Telling Non-Linear Stories with Interval Temporal Logic

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Abstract. Authoring a consistent interactive narrative is difficult without exhaustively specifying all possible deviations from the main path of a story. When automatically generating new story paths, it is important to be able to check these paths for consistency with the narrative world. We present a method of describing the structure of a story as a Kripke structure using Interval Temporal Logic. This allows the model checking of each possible telling of the narrative for consistency with the story world, as well as the ability to construct re-usable story components at different levels of abstraction. This is the first step towards building a fully checkable framework for building story components using modal logic.

Keywords: interactive narrative · model checking · modal logic · interval temporal logic · kripke structures

1 Introduction

Agent-based approaches to interactive narrative generation must strike a balance between authorial control (writing a story structure), user agency and agent's actions (allowing characters to fill in the details of a story). One way to overcome this is to allow the author to describe the structure of a story in a way which constrains the available actions of the agents and user. This introduces a problem: if there are multiple paths through a narrative (chosen by user interaction), how can an author describe alternative scenarios without explicitly writing out every single branch of the story? Here we describe the use of Interval Temporal Logic to build narratives as Kripke structures, ensuring a logically consistent story.

1.1 Propp Example: Sausages and Crocodile Scene

As an example, take the classic British puppet show *Punch and Judy*, whose story is one of farcical violence. The common elements of Punch and Judy can be described in terms of Propp's story functions [1]. Here we pick one scene to use as an example: the scene where Punch battles a Crocodile in order to safeguard some sausages.

The corresponding story functions are:

1. Joey tells Punch to look after the sausages (*interdiction*).
2. Joey gives the sausages to Punch (*provision or receipt of a magical agent*).

$$S = \{S_0, S_1, S_2, S_{3a}, S_{3a_1}, S_4, S_{3b}, S_{3b_1}, S_4, S_5\} \quad (1)$$

$$P = \{\texttt{interdiction(A, B, C)}, \texttt{absentation(A)}, \texttt{struggle(A, B)}, \texttt{victory(A)}, \texttt{villainy(A, B)}, \texttt{violation(A, B)}, \texttt{return(A)}\} \quad (2)$$

$$T = \{D, \overline{D}, O, \overline{O}, A, \overline{A}, B, \overline{B}, L, \overline{L}, E, \overline{E}\} \quad (3)$$

Fig. 1. Modal operators

$$S_0 \wedge interdiction(Joey, Punch, Sausages) \wedge \langle B \rangle @S_1 \wedge \langle E \rangle @S_4 \wedge \langle A \rangle @S_5 \quad (4)$$

$$[@S_1]absentation(Joey) \wedge \langle A \rangle @S_2 \quad (5)$$

$$[@S_2]struggle(Punch, Crocodile) \wedge \langle E \rangle (@S_{3a} \vee @S_{3b}) \quad (6)$$

$$[@S_{3a}]victory(Crocodile) \wedge \langle A \rangle @S_{3a_1} \quad (7)$$

$$[@S_{3a_1}]villainy(Crocodile, Sausages) \wedge \langle E \rangle @S_4 \quad (8)$$

$$[@S_{3b}]victory(Punch) \wedge \langle A \rangle @S_{3b_1} \quad (9)$$

$$[@S_{3b_1}]villainy(Punch, Sausages) \wedge \langle E \rangle @S_4 \quad (10)$$

$$[@S_4]violation(Punch, Sausages) \quad (11)$$

$$[@S_5]return(Joey) \quad (12)$$

Fig. 2. Sausages scene with nominals and Interval Temporal Logic

3. Joey leaves the stage (*absentation*).
4. A Crocodile enters the stage and eats the sausages (*violation*).
5. Punch fights with the Crocodile (*struggle*).
6. Joey returns to find that the sausages are gone (*return*).

2 Interval Temporal Logic

In order to model the story with modal logic, we employ Interval Temporal Logic (ITL), composed of the temporal intervals defined by Allen [2] and developed into modal operators by Halpern and Shoham [3]. This allows the expressiveness necessary to describe branching, parallel and nested paths through stories. The operators defined by Halpern and Shoham are (a bar over an operator denotes its inverse):

- $\langle L \rangle / \langle \overline{L} \rangle$ (Later): The interval occurs at some point after another interval.
- $\langle A \rangle / \langle \overline{A} \rangle$ (After): The interval occurs immediately after another interval.
- $\langle O \rangle / \langle \overline{O} \rangle$ (Overlaps): The interval occurs both during and before or after another interval.
- $\langle E \rangle / \langle \overline{E} \rangle$ (Ends): The interval ends at exactly the same time as another interval.
- $\langle D \rangle / \langle \overline{D} \rangle$ (During): The interval both starts and ends inside the duration of another interval.
- $\langle B \rangle / \langle \overline{B} \rangle$ (Begins): The interval begins at exactly the same time as another interval.

In our example, we combine Halpern and Shoham's temporal operators with the possibility ($\Diamond$) and necessity ($\Box$) operators of modal logic. We follow the convention of

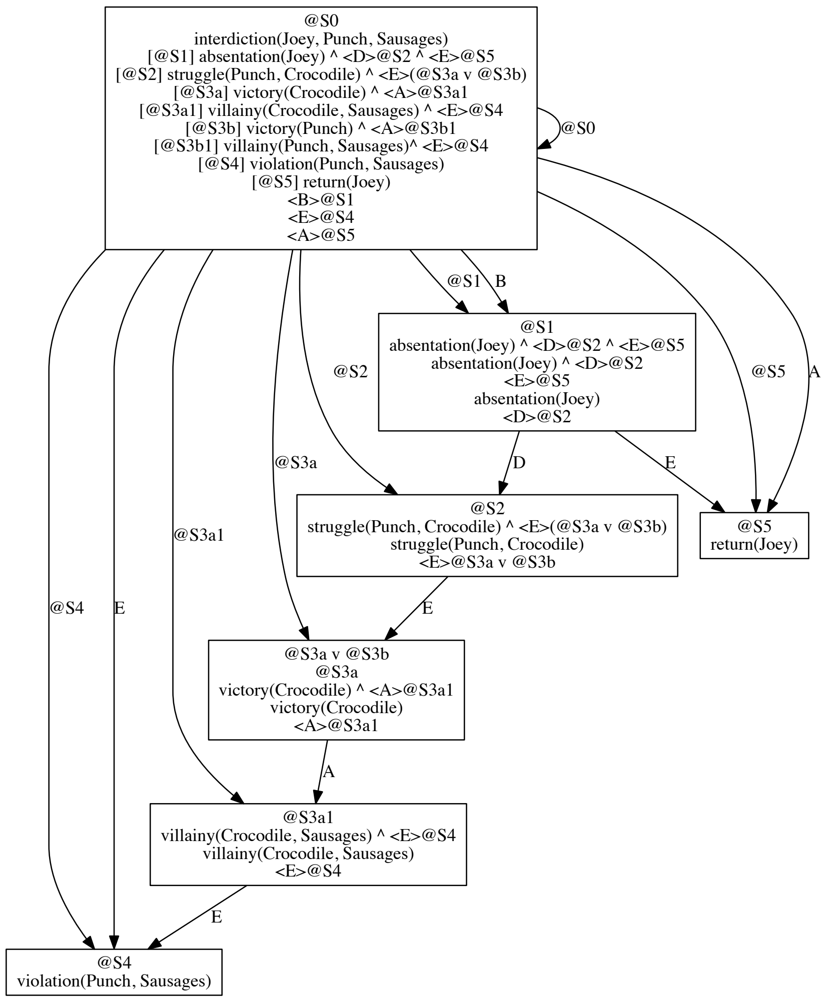

Fig. 3. One model from the sausages scene in LoTREC

writing possibility operators inside angle brackets: $\langle\,\rangle$ and necessity operators within square brackets: $[\,]$.

The example in figure 3 shows the "sausages" scene described in section 1.1, consisting of a set of situations S, containing Propp story functions P. The interval temporal logic operators used in this example are the set T. Figure 1 shows the modal operators we use. A, B and C in formula 2 are variables that represent the characters and objects that appear in the story. We use hybrid logic to identify nodes using the *nominal* operator, shown as @. We can combine this with the Interval Temporal Logic to make statements such as "An absentation starts with state $@S_1$ and end with state $@S_5$." (formula 5).

3 Describing Punch and Judy with Kripke Structures

We use Kripke structures [4] as a method of interpreting the combination of modal logic with Interval Temporal Logic. In order to build and visualise the Kripke structures, we use LoTREC [5], a generic tableaux prover for modal and description logics. It allows the user to build up Kripke models using a domain specific language and display those models in the form of a graph diagram. Using the initial formulas from figure 2 as input, figure 3 shows the model for the case where Punch wins the fight with the Crocodile. One other model exists in this scenario, in which the Crocodile is instead the victor. The example in figure 3 describes a branching story, where either Punch or the Crocodile may win the fight for the sausages. This corresponds to the disjunction in figure 2, formula 6. This leads to the creation of two models: the one in which the Crocodile wins and then goes on to eat the sausages (situation $@S_{3a}$), and the one in which Punch wins (situation $@S_{3b}$).

4 Conclusions and Future Work

This paper demonstrates the use of Interval Temporal Logic for the construction of non-linear narratives. The advantages of this approach are that it enables an author to create re-usable story components at various levels of abstraction. It also allows for the model-checking of a proposed narrative of subset of a narrative to see if it fits with an author's model of a narrative world. From this point, we hope to explore alternative narrative formalisms outside of Propp. Though Propp works well for simple examples, modern media use story motifs that require some stretching of his story functions. We also intend to take our approach outside of the confines of the LoTREC software, into a live interactive storytelling program. In this way, we will be able to evaluate the effectiveness of our approach both in terms of story authoring and believability for the player.

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