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THE ROLE OF NARRATIVE IN EVOLVING ENGINEERING DESIGN DOCUMENTATION

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1. Introduction

Engineering design activities require the use of a range of cognitive technologies that bridge the gap between human cognitive limits and the requirements of complex engineering work. Increasing demands for sustainable design and long-lived products have driven increased development of computational tools to support this often asynchronous, information-intense cooperative work. New potential is sought in navigating the cloudy masses of digital information to find what is relevant for useful design decisions. Graph representations are being introduced as a better fit for the new hyperlinked, non-linear information spaces. This change entails a shift away from more traditional textual documents. These old forms of documents, however, possess many important characteristics that make them effective, otherwise they would not still be in use. Further, the narrative contained within them are often considered a fundamental form of human knowledge [Snowden 2000, Shank 1990, Lloyd 2000].

Although much of the content of documents seems to be transferable to the new graph forms, it is not clear exactly what is lost and what is gained in the transition. There is a potential danger of losing critical functions provided by narratives in the move to hyperlinked information systems. Comparative studies have been done (ex. [Aurisicchio et al. 2007]) but more research is needed before we can understand how to balance the strengths and weaknesses of each form of representation.

This paper reviews key issues surrounding narratives in engineering design documentation to examine the role of narratives in cognitive technologies that support engineering work and to consider how to extend these structures in the context of evolving demands on engineering work. Applications are discussed across varied levels of granularity, from the generation of overview to the importance of "information shape" afforded in an individual's experience of documents. This work aims to contribute to future design, integration and automation of the disparate practices surrounding information artefacts for engineering work. It also seeks to add to the emerging research in knowledge management through narratives by applying this perspective to engineering design.

2. The Evolution of Documentation

Increasing demands on engineering work, motivated by both competition and environmental responsibilities, create pressures on corporations to improve the management and retention of information about their engineering systems. Increasing complexity in engineering systems due to long product lifecycles, multiple stakeholder considerations and custom client demands further push industry (and ultimately research) to look towards improved technologies to augment work. The net result is ever stricter design requirements which test designer's thinking across boundaries of distance, time, technologies, and experience. Experienced engineers, for example, may no longer be able to walk onto a factory floor to interact directly with parts and equipment in their operational context.

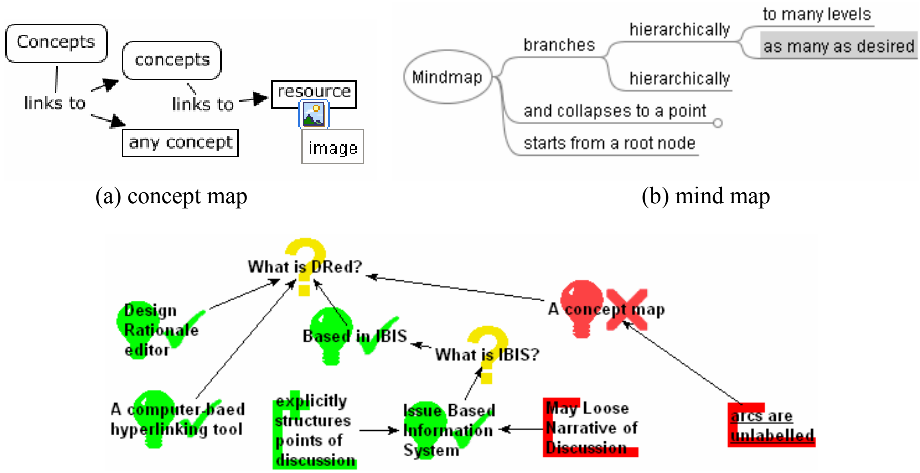
Facts from an old design, thinking from an unknown colleague and problems in a distant machine may need to be combined in unforeseeable ways. This constitutes a significant shift in the demands engineering work puts on its cognitive technologies.

2.1 Base Concepts: Representations and Cognitive Technologies

Representations, in this research, are defined as perceived artefacts (text, diagram, sketch) that provide an interface to a person's internal mental models. They are things that have meaning but that exist outside the mind.
A cognitive technology, as defined by Blackwell et al. [2001], is a combination of a representation and the tool that supports it (paper, computer, foam blocks). Together, these augment a user's limited cognitive abilities by, for example, offloading information into the environment from the user's working memory. This is required to enable the resolution of vast, complex problems in disciplines like engineering using limited human cognitive capacity. A page printout and an Adobe PDF document are both text-based representations that are easily interoperable though printing and scanning. They constitute different cognitive technologies because of the different media of computer and paper and because of what those media afford in terms of interaction. Comparisons between these are possible by examining "cognitive dimensions" within those technologies, some of which are introduced in later sections. These concepts help to describe and compare the representations of interest and how they enhance the use and preservation of detailed knowledge of technical systems over distances and time spans that were once only supported by systems of books, journals and other paper media.

2.2 Thinking in Graphs and Hypermedia

One approach to making sense of these complex webs of information and meaning is to represent elements more or less literally using graph visualizations. A graph is a set of points (or nodes) and links (arcs) between them. It can be represented literally as points and lines or as matrices. In knowledge capture graphs, this structure is used to link text nodes with lines that may consist of arrows or contain labels themselves. This basic construct provides a completely different mode of representation to traditional text, freeing the user to develop meaning from both layout and contents. Key examples of software-supported graphs include concept maps, mind maps and IBIS rationale diagrams shown in Figure 1.



(a) concept map (b) mind map

(c) IBIS rationale diagram

Figure 1. Examples of Graph Tools

The concept map (Figure 1a) allows any topology of linking from concept node to concept node. One characteristic of concept maps is that the links are labelled. This allows explicit specification of the type of relationship between the concepts. Node styles and positions may also be varied to achieve almost any layout. The mind map (Figure 1b) tends to be a “spidering” hierarchy layout which reduces map size and clarifies relationships. They are often used in tasks like brainstorming, for example, because this simple topology replicates that of ideas being built off each-other. The IBIS rationale diagram (e.g. DRed “Issue Based Information System” graph shown in Figure 1c) consists of typed nodes containing issues, answers and arguments. Note the icons denoting if issues (light bulbs) are accepted (check mark) or rejected (cross) as well as the plus (“pro”) and minus (“con”) arguments. This added level of semantic structure allows these maps to be read at different levels, such as visually scanning for accepted decisions when troubleshooting a design and then reading in detail when an interesting branch is found. Layout in IBIS is also free-form. These types of graphs have been deployed in advanced applications such as system design in a global aerospace company [Aurisicchio et al. 2007] and as a potential tool for real-time extravehicular activity (EVA) planning activities with NASA [Clancey et al. 2004]. Computer-based tools to support any of the above graphs are often further augmented by manually inserting hyper-links for navigating information systems such as a local computer file system or the Internet.
The topic of this paper emerges crisply from a detailed study of the Design Rationale editor (DRed) tool presented above. Aurisicchio et al. [2007] performed a study of the value of the rationale graph compared to traditional reporting techniques in a major international aerospace company. The company has been testing and co-developing the software tool for several years, incorporating it into its standard reporting practices. The study looked at the potential for the DRed graphs to match the performance of standard text-based Design Definition Reports (DDRs) used for recording rich information about complex products. The performance was considered to be a function of the speed, accuracy and completeness of understanding derived from the different reporting styles. The importance of this study is that, now that the company has moved to using DRed more extensively for reporting, future documentation will rely on the effectiveness of the graphically-structured text.
This preliminary research suggested that there was an advantage to the structured (graph) form of document. The study was unfortunately based on small samples and all of the source material was reverse-engineered from old narrative documents which allows both loss of content and inadvertent addition of structural cues not present in the original documents. This paper seeks to build on those studies by focusing on narratives and its potential in graph forms in the context of cognitive technologies for engineering design.

2.3 Narratives and Storytelling

Theories of narrative and storytelling have re-emerged as a topic of interest in knowledge management over the last few years. The ambiguity of how some words are used in common practice and the different aims of various theorists seems to have lead to a divergence of meanings in the theoretical discourse. The following sections review literature and propose core definitions, component elements and superstructures in this area.

2.3.1 Core Definitions

The central terminological issue is the contrast between narrative and story. Schröyegg & Koch [2005], among others, note how this distinction is not clear even in the knowledge management literature. They note that commonly discussed elements of story include an intent to entertain, a plot with causal sequence, beginning and end. Lloyd [2000] describes storytelling in engineering design as an activity that helps to connect social, individual and organizational experience. It structures meaning in a way that allows understanding to be carried across the boundaries between those levels. His definition of a story involves something that is read, has various viewpoints, closure and a referring name. He only notes narrative as a structure within story, a thread that links events over a line like time. It is a part of the delivery mechanism of the story formed from a particular viewpoint that may become part of a story. Shank, in his book on stories and memory [1990], discusses stories as “memories” to which we attach particular interest. They serve as patterns to which we continuously compare our current experience in order to decide how to behave next. In this way, he argues, stories are knowledge. Narrative is sometimes described in these ways as well, however, and different authors interchange narrative and story as the highest-level concept.

For the sake of this study, narrative will be defined as a *structural* entity which contains multiple meaningful threads made up of elements at various levels of abstraction (context, actions, etc...). Stories, in contrast will be taken as having an experiential component. The latter is created when a person experiences it (in Lloyd's expression above, as it is “read” [2000]). This experience could be passive, by listening to the story being told, or active, through remembering or retrieval from an archive. Stories self-propagate in the human systems because humans are partaking in the existence of the story. Narratives are a structure that enables the presence of a story. When someone expresses their experience via a narrative, their participation is implicit, therefore it must be a story. This interdependence is perhaps why the discourse on narrative and story interchanges the terms so frequently. A narrative can contain a story if it is rich enough to the reader. A story captured in some sort of representation contains narrative but the narrative need not be pre-existing. It can also emerge as an individual makes up the story.

2.3.2 Component Elements

The most fundamental component units come from the classical reference to stories having a beginning, middle and end. These delimitations serve to give a story a sense of completeness or “closure” [Lloyd 2000]. Constituent elements that can be linked into a narrative to form a story include anecdotes and archetypes. Anecdotes are naturally-occurring factual narratives that may not contain goals or plots but simply come into existence as part of daily activity. Snowden [2000] likens the contrast between an anecdote and a story to the difference between a blink and a wink. The first just “happens”; the latter is full of intent. Archetypes are stereotypical actors within a story whose behaviour is known within the culture of the story. They are the villain or the hero, the diligent worker or the “slacker”. In more general terms, they are elements with known behaviours.

2.3.3 Superstructures

Stories (and the narratives within them) also form specialized superstructures within organisations. Fables, for example, are stories with a simple core message attached to skill-demanding, high-impact delivery [Snowden 2000]. Anyone who hears it will remember the core message very well but the dissemination will be limited because the average person will also fail to tell the story with enough impact to make it memorable. A script is more complex. It is the “official story of an organization” [Snowden 2000] containing the implicit narrative of the natural discourse of an organization. The script is what the organization “thinks” and any new stories must fit within or confront the script to survive.

“Reference names” are superstructures of another kind [Lloyd 2000]. They refer to known stories with very short, almost glib terms. That term enables an “economy of language” in a group's discourse because it enables significant structures of meaning to be attached to particular expressions. In today’s English-speaking engineering culture, a terse story might be “Challenger” or “Newton's apple” because they evoke complete sets of memories and meanings that are a part of the shared experience.

In sum, the highlighted literature covers stories and narrative as mechanisms for understanding, indexing and manipulating shared and individual memory. The importance of narrative emerges as the structure of representations which can be more easily experienced as stories.

3. Roles of Narrative

Any kind of human-computer interaction design is about finding the “best-fit” relationship between what people and computers can do for any given activity. This section outlines some features of how narratives are valuable for this work as well as how they could be compared or combined with existing graph tools. To reiterate, a narrative is defined here as a structure of representation consisting of a rich mix of meaningful elements threaded together in a sequence with a definite beginning middle and end. Given this definition, however, they are not a complete cognitive technology, as defined in the previous section. They must be combined with some tool or medium. This is interesting because it does not constrain narrative to any particular tool or representation. There are many ways of supporting a chain of meaningful elements, some of which are reviewed in the following section.

3.1 The Shape of Experience

The tasks that a single actor can perform (be they a person or computer processor) are necessarily linear. One could view any process with a single entry or exit point as a linear construct. Any iterations or loops between those points need only be described once since they repeat.

The first step is to examine a representative engineering design activity. Engineers spend a significant amount of their time (as much as 30% according to a Lowe et al. for example [2004]) searching for and accessing design information. Search would thus seem to be an important activity to augment. Narrative, as a structure, fits the temporal path that a user experiences when navigating information. In modern browsing systems, this is captured in the "history" function and thus is nothing novel. Strictly listing the record as a narrative is also not necessarily useful for conveying an understanding of it since the structures being browsed are probably non-linear networks. Where narrative becomes potentially valuable is in the capture of this search experience. Specifically, a narrative structure could be imposed on the resulting search history to summarize the valuable parts of the activity for future users. Adding a mix of additional meaningful elements in the form of a *secondary notation* (a cognitive dimension in [Blackwell et al. 2001]) to the narrative (notes, media, etc…) further improves the story that would be "read". Whether this "augmented history" concept is useful would need further testing but it is an example of an alteration that can be inspired by searching for narrative structures.

This example, though not particularly ground-breaking, raises the issue of how to form or extract narratives. The "augmented" history's annotation may require more work on the part of the user who, while searching, probably had other priorities than annotating their navigation history. What incentive is there to take time out to *potentially* help someone who *might*, at some point in the future, benefit from the created trail? This sort of feature is most likely to get used if the augmented history is immediately necessary for communicating an idea. The additional cost of capture, in most cases, probably needs to pay out in terms of immediate cognitive assistance. Where work was already sufficient to keep a user busy, adding work means that additional time needs to be found somewhere. The additional capability probably means giving up something else.

The importance of the structure of information for augmenting use is highlighted by the concept of the "shape" property of information. [Sengupta & Dillon [2006] note that: "on the basis of a life history of reading and using information, people have expectations of how information should be structured, and these expectations are applied during task performance in anticipation of locating target information within a document." This relates to the *closeness of mapping* cognitive dimension which describes how close the structure of the representation is to that of the problem. Here, it is not only related to handling the complexity of the represented material but also to meeting the expectations of the user. If there is a sense of something being lost or ill structured when converting between narratives and graphs, it is probably some element of the "shape of information" that was not transferred. *Conversion of information shape from different document types is not obvious since it is an user's experience* and not necessarily explicit in the document being worked on. The usage practices surrounding a cognitive technology are thus critical in comparing or converting between narrative and graph forms.

3.2 Making Sense of the Information Cloud

One of the critical challenges in the evolving use of information systems in engineering work is maintaining an understanding of the many *relevant* disparate elements in an information system. Information will have been generated in a series of separately used and evolved, it will be stored and accessed through massive information repositories at some point in the future. It is proposed here that narratives exist within and between these many engineering design representations and that they may be useful for maintaining and reusing the information.

Consider the metaphor of a design "space" which contains all the concepts related to a given design across people, artefacts and systems. In order to be manipulated by designers, these concepts must have a corresponding representations that are used to express and communicate all of the concepts in the design space. Being a multidimensional space, it could be viewed in any number of ways but, for the sake of argument, Figure 2 demonstrates the concept using generic axes. A nominal axis organizes elements simply split into named categories. An ordinal axis organizes the representations in a relevant order (such as into project phases in time or a quantitative characteristic). Narratives are shown as lines having starting points (circles), paths and ends (arrowheads). The concept of "span of awareness" was also added to the diagram. Here it means the sum of representations used by an actor to understand a design at any given time. This outline will shift depending on the goals of the actor and the representations that they find useful in fulfilling those goals.

The idea proposed here is that some of this representation space is narrative in structure. An individual develops an awareness and understanding of their work's scope based on representations they are exposed to. Each of these may be part of a narrative that they use to link the representations in their own understanding. Each representation also links to other narratives present (in)formally across the representation space.

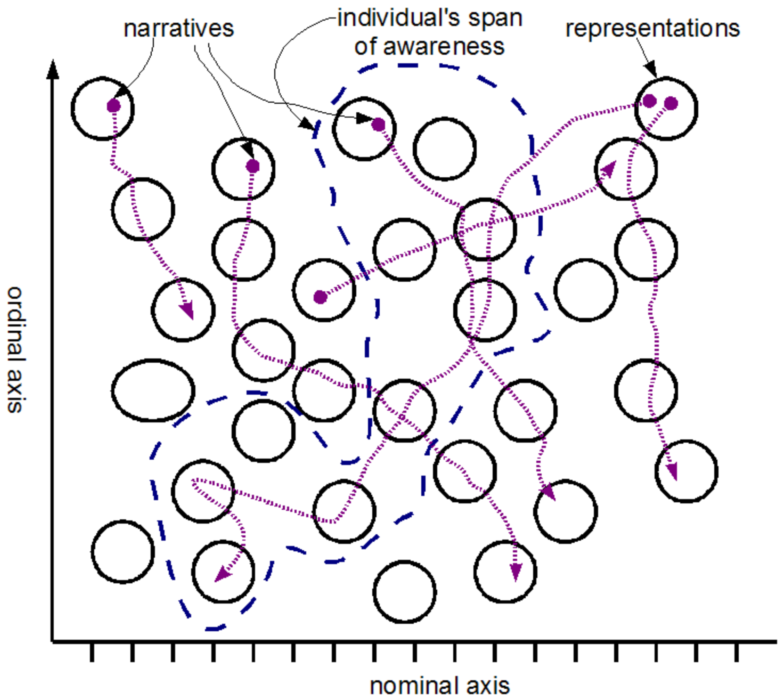


Figure 2. Narrative as a Top-level Structure in Information Space

One could then draw analogies from storytelling and narrative theories. Superficially, the graph itself seems to embody the script of an organization, or at least the digital mirror of it. The concept of fables suggests that some of these narratives need to be carefully constructed and controlled.

Archetypes could be both the standard representations (types of diagrams, reports) and even types of narratives within the space. Archetypal representations would tend to have a particular "information shape" so users know where it should fit into the overall picture and what other representations it should interact with. The important documents and discussions about product change management or critical information sets used on very difficult technical problems could form archetypal narratives. This helps the user make sense of a given narrative faster while focusing additional attention where it is needed in individual cases, that is, where it diverges from the standard behaviour. Reference names create a shorthand to focus on those significant differences, in other words they rapidly "situate" work within this representation space.

Each representation produced as part of daily practice could be seen as an anecdote. Engineers make quick sketches and exchange emails on various issues all the time. They are useful and meaningful when they are created but, in the context of the representation space, they do not necessarily have a place. An engineer will certainly not remember every sketch that they have made. When explaining something they will probably recall a few key ones that really enhanced their understanding of the design. The rest are not part of the narrative representing the engineer's daily work or within their "span of awareness" which contributes to understanding. In current information management systems, there is often a tendency to try to archive every piece of information generated in a project in the hopes that it will contribute understanding in the future. Fundamentally *this seems equivalent to piling together anecdotes and hoping for a story, which is pointless* from the perspective of narratives and storytelling in knowledge management. This correlates in important ways with theories on the relationship between information and knowledge. For an audience to draw knowledge from information, there is an implicit trust that the creator has embedded a message within it [Tuomi 2000]. But where does the message come from if it is not constructed?

4. Conclusion

This paper reviewed the concepts of narrative and storytelling in the context of potential applications in graph-based representations and the emerging involvement of hyperlinked information spaces in engineering design work.

The first challenge was to understand the core concepts. It was known to be inconsistent in the knowledge management discourse and it was observed that this seems due to a neglect of the audience's participation in experiencing narratives as stories. Looking at different levels of structure from the perspective narrative theory provides insights about designing better cognitive technologies for these new information spaces. Analogies can be drawn between concepts in storytelling theory and elements of this emerging information space to provide a coherent vocabulary for describing and reasoning about the information systems. It is proposed that narrative structure may connect disparate representations in a complex information space in the same way that narratives are formed with words or concepts in traditional media. This concept could then be used to inform the collective use of those representations. At a lower level, narrative is closely tied to the form of everyday experience so it is important to keep it a part of documentation in order to meaningfully capture activity. Maintaining a *closeness of mapping* through narrative structure, can help to convey experience but, like any structure, its application and maintenance inherently requires added work and infrastructure. Something trades for something else.

Through the discussion of these trends and the proposed analogies, it was found that:

- At the level of individual representations, it is not only critical to examine the explicit content of a document but also to consider the resultant user experience surrounding how narrative documents are used before assuming they can be converted to graph form;
- At the level of the "representation space" associated with a given product or company, some filtering and structuring of representations is necessary to insure that appropriate awareness is conveyed by the high-level narratives. One can tell stories in this space but it must be done purposefully since "*piling together anecdotes and hoping for a story"* is not useful.

As a philosophical discussion, this sort of work tends to raise more questions than it answers. The perspective presented in Figure 2 creates a focus for many questions such as:

- How does the narrative maintain integrity across each boundary in the figure? What about the boundary between digital and physical artefacts?
- Is there a critical density of narratives in a representation space which insures that they are useful or which over-saturates one's ability to explore it?
- What are the existing or preferable practices in constructing and maintaining these narratives?
- Is there anything that should be done with the "islands" of representation that will inevitably exist disconnected from the meshes of narratives?

Being tied to very old problems and complex, interacting fields, theories can only expect to provide a few insights or new directions without further testing. The authors are currently undertaking further work in a major international engineering company to further examine and test the effects of narrative content and graph representations in documentation. Visualization has always been a popular focus for cognitive technology development because it is well suited to multidimensional problems. As practices evolve, however, it is necessary remember the value of a simple narrative story thread.

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