Cutting Through Uncertainty with Glaive

Pratibha Agarwal
pragarwal@ucdavis.edu

Charlie Ann Fornaca
cafornaca@ucdavis.edu

Sadaf Arshad
sarshad@ucdavis.edu

Kyle Mitchell
kdmitch@ucdavis.edu

Avery Wood
awood@ucdavis.edu

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Abstract

In this paper, we present a conceptual model of uncertainty that draws upon narratological studies of uncertainty within literature. We then describe our attempt to implement a particular mode of uncertainty, the mode of multiplicity, within an extended version of the narrative planning system Glaive. We offer background information on Glaive and narrative planning systems like it, introduce a murder mystery domain and problem definition within which to test our model, and show the solution that Glaive provides to our story problem. Ultimately, we conclude that there is a conflict between Glaive's search-based algorithm and the necessity for stochasticity inherent to our model of uncertainty.

Keywords: narrative planning system, computational storytelling, narratology, Glaive, uncertainty

1 Introduction

Narrative planning systems and theoretical frameworks attempt to resolve the tensions between authorial control and character agency in computationally generated stories. A centralized decision-making agent that guides the story to a desired conclusion often results in unbelievable or inconsistent agents in juxtaposition to how they may have been initially portrayed. However, a decentralized story generation system in which agents are given freedom to act consistently often results in violating established authorial constraints of the story.

Glaive is a narrative planner developed by The Narrative Intelligence Lab in the Computer Science Department at the University of Kentucky that allows the pursuit of authorial constraints such that each constraint is solved in terms

of multi-agent goals and action plans to reach those goals. Some agents' plans might fail thus creating conflict. Yet if the conflict allows for an authorial constraint to be satisfied, it is deemed a valid plan.

Another narrative planner developed by the same laboratory, Sabre, differs from Glaive in that characters can hold beliefs that inform their intentions. For example, if a character wants to buy a potion, and believes that there is a merchant at the market who wants to sell them a potion, the character will go to the market. Sabre, however, lacks representation of uncertainty with regards to beliefs. Extending the previous example, would the character plan something different if they were not sure that the merchant was at the market? If they were uncertain of this fact, perhaps the character might try visiting the merchant's house first.

People and characters with established beliefs rarely operate with complete conviction. Giving room for uncertainty enables narrative planning systems to produce more interesting stories and less predictable characters. While we initially desired to work with Sabre, accessibility was limited such that we decided to work with an extended version of Glaive that supports beliefs and intentions. In this work, we take inspiration from multidisciplinary studies in conceptualizing a model of uncertainty. We then explore if and how this model can be implemented within Glaive via custom problem and domain definitions; our attempts to do so, along with the domain and problem definitions, are described in our methodology section. Finally, we offer some insights as to why we believe narrative planning systems like Glaive may not be suitable for such a model of uncertainty, as reported in our results section.

2 Background

2.1 Defining and Representing Uncertainty

To help define uncertainty, we will refer to the person experiencing a narrative in any suitable form as the consumer (a player, a reader, etc.) and we will refer to the system or person creating the narrative as the author.

When uncertainty is structured, it elicits intense emotions in the consumer. Uncertainty can measure the focusing characteristics of ethical disturbances when applied to a narrative. Uncertainty does this by decoupling the ethics from the content proposed by the author.

The writer and Harvard professor, Namwali Serpell, identifies several writing structures that each contain a total of seven different modes of uncertainty [3]. The structure of mutual exclusion can give rise to oscillation and enfolding to represent uncertainty. The structure of multiplicity can create adjacency and accounting. Repetition can form vacuity and synchronicity. Finally, any number of the previously mentioned structures and modes can give a sense of flippancy. By identifying modes of uncertainty along with the structures that facilitate their classification, we can further codify how we create uncertainty in a narrative.

Using mutual exclusion as a structure to set-up oscillating or enfolding uncertainty will educe a sense of ambiguity and contradiction to the narrative. Mutual exclusion can be reduced to "either/or" grammar or logic. Breaking down mutual exclusion further into oscillation and enfolding can deepen our understanding on how these modes of uncertainty might play out in a narrative.

Oscillation causes the consumer to ask themself "did this really happen?" or "was this all a dream?" Ghost stories, hallucinations, vision tales, and insanity narratives fall under this category. Examples of oscillation as a mode of uncertainty include the films Donnie Darko (2001) and Fight Club (1999). Paranoia can also be an element of oscillation. A consumer may be locked into the character's perspective while the author's language grants the consumer double vision external to the character. Paranoia offers the consumer some measure of distance from the character.

The modern definition of "enfolding" comes from the mid-twentieth century and means "to render useless through damage." As a mode of uncertainty in narratives, enfolding is a term used to summarize the phrase "to spoil the ending". Enfolding changes the experience of the narrative upon re-reading. A narrative can have two or more different endings depending on whether the consumer is reading it for the first time or for a subsequent time. This mode of uncertainty reinforces the indignation that a consumer feels as if it were composed of separable facts. The consumer feels that they will only truly know a narrative if they consume it. This particular mode seems to be more of a meta-mode where the narrative itself, the words or unfolding of the events, do not actually change. One could even say that the events are for certain. The uncertainty comes from the experience of the consumer knowing the outcome or ending as they re-consume the narrative. Things that had gone unnoticed are now noticed. There is an expectation to fulfill in the end.

Using multiplicity as a narrative structure characterizes the presentation of conflicting viewpoints within a given narrative community about some event, object, or character. The language to illustrate multiplicity can be simplified as "both/and". Multiplicity plays into the subjectivity and variability of perception.

Multiplicity works well for portraying uncertainty because it causes the consumers' experience to compete with the reality of what is presented in the narrative media. These scenes can be diegetic which means that authored scenes are solely in the context of the narrative. Often we see postmodern and contemporary fictional narratives implement multiplicity by reinforcing undecidable conflicts rather than more interesting variations between multiple views upon the same event. This can be simply characterized as the phrase, "shades of gray".

To break down multiplicity further, two modes of uncertainty can be identified: adjacency and accounting. Adjacency allows perspectives and stories to coexist with each other without establishing a hierarchy or even a resolution. Similar to mutual exclusion and more specifically oscillation as a mode of uncertainty, adjacency can evoke doubt about "what really happened" by telling the same story by multiple characters. Accounting can be described as a mode

of uncertainty that portrays commitment to conflict that ultimately produces an agnostic and participatory consumer experience. Values, meanings, and interpretations augment and collide with each other.

Repetition as a narrative structure can cut deep furrows of uncertainty into the consumer. Repetition can come in many flavors such as deja vu, compulsion, the uncanny, synchronicity, and simulacra. Notably in gothic works, we often see repetition take the physical form of doppelgangers and mirrors. Repetition boasts a complex relationship between sameness and difference when used as a literary structure.

Meaning is extracted by the difference between repetitive events, states, or modes. Extreme repetition disturbs our sense of reality as both consumers and living people. As repetition intensifies, it also undoes itself in the process. Repetition can destabilize events, temporal continuity, and even meaning itself so that consumers can begin to wonder if the events in a narrative really happened at all to the characters. Uncertainty will increase as repetition confounds the originality, integrity, and continuity of characters, objects, and events. Words become meaningless if they are repeated enough times. Repeated actions performed by characters make the consumer lose the sense of time contained within the context of the narrative.

Once again, Serpell [3] breaks down the introduced structure into a couple of modes of uncertainty. This time she highlights vacuity and synchronicity as modes of uncertainty within repetition.

Vacuity is a hollow but intense uncertainty. It bears the emptying of meaning under repetition of certain themes such as violence, overindulgence, or consumerism. It can be illustrated as "blanking out" of cognitive capacity, numbness, or the unnerving effect of dissociation. Other examples are when sex becomes a void of emotional or human connection or when a character is experiencing violence without being overwhelmed. Vacuity allows us as consumers to contemplate horrors and reflect on how we respond.

Synchronicity builds up on the experiential effect that repetition creates over time. It is the organized repletion of repetition such as moving without resistance, clumsiness, or mess. It could also be to totally agree or to have operations between characters in absolute sync. Endless rehearsals are a motif of synchronicity such as in films like Black Swan (2010) and Whiplash (2014). Synchronicity can occur when material elements are juxtaposed in sync with inmaterial operations or themes without the narrator or the character seeming to notice.

Synchronicity is harmony but in an uncanny way. It gives a sense that space and time is collapsing in a story. There are meaningful parallels but the meaningfulness isn't always attributed to any particular cause. Instead, because it is meaningful, it is not random but because it is synchronous, it is meaningful. Synchronicity inspires our human desire to see patterns and can produce a feeling of the unavoidable.

Sometimes abstract reactions in tandem with each other can illustrate synchronicity such as portraying both horror and laughter together. This relationship brings us to the final mode of uncertainty which stands alone: flippancy.

Finally, flippancy is described as attaining the height of emotional intensity in the formal experiment contained within a narrative. It is a combination of all of the aforementioned modes. Flippancy is the lack of respect or seriousness in a situation.

Additionally, a consumer of media may embody an author or narrator as part of a naturalization process when the author makes their presence felt in the text. It is natural to trust the narrator when consuming a story. What if the third person narrator appears unsure of the facts or events in the context of the story? What if it becomes unclear whether the author or the character is telling the story? [4]

What happens if a narrator discloses their unreliability and might have a good reason to be unreliable? The consumer will have to decide if the narrator is telling the story to the best of their ability. The consumer is less likely to doubt the narrator in this case. The consumer might feel that they have a role in interpreting the narrative in the case of an uncertain narrator. [4]

Finally, In narratology, there is a difference between "uncertainty" and "unreliability". Uncertainty is a different form of unreliability. When the narrator is uncertain, both parties need to work together to determine the story's truth. [4]

2.2 Narrative Planning Systems

Narrative planning defines given actions that can take place in a story. Such actions have pre-conditions that need to hold true before the condition is fulfilled, effects which become true after the action has taken place that need to hold true, and a set that can be empty of characters that must consent to fulfill the actions [7]. In narrative planning systems the initial state of the world and the author's set of goals are defined that must hold true by the end of the story. Glaive is a planner based on Hoffmann and Nebl's Fast-Forward works created to solve the narrative planning problem, in that it achieves not only the author's goals but also keeps track of the individual goals that characters take on and let go of throughout the story.The Glaive algorithm works by starting off with an initial state of a given problem and taking steps to change the state until the author's goal is reached. The Glaive search space can be thought of as a directed tree; the root is the initial state of the problem and an empty plan [7]. The nodes of the tree presents a given state as well as the plan that is made from the steps taken from the root down to a particular node. Along with keeping track of the current state and plan, the search algorithm of Glaive keeps track of character goals along with the set of steps that remain unexplained. Thus, Glaive reasons how characters reach an agreement when there are multiple consenting characters.

Similar to how other planners work, Glaive heuristics are responsible for its speed. Ware and Young define a heuristic as a function of h(n) which is taken in a given node and calculates how many more steps are required to achieve a desired solution. In the case of Glaive, the heuristic is calculated using the maximum of the estimated value derived from backward reasoning from a character's goal and

forward reasoning from the current state to achieve the author's goals. Glaive uses two graphs to derive this value: plan and goal graphs. Plan graphs consist of layers with propositions and steps whereas goal graphs are directed and layered graphs consisting of composed steps. Glaive: A State-Space Narrative Planner Supporting Intentionality and Conflict research paper evaluates eight narrative planning problems and measures the performance of Fast-Forward heuristics versus Glaive's heuristics. It was found that Glaive outperformed significantly when using its heuristics in all 8 problem cases. Thus, it can be concluded that Glaive calculates an accurate heuristic by reducing its branching factors and works very quickly at solving non-trivial problems.

Narrative planning can be seen as a sequence of cause and effect events taking place pertaining to a time that are constructed together to tell a story. Thus, the artificial intelligence paradigm is commonly used for story planning due to its data structures and algorithms used for giving the reasoning about the story. A paper by Ware (2014) looks at a plan-based model that uses conflict for narrative reasoning and generation. Ware explains that conflict is an essential element of stories and to build this plan-based model other computational systems that dealt with conflicts were used. More specifically, the model utilizes a Partial Order Causal Link planning framework to include intentionality and conflict that can provide insight into why actions an agent intended to take but failed to do so [6]. Using the plan-model it was found that Conflict Partial Order Causal Link (CPOCL) limits the expressiveness of plan. In addition, the paper presents an evaluation of CPOCL using two human subject experiments and found the model can be used to predict human reasoning in static textual narratives [6]. However, evaluating CPOCL further it Warn points out that the model applicability is limited due to its speed. Due to such constraints, Warn evaluates Glaive algorithm to test out the model on a suite of narrative planning problems. The findings show that players are able to recognize thwarted plans that are generated by Glaive much more than ones that are generated by authors at design time [6]. As such, the Glaive frameworks distribute the power evenly among the author, audience, and the artificial intelligence machine.

3 Methodology

3.1 Using Extended Glaive

To implement uncertainty, we used the extended Python version of Glaive. This version of Glaive contains a belief-intention compiler that processes input from the Planning Domain Definition Language (PDDL) into a form that can be used by an intentional planner such as Glaive. The specific type of PDDL used is Belief and Intentional PDDL, and differs from standard PDDL in that it supports second order predicates. Predicates are properties of the universal pre-conditions (character, place, thing, or idea) that define how these pre-conditions interact with one another. In example, "has" is a predicate that relates a character to a thing, the character has the thing. Second order predicates, i.e. (intends

?character ?predicate) and (believes ?character ?predicate), relate characters to other truths (or potential truths) of the problem space. An example being (believes tom (at merchant market)), where Tom is shown believing that the merchant is at the market. These second order predicates support actions that a character can try and fail at, causing a separate set of failure effects. The input into this compiler is further divided into domain, problem, solution, and Glaive (optional) arguments. The optional Glaive arguments are there for specifying the path to the Glaive.jar file as well as choosing locations to store outputs from Glaive. For the purpose of this project these did not need to be changed. The solution argument is similar in that it only specifies the location where the plan from the Belief-Intention compiler is stored. The domain and problem inputs are significantly more complex as they both take PDDL files.

The problem input outlines the initial beliefs of the characters and the starting point of the world. This is also where the goal of the problem is stated. In example, we want our character, Tom, to get a potion from a merchant. The goal is for Tom to have the potion and is defined as (has Tom potion), where has is the predicate denoting Tom getting the potion. Similarly in this file we define Tom as believing the merchant has the potion. Since our research is focused on implementing uncertainty into Glaive, the problem input is where the most of our ideas are realized as this is where character beliefs are established.As will be discussed in the following section, we follow the seven modes of uncertainty [3] to determine what our character beliefs should be.

The domain input defines the non-standard predicates and actions that the system can use to solve the problem posed by the problem initialization. As an example, the predicate "has" needs to be defined. It is defined as such, (has ?char - character ?thing - thing) which effectively translates to a character has a thing. This procedure can be followed for any number of predicates of this form that an author desires. After the predicates are defined, the basic actions to be taken in the solution are defined. Each action is coded similarly to a function in that it will have parameters (character, place, thing, etc) that it will then use in conjunction with the previously defined predicates to accomplish the specific action.

3.2 Implementing Uncertainty: Multiplicitous Domains and Problems

The most suitable mode of uncertainty to our current exploration is the mode of multiplicity, mentioned in our conceptual model of uncertainty above. Given that we are using Glaive, a system that imposes using only boolean logic to describe the world, we define uncertainty as holding multiple beliefs about a single object to be true. To resolve this uncertainty, all but one belief about the object must be proven false. Only then will the uncertain character become certain. This, of course, entails that an uncertain character actually tries to disprove their own beliefs. In terms of Glaive, this meant crafting both a domain and problem definition with objects, operators, and predicates that support this method of resolution. Coding such domains and problems became the bulk of

our work.

We wished to implement our model of uncertainty in a fitting domain that could showcase multiplicitous beliefs of characters. As such, we focused on defining a domain and problem that, when fed to Glaive, tell the story of a murder mystery. The setup for our story is rather simple: A character named Hannah gets a new neighbor with a dark secret. Hannah decides to visit her new neighbor, but unwittingly stumbles upon this individual engaging in less-than-legal behavior. Caught by surprise, the neighbor decides to kill Hannah with a weapon found inside their house. Following this event, they are driven by two goals: hide the weapon in another location, and flee both the scene of the crime and wherever they have hidden the weapon. Enter the police, who learn that Hannah has gone missing. The police have multiple goals: find Hannah, find the murder weapon, suspect a character who may have committed the crime, and solve the murder.

Our domain consists of three types: characters, places, and things. We have several predicates defined, ranging from basic predicates like "a character has a thing" or "a character is at a place" to more domain-specific predicates like "a character has committed a murder" or "a character has found a body." Of particular importance are the predicates tied to character intentions: the neighbor commits the murder, the neighbor hides the weapon, the neighbor flees the scene, the police find Hannah's body, the police find the murder weapon, and the police solve the murder. These predicates are used in the goal definition of our problem file to more logically order the story. In addition to the predicates, we have defined basic operators like "move a character from one place to another place" and more domain-specific operators like "commit a murder" or "search for weapon." It is important to note here that the operators defined for both the murderer and the police characters are nondeterministic. For example, the murderer can hide the weapon in any location that is not the crime scene, or the police can search any location for the victim provided they believe the victim is there (regardless of the ground truth).

In our problem, we have several locations established: the neighbor's house, Hannah's house, the house of Hannah's uncle, a storage facility, and a police station. Additionally, we have a cast of characters that includes: the neighbor, Hannah, Hannah's uncle, and the police. It follows that the police have multiple leads for each of their goals. To their knowledge, at least at the outset, Hannah could be anywhere, the murder weapon could be anywhere, and anyone could have done the deed–not excluding Hannah. Each goal can be represented by a multiplicitous collection of beliefs, e.g. the police believe that Hannah is at Hannah's house, the police believe that Hannah is at the neighbor's house, and so on. This representation could be easily achieved by extended Glaive in a first-class way, and thus was the focus of our study. With these multiplicitous beliefs, we hoped to show that Glaive could use the nondeterministic operators defined to provide a variety of ways this story could play out. For example, in one execution of this story, the neighbor might hide the knife in the uncle's house; then, the police may investigate the uncle's house first, find the knife there, and suspect him wrongly. In another version, the neighbor might hide

the knife in Hannah's house; upon finding it there, the police begin to suspect that it may have been a suicide. As we will discuss in the following section, this assumption was proven false.

4 Results and Discussion

We fed the above domain and problem definition to extended Glaive and received one particular telling of the story, which is illustrated in Figure 1. The story plays out in a semi-reasonable way, with the one exception being that the police move to the neighbor's house even before the murder takes place. Beyond this quirk, Glaive's solution does the following: the neighbor murders Hannah at the neighbor's house; the police find Hannah's body at the neighbor's house; the neighbor moves to Hannah's house and hides the weapon there; the neighbor flees the scene to the uncle's house; the police move to Hannah's house and find the weapon there; the police begin to suspect the neighbor given the evidence they have gathered; and finally, the police solve the murder by correctly suspecting the person who committed the murder. On subsequent executions of Glaive, with an identical domain and problem definition, Glaive's solution does not change. There is no room for variation in this story without first modifying the domain or the problem.

We can, however, explain why Glaive provides the above solution. Why, for example, does the neighbor, who has just murdered Hannah, flee the scene to the home of Hannah's uncle, of all places? The operator defined for "the murderer flees the scene" has the murderer choose a place provided that the place is neither the crime scene (where the murder took place) nor the place where the murderer hid the weapon. In our problem definition, we establish our list of places in this particular order: Hannah's house, the uncle's house, the neighbor's house, the storage facility, and the police station. If the crime takes place at the neighbor's house, and the murderer hides the weapon in Hannah's house, the first place in that list that meets the criteria for the operator is indeed the uncle's house. Even though the operator is not defined in a deterministic way, the algorithm used to find the optimal solution is based on search–whatever it finds first that meets the restrictions will be chosen. This problem at the algorithmic level indicates that what we wished to achieve at the outset of this study is not possible–at least not without extensive additions or modifications to the core algorithm, which lies outside the scope of our allotted plan and time.

To better frame our results, we return to the question that motivated this work in the first place: Why do we want to model and implement uncertainty in narrative planning systems? We reiterate here that adding uncertainty to such a system should result in less predictable character behavior, and thus make stories a little more interesting. To go a step further, such a system of uncertainty should treat character behavior stochastically; this is perhaps the most reliable way to elicit a sense of unpredictability. We are inclined to believe that, even with the additional support of beliefs and intentions in Glaive, there is an inherent conflict between the search space optimization techniques that

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kdavi@DESKTOP-NBL4VE7 MINGW64 ~/belief-intention-compilation (kyle-dev)
$ python belief_compiler/belief-intention-system.py paper_domains/murder-domain.
pddl paper_domains/murder-problem.pddl TestFiles/
The Glaive Narrative Planner, by Stephen G. Ware
Reading domain..... [Domain "murder-bompiled": 12 operators, 0 axioms]
Reading problem..... [Problem "murder-bompiled" in Domain "murder-bompiled
"]
Creating state space..... [State Space: 726 literals, 1440 steps, 0 axioms]
Planning with no time limit and no search limit.
A solution was found after 0.039 seconds; 13 nodes were visited; 189 were genera
ted.
(define (plan murder-bompiled-solution)
  (:problem murder-bompiled)
  (:steps (move-from-place-to-place_success police police-station neighbor-house
)
          (murder_success neighbor hannah neighbor-house knife)
          (search-for-victim-in-place_success police hannah neighbor-house)
          (move-from-place-to-place_success neighbor neighbor-house hannah-house
)
          (hide-the-murder-weapon_success neighbor knife hannah-house)
          (flee-scene_success neighbor hannah-house uncle-house)
          (move-from-place-to-place_success police neighbor-house hannah-house)
          (search-for-weapon_success police knife hannah-house)))
Solution written to file.
Compiled Domain
java -jar resources/glaive.jar -d TestFiles/glaive-dom.pddl -p TestFiles/glaive-
prob.pddl -o TestFiles/glaive-plan.pddl
Glaive took 0.48888 seconds
```

Figure 1: Glaive solution of the murder mystery domain and problem.

Glaive imposes and what we would call true uncertainty. Glaive may offer nondeterminism in the sense that a goal state may be reached through any number of paths through the search space provided those paths exist; however, for any problem and domain whose initial state and operators remain unchanged over multiple executions of Glaive, the system will always provide an identical solution–the optimized solution according to the chosen heuristic. As such, Glaive may not be the right system within which to implement a stochastic model of uncertainty–at least in a first-class way.

After drawing upon domain knowledge stemming from literary studies for this particular endeavor, we cannot help but to wonder how much interdisciplinary research goes into the development of a tool such as Glaive. After completing the background research that we felt was necessary to kickstart our implementation of uncertainty in Glaive, it had become apparent that the mapping between what we can represent via literary modes and structures to what is attainable through a tool like Glaive is not quite as straightforward as we had hoped. Our suggestion going forward to anyone with interest in computational storytelling and narrative planning tools would be to include domain experts in the literary fields when developing such a system.

5 Appendix

5.1 Acronyms and Definitions

PDDL-Planning Domain Definition Language
Heuristic-A function of $h(n)$ which is taken in a given node and calculates how many more steps are required to achieve a desired solution.

5.2 Contributions of Team Members

Technical implementation of Glaive-Pratibha Agarwal, Kyle Mitchell
Research code intermediate-Avery Wood
Literature review background research:

- Defining and representing uncertainty-Charlie Ann Fornaca
- Narrative planning systems-Sadaf Arshad

Presentation slides-Charlie Ann Fornaca

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