A Framework for Integrated, Multi-Method Modelling of Dynamic Social Networks

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ABSTRACT

Social Network Analysis (SNA) methods have changed little over the past 50 years or so, based as they are on various matrix manipulation and analysis techniques. A significant limitation of traditional SNA is that it does not easily permit the study of changes in network structure over time. To address this and other limitations, a number of researchers in recent years have developed various Dynamic Network Analysis (DNA) approaches. In this paper, we overview these developments and propose a DNA framework that allows different aspects of a problem domain to be modelled using separate and distinct methods and for sub-models to communicate relatively seamlessly at simulation runtime.

Keywords: Research Methods, Social Network Analysis, Dynamic Network Analysis

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Social Network Analysis (SNA) methods have changed little over the past 50 years or so, based as they are on various matrix manipulation and analysis techniques. A significant limitation of traditional SNA is that it does not easily permit the study of changes in network structure over time. To address this and other limitations, a number of researchers in recent years have developed various Dynamic Network Analysis (DNA) approaches. In this paper, we overview these developments and propose a DNA framework that allows different aspects of a problem domain to be modelled using separate and distinct methods and for sub-models to communicate relatively seamlessly at simulation runtime.

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INTRODUCTION

Many approaches have been suggested as means by which complex organizational and societal problems might be subjected to modelling, analysis, solution diagnosis and scenario simulation, generation and evaluation. These include (but are not limited to) Social Network Analysis (SNA) (Scott, 1990), Dynamic Network Analysis (DNA) (Carley, 2003), system dynamics (SD) (Manni and Cavana, 2000) and agent-based modelling (Borschev and Filippov, 2004). Many instances have been reported of successful field applications of all these approaches but it is our contention that many studies might benefit through the use of multiple approaches. This, however, is a non-trivial issue and means by which multiple, popular modelling and simulation approaches may be applied in an integrated and seamless fashion is the central issue addressed in this paper.

DNA extends traditional SNA in three significant ways: i) DNA starts with *meta-networks* that specify multiple object networks that are both *multi-node* (many types of nodes) and *multi-plex* (many types of relationships); ii) DNA permits the analysis of complex, dynamic changes in network behaviour over time; and iii) agent-based modelling and simulation are employed to explore how networks evolve and adapt and to investigate the impact of interventions (Carley et al., 2009).

Agent-based modelling and simulation may utilize many different modelling approaches and, indeed, any one application domain might demand the use of multiple paradigms if best results are to be realized (Curtis et al., 1992). This, however, necessitates the runtime sharing of data between simulation sub-applications specified (and implemented) using different approaches. In this paper, a DNA modelling and simulation architecture that facilitates this data sharing and application integration is detailed. This research evolved as part of a wider study aimed at linking SNA with the health-seeking behaviour of Australian Aboriginal and Torres Strait Island people and this case study

(McGrath and Wilson-Evered, 2013) is overviewed. DNA, application integration and data sharing examples presented are all taken from this research.

Our paper is organized as follows: some necessary SNA and DNA background is presented in the following section and our DNA framework is then outlined. This is followed by the research design, and the case study overview, together with DNA examples and with reference back to the framework. The final section contains concluding remarks.

BACKGROUND

SNA (Scott, 1990) has long been used within the social sciences (see e.g. Radcliffe-Brown, 1940) to analyse phenomena such as links between ethnic groups within neighbourhoods, and the identification of cliques, power structures, norms and information flows within social groupings. Within SNA, the interaction patterns describing social structures can be viewed as a network of relations. The central tenet is that parties' beliefs, feelings and behaviour are driven not by attributes of the aforementioned parties, but by the relationships between them. The network paradigm is ideal for examining organizational phenomena because it refocuses attention away from parties acting in isolation to a much wider view that sees these parties as nodes in an interconnected set of interdependent relationships embedded within wider organizational and social systems (Zack, 2000).

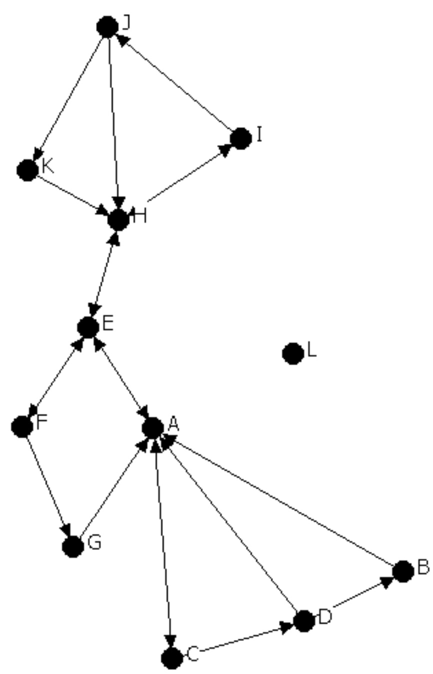

Figure 1: *A communications network represented as a sociogram. (Prepared using the SNA drawing package, NetDraw (Borgatti, 2002).)*

Network relationships may be represented as ‘sociograms’. An example, specifying a communications network is presented in Figure 1. A quick glance at this diagram tells us that there appear to be three distinct *cliques* within the network *({A,B,C,D}, {A,E,F,G}* and *{H,I,J,K}).* In addition, *A, E* and *H* all appear to be situated at vital points within the network: and, in fact, *A* is called a *cut-point* (because its removal would create two disconnected components) and *E-H* is called a *bridge* (because the link provides a bridge between clearly-distinct network components. *L* is described as an *isolate* (for obvious reasons) and *F,* among others, performs the role of a *conduit* (for messages from *E* to *G).* A further point to note is that this graph is *directed* (i.e. it contains directional arrows). If we were interested in something like ‘friendship’ (rather than communications), we would only require an *undirected* sociogram (because friendship is necessarily mutual). Finally, we could annotate each link in Figure 1 – to indicate, for example, the number of messages (strength of the link) or the overall tone of the directional communication (positive or negative).

Sociograms often provide a very useful, visual representation of the interactions within a social network. As networks increase in size though, graphical representations often become unwieldy and difficult to manage. Consequently, it is often preferable to work with various, underlying matrix representations. There are different types of these but the *adjacency matrix* is probably the most common and the matrix equivalent of the network in Figure 1 is presented in Table 1.

Table 1: *Underlying matrix representation of the sociogram in Figure 2.*

		1 A	2 B	3 C	4 D	5 E	6 F	7 G	8 H	9 I	10 J	11 K	12 L
1	A	0	0	1	0	1	0	0	0	0	0	0	0
2	B	1	0	0	0	0	0	0	0	0	0	0	0
3	C	1	0	0	1	0	0	0	0	0	0	0	0
4	D	1	1	0	0	0	0	0	0	0	0	0	0
5	E	1	0	0	0	0	1	0	1	0	0	0	0
6	F	0	0	0	0	1	0	1	0	0	0	0	0
7	G	1	0	0	0	0	0	0	0	0	0	0	0
8	H	0	0	0	0	1	0	0	0	1	0	0	0
9	I	0	0	0	0	0	0	0	1	0	1	0	0
10	J	0	0	0	0	0	0	0	1	0	0	1	0
11	K	0	0	0	0	0	0	0	1	0	0	0	0
12	L	0	0	0	0	0	0	0	0	0	0	0	0

The matrix presented above was prepared using the SNA software package *UCINet* (Hanneman and Riddle, 2007). *UCINet* contains an extremely comprehensive range of SNA including calculations of: i) the network *density* (the proportion of all possible ties between actors that are actually present); ii) *reachability* (determination of whether there is a path of any length between pairs of actors); iii) *distance* (the path length from any one actor to another); iv) *maximum flow* (the number of actors in the immediate neighbourhood of a source that lead to a target); v) *in-degree* and *out-degree* (the number of links to and from an actor from its immediate neighbourhood); and vi) *betweenness* (the extent to which an actor is in a favoured position by being on paths between other actors).

Modern SNA methods can be traced back to Moreno (1953) and, almost without exception, are based on the sociogram and the underlying sociomatrix and, as indicated above, over the years the SNA research community has developed an extremely impressive range of algorithms that may be employed to manipulate sociomatrices in order to provide various measures for network features of interest. Recently, however, various researchers have identified a number of limitations with these methods, including: i) most studies have focused on small bounded networks with only 2-3 (at most) types of links; ii) many real-world networks are large, multi-modal (many types of nodes/actors/agents) and multi-plex (many types of relationships between nodes); iii) most traditional tools do not scale well with network size (e.g. they may be too computationally expensive); and iv) traditional SNA techniques rely on analysis of a network snapshot, whereas a study of changes in network structure over time is often required (Carley, 2003).

The discussion of limitations has led to the development of the emerging *dynamic network analysis (DNA)* field. There are several important features that distinguish DNA from SNA but, most importantly, DNA focuses on network evolution (and the circumstances in which change propogates itself through a network), and agent-based modelling (Borschev & Filippov, 2004) and other types of simulations are employed to explore network evolution, adaptation and the impact of interventions.

An early DNA application of DNA was the *Greta* model of organization decision making described by McGrath and More (2001). Based on the idea of an organization as an 'organized anarchy' (Cohen, March & Olsen, 1972) and Pfeffer's (1981) power sources specification, actors within the Greta world are assigned a credibility degree and this, in turn, determines the 'level of access' (LOA) that each party has to key decision makers. The authors have implemented their model as a management game simulation within the expert system shell *Flex* (Westwood, 2007), which is founded on the frame-based knowledge representation formalism of Minsky (1975); an early predecessor of modern object-oriented modelling and system development methods (Rumbaugh and Blaha, 2004). While the progress of the Greta simulation is driven to a large extent by a classic SNA adjacency matrix (of LOA relationships), this evolves over (simulated) time and is driven by various events, chance, attributes of the different actors and their attitudes to a range of possible actions each may invoke at different points during the game.

Perhaps the most comprehensive and useful set of DNA models and support software produced to date has resulted from research by Kathleen Carley and her CASOS (Centre for Computational Analysis of Social and Organizational Systems) team at Carnegie Mellon University. Their DNA work is underpinned by the use of *meta-networks* (higher-level networks that specify the structure of the actual networks under study and their relationships), *agent based modelling* and *simulation* and, finally, the notion that network links are not binary but represent the *probability* that a link exists (Carley et al., 2009). Moreover, meta-networks are used to specify relationships between fundamental, generic entity types: individuals, knowledge/resources, events/tasks and organizations (Carley and Columbus, 2012). Based on these underlying principles, the CASOS team has developed and applied an impressive array of DNA simulation and decision support aids over recent years. These include:

- **ORA:* A DNA that detects risks or vulnerabilities in an organization's structure (Carley and Comumbus, 2012);
- *Construct:* A multi-agent, dynamic-network simulation system designed to reason about how humans learn, know, believe and act (Carley et al., 2009); and
- *DyNet:* A comprehensive, multi-purpose DNA toolkit (Carley, 2003).

These tools have been applied to applications as diverse as internet topology evolution, crisis management, terrorist network analysis and evolution, organizational design and restructuring, and healthcare system communication and management. Our work is situated within the last of these application categories and examples are presented later in the paper.

DYNAMIC MODELLING FRAMEWORK: OVERVIEW

The modelling philosophy that underpins this research is consistent with the view of Curtis et al. (1992) who have argued that different modelling objectives, user diversity, conflicting requirements, the need to share models (between components) and the need for both large and small-grained levels of abstraction all demand decision support models permitting multi-paradigm representations. A high-level view of our dynamic modelling framework is presented in Figure 2. The key to realizing the objective of a framework that allows models to be implemented within a variety of software packages and to share data is to employ an overall *Conceptual View* that is free of implementation detail and is highly-abstracted (Feldman and Miller, 1986). *Application View 1, ----, Application View n* are external-level schemas developed for individual applications, implemented within specific software shells *(Software Shell 1, ----, Software Shell n).* Examples of these (used in applications implemented to date) are *UCINet* (for SNA applications), *AnyLogic* (for DNA applications), *Excel, Access,* the rule-based expert systems shell *Flex* and the system dynamics simulator, *PowerSim.*

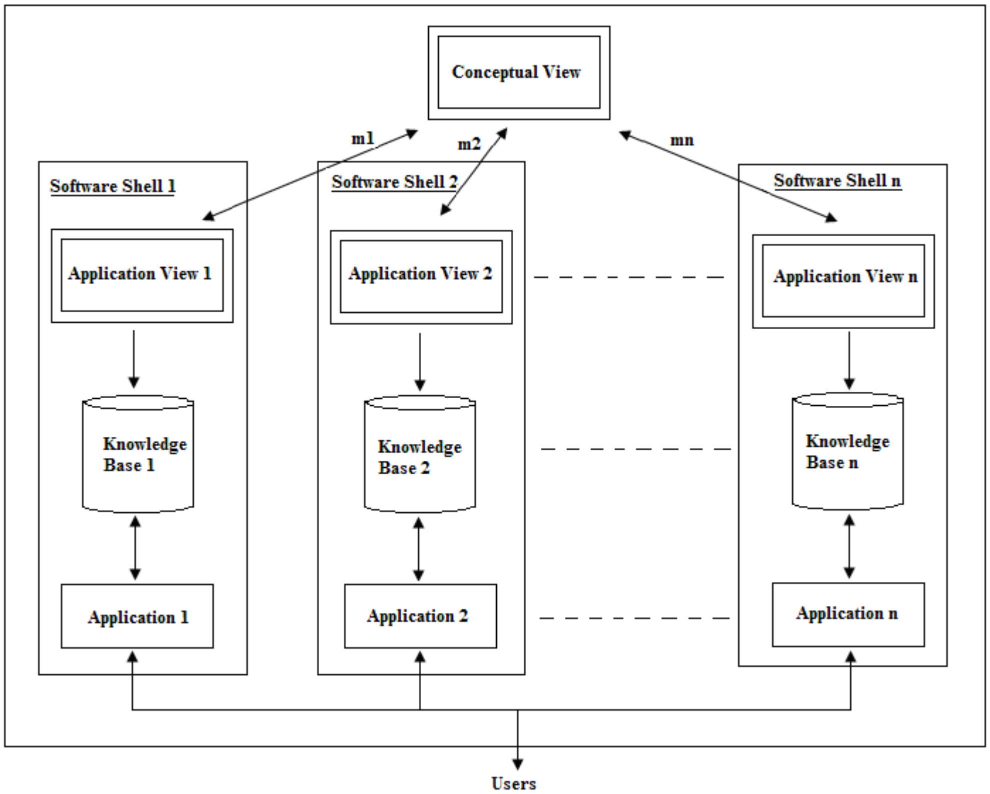

Figure 2: *DNA modelling and simulation framework.*

Our conceptual view is layered (using subtypes) and an entity-relationship (ER) specification (Chen, 1976) of the uppermost level of the model is presented in Figure 3. The ER approach was selected not because it is intrinsically superior to alternative formalisms but because: i) Chen's principal motivation in developing his specification language (and accompanying graphical notations) was to allow a unified view of the database modelling representation schemes popular at the time (the hierarchical, network and relational approaches); and ii) ER modelling (as the name suggests) is concerned primarily with *relationships* – which are at the core of DNA (and SNA).

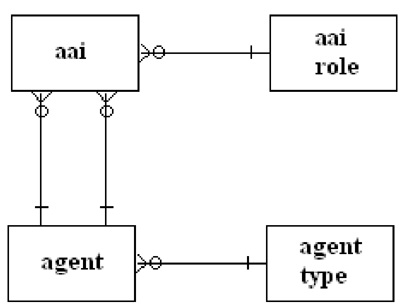

Figure 3: *Conceptual view – top-level.*

The *agent* entity (type) is at the core of the ER diagram in Figure 3 and the *1:n* link from *agent type* to *agent* indicates that all agents must be of one type only but the a single agent type can apply to many different agents. Agents are connected to each other (via an *m:n* relationship) through *aai (agent-agent involvements)* and a single *aaiRole (agent-agent involvement role)* must be associated with each *aai.* To make this a little more concrete and, with reference to the CASOS *Construct* node class classification scheme (Carley et al., 2012) introduced in the previous section, individuals, organizations and resources are agent types, profession is treated as an attribute of an individual agent, knowledge is a resource subtype and an event (in its simplest form) is simply an *aai,* with an *aaiRole* of *transition* (which, in turn, might be triggered by a *rate, timeout, condition* or a *message).* A task is an event already completed, currently underway or scheduled for some time in the future and location is an *aai* with a role of *relPosn (relative position* – distance and direction).

Space does not permit further detail on the modelling framework (and the means by which models of various types communicate with each other via the conceptual view) to be presented here. However, examples presented in the case study section should make this somewhat clearer.

RESEARCH DESIGN OVERVIEW

As noted, this research forms part of a wider research project concerned with the use of network analysis techniques in investigating the help-seeking behaviour of Aboriginal and Torres Strait Islander people (Biddle et al., 2004). The overall research design is illustrated in Figure 4, with the wider project structure on the left, the DNA sub-project design on the right and major interaction points identified.

Preliminary network design (Phase 1) involved the specification of initial, skeleton networks on both the HCSP and client side, together with the identification of the major HCSP-client linkage types. These networks are specified at a very high-level, with detail to be filled out during later stages. Most of Phase 1 has been completed with required information elicited from a literature review and a number if interviews with experts working in the aboriginal health area. The network design was specified using traditional SNA, within the *UCINet* software package. A further, very important output of this research phase was a preliminary identification of the research team’s industry partners’ expectations of the outcomes of the project (essentially, a requirements list). This list, identified in the wider project, was then used within the DNA sub-project to identify the types of DNA DSS applications that will be required to adequately support the needs of the wider project. At the time this paper was being prepared, the project had reached this point.

The major tasks to be undertaken during Phases 2-5 of the wider project will be to fill out the initial networks specified during Phase 1, to identify promising interventions and to evaluate these.

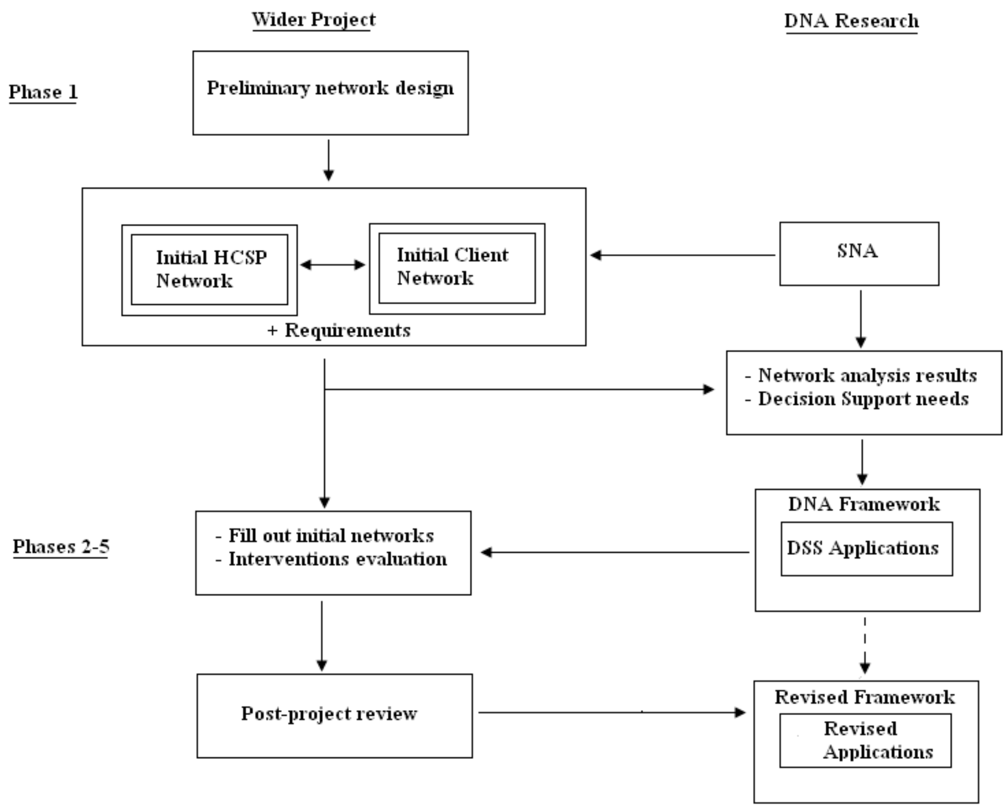

Figure 4: *Research design.*

Two separate model instances will be specified: one each in the Ipswich and Townsville regions. Mixed methods will be employed in identifying key parties and important relationship types on both the HCSP and client side, plus the critical links between the HCSP and client sub-networks. Interviews, surveys, focus groups and scenarios will all be utilized. As an example, use will be made of the 'Critical Incident' technique, employed (for example) by King et al. (2005) to explain healthcare suicide in the UK. This technique is scenario-based, an example being: "Think of a time you were seeking support for a client who has come to you with a substance use issue affecting their well-being and family relationships. How did you help this person and to whom did you refer them."

On the DNA sub-project side, the broad framework has already been specified and prototype (but fairly trivial) applications have been developed and tested. Currently, in parallel with Phases 2-5 of the wider project, the DNA team is developing the initial DSS applications (derived from the user requirements identified during Phase 1). When complete, these applications will be handed over to the wider project team for use in their network analysis and interventions evaluation work. The DNA team will contribute to and assist with this analysis and evaluation work, looking particularly at usefulness and usability aspects. Observations will be included in the Post-project review report and, probably more importantly, will be used to guide revisions and enhancement of the initial DNA framework,

CASE STUDY: ACCESSING INDIGENOUS MENTAL HEALTH SERVICES

There is a very significant gap between Aboriginal and Torres Strait Islander Australia's First Nations people and other Australians in infant mortality, disease, death rates, imprisonment and mental health (see e.g. NATISS, 2008). Reasons suggested include rapid social change in Aboriginal and Torres Strait Islander communities and a lack of understanding of Aboriginal and Torres Strait Islander culture that results in misdiagnosis and inappropriate treatment (Eley et al., 2006; Parker, 2012). In particular, cultural appropriateness, access, types of treatments and the way services are delivered contribute to the lack of appropriate and skilled services taking hold among these peoples. Related to this, other commentators have suggested that the overriding reason why Australia's indigenous population are not taking advantage of the substantial range of healthcare services available is a lack of trust (see e.g. Lowell, 2001; Fuller et al., 2008). Furthermore, a recent study of help seeking among Aboriginal and Torres Strait Islander adolescents suggested that addressing cultural competency in services, hosting school-based education sessions and embracing offline and online contact points are helpful steps youth services could take to encourage formal help-seeking among Indigenous young people (Price & Dagliesh, 2013). Together, the lessons learned from such work is that service providers need to understand how Aboriginal and Torres Strait Islander people communicate and prefer to interact with service providers.

This project is a joint endeavour between researchers at Relationships Australia Queensland (RAQ) and Victoria University, Melbourne. RAQ is a not-for-profit organisation providing services to vulnerable clients in the areas of family relationships, substance misuse and addictions, domestic family violence, gambling, dispute resolution as well as community and psycho-education. As noted above though, many of the most vulnerable clients may not access such services offered in their area. The overall aim of the project is to use SNA to determine gaps and linkages between service information and service channels and the broader Aboriginal and Torres Strait Islander community. A major objective is to gain a deeper understanding of: i) the routes by which vulnerable groups access RAQ (and related healthcare service provider) services; ii) significant blockage points within the access network and the reasons underpinning these; iii) alternative access routes that might be established; and iv) means by which access routes might be maintained and improved.

This research builds on previous work exploring cultural competency and adoption of technology enabled services within RAQ by Wilson-Evered and colleagues (Wilson-Evered, Thomson & Bennet, 2010; Wilson-Evered, MacFarlane and Thomson, 2011) and importantly SNA-based research in this area (see e.g. Fuller et al., 2008). We recognise that an early observation that the aboriginal health management and provision domain is extremely complex remains the case. For example, state and federal governments, Aboriginal and Torres Strait Islander community health providers, the wider (general) health system, various authorities (e.g. the police, social services and the legal system) and the community at-large (Aboriginal and Torres Strait Islander and the wider population) all playing a role. Moreover, each of these parties may be involved (with clients and each other) in a wide variety of roles. A domain *ontology* (see e.g. McGuinness, 2003) was specified to gain a deeper understanding of involved parties, their connections and the roles they play in these connections. A further important outcome of this exercise was that instances of role overlap were identified. The ontology is described in detail in (McGrath and Wilson-Evered, 2013) and a follow-up exercise was to group similar nodes into the higher-level network presented in Figure 5.

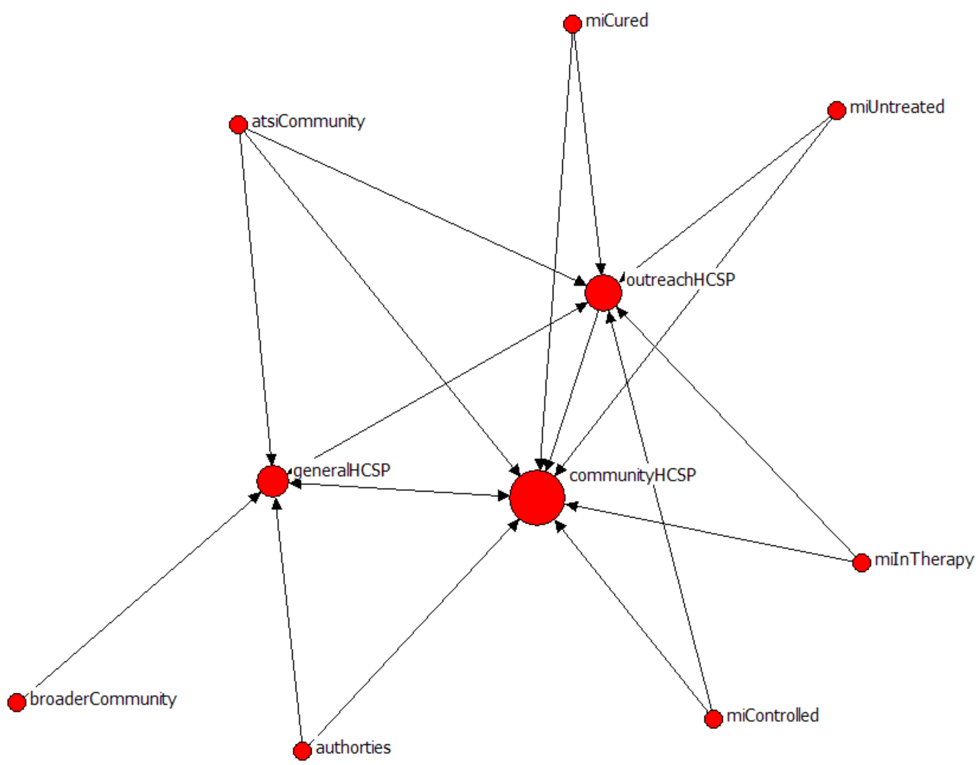

Figure 5: *Sociogram of Aboriginal and Torres Strait Islander community and health care service provider (HCSP) referral relationships.*

Clients (and potential clients) are divided into *miUntreated, miInTherapy, miControlled* and *miCured* (representing *mentally-ill untreated, in-therapy, controlled* and *cured* respectively). As noted, the number of parties involved as an Aboriginal and Torres Strait Islander *health care service provider (HCSP)* in some role or other is considerable and the apparent overlap between roles is complex. However, they may be broadly classified into three groupings: namely *communityHCSP,* *outreachHCSP* and *generalHCSP*. An instance of a *communityHCSP* is the Social and Emotional Wellbeing (SEWB) Unit, within the Townsville Aboriginal and Islander Health Service, an example of an *outreachHCSP* is the Townsville Aboriginal and Torres Strait Islander Health Program and an example of a *generalHCSP* is the Hospital Mental Health Liaison Service Townsville (which is part of the Townsville Hospital and Health Service).

The representation in Figure 5 proved useful but each of the nodes in this sociogram are meta-nodes, in that they represent networks of the class of agent they represent. Furthermore, it was apparent that many of these lower-level networks are extremely dynamic and a deeper understanding was required of the ways in which they change and evolve. Of course, 'snapshots' of the same network, taken at specific (regular or critical) points over a period, may be employed to investigate network dynamics and a number of SNA studies have adopted this approach (see e.g. McGrath and More, 2002; Bradley and McGrath, 2012). However, there are much better ways of observing and analysing dynamic network behaviour and, as noted, one very promising approach involves the use of *agent-based* methods (Grigoryev, 2012).

The first step in establishing an agent-based model is to specify an *environment* and to populate it with *agents*. Thus, we specify an environment of 3,200 Aboriginal and Torres Strait Islander people, in the Townsville region and estimated to be in need of some form of social and mental health service[1]. Each individual is an agent (of agent *class, client)* and, importantly, we may declare that agents are connected within the environment through a variety of *networks* (based, for example, on family groupings, occupations, sporting interests, location etc.). In our introductory example, we simply specify that agents are scattered randomly throughout the environment but that they are likely to connect with others based mainly on geographical proximity.

Figure 6 contains a *statechart* for an individual agent. These provide a means (among many other options) of portraying agent *behaviour.* Thus, the initial state for each agent is *miUntreated* but they may make the *transition* to the second state, *miInTherapy,* in two ways: by *referral* or through *wom (word-of-mouth).* Those who experience successful treatment transition to the *miControlled* state while others (with a less-happy treatment experience) *dropOut* and revert to the *miUntreated* state. Clients may be referred to treatment agencies (particularly the community-based healthcare centres and outreach agencies) by other healthcare professionals or by authorities in the Aboriginal and Torres Strait Islander and wider communities. *Wom* referral may come from anywhere within the environment but we have modelled this so that it emanates from other individuals who have undergone treatment themselves. *Rates* control all the transitions represented in Figure 5 and the

[1] The Townsville Aboriginal and Torres Strait Islander population is approximately 10,000, of which 32% are estimated to suffer high levels of psychological stress (NATISS, 2008).

model has been specified so that *wom* referral is considerably more likely from those who have experienced successful treatment *(miControlled).*

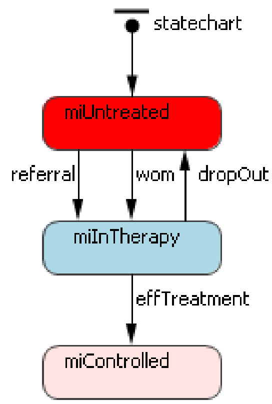

Figure 6: *Agent statechart for an Aboriginal and Torres Strait Islander healthcare network client.*

This statechart was specified and implemented within the multi-method *AnyLogic* modeling and simulation package (Grigoryev, 2012) and it may be employed to evaluate (for example) system responsiveness to variations in different combinations of the various transition rates. Typical output is presented in Figure 7.

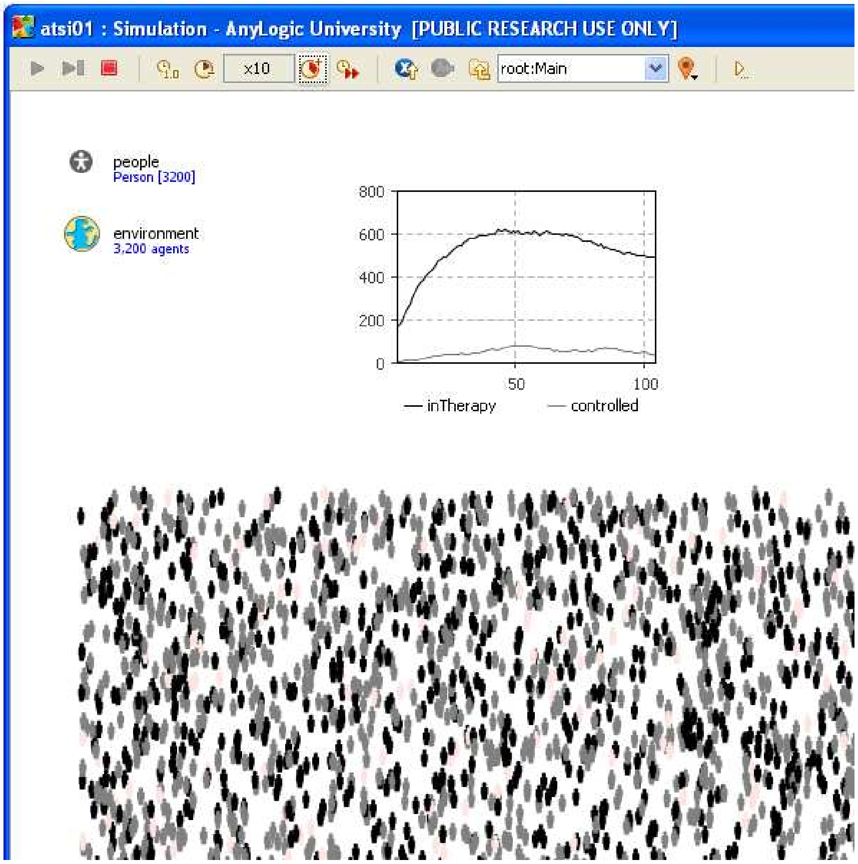

Figure 7: *Sample simulation run output.*

As noted, to this point simple rates have been used to control all state transitions and only the client side of the referral process has been specified. Insofar as the healthcare service providers are concerned, trust has been identified as, quite possibly, *the* most important factor in convincing vulnerable members of the client community that they should seek treatment (Fuller et al., 2008). Trust, in part, depends on competence which, in turn, is a factor of (perceived) treatment effectiveness.

A high-level system dynamics (SD) (Maani and Cavana, 2000) view of these dependencies is presented in Figure 8. This model has also been specified and implemented using *AnyLogic* and, importantly, both this service provider SD model and the client side agent-based model are tightly integrated and feed off each other. Specifically: i) *treatmentEffectiveness* is calculated in the agent-based model as the *effTreatment/dropout* ratio (i.e. the ratio of the totals of each of these two transitions) and is then one of two variables employed to determine *Competence* in the SD model; and ii) *Trust* from the SD model is used in the client statechart to vary both the *referral* and *dropout* rates.

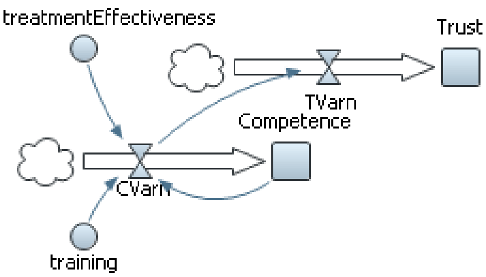

Figure 8: *High-level SD model of key healthcare service provider variable relationships.*

As noted by Grigoryev (2012), in modern simulation modelling there are three basic methods (see Figure 9). Each method serves a particular range of abstraction levels. SD operates at a high abstraction level and is mostly used for strategic modelling. Discrete-event modelling, with its underlying process-centric approach, supports medium and medium-low abstraction. Agent-based models can vary from very-detailed (e.g. when modelling physical objects) to highly-abstract (e.g. when agents are compound, in that they can be broken down into sub-classes – e.g. companies or governments).

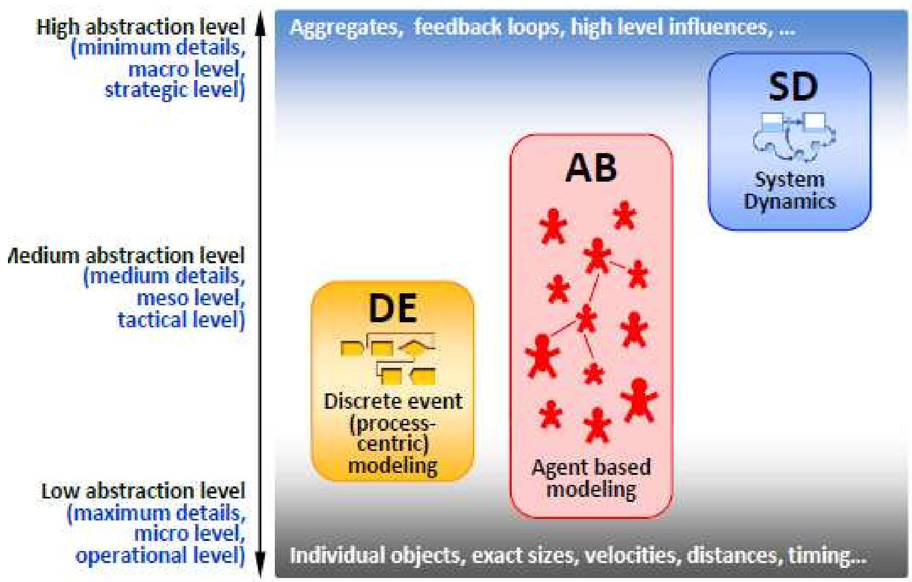

Figure 9: *Modelling approaches versus abstraction level (from Grigoryev, 2012: 13).*

Thus (and, as noted earlier), many research domains require a combination of modelling approaches and a simple example (implemented within *AnyLogic)* was presented above. Working within *AnyLogic,* the modeller can conveniently and seamlessly integrate models and share data between applications specified using its three basic methods (SD, agent-based and discrete-event). However, there are many popular modelling and simulation paradigms beyond the *AnyLogic* world (e.g.

traditional SNA methods, Bayesian belief networks, various mathematical modelling and simulation tools etc.) and, where use of these are required, data sharing may be facilitated using the abstracted conceptual schema presented in the previous section (see Figure 3).

For example, the agent statechart presented in Figure 6 indicates that individuals in the potential client base might seek treatment as a result of *wom (word-of-mouth)* contact with members of other community groups to which they belong (based, for example, on family, sports, occupational or informal social group ties). Each such contact can be specified as an instance of an *agent-agent-involvement (aai)* with *aai-role, successful-treatment-advocation.* This dataset could then be exported into a rule-based expert system shell[2] and the following rule could then be used to find all known instances of community members that might be usefully encouraged in their role as treatment advocates:

```
rule findKeyCommunityAdvocates
 is AAI is an agentAgentInvolvement
 and the aaiRole of AAI is successfulTreatmentAdvocation
 and agent1 of AAI is Agent1
 and the agentType of Agent1 is treatmentAdvocate
 then Agent1 becomes a member of the keyAdvocateList.
```

Having identified this list of key parties, we may wish to establish (for example) a traditional SNA communication network specifying various types of *party-party* interaction. Again, at the conceptual level, we are dealing with another *agent-agent involvement* set and we could export this into *UCINet* for further analysis. Thus, we have modelled various facets of our case study domain using four distinct approaches: agent-based modelling, SD, (expert system) rules and basic SNA. Each of these has been employed for the types of modelling tasks for which they are best-suited but, crucially, each of the four sub-models feeds off the others and communicate within our modelling framework in a relatively seamless manner.

CONCLUSION

We have presented a DNA framework that is multi-paradigm and allows ready communication between applications built around different types of models at simulation runtime. The foundation of this framework is the highly-abstracted conceptual schema through which the various applications communicate. Examples, taken from a wider research study addressing indigenous healthcare problems were used to demonstrate benefits associates with our approach. It must be emphasized that this research project is still in its early stages, with only high-level skeleton models (and associated applications) specified to this point. Over the next 12 months, it is anticipated that these models will

[2] Such as *Flex* (Westwood, 2007).

be filled out and, in parallel with this, we aim to develop a number of decision support applications (within our framework) to be employed in simulated evaluations of identified, promising policy and process interventions. Since an incremental approach to this development work has been adopted, this should provide a demanding test of framework robustness: particularly with regard to scaleability and its ability to cope with modifications and enhancements.

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