Reaching Cognitive Consensus with Improvisational Agents

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Abstract

A common approach to interactive narrative involves imbuing the computer with all of the potential story pre-authored story experiences (e.g. as beats, plot points, planning operators, etc.). This has resulted in an accepted paradigm where stories are not created by or with the user; rather, the user is given piecemeal access to the story from the gatekeeper of story knowledge: the computer (e.g. as an AI drama manager). This article describes a formal process that provides for the equal *co-creation* of story-rich experiences, where neither the user nor computer is in a privileged position in an interactive narrative. It describes a new formal approach that acts as a first step for the real-time co-creation of narrative in games that rely on the negotiated shared mental model between a human actor and an AI improv agent.

Introduction

The field of interactive narrative has trended towards a focus on advancements in the *processes* used for supporting interactivity and player agency in narratives (e.g. drama managers or strongly autonomous systems) and on the *knowledge* that those processes operate on (e.g. story beats, planning operators, story graphs, etc.). The use of this knowledge is typically intended to increase user agency within an unfolding story. Though techniques that involve planning (Cavazza, Charles, and Mead 2002; Young et al. 2004; Riedl and Young 2010), drama managers (c.f. Roberts and Isbell 2008), or other novel techniques like theory of mind (Si, Marsella, and Pynadath 2005) or conceptual blending (Harrell 2005; Zhu and Harrell 2008) have focused heavily on the tradeoffs between user agency and authorial control, few systems have considered how user agency can involve the contribution of story content on the part of the user. Interactive narrative systems tend to focus on *exposing* the user to story content (e.g. exposing a reader to pre-written chapters in a *Choose Your Own Adventure* book) as opposed to actively *creating* content with other humans or AI agents (i.e. improvisation in a theatre game or role playing game).

We can use this observation of the difference between story exposure and creation to revisit the canonical definition of user agency, which can be thought of more specifically as *surface agency* and *deep agency*. Surface agency refers to the common view of how much control a user perceives they have in a narrative environment (Thue et al. 2011). Deep agency, on the other hand, can be used to describe tangible control that a user has both on the creation and ordering of story content. Deep agency in an interactive narrative involves the process of *story co-creation*, a mutual process where neither the user nor computer is in a privileged position in an interactive narrative. While deep agency has been touched on in a handful of systems (Crawford, 2004; Fairclough, 2004; Zhu, et al., 2011), this view of player interactivity in a narrative experience has been vastly underexplored.

This paper presents our ongoing work on developing a co-creative interactive narrative system called the *Digital Improv Project*, which is heavily influenced by our socio-cognitive studies of improvisational actors (Magerko et al., 2009). This work focuses on providing an experience akin to that of an improvised scene, where a player interacts with an AI actor (via gestural input with the Microsoft Kinect) to create a wholly unique scene. The gestural input provides the challenge of dealing with ambiguous communication (much like is seen in the real world) about scene details that provides situations where the AI and human actor may have different models of scene elements (called a *cognitive divergence*). This phenomenon, due to the use of a naturalistic interface like the Kinect, forces us to consider the procedural knowledge involved in "getting on the same page" between actors (i.e. building a *shared mental model* about scene elements). This paper discusses how we formally use situational calculus to represent the process of *cognitive convergence* to create shared mental models between humans and agents and how agents deal cognitive divergences with their fellow actors.

Related Work

Most interactive narrative systems focus on surface agency, which privileges the computer in controlling story content. While this is not necessarily a negative approach to interactive narrative, it has been the primary focus in the field, leaving the space of co-creative experiences largely untouched. Some systems have focused on drama management as a way of managing surface agency, such as Façade (Mateas and Stern 2006) or the work done by (Arinbjarnar and Kudenko 2008). Planning has also been used as another way to manage surface agency in interactive narrative systems, such as Crystal Island (McQuiggan et al. 2008), IN-TALE (Riedl and Stern 2006), Mimesis (Thomas and Young 2007) and work done by Porteous, Cavazza, and Charles (2010). Despite planning being considered a useful tool that provides an engaging narrative experience to the user, it still suffers from an authoring bottleneck and low (surface) user agency in terms of the mutual construction of the story.

Thespian agents (Si, Marsella and Pynadath 2005) behave based on models of emotions and social normative behaviors in addition to having explicit author specified plot design goals, but for the agents to decide on an action they are offered bounded look-ahead policy. Moreover Thespian agents have recursive beliefs about self and others, e.g. my belief about your belief about my goals, which forms a “theory of mind". Although Thespian agents employ theory of mind they cannot act in the absence of explicit goals and an explicit agreement between the agents and each other. Thus Thespian agents cannot be used in improvised / co-creative narrative as this kind of narrative lacks the presence of explicit goals, which consequently implies the difficulty in using planning which requires the presence of unmistakable goals.

All of the systems described above have tried to find the suitable tradeoff between authoring and narrative generation versus user agency. However, as stated earlier, they tend to focus on surface agency with no consideration of how the user could experience deep agency in a co-creative setting. Consequently, it can be seen that the techniques described above are likely not promising enough when it comes to on-the-fly story improvisation. Improvisation is a narrative experience that emerges from how individuals form experiences in their minds. Improv actors have deep agency where their interactions on stage plus any starting material or constraints given to them by the audience solely contribute to the improvised scene. Improvisers typically negotiate a shared mental model on stage only through these diegetic actions on stage rather than with explicit communication about the model (Magerko, Dohogne and DeLeon 2011). Their shared mental model encapsulates the actors’ beliefs about themselves and about the other actors’ mental models. Consequently, they negotiate their shared mental models until a common ground status is reached, which is called *cognitive consensus*. The following in this paper describes our formal efforts for representing improv strategies for reaching cognitive consensus about story elements (e.g. negotiating who is portraying what kind of character) in a step towards supporting deep agency in co-creative story systems.

Improvisational Acting

Improvisational acting (improv), our exemplar for studying processes and background knowledge that support deep agency in interactive narratives, is a creative group performance where actors co-construct stories on stage in real time. Improvisational performances are typically constrained by sets of game rules that guide how a scene should be functionally performed (e.g. “only speak in questions”) (Spolin 1963; Johnstone 1999). Scenes additionally often involve some semantic priming (e.g. audience suggestions) to help improvisers interpret events, formulate beliefs, and build and repair their mental models. Improv actors negotiate their shared mental model solely through presentations to the ongoing scene rather than with explicit communication about the model (Fuller and Magerko 2011).

Shared mental models (SMMs) are a cognitive construct, maintained through the process of reaching cognitive convergence, that incorporates the development of mutual beliefs from the team members’ individual mental models until a common mental model is reached by the team members, either explicitly or implicitly. Research on shared mental models for enhancing team decision making suggests that shared mental models enable communication and mutual understanding; the stronger the shared mental model the better tasks are accomplished (Yen et al. 2006).

Our empirical studies of improv actors have yielded data that clearly maps the collaborative process of improvising scenes to the team-oriented process of building shared mental models (Magerko et al., 2009; Magerko, Dohogne and DeLeon 2011). In an improvised scene, each improviser starts to act and build an individual mental model based on how he observes the world around him. However, improvisers often execute actions that can be perceived or interpreted in many different ways (Magerko, Dohogne and DeLeon 2011). Actors may misinterpret dialogue because of confusion (e.g. mishearing what another actor said). Physical motions can often be interpreted as one of many semantic actions. For example, if one actor holds their fists one on top of the other and moves them from side to side, another actor could interpret this as either raking, sweeping, churning butter, or even dancing. To handle the ambiguities of these presentations, improv actors' mental models must deal with inexact information continuously when improvising a scene with others. In the following subsections, we briefly present the stages improvisers deal with during a scene. As is related below, the process of dealing with inexact information in an improvised scene can be described as *observing divergences* (i.e. noticing conflicting mental models), *repairing* those divergences (i.e. attempting to converge on a shared mental model), and *accepting* the repair (i.e. seeing the result of the attempted repair).

Observing Cognitive Divergences

The ambiguous actions executed on stage and the ease with which improvisers can misinterpret them can cause an improviser to develop a mental model that differs from others' models. The state where improvisers' mental models differ from each other is called *cognitive divergence*[1]. Through the process of *cognitive convergence*, improvisers may repair their divergent mental models to reach a state of consensus where everyone agrees on the shared mental model (i.e. "getting on the same page") (Fuller and Magerko 2011). This is a commonly reoccurring problem, where improvisers are continuously negotiating elements about a scene's introduction, conflict, and conclusion (Sawyer, 2003; Fuller and Magerko 2011).

Divergence Repair Strategies

Improvisers employ different repair strategies to deal with divergences as they occur (Fuller and Magerko 2011). Repair strategies are either *other-oriented* or *self-oriented*. Other-oriented repair strategies aim to affect someone else's mental model through presenting new concepts (presentation) or correcting divergences (clarification). Self-oriented repair strategies try to align one's mental model with others' by learning more about the others' models. For instance, an actor may communicate an uncertain scene detail so that other actors may confirm it (*verification*). Alternatively, the actor may introduce new, vague information to the scene in order to observe how the other improvisers react, hoping that this will reveal some disambiguating information (*blind offer*). Repair strategies help the agents update their mental models and approach consensus.

Acceptance of Repairs

Acceptance is an intentional response to a repair attempt (Fuller and Magerko 2011). After an attempted repair, there are two possibilities that might occur. The first is that the repair fails or goes unnoticed and therefore does not resolve the current divergence. Subsequently, divergence continues or a new one takes its place. The other possibility is that the repair is met with *agreement* (Clark and Schaefer 1989).

Repair Strategies and Situational Calculus

Improv actors utilize repair strategies when a cognitive divergence exists about a particular scene element (e.g. the character of one of the actors is unclear) in order to attempt to reach cognitive consensus. The choice of a repair strategy depends on the state of the agent's mental model in a specific frame of the world. For example, if the agent has high confidence in his mental model and low confidence in his partner's mental model, the agent would choose to do an action that is highly related to his portrayed character trying to amend his partner's mental model (clarification repair strategy). Due to the dynamic nature of the agents' shared mental model, situational calculus is appropriate for the representation of repair strategies. Situational calculus is a logic formalism, first introduced by John McCarthy (1963), which was designed for representing and reasoning about dynamic domains.

We have created a formal model that can enable intelligent agents in interactive narratives to work in an ambiguous environment where users and agents are collaboratively contributing information to the scene that is often unclear due to the ambiguous nature of human communication (e.g. using gestures with a Kinect). In the following we present the special domain fluents used in our model to represent the repair strategies used by the agents to accomplish cognitive consensus. These rules are mainly triggered when a cognitive divergence is encountered.

Independent predicates and functions:

Holds (p, S)—fluent p is true in situation S;

Do (a, S)—the situation that results from performing action a in situation S; S_1= Do (a, S)

Poss (a, S)—action a is executable in situation S.

Fluents that describe the state of the world:

BEL ( ) – whether an agent has a specific belief about a relation or a proposition or not

COM ( ) – whether the agent committed or not

SMM_Bel ( ) – whether the agent_x and agent_y share the same belief or not

Function fluents that describe the state of the world:

CONF ( ) returns the degree of confidence of agent_x about some knowledge

ICON () returns the iconicity of one piece of knowledge to another

Actions that can be performed in the world:

PRES ( ) – provides the agent presents something

VER ( ) – provides the agent verifies something

BOFF ( ) – provides the agent offers something

Successor state axioms:

Each axiom is about a fluent not an action; f Holds in a state after performing an action a.

[1]We currently ignore models built between the actors and the audience, though divergences can exist between them as well.

f true afterwards $\leftrightarrow$ an action made f true $\vee$ f true already and no action made f false

$\forall$ a, s, f (Holds f (do a S) $\Leftrightarrow$ (causes a s f $\vee$ Holds f s $\wedge \neg$ cancels a s f))

Repair Strategy: Presentation

Presentation is a common repair technique that demonstrates what an improviser believes to be true. In other words, presentation introduces new information to the scene that relates to an individual's mental model. In knowledge disparity games such as Party Quirks, presentation typically manifests as a "hint". Presentation is other-oriented (i.e. attempts to change another's model instead of their own) in intent that can be represented in situational calculus as follows:

Action precondition axiom:
Poss (PRES ($agent_x$, p), S) $\leftrightarrow$ Holds (Bel ($agent_x$, p),S) $\wedge$ Holds (ICON (p, $agent_x$, joint_activity)=high, S).

The above axiom states that $agent_x$ can possibly present proposition p if $agent_x$ holds the belief p and p is highly iconic to both $agent_x$ and the joint_activity in situation S.

Action effects axiom:
Poss (PRES ($agent_x$, p), S) $\rightarrow$ COM ($agent_y$, p)

The above axiom states that after $agent_x$ presents proposition p in situation S, $agent_y$ is committed to respond to p.

Successor state axiom:
Holds (BEL ($agent_x$, p, S), Do (PRES ($agent_x$, p), S)) $\leftrightarrow$ causes (PRES ($agent_x$, p), S, BEL ($agent_x$, p, S)) $\vee$ (Holds (BEL ($agent_x$, p, S)) $\wedge$ $\neg$ cancels (a , S, BEL ($agent_x$, p, S)) $\wedge$ a= PRES ($agent_x$, p))

This axiom states that it holds that $agent_x$ believes p after presenting p that is because either presenting p causes $agent_x$ to believe p or $agent_x$ already believes p and presenting p does not change this belief.

Repair Strategy: Clarification

Clarification is another other-oriented repair technique used by improvisers to correct any misunderstandings or misinterpretations of information that has already been communicated. It is different from presentation in that it does not introduce any new concepts (unless those new concepts are meant to clarify old ones). For various types of clarification, see (Magerko, Dohogne and DeLeon 2011). Situational calculus rules for perceived clarification are as follows:

Action preconditions axiom:
Poss (CLAR ($agent_x$, p), S) $\leftrightarrow$ Holds (BEL ($agent_x$, is (agentx, Char), CONF),_, S) $\wedge$ CONF=high $\wedge$ Holds (SMM_Bel ($agent_x$, BEL ($agent_y$, is ($agent_x$, Char), $CONF_1$), _,S) $\wedge$ $CONF_1$=low

The above axiom states that $agent_x$ can possibly clarify proposition p if $agent_x$ has high confidence in its character and $agent_x$ holds, in its shared mental model, that $agent_y$ has low confidence in $agent_x$ character in situation S.

Action effects axiom:
Poss (CLAR ($agent_x$, p), S) $\rightarrow$ COM ($agent_y$, p)

This axiom states that after $agent_x$ clarifies proposition p in situation S, $agent_y$ is committed to respond to p.

Successor state axiom:
Holds (BEL ($agent_x$, p, S), Do (CLAR ($agent_x$, p), S)) $\leftrightarrow$ causes (CLAR ($Agent_x$, p), S, BEL ($agent_x$, p, S)) $\vee$ (Holds (BEL ($agent_x$, p, S)) $\wedge$ $\neg$ cancels (a , S, BEL ($agent_x$, p, S)) $\wedge$ a= CLAR ($agent_x$, p))

This axiom states that it holds that $agent_x$ believes p after doing clarification of p that is because either clarification of p causes $agent_x$ to believe p or $agent_x$ already believes p and doing clarification does not change this belief.

Repair Strategy: Verification

Verification is a self-oriented repair technique (i.e. involves an attempt to change one's own model). It occurs when an improviser has an idea of what another's mental model might be; he often communicates his impression to his scene partner(s) in order to verify it. Verification is not always an exact formulation of what an improviser believes. It can also manifest as a statement that is related to a belief that an improviser wants to test for accuracy (i.e. wants to verify). As we only focus on gestural interactions, situational calculus rules focus only on actions as follows:

Action preconditions axiom:
Poss (VER ($agent_x$, p), S) $\leftrightarrow$ Holds (SMM_Bel($agent_x$, BEL (agenty, is ($agent_x$, Char), _), CONF, S) $\wedge$ Holds (SMM_Bel ($agent_x$, BEL ($agent_y$, joint_activity, _), CONF, S) $\wedge$ Holds (SMM_Bel ($agent_x$, BEL ($agent_y$, is ($agent_y$, $Char_y$), _), CONF, S) $\wedge$ CONF=low.

The above axiom states that $agent_x$ can possibly verify proposition p if $agent_x$ has low confidence in $agent_y$ belief(s) about $agent_x$ character, joint activity, and $agent_y$ character (i.e. $agent_y$ mental model) in situation S.

Action effects axiom:
Poss (VER (Agent$_x$, p), S) $\rightarrow$ COM (agent$_y$, p)

The above axiom stated that after agent$_x$ verfies proposition p in situation S, agent$_y$ is committed to respond to p.

Successor state axiom:
Holds (Bel (agent$_x$, p, S), Do (VER (agent$_x$, p), S)) $\leftrightarrow$ causes (VER (agent$_x$, p), S, BEL (agent$_x$, p, S)) $\vee$ (Holds (BEL (agent$_x$, p, S)) $\wedge$ $\neg$ cancels (a , s, BEL (agent$_x$, p, S)) $\wedge$ a= VER (Agent$_x$, p))

This axiom states that it holds that agent$_x$ believes p after doing verification of p that is because either verification of p causes agent$_x$ to believe p or agent$_x$ already believes p and doing verification does not change this belief.

Repair Strategy: Blind Offer

A blind offer (related to the canonical improv offer, which is when an improviser presents a new potential contribution to a scene) is the final self-oriented repair technique. Improvisers use this term to describe when they intentionally introduce new, vague, and poorly defined information. The purpose of this action is for the improviser's scene partner(s) to take the information and expand upon it, using the blind offer as an opportunity to present or clarify their mental model(s). The designed situational calculus rules are as follows:

Action preconditions axiom:
Poss(BOFF (agent$_x$, p), S) $\leftrightarrow$ Holds (Bel (agent$_x$, MM (agentx), low, S) $\wedge$ Holds (SMM_Bel (agent$_x$, MM(agent$_y$), CONF, S) $\wedge$ Holds (BEL (agent$_x$, p), S) $\wedge$ Holds (ICON (p, agentx, joint_activity)=high, S) $\wedge$ CONF=low.

The above axiom states that agent$_x$ can possibly offer proposition p if agent$_x$ has low confidence in its mental and shared mental models and agent$_x$ believes p and p has low iconicity to both agent$_x$ and the joint_activity in situation S.

Action effects axiom:
Poss(BOFF (agent$_x$, p), S) $\rightarrow$ COM(agent$_y$, p)

The above axiom states that after agent$_x$ offers proposition p, agent$_y$ is committed to p in situation S.

Successor state axiom:
Holds (BEL (agent$_x$, p, S), Do (BOFF (agent$_x$, p), S)) $\leftrightarrow$ causes (BOFF (agent$_x$, p), S, BEL (agent$_x$, p, S)) $\vee$ (Holds (Bel(agent$_x$, p, S)) $\wedge$ $\neg$ cancels (a , S, BEL (agent$_x$, p, S)) $\wedge$ a= BOFF (agent$_x$, p))

This axiom states that it holds that agent$_x$ believes p after offering p that is because either offering p causes agent$_x$ to believe p or agent$_x$ already believes p and offering it does not change this belief.

As seen above, situational calculus allows the representation and reasoning of the dynamic nature of improvisation. It has the ability to capture the fuzziness and uncertainty present in this domain due to imperfect communication via gestures. Situational calculus represents the repair strategies as a set of first-order logic formulae along with a situation argument to each non-eternal predicate which allows the agents to recognize cognitive divergence when it occurs and subsequently decide on a suitable repair strategy to use to address that divergence. This model provides the AI agent with the procedural representation of knowledge needed to interact with a human interactor in the presence of ambiguous gesture-based communication. This model serves as an important step in preserving high user agency and improvisational narrative generation simultaneously, particularly within domains that rely on natural interfaces as a way to introduce ambiguity in the communication between user and computer. It is worth noting that the limited space prevents us from providing an example of the logic based implementation of the formalized axioms.

After an attempted repair, an acceptance state follows that identifies if a repair strategy has failed or succeeded. If the repair attempt fails or goes unnoticed this means that the divergence continues or a new one has taken its place. A repair attempt is successful when perceived or true agreement takes place between the interactors (anon). Therefore, acceptance does not necessarily equate to cognitive consensus, but only defines a state that follows a repair attempt. The ideal form of consensus is true cognitive consensus, which is when an improviser correctly accepts another improviser's mental model. It can only be identified through explicit confirmation by all the improvisers originally involved in the divergence (a phenomenon we capture in our group interview data). Cognitive consensus, however, can be partial: it only means that at least one divergence has been resolved.

Discussion

The work presented here is an important step towards deep user agency where the interactive narrative system focuses on procedural knowledge for co-creating story content.

We have focused on the process of dealing with cognitive divergences, which are natural occurrences in any improvised scene. Divergences are often followed by repair strategies that allows improvisers to deal with their mistakes and reach an understanding, using shared mental models as the foundation for their construction of a scene.

The concept of a shared mental model begins to approximate a theory of mind – a model of beliefs about what others believe. Despite in its current state our approach does not capture all of the complexities of a full theory of mind because assessments are only based on degrees of association, the shared mental models proposed in this paper are enough for an improv agent to begin improvising a scene while considering another agent's beliefs. Theory of mind is explored in systems like Thespian, but while it includes subjective beliefs about a user's knowledge and capabilities, but nothing about the user's beliefs about the system.

In order to depict the repair strategies, traditional techniques as planning would fail because of the absence of explicit representation of goals, which are essential in any planning process. On the contrary, situational calculus captures the dynamic and fuzzy nature of improvisation, specifically the reasoning underlying the repair strategies utilized by the improv actors to deal with cognitive divergence. The designed rules are general enough to be employed in other domains that involve ambiguity, such as argumentation (using natural language) or an AI-based dancing game (using gestures). However, transformation to other domains would likely require editing the axioms to suit that new domain. Given the increase in body-sensing inputs for console game interfaces, being able to handle ambiguity in co-creative settings, such as improvised theatre, dancing games, games based on creative practices, etc. will become increasingly important.

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