Modeling the Resituation of Memory in Neurobiology and Narrative

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Abstract

Narrative structure offers mechanisms for modeling the interpretation of unexpected events in an open world, using situation-theoretic foundations. Our current project applies this method to an example in neurobiology. The process of resolving fear memory is handled across two related domains, cognitive and biological, which we model as interacting contexts. This example enables us to experiment with representational reasoning about cause, implicit knowledge and shifts in dominance between distinct systems – characteristics that usually elude representation.

This work-in-progress indicates that mechanisms of narrative can model cross-system, multi-ontology phenomena. This approach can also inform the visualization of processes that are difficult to represent by conventional methods, such as the shift in dominance between systems or the resulting changes to causal affordance. Capturing implicit agency in biology is thus feasible but comes with challenges in graphical display, which are discussed.

Introduction

An elusive goal in strategic intelligence analysis is to model how causal reasoning occurs in an open world (Devlin, 2009). This is especially challenging when interpreting unexpected events and implicit information. To capture these, we developed a formal system with a graphical modeling syntax based on narrative principles. (Our definition of *narrative* is discussed below.) It is underpinned by situation theory (Barwise & Perry, 1983; Devlin, 1992), to make it implementable as a graphical grammar and syntax.

We report on work-in-progress that applies this method to a different domain: neurobiology, focusing on a phenomenon in which contextual dynamics are key. In this example, 'fear memory' incites a combined neurobiological/cognitive response. This reaction is resolved by a complex process of memory loading and a shift in governance between physical and cognitive situations.

Initial modeling of this process using narrative-based principles suggests they can handle this phenomenon. A main advantage is the ability to capture the interaction among multiple systems and ontologies as whole systems. In biology, there is currently no satisfactory way to represent this (Noble, 2015). This approach also captures dynamics such as shifting governance and implicit or composite agency more completely as first class citizens. The results so far are intuitive and allow a graphic vocabulary.

Two aspects of intelligence are thus represented in this work: the resolution of fear memory and processes of narrative inference. These are connected through underpinning abstractions of contextual shift, so techniques for modeling one can guide the structuring of information about the other. We thus explore connections between these two different notions of intelligence, and extend narrative towards biology via its relationship with cognition.

Contextual Interaction

Combining Narrative and Situation Theory

The target application was originally ontological interoperability, with a goal to understand how to integrate information from differing sources and systems. Priorities were to preserve contextually specific information and to enable the causal aspects of a context (such as a non-logical belief) to be adjusted.

Narrative was the vehicle for this research, as form of commonplace reasoning that enables the interpretation of partial information under changing circumstances. Our definition of *narrative* starts with Prince's description of a story as an event that causes a change of state (Prince, 1973). We expand this premise by anchoring the terms 'cause', 'change' and 'state' in frameworks of causal philosophy, conceptual change and context (Cardier, 2015). The resulting model has mechanisms geared towards causal reasoning through state change (Cardier, 2015).

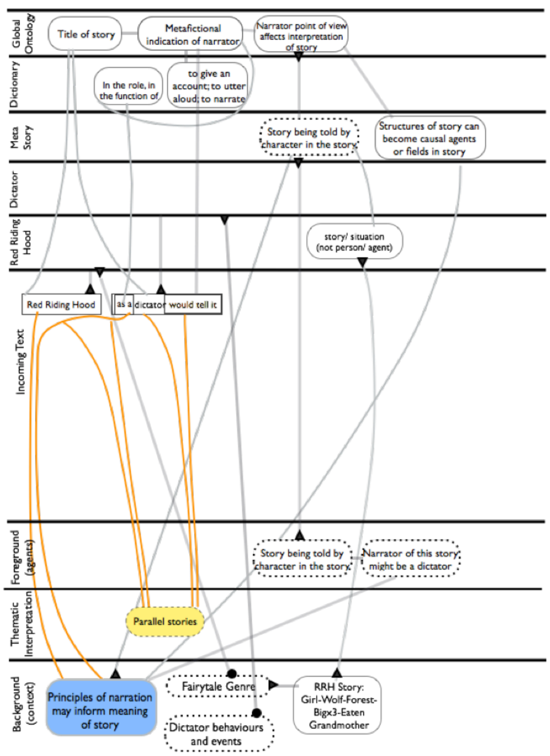

Figure 1: Still image from Cardier's dynamic model of narrative (Red Riding Hood as a Dictator Would Tell It).

Three distinguishing features of this model are:

1) Stories are tracked through progressive states of 'the-story-so-far' instead of the whole story being assessed after completion, as is common in narratology. In the graphical model, this is represented by dynamism – animated operations build structure as each text chunk appears.

2) Inferences are limited in scope; this is the partial reasoning necessitated by context. As each chunk of text appears, new inferences are needed to support the new ideas they contain. These supporting inferences can be composed of large or small networks of concepts, which are grouped into more complex arrangements as structure builds through text progression. In the graphical model, these operations are represented by graphical conventions.

3) An incoming piece of text can be supported by multiple inferences, which might have incompatible structures. This captures an elusive characteristic of narrative, in which ideas are combined in unexpected ways (eg. *Red Riding Hood* = dictator) so no common knowledge reference can support it, thus requiring a reader to finish the story to discover the causal unfolding of that situation (Cardier, 2015). The interaction of multiple inferences is represented by numerous situation 'bands' at the top of the page, in which salient conceptual structures can be activated, and also by the connections built between the concepts across the entire field.

Colors differentiate operations: yellow indicates a group of concepts has been activated, red signals a conflict between them and blue indicates that one is dominating the others, thus imposing its structure on them.

This method tracks how contextual situations can be integrated, how new ones form, and how one influences another when multiple inferences bear on a single piece of information. Together, these aspects enable a detailed description of transitional structure between states.

The Example: Fear Memory

One of us (Sanford) investigates fear memory as a modulator of multiple behavioral and biological systems (Sanford et al., 2014). An extreme case is a human who has experienced a trauma and develops post-traumatic stress syndrome (PTSD). The resulting 'fear memory' can trigger stress, sleep and immune responses much like the initial trauma.

The negative effect of trauma can be altered by allowing behavioral control during stress. In this protocol, mice always receive a mild footshock, but can terminate using a simple escape behavior (Sanford et al 2010). Negative outcomes can also be lessened by re-activating the fear memory in a "safe" context. This modifies of the accompanying a sense of agency over the process.

A distinctive aspect is the way biological and cognitive domains shift in dominance over the fear memory. When the trauma occurs, cognitive processes govern outcomes as much or more than do physical stimuli. Resolution involves altering the way the mind (in the cognitive domain) perceives the feared experience.

We model this process by aligning the mechanisms that facilitate switches between dominant inferences in narrative with switches between the physical systems that govern fear memory. We do not argue that biology produces actual 'narratives'. In psychiatry, the structuring of memories related to a traumatic event are described as 'narratives' (Tuval-Mashiach, 2004) but that description has a different focus from the way we abstract narrative structure for the purpose of modeling. Our work focuses on the process of state-change as expressed through semantics, and the informational architectures that emerge from that change. We instance these stages in the example of fear memory, to see if new insights emerge in either field.

In neurobiology, cognitive governance of fear learning during trauma and of subsequent fear memory after trauma can assist healing. This potential alteration of fear memory after trauma suggests a form of retroactive interpretation by the body in relation to its own biophysical history. A similar kind of retroactive interpretation is common in stories. Further connections are described in 'results'.

Context, Situation, Ontology

The formal foundations for this work leverage situation theory, which emerged to address contextual reasoning during the 1980s and early 1990s (Barwise & Perry, 1983; Devlin, 1995). In line with situation theory, we define a *situation* as a "limited part of reality" which includes the relations between its elements (Devlin, 2009).

Goranson (Goranson & Cardier, 2013) developed a means of coding the dynamic assemblies of narrative using a two-sorted logic, indicated by situation theory. One sort is category theoretic, working with structure that allows explicit representation of the open set. The other sort is based on Cardier's narrative structures. A tool based on this can therefore feasibly model these dynamics and facts, with the promise of future executable, 'intelligent narrative' systems. To demonstrate those dynamics, we have work-in-progress toward a graphical modeling system to communicate the novel features of the example structures.

Method

We aim to improve the ability to model implicit facts and influences and their causal implications. Initial sponsorship came from the strategic intelligence community, with a constraint to abstract only within the semantic space. A goal was to avoid the limits of prevailing solutions that abstract into probability, vectors and/or geometric spaces.

While there is a modest tradition of modeling causal reasoning in narratology (Trabasso, Richardson, Sturgess), those approaches lack the formalism required for a logical audit and computability of the kind described here. We thus chose situation theory as a host for narrative principles, due to its capabilities for rendering contextual shift in a formalizable framework.

We initally tested our approach by modeling real narratives that would confound established methods. These included the shifts of causal interpretation seen in the television show *Game of Thrones* (Cardier, 2014) and the interaction between non-explicit inferences in the story *Red Riding Hood as a Dictator Would Tell It* (Cardier, 2015).

Goranson used that groundwork to model successive facts as structured 'infons' with a constrained type system, expanding situation theory (Cardier, 2013). 'Stories' are linearized logical statements.

Our formal connection to neurobiology came through ontological interoperability. Current efforts to standardize or integrate biomedical ontologies have been disappointing. Goranson has framed Sanford's work to be accessible to these sources, in order to repeat the process of structuring information according to our contextual-integration mechanisms. One concession to biology is the development of a new type system (Goranson et al, 2015) that subsumes the original cognitive domain, includes biological dynamics and conforms to biomedical ontologies and common practice (Goranson & Cardier, 2013).

The goal of this research is to develop an approach that:
1. Is purely semantic without recourse to probability or lossy quantitative abstractions.
2. Conforms to the way humans structure facts as narratives.
3. Allows a path for implementation as structured models and feasibly executable reasoning systems.

Preliminary Results and Observations

So far, our method has been able to capture the contextual interactions evident in the resolution of fear memory. Dynamic animations depicting this will be shown in the presentation. In the course of creating these graphical models, correlations between narrative and cognitive processes have already been identified. These correlations serve two purposes. First, they indicate the reasoning mechanisms that translate across both cognitive and narrative domains. Second, they inform the vocabulary of the modeling method itself. Three examples of this follow.

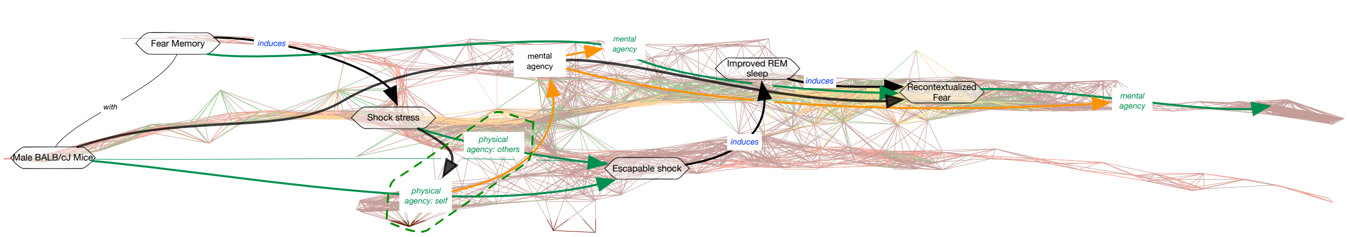

Figure 2. The detailed and complete concept lattices.

1) A single entity can inhabit two distinct systems/contexts. For example, system sentinels can react similarly to both fear (cognition) and physical stress (biology), so fear memory has agency in both processes. This is similar to interpretation of a fact in narrative, when new chunk of information is revealed. A new supporting inference re-contextualizes the fact from a previous inference. Depending on how additional incoming text supports one or the other, interpretation shifts back and forth.

2) If a shift between contexts is substantial enough, it can recast all previous structure until the entire system responds differently to existing or new information. In the fear extension case, the immune system resituates a previously understood event. In narrative, retroactive reinterpretation occurs when information is revealed that changes the perspective on the events so far.

3) When systems interact, the relationship of one to another can be dominant. We speculate that interactions between neurobiological systems might fall on a spectrum, similar to the dominant, mutual or supportive relations observed between narrative inferences. In the example, the cognitive system switches dominance, governing when fear learning occurs, and governing again after the fear memory has been adjusted.

Figure 2, above, is an illustration of how facts will map onto a larger concept lattice of associated narratives. Here, the flow on the top is cognitive space, the center is the cognitive hardware and activity in different parts of the brain. The flow at the bottom represents the unfolding actions of the immune systems. These interlink at key points. It should be noted that the method is animated, and moving transitions indicate how the above examples occur.

Notably, this figure also demonstrates some of the display challenges encountered so far. Our model can *record* the above characteristics but their structures are difficult to *read* once structure accumulates. This difficulty is also due to the simultaneous depiction of macro and micro scales.

We are addressing this problem at a fundamental level, by adding another dimension to our notion of intelligent reasoning: emergent design. The premise is that managing complex information requires design-based principles that optimize through distillation.

Conclusions

This early work indicates that we may usefully model biological dynamics using context mechanisms drawn from narrative. Our method captures shifts in governance among different, seemingly distinct ontologies; common processes can be correlated. In terms of formalization, we have not yet developed a suitable indicator for implicit influences in biology. This will be addressed in examples that include the influence of overlapping, highly reconfigurable communities of the gut microbiome, in an upcoming collaboration with the Eastern Virginia Medical School.

Finally, the issue of readability will be addressed in a non-superficial manner, with choices about representational modeling rooted in theories of forgetting (in neurobiology), emergent design and structural decay (in design).

Acknowledgment

This work is partially supported by a grant from the National Academies Keck Futures Initiative.

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