

Modelling inference in the comprehension of cinematic narratives

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The viewer's processes of inference making in the cinema involve the framing of hypotheses about the world of the narrative that may be overturned by subsequent information and are, therefore, nonmonotonic. The goal of narrative researchers is to understand the nature of those processes and how texts organise the deployment of those processes in order to present a narrative successfully. To do this we need methods capable of describing processes of hypothesis framing and belief revision. In this paper, I describe the application of the Transferable Belief Model to a hypothetical example of narrative comprehension based on an episode of CSI: Crime Scene Investigation as one such method.

Keywords: Film narrative, narrative comprehension, nonmonotonic reasoning, transferable belief model

In *Narration in the Fiction Film*, David Bordwell (1985, p. 35-37) describes a viewer whose active comprehension of a narrative film involves the selection of salient story information and the use of cognitive schemata to make sense of this information. Fundamental to this process is the framing of hypotheses by the viewer about the story-world and its events that are tested against subsequent narrative information. The viewer anticipates the likely course of narrative events based on what she believes to be the state of the world, so that 'cognitive processes help frame and fix perceptual hypotheses by reckoning in probabilities weighted to the situation and to prior knowledge' (1985, p. 31). Similarly, in *Narrative Comprehension and Film*, Edward Branigan (1992, p. 83) emphasises the role of revising narrative knowledge from moment to moment. He links the role of probability in narrative comprehension explicitly to cause and effect: the events of a film are principally defined through cause-and-effect and are linked together by probabilities as the viewer assesses and evaluates the relative likelihood that particular events occur together, drawing upon her cultural knowledge about which actions and transactions are acceptable and, therefore, likely to occur together (1992, p. 26-27).

Both Bordwell and Branigan assume that viewers are actively engaged in complex cognitive processes, and that it is the goal of researchers to understand the nature of those processes and how texts organise the deployment of those processes in order to present a narrative successfully. However, neither addresses the methodological issues of empirically researching how real viewers recognise relevant pieces of narrative information, what weight they give to that information, what hypotheses they frame, and how they reassess the meaning of those hypotheses over time. Although we have detailed theoretical descriptions of the viewer's activities in comprehending

cinematic narratives, we do not have answers to some basic questions about those activities, including

- Which pieces of evidence in a narrative do viewers consider salient?
- What hypotheses do viewers form to explain narrative events, and what role do they play in creating expectations?
- How do different viewers weight the same piece of evidence in their reasoning, and why do they differ?
- To what extent do regimes of generic and cultural verisimilitude determine the weighting of narrative information?
- Do viewers weigh each piece of information individually or do they form their opinions based on clusters of information?
- Is the viewer *sceptical*, withholding belief until the end of a narrative when its conclusion becomes apparent; or is she *credulous*, committing belief early on in a narrative only for her assumptions to be overturned?
- Does the viewer strive to achieve local or global coherence of a narrative?
- Does the viewer make inferences that are unnecessary to the successful comprehension of the narrative?

Branigan writes that narration is ‘determined by a flow of knowledge ... One of the tasks of a narrative theorist is to provide a set of terms and categories with which to uncover the distribution of knowledge in a text and to define the logic which moves our thinking through a series of phases’ (1992, p. 82). If our goal is to understand the logic of viewers’ narrative comprehension then we need methods capable of organising and analysing the data collected through verbal elicitation methods, such as question-answering or think-aloud protocols, so that they may be combined in a multi-pronged approach with theories of discourse processing and behavioural observation (see Magliano, 1999). The purpose of this article is to outline a model of narrative inference capable of describing and analysing the behaviour of real viewers. I begin by arguing that the viewer’s processes of inference making in the cinema involve the framing of hypotheses about the world of the narrative that may be overturned by subsequent information and are, therefore, nonmonotonic. In section three I describe an application of Dempster-Shafer evidence theory developed by Philippe Smets called the *transferable belief model* capable of modelling such processes. To illustrate this method, in section four I describe a hypothetical example based on an episode of *CSI: Crime Scene Investigation* (Jerry Bruckheimer Television, 2000-2015).

Nonmonotonic reasoning and narrative cinema

In everyday reasoning we are required to think and act in situations where we do not – and in many instances cannot – have complete information. Consequently, we arrive at plausible conclusions based on the assumption that the world is ‘normal’ and ‘as expected.’ Without

doing so we could scarcely function in the world. However, we may find that the world is not ‘as expected’ and that a specific situation encountered is atypical or even novel. We must update our flawed conclusions to reflect what we have learnt or discard them entirely and replace them with new conclusions. Such reasoning is *nonmonotonic*: the hypotheses and beliefs we hold about the world are provisional and defeasible and can be overturned by new information without withdrawing any of our original premises. Alexander Bochman emphasises the vital necessity of nonmonotonicity in its relation to everyday reasoning:

Human rational activity is not reducible to collecting facts and deriving their consequences; it embodies an active epistemic attitude that involves making assumptions and wholesale theories about the world and acting in accordance with them. In other words, we also give it structure in order to make it intelligible and controllable (Bochman 2001, p. 1).

Nonmonotonic reasoning involves using *justified* beliefs and *reasonable* assumptions to guide our behaviour and is a theory of forming and testing assumptions in a reasoned and principled way. There are clear similarities between the ‘active epistemic attitude’ of nonmonotonic inference and cognitive theories of narrative comprehension that depend on the framing and testing of hypotheses (Bordwell) and the revising and remaking of narrative knowledge (Branigan). We can therefore use theories of nonmonotonic reasoning to derive the ‘terms and categories’ to describe narrative comprehension and to ‘define the logic’ of narrative comprehension.

The logic of narrative comprehension is necessarily nonmonotonic for a number of reasons. First, narrative films parcel out the presentation of information over time so that the viewer will not possess complete knowledge of a story until its completion, and even then some ambiguity may remain. Second, the information derived from a narrative may be deliberately misleading, providing false leads to generate suspense or delaying the climax of a story. The film encourages the viewer to develop a coherent line of thinking about the world of the narrative only for some revelation that the opposite state of affairs has always been the case to overturn everything she thought she knew. Third, the viewer’s recognition of the relevance and importance of narrative information depends upon the depth and range of her knowledge about a film in particular (obtained from publicity materials, reviews, word of mouth, etc.), about similar films (generic verisimilitude, films by the same producers, etc.), and about the world in general (knowledge of history, laws of physics, social roles and conventions, etc.). Confronted with an unfamiliar film a naive viewer may fail to recognise the saliency of a piece of information or construct hypotheses that subsequently have to be withdrawn because she lacks such critical knowledge. Fourth, in a competitive film market every film needs to be (at least) a little bit different from the last and so each text will (in some way) deviate from the expectations of the viewer. The unexpected may catch out even a

knowledgeable agent who will need to reassess her expectations and interpretations of a film.

Nonmonotonic reasoning covers a range of inferential procedures and the viewer uses different types of defeasible reasoning in the comprehension of narrative films. *Abduction* refers to the process of generating an explanatory hypothesis enabling the inference of a cause from a set of observations. As there may be several possible explanations for the same data, a set of hypotheses may be generated. A viewer with several possibilities to choose from may prefer one hypothesis over the others given the information she has acquired, though this preference may be revised by the introduction of new evidence. Abduction allows the viewer to orientate herself throughout the progression of the narrative by generating plausible explanations to account for what she has observed. The viewer subjects these hypotheses to inferential testing as new information becomes available in a process of *induction*. A second example on nonmonotonic reasoning is the role of *default rules* in genre films. A genre is comprised (in part) of a set of stock characters and narrative situations that are common across a group of films. These common features may lead the viewer to form hypotheses about the status of characters or the future course of events based on her knowledge of what normally occurs in similar narrative situations. In other words, we may infer the outcome of a given narrative situation if it is consistent with the rest of our knowledge about similar films. We can describe this process using *default logic*, which deals with reasoning where a general rule applies while admitting the possibility of exceptions to that rule (Reiter, 1980). Such rules are of the order ‘if *A*, then normally *B*,’ and allow us to form a hypothesis in the absence of contradictory information. We can think of a genre as a database comprising a set of default rules that structure the viewer’s experience of a film by motivating the knowledge she possesses of similar narratives (Redfern 2020).

The transferable belief model

The transferable belief model (TBM) proposed by Philippe Smets (Smets, 1990; Smets & Kennes, 1994) is a development of Dempster-Shafer evidence theory (Shafer, 1976; Liu & Yager, 2008) and is a set-theoretic framework for representing and analysing the subjective beliefs of a rational agent who forms and updates beliefs on the basis of the evidence available to guide her behaviour.

Ω is the set of N exclusive hypotheses, $\Omega = \{h_1, \dots, h_N\}$, for a variable X in which an agent is interested. Ω is the *frame of discernment*; and has the power set 2^Ω that includes Ω , the proper subsets of Ω , and the empty set (\emptyset). The elements of 2^Ω are propositions that represent possible values of X . An element of 2^Ω with non-zero belief is a *focal element*, and the *cardinality* of a focal element ($|\cdot|$) is the number of atoms of Ω it contains. If the hypotheses are exhaustive then Ω is a *closed world*, and there are no solutions outside Ω (i.e., one of the propositions in the

power set 2^Ω must be true). If the hypotheses are not exhaustive, Ω is an open-world with possible solutions that exist outside those explicitly stated in the frame of discernment and \emptyset is the set of unknown propositions outside Ω .

The *basic belief assignment* ($m(\cdot)$) is a set of scores defined on 2^Ω that represent the subjective belief of an agent as a real number by the mapping $m: 2^\Omega \rightarrow [0, 1]$, and which sum to unity:

$$\sum_{A \in \Omega} m(A) = 1.$$

The basic belief assignment of a proposition A is $m(A)$ and represents that part of agent's belief committed to A *only*, but which might support a strict subset of A if justified by further information. For example, if A , A' , and A'' are subsets of Ω , and A' and A'' are subsets of A , then a belief mass assigned to A might support A' or A'' but does not specifically support either. If a new piece of evidence reveals that the truth is in A' then the mass assigned to A is transferred to A' and no mass is assigned to A'' . Belief not committed to A is *not* automatically committed to $\neg A$ (i.e., not- A), but remains allocated as uncommitted belief to the tautology Ω . The model is, therefore, ignorance preserving.

A range of functions that summarise the belief of an agent are constructed from the basic belief assignments. The *belief function* of A quantifies the total justified specific support for a proposition. As belief committed to a proposition is logically committed to any proposition it implies, this function is the sum of the belief masses assigned to the elements 2^Ω of contained within A and the basic belief mass assigned to A :

$$bel(A) = \sum_{B \subseteq A \neq \emptyset} m(B),$$

for all $A \subseteq \Omega$. The *plausibility function* of a proposition is the maximum amount of belief that may be assigned to support it. It is calculated as the sum of the belief masses in propositions that are compatible with A , or as 1 minus the total amount of belief assigned to the negation of A :

$$pl(A) = \sum_{A \cap B \neq \emptyset} m(b) = 1 - bel(\neg A).$$

The belief represented by $pl(A)$ is only potential belief as belief may subsequently be assigned to propositions that are not compatible with A . The *ambiguity function* of a proposition is the difference between its plausibility and its belief functions, and represents the amount of belief that could be assigned to A in the absence of a contradiction (Srivastava, 1997; Srivastava & Mock, 2002):

$$am(A) = pl(A) - bel(A).$$

Although not widely discussed in the context of the transferable belief model, the concept of ambiguity is useful in representing the beliefs held by a viewer about a narrative. Narrative films typically maximise belief and minimise ambiguity – they arrive at a definite and unambiguous conclusion in which the lovers are united, the criminal is caught, the evil mastermind is destroyed, etc. However, there are some circumstances in a narrative may result in a non-zero ambiguity function and a belief function that is not equal to unity, possibly because the narrative leaves some questions unanswered. A non-zero ambiguity function may indicate that a viewer has not maximised her belief in a hypothesis because the saliency of narrative information was not recognised or that the evidence was not regarded as being sufficient to justify narrative causality.

The three functions defined above describe the viewer’s state of knowledge at time k , but we need to be able to understand the updating of belief dynamically. This may be achieved by employing *Dempster’s rule of combination*:

$$m_{1,2}(A) = [m_1 \oplus m_2](A) = \frac{\sum_{B \cap C = A} m_1(B)m_2(C)}{1 - \sum_{B \cap C = \emptyset} m_1(B)m_2(C)},$$

where \oplus is the orthogonal sum of the pieces of evidence m_1 and m_2 in support of A . The denominator is the renormalizing factor for the closed-world scenario in which $m(\emptyset) = 0$. If Ω is an open-world then the combined mass is unnormalized and $m(\emptyset)$ can have positive mass. Other methods of updating belief are available (see Smets, 1991) but are not discussed here.

The transferable belief model has several advantages over Bayesian models of narrative inference, such as that proposed by Abell (2007, 2009). First, the model represents belief as belief and not as a probability, thereby removing this terminological confusion. Second, unlike Bayesian probabilities where 0 and 1 represent opposing forms of certainty, $m(A) = 0$ represents the absence of belief and $m(A) = 1$ represents the total commitment of belief of an agent to A . The transferable belief model makes a clear distinction between *lack of belief* (‘I have no reason to believe A is true’) where $m(A) = 0$, and *disbelief* (‘I do not believe A is true’) where belief is assigned to propositions other than A . This is an important advantage over the Bayesian approach and better reflects the behaviour of real agents by preserving ignorance. The TBM requires the assignment of belief only to those propositions upon which the viewer believes the evidence bears. Third, where the Bayesian method represents belief via a single number the TBM approach is better equipped to deal with the imprecision of subjective beliefs. By defining a number of functions based on the viewer’s assignment of belief masses, the TBM differentiates between the viewer’s justified belief ($bel(A)$), her maximum potential belief ($pl(A)$), and the distance between the two

($\text{am}(A)$). Fourth, the TBM does not require an agent to specify a complete set of hypotheses prior to the assignment of the belief masses. This is useful because many films will not conveniently provide a closed frame of discernment at the start but will proceed by introducing potential solutions at different stages of the narrative. Consequently, the viewer will not necessarily be aware of the possible hypotheses for a variable and will have to consider the possibility of some unknown propositions. By allowing for the assignment of positive mass to \emptyset , the open-world assumption enables contradictory evidence to be dealt with by admitting just such a possibility.

A three-pipe problem

To illustrate the use of belief functions in modelling narrative comprehension I use episode 11 from season five of *CSI: Crime Scene Investigation*, ‘Who Shot Sherlock?’ I assume a hypothetical viewer who is both attentive and rational. In this narrative, CSIs Gil Grissom, Greg Sanders, and Sara Sidle investigate the death of Dennis Kingsley, a Sherlock Holmes aficionado found dead in circumstances that would tax the ingenuity of the great man himself. The variable of interest (X) for this narrative is the identity of the killer(s). $\text{bel}_i(A_j)$, $\text{pl}_i(A_j)$, and $\text{am}_i(A_j)$ are the belief, plausibility, and ambiguity functions for the j th proposition after the i th piece of evidence (E), respectively.

Dennis is found dead in his study with a gunshot wound to the head (E_1). Sanders wonders if the victim’s death is a suicide, but Dennis lived alone (E_2) and there is no sign of the gun (E_3). The viewer might assign some belief to the hypothesis of death by suicide only to then immediately contradict that hypothesis, but this seems unlikely given the presentation of this information in a single scene. It is reasonable to assume that the viewer takes these pieces of evidence as a whole rather than as two competing sets of information that would induce contradictory beliefs – suicide is a possible solution but does not yet lead the viewer to assign any belief to this proposition. Physical evidence collected at the scene includes a round from Colt .45 revolver (E_4), a syringe (E_5), a mother of pearl chip with some red dust on it (E_6), a blood-stained copy of ‘The Hound of the Baskervilles’ (E_7), and some tobacco ash (E_8). There is also evidence to indicate someone has broken into Dennis’s home (E_9), and so the CSIs’ minds turn to murder.

Some potential suspects become immediately apparent when the CSIs confront three people dressed as characters from nineteenth century London – Josh, who does not smoke; and Kay and Nelson, who both have pipes (E_{10}). Together they formed a Sherlock Holmes appreciation society (E_{11}) that met regularly at Dennis’s house (E_{12}); but this was to be their last meeting after Dennis announced he was leaving the group (E_{13}). The frame of discernment for this narrative is $\Omega = \{Josh, Kay, Nelson, suicide\}$, and Table 1 presents the propositions that constitute 2^Ω . As the set of possible values of X has been limited at the beginning of the narrative, we will assume that Ω is a closed-world.

Clearly, some of these propositions are impossible – the solution to this narrative is not going to reveal that Josh killed Dennis *and* that Dennis’s death was a suicide. Consequently, belief masses will be assigned to some of these propositions and not others. Note also that the order in which the elements of a proposition are listed is irrelevant.

Table 1

The power set defined for the frame $\Omega = \{Josh, Kay, Nelson, suicide\}$ for a narrative in *CSI: Crime Scene Investigation* 5.11, ‘Who Shot Sherlock?’

Proposition	Elements	Proposition	Elements
\emptyset	Empty set	A_8	Kay, Nelson
A_1	Josh	A_9	Kay, suicide
A_2	Kay	A_{10}	Nelson, suicide
A_3	Nelson	A_{11}	Josh, Kay, Nelson
A_4	suicide	A_{12}	Josh, Kay, suicide
A_5	Josh, Kay	A_{13}	Josh, Nelson, suicide
A_6	Josh, Nelson	A_{14}	Kay, Nelson, suicide
A_7	Josh, suicide	Ω	Josh, Kay, Nelson, suicide

Further evidence is presented: the autopsy confirms the gunshot wound to be the cause of death (E_{14}) and reveals that Dennis had high levels of cocaine in his urine and track marks from injections indicating a long-term drug problem (E_{15}). The victim had a large dose of pharmaceutical grade morphine in his system (E_{16}) and the drug was also found in the syringe collected at the crime scene (E_{17}). The CSIs find gunshot residue on the victim’s hand (E_{18}), but the level of morphine in his system indicates that he would have been incapacitated and could not have fired the fatal shot. So far, the viewer has been presented with a lot of information but has not yet been able to interpret this information in context, and is, therefore, unable to express any measure of belief with regard to X . The recovery of tobacco ash from the crime scene means nothing until the viewer is able to interpret the significance of this evidence. Before evaluating any evidence with respect to X the viewer has no reason to assign any belief to the proper subsets of Ω , and so assigns all her belief to the frame of discernment itself. This is the *vacuous belief function* and represents the complete ignorance of the viewer with regard to the cause of Dennis’s death. It is also important to recognise that some evidence will play a key role in allowing the viewer to interpret other pieces of evidence but will not induce a belief assignment.

The first piece of evidence that relates to the possible suspects is the revelation that the tobacco ash recovered from the crime scene is not a match to that of the victim (E_{19}) and must belong to the killer. As we know that two of the suspects (Kay and Nelson) have pipes we can take this as evidence that the true value of X lies in A_8 , but that we do not have

any reason to prefer one of the elements of this proposition to the other. Suppose that the viewer finds this evidence suspicious but not compelling – we know that both Kay and Nelson have been to Dennis’s house before – leading her to assign a low level of belief to the proposition that the truth is in A_8 : $m_{19}(A_8) = 0.2$. The uncommitted belief remains assigned to Ω as a tautology: $m_{19}(\Omega) = 0.8$. The viewer is anticipating more evidence and suspends her belief until justified by subsequent information. As this is the first piece of evidence encountered by the viewer to induce the assignment of mass to a proposition, the belief function of the proposition A_8 at this time is simply equal to the mass assigned to the first piece of evidence that supports it ($\text{bel}_{19}(A_8) = 0.2$). As the viewer has no evidence to support any of the other potential values of X , no mass assigned to the other propositions at this time and their belief functions are zero. The belief function for the frame of discernment is $\text{bel}_{19}(\Omega) = m_{19}(A_8) + m_{19}(\Omega) = 0.2 + 0.8 = 1.0$. Once the belief functions have been calculated, the plausibility and ambiguity functions may be determined. The plausibility of A_8 after the first piece of evidence is the difference between $\text{bel}_{19}(\Omega)$ and the complement of A_8 (i.e., the sum of the belief assigned to propositions other than A_8). Therefore, the plausibility that the killer(s) is in $\{\text{Kay}, \text{Nelson}\}$ is $\text{pl}_{19}(A_8) = \text{bel}_{19}(\Omega) - \text{bel}_{19}(\neg A_8) = 1.0 - 0.0 = 1.0$, and the ambiguity function is $\text{am}_{19}(A_8) = \text{pl}_{19}(A_8) - \text{bel}_{19}(A_8) = 1.0 - 0.2 = 0.8$. After this piece of evidence, the viewer’s belief that the killer(s)’s identity is in A_8 has increased by a small amount and the level of ambiguity for this proposition reduced.

The second piece of evidence to induce a belief mass is the fact that Nelson has the victim’s blood on his shoes (E_{20}). As this evidence is supposed reliable, the viewer assigns a basic belief mass to this evidence, so that $m_{20}(A_3) = 0.3$ and $m_{20}(\Omega) = 0.7$. The mass assigned to this evidence must be combined with that assigned to E_{20} by the viewer in order to update her belief that Nelson is the killer. This process of combining evidence can be represented by arranging the masses assigned to the evidence in a grid to make explicit the two stages in the calculation of the orthogonal sum (see Schum, 2001, p. 240). In Table 2, the masses for the focal elements relating to E_{19} are arranged on the horizontal axis, while the masses for the focal elements relating to E_{20} are arranged on the vertical axis and are multiplied where the focal elements intersect – that is, where focal elements with elements of 2^Ω in common meet. Two of the intersections in Table 2 result in A_3 , and the belief function for this proposition is the sum of the product of the masses at each intersection: $\text{bel}_{20}(A_3) = 0.06 + 0.24 = 0.3$. One intersection results in A_8 , so that $\text{bel}_{20}(A_8) = 0.06 + 0.24 + 0.14 = 0.44$. The remaining intersection is the updated mass of Ω and represents the unassigned belief of the viewer. The belief function of the frame of discernment is the sum of all the intersections: $\text{bel}_{20}(\Omega) = 0.06 + 0.24 + 0.14 + 0.56 = 1.00$. Having updated the belief functions, the plausibility and ambiguity functions are recalculated to account for this new information.

Table 2

The orthogonal sum of conjunctive belief masses assigned by a viewer for E_{19} and E_{20} for a narrative in episode 5.11 of *CSI: Crime Scene Investigation*, ‘Who Shot Sherlock?’

Evidence		E_{19}		
	Focal elements	A_8	Ω	
	$m_i(A_j)$	0.2	0.8	
E_{20}	A_3	0.3	A_3 $0.2 \times 0.3 = 0.06$	A_3 $0.8 \times 0.3 = 0.24$
	Ω	0.7	A_8 $0.2 \times 0.7 = 0.14$	Ω $0.8 \times 0.7 = 0.56$

Next, the viewer learns the tobacco ash is a match to Nelson’s brand (E_{21}). She therefore transfers the remaining belief in A_8 to Nelson alone and adds this to the belief already assigned to A_3 . In light of this evidence, $m_{21}(A_3) = m_{20}(A_3) + m_{20}(A_8) = 0.3 + 0.14 = 0.44$; and therefore $bel_{21}(A_3) = 0.44$, $pl_{21}(A_3) = 1.0$, and $am_{21}(A_3) = 0.56$.

So far, the viewer’s belief in Nelson’s guilt has increased and the ambiguity of the narrative diminished, while the plausibility of the other propositions has decreased. However, it is revealed that the blood evidence is inconsistent: the blood found on Nelson’s shoes is both old (clotted red blood cells) and recent (unclotted red blood cells) and cannot result from Dennis’s gunshot wound (E_{22}). Therefore, someone is framing Nelson for the murder and all the belief masses assigned to propositions that contain ‘Nelson’ must now be discarded. This leaves the possibilities that Dennis’s death was a suicide staged in such a way as to frame Nelson or that either Kay, Josh, or both killed Dennis and tried to frame Nelson. The viewer thus assigns all the belief in this evidence to the proposition containing the elements {Josh, Kay, suicide}: $m_{22}(A_{12}) = 1.0$. There is a conflict between the evidence the viewer has so far accumulated and this new information, and so it is necessary to include the renormalization of belief masses in the process of updating belief. In Table 3, we see that the intersection Ω and A_{12} leads to a mass of 0.56 being transferred from the frame of discernment to this subset, and that the intersection of between A_3 and A_{12} results in dissonance with a mass of 0.44. The mass assigned to A_{12} is thus calculated as $0.56/(1.0 - 0.44) = 0.56/0.56 = 1.0$; and the mass assigned to A_3 is $0.0/(1.0 - 0.44) = 0.0/0.56 = 0.0$. Therefore, $bel_{22}(A_{12}) = 1.0$ and $bel_{22}(A_3) = 0.0$.

Table 3

The orthogonal sum of contradictory belief masses assignments for E_{21} and E_{22} for a narrative in episode 5.11 of *CSI: Crime Scene Investigation*, ‘Who Shot Sherlock?’

Evidence		E_{21}		
	Focal elements	A_3	Ω	
	$m_i(A_j)$	0.44	0.56	
E_{22}	A_{12}	1.0	<u>Dissonance</u> $0.44 \times 1.0 = 0.44$	A_{12} $0.56 \times 1.0 = 0.56$
	Ω	0.0	A_3 $0.44 \times 0.0 = 0.0$	Ω $0.56 \times 0.0 = 0.0$

The next suspect to come under scrutiny is Josh, whose blood is identified on Dennis’s copy of ‘The Hound of the Baskervilles’ (E_{23}). Josh explains this is the result of a papercut sustained in a struggle with Dennis, who had reneged on their deal for the purchase of this volume (E_{24}). According to Josh, Dennis was selling his Sherlock Holmes memorabilia via an auction (E_{25}), including his Colt .45 revolver with a mother of pearl handle (E_{26}). This is weak evidence that Josh is the killer, and the viewer assigns only a small amount of belief to this proposition ($m_{23}(A_1) = 0.1$) and updates her belief accordingly. This line of inquiry is soon forgotten when Sanders matches the red dust on the mother-of-pearl chip he collected at the crime scene to the clay bricks of Dennis’s fireplace (E_{27}). Examining the fireplace, he discovers the missing revolver in the chimney attached to some surgical tubing (E_{28}). This mean that once Dennis had pulled the trigger and let go of the gun it disappeared into the chimney to create the impression it was missing for the crime scene. This suggests that in staging his death, Dennis created an elaborate puzzle in homage to Sir Arthur Conan-Doyle. Sanders therefore concludes that Dennis’s death was a suicide. Complex, mysterious, certainly improbable, but nonetheless a reasonable explanation within the context of the show. The viewer assigns all the belief to this evidence to the proposition that Dennis’s death was a suicide, so that $bel_{28}(A_4) = 1.0$ after updating.

It would appear we have arrived at a solution for X . However, Grissom remains puzzled by the fact that a long-term cocaine user would have morphine in his syringe and argues that the case remains open until all the evidence is understood in its proper context. The viewer is able to recover discarded propositions by disjunction introduction and is now faced with the possibilities that Dennis’s either was suicide or was not

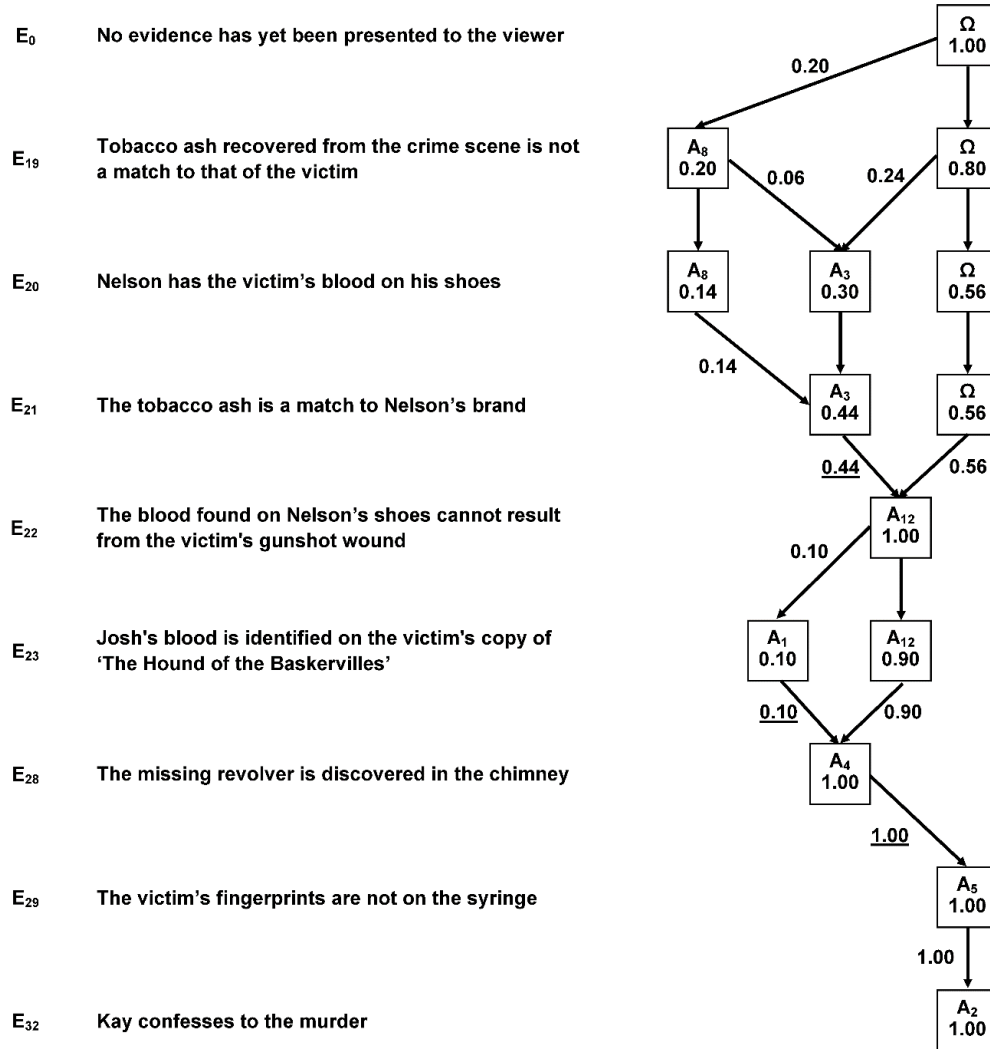
suicide, where ‘not-suicide’ is logically equivalent to the proposition (A_5) that {Josh, Kay} are the killer(s). This leaves the viewer with the exclusive disjunction $A_4 \vee A_5$; and as the victim’s fingerprints are not on the syringe (E_{29}), the CSIs conclude that Dennis’s death was not suicide ($\neg A_4$). By disjunctive syllogism, this entails A_5 , the belief assignment $m_{29}(A_5) = 1.0$, and the belief function $bel_{29}(A_5) = 1.0$. Ultimately, it is revealed that Kay is the killer – the tobacco leaf found in the surgical tubing is matched to her brand (E_{30}), she has access to morphine and surgical tubing from caring for her terminally ill mother (E_{31}); and she confesses to the murder (E_{32}), to framing Nelson (E_{33}), and to staging the suicide (E_{34}), all of which were motivated by her anger at Dennis’s decision to break up the group (E_{35}). The viewer’s belief is therefore transferred to A_2 as a subset of A_5 , and $bel_{32}(A_2) = 1.0$, $pl_{32}(A_2) = 1.0$, and $am_{32}(A_2) = 0.0$. The narrative thus concludes by maximising the viewer’s belief in and minimising the ambiguity of the proposition that Kay is the killer.

This episode is a good example of nonmonotonic reasoning in narrative comprehension. Confronted with a range of possible solutions the viewer must generate hypotheses about the possible identity of the killer (abduction) and reasons to the best hypothesis by assessing and reassessing the strength of her belief as evidence becomes available over the course of the narrative (induction). This is a complex process but can be easily visualised as a directed acyclic graph to make easier analysis of which items of evidence the viewer considers salience, the weight she attaches to those items, and how her beliefs evolve over time. Figure 1 presents the transfer of belief masses between propositions in 2^Ω for the example described above.

Conclusion

Narrative comprehension is a cognitive process in which an agent generates plausible hypotheses about a film’s diegesis based on incomplete and changing information and which she updates or discards when presented with new information. The reasoning of an agent is necessarily nonmonotonic and can be represented formally using mathematical and graphical models. The transferable belief model provides a simple but powerful mechanism for describing the psychological processes of the viewer that capture the complexity of narrative reasoning. The use of such models can help to us to better understand the cognitive processes involved in reasoning in narrative cinema, in discovering and establishing normative rules of behaviour through the empirical analysis of real viewer. It is a tool that will allow us to go beyond the theoretical description of ideal viewers to develop a theory of film spectatorship with a solid empirical grounding.

Figure 1. The transfer of belief masses for those propositions that are the focal elements of a narrative in *CSI: Crime Scene Investigation* 5.11, ‘Who Shot Sherlock?’ in chronological order. Underlined figures indicate dissonance between propositions.



There are some issues to be considered when attempting to apply the transferable belief model to motion picture viewers. A drawback of adopting the set-theoretic approach of the TBM is that, because the basic belief assignments are mapped over the propositions that comprise the power set of Ω , it can become over-complicated even when Ω contains a relatively small number of hypotheses. This is due to the fact that the number of propositions in 2^Ω grows at an exponential rate as Ω increases in size. In most cases this will not be of practical significance: narratives typically focus on a small group of characters, and so the size of Ω will be restricted to a manageable level. However, on those occasions when an agent is faced with many possible solutions the task of representing that belief numerically can quickly become impractical. Second, the

illustration of the TBM in this article used Dempster's rule of combination as a means of updating the viewer's belief. It is by no means certain that this is the best method of combining beliefs and, as noted above, there are other methods that may prove appropriate in this context. The decision about which rule should be applied to combining beliefs is one that will require consideration by the researcher. Finally, in applying the transferable belief model, it is important to avoid reifying the viewer's rational activities of narrative comprehension. The TBM is a method by which the viewer's beliefs about a narrative can be represented dynamically but any model of the viewer will also include aspects of their experience of a film not captured by the TBM (such as her emotional and/or physical responses). Additionally, other types of films (e.g., advertising, avant-garde cinema, experimental films, video art, etc.) do not require the viewer to form a belief about the diegesis and so the application of the TBM is not appropriate in these cases. The transferable belief model should not, therefore, be mistaken for a general theory of film spectatorship.

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