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THE CAT'S CRADLE NETWORK

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ABSTRACT

In this paper we will argue that the representation of context in knowledge management is appropriately served by the representation of the knowledge networks in an historicised form. Characterising context as essentially extra to any particular knowledge representation, we argue that another dimension to these be modelled, rather than simply elaborating a form in its own terms. We present the formalism of the cat's cradle network, and show how it can be represented by an extension of the Pathfinder associative network that includes this temporal dimension, and allows evolutions of understandings to be traced. Grounding its semantics in communities of practice ensures utility and cohesiveness, which is lost when mere externalities of a representation are communicated in fully fledged forms. The scheme is general and subsumes other formalisms for knowledge representation. The cat's cradle network enables us to model such community-based social constructs as pattern languages, shared memory and patterns of trust and reliance, by placing their establishment in a structure that shows their essential temporality.

1. INTRODUCTION

Alavi and Leidner (2001) have described the problem of storing of contextual information together with the created knowledge as one of the important challenges yet to be solved in knowledge management. Such information is required to unambiguously frame the products of organisational knowledge creation, so that later decisions based upon it can be trusted. How to model this information, and how much to model, of is a significant open question. In this paper we will argue that the representation of context in knowledge management is appropriately served by the representation of the knowledge networks in an *historicised* form.

Representation of knowledge as essentially atemporal is part of a modernist paradigm of explanation that can no longer be considered reliable by the knowledge management community, yet it continues to inform the current models and data structures of knowledge representation. Clearly, any system of knowledge production occurs within a temporal context, and is used within a temporal context. These mark the availability of information pertinent at a given time, and relate to the prevailing priorities, workgroups and themes applicable in the knowledge production. In a learning organisation, where understanding may evolve, the associated productions of knowledge are reinforced, and mature and develop through use over time. This provides a context for interpretation of particulars that is understood within its community.

Despite its potential importance for understanding the knowledge productions of a community, however, this historical context is not usually modelled. In this paper we therefore consider what is involved in modelling temporal context, and present a new formalism for a contextualised, historicised network: the cat's cradle network.

1.1 The Paradox of Modelling Context

Modelling context seems inescapably paradoxical: we find that context must be both within the model (being modelled), and outside it (informing the modelling process). Any knowledge stored without a context is meaningless, while trying to put the context in the model leads to an infinite regress of meta-contexts.

This problem is not new: it has troubled researchers in the field for a long time and has set limits on many an attempt at a systematised knowledge management. Early attempts to capture knowledge in tree structured rule formats foundered, since the required number of rules becomes ever expansive, with the depiction always remaining essentially incomplete (Collins, 1987). Furthermore, relying upon symbolised entities and relationships, such as symbolic rules and associations (but by extension any formalisation of human knowledge production such as a discussion database, a repository of documents or a glossary based scheme), leads to a requirement to decide granularity and depth of representation on a domain-specific, and possibly purely expedient, basis. Data-set bound sub-symbolic representations suffer from the same problems: there is nothing fundamentally different between (say) artificial neural net and symbolic representations in this regard, and both symbolic and subsymbolic representations of knowledge are fundamentally limited by the selection of possibilities from an articulated population.

This is not to say that there is no value to be had by adding information, increasing samples, elaborating rulebases and linking to auxiliary knowledge sources: many effective systems in limited domains have been constructed in this way. This might suggest a research agenda based around elaborating the representation within its own framework, as Alavi and Leidner (2001) seem to imply with their generic 'how much context to model' research question. This, however, still runs directly into the *applicability* problem, described by Collins (1987), using Wittgenstein's (1953) formulation that "rules do not contain the rules for their own application". Collins thus scopes the potential for storing full contextual information, and shows that modelling context as a set of 'metarules' amounting to metaknowledge is to all intents and purposes futile. The *extra* information about the applicability of knowledge in any given circumstance must be provided by context over and above the ruleset by which it is supposed to be represented. Eventually such an approach leads into the pragmatist trap of deciding some finite number of metarules on a circumstantial basis. Not that such a strategy is necessarily ineffective for everyday purposes, but it misses the essential point about context.

Within the knowledge management literature, appeal has frequently been made to Polanyi's (1952; 1966) concept of 'tacit knowledge', tangibly realised in many systems by having a 'user in the loop'; an open interpreter of symbolised outputs into an active situation. This strategy avoids many of the problems of context, but potentially introduces degrees of freedom to the interpretation of modelled knowledge which are incompatible with the learning and intentionality embodied in the symbolised representation. Moreover, when Polanyi first conceived of the tacit dimension of knowledge, he was engaged in a project to remove just such subjectification in the empirical investigative framework. He achieved this by neatly sidestepping the problem of recording context, instead having it as part of the tacit dimension of the investigative framework. The knowledge that a system would represent is seen as an *action from* a context *to* an area of application: importantly, Polanyi showed how the significant portion of both the tacit and explicit are dynamically bound, rather than fixed as static domains.

If it is the case that not only the problem, but also the domain and the context, are late-binding in their values, the problem of representation can then be seen as one of mapping the *action* of knowing.

This leads us to the consideration of another, hidden problem that underlies all knowledge representation formalisms: the problem of time. Time is hidden because it is implicit in the context, and so in the application of the context to the representative framework. The technological frameworks that support knowledge management fundamentally require an explication, some *formal* articulation that can be represented and communicated, whether it be a database, a yellow pages, a glossary, a document archive or a procedure manual. All of these formalisms have as their underlying representation a graph (a finite and closed network). This basic form is excellent at showing the interconnectedness of the components of knowledge, but ultimately it shows only a particular state, or snapshot, without direct reference to how the relations between the components came to be seen as representatively significant.

What is missing in the represented network is the historicised context of *why* the relations are as they are, and the procedural mechanisms to determine the significance of the historical relations in the present situation. Making the network 'bigger' does not overcome this. Instead, by the introduction of temporality into knowledge networks, we may separate the immediately precedent (and hence proximally causal) context from the deeply cumulative context. By the consideration of history in our representations, we can make manifest the continuous nature of the formation and reformation of the contextual framework itself. We can thus take the closed nature of symbolised representations, and open them up through contextual interpretation into active situations.

The historicised knowledge framework goes only part of the way towards solving the problem of the representation of context, however. Part of the explicative process for any event or situation is not only the immediately precedent facts, but also an assessment of the *intentions* of the agents who may have been responsible for the creation of the causal chains in the first place. And to understand these intentions, we find ourselves in the curious position of representing the anticipated future that led to the decisions at the start of the causal chains. And as part of that process in turn we must account for an understood past in the mind's eye of the agent.

Thus we need a structure for representation that is not only capable of representing associative networks of knowledge, but also of showing their temporal and purposive aspects. Knowledge networks are not only weighted directed acyclic graphs (DAGs), they are weighted DAGs with a pedigree. Any static representation of a knowledge network will therefore miss this point: knowledge networks, even 'pre-packaged', cannot be created out of nothing, but must be built up step by step.

A best-practice modelling tool for knowledge networks must therefore take into account not only the current disposition of nodes and links, but also what has gone before and what is yet to come. It is the aim in this paper to specify the requirements for modelling the temporal and purposive aspects associated with human knowledge production.

2. THE CAT'S CRADLE NETWORK

All networks of linked semantic nodes possess a history separate from the mere geometry or topology as presented in a conventional network diagram. The process of adding newer nodes, of different agencies and episodes of agency, all create a situation where whatever is embodied in a network of knowledge-context only becomes apparent when three separate phases are recognised and represented:

1. The past and its complete record both of becoming and intention to become, and what each step meant on its own and in process
2. The present and its being and its self-description
3. The anticipated and actual future states

In modelling the knowledge networks in a way that represents their inescapable temporality, we have to bear in mind that the model should not allow for 'short cuts' – ways of short-circuiting the timeliness by permitting an asynchronous unfolding process. In other words, some lineally ordered constructive process that has a specifically evolved integrity is required, so that the provenance of a knowledge production can be trusted. We need a model that can only have come into being in one way, whilst still allowing for multiple departure points from any one stage. Above all, it must not be possible to create the final model in one stroke. These conditions preclude fraudulent or inadvertently spurious representation of a knowledge network.

Our model for the analysis of purposively constrained information networks is the 'cat's cradle', the canonical string figure.[1] For our purposes, the significant feature of a cat's cradle is that it is quite impossible to come to any step in the figure's construction without having first gone through all of the prior stages. One cannot simply make a cat's cradle *ex nihilo*, or take short cuts. The form it takes directly follows its evolutionary history. An evolved and recognisable form may appear fully fledged in a communicable and recognisable picture, but this is to lose the process by which it was created, the

[1] String figures are designs formed from a loop of string, and woven with hand movements into particular identified shapes, such as 'Jacob's ladder' or 'Fish Spear' (ISFA, 2001). Starting from the simplest configuration of a loop or cycle, particular operations form distinctive shapes, which are partially determined by the preceding usage context, and which, consequent on the history of moves made, will achieve an intended design.

turns it has taken on the way, and the purposive development of the form. This recognition is challenging, but it is fair to say that the difference between a purposive network and its reduction into a set of lines and small circles purporting to represent it is precisely in the 'bits left out'. A network *simple* would reflect the externalities of a knowledge production process, but until a network simple is contextualised into a cat's cradle network with history, intent and description it is inadequate to the job of modelling context.

2.1 Properties of a Cat's Cradle Network

Extending a simple network involves retaining all of the properties of the network formalism including implicit hierarchical structure, direction, weighting and biasing disposition. What is required, however, is a mechanism to handle change, sequences of state transitions and temporal proximity as is required for modelling context. In modelling we are interested in both representing and measuring these changes. A starting point for the creation of such a model is the Pathfinder network (Schvaneveldt, 1990), which is a dynamic, weighted network used in eliciting and representing human knowledge. It subsumes both other network formalisms and hierarchical clustering schemes such as are used in knowledge modelling, and is therefore an equivalent basis to any particular ontology or causal graph.

We aim to augment the Pathfinder network to enable its disposition through time. We draw on Schvaneveldt's insight when he states "dynamic instantiations of schemata are realised by a procedure in which particular nodes are activated continuously [and activation spreads] until a stable pattern of activation across all of the nodes is attained" (Schvaneveldt, 1990; p.136). This approach iterates on the relationship amongst identified entities until an optimal configuration (according to user specifiable criteria) is reached. Once achieved, the network state can be recorded.

The Pathfinder formalism may be extended to express the historicisation of network states and thus implement a cat's cradle network. To accomplish this we need to add specific procedures to enable us to portray and model sequences of state change that permit an explanation of any aspect of the current network configuration. We define a cat's cradle network as an 8-tuple where the first seven are the defined Pathfinder properties[2] (Schvaneveldt, 1990) and the eighth is a vector representing its position within a lattice of federated Pathfinder networks. The bounds of the federation are determined by procedural semantics: a mechanism already implicit in Schvaneveldt's discussions. A corollary of this is that formally any Pathfinder network is a cat's cradle network where the eighth tuple is a singleton, just as it can be shown (Durso & Coggins, 1990) that all other networks are Pathfinder networks where one or more tuples has a singleton or null as value. Thus our scheme is general, subsuming other knowledge modelling formalisms such as Petri nets and entity-relationship diagrams.

As a semantic structure unfolding through time, the cat's cradle network can be seen as one of a family of models where becoming through change, and the necessity of contextualisation in the model's mechanism, are as important as representation of the states in that process (such as Barsalou's formulation of the operation of human long term memory (Barsalou, 1982; Barsalou et al., 1993), or Wenger's (1998) model of communities of practice). What is common amongst these explicative systems is not the fact that they extend through time, but that they show how atemporal explanations are insufficient to account for all observable phenomena. In the same way we must move the modelling of knowledge networks away from a fixed, canonical, and indexable form, to a coherent and

[2] A Pathfinder Associative Network (PFNET) is a mechanism for representing proximity data. For any set of complete data (termed a DATANET) a PFNET is a 2-value constraint PFNET(r,q), where q limits node-traversal, and r qualifies the cumulative weighting of the edges.
The 7-tuple is given by the definition:
PFNET(r,q) = {N, E, W, LLR, LMR, r, q} where
N is the set of nodes
E is the square matrix of the named links
W is the square matrix of the link weights
LLR is the link-labelling rule
LMR is the link-membership rule

contextualised evolution of understanding. Pathfinder networks show how concepts are related in the minds of individuals or groups, and have mapped the differences between expert and novice understandings (e.g. Durso & Coggins, 1990). Adding a temporal dimension to them, as the cat's cradle network does, permits this to be traced over time, as understanding evolves.

3. PRACTICAL IMPLICATIONS

Not only is the cat's cradle network useful for introducing the representation of context in small-scale knowledge networks, it can usefully scale up (in a way that does not rely on network effects) to highlight the nature of the knowledge of communities by the same process of representing contextualisation as historicisation. The cat's cradle network enables us to model such community-based social constructs as pattern languages, shared memory and patterns of trust and reliance, by placing their establishment in a structure that shows their essential temporality.

When Alexander (1979) elicits pattern languages from a community of practice in building design (which he describes as "the timeless way of building"), the language in use is verified by the experience of individuals through their perception of morphological and functional completeness for any single instance. Becoming acquainted with the pattern languages is part of growing up within a community. For such a language to exist it has to be continuously revitalised – the language patterns are used to build new structures that conform to a use, while the new uses gradually both consolidate and redirect the patterns over time. To represent patterns as static mechanisms is to keep them tied to a moment, becoming rapidly obsolescent. In Alexander's terms, we would be mistaking the building for the pattern it instantiated.

In the same way, organisational histories and experience are not simply mandates for re-enacting traditions, to be clung to or overthrown, but provide valuable sources of learning, if their provenance-in-context is communicable. Without mechanisms for reflecting context, this value is reduced, and misrepresentation likely.

The cat's cradle network illuminates the roles between individual documents as knowledge artefacts, and both the document repository and the organisation itself. As socially held information, an organisational culture provides a backdrop to constrain individual configurations of representation for its artefacts. When we create a document it is grounded in the provenance of its culture: the stories the organisation tells about itself, its myth of identity. This implicit contextualisation means that any given document will occur within at least one, or more likely very many, document sequences. This holds true for all such sequences, from continuous chains of correspondence, or actioned minutes of meetings, all the way up to large scale audits and process reviews. It shows us that when we consider the addition of new documents into the system the cat's cradle network enables them to be grounded in the evolving usage context of communities of practice[3], providing a model to guide this aspect of knowledge management implementation for organisations.

This gives a semantic grounding for the stored representations, relevant to establishing provenance and basis for particular configurations of representation. By considering the shared context as *noetic umwelt*[4], we have a sense of the necessity of timeliness and situation. Both of these readily comport with psychological understandings of memory function, and implicate histories of use as partial, but not inevitable, determinants of meaning.

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[3] This approach motivated the IDIOMS project (Gammack, Fogarty, Battle, Ireson, & Cui, 1992), a distributed decision system that generated decision rules from a live and continuously updating corporate database.

[4] An *umwelt* (Uexkull, 1934) is a specific perceptive universe – the universe as perceived by an individual species. Fraser (1975) extends this concept to the *noetic* umwelt, wherein the notions of temporal or metaphysical transcendence are paramount. A noetic umwelt looks out at not only the physical universe, but also the created constructs in that universe, and the structures that are perceived to transcend it.

Considering communities of practice in the business sector as noetic umwelts is more than a semiotic shorthand, or an expedient justification of an existing practice being moved to the electronic domain. It makes sense of the existence of communities of *trust* through shared understanding, and of practices that are grounded in that understanding such as proof of identity, establishment of credit, or reputation for reliability[5]. These cannot be created from nothing – they must be established and reinforced over a period of time: the greater the time, the greater the degree of reliability of any expression of that trust.

There is also an implicit regionality in such things as proof of identity, grounded in local practices, and the localisation of trust (in any one of the topographical, topological or analogical umwelts to which an organisation may belong). As an example, consider the establishment of identity (say for the purpose of cashing a cheque): the proof of identity through a local rental agreement, or membership of a sporting club, will be more relevant and so more trustworthy than a document that is in the abstract more reliable (such as a bank account, driver's licence or passport). Similarly, a well-known point of reference such as a school-teacher or a parole officer may be entrusted with supplying far greater numbers of references than would normally be acceptable for a warranting system.

As well as showing the process of building up trust, the cat's cradle network can also make for a better representation of catastrophe events (Thom, 1975), such as a departure from a team or organisational unit. These phenomena are essentially temporal: an isolated knowledge network structure would represent them as either stasis (the pre-catastrophe condition) or a lacuna (the post-catastrophe condition). However, with the representational potential of a cat's cradle network, we can both show and measure the increasing tensility of a stationary node under increasing stress, until the point of disruption. This alone leads to several interesting new possibilities in the modelling of knowledge organisations' entity life histories, not the least of which is the potential for prediction of such catastrophe events, by modelling the localisation of edge tensor change around an isotropic node. In effect, this is a modelling of contingency, without the assumption of eventuality.

4. CONCLUSION

We began by considering context as the *extra* information brought to declarative representations to make them actively useful, and how there is more to context than a linear expansion of a knowledge structure. We noted that the way in which symbolised knowledge is brought into being involves an essential extension in time to be either represented or explained, rather than deciding how much more 'to include'. The old distinction between declarative and procedural forms of knowledge applies here, although context goes beyond simply procedural knowledge, which can be declaratively specified.

Although tradition and history may provide a strong determinant of understood human meaning, the decision to trust a preconceived interpretation and apply it in the current context lies outside that. So although useful patterns can be identified for any given community of practice, they are essentially temporal, and bound by the norms of the community or culture who lend meaning to them in temporal contexts.

We have introduced the model of the cat's cradle network, a temporally-arrayed series of knowledge representations that permits the recording of context as an emergent phenomenon of that series. We showed how this model is in turn a higher order network (a network of networks), which may be recorded using an extension to the Pathfinder associative network. By tying the representation of contextuality into the series of similar representations rather than a larger representative framework, we can see the explicative power inherent in the examination of the cumulative precedent. Adding new

[5] This approach motivated the commercial development of Moneypenny (Pigott & Poulson, 2002), a contextual environment for document and profile creation in the domain of short-term financial advice and assistance. A system, called the Peer-Association Pooled Assurance System (PAPAS), was developed to mimic the trust that already existed between practitioners in the field, of shared referencing and systems of identification.

instances of knowledge representations in a temporal framework of similar representations ensures their localised integrity. This permits documents to be elucidated and contextualised by their place in a document series, and gives meaning to incidences of trust or distrust by showing them to be rational responses to accumulated experience, rather than singular instances of emotion or judgement.

Part of the context of change will always be the set of anticipated outcomes that includes the smaller set of preferred future outcomes, so the chosen outcome has as part of *its* context the alternatives not chosen. Just as deeply historic context becomes less relevant through time, so do these 'first cousin' possible outcomes become less and less relevant to the current context. Identifying the range of considered possible future states is as much a part of representing context as is recording the past. This is critical for organisational learning, since without knowing why something was rejected, failed or not selected, future decision makers may repeat avoidable errors. Specifying a mechanism to handle this provides one future challenge for this research.

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