Identifying the structure of a narrative via an agent-based logic of preferences and beliefs: Formalizations of episodes from *CSI: Crime Scene Investigation*™

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Abstract. Finding out what makes two stories equivalent is a daunting task for a formalization of narratives. Using a high-level language of beliefs and preferences for describing stories and a simple algorithm for analyzing them, we determine the doxastic game fragment of actual narratives from the TV crime series *CSI: Crime Scene Investigation*™, and identify a small number of basic building blocks sufficient to construct the doxastic game structure of these narratives.

1 Introduction

1.1 General Motivation

As theorists working on narrative-based computer games, we are interested in understanding the relevant structural properties that makes narratives more or less interesting, or more or less interesting for a particular target group, or, in general, to understand our notion of two stories being "essentially the same"

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that human agents seem to be able to grasp easily but which escapes a proper formalization so far.[1]

Any formalization of narratives provides an obvious answer to this most general question: given a formal language to describe narratives, two narratives are "essentially the same" if they are structurally isomorphic in that formal language. Whether the answer given by a fixed formalization is good depends very much on the formal language chosen. If you choose too rich a language, then minute differences between narratives become expressible, and thus the derived notion of isomorphism will fail to identify some narratives as identical even though human readers would think that they are "essentially the same". On the other hand, if your language is not very expressive, then all too many narratives will be considered equivalent by the system.

So, what is the right level of detail that allows us to identify the right notion of isomorphism? Only an empirical investigation of narratives and our willingness to identify them as equivalent will help.

Beyond the obvious general interest in understanding our perception of narratives as structurally equivalent, there are various applications for such an understanding. If we had empirical data on which structural elements tend to make a narrative more interesting, or which structural elements would be more appropriate for certain genres or audiences, we could use this in combination with existing story synthesis engines (e.g., MEXICA [19] or *Façade* [15]; both of which still use human intervention for story creation) for automated story production in computer games.

1.2 This paper

We do not claim that we have a definitive or good answer to our above questions: the formalization given in this paper gives a first approximation based on an agent-language with beliefs and preferences that might be a step towards a more complete description.

In [13], the authors proposed a simple algorithm for analyzing narratives in terms of belief states based on notions of doxastic logic. The algorithm requires focusing on the purely doxastic part of the narratives, i.e., the game structure in which all actions are determined by iterated beliefs about preferences of the agents. Then, the narrative can be analyzed as a perfect information game in which all agents may be mistaken about their iterated beliefs.

Whereas in [13, § 4], the algorithm was used to analyze a fictitious narrative about love and deceit, in this paper, we focus on narratives commercially produced for television broadcasting. In a *descriptive-empirical* approach we investigate their common structural properties based on a formalization in our system, reducing the rich narrative structure of the stories to their doxastic game trees. The empirical results of this paper point towards the possible conclusion

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[1] Cf. the discussions of the notion of "analogy" in the cognitive science literature [22,10]; cf. [11, p. 791–792] for an overview of existing formal models.

that from a large number of possible formal structures, commercial crime narratives only use a very small number of doxastically simple basic building blocks (§ 2.4).

1.3 Related Work and Background.

We are interested in a fragment of the formal structure of narratives, so we aim at ignoring their presentation (i.e., choice of actors, details of dialogue, facial expressions of actors, lighting, cuts, etc.) unless it is relevant for determining the formal structure. In narratology, these components are normally called "story" and "discourse" (alternatively, "фабула"/"сюжет" or "histoire"/"récit") [4]. From now on, we shall use the term "*discourse*" to refer to the presentation of the narrative. The abstraction of a narrative to a part of its formal structure relates our research to the vast literature on "*Story Understanding*"[2] which has made tremendous progress towards analysing and synthetizing narratives:

> "there is now a considerable body of work in artificial intelligence and multi-agent systems addressing the many research challenges raised by such applications, including modeling engaging virtual characters ... that have personality ..., that act emotionally ..., and that can interact with users using spoken natural language." [26, p. 21]

Most of the work on *Story Understanding* goes into far more detail than our formalization, including the *discourse* of the narrative. Especially applications of logic for *Story Understanding* deal with the understanding of the grammatical structure of the *discourse* (cf. [25]). Even models just focusing on the *story*/фабула in general take more into account than our doxastic fragment.[3] In terms of Mueller's "shallow"/"deep" distinction [16, § 1.3], the depth of our formalization is below that of the shallow understanding. Relatively close to our approach are *Story Grammars* [23], invented by Rumelhart inspired by the structuralist investigation of fairy tales by the Russian narratologist Propp [21], the *Story Beats* in *Façade* [15], and Lehnert's *Plot units* [12].

Almost none of these approaches model beliefs and knowledge of agents in an explicit way[4]. A rare exception is the AIIDE 2008 paper by Chang and Soo [3] which is very programmatic and preliminary. The restrictions to doxastically simple building blocks and explicit modelling of theories of mind clearly relates our formalization to work in cognitive science. For these relations, cf. § 5.1.

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[2] There is "a great variety of applications, which differ widely in the way they use, create or tell stories [24]". Cf. [1,17] for surveys, and [6,7,27] for work on interactive story telling ("Interactive story creation ... takes place in role-playing games that can be seen as emergent narratives of multiple authorship. ... Interactive story telling instead relies on a predefined story, a specific plot concerning facts and occurrences. [27, p. 32]").

[3] Cf. Young's characterization of the *story*/*discourse* divide: "A *story* consists of a complete conceptualization of the world in which the narrative is set [32]".

[4] Cf. [31] for a discussion of the lack of modelling of higher order knowledge in artificial intelligence.

1.4 Structure of the Paper.

In §2 of this paper, we shall introduce our system, modified from [13, § 3] to incorporate event nodes (at which no agent is playing) and partial states. We also discuss the basic building blocks of belief structures that we shall later encounter in the analyzed narratives. In §3, we discuss the process of taking an actual narrative and transforming it into a game of mistaken and changing beliefs, focusing in particular about the restrictions that we imposed upon ourselves by the choice of our formal framework. Finally, in §4, we then present the formalization of six narratives from the first four episodes of the TV series *CSI: Crime Scene Investigation*™ in which we can see that the eight doxastic building blocks from § 2.4 are enough to formalize all narratives. In § 5, we summarize the findings of the paper, connect them to phenomena in cognitive science about iterated beliefs (§ 5.1), and discuss future directions (§ 5.2).

2 Definitions and fundamental structures

2.1 Definitions

We give a short version of the definitions from [13, § 3]. As opposed to the discussion there, we shall explicitly use *event nodes*, i.e., nodes in which none of the agents makes a decision, but instead an event happens. Structurally, these nodes do not differ from the standard *action nodes*, but beliefs about events are theoretically on a lower level (of theory of mind[5]) than beliefs about beliefs.

Let I be the finite set of agents whom we denote with boldface capital letters. We reserve the symbol $\mathbf{E} \in I$ for the event nodes. If $\vec{\mathbf{P}} = \langle \mathbf{P}_0, ..., \mathbf{P}_n \rangle$ is a finite sequence of agent symbols, we write $\vec{\mathbf{P}}\mathbf{P}$ for the extension of the sequence by another player symbol $\mathbf{P}$, i.e.,

$$\vec{\mathbf{P}}\mathbf{P} := \langle \mathbf{P}_0, ..., \mathbf{P}_n, \mathbf{P} \rangle.$$

A tree T is a finite set of nodes together with an edge relation (in which any two nodes are connected by exactly one path). Let $\mathtt{tn}(T)$ denote the set of terminal nodes of T, and for $t \in T$, let $\mathbf{succ}_T(t)$ denote the set of immediate T-successors of t. The **depth** of the tree T is the number of elements of a longest path in T, and we denote it by $\mathrm{dp}(T)$.

We fix I and T and a **moving function** $\mu : T \backslash \mathbf{tn}(T) \to I$, where $\mu(t) = \mathbf{P}$ indicates that it is $\mathbf{P}$'s move at node t. If $\mu(t) = \mathbf{E}$ we call t an **event node**, otherwise we call it an **action node**. We call total orders $\succeq$ on $\mathbf{tn}(T)$ **preferences** and denote its set by $\mathcal{P}$. A map $\succeq : I \to \mathcal{P}$ is called a **description**. We call functions

$$S : T \times I^{\leq \mathrm{dp}(T)} \to \mathcal{P}^I$$

states, interpreting the description $S(t, \varnothing)$ as the **true state of affairs** at position t. If $S(t, \vec{\mathbf{P}})$ is one of the descriptions defined by the state S, we interpret $S(t, \mathbf{P}\vec{\mathbf{P}})$ as player $\mathbf{P}$'s belief about $S(t, \vec{\mathbf{P}})$.

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[5] Cf. §§ 2.4 and 5.1.

2.2 The analysis

Given a tuple $\langle I, T, \mu, S\rangle$, we can now fully analyze the game and predict its outcome (assuming that the agents follow the backward induction solution). In order to do this analysis, we shall construct labellings $\ell_{S_{\vec{\mathbf{P}}}} : T \to \mathsf{tn}(T)$ where $\ell_{S_{\vec{\mathbf{P}}}}$ is interpreted as the subjective belief relative to $\vec{\mathbf{P}}$ of the outcome of the game if it has reached the node t. For instance, $\ell_{S_{\mathbf{A}}}(t) = t^* \in \mathsf{tn}(T)$, then player $\mathbf{A}$ believes that if the game reaches t, the eventual outcome is t^*.

The labelling algorithm If t is a terminal node, we just let $\ell_U := t$ for all states U. In order to calculate the label of a node t controlled by player $\mathbf{P}$, we need the $\mathbf{P}$-subjective labels of all of its successors. More precisely: if $t \in T$, $\mu(t) = \mathbf{P}$ and we fix a state U, then we can define ℓ_U as follows: find the U-true preference of player $\mathbf{P}$, i.e., $\succeq = U(t, \varnothing)(\mathbf{P})$. Then consider the labels $\ell_{U_{\mathbf{P}}}(t')$ for all $t' \in \mathsf{succ}(t)$ and pick the $\succeq$-maximal of these, say, t^*. Then $\ell_U(t) := t^*$. Concisely, $\ell_U(t)$ is the $U(t, \varnothing)(\mu(t))$-maximal element of the set $\{\ell_{U_{\mu(t)}}(t')\,;\, t' \in \mathsf{succ}(t)\}$.

Computing the true run of the game After we have defined all subjective labellings, the true run can be read off recursively. Since our labels are the terminal nodes, for each t with $\mu(t) = \mathbf{P}$ and S, there is a unique $t' \in \mathsf{succ}(t)$ such that $\ell_{S_{\mathbf{P}}}(t') = \ell_S(t)$. Starting from the root, take at each step the unique successor determined by $\ell_S(t)$ until you reach a terminal node.

2.3 Partial states, notation, and isomorphism

Note that in actual narratives (as opposed to narratives invented for the purpose of formalization, such as the narrative in [13, § 2]), we cannot expect to have full states. Instead, we shall have some information about agents' preferences and beliefs that is enough to run the algorithm described in § 2.2. If $\mathcal{P}^{\mathrm{p}}$ is the set of partial preferences (i.e., linear orders of subsets of $\mathsf{tn}(T)$) and $\mathrm{PF}(X, Y)$ is the set of partial functions from X to Y, then we call partial functions from $T \times I^{\mathrm{dp}(T)}$ to $\mathrm{PF}(I, \mathcal{P}^{\mathrm{p}})$ **partial states**.

In the following, we shall use the letters v_i for non-terminal nodes of T and t_i for terminal nodes. If we write

$$S(v_i, \vec{\mathbf{P}})(\mathbf{P}) = (t_{i_0}, t_{i_1}, ..., t_{i_n}),$$

we mean that in the ordering $\succeq\; := S(v_i, \vec{\mathbf{P}})(\mathbf{P})$, we have $t_{i_0} \succeq t_{i_1} \succeq ... \succeq t_{i_n}$. If in such a sequence, we include a non-terminal node v_i, e.g.,

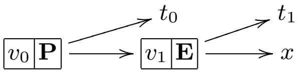
$$S(v_i, \vec{\mathbf{P}})(\mathbf{P}) = (t_j, v_k),$$

we mean that t_j is preferred over *all* nodes following v_k. Similarly,

$$S(v_i, \vec{\mathbf{P}})(\mathbf{P}) = (v_j, v_k)$$

means that every outcome following v_j is preferred over every outcome following v_k. We normally phrase preferences in these terms. When we are drawing our game trees, we represent non-terminal nodes by $\boxed{v_i}\boxed{\mathbf{P}}$ indicating $\mu(v_i) = \mathbf{P}$. In our discussions, we shall assume introspection of all agents, i.e., agents are aware of their own preferences and iterations thereof, even though there is evidence that introspection is not necessarily a feature of human mental processes and awareness [18]. This simplifies notation considerably, and there are no indications that failure of introspection is relevant in any of the narratives we analyzed.

To illustrate this, let us look at the two building blocks *Expected Event* and *Unexpected Event* in Figure 1. In both cases, agent $\mathbf{P}$ prefers outcome t_1 over t_0. Also in both cases, he thinks that the event will produce outcome t_1 (expressed in our language, somewhat awkwardly, as "the event agent prefers t_1 over x"). In $\mathsf{ExEv}(\mathbf{P})$, the latter belief is correct; in $\mathsf{UnEv}(\mathbf{P})$, it is incorrect.



$\mathsf{ExEv}(\mathbf{P})$: $S(v_0, \varnothing)(\mathbf{P}) = (t_1, t_0)$; $S(v_0, \mathbf{P})(\mathbf{E}) = (t_1, x)$; $S(v_1, \varnothing)(\mathbf{E}) = (t_1, x)$
$\mathsf{UnEv}(\mathbf{P})$: $S(v_0, \varnothing)(\mathbf{P}) = (t_1, t_0)$; $S(v_0, \mathbf{P})(\mathbf{E}) = (t_1, x)$; $S(v_1, \varnothing)(\mathbf{E}) = (x, t_1)$

Fig. 1. The basic building blocks $\mathsf{ExEv}(\mathbf{P})$ and $\mathsf{UnEv}(\mathbf{P})$ of *Expected Event* and *Unexpected Event*.

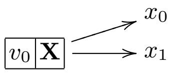
The notion of partial states give an obvious definition of **isomorphism** of two formalized versions of narratives: if $\langle I, T, \mu, S\rangle$ and $\langle I^*, T^*, \mu^*, S^*\rangle$ describes two narratives (where S and S^* are partial states), then they are isomorphic if there are bijections $\pi_0 : I \to I^*$ and $\pi_1 : T \to T^*$ such that

1. π_1 is an isomorphism of trees,
2. $\pi_0(\mathbf{E}) = \mathbf{E}$,
3. $\mu^*(\pi_1(x)) = \pi_0(\mu(x))$, and
4. $S^*(\pi_1(x), \pi_0(\vec{\mathbf{P}}))(\pi_0(\mathbf{P})) = (\pi_1(t), \pi_1(t'))$ if and only if $S(x, \vec{\mathbf{P}})(\mathbf{P}) = (t, t')$ (where $\pi_0(\vec{\mathbf{P}})$ is the obvious extension of π_0 to finite sequences of elements of I).

2.4 Building blocks of narratives

While working with the actual narratives, we identified a number of fundamental building blocks that recur in the investigated narratives and that can describe all of the narratives under discussion. For our reconstruction of the narratives, we need eight building blocks.

These building blocks can be stacked. We use the symbol x in our building blocks to indicate that this could either be a terminal node (at the end of the narrative) or a non-terminal node which would now become the top node of the next stack. If the last node of a building block is controlled by an agent, then the doxastic structure of the building blocks overlaps, as the first node of the second block becomes the last node of the first block. In the case of blocks of length 3, there could also be larger overlap, but we did not find instances of this in the narratives investigated.

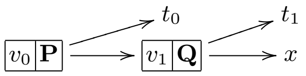


$S(v_0, \varnothing)(\mathbf{X}) = (x_1, x_0)$

Fig. 2. The basic building block $\mathsf{Act}(\mathbf{X})$ of *Action*.

The trivial building blocks are just actions that happen with no relevant reasoning about them (described in Figure 2); these could be called doxastic blocks of level -1. We denote it by $\mathsf{Act}(\mathbf{P})$ for an action by player $\mathbf{P}$. Typical examples are actions where agents just follow their whim without deliberation. Note that being represented by a building block of level -1 does not mean that the *discourse* of the narrative shows no deliberation; in fact, in our investigated narratives we find examples of CSI agents discussing whether they should follow their beliefs (i.e., perform a higher level action) or not, and finally decide to perform the action without taking their beliefs into account. These would still be formalized as blocks of level -1.

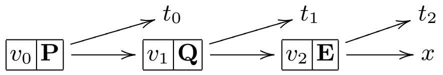
The next level of basic building blocks are those that have reasoning based on beliefs, but not require any theory of mind at all, i.e., building blocks of level 0. The two fundamental building blocks here are *expected event* ($\mathsf{ExEv}(\mathbf{P})$) and *unexpected event* ($\mathsf{UnEv}(\mathbf{P})$), explained before and described in Figure 1.



$\mathsf{ExAc}(\mathbf{P},\mathbf{Q})$: $S(v_0,\varnothing)(\mathbf{P}) = (t_1,t_0)$; $S(v_0,\mathbf{P})(\mathbf{Q}) = (t_1,x)$; $S(v_1,\varnothing)(\mathbf{Q}) = (t_1,x)$
$\mathsf{UnAc}(\mathbf{P},\mathbf{Q})$: $S(v_0,\varnothing)(\mathbf{P}) = (t_1,t_0)$; $S(v_0,\mathbf{P})(\mathbf{Q}) = (t_1,x)$; $S(v_1,\varnothing)(\mathbf{Q}) = (x,t_1)$

Fig. 3. The basic building blocks $\mathsf{ExAc}(\mathbf{P},\mathbf{Q})$ and $\mathsf{UnAc}(\mathbf{P},\mathbf{Q})$ of *Expected Action* and *Unexpected Action*.

Moving beyond zeroth order theory of mind, we now proceed to building blocks that require beliefs about beliefs. There are two such building blocks used in our narratives, *Expected Action* ($\mathsf{ExAc}(\mathbf{P},\mathbf{Q})$), *Unexpected Action* ($\mathsf{UnAc}(\mathbf{P},\mathbf{Q})$), and *Collaboration gone wrong* ($\mathsf{CoGW}(\mathbf{P},\mathbf{Q})$) whose structure we give in Figures 3 and 4. Let us give examples from the investigated narratives from § 4. In the narrative *The severed leg* (cf. Figure 14), agent Willows informs the victim's husband of the state of the investigation. Based on this information, the husband concludes that the current suspect Phil Swelco has murdered his wife and kills Swelco. In the tree in Figure 3, the node t_0 corresponds to "Willows does not give information to the husband" and t_1 corresponds to "Willows is nice to the husband, and the husband does not do anything with the information given to him", whereas x is the actual outcome. Willows believes that the husband prefers t_1 over x and prefers t_1 over t_0 herself.

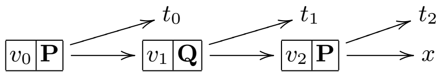


$$S(v_0,\varnothing)(\mathbf{P}) = (t_2,t_0);\ S(v_0,\mathbf{P})(\mathbf{Q}) = (t_2,t_1);\ S(v_1,\varnothing)(\mathbf{Q}) = (t_2,t_1)$$
$$S(v_0,\mathbf{P})(\mathbf{E}) = (t_2,x);\ S(v_0,\mathbf{PQ})(\mathbf{E}) = (t_2,x);\ S(v_1,\mathbf{Q})(\mathbf{E}) = (t_2,x)$$
$$S(v_2,\varnothing)(\mathbf{E}) = (x,t_2)$$

Fig. 4. The basic building block $\mathsf{CoGW}(\mathbf{P},\mathbf{Q})$ of *Collaboration gone wrong*.

The building block *Collaboration gone wrong* is discussed in more detail in § 3.3. Kyle kills James and expects Matt to cooperate in covering up the murder as a suicide. Matt actually helps Kyle in that respect, but it doesn't work, as the autopsy reveals that James did not hang himself (cf. Figure 15).

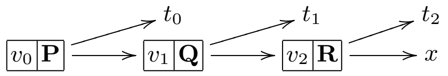
Finally, we move to the building blocks that use second order beliefs. In our narratives, there are only two such building blocks: *Betrayal* ($\mathsf{Betr}(\mathbf{P},\mathbf{Q})$) and *Unsuccessful Collaboration with a Third* ($\mathsf{UnCT}(\mathbf{P},\mathbf{Q},\mathbf{R})$) (given in Figures 5 and 6).



$$S(v_0,\varnothing)(\mathbf{P}) = (x,t_0);\ S(v_0,\mathbf{P})(\mathbf{Q}) = (t_2,t_1);\ S(v_1,\varnothing)(\mathbf{Q}) = (t_2,t_1)$$
$$S(v_0,\mathbf{PQ})(\mathbf{P}) = (t_2,x);\ S(v_1,\mathbf{Q})(\mathbf{P}) = (t_2,x);\ S(v_2,\varnothing)(\mathbf{P}) = (x,t_2)$$

Fig. 5. The basic building block $\mathsf{Betr}(\mathbf{P},\mathbf{Q})$ of *Betrayal*.

To give an example for *Betrayal* from the narrative *Faked Kidnapping* (cf. Figure 12): Chip and Laura plan to fake a kidnapping of Laura in order to get money from Laura's husband. Laura agrees to this, but Chip betrays her and buries her in a crate in the Nevada desert. Notice that we model the joint plan to fake the kidnapping as a sequence of actions by Chip ("proposing the faked kidnapping") and Laura ("agreeing to the faked kidnapping") with outcomes x ("Laura is buried in the desert"), t_2 ("Laura and Chip get the money from her husband"), t_1 ("Laura does not want to be part of the faked kidnapping"), and t_0 ("Chip does not propose a faked kidnapping").



$$S(v_0,\varnothing)(\mathbf{P}) = (t_2,t_0);\ S(v_0,\mathbf{P})(\mathbf{Q}) = (t_2,t_1);\ S(v_1,\varnothing)(\mathbf{Q}) = (t_2,t_1)$$
$$S(v_0,\mathbf{P})(\mathbf{R}) = (t_2,x);\ S(v_0,\mathbf{PQ})(\mathbf{R}) = (t_2,x);\ S(v_1,\mathbf{Q})(\mathbf{R}) = (t_2,x)$$
$$S(v_2,\varnothing)(\mathbf{R}) = (x,t_2)$$

Fig. 6. The basic building block $\mathsf{UnCT}(\mathbf{P},\mathbf{Q},\mathbf{R})$ of *Unsuccessful Collaboration with a Third.*

3 Methodological issues

In the introduction (§ 1.1), we pointed out that finding the right notion of formal representation for narratives is subtle and difficult. If you allow your formal language to be too expressive, then narratives that are considered “equivalent” by human audiences would be separated, whereas if your language is too coarse, then non-identical narratives will be identified.

It is not at all obvious what elements a formalization with the right balance should contain, and we consider this study as part of the endeavour of finding out how much detail we need. Certainly, the system we propose here errs on the side of being too coarse: Already separating *story* from *discourse* is a difficult task, and reducing the narrative to our parsimonious doxastic fragment from §2 requires a number of hand-crafted modelling decisions in order to fit the narratives into our framework. In this section, we discuss a number of issues related to the formalization of narratives in our formal language.[6]

3.1 The sequence of events

The narrative of a TV crime episode rarely proceeds chronologically. Often, it starts when the corpse is found, and then proceeds to tell the story of the detectives unearthing the sequence of events that led to the murder. Sometimes, we see scenes of the past in flashbacks, sometimes, they are being reported by agents. We consider all this part of the *discourse* of the narrative and shall build our structures of actions and events in chronological order. Note that one consequence of this is that our models do not take into account the beliefs of the audience.

3.2 Imperfect or incomplete information

Our model is based on perfect information games with mistaken beliefs. However, in many cases, imperfect or incomplete information can be mimicked in our system by event nodes. Let us give a simple examples:

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[6] The corresponding caveat for Lehnert’s set-up of *Plot units* is the problem of “Recognizing plot units” [12, § 10].

Example. *Detective Miller thinks that Jeff is Anne's murderer while, in fact, it is Peter. Miller believes that Jeff will show up during the night in Anne's apartment to destroy evidence and thus hides behind a shower curtain to surprise Jeff. However, Peter shows up to destroy the evidence, and is arrested.*

The natural formalization would be an imperfect or incomplete information game, but the structure given in Figure 7 can be used to formalize the narrative with **M** representing Miller, **J** Jeff, and **P** Peter. The event node v_1 should be read as "Peter turns out to be Anne's murderer". Nodes t_1 and t_3 are "Peter (Jeff) is the murderer, returns to the apartment and is caught", respectively; nodes t_2 and t_4 are "Peter (Jeff) is the murderer and does not return to the apartment".

We let $S(v_0, \mathbf{M})(\mathbf{E}) = (v_3, v_2)$ (i.e., Miller believes that Jeff will turn out to be the murderer), $S(v_3, \mathbf{M})(\mathbf{J}) = t_3$, $S(v_1, \varnothing)(\mathbf{E}) = (v_2, v_3)$ (i.e., Peter is the actual murderer), and $S(v_2, \varnothing)(\mathbf{P}) = (t_1, t_2)$ (i.e., Peter in fact plans to return to the apartment).

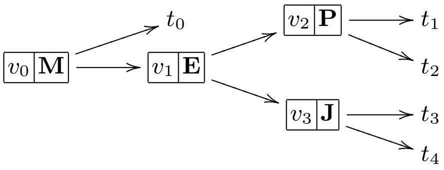

Fig. 7. Mimicking imperfect information by an event node v_1 representing "Peter turns out to be the murderer".

Note that this is not a natural way of modelling imperfect information and future proposals for a formalization would have to deal with this by having a more liberal underlying structure. However, we found that for the chosen narratives from the series *CSI: Crime Scene Investigation*™, the impact on the adequacy of our formalizations was relatively minor.[7]

3.3 Not enough information

As mentioned in § 2.3, we often do not have enough information to give the full state, but only enough of the state that allows us to formally reconstruct the sequence of events and actions. In general, this is not a problem, but sometimes, the narrative is ambiguous on what happened or why it happened, and we are not even able to reconstruct the formal structure without any doubts.

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[7] We suspect that one of the reasons is that "strictly go by the evidence" is one of the often repeated explicit creeds of the CSI members, prohibiting the actors from letting beliefs about facts influence their actions. This has its formal reflection in the fact that the investigators play only a minor rôle in our formalizations, often occurring in event nodes, and rarely making any decisions.

We can give an example from the narratives investigated in § 4: In the narrative *Pledging gone wrong*, we see in a brief flashback scene that (the student) Kyle murders (his fellow student) James. There is a cut, and after that we see that (the student) Matt enters, and Kyle and Matt discuss what to do. The whole scene lasts but a few seconds, and the narrative does not give any clue whether Kyle was expecting Matt to enter or not. There are various different ways to formalize this brief sequence of events as described in Figure 8. In option (a), we consider Kyle's action almost as a joint action: he is murdering James under the (correct and never discussed) assumption that Matt will help him to cover this up. In option (b), we allow Matt to consider not helping Kyle, and then have to model Kyle as correctly assuming that Matt will help him, i.e., $S(v_1, \mathbf{K})(\mathbf{M}) = (x, t_1)$ and $S(v_1, \varnothing)(\mathbf{M}) = (x, t_1)$. In option (c), we now model the entering of Matt after the murder as an event and have to decide whether Kyle expected that this happens or not. One could take the casual tone of Kyle when Matt enters as an indication of lack of surprise, and therefore choose $S(v_1, \mathbf{K})(\mathbf{E}) = (v_2, t_1)$.

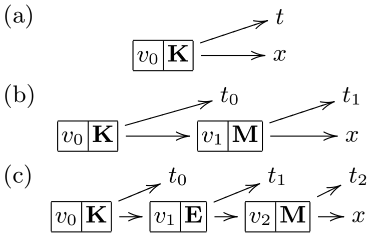

Fig. 8. Three different formalizations of the interaction between Kyle and Matt in the narrative *Pledging gone wrong*.

Which of the three options is correct? We believe that there is no good answer that does not take into account the narrative as a whole. In this particular case (see § 4), we decided to go with option (b), as Matt's decision is explicitly relevant in the last scenes of the narrative when Matt decides to tell the truth. We therefore decided that having a decision node for Matt represents the character of the narrative most appropriately. It is unlikely that modelling decisions like this can always be uncontroversial. The problem of judging what is the natural formalization from the narrative is exemplified once more in § 3.4.

3.4 Relevant information

In § 3.3 we have seen that the narrative sometimes does not allow us to uncontroversially choose the formalization. The dual problem to this is that the *discourse* is often much richer than the structure necessitates. Let us explain this in the following three examples:

Example 1. *John and Sue are a happily married couple when John's old friend, Peter, suddenly shows up after no contact for seven years, inviting himself for dinner. Peter asks John for a large amount of money without giving any reasons. Sue had always disliked Peter, and after Peter had left, Sue urged her husband not to give him any money. After a long discussion, John sighs and agrees to Sue's request. The couple goes to bed, but after Sue is sound asleep, John sneaks into the living room, gives Peter a call and promises to pay. After two weeks, Sue finds out that a large amount of money is missing from their joint bank account.*

Example 2. *... The couple goes to bed, but after Sue is sound asleep, John sneaks into the living room, gives Peter a call and promises to pay. Peter is honestly surprised, as he had not expected this after the rather icy atmosphere at the dinner table. After two weeks, ...*

Example 3. *... John sneaks into the living room, and gives Peter a call, intending to give him the money. However, John did not know how deep in trouble Peter was. After Peter noticed the icy atmosphere at the dinner table, he had taken the elevator to the rooftop of John's apartment building. There, he takes John's call, says "Good bye, John, you were always a good friend", and jumps, before John can tell him that he'll give him the money. John shouts "I'll give you the money" into the phone, but it is too late. When he turns around, Sue is standing behind him.*

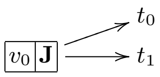

Fig. 9. The tree diagram for all three example narratives about John, Sue and Peter.

The tree structure of all of these narratives is the same, viz. the one depicted in Figure 9. Only the partial states differ slightly. In Example 1, we have $S(v_0, \mathbf{S})(\mathbf{J}) = (t_0, t_1)$ and $S(v_0, \varnothing)(\mathbf{J}) = (t_1, t_0)$ which explains Sue's surprise. In Examples 2 and 3, we have in addition $S(v_0, \mathbf{P})(\mathbf{J}) = (t_0, t_1)$ representing Peter's belief in both narratives that John will not give him the money.

Structurally, Examples 2 and 3 are isomorphic in the sense of § 2.3 and slightly different from Example 1. However, we are sure that most readers will agree that Examples 1 and 2 are closer to each other than to Example 3. This difference does not lie in the event and action structure of the narratives, but in the *discourse*. In Example 3, Peter's disbelief in John giving him the money intensifies the emotional difference between the terminal nodes t_0 and t_1, and thus creates a different feeling. As the modeller, we should have to make the decision of whether we include $S(v_0, \mathbf{P})(\mathbf{J}) = (t_0, t_1)$ in the formalization of Example 2.

4 The six narratives formalized

In this section, we shall give the formal structure of six narratives from the first four episodes of season one of the drama series *CSI: Crime Scene Investigation*™. These four episodes contain ten narratives some of which involved material from other episodes than the first four and others had interlinking events between narratives; we left these unconsidered for the sake of simplicity.[8]

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[8] Cf. [2]. Episode 1, entitled "Pilot", was written by Anthony E. Zuiker and directed by Danny Cannon; Episode 2, entitled "Cool Change" was written by Anthony E. Zuiker and directed by Michael W. Watkins; Episode 3, entitled "Crate 'n Burial",

Trick roll (episode 1; agents victim, **V**, Kristy Hopkins, **K**)

> A prostitute, Kristy Hopkins, puts the drug scopolamine on her breasts to knock out her customers and steal their possessions. A victim is found robbed at a crime scene by agent Nick Stokes with a discolouration around his mouth. Shortly afterwards, Hopkins loses consciousness while driving. Agent Stokes connects the two cases and finds a similar discoloration on Hopkins's breast.

Winning a fortune (episode 2; agents Jamie Smith, **J**, Ted Sallanger, **T**)

> Jamie Smith and her boyfriend Ted Sallanger are gambling in Las Vegas. Smith urges Sallanger to continue and Sallanger wins the $40 million jackpot. Shortly afterwards, Sallanger breaks up with Smith, and they have a fight during which she hurts him with a bottle and leaves the apartment. Later on, she returns to kill him with a candlestick. Her return is not properly filed by the key card system of the hotel, so at first the key card records of the hotel seem to confirm her story that she did not return to the room after the fight.

Faked kidnapping (episode 3; agents Chip Rundle, **C**, Laura Garris, **L**, the CSI unit, **U**)

> Chip Rundle and Laura Garris plan to fake a kidnapping and get a ransom from Garris's husband. However, after the staged kidnapping, Rundle turns on Garris and buries her in a crate in the Nevada desert. Based on some dirt on the bedroom carpet, the CSI unit manages to find Garris before she dies. In the meantime, Garris's husband has paid the ransom. When he collects the ransom, Rundle is arrested. Confronted with the facts, Garris does not tell the police that Rundle was the kidnapper, but his voice is matched to the voice of the ransom phone call. The CSI unit decides to investigate further and finds that the evidence is not consistent with a real kidnapping. A blood test confirms that Garris was never drugged and leads to Garris's arrest.

Hit and run (episode 3; agents Charles Moore, **C**, James Moore, **J**)

> The young James Moore kills a young girl in a car accident and flees the scene. The CSI unit finds an imprint of the license plate on a bruise on the body of the victim and traces Moore. Moore's grandfather Charles wants to protect his grandson and claims that he was the driver. The CSI unit finds that the position of the car seat is not consistent with this claim. The grandfather modifies the story and claims that he was the driver at the time of the accident, but after that, the grandson took the wheel as Charles had banged his head during the accident. Further investigation brings forward a piece of tooth that the driver lost during the accident and the CSI unit matches this to James Moore.

The severed leg (episode 4; agents Catherine Willows, **C**, Winston Barger, **W**)

> A female body with a severed leg is found in Lake Mead. Her stomach contents lead the CSI to a restaurant near the lake where it is established that she had dinner with a Phil Swelco. Swelco admits that he was having an affair with the victim. The discussion between the CSI and Swelco is observed by the victim's husband, Winston Barger, who asks how Swelco is related to Wendys death. CSI Willows informs Barger about the state of the investigation. The CSI find the boat and establish that the victim tried to restart the engine, dislocated her shoulder, lost her balance, hit her head, and fell into the water. When the CSI come to Swelco, they find him dead in his house, murdered by Barger who thought he was avenging his wife.

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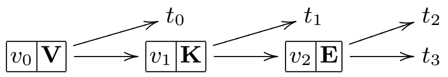
was written by Ann Donahue and directed by Danny Cannon; Episode 4, entitled "Pledging Mr. Johnson", was written by Josh Berman and Anthony E. Zuiker and directed by Richard J. Lewis.

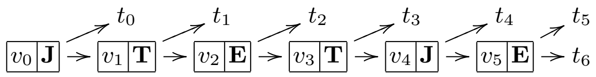
Pledging gone wrong (episode 4; agents James Johnson, **J**, Jill Wentworth, **W**, Kyle Travis, **K**, Matt Daniels, **M**)

> During a pledging ceremony in a fraternity, James Johnson is being bullied by Kyle Travis. The new students have to go to a sorority and get some body part signed by the female students. Johnson asks Travis's girlfriend, Jill Wentworth, to sign his private parts and she agrees. Travis is very angry and asks Johnson privately to allow him to insert a piece of raw liver on a noose. When Travis tries to pull it out, the noose breaks and Johnson chokes to death while Travis watches. Matt Daniels enters and is convinced by Travis to cover up the murder. They stage Johnson's death as a hanging suicide. However, the autopsy reveals that the death was not death by hanging, and the piece of raw liver is found. Travis and Daniels change their story and tell that they tried to save Johnson by performing the Heimlich maneuver, but no evidence of this is found. The CSI unit finds out that the signature on Johnson's private parts belongs to Travis's girlfriend, and finally Daniels tells the truth.



$$S(v_0,\mathbf{J})(\mathbf{K}) = (t_1, v_2);\ S(v_1,\varnothing)(\mathbf{K}) = (t_2,t_1);\ S(v_1,\mathbf{K})(\mathbf{E}) = (t_2,t_3)$$
$$S(v_2,\varnothing)(\mathbf{E}) = (t_3,t_2)$$

Fig. 10. The formalization of *Trick roll*, consisting of $\mathsf{UnAc}(\mathbf{V},\mathbf{K})$ and $\mathsf{UnEv}(\mathbf{K})$.



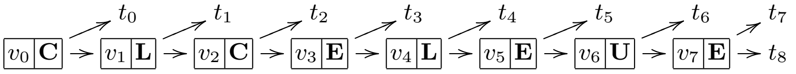
$$S(v_0,\mathbf{J})(\mathbf{T}) = (t_1,v_2);\ S(v_1,\varnothing)(\mathbf{T}) = (v_2,t_1);\ S(v_0,\varnothing)(\mathbf{J}) = (t_1,t_0)$$
$$S(v_2,\mathbf{T})(\mathbf{E}) = (t_2,v_3);\ S(v_1,\varnothing)(\mathbf{T}) = (t_2,t_1);\ S(v_2,\varnothing)(\mathbf{E}) = (v_3,t_2)$$
$$S(v_3,\mathbf{T})(\mathbf{J}) = (t_4,v_5);\ S(v_3,\varnothing)(\mathbf{T}) = (t_4,t_3);\ S(v_4,\varnothing)(\mathbf{J}) = (t_5,t_4)$$
$$S(v_4,\mathbf{J})(\mathbf{E}) = (t_5,t_4);\ S(v_4,\varnothing)(\mathbf{J}) = (t_5,t_4);\ S(v_5,\varnothing)(\mathbf{E}) = (t_4,t_5)$$

Fig. 11. The formalization of *Winning a fortune*, consisting of $\mathsf{ExAc}(\mathbf{J},\mathbf{T})$, $\mathsf{UnEv}(\mathbf{T})$, $\mathsf{UnAc}(\mathbf{T},\mathbf{J}$, and $\mathsf{UnEv}(\mathbf{J})$.

Here, we shall reconstruct all six narratives in terms of the basic building blocks given in § 2.4.

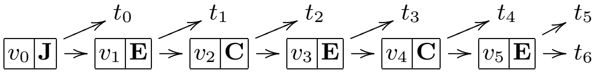
One of our narratives does not even contain first-order beliefs: *Hit and run*, formalized as Figure 13.

Half of our narratives involves basic building blocks of at most level 1, formalized in Figures 10, 11, and 14. The remaining two narratives have blocks of level 2. These are *Faked kidnapping*, formalized in Figure 12 and *Pledging gone wrong*, formalized in Figure 15.



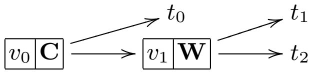
$$S(v_0,\varnothing)(\mathbf{C}) = (t_3,t_2,t_0,t_1);\ S(v_2,\varnothing)(\mathbf{C}) = (t_3,t_2);\ S(v_2,\mathbf{C})(\mathbf{E}) = (t_3,v_4)$$
$$S(v_0,\mathbf{C})(\mathbf{L}) = (t_2,t_1,v_3);\ S(v_0,\mathbf{CL})(\mathbf{C}) = (t_2,v_3);\ S(v_1,\mathbf{L})(\mathbf{C}) = (t_2,v_3)$$
$$S(v_1,\varnothing)(\mathbf{L}) = (t_2,t_1,v_3);\ S(v_3,\varnothing)(\mathbf{E}) = (v_4,t_3)$$
$$S(v_4,\mathbf{L})(\mathbf{E}) = (t_5,v_6);\ S(v_4,\varnothing)(\mathbf{L}) = (t_5,t_4);\ S(v_5,\varnothing)(\mathbf{E}) = (v_6,t_5)$$
$$S(v_6,\varnothing)(\mathbf{U}) = (v_7,t_6);\ S(v_7,\varnothing)(\mathbf{E}) = (t_7,t_8)$$

Fig. 12. The formalization of *Faked kidnappping*, consisting of $\mathsf{Betr}(\mathbf{C},\mathbf{F})$, $\mathsf{UnEv}(\mathbf{C})$, $\mathsf{UnEv}(\mathbf{J})$, and $\mathsf{ExEv}(\mathbf{U})$.



$$S(v_0,\mathbf{J})(\mathbf{E}) = (t_1,v_2);\ S(v_0,\varnothing)(\mathbf{J}) = (t_1,t_0);\ S(v_1,\varnothing)(\mathbf{E}) = (v_2,t_1)$$
$$S(v_2,\mathbf{C})(\mathbf{E}) = (t_3,v_4);\ S(v_2,\varnothing)(\mathbf{C}) = (t_3,t_2);\ S(v_3,\varnothing)(\mathbf{E}) = (v_4,t_3)$$
$$S(v_4,\mathbf{C})(\mathbf{E}) = (t_5,t_6);\ S(v_4,\varnothing)(\mathbf{C}) = (t_5,t_4);\ S(v_5,\varnothing)(\mathbf{E}) = (t_6,t_5)$$

Fig. 13. The formalization of *Hit and run*, consisting of $\mathsf{UnEv}(\mathbf{J})$, $\mathsf{UnEv}(\mathbf{C})$, and $\mathsf{UnEv}(\mathbf{C})$.



$$S(v_0,\mathbf{C})(\mathbf{W}) = (t_1,t_2);\ S(v_0,\varnothing)(\mathbf{C}) = (t_1,t_0);\ S(v_1,\varnothing)(\mathbf{W}) = (t_2,t_1)$$

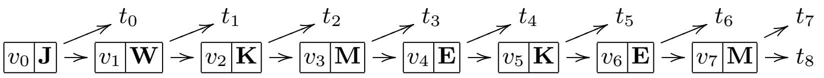
Fig. 14. The formalization of *The severed leg*, consisting of $\mathsf{UnAc}(\mathbf{C},\mathbf{W})$.

5 General conclusion

In § 4, we have seen that ten narratives from a crime series commercially produced for TV entertainment show a lot of recurring structures. A total number of eight basic building blocks is able to describe the event and action structure of all of the six narratives; most of the building blocks involve only zeroth- and first-order beliefs, and there are only two instances of genuine second-order beliefs. Not surprisingly, we see that second-order beliefs typically show up in those parts of the crime narratives that do not directly related to solving the crime, but to interpersonal interaction between the agents. While mistaken belief is a relatively common phenomenon, changing preferences and beliefs did not occur in any of the formalized narratives.

5.1 Restrictions on orders of theory of mind

The fact that in concretely given narratives, we only encounter building blocks of level 2 and lower corresponds very well to experimental research in orders of



$$S(v_0,\mathbf{J})(\mathbf{W}) = (t_2,t_1);\ S(v_0,\mathbf{JW})(\mathbf{K}) = (t_2,v_3);\ S(v_0,\mathbf{J})(\mathbf{K}) = (t_2,v_3)$$
$$S(v_0,\varnothing)(\mathbf{J}) = (t_2,t_0,t_1);\ S(v_1,\varnothing)(\mathbf{W}) = (t_2,t_1)$$
$$S(v_2,\mathbf{K})(\mathbf{M}) = (t_4,t_3);\ S(v_2,\mathbf{K})(\mathbf{E}) = (t_4,v_5);\ S(v_2,\mathbf{KM})(\mathbf{E}) = (t_4,v_5)$$
$$S(v_2,\varnothing)(\mathbf{K}) = (t_4,t_2,t_3);\ S(v_3,\varnothing)(\mathbf{M}) = (t_4,t_3);\ S(v_4,\varnothing)(\mathbf{E}) = (v_5,t_4)$$
$$S(v_5,\mathbf{K})(\mathbf{E}) = (t_6,v_7);\ S(v_5,\varnothing)(\mathbf{L}) = (t_6,t_5);\ S(v_6,\varnothing)(\mathbf{E}) = (v_7,t_6)$$
$$S(v_7,\varnothing)(\mathbf{M}) = (t_7,t_8)$$

Fig. 15. The formalization of *Pledging gone wrong*, consisting of $\mathsf{UnCT}(\mathbf{J},\mathbf{W},\mathbf{K})$, $\mathsf{CoGW}(\mathbf{K},\mathbf{M})$, $\mathsf{UnEv}(\mathbf{K})$, and $\mathsf{Ac}(\mathbf{M})$.

theory of mind. Both in experimental game theory (as a reaction to the fact that human beings do not seem to follow the mathematical predictions of game theory) and in psychology and cognitive science, researchers have investigated the limits of the capacity of human cognition to reason about iterated beliefs.

In game theory, this led to Herbert Simon's notion of "Bounded Rationality". Stahl and Wilson have investigated levels of belief in games [29] and identified "most participants' behavior ... as being observationally equivalent with one specific type" from their list of five types: 'level–0', 'level–1', 'level–2', 'naïve Nash', and 'worldly'. There is evidence from evolutionary game theory [28] that even in a population with players of arbitrary depth of theories of mind, the simple types will never be driven out of the population (this argument is the foundation of the decision of Stahl and Wilson to restrict their attention to the above mentioned five types as there is little advantage to move beyond level–2 [29, p. 220]).

In psychology, the study of the development and use of second-order beliefs started with Perner and Wimmer [20] and was continued in experiments by Hedden and Zhang [8], Keysar, Lin, and Barr [9], Verbrugge and Mol [30], and Flobbe, Verbrugge, Hendriks, and Krämer [5], to name but a few. The experimental evidence suggests that many adults only apply first-order theory of mind (even this is not always done without errors, cf. [9, Experiment 1]) and few progress to second-order theory of mind and beyond. Our results are perfectly in line with this.

5.2 Future work

A lot of the suspense and enjoyment in crime narratives comes from the fact that the audience (and the detectives) do not know who committed the crime. As a consequence, the most natural way to model crime narratives would be by imperfect information games or incomplete information games or games involving awareness. Our formal model described in § 2 is purely based on a perfect information game model. In § 3.2, we saw that this was not a serious restriction for the investigated narratives, but in general, we feel that a formal language should be able to express these phenomena. We see it as a major task for the future to develop a version of our formal model that incorporates some aspects of imperfect or incomplete information or awareness. Such a model would be able to deal much more easily and naturally with the issues discussed in § 3.2. Another component that could turn out to be important is the representation of plans of agents (cf. [33] for the inclusion of planning into a story engine, and [14] for the inclusion of a planning engine for artificial agents) in the formal language. This leads to the natural proposal to enhance our formal system by including these aspects; however, this will have to be done with caution in order to retain the simplicity of the system: there are many formal models that can powerfully deal with various aspects of communication and reasoning, but we do not want to jeopardize perspicuity and ease of use of our formal system.

Once a system has been developed that can capture many relevant aspects of narratives, larger numbers of narratives, also from different genres could be translated into this formal system in order to form a corpus for investigating various important and wide-ranging empirical questions.

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