A New Data Model for Depicting Traditional Ecological Knowledge in GIS via Motifs, Folk Thesauri and Narratives

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Abstract

Current GIS data models have problems representing fuzzy, interconnected data sets, due to problems inherent with the underlying abstractions used for storing and manipulating geographical information. These limitations are becoming problematic when processing traditional knowledge of spatio-temporal patterns. The authors present a new approach to the representation of fuzzy, spatio-temporal knowledge, as found in traditional knowledge systems. The approach used centres on the motif, the folk thesaurus, narratives, and a data model that connects them. The authors suggest modelling spatio-temporal knowledge in a way that maintains some of the strengths of oral depiction, interconnectedness, and precise ambiguity. We discuss how spatio temporal motifs interact with other motifs via shared elements, via narratives and via processes. Finally; we explore how a working data model centred on motifs may be conceptually and logically represented.

Keywords: Spatio-temporal Data, Traditional Ecological Knowledge, Ontology, Data Model, Motif, Thesaurus, Narrative, Folksonomy.

1. Introduction

Spatio-temporal Traditional Ecological Knowledge (ST-TEK) is complex. There are multiple ways of categorising types of space, types of time, and types of events. These often fall outside of the clock and calendar time, of cadastral space, of crisp (non-fuzzy) timestamps, and of demarcated boundaries. Traditional Ecological Knowledge (TEK) often comes in the form of a more abstracted sense of the right time and place for given activities. The data does not always have solid co-ordinates attached. The times involved are seldom unambiguous. Patterns of behaviour are often recurrent. Much of the data is qualitative, and its quantitative aspects are not always accurately parsed by the western calendar. This paper presents a new model for representing traditional and Indigenous ST-TEK, and provides a recipe for a more complex understanding of space and time than is currently available with current GIS design. The core of this approach is the **motif**. This is a repeating pattern of spatial and temporal context around a given action or state, as temporal reckoning is often multi-cyclic and contextual. Ontological categories likewise are not necessarily easily translatable to universalised categories now common in GIS. These interrelate via a **folk thesaurus**, which contextualises terms for times, spaces, and actors via a web of nested and interrelated types of semantic relationships. The emphasis is on verbs, not nouns; change, not stasis.

The model allows for spatial, temporal, and semantic fuzziness. It allows for more qualitative spatial and temporal structures. The concepts of the motif and folk thesaurus allow for creation of ad-hoc semantic relations in a robust, yet flexible way. Motifs can also be threaded together into a **narrative**, and narratives can intertwine and interrelate in a number of ways.

Current GIS data models have problems representing interconnected data sets, due to the underlying static data abstractions used for storing and manipulating information. Spatio-temporal motifs are data structures set up around a statement and a context and are meant as an alternative data model to the current GIS systems that provide an incomplete view of time, events and processes. In this paper we discuss how spatio temporal motifs interact with other motifs via shared elements, via narratives and via processes. We also explore how a working data model centred on motifs may conceptualised. These motifs should provide a more natural fit to TEK and other knowledge systems with looser schema than what a GIS usually allows.

2. Challenges of Modelling ST-TEK

Due to the ebb and flow of natural events and processes, traditional knowledge systems seek ways of finding the right time and avoiding the wrong time for given activities. Some cultures may have fairly rigorous and systematised ways of keeping track of time, but for others, timing is very much tied to a given place. A question like “when is it a good time to fish for salmon” opens up a rich universe of timing. This timing can be contingent on the person, the place, the weather, the gear, the particular species of salmon, and habitat conditions.

2.1. Fuzzy Time and Space and the Need for Narratives

Spatial characteristics of this data can also be vague. A herd of animals or a forest can be treated as either an object or a field (Turk, 2006). Semantic fuzziness is also a key characteristic, where natural language is rife with ambiguities. The same species may have multiple names depending on age, sex and usage; consider the terms hack, stallion, mare, gelding, foal, filly, and colt for horse. Because of these ambiguities, it is important to construct local ontologies that are relevant to the material on hand and the patterns to be mapped (Janowicz, 2012). We need data models for spatial depictions that represent the underlying cosmovisions of different cultures in order for those visions to be able to thrive on their own terms.

Narratives play a key role in human understanding of complex systems, and narratives track processes well, but are not well modelled in GIS or databases in general in a manner that facilitates their use for querying and comparison. Without narratives, we cannot make sense of how different aspects relate to one another, or why certain elements of information are more salient than others. We cannot understand why a dam built 400 miles away may affect moose hunting in another location. We cannot understand how impacts become cumulative. We can connect different times and places structurally, but not how they connect via processes. Narratives also allow for analogical reasoning (Hall, 1989; Dehghani, 2009; Paskey, 2014). Finding narratives associated with a given topic, or being able to search for similarities between narratives would be valuable for understanding complex systems, legal narratives, and historical narratives (Hannibal-Paci, 2000; Stevenson, 2006; Waitangi Tribunal, 2011).

What is a narrative, in a cartographic or GIS sense? One approach to narratives is to see them as way of making sense of the steps between cause and effect in a model (Reitsma, 2010). Another way to understand narrative is as a combination of story and discourse, story being the events that occur and discourse being how that story is told (Prince, 1987, cited in Pearce, 2009, p.4). Narratives can also be seen as "accounts of events or series of events" that are connected chronologically (Kwan and Ding, 2008, p.449). Zarri (2014, p.82) in turn posits that the term narrative is a "general unifying framework" for making sense of stories, real or fictional, and the common relationships between characters.

2.2. Existing Approaches to Modelling ST-TEK

Reality is not always machine-friendly, and forcing it to be so leads to heavy distortion of our understanding. The current core representational model for GIS, underlying most of the basic data models such as raster and vector, is that of the geo-atom (Goodchild et al., 2007). Although there are crisper and less crisp boundaries of natural and traditional times and places, not all have an inherent boundary. Forests move. Locations of animal herds move. Research prototypes aside, all current GIS data models represent all of this with crisp boundaries and points. Due to the data models and structures of current GIS, layers and features within layers traditionally remain divorced from one another unless explicitly linked in a map or in a specific model. We have but a handful of ways of representing narratives, and they tend to take for granted linear time and crisp objects. These ways can be classed as either collecting a set of layers and stringing them together in some way, as in a series of snapshots, e.g. geo-narratives (Kwan and Ding, 2008), story maps (Battersby and Remington, 2013), and extensions of these like spatial video geonarratives (Curtis et al., 2015), or associating with a feature or a set of features in a single layer some kind of narrative embedded in text or other media.

Multiple narratives can be represented in a single map, with story components associated with features obtained via interviews when creating map biographies (Ellanna et al., 1985; Hakopa, 2011; Olson et al., 2016). These interviews are tied to given points on a map, and given points on a map are tied to evidence of the interview (transcript, time signature, video etc.). While it is also possible to have multiple interconnected narratives, they are linked via their depiction in the map, and not in the data model itself, the interpretation for how narrative elements interconnect and the significance of those interconnections are not addressed (Denil, 2016), which is critical for making narratives computationally accessible.

For narratives the flaws with the current GIS model lie deeper at its foundations, entity-relationship based models and most current graph databases do not support the nesting required for a full exploration of narratives. Ecological systems tend to be nested, with humans and other organisms having internal processes that are not required to be expanded in more detail when discussing the relationships between organisms, for instance (Gignoux et al., 2017). Process structures for the creation of an item also has nested processes at each stage (Kettula and Hyvönen, 2012). Meronymic relations in narratives and elsewhere allow for a part to stand for a whole, either as a process or semantically (Casanova et al., 2012), and there is no basic support for these sorts of nesting relationships in our current GIS models. Other systems looking to represent stories on a deeper level can be found in the field of Artificial Intelligence (AI), and there has been recent work fusing narratives, GIS and AI (Blaschke 2018). Early work by Sowa produced a stripped down system called Conceptual Graphs that is theoretically suitable for representing any human utterance and some of the logic behind it (Sowa, 1992). Conceptual Graphs evolved over time and nested graph models emerged. The Conceptual Graph and Narrative Knowledge Representation Language (Zarri, 1996;2019), is the work that this paper builds upon.

The Semantic Computing Research Group (SeCo) of Finland has also done some pertinent work for representing narratives (Hyvönen, 2009). Underpinning some of their work was an approach to link and describe semantic content via situations and actions with their "Situation Ontology" (Junnila et al., 2006 p.16). This approach followed Sowa's work on knowledge representation that is also verb-centric and lends itself well for representing narratives in an interconnected and comparable way. However, this was never explicitly extended to fully include a temporal GIS capable of dealing with both abstract and contextual space (choros and topos) and both abstract and contextual time (chronos and kairos) as laid out by Rämö (1999), and later Sui (2012), and Mackenzie et al. (2019). Not all time is uniform and chronological, just as not all place is Cartesian.

3. Proposed Approach

The proposed approach brings together motifs, folk thesauri, and narratives. A motif is a container for grouping different instances, concepts, and materials together based on a recognised essential similarity, and can be made of qualitative and quantitative representations of time, space, timing, place, actors and actions. A folk thesaurus groups motifs together, with overlap or containment between motifs based on hierarchical and associative relationships between the various elements making up the pattern. Narratives can string motifs together into patterns of processes, and any given motif can participate in multiple narratives.

3.1. The Motif

The Motif model is a new way of documenting ST-TEK. It allows for a more flexible approach to space and time than currently possible with other forms of spatio-temporal modelling. A motif is a recurring pattern of processes. A motif can be seen as a container for a contextualised action. This contextualisation is organised into facets. Missing facets in a simple motif are interpreted as being indeterminate. Facets may contain conditionals. Elements of the motif are organised along thematic lines (agent and patient) rather than syntactic lines (subject and object) (Sowa, 1992). Agents and patients are both actors. A modal statement about the motif can also be part of the motif. This can include terms like good, bad, forbidden, off-limits. Other pertinent information not fitting this schema can still be utilised for the motif container, like privacy information. Motifs are then anchored to other media including raster and vector depictions, transcripts from interviews, video, audio, or sketches. Motifs are likely to be constructed in different ways by members of different cultures. Not all languages have a verb for "to be", for example. The motif sits somewhere between the situation ontology of Junnila et al. (2006). and the Simple Event Model of van Hage et al. (2012). Motifs are represented via a "star graph" (Chein and Mugnier, 2009) made up of concept and relation nodes, centred on an activity or state, with edges connecting that relation to contextualising facets of that relation (Figure 1). These in turn take their structure from Sowa's Conceptual Graphs, or Chein and Mugnier's Basic Conceptual Graphs. Sowa's notation uses boxes or square brackets []

for concepts and ovals or rounded parentheses () for conceptual relations (Sowa and Way, 1986, Sowa 2001).

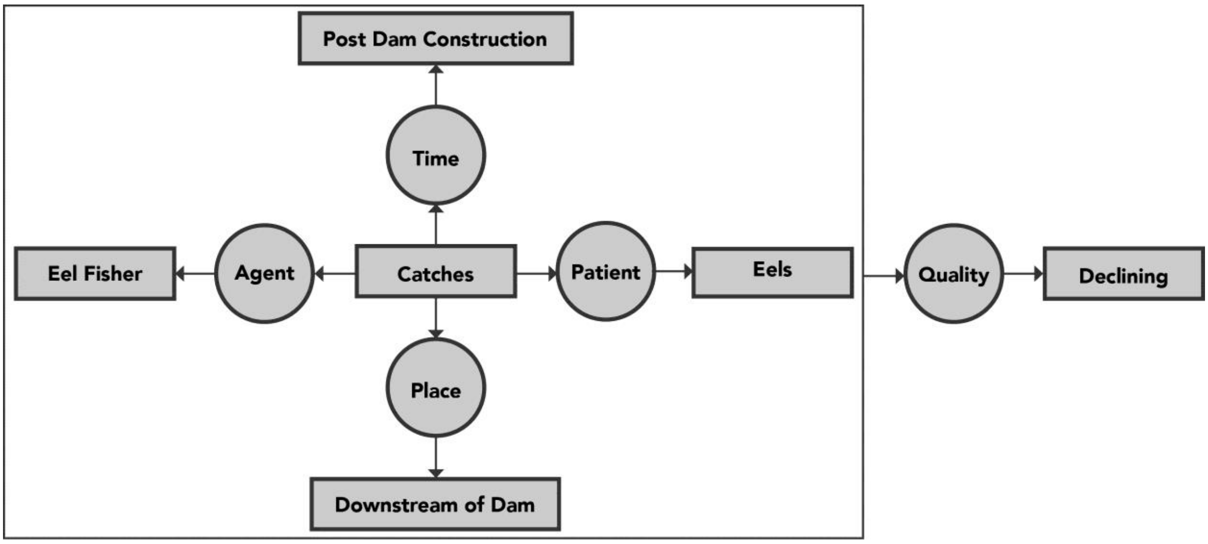

Figure 1: Example of a Motif.

Motifs are enclosed into a supernode that can then be linked to other motifs via shared facets, shared elements of facets, shared relations, or tied together via narratives in the form of correlation, causation, or otherwise. Motifs are also linked to one another via a folk thesaurus, which is an evolving editable thesaurus linking concepts and relations to other concepts and relations via semantic relations.

3.2. The Folk Thesaurus

In order to make clear how a given motif is related to other motifs along semantic lines, a different subset of motifs is required to keep track of the various semantic domains and the web of interrelations particular to a cultural framing. Thesauri in data modelling are used for providing a way of showing how different terms in a subject area interrelate, so as to facilitate retrieval and organisation. Thesauri allow for a priori relationships to be made explicit (Aitchison et al., 2000), and can be used for indexing and searching.

A folk thesaurus organises a collection of motifs, structuring traditional knowledge and domains along semantic lines. The folk thesaurus also acts as a repository for proper names of places, actors and times. Folk thesauri act like faceted thesauri, with multiple domains for spatial qualities, temporal qualities, actions and states, and the thematic roles associated with a motif. Semantic domains vary from culture to culture, and a folk thesaurus acts as a knowledge base of these domains, and provides a location for storing how various semantic terms are related as viewed by those working with the terms. The folk thesaurus allows for finding motifs related to a given motif along structural lines. A folk thesaurus has structure but is open. As terms come up that are not in the database, they can be entered in via typical semantic relationships to other terms extant in the database. With the folk thesaurus, a query for searching for motifs takes on the same type of structure as a motif itself. An open ended approach to creating is not entirely new. Kiu and Tsui (2011) suggest a similar approach with their TaxoFolk approach.

Reasoning along taxonomic lines via ontologies and the like are already well developed in the literature (Keet and Artale, 2008; Munn and Smith, 2008; Reitsma et al., 2009; Keet, 2018). However, reasoning with open polyhierarchical systems are less well developed (Hider, 2009; Duclos et al., 2014; Vigo et al., 2014). There are difficulties but they should not be avoided as concepts tend to form semi-structured lattices, not trees. These terms can be added as they are found, and relationships between terms can be built up over time and can be roughly categorised into three kinds that form the basis for modern thesauri (Harpring, 2010):

1. Equivalence relationships Use (USE)/ Used For (UF),

2. Hierarchical relationships (Broader Term (BT) / Narrower Term (NT)), and

3. Associative relationships (Related Term (RT)).

Other core relationships are possible. With a folk thesaurus, preferred equivalence terms are likely to vary from community to community, and preferred terms are likely to evolve over time as they do with folksonomies. Therefore, Equivalence, or EQ may be a better tag. Also of interest are the various hierarchical relationships, as by utilising these terms, it becomes possible to generalise motifs into other motifs by using the underlying folk thesaurus. Likewise, motifs have the advantage of also being their own querying structure, based on those same hierarchies of terms recorded in the folk thesaurus. These follow the same structure as generalisation hierarchies of conceptual graphs (Sowa, 1993).

3.3. The Narrative

A narrative is a way of reporting connected events. While a simple motif focusses on a single action or state, merging multiple simple motifs creates a narrative that shows how the motifs relate to one another. Narratives can be oral, written, or via moving images, or even danced. They are a cultural universal and one of the oldest and deepest ways our species has of making sense of complex information. Repeated patterns make up a great deal of behaviour on all scales, in areas like music, art, species behaviour, and genetic expression and these can also be modelled via narratives. Ultimately, what makes a narrative is the juxtaposition of two or more motifs that are connected in some way so as to provide a sense of flow. These connections can be but are not necessarily causal. Some of the different kinds of motifs that help shape a narrative include inaugural motifs (beginning a process), transitional motifs (maintaining a process), and terminating motifs (ending a process) (White, 1975). Narratives utilising motifs can be seen as story-like or process like, and flow from motif to motif in order to make sense of patterns too complicated to be summed up by a single action or state.

We utilise the four major ways of connecting parts of a narrative developed by PUC-RIO (Ciarlini et al., 2009; Karlsson et al., 2009; Casanova et al., 2012) incorporating the four master tropes of Burke (1941) into a more developed system of semiotics designed explicitly to create, compare and contrast narratives. Burke’s tropes, useful for narratives and any other complex set of interrelations are those of metaphor, metonomy, synecdoche and irony (Burke, 1941). These in turn are related to four semiotic relations, and these make a complete system for how the world can be comprehended in language (Furtado et al., 2014). These are related as follows (De Lima et al., 2016):

Semiotic relation	Meaning	Operator	Type relationship	Trope
Syntagmatic	Connection	And	*complements*	Metonomy
Paradigmatic	Similarity	Or	*analogously replaces*	Metaphor
Meronymic	Unfolding	Part-whole	*unveils elements of*	Synecdoche
Antithetic	Opposition	Not	*is in opposition to*	Irony

Table 1: Semiotic relations from De Lima et al., 2016

There are four major ways that the motifs making up a narrative can be linked into more complex structures using their model (Karlsson and Furtado, 2014). These are via the following. Syntagmatic relations show how one action flows from another and can be linked to causality. Paradigmatic relations are alternative ways of accomplishing the same thing. Antithetic relations occur when one set of actions would usually preclude another set from occurring. Meronymic relations allow for more or less detailed depictions of aspects of a narrative (Ciarlini et al., 2009).

These four relations can also be described in terms of AND, OR, NOT and part-whole relations, and these mirror the four master tropes. AND can be used to create sequences of motifs, each one representing some sort of action or state of some actor or system. OR can be used to provide a fork before outlining alternate sequences that relate to a previous sequence. NOT can be used to highlight sequences made impossible or unlikely due to some event or set of events. Part-whole relations can be used to unpack a simple statement into smaller components, or likewise provide a way of summing up a complex set of statements into a single statement.

For an example, let’s look at the narrative of “migration disrupted by a dam”. This could apply to a number of species, with caribou not being able to follow a traditional track, to fish not being able to reach certain parts of a river, or make their way to their spawning grounds. The dam construction could be broken down into multiple stages, all able to be represented via a narrative, if that is pertinent to the disruption. The effects of the dam can also be visualised (Figure 2).

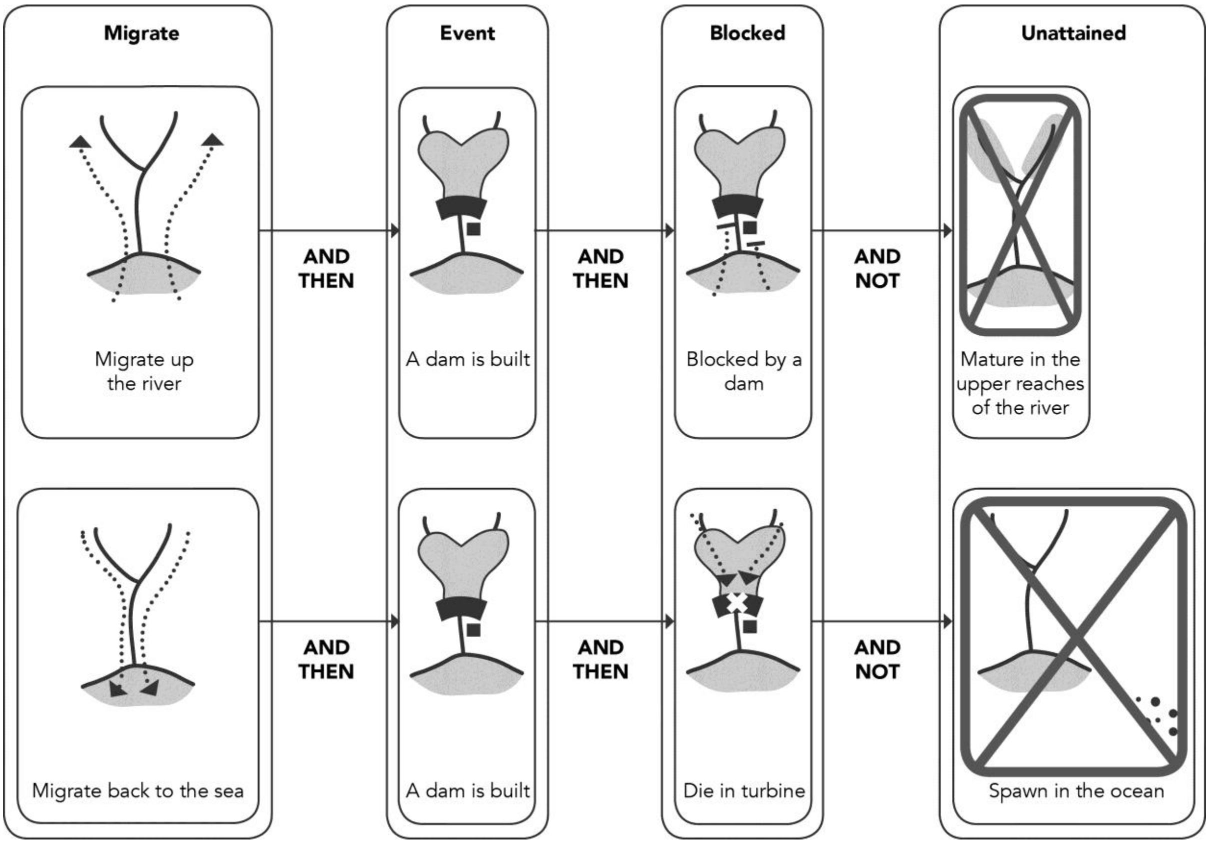

Figure 2: A complex motif diagram of the narrative:
"migration disrupted by a dam" as it applies to eels.

Although the sequence plays a key role for most narratives, some elements do not need to be sequenced, or can be thrown together in a non-sequenced fashion. If I am making a meal, I may need to follow steps to cook the meal, but I do not need to buy ingredients in a given order.

The four core relationships are flexible and can provide for a wide range of representations. They may not, however, be complete, as human cultures and forms of expression can be a source of endless complexity. Toolkits should be able to be edited to serve the needs of those using them, and we must maintain room for core narrative forms that may not fit the model given.

4. Towards an Implementation of the Motif Approach

In order to highlight how the model works as a whole, we have made a mockup of how we envision the Motif approach would be implemented using the examples given in Figures 1 and 2. Initially, such a narrative might come from interviewing knowledge holders that catch eels in the river, or via reports or papers or social media. There will be multiple eel fishers that have been watching their ability to catch eels decline, and some may have mapped their eeling spots previously, or rivers where they are declining may have been mentioned in media. The Motif allows us to group all of this into a whole, with various instances of the motif being anchored to more specific times, places, agents, places and referents. Here, the example given in Figure 1, now in linear form:

[Declining] ←(Quality) –

[[Catches] → (Agent) → [Eel Fisher]

→ (Patient) → [Eels]

→ (Time) → [Post Dam Construction]

→ (Place) → [Downstream of Dam]]

Becomes anchored in one instance as follows:

[Declining] ←(Quality) –

[[Catches] → (Agent) → [Eel Fisher: John Doe]

→ (Patient) → [Eels: Longfin]

→ (Time) → [Post Dam Construction: 1981+]

→ (Place) → [Downstream of Dam: Rangataiki River, downstream of Aniwhenua Dam -38.3083,176.7906]]

[Map: Figure 3]

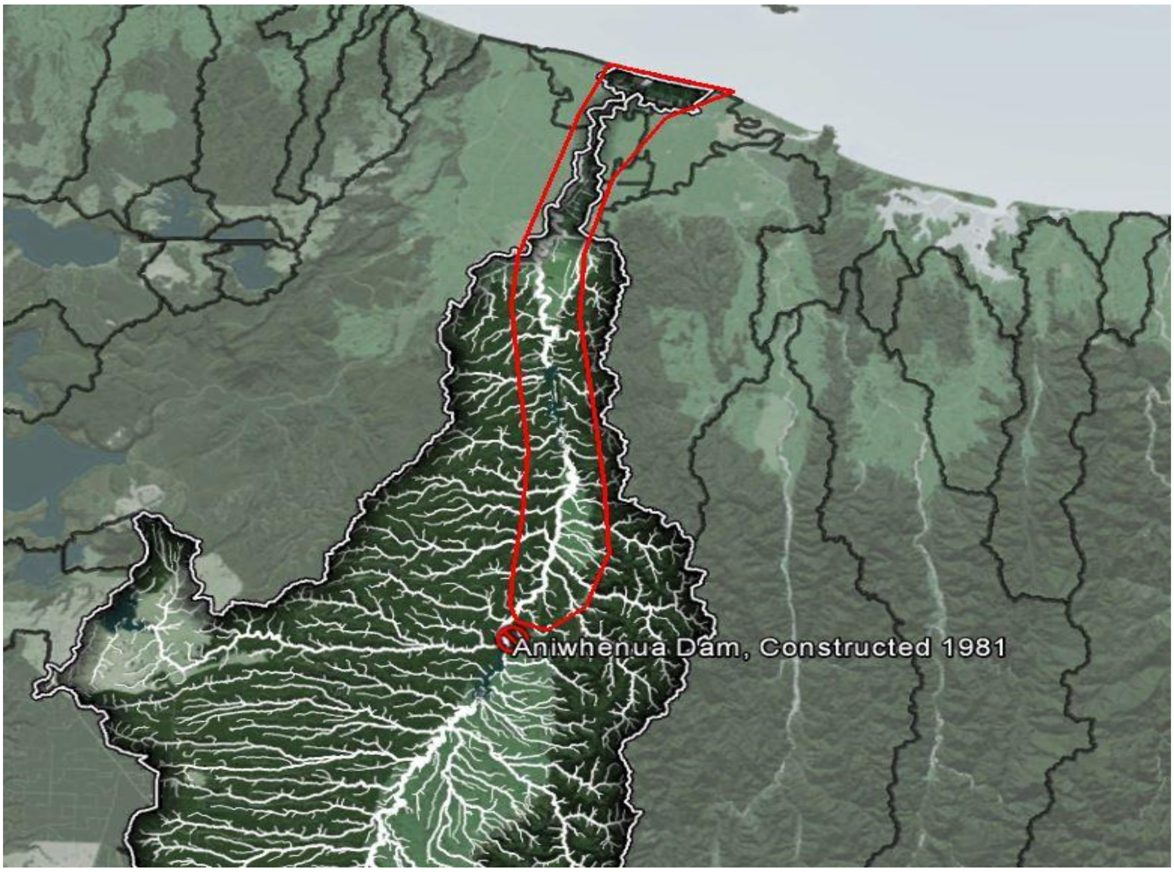

Figure 3: Mockup of Motif anchor with the Aniwhenua dam instance.

The term ‘eel’ covers a number of species and age categories, and as some of the literature may discuss multiple age categories, and there may be a number of terms for different eels based on their age, sex, and species, we would want to be able to find all of those variants in our search and include them in our motif. Likewise, a broader motif focussing on fish in general being impacted by dams may want to include all the instances of the eels mentioned above. This is what the folk thesaurus can do, and it can be updated as new synonyms, related terms and hierarchical terms come to the fore.

We can string together some motifs concerning the eel lifecycle together into a narrative, with different possible worlds. One possible world is a river where no dam has ever been built and/or a pre-dam river. Another possible world is one where a dam has been built on a river, and there has been no effort to mitigate impacts. Another possible world might be a dam with mitigation. We can now see why the eels are declining. They are being chewed up by the turbines, and can not spawn in their spawning grounds.

We can also start asking questions like ‘what other dams have this problem?’, and ‘are there counter-examples where this isn’t a problem?’ Perhaps we look wider and ask ‘what else is interfering with eel migration?’ John Doe participates in multiple motifs and narratives, and perhaps the eels he catches are to be shared out. If John Doe has previously discussed who he shares eels with, we can also ask ‘Who else is impacted because John catches fewer eels?’ If we have entered in information on what other species prey on eels, we can ask ‘What other species will be impacted by eel declines?’ If we know of other factors linked to eel declines, we can bundle them together as well. Overfishing, habitat destruction, drainage ditches all help compile a wider picture, and we can constantly expand the folk thesaurus as we follow the lines of questioning and collect the data for a bigger picture. We also don’t need individual instants of motifs to create motifs, as they are generalised and generalisable. Filling in crisp locations and dates can come later or in a variety of formats, including traditional timing and traditional ways of locating position.

Maybe now that we know that dams interfere with migration patterns, we may ask ‘what happens to the ability of salmon to reproduce when dams are built, seeing as they spawn in headwaters?’ What other species have their lifecycles disrupted by development projects and how? Depending on how we structure a motif, and whatever data we have managed to compile or generate, we may be able to take the one basic motif and chain it to all sorts of other interrelated questions.

Many of these questions are harder to query with our current models, and tend to be siloed off in different layers. Research may be directed based on schema set out a priori before dealing with data out in the world. Uncertain, incomplete and inconsistent data is the norm, not the exception, and integrating data is vital to a more holistic understanding of complex systems.

The front end of a motif-based database needs to be parseable by humans and follow along syntactic lines. However, the underlying model does not necessarily need to be so, and other models for knowledge, like Convolutional Neural Networks CNN for AI, Regional Connection Calculus models used for spatial, temporal and conceptual nesting and overlap, or sparse graph models may be useable for the back end. The front end should have analogies to oral forms themselves, particularly for more ‘qualitative’ or ‘ambiguous’ data.

5. Conclusion

The motif data model and support for narratives is a tool that may be useful for documenting Indigenous concerns towards landscape use, aid in drawing parallels between cases for biologists and courts and other interested parties, and aid in management and co-management decision making when other parties are involved. Narratives are of critical importance for explaining change, processes, and previous events and how those events may affect or be echoed by future decision-making. Future work includes building the motif, folk thesaurus and narrative structure into a logical representation. To build a motif GIS, first we need basic support for the motif itself. A motif needs to be anchorable to a number of things, including spatial and temporal depictions, whether those be choros or topos depictions of space or chronos and kairos depictions of time. Supports for folk thesauri need to be developed as they provide an alternative to more rigid ontologies or overly flexible folk taxonomies, and allow for classification of simple motifs. We need support for syntagmatic, paradigmatic, antithetic and part-whole relationships. We need to be able to support modal logics. Nested graphs provide a direction to explore to represent nested relations as well as conceptual graphs that can represent basic relationships. Lastly, querying facilities are required to leverage the strengths of the motif model in ways that are more difficult to carry out with current GIS models.

6. Acknowledgements

Figures 1 and 2 in the paper were illustrated by Katie Wilson. Figure 3 relied on a basemap produced by Duane Wilkins.

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