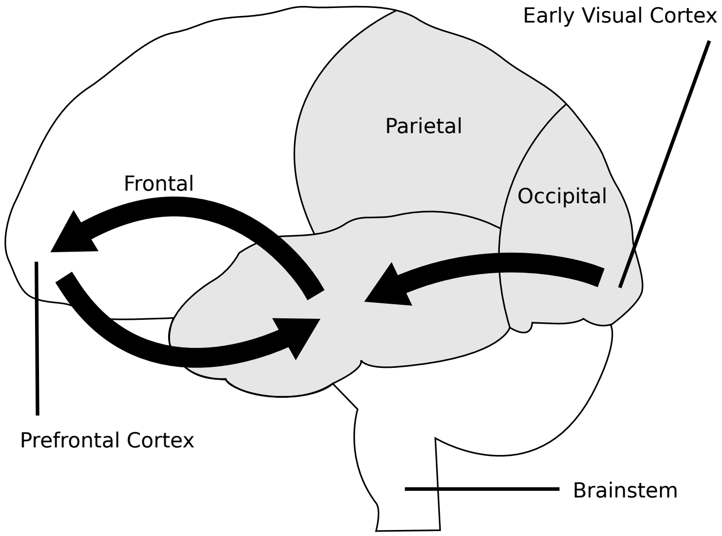


Figure 2. : The Integrative Theory unifies external perception, mental imagery, mind-wandering and dreaming.

4. Graham et al. (2010) link perception and memory and propose that TL damage leads to deficits in memory recall and perception. The representations implied in mental imagery are shared with external perception, and therefore presumably also in dreams.

5. Domhoff (2011) and Nir & Tononi (2010) cite lesion studies that show that damage to the TL subsystem of the default network, in particular at the temporal-occipito-parieto junction, leads to deficit in dreams, *initiative, curiosity and fantasy,* and even total cessation of dreaming.

Together, these points support the argument for a central functional role of perceptual representations located in the TL in visual mentation. While Hypothesis 1 is fairly well established, the cause of the activation of perceptual representations is disputed. In order to arrive at a cohesive conception, some aspects of the discussed theories must be rejected. We identify two explanations: perceptual representation activation results from (1) early VC activation, as in external perception (Hobson, Kosslyn), (2) prefrontal control (Domhoff, Nir and Tononi).

The functional role of early VC in mental imagery and dreaming is key to the theories proposed by Hobson and Kosslyn. The relation between mental imagery and external perception has been a topic of study since the 1970s and often conflate image recall (the recall of a particular visual memory), imagery of a memorized image (mental imagery of a learned visual image) and novel imagery (the construction of a new mental image not in memory nor perception). Studies have shown that mental imagery and perception share similar constraints, including field of view (Finke, 1980; Marzi et al., 2006) and scan time (S. Kosslyn, 1973; Lea, 1975; S. M. Kosslyn et al., 1978). Scanning time experiments, such as documented by S. Kosslyn (1973), involve the subject memorizing a map containing a number of landmarks. The subject is then asked to imagine the map with a virtual cursor superimposed on a particular landmark. The subject is then asked to smoothly shift their mental image, while keeping the cursor static, to a target landmark, and report when they arrive. The actual distance between landmarks is correlated with the mental scanning time. This was also reproduced in three dimensions by Pinker (1980).

It has also been shown that the scale of objects in perceptual and mental images appear to take up similar amounts of a virtual field of view of limited resolution: objects imagined at relatively small scales take longer to interpret than objects at large scales (S. Kosslyn, 1976). Studies also have shown that the ability to attend to details of objects imagined at a small scale is more difficult than when imagined at a large scales (Moyer, 1973; S. M. Kosslyn, 1975; Paivio, 1975; S. Kosslyn, 1976; S. M. Kosslyn et al., 1977). There is also evidence for interactions between perception and imagery, including visual illusions (Mohr et al., 2011), perceptual deficits during imagery (Wais et al., 2010) and the effect of the mental imagery on the perception of subsequent perceptual images (Diekhof et al., 2011). The general argument for a functional role of the early VC in mental imagery is that similar constraints imply similar mechanisms. These experiments support the notion of mental imagery as depictive rather than symbolic, although it has been demonstrated in a computational model by Sima (2011) that a symbolic system could still explain the mental image scanning results.

In Marzi et al.'s study (2006), a subject with damage to the early VC had no perceptual ability in one visual quadrant, and yet was able to construct whole mental images. Most interestingly, perceptual constraints in the blind quadrant — reaction time effects dependent on location of stimulus in the field of view (Chelazzi et al., 1988) — did not apply to mental images as in normal subjects. This indicates that the early VC modulates mental images but is not functionally required. The lack of a functional requirement for the early VC is also supported recent studies which found that multiple patients that acquired total cortical blindness have preserved mental imagery (Zago et al., 2010; Bridge et al., 2012).

Recent fMRI decoding studies have allowed a more detailed examination of the role of the early VC in mental imagery. Decoding studies have attempted to correlate patterns of brain activity with particular visual stimuli. An analysis of brain activity can predict which visual stimulus a subject is currently viewing. S. Lee et al. (2012) demonstrated that activity in the VC and TL could predict an image either seen or imagined (after memorization) by a subject. During imagery, they found a high degree of correlated activation relevant to the memorized stimulus in the TL, and low stimulus-correlated activity in the VC. During perception, they found the opposite pattern, greater stimulus-correlated activation in the VC and less stimulus-correlated activation in the TL.

As dreams occur in the absence of PGO waves, we can conclude that the experience of images in the mind (mental imagery and dreams) is likely due to activity of perceptual representations in the TL (Hypothesis 2) that is independent of the early VC. We are then left with two possibilities in the case of dreaming: the activation of perceptual representations is due to intentional control from the PFC, or it is due to endogenous activation of the TL. The DMN spans structures in both the PFC and the TL, and due to the established link between mental imagery, dreaming, mind-wandering and the default network, we can conclude that activation in the TL is due to activation in the DMN system including portions of the PFC. The difference between the various states of visual mentation are due to differing dynamics of the DMN: mental imagery results from intentional functions of the PFC, external perception is highly dependent on external stimuli impacting the early VC, and mind-wandering and dreaming are the result of non-uniform endogenous activation within the DMN.

Figure 2 depicts the causal patterns of three modes of visual mentation: External perception is the result of exogenous activation of early VC which in turn causes perceptual representation activation in the TL. Mental imagery is the result of PFC control mechanisms causing the activation of perceptual representations, which result in the experience of mental images. Visual aspects of dreaming and mind-wandering are the result of endogenous activation within the DMN, modulated by varying degrees of control initiated by the PFC. This endogenous activation could be structured as a feedback loop between the TL and PFC aspects of the default network. The PFC initiates activation in the TL, which results in further activation of the PFC, and results in subsequent activation of the TL. Hesslow (2002) describes a similar feedback loop in terms of *simulating chains of behavior* operating in perception where, "...during normal behavior, we will always, 'in our thoughts', be a few steps ahead of the actual events."

The exploitation of shared perceptual representations in visual mentation supports the various constituents of visual mentation are contiguous and can causally effect one another. For example, it has been shown that waking perception in the hours before sleep has a significant effect on dream content (Stickgold et al., 2000). Antti Revonsuo describes the continuity of perception and dreaming: "We are dreaming all the time, it's just that our dreams are shaped by our perceptions when awake, and therefore constrained" (Tucker et al., 2009). We can then consider the differences between the various constituents of visual mentation as due to the same or similar neural mechanisms engaged in differing dynamics. These dynamics can even extend beyond the waking / sleeping barrier, where some parts of our brain engage in sleep, while others remain vigilant, simultaneously: "[S]leep or wakefulness may regularly occur independently in different brain regions." (Nir et al., 2013)

Hypothesis 3 states that a key functional attribute shared between processes of visual mentation is simulation. Considering the constructive aspects of external perception, we can conceive of our experience of the world as a simulation that is anchored in sensory information. By contrast, mental imagery is a simulation relatively decoupled from external stimuli, but intentionally controlled and constrained by task demands. Dreaming and mind-wandering result from these same mechanisms of simulation, but operating independently of both task demands and sensory anchoring.

Dreaming and mind-wandering are then free-running simulations that exploit our predictive models of sensory reality. These simulations provide banal experiences related to waking concerns due to their shared mechanisms with external perception. They may also provide the bizarre aspects of dreams such as chimeric elements and discontinuity because they lack the stability provided by external sensory information. The predictions themselves have functional value in perception (perceptual priming) and social interaction: "Perhaps a primary function of mind-wandering is to generate the autobiographical predictions necessary to successfully navigate the complex social world." (Schooler et al., 2011) Despite the possibility of their lack of cohesion (compared to waking perception), the free running simulations could also provide adaptive functions including the development of the "protoself" (J. A. Hobson, 2009) and the rehearsal of threatening situations Revonsuo (2000).

The particular brain systems that enable all of these simulations are a subset of the DMN; which has been implicated in dreaming and mind-wandering. Domhoff characterizes dreams as the *quintessential cognitive simulation* (Domhoff, 2011) because they are a *more fully developed form of mind-wandering*. In summary, the Integrative Theory proposes that visual mentation is set of closely related phenomena that all exploit the same mechanisms of representation and simulation. The next section discusses the computational model and artwork that manifests key components of the Integrative Theory.

Computational Model: *A Machine that Dreams*

The *Integrative Theory* is the foundation for the computational model. While the theory includes a role for executive function in task-oriented mental imagery, the computational model is centrally focused on aspects of visual mentation (perception, mind-wandering and dreaming) independent of executive mechanisms such as working memory, attention and planning. Additionally, the focus of the system design is the dynamics of percept activation that leads to dreaming and mind wandering images, not the construction of percepts themselves. The process leading to percepts is simply a method to provide the system a variety of perceptual information, and not a model perceptual processes. The key features of the proposed theory manifest in the computational model include: shared representations and processes utilized in perception, mind-wandering and dreaming, and the explicit contiguity of those three processes of simulation.

Computational modeling provides a compelling framework for the theorization and critique of biopsychological conceptions. The implementation of these ideas in formal language requires sufficient detail as to force the specification of tacit aspects. The computational model is realized as a situated agent that captures visual images with a video camera, and displays a window into its 'mental' images. This display is a visualization of the perceptual, mind-wandering and dreaming processes of the system.

During the day, the system memorizes and learns a predictive model of the visual world's spatial and temporal properties from visual information collected by the camera. 'Dreaming' (at night) and 'mind wandering' (during low arousal) is the result of the exploitation of the predictive model. The system's processes simulate reality as constructed from perceptual representations (learned during waking) and differ only in the degree to which these processes are anchored in sensory information. For simplicity, sleep is not broken into stages and all sleep entails dreaming. The arousal of the system (the degree of change in external stimuli) and a circadian clock cause the transition between these contiguous processes. The limitations of the system's experience, memory and recognition ability lead to impoverished visual mentation. The design of the computational model manifests the following key attributes:

- Dreaming and mind-wandering are enabled by endogenous activation of predictive mechanisms causing activation of perceptual representations, following the *Integrative Theory*.
- External perception, mind-wandering and dreaming are contiguous processes modulated by varying degrees of influence from exogenous and endogenous activation.
- Visual mentation is a simulation of the external visual world resulting from the activation of perceptual representations as a result of feedback in the predictive model.
- The system is a partial artificial agent that lacks executive mechanisms.

System Architecture

Figure 3 shows the architecture of the system. STIMULUS provides images (S_t) captured by the camera at time t, which are passed onto SEGMENTATION. For each frame, SEGMENTATION breaks S_t into color regions using mean shift segmentation (Comaniciu & Meer, 2002), and passes the set of segmented regions (Rs_t) onto CLUSTERING, which clusters segmented regions according to features and constructs new PERCEPUNITS that represent similar regions in subsequent frames. A stimulus is recognized when it is associated with an existing cluster. The set of PERCEPUNITS (Ps_t) is passed onto SUPPRESSOR, which determines the balance between exogenous (caused by external stimuli) and endogenous (caused by feedback from PREDICTION) activation. This balance determines the weighting and combination of inputs from CLUSTERING and PREDICTION —

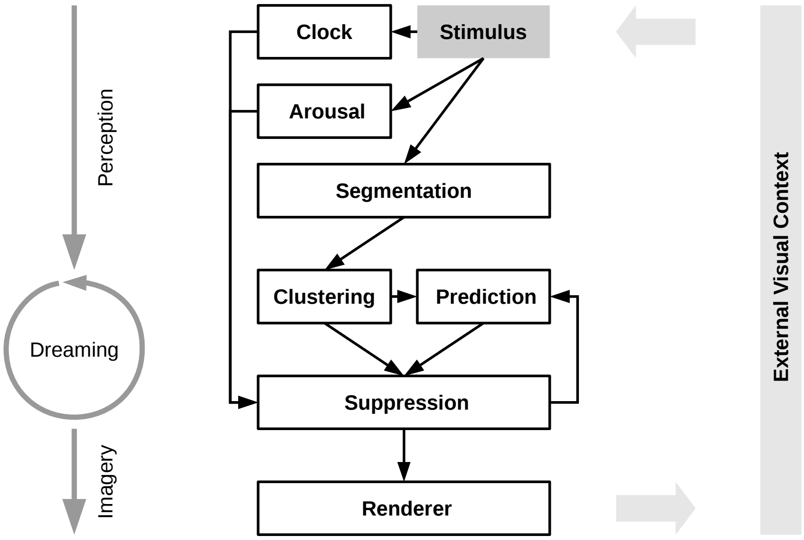


Figure 3. : System Architecture

as controlled by AROUSAL and the circadian CLOCK in the absence of executive mechanisms. The CLOCK indicates day or night as determined by the brightness of STIMULUS and AROUSAL indicates the change in STIMULUS over time. Activated PERCEPUNITS are made visible on the display by the RENDERER. PREDICTION learns to predict the next state of PERCEPUNIT activation considering the current state of PERCEPUNIT activation. These predictions are feed back into PREDICTION, as mediated by SUPPRESSION. Each of these modules is described in detail in the following sections.

STIMULUS. This module provides visual stimuli to the system, an example of which is pictured in Figure 4. The stimulus is a single video frame (S_t, where t is the frame number). The current stimulus is passed to SEGMENTATION and AROUSAL, while its mean luminosity (S_t^l) feeds the circadian CLOCK.

CLOCK. The CLOCK is a discrete square wave that indicates day when the mean luminosity of STIMULUS ($mean(S_t^l)$) is above a threshold (T_l), and night otherwise: $if\ S_t^l > T_l$ then $clock = 1$, otherwise $clock = 0$. The CLOCK provides the onset of day and night and modulates SUPPRESSION, to be discussed later.

AROUSAL. The AROUSAL produces a discrete square wave that indicates change in STIMULUS between $t-1$ and t. It is calculated from the absolute difference in mean luminosity of all pixels in S_{t-1}^l and S_t^l. If the difference is above a threshold, $\parallel mean(S_{t-1}^l), mean(S_t^l) \parallel > T_a$, then $arousal = 1$, otherwise $arousal = 0$.

SEGMENTATION. SEGMENTATION breaks STIMULUS into color regions according to the mean shift segmentation method described by Comaniciu & Meer (2002). The resulting regions, an example of which is pictured in Figure 6, are extracted through thresholding and contour finding as

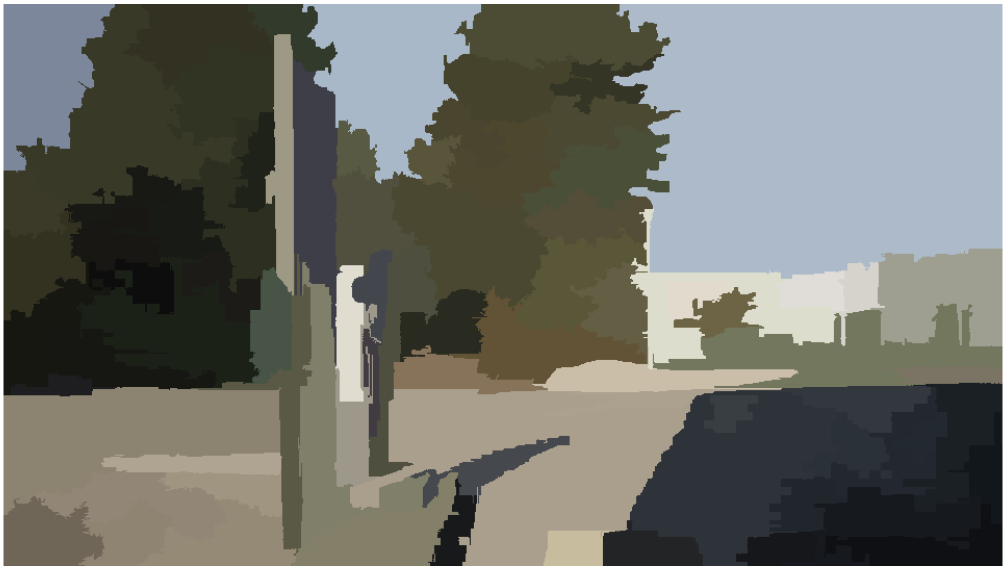
Figure 4. : Example STIMULUS provided to system.

follows and detailed in Algorithm 1: The mean shift algorithm (Line 2) is run on a hue, saturation and value (HSV) color-space version of STIMULUS (Line 1). A histogram (H) is computed from the value channel of the resulting image (Line 4), and used to determine the pixel values of segmented regions. For each bin (b) of the histogram (Line 5), if there are pixels in this bin (Line 6) a binary image (BI) is calculated where white pixels indicate the value of the bin (b^v) matches the segmented region (Line 7); As each pixel value may contain multiple discontinuous color regions, contour finding is used to determine the bounding box around each contiguous region (Line 8), and its center position (Line 9); A region instance (R) is constructed from STIMULUS (Line 10), using the bounding box (bb) and binary image (BI) to calculate a mask, and is associated with an x, y position in the frame, as pictured in Figure 6.

Algorithm 1 SEGMENTATION

```
1:  $S_t^{hsv} \leftarrow hsv(S_t)$
2:  $S_t^{ms} \leftarrow meanShiftSegmentation(S_t^{hsv})$
3:  $S_t^{l,ms} \leftarrow value(S_t^{ms})$
4:  $H \leftarrow hist(S_t^{l,ms})$
5:  for $b \in H$ do
6:      if $b^c > 0$ then
7:          $BI \leftarrow S_t^{l,ms} = b^v$
8:          $bb \leftarrow boundingBox(findContours(BI))$
9:          $x,\ y \leftarrow position(bb)$
10:         $R \leftarrow regionUnit(S_t,\ BI,\ x,\ y)$
```

The resulting region instances, an example of which is pictured in Figure 6b, are stored in a



(a) Results of mean shift segmentation of STIMULUS.

(b) Grey scale version of mean shift output ($S_t^{l,\,ms}$).

Figure 5. : STIMULUS is broken into regions according to the mean shift segmentation method.

(a) Boolean image (BI) resulting from a comparison of histogram values and gray-scale mean shift output.

(b) The image in Figure 6a is used to calculate a number of contours. For each contour is used to extract S_t, where the mask is applied as an alpha channel.

Figure 6. : An example region extracted from mean shift output (S_t^{ms}).

set ($Rs_t \leftarrow \{R^0, \ldots, R^n\}$) and passed onto Clustering. Each region is associated with an image, a mask and the following *features* (f):

- $R_{x,y}$ Position of the center of the segmented bounding box around the contour calculated during Segmentation, normalized to range from 0 to 1, where $x = 1,\ y = 1$ corresponds to the far bottom right corner of Stimulus.
- $R_{h,s,v}$ Mean color values in hue, saturation and value color-space of S_t, normalized to range from 0 to 1.

Clustering. Each R extracted from S_t represents a contiguous region of pixels at a particular moment in time. Clustering allows the recognition of regions that persist over time, through the construction of PercepUnits from regions captured at differing times. PercepUnits, an example of which is pictured in Figure 7, are abstractions of the raw stimuli provided by Segmentation, and are, like regions, associated with images, masks, and the region features. Clustering compares regions segmented from the current frame (Rs_t) to PercepUnit clusters (Ps) composed of regions segmented from previous frames. These PercepUnits are destructive in that all regions belonging to a particular cluster are represented by a single PercepUnit whose properties are a weighted average of constituent regions, including images, masks and features. Hereafter, this process of destructive clustering will be referred to as *merging*. When a newly segmented pixel region is merged with a PercepUnit, it is analogous to the system's recognition of that sensory information, where the PercepUnit is updated to take into account the new sensory information. For each merge, the resulting PercepUnit is set with an initial activation ($P^A = 1$, where $0 \leq P^A \leq 1$).

The clustering method is a modified version of the Basic Sequential Algorithmic Scheme (Theodoridis & Koutroumbas, 2009). Clustering begins with an empty set of PercepUnits (Ps_t) and is detailed in Algorithm 2, where the maximum number of PercepUnits (q) is specified a priori and clustering proceeds for each t and n is the current number of PercepUnits: loop through each newly segmented region (Line 1) and determine which PercepUnit is closest to this region (R_t) over all features (Line 2); If we have not reached the maximum number of PercepUnits, and the distance between the region (R_t) and the nearest PercepUnit is above a threshold (Line 3), then make a new cluster from the region (Line 4), activate it (Line 5) and increment n; otherwise update the closest cluster (C) by merging it with the region (Lines 8 and 9) and activate it.

The result is a set of PercepUnits (Ps_t) that eventually converges to a fixed size (q) where

Algorithm 2 Clustering

```
for $R_t \in Rs_t$ do
    $C \leftarrow argmin_i \parallel R^f_t,\ P^f_i \in Ps_t \parallel$
    if $\parallel R^f_t,\ C^f \parallel > T_s$ and $n < q$ then
        $Ps_{t+1} \leftarrow Ps_t \cup R_t$
        $R^A_t \leftarrow 1$
        $n \leftarrow n + 1$
    else
        $P_{t+1} \leftarrow merge(P_t,\ C)$
        $C \leftarrow P_{t+1}$
        $C^A \leftarrow 1$
$t \leftarrow t + 1$
```

each approximates a point in feature space and is represented by the weighted average of the constituent regions. Figure 8 shows a collection of PERCEPUNITS constructed over 150 frames, where $q = 900$. The output of CLUSTERING is the state of activation of all PERCEPUNITS ($A_t \leftarrow \{Ps_t | Ps^A_t = 1\}$) and is passed to both SUPPRESSION and PREDICTION.

Figure 7. : An example of the image corresponding to a clustered PERCEPUNIT which is constructed from pixel regions segmented at different times.

PREDICTION. The PREDICTION module is a Multilayer Perceptron (Rumelhart & Williams, 1986) which serves as a generic prediction mechanism. The network consists of the same number of input units as there are clusters (q), $q/2$ hidden units in one layer and q number of output units. The hidden and output units use symmetric sigmoid activation functions with slopes of 1. This module buffers the state of activation that corresponds to the previous frame (A_{t-1}), which is fed to the network as a training sample. The current state of activation (A_t) provides the target vector for supervised back-propagation learning. The output units are discretized as a vector of Boolean values where each element corresponds to each PERCEPUNIT (Ps^P_{t-1}), where 1 indicates the PERCEPUNIT is predicted to be present at t and 0 otherwise. The learning rate is fixed at 1 as the network is learning from continuous live data and learning samples are not repeated.[3]

The training delta (error) is the binary distance between Ps^P_{t-1} and A_t. In order for the network to descend towards convergence, A_t is only fed to the network when the difference between

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[3] The system does not buffer activation patterns over time and thus learning is continuous, rather than epoch, oriented.

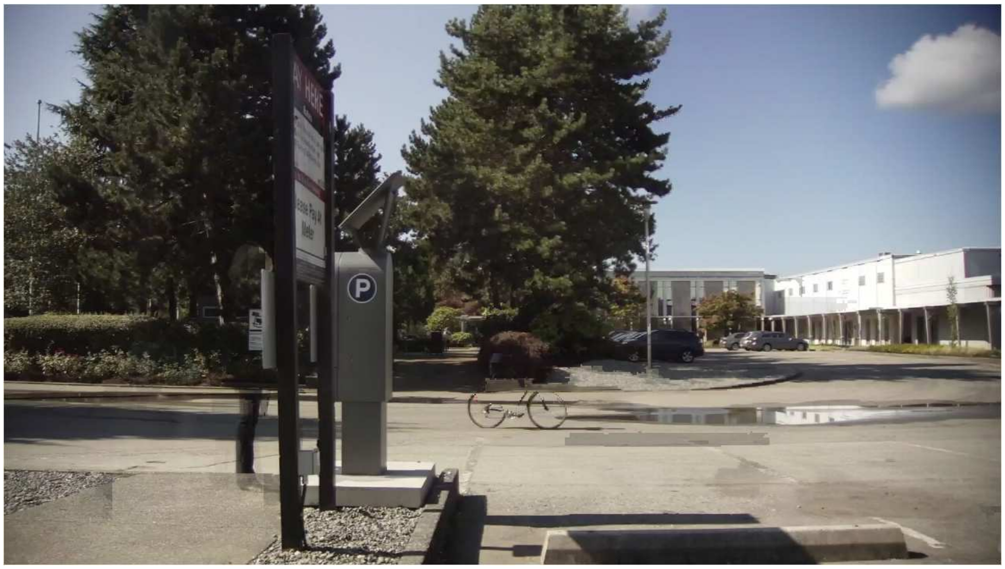

Figure 8. : A collection of approximately 900 PERCEPUNITS drawn in the location in which they were segmented. The lack of temporal stability in the mean-shift edges cause fragmented percepts which is compounded by arbitrary stacking of percepts in this rendering, e.g. the bicycle without a rider above.

Ps^{p}_{t-1} and A_t is above a threshold. At time t, the network provides a prediction of what PERCEPUNITS are expected to be activated at $t+1$ such that when the prediction is perfect ($delta = 0$) then $Ps^{P}_{t-1} = A_t$. PREDICTION learns from current perceptual activation from CLUSTERING, and exploits that learning by calculating a prediction of the next state (Ps^{P}_{t}), based on the current state (A_t), which is passed onto SUPPRESSION along with the expected prediction for this t (Ps^{P}_{t-1}).

SUPPRESSION. SUPPRESSION determines the balance between activation caused by feedback from PREDICTION (endogenous) and activation caused by external STIMULUS (exogenous), as shown in Figure 3. It's input from CLUSTERING is the set of all activated PERCEPUNITS (A_t) while it's input from PREDICTION is the set of all percepts predicted to be currently activated (Ps^{P}_{t}). When the system is waking ($clock = 1$ and $arousal = 1$), the output of SUPPRESSOR is both predicted (Ps^{P}_{t}) and activated percepts (A_t), which are passed to RENDERER, to be explained later. When the system is mind wandering or dreaming ($clock = 1 \vee 0$ and $arousal = 0$), activation from STIMULUS (A_t) is suppressed and predicted PERCEPUNITS are fed back to PREDICTION as inputs for the next frame ($A_t \leftarrow Ps^{P}_{t}$).

RENDERER. This module visualizes the system's current state of activation (A_t) and the degree to which those activations are expected (Ps^{P}_{t-1}) for this t. During waking, all activated percepts are rendered. If the percepts are not predicted, then they are rendered 100% opaque, indicating they are a surprise. If the percepts are predicted, then they are rendered with 50% opacity. As a subset of PERCEPUNITS is active at any one moment during perception, mind wandering and dreaming, there are portions of the rendered image that do not include perceptual information.

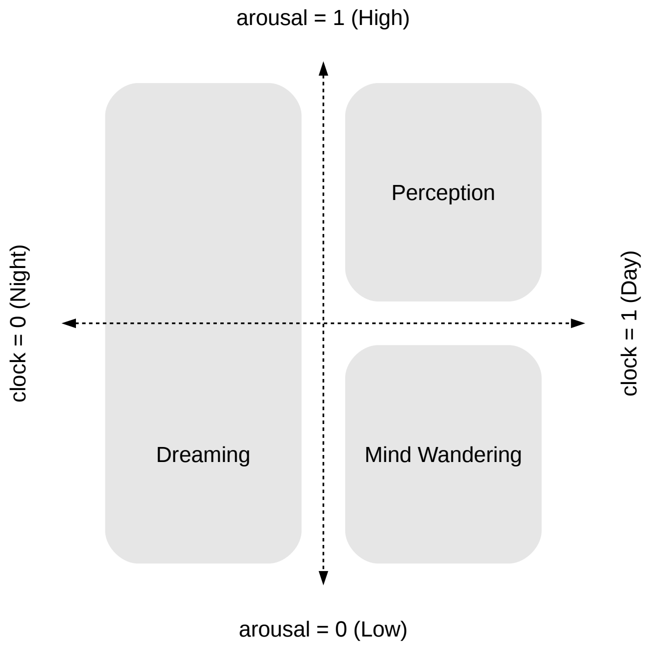

Figure 9. : Cognitive processes in relation to CLOCK and AROUSAL states.

In order to deemphasize these areas of the image, activated percepts are drawn on top of a background image, except during dreaming: During waking, the background is the result of a running average filter of current stimulus over time ($\sum_{t-10}^{t} S_t/10$), as pictured in Figure 10. During mind-wandering, the background is the result of a running average filter of mean shift segmentation results ($\sum_{t-10}^{t} S_t^{ms}/10$), as pictured in Figure 12. During dreaming, the background is solid black, as pictured in Figure 11.

Cognitive Processes

The modules described above are the framework for the three cognitive processes of the system: Perception, dreaming and mind-wandering. These processes are contiguous, as they are enabled by the same mechanisms with differing dynamics. The differing dynamics of the system are controlled by the weighting between internal feedback from prediction (endogenous) and activation caused by STIMULUS (exogenous) as mediated by SUPPRESSION, which is controlled by the states of CLOCK and AROUSAL, as pictured in Figure 9.

Perception. This is the initial process of the system, as without collecting any sensory information there would be no mind wandering or dreaming content. The sub-processes of SEGMENTATION and CLUSTERING occur only during day-time perception when high fidelity sensory information is available. Waking perception occurs when the CLOCK indicates daylight ($clock = 1$) and AROUSAL

Figure 10. : An example perceptual image. Moving foreground objects appear blurry as they augment perceptual clusters such that STIMULUS is less weighted than the existing cluster.

indicates change in stimuli over time ($arousal = 1$). Activation of PERCEPUNITS results from the clustering process. During perception, SUPPRESSION inhibits feedback to PREDICTION, such that endogenous activation is inhibited. The result is that the rendering of activated PERCEPUNITS causes the display to resemble the image captured by the camera. Perception is as constructive as dreaming and mind-wandering, but is constrained and anchored in sensory information.

Dreaming. Dreaming occurs during night time (when $clock = 0$) and the activation of perceptual representations are caused by feedback in the prediction mechanism while activation caused by STIMULUS is suppressed. Latent activation from STIMULUS is the baseline ground from which both dreaming and mind-wandering arise. AROUSAL allows PREDICTION to generate feedback as mediated by SUPPRESSION. The resulting dream is a chain of predictions, seeded by recent perceptual activation. The inhibition of activation from STIMULUS results in sequences of activation that become increasingly divorced from the latent perceptual activation that seeded them. Perceptual information that is tenuously related to the current context is included in dreams, whose resulting images may appear divorced from plausible external reality. As during perception, activated PERCEPUNITS are rendered on the display, as shown in Figure 11.

Mind-Wandering. The mind-wandering process is analogous to dreaming, except the CLOCK indicates day-time ($clock = 1$). A lack of AROUSAL ($arousal = 0$), due to static stimuli, causes SUPPRESSION to increase feedback activation from PREDICTION and inhibits perceptual activation caused by STIMULUS. This leads to the activation of PERCEPUNITS not related to current stimuli, as pictured in Figure 12. When changes in STIMULUS are manifest in an increase of arousal ($arousal = 1$), mind-wandering ends and the perceptual process resumes. This allows the system to switch its cognitive process away from internally oriented imagery (mind wandering) towards external

Figure 11. : An example dream image where endogenous activations in the PREDICTION module construct sequences of activation that are increasingly unrelated to perceptual activations that initiated them.

STIMULUS (perception).

Implementation

The computational model is written in C++ using the openFrameworks (Zach Lieberman & Castro, 2014) environment to manage OpenGL (Silicon Graphics Incorporated, 2014) rendering for visualization and OpenCV (Bradski, 2014) for segmentation and pixel operations. The MLP in the prediction module is written using FANN (Nissen, 2003). The system is fed visual stimulus by an Avigilon IP camera which provides 1440×1080 pixel video images as a JPEG sequence. Through development stimulus was provided by a set of video frames (1 per second recorded over three consecutive days) captured during an artistic exhibition, described below.

Exhibitions

Various revisions of the computational system have been exhibited internationally in artistic and academic contexts. The system is meant for long-term installation in a public setting in order to be exposed to as much variety of visual material as possible. An early associative version of the system was shown at the New Forms Festival (2012) in Vancouver, Canada, an example of which is pictured in Figure 13. Work-in-progress on the perceptual subsystem was presented at ACM Creativity and Cognition (Bogart et al., 2013) in Sydney, Australia.

Figure 12. : An example mind-wandering image where endogenous activations in the PREDICTION module cause a shift away from external stimulus toward internally generated imagery.

Discussion

Behavior of the Computational Model

The model behaves as expected, with the exception of the observation that mind wandering appears to generate more variation and complex imagery than dreaming. Perceptual processes result in cohesive simulations that resemble stimulus images. The feedback mechanism in the predictor leads to complex system dynamics that range from static, through periodic to complex patterns of percept activity. The dynamics are highly sensitive to the state of the predictor's learning and the initial conditions — the previous stimuli and latent perception that initiates dreaming and mind wandering. In the following paragraphs we describe how these dynamics of the simulator are visually manifest.

In the perceptual mode, the simulation (e.g. Figure 10) resembles the visual stimulus provided to the system. The clustering process leads to blurry moving objects, where clusters and newly segmented regions are weighed equally and clusters are not spatially invariant. Over time, the perceptual process generates simulations similar to a sequence of long photographic exposures, where clustering causes static objects to slowly fade in and moving objects to slowly fade away. This aesthetic is reinforced by the rendering of percepts on top of a running average of the unprocessed stimulus. The video footage used to train the system contains bursts of activity (e.g. rush hour on weekdays) that appear intermittently in what is predominantly a static image with little change between frames. During these periods of static stimuli, the system's prediction error is low and many percepts are rendered transparently. As arousal stays low while there is little change in stimuli, the majority of the system's daylight time is spent mind wandering, and not perceiving.

Figure 13. : Sample image from an exhibition of work-in-progress on the perceptual subsystem of the computational model, exhibited under the title: *An Artist in Process: A Computational Sketch of Dreaming Machine #3*

During mind wandering, the simulation begins by continuing the stimulus from latent perception. This makes the transition between perceiving and mind wandering appear smooth and contiguous. As feedback activation from the predictor takes over from activation caused by external stimuli, the simulations tends to drift away from the initial state of activation. The percepts that are activated by external stimuli are evenly distributed over the field of view while the simulation is composed of percepts that are less evenly distributed. As the mind wandering percepts are drawn on top of a running average of the mean shift segmentation results, as pictured in Figure 12, the simulated portions of the image — those that correspond to percept activation — appear detailed and nearly photographic. The unoccupied areas show simplified color patches as generated by the segmentation system. As the simulation drifts, images appear both recognizable (clearly show a place in space and time) and abstracted, where percepts not perceived at the same time may be simultaneously present. The activation of percepts at different locations over time changes the distribution of percepts over the field of view, leading to dynamism in the simulations. Subsequent images in the simulation may include large changes in composition due to changes in percept activation. Mind wandering is often interrupted by increases in arousal — e.g. due to a person or car entering the frame — which ends the mind wandering process. This transition is sudden as the state of activation in the simulation differs significantly from the perceptual activation, due to drift in the feedback process, and changes in stimuli.

As night falls, the external context is more likely to be static. Thus there is an increase of mind wandering during the periods before the night. This is consistent with Domhoff's (2011) proposal and shows mind wandering through to dreaming is a contiguous process involving the constant activation of a subset of the default network. Intermittent increases in arousal occur, and the system shows very short periods of perception during this time. Due to the complexities of the environment, the total luminosity of the image tends to shift dramatically. In the test footage, the sun sets in front of the camera passing behind a pair of trees. When the sun is behind the trees, the system enters dreaming, from which it is awakened when the sun is visible again. This leads to a complex oscillations where perception, mind wandering and dreaming all occur for short periods in close succession. Eventually, the sun sets and once stimuli is dark, the system enters a stable dreaming period — e.g. as pictured in Figure 11. Due to the dynamics of the system while the sun sets — where drastic changes in light and reflection lead to large changes in percept content — there tends to be a lack of diversity in percepts at the onset of dreaming. Dreams show the same internal dynamics of mind wandering — the activation of percepts not seen in the same stimulus and the uneven distribution of percepts over the visual field. The lack of diversity of percepts, and the lack of intermittent perceptual states, causes dreams to appear more static and periodic than mind wandering. The drift seen in mind wandering appears to stabilize over a number of iterations, and thus the long periods of dreaming tend to involve the simulation of repeated sequences of similar images.

Limitations of The Computational Model

The computational model described above is a formalization of the Integrative Theory —- which is oriented toward dreaming in mammalian brains. While the perceptual representations described in the Integrative Theory describe classes of concrete objects (e.g. concepts referring to perceptual information such as 'dog' or 'chair' and not abstract concepts such as 'justice' or 'freedom'), those implemented in the computational model are simplistic. The percepts generated by the system are restricted to sensory information and lack the context dependence and dynamism of concepts. While mammalian visual processing involves a degree of separation between spatial properties (such as the position in space) and object-centric properties (such as color) (Murray et al., 2007), perceptual representations in the model are fixed in space and not invariant to scale and orientation. For example, if two identical objects are presented in two different parts of the visual field, they would be represented by two different percepts. As the computational model is an on-line system that learns continuously, computer vision methods for generating scale invariant features such as SIFT (Lowe, 2004) and SURF (Bay et al., 2006) are too computationally taxing. The mean shift method of segmentation is highly sensitive to subtle changes in lighting over time. This results in variable percept boundaries, which adds additional noise to the clustering process which assumes changes in region features are due to significant changes in the environment, not changes in the borders around regions. The more noise in the percepts, the more likely they are to represent redundant information.

These limitations in the model's perceptual representations lead to a significant deficit in terms of its perceptual ability compared to humans, children and likely even non-human mammals. As the dreams reflect the perceptual abilities of the dreamer, the perceptual deficits of the computational model result in parallel deficits in dreams and mental imagery. In humans with face-blindness (prosopagnosia), dreams contain indistinct and unrecognizable faces. The dreams generated by the computational model can only 'imagine' percepts in the same positions in which they were perceived. The world as perceived and dreamt by the system is simplified and highly constrained.

The label "Default Network" implies that the default state of the brain is related to the self-oriented process of simulation we call mind-wandering, rather than external perception. In the computational model, the central integrative process is simulation which runs continuously whether the system is perceiving, mind-wandering or dreaming. Thus the default state of the system is simulation, with the caveat that the simulation requires periods of perception from which to train the predictive model. In terms of function, we do not seek a special role for dreaming and mind-wandering, but rather propose that the simulation processes that enable dreaming and mind-wandering are always occurring. The metabolic cost associated with dreaming and mind-wandering is the base metabolic cost of the brain functioning normally. The low activation (and therefore low metabolic cost) during slow wave sleep is then the special case, while REM sleep reflects normal waking function.

Constructive Imagery

Nir & Tononi (2010) and Fosse et al. (2003) note that dreaming does not involve the replay of episodic memories. As dreams obviously involve the experience of familiar places and people, we can conclude that dreams are composed of concepts, just concepts not contextualized in episodes. The sequences of events supplied by the predictive model are implicit and not accessible to consciousness in the way that episodic memory is accessible. If dreams are simply the result of our implicit predictions of what to expect next, then why can dreams be experienced as bizarre and discontinuous? As stated above, dreams are predominantly more banal and related to daily lived experience than we tend to think. That being said, dreams may still unify strange, implausible events and chimeric elements (fusions of multiple places or people) into a cohesive experience that would be unlikely to occur in reality. This paradox is resolved by the requirement for a predictive model to be a reduction of reality, always containing imperfections. The predictive model is exploited in the computational model through feedback, which amplifies these imperfections and causes predictions in the absence of sensory information to potentially diverge significantly from plausible experience. The discontinuity of dreams can be explained by the absence of anchoring in sensory information provided by reality which mitigates the effects of the imperfections in the predictive model.

Future Work

This section is divided into three subsections, each concerned with future plans for a particular aspect of this research. The Integrative Theory itself could be extended in a number of ways. The computational model deserves significant refinement. While the computational model is framed as an artwork, the research process has inspired plans for a number of additional artistic works.

Integrative Theory

The Integrative Theory holds that the experience of perception, mind-wandering and dreaming result from the activation of visual representations of concrete objects. It is expected that dreaming in brains involves not just the activation of representations of concrete perceptual objects but also higher level conceptual representations. Barsalou (1999) proposes that the difficulty in pinning down the definition and origin of concepts is that they are not fixed representations but simulations in themselves. These simulations shift their content to match the particular needs of the current task. On the surface, the focus on simulation in Barsalou's conception is highly complimentary to the Integrative Theory. Still, there remains a major issue in the task-dependence of concepts in Barsalou's conception. Mind-wandering and dreaming, with their correlation with the default network, are particularly non-task oriented and stimulus independent. It is unclear how those simulations would be constrained independently of task demands. Perhaps conceptual simulations are not task dependent so much as they are context dependent.

The Integrative Theory, as currently conceived, has associated working memory, executive and attentional mechanisms with the PFC in general. This particular conception glosses over differences in activity across the various regions of the PFC, including dorsolateral and ventromedial areas. The Integrative Theory would benefit from a finer grained conception sensitive to constituent regions of the PFC and an integration of executive functions associated with the PFC, which is out of scope of the research described in this paper.

Computational Model

The computational model is framed as a situated agent, although its agency is extremely impoverished in the absence of intention and other executive functions, which are out of scope of the computational model. One avenue of development would be the inclusion of executive mechanisms and integrating the system into an existing cognitive agent architecture (such as CLARION (Hélie & Sun, 2010) or SOAR (Laird, 2012)). This would also entail a richer and hierarchical system of representations, although cognitive architectures tend to lack a basis in brain anatomy which is central to the Integrative Theory.

The MLP was chosen to facilitate implementation and for its proven flexibility and performance. As prediction is inherently about patterns occurring over time, a machine learning method specifically developed for temporal prediction could improve the ability of the system to predict sensory information, and therefore enrich dream sequences. The authors will examine Recurrent Neural Networks (Dorffner, 1996) and Deep Belief Networks (H. Lee et al., 2009) as possible methods to improve the model's predictor. Additionally, the authors will examine replacing the hard threshold used in the circadian clock with a proper oscillator entrained by visual brightness.

The combination of the noise sensitivity of mean shift segmentation over time, and the relatively small number of perceptual representations, has lead to quite unstable region edges, even in cases where the edges appear quite distinct to a human observer. This is due to a lack of temporal information used in the segmentation, which simply treats each frame as a new and unique image. Bailer et al. (2005) have proposed a method to improve the temporal stability in mean shift image segmentation, which could be included in the system.

While the discussion section above describes initial results of the dynamics of the system, no formal analysis has yet been undertaken. Such an analysis would provide valuable data in refining the system and increasing the diversity of dream, in particular, and mind wandering content. The model, as described in this paper, involves no random variation in the activation of percepts. This differs significantly from brains where neurons associated with perceptual representations are likely to be constantly, but weakly, active. These weak but constant activations are likely to significantly impact the feedback process by constantly shifting the current state of the system. This could mitigate the tendency of long periods of dreaming seen on our model to converge to stability. The inclusion of a small degree of random variation in the computational model is expected to significantly increase the diversity and complexity of dreams.

Artwork

The research process that lead to the Integrative Theory began with an artistic intention to create the artwork *Dreaming Machine #3*. The development of the theory, and implementation of the computational model, resulted in concepts for further artworks. While *Dreaming Machine #3* is meant for situated installation in the real world, artifacts of visual culture could also be used as source material. For example, time-based narrative media such as film and television. One artwork, tentatively titled *Watching and Dreaming* would be fed frames from film or television shows. The segmentation and arousal modules would be tuned to the movement and scene changes present in film and television. The system's circadian clock would be on a fixed schedule where the system would alternate between being fed frames from film or T.V. (during perception and mind-wandering) and black frames (during dreaming). The repetition of the film or T.V. show would allow epoch learning, which would change the quality of dreams with increasing exposure of the visual material.

Another proposed artwork, titled the *Dreaming Mirror*, would be tuned to the segmentation and reconstruction of facial images in particular. The system would break faces into multiple regions stored in a corpus where the regions would be used to reconstruct the face of the person currently in front of the work. The system would learn correlations between regions of the same face (prediction over space rather than time). In the absence of a face, the system would then 'dream' by reconstructing faces from the visual corpus, using the most recent face as a starting point.

Dreaming Machine #3 (Landscape), has been accepted to be exhibited at the International Symposium on Electronic Art (2014) in Dubai. This version of the system is tuned to perceiving the landscape and predict its changes over longer time-scales. The system will ignore foreground objects and the patterns of their short-term movement to emphasize shifts in light and inanimate objects in the urban landscape of Dubai.

Conclusion

Perception, mind-wandering and dreaming are all simulations of reality. While we are awake and interacting with the world, we learn concepts and build predictive models of what we should expect to occur. These predictions tell us what is routine, what surprises we should attend to, and assist us in making sense of ambiguous sensory information. Predictive mechanisms are continuously exploited, with the possible exception of slow-wave sleep. In the absence of sensory information, predictions feed back on themselves leading to simulations of reality that result in dreams. When sensory information is static, for example due to habituation, mind-wandering occurs as a shift of attention away from external stimulus toward endogenously simulations.

Perhaps the search for the adaptive functions of dreaming is misguided. If dreaming is constructed from predictive mechanisms exploited and learned in waking consciousness, then perhaps simulation really is the "default" mode of the brain. The value of these simulations in both waking and sleeping offsets their metabolic cost. Simulation is the default mode of the brain, and occurs whether or not external stimulus is present.

In this paper, we have reviewed a number of biological mechanisms of visual mentation that are unified in the proposed Integrative Theory. According to this proposal, dreams, mental imagery and mind-wandering all entail the activation of perceptual representations that result in the phenomenology of visual images in the mind. As these representations are shared between various modes of visual mentation, activity in one mode effects activity in another. This explains how dreams reflect normal waking concerns, in particular the effect of waking stimulus in the hours before sleep. Dreams are indeed mental imagery, and perceptual representations are activated via endogenous activation from the PFC in the default network.

Dreams can be narrative-like because they exploit predictive mechanisms of the default network (rather than PGO waves) we use to make sense of the complexity of the world. Dreams can be bizarre and discontinuous because constituent predictions lack the anchor of ongoing sensory reality to constrain them. Predictions are centrally important for their role in priming perceptual processes. In dreams and mind-wandering, predictions show their true potentially discontinuous character. Our perceptual simulation of reality is cohesive because of stability and structure in the sensory information we receive from the world. Our dream simulations are approximate caricatures of normal waking experience. They are thus inherently meaningful as they encapsulate tacit knowledge over a life-time of experiences and have a central role in how we make sense of the world.

The presentation of the computational theory as an artwork is meant to expand public engagement in brain-science in general, and the science of perception and dreaming in particular. A visually enticing and on-line model of dreaming provides a powerful entry-point for the viewer to consider the illusion of their perceptual simulation of reality. When looking at *Dreaming Machine #3,* the viewer is looking through cultural, technical and scientific systems toward the very processes that allow us all to make sense of the world. As we look into the machine to seek meaning and understanding, so too does the machine look into us.

References

Aserinsky, E., & Kleitman, N. (1953). Regularly occurring periods of eye motility, and concomitant phenomena during sleep. *Science*, *118*, 273–274.

Ashby, W. R. (1947). Principles of the self-organizing dynamic system. *The Journal of General Psychology*, *37*(2), 125–128.

Bailer, W., Schallauer, P., Haraldsson, H. B., & Rehatschek, H. (2005). Optimized mean shift algorithm for color segmentation in image sequences. In *Image and video communications and processing 2005* (Vol. 5685, pp. 522–529).

Barsalou, L. (1999). Perceptual symbol systems. *Behavioral and brain sciences*, *22*(04), 577–660.

Bay, H., Tuytelaars, T., & Gool, L. (2006). Surf: Speeded up robust features. In A. Leonardis, H. Bischof, & A. Pinz (Eds.), *Computer Vision — ECCV 2006* (Vol. 3951, pp. 404–417). Springer Berlin Heidelberg.

Bogart, B. D. R., & Pasquier, P. (2013). Context machines: A series of situated and self-organizing artworks. *Leonardo*, *46*(2), 114–122.

Bogart, B. D. R., Pasquier, P., & Barnes, S. J. (2013). An integrative theory of visual mentation and spontaneous creativity. In *Proceedings of the 9th ACM Conference on Creativity & Cognition* (pp. 264–273). New York, NY, USA: ACM.

Borst, G., & Kosslyn, S. (2012). From mental imagery to spatial cognition and language: Essays in honour of Michel Denis. In V. Gyselinck & F. Pazzaglia (Eds.), (pp. 19–42). Psychology Press.

Bradski, G. (2014). *OpenCV*. Available from `http://opencv.org/`

Bridge, H., Harrold, S., Holmes, E., Stokes, M., & Kennard, C. (2012). Vivid visual mental imagery in the absence of the primary visual cortex. *Journal of Neurology*, *259*(6), 1062–1070.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network. *Annals of the New York Academy of Sciences*, *1124*(1), 1–38.

Callaway, C. W., Lydic, R., Baghdoyan, H. A., & Hobson, J. A. (1987, June). Pontogeniculooccipital waves: spontaneous visual system activity during rapid eye movement sleep. *Cellular and Molecular Neurobiology*, *7*(2), 105–149.

Chelazzi, L., Marzi, C., Panozzo, G., Pasqualini, N., Tassinari, G., & Tomazzoli, L. (1988). Hemiretinal differences in speed of light detection in esotropic amblyopes. *Vision Research*, *28*(1), 95–104.

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences*, *106*(21), 8719–8724.

Comaniciu, D., & Meer, P. (2002). Mean shift: a robust approach toward feature space analysis. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, *24*(5), 603–619.

Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological Science*, *15*(8), 559–564.

Diekhof, E. K., Kipshagen, H. E., Falkai, P., Dechent, P., Baudewig, J., & Gruber, O. (2011, January). The power of imagination — how anticipatory mental imagery alters perceptual processing of fearful facial expressions. *NeuroImage*, *54*(2), 1703–1714.

Domhoff, G. W. (2011). The neural substrate for dreaming: Is it a subsystem of the default network? *Consciousness and Cognition*, *20*(4), 1163–1174.

Dorffner, G. (1996). Neural networks for time series processing. *Neural Network World*, *6*, 447–468.

Finke, R. (1980). Levels of equivalence in imagery and perception. *Psychological Review*, *87*(2), 113–132.

Fosse, M. J., Fosse, R., Hobson, J. A., & Stickgold, R. J. (2003, January). Dreaming and episodic memory: A functional dissociation? *Journal of Cognitive Neuroscience*, *15*(1), 1–9.

Fox, K. C. R., Nijeboer, S., Solomonova, E., Domhoff, G. W., & Christoff, K. (2013). Dreaming as mind wandering: evidence from functional neuroimaging and first-person content reports. *Frontiers in Human Neuroscience*, *7*(412), 1–18.

Friston, K. (2010, February). The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience*, *11*(2), 127–138.

Goodale, M. A., & Westwood, D. A. (2004). An evolving view of duplex vision: separate but interacting cortical pathways for perception and action. *Current Opinion in Neurobiology*, *14*(2), 203–211.

Graham, K. S., Barense, M. D., & Lee, A. C. H. (2010). Going beyond LTM in the MTL: A synthesis of neuropsychological and neuroimaging findings on the role of the medial temporal lobe in memory and perception. *Neuropsychologia*, *48*(4), 831–853.

Gregory, D. (2010, September). Visual imagery: Visual format or visual content? *Mind & Language*, *25*(4), 394–417.

Hélie, S., & Sun, R. (2010). Incubation, insight, and creative problem solving: A unified theory and a connectionist model. *Psychological Review*, *117*(3), 994–1024.

Hesslow, G. (2002). Conscious thought as simulation of behaviour and perception. *Trends in Cognitive Sciences*, *6*(6), 242–247.

Hobson, J., & Friston, K. (2012). Waking and dreaming consciousness: Neurobiological and functional considerations. *Progress in Neurobiology*, *98*(1), 82–98.

Hobson, J. A. (2009). REM sleep and dreaming: towards a theory of protoconsciousness. *Nature Reviews Neuroscience*, *10*(11), 803–813.

Hobson, J. A., & McCarley, R. W. (1977). The brain as a dream state generator: an activation-synthesis hypothesis of the dream process. *American Journal of Psychiatry*, *134*(12), 1335–1348.

Hobson, J. A., Pace-Schott, E. F., & Stickgold, R. (2000). Dreaming and the brain: Toward a cognitive neuroscience of conscious states. *Behavioral and Brain Sciences*, *23*, 793–842.

International Symposium on Electronic Art. (2014). Available from `http://www.isea-web.org/`

Kandel, E., & Wurtz, R. (2000). Constructing the visual image. *Principles of neural science*, *4*, 492–506.

Kosslyn, S. (1973, February). Scanning visual images: Some structural implications. *Attention, Perception, & Psychophysics*, *14*(1), 90–94.

Kosslyn, S. (1976, May). Can imagery be distinguished from other forms of internal representation? Evidence from studies of information retrieval times. *Memory & Cognition*, *4*(3), 291–297.

Kosslyn, S. M. (1975, July). Information representation in visual images. *Cognitive Psychology*, *7*(3), 341–370.

Kosslyn, S. M. (1980). *Image and mind*. Harvard University Press.

Kosslyn, S. M. (1981). The medium and the message in mental imagery: A theory. *Psychological Review*, *88*(1), 46–66.

Kosslyn, S. M. (1994). *Image and brain: the resolution of the imagery debate*. MIT Press.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception and Performance*, *4*(1), 47–60.

Kosslyn, S. M., Murphy, G. L., Bemesderfer, M. E., & Feinstein, K. J. (1977). Category and continuum in mental comparisons. *Journal of Experimental Psychology: General*, *106*(4), 341–375.

Kosslyn, S. M., Pinker, S., Smith, G. E., & Shwartz, S. P. (1979). On the demystification of mental imagery. *Behavioral and Brain Sciences*, *2*(4), 535–581.

Kosslyn, S. M., & Thompson, W. L. (2003). When is early visual cortex activated during visual mental imagery? *Psychological Bulletin*, *129*(5), 723–746.

Kosslyn, S. M., Thompson, W. L., & Ganis, G. (2006). *The case for mental imagery*. Oxford University Press.

Laird, J. (2012). *The Soar Cognitive Architecture*. MIT Press.

Lea, G. (1975). Chronometric analysis of the method of loci. *Journal of Experimental Psychology: Human Perception and Performance*, *1*(2), 95–104.

Lee, H., Grosse, R., Ranganath, R., & Ng, A. Y. (2009). Convolutional deep belief networks for scalable unsupervised learning of hierarchical representations. In *Proceedings of the 26th annual international conference on machine learning* (pp. 609–616). New York, NY, USA: ACM.

Lee, S., Kravitz, D. J., & Baker, C. I. (2012, February). Disentangling visual imagery and perception of real-world objects. *NeuroImage*, *59*(4), 4064–4073.

Lowe, D. G. (2004). Distinctive image features from scale-invariant keypoints. *International Journal of Computer Vision*, *60*(2), 91–110.

Marks, D. (1973, February). Visual imagery differences in the recall of pictures. *British Journal of Psychology*, *64*(1), 17–24.

Marzi, C., Mancini, F., Metitieri, T., & Savazzi, S. (2006). Retinal eccentricity effects on reaction time to imagined stimuli. *Neuropsychologia*, *44*(8), 1489–1495.

Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in neurosciences*, *6*, 414–417.

Mohr, H. M., Linder, N. S., Dennis, H., & Sireteanu, R. (2011). Orientation-specific aftereffects to mentally generated lines. *Perception*, *40*(3), 272–290.

Morin, L., & Allen, C. (2006). The circadian visual system, 2005. *Brain Research Reviews*, *51*(1), 1–60.

Moyer, R. (1973). Comparing objects in memory: Evidence suggesting an internal psychophysics. *Attention, Perception, & Psychophysics*, *13*(2), 180–184.

Murray, E. A., Bussey, T. J., & Saksida, L. M. (2007). Visual Perception and Memory: A New View of Medial Temporal Lobe Function in Primates and Rodents. *Annual review of neuroscience*, *30*, 99–122.

Muzur, A., Pace-Schott, E. F., & Hobson, J. (2002). The prefrontal cortex in sleep. *Trends in Cognitive Sciences*, *6*(11), 475–481.

New Forms Festival. (2012). Available from `http://2012.newformsfestival.com/`

Nielsen, T. A. (2000, 12). A review of mentation in REM and NREM sleep: REM sleep as a possible reconciliation of two opposing models. *Behavioral and Brain Sciences*, *23*, 851–866.

Nir, Y., Massimini, M., Boly, M., & Tononi, G. (2013). Sleep and consciousness. In A. E. Cavanna, A. Nani, H. Blumenfeld, & S. Laureys (Eds.), *Neuroimaging of consciousness* (pp. 133–182). Springer Berlin Heidelberg.

Nir, Y., & Tononi, G. (2010). Dreaming and the brain: from phenomenology to neurophysiology. *Trends in cognitive sciences*, *14*(2), 88–100.

Nissen, S. (2003). *Implementation of a fast artificial neural network library (FANN)* (Tech. Rep.). Department of Computer Science University of Copenhagen (DIKU). Available from `http://fann.sf.net`

Paivio, A. (1975, November). Perceptual comparisons through the mind's eye. *Memory & Cognition*, *3*(6), 635–647.

Pinker, S. (1980). Mental imagery and the third dimension. *Journal of Experimental Psychology: General*, *109*(3), 354–371.

Pinker, S., & Kosslyn, S. (1978). The representation and manipulation of three-dimensional space in mental images. *Journal of Mental Imagery*, *2*(1), 69–84.

Pylyshyn, Z. W. (1981). The imagery debate: Analogue media versus tacit knowledge. *Psychological Review*, *88*(1), 16–45.

Pylyshyn, Z. W. (2002). Mental imagery: In search of a theory. *Behavioral and brain sciences*, *25*(02), 157–182.

Pylyshyn, Z. W. (2003a). Return of the mental image: are there really pictures in the brain? *Trends in cognitive sciences*, *7*(3), 113–118.

Pylyshyn, Z. W. (2003b). *Seeing and visualizing: It's not what you think*. The MIT Press.

Revonsuo, A. (2000, 12). The reinterpretation of dreams: An evolutionary hypothesis of the function of dreaming. *Behavioral and Brain Sciences*, *23*, 877–901.

Rumelhart, G., D.E. Hinton, & Williams, R. (1986). Parallel distributed processing: Explorations in the microstructure of cognition. In (pp. 318–363). MIT Press, Cambridge, MA.

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences*, *15*(7), 319–326.

Siegel, J. M. (2008). Do all animals sleep? *Trends in Neurosciences*, *31*(4), 208–213.

Siegel, J. M. (2011). REM sleep: A biological and psychological paradox. *Sleep Medicine Reviews*, *15*, 129–142.

Silicon Graphics Incorporated. (2014). *OpenGL.* Available from `http://www.opengl.org/`

Sima, J. (2011). The nature of mental images — an integrative computational theory. In *Proceedings of the 33rd annual meeting of the cognitive science society.*

Snyder, F. (1970). The psychodynamic implications of the physiological studies on dreams. In L. Madow & L. Snow (Eds.), (pp. 124–151). Thomas.

Solms, M. (2000). Dreaming and REM sleep are controlled by different brain mechanisms. *Behavioral and Brain Sciences*, *23*, 843–850.

Stickgold, R., Malia, A., Maguire, D., Roddenberry, D., & O'Connor, M. (2000). Replaying the game: Hypnagogic images in normals and amnesics. *Science*, *290*(5490), 350–353.

Stokes, M., Thompson, R., Cusack, R., & Duncan, J. (2009, February). Top-Down activation of Shape-Specific population codes in visual cortex during mental imagery. *The Journal of Neuroscience*, *29*(5), 1565–1572.

Theodoridis, S., & Koutroumbas, K. (2009). *Pattern recognition*. Academic Press.

Triesch, J., Ballard, D. H., Hayhoe, M. M., & Sullivan, B. T. (2003). What you see is what you need. *Journal of Vision*, *3*(1), 94–86.

Tucker, L., Thompson, A., Smith, J., Cohen, A., Clark, M., & Barrett, M. (2009, Feburary). *Why do we dream?* Documentary Television Program. (BBC Horizon Documentary)

Wais, P. E., Rubens, M. T., Boccanfuso, J., & Gazzaley, A. (2010, June). Neural mechanisms underlying the impact of visual distraction on retrieval of Long-Term memory. *The Journal of Neuroscience*, *30*(25), 8541–8550.

Wechsler, D. (1967). *Manual for the wechsler preschool and primary scale of intelligence*. The Psychological Corporation.

Young, M., & Yamane, S. (1992, May). Sparse population coding of faces in the inferotemporal cortex. *Science*, *256*(5061), 1327–1331.

Zach Lieberman, T. W., & Castro, A. (2014). *openFrameworks.* Available from `http://openframeworks.cc/`

Zago, S., Corti, S., Bersano, A., Baron, P., Conti, G., Ballabio, E., et al. (2010). A cortically blind patient with preserved visual imagery. *Cognitive and behavioral neurology*, *23*(1), 44–48.

Chapter 6

Discussion and Results

The published (Chapter 4) and submitted (Chapter 5) articles included in this thesis are steps in the development of both the Integrative Theory, and also the computational model. In this chapter, the relation between the two formulations of the Integrative Theory will be discussed, as well as their impact on the development of the computational model, whose dynamics and architecture have changed significantly between the two formulations. In addition, we summarize related computational approaches to modelling dreaming. The chapter concludes with a description of the three artistic realizations of the current system, and related artworks.

6.1 Integrative Theory: Associative and Predictive Formulations

In the previous chapters, two formulations of the Integrative Theory are described: associative and predictive. According to the associative conception, dreams are simulations that result from the propagation of activation through an associative network of perceptual representations. The associative network is constructed such that the association between percepts is proportional to the similarity of their features. In the predictive formulation, the associative network based on visual features is replaced with a generic predictive mechanism where associations between perceptual representations are based on shared contexts. Simulations are the result of feeding the output of the predictive model back to its input, creating a feedback loop that generates a sequence of activation.

The dependence of the associative formulation on a network of associations, reflecting feature similarity, extends the previous work on *Memory Association Machine* (Bogart, 2008, 2009), and *Dreaming Machines* #1 and #2 (Bogart & Pasquier, 2013a), described in Chapter 2. A strength of the associative formulation is its explicit link with the neurological basis of creativity as proposed by Dietrich (2004), where a spontaneous mode of creativity is linked with continuous associative and endogenous activity in the temporal, occipital and parietal cortices. Dietrich (2004) additionally considers dreams an *extreme* result of the very same processes of associative activity in play during spontaneous creativity. This conception supports the assertion of dreams as predominantly bizarre as associative processes lead to *random, unfiltered, and bizarre* thoughts, which conflicts with the notion of dreams as reflecting ordinary waking concerns. The characterization of associative activation according to visual features as *simulation* is at odds with Hobson's (2009) view that dreams are a *virtual reality* and allow the dreamer to interact with an environment supporting the development of the protoself. Consistent with Hobson's (2009) consideration of dreams as virtual reality (simulation), Revonsuo (2000) proposes the *threat simulation hypothesis*. According to this hypothesis, dreams are simulations of reality that are highly biased towards threatening and unpleasant events. Dreams' adaptive value is due to improvements in threat perception and the rehearsal of threatening experiences in the absence of real consequences. Revonsuo (2000) notes that "[t]he form and content of dreams is not random but organized and selective...", which indicates a conflict with Dietrich's (2004) consideration of dreams as an *ultimate form* of spontaneous creativity as *random, unfiltered, and bizarre.*

The predictive formulation resolves this issue by excising Dietrich's notion of spontaneous creativity from the Integrative Theory. A consequence of removing creativity from the predictive formulation is that "endogenous (self-regulating) TL activation" (Bogart & Pasquier, 2013b, Chapter 4) is no longer considered a possible cause of the activation of perceptual representations, and thus is not pictured in Figure 2, Chapter 5. The result is an expectation of greater importance of the PFC in dreaming and mind wandering under the predictive formulation than is considered according to the associative formulation. In the absence of the notion of dreams as predominantly bizarre, the notion of dreams as simulation is emphasized. Rather than being generated by associative activity according to visual features, dreams are the result of the exploitation of a predictive model that is of adaptive value and functional across all modes of visual mentation.

Considering the predictive formulation, we can revisit the notion of association from a different perspective. The association of perceptual representations — based on the similarity of their visual features — is a highly limited form of association. Many priming experiments — e.g. Davenport & Potter (2004) — depend on associations between various familiar objects (e.g. baseball players and stadiums, priests and churches, etc.) that are associated because of context, not because of similarities in their features. We learn these associations because of the co-occurence of the objects in time and space. Once we are primed by images of churches we recognize priests more quickly because they are *expected*. These contextual associations could be considered manifestations of the very same predictive mechanisms on which dreaming and mind wandering depend. The difference between these contextual associations and predictions is in their directionality. A priest can prime a church as well as a church can prime a priest, a toaster can prime a kitchen as well as a kitchen can prime a toaster. A prediction adds to this a notion of causality: the presence of certain clouds predicts a likelihood of rain. According to the predictive formulation, dreams are predominantly normal experiences related to normal waking concerns where apparent bizarreness of dream content is the result of errors accumulating in the absence of sensory anchoring in reality.

The interpretation of Hobson's AIM theory differs between Chapter 4 (Bogart et al., 2013) and Chapter 5 (unpublished). In the former, the activation of the VC due to PGO waves is considered 'random' in the context of AIM's precursor — the activation-synthesis (J. A. Hobson & McCarley, 1977) theory. Under this interpretation, low level and reflex activations in the brain-stem cause the rapid eye movements associated (according to Hobson) with dream sleep, which result in the generation of visual imagery in the early visual cortex: "...the forebrain may be making the best of a bad job in producing even partially coherent dream imagery from the relatively noisy signals sent up to it from the brain stem." (J. A. Hobson & McCarley, 1977) The impetus for the shift from the association over visual features (associative formulation) to the simulation of reality exploiting a predictive model of the world (predictive formulation) was inspired by J. Hobson & Friston (2012), who put prediction and simulation at the centre of the dream function and make no claim that PGO waves are random. The interpretation of AIM was revised by removing consideration of any possible random properties of PGO waves. According to J. Hobson & Friston (2012), PGO waves generate eye movements, which cause 'top-down' processes to generate ('infer') visual images in the early visual cortex: "...waking percepts are driven by the need to explain unpredicted visual input, while dreaming percepts are driven by the need to explain unpredicted oculomotor input." Dream images result from the expectation that an image will be present after a REM saccade. This proposal is consistent with S. M. Kosslyn & Thompson (2003) as the early visual cortex is functionally required in the phenomenology of dream imagery. Additionally, the notion of predictive mechanisms underpinning dream mentation is key for J. Hobson & Friston (2012), and those mechanisms are expected to be shared with waking perception.

6.2 Computational Model

The shift from an associative to predictive formulation of the Integrative Theory has lead to significant changes to the design of the computational model. Some of these changes are a direct result of changes to the theory, while other changes are independent refinements of the computational model. The two models differ at both the level of architecture / modules (Figure 3 in Chapters 4 and 5), and the level of cognitive processes / system dynamics. In order to contextualize the computational model, we summarize two related computational models of dreaming.

6.2.1 Related Computational Models

6.2.1.1 Zhang's AI Dreamer (2009)

Q. Zhang (2009) proposes a computational model, the AI Dreamer, that considers dreaming a mechanism to improve memory consolidation. Zhang's proposal is that dreaming allows memory consolidation by integrating learning in episodic memory (associated with the hippocampus) with 'semantic' knowledge (associated with the neocortex). According to the mode, this process of consolidation is improved when the episodic memory system randomly replays stored sensory input to be integrated into semantic memory. Q. Zhang (2009) considers PGO waves random, which aligns with the interpretation of Hobson described in Chapter 4, and thus the mechanism that allows the random replay of semantic memory. The central proposal informing the computational model is that dreaming is the result of random activation, and that random activation is functionally valuable in the consolidation process.

The model is a supervised learning system that consists of two 'hemispheres', one dedicated to the processing of low level sensory features (binary sequences), while the other deals with the processing of higher level representations (labels). Each hemisphere contains an independent memory system in which patterns are stored in 'interlocked memory triangles' (Q. Zhang, 2009) — assemblies of neuron-like units that store patterns. The third major component of the system is the episodic memory module which is independent of both hemispheres. During learning, the low-level sensory features are abstracted into 'concepts' and linked with representations in the semantic hemisphere. The system is fed pairs of values: A sequence of binary values is presented to the sensory hemisphere, while a label is fed to the representation hemisphere. The model learns by associating the label with the binary sequence. This bihemispherical system is inherited from previous work, the AI Counter (Q. Zhang, 2005), which requires multiple epochs of training to learn to associate 'higher order' hierarchical sequences with their labels. The higher order the learning, the deeper the hierarchy and the larger the number of epochs required.

The AI Dreamer adds to the AI Counter through the inclusion of an episodic memory system that improves learning by caching unlearned input sequences. The episodic memory stores patterns similarly to the sensory hemisphere, using the same 'interlocked memory triangles'. Sensory sequences can be replayed from episodic memory in their original order, or randomly. Episodic memory is populated by sequences and labels that were not associated in the bihemispherical system during training. During 'waking' the system learns from sensory patterns and labels, where possible, while during 'dreaming' the system associates already presented, but unlearned, patterns and labels in episodic memory that are randomly ordered. The ability for the system to learn from memory results in an improvement of performance because the whole set of pattern / label pairs need only be presented once, and in an arbitrary order.

The emphasis of Zhang's computational model is on the supervised learning of pairs of labels and binary sequences exploiting a biologically plausible memory system. While framed as facilitating memory consolidation, dreaming in the model is effectively the random ordering of cached pattern / label pairs to allow offline learning. While the model provides a plausible functional purpose for dreams, the conception of dreaming mechanisms, as the simple random activation of episodic memory, is weak. As discussed earlier, the notion of dreams as the result of random activation is problematic and this notion is the lynch-pin of Zhang's computational model. The system is best thought of as a biologically inspired machine learning method, but does not contribute to theories of dreaming. The impoverished nature of the system's sensory input, and the dependence on supervised learning, contributes little to our understanding of the mechanisms or function of dreaming, and in particular how dream images are generated.

6.2.1.2 Treur's Computational Agent Model of Dreaming (2011)

While Zhang's AI Dreamer focuses on memory structure and the potential learning mechanisms of dreaming, Treur (2011) proposes a computational model that emphasizes the emotional dynamics of dreams, and considers dreams as functional simulation: "dreaming can be considered a form of internal simulation of real-life-like processes as a form of training in order to learn, adapt or improve capabilities, which would be less easy to achieve in real life." (Treur, 2011) The proposed computational model constructs simulations by activating sensory representations to generate mental images and activate associated emotions. The driver for these simulations is emotional regulation, where the purpose of dreams is to increase emotional arousal. Bizarre dream content could be explained by the sequencing of events according to their emotional, rather than sensorial, properties. These dreams simulations are of functional use because the presence of mental images cause the activation of "preparation states for actions or bodily changes" (Treur, 2011), leading to the rehearsal of stimulus and response behaviours. During these rehearsals, bodily changes cause additional mental images, driving a feedback loop between mental images, emotions and simulated action. Each preparation for bodily response leads to an emotional response, which leads to the experience of an emotion based on the imagined bodily response. Treur (2011) states that the computational model provides 'fearful situations' which are "built on memory elements suitable for fear arousal", but does not commit to the consideration of dream function as the practice of threat response, as proposed by Revonsuo (2000) and described in Section 6.1, or the regulation of fearful emotions.

Treur's (2011) computational agent model formalizes the simulation loop, described in the previous paragraph, which is initiated by an external trigger associated with a high degree of fear, which then causes the activation of a sensory representation. This sensory representation leads to bodily preparation and fear response, which leads to the increased experience of fear. A regulation mechanism suppresses the sensory experience, and the experience of fear, but not the bodily preparation. This suppression of the sensory representation, and associated fear, corresponds to the blocking of a traumatic event from memory. Representations in the system that are associated with a lesser degree of fear, but still associated with the current state of bodily representation, are activated according to the strength of the association between the bodily state and the sensory representations. As these representations are activated simultaneously, they compete for dominance. Activated representations are still associated with fear and thus the resulting bodily preparation involves an increase of fear. This increase of fear causes emotional regulation to suppress the sensory representation and the fear response. Thus, a dream is a sequence of sensory representations that are selected based on the degree to which they are associated with fear. The simulation is driven forward by the regulation of emotion that keeps the experience of fear in check. The relations between these various competing states of emotion, bodily preparation and sensory representations are modelled using methods used in Continuous Recurrent Artificial Neural Networks (RNNs) and can be described as a set of differential equations. The resulting behaviour of the system is a complex dynamic initiated by external stimulus.

The agent model proposed by Treur (2011) emphasizes the complex dynamics that relate sensory representations, preparatory bodily states and emotions. At the same time, the model is totally abstract in that the content, the sensory representations, the bodily states and emotions do not refer to any content. The specific bodily states, emotions (beyond fear), and sensory representations are not considered important; the dynamics that result from their interactions is the focus. As these variables are not tied to any real content, the weights between them are arbitrary. This makes it unclear how to interpret the dynamics of the system — for example, in the process of empirical validation. The model does not easily fit into an overarching cognitive framework due to the lack of learning and the degree of abstraction.

The significant differences between the computational model described in Chapter 5 and those summarized in this section reflect the lack of consensus regarding the mechanisms and function of dreaming, and their possible integration into cognitive architectures, briefly discussed in Chapter 7. One could take the learning approach and consider dreams as a solution to a machine learning problem, as Q. Zhang (2009), or one could focus on the emotional aspects of dreaming and construct a dynamical model that generates complex sequences of events based on the increase and subsequent suppression of fear, as Treur (2011). In both cases, the definitions of dreaming are quite narrow. Dreaming is considered a special case, largely independent of other modes of cognition, which is quite different than the approach taken in the research described in this thesis. The models described in this section don't explain dreams ranging from banal and unemotional, to threatening, to even highly structured complex narratives occurring in REM and NREM stages of sleep. These models are quite abstract and exploit complex network dynamics in an impoverished sensory, and imagery, context. While they model specific features of the dynamics of dreaming mechanisms, they provide little insight into how dream images are constructed, nor do they significantly validate or critically reflect on theories of dreaming. In contrast, the research described in this thesis emphasizes an overarching cognitive framework that learns from real-world sensory information and constructs dream imagery. In the following sections, the differences between the associative and predictive computational models are discussed.

6.2.2 Differences in Architecture and Modules

In the model coupled with the associative formulation, hereafter referred to as the *Model* A, the architecture includes an explicit gating system that inhibits external sensory information, thereby inhibiting sensory activation, corresponding to gating in Hobson's *Activation, Input/Output Gating and Modulation* (AIM) model (J. A. Hobson, 2009). In the model coupled with the predictive formulation (*Model P*), gating at the level of sensory input is replaced with a suppression system that operates at the level of percept activation. Perceptual processes continue to operate in all stages, except their activations are inhibited. This change allows suppression to modulate the competing activations from external perception, and from internal feedback, simultaneously. Thus, Model P's dynamics are not dependent on strong external activations drowning out weak internal activations, unlike Model A.

In Model A, habituation allows the system to ignore activation resulting from familiar and routine objects due to their consistent activation. This mechanism would decrease activation caused by repeated stimuli and thereby allow novel stimuli to cause greater activation. In Model P, the explicit inclusion of a predictive mechanism makes this low level consideration of routine presence unnecessary. Percepts that occur and are expected are rendered differently than percepts that are not expected, and thus effects only the visualization of percepts and not their activation. To give the system a sense of novelty, Model P includes an arousal module that provides a representation of how much change occurs at the sensory level, which is used to drive perceptual vs mind wandering processes. A number of alternative arousal measures were examined, including the mean squared error of the clustering process, and the error from the predictor, but those were ruled out as they exhibited significant noise and did not appear to reflect actual changes in sensory information.

In Model A, the associative mechanism was considered part of the Memory module, which included the storage, the sorting (according to feature) of percepts and the propagation of activation between them. In Model P, there is no monolithic memory module. Percepts are stored independently and created and modified by segmentation and clustering modules, respectively. Prediction and suppression modules only manage the degree of activation and prediction without altering the percepts themselves.

In order to provide the system a rich diversity of perceptual information, Model A includes a segmentation method that first extracts the foreground from background, and then further segments the background into multiple regions. There are then two sets of percepts, foreground and background. Foreground percepts are clustered only with foreground percepts, and the same for background percepts. Model P is totally naïve and considers no difference between foreground and background. Each raw frame is segmented into regions which represent both foreground and background objects. In the implementations leading to the images in Section 6.3.3, perception only occurs when there is both sufficient arousal and when no foreground objects are present. This significantly reduces the noise in percepts, which allows them to represent a greater diversity of stimuli.

The circadian clock oscillator described in relation to Model A is biologically plausible, but was never implemented due to the complexity of considering seasonal changes that manifest in differing lengths of night and day. Model P's simple threshold clock allows the system to be much more responsive to its environment, where darkness during the day would be interpreted as night and result in dreaming. This responsiveness leads to oscillations between perceptual, mind wandering and dreaming modes during sunrise and sunset, as described in Chapter 5, under the heading *Behavior of the Computational Model.*

The Imagery and Renderer modules in Models A and P, respectively, are functionally identical and hold the methods used to generate images from individual percepts. The change of name reflects that these modules are only required to visualize the behaviour of the computational model, and are not mechanisms informed by the Integrative Theory that effect the behaviour of the system.

6.2.3 Differences in Cognitive Processes and System Dynamics

The differences in the architecture and modules between Model A and P result in differences in the system dynamics. The largest difference between the two architectures is the shift of dream simulation as the result of the propagation of associative activation according to visual features to simulations resulting in the exploitation of a predictive model. In Model A, all the dynamics occur inside the memory module as modulated by the circadian clock. In Model P, clustering, prediction and suppression all interact to generate the system's behaviour, which is then modulated by arousal and the clock.

A strength of Model A is the inclusion of a mechanism that oscillates between two types of activation during dreaming: the system alternates between a phase showing a global increase of activation followed by a phase showing a global decrease of activation. These two modes resemble the relation between REM and deep NREM sleep, where overall activation is highest in REM, and lowest in NREM3. The purpose of this mechanism is to allow high degrees of activation, as seeded by latent perceptual activation, without risking the system becoming over-activated. This multi-phase activation could allow the pruning of associations: as global activation increases, it initially amplifies those weak latent activations from perception while simultaneously strengthening the associations between all associated percepts. In the next phase, the decreasing activation would decrease the associations between all percepts. As some percepts are expected to be initially weakly associated, this phase could function as a pruning process, reducing the weak associations to zero. Although this mechanism was never implemented, it is expected that high activity would lead to very dense imagery involving many contradictory percepts, while low activity would be largely devoid of visual information, resulting from a lack of percept activation. Such dream sequences would certainly appear similar to those mechanisms described by Dietrich (2004), and support the notion of dreams as bizarre, but it is quite unclear how such mechanisms could lead to anything resembling a banal dream of an ordinary experience or narrative sequence of events.

The notion of mind wandering differs significantly between the two models. In Model A, mind wandering is a fusion of perceptual and dreaming modes, where percepts can be activated by either external stimuli, or internally. This is at odds with our phenomenological experience of mind wandering where we are certainly not attending to external stimuli. In fact, a popular test used to determine if a person is mind wandering is by checking to what degree they are aware of external stimuli. In Model P, mind wandering and dreaming are identical mechanisms that differ only in which processes caused them — low arousal or darkness.

6.3 Artistic Realizations

This chapter provides documentation and discussion of three artistic realizations of the *Dreaming Machine #3* system. The first installation of work-in-progress toward *Dreaming Machine #3* is entitled *An Artist in Process: A Computational Sketch of Dreaming Machine #3.* This realization was produced early in the development of the Integrative Theory, where dreams are considered the results of associative activity according to visual features. The latter two realizations, tentatively titled *Dreaming Machine #3 (Landscape)* and *Watching and Dreaming (2001: A Space Odyssey)*, are works-in-progress. The former has been accepted to be shown at the International Symposium on Electronic Art in Dubai in November 2014, while the latter was shown at the Blurred Lines exhibition associated with Expressive 2014, in August 2014. The landscape qualification for *Dreaming Machine #3* marks a shift of emphasis away from events occurring in short time-spans, i.e. the behaviour and movement of foreground objects, to larger changes in lighting expected to occur through longer-term exhibitions of the project. In order to contextualize the artistic contribution of these realizations, the section begins with a summary of two related artworks — *Controlled Dream Machine* (Franco, 2007) and *Selective Memory Theatre* (Dörfelt, 2011). The former is a kinetic robotic installation that 'dreams', while the latter is a two channel generative installation that perceives images from Flikr,[1] and highlights the constructive nature of perception and memory.

6.3.1 Related Artworks

Controlled Dream Machine (Franco, 2007) consists of a pair of illuminated and kinetic sculptural legs, which are suspended from the ceiling in front of a projection showing the dreams of the machine, as shown in Figure 6.1. The legs are meant to represent the body of the dreamer, while the projection shows the unconscious experience of the dreamer. The movement of the legs is tied to the types of dream experiences, which can be one of five different categories: sensations, memories, traumas, nightmares and the collective unconscious. The behaviour of the system is manifest in the movement of the legs, the pattern of light emanating from them, and the selection of imagery in the projection. This behaviour is driven by the electrical activity of a culture of embryonic rat neurons, recorded in Dr. Steve Potter's Neuroengineering Lab at Georgia Tech.

Each of the categories of dream experience is manifest in specific predetermined behaviours exhibited by the legs, and selected by the neural culture recording. For example, during 'nightmares' the legs shake continuously, while during 'sensations' the legs make a walking motion. Each of the dream experiences is manifest in the projection of short films, each under three minutes in duration, composed by the artist using drawing, video, stop-motion and 3D animation methods. In these films, which appear predominantly like children's drawings, a third person perspective on the experience

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[1] `http://www.flickr.com/`

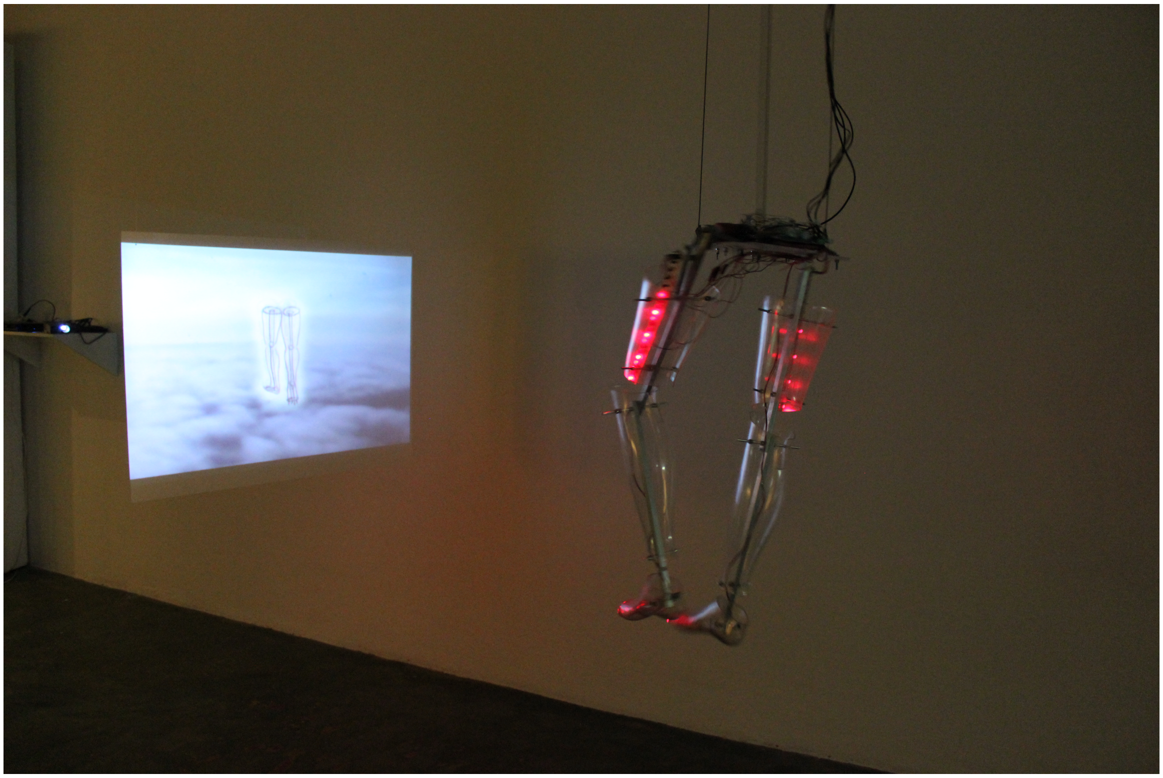

Figure 6.1: *Controlled Dream Machine* (Franco, 2007). © Anaisa Franco 2007 (reproduced here with permission)

Figure 6.2: *Controlled Dream Machine* (Franco, 2007) — The Delicate Spiders Relation. © Anaisa Franco 2007 (reproduced here with permission)

of the dream is presented, as shown in Figure 6.3. Illustrations of the legs appear in the dreams where they interact with other figures and objects, such as the two giant spiders that occupy the 'sensations' category (Figure 6.2), and the child and man in 'traumas and nightmares' (Figure 6.3).

The central intention of the *Controlled Dream Machine* is the concept of a dreaming machine. Rather than considering the mechanisms of dreaming, the production emphasizes the content of dreams. The dream imagery is considered in a Jungian context and the animations that represent them are meant to be archetypal. The short films that constitute dreams are sequenced by the behaviour of the neural culture, but it is unclear how exactly the mapping is made. The inclusion of cultural notions of dreaming, a physical and kinetic embodiment, and the use of data recorded from real neurons indicates an interest in creating a whole system that is more than a representation of dreaming.

Selective Memory Theatre (Dörfelt, 2011) is a two channel generative art installation, pictured in Figure 6.4, that retrieves images from Flikr that serve as sensory images. The work is not concerned with dreaming, but with the difference between perfect machine memory and constructive, forgetful and imperfect human memory. The work is selective in that (1) perception does not appear exactly like the Flikr images retrieved by the system, but distorts those images in the process of perception, and (2) only a subset of perceptual images result in the activation of memory.

The perception of the system captures the most recent images uploaded to Flikr, which serve as the sensory images fed to the system. These images are 'distorted, mixed and blended', as pictured

Figure 6.3: *Controlled Dream Machine* (Franco, 2007) — Traumas and Nightmares. © Anaisa Franco 2007 (reproduced here with permission)

in Figure 6.5, in order to highlight the difference between what the mind sees and what the eyes sense. These perceptual results are shown on one screen, right projection in Figure 6.4. For each new perceptual image, the system searches its memory for an image previously seen that is most similar. The similarity of images is not based on their visual appearance, but on the similarity of the Flikr meta-data (tags) associated with them. If a similar image is found in memory, it is highlighted on the second screen, left projection in Figure 6.4. The installation is a diptych, with perception and memory occupying each of the two projections whose relationship represents a semantic dialogue between memory and perception. Once each image has been perceived, it is saved in memory to be potentially activated by new stimulus in the future.

The perception and memory images are anchor points in a dynamic composition. The perceptual image flies through the many images added to Flikr, giving the photographs new dynamic lives in the context of the machine's perception. The diversity of imagery and the distortion of their features makes the perceptual screen appear like a blur of nearly unresolvable imagery. The perceptual system settles on an image, allowing its features to be clearly resolved, only when it has lead to the activation of a memory. Before a memory is activated, each memory appears on the left projection as a orb connected by tendrils to memories considered similar, as pictured in Figure 6.6, where orbs circle and dance around each other. When an orb is activated by stimulus, it changes colour and explodes into a field of particles that reconstruct the image stored in that memory location, as

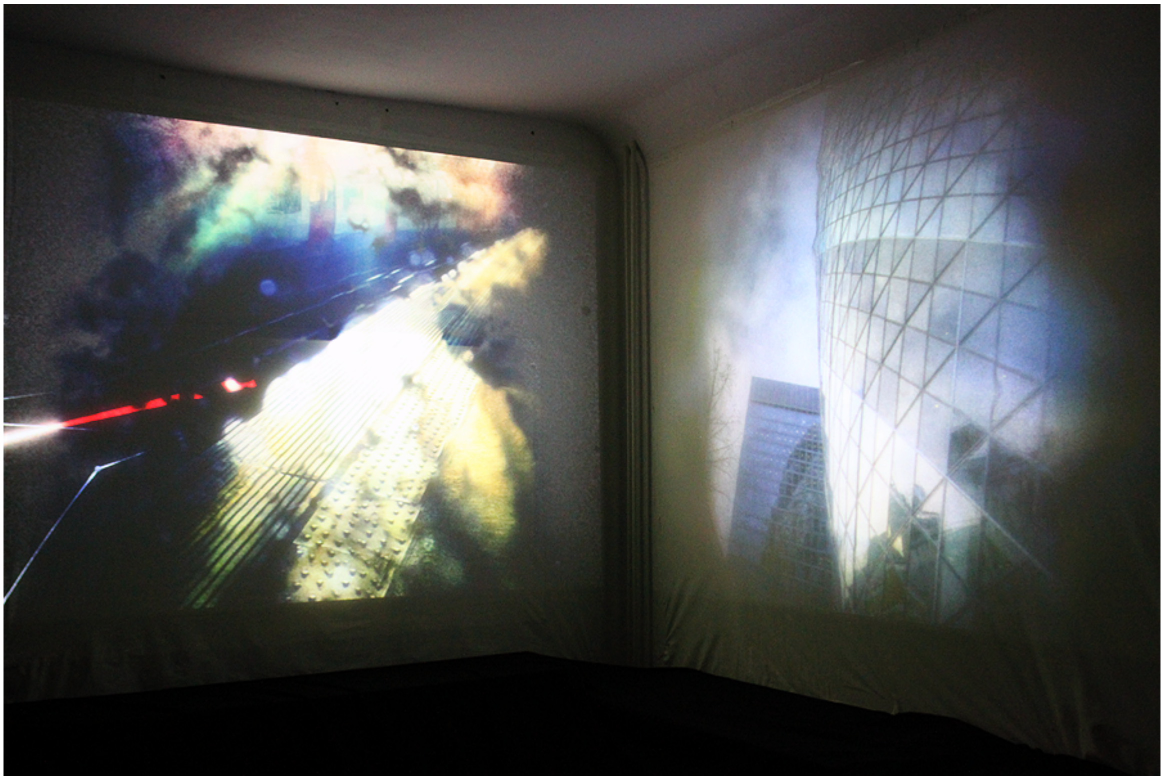

Figure 6.4: *Selective Memory Theatre* (Dörfelt, 2011). © Matthias Dörfelt 2011 (reproduced here with permission)

Figure 6.5: *Selective Memory Theatre* (Dörfelt, 2011) — Perceptual Distortion. © Matthias Dörfelt 2011 (reproduced here with permission)

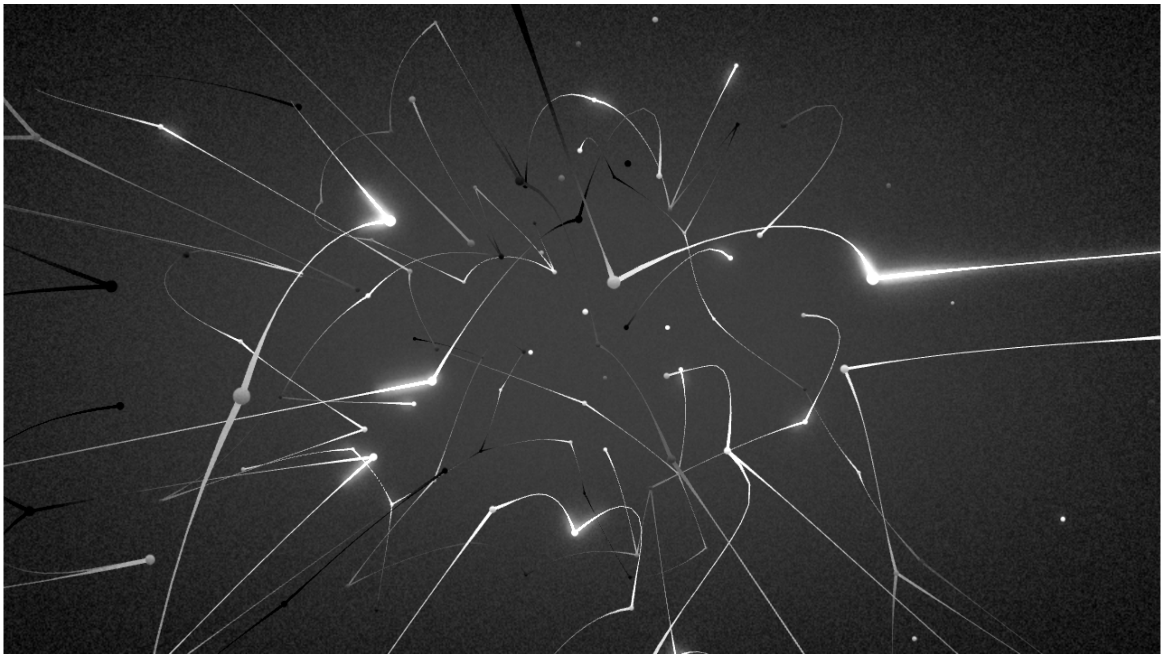

Figure 6.6: *Selective Memory Theatre* (Dörfelt, 2011) — Memory Orbs. © Matthias Dörfelt 2011 (reproduced here with permission)

shown in Figure 6.7.

While *Selective Memory Theatre* does not deal with dreaming directly, it is centrally concerned with constructive perception and memory. These aspects of cognition are highly related to dreaming, and therefore the research described in this thesis. The use of images from Flikr allows the system to consider images on a semantic basis by comparing the meta-data of images, rather than their visual properties. A family portrait in perception may lead to the activation of another family portrait in memory. The diptych then highlights a semantic relationship between the two projections, and therefore between perception and memory.

Controlled Dream Machine and *Selective Memory Theatre* are related to this research in terms of their thematic interests, but examine dreaming, perception and memory from very different perspectives. While both these artworks are concerned with cognition, both are highly disembodied. While the kinetic form of the *Controlled Dream Machine* occupies space, the physical world does not effect the dreams of the system, whose content is predetermined and fixed. The neural culture further disembodies the work, by considering the 'mind' a recording of a distant (and likely long since dead) collection of cells. *Selective Memory Theatre* only perceives the world as seen through images posted to Flikr. These images are unconstrained in their subject matter; there is nothing that holds them together as a unified set reflecting a particular place in space and time. This disembodiment contrasts highly with the *Dreaming Machine* that emphasizes generative processes in the

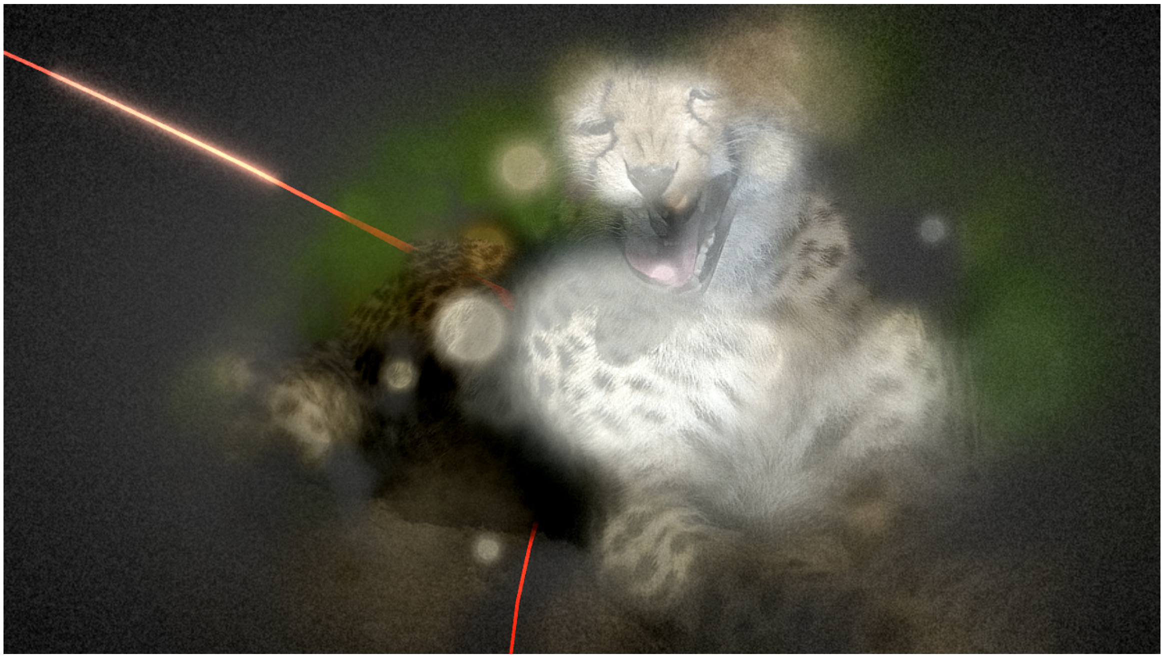

Figure 6.7: *Selective Memory Theatre* (Dörfelt, 2011) — Memory Activation. © Matthias Dörfelt 2011 (reproduced here with permission)

context of site specificity. *Dreaming Machine* sets itself apart most in terms of the rigorous and conceptually unified Integrative Theory that informs it. The intention of the artworks described above is centred on the metaphorical representation of dreams and cognitive processes. The *Dreaming Machine* exists at the intersection of science and art, where it is both a model of dreaming, and also a representational process of art. This constrains the process and methods used in the work where aesthetic choices are made in the context of empirical knowledge in a way that is unnecessary, and perhaps even undesirable, for the artists producing the works described above. In the following sections, three in-progress realizations of *Dreaming Machine #3* are described.

6.3.2 An Artist in Process:
A Computational Sketch of Dreaming Machine #3

In 2012 I was invited by Malcolm Levy to do a short residency and exhibit a prototype of *Dreaming Machine #3* during the New Forms Festival in September 2012. At that point, the research was focused on the development of the associative formulation of the Integrative Theory, and the implementation consisted of only image segmentation and rudimentary clustering. The exhibition was a valuable opportunity to capture images over a long time-spam, as the data used in developing

Figure 6.8: Overview of New Forms Festival Installation of An Artist in Process: A Computational Sketch of Dreaming Machine #3. © Scott Kaplan 2012 (reproduced here with permission)

the system up to that point was one hour of footage (Dataset 1) shot in rainy conditions. The concept of the residency is that I would (1) continue developing and explore the aesthetic possibilities of the segmentation and clustering methods, (2) implement a dream-imagery simulator exploiting the propagation of associative activation according to visual features, and (3) collect a corpus of imagery (Dataset 2) used in the development of the system. Each of these three activities was realized as a separate piece of software.

The first priority of the residency was to explore the aesthetic potential of the segmentation and clustering methods that were being implemented. This resulted in a number of studies that were printed in the exhibition space, pictured in Figure 6.8, and pinned to a wall. Figures 6.9 and 6.10 show images generated from Datasets 1 and 2, respectively. These images were produced by capturing a number of frames, segmenting, clustering and then aggregating the resulting regions. The clustering system averaged multiple occurrences of the same object over time, considered according to features described in Chapter 4, and regions were drawn in the same location from which they were segmented. Viewers often described the images pictured in Figure 6.10 as similar to watercolours. This effect is due to segmented regions being drawn on white backgrounds, and the clustering process merging highly different regions including both foreground and background objects. The poor quality of the clustering process leads to large amounts of transparent pixels in non-overlapping areas of constituent images, diluting the colours.

The clustering method was abandoned during the residency due to a memory leak which caused the software to crash before a sufficient diversity of regions was generated. Figure 6.11 shows additional studies of Dataset 2, where raw segmented regions are not clustered. Due to the memory leak, the number of regions used in Figures 6.9 and 6.10 is quite small. Without clustering, the segmentation software was able to generate a much larger variety of regions — despite significant redundancy — leading to the increase of density in Figure 6.11. The top image was rendered such that small regions where rendered on top of large regions, where in the bottom image, regions segmented earlier in time are behind regions segmented later.

In parallel with generating and printing these static aesthetic explorations of the system, dream imagery was generated from Dataset 2 according to associative mechanisms summarized in Chapter 4. The software used to generate the dreams was written during the residency period and revised through the exhibition. Input frames collected over a few days were segmented and written to disk to be read by the dream generating software. The dreams were oriented toward foreground objects due to the small amount of variation in the background over a relatively small number of frames available at the time. A subtle static background, constructed offline from segmented background regions, was rendered behind the foreground percepts whose sequence was determined by associative propagation, as pictured in Figure 6.12.

At this point in development, the images are segmented into thousands of regions, some of which are very small in area and supply little visual information. In order to reduce this amount,

Figure 6.9: Images generated from Dataset 1 according to early segmentation and clustering methods.

Figure 6.10: Images generated from Dataset 2 according to early segmentation and clustering methods.

Figure 6.11: Images generated from Dataset 2 without clustering.

regions are filtered by area such that small regions are not kept in memory. Images reconstructed from these larger regions then show gaps in the areas once occupied by many small regions, often at region borders. This is particularly clear in the segmentation of trees in Dataset 2, as pictured in the background of Figure 6.12, where the white background is visible. Moving objects are considered by the segmentation system as foreground, thus when clouds pass over the sky, the sky regions are considered among foreground objects. Images of the sky then appear in associative dreams, as seen particularly in Figure 6.12 (bottom). The complexity and noisiness of the region boundaries are the result of the particular methods used in segmenting background and foreground regions. The dreams were projected on a wall in the exhibition space, as pictured in Figure 6.8. As the simulation software generating dreams was independent of the segmentation system, it loaded a fixed number of regions into memory and continuously associated through that corpus.

The purpose of this installation was to continue developing the project while exhibiting it. As is implied by the title (*An Artist in Process...*), the artist's presence and work process was framed as an artwork in itself, which reflects the framing of this work as art-as-research. While the exhibition was open, the artist was working in the space and available to discuss the work with viewers. The artist was available to answer any questions and provide a richer and more audience specific context for the work than offered by the exhibition text alone. Additionally, as the work was revised during the exhibition, it allowed discussion of the work as it currently stood. The aesthetic variation of the work was significant and supported by the viewer's comments, despite the banal parking-lot as subject. The focus on foreground objects in the dream rendering contrasts highly with the realization discussed in the next section, where an interest in the diversity of the landscape entails a shift away from an emphasis on foreground objects. In fact, the foreground is almost entirely erased from *Dreaming Machine #3 (Landscape)*, to be discussed next.

6.3.3 Dreaming Machine #3 (Landscape)

This realization of the project differs slightly from the implementation described in Chapter 5. These differences are partially due to developments of the computational model, and partially due to shifting artistic concerns. *Dreaming Machines* are meant for long-term public exhibition; they are ideally viewed for short periods that repeat over a long time-span such that the long-term changes in imagery can be considered. Over long-term installation, the system is exposed to a much greater diversity of visual information and thus also has the potential to incorporate greater diversity of imagery into its perceptual memory. This entails a shift of emphasis away from quickly moving objects, such as cars and pedestrians, as discussed above, toward changes in large static objects that constitute the landscape. This entails an emphasis on slow and subtle shifts of light, weather and plants through days and even seasons.

Figure 6.12: Screen-shots of dream simulation generated by the associative method.

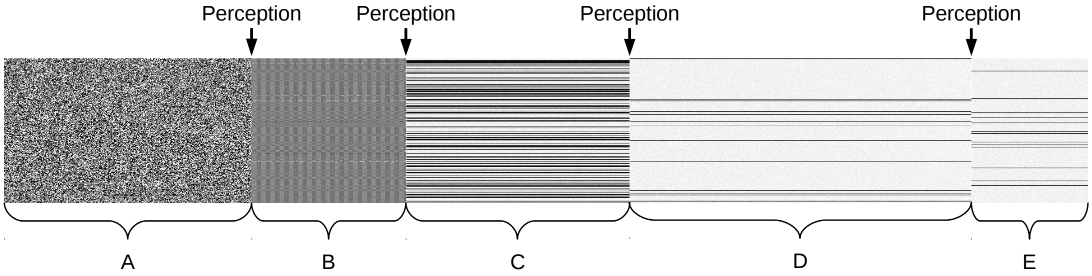

Figure 6.13: Predictor feedback during early stages of training.

6.3.3.1 System Dynamics

In order to facilitate the system's collection of as much visual diversity as possible, this implementation uses a very high arousal threshold to trigger perceptual processes. Perception occurs for very short durations (as short as a single frame) that interrupt the mind wandering process, which is the dominant process during daylight (Figure 6.13, A through E). As the clustering process only occurs during perception, the diversity of percepts is increased due to the integration of diverse content occurring at moments of high arousal. The resulting corpus tends to have more variation and is more evenly distributed over time. In previous implementations, low arousal leading to longer periods of perception saturated the percepts with more subtle visual changes occurring over smaller time-scales. In this implementation, the rarity of perception makes foreground objects spurious — contributing additional noise to the process of learning predictions. Thus, perceptual clustering only occurs when arousal is high and there are no foreground objects present.

The dynamics of the system in this implementation differ from those described in Chapter 5: (1) percepts are filtered to avoid over-activation (not pictured in Figure 6.13), (2) the network output is not discretized before it is fed back, and (3) in order to increase diversity of dreams, noise is added during predictor feedback.

Early in the training process, the result of predictor feedback proceeds through a number of initial stages, as pictured in Figure 6.13. In this figure, the x axis is time, while the y axis corresponds to a subset of perceptual clusters. A black pixel (corresponding to +1) indicates the cluster is present at that time, while a white pixel (corresponding to -1) indicates the cluster is not present. Each perceptual moment is marked in Figure 6.13, and indicates a single iteration of training. Since the network's weights are initially random, the initial period of mind wandering (A) is random. With each training iteration, the output of the network changes from random (A), through periodic (B), through to over-active and stable (C) and eventually settles (D and E) such that the number of predicted percepts approximates the number of perceptually activated percepts. After the first few iterations of training, predictor feedback tends to result in static simulations that don't change over time (D and E). The initial over activation of percepts (A through C) may cause the renderer to

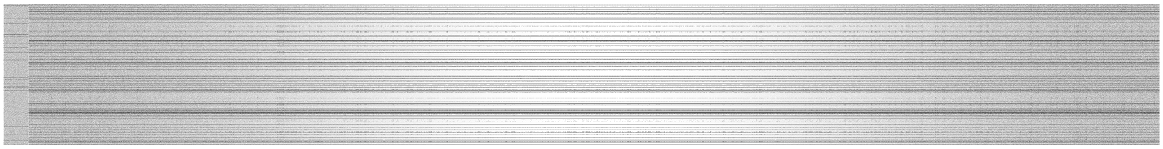

Figure 6.14: Onset of an approximately 90 minute period of dreaming showing the oscillation of random variation. The left edge of the image is a moment of perception which is followed by a period of dreaming and mind wandering, which is interrupted by a second moment of perception that occurs just before a long period of dreaming which continues to the right edge.

display the majority of percepts currently in memory. To avoid this, we specify an upper limit (T_A) for the maximum number of percepts that can be rendered. When the number of activated percepts exceeds T_A, then T_A random percepts are selected to be rendered.

In order to increase the diversity of dreams, an amount of random variation is added to the predictor feedback process. While the activation of percepts is binary (a percept is either present or not), the feedback process is continuous and increases the diversity and complexity of predictive sequences. This continuous feedback allows for the injection of noise to each percept before the predictor output becomes the next input. This noise appears as subtle variations in activation, as pictured in Figure 6.13. At each time-step the continuous activations resulting from predictor feedback are discretized such that percepts with an activation greater than 0 are rendered.

As the duration of dreams are much longer than mind wandering, the amount of noise injected into the system is modulated by a sinus oscillator, as pictured in Figure 6.14, in order to increase the variation of activation occurring over the course of long dreams. This oscillator begins at its crest, where it generates pseudo random numbers between 0 and 0.95. These numbers are added to percepts where $P^A < 0$ and subtracted from percepts where $P^A > 0$. The oscillator descends until the range of random numbers is 0, at which point it ascends again with a period of ninety minutes — the approximate time for one human sleep cycle. Over the short durations of mind wandering, this oscillation injects an approximately constant high value of noise into the feedback process — as seen in the small period of mind wandering before the onset of sleep in Figure 6.14 (far left). The oscillator begins at a crest in order to modulate the predictive sequence away from the most recent latent perception that initiates mind wandering. Weakly activated percepts that are increased by random activation only remain activated if the feedback process reinforces (rather than ignores) those activations. Thus, the activation at the onset of dreaming and mind wandering is both a function of latent perceptual activation and also by the dynamics of the predictor.

Figure 6.15 shows a detail of Figure 6.14, where a waking moment interrupts the process of mind wandering and leads to a long period of dreaming. The left side of Figure 6.15 shows two percepts activated during mind wandering — indicated by black lines (A). This period of mind wandering is interrupted by a moment of perception, in which two percepts are activated (B) — shown as two black pixels. After perception, the right side of Figure 6.15, dreaming continues where the one

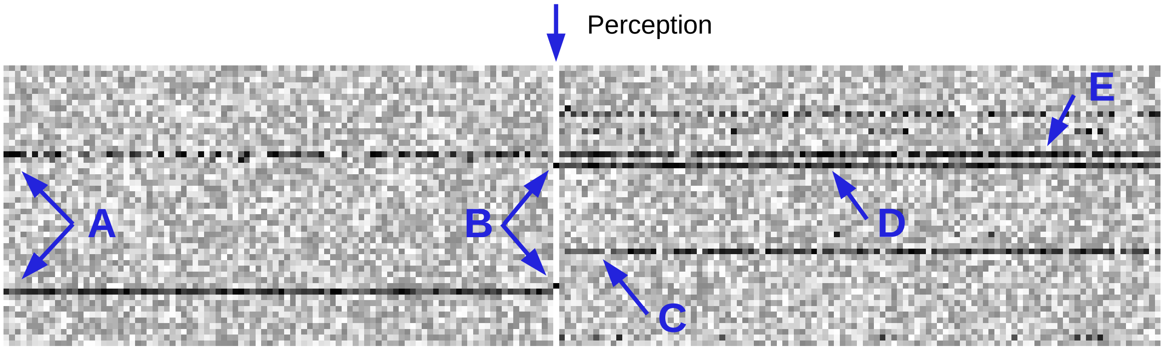

Figure 6.15: Detail of Figure 6.14, showing the onset of sleep. A: Two percepts activated during mind wandering. B: Perceptual processes interrupt the mind wandering process and causes the activation of two percepts. C: Activation of a percept during the dream which is not related to external stimuli. D: Integration of perceptual stimuli into the dream. E: Continuation of activation of a particular percept through mind wandering to dreaming.

perceptual activation (top black pixel) is incorporated into the dream (D). During the dream, new percepts become activated that are not related to the perceptual activation (C and E). One of the percepts that was active during previous mind wandering is also activated in the subsequent dream (E).

The dynamics of dreaming and mind wandering are highly sensitive to initial conditions, including both the initial state of network weights, and also the input vectors fed to the predictor. Figure 6.16 shows a subset of a dream where the pattern of activation of individual percepts is not periodic, nor static. This subset of dream activation is extracted from a portion of the dream where little random noise is injected into the feedback mechanism. While the structure is complex, it still involves a significant portion of percepts that are constantly active through the whole dream, and small oscillations where one percept is active nearly every second iteration. As the perceptual system only perceives when there are no foreground objects, many stable percepts are expected to be visible for long periods, which occurs in the pattern of activation used to train the predictor — as subset of which is pictured in Figure 6.17. The next section discusses how these dynamics are manifest in the generation of images.

6.3.3.2 Aesthetics of Simulations

Figure 6.18 shows the raw stimulus input (top) and an example perceptual simulation generated by the system (bottom). Perceptual simulations are reconstructions of sensory data using the corpus of percepts stored in memory. Percepts activated by the segmentation system are rendered on top of a running average filtered version of the raw stimulus, as described in Chapter 5. The background serves as a proxy for perceptual mechanisms that extend visual patterns, filling portions of the visual

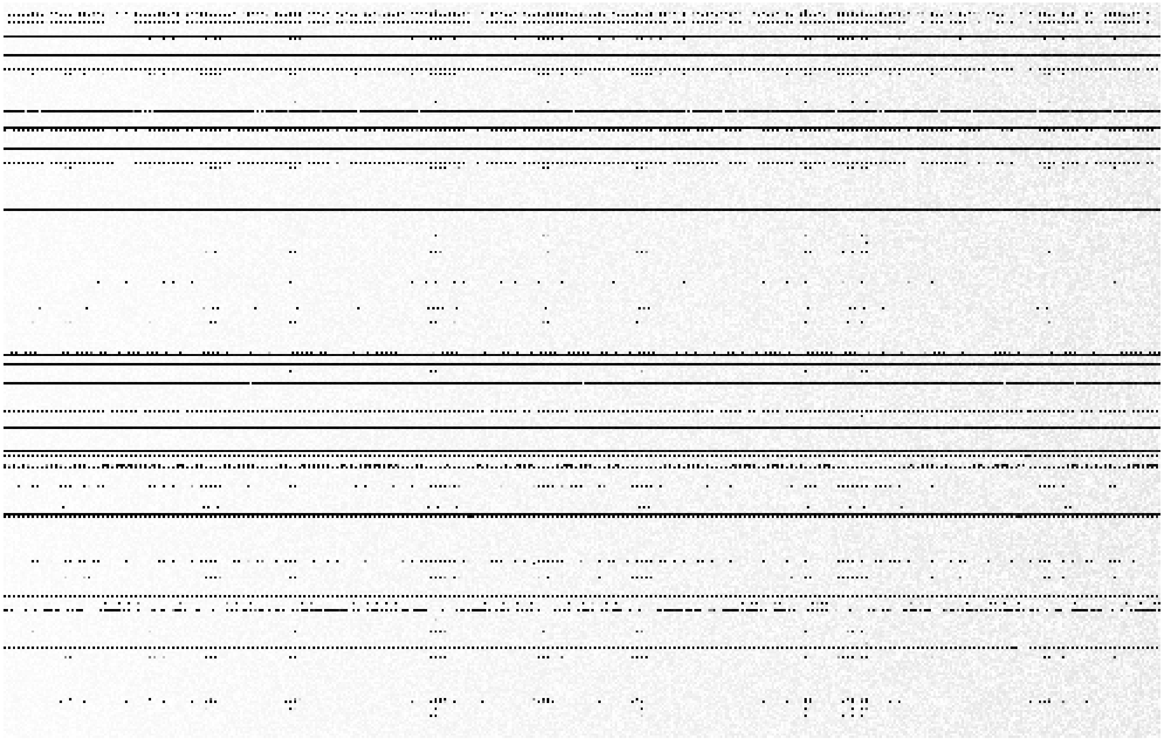

Figure 6.16: Detail of dream dynamics. The x axis is time, while the y axis is a subset of the perceptual clusters; black indicates a cluster is present at that time, and white indicates it is not. Note that some percepts tend to stay activated for long periods, while others appear intermittently during the dream.

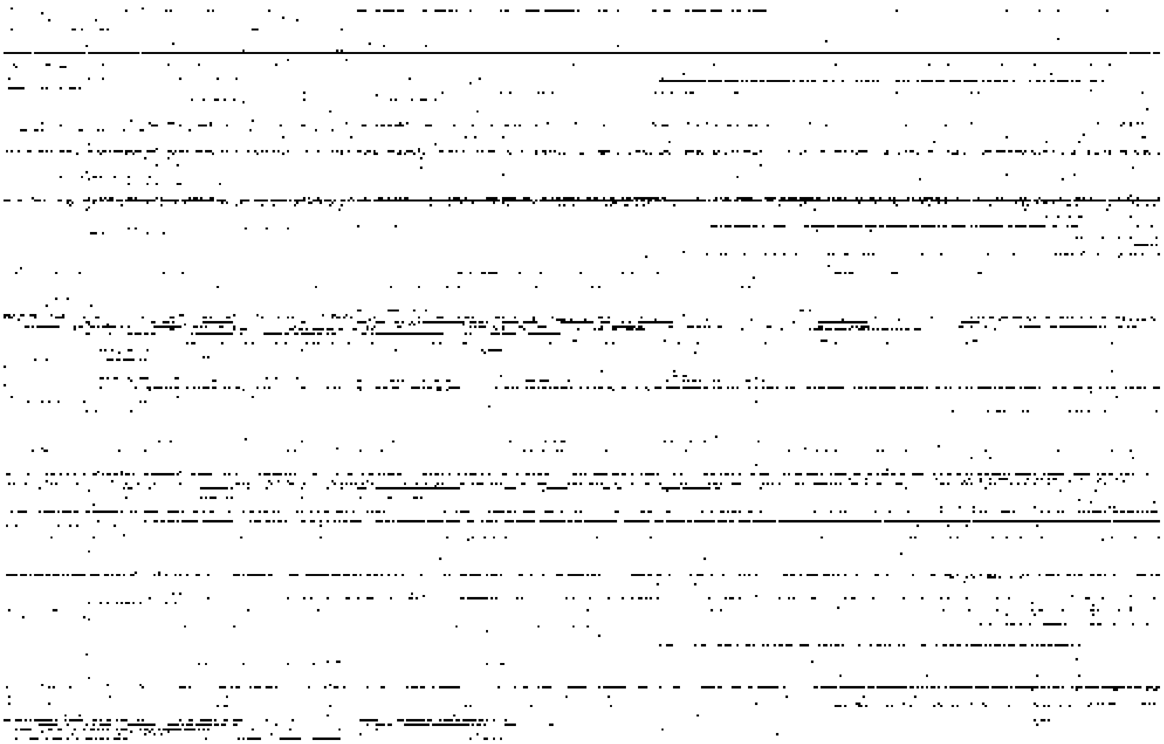

Figure 6.17: Activation of percepts during perceptual moments. Each column shows one perceptual moment arranged over the y axis in consecutive order. Each column corresponds to a single training vector fed to the predictor. Note that some percepts are active over long periods, and others being activated quite intermittently.

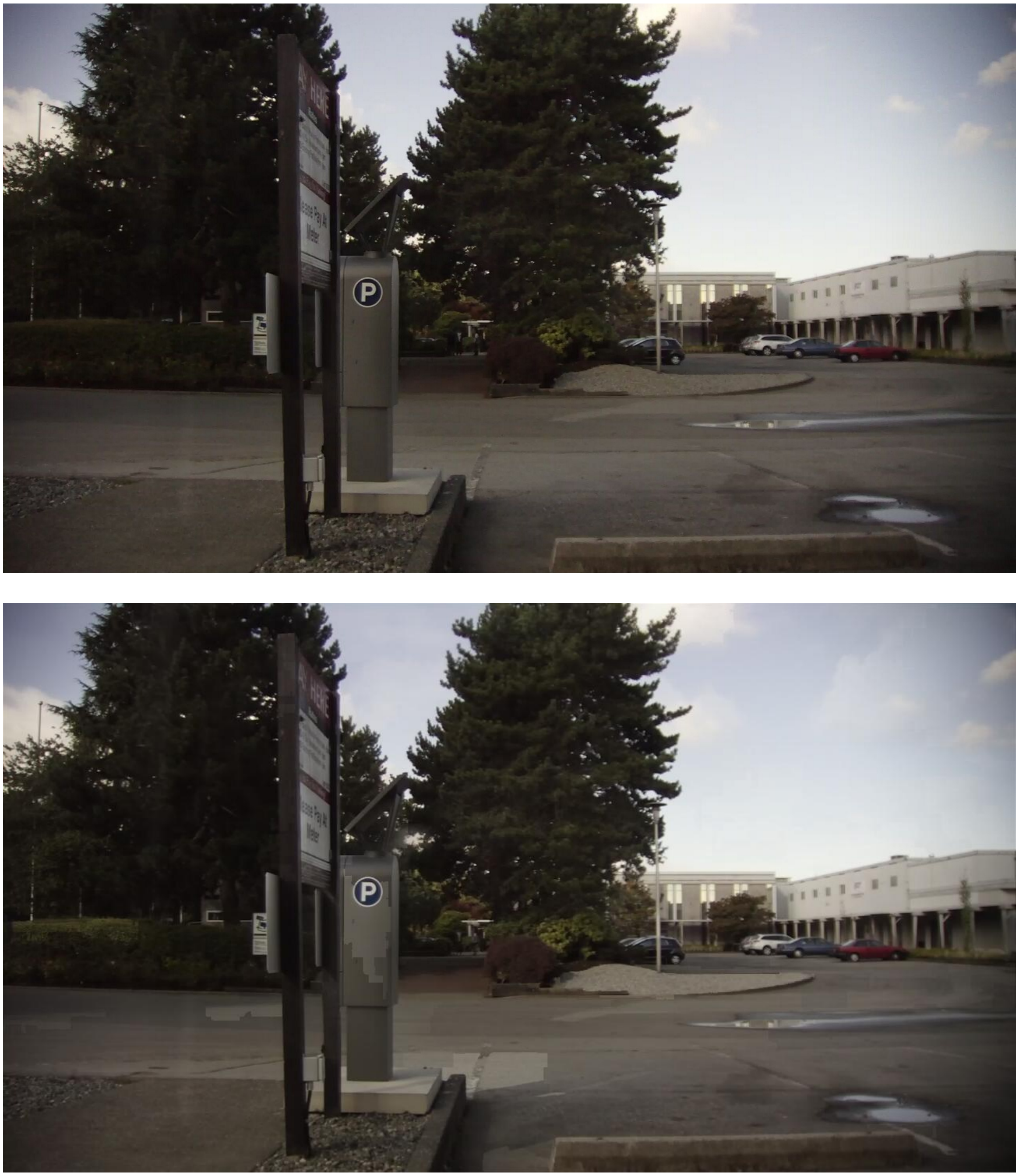

Figure 6.18: Example of raw stimulus fed to the system from Dataset 2 (above) and the corresponding perceptual simulation constructed from perceptual clusters (below).

field not occupied by percepts. Although the image is a reconstruction, it very closely resembles the sensory input. A period of mind wandering, following shortly after the perceptual moment pictured in Figure 6.18, is pictured in Figure 6.19. Activated percepts diverge significantly from the external stimulus, as evidenced by the inclusion of blurry percepts (which were captured hours earlier than the perceptual stimulus) and blue sky.

While the diversity of mind wandering simulations is significant, dreaming still involves a quite restricted number of precepts. Dreams tend to involve little diversity of perceptual clusters, despite the injection of noise into the system, two examples of which are pictured in Figure 6.20. This lack of diversity, combined with the black background, makes dream simulations relatively unsuccessful as plausible simulations of reality.

The long-term solution is to replace the MLP with a prediction mechanism better suited to temporal sequences, as discussed in the Future Work section of Chapter 7. During perception and mind wandering, the background behind the activated percepts serves as a proxy for perceptual processes filling in context dependent detail, this does not extend to dreaming, where the lack of context makes any background choice problematic. One option to increase the diversity of activations during dreaming is to increase the noise injected into the system beyond the range used in the current implementation. Adding more noise is likely to obliterate any output from the predictor, making dreams effectively random, which is not supported by the Integrative Theory. Another option is to lower the threshold for detecting night, which would increase the probability of perceptual moments occurring during the night, and thus increase dream diversity. In practice, an installation of the work in a dynamic urban setting would likely cause such an effect, due to increased brightness and activity during the night. As the system's daylight time is largely spent in mind wandering, it is reasonable for those images to be more aesthetically interesting and plausible as simulations of perceptual reality. In the next section, we discuss *Watching and Dreaming*, a spin off artwork where the system is fed images from films, in this case *2001: A Space Odyssey* (1968). This film's long and slowly moving sequences incorporating dark frames facilitates the inclusion of both dreaming and mind wandering within the duration of the film.

6.3.4 Watching and Dreaming (2001: A Space Odyssey)

In this realization, the system is fed frames from the film *2001: A Space Odyssey* (1968), rather than live images captured in a context of installation. This section describes current work-in-progress where only minimal changes have been made to the implementation described above. Through initial experimentation, three major differences between the film (Dataset 3) and Dataset 2 have been observed:

1. The constructed nature of the film means that large changes (peaks of arousal) are more unevenly distributed over time.

Figure 6.19: Two examples of mind wandering images produced by predictor feedback following the perceptual stimulus pictured in Figure 6.18.

Figure 6.20: Examples of dream simulations showing limited aesthetic variation.

Figure 6.21: Example imagery generated during perception (bottom) by *Watching and Dreaming (2001: A Space Odyssey)* that resembles the original scene from *2001: A Space Odyssey* (1968) (top).

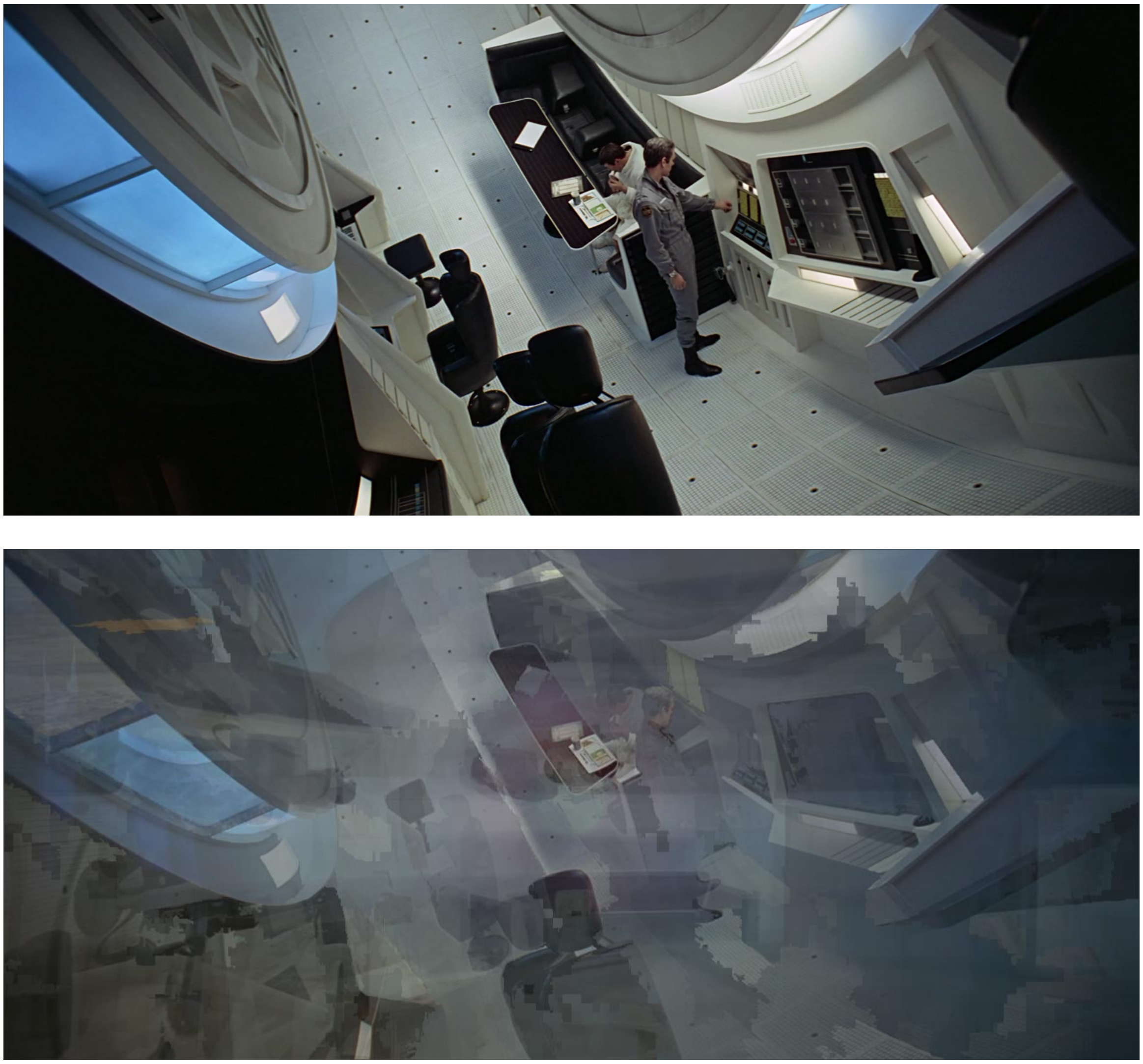

Figure 6.22: Example imagery generated during mind wandering (bottom) by *Watching and Dreaming (2001: A Space Odyssey)* that resembles the original scene from *2001: A Space Odyssey* (1968) (top).

2. The tight control of lighting and subject matter lead to extremely strong region boundaries, and thus the segmentation method performs very well in many scenes.
3. The presence of drastic scene changes in the film are problematic for the use of running average filtered backgrounds behind percepts.

The combination of 1 and 2 results in images that may appear similar to the original, as pictured in Figures 6.21 and 6.22. In order to divorce the imagery from the original film, the weighting for the running average background was changed from 0.9 (previous stimuli) / 0.1 (new stimulus) to 0.99 / 0.01, respectively. This makes the background appear less similar to a particular frame, and more similar to the colour and structure of a scene in general. The approximately 30 frames per second of the film means there is little difference between subsequent frames, compared to Dataset 2. The combination of processing every 30th frame, and changing the running average weight, results in images that are less likely to resemble the original scenes.

As mentioned in the previous section, the emphasis of this realization is mind wandering over dreaming, and thus perhaps would be more accurately titled *Watching and Mind Wandering*.[2] While in *Dreaming Machine #3 (Landscape)*, the rarity of perception over time increases the diversity of percepts to be included in dreams, this is much less significant in the case of a film where the diversity of frames is much greater and dreaming is de-emphasized. The combination of long and nearly static sequences with periods of darkness (e.g. outer space scenes) leads to dream generation within the film sequence. Thus, it is unnecessary to append black frames to the end of the film, as proposed in the Future Work section of Chapter 5.

The high degree of diversity in Dataset 3 leads to highly diverse generative imagery. Simulations may appear as painterly abstractions, as pictured in Figures 6.21 and 6.22, where the images resemble the original scenes. These occur during perception and mind wandering where the activation of percepts is highly constrained to recent perceptual activation. The degree to which imagery resembles stimulus is highly variable; some images appear like stimulus images but are also significantly manipulated, as pictured in Figure 6.23. In other mind wandering sequences, content from other scenes could be integrated into the simulation. In the case of Figure 6.24, the previous scene change did not generate sufficient arousal to trigger perception, resulting in the continuation of the previous mind wandering process, despite the change in stimulus. A subset of these images, as pictured in Figures 6.25 and 6.26, combine clearly readable photo-realistic percepts with highly clustered percepts and backgrounds, leading to imagery that fuses with photography.

In the previous section, even the most incongruent dreams still generate images that are spatially cohesive, as all percepts are rendered where they were segmented and all frames are locked into the same view-point by the use of a static camera. The diversity, and the lack of a single point of

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[2] The Integrative Theory and computational model hold that dreaming and mind wandering are enabled by the same mechanisms, and thus the terms are technically synonymous in this context.

Figure 6.23: Bottom: Example imagery generated during mind wandering by *Watching and Dreaming (2001: A Space Odyssey)*. Top: The stimulus frame from *2001: A Space Odyssey* (1968) that corresponds to this mind wandering imagery.

Figure 6.24: Example imagery generated during mind wandering (bottom) by *Watching and Dreaming (2001: A Space Odyssey)*, where content diverges significantly from the corresponding stimulus from *2001: A Space Odyssey* (1968) (top).

Figure 6.25: Bottom: Example imagery generated during perception by *Watching and Dreaming (2001: A Space Odyssey)*, where photo-realistic content is integrated. Top: The stimulus frame from *2001: A Space Odyssey* (1968) that corresponds to this perceptual imagery.

Figure 6.26: Bottom: Example imagery generated during mind wandering by *Watching and Dreaming (2001: A Space Odyssey)*, where photo-realistic content is integrated. Top: The stimulus frame from *2001: A Space Odyssey* (1968) that corresponds to this mind wandering imagery.

view, of Dataset 3 leads to highly bizarre combinations. Imagery, such as pictured in Figure 6.24, diverges significantly from the stimulus currently presented to the system. As a sequential clustering method is used, the final clustering result is highly dependent on the sequence in which regions are clustered. In this case, this leads to a greater number of percepts that were segmented near the start of Dataset 3, and also happen to lean to a palette of reds and yellows. As the system's memory contains a disproportionate number of percepts clustered early in the film, there is a tendency for random influence on dreaming and mind wandering to activate those percepts. In the case of Figure 6.24, this leads to the high contrast between the blues and blacks (resulting from latent activation of percepts clustered in the previous space scene) and the reds and yellows (resulting from random activations reinforced by predictor feedback). One significant benefit to training the system on the finite number of frames in a film, which is not possible in a live installation context, is that epoch training can be used; this would improve both the clustering and predictor learning.

The realizations discussed in this section show the breadth of the aesthetic potential of the generative processes of *Dreaming Machine #3*. The imagery generated by the system ranges from painterly abstraction, through collage and near photo-realism. The theoretical context that informs this work is one of its main contributions and sets it apart significantly from related works in both media art and the computational modelling of dreaming processes. Other artistic examinations of dreaming and constructive perception tend to be more concerned with an intuitive sense of what dreaming, perception and memory are, without undertaking a critical examination of theories and conceptions of the mechanisms of dreaming and constructive perception. Related efforts to model dream processes emphasize the computational aspects of memory storage, or dynamics specified by complex differential equations, but tend not to examine dreaming in a broader framework of cognition nor attempt to rigorously link computational systems and corresponding theories. The interest in dreaming mechanisms for their generative and image-making potential is largely unexamined.

Chapter 7

Future Work and Conclusion

In this chapter, future directions of research are discussed, as well as concluding remarks. The first four sections discuss future directions of development for this art-as-research practice, the Integrative Theory, the computational model and future artistic works inspired by the research process. The final section concludes the thesis by returning to some of the initial artistic motivations of this research.

7.1 Art-as-Research

This research is composed of three major components: (a) the Integrative Theory, which depends on the biopsychological literature on the mechanisms of visual mentation; (b) the computational model that manifests aspects of the theory in a formalization suitable for software implementation, and (c) the art objects themselves being software implementations of the model executed in computer systems. One may ask why this particular constellation of disciplinary lenses is in play in this research. The biopsychological level of description is used because the scope of the research centres on the mechanisms of dreaming, and those mechanisms of dreaming are most understood at a biopsychological level. The computational model formalization was integral in bridging the Integrative Theory and the implementation by providing a site of collaboration with Philippe Pasquier (senior supervisor) in order to incorporate disciplinary knowledge in cognitive agent modelling and machine learning. The software implementation of this work is framed within generative and electronic media art because that is the disciplinary field of the author of this research. At the time of writing, there has been no formal analysis on how these various components contribute to one another. An examination of the production blog (Bogart, 2008–2014)[1] would make explicit these

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[1] The production blog documents the development of all the *Dreaming Machines* from the early work on *Dreaming Machine #1* and *Dreaming Machine #2* — produced thanks to the support of the Canada Council for the Arts — through to the

relations and could contribute to art-as-research beyond this project. That being said, there are some general observations on these relations that can be gleaned, as summarized in Figure 7.1 and described in the remainder of this section.

Research began at the conceptual level and focused on the intuitive question: what are the atoms of experience, be them memories, perceptual information or concepts? This initial research was conducted during a directed readings course under the supervision of Steven Barnes (committee member). The assumption was that concepts were the atoms of experience and therefore the content of dreams. Following from this, significant time was spent on the literature of concept formation in developmental psychology (e.g. Piaget et al., 1971; Müller et al., 1998; Müller & Overton, 2000; Mandler, 2004, 2008) and developmental robotics (e.g. Marshall et al., 2004; Asada et al., 2009). In the end, this line of theory was abandoned because the theories of concept development examined assume underlying biological autonomy and inherent biological drives. Once this line of enquiry was set aside, the research process focused on dreaming, mental imagery, and perception. Later, the biopsychology of creativity (Dietrich, 2004) and the default network, in relation to dreaming and mind wandering (G. W. Domhoff, 2011; Fox et al., 2013), was considered.

As this expanded literature search continued, the Integrative Theory was being developed in collaboration with Steven Barnes and Philippe Pasquier. Simultaneously, a simple perceptual system was being implemented. While much progress was made in making sense of the literature and integrating various diverse theories, the implementation process was lagging behind. The Integrative Theory was already quite well formed — in its associative formulation — leading up to the New Forms Festival exhibition (Section 6.3). At this time, the implementation was composed of rudimentary segmentation and clustering algorithms. As these perceptual clusters are the content of dreams, their properties have the greatest effect on the spatial quality of generated images. The production log contains many iterations of refinement of both segmentation and clustering implementations. Early segmentation methods and poor clustering lead to highly complex and aesthetically interesting images (Section 6.3), but those images did not reflect the clustering process as conceptualized — allowing the recognition of objects and the persistence of objects over time. The bulk of the implementation process was getting this perceptual system to the stage that mental images could appear similar to the images seen by the camera.

Figure 7.1 shows how each of these major components contributes to the others. The Integrative Theory was the initial site of enquiry, where the motivation was to make sense of the literature, with the support and supervision of Steven Barnes, and arrive at a cohesive concept of what dreams are, what they are composed of, and their relation to perception. While this is considered part of the art-as-research practice, it did not yet involve any implementation, or image-making. The theory was the primary validation of the choices made in the early implementations.

PhD and the development of *Dreaming Machine #3* and early work on *Watching and Dreaming*.

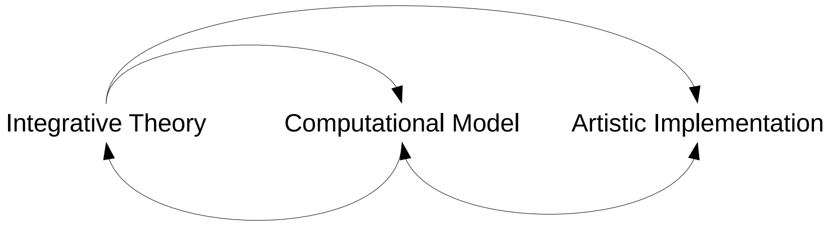

Figure 7.1: The relationships between various components of research during development.

The notion of the computational model, as a formalization of the Integrative Theory, but separated from implementation details, was proposed by Philippe Pasquier. This was manifest in a writing process where the system, as currently conceptualized, was described, clarified and streamlined in discussion with Philippe Pasquier. As modules of the system were implemented, the resulting images where evaluated in terms of their aesthetic properties — which were largely the result of segmentation and clustering — and how they manifest the Integrative Theory. For example, the gaps between segmented regions visible in the New Forms Festival exhibition (Section 6.3), implied a lack of perceptual cohesion in the system's mental imagery. The choice of using a background to fill in these gaps was made to reflect the seamless unification of perceptual information expected in human imagery. As the implementation was written, it also effected the computational model because some appropriate architectural and computational choices (from the perspective of computer science) where out of scope or difficult to implement, and thus were dropped (e.g. reinforcement learning). Thus, the implementation and computational model were refined and developed in tandem, as supported by the Integrative Theory. The predictive formulation of the Integrative Theory was developed at the level of the computational model, and it was this emphasis on prediction that lead to the shift from association according to features to association according to context.

This rough analysis shows that the links between the Integrative Theory (as biopsychological argument), the computational model (as a formalization of the Integrative Theory), and the implementation (as a generative artwork) are complex, parallel and difficult to disentangle. The Integrative Theory is strong in terms of its rigorous links with the biopsychological literature, while the implementation is strong aesthetically — in terms of the qualities of the images it produces. The computational model and implementation are relatively weak in terms of their exploitation of knowledge in machine learning and agent architecture. Each of these components can be seen as a separate research project, oriented to different disciplinary interests:

- under Biopsychology, the Integrative Theory would benefit from empirical validation to test its hypotheses;

- under artificial intelligence and metacreation, the computational model could be greatly improved in the form of a cognitive architecture integrating mind wandering and dreaming into task-oriented internal simulations;
- under a generative art practice, the final implementations themselves could be pushed significantly in the direction of increasing the breadth of spatial and temporal imagery it could produce.

The multi-disciplinary nature of this research has meant scoping out these disciplinary examinations, as each itself could be the basis of a doctoral thesis. The fact of developing all these components together makes this research process highly challenging as tensions between these various perspectives, i.e. Biopsychology, computer science / cognitive modelling and generative art, are inevitable. As a result, some aspects of the project received more attention than others, and perhaps there is an over-emphasis on the scientific aspects of the work at the detriment of the central motivation as an artistic practice. Despite these tensions, the work is broader and more conceptually unified because of this approach, and a hybrid art-science practice is likely to irk those on either side to discount the validity of the other. In the next three sections, future work is described for each of the three major components of this research.

7.2 Integrative Theory

The Integrative Theory holds that the experience of perception, mind wandering and dreaming result from the activation of visual representations of concrete objects. It is expected that dreaming in brains involves not just the activation of representations of concrete perceptual objects but also higher level conceptual representations. Barsalou (1999) proposes that the difficulty in pinning down the definition and origin of concepts is that they are not fixed representations but simulations in themselves. These simulations shift their content to match the particular needs of the current task. On the surface, the focus on simulation in Barsalou's conception is highly complimentary to the Integrative Theory. Still, there remains a major issue in the task-dependence of concepts in Barsalou's conception. Mind wandering and dreaming, considering their correlation with the default network, are particularly non-task oriented and stimulus independent. It is unclear how those simulations would be constrained independently of task demands. Perhaps conceptual simulations are not task dependent so much as they are context dependent, and thus such conceptual simulations may also depend on predictive mechanisms.

The Integrative Theory, as currently conceived, has associated working memory, executive and attentional mechanisms with the PFC in general. This particular conception glosses over differences in activity across the various regions of the PFC, including dorsolateral and ventromedial areas. The

Integrative Theory would benefit from a finer grained conception sensitive to constituent regions of the PFC and an integration of executive functions associated with the PFC.

7.3 Computational Model

The computational model is framed as a situated agent, although its agency is extremely impoverished in the absence of intention and other executive functions, which are out of scope of this research project. One avenue of development would be the inclusion of executive mechanisms such as planning and volition and integrating the system into an existing cognitive agent architecture — e.g. CLARION (Hélie & Sun, 2010) or SOAR (Laird, 2012). This would also entail a richer and hierarchical system of representations, although cognitive architectures tend to lack a basis in brain anatomy which is central to the Integrative Theory. The inclusion of volition in the system would promote the system to a cognitive agent with both task oriented and freely simulated (mind wandering and dreaming) mentation. These two modes of mentation respectively resemble *System 2* and *System 1*, as proposed by Kahneman (2011).

The multi-layer perceptron was chosen to facilitate implementation and for its proven flexibility and performance. As prediction is inherently about patterns occurring over time, a machine learning method specifically developed for temporal prediction could improve the ability of the system to predict sensory information, and therefore enrich dream and mind wandering sequences. Recurrent Neural Networks (Dorffner, 1996) and Deep Belief Networks (H. Lee et al., 2009) will be examined as possible methods to improve the model's predictor. Additionally, replacing the hard threshold used in the circadian clock with a proper oscillator entrained by visual brightness will be examined.

The combination of the noise sensitivity of mean shift segmentation over time, and the relatively small number of perceptual representations, has lead to quite unstable region edges, even in cases where the edges appear quite distinct to a human observer. This is due to a lack of temporal information used in the segmentation, which simply treats each frame as a new and unique image. Bailer et al. (2005) have proposed a method to improve the temporal stability in mean shift image segmentation, which could be included in the system.

7.4 Artwork

The research process that lead to the Integrative Theory began with an artistic intention to create the artwork *Dreaming Machine #3*. The development of the theory, and implementation of the computational model, inspired concepts for future artworks. At the time of writing, *Watching and Dreaming (2001: A Space Odyssey)* is slightly modified from *Dreaming Machine #3*. The finite nature of a film source leads to the potential of a live system that continuously watches the film over many epochs, which could improve the performance of some prediction algorithms. This would change the structure of dreaming and mind wandering over time such that each epoch would lead to different generative sequences. Versions of *Watching and Dreaming* are planned that use Metropolis (1927) and Blade Runner (1982) as input sources, chosen for their contribution to cinema and their representations of artificial intelligence. Another version of *Watching and Dreaming* could be fed frames from live television and run continuously as the site-specific *Dreaming Machines*.

Another proposed artwork, titled the *Dreaming Mirror*, would be tuned to the segmentation and reconstruction of facial images in particular. The system would break faces into multiple regions stored in a corpus where the regions would be used to reconstruct the face of the person currently in front of the work. The system would learn correlations between regions of the same face (prediction over space rather than time). In the absence of a face, the system would then ’dream’ by reconstructing faces from the visual corpus, using the most recent face as a starting point.

Dreaming Machine #3 (Landscape), will be exhibited at the International Symposium on Electronic Art (2014) in Dubai. This version of the system is tuned to perceiving the landscape and predict its changes over longer timescales. The system will ignore foreground objects and the patterns of their short-term movement to emphasize shifts in light and inanimate objects in the landscape of Dubai.

The machine learning and computer vision methods used in the context of this research could be applied outside of the conceptual framework of the Integrative Theory or the computational model. In such a case, the intention would be to examine the breadth of the aesthetic potential of these methods without the constraints of the theoretical framework. *Self-Organized Cinema* is such a body of work and exploits these various computational methods with an emphasis on their structural and aesthetic properties as applied to the filmography of Stanley Kubrick.

7.5 Conclusion

At the start of this thesis a few questions were posed: (a) What is a dream? The argument presented in this thesis is that a dream is a simulation of reality constructed in our minds from a predictive model of the world that allows the reproduction of lived day-to-day sensory experience; (b) What is the relationship between dreaming, mind wandering and external perception? Dreaming and mind wandering are contiguous processes enabled by mechanisms of simulation correlated with the default network. Perception itself is a simulation — a simulation highly constrained by sensory information that fills in details not available to our sensory organs.

While we have constructed cultural notions of dreams as bizarre narratives, we tend to dream of somewhat familiar places in which people engage in relatively normal activities. It is difficult to draw the line between our experience of dreams, how we report dreams, and the cultural concepts of what dreams are and should be. The consideration of perception as a process of simulation closes the gap between dreams and external perception. The ontological position of this thesis is that there is an objective reality out there, and that perceptual simulations are anchored in the real. Dreams and mind wandering are free of this anchoring and reflect culturally biased predictions of reality. Considering the contiguity of visual mentation, dreams are meaningful in the context of our lived waking experience of the world and each other, and thus a strong relation to culture is inevitable. Dreams allow us to experience the world as it is understood by the unconscious predictive mechanisms of our mind/brains. It is interesting to consider the implications of Hobson's (2009) proposal for the development of the protoself in the context of ontology. If REM sleep and 'virtual reality' simulation occur before birth, then what reality is being simulated? This should be considered in relation to Chapter 3 where the notion of internal simulation and external influence arriving at a mutually reinforcing pattern, which is not reducible to either in isolation, is discussed. While black and white television has apparently not caused us to perceive the world as black and white, we likely do experience the world through cultural narratives often presented in time-based media. Dreams are sequences of events that appear narrative-like because they are an unfolding of predictive mechanisms that may also be the basis of narrative structure. Dreams appear bizarre because the lack of anchoring in sensory information no longer mitigates the errors in prediction. These predictive errors accumulate, resulting in failures in continuity and bizarre juxtapositions.

Dreams are meaningful because they manifest the implicit sense of how events are likely to occur over time. Without the interference of sensory reality, these simulations show us the world as we understand it, rather than how it is. They expose the constructed nature of our perceptions which is a function of both how we conceptualize it, and how it appears to our sensory organs. Visual arts are about the act of representation, about the very process of taking that which is real and observed of the world and transforming it through culture, concepts, recognition and expectation. By making a *Dreaming Machine*, the hope is that the viewer reflects on the apparent stability and certainty of their own perceptions and to question: what is the relation between the world as we see it, the world as it is, and the world as it is culturally constructed by artists and scientists? The cultural baggage that defines what a dream is changes how we conceive of our dreams. Much of the world in which we live, at least in the west, is saturated with visual culture — the result of processes of representation and transformation of reality.

When a viewer gazes at the *Dreaming Machine*, they look through layers of complexity. On the surface is the image, the representation of the world. From a distance the image may appear photographic. Upon closer inspection, the constructed nature of the image is betrayed in the details, the nonsensical combinations of light and form. The whole appears uniform and true, while the individual elements could be impossible. When the viewer looks at the machine that dreams he or she is looking through the representation to a computational process — a model of mechanisms of perception and dreaming that are in themselves representations. Through these layers of representation, and impenetrable meaning, we see a glimpse of ourselves. By looking at the machine that dreams we are looking at the results of the kinds of processes we use to make sense of the world, transformed and reconfigured through those very same mechanisms. In a machine that dreams, we see not representations of ourselves, but representations of how we conceive of ourselves. We see the simulation, not the reality.

References

Agre, P. E. (1995). The soul gained and lost: artificial intelligence as a philosophical project. *Stanford Humanities Review*, *4*, 1–19.

Ahson, S., & Buller, A. (2009). Toward daydreaming machines. In Z. Hippe & J. Kulikowski (Eds.), *Human-computer systems interaction* (Vol. 60, pp. 245–256). Springer Berlin Heidelberg.

Almassy, N., Edelman, G. M., & Sporns, O. (1998). Behavioral constraints in the development of neuronal properties: a cortical model embedded in a real-world device. *Cerebral Cortex*, *8*(4), 346–361.

Amedi, A., Malach, R., & Pascual-Leone, A. (2005, December). Negative BOLD differentiates visual imagery and perception. *Neuron*, *48*(5), 859–872.

Andrews-Hanna, J. R., Reidler, J. S., Sepulcre, J., Poulin, R., & Buckner, R. L. (2010). Functional-anatomic fractionation of the brain's default network. *Neuron*, *65*(4), 550–562.

Annunziato, M., & Pierucci, P. (2003). The emergence of social learning in artificial societies. In *Applications of evolutionary computing* (pp. 293–294).

Arnulf, I. (2011). The 'scanning hypothesis' of rapid eye movements during rem sleep: a review of the evidence. *Archives Italiennes de Biologie*, *149*, 1–16.

Asada, M., Hosoda, K., Kuniyoshi, Y., Ishiguro, H., Inui, T., Yoshikawa, Y., et al. (2009). Cognitive developmental robotics: a survey. *Autonomous Mental Development, IEEE Transactions on*, *1*(1), 12–34.

Aserinsky, E., & Kleitman, N. (1953). Regularly occurring periods of eye motility, and concomitant phenomena during sleep. *Science*, *118*, 273–274.

Ashby, W. R. (1947). Principles of the self-organizing dynamic system. *The Journal of General Psychology*, *37*(2), 125–128.

Bailer, W., Schallauer, P., Haraldsson, H. B., & Rehatschek, H. (2005). Optimized mean shift algorithm for color segmentation in image sequences. In *Image and video communications and processing 2005* (Vol. 5685, pp. 522–529).

Barsalou, L. (1999). Perceptual symbol systems. *Behavioral and brain sciences*, *22*(04), 577–660.

Bartolomeo, P. (2002). The relationship between visual perception and visual mental imagery: A reappraisal of the neuropsychological evidence. *Cortex*, *38*(3), 357–378.

Bartolomeo, P. (2008, February). The neural correlates of visual mental imagery: An ongoing debate. *Cortex*, *44*(2), 107–108.

Bay, H., Tuytelaars, T., & Gool, L. (2006). Surf: Speeded up robust features. In A. Leonardis, H. Bischof, & A. Pinz (Eds.), *Computer Vision — ECCV 2006* (Vol. 3951, pp. 404–417). Springer Berlin Heidelberg.

Behrmann, M. (2000, April). The mind's eye mapped onto the brain's matter. *Current Directions in Psychological Science*, *9*(2), 50–54.

Benca, R. M., Obermeyer, W. H., Larson, C. L., Yun, B., Dolski, I., Kleist, K. D., et al. (1999). EEG alpha power and alpha power asymmetry in sleep and wakefulness. *Psychophysiology*, *36*(04), 430–436.

Bentes, C., Costa, J., Peralta, R., Pires, J., Sousa, P., & Paiva, T. (2011). Dream recall frequency and content in patients with temporal lobe epilepsy. *Epilepsia*, *52*(11), 2022–2027.

Blagrove, M., & Pace-Schott, E. F. (2010). Trait and neurobiological correlates of individual differences in dream recall and dream content. *International Review of Neurobiology*, *92*, 155–180.

Blumberg, M. S., Karlsson, K. A., Seelke, A. M. H., & Mohns, E. J. (2005). The ontogeny of mammalian sleep: A response to frank and heller (2003). *Journal of Sleep Research*, *14*(1), 91–98.

Boden, M. A. (1998, August). Creativity and artificial intelligence. *Artificial Intelligence*, *103*, 347–356.

Boden, M. A. (2004). *The creative mind: Myths and mechanisms* (2nd ed.). Routledge; London.

Bogart, B. D. R. (2005). *untitled iterations.* Available from `http://www.ekran.org/ben/wp/2007/untitled-iterations-vagueterrain-2006/`

Bogart, B. D. R. (2008). *Memory association machine: An account of the realization and interpretation of an autonomous responsive site-specific artwork.* Unpublished master's thesis, Simon Fraser University.

Bogart, B. D. R. (2008–2014). *Dreaming machine production log.* Blog. Available from `http://www.ekran.org/ben/wp/category/production/dreaming-machine/?order=ASC`

Bogart, B. D. R. (2009). The handbook of research on computational arts and creative informatics. In G. V. . G. T. J. Braman (Ed.), (pp. 213–232). IGI Global.

Bogart, B. D. R. (2012, September). *An Artist in Process: A Computational Sketch of Dreaming Machine #3.* Exhibition.

Bogart, B. D. R., & Pasquier, P. (2011). Context machines: A series of autonomous self-organizing site-specific artworks. In *Proceedings of the 17th international symposium on electronic art (ISEA) 2011, sabanci univeristy, istanbul, turkey.* Available from `http://isea2011.sabanciuniv.edu/paper/context-machines-series-autonomous-self-organizing-site-specific-artworks`

Bogart, B. D. R., & Pasquier, P. (2013a). Context machines: A series of situated and self-organizing artworks. *Leonardo*, *46*(2), 114–122.

Bogart, B. D. R., & Pasquier, P. (2013b). Dreaming Machine #3 (prototype 2). In *Proceedings of the 9th ACM conference on creativity & cognition* (pp. 408–409). New York, NY, USA: ACM.

Bogart, B. D. R., Pasquier, P., & Barnes, S. J. (2013). An integrative theory of visual mentation and spontaneous creativity. In *Proceedings of the 9th ACM conference on creativity & cognition* (pp. 264–273). New York, NY, USA: ACM.

Borisyuk, R., Kazanovich, Y., Chik, D., Tikhanoff, V., & Cangelosi, A. (2009). A neural model of selective attention and object segmentation in the visual scene: An approach based on partial synchronization and star-like architecture of connections. *Neural Networks*, *22*(5-6), 707–719.

Borst, G., & Kosslyn, S. (2012). From mental imagery to spatial cognition and language: Essays in honour of Michel Denis. In V. Gyselinck & F. Pazzaglia (Eds.), (pp. 19–42). Psychology Press.

Borst, G., Niven, E., & Logie, R. (2012). Visual mental image generation does not overlap with visual short-term memory: A dual-task interference study. *Memory & Cognition*, *40*(3), 360–372.

Bradski, G. (2014). *OpenCV.* Available from `http://opencv.org/`

Bradski, G., & Kaehler, A. (2008). *Learning OpenCV: Computer vision with the OpenCV library*. O'Reilly Media, Incorporated.

Brand, S., Beck, J., Kalak, N., Gerber, M., Kirov, R., Pühse, U., et al. (2011). Dream recall and its relationship to sleep, perceived stress, and creativity among adolescents. *Journal of Adolescent Health*, *49*, 525–531.

Breton, A. (1924). *Manifesto of surrealism* (Vol. 15). Available from `http://theanarchistlibrary.org/library/andre-breton-manifesto-of-surrealism.pdf`

Bridge, H., Harrold, S., Holmes, E., Stokes, M., & Kennard, C. (2012). Vivid visual mental imagery in the absence of the primary visual cortex. *Journal of Neurology*, *259*(6), 1062–1070.

Brooks, R. A. (1992). Intelligence without representation. *Foundations of Artificial Intelligence*, *47*, 139–159.

Brooks, R. A., Breazeal, C., Marjanović, M., Scassellati, B., & Williamson, M. M. (1999). The Cog project: Building a humanoid robot. In *Computation for metaphors, analogy, and agents* (pp. 52–87).

Buchloh, B. H. D. (1990). Conceptual Art 1962-1969: From the Aesthetic of Administration to the Critique of Institutions. *October*, *55*, 105–143.

Buckner, R. L. (2012). The serendipitous discovery of the brain's default network. *NeuroImage*, *62*(2), 1137–1145.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network. *Annals of the New York Academy of Sciences*, *1124*(1), 1–38.

Bulkeley, K. (2010). Dreaming as inspiration: Evidence from religion, philosophy, literature, and film. *International Review of Neurobiology*, *92*, 31–46.

Burnham, M. M., & Conte, C. (2010). Developmental perspective: Dreaming across the lifespan and what this tells us. *International Review of Neurobiology*, *92*, 47–68.

Busch, K. (2009). Artistic research and the poetics of knowledge. *ART & RESEARCH, A Journal of Ideas, Contexts and Methods*, *2*(2), 1–7.

Byers, Z., Dixon, M., Smart, W. D., & Grimm, C. M. (2004). Say cheese! Experiences with a robot photographer. *AI magazine*, *25*(3), 37–46.

Callaway, C. W., Lydic, R., Baghdoyan, H. A., & Hobson, J. A. (1987, June). Pontogeniculooccipital waves: spontaneous visual system activity during rapid eye movement sleep. *Cellular and Molecular Neurobiology*, *7*(2), 105–149.

Candlin, F. (2000). A proper anxiety? Practice-based PhDs and academic unease. *Working Papers in Art and Design*, *1*, 1–14.

Cappucio, F. P., Lanfranco, D., Strazzullo, P., & Miller, M. A. (2010). Sleep duration and all-cause mortality: A systematic review and meta-analysis of prospective studies. *Sleep*, *33*(5), 585–592.

Carey, S. (2009). *The origin of concepts*. Oxford University Press.

Cattaneo, Z., Bona, S., & Silvanto, J. (2012, February). Cross-adaptation combined with TMS reveals a functional overlap between vision and imagery in the early visual cortex. *NeuroImage*, *59*(3), 3015–3020.

Cavallero, C., & Foulkes, D. (1993). Dreaming as cognition. In C. Cavallero & D. Foulkes (Eds.), (pp. 133–138). New York: Harvester-Wheatleaf.

Chelazzi, L., Marzi, C., Panozzo, G., Pasqualini, N., Tassinari, G., & Tomazzoli, L. (1988). Hemiretinal differences in speed of light detection in esotropic amblyopes. *Vision Research*, *28*(1), 95–104.

Chong, H. Q., Tan, A. H., & Ng, G. W. (2007). Integrated cognitive architectures: a survey. *Artificial Intelligence Review*, *28*, 103–130.

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences*, *106*(21), 8719–8724.

Cichy, R. M., Heinzle, J., & Haynes, J. D. (2012). Imagery and perception share cortical representations of content and location. *Cerebral Cortex*, *22*(2), 372–380.

Cipolli, C., Bolzani, R., Cornoldi, C., De Beni, R., & Fagioli, I. (1993). Bizarreness effect in dream recall. *Sleep*, *16*(2), 163–170.

Clarke, A. C. (1982). *2010: Odyssey two*. RosettaBooks.

Cohen, H. (1979). What is an image? In *Proceedings of ijcai* (Vol. 2, pp. 1028–1057).

Cohen, H. (1995). The further exploits of Aaron, painter. *Stanford Humanities Review*, *4*, 141–158.

Collerton, D., & Perry, E. (2011). Dreming and hallucinations – continuity or discontinuity? perspectives from dementia with lewy bodies. *Consciousness and Cognition*, *20*, 1016–1020.

Colton, S., Mantaras, L. de, & Stock, O. (2009). Computational creativity: Coming of age. *AI Magazine*, *30*(3), 11–14.

Comaniciu, D., & Meer, P. (2002). Mean shift: a robust approach toward feature space analysis. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, *24*(5), 603–619.

Coyne, R. (1997). Creativity as commonplace. *Design Studies*, *18*(2), 135–141.

Cramer, F. (2002). *Concepts, notations, software, art.* Available from `http://www.cramer.pleintekst.nl/all/concept_notations_software_art/concepts_notations_software_art.pdf`

Crick, F., & Mitchison, G. (1983). The function of dream sleep. *Nature*, *304*(5922), 111–114.

Crutchfield, J. P., Kahn, N., Institute, S. F., & Exploratorium. (1996). *Turbulent landscapes: A dialogue.* Available from `http://www.santafe.edu/research/publications/workingpapers/96-07-051.pdf`

Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological Science*, *15*(8), 559–564.

Davis, J. (1996). Microvenus. *Art Journal*, *55*(1), 70–74.

Dement, W. (1955). Dream recall and eye movements during sleep in schizophrenic and normals. *Journal of Neural Engineering*, *122*, 263–269.

Dement, W., & Kleitman, N. (1957). The relation of eye movements during sleep to dream activity: an objective method for the study of dreaming. *Journal of Experimental Psychology*, *53*, 339–346.

Dement, W., & Kleitman, N. (1958). Cyclic variations in eeg during sleep and their relation to eye movements, body motility, and dreaming. *Electroencephalography and Clinical Neurophysiology*, *10*, 291–296.

Dement, W., & Wolpert, E. A. (1958). The relation of eye movements, body motility, and external stimuli to dream content. *Journal of Experimental Psychology*, *55*, 543–553.

Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience*, *11*, 114–126.

Diekhof, E. K., Kipshagen, H. E., Falkai, P., Dechent, P., Baudewig, J., & Gruber, O. (2011, January). The power of imagination – how anticipatory mental imagery alters perceptual processing of fearful facial expressions. *NeuroImage*, *54*(2), 1703–1714.

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review*, *11*, 1011–1026.

Dijk, D.-J. (2012). Sleep research: observing dreams and inducing hypnagogic images. *Journal of Sleep Research*, *21*, 1–2.

Dijksterhuis, A., & Meurs, T. (2006). Where creativity resides: The generative power of unconscious thought. *Consciousness and Cognition*, *15*(1), 135–146.

Domhoff, G. (1996). *Finding meaning in dreams: A quantitative approach*. Springer.

Domhoff, G. W. (2011). The neural substrate for dreaming: Is it a subsystem of the default network? *Consciousness and Cognition*, *20*(4), 1163–1174.

Domhoff, G. W., & Schneider, A. (1998). New rationales and methods for quantative dream research outside the laboratory. *Sleep*, *21*(4), 398–404.

Domhoff, G. W., & Schneider, A. (2008). Similarities and differences in dream content at the cross-cultural, gender, and individual levels. *Consciousness and Cognition*, *17*, 1257–1265.

Dörfelt, M. (2011). *Selective Memory Theatre, Eine Installation über das selektive Wahrnehmen, Erinnern und Vergessen anhand von Bildern aus dem Internet.* Unpublished bachelor thesis, Muthesius Kunsthochschule. Available from `http://mokafolio.de/works/Selective-Memory-Theatre`

Dorffner, G. (1996). Neural networks for time series processing. *Neural Network World*, *6*, 447–468.

Dorin, A., & McCormack, J. (2001). Introduction: First Iteration—A conference on generative systems in the electronic arts. *Leonardo*, *34*(3), 239–242.

Ednick, M., Cohen, A., McPhall, G. L., Beebe, D., Simakajornboon, N., & Amin, R. S. (2009). A review of the effects of sleep during the first year of life on cognitive, psychomotor, and temperament development. *Sleep*, *32*(11), 1449–1458.

Ellamil, M., Dobson, C., Beeman, M., & Christoff, K. (2012). Evaluative and generative modes of thought during the creative process. *NeuroImage*, *59*(2), 1783–1794.

Farah, M. J., Levine, D. N., & Calvanio, R. (1988, October). A case study of mental imagery deficit. *Brain and Cognition*, *8*(2), 147–164.

Feinberg, I. (1978). Efference copy and corollary discharge: Implications for thinking and its disorders. *Schizophrenia Bulletin*, *4*(4), 636–640.

Finke, R. (1980). Levels of equivalence in imagery and perception. *Psychological Review*, *87*(2), 113–132.

Finke, R. (1985). Theories relating mental imagery to perception. *Psychological Bulletin*, *98*(2), 236–259.

Finke, R. A., & Kosslyn, S. M. (1980). Mental imagery acuity in the peripheral visual field. *Journal of Experimental Psychology: Human Perception and Performance*, *6*(1), 126–139.

Finke, R. A., & Kurtzman, H. S. (1981). Mapping the visual field in mental imagery. *Journal of Experimental Psychology: General*, *110*(4), 501–517.

F. J. Varela, E. T., & Rosch, E. (1991). The embodied mind: Cognitive science and human experience. In (chap. Symbols: The Cognitivist Hypothesis). MIT Press.

Fosse, M. J., Fosse, R., Hobson, J. A., & Stickgold, R. J. (2003, January). Dreaming and episodic memory: A functional dissociation? *Journal of Cognitive Neuroscience*, *15*(1), 1–9.

Foster, R., & Kreitzman, L. (2005). *Rhythms of life: The biological clocks that control the daily lives of every living thing*. Yale University Press.

Fox, K. C. R., Nijeboer, S., Solomonova, E., Domhoff, G. W., & Christoff, K. (2013). Dreaming as mind wandering: evidence from functional neuroimaging and first-person content reports. *Frontiers in Human Neuroscience*, *7*(412), 1–18.

Franco, A. (2007). *Controlled Dream Machine*. Unpublished master's thesis, University of Plymouth. Available from `http://www.anaisafranco.com/controlled.html`

Frank, M. G., & Heller, H. C. (2003). The ontogeny of mammalian sleep: A reappraisal of alternative hypotheses. *Journal of Sleep Research*, *12*, 25–34.

Freud, S. (1913). *The interpretation of dreams* (Third ed.). New York: The Macmillan Company.

Friston, K. (2010, February). The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience*, *11*(2), 127–138.

Gabora, L. (2000). Creative evolutionary systems. In D. W. Corne & P. J. Bentley (Eds.), (pp. 147–161). Morgan Kaufman Publishers Inc., San Francisco, CA.

Gabora, L. M. (2000a). Art, technology, consciousness: Mind at large. In R. Ascott (Ed.), (chap. Toward a Theory of Creative Inklings). Intellect Press, Oxford England.

Gabora, L. M. (2000b). Toward a theory of creative inklings. In R. Ascott (Ed.), (pp. 159–164). Intellect Press, Oxford England.

Gabora, L. M. (2002). Creative evolutionary systems. In P. Bentley & D. Corne (Eds.), (pp. 147–161). Morgan Kaufman Publishers Inc., San Francisco, CA.

Galanter, P. (2003). What is generative art? complexity theory as a context for art theory. In *In GA2003–6th generative art conference* (pp. 1–21).

Galanter, P. (2008). The art of artificial evolution. In J. Romero & P. Machado (Eds.), (pp. 311–332). Springer.

Gallichio, L., & Kalesan, B. (2009). Sleep duration and all-cause mortality: A systematic review and meta-analysis. *Journal of Sleep Research*, *18*, 148–158.

Goldberg, B. (1991). Investigating psychology: Sciences of the mind after Wittgenstein. In J. Hyman (Ed.), (pp. 48–65). New York: Oxford University Press.

Goldberg, K., Santarromana, J., Bekey, G., Gentner, S., Morris, R., Wiegley, J., et al. (1995). The telegarden. In *Proceedings of ACM SIGGRAPH* (pp. 135–140).

Goodale, M. A., & Westwood, D. A. (2004). An evolving view of duplex vision: separate but interacting cortical pathways for perception and action. *Current Opinion in Neurobiology*, *14*(2), 203–211.

Gordon, I., & Hayward, S. (1973, June). Second-order isomorphism of internal representations of familiar faces. *Attention, Perception, & Psychophysics*, *14*(2), 334–336.

Gottesmann, C. (2010a). The development of the science of dreaming. *International Review of Neurobiology*, *92*, 1–16.

Gottesmann, C. (2010b). To what extent do neurobiological sleep-waking processes support psychoanalysis? *International Review of Neurobiology*, *92*, 233–271.

Graham, K. S., Barense, M. D., & Lee, A. C. H. (2010). Going beyond LTM in the MTL: A synthesis of neuropsychological and neuroimaging findings on the role of the medial temporal lobe in memory and perception. *Neuropsychologia*, *48*(4), 831–853.

Gregory, D. (2010, September). Visual imagery: Visual format or visual content? *Mind & Language*, *25*(4), 394–417.

Grieco, B., Lima, P., Gregorio, M. D., & França, F. (2010). Producing pattern examples from "mental" images. *Neurocomputing*, *73*(7-9), 1057–1064.

Guhe, M., Smaill, A., & Pease, A. (2010). Towards a cognitive model of conceptual blending. In *Proceedings of the 10th international conference on cognitive modeling* (pp. 293–304).

Guion, L., Diehl, D., & McDonald, D. (2011). *Triangulation: Establishing the validity of qualitative studies* (Tech. Rep. No. FCS6014). University of Florida press, Gainesville. (Tech. Rep. No. FCS6014)

Haarmann, A. (2010). Artistic Research: A Tool of Cognition Parallel to Philosophy? *Proceedings of the European Society for Aesthetics*, *2*, 193–208.

Haralick, R., Sternberg, S. R., & Zhuang, X. (1987, July). Image analysis using mathematical morphology. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, *PAMI-9*(4), 532–550.

Hawkins, J., & George, D. (2006). *Hierarchical temporal memory: Concepts, theory and terminology* (Tech. Rep.). Numenta Inc.

Hayles, N. K. (1996). Narratives of artificial life. In (pp. 146–164). Psychology Press.

Healey, C. G., & Enns, J. T. (1996). *A perceptual colour segmentation algorithm* (Tech. Rep.). Vancouver, BC, Canada, Canada: University of British Columbia.

Hélie, S., & Sun, R. (2010). Incubation, insight, and creative problem solving: A unified theory and a connectionist model. *Psychological Review*, *117*(3), 994–1024.

Hesslow, G. (2002). Conscious thought as simulation of behaviour and perception. *Trends in Cognitive Sciences*, *6*(6), 242–247.

Hill, C. E., & Knox, S. (2010). The use of dreams in modern psychotherapy. *International Review of Neurobiology*, *92*, 291–317.

Hobson, A., & Schredl, M. (2011). The continuity between waking and dreaming: Unidirectional or bidirectional? *International Journal of Dream Research*, *4*(1), 3–7.

Hobson, J., & Friston, K. (2012). Waking and dreaming consciousness: Neurobiological and functional considerations. *Progress in Neurobiology*, *98*(1), 82–98.

Hobson, J. A. (2002). Sleep and dream suppression following a lateral medullary infarct: A first-person account. *Consciousness and Cogition*, *11*(3), 377–390.

Hobson, J. A. (2009). REM sleep and dreaming: towards a theory of protoconsciousness. *Nature Reviews Neuroscience*, *10*(11), 803–813.

Hobson, J. A., & Kahn, D. (2007). Dream content: Individual and generic aspects. *Consciousness and Cognition*, *16*, 850–858.

Hobson, J. A., & McCarley, R. W. (1977). The brain as a dream state generator: an activation-synthesis hypothesis of the dream process. *American Journal of Psychiatry*, *134*(12), 1335–1348.

Hobson, J. A., Pace-Schott, E. F., & Stickgold, R. (2000). Dreaming and the brain: Toward a cognitive neuroscience of conscious states. *Behavioral and Brain Sciences*, *23*, 793–842.

Hobson, J. A., & Voss, U. (2011). A mind to go out of: Reflections on primary and secondary consciousness. *Consciousness and Cognition*, *20*, 993–997.

Holt, N. (2008). Representation, legitimation, and autoethnography: An autoethnographic writing story. *International Journal of Qualitative Methods*, *2*(1), 18–28.

Innocent, T. (2001). The language of iconica. *Leonardo*, *34*(3), 255–259.

International Symposium on Electronic Art. (2014). Available from `http://www.isea-web.org/`

Intons-Pererson, M. (1980). The role of loudness in auditory imagery. *Memory & Cognition*, *8*(5), 385–393.

Ishai, A., Ungerleider, L. G., & Haxby, J. V. (2000, December). Distributed neural systems for the generation of visual images. *Neuron*, *28*(3), 979–990.

Jakobson, A. J., Fitzgerald, P. B., & Conduit, R. (2012). Induction of visual dream reports after transcranial direct current stimulation (tdcs) during stage 2 sleep. *Journal of Sleep Research*, *21*(4), 369–379.

Johnson, M. R., Mitchell, K. J., Raye, C. L., D'Esposito, M., & Johnson, M. K. (2007, August). A brief thought can modulate activity in extrastriate visual areas: Top-down effects of refreshing just-seen visual stimuli. *NeuroImage*, *37*(1), 290–299.

Kaas, A., Weigelt, S., Roebroeck, A., Kohler, A., & Muckli, L. (2010, January). Imagery of a moving object: The role of occipital cortex and human MT/V5+. *NeuroImage*, *49*(1), 794–804.

Kahan, T. L., LaBerge, S., Levitan, L., & Zimbardo, P. (1997). Similarities and differences between dreaming and waking cognition: An exploratory study. *Consciousness and Cognition*, *6*, 132–147.

Kahan, T. L., & LaBerge, S. P. (2011). Dreaming and waking: Similarities and differences revisited. *Consciousness and Cognition*, *20*, 494–514.

Kahn, D., & Gover, T. (2010). Consciousness in dreams. *International Review of Neurobiology*, *92*, 181-195.

Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

Kamal, N., Tsou, L., Al Hajri, A., & Fels, S. (2010). DreamThrower: Creating, Throwing and Catching Dreams for Collaborative Dream Sharing. In H. Yang, R. Malaka, J. Hoshino, & J. Han (Eds.), *Entertainment computing - ICEC 2010* (Vol. 6243, pp. 20–31). Springer Berlin / Heidelberg.

Kandel, E., & Wurtz, R. (2000). Constructing the visual image. *Principles of neural science*, *4*, 492–506.

Kaufman, A., Kornilov, S., Bristol, A., Tan, M., & Grigorenko, E. (2010). The cambridge handbook of creativity. In J. C. K. . R. J. Sternberg (Ed.), (pp. 216–232). Cambridge University Press.

Ke, H., Zhang, D., & You, W. (2009). Mental imagery knowledge representation mode of human-level intelligence system. In P. Wen, Y. Li, L. Polkowski, Y. Yao, S. Tsumoto, & G. Wang (Eds.), *Rough sets and knowledge technology* (Vol. 5589, pp. 232–238). Springer Berlin Heidelberg.

Klein, I., Dubois, J., Mangin, J., Kherif, F., Flandin, G., Poline, J., et al. (2004, December). Retinotopic organization of visual mental images as revealed by functional magnetic resonance imaging. *Cognitive Brain Research*, *22*(1), 26–31.

Klein, I., Paradis, A., Poline, J., Kosslyn, S. M., & Le Bihan, D. (2000). Transient activity in the human calcarine cortex during Visual-Mental imagery: An Event-Related fMRI study. *Journal of Cognitive Neuroscience*, *12*(supplement 2), 15–23.

Klein, Y. A. (1998). Living sculpture: the art and science of creating robotic life. *Leonardo*, *31*(5), 393–396.

Knauff, M., Kassubek, J., Mulack, T., & Greenlee, M. (2000). Cortical activation evoked by visual mental imagery as measured by fMRI. *NeuroReport*, *11*(18), 3957—3962.

Kohonen, T. (1990). The self-organizing map. *Proceedings of the IEEE*, *78*(9), 1464–1480.

Kohonen, T. (2001). *Self-organizing maps*. Springer.

Kosslyn, S. (1973, February). Scanning visual images: Some structural implications. *Attention, Perception, & Psychophysics*, *14*(1), 90–94.

Kosslyn, S. (1976, May). Can imagery be distinguished from other forms of internal representation? evidence from studies of information retrieval times. *Memory & Cognition*, *4*(3), 291–297.

Kosslyn, S. M. (1975, July). Information representation in visual images. *Cognitive Psychology*, *7*(3), 341–370.

Kosslyn, S. M. (1976, June). Using imagery to retrieve semantic information: A developmental study. *Child Development*, *47*(2), 434–444.

Kosslyn, S. M. (1980). *Image and mind*. Harvard University Press.

Kosslyn, S. M. (1981). The medium and the message in mental imagery: A theory. *Psychological Review*, *88*(1), 46–66.

Kosslyn, S. M. (1994). *Image and brain: the resolution of the imagery debate*. MIT Press.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception and Performance*, *4*(1), 47–60.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2003). Mental imagery: Against the nihilistic hypothesis. *Trends in Cognitive Sciences*, *7*(3), 109–110.

Kosslyn, S. M., Murphy, G. L., Bemesderfer, M. E., & Feinstein, K. J. (1977). Category and continuum in mental comparisons. *Journal of Experimental Psychology: General*, *106*(4), 341–375.

Kosslyn, S. M., Pinker, S., Smith, G. E., & Shwartz, S. P. (1979). On the demystification of mental imagery. *Behavioral and Brain Sciences*, *2*(4), 535–581.

Kosslyn, S. M., & Thompson, W. L. (2003). When is early visual cortex activated during visual mental imagery? *Psychological Bulletin*, *129*(5), 723–746.

Kosslyn, S. M., Thompson, W. L., & Ganis, G. (2006). *The case for mental imagery.* Oxford University Press.

Kosslyn, S. M., Thompson, W. L., Kim, I. J., & Alpert, N. M. (1995). Topographical representations of mental images in primary visual cortex. *Nature*, *378*(6556), 496–498.

Krueger, M. W. (1977). Responsive environments. In *Proceedings of the June 13–16, 1977, national computer conference* (pp. 423–433).

Kubrick, S. (Director). (1968). *2001: A Space Odyssey.* Motion Picture.

Kuhn, T. S. (1962). *The structure of scientific revolutions: 50th anniversary edition*. University of Chicago Press.

Kwon, M. (2004). One place after another: Site-specific art and locational identity. In (pp. 11–31). Boston: MIT Press.

LaBerge, S. (2000, 12). Lucid dreaming: Evidence and methodology. *Behavioral and Brain Sciences*, *23*, 962–964.

Laird, J. (2012). *The Soar Cognitive Architecture*. MIT Press.

Lang, F. (Director). (1927). *Metropolis.* Motion Picture.

Lea, G. (1975). Chronometric analysis of the method of loci. *Journal of Experimental Psychology: Human Perception and Performance*, *1*(2), 95–104.

Lee, H., Grosse, R., Ranganath, R., & Ng, A. Y. (2009). Convolutional deep belief networks for scalable unsupervised learning of hierarchical representations. In *Proceedings of the 26th annual international conference on machine learning* (pp. 609–616). New York, NY, USA: ACM.

Lee, S., Kravitz, D. J., & Baker, C. I. (2012, February). Disentangling visual imagery and perception of real-world objects. *NeuroImage*, *59*(4), 4064–4073.

Legrady, G. (1996). Slippery traces: The postcard trail. *Artintact*, *3*, 101–104.

Legrady, G., & Honkela, T. (2002). Pockets Full of Memories: an interactive museum installation. *Visual Communication*, *1*(2), 163–169.

Levin, G., Lieberman, Z., & al. et. (2004). *Interactive bar tables.* Available from `http://www.flong.com/projects/tables/`

Lewis, K., Borst, G., & Kosslyn, S. (2011, July). Integrating visual mental images and visual percepts: new evidence for depictive representations. *Psychological Research*, *75*(4), 259–271.

LeWitt, S. (1969, May). Sentences on conceptual art. *Art & Language*, *1*(1), 11–13.

Limosani, I., D'Agostino, A., Manzone, M. L., & Scarone, S. (2011). The dreaming brain/mind, consciousness and psychosis. *Consciousness and Cognition*, *20*, 987–992.

Llewellyn, S. (2011). If waking and dreaming consciousness became de-differentiated would schizophrenia result? *Consciousness and Cognition*, *20*, 1059–1083.

Loftus, E. (2003). Our changeable memories: legal and practical implications. *Nature Reviews Neuroscience*, *4*(3), 231–234.

Loomis, A. L., Harvey, E., & Hobart, G. A. I. (1937). Cerebral states during sleep, as studied by human brain potentials. *Journal of experimental Psychology*, *21*, 127–144.

Loomis, A. L., Harvey, E. N., & Hobart, G. (1936). Electrical potentials of the human brain. *Journal of experimental Psychology*, *19*(3), 249–279.

Lowe, D. G. (2004). Distinctive image features from scale-invariant keypoints. *International Journal of Computer Vision*, *60*, 91–110.

Mahowald, M. W., & Schenck, C. H. (2005). Insights from studying human sleep disorders. *Nature*, *437*(27), 1279–1285.

Mandler, J. M. (2004). Thought before language. *Trends in cognitive sciences*, *8*(11), 508–513.

Mandler, J. M. (2008). On the birth and growth of concepts. *Philosophical Psychology*, *21*(2), 207–230.

Manni, R., Terzaghi, M., Ratti, P.-T., Repetto, A., Zangaglia, R., & Pacchetti, C. (2011). Hallucinations and rem sleep behaviour disorder in parkinson's disease: Dream imagery intrusions and other hypotheses. *Consciousness and Cognition*, *20*, 1021–1026.

Manovich, L. (2001). *The language of new media*. MIT Press.

Marks, D. (1973, February). Visual imagery differences in the recall of pictures. *British Journal of Psychology*, *64*(1), 17–24.

Marshall, J., Blank, D., & Meeden, L. (2004). An emergent framework for self-motivation in developmental robotics. In *Proceedings of the 3rd international conference on development and learning (ICDL 2004), salk institute, san diego* (pp. 104–111).

Marzano, C., Ferrara, M., Mauro, F., Moroni, F., Gorgoni, M., Tempesta, D., et al. (2011). Recalling and forgetting dreams: Theta and alpha oscillations during sleep predict subsequent dream recall. *Journal of Neurosience*, *31*(18), 6674–6683.

Marzi, C., Mancini, F., Metitieri, T., & Savazzi, S. (2006). Retinal eccentricity effects on reaction time to imagined stimuli. *Neuropsychologia*, *44*(8), 1489–1495.

Mateas, M. (2001). Expressive AI: A Hybrid Art and Science Practice. *Leonardo*, *34*(2), 147–153.

Mazard, A., Laou, L., Joliot, M., & Mellet, E. (2005, August). Neural impact of the semantic content of visual mental images and visual percepts. *Cognitive Brain Research*, *24*(3), 423–435.

McCorduck, P. (1991). *Aaron's code: meta-art, artificial intelligence, and the work of harold cohen*. WH Freeman.

McCormack, J. (2006). New challenges for evolutionary music and art. *SIGEVOlution*, *1*, 5–11.

McNamara, P., Johnson, P., McLaren, D., Harris, E., Beauharnais, C., & Auerbach, S. (2010). REM and NREM sleep mentation. *International Review of Neurobiology*, *92*, 69–86.

Meeter, M., & Olivers, C. N. L. (2006). Intertrial priming stemming from ambiguity: A new account of priming in visual search. *Visual Cognition*, *13*(2), 202–222.

Merleau-Ponty, M. (1968). *The visible and the invisible, trans*. Evanston: Northwestern University Press.

Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in neurosciences*, *6*, 414–417.

Mistlberger, R. E., Groot, M. H. de, Bossert, J. M., & Marchant, E. G. (1996). Discrimination of circadian phase in intact and suprachiasmatic nuclei-ablated rats. *Brain Research*, *739*(1–2), 12–18.

Mohr, H. M., Linder, N. S., Dennis, H., & Sireteanu, R. (2011). Orientation-specific aftereffects to mentally generated lines. *Perception*, *40*(3), 272–290.

Mohr, H. M., Linder, N. S., Linden, D. E., Kaiser, J., & Sireteanu, R. (2009, August). Orientation-specific adaptation to mentally generated lines in human visual cortex. *NeuroImage*, *47*(1), 384–391.

Monterege, J. T. (1989, July). The creation of digital consciousness. *SIGART Bull.*, *109*, 30–33.

Morin, L., & Allen, C. (2006). The circadian visual system, 2005. *Brain Research Reviews*, *51*(1), 1–60.

Moro, V., Berlucchi, G., Lerch, J., Tomaiuolo, F., & Aglioti, S. M. (2008, February). Selective deficit of mental visual imagery with intact primary visual cortex and visual perception. *Cortex*, *44*(2), 109–118.

Moser, D., Anderer, P., Gruber, G., Parapatics, S., Loretz, E., Boeck, M., et al. (2009). Sleep classification according to AASM and Rechtschaffen & Kales: Effects on sleep scoring parameters. *Sleep*, *32*(2), 139–149.

Moyer, R. (1973). Comparing objects in memory: Evidence suggesting an internal psychophysics. *Attention, Perception, & Psychophysics*, *13*(2), 180–184.

Müller, U., & Overton, W. F. (2000). How to grow a baby: A reevaluation of image-schema and Piagetian action approaches to representation. *Human Development*, *41*(2), 71–111.

Müller, U., Sokol, B., & Overton, W. F. (1998). Reframing a constructivist model of the development of mental representation: The role of higher-order operations. *Developmental Review*, *18*, 155–201.

Murray, E. A., Bussey, T. J., & Saksida, L. M. (2007). Visual Perception and Memory: A New View of Medial Temporal Lobe Function in Primates and Rodents. *Annual review of neuroscience*, *30*, 99–122.

Muzur, A., Pace-Schott, E. F., & Hobson, J. (2002). The prefrontal cortex in sleep. *Trends in Cognitive Sciences*, *6*(11), 475–481.

New Forms Festival. (2012). Available from `http://2012.newformsfestival.com/`

Nielsen, T. A. (2000, 12). A review of mentation in REM and NREM sleep: REM sleep as a possible reconciliation of two opposing models. *Behavioral and Brain Sciences*, *23*, 851–866.

Nir, Y., Massimini, M., Boly, M., & Tononi, G. (2013). Sleep and consciousness. In A. E. Cavanna, A. Nani, H. Blumenfeld, & S. Laureys (Eds.), *Neuroimaging of consciousness* (pp. 133–182). Springer Berlin Heidelberg.

Nir, Y., & Tononi, G. (2010). Dreaming and the brain: from phenomenology to neurophysiology. *Trends in cognitive sciences*, *14*(2), 88–100.

Nissen, S. (2003). *Implementation of a fast artificial neural network library (FANN)* (Tech. Rep.). Department of Computer Science University of Copenhagen (DIKU). Available from `http://fann.sf.net`

Occhionero, M., & C., C. P. (2011). Autoscopic phenomena and one's own body representation in dreams. *Consciousness and Cognition*, *20*, 1009–1015.

O'Craven, K. M., & Kanwisher, N. (2000). Mental imagery of faces and places activates corresponding Stimulus-Specific brain regions. *Journal of Cognitive Neuroscience*, *12*(6), 1013–1023.

Oliva, A., & Torralba, A. (2007). The role of context in object recognition. *Trends in Cognitive Sciences*, *11*(12), 520–527.

Osborn, E. (1996). *Parabolica.* Available from `http://www.roving.net/installations/parabolica.html`

Pace-Schott, E. (2010). Principles and practice of sleep medicine: Expert consult premium edition - enhanced online features. In M. Kryger, T. Roth, & W. Dement (Eds.), (pp. 563–575). Elsevier Health Sciences.

Paiva, T., Bugalho, P., & Bentes, C. (2011). Dreaming and cognition in patients with frontotemporal dysfunction. *Consciousness and Cognition*, *20*, 1027–1035.

Paivio, A. (1975, November). Perceptual comparisons through the mind's eye. *Memory & Cognition*, *3*(6), 635–647.

Palagini, L., & Rosenlicht, N. (2011). Sleep, dreaming, and mental health: A review of historical and neurobiological perspectives. *Sleep Medicine Reviews*, *15*, 179–186.

Payne, J. D. (2010). Memory consolidation, the diurnal rhythm of cortisol, and the nature of dreams: A new hypothesis. *International Review of Neurobiology*, *92*, 101–134.

Payne, J. D., & Nadel, L. (2004). Sleep, dreams, and memory consolidation: The role of the stress hormone cortisol. *Learning & Memory*, *11*(6), 671–678.

Penny, S. (1997). Embodied Cultural Agents: at the intersection of robotics, cognitive science and interactive art. *In AAAI Socially Intelligent Agents Symposium*, 103–105.

Pérez, R. P., Sosa, R., & Lemaitre, C. (2007). A computer model for Visual-Daydreaming. In *Intelligent narrative technologies: Papers from the 2007 AAAI fall symposium, technical report FS-07-05* (pp. 102–109).

Piaget, J., Inhelder, B., & Chilton, P. A. (1971). *Mental Imagery in the Child: In Collaboration with M. Bovet*. Routledge & Kegan Paul.

Pinker, S. (1980). Mental imagery and the third dimension. *Journal of Experimental Psychology: General*, *109*(3), 354–371.

Pinker, S., & Finke, R. A. (1980). Emergent two-dimensional patterns in images rotated in depth. *Journal of Experimental Psychology: Human Perception and Performance*, *6*(2), 244–264.

Pinker, S., & Kosslyn, S. (1978). The representation and manipulation of three-dimensional space in mental images. *Journal of Mental Imagery*, *2*(1), 69–84.

Podgorny, P., & Shepard, R. N. (1978). Functional representations common to visual perception and imagination. *Journal of Experimental Psychology: Human Perception and Performance*, *4*(1), 21–35.

Poissant, L. (2007). Media art histories. In O. Grau (Ed.), (pp. 229–250). MIT Press.

Pylyshyn, Z. W. (1981). The imagery debate: Analogue media versus tacit knowledge. *Psychological Review*, *88*(1), 16–45.

Pylyshyn, Z. W. (2002). Mental imagery: In search of a theory. *Behavioral and brain sciences*, *25*(02), 157–182.

Pylyshyn, Z. W. (2003a). Return of the mental image: are there really pictures in the brain? *Trends in cognitive sciences*, *7*(3), 113–118.

Pylyshyn, Z. W. (2003b). *Seeing and visualizing: It's not what you think*. The MIT Press.

Rechtschaffen, A., & Kales, A. (1968). A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects [Computer software manual]. Washington DC: US Government Printing Office, US Public Health Service.

Reddy, L., Tsuchiya, N., & Serre, T. (2010, April). Reading the mind's eye: Decoding category information during mental imagery. *NeuroImage*, *50*(2), 818–825.

Revonsuo, A. (2000). The reinterpretation of dreams: An evolutionary hypothesis of the function of dreaming. *Behavioral and Brain Sciences*, *23*, 877–901.

Roffwarg, H. F., Dement, W. C., Muzio, J. N., & Fisher, C. (1962). Dream imagery: Relationship to rapid eye movements of sleep. *Archives of General Psychiatry*, *7*, 235–258.

Rokeby, D. (1987). *Echoing Narcissus.* Available from `http://homepage.mac.com/davidrokeby/echo.html`

Rokeby, D. (1995). Transforming mirrors: subjectivity and control in interactive media. In S. Penny (Ed.), (pp. 133–158). SUNY Press.

Ruby, P. M. (2011). Experimental research on dreaming: state of the art and neuropsychoanalytic perspectives. *Frontiers in Psychology*, *2*, 1–10.

Rumelhart, G., D.E. Hinton, & Williams, R. (1986). Parallel distributed processing: Explorations in the microstructure of cognition. In (pp. 318–363). MIT Press, Cambridge, MA.

Salakhutdinov, R., & Hinton, G. (2009). Deep boltzmann machines. In *Proceedings of the international conference on artificial intelligence and statistics* (Vol. 5, pp. 448–455).

Saunders, R., & Gero, J. S. (2002). How to study artificial creativity. *Proceedings of the 4th conference on Creativity & cognition*, 80–87.

Scassellati, B. (2002). Theory of mind for a humanoid robot. *Autonomous Robots*, *12*(1), 13–24.

Schmidhuber, J. (2009). Simple algorithmic theory of subjective beauty, novelty, surprise, interestingness, attention, curiosity, creativity, art, science, music, jokes. *Journal of the Society of Instrument and Control Engineers*, *48*(1), 21–32.

Schön, D. A. (1983). The reflective practitioner: How professionals think in action. In (pp. 3–71). Basic Books.

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences*, *15*(7), 319–326.

Schredl, M. (2011). Dream research in schizophrenia: Methodological issues and a dimensional approach. *Consciousness and Cognition*, *20*, 1036–1041.

Schredl, M., & Hofmann, F. (2003). Continuity between activities and dream activities. *Consciousness and Cogition*, *12*, 298-308.

Schwitzgebel, E. (2002). Why did we think we dreamed in black and white? *Studies in History and Philosophy of Science Part A*, *33*(4), 649–660.

Scott, R. (Director). (1982). *Blade Runner.* Motion Picture.

Seaman, B. (1997). *Models of poetic construction and their potential use in recombinant poetic networks.* Available from `http://projects.visualstudies.duke.edu/billseaman/pdf/modelsOfPoeticConstruction.pdf`

Searle, J. (1980). Minds, brains, and programs. *Behavioral and brain sciences*, *3*(03), 417–424.

Shah, M. (1997). *Fundamentals of computer vision* (Tech. Rep.). Computer Science Department, University of Central Florida, Orlando, FL.

Shepard, R. N., & Chipman, S. (1970, January). Second-order isomorphism of internal representations: Shapes of states. *Cognitive Psychology*, *1*(1), 1–17.

Sherry, D. F., & Schacter, D. L. (1987). The evolution of multiple memory systems. *Psychological Review*, *94*(4), 439–454.

Shredl, M. (2010). Characteristics and contents of dreams. *International Review of Neurobiology*, *92*, 135–154.

Siagian, C., & Itti, L. (2007). Rapid biologically-inspired scene classification using features shared with visual attention. *IEEE transactions on pattern analysis and machine intelligence*, *29*(2), 300–312.

Siegel, J. M. (2005). Clues to the functions of mammalian sleep. *Nature*, *437*(27), 1264-1271.

Siegel, J. M. (2008). Do all animals sleep? *Trends in Neurosciences*, *31*(4), 208–213.

Siegel, J. M. (2009). Sleep viewed as a state of adaptive inactivity. *Nature Reviews Neuroscience*, *10*, 747–753.

Siegel, J. M. (2011). REM sleep: A biological and psychological paradox. *Sleep Medicine Reviews*, *15*, 129–142.

Silicon Graphics Incorporated. (2014). *OpenGL.* Available from `http://www.opengl.org/`

Sima, J. (2011). The nature of mental images—an integrative computational theory. In *Proceedings of the 33rd annual meeting of the cognitive science society* (pp. 2878–2883).

Sims, K. (1991). Artificial evolution for computer graphics. *Computer Graphics*, *25*(4), 319–328.

Sinclair, S. V., & Mistlberger, R. E. (1997). Scheduled activity reorganizes circadian phase of syrian hamsters under full and skeleton photoperiods. *Behavioural Brain Research*, *87*(2), 127–137.

Slotnick, S. D., Thompson, W. L., & Kosslyn, S. M. (2005, October). Visual mental imagery induces retinotopically organized activation of early visual areas. *Cerebral Cortex*, *15*(10), 1570–1583.

Slotnick, S. D., Thompson, W. L., & Kosslyn, S. M. (2011). Visual memory and visual mental imagery recruit common control and sensory regions of the brain. *Cognitive Neuroscience*, *3*(1), 14–20.

Snyder, F. (1970). The psychodynamic implications of the physiological studies on dreams. In L. Madow & L. Snow (Eds.), (pp. 124–151). Thomas.

Solms, M. (1997). *The neuropsychology of dreams: a clinico-anatomical study*. L. Erlbaum Associates.

Solms, M. (2000a). Dreaming and rem sleep are controlled by different brain mechanisms. *Behavioral and Brain Sciences*, *23*, 843–850.

Solms, M. (2000b). Dreaming and REM sleep are controlled by different brain mechanisms. *Behavioral and Brain Sciences*, *23*, 843–850.

Sommerer, C., & Mignonneau, L. (1993). *Interactive plant growing.* Available from `http://90.146.8.18/de/archiv_files/19931/1993_408.pdf`

Steinheider, B., & Legrady, G. (2004). Interdisciplinary collaboration in digital media arts: A psychological perspective on the production process. *Leonardo*, *37*(4), 315–321.

Sternberg, R., & Lubart, T. (1999). The concept of creativity: Prospects and paradigms. *Handbook of creativity*, *1*, 3–15.

Stickgold, R., Malia, A., Maguire, D., Roddenberry, D., & O'Connor, M. (2000). Replaying the game: Hypnagogic images in normals and amnesics. *Science*, *290*(5490), 350–353.

Stokes, M., Thompson, R., Cusack, R., & Duncan, J. (2009, February). Top-Down activation of Shape-Specific population codes in visual cortex during mental imagery. *The Journal of Neuroscience*, *29*(5), 1565–1572.

Strehovec, J. (2009). New media art as research: art-making beyond the autonomy of art and aesthetics. *Technoetic Arts: a Journal of Speculative Research*, *6*(3), 233–250.

Sullivan, G. (2005). Art practice as research: Inquiry in the visual arts. In (chap. Practice as Theory). Sage Publications Inc.

Sun, R. (1994). CONSYDERR: a two-level hybrid architecture for structuring knowledge for commonsense reasoning. In *Neural networks, 1994. IEEE world congress on computational intelligence., 1994 IEEE international conference on* (Vol. 3, pp. 1475–1480).

Sung, Y., & Ogawa, S. (2008, December). A property of face representation at the categorical level. *Neuroscience Letters*, *448*(1), 1–5.

Takeuchi, H., Taki, Y., Hashizume, H., Sassa, Y., Nagase, T., Nouchi, R., et al. (2012). The association between resting functional connectivity and creativity. *Cerebral Cortex*, *22*(12), 2921–2929.

Tamblyn, C. (1990). Computer art as conceptual art. *Art Journal*, *49*(3), 253–256.

Teller, D. Y., McDonald, M. A., Preston, K., Sebris, S. L., & Dobson, V. (1986). Assessment of visual acuity in infants and children; The acuity card procedure. *Developmental Medicine & Child Neurology*, *28*(6), 779–789.

Theodoridis, S., & Koutroumbas, K. (2009). *Pattern recognition*. Academic Press.

Thirion, B., Duchesnay, E., Hubbard, E., Dubois, J., Poline, J., Lebihan, D., et al. (2006, December). Inverse retinotopy: Inferring the visual content of images from brain activation patterns. *NeuroImage*, *33*(4), 1104–1116.

Thomas, N. (1999). Are theories of imagery theories of imagination? an active perception approach to conscious mental content. *Cognitive Science*, *23*(2), 207–245.

Tomlinson, B., Baumer, E., Yau, M. L., Alpine, P. M., Canales, L., Correa, A., et al. (2007). Dreaming of adaptive interface agents. In *Chi '07 extended abstracts on human factors in computing systems* (pp. 2007–2012). New York, NY, USA: ACM.

Treur, J. (2011). A computational agent model using internal simulation to generate emotional dream episodes. In *Biologically inspired cognitive architectures 2011: Proceedings of the second annual meeting of the BICA society* (pp. 389–400).

Triesch, J., Ballard, D. H., Hayhoe, M. M., & Sullivan, B. T. (2003). What you see is what you need. *Journal of Vision*, *3*(1), 86–94.

Tucker, L., Thompson, A., Smith, J., Cohen, A., Clark, M., & Barrett, M. (2009, Feburary). *Why do we dream?* Documentary Television Program. (BBC Horizon Documentary)

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology*, *53*, 1–25.

Turing, A. (2004). The essential turing: Seminal writings in computing, logic, philosophy, artificial intelligence, and artificial life, plus the secrets of enigma. In B. Copeland (Ed.), (pp. 433–464). Oxford University Press, USA.

Tye, M. (2000). *The imagery debate*. The MIT Press.

Valli, K. (2011). Dreaming in a multilevel framework. *Consciousness and Cognition*, *20*, 1084–1090.

Verostko, R. (1997). Diamond lake apocalypse: Buddha. In *ACM SIGGRAPH 97 visual proceedings: The art and interdisciplinary programs of SIGGRAPH'97* (pp. 56–56).

Vertes, R. P., & Eastman, K. E. (2000). The case against memory consolidation in REM sleep. *Behavioral and Brain Sciences*, *23*, 867–876.

Voss, U., Hotzmann, R., Tuin, I., & Hobson, J. (2009). Lucid dreaming: A state of consciousness with features of both waking and non-lucid dreaming. *Sleep*, *32*(9), 1191–1200.

Wais, P. E., Rubens, M. T., Boccanfuso, J., & Gazzaley, A. (2010, June). Neural mechanisms underlying the impact of visual distraction on retrieval of Long-Term memory. *The Journal of Neuroscience*, *30*(25), 8541–8550.

Wang, H., Ke, H., Zhao, H., & Liang, K. (2010). Visual mental imagery memory model based on weighted directed graph. *Journal of Computers*, *5*(8), 1256–1263.

Wechsler, D. (1967). *Manual for the wechsler preschool and primary scale of intelligence*. The Psychological Corporation.

Weisberg, R. W. (2006). *Creativity: Understanding innovation in problem solving, science, invention, and the arts*. John Wiley & Sons.

White, N. (1987–1996). *The helpless robot.* Available from `http://www.year01.com/helpless/statement.html`

Whitelaw, M. (2004). *Metacreation: art and artificial life*. MIT Press.

Wilson, S. (1995). Artificial intelligence research as art. *Stanford Electronic Humanities Review*, *4*(2), 171–186.

Wilson, S. (2002). *Information Arts: Intersections Of Art, Science, and Technology*. The MIT Press.

Windt, J. M., & Noreika, V. (2011). How to integrate dreaming into a general theory of consciousness—a critical review of existing positions and suggestions for future research. *Consciousness and Cognition*, *20*(4), 1091–1107.

Yi, D., Turk-Browne, N. B., Chun, M. M., & Johnson, M. K. (2008). When a thought equals a look: Refreshing enhances perceptual memory. *Journal of Cognitive Neuroscience*, *20*(8), 1371–1380.

Young, M., & Yamane, S. (1992, May). Sparse population coding of faces in the inferotemporal cortex. *Science*, *256*(5061), 1327–1331.

Zach Lieberman, T. W., & Castro, A. (2014). *openFrameworks.* Available from `http://openframeworks.cc/`

Zago, S., Corti, S., Bersano, A., Baron, P., Conti, G., Ballabio, E., et al. (2010). A cortically blind patient with preserved visual imagery. *Cognitive and behavioral neurology*, *23*(1), 44–48.

Zhang, Q. (2005). An artificial intelligent counter. *Cognitive Systems Research*, *6*(4), 320–332.

Zhang, Q. (2009). A computational account of dreaming: Learning and memory consolidation. *Cognitive Systems Research*, *10*(2), 91–101.

Zhang, X., Wang, D., Ren, L., & Liu, P. (2010). Biomimetic construction of category mental imagery based on recognition mechanism of visual cortex of human brain. *Journal of Bionic Engineering*, *7*, S238–S244.