A NEW GIS DATA MODEL FOR DEPICTING TRADITIONAL KNOWLEDGE OF SPATIO-TEMPORAL PATTERNS VIA MOTIFS, FOLK THESAURI, NARRATIVES AND ACCOMPANYING VISUALISATIONS

A thesis submitted in partial fulfilment of the

requirements for the degree of

Doctor of Philosophy in Geography

at the

University of Canterbury/ Te Whare Wānanga o Waitaha

by

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2018

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Acknowledgments

No thesis is completed without support from friends, colleagues, family and loved ones. I have had some wonderful people help me stay the course. I would like to thank Femke Reitsma first and foremost for keeping me going, and always being up for a chat, with helpful suggestions and a depth of experience. I'd also like to thank John Pirker for keeping an eye on the process, and Simon Lambert for keeping things in perspective.

I'd also like to thank my fellow authors. Liliana Clarke has a deep understanding of traditional timing and understood what I was trying to do immediately. Willington Siabato put together an excellent Graphical User Interface. Christophe Claramunt had interesting questions that led me down a number of pathways.

I'd like to thank a few of my fellow ethnobotanists as well. It was a conversation with Janelle Marie Baker that got me started, and conversations with Linda Black Elk and Jessica Dolan helped keep it in perspective.

I'd also like to thank two of my Indigenous GIS colleagues. Lisa Lone Fight for thinking I was on the right track and talking with me about her grandmother, Steven DeRoy for the conversations and the training in direct-to-digital mapping.

I'd also like to thank Paul Whitinui and Angus Hikairo Macfarlane for giving me a solid grounding in Kaupapa Māori in the early days of this journey. It has served me well.

I'd also like to thank a handful of wizards, namely The Wizard of New Zealand, who was helpful with Whiteheadean Process Philosophy, Ari Freeman who was helpful with signs and musical notation and their interrelations, and Dylan Kirk for conversations about all sorts of things, including Artificial Intelligence.

I’d like to thank Ruiha Collier and Hineamaru Lyndon as well, for treating me like whanau, teaching me about Te Ao Maori, and helping me see the world through different eyes.

I’d like to thank my mother, Maureen Mackenzie, and my father, Richard Mackenzie, as they believed in me and made sure I could continue on the path even when I was no longer sure.

Finally, I’d like to thank my partner Katie Wilson, who did lots of the diagrams, acted as a sounding board, read things closely that needed to be read closely, listened to me talk for hours about all sorts of things, and believed in me. She made it work.

Abstract

The current standard GIS data models have some limitations, particularly when dealing with interconnected data. These models, such as raster and vector data models, rely on features and layers that by nature are divorced from one another, other than via various queries and transformations desired by the user. Time is linear if utilised, and space is seen in terms of co-ordinates linked to some given set of semantic content or values at a given set of co-ordinates. The model is flexible, but lacks holism. It is the logic of the spreadsheet. Traditional knowledge systems tend to have the interconnected nature of the spoken word or living systems, and we have developed a data model and knowledge model to capture this.

Motifs act as containers for an action, a set of actions, a state, or a set of states that are contextualised via components like actors, location, time period and the like. They form the basic component of the model. They can function much in the same way as the current standard GIS vector data model that ties a single vector object to a tuple or range of markers in a database, but can also operate more abstractly than the current GIS model by allowing for grouping and interconnection of features in ways that would otherwise be difficult, and by focussing on process and action beyond just existence values.

Another drawback to current GIS approaches is the need for strong *a priori* schema and ontologies. These require in depth planning and often reflect western understandings of how the world should be classified. They also tend to be tree-like instead of lattice like. We propose a Folk Thesaurus, which collects Motifs via the semantic relationships between the components of the facets of a motif, thereby allowing for the querying of a motif database via queries that are themselves motifs. This improves querying by making it more like thought or natural language. By pairing motifs with a folk thesaurus, we allow for those classifying the motifs to be able to utilise equivalence, hierarchical and associative relationships to draw

connections to motifs, and to group more specific motifs properly under their more generalised equivalents. Folk thesauri also allow for traditional concepts of time, space, actors and actions to be utilised and added upon as data is compiled, rather than having a solid schema beforehand, and allows for semantic and multifaceted depictions of time and space along with the linear and crisp notions that prevail in GIS. We have also built a graphical user interface to keep track of things like multi-cyclical time, and the right time and wrong time for activities.

We then use narratives to string simple motifs into more complex motifs, thereby allowing for traditional knowledge structures in the forms of narrative to be represented directly, as well as providing a data structure for modelling processes. We utilise syntagmatic, paradigmatic, antithetic and meronymic relations to tie motifs together, and utilise modal logic to shape the contours of those narratives by tagging the submotifs to the narrative, allowing for the motif model to provide the starting point for analogical reasoning via other models.

The Motif, Folk Thesaurus and Narrative, when combined, provide the schema or a future GIS database that goes beyond the latest graph databases, via the multiple levels of interrelation and the support for multiple understandings of the world and its workings, making it more suitable for recording systems relations and providing a solid base for analogical reasoning.

1 General Introduction

1.1 Research Overview

The aim of the thesis is to provide a data model for spatio-temporal information that is more like oral transmission in nature and is better at depicting interconnected and holistic data than current atomised approaches embodied by current GIS practices. It does so via visualisation, and data structures known as motifs, folk thesauri, and narratives. These interrelate and allow for tools and methods that are customisable and adaptable for a wide variety of groups with a wide range of worldviews. They are also capable of being able to model what can already be modelled with relational database-based GIS systems.

1.2 Background

Mapping of traditional knowledge and practices has become one of the more powerful tools available for Indigenous peoples to defend their rights and their territories. Maps help make sure that Indigenous peoples are consulted on issues that affect them, and maps are effective persuasion tools in courtrooms. One of the more effective mapping methodologies is that of Use-and-Occupancy mapping (Tobias 2009), but part of its effectiveness is the way it embraces quantitative and crisp over other representation strategies. This has been useful for obtaining recognition of land use, but it is insufficient for management and co-management purposes, and is not a good reflection necessarily of what people know about the landscape and how they themselves view it. Current GIS has its roots in cadastral surveys, factory time, and accountants' ledgers, and it shows. Other data models are possible and desirable, especially now that the return of traditional management practices is on their way in some areas, and the recognition of the importance of traditional management is recognised in other areas. This will continue to bring up scenarios where Indigenous peoples and others will need to share their knowledge and practices, but may find that the current support offered by spatio-temporal software is inadequate for certain tasks.

1.3 Contribution of Thesis

This thesis adds to the traditional knowledge and Indigenous mapping literature, and helps provide some tools for dealing with the complexities of traditional knowledge system that current relational database approaches have difficulty with, particularly non-co-ordinate time. The thesis provides a new data model based on conceptual graphs known as the motif, which focusses on the abstracted general sense as primary over the instances that carry the same signature of space, time, actors and actions. The thesis also ties together other requirements to make such a model work, and may provide future directions for documenting patterns of behaviour and knowledge likely to be missed using the current paradigms embodied in current GIS practices. The thesis also provides new avenues of research.

1.4 Thesis Structure

This thesis was completed by preparing a series of academic papers, with the objective of providing useful tools for those documenting or supporting traditional knowledge systems with GIS. In accordance with University of Canterbury standards, I am the first and primary author of these papers. The chapters are as follows.

Chapter 2: The Course of Heaven and Earth: The Biocultural Diversity of Space and Time

This paper was written for the journal *Langscape Magazine*, which specialises in issues surrounding biocultural diversity. The paper talks about different kinds of diversity of time and space for humans and non-humans, and how traditional timing and industrial timing are at variance with one another. The paper makes a plea for more room for diversity and the need for spatial and temporal tools for documenting interrelations between people, other species and the lands and waters around them for the sake of better guardianship of our fellow species.

Mackenzie, K. (2015). The course of heaven and earth: the biocultural diversity of space and time. *Langscape Magazine*, 4(1), 12–14.

Chapter 3: Spatio-temporal Visualisation and Data Exploration of Traditional Ecological Knowledge/Indigenous Knowledge

The paper acts as a review of current depictions of traditional knowledge of space and time. Seasonal and narrative visualisations are fairly well explored, but the paper notes that there is poor support for both multi-cyclical data and localised timing. The paper makes some suggestions about what may be needed for richer Traditional Ecological Knowledge/Indigenous Knowledge visualisation, citing the need for cyclical and multi-cyclical timing and multiple constraints, adaptive and dynamic boundaries, support for narratives and contingencies, and support for privacy and sensitivity measures.

Mackenzie, K., Siabato, W., Reitsma, F. & Claramunt, C. (2017). Spatio-temporal Visualisation and Data Exploration of Traditional Ecological Knowledge/Indigenous Knowledge. *Conservation and Society*, *15*(1), 41–58.

Chapter 4: Towards A Spatio-Temporal Data Model for Traditional Ecological Knowledge/Indigenous Knowledge: The Motif

The paper is currently accepted for resubmission with revisions, and forms the heart of the thesis. Current GIS tends to take spatial co-ordinates and temporal co-ordinates and describe some attribute or set of attributes at a given set of points. This is not the only way to model time and space. The data model presented makes room for choric (x,y) as well as topic (attribute) space and chronic (co-ordinate) as well as kairic (attribute) time, following Rämö (2004) and Sui (2012), by acting as a container-like object holding different instances of points, lines, polygons or rasters together due to perceived shared similarity.

Mackenzie, K., Pirker, J. & Reitsma, F. (2018). Towards a Spatio-Temporal Data Model for Traditional Ecological Knowledge/ Indigenous Knowledge. – (Accepted and resubmitted with revisions to *Cartographica*)

Chapter 5: Representation of Spatio-Temporal Traditional Ecological Knowledge in GIS with a New Data Model: The Folk Thesaurus

The motif itself is a useful tool, but concepts tend to nest inside one another. The geo-atom approach (Goodchild et al. 2007), which underpins most current representations, associates a single feature with a tuple, or set of attributes, and these are divorced from other features unless they share an attribute. The motif, which can be seen as a “repeating pattern of spatial and temporal context around a given action or state" can interrelate based on shared semantic relationships. These come in three major types, equivalence relationships, hierarchical relationships, and associative relationships (Harpring 2010). The paper also discusses various types of fuzziness and how they might be represented in the motif model. We illustrate thesaurus relationships with examples from Maxi'diwiac/Buffalo Bird Woman, a Hidatsa woman whose gardening practices have been well documented (Wilson and Maxi'diwiac 1987, Wilson 2014).

Mackenzie, K. & Reitsma, F. (2018). Representation of spatio-temporal traditional ecological knowledge in GIS with a new data model: the folk thesaurus. (To be submitted to the journal *Environmental Modelling and Software*).

Chapter 6: A Visualisation Tool for Multi-Cyclic Time for Documenting and Displaying Traditional Ecological Knowledge in a Temporal GIS

To make the best use of multi-cyclic time, it would help to have tools to record it, visualise it, and query it. The paper looks at how an interface for such a sense of time might work, using an interface with multiple wheels keeping track of the tidal, diurnal, lunar and seasonal cycle among others. The seven day count in the form of the week is also of broad importance. The paper also touches upon traditional timing from a Māori perspective, and presents an interface built using Google Maps API.

Mackenzie, K., Siabato, W., Clarke, L., Claramunt, C. & Reitsma, F. (2018). A visualisation tool for multi-cyclic time for documenting and displaying Traditional Ecological Knowledge in a Temporal GIS. (To be submitted to *Journal of Visual Languages and Computing*)

Chapter 7: GIS Data Models for Depicting Traditional Knowledge of Processes: Connecting Spatio-Temporal Motifs into More Complex Narrative Structures

The final paper discusses how motifs might be structured into larger and more complicated structures via narratives. Narratives have already been highlighted as critical for documenting traditional knowledge systems in the earlier papers (Pearce 2008, Hakopa 2011) and mark a key difference data model wise from the capacities of current GIS systems. The core relationships here are syntagmatic, paradigmatic, meronymic and antithetic relations, following work done by the PUC-Rio team (De Lima et al 2016). The paper also discussed the contours of narratives, and how modal logic can map out contours of certain kinds of narratives.

Mackenzie, K. & Reitsma, F. (2018). GIS Data models for depicting traditional knowledge of processes: Connecting spatio-temporal motifs into more complex narrative structures. (To be submitted to the journal *Environmental Modelling and Software*).

1.5 Additional Contributions during the Course of Study

During the course of the PhD, the author also:

- Presented at the 2011 Māori and Indigenous (MAI) Doctoral Conference in Whakatane

  Mackenzie, K. (2011). Carrying out a Traditional Land Use Study for Non-Humans: Asking Indigenous Mahouts about the cultures of the Asian Elephants. 2011 MAI Doctoral Conference. Whakatane, NZ.

- Presented a paper at the 2012 American Anthropology Association conference in San Francisco

  Whitinui, P., Mackenzie, K. and Macfarlane, A.H. (2012). Kaupapa Maori: Contextualizing Indigenous Knowledge Theories and Methodologies from

Aotearoa, New Zealand. 111th Annual Meeting of the American Anthropological Association. San Francisco.

- Helped organise a symposium on human elephant relations held at the University of Canterbury in 2013 and presented at that symposium

  Mackenzie, K. (2013). Mapping Traditional Ecological Knowledge as a Methodological Approach for Understanding Human Elephant Interactions: Asking Mahouts and Other Experts about Elephant Land Use and Culture.

- Acted as a guest editor for an issue of *Langscape Magazine.*

  Dilts, O. & Mackenzie, K. (2013). Emerging Paradigms Series: Part 2: Weaving Tradition and Innovation. *Langscape Magazine*, 2(13).

- Contributed mapping and interview services towards the Native Oyster Claim for the Whangaroa Hapū to be used in front of the Waitangi Tribunal

  (2014). Wai 1040, N6(a): Wai 1918 - The Native Tio Claim Presentation

- Was one of the keynote speakers at the fifth national Maori GIS conference in 2015 held in Waitangi

  Lyndon, H., and Mackenzie, K. (2015). Landscapes: Occupancy mapping in te Tai Tokerau. PLACE2015, 5th National Maori GIS conference, Waitangi

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Tobias, T. N. (2009). *Living proof: The essential data-collection guide for Indigenous use-and-occupancy map surveys*. Vancouver, BC, Canada: Union of BC Indian Chiefs and Ecotrust Canada.

Wilson, G. L. (2014). *Uses of plants by the Hidatsa of the northern plains*. Lincoln, NE: University of Nebraska Press.

Wilson, G. L. & Maxi'diwiac. (1987). *Buffalo bird woman's garden: Agriculture of the Hidatsa Indians (Originally published as Agriculture of the Hidatsa Indians: An Indian Interpretation)*. St. Paul, MN, USA: Minnesota Historical Society Press.

2 The Course of Heaven and Earth:

The Biocultural Diversity of Space and Time

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The rhythms of the sky and the lands and the seas are one, and they are all interconnected. The cycles of the seasons, the phases of the moon, day and night, and the ebb and flow of the tides have all been utilised in traditional forms of time-keeping, as have weather patterns, the flowering of different species, and the appearance of different species of birds and fish. Non-human communities likewise use many of these cues and others to guide them in their activities.

In order to make sense of the world and our place in it, we need to have tools to understand it and the composite parts of space and time around us. We must know where and when to plant, to harvest, where we can gather, where we can hunt, and so on. This is especially true for people living closer to the other species on the planet. For those of us who do not farm, nor fish, nor hunt, it is possible for a Wednesday in March at the climate controlled workplace to be not that different from a Thursday in October, with the holidays and their colour schemes marking the transition of the year.

Traditional forms of timing vary from culture to culture, from nation to nation, but in much of the world, the typical way of dividing time uses an Industrial regularised grid of years, months, days, hours, minutes, seconds, milliseconds, all the way down to the vibrations of atoms, chosen for the purpose of time-keeping due to their extreme regularity. We add leap seconds to some years because this framework is more regular than the planet itself, once seen as the epitome of regular. This industrial time has displaced the natural rhythms of the sun and moon, winds and waves.

Everything is connected to everything. Fulfilling the needs of any group of people entails interacting with the rest of the world to satisfy the requirements of food, clothing, and shelter. The species we eat, wear, and construct our homes from likewise need interactions with the wider world for food, nutrients, pollination, or proper growing conditions. There is nothing on this earth that is not tied to everything else, either directly or indirectly.

How individuals of different species interact with other species and the rest of the world can be glossed with Von Uexkull's term *umwelt*, and although we may live in the same world as a moth, or a deer, or an oak tree, our lived experience is very different. That which is of significance to a daisy may not be significant to a sparrow. This extends to distinctions between humans. If I am a hunter, I will notice things that non-hunters do not. If I am a fisher, I will notice things about fish that people who do not fish would never think of. We depend on other species, and we cause them damage when we do not leave them room and time to carry out their activities in their own way.

Time is not uniform. Human and nonhuman communities utilise different areas and different seasons, times of day and other timings for different activities. Activities are cyclical. There is a time to plant, a time to harvest, a time when the fish are more likely to bite. There are other times when the best thing to do is to leave areas alone. By keeping track of these differences it is possible to allocate time and space effectively and prepare for the inevitable lean times.

The cultural variance of recognition of soils is referred to as ethnopedology, that of landforms as ethnophysiography, that of the stars is ethnoastronomy, and that of time could be referred to as ethnochronology. Cultural practices inform the recognition and importance of these distinctions, and help a community to pick better places and times. The non-human equivalent for other species is folded into the term niche, encompassing the whens, wheres, and whats a given species needs to survive.

Uniform approaches to time, space, and production that have become standard globally through waves of colonisation do not always make these distinctions. Traditional patterns of tenure and land allocation have been disrupted. Traditional calendars have been replaced by Gregorian time. The climate has shifted enough that the phenology of many species is now noticeably different, and species are shifting in their distribution patterns to suit the new normal. Over much of the world, nights are no longer dark enough to see the stars, and species like hatching turtles are fooled by artificial lights. Meanwhile, farmers that may have traditionally practiced polyculture systems are displaced or deskilled in favour of monoculture green revolution techniques, and optimise the production of commodities united by universal currencies at the expense of traditional varieties and traditional breeds. There is a price to be paid by this uniformity, and that has been the destruction of forests and waterways, erosion of biodiversity, and extinction of species that no longer have anywhere to go in the areas that were once their strongholds.

Ultimately, the old ways in some areas are lost, are thriving in other areas, and are being resurrected in yet other areas. What traditional systems teach in general is to pay attention to the lands and waters and species around you and to pay attention to the cycles that unfold over time where you are. Much of the information remains invisible to those who currently hold much of the power. Those entering and destroying a landscape have incentives to be wilfully ignorant of damage done. Those whose territories are being entered have incentives to keep sensitive information to only those who need to know, or have the right to certain forms of knowledge.

However, as the importance and the rights of guardianship over the lands and waters become increasingly recognised, finding ways to share the traditional understandings of space and time with those utilising a more cadastralised and universalised approach becomes necessary. Tools for this purpose have already been created with participatory mapping methodologies and Use-and-Occupancy studies and the like. These spatial tools need to be complemented with temporal tools that document recognised interrelations between people, other species and the lands and waters around them. The best tools would be open access and customisable for communities. The default patterns of current western timekeeping, these being universalised, linear and discrete. Traditional timekeeping tends to be localised, multi-cyclic, and continuous.

The 21st century cannot be a repeat of the destruction of the 20th. We need to find ways to limit the damages wreaked by current globalising forces, and to return healthy conditions back to areas that have been damaged. Humanity as a whole has centuries of experience in making mistakes, and correcting them via observation, humility, and making room for other species. How we relate to time and space underpins many of the problems we are facing, and many of the solutions, too.

2.1 Suggested Reading

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3 Spatio-Temporal Visualisation and Data Exploration of Traditional Ecological Knowledge/Indigenous Knowledge

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Abstract

Traditional Ecological Knowledge (TEK) has been at the centre of mapping efforts for decades. Indigenous knowledge (IK) is a critical subset of TEK, and Indigenous peoples utilise a wide variety of techniques for keeping track of time. Although techniques for mapping and visualising the temporal aspects of TEK/IK have been utilised, the spatio-temporal dimensions of TEK are not well explored visually outside of seasonal data and narrative approaches. Existing spatio-temporal models can add new visualisation approaches for TEK but are limited by ontological constraints regarding time, particularly the poor support for multi-cyclical data and localised timing. For TEK to be well represented, flexible systems are needed for modelling and mapping time that correspond well with traditional conceptions of time and space being supported. These approaches can take cues from previous spatio-temporal visualisation work in the Geographic(al) Information System(s)/Science(s) GIS community, and from temporal depictions extant in existing cultural traditions.

Keywords: *visualisation, spatio-temporal data, traditional ecological knowledge (TEK), Indigenous knowledge (IK), cyclical time, data exploration*

3.1 Introduction

Over the years, there has been a tremendous amount of work on the visualisation of spatio-temporal data (Andrienko et al. 2000; Ott and Swiaczny 2001; Guo et al. 2006; Roth 2011; Ramakrishna et al. 2013). Likewise, there has been a large movement to find better ways of mapping Indigenous Knowledge (IK)/ Traditional Ecological Knowledge (TEK) (Chambers et al. 2004; Chapin et al. 2005; Chapin and Threlkeld 2008; McCall 2012; McLain et al. 2013). However, the overlap between these two bodies of literature is scant. This is despite the importance of IK from epistemological (Rundstrom 1995), ecological (Johnson 2010), and governance (Rambaldi et al. 2006) perspectives.

IK is a complex field, and the modelling of spatio-temporal aspects of this diverse body of knowledge is problematic. Indigenous systems of timing do not gel neatly with the Clock and Calendar (Postill 2002) or industrial (Adam 1998) standardised Gregorian approach to time that is the norm in Geographic(al) Information System(s)/Science(s) (GIS), nor are the spatial components as clear cut. Clock and Calendar Time has some critical ontological underpinnings that are problematic from an Indigenous perspective when it comes to making sense of when the 'right' time or 'wrong' time for an activity is, whether that be collection or management of resources, ceremonial life, or the ebb and flow of seasons. It is de-contextualised, as it is a universalised calendar. It posits that linear time is the true standard, and that time flows inexorably in a single direction. It is broken down into granules of a standard span, and it structured for both the commodification of time, and the measurement of abstracted motion (Adam 1998). These are inherently problematic for cultures where time is seen as made up of multiple natural cycles, or where boundaries can be fluid or more ambiguous (Hakopa 2011). When working with Indigenous peoples and documenting traditional patterns of use and management, using Western timing to pinpoint an activity can place a large response burden on the participant (Tobias 2009). Although many Indigenous groups use writing, much of the transmission and maintenance of information occurs orally and via practice.

Efforts have been made in the GIS community to accurately depict Indigenous conceptions of landforms, with the ethno-physiographic approach of Mark and Turk (2003). Likewise and in parallel, landscape ethno-ecology continues to explore Indigenous understandings of the world (Johnson 2010; Johnson and Hunn 2010). There has also been work on Indigenous conceptions of time (Tedlock 1992; Lantz and Turner 2003; Woodward 2008). Western conceptions of time have put pressure on and displaced traditional senses of time for many Indigenous peoples (Goehring and Stager 1991; Smith 2008; Davison 2013). Representations of Indigenous conceptions of time and space are inadequately explored in mapping (Wilcock 2011). Rundstrom's litany of gaps (1998) (Johnson et al. 2005) still apply. They are as follows:

> ...the principle of the ubiquity of relatedness; nonanthropocentricity; a cyclical concept of time; a more synthetic than analytic view of the construction of geographical knowledge; non-binary thinking; the idea that facts cannot be dissociated from values; that precise ambiguity exists and can be advantageous; an emphasis on oral performance and other non-inscriptive means of representation; and the presence of morality in all actions (Rundstrom 1998:8).

Indigenous mapping and counter mapping (as coined by Peluso 1995) have proven to be critical tools for Indigenous peoples for the documentation of oral knowledge in a variety of contexts. Counter-maps allow for communities to control their own representations of themselves, their territories, and their own claims to resources (Peluso 1995). Poole (1995) found that local mapping applications tended to fall into five categories, with one application leading to another in the following sequence: 1) recognition of land rights; 2) demarcation of traditional territories; 3) protection of demarcated lands; 4) gathering and guarding traditional knowledge; and 5) management of traditional lands and resources. In Canada, documenting Indigenous land use as a way of securing Indigenous rights has been part of the legal milieu since the Inuit land use and occupancy project of 1976 (Freeman 1976, 2011), and map biographies soon became a key method of documentation for the official claims process (Usher et al. 1992), largely due to their visual effectiveness and perceived objectivity. Indigenous mapping has been vital for representing Indigenous claims to territory in Canada (Usher et al. 1992; Sparke 1998). The Crown in Canada has a duty to consult with First Nations when development may impact their rights. Mapping is a vital tool to support this process (Cowan et al. 2012). In Australia, Indigenous mapping has taken on new importance since 'Mabo and others v the State of Queensland (no.2)' and mapping tenure is required when documenting native title (Brazenor 2000; Reilly 2003). Management and co-management also makes use of Indigenous mapping (Johnson 1999; Harmsworth et al. 2005; DeRoy 2008).

Indigenous communities have a wide range of expertise when it comes to using technologies like GIS. This includes some nations that are constantly innovating new practices, with a track record of using GIS and making maps for decades, and others that have participated in non-digital participatory mapping. Other nations have never interacted with Western mapping techniques at all. Indigenous academics and practitioners involved in GIS like Renee Pualani Louis (2013), Jay T. Johnson (2003), Garth Harmsworth (1999), Steven DeRoy (2008), Huia Pacey (2005), Margaret Wickens Pearce (2014), and Hauiti Hakopa (2011) are constantly looking at ways of strengthening depictions of IK, and using GIS and cartography in innovative ways that better represent Indigenous ontologies. The importance of critical approaches to cartography and GIS has been recognised by Indigenous academics working in the field of Indigenous Geography (Johnson et al. 2005). For Indigenous nations without extensive experience utilising GIS, training with the intention of building up local capacity should be a part of any project. This can be difficult, but the Centre for Indigenous Environmental Resources (2010) provides a comprehensive guide for what is required to build and maintain a solid Aboriginal mapping programme. Tools such as Google Earth have an easy learning curve, but are not capable of some of the heavy processing required for some depictions of traditional information. Cardboard models, pen and paper, and other non-digital technologies are inexpensive and effective as well, but in this paper we will concentrate on digital representations. For Indigenous nations with GIS experience, GIS can be one key element of a much wider digital strategy for maintaining and securing sovereign rights through information and communication technologies (Duarte 2013). Indigenous mapping is not without problems. It can be costly, it can be difficult to maintain a mapping programme, research can be co-opted by industry interests, long-term storage of and access to data can be problematic, and there are misrepresentation problems that can come with a quantified approach to Indigenous connections with the land (Natcher 2001).

As management and co-management becomes more common in the traditional homelands of Indigenous peoples, the ability to communicate traditional patterns of landscape use and management becomes more critical. Globally, Indigenous peoples are seeing their lands and waters degraded by development that ignores Indigenous rights and ecosystem health. Due to the nature of court and government systems in modern nation states, Indigenous peoples are often put in a position where there is a need to demonstrate their ties to the land to non-Indigenous peoples. In order to do this effectively, tools are required that make some of those connections transparent to outsiders in positions of power, although this poses some risks. Traditional management practices are undergoing revitalisation in some areas and loss in others (Berkes 2012; Maffi and Woodley 2012). Finding new ways of documenting and passing on traditional methods are also important for communities themselves for a number of reasons, including for reasons of cultural preservation and continuity, for strengthening cultural norms and practices, and for conservation planning (Berkes 2012). Currently, GIS has an unspoken underpinning of cadastralisation and mechanisation that has become the norm in the globalised West. Tools that are more suitable for Indigenous understandings provide a counterpoint to the dominant world view. The process of documentation itself can be problematic, due to the need for particularisation, and generalisation that also comes hand in hand with the documentation of IK systems into a westernised framework (Agrawal 2002). These inevitably lead to a de-contextualisation of knowledge systems. Depictions cannot be a replacement of traditional knowledge systems, but may function as an augmentation of the narratives a given Indigenous group may be wishing to portray and share with a wider audience.

Indigenous conceptions of time and space need to be better reflected in a GIS context. This is no small task. Central to this endeavour is developing visualisations and interactive tools that will facilitate the documentation of spatio-temporal traditional knowledge. Due to the multi-cyclic, multi-factored and local character of this endeavour, any tools developed must be customisable for and by Indigenous groups, and focused on accurately depicting the sense of proper and improper times and places for a range of activities. Due to the underlying ontological differences between Western universalised timing and traditional multi-factored and local timing, there may be need for a deeper work in the structuring of the GIS. There needs to be a move away from crisp, atomised depictions of spatio-temporal data to depictions that are interconnected, culturally relevant, and maintain a level of 'precise ambiguity' (to use Rundstrom's (1995:50, 1998:8) phrase) that are currently inadequately supported.

Many researchers are working on ways of better documenting IK in cartography and GIS, but there remain a number of gaps, particularly with temporal conceptions. This paper serves: 1) to identify some of the key areas required for a fuller representation of Indigenous spatio-temporal conceptualisations in a GIS context; 2) to identify the biases that predominate in GIS, identifies how ‘spatio-temporality’ is currently symbolised in Indigenous mapping contexts; and 3) to look towards how gaps between needed visualisations and present visualisations may be approached.

3.2 What Characterises IK?

TEK is the ever-evolving corpus of observations, practices, and beliefs held by a group of people about the lands and waters where they live, and it is constantly being built up over generations. Although the term is often associated particularly with Indigenous peoples, any group living in an area quickly begins to build up such a corpus. It provides a counterpoint to state and scientific environmental knowledge in that TEK is tied to the area, and is not usually approached in universalised terms. A particular place may be important for a particular species of fish, or a particular rock may be a nesting site for a particular species of bird. Individuals in a group are constantly making observations as they carry out their livelihoods, and as time goes by, some portions of information are discarded as no longer applicable, and new portions are added and shared with other community members if useful or effective. TEK stands in contrast to Scientific/State Environmental/Ecological knowledge (SEK) in that it does not aim for a single uniform or universalised understanding of the world.

TEK has several strengths that compliment other forms of knowledge. People who have lived in an area for a long time tend to have deeper diachronic data, as opposed to the reliance placed on synchronic data found in SEK (Gadgil et al. 1993: 155). An Indigenous group living in the same territory for long periods of time not only can draw on the biographical knowledge of the living members, but also on the stories and the things deemed worthy of communicating through many generations. Because of this depth, TEK gives a more fluid understanding of what may make up a “baseline” for understanding the environment (Usher 2000: 187). This understanding is referred to as mētis, practical knowledge embedded in experience (Scott 1998). It is a different approach, and a valid one, albeit not necessarily as transparent to outsiders lacking cultural expertise and time spent in the locale.

Traditional knowledge is adaptive and adaptable. Due to the grounding of traditional knowledge in experience, those bearing and utilising traditional knowledge are constantly adjusting and readjusting their understanding of the landscape and seascape. Traditional knowledge does not exist in a vacuum, and continues to evolve and adapt.

Although there is an abundance of literature on documenting IK with maps, mapping out the temporal components and processes utilised by Indigenous peoples in their day-to-day maintenance and use of their respective territories is limited. When temporality is included, it tends towards linear depictions of timing, and occasionally some low resolution depictions of seasonal use patterns. Indigenous spatial information is likewise often reduced and simplified due to the nature of modelling with polygons. Johnson (2010) mentions a few problems with IK including but not limited to: boundaries are not always rigid, specific sites are not always shareable to outsiders, some areas shift or are by their nature ambiguous, and locations of some resources, like a caribou herd are probabilistic in the wider landscape and not anchored to a specific space or time.

What is missing is the robust documentation and tools for documenting cyclical and contingent timing for Indigenous management and use of territorial areas, as well as tools that deal well with fluid and dynamic boundaries. As we enter into a time where co-management will become more frequent, and more lands and waters will return to the management of and by Indigenous peoples, the need for documenting traditional understandings and patterns of use will become more and more important in order to facilitate the conversation between Indigenous peoples and the respective governments and agencies present in the territories, for both strengthening their position, and defending their territories from damage by other interest groups. Management and co-management are becoming established in New Zealand under government recognition with Taiāpure areas, Mātaitai reserves, and conservation rāhui (temporary closures) (Barr 1999). Since the release of the Flora and Fauna claim (Wai 262) by the Waitangi Tribunal (2011a,b,c) recognising traditional conservation and traditional relations with *taonga* (treasured) species, the movement towards management and co-management will only increase. Canada has had several recent court decisions that also recognise unextinguished Aboriginal sovereignty. In India, the Forest Rights Act opens the way for *Adivasi* (Indigenous peoples of India) to enter into arrangements that are more respectful of their traditional ties to the landscape. Internationally, the United Nations (UN) Declaration of the Rights of Indigenous Peoples also recognises Indigenous rights to manage their own territories. How much of that recognition will translate into action remains to be seen. Cumulative changes should also be tracked, as some areas can be overrun with development, and other areas are slowly coming back to health. In order for a healthier dialogue, it is important to look at some of the key features of IK that need to be supported. The next six sections will look at some of those key features. The key features identified are: 1) cyclical or multi-cyclical timing; 2) multiple constraints; 3) adaptive and dynamic spatio-temporal boundaries; 4) narrative; 5) contingencies; and 6) privacy and sensitivity.

3.2.1 Cyclical or multi-cyclical timing

Traditional temporal representations abound. There are a variety of traditional calendars that are used, and many groups have multiple calendars. Solar cycles and lunar cycles are especially important for counting larger blocks of time, and diurnal and tidal patterns are important over the length of a day. There are also day counts. In an extreme example, a certain people might use all forms of calendars, like the Balinese, who use a day count calendar, a lunar calendar, a traditional solar calendar and the Gregorian calendar. Syncing calendars and keeping track of calendars can be done via formula or observation. Representations of time can be purely oral, diagrammatic, iconic, or any mix thereof. This multiplicity of approaches occur anywhere outside of the standardised approaches common in the western Clock and Calendar time/ Industrial time that currently predominates in the world today.

Indigenous spatio-temporal data is rich. Observations are not limited to harvest alone, but also encompass life cycles for species of interest, shifting patterns of behaviour, interactions between species, cues given by species that can indicate the health of another species, as well as other salient factors. Species will shift the location and timing of activities based on changes in the environment around them. Consequently every species member has constraints of where and when they can carry on activities in the life cycle based on a number of factors including temperature, humidity, rainfall, the presence or absence of other species, presence or absence of pollutants, harvest regime, food sources, predators, prey, competing species, invasive species, and so on. Many of these sets of observations are grounded in cyclical patterns.

Some of the key cycles involved in Indigenous timing include the seasonal cycle, the cycle of the phases of the moon, the daily and nightly cycle, and the tidal cycle. Much of the chronobiology literature emphasises the importance of seasons, daily patterns, lunar patterns, and tidal patterns for many other species (Morgan 2004; Naylor 2005; Foster and Roenneberg 2008; Kronfeld-Schor et al. 2013). These four rhythms act as timekeepers for a variety of biological and ecological processes. For people dependant on the timing of other species, it makes sense to incorporate these rhythms into a system.

Other cycles include ecological cycles inherent in behaviours like swidden farming which goes from land clearance to gardening to abandonment to the return of a complex forest. There also exist multiyear cycles because of this, where many patches may be in fallow or in use as part of a larger cycle. Often multiple patches of habitat, lands or waters are connected in this way. Many of the cycles utilised are also key time cues for key species in timing their own activities like spawning, migration, and nest building.

Because of the importance of cyclical patterns, cultures around the world use them as cues in how to structure and make sense of the passage and quality of time. Solar calendars, based on the cycle of the year, are common. Traditional solar calendars are usually, but not always, observation based, meaning that to fix the time of a given day observations need to be made directly. Heliacal rising of certain celestial bodies are one key indicator for seasonal timing for cultures around the world. Using the first rising of stars to mark seasons has been used customarily by Māori (Best 1922, Harris et al. 2013), Australian Aborigines (Hamacher 2012), Micronesians (Martinsson-Wallin and Thomas 2014), and others. Heliacal risings were also used by Palaeolithic people in France (Saletta 2011), the ancient Egyptians (Sparavigna 2008), the ancient Greeks (Lehoux 2000), and the Romans (Robinson 2007). The utilisation of Heliacal risings are accurate ways of marking different times of the seasonal round, and are flexible enough that different local lore could be built up around the rising of each star. The Pleiades in particular have been important for cultures around the globe. Heliacal rising times vary depending on the latitude of the observing community.

Keeping track of solstices and equinoxes provide another way of fixing time in an annual cycle (Figure 3.1). It appears that the classical Maya utilised solstice and equinox directions in the orientation of their buildings (Fuson 1969). Solstices are also important for the Hopi (McCluskey 1977). Medicine wheels have been used on the North American plains for fixing solstices and equinoxes by the Cheyenne and Sioux (Bender 2008). The Balinese also use solstices for fixing one of their calendars (Chatterjee 1997).

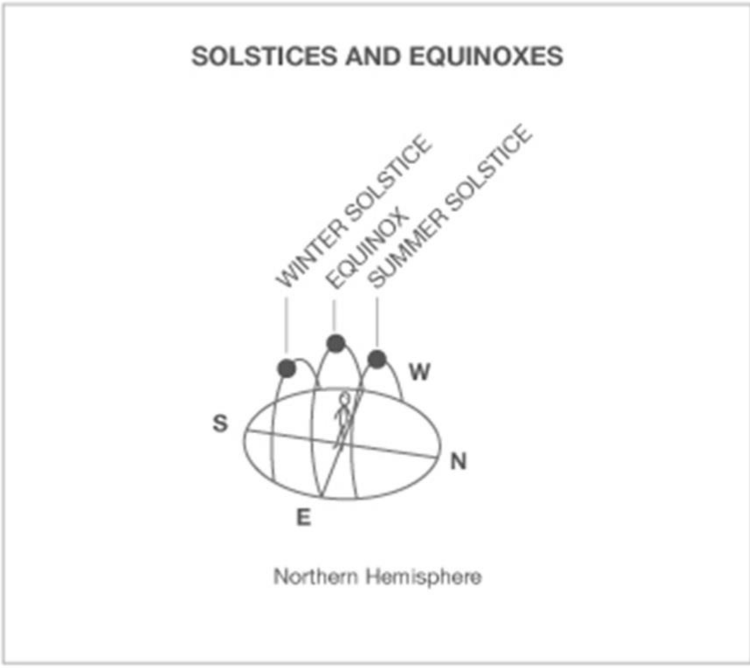

Figure 3.1: Due to the tilt of the earth's axis, days and nights vary in length. Solstices mark the longest and shortest days and nights. Equinoxes occur when the sun appears to rise directly east and set directly west. Illustrated by Katie Wilson

Animal and plant species are also used as guides for the unfolding of the year. The first flowering of a certain species or the appearance of certain birds may indicate when another species is ready for harvest. These are referred to in the literature as phenological indicators (Körting et al. 2013). The use of these indicators for keeping time have been discussed in a few sources (Turpin 2013; Lantz and Turner 2003).

Depictions of local patterns of use, weather, and species utilised are also common in the TEK literature. Winter, spring, summer, and autumn are not universal, but are utilised in many seasonal round calendars (Dacker 1994; Hornsby et al. 1999; Pitcher and Haggan 2003). Seasonal patterns can include wet and dry seasons, hot and cold seasons, tidal seasons or any number of types of season. These seasons do not always begin or end on a certain date, and can overlap, as in the case of the calendar of the Warlpiri (Prober et al. 2011). Temporal granularity varies from calendar to calendar, but most representations vary by season

(Hornsby et al. 1999; Pitcher and Haggan 2003) or by western month (Dacker 1994; Kassam 2009). Some are careful to use the Indigenous language of the group (Prober et al. 2011).

Seasonal calendars usually have different species that are harvested at different times of year depicted, either by text (Dacker 1994; Pitcher and Haggan 2003; Prober et al 2011) or icon, or a mixture of both text and icon (Hornsby et al 1999; Kassam 2009). Kassam’s seasonal profile for Ulukhaktok/ Holman, NT, Canada is especially interesting, as it indicates the relative intensity of the use of key species via a silhouette graph. Kassam (2009) also makes explicit reference to spatial representation with his seasonal calendar, with icons on the seasonal round calendar being linked to icons on a use map of the same area.

Seasonal calendars are an idealised representation of the seasonal round. Prober et al. (2011) discuss the importance of ecological calendars for passing on traditional information, but caution that they need to be paired up with longer term linear calendars due to temporal variations in indicators over time. Prober et al. (2011) also discuss the use of astronomical phenomena for monitoring species, but indicate that much of that information can be culturally sensitive. Sensitivity is discussed again further in the paper.

Lunar calendars are also common for Indigenous peoples. The Myaamia of North America have one and are currently working on reviving it (Voros 2009). They use 12 months to the year, creating a lunar year of about 354 to 355 days, but appear to have added intercalary months when needed traditionally. This would properly make their calendar a lunisolar calendar. Māori also utilise a lunar calendar and have a series of named days. These named day lists include anywhere from 29 to 32 days, and each new moon cycle was marked via observation (Roberts et al. 2006; Ropiha 2010). Bali also uses a lunisolar calendar, in addition to several others (Chatterjee 1997). The Nuu-chah-nulth of Vancouver Island use a lunar calendar with intercalary months to keep in line with the seasons (Karpiak 2003). Not all traditional lunar calendars use intercalary months. For example, the traditional Islamic lunar calendar does not (Dershowitz and Reingold 2008).

There are also calendars utilising diurnal and tidal patterns during the year. Aswani and Lauer (2006) discuss one in their work on fisher knowledge on New Georgia, that is based on whether the tide during the day was low, high, or intermediate. Tidal patterns are used by Māori for keeping track of specific times (Best 1922), and tides have been traditionally understood by Indigenous groups to be influenced by the moon (Best 1922; Hamacher 2012). Patterns of tides and diurnal patterns provide windows for certain activities. Turner and Clifton (2009) record the importance of low tides in the early morning in May for seaweed harvest of the Gitga'at. Many of these patterns of harvest are no longer working due to shifting weather and climate patterns that affect precipitation, wind, and the timing of multiple species.

Diurnal patterns and tidal patterns are also important for navigation for the Bugis (Ammarell 2002) and others. On top of these four more 'natural' cyclical rhythms are the calendars based on day counts. Day count systems are fairly well represented in traditional calendrical systems, and several traditional systems use interlocking day counts. The Maya and other Mesoamerican Indigenous peoples utilise an interlocking cycle of 260 days for one of their primary calendars, made up of interlocking cycles of 13 and 20 days respectively (Figure 3.2). The 260 day cycle may be tied to the life cycle of maize (Tedlock 1992). Likewise, the Balinese keep a day count of 210 days, also made up of interlocking cycles, which may be linked to the lifespan of rice (Lansing 1987).

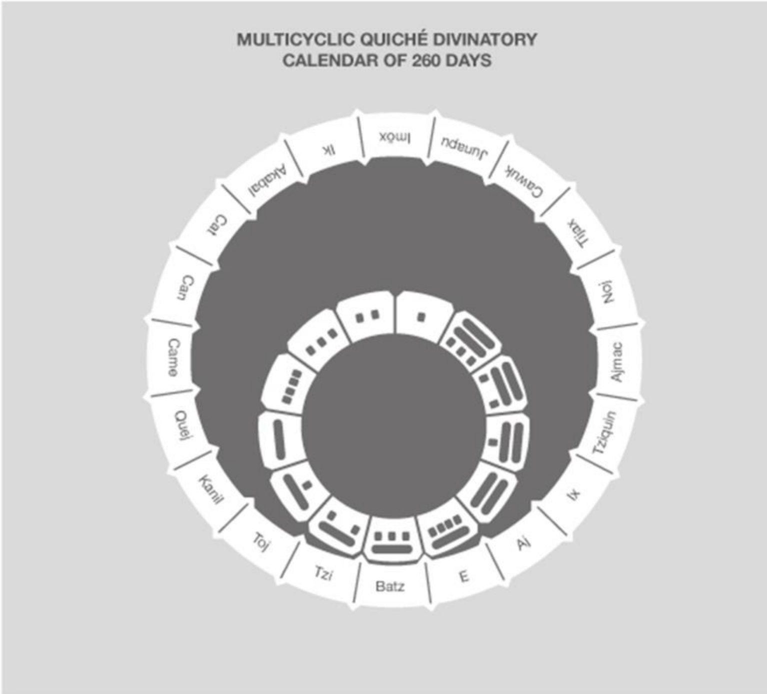

Figure 3.2: The Maya use many calendars, but one of the key calendars is the Tzolk'in, made up of interlocking cycles of 13 numbered days and 20 named days for a total cycle of 260 days. The calendar is used for maize cultivation, divination, and for determining suitable days for activities. Illustrated by Katie Wilson

3.2.2 Multiple constraints

While the predominate depiction of time is of a line stretching from the past to the future, with a standardised set of granularities, Indigenous perceptions of time are often a combination of multiple senses of linear time and a variety of cycles that give a qualitative sense of whether a moment is a good time or not for an activity. These depictions are more likely to be localised, which can be difficult for those used to a single universal calendar made up of days with regularised hours, minutes, and seconds. The multiple natures of the constraints are referred to in some Maramataka (Māori lunar calendars) where certain times of day or tide are better on certain lunar days for particular activities (Ropiha 2010). Tidal patterns also affect accessibility and movement, as certain areas may only be able to be reached at high tide via boat, or at low tide via foot, horse or other method of conveyance.

3.2.3 Adaptive and Dynamic Spatio-Temporal Boundaries

In GIS there is a tendency, due to the tools used, for crisp and hard boundaries and features. Points, lines, and polygons are given express coordinates, and timestamps usually indicate a single beginning point and a single end point. Layers themselves can also include timestamps as part of their metadata. This makes for easier manipulation and storage, but it masks underlying complexities. Ambulatory boundaries, recognised in mainstream cadastral mapping for cases like rivers (Donnelly 2014) are common. Unlike western mapping, where ambulatory boundaries of significance can be slow to change, like the shore of a lake, Indigenous areas are often literally ambulatory, like the location of a herd. There is a tendency in GIS to put an emphasis on precision, but false precision is problematic (McCall 2006). There are always elements of ambiguity and dynamism to any spatial representation that are important to incorporate for reasons of accuracy and true reflection of culture or subtle movements.

Some boundaries are fairly fixed. Territorial boundaries for Indigenous peoples are often relative, often following natural features like heights of land or watercourses, but can also include boundary markers from historical events. These boundaries are sometimes passed down from generation to generation via oral history. Ignace (2008) gives an excellent description of the boundaries of the Secwepemc and how boundaries are related to the distribution of certain plants, storied places from events involving the ancestors, pictographs, and physical markings like rock formations. In Australia too, creeks and rivers can be boundaries, as well as changes of vegetation (Turk 2006). Territories can also follow seasonal and vegetation patterns in Australia (Brazenor 2000). Different cultures have different ways of maintaining, marking and passing on boundary and boundary-zone information.

The wide ranging and complex nature of traditional tenure systems require flexibility in the forms of representation. This becomes especially apparent when attempting to map some of these complexities via a GIS, when models have bias towards linear time and gridded space. The natures of traditional territorial boundaries do not always lend themselves well to a cadastral-style vector representation. Overlapping and shared areas of interests can also occur between adjacent or related groups, and in cadastral thinking, this can become problematic. By giving exclusive rights to a single group, other groups can be excluded, as in the case of the Nisga'a Treaty in Canada, where neighbouring Nations were dispossessed of areas of interest by the cadastralisation of the Nisga'a claim (Sterritt 1998). Consequentially, the marking and mapping of territorial boundaries is a sensitive matter. McCall and Dunn (2012) stress the importance of having room for representing local and IK that allows for ambiguity, is "flexi-scale", multisensory and dynamic.

When it comes to denoting areas of use or other forms of activity by groups or the species they depend on, further complications arise, from a mapping point of view. Representing TEK can be difficult. TEK requires continuous interpretation of the environment, from the point of view of the individual and community who are embedded in it. Berkes and Berkes (2009: 7) discuss the parallels between fuzzy logic, fuzzy expert systems and IK. Indigenous experts tend to consider "...a large number of variables qualitatively, while Western science tends to concentrate on a small number of variables quantitatively." Temporal depictions of Indigenous or local data are likely to encounter similar problems.

Point-based instance mapping is common in Use-and- Occupancy mapping to avoid some of the complications, where each point represents a 'who-what-when-where' for a given discrete event. However, this approach does not necessarily capture the thinking and heuristics driving the instances of use. When mapping polygons in an interview setting, in a response to a question like ‘where do you hunt?’ or ‘where are the caribou at this time of year?’, there is an interplay between the question, the knowledge of the participant, the previous questions, the map itself, and the actual condition that people are attempting to represent. This leads to features of a more general nature to be somewhat ambiguous and more indicative in nature than a crisp, clear depiction of a phenomenon that is not necessarily clear. Raster depictions would be helpful and have been developed to some extent. Polfus et al. (2014) utilise raster maps generated via expert knowledge mapping for their work. For interface design utilising fuzzy raster-like inputs, spray-can techniques utilised for vernacular geography (Waters and Evans 2003; Evans and Waters 2007) could be useful for cataloguing IK.

Some ambiguity is deliberate, and many kinds of sites, including places for medicines, burial sites, or sacred places need protection. Collecting data on fishing spots is sensitive, and many people who fish are reluctant to show exactly where they fish, but may allow for a wider area containing their fishing spot to be depicted. Sites of importance can also be masked with fuzziness, or ambiguity (Pacey 2005), randomised buffer (Steven DeRoy, pers. comm. 2015), or coarser resolution in the case of raster data.

Temporal boundaries that depend on an interaction between phenomena are likewise shifting. The dates of the full moon shift year by year in relation to the solar year. Tidal cycles are not in phase with diurnal cycles. Phenological indicators shift from location to location, and season to season. Phenological indicators are now shifting noticeably for some Indigenous peoples (Lantz and Turner 2003; Turner and Clifton 2009; Jackson et al. 2011). Not all ambiguity in representation necessarily represents an underlying ambiguity. If one were to ask someone familiar with calculating when Easter occurs, in general, one would get a period stretching from March 22 to April 25. However, each and every Easter falls on a discrete date, based on the equinox, and phase of the moon. Likewise, asking general spatial or temporal answers can generate a broader area or time period than actual experience on a given day would yield.

3.2.4 Narrative

Cyclical patterns are not the only patterns salient to Indigenous peoples. Linear time is of importance, and this can come in the form of generational time, life cycle time, and standardised calendrical time. Varieties of linear time are addressed by storytelling, biographies, and spatialised genealogies. Longer term variations and rare events of significance can be retained via linear time in a way unsuitable for documenting with cyclical time. Krech (2006: 571) lists some of the ways North American Indigenous peoples traditionally kept linear time, including "...knotted strings, notched and carved sticks, and pictographs on animal hides." Winter counts for the Indigenous of the North American Plains would keep track of years of scarcity and abundance, rare astronomical events, wars, or epidemics for example.

Traditional narrative structures were and are also used to maintain elaborate sets of data on the activities of ancestors and the state of the landscape over generations. Māori techniques of maintaining deep time offer an excellent example, utilising *whakapapa* (genealogies), *karakia* (prayers and incantations), and *mōteatea* (chants) to retain key historical events and the actors involved (Hakopa 2011). Indigenous peoples in some areas have an extremely long history of writing down annual observations as well, and Indigenous peoples continue to document their histories and the events around them. Although these relationships and stories extend from past to present, for many Indigenous peoples, narratives interweave and link places and beings together in a web of interconnected nodes (Wilcock 2011). The past may be the past, but it is also here and now, and affects how particular areas are treated, and the rights accruing to individuals in a society.

3.2.5 Contingencies

There are also contingency-based or episodic events, many of which do not fit neatly into a linear/cyclical dichotomy. Some of these are triggered by sociocultural events such as births, weddings, funerals, feasts, treaties, and other social events. Certain areas may be set aside for provisioning these key events. Other contingency-based events include ones that come into play after a certain weather event, such as the first frost, or the first rains of monsoon, or the first hailstorm, or the appearance of a rare phenomenon.

3.2.6 Privacy and Sensitivity

Lastly, IK can be sensitive. Species concentrations and life cycles can be of interest to other people who do not necessarily have long-term viability as a priority. Areas that are of spiritual significance are also considered private. Some types of information may only be for certain eyes. Any documentation of Indigenous spatio-temporal information must have some ways available to restrict certain forms of information from being disseminated to a wider audience. This is not limited to spatio-temporal data, but in many areas of IK. Key safeguarding principles include ownership, control, access, and possession of data (Schnarch 2004). Harmsworth (1999) discusses the importance of protecting confidentiality and addressing intellectual property rights, and offers a typology for Māori GIS users on levels of privacy, with some information that may be suitable for the public, some suitable for sharing with outside agencies, some secured at the *iwi* or *hapū* tribal levels, and some for the *whānau* (family) or individual level. Disclosure of sensitive information can lead to the destruction of sites and key resources, and gaps in data can be interpreted by outsiders as lack of use. Extractive industries like mining, oil and gas, and timber could potentially utilise sensitive data in ways that damage or destroy key sites. Indigenous land use data is also of use to military interests (Bryan and Wood 2015). Mapping can also backfire if constructed in a way that excludes Indigenous peoples, even if the maps are there to ostensibly benefit Indigenous groups (Klopp and Sang 2011).

3.3 Review of Spatio-temporal Visualisations

Within the cartographic community, finding ways of representing time has been a concern for well over a century. One of the earlier depictions is Minard's map from 1861, depicting the doomed invasion of Russia by Napoleon (Kraak 2003). The discussion of how to represent time has accelerated since the widespread adaptation of GIS. Siabato et al (2014) provide a good review of temporal dynamics in GIS. The article links to the TimeBliography site, an interactive bibliography dedicated to archiving the literature on temporal GIS in geography, information science, computer science and Geographic Information Science. These are then divided into core themes, secondary themes, related themes, and standards. The current TimeBliography site can be found at http://spaceandtime.wsiabato.info/tGIS.html. The raw references can be found at http://spaceandtime.wsiabato.info/tGIS_References.php.

Temporal depictions come in several forms, but the two core ones are linear and cyclical (Li 2010). Combinations of linear and cyclical time can be seen as spiral or skewed time (Kraak 2005), or be depicted as time waves (Li and Kraak 2008). Time can also be absolute or relative, and continuous or discrete (Li 2010). There are a wide variety of techniques for displaying time (Aigner et al. 2011). Linear time is often depicted with a line, as one would expect. Cyclical time is often charted out with circles. Absolute time works well with timestamps and points on a line with dates. Relative time may be better depicted with a certain fuzziness, like after coffee, or at dusk, or when a certain species flowers. Continuous time can be depicted with a range, while discrete time might be a number of points. All have their advantages and disadvantages, and no single depiction can show all important data or information. Discussions of different validities of time can take on the tone of the vector vs raster debates of early GIS. Although linear and discrete systems predominate, all variations are utilised (Aigner et al. 2011). Ultimately, a complete system is one equipped to deal with both.

There are a wide variety of methods used to represent and explore spatio-temporal data, but certain clusters of representation have been noted, and several authors have created typologies in approaching cartographic representation. Monmonier (1990) discussed three potential dichotomies, these being spatial and non-spatial, single-view or multiple view, and static or dynamic. Kraak and Ormeling (2010) following Monmonier provide a typology of single static maps, series of static maps, and animation as three major ways of depicting time and space together. Animated maps in turn can be placed on a spectrum of interactivity (Roth 2011). Here we will use a typology differentiating between static maps and animated maps.

3.3.1 Static Maps

There are several different ways of representing time in static depictions that have been developed over the years. Static maps have a limited vocabulary of graphic variables to use. Bertin (1983) gave seven graphic primitives: 1) location, 2) size, 3) colour value, 4) texture, 5) colour hue, 6) orientation, and 7) shape (Kraak and MacEachren 1994). Despite the limitations of static depiction, a wide range of techniques have been developed to give life to static maps, many of them utilising the seven graphic primitives. Arrows as a graphical element can be useful for showing directional changes like migration (Mullaw 2008). Choropleth maps, those using different shades or patterns to depict different values, can indicate the change in a given fixed area over time in a change map (Monmonier 1990). Marginalia in the form of titles, legends, graphs (Del Mondo et al. 2010), and timelines can also be used communicate the timing information being represented (Buckley 2013). Static maps by their nature are limited in the amount of data that can be shown, and the range of time units that can be displayed (Mullaw 2008; Andrienko et al. 2010).

A single map can depict time via something as simple as an embedded textual date stamp, or graphical features like different textures or colours to show how a given feature evolves or moves. Arrows can show the general trend of movement in a map. Location, size, and value can all be used to show changes over time. Single static maps are not that useful when dealing with complex data over multiple time periods, however, many researchers have been working on ways around this limitation. One early example that made use of many of Bertin's (1983) graphic primitives was Minard's 1869 map of Napoleon's campaign against Russia, and the destruction of his army (Kraak 2000; Ma 2012). Single static maps can take many forms including change maps (Monmonier 1990), flow maps (Moshirsalimi 2010), dance maps (Monmonier 1990), certain depictions of the space-time cube, like the space time aquarium (Hägerstrand 1970), and density maps (Scheepens et al. 2011).

Multiple static maps are more flexible than single static maps, in that there is room for multiple depictions of the same information, or multiple slices of the same region, thereby allowing for change to be represented in a cleaner manner. There are a number of ways of showing two or more representations to give sense to time. Monmonier's chess map (1990) covers the juxtaposition of spatial patterns in the same area over two different times. Juxtaposition of different time slices over a common area can further clarify temporal patterns in the same region. Other graphical elements can support the narrative.

Andrienko et al. (2010) provide an example of multiple depictions of the same information. Here they provide a computation of space-time density via aggregating several tanker trajectories in the Gulf of Finland. Densities are placed along a spectrum from blue to orange. The depiction is intuitive, but it becomes difficult to see where the stacks stop and how they relate to the actual features on the map. Andrienko et al. (2010) have anticipated this, and above the density map is a depiction of the same data as part of a space-time cube representation. By shifting the gaze between the two depictions of the same data, it becomes easier to localise (temporalise) oneself in what the data is trying to communicate.

3.3.1.1 Indigenous examples of static maps

3.3.1.1.1 Single static maps

Single static maps are one of the more common ways of demonstrating Indigenous spatio-temporal knowledge. They are concise and fit well into publications. Time is not usually precise, but the general pattern is apparent, and this is where single static maps work best. Johnson et al. (2005) present the Wallum Olum map showing the Lenni Lenape migrations in North America, based on traditional stories (Figure 3.3). The map is done in a flow map style with red flows signifying movement, and yellow indicating present territories. Traditional symbolism is incorporated into the map, with the four colours of the medicine wheel, and the continent sitting on the back of a turtle. The migrations would have occurred over millennia.

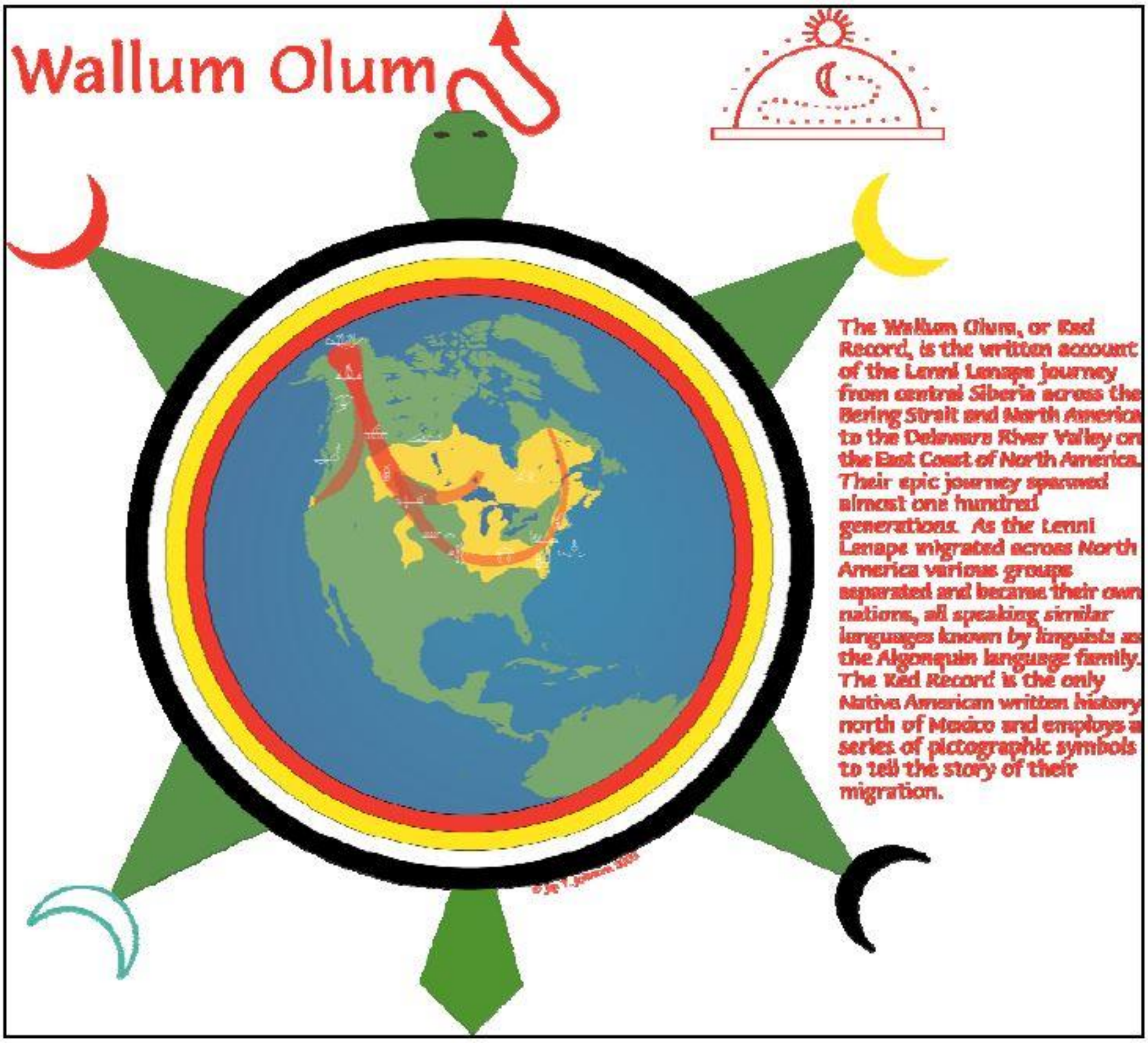

Figure 3.3: "Wallum Olum" map, illustating the Lenni Lenape migration utilising traditional symbols, red flows for movement, and yellow areas for territories. Illustrated by Jay T Johnson. Reproduced with permission. From Johnson et al. 2005

Single static maps work best when there is a single overarching pattern that the cartographer is trying to highlight. Indigenous territories in Canada are constantly the subject of government efforts to fit them into a clear territory with clear dividing lines. With a simple yet effective map, Thom (2009) shows that cadastralised divisions do not work well with Indigenous groups on the coast of British Columbia (Figure 3.4). He does this by showing the web of interrelationships between winter villages and summer localisations of family groups. The lines interconnecting the places are not literal travel routes, but provide a concise iconographic depiction of seasonal movement.

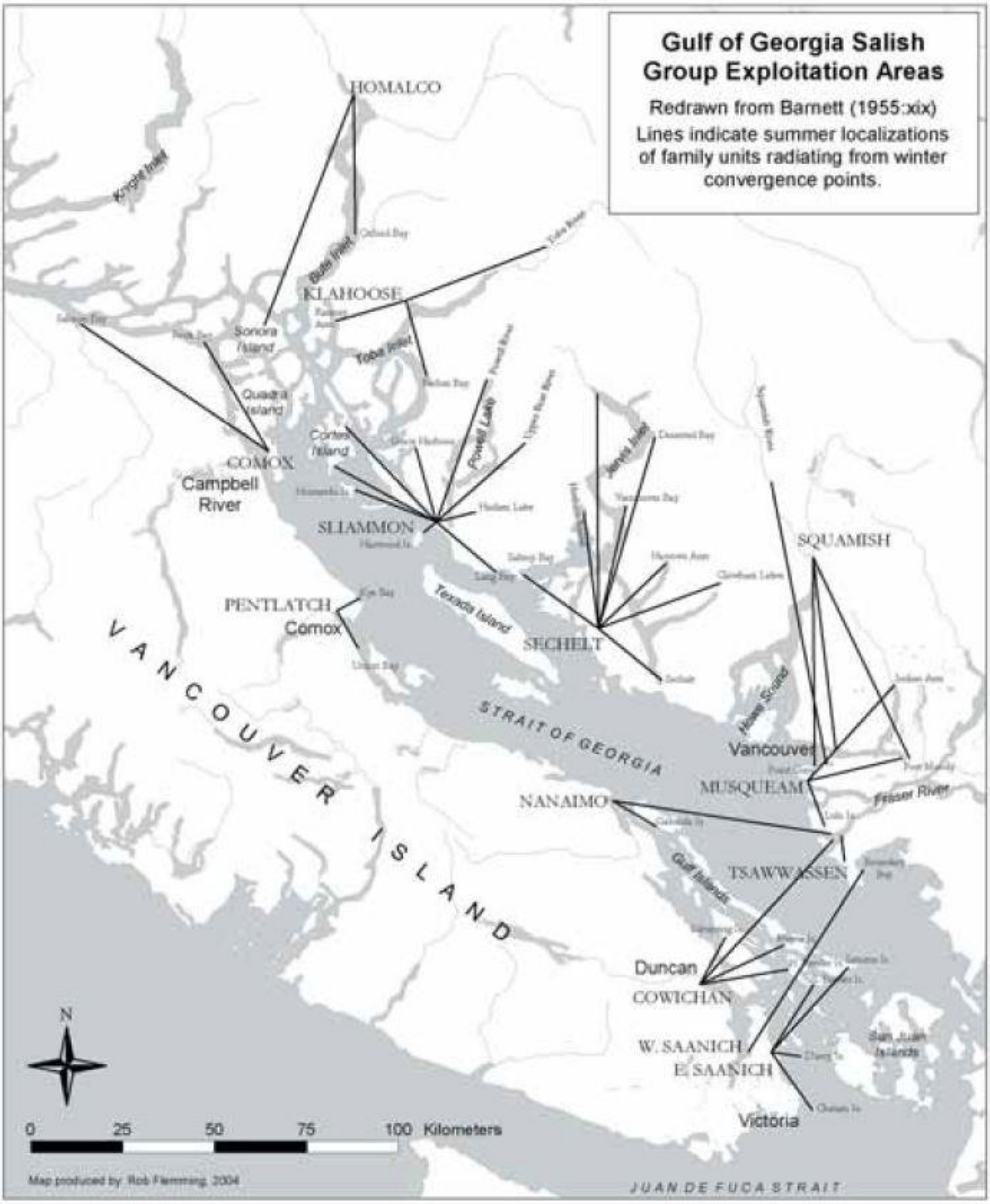

Figure 3.4: Gulf of Georgia Salish group exploitation areas. Illustrated by Brian Thom and Rob Flemming. Reproduced with permission. From Thom 2009

Another seasonal depiction is provided by Gagnon and Berteaux (2009). Here they constructed a series of maps with spatio-temporal information while working with Inuit experts from Mittimatakik, Nunavut, Canada. They use several of the visual primitives outlined by Bertin (1983) in doing so. In one single static seasonal based map, they show the flight routes and stopover points of snow geese in autumn and spring. Migration routes are labelled via directional arrows. Stopover areas are labelled by polygons. The two seasons use a simple colour code to sort the data by season. Long-term change can also be depicted using the same primitives. Gagnon and Berteaux (2009) include another map showing declines and increases in abundance and nesting abundance for the same species in the same area. This time, black arrows show the shifts. The map does not make clear how long this shift has been happening, nor does it show intermediary steps, but it remains a legible expression of the movement of a cultural keystone species.

3.3.1.1.2 Multiple static maps

Seasonal data is well suited for small multiple representations due to clear differences between the seasons, and allow for readers to visually scan between the seasonal depictions as via the chess-map technique outlined by Monmonier (1990). Aswani and Lauer (2006) provide a seasonal representation of fishing practices in the Solomon Islands. The community at Roviana Lagoon, New Georgia, has three locally recognised seasons in Roviana Lagoon, based on the timing of the low and high tides. The small-multiple map they created reflects the mean net rate of return and the total seasonal foraging time expressed as a percentage, and contrasts the day low season with the day high season, and the intermediate tidal season. Polygons representing fishing areas were draped over photographic imagery for this purpose. Hue values change as the importance of different locations change, and some polygons disappear in some seasons as the area goes fallow at different parts of the year.

Although the majority of depictions tend towards vector approaches to demonstrating temporal patterns, this is not always the case. Polfus et al. (2014) have an excellent small, multiple multi-year map in their work comparing the TEK of Taku River First Nation with western science that utilises rasters distinguished via a colour ramp to highlight the core areas used by caribou during different seasons (Figure 3.5).In the map, small multiples of the same area are used to contrast both the summer and winter predictions, and the RSF (resource selection functions, based on western science) and TEK-HSI (traditional ecological knowledge-habitat suitability index, based on traditional knowledge) predictions, using the generated rasters. Although the overlap between the two models was high, there were differences. Polfus et al. (2014) stressed that the two models were complementary, and underlined the importance of TEK for giving a fuller and more complete picture of the needs for caribou.

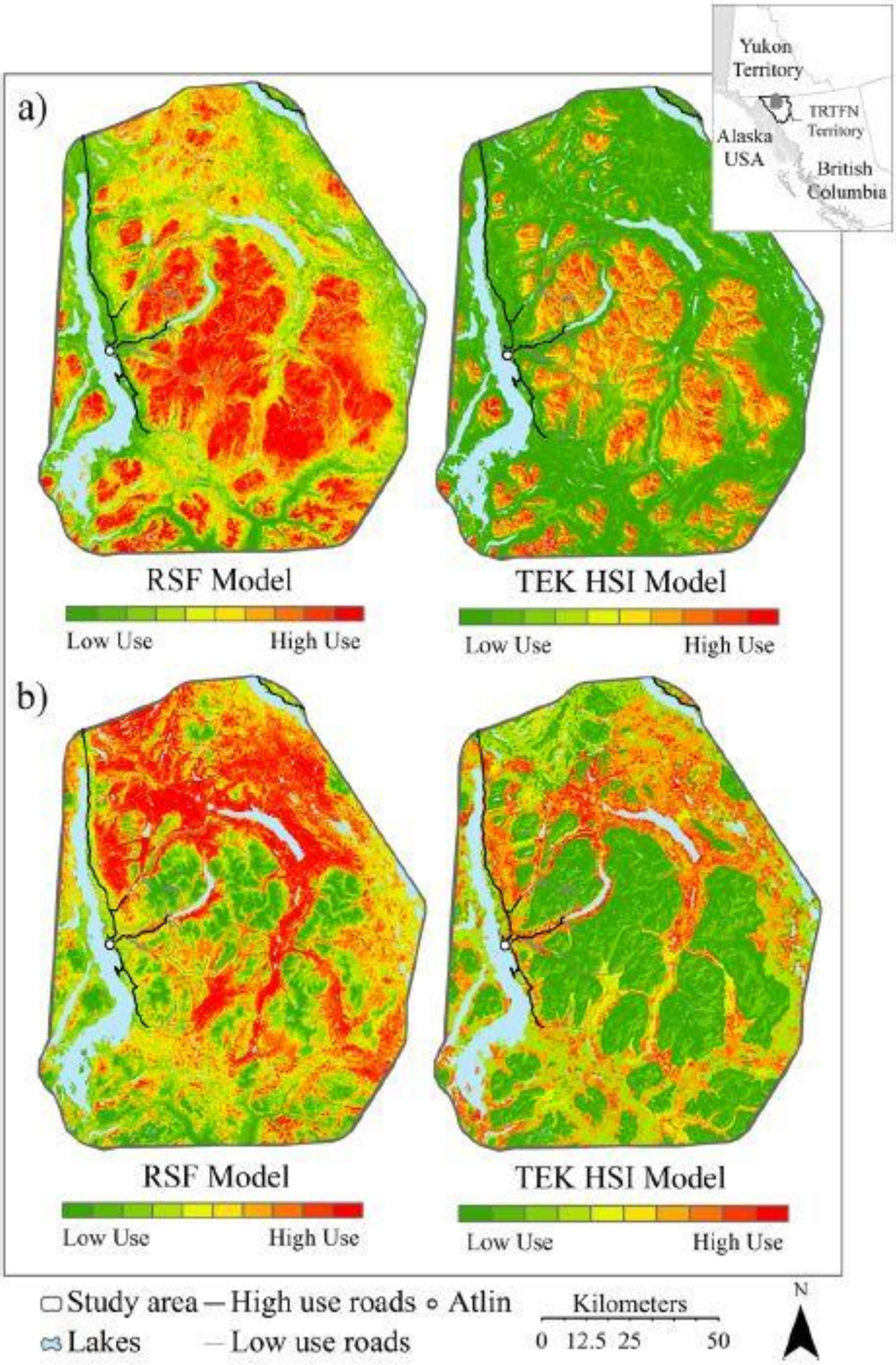

Figure 3.5: Map contrasting models based on northern woodland caribou GPS collar locations (left) and on Indigenous knowledge (right) and contrasting habitat use from seasons (a) summer and (b) winter. Reproduced with permission. From Polfus et al. 2014

Multiple static maps are also useful for multi-annual depictions illustrating change over time. Although not technically Indigenous maps, the work by Hall et al. (2009) is an excellent example of time series multiple maps that are directly pertinent to the sorts of issues

Indigenous peoples face. Hall et al. (2009) were interested in mapping out the local knowledge of oyster-men in Bluff, New Zealand. They took two different approaches in doing so. In their first map, they took polygons from decade by decade time periods that were generated via map interviews. Oyster-men would be asked pairs of questions, such as, “Did you fish around Lee Bay in the 1960s?” and “Can you draw on the map the approximate limits of the Lee Bay bed where you fished during that decade?” (Hall et al. 2009: 2060). The resulting polygon would be digitised and coded. The resulting map would be made of overlapping polygons that would show the expansion and contraction of the oyster harvest. The second map shows the movement of the oyster beds themselves. Polygons change in size from season to season, and a density map approach is generated by using different hues to indicate areas where overlap between informants is strongest.

Some mappers working with Indigenous data include multiple depictions of the same information from multiple standpoints. Hakopa (2011) includes a genealogical timeline, a genealogy, a map of the given area rendered in western style cartography, a hand drawn map of the same area, and a portion of Mōteatea, or traditional oral poetry, usually with historical context in some of his depictions. These are all examples of what Buckley (2013) refers to as marginalia, but in Hakopa’s work the map provides a visual context to an underlying narrative, and it is the narrative itself that remains primary, making the map itself another form of marginalia. Mapping out cultural consistency is another task suitable for multiple views. Aporta (2009) provides an example of two juxtaposed snapshots of data for the same trail almost 100 years apart, and it becomes evidence at a glance that the same areas are still being used today. Lack of change for spatio-temporal mapping can be as interesting as change itself. The two maps use completely different iconography, one being digital, one being hand drawn, but it is the juxtaposition of the two that tells the story.

3.3.2 Animated Maps

Animated maps allow for the dynamism of the temporal information to be preserved, and as such animated maps are the preferred medium for complex spatio-temporal visualisation. Interactivity is not an all or nothing category, and can be understood as a spectrum stretching from pure animation, to fully interactive visualisation environments (Roth 2011). Animated maps can still make use of all the static graphic visual primitives as given by Bertin (1983), but have the additional advantage of being able to make use of dynamic visual variables as well.

There is a core list of six dynamic visual variables that are used in map animation: 1) scene duration; 2) rate of change between scenes; 3) scene order; 4) display date; 5) frequency; and 6) synchronisation (DiBiase et al. 1992; MacEachren 1994). The display date or moment of display refers to the real-world time being represented (Edsall and Peuquet 1997). Duration refers to the time each scene is held, in which, no change occurs (Kratochvílová 2013). Order refers to the sequence of the frames. Chronological ordering via date-stamp is the most obvious order, but other orderings could be based on a particular attribute (DiBiase et al. 1992). Frequency is the number of identifiable states per unit time (Kraak and MacEachren 1994), and is also referred to as the temporal texture. Synchronisation is the temporal correspondence between two or more time series (Kraak and MacEachren 1994). This is the key variable for cyclical time representations.

Not all animated maps focus on the display of time series. Kraak (2007) lists two further types of animated maps: 1) animation and successive build-up is one type, and here multiple layers are added to one another to give a sense of the spatial patterns in a region; and 2) another type of non-temporal animation is that of changing representation. Kraak offers the fly-by as an example.

These depictions have been useful for representing time under a variety of conditions, but they are limited in how they represent cyclical restraints and patterning. Synchronisation is possibly the dynamic variable, most analogous to the needs inherent in modelling multiple overlapping conceptions of time. In a multi-cyclic world view, full moons all have a certain similarity, as do low tides, as do say, spring times, as do mornings, therefore, in some ways all spring mornings at low tide with full moons share a common time. Different time windows from different cycles can be treated as constraints or openings, and activities are best planned for times when openings line up. This conceptualisation of time appears to be largely absent from current spatio-temporal depictions. Fuzzy time intervals are also addressed in the literature (Ohlbach 2007, Qiang et al. 2012), but do not seem to appear much in spatio-temporal cartographic depictions. The holistic aspects of Indigenous time are also not well represented. One visual approach to time that could be useful for Indigenous multi-cyclic time is that of semi static animation, as outlined by Nossum (2012). Here, mini representations of the entire trend are included iconographically alongside the feature in question.

3.3.2.1 Indigenous Examples of Animated Maps

Indigenous information does make its way into animated maps. These maps make use of some of the six dynamic visual variables outlined by DiBiase et al. (1992) and MacEachren (1994). The Saylor Academy (2012) illustrates the loss of lands of Native Americans by the expansion of the United States. The animation is a series of time slice maps put together into a video. A display date indicates the passing years, and different colours are used to indicate lands lost and lands still in the hands of Native Americans. An initial map is shown depicting land claims by tribe in multiple colours and textures before the land loss information is shown. Groves (2013) contains two animated maps, both utilising display dates to illustrate the date of the time slice portrayed. The maps are of Idle No More events in Canada from

December 9, 2012 to March 1, 2013, and are based on an Access to Information request with the department of Aboriginal Affairs. Groves uses sticky dots for both animations. When dots are added to the map, they are initially larger, so that the eye can better track their addition. Blockades are coloured differently from rallies and other events. These maps are framed via narrative and supporting imagery of associated paperwork.

For a more complex demonstration of animated mapping, Equipeact (2009) tells the story of the dispossession of the Surui in the Brazilian Amazon. Display dates help orient the viewer in the animation. The rate of change is not standardised, but it moves forward as the associated narrative moves forward. The map uses interviews, overlays, icons, and time series to show their story. At various time periods, the map zooms and pans to different areas to illustrate different parts of the overarching narrative. Equipeact utilises Google Earth to put together their animation, and Google Earth now has a wide range of tools for creating animated tours, both as video or in an interactive format. The interactivity is important for adding depth and an exploratory environment to the data.

One key methodology for displaying spatio-temporal cultural information in an interactive environment is via the use of electronic cultural atlases. These were originally formulated by the Electronic Cultural Atlas Initiative in 1997 (Zerneke et al. 2013), and are a useful approach in the humanities and social sciences for placing information into a wider context. As envisioned by Lancaster and Henderson (1998) cultural atlases were to contain a map (where), a menu of cultural features (what), and a timeline (when) as well as a text window stitching the features together. Meanwhile, in 1997, Johnson presented a "prototype Windows-based mapping application with time filtering and a set of proposals for recording historical entities as time-stamped objects in GIS datasets" (Johnson 2008: 33).This application is called TimeMap and has been used successfully for many projects, including the Interactive Macquarie Atlas of Indigenous Australia. TimeMap supports playback, zooming, timelines, and layers can be switched on and off (Owens 2007).

These atlases are still key tools for documenting spatio-temporal information for Indigenous peoples. Caquard et al. (2009), have an excellent article on the Cyber-cartographic Atlas of Indigenous Perspectives and Knowledge of the Great Lakes Region in Ontario, Canada. The Atlas was developed to portray the interrelations between multiple forms of cultural expression, including artwork, traditional stories, historical, and linguistic data. They did this via embedding photographs, video, and audio clips into the map. In some cases timelines were used. The process uses local community members, and the technology was picked for accessibility. The atlas itself includes audio, playback controls, and a timeline, as well as historical imagery. The Cyber-cartographic Atlas is a work in progress, and continues to undergo iterative design. Both the development and display in the atlas take a hodological approach, where pathways are given central importance (Pyne and Taylor 2012). This stands in contrast to much of mainstream mapping where points and polygons are often given primacy. As Turnbull (2007: 143) says, “Telling a story and following a path are cognate activities, telling a story is ordering events and actions in space and time...”

3.4 Interacting with Spatio-Temporal Data/Visualisation Interfaces

There are several standard operations that have come into play when dealing with spatio-temporal data visualisation. Users need the ability to focus on particular moments or spans of time (when). Users must be able to focus on particular locations (where), and users must be able to search for different activities or types of things (what). Added to these operations, one might add searching for individuals or groups involved in an event or activity (who), but this is often subsumed under 'what'. The first of these three operations are those laid out in Peuquet's (1994) triad model.

For existing datasets, the ability to search for features fitting different descriptions requires a variety of search tools. In a fully functional GIS, this is accomplished by querying the associated attribute table, but in a visualisation environment, different widgets or tools may be set up for the task. Temporal slider bars can be used to query linear time, or an interactive time wheel control could be used to query cyclic time. Nöllenburg (2007) posits a complex time wheel with multiple wheels for multiple temporal granularities (hours, days, and months). These search functions and selection functions in a visualisation environment can be referred to as a temporal legend. Harrower (2009) lists three main kinds of temporal legends: 1) the digital clock; 2) the cyclical time wheel; and 3) the linear bar. In an animation mode, these display how what is on the screen relates to overall time. Temporal legends can be used for stopping, starting, and brushing time (Köbben et al. 2012). Temporal brushing is where the user might select information or item in one display, and have data matching that information or item appear in other displays. Using an interactive timeline, for example, one could view all features that were active in 1987, or 1983-2009. Another cyclical interface could be used to select all events occurring in spring or winter. Temporal zooming, panning, querying, and playback control can all be done via well designed temporal legends (Edsall et al. 2009). These temporal components have spatial and thematic equivalents. Roth (2012) provides an excellent synthesis of cartographic interaction primitives.

Users working with spatio-temporal data need to have ways of adding new features, deleting old features, and editing existing features. Different tools can be created to enter in points, lines and polygons, and code them temporally, as well as entering descriptive data. The user may want to enter in a seasonal stream, so perhaps they would mark it out with a line, colour it blue, make it a dotted line, and add some sort of stamp for springtime. Perhaps the user wants to mark a kill site, so the user might pick a symbol of a moose or use a text code, give it a colour, and timestamp it with a particular date.

The point of an interaction and visualisation environment is to enable the user to search for patterns in the data. Multiple views of the same data can make this easier. This is where brushing and linking comes in handy. With multiple views, one may want to select all the features that fit particular constraints on a chart that is contained in the visualisation environment. Immediately, those same features would be highlighted on the map, and on the temporal legend. A series of filters can be used to facilitate the process. The user may only be looking for mammals, or birds, or only ducks, and only hunting sites, or nesting sites, etc. It is a key point to make, but only systematised data is easily accessible via filter or query. Finding ways to systematise data in a culturally appropriate fashion is in itself problematic.

There have been many visualisation packages put together for exploring spatio-temporal data over the years. TEMPEST (Edsall and Peuquet 1997) was one of the earlier ones, with a query tool that allowed for multiple forms of cyclical time to be represented like months of the year or days of the week, as well as linear time. A longer litany would include STNexus (Weaver et al. 2005), GeoSTAT (de Oliveira et al. 2012), and LISTA-Viz, a component of the GeoViz Toolkit (Hardisty and Klippel 2010).

3.5 Missing Components for TEK/IK Spatio-Temporal Visualisation

There is good support in current TEK spatio-temporal visualisation for seasonal patterns, narratives, and linear depictions of change over time and these are supportable in static and animated maps. Depiction modes usually utilise vector depictions, but raster depictions have been utilised. Some depictions of spatial fuzziness have been developed with density mapping, where multiple views are synthesised and overlapping polygons offer a proxy for consensus. However, many visualisation problems remain. Some of these problems will be discussed below.

3.5.1 Cyclical or Multi-cyclical timing and Multiple Constraints

Of the four main natural rhythms of the annual cycle, lunar cycle, diurnal cycle, and tidal cycle, representations have only really been developed for seasonality, despite other cycles being of importance to Indigenous peoples, and to the species they depend on. A fully fledged visualisation for TEK spatio-temporal data should have support for the documentation and display of all four cycles. This is not easily accomplished with a standard linear Gregorian Calendar and 24 hour clock backbone. Support for astronomical data in the visualisation, like the localised timing and positions of Heliacal risings and solstices could be useful.

Visualisation interfaces should also be customisable. Different cultures recognise different seasons, and lunar counts, and perceptions of how to keep track of the lunar cycle also vary. Likewise, what constitutes a day can vary from group to group (sunset to sunset, sunrise to sunrise, midnight to midnight), and the recognised parts of the day will also vary from group to group. Tidal patterns pose problems because on top of the pattern of high tide and low tide are the patterns of spring tides, neap tides, and king tides that are related to the lunar cycle.

There should also be some form of support for phenological and meteorological indicators. These are often tied to the seasonal cycle, but can shift from year to year and from decade to decade. Phenological shifts in particular are already being recognised by some Indigenous peoples (Turner and Clifton 2009). Weather patterns are changing as the global climate also changes. Ideally phenological and meteorological indicators would be incorporated into the visual display.

Day count systems should also be supported or supportable for those cultures that utilise them. The ability to enter in day count systems should be part of the querying apparatus. Day counts are probably the most straightforward traditional calendars to visualise and to model as the underlying logic is closer to that of Clock and Calendar time. These systems are critical for several Indigenous groups, including traditional Mayan and Balinese timekeeping (Dershowitz and Reingold 2008).

When documenting the four main natural rhythms, there needs to be some way to link how patterns of restriction and ease interrelate with one another. This could cause difficulties, but a complete depiction of spatio-temporal data should offer a good idea of when and where a good time for an activity exists in space-time. A look-up tool for regional celestial indicators and tidal patterns may also be useful.

3.5.2 Adaptive and Dynamic Spatio-Temporal Boundaries

Due to the differences in perception between the A/ not A logic of western time and space and the more flexible, localised and ‘fuzzier’ sense of traditional locality and temporality, ideally any visualisation tools would have room for a fuzzier logic built in from the start and fuzzier ways of indicating locations, routes and time windows. Observational based timing can change from year to year and season to season. Rains can fall later or earlier, so when documenting when the rains fall in a given genericised cycle, room for fuzziness must be allowed. This fuzziness has parallels in the shifting of growing seasons for farmers in the West. It may be wise to give room for something like a whisker box plot to show the earliest time of onset vs the latest time of onset, and earliest and latest times of closure. Aigner et al. (2005) provide a glyph that allows for this sort of fuzziness. Likewise, density maps of multiple interpretations of the same data provide a reflection of spatial fuzziness, as do raster-based habitat models. Individuals of species themselves are more likely to show up in different times at different places for different activities in different states of health.

Due to the deliberate need for ambiguity for when it comes to protecting traditional sites of importance, the ability to generate a random polygon, or randomised buffer may also be of use for Indigenous users (Pacey 2005). These could include sites for medicine, fishing spots, and so forth. The ability to mask data in a fuzzy way is also useful for areas where human remains or other sites of significance can be both marked for their protection and hidden at the same time.

Fuzziness in the sense used by Zadeh (1965) has also been used for Indigenous spatial mapping. Hunter and Ballantyne (2000) discuss the potential for modelling native land occupation based on ranked land use membership groups. Their model utilises occupation and cultural significance to weight the importance of different areas based on archaeological sites, and was centred on Shuswap occupancy near Gustafsen Lake. Cohn and Hazarika's (2001) approach of qualitative spatial representation and reasoning may make for a good fit with Indigenous mapping. In some ways traditional spatio-temporal conceptions more closely mirror a probability cloud of an atom when individuals are planning an activity than a mechanised clock and a piece of graph paper. Visualising spatio-temporal data from this perspective is not straightforward, but more work is needed on finding ways of making the data legible, and creating interfaces that are logical to users.

3.5.3 Narrative and Contingencies

Narrative structures should be supportable. Stories, legends, myths, and memory not only explain a place, but also tie a place to other places, and orient the activities of a site in relative time, as well as seasonal time. Likewise, stories of place and time can indicate what areas are dangerous during certain events. Areas where people have been injured or killed may be more dangerous than others and marked by story accordingly. Narratives in the form of oral recitations also can act as fuzzy boundary markers. Turk (2006) discusses how for Australian Aboriginal groups, boundary markers can be included in songs, ceremonies and forms of non-permanent symbol making, and how boundaries can shift as descendants responsible for caring for an area diminish. The main theme of Ignace's thesis (2008) is how oral histories mark out the territory. Likewise, traditionally Māori mark boundaries via natural landscape features, markers on the ground, and accompanying narratives to demarcate areas of rights and responsibilities (Hakopa 2011). Sletto (2009: 268) discusses how the Pemon of Venezuela find western conceptions of rigid, unchanging demarcation lines problematic, as traditional forms of boundary making result in "...fluctuating, porous, and often relative wide zones that are commonly agreed-upon, semi-permanent, and contingent on changing social relations and geographies...".

The human dimension could use better support for social contingencies that set off a process, like weddings, births, ceremonies, and funerals. These events are not always tied to a particular date, but are still used as cues for different patterns of activities. As well, there should be room for adding who to the traditional what, when and where of Peuquet's Triad framework (1994), as who a person is and their associated rights by birth, deed and circumstance have an enormous effect on what areas they can use and cannot use.

3.5.4 Privacy and Sensitivity

Privacy and sensitivity concerns do not exist in a vacuum, and different people and different groups have different risk tolerances. Some groups may not consider hosting data externally on the cloud sufficiently safe for the most sensitive data. Some groups may not consider the documentation of any data safe, and some groups may be willing to share much of the data. Ideally any applications for documenting Indigenous spatio-temporal data has ways of storing all data locally, or, if on the cloud, in ways that are password protected and assigned in a way that sensitive data belonging to a group or sub-group can only be viewed by those they are comfortable with seeing it. Built in obfuscation methods may also be useful. Addressing privacy options concerning Indigenous mapping is a broad topic, and beyond the scope of this paper. Harmsworth (1998) and Pacey (2005), discussed earlier, describe levels of privacy and obfuscation techniques, respectively. Due to information we have now about storing information on cloud systems, cloud storage cannot necessarily be seen as secure. Bryan and Wood (2015) discuss in detail some of the issues surrounding IK and the military. Information is ideally stored locally, with backups, under the control of people the community as a whole trust. The specifics may vary from place to place. One could make a case that the most sensitive data should never be put online, and the understanding that others may use information in a way that is not to the community's benefit needs to be made clear throughout a project. Those participating in a project should never be pressured to document sensitive information, and need to be given the opportunity to decide how sensitive their own information is. There are still no clear paths on how best to fit privacy and sensitivity requirements that are useful across the board.

3.6 Conclusion

Future work on Indigenous spatio-temporal modelling must address natural temporal rhythms, phenological and meteorological indicators, and have some sort of way of depicting the underlying fuzzy and adaptable logic underneath. Any set of tools for depictions must be customisable and adaptable to place. Indigenous timing is not universal from place to place, but similar patterns emerge in widely varied areas. Visualisation techniques must be usable for both static and animated maps, and ultimately, a visualisation environment specifically set up for the concerns and constraints posed in Indigenous ways of timing may need to be addressed. Current spatio-temporal depictions, albeit widely varied almost all utilise the same universalised timestamp form of representation, and multi-cyclic timing is poorly supported. Likewise, dealing with fuzzy logic and fuzzy depictions are limited at this time. In order for IK to be utilised more effectively in management and co-management scenarios, more work needs to be done to develop ways of depicting these complexities to a wider audience when desired. Techniques suitable for displaying these complexities may also have applicability in non-Indigenous contexts.

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4 Towards a Spatio-Temporal Data Model for Traditional Ecological Knowledge/ Indigenous Knowledge: The Motif

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Abstract

Indigenous peoples have been making maps, and utilising GIS for some time, and have been mapped and cadastralised for some time as well. Models of Indigenous spatiality have been the topic of some work, but the data for modelling Indigenous spatio-temporality remains scant, and the subject matter is rich. This paper suggests another layer of representation for GIS when dealing with complex data with a strong relational and qualitative component. In this paper we present a new data model that we are calling the spatio-temporal motif. It is an open data model incorporating choric (x,y) as well as topic (attribute) space and chronic (co-ordinate) as well as kairic (attribute) time. The model aims to fill gaps in other data model depictions concerning lack of support for cyclical time, multiple constraints on what constitutes a proper time or place for a given activity, fluid and dynamic spatio-temporal boundaries, support for narratives and contingencies and privacy and sensitivity concerns.

Keywords: *Indigenous, GIS, spatio-temporal, data model, topos, kairos, chronos, chora, motif*

4.1 Introduction

Many approaches have been taken over the years for modelling spatio-temporal data. Timestamps predominate for indicating the temporal component, and these centre on time as made of granular, gridded time, where every instance or event happens once in a Cartesian framework, utilising the familiar grid of Years, Months, Days, Hours, Minutes and Seconds. Locations are given in vector form of points, lines and polygons, with features altering into yet more points, lines or polygons at another given moment in time, or they are represented as pixels in a raster, with features altering into other pixels in a raster at another given moment in time. Features tend to be crisp, although there is now a substantial literature on both fuzzy boundaries and locations for space, as well as fuzzy temporal windows. These models have their place, and the reduced, uniform 4-D grid is one that is unavoidable in representations of space and time in a GIS. However, these methods of modelling are limited, and provide a fairly narrow view of space-time, centred as it is on absolute co-ordinates. Rämö (2004) would categorise these approaches as Chronochoric. Hägerstrand referred to this approach as chorochronology (Sui 2012).

GIS as a field stems from a high modernist tradition of standardised time, and standardised space. This allows for more legibility, but at the expense, sometimes, of nuance. Indigenous peoples maintain a strong interest in mapping their territories and activities despite the boxes that are imposed by cadastral, calendar and clock systems because of the need to defend rights in courts, and to communicate effectively with others in their territories. Maps are tools. To paraphrase Scott (1998), a map that aspired to represent every bush and every tree and every fish would threaten to become as large and as complex as the territory that it depicted.

What is needed by Indigenous peoples, then, is not necessarily to map all lands and waters and species and uses, but rather to provide an open ended customisable toolkit so that Indigenous peoples can more effectively tell the stories they want to share with themselves, and with outsiders. Reasons for documenting and sharing stories include for establishing tenure (McLain et al. 2013), for demonstrating previous or potential impacts to traditional rights including cumulative impacts (Herrmann et al. 2014), for use in management or co-management of traditional territories and important species either alone or involving outside parties (McLain et al. 2013), and for maintaining and adapting guardianship or stewardship activities over time (Kainamu-Murchie et al. 2018).

There are a variety of factors that Indigenous peoples take into consideration when deciding when and where to carry out a certain activity. Many factors will not be transparent to outsiders who do not have experience with the territory. The model for dealing with this complexity over the last century has been what Scott (1998) refers to as "Authoritarian High Modernism", that is to make the landscape and the people legible to outsiders. Indigenous mapping of the 20th and 21st century have also dealt mainly with legibility to outsiders, either to maintain and protect territories, or, when subsumed by military interests (Bryan and Wood 2015), to make it easier for outsiders interested in Indigenous territories to operate. To be legible is to be controllable. To not be legible is to be invisible. Mapping is a two-edged sword.

Indigenous and much of pre-enlightenment worldviews are not limited to time and space as grid representations, although some non-Western cultures do make use of similar concepts. Time has both a linear component, a multi-cyclical component, and a relational component. Spatial areas tend to shift over the long term in a linear way, and ebb and flow in a multi cyclical way. Indigenous relations to other species likewise ebb and flow as species alter their use of the landscape over linear, multi-cyclic and relational time. Multiple timekeepers are utilised, and there are a multiplicity of boundaries, some crisper, some softer. Some of these dynamics are better classed as what Rämö (2004) would call Kairos – Time and Topos – Space.

Rämö (2004) breaks down both time and space into two complementary views. For time, he makes the distinction between Chronos, which is the quantified notion of time that is familiar with calendars, clocks, schedules and timestamps, and Kairos, which is time in the sense of the right time to do things. Likewise, he breaks down space into Chora, which is tied to co-ordinate place, and Topos, those qualities that make the place that particular place, or the web of interconnections that that place has. As Sui (2012) notes, Hägerstrand's vision of time geography is very much "chorochronic", and occurs in a Cartesian framework + clock time. This is abstracted time, and although it is very useful, it is not the entire picture. Tools need to be developed to better reflect Kairos time, to allow for other forms of Chronic time, and to better allow for the interconnection inherent in Topos space. Crang (2005:212) sees chrono-chora approaches as "anywhere-whenevers" fitting everything into "abstractly identical time-space units" and that this approach is the norm for time-space in time geography. He stresses the need for developing kairo-chora, chrono-topos and kairo-topos senses of time-space to counterbalance this. One way to deal with this underlying imbalance is to look at different forms of time and space and how they might be modelled.

The distinctions, then are between two kinds of space, Chora (Cartesian co-ordinates) and Topos (concrete place and landscape), and two kinds of time, Chronos (clock/calendar time) and Kairos (embedded/event time). Chora and Chronos lend themselves well to depiction via quantitative co-ordinates. Topos and Kairos are relational and fit better with a qualitative approach. With two kinds of time and two kinds of space being available, a multiplicity of different ways of approaching spatio-temporal data are created. Sui (2012) offers a typology of approaches using these concepts, with nine overarching spatio-temporal models.

Current depictions of spatio-temporal data are not completely adequate for these forms of representation. Some come close, in particular the work of Stephenson (2005) with her Dimensional Landscape Model, made up of nodes, networks, spaces, webs and layers, and Wilcock's work on ethnoegomorphology (Wilcock 2011), which makes clear the importance of narrative, travel and interconnection to Indigenous peoples in Canada and Australia. Efforts to include Indigenous conceptions of Topos and Kairos have included components utilising embedded video, text, and other forms of narrative to flesh out these other senses of space and time, and this has been a productive approach, but other depictions are still required, and other ways of modelling spatio-temporal data are needed. These are useful but they fall short in including all the various salient categories that people use for highlighting places and times for carrying out activities, and the interconnections between places, times and activities in a data model that explicitly makes room for these depictions within a single data model.

Rämö (2004) and Sui (2012), via their use of the chora/topos and chronos/kairos distinctions provide equal weight to non-Cartesian depictions that should be able to be entered and queried in a GIS context interactively in ways that go beyond current methods. Qualitative time is much easier for people to remember in general, although people may not remember all the factors involved. It was a sunny day, it was rainy, it was in the morning, it was winter. This is especially true for outdoor activities. This is further cemented when the participant timed his activities based on qualitative factors. A fuller representation of Indigenous spatio-temporality in a GIS then, must have room for quantitative and qualitative temporal and spatial components. In this paper we propose a way of providing that footing via the spatio-temporal motif.

4.2 Required Patterns

A previous paper by Mackenzie et al. (2017) discussed some of the things that a data model for Indigenous knowledge needs to be able to cope with in order to do that. As listed in the previous section, they are as follows: 1) Support for cyclical or multi-cyclical mapping; 2) Multiple constraints on what constitutes a proper time, proper space, and proper agents for a given activity; 3) Fluid and dynamic spatio-temporal boundaries; 4) Support for narratives; 5) Support for contingency based timing; and 6) Privacy and sensitivity safeguards as part of the model.

4.2.1 Support for Cyclical or Multi-Cyclical Mapping

Cyclical mapping is fairly limited for Indigenous mapping beyond seasonal rounds, with a few notable exceptions (Aswani and Vaccaro 2008). Ecologists have explored some patterns, but usually one at a time for seasonal patterns (Basille et al. 2013), lunar patterns (Woodside 2010), diel (day/night) patterns and tidal patterns (Pearce and Louis 2008), and the ecological work indicates that there are a number of species that change their behaviour and location based on these four cycles in particular. It is not uncommon for Indigenous mapping projects to include a summer/winter map, or a four season map. Seasonal rounds are often documented, but rarely tied directly to landscape.

Aswani and Vaccaro (2008) discuss the importance of some of these regular cycles for timing in Roviana. Here they compile information on key windows utilised by various species under certain cyclical conditions, and the local categories of marine areas where those patterns are apparent. These however, are not explicitly tied to a map. Their table structure for the data includes the following: “major fishing methods”, “technology employed”, “major habitats targeted”, “principle prey species”. and “principle season(s)” (Aswani and Vaccaro

2008:337). With a good connection between a table like this and a map of the habitats, a usable cyclical map could be easily generated.

Spatio-temporal modelling of Indigenous information does occur, but it has largely been marine-centric. Aswani and Lauer (2006) go into some detail about mapping spatio-temporal patterns of human-environment relationships in the Solomon Islands, particularly with marine protected areas. Aswani and Lauer use locally defined seasons and "indigenously delineated bio-physical areas (Aswani and Lauer 2006:92)". For the temporal component, they include seasonal spatio-temporal data for spawning aggregations, nesting sites and nursery sites for a variety of species. As well, they look at variations in fishing patterns over the different seasons. Aswani and Lauer's work is solid, and points the way to some robust ways of mapping Indigenous spatio-temporal data. Others have followed in their wake (Moreno-Báez et al. 2012, Beitl 2014).

4.2.2 Multiple Constraints on What Constitutes a Proper Time, Proper Space, and Proper Agents for a Given Activity/State

Indigenous peoples utilise their territories with a keen eye towards spatial and temporal suitability for activities. There is a right and a wrong time to burn, good and bad times to harvest certain species in their life cycle, excellent and poor times to fish and so on. Successful gardeners, hunters and fishers around the world are likewise familiar with these principles.

One of the better and clearer demonstrations of the multiple constraints utilised by Indigenous peoples when timing their activities and the relationship of that timing to particular areas can be found in Aswani's work. Aswani has looked at patterns of marine harvest in terms of seasonality for catching different species, and constraints for harvesting due to shifts in tidal and lunar cycles as well, in terms of foraging efficiency (Aswani 1998).

Aswani's approach centres on emic (local perspective) divisions of time, emic classifications of land and seascapes, as well as emic understandings of what makes for good times and poor times for harvest, backed up with self-reported foraging journals and diaries (Aswani 2014). Not all of these temporal dynamics are reflected directly in the maps created, however.

External factors have also been mapped as yet another set of constraints. Outside factors like privatisation, pollution, contamination, depletion and lack of access have been noted by some communities engaged in mapping traditional use (Hul'qumi'num Treaty Group 2005). Unlike traditional constraints, external factors tend to be ongoing and cumulative in their restrictions. Cumulative impacts along these lines destroy the ability for people to maintain their traditional ways and is a violation of rights, or such was the ruling from the OAS Inter-American Commission of Human Rights in 2009 concerning Canada's actions against the Hul'qumi'num peoples (Thom 2014).

Constraints are also used in the literature when analysing archaeological data for behavioural strategies (Ladefoged 1995). By seeing where people from the past have built and left remains, it becomes possible to get a sense of what areas were richer and poorer in resources, and based on the remains, it can be possible to identify what areas were used in which seasons.

4.2.3 Fluid and Dynamic Spatio-temporal Boundaries

Indigenous data has been used for modelling habitat use in wildlife management. Polfus et al. (2014) used caribou habitat requirements as listed by experts to pre-existing data to create a raster data model for habitat suitability for caribou in winter and summer. They compared this model to a habitat model derived from resource selection functions based on western science, and the actual locations of collared caribou, and there was high spatial agreement.

Raster approaches and models utilising expert knowledge generate weighted values and fuzzy boundaries for the potential presence/absence of a species in a given area.

The importance of using local classifications for landscape features has been noted by several authors. Mark et al. (2011) compiled an entire volume to what they refer to as ethnophysiography, or the cultural understanding of landforms. Although some locations and sites are relatively fixed over long periods of time, like mountains, others shift over time, like the locations and extents of rivers, and wetlands. Utilising local mereotopological terms and boundaries allows for a better reflection of the underlying cultural ontologies (Wellen and Sieber 2013). Indigenous ontologies need better support.

Ethnopedological (cultural soil classifications) have also been the topic of study by several scholars (Barrera-Bassols et al. 2006). Soil taxonomies can be constructed via interviews, focussing on what is salient to the people of the area, and maps were created via interviews and transect walks. The ethnopedological community tends to utilise a Kosmos-Corpus-Praxis (K-C-P) approach, where questions focus on the symbolic, cognitive and management dimensions, and where all dimensions integrate with one another. These can be compared to western scientific soil classifications, but are highly localised. Most soil maps are snapshot maps, but Barrera-Bassols (2003) explicitly addresses processes and change in his thesis, and models changes in Indigenous classifications of soil over time. It is this plasticity and dynamic sort of boundary that needs to be central to Indigenous mapping efforts.

Technical approaches to documenting the non-crisp nature of many Indigenous senses of space have also been utilised. Different individuals when interviewed have different styles of indicating an area on a map, as opposed to orally. Carver et al. (2009) discuss how some will draw “broad sweeping circles” and others “small, crisply outlined regions”. To get around this dichotomy, they utilised an Applet called “Tagger” that works like a spray-can, so that users could better vary density, extent and shape. These were then converted into raster GIS maps.

Boundaries are not always the best representation of the territories of a given group of people. Thom (2014) discusses the difficulties of trying to represent traditional Coast Salish kin-based land tenure in a way that the government of Canada regards as transparent. Those expectations stem from the same issues of Authoritarian High Modernism and the ideal of “legibility” outlined by Scott (1998) that we referenced earlier.

4.2.4 Support for Narratives

Narrative-based mapping and support for narratives is one area in particular where current Indigenous mapping as narratives can contain a multiplicity of information, narrative support also provides some support for documenting how Indigenous peoples view appropriateness of time, place, and agent(s) for given activities, and the histories and cosmologies that underpin the worldview. Narratives receive support in various mapping models via embedded links to video and audio in an interactive format. Palmer likewise talks of the importance of placing narratives in a central position for what he refers to as “Indigital geographic information networks” (Palmer2012:80). Stories are explicitly included in Wellen’s work, and he discusses the possibility of using an ontology of stories as a potentially good design for Cree users (Wellen 2008). Narratives as a form of coming together are also discussed and utilised by Wilcock (2011). Narratives do not function either as a moment in a linear sequence, nor as a cross-section over changing time-space, but are dynamic and interweave past and present. Stories can organise and interrelate locations into a whole via interrelationships in a way that would be difficult to do otherwise, and networks of stories form their own reference system (Pearce 2014).

What Turnbull (2007) refers to as hodological or pathway based mapping has also been utilised. Pyne and Taylor (2012) discuss the process utilised for the treaties module for the Living Cybercartographic Atlas of Indigenous Perspectives and Knowledge as a hodological approach, where the emphasis is on trail making, and trail following. Stories are given primacy, and intersections between stories at various places are identified and linked. The importance of pathways is important for Australian Aborigines in the dreaming (Saab 2003), as well as other groups that spend much of their time moving. Hakopa (2011) includes multiple passages highlighting the importance of pathways for Māori. Pathway type places connect nodal type places, and their importance is likely for any group that spends time travelling, much as road and rail networks are important in GIS. Pathways as a form of connecting and interrelating nodes allows for narratives to be represented more efficiently. Pathway models for narratives are excellent for representing interconnected ideas, times, places and actors, and could be adapted for cyclical narratives as well.

4.2.5 Support for contingency Based Timing

Contingency based timing does not appear to be addressed frequently. Some possible work for what may be suitable for a contingency approach may be for processes set in motion when a certain event occurs, be that a funeral, a wedding, a tsunami, or an earthquake. Weather events and planning ahead based on indicators could also fit in this area. Some work has also been done on ethnometeorological indicators, albeit loosely coupled to spatio-temporal data. Traditional knowledge indicators for drought forecasting and weather prediction have also been created by some authors. Chisadza et al. (2013) look at some of the indicators in the Mzingwane catchment, and note the use of plant phenology, insects and birds, as well as the wind, moon and sun to predict future drought. The signs used are localised, and do not necessarily translate to other areas. Chisadza et al. interviewed people in several catchments and kept indicators of the same catchment together. They sorted the indicators into three groups, these being indicators based on trees and plants, indicators based on insects, birds and animals, and indicators based on the sun, moon and wind. Chisadza et al. focussed solely on indicators for drought.

4.2.6 Privacy and Sensitivity Safeguards as Part Of The Model

Sensitivity and security are important for Indigenous peoples, and the issues with the need to have ways of classifying data by sensitivity have been long known. Harmsworth (1999) provides a typology for privacy, and notes that some themes, like sacred sites and metaphysical areas are more sensitive than others. For these he encourages that layers be kept to families or tribal groupings if based on Māori values, and that the potential for sensitive data exists for classifications of land, vegetation, animals and the like, and that such data should be coded appropriately for those different levels of privacy. Different types of features and layers can then be sorted via privacy categories. Mallie (2007) likewise works on systems that separate men's knowledge from women's in Australia, where such a distinction is culturally significant. Other constraints due to sensitivity are listed by Saab (2003:70), including "sacred knowledge, gender-specific knowledge, cross-generational constraints, [and] issues of trust and power". One method of protecting data is by creating layers that mask sensitive features, and contain no information other than the shapes entered as masking layers themselves (Cowan et al. 2012). These can then be shared to highlight sensitive areas without sharing any other information.

4.3 Review of Past Data Models for Mapping Indigenous Knowledge

There is a ubiquitous web of relations in Indigenous thought; connecting in one way or another everything to everything else, and other species and landforms are fellow beings with agency, rather than static objects (Rundstrom 1995). GIS as noted before has a tendency towards an atomised approach dealing with discrete objects in a regularised spatio-temporal grid. Of the data models for Indigenous Knowledge that the authors are aware of, all ignore some or all of these problems. These data models are not flawed, and they are useful, but they offer an incomplete picture of Indigenous spatio-temporal knowledge. Of course all models are incomplete. Some of the most effective maps for capturing Indigenous knowledge hold closely to the inherent strengths of GIS.

There is a large body of work associated with mapping Indigenous knowledge. McCall (2017) maintains a handy and sporadically updated bibliography on local and Indigenous spatial knowledge that as of 2017 runs 171 pages long. McCall's bibliography is broad ranging, with a good selection of papers covering mapping efforts and methods for documenting Traditional Ecological Knowledge (TEK), Local and Indigenous Spatial Knowledge, (LSK, ISK), participatory GIS techniques, Indigenous Technical Knowledge (ITK), tenure mapping, boundary mapping, Use-and-Occupancy mapping and other related literature. One excellent guide to the literature is given by McLain et al. (2013), who refer to this body of literature as Human Ecology Mapping. They provide a schema for the literature and sort it into three major categories, these being Tenure and Resource Use Mapping, Local Ecological Knowledge Mapping, and Sense of Place Mapping. The oldest of these, and still the most influential, is Tenure and Resource Use Mapping, and of the methodologies that make up this category, Use-and-Occupancy mapping is the oldest and most well developed.

In Canada, Use-and-Occupancy mapping is the main approach towards mapping Indigenous Knowledge. It has also been utilised widely and remains influential for Indigenous mapping approaches elsewhere. It is explicitly positivist, focussing on events that can be verified, at the expense of what Tobias (2009:47) refers to as the "opinions, knowledge and wisdom" of Traditional Ecological Knowledge studies. This is due to its origins in providing evidence for Canadian court hearings, and the need for the methodology to fit court standards. This is not a failing, in that it has been an effective tool in the hands of Indigenous peoples. The "Inuit Land Use and Occupancy" project of 1976 was the first of many (Freeman 1976), and the methodology continues to be used today, with Tobias' book, "Living Proof" being the current methodological handbook (Tobias 2009).

Use-and-Occupancy mapping centres on mapping biographies of individuals in the community, where the individual has carried out activities that provide evidence of use, like hunting, fishing, gathering and trapping activities. These are collected with who, what, when and where in mind, or as Tobias (2009:47) refers to them as "data diamonds". Timing is usually of the timestamp variety when possible, or as much accuracy as the participant can remember. Seasonal activity patterns are also sometimes collected. Earlier Use-and-Occupancy maps often used polygons in response to a question like "where do you hunt?", but most people now collect instances of hunting, fishing gathering or trapping, and lean towards a point-based representation. Codes for different species and activities are used, these often belonging to a larger category or set of categories. For instance, hunting moose or elk might be subsumed under a "game" category, and multiple species of fish may fit under a "fishing" category. Databases are usually put together on a single spreadsheet, with additional information gathered on the users themselves. Raw data is not usually shared, and may be obfuscated via buffering, randomisation, and the use of higher level generalisations. Use-and- Occupancy focusses intentionally on use categories. Data is usually stored in vector format as points, lines and polygons with a primary key generated by a use code, a numerical ordering for the individual being interviewed, and an interviewee code.

Use-and-Occupancy Mapping follows a “map biography” approach which does open the way for Indigenous understandings of the landscape via recording oral histories and ecological knowledge while mapping (Usher 2003). This does add a deeper dimension to the maps, as the maps are embedded into a wider form and support stories. In this way, Use-and-Occupancy mapping makes room for narratives. However, the narratives are not necessarily explicitly embedded in the map itself. Unique identifier codes allow for a direct linking between video, transcripts and the maps made. Cyclical data is sometimes gathered, but the narratives are not usually entered into the data model itself.

Kill sites are the focus of much of the spatio-temporal work with Indigenous practices (Read et al. 2010, Iwamura et al. 2014). They are well suited for GIS representation because they occur at a given location at a given time. This precision fits neatly into chronochoric spatio-temporality, with very little ambiguity. Iwamura’s work in particular is highly quantitative in approaching the interactions between the Indigenous peoples of the Rupunui region of Amazonian Guyana via their hunting and forest clearing practices, and this emphasis on quantifiability allows for the construction of robust models (Iwamura et al. 2014).

Participatory mapping also usually follows standardised conventions. Colás (2013) bases his database for representing Indigenous information on a standardised ISO compliant land administration domain model. This would entail crisply bounded parcels with crisp ownership, and does not adequately address the complexities that such an approach simplifies via standardisation. Colás takes a standardised approach because the information needed to be integrated with a Spatial Data Infrastructure for Honduras. Likewise Mohamed and

Ventura (2000) take a crisp approach to documenting Indigenous land tenure systems. They discuss how delineating parcels can cause disagreements and differences of opinion amongst those being mapped, but rather than take it as a cue that boundaries can be indistinct, see it instead as something to be resolved.

4.4 Key Indigenous Knowledge Data Model Requirements

Western depictions of time and space, particularly in a GIS setting have focussed on chronochoric, or chorochronic understandings of time, and are tied closely to a Cartesian framework that events and processes occur within. This has been an extremely useful approach, but there is nothing inherently universal about utilising a universal grid when it comes to human spatio-temporal conceptions. A universalised grid also, like any good tool, comes with blindspots. Sui and Goodchild (2003:12) point out that data models can "force representations" as the medium is set up best to deal with complex systems dissected into layers of crisp Boolean categories, and with ignoring uncertainty and fuzziness being simpler than representing it. This crispness, and the atomised view that comes with it is inherently problematic for a wide range of phenomena and ways of knowing, but is particularly problematic for Indigenous systems of knowledge, practice and belief.

There is no one Indigenous way of keeping time, and methods of keeping time are often highly localised. There are, however, commonalities. There are obvious natural cycles of different lengths that people use to keep track of activities in their territories, and a data model should have ways of keeping track of these. The annual cycle, lunar cycle, diel (day/night) cycle and tidal cycle are key for many people, although how people keep track of them vary from culture to culture, location to location.

The annual cycle is usually divided up into seasons, as well as finer divisions, and these may be standard divisions, as in the west, or lunar divisions, with intercalary months, as in the Chinese calendar, or based on various cues like shifting weather patterns, the flowering of certain plants, etc. The lunar cycle can either be tracked via the sidereal (relative motion to the stars) of around 27.32 days or the synodic (phase) cycle of around 29.53 days

(Dershowitz and Reingold 2008). Cultures may have a sequence of named days or lunar mansions when tracking the moon.

The day may be divided up into regular equal timed divisions, like the Chinese calendar, or may be divided up into time periods of different lengths. Sunrise and sunset change time and location over the seasonal round. Tidal cycles also vary over the course of a lunar cycle, and may have different local gradations, and distinctions between a neap tide and a spring tide. Plant behaviour, animal behaviour and meteorological patterns also occur in regular patterns, often tied to these four main cycles. In addition to these cycles, cultural cycles can be of importance, like the 60 day cycle for the Chinese calendar, the 210 day Balinese cycle, or the 260 day Mesoamerican cycle (Dershowitz and Reingold 2008).

Although some cycles are theoretically modellable as quantitative data, particularly regular cycles of the year, the lunar cycle, the tidal cycle, and the daily cycle, as well as various calendrical systems of day-counts and other regular calendars, not all of the attributes lend themselves well to a quantitative approach. Even those cycles that do lend themselves well to a quantitative approach may be best approached qualitatively as attributes for circumstances that reoccur. Narratives involving relative temporal indicators, like generational information likewise may not be securely anchored to a Western calendar, but how that relationship is related to other generations, (before, after, at the same time) can be touched upon qualitatively. Traditional activities also have multiple constraints on where and when it is appropriate or inappropriate for an individual from a certain group to go. These restrictions can be seen as analogous to places and times set aside for conservation, places and times seen as dangerous, places and times set aside for use by members of a group, and places and times that are open for all. Due to shifting conditions, shifting patterns exhibited by key species, and shifting patterns of rights and responsibilities, many spatio-temporal boundaries are rarely fixed, although there are some that are closer to a western conception of a crisp boundary. Temporally, cues like plant, animal and meteorological behaviour would shift from year to year against the background regularity of the sun, moon and tides. Individual understandings of core areas versus periphery areas are likewise flexible in cultures that have not been cadastralised.

Narratives play a central role in Indigenous conceptions of time and space, and any given event, person, location or species will be related to many others. Narratives also explain why certain areas may be dangerous or good places for certain activities, and act to make sense of the landscape and timescape as a whole. A data model for Indigenous spatio-temporal knowledge must be able to link and support narratives. Indeed, as narratives have been the central way of correlating and cataloguing Indigenous knowledge, practices and beliefs for most cultures, supporting narratives and incorporating narratives must be central to any form of Indigenous spatio-temporal depiction.

Not all timing is cyclical or predictable, and yet certain events are expected through the course of life. Once certain events occur, contingent processes are set in motion. There may be weather related contingencies, social contingencies, and rare event contingencies, like an earthquake, an eruption, a tsunami, etc.

Finally, Indigenous data is often sensitive, and due to the double edged nature of documenting information, not all data needs to be seen by everyone. Some cultures have strict rules about whether men or women can be told certain stories, or shown certain places. Obfuscation methods are useful, as are passwords etc. Cloud data can be compromised. Users need to be made aware of risks so that they can choose to disclose or not disclose information as they see fit, and assign information a proper level of security.

4.5 Data Model for Traditional Knowledge – The Spatio-Temporal Motif

The term motif comes from multiple sources, including literature, music, folklore, and genetics, and signifies a repeating pattern that is similar to other instances of the same motif. Motif has been used by others working with spatio-temporal data before for suites of patterns (Condotta et al. 2005, Li et al. 2006, Li et al. 2011). We can take this concept and extend it to the documentation of traditional spatio-temporal patterns. These form a web of interconnecting themes and variants. A motif can be made up of other motifs, and can be chained together in a narrative way to illustrate a point or a pattern determined by the mapper/community/interested party. An alternate name for these patterns might be Vik, from the Inuit postbase "-vik", meaning both place and time (Gombay 2009). Motifs can be strung along into narratives, and multiple narratives can flow through the same motif. Motifs are also hierarchical, in that more refined and specific forms of the motif nest within more general categories Day>summer's day> hot summer's day>hot summers day on a mountaintop. Motifs are potentially made up of Chronic (clock/calendar) and Kariotic (embedded) time components, and Choric (co-ordinate) and Topic (concrete and landscape) place as well as salient agents.

Let us take the harvesting of a mobile species. The species is only ready for harvest at certain times of the year, and only present at certain times of the year. The species is only active during the day, and prefers wet days to dry days. A given harvesting event might be represented by the following:

- Co-ordinates giving the location of the harvesting event.
- A timestamp giving the Year, Month, Day, and Hour of the harvesting event.

- Attributes associated with the event. This could include the harvester, the species harvested, and the number of the species taken in that harvesting event, and potentially the meteorological conditions of the day.

We end up with "Point 1: xyz, timestamp, attributes; point 2: xyz, timestamp, attributes;" These harvesting events will cluster towards different locations, different times of the year and day, and, if the records are solid enough, the events might cluster under different meteorological conditions. If all we had was the points, we might gather enough information to explain where the clusters are and when they are, building up a model from the raw events. When working with Indigenous knowledge, and Indigenous peoples, those models already exist in the minds of the harvesters, and the events take place when and where they do due to the previous experience of the harvester, observations made by the harvester, multi-generational experience that the harvester has learned, and so on. Consequentially, we need a format where these sorts of models can be recorded for a given species, or a given site, or a given time window, or all three together.

We will call that model a "motif". A motif is a container like object that holds different instances, represented by points, lines, polygons or raster together due to a recognised essential similarity. For a broad example, we can look at the activity of catching chinook salmon during the spawning season. A more generalised motif might be (fishing in winter in rivers in British Columbia). A more specific motif might be (adult chinook salmon in November in the Adams river), and an even more specific motif could be (gaffing for adult chinook salmon on sunny days in the Adams river at a certain set of rapids). Points, lines and polygons can be generated via interview, and rasters could theoretically be built from multiple pre-existing layers based on models based on Indigenous knowledge. Motifs do not have to include cyclical time, so it's possible that one could generate a motif for (salmon fishing sites from the 1950s) and compare it with (salmon fishing sites from the 1980s). Motifs should utilise emic (local) categories of time division, habitat division, spatial division and species division where possible, and interfaces for capturing motif information need to be able to be customisable by Indigenous groups for that purpose. Basic Formal Ontology discusses the difference between SNAP vs. SPAN ontologies, making a distinction between continuants like a rock or a city, and occurrents, which are tied to processes and activities (Grenon and Smith 2004). Motifs linked via containing the same entity could be seen as identical to a continuant. Motifs that describe a single instance of a process at a given location could be seen as identical to an occurrent. Most motifs would be better seen as recurrents in that the patterns they describe occur repeatedly when the conditions given by the motif exist.

Motifs are or can be made up of the following:

- A given set of temporal attributes that indicate when the right time (or wrong time) for an activity may be.
- A given set of spatial attributes, or a particular place that indicate where the right place (or wrong place) for an activity may be.
- These places and times may be fuzzy or crisp, and temporality may be linear or cyclical, or multi-cyclical.
- A given set of personal attributes, or group attributes that indicate who the right person/people (or wrong person/people) for an activity may be.
- A given set of species attributes that indicate what the right members of the species (or wrong members) for a harvest might be.
- A given set of circumstances or events that will trigger a motif or series of motifs. These are contingency based events.

- Links to audio, video or text files containing narratives about the activity.
- A privacy rating, or some sort of privacy formalisation specifying what level of information gets shared with what groups of people, either at the family level, band level, tribal level, etc. If a cloud-based system is used, these levels of privacy and who shares in different levels could be set by the knowledge holder.

Motifs are related in several ways:

- Motifs are related implicitly, either by parts to whole relationships (more specific submotifs as part of larger more general motifs) or by adjacency (semantically related motifs can be adjacent if they vary via a single attribute, are adjoining regions, or come before or after another motif on a temporal dimension). Utilising Worboys' concept of handshakes (Worboys 2005), motifs can be connected temporally in synchronous and asynchronous fashions, and in syntopic and asyntopic fashions.
- Motifs can be related explicitly via relationship narratives.
- Motifs can be more node-like, path like or region like based on the regions identified, and two node-like motifs can be linked via a path-like motif. For instance, a trip from an encampment via a trail to a fishing location.
- Motifs can overlap, and are rooted in individual and cultural emic breakdowns of space and time.
- Multiple motifs can be clustered into a super-motif, and motifs can be broken down into sub motifs.

We might end up with something that looks like, in this river, at this location, the best time to fish for the adults of this species is in winter just after a major rain, and this site is harvested only by members of this group. This is a detailed motif, and is how the harvest of that site may be regulated. Multiple motifs can cluster for a more detailed description of the harvest of that species at different age categories, at different times of the year, or by multiple groups.

A number of features (points, lines and polygons) that describe instances of the harvest can be subsumed under the same motif. Likewise, there would be ways to indicate the spatial, temporal, social, and other boundaries around the motif in a GIS. The original points under discussion would be examples of the motif, but the motif includes many other space-time points that have never been documented from the past, and those that have yet to happen. A motif may be bound to a certain spatial extent, and a certain temporal extent, applying to a certain decade, and perhaps an island or a watershed, or several watersheds.

Motifs can also be linked or threaded together in narratives, paths, or loops. A narrative might involve the motifs for certain storied places. A path may have several motifs along the way that are utilised in order during certain time windows. Motifs may also be related in loops that could be tied to the life cycle of a species, or a seasonal cycle, or lunar cycle. More detailed motifs can be subsets of more general motifs, and multiple motifs could make up a supermotif. Something like eel harvesting would have different motifs for different rivers, different stages of the eel lifecycle, different fishing methods, different groups of people, and so on.

As conditions change, motifs change. Indigenous knowledge is a living body, and will shift and change over time when previous patterns no longer apply due to things like climate change, changes in the harvest location, etc. Documenting motifs allows for a more straightforward representation of how people decide to harvest, as well as what areas are to be left alone at certain times.

To illustrate how narratives embodied by motifs can be linked to different places while sharing a general time and path, we use a quote from Te Rangi Hiroa (McDowall 2011:435-436) (Figure 4.1):

> "For centuries the Maori has known that the eel made an annual migration down to the sea to spawn. On this knowledge depended the building of eel-weirs of different types. When the rains of late March or early April commenced, the eel-traps were set. The tuna heke, or migrating eel, was caught in immense quantities, and all through the migrating period, the families were busy through the nights, and by day cleaning, splitting and drying the season's supply."

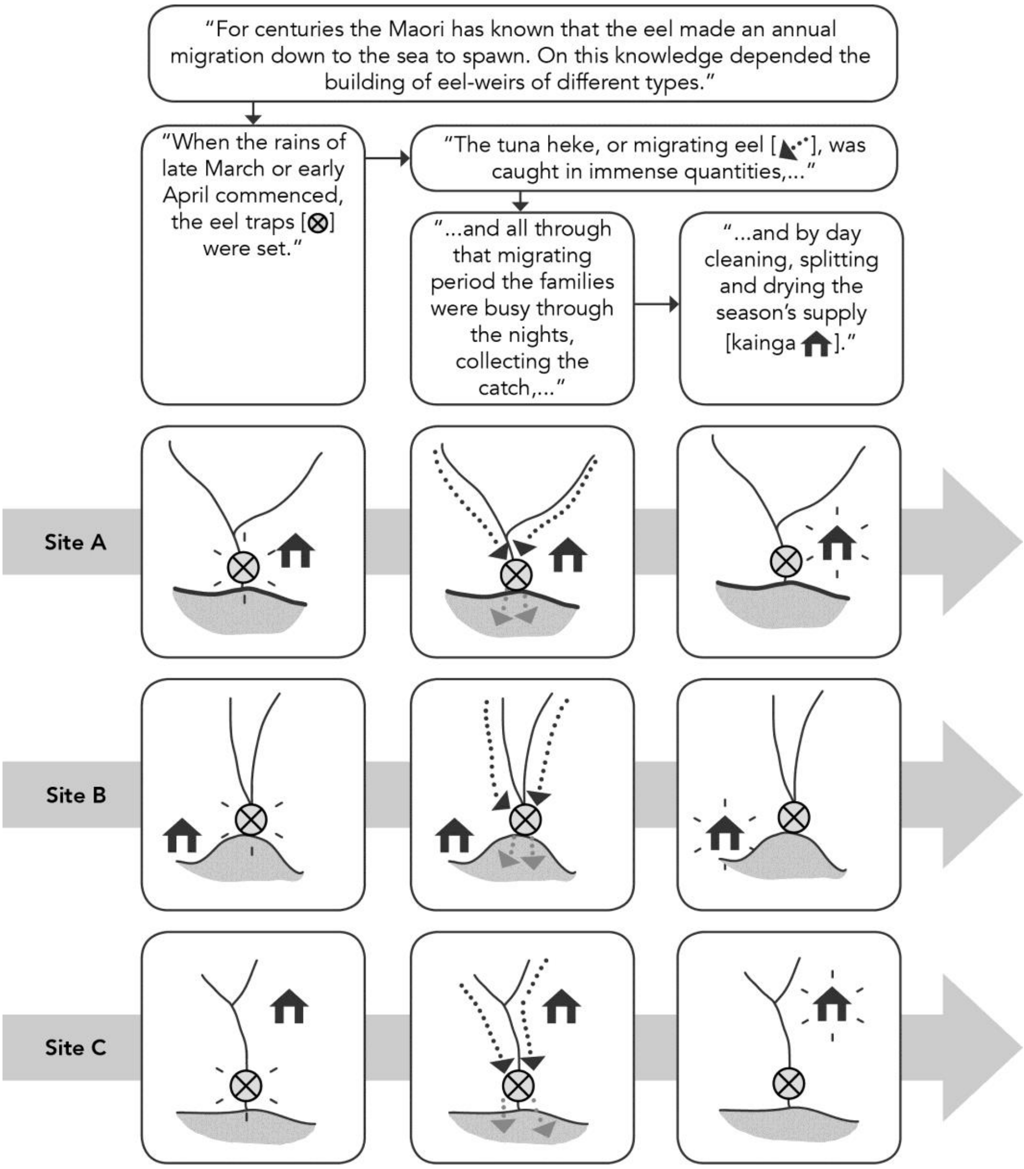

Figure 4.1:. Te Rangi Hiroa on the Tuna Heke Harvest. Illustrated by Katie Wilson

We can also contrast motifs after a key event. In our second example, we use the traditional eel harvest at Okorewa, at the mouth of Lake Ōnoke (Saunders 1965), and now destroyed as predicted by Saunders by flood mitigation strategies used in the area (McDowall 2011) (Figure 4.2.). The mouth of the lake used to close seasonally, which would allow for eels to become concentrated in number, and therefore easier to trap. The mouth would open and close intermittently during the tuna heke or eel run, and traps would be set as eels would attempt to make their way into the sea and back to their spawning areas. This has been destroyed by the flood mitigation, which opens the mouth up wide as soon as it shuts (Saunders 1965, McDowall 2011).

Our motif-based model could continue to be of use for current eel management, particularly in co-management scenarios. The opening of Te Waihora (Lake Ellesmere) to the ocean was strictly controlled during pre-European Māori times to prevent flooding and to allow for the migration of eels and flounder at key times of the year. This practice is continues today but integrates flood prevention of surrounding catchment, cultural, historic and recreational values through a co-governance approach.

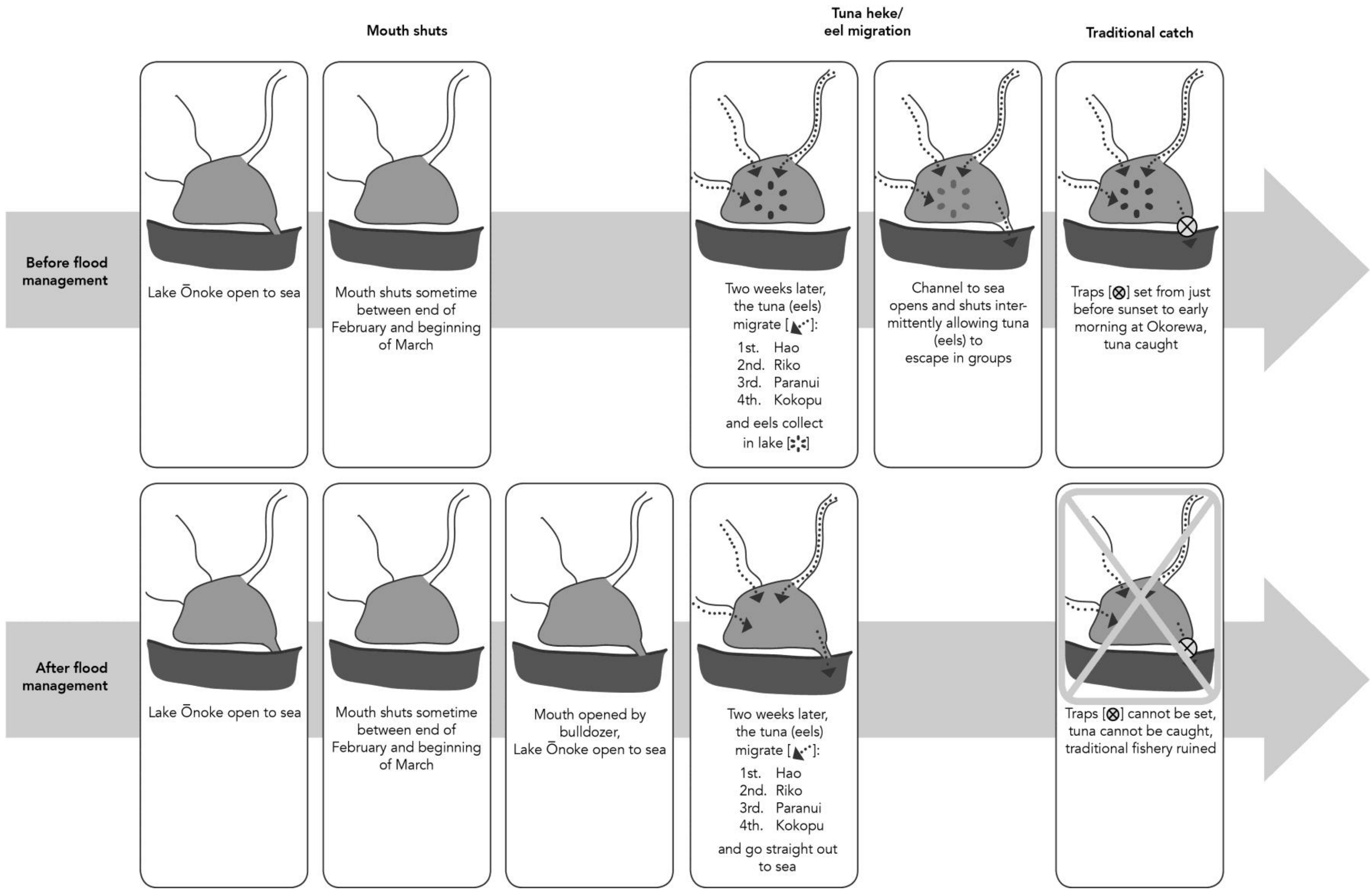

Figure 4.2: Tame Saunders on the Tuna Heke harvest at Okorewa. Illustrated by Katie Wilson

4.6 Conclusion

GIS has come a long way over the years when it comes to dealing with complex spatio-temporal data, but the grid system that is standard has a number of shortcomings that need to be addressed, particularly when it comes to rhythms critical for those whose livelihoods depend on understanding other species. The spatio-temporal motif offers a higher level of abstraction when dealing with Indigenous spatio-temporal data. Motifs allow for the expression of both quantitative and qualitative approaches. Cyclical and multi-cyclical data are supported by both implicit and explicit relations. Constraints are utilised to judge the rightness or wrongness of a given activity in a given area at a given time by a given actor. The instance basis of mapping motifs allows for fuzziness and non-precise forms of highlighting areas to come to the fore. Similar motifs can allow for a temporal blur. Narratives provide context for individual motifs, and explicitly link motifs into wider patterns via relationships, threads and webs. Contingency motifs are the trigger for cascades of other motifs that are linked by narrative. Privacy has been an ongoing concern for those working with Indigenous knowledge, but patterns of obfuscation, omission, and password protection are common, as well as different layers of privacy. Due to the strengths of GIS, and the flexible nature of the systems, it should be possible to make more room for Indigenous representations in all their forms. Any tools need to be customisable, extensible, and secure, but at the same time, they cannot be unusable.

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5 Representation of Spatio-Temporal Traditional Ecological Knowledge in GIS with a New Data Model: The Folk Thesaurus

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Abstract

Spatio-temporal Traditional Ecological Knowledge is complex and rich, and carries with it difficulties that are not easy to tackle with current tools in GIS. The geo-atom approach, underpinning the majority of data models utilised in GIS is somewhat problematic when dealing with the interrelational and dynamic dimensions of traditional ecological knowledge. The authors suggest what approaches to the fuzzy aspects of Indigenous knowledge schema might look like in a GIS environment, and describe how the motif concept may work with the precise ambiguity of traditional forms of timing and spatial utilisation. The authors suggest a complementary model here that focusses on the ability to model spatio-temporal knowledge in a way that maintains some of the strengths of oral depiction, interconnectedness, and precise ambiguity.

Keywords: *geo-atom, GIS, ontology, folksonomy, folk taxonomy, traditional ecological knowledge, data model, knowledge modelling*

5.1 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 that fall outside of the clock and calendar time, of cadastral space, of crisp (non-fuzzy) timestamps and of clear boundaries. A given culture may utilise a given set of species and their behaviour as a way of keeping track of the seasons. Daytime varies in length throughout the year making for a poor match between sunset and a clock. Years can vary in length based on how they are reckoned, and may be reckoned based on significant events, not on the Gregorian year. What is the right time and place for one person may be forbidden to another person. Tenure systems are not always transparent to outsiders. Much of this conflicts with the assumptions of current spatio-temporal GIS practice, particularly the geo-atom approach.

The two main sources of data when discussing traditional systems of tenure, traditional activities, and traditional rights, is from practitioners past and present. The data does not always have solid co-ordinates attached, nor are the times involved unambiguous, and patterns of behaviour are often recurrent. Much of the data is qualitative, and quantitative aspects are not always in the western calendar. Likewise, previous documentation may also have spatial and temporal data, but via place name or via traditional calendar. Any form of documentation should ideally capture traditional information in its own context. This can include traditional classifications involving landscape, meteorological conditions, seasons, and species classification. These systems of classification themselves are also rich stores of valuable information.

Lastly, Traditional Ecological Knowledge (TEK) often comes in the form of a more abstracted sense of the right sorts of time and places for given activities. This particular sense is not seen or discussed often in the GIS literature. It is rarely discrete and unambiguous enough that it fits cleanly within data models from a western paradigm. Temporal reckoning is often multi-cyclic and contextual. Ontological categories likewise are not necessarily easily translatable to universalised categories now common in GIS. As such, there are complex challenges in representing Indigenous spatio-temporal knowledge.

The purpose of this paper is to present a new knowledge model and data model for representing traditional and Indigenous spatio-temporal knowledge. The model allows for fuzziness and vagueness spatially, temporally and semantically, and allows for more qualitative spatial and temporal structures. The core of this approach is the **motif**, which is a repeating pattern of spatial and temporal context around a given action or state. 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 paper provides a recipe for a more complex understanding of space and time than is currently available with current GIS design because of the allowance for creation of semantic relations as needed in a robust, yet flexible way. The folk thesaurus allows for the expression of traditional classificatory systems in a way that is difficult using strict tree-like hierarchies that are the norm for ontologies in GIS otherwise.

5.2 Challenges of Indigenous Temporal, Spatial and Semantic Information

5.2.1 Temporal Fuzziness

Much of Indigenous timing is associated with finding the right time for a given activity, and to avoid the wrong time for other activities. Ensuring that timing is correct maintains and aids the rhythms of other beings, while poor timing can damage those other beings that a group may depend on. All sorts of factors can come into play including the time of year and the positions of the stars, the lunar cycle, the time of day, weather behaviour, plant behaviour, animal behaviour, social patterns, and other cues. When the climate in a given area is fairly stable, it will be a fairly reliable cue from year to year. In areas with more pronounced differences from season to season, or, as is the case in much of the world, the climate is shifting to some unknown new normal, many of these cues no longer work as well as they once did, but are being updated by people on the landscape. On top of these complexities come the consequences of colonialism and the expansion of western thought, meaning that for some Indigenous groups, traditional knowledge about timing is not as robust as it once was, or has shifted, and people now utilise or incorporate the Gregorian Calendar/24 hour clock as a primary means of keeping time.

What this means in practice is that a question like "when is it a good time to fish for salmon" opens up a rich universe of timing that is contingent on the person, the place, the weather, the gear, the particular species of salmon, previous experience from other years, monitoring information from other fishers, habitat conditions, and whether one means today, or in general, and so on. 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. It also means that for a fully developed interface, there needs to be ways of representing multiple cues, and whether it is a better or worse time for an activity. Activities are not tied solely to harvest, as there are also activities like transplanting organisms from one area to another, or burning, or planting that ensure abundance for the season or years to come. Information from respondents is likely to be varied, and not always binary, so tools must be set up to allow for “precise ambiguity”, to use Rundstrom’s term (Rundstrom 1995:50).

For many cultures, pinpointing the timing of certain events might be part of the role of a specialised knowledge holder for a given location or species. For other activities, each person might base their timing on what they have been taught, and what they themselves have observed. For most cultures, individuals learn about timings and place by practice and observation with older generations, and passing practices on to younger generations. This information can be quite sensitive, so respondents may choose to not answer certain questions, or leave their responses ambiguous.

5.2.2 Spatial Fuzziness

The world is in flux. Everything from the mountains and hills underfoot, to the forests cloaking them, to the rivers flowing through them, to the clouds in the sky overhead is constantly in motion. A herd of animals and/or a population of trees can be treated as either an object or a field. Herds of animals are constantly on the move, and in some ways can be seen as being like weather. Meanwhile, a forest tends to move, expand and contract over longer timescales, making them more like hills or rivers. Depending on the salient temporal dimension, a river might be quite crisp, or meander repeatedly across the plain, like a palimpsest of all the previous courses. With animals it is obvious that they are on the move, less so with more stable features. The slowest moving features like mountain peaks anchor the scene.

There are a number of ways in which a good portion of Indigenous spatial knowledge is likely to be better suited to “fuzzy” or “vague” representations over the crisp depictions that are the norm for GIS. Oral cultures tend to allow for multiple versions of stories and an easy facility towards semantic ambiguity. For many cultures, there is not so much a boundary, but a boundary zone. Thin dichotomous boundaries are rare (Rundstrom 1995) and ambiguity is not seen as problematic as it often is in the West. Likewise, representations of spaces and places are best left to methods that allow for, or are anchored in ambiguity. This sort of ambiguity allows for buffer zones or interstices to flourish, and allows for areas to ebb and flow.

Individuals themselves vary in what they consider to be an important place, or what they may regard as belonging to a place, or how they choose to depict a place. The more expressive the tools, potentially the more expressive the spatial information recorded. No two people will chose to mark down an area in the same way, and without a cadastral body to regulate which version is the “official” version, all have merit. Turk (2006) gives a sense of some of the features that might be used including rivers, watersheds and changes in vegetation. Boundary markers do exist for many Indigenous peoples and may be agreed on, but even then, there is usually some ambiguity. Some are defined via song or performance.

Areas held by a group may be non-continuous, and may change as responsibilities change and are negotiated. Transition zones can exist, and concepts of boundaries can vary depending on factors like gender, seniority and kinship. In other cultures, areas overlap with some Indigenous groups specialising in one set of resources, and other groups specialising in other resources. Boundaries can be represented by zones, and not clean lines (Turk 2006).

Indigenous nations are often pushed into marking crisp boundaries as the dominant culture expects them, and the law courts treat land as a collection of well-defined objects. These lines end up being disruptive for property and family connections between groups. There needs to be more room for spatial depictions that better represent the underlying cosmovisions of

Indigenous peoples in order for those visions to be able to thrive on their own terms. Thom (2009) discusses some of the problems with a western approach to boundaries of the Coast Salish of the west coast of North America, and discusses the permeability of boundaries, the movement of family groups and the patterns of sharing that make for systems where clear, unambiguous boundaries are deceptive oversimplifications of a far more complex underpinning.

5.2.3 Semantic Fuzziness

Natural language is rife with ambiguities. Temporal terms like morning or spring can be defined rigorously but people may differ on when morning begins, or spring ends. Toponyms like downtown or Mt Everest likewise have boundaries that are not necessarily clear. This extends across to other forms of categorisation. What constitutes a forest? How does one distinguish between different kinds of water features?

In the ethnobiology literature there does appear to be fairly crisp boundaries across multiple cultures for the category of species, but species of low salience may be grouped together, and species of high salience may be subject to finer divisions (Berlin 1973, 1992, Dougherty 1978). As well, 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 the culturally salient species, Horse (Equus ferus caballus).

The name for an important species or group of species of a certain type may also be used as the generic term for a larger group; for instance, in Tlingit the word **x̱áat** usually is a generic term for the different species of salmon, but it can also be used for any other fish except for sharks (Crippen 2010).Other levels of categorisation may be covert, in that there is no linguistic term for a category that people nevertheless utilise (Berlin et al. 1968, Berlin 1974). Taxonomies may be constructed along lines quite different from western biology, indeed in western biology taxonomies are currently undergoing a massive reshuffling due to a shift in emphasis from morphological characteristics to genetic relatedness. The same term may also be used for species that are not related genetically, but play a similar role. In addition to all that complexity, dialectical differences may assign different words to the same category, and the same word to different categories. Different kinds and levels of expertise also lead to different recognitions of what is salient and what is not (Rival 2014).

Because of these ambiguities, in order to make for clear knowledge on what is being mapped, it can be quite important to construct local ontologies that are relevant to the material on hand and the patterns to be mapped. The need for local ontologies that are developed bottom up out of observational data as contrasted with authoritative, top-down global approaches has been highlighted before (Janowicz 2012), and marks a paradigm shift already occurring in GIS. For ontologies used to document ST-TEK, these observations and local definitions and webs of relations between terms are vitally important for a better depiction of traditional observations and patterns of action.

5.3 Existing Approaches to Modelling Fuzziness

Reality is not always machine friendly, and forcing it to be so leads to heavy distortion of our understanding. Although there are crisper and less crisp boundaries of natural and traditional times and places, not all have an inherent one. Forests move. Locations of animal herds move. Rivers move. Seasons bleed into one another. Day and night bleed into one another. Even sunrises or sunsets take time. However, current GIS data models represent all of this with crisp boundaries and points.

5.3.1 Spatial, Temporal and Spatio-Temporal Fuzziness

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, which provides the basic “primitive” or structure (Goodchild et al. 2007). Geo-atoms themselves are defined as an association between a point in space-time (linear time) combined with a property expressed in a tuple, or a string of values for a given set of properties. All other features are constructions of this abstraction, and all other higher dimensional objects are aggregations of geo-atoms, including pixels, lines, areas, and volumes. The properties are exclusionary in that a single property at a single point at a single time can have a single value. They are an excellent tool, but they are not well suited to ST-TEK conceptions of time and space. Every geo-atom is unique, never to appear again, and decontextualised from its neighbours. Fuzzy values are rarely used. GIS data tends to follow either the logic of objects or the logic of fields (Silván-Cárdenas et al. 2009) but both are underpinned in a fundamental way by the geo-atom data model.

Fuzziness is supported via the geo-atom approach and GIS in general via having by having the membership of a given geo-atom for a given attribute being expressed as a number from 0 to 1 (Ahlqvist 2007), and this in turn can be depicted via vector or raster in a number of ways. In a raster depiction, each pixel can be given a value based on their level of belonging. One tool that has been used in this regard is the spray-can approach (Huck et al, 2014). In a vector depiction, isolines of equal probability can be constructed (Montello et al. 2003), or sets of nested polygons can be used (Schockaert and Smart 2010). One such model using two polygons is the egg-yolk model (Lehmann and Cohn 1994, Schmitz and Morris 2006). Temporal fuzziness or ambiguity can be indicated in the geo-atom approach with multiple timestamps, akin to the egg-yolk model for spatial data, with an earliest potential start time, a latest potential start time, an earliest potential end time and latest potential end time (Van Hage et al. 2012) Fuzzified time operators and fuzzy temporal intervals based on Allen relationships (Allen 1983) are also possible (Schockaert and De Cock 2008, Kauppinen et al 2010, Pons Frías 2013).

As the data models rooted in the geo-atom approach deal best with discrete events occurring once with clear boundaries, maps used for documenting traditional practices tend to focus on events like animal kills, or relatively fixed locales, like burial sites and cabin sites. There is not inherently anything wrong with these approaches, but the richness of spatio-temporal experience is lost, and the depth of ecological information is not well conveyed. Mapping of traditional knowledge continues to use the geo-atom based model, particularly the entity based variant, or as Potter et al. (2016:8) put it, “the same entity-based model of space which underpins cadastral mapping and has contributed to the dispossession of Indigenous peoples”.

Use-and-Occupancy map surveys are good at documenting spatial distributions of the use and occupancy of a given group, but poor at providing context or explanation on their own, without supporting documentation (Tobias 2009). They are rooted heavily in the geo-atom approach discussed earlier, although documentation is event centred, focussing on a respondent engaged in an activity, at some time at some specific place. The biases baked into Use-and-Occupancy mapping make them useful for demonstrating activities significant from a legal perspective, but is not set up well for cataloguing more in depth ethnoecological information, nor is it completely useful for documenting the intricacies of Indigenous knowledge about species behaviour and interconnections that will become more central as management and co-management agreements become the norm.

There have been some notable efforts for documenting ST-TEK using GIS with more in-depth ecological information (Close 2003, Aswani and Lauer 2006, Pearce and Louis 2008, Aporta 2009, McLain et al. 2013 Polfus et al. 2014). There is also a long tradition of discussing the limits of current GIS approaches when dealing with Indigenous information. Time is not always seen as fixed or linear, can be seen as social and having agency of its own (Reid and Sieber 2016). These remain underexplored. Natural cycles, like tides or seasons, need to be taken into account (Pearce and Louis 2008, Mackenzie et al. 2017). In many cases, the best way to deal with spatio-temporal fuzziness is to treat space and time more semantically.

5.3.2 Semantic Fuzziness

GIS data models are usually stored in a Relational Database Management System (RDBMS). Due to the nature of these systems, information becomes siloed into different features and layers that are likewise atomised from each other. Querying involves searching a field for a value in a given tuple. Layers need to be combined with a range of operations in order for them to truly communicate, or via join tables.

Fuzzy logic is well developed for attributes, with different core semantic terms like Hot, Warm, and Cold overlapping. This area of depiction is of special concern to Zadeh, who argues that fuzzy logic as a way to compute with words (Zadeh 1996), and depictions of semantic fuzziness are well suited for the ambiguities inherent in natural human speech and classification (Ellen 1993, Zadeh 1999). The utility of Zadeh's approach for documenting the depth and range of TEK has been noted before (Berkes and Berkes 2009).

Fuzzy logic can and is extended into fuzzy hierarchies and ontologies in GIS (Cross and Firat 2000, Sun et al. 2006, Owens et al.2009, Bakillah and Mostafavi 2011). There are a few weaknesses with fuzzy logic in a GIS setting. These include the need to assign crisp membership functions to every property and value for raster based depictions, and the lack of distinction between no information and situations where knowledge pulls in both directions equally (Malek and Twaroch 2004). Fuzzy logic is already being used to map out Indigenous values and semantic relations to landscape in a GIS setting (Potter et al. 2016), and this can be seen in some ways as an extension of expert knowledge-based approaches combined with fuzzy inference used elsewhere with GIS (Locatelli et al. 2011, Zhu et al. 2014).

There are some promising approaches that do take advantage of the powers of semantic systems that can be joined to a more standard GIS. Research efforts joining culture to the semantic web were a key part of the CultureSampo project (Hyvönen et al. 2009). Although these efforts were aimed particularly for cultural heritage documentation for museums, much of their work laid down a foundation for spatio-temporal work (Kauppinen 2010, van Hage et al. 2011). Of particular interest is the CultureSampo work from the Semantic Computing Research Group (SeCo) of Finland, combining cultural semantic content, situations and actions (Junnila et al. 2006). Their approach is very much like our motif approach.

5.4 Proposed Approach

5.4.1 The Motif

The Motif model is a new way of documenting ST-TEK in a way that allows for a more flexible approach to space and time than currently possible with other forms of spatio-temporal modelling. As discussed above, while most current approaches tend towards an emphasis on quantitative data and crisp representations of space and time, Traditional and Indigenous models tend not to be cadastralised or clockwork-like to the extent that Western knowledge is.

The Motif model represents spatio-temporal knowledge with ‘motifs’, which are reoccurring patterns of processes. A motif can be seen as a container for a pattern made up of a given action and surrounding contextualisation. This contextualisation is organised into facets, the core ones being a given sort of activity at a given sort of time at a given sort of place by a given agent to a given patient (Figure 5.1). Agents and patients are in turn both kinds of actor. 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 or information. Different facets can contain a number of conditionals.

For the examples, we will look at knowledge held and documented by Hidatsa of the Plains of the United States. Maxi'diwiac (Buffalo Bird Woman)’s agricultural knowledge was documented in some detail in 1917 in a classic text of ethnobotanical information (Wilson and Maxi'diwiac 1987). In it she discusses how to begin a garden, the layout of gardens, and the growing of several crops including sunflowers, corn, squash and beans, as well as their preparation and use. All of these descriptions centre on her garden that she grew in the then abandoned and now flooded Like-A-Fishhook Village near the trading post of Fort Berthold.

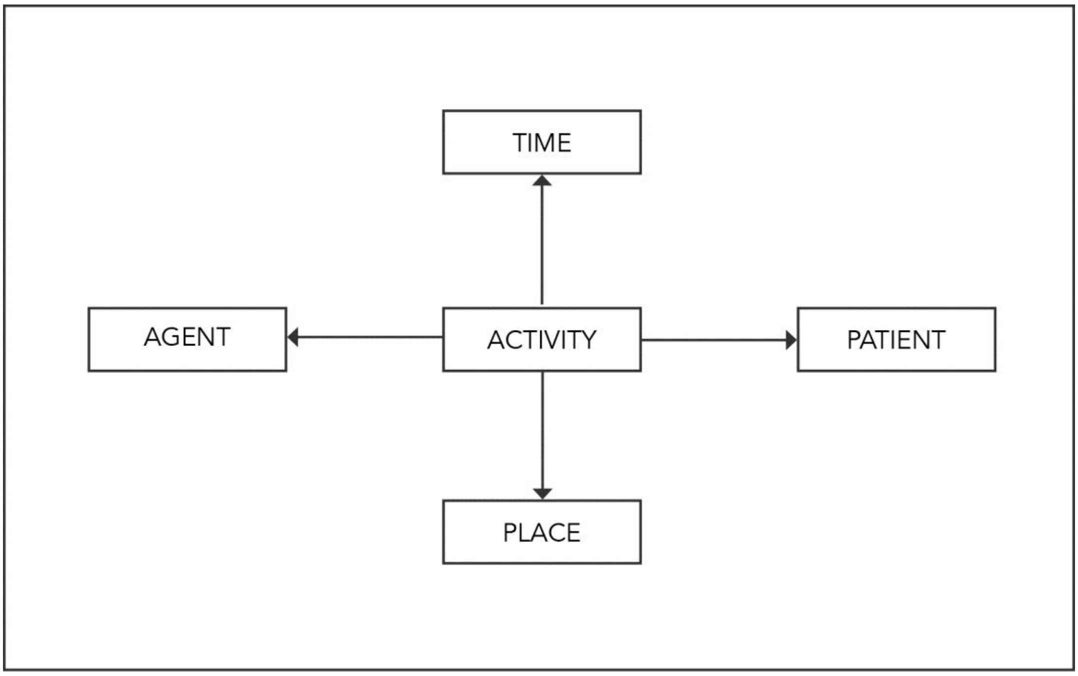

Figure 5.1: Motif Structure. Illustrated by Katie Wilson

For example:

Time: Spring

Agent: Gardener

Activity: Plants

Patient: Corn

Place: Village Fields

A submotif of this motif can be made more specific:

Time:

Time of Day: Morning

Time of Year: May – June

Phenology: Gooseberry bushes in full leaf

Years: 1845-1885

Agent (Noun): Buffalo Bird Woman

Activity (Verb): Plants

Patient (Noun): Corn

Place: Into pre-existing mounds, in fields in the valley bottom land at Like-a-Fishhook village

Place (GIS feature): Point indicating location of Like-a-Fishhook village

Place (Archival depiction): Hand drawn maps and schema

This motif indicates that Hidatsa planted corn in their valley bottom fields at Like-a-Fishhook village in the mornings from May to June when the gooseberry bushes were in full leaf from the years 1845-1885. This would not be easy to construct in an RDBMS when it is not straightforward what the schema would be in advance. With the proper software, it may be possible to populate a range of potential beginning and ending timestamps in order to map such a motif to a regular T-GIS database, but leaving it in the original form is in many ways more informative.

Missing facets in a simple motif are interpreted as being indeterminate. 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. (2011, 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 arcs connecting that relation to contextualising facets of that relation (Figure 5.2). 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).

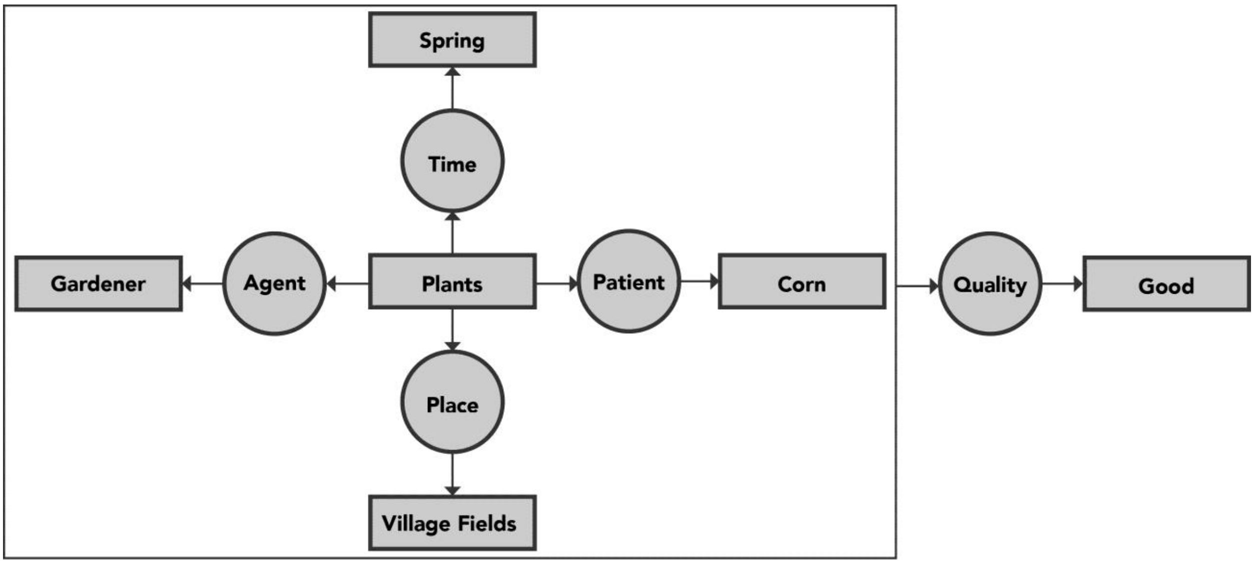

Figure 5.2: Example of a Motif. Illustration by Katie Wilson

It is important to note that Conceptual Graphs use thematic relationships rather than subjects, objects and verbs for the breakdown of the roles of facets inside a motif. These allow for better representation of a statement with less ambiguity. By centring on the activity or state, it is also possible to reflect constructions of higher valencies than those usually represented in RDF, including avalent (it rains), intransitive (she plants), transitive (she plants corn), ditransitive (she gave them corn) and tritransitive (she traded corn with them for meat) constructions (Pfeiffer and Sowa 2001). The spatio-temporal context provides a setting for these statements.

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. This will be discussed further below.

Motifs, because of the interconnected nature required of them and the problems with developing a single uniform a priori schema for them, are better suited to representation in a NoSQL database. Graph databases are almost ideal, but current graph databases like Neo4j or multi-model databases like ArangoDB do not at the current time support nested nodes. Similar systems use RDFS, but Sowa recommends JSON for Conceptual Graph representation as it is more readable by humans and more computationally efficient (Sowa 2011).

5.4.2 The Folk Thesaurus

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 a faceted thesaurus, with multiple domains for spatial qualities, temporal qualities, actions and states, and the thematic roles associated with a motif. The need for ontological diversity for depicting ST-TEK stems from there being no authoritative body in most cases, and due to shifting meanings in words and taxonomies, sometimes from community to community. Terms in the folk thesaurus still take the generalised motif pattern of statement and context.

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. One tool that has been used previously in information retrieval that is pertinent to the needs of relating motifs to one another is that of a thesaurus. 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. The importance of culturally appropriate thesauri to underline Indigenous perspectives has already been noted by others and has been compiled for Pequot (Littletree and Metoyer 2015), Māori (Bryant 2015) and others (Doyle 2013).

A “folk thesaurus” is a knowledge base of these “ethnosemantic” 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. Ontological systems are often mapped out in advance. Folksonomies are flexible and adaptive but tend to lack structure, and this can cause difficulties when trying to retrieve information (Noruzi 2007), and in some cases disambiguation and contextualisation would make them more useable (Vander Wal 2004). A folk thesaurus lies somewhere in between the two. The rigour of ontologies over thesauri can be desirable over the long term, but require sustained effort. In this case, thesauri provide good materials for ontology development later on (Ruotsalo et al. 2008).

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. A new variety of corn could be clustered with previously existing varieties of corn. Other crops might be clustered with corn under the heading “crop”. A herb that is cultivated might also be contextualised as food or medicine. A time period might be clustered with another time period. An individual might be clustered with a group of people due to their affiliations. 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.

One way of approaching how the various thesaurus concepts interact is via the notion of “conceptual spaces” that can overlap one another, be subsets of one another, and be (largely) identical to one another (Gärdenfors and Williams 2001). As boundaries are not clear, definitions requiring boundaries are left out, leaving us with the five major relations of RCC-5 (Ibrahim and Tawfik 2004). However these are ambiguous in how they fit together. Rather than see motifs or folk thesaurus terms as nodes in a web, it can help to visualise each term or lexeme as corresponding to a semantic area. This allows for the use of mereological techniques and patterns of overlap like RCC-5 or RCC- 8 to better contextualise how the terms relate. These mereological relations run parallel to the standard thesaurus relationships. Overlap could be characterised via a percentage or a number from 0-1, or utilise other categorisations stemming from the egg-yolk model (Gärdenfors and Williams 2001). These sorts of values could emerge as knowledge holders share data, or could emerge from a protocol like pile sorting, used frequently in ethnobiology (Martin 1995).

The egg-yolk model can also be used as a template when dealing with concepts that have fuzzier boundaries. Key examples would be placed centrally, core examples for a concept more peripherally. For example, corn is a major food crop. Dandelions are also edible, but are not as central in importance for food. Community members that live in a town and share relatives act more like core members to the town as a whole than people passing through. Using a pogo stick is indeed a method of transport, but not a key one.

Cumulative records put together by multiple users or knowledge holders allow for numbers to be assigned to how often two concepts are put together and what terms are used to describe their relationship. The corresponding pattern from the ethnobiological literature would be the use of pile sorts for exploring taxonomical systems (Martin 1995). Terms collected can be of both concepts and conceptual relations and can also be broken down into different kinds of facets, from temporal terms to location types to actors and other facets used to contextualise motifs. These may vary from culture to culture, but Aitchison et al (2000) give entities, activities, agents and properties as some fundamental relationships.

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 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,
2. Hierarchical relationships, and
3. Associative relationships.

5.4.2.1 Equivalence relationships (synonyms)

Two terms that are largely equivalent with one another (label the same set), and can be treated as identical. Sometimes they are not completely identical, and fuzzy techniques need to be used. This means that there are some members labelled by one term that are not labelled by the other term. Equivalency relationships are coded in modern thesauri as Use/Used for pairs (USE/UF).

Usually in thesaurus design, there are preferred terms and non-preferred terms. This may be more difficult to create in situations where there is no central authority to decide which variants of a word should be key. Non preferred terms are synonyms or quasi-synonyms of preferred terms (Aitchison et al. 2000). Ideally preferred terms would emerge over time with a folk thesaurus as they do with folksonomies.

Multiple languages may all point to the same sort of entity. In the case we have been following, the name Buffalo Bird Woman is a synonym of *Maxi'diwiac* and corn is a synonym of *Ko'xati*, and both corn and *Ko'xati* are synonyms of *Zea mays* (Wilson and

Maxi'diwiac 1987). If one was querying a motif database for motifs related to *Maxi'diwiac* and *Ko'xati*, one would want to also see those results for Buffalo Bird Woman and Corn.

If two elements are equivalent, they can be treated as identical. However, this is not always obvious, and some equivalencies are stronger than others. The egg-yolk model for concepts (Lehmann and Cohn 1994) provides one way for dealing with ambiguity at this level by placing related terms as either closer to the target term or further away. For instance, a term for a kind of bird may refer to multiple species of bird, so we cannot treat the name for the bird as exactly equivalent to a given scientific species name. Disambiguation techniques, like links to photo references, can help make the various equivalencies clearer, but a motif utilising a term that covers a range of phenomena and has not been disambiguated may need to be treated as if it should potentially be included in queries referring to one of the many senses. Terms that need to be disambiguated need to be qualified in some manner.

5.4.2.2 Hierarchical relationships (hypernyms and hyponyms)

If two elements are related in a hierarchical fashion, then instances of the more specific motif are also instances of the more general motif. Instances of the more general motif may or may not apply to the more specific motif. Occasionally some terms may belong to multiple hierarchies. A bat belongs to both mammals and things that fly, and a penguin belongs to things that swim and birds. Properties of the more general category do not always translate down to the more specific terms. Most birds DO fly, but penguins do not. Hierarchical relationships between elements can further be broken down into three types: Generic (subclass/superclass), Instance (class/instance) and Partitive (whole-part) (Tudhope and Binding 2008). In library thesauri, the term BT (Broad Term) and NT (Narrow Term) are used to help disambiguate these terms from others.

A given term can be a subset of more than one set given by another term. For example, “bats” refers to organisms that are a subset of “things that fly” and “mammals”. Generally, terms in a folk thesaurus, like other thesauri, can be grouped into some fundamental categories. These may vary from culture to culture, but Aitchison et al. (2000) give entities, activities, agents and properties as some fundamental relationships. Terms must be members of the same fundamental categories to have the potential of a hierarchical relationship (Aitchison et al. 2000). In current practice, hierarchical relationships are often referred to by Broader Term (BT) or Narrower Term (NT) pairs. These can then be broken down into three more classes. Heteronyms are terms that are sister terms that are both narrower terms of the same broader term. An equivalent set of terms used elsewhere are subtype and supertype.

Utilising the hierarchical 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, Sowa and Majumdar 2003) (Figure 5.3).

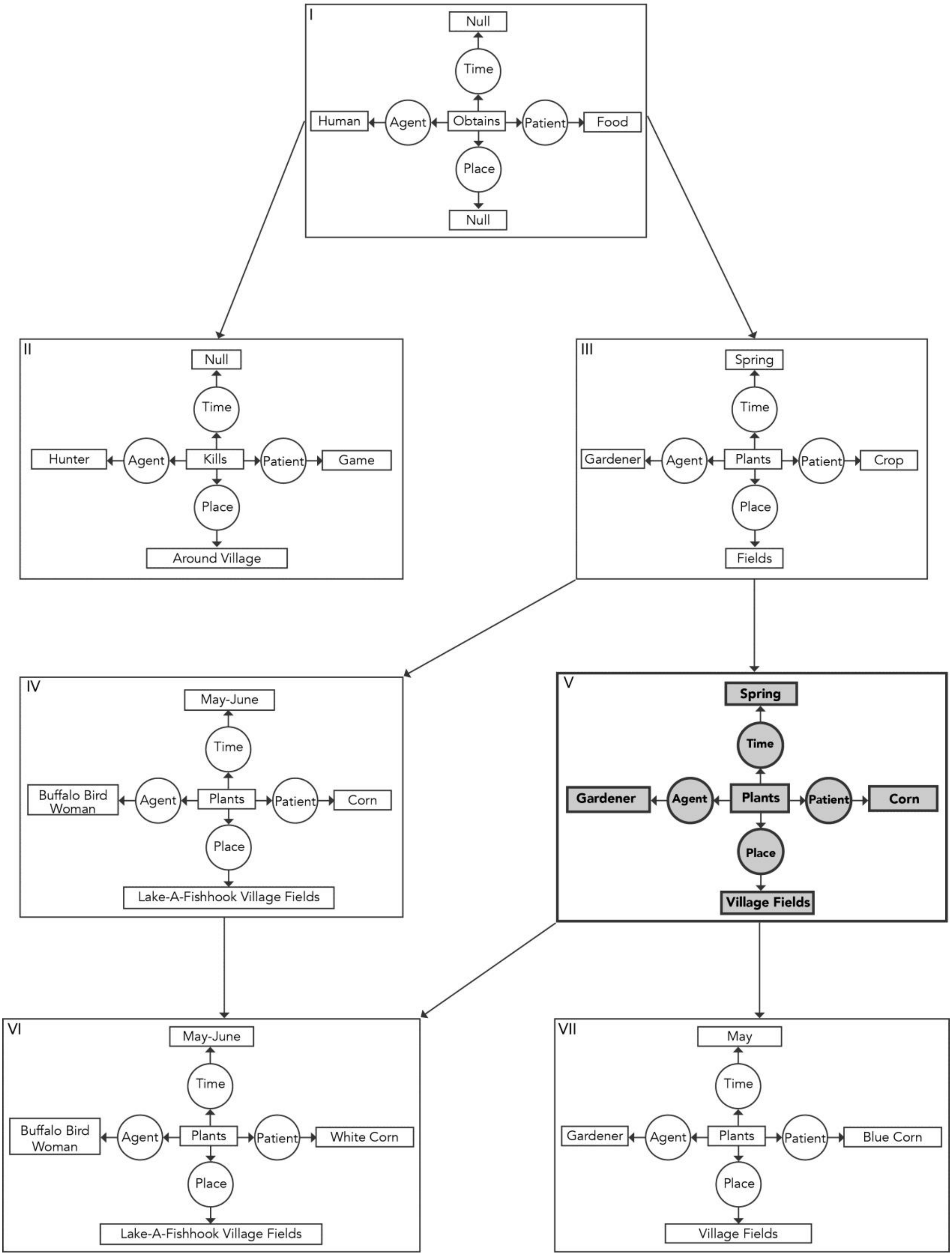

Figure 5.3: Generalisation Hierarchy Utilising Underlying Folk Thesaurus. Illustration by Katie Wilson

Via the folk thesaurus, it is possible to search for restricted and unrestricted versions of a given motif as restricted and unrestricted hierarchies of motifs can also be used for querying data (Chein and Mugnier 2009). Motifs made of facets that are subtypes of those in the query will also be shown in that query via hierarchies mapped out with hierarchical relationships. To give an example, "*A woman is planting crops"* is an unrestricted version of the statement *"Buffalo Bird Woman is planting corn".* Likewise, the spatio-temporal contexts of such statements can be restricted and unrestricted if they were to be incorporated into a spatio-temporal motif.

5.4.2.2.1 Generic relationships

Generic relationships refer to the various kinds that make up a larger group. In the case of Hidatsa traditional varieties of corn as discussed by Buffalo Bird woman (Wilson and Maxi''diwiac 1987), *Atạ'ki Tso'ki, Atạ'ki, Tsï'di Tso'ki, Tsï'di Tapä', Do'ohi, Hi'ci cĕ'pi, Hi'tsiica,* and *Ma'ikadicakĕ* are all varieties of *Ko'xati*, or corn. Generic relationships exist in Broader Term – Generic (BTG)/ Narrower Term Generic (NTG) pairs.

5.4.2.2.2 Partitive relationships

Partitive relationships refer to the various parts that make up a larger whole. In the example we are using, corn has parts that include leaves, hush, roots, corn silk and stalk, as well as the cobs and the kernels. Partitive relationships exist in Broader Term –Partitive (BTP)/ Narrower Term –Partitive (NTP) pairs.

5.4.2.2.3 Instance relationships

Instance relationships refer to instances of a given higher concept. In this case, the Missouri River is a river, and Like-a-Fishhook village is a village. These again exist in Broader Term – Instance (BTI)/ Narrower Term Instance (NTI) pairs. A single actual corn plant would be an example of an instance of corn. Individual people are also instances.

5.4.2.3 Associative relationships (see also).

If two elements are related in an associative relationship, then their relevance to each other falls outside the equivalence and hierarchical relationships. This is the general case when compared to the other two sets. In the broader sense, both equivalence and hierarchical relationships are other kinds of associations, leaving associative relationships to fill the rest. For a motif database, these can help link different related areas when a query is given.

RT (Related Term) is used in library thesauri for these terms. Related Terms (RT) exist in reciprocal pairs. For locations, Like-a-Fishook was not part of Fort Berthold, nor was Fort Berthold part of Like-a-Fishook, but one querying for one may be interested in the other. Likewise, the Hidatsa are not Mandans or Arikaras, but all three groups of people are related. Gardening is related to the tools used.

Some associative relationships are context dependent. Autumn may be associated with falling leaves, September, October, November and December (Northern Hemisphere) or March, April, May (Southern Hemisphere) and it comes after Summer and before Winter. These sorts of minutiae help refine the term. RT (Related Term) is used in library thesauri for these terms.

5.4.2.4 Other culturally mitigated core relationships

Other cultures may have other ways of relating and grouping terms with other terms. Genealogy often forms one set of templates that may fit well with a traditional thesaurus' hierarchical relationships, or may not. Sometimes terms are related due to cultural reasons that may be opaque to outsiders. A folk thesaurus needs to have the ability to add other key relationships other than the main three discussed above if required.

5.4.3 Motif and Folk Thesaurus Walkthrough

In order to generate a new folk thesaurus, much like other thesauri, a user or group of users need to compile some core terms and give them some relationships between them. This can begin by taking a subset of a pre-existing thesaurus or taxonomy, or combing literature for terms, or by documenting these interrelations with a key knowledge holder or group of knowledge holders. Disambiguation material can be linked to these terms, and if senses vary, these senses are further distinguished. Data that has not been disambiguated remains fuzzy, and can belong to multiple categories as a potential fit.

As motifs are documented, the various facets of the statements and contexts of the motifs are in turn added to the thesaurus, and contextualised with the other terms if they are not already present. Over time fewer terms are added to the thesaurus and motifs generated already have existing equivalency and hierarchy relationships so that generalisation hierarchies (Figure 5.3) and query motifs can be put to work. Here are a few examples from Buffalo Bird Woman's Garden.

We know from reading the text that the folk thesaurus will need to contain crop relations, and these fit into a hierarchy. Here we create the supercategory "CROP". We can use indents to show that the terms are hyponyms of the term CROP, and we can mark the relationship with NTG, or Narrower Term Generic. Meanwhile, CROP is a BTG, or Broader Term Generic for the same terms, as BTG and NTG relations exist in reciprocal pairs.

CROP

NTG CORN

BEANS

SQUASH

SUNFLOWER

We also know that there are a number of actions that take place within the gardening context, so we will construct a similar set for those. Here we could use NT for narrative term, or NTP for Narrower Term Partitive, as the other three activities are part of the gardening process.

GARDENING

NTP PLANTING

WEEDING

HARVESTING

We also know from the text that there are certain parts of the day mentioned. These terms are mentioned in the text. Here we are using Day in the sense of a 24 hour period. Most languages use different terms for the sunny part of that 24 hour cycle and the 24 hour cycle itself, but English does not. We can disambiguate by calling them DAY-1 and DAY-2, or use some other way of indicating that there is a distinction. This is a partitive relational difference again, so we can use NTP.

DAY-1

NTP MORNING

AFTERNOON

EVENING

NIGHT

BEFORE SUNRISE

AFTER SUNRISE

BEFORE SUNSET

AT SUNSET

DAY-2

And we have different parts of the year mentioned. Again we have a partitive relationship.

YEAR

NTP SPRING

SUMMER

AUTUMN

WINTER

We also know from reading the text some of the spatio-temporal context that the statements in the text relate to.

Place: Like-A-Fishhook Village

Time: Years: 1845-1885

There are also a number of agents named in the text, particularly Maxi'diwiac/Buffalo Bird Woman

Maxi'diwiac SYN Buffalo Bird Woman

Buffalo Bird Woman SYN Maxi'diwiac

Maxi'diwiac was a Hidatsa woman, so we also have the following relationship. NTI is “narrower term instance”, as there is only one Maxi'diwiac.

HIDATSA

NTI Maxi'diwiac

We have the traditional thesaurus terms to work with, but as it is a folk thesaurus, there may be other hierarchical and non-hierarchical relations that people may wish to use.

We can construct a group of motifs with these facets. Here are some statements we can contextualise. We are using Sowa’s notation of boxes or square brackets [] for concepts and ovals or rounded parentheses () for conceptual relations as discussed earlier (Sowa and Way 1986).

[Hidatsa]<-(agent)<-[growing]->(patient)->[crops] and the associated contextualisation and anchors. Because of our hierarchical relationships, we get the following restricted motifs, and in this way we can enter in specific details and be sure more generic queries will still find the features we want. Each of these motifs can be anchored to a given set of spatial features, be they points, lines, polygons, or rasters, or links to an existing map or diagram.

[Maxi'diwiac]<-(agent)<-[plants]->(patient)->[sunflowers];

[Maxi'diwiac]<-(agent)<-[plants]->(patient)->[corn];

[Maxi'diwiac]<-(agent)<-[plants]->(patient)->[squash];

[Maxi'diwiac]<-(agent)<-[harvests]->(patient)->[sunflowers];

[Maxi'diwiac]<-(agent)<-[harvests]->(patient)->[corn];

[Maxi'diwiac]<-(agent)<-[harvests]->(patient)->[squash];

[Maxi'diwiac]<-(agent)<-[makes]->(patient)->[soup:sunflowers, corn, squash];

The spatial and temporal contexts themselves can be binned (sorted into discrete categories) or otherwise arranged for disambiguation. For instance, thesaurus terms for time could be turned into an interface where it is possible to pick more than one term in order to be clearer on what kind of time or place a given activity tends to require.

Higher level categories are likely to need a basic set of tools for disambiguation and relation. In the case of information from Buffalo Bird Woman, she discusses how kinnikinnick, the local English name for *opi ihaca* or Cornus sericea can also refer to *ama-matsu* or Arctostaphylos uva-ursi (Wilson 2014). Ambiguity makes some forms of reading more difficult.

The various terms gathered eventually form a functioning ontology for the folk thesaurus, but again, folk thesauri allow for a conceptual lattice to form, and not a strict tree. Some terms are easier to contextualise than others, some terms less so. What does one do with plants that are not usually eaten, but are sometimes eaten? How does one classify marshes or bogs? Do they fit under land, water or form their own category? Thesauri and ontologies do not always allow for a concept to belong to more than one category, but this can be troublesome. By weighting a term or seeing it as being able to fit into multiple hierarchies, classifiers do not need to choose one and only one category, and the term can belong under multiple headings.

Ad hoc hierarchies are also possible with a folk thesaurus. Perhaps there are a number of motifs pertaining to the food procurement strategies of Buffalo Bird Woman in a particularly bad year, and rather than sort the data into crops grown in the garden, fish harvested, and trade, we wanted them all to show up in a single query, then we could create a term or motif that covered these sources and events and allow for that query to be repeated as needed. We will discuss narratives in a future paper, as narratives are also tied to constraint patterns for motifs.

5.5 Conclusion

With the combination of motifs, composed of instances, and strung together in wider structures either via a folk thesaurus or by narrative means, models and representations of traditional spatio-temporal knowledge should be more feasible and truer to type than current geo-atomic approaches. These techniques should complement the geo-atom approach, and help with looser and fuzzier situations in general. Representations for spatial and temporal fuzziness are reflected both qualitatively and semantically at the motif level, and quantitatively and akin to the geo-atom model at the instance level. Instances can link motifs by sharing a time and or location and can be linked via the motif level in narratives.

Semantic fuzziness is captured using a folk thesaurus that stores word relations. These allow for motifs to have a natural relation to and from other motifs based on vocabulary. Folk thesauri also can have a controlled core vocabulary that guides interface design for different kinds of time, weather patterns, location, and activities. These in turn can have new terms added as required, which are then fitted into the core.

The combination of the motif and the folk thesaurus allows for a closer representation to natural language, and this provides a more solid basis for analogical reasoning (Sowa and Majumdar 2003). The motif model and the folk thesaurus both follow Sowa's conceptual graphs, and can utilise some of the same strengths, like generalisation hierarchies (Figure 5.3), as well as often being more concise than RDBMS representation. Folk thesauri themselves are more flexible than a priori schema, are not as rigid as a standard ontology, and provide more structure than folksonomies do.

The authors have worked on interfaces and some of the tools required for the approach, but more time and effort is required for a fully functional model. Some folk thesaurus tools have been developed already utilising a dial system allowing for expression and cataloguing of some key temporal cycles. More work is to come.

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6 A Visualisation Tool for Multi-Cyclic Time for Documenting and Displaying Traditional Ecological Knowledge in a Temporal GIS

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Abstract

Temporal Geographic Information Systems tend to keep track of time via the Gregorian Calendar and the universal 24 hour clock. This perspective is so ingrained that alternatives are sometimes hard to see. The paper focusses on the collection and display of multi-cyclical time, utilising a multi-wheeled interface. The wheels provide a method of interactively selecting a portion of time. Key cycles utilised by many cultures include the tidal cycle, day and seasonal cycle, and the lunar cycle. Day counts, of which the week is one example, are also used widely. The interface incorporates a selection of these cycles to demonstrate how time might otherwise be visualised and queried outside of current approaches.

Keywords: *spatio-temporal data, cyclic patterns, temporal visualisation*

6.1 Introduction

Everything we do and see and say is bound in some way by place and time. We can say, "I went to the shop this morning", and we will mean a particular shop, on this particular morning. But we can also say "you'll want to plant those seeds somewhere with full sun after the last frost has come and gone" and we will still be talking about a particular kind of place at a particular kind of time.

There have been more than a few attempts to model particular kinds of places and times in the GIS literature, but they usually come from a universalised Western perspective. However, there are many, many cultures on this earth, and likewise there are many, many ways of looking at kinds of places and kinds of time. The GIS literature has already touched on the different ways that cultures classify kinds of place with the ethnophysiography work of Mark and Turk (2003) and others. Although more intuitive representations of space have been suggested (Egenhofer and Mark 1995), there is still a need to develop alternative conceptualisations of time in GIS to look at the different ways that time can be perceived and communicated.

Time as a line tends to be privileged over time as a circle, or time as a spiral in the current Western worldview, but there have been many efforts in the GIS community to include cyclical time, to model it, and to find easier ways of visualising and querying it. The basic crisp cyclic interval relations over a single given cycle have already been mapped out, for example (Hornsby et al. 1999), as have some arrangements between two cyclic intervals and the associated constraints (Campos and Hornsy2004). These have put the study of time and space on a solid footing, but the majority of depictions utilise an atomised sense of time, with uniform granularity and predominantly following the Gregorian calendar and the 24 hour clock. The ubiquitous timestamp is standard for temporal databases and in T-GIS. Yet there are a number of reasons why support for other cycles and forms of time keeping is warranted.

Some of the features utilised by the Gregorian Calendar and 24 hour clock are not universal, and other factors are salient for keeping time in other cultures. Sense of time is complex, much of it is tied to various events or accidents of history, but much of human behaviour and the behaviour of other species that humans are tied to are cyclical. Birds migrate seasonally. Different species are either diurnal or nocturnal. Fish spawning events have been tied to the phases of the moon. Travel for multiple species in an aquatic environment is altered by the tidal cycle. Cultural cycles like the days of the week in the west, or other day count systems are used to organise cultural behaviour globally. Without solid methods of gathering and querying this sort of knowledge, it will tend to get ignored, and a key component of Traditional Ecological Knowledge/Indigenous Knowledge (TEK/IK) can be lost, or overlooked by outside agencies.

These cyclical and culturally idiosyncratic aspects of human time keeping will be the focus of this paper. Traditional timing methods are widely varied and intricate, and not reflected utilising the current timestamp model The authors give an analysis of some of the techniques used to track time, and have developed a multi-cyclical querying Graphical User Interface tool that may make it easier for the capturing and display of traditional spatio-temporal knowledge. A complete version would be customisable and would have a variant for better data capture. This paper focuses on the cyclical and multi-cyclical aspects of traditional timekeeping. These are but one component of traditional timekeeping and time sense-making systems, but they are some of the easier ones to document. There are multiple dimensions of qualitative and quantitative horology that are not included with the interface as it stands.

6.2 Literature Review

In the GIS literature, the need for ethnophysiographic approaches to landscape ontologies and the documentation of traditional knowledge systems have been well analysed by Mark and Turk (2003, Mark et al. 2007) with their work on Yindjibarndi views of the landscape, and how one culture's schema for space and geographic features does not necessarily map well onto the geographic features of another culture. This has been a key insight for the GIS community spatially, and some efforts have been made to formalise the ontological systems underpinning traditional classifications, like the hydrographic classifications of the Cree of Quebec (Wellen 2008).

Likewise, it can be said that there is also an "ethnohorology", or a range of different methods of measuring and understanding time that different cultures bring to the fore when they view the world. In many ways "when" is understood that is just as complex as the "where". These differences add a complicating factor to Temporal GIS, but one that is needed when traditional or local knowledge is being documented. Due to the importance of cyclic and multi-cyclic phenomena in traditional and biological timekeeping, and their ubiquity for pinpointing the right time for activities in traditional societies, we will begin by reviewing this sort of timekeeping in order to understand what needs to be represented in a GIS and how we might represent it.

6.2.1 Multi-Cyclic Phenomena

There have been a number of ways of keeping track of space and time over the centuries, and we humans are not the only species to do so. There is a rich literature on chronobiology focussing on lunar and solar mediated "zeitgebers" or time givers in biology (Naylor 2010, Tessmar-Raible et al. 2011, Kronfeld-Schor et al. 2013). Many of the key ones are linked to the annual cycle of 365.25 (Farner 1985, Carey 2009), the diel (day and night) cycle of 24 hours (Buchholz et al. 1995, Silverin et al. 2009), the synodic lunar cycle of 29.5 days (Takemura et al. 2004, Tessmar-Raible et al. 2011) and the tidal cycle of 12 hours and 25 minutes/24 hours and 50 minutes (Bornemann et al. 1998, Neumann and Heimbach 1984, Northcott et al. 1991). These in turn are utilised for timing individual behaviour and correlating behaviour with other members of a species. These cycles form much of the basis of natural timing for the living world, and have been by and large ignored in GIS.

	biological rhythm	environmental cycle	cycle length
solar influence			
	circadian annual / seasonal	daily annual	24 hours 365 days
lunar influence			
	circalunar circasemilunar circatidal	lunar semilunar tidal	29.5 days 14.8 days 12.4 hours

Figure 6.1: Common biological rhythms under solar and lunar influence. Reproduced with permission. From Tessmar-Raible et al. 2011

The key biological and environmental cycles are given in Figure 6.1, taken from Tessmar-Raible et al. (2011). The earth's relationship to the sun gives both the daily and annual cycle. The earth's relationship to the sun and moon gives the lunar and semi lunar cycles, and the earth's relationship to the moon and the hydrogeography of the planet gives the tidal cycle. All these cycles have regular lengths, although there are a few extra complexities when it comes to the lunar cycle. As humans rely on other species, they keep track of these patterns. Plant patterns like flowering, fruiting, and shedding leaves may all have relevance, as do animal behaviours like breeding, spawning, and general condition. A recent paper by Mackenzie et al. (2017) discussed some of the key needs for temporal visualisations for TEK/IK and how TEK/IK relates to some of these natural cycles.

These cycles are in turn broken down in different ways, depending on the culture. The day as divided up into 24 equally spaced hours is not universal, with traditional divisions of time sometimes depending on the time of year, rising and setting of the sun, and other observations.

The lunar month is addressed in a number of different ways as well. For Māori Maramataka calendars, there can be anywhere from 28 to 32 named days used for keeping track of synodic lunar rhythms (Roberts et al. 2006). These depend on factors like the number of days from first sighted crescent to the next, and whether counts depend on moon risings and settings or on day counts.

The annual cycle can be divided in a number of ways. In some calendars, lunar months are fitted into the year with intercalary months inserted so that lunar and solar calendars line up (Chatterjee 1997, Dershowitz and Reingold 2008). Other cultures, like the current Western Calendar, largely discard the phases of the moon as a timekeeping device. Some cultures maintain a solar calendar for planting times or other seasonal activities and utilise another calendar or calendars for other matters (Khoo 1997, Tobisson 1998). The annual cycle is also often divided into seasons, with the most common season divisions being either the equivalent of spring, summer, autumn and winter or rainy and dry. However, there are other season systems. Aboriginal Australian seasonal systems vary considerably from culture to culture with the number and kind of seasons recognised (Prober et al. 2011). The Ngan'gi have 13 seasons, but this is at the higher end (Woodward 2008).

On top of these natural cycles are systems that can be described as day counts. The week is a day count of seven, but other cultures use counts of 10, 12, 13, 20 or other numbers. These are sometimes combined in ways that create a longer basic day count unit, like the 260 days of one of the Mayan calendars, or the 60 days of the sexagenary cycle that is of importance in East Asia. Dimensions that are missing from this approach include such matters as "timeliness, destiny, divination, religious ritual, and cosmology," to use the short list Tedlock (1992:3) puts together when coining the phrase "ethnohorology".

A key reason for timekeeping in any society is for keeping track of the right time for a given activity, or for synchronising the behaviour of members of that society. There are often a number of restrictions in play for where an appropriate place, or when an appropriate time for a given activity might be. Faucher et al. (2010:50) discuss "potential practice" as one approach to time and space, with a Temporal Potential Practice (TPP) for a given activity emerging via multiple temporal constraints (See Figure 6.2). Likewise, spatial dimensions also have constraints giving a Spatial Potential Practice (SPP). Similar constraints face traditional practices of harvest. Faucher's approach to time is not that different from what we envision with our visualisation tool, that is, understanding when given activities are possible, impossible, or somewhere in between. Faucher did not design a spatio-temporal interface, but the underlying logic is one that is promising and needs to be elaborated upon.

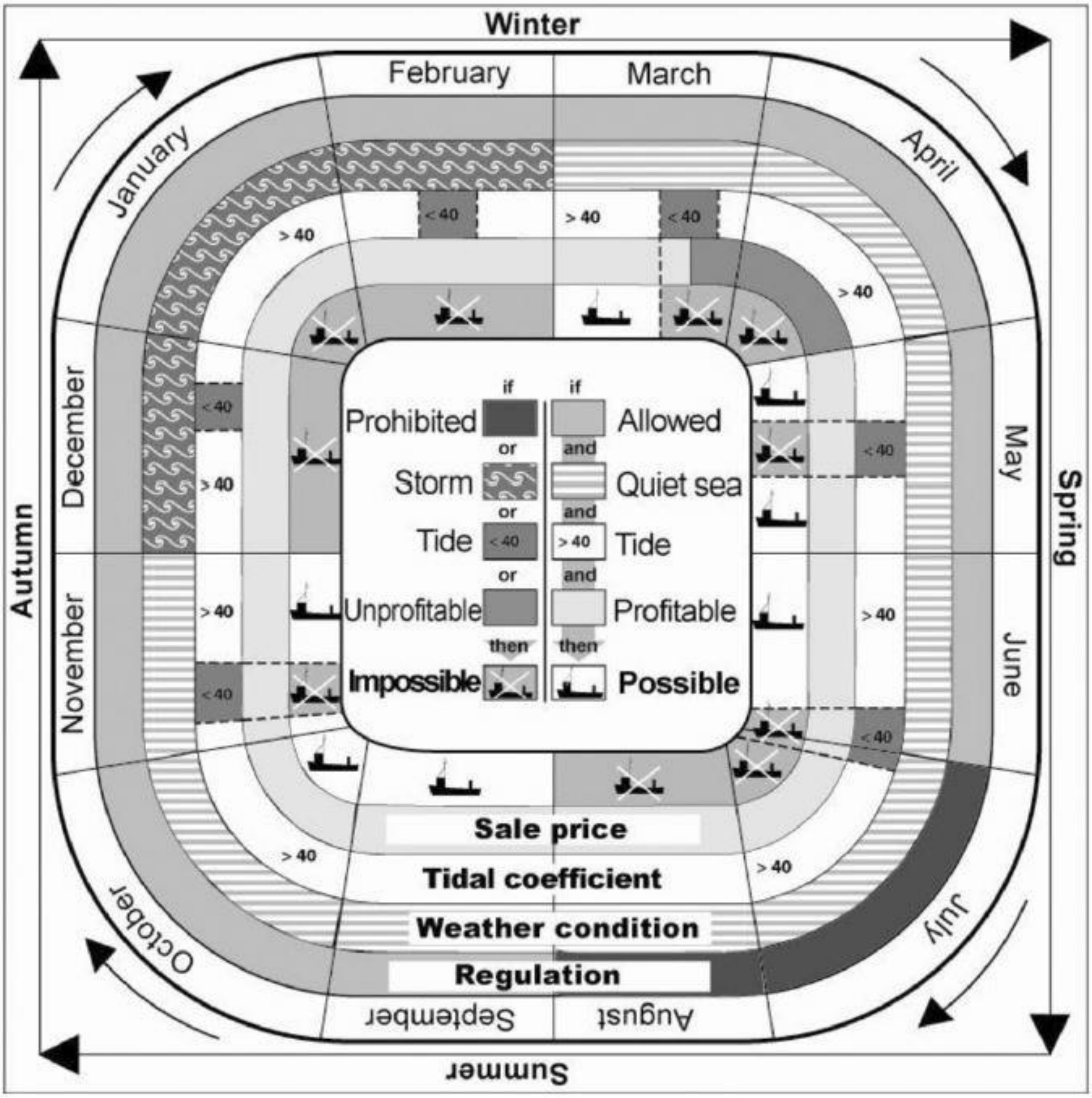

Figure 6.2: Temporal Potential Practice for *Donax trunculus* digging. Reproduced with permission.. From Faucher et al. 2010

6.2.2 Spatio-Temporal Interfaces

Human cultures have been keeping track of the lunar and annual cycles for a very long time, with some evidence of timekeeping going bac to the Paleolithic (Rappenglück 1999). One of the earlier forms of timekeeping was the use of parapegmata, or peg boards used to track cyclical phenomena in the ancient world (Lehoux 2000). Timelines and time wheels have also been used to track linear and cyclical time. In earlier days volvelles (paper instruments with turning wheels) were also frequently used for cyclical patterns (Drennan 2012). The latest of all has been the reliable and portable watch, and much has been written on the transformative aspects of portable accurate universalised time. For spatial, there have been various schema of several descriptions but most now fit under the larger category of “map”. Despite spatiality being theoretically more complex than time, it is time that appears to be harder to depict.

Time is often understood in spatial terms with the future often being ahead in English, and the past behind. Cyclical time moves clockwise in the Northern hemisphere, as this is the path taken by the sun in the sky. We have difficulties thinking of time without these sorts of metaphors. Because of this aspect of time, spatialised interfaces are a useful and necessary evil. Some of the assumptions that might be made based on spatialisation of time from an English Language perspective do not necessarily hold for other cultures (Galton 2011).

Interfaces act as restriction devices on spatial, temporal and attribute characteristics for either a feature being entered into a larger dataset, for modifying features, or for querying pre-existing. Most spatio-temporal geovisualisation interfaces for GIS have a time window, a location window, and an attribute window, with the timeline and time wheel placed in the time window (Gautier et al. 2016) (Figure 6.3).

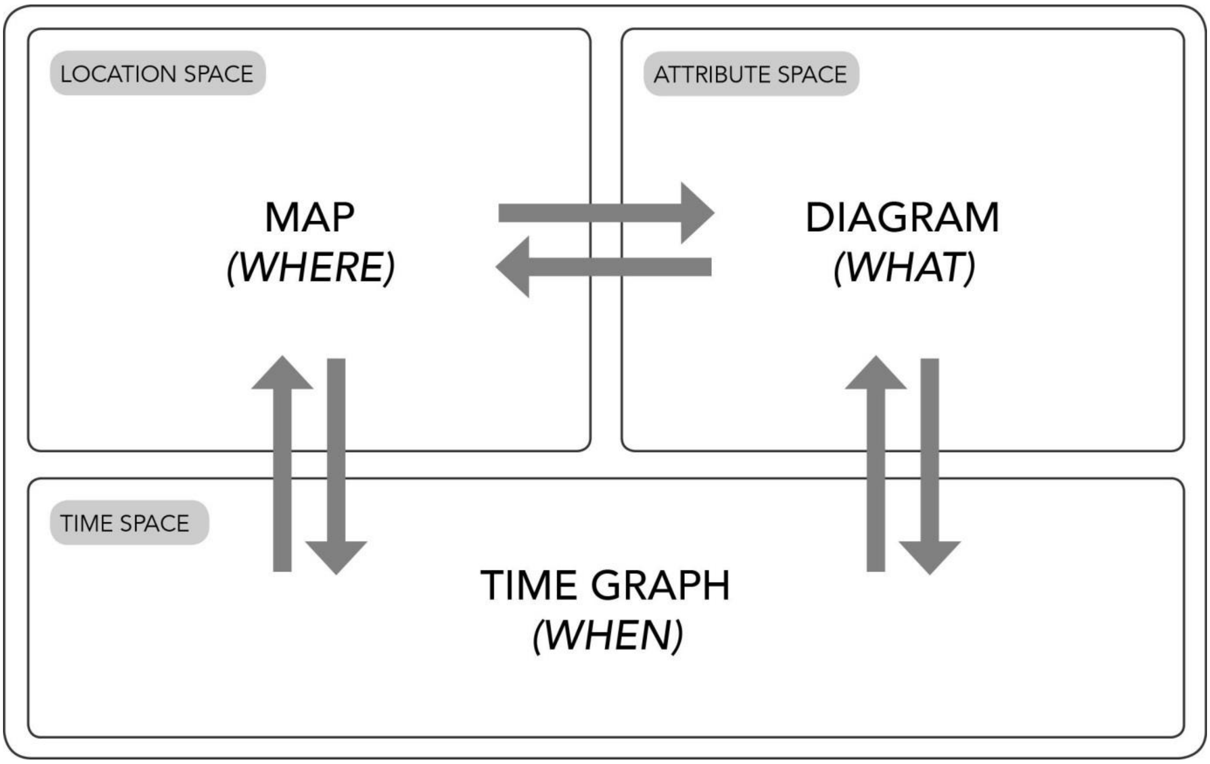

Figure 6.3: Principle of spatio-temporal geovisualisation interfaces. Illustrated by Katie Wilson. Based on figure in Gautier et al. 2016

Current multi-cyclic approaches tend to be based around the 24-hour clock and the Gregorian Calendar. TEMPEST (Edsall and Peuquet 1997, Edsall and Sidney 2005, Andrienko et al. 2003), one of the earlier multi cyclic approaches, utilises clock and calendar time, but with exploration facilitated by a cyclical interface and working on different granularities. As noted, a typical way of creating interfaces for cyclic temporality is the use of the wheel. The TEMPEST interface provides an early example of a GIS interface incorporating linear and cyclical time. TEMPEST followed the logic of a WHAT, WHEN, WHERE triple and is made up of three views, a location window showing the spatial information, a temporal window, highlighting the temporal information, and an object window, listing spatial objects ranging from lakes and powerlines, but also including events and conditions (Edsall and Peuquet 1997). The temporal window provides support for both cyclical timing and linear timing, and the object window follows a tree model, Cyclical support included cycles for months, weeks, days and hours, as well as timeline support. TEMPEST remains a high bar for any further work in this area. TEMPEST also allowed for querying multiple cycles at once, as well as providing timeline support.

Another alternative to wheel diagrams is that of the Time Wave (Li, 2010). This view allows for multiple cycles to be viewed simultaneously, under different granularities. It also works off of seconds, minutes, hours, days, weeks, months, seasons and years (Figure 6.4).

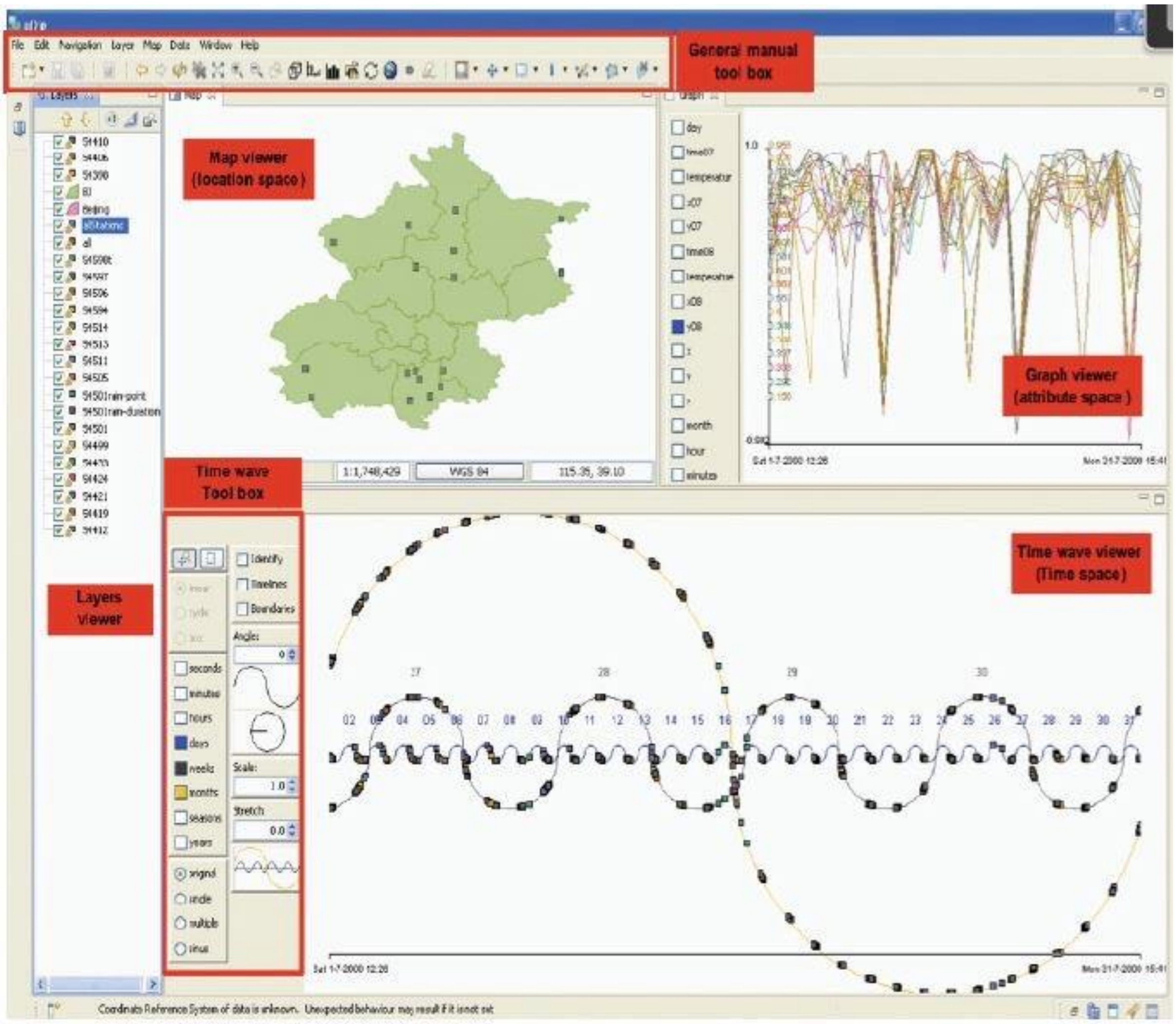

Figure 6.4: The generic overview of the triple space interface in the program uDig. Reproduced with permission (M.-J. Kraak). From Li 2010

The Timeline Kit as set out by Wang and Kraak (2014) allows for plotting different granularities together, like days against months or hours against days. This allows for better querying of temporal data in a more visually intuitive manner (Figure 6.5).

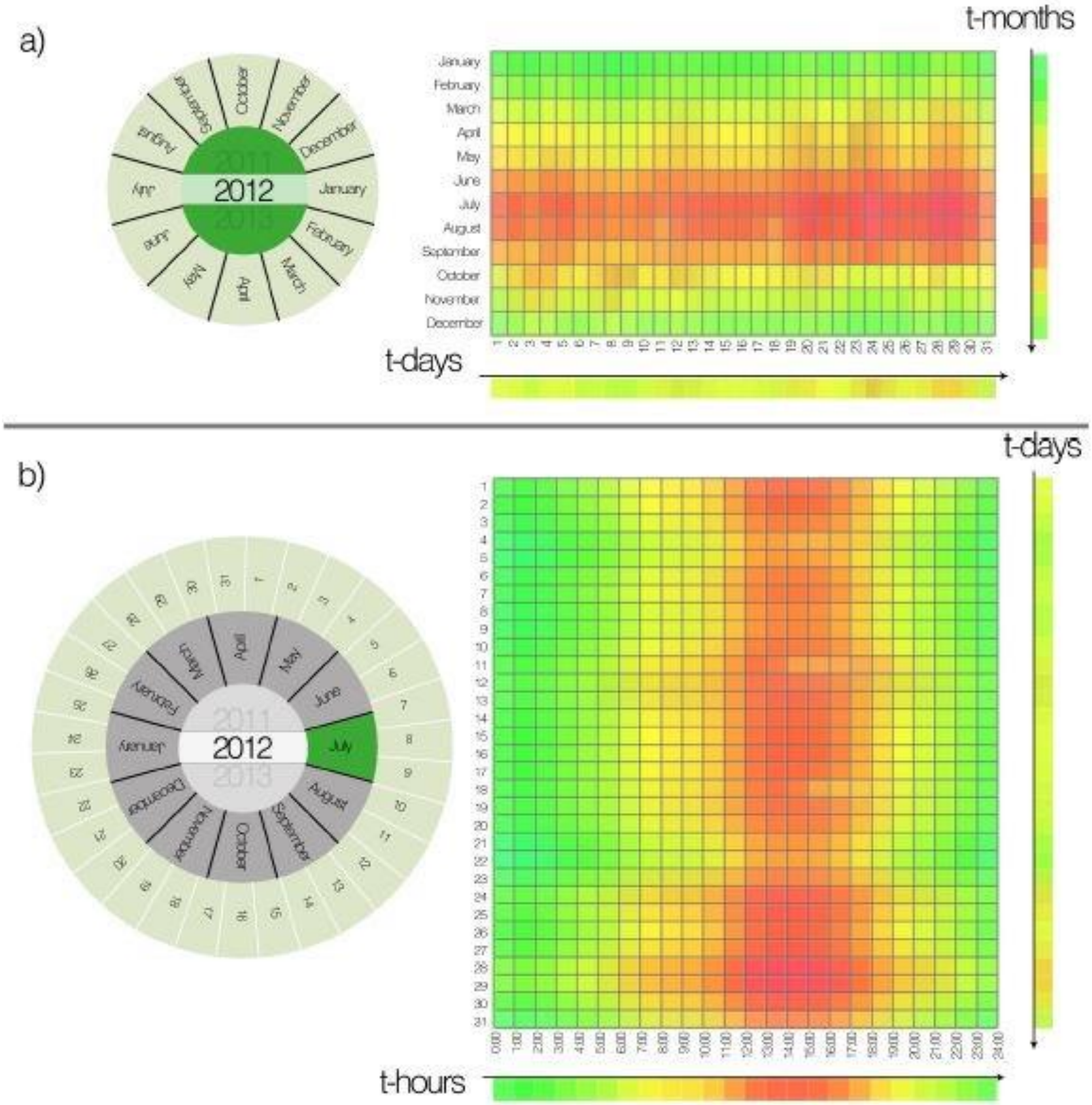

Figure 6.5: Example of temperature change in different time granularities, (a) days and months in 2012, (b) hours and days in July 2012. Reproduced with permission. From Wang and Kraak 2014

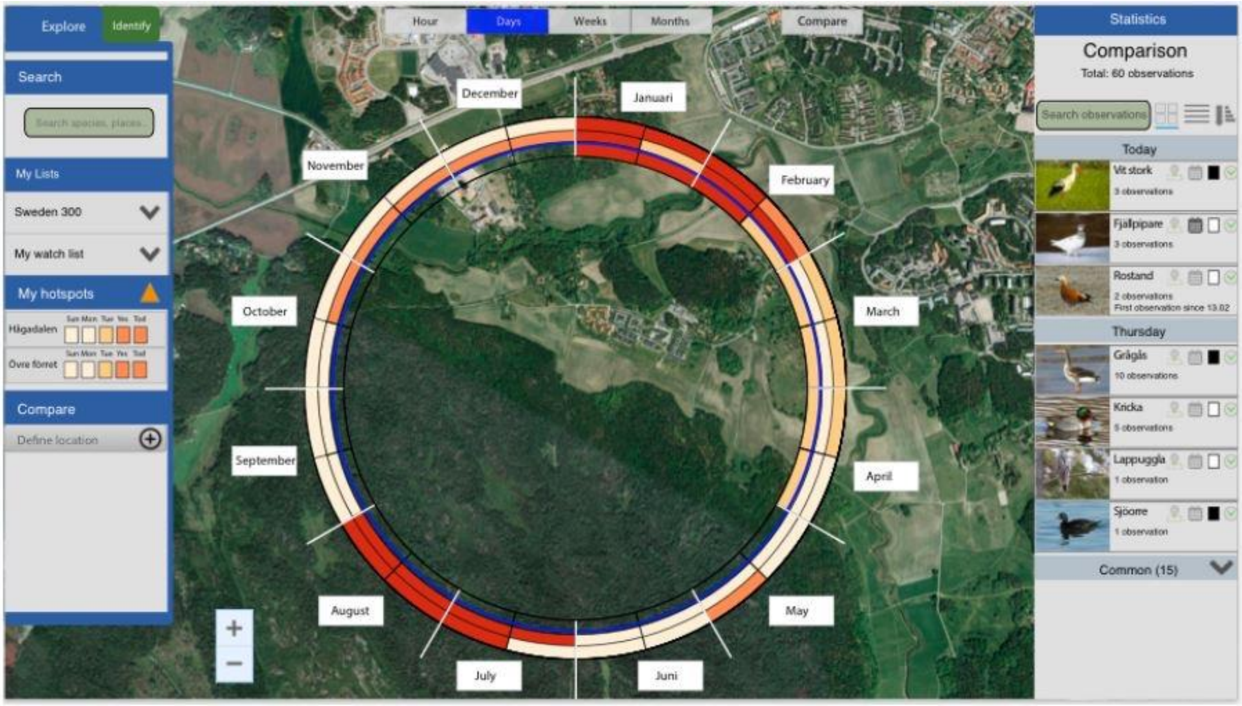

Figure 6.6: Viewing the yearly activity of a bird. Reproduced with permission. From Fledderus 2016

Figure 6.7: Observations of two days, distinguished by texture Reproduced with permission. From Fledderus 2016

Fledderus (2016) has developed a visualisation tool along the same lines as the authors for environmental data generated by citizen science in Sweden. Here multi-cyclic data can be displayed one ring at a time for exploring ecological patterns and making them transparent to citizen scientists. Fledderus goes further than we have for display, but seems to limit the number of rings that can be explored at a time (Figures 6.6 and 6.7).

Animation has been used in mainstream GIS for making sense of time, but tends to focus on linear time. There have been some efforts for depicting cyclical time patterns with animation (Kraak 2007, Li 2010, Li and Kraak 2012). More work on this front is needed, particularly from a TEK/IK perspective.

6.2.3 Current Missing Aspects

Most of the multi-cyclic tools are based on displaying extant data that already has clock and calendar timestamps. When working in the area of TEK/IK, that is not always an assumption that can be made. Often recollections of specific times will be limited to things like "a winter morning, maybe January" or "during the weekend". Extant tools also work better with solidly quantitative data.

Current tools also centre on the ubiquity of Western Clock and Calendar time, and this is not universal. There is a metronome quality to that system of time keeping that is often unsuitable for other peoples or other species. Seasons may be reckoned in different ways, repeating day counts that do not have seven days may be the norm, and behaviour, particularly in coastal communities, may be based on tides in a way that is not reflected directly in current tools. Customisable tools and conceptual support for multiple cycles are needed. The current Gregorian Calendar/24 hour clock method of keeping time does not keep track of certain key cycles easily. Timestamps are the standard way to depict and query temporal data but likewise, they are not the only solution for keeping track of time. Alternatives are needed.

Interface design may also have issues, as certain conventions are applied as standards. For example, in the Northern hemisphere, tracing out the movement of the sun throughout the day results in a clockwise motion. In the Southern hemisphere, this is reversed. Lunar phases likewise appear different north or south of the equator, with the first crescent facing in a different direction. Other hemisphere problems include the interrelationships between seasons and months. For cultures that read left to right, left to right is associated with past to future, but that too is not universal.

Depictions of TEK/IK in the literature and as documented from interviews with knowledge holders will consist of both episodic and semantic recall, with episodic recall being that of a particular time, activity and place, and semantic being a more generalised depiction. These generalised depictions get clustered over time in a culture and in a location into localised calendrics, knowledge about what time of year/ lunar cycle/ tidal cycle or combinations thereof are suitable/ unsuitable for a given activity. It is these generalised semantic depictions that visualisation tools need to be able to support from both querying and documentation aspects in order to facilitate the use, documentation and dissemination of TEK/IK. Although this form of documentation is not as precise from a co-ordinate perspective as a GPS fix with a timestamp, it is more accurate in other ways, namely in that the semantic descriptions describe the context itself in a way that co-ordinates alone cannot. There is a "precise ambiguity" to traditional knowledge (Rundstrom 1995:50) that requires a step away from the rigidity of the timestamp. Cultural and ecological information is complex, and there is a strong desire and need to simplify and sometimes oversimplify relations for transparency. Carpenter et al. (2009) point to two filters that are often operating that lead to constrained points of view, these being a focus on the computable, and a tendency to believe in dominant models. Better tools and ways of dealing with complexity do not make this problem go away, but they do offer other windows to view the world through.

6.3 Method and Use Case

To explore TEK/IK, and to represent and analyse how Indigenous peoples utilise a wide variety of techniques for tracking time, we have defined a spatio-temporal Graphic User Interface (GUI) and a simple but flexible system to show interactions between multimodal **time**, knowledge descriptions (**theme**), and geographical **locations**. By multimodal time one can understand different cycles of time like the year, the lunar cycle, the day/night cycle, the tidal cycle, and the days of the week amongst others. Such cycles set the rules for **when** it's the right time for doing certain activities (**what**) that necessarily are developed or executed some**where**.

The triad framework proposed by Peuquet (1994) allows for the integration and relation between the three main components of geographic information, these being **theme, location,** and **time**, as defined by Berry (1964) and Sinton (1978). By integrating the elements, it is possible to ask and answer questions relative to each of them, with the core questions being what, where and when. This perspective can be used to set up a strong scenario to analyse TEK/IK from these different dimensions.

More complex analyses about geo-historical facts and changes can be supported by the triad framework because of the way it relates thematic, spatial and temporal predicates into a single structure. It allows for tracing evolution of a situation and describing the consequences (Claramunt et al. 1999). The interrelation between elements opens the door to a number of potential models. The triad framework fits some of the requirements for describing TEK derived from Indigenous cultures, and that’s why we have based our approach on it. Furthermore, it provides the components to manage each predicate independently.

6.3.1 Example Case – Traditional Māori Timekeeping

Traditional Māori timekeeping provides one example of a traditional multicycle system that our interface could support, with some modification. Māori timekeeping is part of a much broader Polynesian-wide family of timekeeping systems that are tied to many cycles, particularly the moon. The Māori lunar calendar is the Maramataka, and the names used overlap with calendars from Easter Island to Hawai'i, including lunar calendars in Tahiti, the Marquesas and elsewhere (Horley 2011).

The body of knowledge that is contained within the Maramataka continued its incremental expansion over many centuries and generations of Māori living in close contact with nature. This knowledge would be maintained before European contact via oral transmission and direct practice, but those methods have been accompanied by written texts and models ever since. Drawing from its original multiple sources including traditional Māori beliefs and teachings; from *tohu* (traditional Māori signifiers) (Gibson 2006, Roskruge 2007), from Māori observations and predictions (Williams 2004, Hikuroa 2017); and not least from Māori astronomy (Harris et al. 2013), the Maramataka became consolidated and entrenched, relevant, and most crucially - specific to Aotearoa.

Maramataka reflect the sophisticated and comprehensive scientific knowledge bases and technological traditional practices of Māori time keeping. In the first instance, as we have seen from the earliest evidence of the use of the lunar calendar, these practices were born out of the basic need for survival and sustenance and the subsequent necessary provision and preparation of food in order to ensure that survival (Whaanga et al. 2018).

Conditions and calendars vary between different areas and different Iwi. For Ngāpuhi, in the north, for example, horticultural activities play a central role due to the warmth of the climate and the richness of the soil (Roberts et al. 2006). For Te Whānau-ā-Apanui and Ngāi Tahu sea fishing is important due to an abundance of migrational species and ready access; birds and rats among inland peoples such as Tūhoe and Waikato/Tainui tribes, again due to ready access and plentiful bird species. Freshwater fish and tuna (eels) are important wherever they are found.

The monthly lunar calendars can be quite detailed, highlighting the specific days on which certain activities are or are not advised (Roberts et al. 2006). Each lunar phase represents the particular aspect or nature of the moon at this time of the month. Below is an example of one lunar phase within Maramataka and an explanation of what this particular phase is good for and how we can ascertain certain movements and indicators. These vary from place to place.

Rākaunui	Everything is vibrant and full. A good day for planting crops (Gibson 2006, Tāwhai 2013). Excellent day for planting kumara, but those planted on Rākaunui won't store well (Tāwhai 2013). In some areas, good for sea food (Best 1922). This night is the fullest of the full moon phases and is used to calibrate the Maramataka in the lunar cycle (Tāwhai 2013). It is also the first day of the lunar month for some Iwi, like Te Whānau-ā-Apanui (Tāwhai 2013).

6.3.1.1 Ngā Marama - the months of the year

The monthly calendar and table of attendant stars outlines what is happening during this period and what to expect. It provides a series of weather observations and the anticipated temperatures that will ensue for that particular time of the year.

Pipiri	Pipiri or Pipirioterangi and the two stars Hamal and Sharatan in the constellation of Aries (Moorfield 2018). Pipiri is the first month and Matariki (the Pleiades) appears at this time, acting as the symbol of the new year (Collier 2009).	This is the month when winter starts to appear, the ground starts to get cold and everyone starts to gather together to begin Wānanga (learning workshops), traditionally held over the winter (Collier 2009).

6.3.1.2 Ngā Tau – The Seasons

Seasons break up the year into components with similar weather patterns and vary from culture to culture. Tropical areas often use a two season system with a wet and dry season (Roberts et al. 2006). Seasonal systems in temperate regions, including the seasonal model of Spring, Summer, Autumn/Fall and Winter in the northern hemisphere centres on the solstices (shortest and longest days) and equinoxes (equal day and night), to break the year into four. For Māori timekeeping, the year is divided two halves. These halves are personified by Hine-takurua and Hine-raumati. Tama-nui-te-rā (the Sun) had two wives. In the winter time he would reside with his wife Hine-takurua (the Winter maiden) and then in the summertime he would reside with his wife Hine-raumati (the Summer maiden) (Best 1899). At the winter solstice, Tama-nui-te-rā leaves Hine-takurua and begins his journey to Hine-raumati (Best 1922). The halves can be divided again. Below are the four names for the seasons of the year for Māori. Takurua, Kōanga, Raumati and Hōtoke and are roughly equivalent to Winter, Spring, Summer and Autumn, respectively. Spring is also sometimes called Mahuru, and

Autumn Ngahuru (Harris et al. 2013). Sometimes Hōtoke is used as a synonym for Winter as well (Orchiston 2016).

Tau (Season)	Description
Takurua	Takurua takes place from Pipiri to Here-turi-kōkā. (Approximately June to August)
Kōanga	Kōanga takes place from Mahuru to Whiringa-ā-rangi (Approximately September to November).
Raumati	Raumati takes place from Hakihea to Hui-Tanguru. (Approximately December to February)
Hōtoke	Hōtoke takes place from Poutū-te-rangi to Haratua. (Approximately March to May)

These cycles and timing patterns can also combine with other cycles, like those of the day and night and the tidal cycle, to regulate activities of all sorts of kinds. Seasons are sometimes broken down into further distinctive time periods.

6.3.1.3 Examples

Gibson (2005) provides an example of multi-cyclic timing from the traditional practices of Ngāti Konohi. *Toitoi Kōura*, or Crayfish bobbing would occur on days when there was a midday and a midnight low tide. These occur during Hoata, Tamatea-Āio, Rākaunui, Rākaumatohi, Tangaroa-ā-mua, Tangaroa-ā-roto, Tangaroa-kiokio, Otaane, and Ōrongonui. Bait for the traps would be caught during the midday low tide, and then set on the midnight low tide. This could only occur when the season, moon phase, weather and tides were all lined up. Tāwhai (2013) provided a number of examples throughout his discussion of the Maramataka of Te Whānau-ā-Apanui. For the nights from Tangaroa-ā-mua to Ōmutu, the 8^{th} to the 14^{th} nights after the moon is fullest, fishing at night by torch light is apparently easier as species active at night are “strangely docile” during this time period (Tāwhai 2013:31). Recent work by Clarke and Harris (2017:133) lists the five key cycles as “maramataka, lunar, seasons, year” and “tidal” for understanding the behaviours of key species for Māori and works towards documenting these patterns.

6.3.2 Tool Requirements

The authors have developed a method for displaying some of the key cycles utilised in Traditional Knowledge systems for documenting and querying TEK/IK knowledge. Multiple wheels are used to keep track of temporal constraints utilised by people as well as the various species they depend on to highlight when certain activities are suitable and unsuitable. These in turn are highlighted or not depending on the constraints displayed by the wheels.

Distinction needs to be made for features or activities that cannot occur due to the settings, features that fit all the requirements of a given query, and features that fit all the requirements for a given query for those fields for which they have information, i.e. if the user queries query Friday Evenings and the activity occurs on Fridays but we have no information whether it is done in evenings or mornings, we must consider it as potentially fitting the pattern, but not necessarily fitting the pattern.

Each wheel either tracks a different cycle, or in the current incarnation tracks different granularities of the same cycle (seasons versus “months” in the case of the annual cycle). Here we are keeping track of the tidal cycle, two granularities of the annual cycle, lunar phase and days of the week, as well as having some support for linear time (Figure 6.8).

Figure 6.8: GUI to represent TEK/IK

What could be referred to as the flavour of time depends very much on the various multiple cycles that are at play at any given moment, and where in those cycles the moment lies. Mornings have a certain commonality, as do evenings. Winters have a certain commonality, as do summers. Summer mornings have more in common than winter mornings, and summer evenings have more in common than winter evenings. Other key cycles, important for other species as well as some human activities include the lunar cycle and the tidal cycle. Artificial cycles that are of significance include the days of the week. The various cycles can be broken down into different levels of granularity, not all of which are necessarily of even length. The year is often broken into the four seasons: spring, summer, autumn and winter. There is nothing particularly universal about four seasons, and other cultures may keep track of two, or three, or six. The year can also be broken into 12, with the months of the year. Again, there is nothing particularly universal about 12 largely even divisions, and the year could be broken into 10 or 12 or 13 month-like units. These are close to the divisions of the year into lunations, but depending on the calendar system either follow the moon closely, or fudge the cycles for more standardised units as the Gregorian calendar does. The year can also be broken into 365 and 366 depending on the year.

The terms used for a given cycle form a directed cycle graph, and when multiple cycles are entwined, one ends up with a multi-cyclic and directed in many/most cases, the transitions between semantic terms is not crisp. Spring may come before Summer, but Summer can be defined alternatively as the days between June 21st and September 21st in many countries in the Northern Hemisphere, or the days between December 1st and March 1st as it is in the Southern Hemisphere, or as a period where summerlike weather is occurring, which allows for sentences like “it was a late summer” or “it was an early summer”. This semantic ambiguity is normal, but much of the 21st century has tried to avoid it. However, when either using humans as sensors (Goodchild 2007) or when documenting non-crisp patterns (as is often the case with local, traditional, or Indigenous knowledge) this ambiguity should be expected.

The original prototype was a volvelle (paper instrument with turning wheels) constructed out of paper with sliders for the solar cycle, the lunar cycle, the diurnal cycle, and the tidal cycle. Depending on how it was adjusted, a span of a month or a few days could be set for the solar year, one or a few nights could be set for the lunar cycle, different aspects of the day could be set, and whether the tide was in, out, coming in, or coming out. The volvelle was created and shown to various colleagues familiar with traditional timing, to see whether the concept had some validity. Several suggestions were made, and it quickly became apparent that any set of wheels would have to be alterable to suit a given group of people. Indeed, due to the occasionally idiosyncratic nature of traditional timing in some areas and amongst some cultures, the ability to adapt the display might be necessary person to person.

The current display is made of semi-transparent rings overlaid on a regular map, and currently utilises google maps as the base layer. The rings can either be displayed over the map, or minimised into a browser window below. The tool works via a series of wheels and bins for a number of key temporal cycles. In the current mock-up, five key temporal cycles were picked. These were the tidal cycle, the annual cycle, the seasonal cycle, the lunar phase, and the weekday cycle. Depending on the activity, any one, or a combination of many of these cycles may be key in deciding when an individual may carry out an activity. The underlying logic for display is currently that of Faucher et al. (2010), where only if all pertaining wheels are highlighted and in the right position is an activity possible, otherwise being catalogued impossible. NULL values can be interpreted as “possible” if there is no information for a given cycle, but a distinction would be handy between features that fit all the wheels as displayed, and features that fit some of the wheels as displayed and are data deficient for the others. Wheels can be queried one at a time, or together.

A more nuanced logic might allow for more distinctions than the possible/impossible distinctions of Faucher et al. (2010). For example, some birds are migratory and are present only during certain seasons. Some fish, salmon for instance, have runs at certain times of the year. Some game animals may be left alone for much of the year, and be active only at certain parts of the day. Birds are known for their dawn chorus and are most active at dawn and dusk.

Although we include linear time within the interface, the focus is on cyclic time. The interface as it exists only includes support for the Common Era (CE) year, but a fully fleshed out interface might include support for cultural temporal markers like the reigns of kings, or other significant dating systems. This would help support scenarios where a given activity used to be fine at a certain time, but is no longer so, or when a given activity used to be impossible at a given time and location at some time in the past, but is possible now.

6.4 The Visualisation Tool

6.4.1 Technical Aspects of the Visualisation Tool

The Graphic User Interface has been developed under JavaScript, HTML5 and CSS3. This set of standard programming languages provides the GUI with enough flexibility so that the behaviour of the system can be similar on any browser. We have tested the interface on Mozilla Firefox, Chrome, Opera, Safari and Microsoft Edge. The results in terms of speed and rendering quality are acceptable. The GUI takes a few seconds to upload due to the graphical symbols representing the cycles on the *TimeWheel Controls*, however once they are loaded, it performs very quickly. For JavaScript, the GUI performs on jQuery and jQuery UI. The interface is composed of three dimensions (predicates): spatial, thematic and temporal.

For the spatial dimension, we have implemented the Google Maps JavaScript API. This tool is robust enough to include the implementation of thematic and temporal dimensions alongside the spatial dimensions. We also considered the implementation of OpenLayers together with OpenStreetMap, however, for the first approach we selected the Google's API because of the flexibility and ease of installation and implementation. In addition, the Google Maps API provides imagery and this is a key consideration when displaying and documenting activities such as fishing and farming. While imagery may not always be up to date, there will always be one image available to get an idea of the geographic status of the area of interest. As well, Google has historical imagery included with Google Earth, and potentially, this sort of imagery may be accessible in the future for interfaces. Moreover, the API provides global coverage.

The thematic dimension has been implemented through a simple ontology; it permits us to classify the activities and make easier querying by integrating the spatial and temporal dimensions. The ontology takes into consideration the various relevant temporal characteristics for each activity, for instance, sowing and harvesting periods, and other regular activities. The thematic dimensions are expandable based on the depth of the ontology used. New levels can be integrated as long as they are accompanied with the respective spatial and temporal information.

The temporal predicate is described below in Section 6.4.2. The key characteristic of this proposal is the integration of multiple sorts of times in a single tool. This temporal querying tool provides the user with the ability of mixing different time scales simultaneously. Dial and resizing tools enables the querying of the thematic predicates, while considering the spatial locations and their temporal restrictions. The GUI effects are based on jQuery UI. Utilising the interface for documenting temporal patterns is not part of the current design.

6.4.2 Visualisation Tool Walkthrough

Figure 6.8 shows the components of the proposed Graphic User Interface. We have based the development on the multimodal cycles. To represent the temporal predicate we have setup five cycles of time (days of the week, lunar, seasons, year, tidal) and a temporal line to separate and classify such cycles. The spatial predicate is represented by the Google Maps API base map as well as a set of layers that represent and locate the activities developed by Indigenous people, i.e., fishing, farming, hunting and others. Finally, the thematic predicate describes the activities by using an ontology; this permits to classify Traditional Ecological Knowledge from different perspectives, and mainly, to adapt the base knowledge to the spatial predicate and show interactions according to temporal cycles.

In addition to this, we provide the *TimeWheel Controls*, a set of controls to manage predicates and, mainly, to visualise interactions. Cycle controls allow one to activate/deactivate the whole GUI in order to enable interaction with the base map and activity layers without restrictions or jams. They also allow scaling and separating the temporal wheel controls as shown in Figure 6.8, each circle represents a kind of cycle. This functionality is useful when the *theme predicate* requires to be filtered by considering several cycles of time, for instance, high/low tide during winter time. In the mock data displayed in the example from Figure 6.8, we can see that for the constraint condition of full moon during winter time it is possible to prepare land for farming but that fishing is not favourable. In the data represented by Figure 6.9, we can see that the tuna (eel) harvest occurs during a new moon in autumn at the mouth of Te Roto o Wairewa/Lake Forsyth at Birdling's Flat.

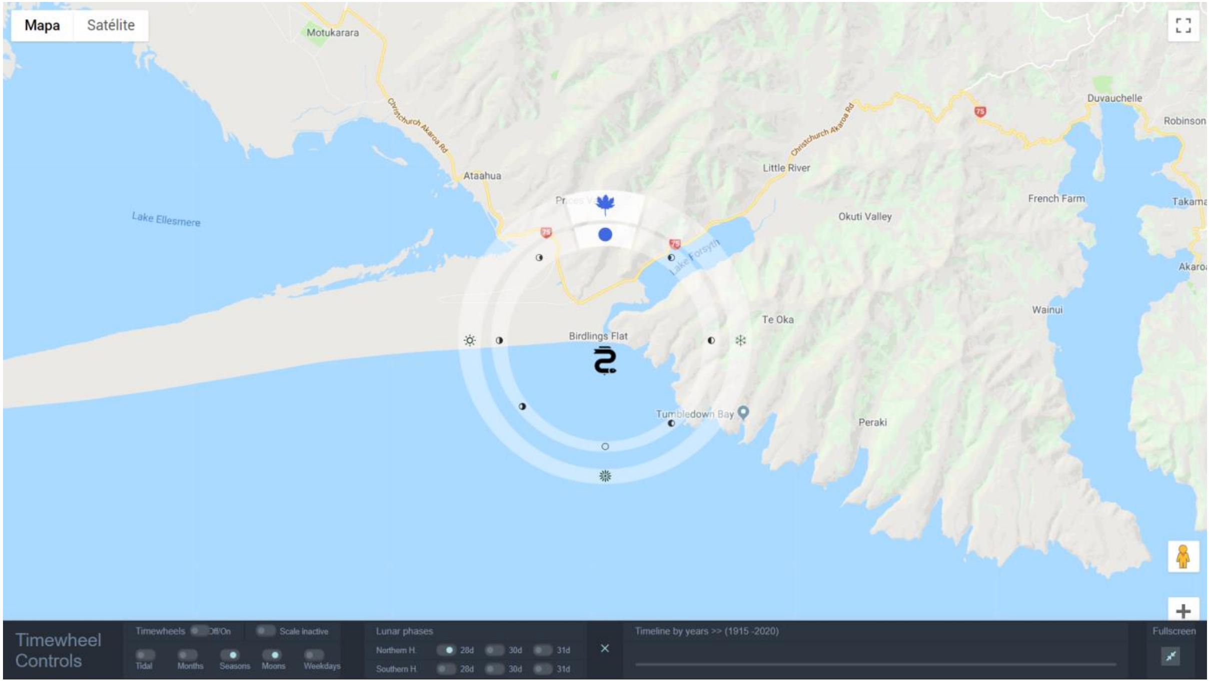

Figure 6.9: Tuna (eel) harvest during a new moon in autumn at the mouth of Te Roto o Wairewa/Lake Forsyth

The lunar phases and hemispheres tool also plays a key role. Lunar counting systems can vary from place to place depending on how the lunar cycle is divided, depending on whether the lunar cycle is counted off by days, by lunar risings and settings, by sidereal or synoptic periods, whether days are counted more than once as can occur with the new moon, and whether a count continues until the sighting of a new crescent after a new moon. Because of all these variables, we've included a lunar count of 29, 30, or 31 days depending.

Activities are classified and located according to temporal descriptors, i.e., cycles of time. This way, the GUI provides a framework for some of the key cycles for TEK/IK multi-cyclic timekeeping in systems around the world. Local adaptations would be required, and more functionality along customisation lines would need to be incorporated for later versions.

This basic system represents the way in which native cultures define/identify its productive periods and activities according to the cyclical perception of time. In the near future, we will integrate more functionality to aggregate even more the interactions between the cycles of time and the three predicates. This GUI represents an innovative way to show TEK/IK and spatio-temporal interactions.

6.5 Conclusion and Future Research

Multi-cyclic data continues to come second to other views of time and is more complex than the linear view that remains the default position. Non Western Clock and Calendar time remains almost completely unsupported, and time stamps are still the key way of recording temporal information. Hopefully this interface helps address those two issues.

The issues facing the recording and display of TEK/IK temporal data are similar to issues for mapping other temporal patterns. Some ethological and ecological pattern recording could benefit from our approach, as could other efforts in recording citizen science in a number of knowledge areas.

The visualisation and querying components are largely complete at this point, but a fully-fledged tool would have to have an interface for customisation of the various cycles used by a given person or group. Some cycles are more or less pertinent to some groups, some are not pertinent at all. Tidal cycles mean little to inland people, for instance.

Due to the visual nature of the interface, icons for a given region that function for marking seasons or times of day or tide may also be different. A snowflake does not mean “winter” to areas that do not get snow, and there are other seasonal cues for annual cycles with more or less than four seasons.

The current tool needs a complementary tool for recording patterns of data suitable for querying via the visualisation tool. Current time wheel type displays focus almost entirely on timestamp data, and as discussed earlier, this is not always the form that temporal data is likely to come in when documenting traditional knowledge. The complementary tool is likely to have sliders as the prototype tool had.

Additionally, the ability to allow for the display to animate data via playing it could be of interest. This would work by fixing all cycles save one. For example, one could see how the day and night cycle plays out during the winter, or fix the day component and see how activities change over the seasons.

Not all traditional timing comes down to repeatable cycles. Weather patterns, social patterns, and other key markers also affect when the right time or place for an activity may be. This can be seen in the approach taken by Faucher et al. (2010) who include such restrictions as weather, market and regulation to their temporal restrictions. Parallel or sometimes identical constraints affect traditional patterns of activity. One advantage/ problem with multiple wheels and dimensions of time are the exponentially increasing number of search parameters that can be utilised. With single dimensional linear time, one can either choose to search by time or not, and an event is either in the range specified, or it is not.

The visualisation tool could have uses outside of traditional knowledge as well; parking for instance. We could notate that parking is free on all Saturdays and Sundays, free in the summer, free from 5:00pm to 8:30 am and 2 dollars an hour on weekdays from 8:30am to 5:00pm in Winter, Spring and Summer. The operating cycles would be the days of the week, the months of the year, and the time of day.

Lastly, the current interface is fairly stripped down so far as relating to other components of data that might be queried or visualised, focussing solely on the cycles themselves and a few activities. Fledderus (2016) provides some examples on how a stronger interactive display could be developed for particular areas of interest like bird behaviour. For knowledge holders of TEK/IK, this sort of more in depth interface might be good for highlighting patterns of knowledge to outsiders. Ultimately, maps, interfaces and visualisations are there to inform and to highlight patterns for all.

6.5.1 Future Steps:

For utilisation by different cultural groups, the interface design would have to be customisable. Although the overall design has been designed to be fairly generic and adaptable, different cultures use different cues for decision making, and cycles are divided differently depending on local climate and circumstance. The annual cycle can be divided into months or month like units, seasons, of which there can be anywhere from two (rainy, dry) to six or seven or more (see traditional Australian Aboriginal calendars). Divisions of cycles are not predictable a priori and will either emerge via previous documentation or via knowledge holders.

Allowing for overlapping bins for a given cyclic behaviour, may be one way to better reflect traditional terminology. The ability to customise the interface would be important, but goes against the GIS tradition of universality. However, Janowicz (2012) has discussed the need for a paradigm shift from top-down universalised ontologies to bottom-up localised ontologies. Claramunt and Stewart (2015) also stress the need for other complementary understandings and interpretations of time.

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7 GIS Data Models for Depicting Traditional Knowledge of Processes: Connecting Spatio-Temporal Motifs into More Complex Narrative Structures

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Abstract

Current GIS data models have problems representing interconnected data sets, due to problems inherent with the underlying relational database structures used for storing and manipulating information. Graph databases have come some of the way to reducing this problem for non-spatial data, but also have their own blind spots. The authors have been working on a new model, rooted in the nested graph model of Sowa (2003). 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 RDBMS based GIS systems that are currently the norm. RDBMS systems are, despite the name, not very good at relations between features, or layers and current temporal GIS tends to focus on the utilisation of timestamps, which provides an incomplete view of time. 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 be implemented, and shortcomings to current technologies related to implementation. These motifs should provide a more natural fit to traditional ecological knowledge and other knowledge systems with looser schema than what a RDBMS usually requires.

7.1 Introduction

Current models of mapping and GIS tend to follow western constructs of time and space, sometimes in ways that actively undermine other understandings of time and space. Although this may not be intentional, the easiest data to model and account for is that which is crisp and easily corresponds to points, lines, and polygons, or behaves like a field where a single property changes via a numerical value over a large area. Ideally, the data fits nicely into individual layers, and any interactions between those layers are those sought out by someone doing geospatial analysis. We are given a God's Eye View, and the model is somehow beyond narrative. Time, if included, lies at right angles to breadth, width, and height forming a fourth dimension, likewise measured off, albeit not in the same units. Every time-place possible will store values for properties and those sit perfect in their perfectly crisp defined boxes for eternity. It is the land of God the Architect, frozen in its perfection. It is TRUE.

Traditional cultures often have long forms of narrative that are maintained that are anchored to key times and places on earth. Hakopa (2011) discusses the importance of oral narratives for Māori as well as Indigenous peoples in the wider sense. What makes a place come alive is for the ability of multiple narratives to come alive for a given place. Hakopa also discusses the importance of the Lienzo in his work, a map that tells a story.

Why are narratives important? 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. What we end up with without narratives are sticky boxes that can be connected structurally, but cannot truly flow and breathe. We cannot make videos. We cannot do animations, except in a more limited sense. Narratives also allow for analogical reasoning (Hall 1989, Dehghani 2009, Zarri 2010a, Paskey 2014, Bex and Bench-Capon 2017).

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 as cited by Pearce 2009). Narratives can also be seen as "accounts of events or series of events" that are connected chronologically (Kwan and Ding 2008:449). Zarri (2014:82) 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.

Every model we can create of reality hides falsehoods, and expectations. Some things are easier to see than others depending on the model chosen. We end up, if we are not careful, like Nasreddin looking for his keys where the light was better, despite losing them elsewhere (Esmaili et al. 2014). This is the streetlight effect.

If we want to explore the messy and the interconnected and the evolving nature of life, language and living tradition, we may not always find what we are looking for with the current cadastralised and mechanised view of time and space inherent to relational database management system (RDBMS) depictions of our world and what lives and breathes here. That is not to say that it is impossible to do so, as many have found ways to depict ecology, oral history, and folk knowledge utilising the ever expanding toolkit that current GIS technology provides (Sirait et a. 1994, Aswani and Lauer 2006, Joyce and Canessa 2009, Gearheard et al. 2011, Pulsifer et al. 2011, Eisner et al. 2012, 2013). Some of the work on Inuit sea ice knowledge already documents key processes and the interactions between different kinds of ice and weather conditions (Laidler et al.2008). However, the GIS systems utilised are still RDBMS systems. The problem lies deeper. The problem is the little boxes of things, and what we are looking for is patterns of processes. The world behaves more like the spoken language than the written word. But of course, we still have to write things down.

Languages are magical. They often encode worldviews and systems of practice, and we know that linguistic and cultural diversity and biodiversity appear to be intertwined (Maffi 2005, Gorenflo et al. 2012). Traditional knowledge systems coupled to healthy languages continue to evolve over time and speakers of languages pass on information about the world around them, including the history of places, the life cycles and needs of other species, and the rules governing how to behave in different places (Parlee 2006, Turner and Clifton 2009, Berkes 2012, Thornton and Scheer 2012).

Despite this richness, most current GIS documentation of traditional knowledge tends to focus on extent over nuance or over a subdomain of knowledge at a time. The interconnectedness inherent in language and syntactic structures often gets lost, or other representations are used instead. That is not necessarily a bad thing, but if GIS and maps are to be leveraged to their full extent, that same interconnectedness is desirable. It is also not impossible to do. We need data models that interweave and interconnect multiple times, places and activities easily, rather than segregate them into different layers and databases. Stories intersect and interweave, as do ecosystems and other complex systems.

The core of Common Law legal systems and legal systems around the world centres on analogical reasoning (Sunstein 1993), and dealing with court systems remains a core use for the mapping of traditional knowledge. Indigenous groups use maps to anchor claims to the landscape, and to highlight impacts stemming from development decisions, past, present and future (Chapin et al. 2005, McCarthy et al 2012, Olson et al. 2016).

Traditional landscape management usually occurs in an environment where things are always the same and never the same, so oral history, stories, written records, and the reasoning in the field by practitioners informs the practices ahead. The rights of Indigenous peoples to manage their own territories, as well as management and co-management by and with Indigenous peoples is becoming increasingly the norm in countries like Australia, Canada and New Zealand, as well as other non-commonwealth nations (Beltrán 2000, Hannibal-Paci 2000, Craig 2002, Sadler 2005, Stevenson 2006, Edgar 2009, Ruru 2009, Waitangi Tribunal 2011). Unfortunately, that which is not catalogued, measured or searchable often does not exist as far as decision making processes go and proponents of a given project often ignore data that does not suit a plan. New tools will not necessarily stop those problems, but they so make knowledge harder to ignore. What is useful for courts for territorial rights is not necessarily what is most useful for management.

The ability to share these stories and reasoning patterns with outside groups like law courts, biologists, ministers, communities and the public at large becomes increasingly important. A GIS ideally needs to be able to be used for these sorts of narrative purposes, as well as supporting the analogous reasoning that would help make the case in legal environments when required. Complete legibility is impossible and may be undesirable, but purposeful construction of GIS information to highlight arguments or knowledge is feasible. In this paper we will look at how narratives may be incorporated for GIS with an extension of the motif model developed by Mackenzie et al. (2018).

7.2 Literature Review

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 such that they can be used for query and comparison. Finding narratives associated with a given topic, or being able to search for similarities between narratives could be of value in ecology for understanding complex systems, legal narratives, and historical narratives. We need to be able to collect together features and layers and stitch them together in the right order to compose a narrative describing an event. Narratively linked interconnected features should help with things like cumulative impact assessments and avoiding destruction via ignorance as well.

Due to the data models and structures of current GIS, layers and features within layers 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 are tied to various forms of visualisation. 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, or associating with a feature or a set of features in a single layer some kind of narrative embedded in text or other media.

As a series of layers, GIS based narratives can be represented as navigable stories or via animations, which can include a range of maps and supported media. These have seen many variants, including geo-narratives (Kwan and Ding 2008), story maps (Battersby and Remington 2013), cybercartographic atlases (Pyne and Taylor 2012), and extensions of these like spatial video geonarratives (Curtis et al. 2015).

Multiple narratives can be represented in a single map, with story components associated with features obtained via interviews when creating map biographies (Brody 1982, Ellanna et al. 1985, Tobias 2000, Tobias 2009, 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.). Narratives can be embedded into cartographic depictions to good success, and provide a "consciousness of place" (Pearce 2008:21) that imbues locations with deeper meaning. 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. Hakopa's work on narratives in GIS points the way to a more integrated representation. The complexities of traditional systems of tenure are in part related to the depth and complexity of oral history and interrelationships between communities over time and space (Thom 2014).

In both cases, as a series of layers or a single layer of story elements, one cannot look for narratives that are like other narratives, or share given actors or events necessarily. Cartographic depictions alone do not necessarily construct a narrative. Interpretation for how elements interconnect and the significance of those interconnections is also important (Denil 2016). Current GIS models allow for models to be constructed out of the points, lines and polygons in layers stored away, but each feature and each layer lies as a feature tied to a tuple. Schemas tend to be rigid. Ontologies tend to be rigid and tree-like. The boxes are not sticky and interconnected. Time is linear. Data is crisp. Mackenzie et al. (2017) discuss some of the shortcomings of current GIS visualisation when it comes to fuzzy boundaries, interrelated narratives, and non-linear timing like cyclical patterns.

The flaws with the current GIS model lie deeper at its foundations. The underlying entity-relationship data structure embedded within GIS limit our ability to represent narratives because of some of the limitations existing with relational databases including query time, the limitations of two-dimensional tables when dealing with heterogeneous entities with multiple links, inflexibility, and lack of actual relationality, despite the name (Kantabutra et al. 2014).

As well, 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. 2011), and there is no basic support for these sorts of nesting relationships in our current databases. Casanova et al. (2011) do discuss what is needed to extend the ER models and RDF to allow for these sorts of relationships. Data model where everything is interconnected, and where small world effects and overlaps are apparent from the data itself are needed. Karlsson et al. (2009) also discuss how their work on plots compares with and can extend Codd's basic relations in the relational model underpinning RDBMS, with meronymic relationships providing the necessity for that extension.

Other systems looking to represent stories on a deeper level can be found in the field of Artificial Intelligence (AI). AI models provide an alternate understanding of spatio-temporality and process in a way that is systematisable for computers in the same way that GIS is computer friendly. Some of the earlier work by Sowa on knowledge representation is of particular interest (Sowa 1976, Sowa 1992). Sowa, working from Peirce's logical diagrams, came up with a stripped down system called Conceptual Graphs that is theoretically suitable for representing any human utterance and some of the logic behind it.

Conceptual Graphs evolved over time and nested graph models emerged. This is the work that this paper builds upon.

Another approach is the Narrative Knowledge Representation Language (NKRL). It provides a conceptual language for documenting the semantic content of narrative documents. Formal representations, called predicative templates centre on a verb with branching arguments in the form of roles like subject, object, source and destination. In this way, it is much like Sowa's conceptual graphs. These can then be strung along and interconnected into narratives (Zarri 1996). NKRL has been expanded to include temporal reasoning utilising Allen relations (Zarri 1998), and tends to approach time with timestamps. NKRL is still a work in progress, but as of yet it does not appear to have been utilised in a GIS context. This is likely to do with the incompatibility of NKRL and the standard GIS model, dependent as it is on an RDBMS framework. However it provides a good example of how to structure powerful semantic tools for constructing and handling complex narratives. This is very similar to what we are trying to do with motifs, but lack the context aspects of the motif model.

The Semantic Computing Research Group (SeCo) of Finland has done some pertinent work for representing narratives. In the CultureSampo project, efforts were made to create a place for Finnish culture on the semantic web. Large amounts of cultural content needed to be made accessible and part of the process of making it accessible was to make it easier for semantic searching and browsing via semantic associations between objects (Hyvönen 2009). Underpinning some of the work was an approach to link and describe semantic content via situations and actions with their "Situation Ontology" (Junnila et al. 2006:16). 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. The approach also allows for "semantic linking" (Junnila et al. 2006:20). to a variety of cultural content, including “paintings, artifacts, photographs, videos, cultural processes, and stories” (Junnila et al. 2006:13). 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. (2018). Not all time is uniform and chronological, just as not all place is Cartesian.

The work of the group also extended to creating geo-ontologies (Henriksson et al. 2008), and finding other ways of recording cultural spatio-temporal knowledge (Kauppinen et al. 2006). The narrative branches and the geo-ontology branches did not combine in the SeCo work directly, however Kauppinen, one of the members of the Finnish team, has been influential in pushing for a linked data approach (Kuhn et al. 2014). Some of the ideas from SeCo will be discussed further in the modelling portion of this paper. Kauppinnen’s own work has been to approach geospatial and temporal work from a strong semantic standpoint, using some of the strengths from SeCo, but his approach has also followed along an RDF pathway, and temporal references focus on crisp times.

The work by SeCo and Zarri’s work all point to some sort of graph database being required, but currently there is little support for nested graph databases. A nested graph is one where nodes can themselves be graphs, thereby making them hypernodes (Angles 2012). Angles and Gutierrez (2008) refer to graph databases that can support nested graphs as hypernode databases. Angles (2009) has discussed previously how nested graphs might be used to visualise RDF data, but current leading graph database software like .Neo4j or the like. JSON, OEM and XML are all trees, according to Angles and Gutierrez (2017) and these are too structured and lack some of the abilities desired that are present in nested graphs. However, most graph databases are either based on simple graphs or attributed graphs, and although there are hypergraph databases, there were no nested graph databases in 2012 (Angles 2012). This is problematic, because the multilevel nesting allowed by nested graphs is not modellable by other structures (Angles 2012).

7.3 Model

Our model revolves around a basic structure called a motif, which acts as a general depiction of an action, state or set of actions or states that can then be anchored to given spatio-temporal features or other depictions. Motifs tend to repeat and share some similarities with feature classes in traditional GIS. Narratives are used to tie motifs together into more complex forms, like processes. Folk thesauri allow for motifs that deal with similar matter to be clustered together much like an ontology. For this section we will use examples involving a dam and some eels affected by that dam.

7.3.1 Motifs

The motif can be seen as a container holding different instances, which can be represented by points, lines, polygons or rasters that anchor a given action or state and surrounding contextualisation. The action or state distinction allows for two main types of simple motif – those that establish context (existence motifs), and those that establish movement (other verbs that are not "to be" based. An object is paired with a verb. If there is no apparent verb, the implied verb is the copula. You can say that a dam exists at such and such a place and time, and end up with a depiction very similar to the norm for current RDBMS-based GIS systems. Alternatively, you can say that the dam generates power, or blocks migration. This is an action involving the same dam. The authors have discussed motifs previously in papers that have been recently submitted to journals (Mackenzie et al. 2018, Mackenzie and Reitsma 2018).

Motifs can contain chronic (clock/calendar) and kairotic (embedded) time and choric (co-ordinate) and topic (concrete and landscape) place as well as include salient agents. A modal statement about the motif (good, bad, off limits, declining, improving) can also be included, as well as pertinent information on things like privacy. Motifs are also hierarchical, with more refined or specific motifs nesting inside broader motifs. This is done via a folk thesaurus (Mackenzie and Reitsma 2018). They can also be combined into path-like narratives, and multiple narratives can flow through the same motif. The pathways themselves can also be treated as motifs. Motifs can be related to one another structurally via shared members, shared facets, or via hierarchies outlined in a folk thesaurus.

7.3.2 Narratives

In the broadest sense possible, 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. One could argue, as Fisher (1989) does, that all meaningful communication is via storytelling and narration. Narratives can be used to model processes, and processes can be seen as narrative in nature. Narratives are rooted in story, and others refer to the same as utterances and texts, depending on the media. In a typical RDBMS GIS, a dam exists as a feature tied to a database, and temporally, that database may have a timestamp. In a motif database, the dam as an object can be unpacked into the process that went towards building the dam (See Figure 7.1), and may feature in other narratives. Perhaps the dam interferes with the migration of certain fish species; eels for example (Figure 7.3).

Narratives do not necessarily need to be linear, either. Repeated patterns make up a great deal of behaviour on all scales, and can also be modelled via narratives. The term "motif" in the repeating of story elements is already used in folk literature. It is also used in genetic studies for repeating patterns in DNA, and in music for repeating patterns of notes, as well as in art, where motifs are also repeated again and again. There are indeed guides for motifs. These repeating elements do not just occur in literature, art, music, and genetics, of course. Human behaviour also has repeating motifs, like getting up in the morning, going to work, coming home and sleeping , or with shops being open during a set period every day.

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. A "good" story or narrative should also have a beginning, a middle, and an end, or close a loop. A narrative should hang together in some way and cohere in some way (Van Noort 2016). To some extent, what makes for a good story is somewhat subjective. Some of the different kinds of motifs that help shape a narrative include inaugural motifs, terminating motifs and transitional motifs (White 1975). Inaugural motifs begin a process. Transitional motifs maintain the process. Terminating motifs are used to show the end of a process.

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. One can imagine beads on a string, nodes in a graph, or stars in a constellation. Motifs that are joined via a narrative tend to have things in common from connection to connection, or the narrative as a whole has some higher and simpler representation. One of the actors may remain the same, or the place may stay the same, or the process unfolding may fold back upon itself so as to repeat. Facets of the motifs involved in the narrative that remain constant can be extended in a linear depiction as a labelled line or bar. Transitions can be marked as a break in that bar. Narratives can also be unpacked and complexified.

7.3.3 Relationships among Motifs Utilised for Creating a Narrative

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, 1969) 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 2016):

Table 1
Semiotic relations.

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

Source: De Lima 2016

The PUC-Rio work revolved around folk tales, but much of the work on folk tales can be modified and adapted for other narrative forms. De Lima et al. (2015, 2016) utilise a framework revolving around the tale types and motifs put together by Aarne and Thompson (1961). However, because we are using motifs in a broader sense than how it is used in folktale classification, we will utilise motif for both of the concepts. In our model, events can be encapsulated by fairly simple motifs that are then combined.

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 do not just apply to fictional narratives, but can indeed be utilised for unpacking or understanding any narrative or narratisable set of interrelations.

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. Both Zarri (2010b) and SeCo (Kettula and Hyvönen 2012) also utilise hierarchies when discussing events and process chains. A single motif containing multiple motifs can be seen as a supermotif for those motifs, and likewise they in return are submotifs of that supermotif.

For examples to think with, we will start with the narrative “migration disrupted by a dam”. This can be expanded in a number of ways. For our example, we will discuss eels and their migration patterns, and how their behaviour patterns and the consequences of building a dam highlight the various patterns outlined above. Something like UML diagrams can be used to trace out a system or the various alternatives of a system.

We will move to a more specific case, first “eel migration disrupted by a dam”, and in order for the dam to disrupt anything, it would have to be built. “Building a dam” becomes a string of sub motifs. Here is one way of breaking down dam construction (Bhattaraiet al. 2016) (Figure 7.1):

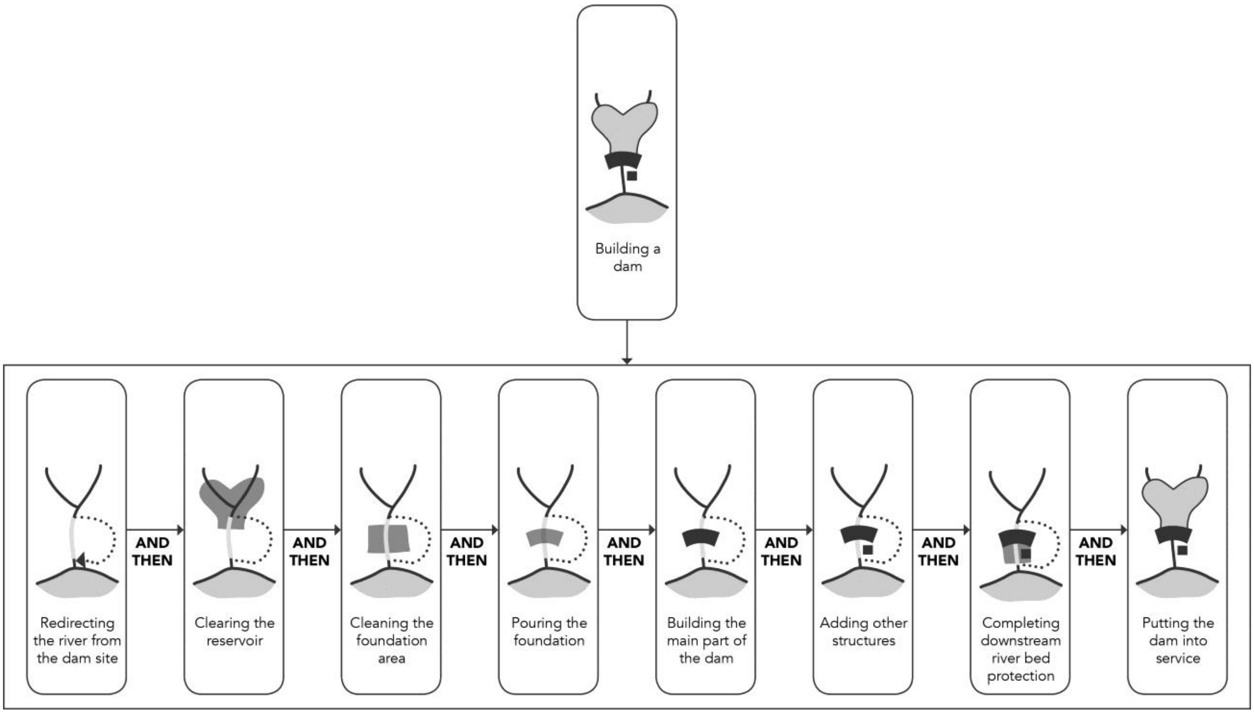

Figure 7.1: Submotifs of "Building a Dam". Illustrated by Katie Wilson

These become submotifs of the building a dam super motif. If they had used a different methodology or could use a different methodology, that chain would begin with a fork starting with an OR, as in "You could have tea OR you could have coffee." Not all dams may follow the same sequence, but many dams will, and it is possible to anchor this narrative to features in a traditional GIS utilising polygons and timestamps, or to other depictions of space and time like traditional calendrics and traditional spatial depictions. By anchoring the motif to locations and times where the motif or submotifs of building a dam apply, they are marked as of being of the same sort, or equivalent in a sense.

Meanwhile, before the dam was built, the eel cycle was the following, with some attrition along the way (Figure 7.2):

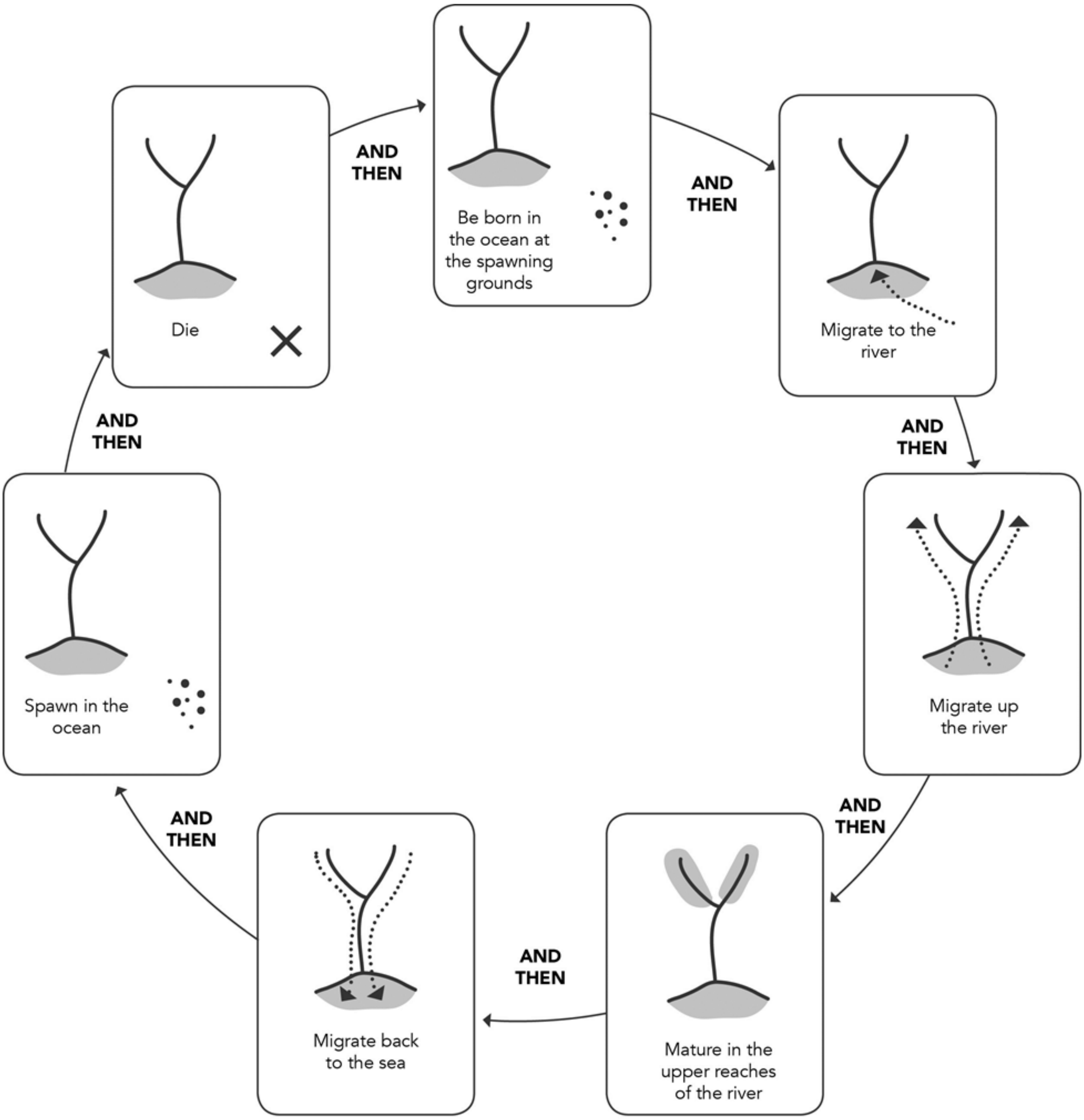

Figure 7.2: Eel Life Cycle. Illustrated by Katie Wilson

Again, the rivers in the motif and the migration routes may vary from eel to eel, but they are mappable in theory. For some aspects, like spawning location, the understanding of where eels go is still not well established, so fuzzy spatial depictions would work better than crisp depictions. Points, lines, polygons and raster depictions can be utilised together or separately for each stage of the lifecycle, and each of those instances could be linked to precise timestamps if known, or traditional or biological multi-cyclic timing utilising known zeitgebers or traditional timekeeping. Timing of events like migration may vary as well from year to year and so temporal depictions that speak in a more general sense, as opposed to depictions following a given individual, likewise need to include that ambiguity, ideally. We now imagine that some of these eels are now facing a disruption. A dam has been built, or will be built. What happens to the eels? Let us look at some new narratives that stem from the intersection of eels and dams (Figures 7.3a and 7.3b).

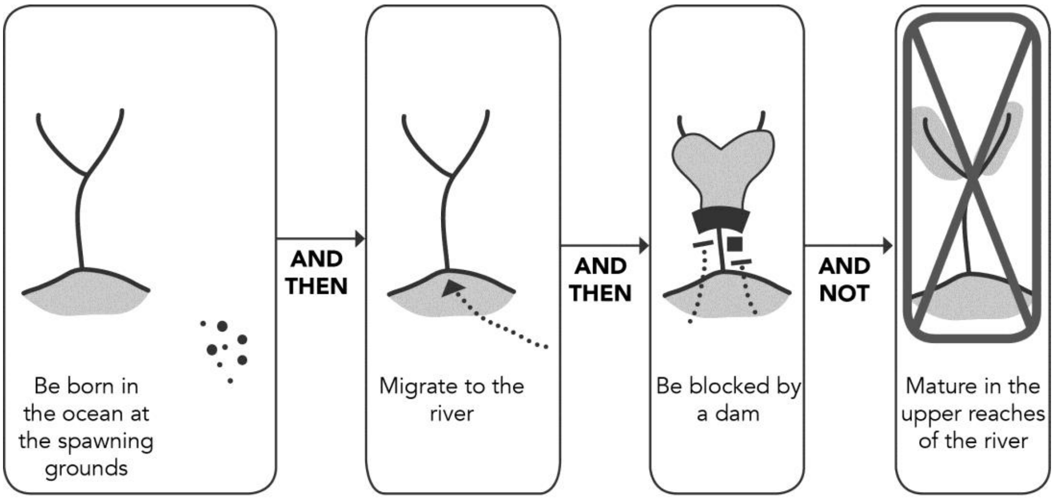

Figure 7.3a: Dam Impact on Upstream Migration of Elvers (Young Eels)

OR

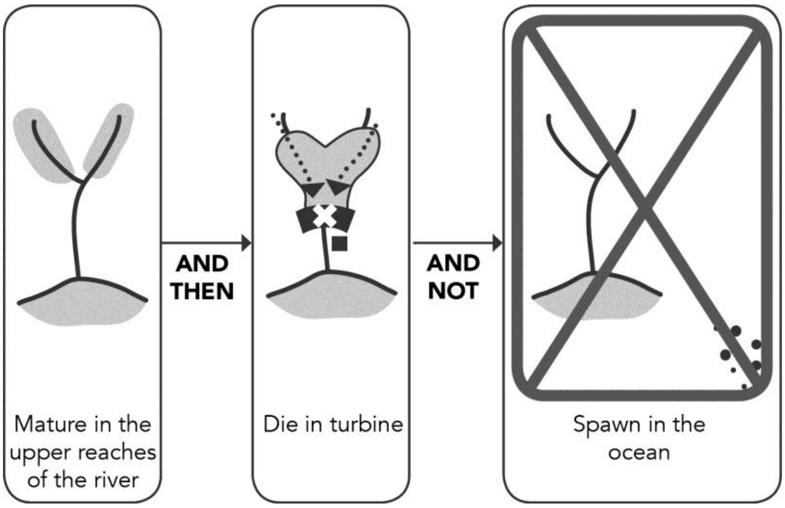

Figure 7.3b: Dam impact on downstream migration of mature eels

So we either posit, or have observed that eels have some difficulties migrating past dams, either as mature eels swimming back to spawn, or immature eels swimming upstream. These two can be combined into a more complex narrative representing the original motif, "eel migration disrupted by a dam", as follows (Figure 7.3c):

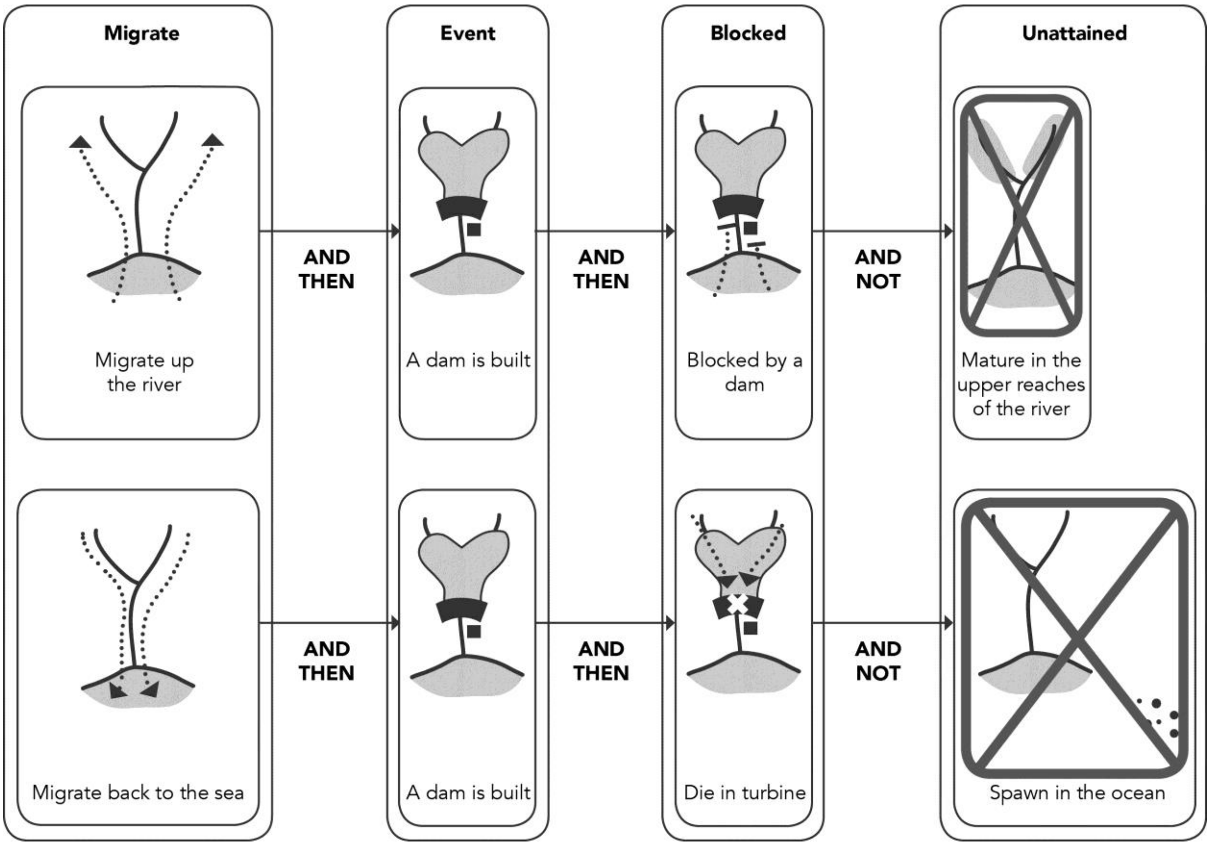

Figure 7.3c: A more complex motif diagram of the original narrative: "migration disrupted by a dam". Illustrated by Katie Wilson

These patterns will not apply to just one river, or just one dam, and each river with a population of eels that has the same issues can be linked to as an anchor to this narrative via the various motifs, and they could be linked via point, line, polygon, or raster image as in a traditional GIS, or to a gazetteer of names, or a drawn or painted map, or audio or video recordings pertinent to the motifs and the narrative. If a motif database is paired up with a RDBMS-based GIS, then features can be used for the individual dams and migrations that fit the narrative, and these features can be given things like timestamps. Ideally, however, the representational structure used to depict actions and events in the motif model also has the capacity to represent space and time in a fuzzy fashion.

Allowing for better top down modelling about generic cases rather than the bottom up, specifics first approach that is almost inherent with RDBMS databases is one advantage of the model. This also opens the way for analogical reasoning, as if two different projects share a similar narrative at some level of abstraction, there is a chance that they will share some of the same problems.

As an aside, although our narratives have all had sequence play a key role, 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.

7.4 Reasoning with Motifs and Narratives

Motif-based databases will have some advantages over purely RDBMS-based GIS. With standard RDBMS-GIS we can query where things are, and the spatial relationships among features. If we utilise timestamps, if there are a beginning and end date we can see if they were potentially in the same area at the same time. We can also build models based on joins and relations between various datasets, but they are rooted in how things intersect and overlap. This approach is powerful, and has in some ways remained essentially unchanged since the days of Tomlinson (1962, 1968) albeit facilitated by Codd's (1970, 1979) insights into database design. The key term is discrete. Each feature, joined together with its own tuple, is its own universe onto itself. It is the logic of objects, not of processes. Processes make things messy, and connect everything. For vector data, RDBMS systems work best with clear lines, clear memberships and with features that are cadastral-like in nature. Private land rights do not necessarily work well with the environmental logic underpinning traditional systems of tenure (Århem 2014). What may work with individual parcels might not work for a whole region once processes are taken into consideration (Scott 1998).

Current GIS techniques are excellent for a particular set of problems, but do not deal well with data that does not have solid representation from a geo-atom perspective, lacks support for semantic reasoning, and works from instances up to more generic situations, but not vice versa. With crisp data and linear time, it works exceedingly well. However, this is not always how data comes, nor is it always how a given group of people will record things. Modern GIS has made strides towards representing qualitative reasoning and working with ontologies, but some of the problems stem from the data model itself, including the need for good schema ahead of time, and the insistence of the model to separate feature classes from one another.

With motifs paired with narratives, we can construct data models that are more akin to human speech, and are by nature interconnected and interconnectable. This allows for modelling of systems and processes as narratives, and helps preserve the transparency of the model. The ability for the human eye to read a database is no small matter. We can talk about what might potentially result from something in the future based on previous sets of events in the past. We have better tools for analogical reasoning, and we are better equipped to think in terms of systems. Our blindspots become evident in the model itself as we build it. The models we built with a motif database should be able to reflect the mental models and cultural constructions of traditional expert knowledge, and should be able to provide a starting point at the very least for a range of other modelling techniques for complex systems that are already in use. We have described earlier how motifs themselves can be used to query a motif database (Mackenzie and Reitsma 2018), and we will continue to use Sowa's notation of boxes or square brackets [] for concepts and ovals or rounded parentheses () for conceptual relations.

A query like:

[[Dam]<-(Effector)<- [Alter]->(Patient)->[Species Lifecycle]]->(quality)->[Worsen]

This would translate as "show me all the dams that have altered species lifecycles for the worse", and would bring up species that lost habitat, species that were bulldozed, and species whose migratory patterns were altered. Migration patterns of eels are part of their lifecycle, and they would be disrupted. We may also find that there are dams that interfered with salmon migrations or with caribou migrations. We can still use other modifiers for spatial and temporal extents. We could also modify the query via spatial extent, searching for only those motifs that have instances in a given area, either by drawing a bounding box, or using a previously defined territorial extent, or semantic term for an area. Spatial instances of a motif could either be stored inside the motif database itself, or in an external conventional GIS database and connected to via some sort of bridging software or intermediate software like QGIS.

There are already a number of logics used in GIS. Boolean logic is the norm for most conventional GIS , as it is crisp and clear and does not allow for imprecision (Sui 1992). Membership of an element in a set is either zero or one. Fuzzy logic has grown in importance over time in areas like soil science, where boundaries are not clear (Puig2011), and fuzzy logic can allow for memberships of zero or one or all the points in between. However, fuzzy logics on their own lack contextualisation. Description Logics paired with Ontology Web Language (OWL) are important in GIS for work involving the semantic web and interoperability of multiple ontologies (Lutz 2005), but the ontologies cannot be updated on the fly, lack flexibility, and are tree-like rather than semi-lattice like constructions. This poses issues with our folk thesaurus model. Further, the description logics are less intuitive and language-like when compared to the multiple interrelated modal logics. However, the work done with OWL and description logics is closely related to what the authors hope to be able to do with a motif-based system.

Modal logics have been suggested before for spatio-temporal reasoning (Worboys 1991, Bennett and Cohn 2002). Modal logics are also capable of handling topological relations and spatial reasoning, like the various relationships between two areas laid out by RCC-8 (Renz 2002, Lutz and Wolter 2006, Ligozat 2012). We use modal logics because, unlike most other logics, a statement is not always true or false without knowing what the setting or context is, and truth values can vary from zero to one when using fuzzy modal logics. A dam that was constructed with eels in mind, not on the main stem of a watershed, and with mitigation components may not be BAD compared to a high dam on the main stream with no mitigation.

Fishing for eels in one area may be forbidden for one purpose, say for the commercial pet food trade, but allowed for another purpose, like subsistence. Some nights might be good for eel fishing and other nights bad for eel fishing. The dam itself may be bad for eels, but good for introduced species.

7.4.1 Plot Classification Based on Shapes and Contours of Narratives

Plots and stories can have basic shapes that allow us to classify them together. There are a number of ways of doing so. Vonnegut (2005, 2009) marked out stories as if they were on a two axis plot, one signifying good fortune and ill fortune, and one signifying the beginning and the end. With this schema he marked out some basic shapes that stories can take. Karlsson and Furtado (2014) propose plot libraries for similar narratives based on the PUC-Rio work.

Recently a paper (Reagan et al. 2016) followed on Vonnegut's work, and after inspecting a large corpus of literary pieces they came to find that six major story types represented most stories. In their methodology, certain words were marked as positive or negative, thereby tying them to the good fortune/ill fortune axis of Vonnegut's model. These plots graphed out as:

> Good to Bad and its reciprocal Bad to Good
>
> Good to Bad to Good and its reciprocal Bad to Good to Bad
>
> Good to Bad to Good to Bad and its reciprocal, Bad to Good to Bad to Good.

Vonnegut (2005) used more than two values, including a neutral value, and gradations of negative value. One of the stories that may interest us is Hamlet, which starts and ends in ambiguity. As far as our dam example goes:

Eels used to migrate unimpeded (and that was good)

AND

Now they are impeded by a dam (and that is bad)

So we now have a good to bad plot. In law, there is often a right for redress or mitigation, and there can be other mitigation practices. Perhaps eels are now moved around the dam.

AND

now some of the eels are moved around the dam (and that is good)

but NOT as good as unimpeded migration.

We can compare with other dams too, and other species

Salmon used to migrate unimpeded (and that was good)

AND now they are impeded by a dam (and that is bad)

AND their numbers are declining (and that is bad)

Here we have two bads in a row, so we can just count it all as part of the same dip.

There can be multiple indices working via the same incident, however. The Mauri Model (Morgan 2006), for example, which also provides a modal assessment of events works on several different sets of indicators to make sense of whether an event is increasing Mauri, or life force, or decreasing mauri, or life-force. Things can be better or worse, or signify a return or a diminishment of *mauri*, or binding force (Morgan 2006), or otherwise provide the contours of a plot. There are a number of indicators that have been developed over the years for representing health and well-being for social-ecological systems that would work in this capacity, from the Mauri Model laid out by Morgan (2006) and underpinned by Māori values to indicator sets developed in Hawai'i, Peru, and Melanesia (Sterling et al. 2017). These systems are usually multi-factored.

Using modal statements that point generally in a better or worse direction, like good, bad, or healthy, unhealthy allow us to have a deeper structure to compare narratives with in a way that would be impossible normally with a database that only keeps track of locations of objects in space and time as RDBMS-GIS databases typically do. There are a number of basic plots, and a common one facing Indigenous peoples is the one where things were going OK, a disruption came, and now things are worse. This is a common one in court systems as well.

If we take that basic plot, in our example above we have an eel population that is important for food. The dam is built, and this disrupts the eel population. Now the eels are not doing as well and the ability for that population to serve as a food source is compromised. We can imagine another species elsewhere, perhaps caribou. A dam is built and now they cannot migrate along its old pathways. Their numbers decline, and now the ability for that population to serve as food is compromised. A combination of the contours and some of the actors involved allows us to query across a whole range of different scenarios, past and future.

7.4.2 Modal Logic

Motifs, like other narratives can require modifiers. Modal logic provides ample room for traditional modifiers. Graesser et al. (1996:178) provide an excellent overview of the various kinds of modal logic:

> alethic logic (involving necessity, possibility, and impossibility),
>
> deontic logic (permission, prohibition, obligation),
>
> axiological logic (goodness, badness, indifference),
>
> epistemic logic (knowledge, belief, ignorance),
>
> and the logic underlying goal- oriented planning strategies.

All of them can serve roles when making sense of narratives, and culturally specific modalities, like the related concepts of *tapu* and *noa* for Māori (Barlow 1991), may be different enough from the systems mentioned to warrant their own axis for cataloguing certain kinds of narratives.

This flexibility for reasoning is desired. Different modal logics can interfere and interact with one another. It might be permissible to catch eels (deontic logic), but impossible to do (alethic) as there are not any to catch, for example. It might also be permissible to catch eels (deontic logic), possible to do (alethic), but the eels are believed to be contaminated (epistemic), so the place becomes a bad place (axiologic) for catching eels.

Modal logic is a key component of any traditional land use system. What may be forbidden or impossible at one point of the year is of the utmost necessity at another point of the year, and areas that are usually open for fishing may be closed for conservation or ritual purposes. Modal logic is undersupported in current data models. Sowa's approach stems from earlier work by Peirce (Sowa 1997), and Peirce (1906) was used to working in a tradition where things were either true or false, but realized the importance of modality. What may be true in one situation may be false in another. According to Sowa (2000), Peirce suggested reflecting modality with a pad of paper, inscribing sheets with what may be true in some state of affairs on some sheets, and things that are necessarily true on all sheets. This is not sufficient for our purposes, but does help indicate how a given data model might work. The spatio-temporal motif consists of a verb-centric statement, a truth value (true, false, sometimes, usually) and a context (location on a map, kind of weather, kind of time etc. The statement "I go fishing" is true, but not under all contexts. Not all motifs will be this complex. A place exists or an actor exists without additional context is still a motif.

Modal logic would be a great aid to constructing narratives. Deontic logic, concerned with obligations, permitted activities, and forbidden activities can be used for keeping track of traditional stories and harvesting rules, for example. Things are not always true, but are true in certain contexts and false in other contexts. Motifs involve a statement, and the context in which what is stated in the statement is true or false or somewhere in between. With modal logic, it is possible to discuss how a given situation is worse or better than before, or more or less productive, and can discuss how confident you are in that assessment. Modal statements can also be used to discuss traditional management options like the closure of an area, and who is permitted to fish in a given location or not. Certain kinds of modal statements, particularly those of improvement and decline, or good and ill fortune allow us to create shapes of narratives, thereby allowing for better comparison between narratives and facilitating analogical reasoning.

For narratives that incorporate a branching structure, modal logic can be used to compare and contrast different outcomes under different scenarios. The fate of eels going downstream, used in previous examples, is not cut and dried and there are a number of outcomes mature eels can face, from being caught for food to dying in a turbine, to making it home to the spawning beds (Figure 7.4). Such a diagram can then be used for generating weighted models for reasoning, like those used for Bayesian Belief Networks (Marcot et al. 2006, McCann et al. 2006, Nyberg et al. 2006).

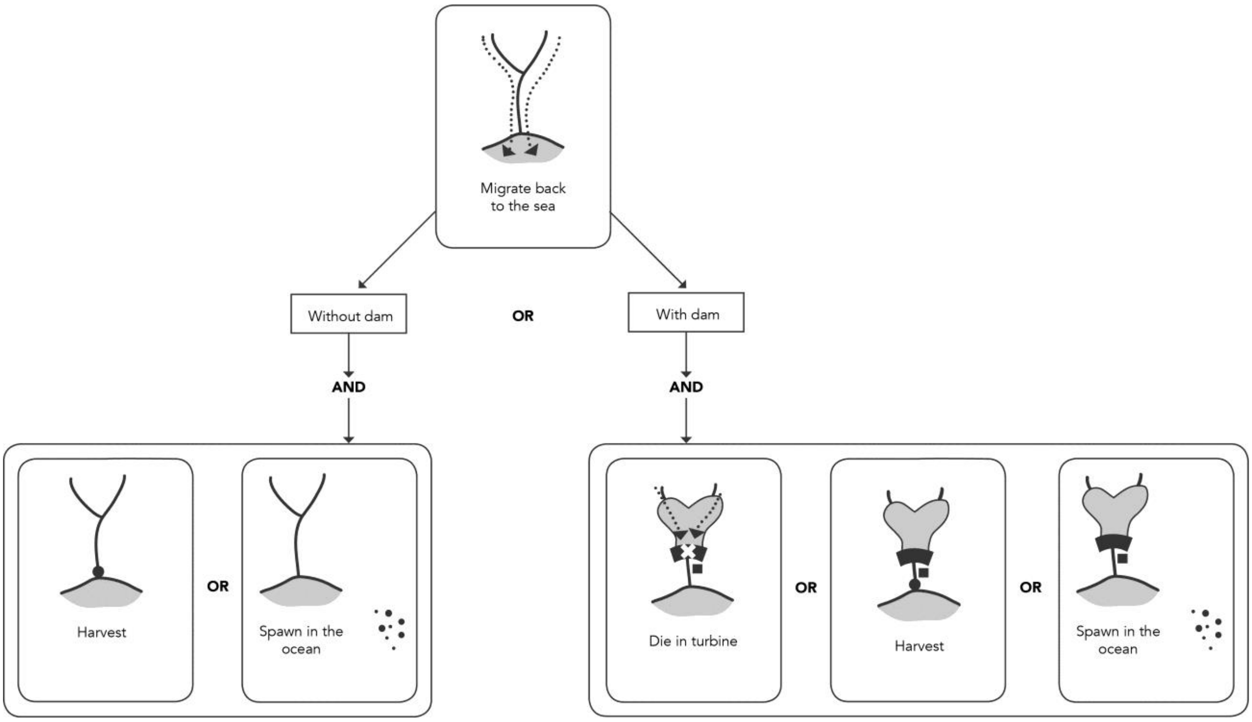

Figure 7.4: Different fates of different eels depending on whether a dam is built or not. Illustrated by Katie Wilson

Modal logic allows for fuzziness in the semantic realm to exist, and this pairs well with fuzzier depictions of space and time that we can also utilise with our model. It also allows for more expressive understandings of contexts and statements, and can provide the first run for putting together systems models. X usually happens, Y rarely does.

For our dam example, maybe we have the two outcomes without a dam and the three with a dam, and we can say that more spawn in the ocean without the dam than spawn in the ocean with the dam, and that harvests are bigger without the dam than with the dam over time. Or if the comparison is pre and post dam, we can say that harvests were big and now they are small. Maybe fishing will be forbidden till numbers improve. We can also compare dams, so one with mitigation has fewer die than one without. We can also use indices to generate modal statements about a given process or state.

Modal logics provide some of the underpinning for semantic reasoning in our model, along with the explicit relations given and formed with the folk thesaurus and narratives themselves. Modal statements allow us to compare different narratives to one another, and reason whether an area or time is good for an activity or not. In the motif model, objects and processes exist together for contextualisation, and modal and qualitative statements allow for knowledge-holders to talk about how different motifs compare to other motifs for a given action.

7.5 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.

For our dam example, it may prove pertinent for other species that are also impeded by dam construction, either sharing the same habitat as the eels, or abroad, where other dams also affect fish migration. Dams play other roles, and narratives about the power generated, who it serves and who profits may also be of interest, for example. We can compare via shared places, times, actors, and actions as well as via similarities. We end up with a narrated and narratable world as far as a GIS goes in ways that may not be so straightforward with the current RDBMS based data models that make up most of GIS today.

The authors have not realised the model in a working database at this point. So far, the motif model is a theoretical construct only, but many of the pieces required already exist, as do the theoretical underpinnings in other fields, from hypernodes and nested graph models to plot algebra and motif manipulation, as well as process models and semantic relations. The next steps would be stitching all of these into a working model, and then testing localised models in a number of contexts.

To build a motif database, first we need basic support for the motif itself. A motif needs to be anchorable to a number of things, but for our interests it must be able to be anchored to spatial and temporal depictions, whether those be choros or topos depictions of space or chronos and kairos depictions of time. We need support for nested graphs, to allow for nested relations. We need support for syntagmatic, paradigmatic, antithetic and part-whole relationships. We need to be able to support various modal logics like alethic, deontic, axiological and epistemic logics. We need to be able to support the basic relationships used by conceptual graphs. We need to be able to support a folk thesaurus as it provides an alternative to more rigid ontologies or overly flexible folk taxonomies, and that allow for classification of simple motifs. We need to be able to construct a library of similar narratives to facilitate comparison between narratives, allowing for classification of more complex motifs. Lastly, we need querying software that allows us to leverage the strengths of the motif model in ways that RDBMS-GIS models have difficulties with. A motif graph database could clip on top of existing GIS software, as has already been demonstrated with the spatially enabled NoSQL database software MongoDB paired with QGIS (Kalogirou and Boehm 2017). This is the basic toolkit.

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8 Conclusion

8.1 Summary of Research

We begin by discussing how timing works for other species, and how the systems we model are interconnected. Traditional livelihoods revolve around other species, and for successful harvesting and management, there is a need to pay keen attention to the rhythms those species follow. Salience for what signals are important and the level of detail required to understand those signals varies from species to species, as well as on the experience and knowledge of the perceiver. There are problems with uniform depictions, and there needs to be more diversity in representation.

Any system working with traditional spatio-temporal knowledge and practices needs to be able to deal with traditional timing methods and time markers. This requires being underpinned by some sort of adaptable and fuzzy logic. Customisable representations and time keeping that step away from universalised and ubiquitous western timing need to be able to be supported. Some of the techniques that will help with representing traditional knowledge systems may be applicable in other settings as well.

Many of the requirements needed are not well suited to the current data models used for GIS, and other models are possible. Problems with time other than linear uniform time are especially obvious. A new data model, based on motifs can help with some of these problems. These allow for discussions of the rightness or wrongness of a given activity in a given area at a given time by a given actor. They can be linked together in narratives, and can be utilised for both qualitative and quantitative data. Motifs are anchored via instances of their more generalised pattern.

Motifs are also connected via folk thesauri, which keep track of equivalence, hierarchical and associative relationships between terms utilised to construct a motif. Kinds of actors, times, places, and actions all relate in a web of meaning via those three basic relationships, and by keeping track of these relationships we can see which motifs are submotifs or supermotifs of other motifs. Motifs act in a faceted manner, and do not need to form tree-like structures alone. It is possible for aspects of a motif to fit under more than one overarching concept.

Interface design is required for full expression of folk thesauri. Time is one area that has been neglected. Because of the importance of multi-cyclical time sense for a range of species, and cultures relying on those species, our graphical user interface and query tool centred on how multi-cyclical data might work in a geospatial context. Although we concentrated on a querying tool, an adaptation of the same tool could be used for documenting traditional knowledge and practices as well.

Finally, motifs can be connected into narratives to tell more complicated stories and to map processes. Narratives can be compared and contrasted and can be used for underpinning various forms of reasoning, particularly analogical reasoning. In order for narratives to work, they require logical support and modal logics appear to have the right level of overlap with regular semantic patterns as well as reasoning power.

8.2 Current Limitations and Further Work

There are a few loose ends that still require pursuing in order to make for a more usable toolkit. Privacy concerns and how privacy might work in a motif database requires further work. It is a key priority for many Indigenous peoples and needs to be worked into any model at a base level. This allows for sensitive information to be kept to those who need to know only, and to obscure or hide data otherwise if that is the most suitable course of action.

Temporal interfaces need to be able to be customisable by different groups, and cycles need to be able to be subdivided as is appropriate for different cultures. Boundaries between cycles may need to have gradations in meaning, and a range of times may be needed to define a motif. A fuller interface would support other non-cyclical time components like weather patterns or social patterns that influence when the right time for an activity or set of activities might be. The ability to animate processes would be another key component of a more in depth visualisation and querying tool. A corresponding interface for place classifications for data entry and querying would also be of value. This would take into account ethnophysiographic understandings of landscape, and would be modifiable and able to evolve.

The requirements for a motif database include being able to be anchored to spatial and temporal features, be stored in a nested graph database, have support for a range of relationships utilised for narratives elsewhere, and have support for modal logics. The model also requires the ability to utilise folk thesauri, compare narratives, and have querying and data capture tools. Bridging software that allows for a motif database to interact with GIS software like QGIS is also required.

There are a few places where the research can go from this point. A working model of a motif database is required in order to test many of these ideas and to see what else might be missing. Likewise, a toolkit for putting together folk thesauri and tying them to customised interfaces for data capture and querying is a logical next step. Software that pulls motifs from extant literature and oral records would also aid in the overall project. Reasoning support and work on analogical reasoning would also help utilise the strengths of the motif model in ways that could be helpful. The idea behind the work was to make a data model for spatio-temporal data that is more like the spoken word and like oral and practical transmission, and less like an accountant's log, so as to facilitate things like co-management. There is a long way to go.