UNIVERSITY OF CALIFORNIA, SAN DIEGO

Theory and Technology for Computational Narrative: An Approach to Generative and Interactive Narrative with Bases in Algebraic Semiotics and Cognitive Linguistics

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Computer Science and Cognitive Science

by

Douglas Alan Harrell, Jr.

Committee in charge:

Professor Geoffrey Voelker, Chair
Professor Gilles Fauconnier, Co-chair
Professor Lev Manovich
Professor Simon Penny
Professor Victor Vianu

2007
Copyright

Douglas Alan Harrell, Jr.

(a.k.a. D. Fox Harrell)

All rights reserved.
Theory and Technology for Computational Narrative: An Approach to Generative and Interactive Narrative with Bases in Algebraic Semiotics and Cognitive Linguistics

by

Douglas Alan Harrell, Jr.

Doctor of Philosophy in Computer Science and Cognitive Science

University of California, San Diego, 2007

Professor Geoffrey M. Voelker, Chair

Professor Gilles Fauconnier, Co-Chair

This dissertation presents theoretical and technical support for, and implementations of, narrative computational media works with the following characteristics: generative content, semantics-based interaction, reconfigurable narrative structure, and strong cognitive and socio-cultural grounding.

A system that can dynamically compose media elements (such as procedural computer graphics, digital video, or text) to result in new media elements can be said to generate content. The GRIOT system, a result of this dissertation, provides an example of this. It has been used to implement computational poetry that generates new narrative poems with varying particular concepts, but fixed themes, upon each execution. This generativity is enabled by the Alloy system, which implements an algorithm that models key aspects of Gilles Fauconnier and Mark Turner’s theory of
conceptual blending. Alloy is the first implementation of Joseph Goguen’s algebraic
semiotics approach to blending. (Fauconnier & Turner, 2002; Goguen, 1998) This
research also contributes to the theory of algebraic semiotics by developing a
blending-based notion of style.

Semantics-based interaction means here that (1) media elements are structured
according to the meaning of their content, and (2) user interaction can affect content of
a computational narrative in a way that produces new meanings that are constrained by
the system’s author. “Meaning” in this case indicates that the author has provided
formal descriptions of domains and concepts pertinent to the media elements and
subjective authorial intent.

Meaning can also be reconfigured at the level of narrative discourse. The
formal structure of a computational narrative can be dynamically restructured, either
according to user interaction, or upon execution of the system as in the case of
narrative generation.

Strong cognitive and socio-cultural grounding here implies that meaning is
considered to be contextual, dynamic, and embodied. The formalizations used derive
from, and respect, cognitive linguistics theories with such notions of meaning.
Furthermore, the notion of narrative here is not biased toward one particular cultural
model. Using semantically based media elements as a foundation, a cultural producer
can implement a range of culturally specific or experimental narrative structures.
Chapter 1 Introduction

1.1 Goals and Perspectives

Imagination, computation, and expression blend in the goal of inventing new narrative forms for new media. New narrative forms may become lost to history as mere curiosities, or they may revolutionize and invigorate our possibilities for communicating our thoughts, feelings, dreams, social constructions, and even our senses of selves to one another. New media technologies, likewise, may fade to grey obsolescence, or they may become the basis for new conventions sending its artists and theorists scrambling to discover its language – a language that allows one to manipulate the characteristics of the medium to convey a range of expressive work ranging from functional data to evocative fictions. The hope here is to offer theory and technology as a step on the path toward the revolutionary and convention-establishing fates, while leaving behind the disappointments of the lost and obsolete.
The basis for this hope is a novel and integrated perspective on creative imagination, computer science, and cultural expression.

While this dissertation offers specific advances in computational narrative, perhaps its central contributions are theoretical and methodological. Unified by the overarching goal of expression and a central concern for narrative, this research tightly integrates approaches from computer science, cognitive science, and artistic production such that each of these areas mutually informs the others:

1) **Imaginative Cognition | Computer Science**
   Computer science allows for formalization, precise modeling, implementation, and experimentation with recent cognitive science theories that understand cognition as distributed, embodied, and situated.

2) **Computer Science | Artistic Production**
   Artistic production drives computational solutions and enables critical technical practices by introducing subjectivity and human-centricity.

3) **Artistic production | Imaginative Cognition**
   Cognitive science investigation of imagination provides scientific accounts of how narrative imagining, metaphor, conceptual integration, and related phenomena are fundamental to human thought, and of how imaginative fiction maps on to real human conditions.
The goals and approaches outlined above are important because I believe that computing can contribute to understanding and expressing nuances of the human social condition, a domain traditionally investigated by the humanities. Narrative is central to human communication. However, many forms of computer-based interactive narrative have failed so far to capture the popular consciousness. Computer gaming has produced many examples of popular narrative experiences, and both computer gaming artifacts and theory of computer gaming deeply inform the work here. However, many computer games are not primarily narrative, and even those that are often do not feature technical support for allowing user interaction to dynamically generate narrative meaning (though players undoubtedly generate their own narrative interpretations of gameplay). I believe that an approach that takes seriously culturally based forms of narrative imagination and its expression, at the same time as considering the (cognitive) scientific underpinnings of that imagination and its expression, and looking critically at the ways that computational media can allow for manipulation of those statements at the semantic level, holds great promise for the development of effective computational narratives.

This dissertation does not define a singular eventual form of computational narrative such as virtual reality, hypertext, or narrative computer games. Instead, the starting point is meaning and narrative cognition. I propose a model to allow an author to represent her or his subjective meanings, and I theorize how these meanings can interact with knowledge bases of media assets, data structures for representing a wide range of discourse structures, and an engine to orchestrate interactive events. This basis allows the author of an interactive narrative to utilize a combination of
semantic data structures, algorithmic blending of those structures, a reconfigurable model of narrative structure, and a subjective (but less easily manipulable by computational means because semantics are not explicitly represented) knowledge base. My approach starts by considering what meaningful content an author has to express, and how structure and interaction can enable expression of that content.

This approach encourages an author to utilize whatever computational means necessary in order to convey her or his particular narrative. At the same time, it also allows an author to create constructive spaces in which user interaction or content production are the core expressive aspects of the work. This point of view contrasts to those that start from imagining one futuristic form of computational narrative as a “holy grail,” for example, allowing users to manipulate objects and interact with characters within a narrative virtual world. The theoretical bases proposed here are sufficiently general as to be used to articulate models of immersive virtual worlds, computationally generative poetry, narrative computer games, and other related forms.

The view of narrative and poetry taken in this dissertation can be captured by integrating the following quotations:

Poetics deals with problems of verbal structure, just as the analysis of painting is concerned with pictorial structure. Since linguistics is the global science of verbal structure, poetics may be regarded as an integral part of linguistics. (Jakobson, 1960)

… models of language and linguistic organization proposed should reflect what is known about the human mind, rather than purely aesthetic dictates such as the use of particular kinds of formalisms or economy of representation … (Evans, Bergen, & Zinken, 2006)

Poetry, narrative, and their analyses are seen as within the domain of inquiry of linguistics (if not the structuralist model of Jakobson’s time). Linguistic phenomena
are seen as observable manifestations of human cognitive processes. (Fauconnier, 2000) Since I am interested in developing new media forms and genres that may or may not possess all of the characteristics of narrative or poetry from strictly literary traditions, my view is necessarily broad. I begin with cognitive perspectives on narrative imagining, and its component structures and processes, as basic semantic “building blocks.” Poetry is taken to be the wide domain of verbal art, which is not given status greater or less than other linguistic phenomena. Indeed, a major insight of the cognitive linguistics enterprises is that the same cognitive processes involved in everyday common sense reasoning also underlie literary creativity.

This does not mean that I ignore the cultural specificity of narrative and poetic forms or the entire history and insight to be gained by literary theoretic or other approaches to narrative. Rather, I invoke cognitive definitions in order to admit a wide range of specific influences and insights. The following is intended to roughly distinguish this approach from related approaches in the area of narratology (the study of narrative). This discussion is meant to provide an orientation for readers unfamiliar with this field.

There is no consensus on definitions of terms such as “story” or “narrative.” N. Katherine Hayles summarizes the situations well in (Hayles, 2005) as follows:

The binary established by the Russian formalists of fabula and sjuzhet followed the distinction, dating back to what Gerard Genette calls the “pre-history” of narratology, of story and plot. Mieke Bal defines fabula as the “material or content that is worked into a story,” while the story itself is “defined as a series of events.” This definition is more or less echoed by Genette, Seymour Chatman, Shlomith Rimmon-Kenan, and others. The sjuzhet, on the other hand, is the order of appearance of the events in the work itself, or [as] Chatman, quoting Boris Tomaskevsky, puts it, “how the reader becomes aware
of what happened.” Different theorists transpose these older terms into binaries with slightly different inflections, including story and discourse (Chatman), fabula and story (Bal), and story and narrative (Genette), who sees both these terms deriving from a third term, narrating. As these examples show, there is no consistent terminology...

Within cognitive science, Mark Turner has described stories as “dynamic interactions of events, actors, and objects,” presenting a quite minimal model of narrative aimed at capturing the skeletal pattern underlying narrative imagining. (Turner, 1996) This does seem to parallel the minimal literary theoretic definition provided by Manfred Jahn in (Jahn, 2005), in which stories are sequence of events involving characters (‘events’ including “both natural and nonnatural happenings”). Jahn also presents a minimal definition of narrative as “story presented via media,” as in Genette’s terminology in the Hayles quotation above. As a broad frame, this dissertation shall accept Turner’s view of narrative, with the realization, however, that it is quite a general description narrative when analyzing the rich conventions, innovations, and meanings of any specific cultural form. Under such view of narrative, the examples of computational poetry discussed here are also considered to be narrative, though the underlying technology is not limited to producing narrative discourse.

It is informative to distinguish how this cognitive linguistics perspective on narrative affects the framework for analysis. Jahn describes two major approaches to narrative analysis as “discourse narratology,” which “analyzes the stylistic choices that determine the form or realization of a narrative text,” and “story narratology,” which
“focuses on the action units that ‘emplot’ and arrange a stream of events into a trajectory of themes, motives and plot lines.” (Jahn, 2005) David Herman describes another approach called “cognitive narratology,” in which “both narrative theory and linguistics should instead be construed as resources for cognitive science. Or rather, narratology, like linguistics, can be recharacterized as a subdomain of cognitive-scientific research. From this perspective, both language generally and narrative specifically can be viewed as tool-systems for building mental models of the world.” (Herman, 2000) From the perspective of cognitive linguistics, cognitive narratology would focus on elaborating, for example, projection of action-stories onto event-stories, how these arise stories arise from image schema, conceptual metaphor and blending, and related cognitive phenomena described later in Section 2.2.

“Computational narratology,” in the sense employed occasionally by the author and Joseph Goguen, is deeply influenced by the cognitive linguistics approach to narrative, and provides techniques from computer science to provide a language to describe cognitive insights and to implement narrative effects of the type analyzed in discourse narratology.

This approach reflects a paradigm shift in cognitive science away from elegant formal views of language that are not necessarily cognitively grounded (or even plausible), toward grounding in empirical results regarding cognitive phenomena underlying language. This computational approach to narrative also represents a paradigm shift in computer science. The computational narrative system presented in this dissertation does not attempt to implement a model of creativity (human or computer). Instead, it aims to provide a language for representing the human author’s
expressive intentions along with subjective and constructive possibilities for user interaction and content generation. That is, the goal is to enable a human author to construct computational narratives featuring semantic underpinnings informed by cognitive science, and all of the potential for interpretively meaningful interaction and generation that such an underpinning provides. Human narrative imagining, conceptual blending, and related processes allow for user and author to negotiate meanings. The underlying computational structures an algorithms merely exploit regularities of such human cognitive processes, but do not simulate them.

1.2 Contributions

The research described here consists of theoretical and technical support for, and implementations of, narrative computational media works with the following characteristics: generative content, semantics based interaction, reconfigurable narrative structure, and strong cognitive and socio-cultural grounding.

Generative content means that the system should be able to compose new content from media elements (in the forms of text, computer graphics, audio, or other media) on the fly. The GRIOT system, one of the results of this effort, provides an example of such generation. (Harrell, 2005a, 2005b, 2007) It has been used to implement computational poetry that generates a new narrative poem with fixed themes but varying metaphors upon each execution. This computational poetry is implemented on the basis of several knowledge bases entered by the author of a
computational poem. The author constructs a knowledge base of domains (sets of typed binary relations), a narrative structure implemented as a new type of automaton called a “probabilistic bounded transition stack machine” or “Event Structure Machine,” a knowledge base of textual templates organized according to narrative type and featuring variables that can be replaced with generated content. (Goguen & Harrell, 2007b; Harrell, 2006) A key aspect is that the author defines the semantic rules that determine how content is generated.

Generativity is enabled by the Alloy system. Central to Alloy is an algorithm that implements key aspects of Gilles Fauconnier and Mark Turner’s theory of conceptual blending; it is also the first implementation of Joseph Goguen’s algebraic semiotics approach to blending (in turn, the first formal mathematical approach to blending). (Fauconnier & Turner, 2002; Goguen, 1998) Alloy takes in a data structure called an “input diagram” consisting of data structures representing Fauconnier and Turner’s conceptual spaces and mappings between them. Alloy returns an output diagram consisting of a “blended” conceptual space that integrates elements from conceptual spaces in the input diagram, and mappings to the blended conceptual space. Alloy, however, is not considered to model human cognitive processing. It is seen as a system to allow a researcher to formally describe conceptual spaces empirically determined or hypothesized by cognitive science researchers and to explore structural combinations of the conceptual spaces. As such, it is not intended as an “artificial intelligence” project, but rather as a system that allows researchers to invoke the utility of computational experimentation when appropriate, while respecting the limitations of computational models for describing human conceptual
processes. The formalization used in Alloy and GRIOT is based in Joseph Goguen’s algebraic semiotics, which uses algebraic semantics and specification to describe sign systems.

Semantics-based interaction means that (1) media elements are structured according to the meaning of its content, and (2) user interaction can affect content of a computational narrative in a way that produces new meanings that are constrained by the system's author. “Meaning” in this case means that the author has provided formal descriptions of domains and concepts (as described above) pertinent to the media elements and authorial intent.

Reconfigurable narrative structure means that the formal structure of a computational narrative can be dynamically restructured, either according to user interaction, or upon execution of the system as in the case of narrative generation. The “Event Structure Machine” is the component that affords reconfigurable narrative structure. (Goguen & Harrell, 2007b; Harrell, 2006)

Strong cognitive and socio-cultural grounding here implies that despite the use of formal descriptions of semantic concepts, meaning is considered to be dynamically constructed, distributed among our selves and our artifacts, situated in social contexts, and embodied in our physical experiences. (Fauconnier & Turner, 2002; Hutchins, 2000; Lave & Wenger, 1991; Varela, Thomson, & Rosch, 1991). The formalizations used also are inspired by, and respect, cognitive linguistics theories with such notions of meaning, and in practice a system author must be sensitive to these issues to effectively utilize the technical framework provided. Furthermore, the notion of narrative here is emphatically not biased toward one particular cultural model. The
architecture is layered so that, atop a technical layer that provides an authoring platform, a cultural producer can implement her or his desired model of narrative (whether Labov’s empirically based narrative structure of personal experience from sociolinguistics, or Gerald Vizenor’s narrative theory of Native American trickster tales). (Harrell, 2005a; Labov, 1972; Vizenor, 1989)

Toward all of these ends, the work here also contributes to the theories of algebraic semiotics and cognitive semantics by developing a blending-based notion of style and some mathematics in order to extend the algebraic semiotics model to allow for generativity and the specific applications described above.

1.3 Dissertation Outline

A challenge, and boon, of an interdisciplinary dissertation is the fact that such work invites readers from differing disciplinary backgrounds to consider it. While a boon, of course, is that the work may be influential and interesting to people of varying intellectual traditions, one challenge is that necessary background for one audience may prove to be either rudimentary, advanced, or auxiliary for another. Worse, each tradition carries with it a set of values, methods, and goals which may be challenging to integrate, and at worst may be incommensurable.

The challenge is handled in this dissertation by defining an overarching set of goals and presenting individual results on the path toward those goals in the language of the discipline to which the results are most relevant (e.g., the description of the Alloy algorithm is presented within the tradition of computer science and
At times, a hybrid discourse is constructed because a natural alignment between the goals of multiple disciplines is formed (e.g., the work in computational poetry speaks to an integrated framework of creative writing, literary theory, cognitive science, and computer science). At other times, it is necessary to clearly articulate the relationship between disciplines and that clear articulation becomes a new theoretical result (e.g., clearly describing the role of computational modeling for scientific experimentation with conceptual blending theory). At other times again, it is important to offer an introductory account of an entire field of study because practitioners from one field may have had no previous exposure to the field (e.g., some practitioners from engineering may have had little exposure to semiotics theories).

This dissertation attempts to balance all of these concerns into a coherent and compelling text. A gentle request is made to the reader to put aside disciplinary biases and submit to the possibility of integrated interdisciplinary goals. The read will be more pleasurable, and in that light I believe the contributions here can be most sensitively received and evaluated.

Bearing in mind the interdisciplinary relationships described above, Chapter 2 of this dissertation describes the theoretical foundations of the dissertation’s contributions. Section 2.1 and its subsections describe various approaches to narrative ranging from sociolinguistics to experimental literature, and including various forms of narrative in computational media. By presenting this overview of approaches and antecedent computational narrative forms, Section 2.1 comprises a review of literature that influences the approach here and a vision of how they are integrated into a coherent research project.
Section 2.2 presents ideas from the enterprise of cognitive linguistics within the field of cognitive science that are central to the research problem here. This account is aimed primarily at readers outside of the field of cognitive linguistics and helps to situate the theories developed within that enterprise in relation to earlier theories. The account of cognitive linguistics is also aimed at relating the aims of the enterprise to issues in linguistics that have proven influential in computer science and artificial intelligence. To better situate the empirical foundations and theoretical import of the specific cognitive linguistics theories, Subsection 2.2.1 describes a high level view of the philosophical commitments and historical context of the cognitive linguistics enterprise. Subsection 2.2.2 describes methods used in cognitive linguistics. Subsection 2.2.3 presents an overview of the influential theory of metaphor. Subsection 2.2.4 presents an overview of conceptual blending theory, one of the central theoretical influences on the research here. Conceptual blending theory is a young and developing theory and, as such, is not without its controversies. Subsection 2.2.5 presents some of the central controversies and criticisms of the theory and offers some remarks on them. Since one of the results of this dissertation is an algorithm that implements aspects of conceptual blending, Subsection 2.2.6 presents a review of other work that applies computational techniques to conceptual blending and related areas in cognitive science.

Section 2.3 presents Joseph Goguen’s theory of algebraic semiotics. (Goguen, 1998) Together we pioneered the use of his theory toward the purpose of computational narrative. Indeed this theory forms the bridge between cognitive science and computer science used here. It also forms the bridge between computer
science and socio-cultural and artistic meaning, so it is one of the most crucial aspects
of the theory and technology underlying all of the results of this dissertation.

Algebraic semiotics is used to formalize conceptual blending theory, but just as
important is the philosophy underlying algebraic semiotics, i.e., formalization is used
only as a descriptive (and implementable) tool. Language and meaning themselves are
not viewed as formal by nature, and this work respects the insights of the cognitive
linguistics enterprise in which human meaning is considered to be embodied,
distributed, and situated. Formalization alone does not offer any greater cognitive
plausibility to research results. This balance between formal methods that are
necessary in computer science and deep understanding of the socially, culturally,
bodily, and cognitively constructed nature of meaning is a reason why the algebraic
semiotics approach is desirable for computational narrative applications. This section
is not merely a literature review, but includes new results by Joseph Goguen and the
author.

Chapter 3 presents the Alloy system, including its knowledge (data)
representation structures in Section 3.1, and its algorithm for conceptual blending in
Section 3.2. Section 3.3 presents an account of the limitations of the system and how,
in part, these limitations reflect the natural limitations of computational methods as
tools for cognitive linguistics research. In this regard, the algorithm itself, and the
theoretical discussion of its relationship to human meaning construction, are both
presented as important results.

Chapter 4 presents the GRIOT system for implementing computational
narratives. Section 4.1 formally describes the problem of narrative construction
within the framework of algebraic semiotics as the blending of structures. **Section 4.2** presents a detailed view of the GRIOT architecture. **Section 4.3** describes various levels of use including multiple levels authorship, readership, performance (and uses that exist in-between all three) enabled by GRIOT. **Section 4.4** presents several examples of computational poetry as case studies implemented with GRIOT. Each of these case studies raises unique theoretical issues and introduces particular implementation advances. **Section 4.4** concludes with remarks toward evaluating the “success” of the case studies, understanding that engineering and scientific models of success may not apply to aesthetic works.

**Chapter 5** concludes the dissertation with a recapitulation of the results and contributions, remarks on how the approach here broadly can lead to new accounts of “style” in aesthetic and cultural expression, and reflection on the possibilities and future directions left to explore along the trajectory begun here.