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'Knowledge making': issues in modelling local and indigenous ecological knowledges

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Abstract

Modelling, particularly computer-based modelling is increasingly used in political, managerial, and scientific contexts to enable and justify decisions. Technocratic decision makers also aspire to understand and incorporate local knowledge, albeit at times only superficially. We analyse one consequence of this situation – ongoing attempts to formalise, synthesize and integrate local and/or indigenous knowledge in to models. Field experience of knowledge projects with indigenous Australians underpins our analysis, but we primarily discuss *a priori* and general issues: the political and ethical context of such projects; knowledge making as terminology; key characteristics of (scientific) models; local capacity, participation, and representation; and examples of computer-based tools for knowledge representation. Such formal abstractions will always be controversial, but demand for them seems likely to continue. To improve interdisciplinary understanding of what might be entailed by genuine attempts to meet that demand; our paper provides signposts to and analysis of important features of local ecological knowledge modelling.

Keywords: local knowledge; modelling; visualisation; Indigenous Ecological Knowledge; causality

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Introduction

Work on local and indigenous knowledge has been an aspect of ethnographic investigations since the early days of anthropology, although describing it in such terms is a more recent phenomenon. Some work, such as taxonomic classification, has been at the heart of the anthropological project of interrogating human cognition, similarity and difference (Levi-Strauss 1966, Ellen and Reason 1979, Berlin 1992, Ellen 1993). More recently, this academic research interest has been bolstered by political considerations, bureaucratic requirements and genuine ethical and sentimental motivations to generate an ongoing level of demand for local knowledge and for the time, effort, intellect and generosity of the people who hold it.

Such local knowledge (particularly in its 'indigenous' form) has also been an increasingly important tool for politically marginalised peoples in their attempts to gain credibility, attention, and political leverage in wider forums and policy debates. Yet the various categorisations (Local Knowledge, Indigenous Knowledge, Traditional Ecological Knowledge, etc.) are frequently critiqued in the research literature of the humanities and social sciences (Berkes et al. 2000, Agrawal 2002, Robbins 2003, Ellen 2004, Palmer and Wadley 2007, Agrawal 2009, Lepofsky 2009, Sillitoe and Marzano 2009, Brosius and Hitchner 2010, Davis and Ruddle 2010). Within narratives of development, local knowledge has been depicted variously as a barrier, as a crucial inclusion for success, and as an inherently problematic categorisation likely to lead to significant error (Sillitoe et al. 2005).

The result is a degree of disconnect, where such knowledge is considered from stances ranging from scepticism to enthusiasm by those in the research community

(Stephenson and Moller 2009, Wohling 2009), strongly advocated for by its supporters in the political domain, and deployed somewhat uneasily by many who are aware of these competing discourses but nevertheless find the term(s) useful. At its most positive, the recent period can perhaps be viewed as one of self-aware and strategic usage of the terminology and of investigation of the content of local and indigenous knowledges, set against a backdrop of cautionary critique of the categorisations (Agrawal 1995, Sillitoe et al. 2005, Sillitoe and Marzano 2009). This paper is directed to a range of readers: anthropologists and other researchers aware of such debates and engaged in issues of knowledge systematisation; scientific modelling practitioners interested in local knowledge; and informed local or Indigenous knowledge practitioners thinking through the implications of new forms of systematisation and application. Depending on the reader, certain aspects of what follows may be familiar, even self-evident, while other aspects may be unusual or novel. We primarily focus on modelling ‘with’ local and indigenous knowledge holders – the representation of worldviews and perspectives- rather than on the (often researcher-generated) modelling ‘of’ such peoples as a functional part of wider socio-ecological and economic systems (for example as ‘resource users’). However this distinction is not clear cut, as much local knowledge explicitly deals with the place of human beings in a wider world.

Local participation in knowledge modelling and representation projects can take various forms and is crucial to the accuracy and credibility of the results of such processes. In effect, modelling can be seen as a subset of wider processes of ‘integration’ (Bohensky and Maru 2011), and co-option (and in the worst cases, coercion) remain significant risks in processes where real power imbalances exist between local research participants and non-local academic and development researchers (Ross and Pickering 2002, Nadasdy 2005). Yet local participants can also make self-aware and strategic calculations about their involvement in a similar manner to non-local workers, albeit often emphasising different criteria (Sillitoe et al. 2005). Local motivations can include concerns with knowledge loss and appropriate documentation, but also the desire to gain credibility in political forums and influence sovereign claims for territory and control of management decisions about key places and resources (Hill et al. 2012).

Nonetheless, alongside that political credibility, ongoing marginalisation exists, particularly with respect to scientific and technical knowledges and the discourses they legitimate. The strategic deployment of local knowledge is not always politically influential, even when its utility for local practitioners is clearly evident. The scale, scope, and transformative capacity of wider technoscientific knowledge regimes can overwhelm tacit and/or locally specific knowledges, enabling domination. Well-intended aspirations to incorporate or integrate local knowledge (Bohensky and Maru 2011) into wider technocratic knowledge regimes raise issues of intellectual property rights, co-option and capture (Nadasdy 2003) in addition to the more commonly asked 'how' questions of knowledge modelling, compatibility and alignment (Jones et al. 2011).

Even when integration is not the stated goal, the documentation, synthesis and representation of such knowledge raises similar issues, particularly when that re-representation emphasises contemporary technocratic and academic research categories, conventions, processes and potential audiences (Crane 2010, Jones et al. 2011, Hill et al. 2012). Taking the argument one step further, such projects can be problematic not only in the sense that they obscure or misrepresent local knowledges and local peoples or that they fail to afford greater local influence over decisions. They can also obscure or elide their own role in extending technocratic and bureaucratic reach further into local peoples' lives and communities (Nadasdy 2005). Most knowledge projects only consider power relations and ethics in terms of content and intellectual property, rather than their wider role in facilitating an ongoing process of governmentality (Nadasdy 2003, Brosius and Hitchner 2010) and the creation of particular kinds of environmental subjects (Agrawal 2005).

There are real and ongoing issues in such work regarding the presumptions of scientific instrumentalism and technocratic intervention, local representation and power imbalances, and the accuracy (and even the morality) of conceptualising abstract 'systems' as a basis for understanding human life. However local knowledge, both as categorisation and content, remains valuable currency and those who hold and use it continue to champion its integrity and ongoing relevance. The ongoing process of making knowledge (Marchand 2010a) about the world also takes many forms - collaboration and hybridity on the one hand, and precision and discipline on the other, can be crucial elements of innovation and creativity of all kinds. The critical question for local knowledge research projects is whether the appropriate balance of these conditions can be established and maintained amongst scientific and local co-researchers in ways that neither try to deny, nor completely founder on, the political and ethical context described above.

Such conditions may be rare, even rarer when the ambition is 'to model' rather than 'to document' such knowledge, where model is understood as the production of a standardised, integrative and systemic account, potentially with iterative, causal, and/or predictive aspects. But although rare, such conditions are not implausible, and as noted at the outset, the demand for what might emerge from establishing those conditions and revealing human understandings of such matters as cause and effect relationships remains strong (Jones et al. 2011). In what follows, we consider some implications and consequences of taking this ambition seriously in processes which may be both valuable and problematic, which may aid understanding, respect for local authority, and informed decision making, but at some risk of immediate reification and subsequent de-authorisation and domination (Nadasdy 2005, Ellen 2006, Haynes 2010). However before turning to the issue of 'knowledge models', we will consider some general features of each of these terms in turn.

Knowledge

A deep philosophical interrogation of what it means for human beings to 'know' is well beyond the objectives of this paper, and more detailed anthropological discussions of knowledge exist elsewhere (Crick 1982, Cohen 2010). However it is important to note some key elements of knowledge and knowledge making as they pertain to this analysis, and the points below act as signposts of the broader context to the more detailed discussion of knowledge making and modelling which follows.

Knowledge can have a range of definitions, but it is understood here as principles and truths acquired from other sources (people, written records, music, etc.) and/or generated from analysis and reflection, but which also incorporates physical skills acquired through experience and practice – knowledge does not lie on one side of a distinction between mind and body, or between an individual and a collective. This aspect of a definition of knowledge is particularly important in considerations of local and indigenous knowledges, where such dualisms are rarely operative. Definitions may have other, more contextually-specific features; terms such as 'fact' and 'theory', as well as the relationship between them, may be particularly prominent in definitions of scientific knowledge. However as a minimum, a more generally applicable definition of knowledge in this context needs to encompass formal principles and truths, tacit understanding, physical skills and experiences, and individual and collective generative processes.

Also implicit in any discussion of knowledge are issues of scale, specificity, and purpose, and an appropriate understanding of these are crucial to any further progress. Sensitivity to purpose - why particular truths, principles and practices have been generated and/or retained in a particular cultural context – is a question with an extended anthropological history dating back to early anthropological debates about functionalism, and it can be construed from both the perspective of an external social analyst and/or the local knowledge holder. Purpose is relevant to mention here partly to ensure that unreasonable expectations are not placed on local knowledges and their practitioners, but also to ensure that the objectives of any intended work are clear – what are the goals and purposes of the knowledge which is to be made through any new process, how have they been established, and by whom (Crane 2010)? Also relevant, but not considered here in great detail, are questions of how knowledge is passed on – of acquisition, transmission, distribution, erosion and regeneration.

Finally, (and crucially for many Indigenous and local communities), there are issues of intellectual property and control over documentation and distribution. Despite the reservations about power and potential co-option noted in the introduction, much guidance now exists regarding such protocols, and this area is handled far better and more extensively than it previously has been, particularly in Fourth World contexts such as Aboriginal Australia (Holcombe and Gould 2010) and Canada (Casteldon et al. 2012) where, since the 1980s, indigenous organisations and funding agencies have produced ethics statements, guidelines, and policies.

Knowledge making

As the title suggests, knowledge documentation and re-representation of the kind emphasised here has constructive and creative aspects – it is knowledge being made rather than just passively recorded (Marchand 2010b). Adding the verb also emphasises particular characteristics of knowledge itself - it is used here to emphasise collaborative, dynamic and processual aspects of knowledge – its situated co-production, sharing, communication and variability.

An additional reason for emphasising making is that, in terms of knowledge modelling, it avoids the assumption that the goal is to formalise and represent what is already known, rather than modelling being a process of making new knowledge – of learning new things, better understanding and specifying relationships, of identifying emergent properties, etc. The most valuable scientific models are usually dynamic and iterative, tools for investigation and (re)processing rather than static, one-off representations. However making a static representation can nevertheless be a process that yields new insights. Understanding the modelling of local knowledge as one of knowledge making or construction alters the emphasis provided by knowledge documentation and (re)presentation (or indeed by discovery and revelation). The recording of existing data (or the uncovering of a pre-existing but heretofore unrecognised fact or truth) may be highly significant events in a knowledge making process, but the current analysis emphasises the collaborative production of a novel human construct – modelling as one process of knowledge making. That the construct is in some senses reified is a given of such processes. Yet this fact does not of itself invalidate the worth of either the process or the heuristic 'boundary object' that may result from it (Crane 2010).

(Scientific) models and modelling

Models assume that a system exists, that it can be comprehended, and that this comprehension can be both generated and demonstrated through the means of another (constructed) system. What is meant by the term in political, managerial and scientific contexts is usually computer-generated modelling, often with a predictive, simulative, or scenario-based component – elements and relationships are described in order to establish the potential consequences of a particular occurrence or action. Our focus here on scientific and computer-driven knowledge representations reflects the research and organisational context in which we work, the growing rhetorical and practical power of computer techniques in NRM and wider political and bureaucratic domains, and the desire to generate representations that can be rapidly altered based on new information.

However even leaving aside issues of co-option and reification, the decision to adopt a computer-based approach has some significant consequences. Depending on the context of their use, computers can be a significant barrier to participation rather than being an enabling device. It is a step from the recording and understanding of knowledge to the 'modelling of knowledge', and a further step from there to the 'computer modelling of knowledge'. The introduction of such mediating technology can shape the interactions between those involved in unpredictable ways, limit the nature of the conversation, shift the balance of attention from the content to the mode of representation, potentially enable undesired levels of dissemination, and generally affect the outcomes of any attempt to the point where what might otherwise have been a success turns into failure.

The decision to focus on this kind of modelling is therefore a consequential one. However in adopting this focus, we do not discount the wide array of constructive approaches to knowledge recording and representation that rely on far simpler technology, or on alternative approaches - in our own field context, others are also searching for the wider enabling effects of computer technologies for Indigenous Australians outside of formal modelling (Christie 2005, Verran et al. 2007, Wyeld et al. 2008, Wyeld et al. 2009, Hart 2010, Bradley et al. 2011). Our approach emphasises causes rather than the cartographic approach more common in studies of local knowledge systems. We simply wish to consider what possibilities are created and what implications are generated by the growing suite of scientific and computer based approaches to the qualitative representation of knowledge. Before considering such approaches directly, it is perhaps useful to a generalist reader to note some key features of models and modelling which are relevant when knowledge modelling is being attempted.

Key features of models

Scientific and/or knowledge modelling is a complex process involving classification, simplification, generalisation, standardisation, ordering and abstraction. Based on materialist foundations, correlative and/or causal links and chains are determined, and depending on the context, a process of aggregation (combining and collapsing phenomena into broader categories) or disaggregation (in which the constituent elements of a complex phenomena are individually specified and linked) occurs. A model constructed on such foundations may be static or dynamic and iterative, and may place greater emphasis on description or prediction respectively. In terms of prediction, models may be atemporal (predicting what but not when) or highly temporalised in their description and their consequences. In describing a system, they may highlight the existence of one or a series of more probable states and they may also demonstrate emergence, in which the assembled sum of linked parts reveal patterns and properties that are not evident from the individual components.

The relationship between precision and accuracy is also important, as models may contain precisely described elements and relationships and produce consistent results, yet those results are not accurate in terms of the system the model purports to describe. Similarly, a model may contain imprecision in its structure yet still accurately describe wider systemic relations and/or likely outcomes. Models contain a range of uncertainties – there may be structural uncertainty associated with specifying the existence of particular nodes and links at all, or a more focused uncertainty in specifying the exact nature of the node or link. Such uncertainties become greater with models requiring greater specification. Sensitivity is an additional issue, as models may be sensitive to changes in elements and links within them, or highly robust to both internal and external changes. Models may be verified based on the observed reality they originally described, and/or validated against circumstances elsewhere to see how robust or general they are – depending on the circumstances, either synchrony or diachrony or both may both be important.

In terms of representation, a model need not be visual, either in its workings or its output, and in many circumstances any visual representation generated may be a superficial addition rather than a structural necessity. However in local knowledge modelling, representation and visualisation may be paramount issues and objectives. Even the most dynamic and effective models are ultimately reifications or solidifications of complex reality and in local knowledge contexts this again raises issues of scientism, co-option and capture. However such reified generality can, in certain contexts, actually avoid some of the intellectual property issues associated with knowledge attached to specific localities or people - the process of abstraction can carry both risks and advantages.

The capacity to predict is an attractive one and has long been a basis for exerting power in human affairs (Evans-Pritchard 1937, Parsons 1942). Contemporary models and their predictions are part of a wider suite of tools which enable and justify technocratic managerialism and technoscientific interventions. They can generate the presumption of understanding, underpin the legitimacy to intervene, and create confidence in the ability to have an (intended) effect. In terms of models of humans, the focus on systems rather than individuals, and the assumptions required to do so, can affect the accuracy (and even the morality) of the results (Sen 1977). In terms of models about human behaviour (such as knowledge models), confidence in their robustness can lead to the danger of assuming that complex and historically contingent identities are fixed, that consulting the model rather than the person/population whose views it purports to represent is sufficient, or that people can be assessed based on their knowledge of and adherence to the model (Haynes 2010).

As model sophistication increases, so does the risk of the tool or model becoming an end in itself, a demonstration of the capacities of the modelling and research team rather than the utility or wisdom of the output and the action it enables (Lynam et al. 2007). Increasing sophistication also increases the demand for resources (Lynam and Brown 2012), and in local contexts where model generation is an imposition rather than a profession, time and energy may be particularly precious and closely guarded. The need for accessible processes is matched by the need for accessible outcomes - complex, disembodied abstract diagrams can alienate rather than inform those not directly involved in their construction, and as described above, can only represent a small fraction of what is consciously and formally known, let alone what is tacit and embodied knowledge (Ellen 2006).

Capacity and participation

Moving from a general discussion of models to local knowledge co-generation raises issues of capacity and participation. In discussing participatory modelling, we are assuming that the desire and the capacity for abstraction, reflection, constructive simplification and visualisation are not specific to particular places and times, but are in some sense inherent capacities within human populations. The word *within* is also significant here, as it is important not to assume that all individuals within a particular human population or society share an equivalent interest in, or need to, reflect on their everyday lives and generate formal abstractions or descriptions from it. Yet we do assume that all populations contain people who do, and that on this basis the understanding and comparison of existing abstractions, and the participatory generation of new ones from those immersed in the system being represented, can be a useful task (Crane 2010). Nevertheless, in making this assumption, we equally acknowledge the wide geographical and historical variations in the form, purposes, detail, etc. of abstractions generated by humans, which in turn demonstrate that the specific focus on system, material cause, and prediction characteristic of contemporary scientific modelling is historically and culturally unusual (Ellen 2004).

Human potential is crucial, but abstract thinking is not just a consequence of individual capability - it is refined through education, through the development of conceptual, visual, numerical and/or textual literacy. Generating the confidence and the credibility to become involved in creating formal abstractions requires a combination of education, appropriate experience, and knowledge of the specific local content involved. These are both sweeping generalisations and relatively mundane propositions- those who are older, have a higher intelligence level, and are better educated, are more equipped to think in abstract terms, and they require time and space to do so. The terms may not always be appropriate but philosophers, scholars, researchers and creative thinkers emerge from all human populations.

Yet those with such capacities are not common, and the capacities themselves need to be developed through structured education. These underlying capabilities combined with a history of education in abstract thinking then interact with other more local and immediate factors – available time and energy, project resources, project priority relative to other obligations, and so on. It is this combined set of conditions that governs overall capacity to participate.

Participation levels in modelling processes depend on these questions of capacity, available resources, and chosen methodology. Creating formal abstractions is an unusual activity, often relegated to specialists in larger scale societies and whilst broad participation may be desirable, it does not necessarily follow that fewer participants results in an empirically deficient representation, even if it may lead to a socio-politically less authoritative one (Lynam et al. 2007, Stone-Jovicich et al. 2011). In addition, the question of local authority is rarely simply a question of the number of participants (Davis and Wagner 2003). Knowledge, and the authority to impart it, frequently resides in key individuals with widely recognised seniority or specialist knowledge rather than being evenly distributed across a broad population (Sillitoe et al. 2005). The credibility of any representation generated derives as much from the involvement of such key individuals as it does from the overall size of a broader group of participants.

Yet the focus on generating a representation does slant projects in particular ways – rather than attempting to assess the breadth of distribution of the knowledge depicted by the representation within a given population, such projects focus on generating the most adequate representation. There may be a range of people willing to endorse the final representation that would not themselves have been capable of independently generating it. In the language of systems, they have the understanding to live and act within the system, without having previously conceptualised that system.

Related to questions of knowledge distribution and authority is the matter of consensus (Ellen 2006). Even without the imposition of unfamiliar perspectives and modes of representation associated with a collaborative scientific modelling project, the kind of simplification and generalisation required to produce abstract synthesis provides fertile ground for controversy – decisions must be made which elide or erase more complex reality. Where such debates are reflections of skilled thinking by expert practitioners in the local paradigm, they may be highly productive events, but such 'academic' debates are perhaps rarer than those which have their origins in matters unrelated to the specific task at hand. Past political and personal divisions and debates can be revived, and new ones potentially generated in such moments. Resolving such debates may be well outside what is possible in a research modelling process, and may derail that process completely. In addition, successfully producing a robust and agreed representation provides no guarantee of avoiding such debates – dissemination to a wider audience, changes over time in local social life, and/or new knowledge and information may all be grounds for a critique of the existing representation. Any such critique should not be seen to automatically discredit the existing model or the process which generated it. Rather it is a likely, even necessary, consequence of creating a representation that will persist beyond the particular time and place it was created.

Modelling and systematisation tools

An extensive search for qualitative knowledge modelling and systematisation tools was conducted as part of the research underlying this paper. A range of approaches to systematising local environmental knowledge have been used and common ones include archival databases focused on various forms of classification (Bradley et al. 2005) and history (Verran et al. 2007, Hart 2010), spatial or mapping based approaches (Bradley et al. 2003, Robbins 2003, Balram et al. 2004, Morphy and Morphy 2006, Dunn 2007, Palmer 2009, Pesek et al. 2009, Sletto 2009) and temporally oriented systematisations focused on annual (seasonal) cycles and/or change over time (Clarke 2009, Haynes 2010, Woodward 2010, Prober et al. 2011). When causal relationships are considered, a range of additional approaches and tools become more relevant (Jones et al. 2011). By way of demonstration, some key examples of these kinds of tools are examined here.

The tools reviewed can be differentiated and placed in sequence based on the level of detail with which they specify elements and relationships within the systems they represent. The contexts for which particular tools might be applicable are too varied to be able to be specified here. Rather we identify the specificity of information that the modelling tool requires to generate a model of that type. The degree to which modelling participants possess and are willing to articulate such specificity will determine whether that tool, or a more or less sophisticated one, may be appropriate in a given circumstance.

At one end of the spectrum is a simple diagram, in which elements are depicted in relationship to one another through a link without the nature and intensity of that relationship being specified by the link. A correlative or causal relationship is assumed but not depicted. A refinement of such diagrams can provide some directionality to the link with no further detail. A signed directed graph, or digraph, produces models in which positive or negative influences are assigned to those directed links, providing further specification of the relationships and enabling the analysis of system dynamics, potential states, and emergent properties (Hage and Harary 1983, Dambacher et al. 2007). In this sense, such models are predictive. Fuzzy cognitive mapping (FCM) involves assigning not just a positive or negative sign to the link but a number between -1 and +1, indicating the directional strength of the relationship (Özesmi and Özesmi 2004, Murungweni et al. 2011). This enables the construction of matrices depicting the links, which are in turn amenable to a range of further calculations. The progressive increase in specification of the link (from unspecified, to directed, to signed, to quantified) enables additional systemic information to be recorded, but also increases the number of decisions (and therefore the time and energy) required to construct the model.

In each of the above extensions to an undirected diagram, the additional information in the model is added to and represented through further specification of the links. Modelling tools such as Concept enable the depiction of elements, links, feedback loops, etc. in similar ways to diagrams and digraphs, but tools such as this also have two additional features (Grice et al. 2009, Tan et al. 2009, eWater CRC 2012). The condition of elements can be specified on a sliding scale (from poor to favourable) and the links between model elements can be characterised by linear relationships (straight line, curve, parabola, etc.) on an x-y graph rather than through a single integer, as with FCM. Directional links mean that the condition of one element influences the condition of a dependent element according to the linear relationship specified. However this influence can be mediated or countered by reciprocal relationships or feedback loops – the models contain dependent relationships, but need not necessarily be hierarchical.

In such tools, although it is unnecessary to arrive at a definitive number to characterise the link, the understanding needed to generate an appropriate linear relationship between two elements in a model can be substantial. It requires knowledge of both the condition of the elements and of the condition-dependent, variable relationship between them.. This means that significant work may be required to build a Concept-style model in a participatory way. However, the ability to specify and change the condition of elements on a sliding scale also means the model can be analysed not just in terms of structural loops and emergent properties (as with digraphs) or turned into a matrix of numbers representing links (as with FCM). It also has a dynamic quality in which changing the condition of one element enables immediate consideration of how the condition of other elements are directly and indirectly affected.

The above tools are in a sequence of increasing specification requirements for links – links are depicted (diagram), specified through signs (digraph), through positive and negative integers (FCM), and through linear relationships (Concept). Concept additionally specifies the state of nodes in the diagram, and varies them accordingly, and this dynamic quality related to the condition (or state) of dependent elements is found in another popular modelling tool – the Bayesian Belief Network or BBN (Newton 2009, Kuhnert et al. 2010). Rather than focusing on specifying links, BBNs specify the state of system elements through assigning discrete probabilities to those states. The networks are hierarchical, and the state of elements higher up the hierarchy probabilistically influences the states of those dependent elements connected to them. The ability to assign probabilities to elements in dependent sequences make BBNs a very useful tool for scientific expert knowledge modelling (Newton 2009, Kuhnert et al. 2010) and for making preliminary predictions about the consequences of particular events, decisions or actions.

However, unlike the other diagrammatic approaches described above, the hierarchical nature of BBNs does not allow for the direct depiction of feedback loops and reciprocal relationships between model elements. A form of overall feedback can be represented by identifying how the model outputs (or dependent conditions) in one state may influence the inputs (independent conditions) of a subsequent run of the same model, but it is not possible to directly represent feedback loops and reciprocal relationships. This is potentially an important limitation in local knowledge modelling where such relationships can be integral to understanding. The work necessary to generate probability tables for each element is also substantial, requiring an understanding of proportionality and a degree of numeracy. This makes the participatory building of a BBN in local community contexts a significant task (Liedloff et al. 2009, Merrit et al. 2009, Chan et al. 2010).

One final influential tool for qualitative exploratory computer modelling should be noted here. Instead of specifying links and/or the state of elements, Agent Based

Modelling (ABM) focuses on defining rules governing the interactions of individual agents in a system and then exploring via computer simulation the net outcome of those individual interactions (Gilbert 2008). The models can effectively explore how complexity and emergent properties can arise from simple rules, but although inspired by complex biological and social systems, much past ABM research has not engaged with empirical data (Janssen and Ostrom 2006). More recent initiatives have incorporated 'stakeholder' perspectives and responses in researcher-driven models (Huigen et al. 2006, Aktipis et al. 2011) and in cases where engagement by local participants is high, have been able to produce ABMs with a significant degree of local participation and validation (Castella et al. 2005). ABM offers significant opportunities for novel insights in modelling, but the existing literature suggests that it has not been extensively used as the primary tool for generating visual representations of local or indigenous knowledge in its own terms.

The above selection of qualitative knowledge modelling tools identifies some key types and some gradations and variations amongst those types, but is by no means definitive. Existing reviews have considered different tools and are based on different perspectives and requirements (Lynam et al. 2007, Lynam and Brown 2012). Early anthropological attempts with computer based systems (Guillet 1989, Kippen and Bel 1989) were followed by at least one large scale attempt to systematise local ecological and agricultural knowledge through the identification and collation of statements about the natural world (Sinclair and Walker 1998, Walker and Sinclair 1998, Sillitoe et al. 2005). New forms of digital databases which more accurately reflect local and indigenous perspectives are also being developed (Verran et al. 2007, Hart 2010). The 'mental models' paradigm has been fruitful for a range of researchers and although it primarily emphasises individual rather than collective understandings of the world (Jones et al. 2011), it has been adopted as a framework for eliciting and analysing wider collective representations of causality (Jones et al. 2011, Stone-Jovicich et al. 2011, Lynam and Brown 2012). Other generic approaches to knowledge representation appear under terms such as knowledge visualisation and concept mapping (Novak and Cañas 2006, Tergan et al. 2006).

One of the challenges with our original search for flexible, qualitative knowledge visualisation tools applicable for community contexts was that such tools may appear under a range of generic and widely used terms (concept, information, knowledge, etc.) or indeed under specific names which do not relate to any standard term. Such differences in terminology potentially reflect major differences in epistemology and in a practical sense can reflect significant variations in capacity and orientation between different tools (Eppler 2006). 'Information' tools tend to focus on large bodies of data, while 'concept' tools are usually intended to depict broad categories and associations and contain limited direct processing power. Knowledge potentially encompasses both fields, but such distinctions are not clear cut, either in a definitional sense or in terms of the orientations and capacities of particular tools (Eppler 2011). Tools and techniques with similar names may actually possess quite different capabilities based on the research objectives and disciplinary and geographic location in which they were developed. The tools described here involve a sequence focused on qualitative and relational visualisations of knowledge and/or are tools that have received recent attention in the modelling of local and community contexts more generally.

Modelling with and for Indigenous Australians

Understanding the general features of modelling, the underlying human capacities, the information requirements of particular tools and the implications of those requirements for community resourcing and participation levels are important steps in assessing the viability of any modelling process. A further useful step is to identify particular socio-cultural features or general community characteristics that may impact on local capacity and/or on tool selection. Rather than attempting to produce global-scale generalisations about such features, by way of example we note some key aspects of indigenous Australian societies that can have a direct bearing on fruitful modelling approaches in this and potentially other contexts. These also provide an introduction for some recent examples of models generated in partnership with indigenous Australians.

Even when adopting the scale of a discrete continent rather than the globe, the potential geographic, socio-cultural, and historical diversity render generalisations highly problematic. Identifying and categorising what might constitute specifically Indigenous Australian models, abstractions, and/or representations would be a sizeable task, and identifying how such models or abstractions had their roots in pre-colonial societies and cultures would be even more difficult. All we wish to do here is to note two well-known and distinctive characteristics of many traditional Indigenous Australian societies that still have relevance to contemporary life, and also identify two important features of the current demographics of Indigenous Australia that are relevant to the discussion here.

The most well-known classical traditional representations produced by Indigenous Australians, and certainly the most well known internationally, are visual artworks. Their production represents an important contemporary industry as well as a means for individual artists to re-represent their ancestral past and demonstrate their knowledge of important places (Bardon 1991; Morphy 1991, 1998). What is particularly relevant here is the conceptual and visual sophistication of these multifaceted and multilayered productions (Morphy 1991). Once understood and interpreted appropriately, they can reflect a deep understanding of both the subjects they depict and the conceptual and iconographic language used to express that understanding (Morphy 1998, Sutton 1998). They also link people to places in a wider cosmological landscape. The degree to which art and the kind of utilitarian decision making tools emphasised here can perform similar functions or are, in important ways, similar constructs cannot be explored in the space available. But the existence of such artwork suggests that, at least as far as traditional Indigenous societies are concerned, people were comfortable with generating and interpreting complex, detailed and multivalent visual representations of their surroundings and of the place of human and non-human beings within those surroundings.

The second feature of traditional Indigenous societies relevant to generalised local modelling capability are the elaborate kinship systems (Hiatt 1965, Shapiro 1979). These varied in form and structure across the country, but based on the knowledge of those that have been well documented, they related people in complex but regularised ways that generated recurrent patterns across time and space (Elkin 1979). The systems were also integrated with land and seascapes, further developing complex networks of relationships between people and places. The description above could be elaborated in a great many ways, but what we wish to draw from the existence (and in some places ongoing generation) of such formal systems of relatedness is the underlying human capacity they demonstrate. Within Indigenous Australia, elaborate networks or systems have been conceived and maintained which both explain and guide human thought and action, and which relate that action to phenomena in the wider world.

Such complex systems of relatedness, and the sophisticated visual and spatial representations characteristic of Indigenous art, suggest a strong capacity for processes of formal analysis and abstraction continue to exist within Indigenous societies. They also suggest particular orientations to any kind of modelling process with Indigenous people – that visual and relational qualities are highly valued, and that models which prioritise these may be more easily generated than, for example models emphasising numerical estimation and valuation.

Yet such generalisations about the characteristics of traditional societies need to be contextualised against the conditions of contemporary life. Colonisation has radically altered life for Indigenous Australians, affecting the transfer of the formal knowledge required for artistic representation and the ongoing retention and daily use of such elaborated kinship systems (Elkin 1979, Maddock 1982). Beyond these impacts, we also note four further characteristics of the Indigenous Australian population – a relatively high proportion of young people, low incomes, low levels of formal education, and a growing demographic shift away from ancestral lands to regional towns and urban areas (Australian Human Rights Commission 2008). The majority of Indigenous communities with which we are familiar are very under-privileged and under-resourced, meaning that high-capacity individuals are heavily stretched. This is particularly true for those with substantial traditional authority, formal education and/or experience of environmentally and ancestrally significant places. The time and space for reflection is not normally available to them, except in unusual circumstances. These are crucial facts for many aspects of life, but are particularly important with respect to the potentially esoteric task of knowledge modelling.

Based on the above analysis, we would suggest that there exists a clear capacity for abstract systemic thinking within Indigenous Australian communities, and that this capacity was and is particularly well developed in terms of complex systems of recurring relationships and of visual representation. However colonisation has significantly impacted the ongoing transmission of such systems in many areas and inhibited regular interaction with ancestrally and/or ecologically important areas. Historical and demographic changes are particularly significant for processes that require reflection, interpretation, and the elaboration of complex socio-ecological phenomena. Culture and history intersect and interact with local and individual capacities in ways which affect ambitious research and representation projects, influencing the field of possible locations and collaborators, the techniques and tools chosen, and the likelihood of success.

Models of local socio-ecological knowledge and understanding have been and continue to be generated through collaborations with Indigenous Australians (Liedloff et al. 2009, McGregor et al. 2010, Woodward 2010, LaFlamme 2011, Prober et al. 2011, Woodward et al. 2012, Holmes and Jampijinpa 2013, Walsh et al. 2013, Barber et al. 2014). Not surprisingly, given the above discussion, these reflect a strong orientation towards visually sophisticated and multivalent but static representations. Such representations may be causal and hierarchical diagrams (Barber et al. 2014), circular calendars depicting ecological correlations across an annual cycle (Woodward 2010, Prober et al. 2011, Woodward et al. 2012) or hybrid structures depicting correlations and feedback loops (LaFlamme 2011, Walsh et al. 2013). They are not specified numerically, and the apparent simplicity of the output can sometimes belie the level of effort and consideration behind their production. Although they can be predictive, such models are not dynamic and iterative – they are usually understood as the collectively averaged product of 'real life - real time' iterations. In certain circumstances, the construction of dynamic and potentially iterative models such as BBNs is possible (Liedloff et al. 2009, McGregor et al. 2010). However the level of translation and researcher interpretation required to populate models needing numerical or probabilistic data can represent a step away from local understanding and towards researcher abstraction (Liedloff et al. 2013). This can be mitigated through techniques such as user-friendly interfaces and by the potential legitimation and influence derived from successful model construction (McGregor et al. 2010). Yet in general, the Indigenous Australian context demonstrates few numerically-based or overtly iterative models relative to those which are visually sophisticated spatial representations. This correlates with the general features of Indigenous societies outlined earlier.

The tools reviewed above all have a visual component, but none automatically generate spatial reconfigurations as a form of analysis. Increasing analytical sophistication in modelling tools usually entails increasing requirements for quantification (both of input data and of subsequent outputs) and a capacity for spatially explicit outputs. Software which does generate spatial reconfigurations (e.g. social network analysis) usually does so based on the specification of individual linkages between functionally equivalent nodes, rather than the kind of 'free drawing' associations between diverse kinds of nodes characteristic of digraph and FCM models. Complex mathematics lie behind such spatial reconfigurations, and most modelling development effort is oriented towards larger and more precise data sets, rather than flexibility in qualitative spatial representations. Yet new aids to analysis and visualisation are continually being developed, and modelling tools which, as a form of analysis, produce parsimonious spatial reconfigurations in response to the introduction or deletion of particular nodes or the alteration of particular linkages may be of considerable worth in Indigenous contexts characterised by relatively low numerical but high relational, spatial and visual sophistication. The general caveats about modelling processes in such communities still apply, but tools which are visual, flexible, and spatially sophisticated may be 'good to think with' in such contexts.

Conclusion

As noted at the outset, two objectives drive the technocratic agenda behind local and indigenous knowledge modelling: the derivation of understanding and management legitimacy through systematic modelling processes, and the aspiration to recognise and incorporate local and Indigenous knowledges into wider decision making. These objectives may be far from complementary in many circumstances, but neither seems likely to diminish with time. On the positive side, non-local objectives may align with local perceptions that collaboration will aid the recording, demonstration and wider legitimation of local and Indigenous knowledges, as well as the standing of those who hold and use them (Palmer 2009).The appeal of modelling to technocratic elites and decision makers can facilitate the flow of resources to local and indigenous-oriented knowledge research. The co-generation of synthetic representations can be productive in experimentation and in furthering collaborative understanding, and the products of successful collaborations may have considerable impact. Lastly, such attempts also assume that the capacity for novel constructive simplification and visualisation are inherent capacities within all human populations, and therefore that creating the conditions where such capacities can be exercised is a valuable task.

Yet despite the above observations about favourable characteristics and conditions, participatory knowledge modelling focused on systemic abstraction and causality is perhaps best understood as a rarified project activity entailing a considerable amount of risk, and numerous authors cited in this paper have identified the risks in such reifications. Even in circumstances which initially appear favourable, modelling must remain a highly contingent objective, subject to negotiation and adaptation following careful consideration ofthe appropriate allocation of available resources, the level of effort required from participants, and the objectives of and audience for a successful outcome. As one subset of a broader set of situated practices focused on collaborative integration, assembling diverse knowledges in effective local knowledge modelling projects demand considerable effort (Turnbull 2009), requiring the careful combination of engagement and abstraction that has characterised good anthropological and wider participatory research for decades.

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