Nurse-led ontology construction: A design science approach.

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Abstract

Purpose: Most nursing quality studies based on the structure-process-outcome paradigm have concentrated on structure-outcome associations and have not explained the nursing process domain. This thesis turns the spotlight on the process domain and visualises nursing processes or ‘what nurses do’ by using ‘semantics’ which underpin Linking Of Data (LOD) technologies such as ontologies. Ontology construction has considerable limitations that make direct input of nursing process semantics difficult. Consequently, nursing ontologies being constructed to date use nursing process semantics collected by non-clinicians. These ontologies may have undesirable clinical implications when they are used to map nurse processes to patient outcomes. To address this issue, this thesis places nurses at the centre of semantic collection and ontology construction.

Method: Design science methodology enables nurses to contribute their process domain semantics ‘first hand’. A sample of nurses working in various specialities was recruited to draw their process domain using node-arc-node ‘graphs’. Graphs are a visual representation of the language used to construct ontologies. Graphs contain semantics supplied by nurses; graphs are used to construct OWL-DL ontologies. OWL-DL ontologies are used because they are web-based and have a logic-and-rule construction. The ontologies were analysed by robots to evaluate their term ‘closeness’ and logic consistency.

Results: Graphs depicting four different process domains were produced and used to construct OWL-DL ontologies. Graphs revealed differences from one process domain to another; clusters of ‘responsibility’ varied between graphs and the focus on nursing roles varied from graph to graph. Graphs also revealed ‘hidden’ processes. The software robots graded the ‘closeness’ of terms between ontologies and found all of the ontologies had exclusive terminology. Three of the four ontologies were logically consistent.

Conclusion: Semantic technologies have proven to be a valuable analytical tool to describe the nursing process domain. Graphs allow nurses to input process semantics directly into ontology construction. Robots can evaluate ontologies constructed from nursing graphs.

Student Declaration

Doctor of Philosophy Declaration

“I, Philip John Shields, declare that the PhD thesis entitled ‘Nurse-led ontology construction: A design science approach’ is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work”.

Signature: [redacted] Date: April, 2016

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CHAPTER ONE: Introduction to the thesis

1.0 Introduction to the chapter

This thesis sets out to address a lack of nursing process domain semantics. Semantics, in the design science context, describe concepts and their relationships. Concepts in a nursing process domain may be ‘concrete’ entities like ‘nurses’ and ‘patients’ or abstract entities like ‘nursing care’. If enough process semantics are collected they may provide a clearer picture of the scope of nursing processes. Donabedian (1988) defined a ‘process’ as a set of activities which proceed within and between practitioners and patients. Unfortunately, process domain semantics are elusive.

Donabedian’s well-known Structure-Process-Outcome (SPO) model of quality improvement (Donabedian, 1988) is widely applied in health research. Studies which used Donabedian’s SPO frequently bypassed the process domain in favor of linking the structure domain directly to the outcome domain. The reason frequently cited is that process semantics are hard to capture because they are often ‘hidden’ in documentation or described by ‘impenetrable’ medical terminology.

This thesis uses semantic technology such as ontologies to depict the process domain. Ontologies and their related concepts are explained in a glossary at the end of this chapter. Ontologies were selected because they can depict a human domain of interest such as a nursing process domain. Also, ontologies are machine-readable, shareable and can specify semantics. Until now, nursing semantics were not provided directly by nurses to construct ontologies. Instead, nursing semantics were sourced ‘third hand’ by non-clinicians who constructed the ontologies. There is a good reason why non-clinicians construct ontologies; the language used to construct ontologies is complex. The motivation for the thesis is to enable nurses, who are not experts in ontology construction, to impart semantics that could be used to construct an ontology. Underpinning this thesis is the supposition that semantics will be more relevant to nursing processes if they are sourced directly by the front-line nurses who implement them in practice.

The sourcing of nursing process semantics is supported by the Visual Understanding Environment (VUE). VUE is a software program that negates the need to know complicated ontology languages; the software enables participant nurses in this thesis to construct ‘graphs’. Graphs are a visual representation of the ontology construction language. Graphs are used in this thesis because they are easy to use and are understandable for both nurses and computer science researchers. Also, graphs can be used to construct ontologies that can be evaluated by software robots.

So in essence, this thesis turns the spotlight on the process domain and visualises nursing processes by acquiring nursing semantics directly from nursing domain experts. Graphs produced by nurses are ‘human readable’ documents, which are turned into ‘robot-readable’ ontologies. Both the graphs and ontologies contain the same semantics. Graphs are evaluated for patterns of nurse roles and clusters of process activity. Ontologies are evaluated for the ‘closeness’ of language and logic consistency of the ontology’s structure.

This chapter provides an overview and identifies the problem that the thesis addresses. The research question, aims and significance of the thesis are stated. The chapter concludes with a glossary of terms.

1.1 Background to the thesis

1.1.1 The lack of nursing process semantics

Burnes Bolton, Donaldson, Rutledge et al. (2007) conducted a literature search of 4,000 systematic/integrative reviews and 500 meta-analyses covering seven areas of nursing care for the period 1999-2005. The literature search revealed that limited semantics, which describe nursing processes, severely impaired the ability to establish a direct association between nursing processes and patient care outcomes. Burnes Bolton et al. (2007) concluded that it is essential for the nursing research community to increase the number and quality of semantic studies linking nursing processes.

Clark and Lang (1992), introduced their case for the development of process semantics at the US National Quality Forum by stating: “If we cannot name it, we cannot control it, finance it, teach it, research it, or put it into public policy” (p.109). Similarly, Needleman, Kurtzman, and Kizer (2007) note that effective nursing process acquisition systems “will enable health care stakeholders to better understand and monitor the degree to which nursing care influences patient safety and health care quality” (p.28).

Mallison (1990) identified that semantics describing ‘what nurses do’ in the process domain, and particularly how this impacts on patient outcomes, were rarely captured. Butler, Treacy, Scott et al. (2006) identified a so-called nursing ‘invisibility’ in healthcare data systems is linked to the lack of standardised process semantics. Likewise, literature reviews conducted by Savitz, Jones, and Bernard (2010) and Burnes Bolton et al. (2007) found little or no evidence of research activity identifying nursing processes. It is suggested that, in some contexts, the lack of semantics describing the types of services that nurses provide and their contribution to patient outcomes, has disadvantaged the progress of nursing science.

The challenge of acquiring nursing processes was highlighted by the Institute Of Medicine (IOM). The IOM is the health arm of the American National Academy of Sciences. In 2008, the IOM, in conjunction with the Robert Wood foundation, launched a two-year study to assess the current state of nursing. The joint effort produced eight recommendations to guide the future transformation of the nursing profession. This thesis addresses their eighth recommendation which identifies the importance of improvements in health data research, particularly focussing on the implementation of efficient nursing process semantic collection and analysis (IOM, 2011).

1.1.2 The lack of studies which include Donabedian’s process domain

Donabedian (1988) defined nursing processes as a set of activities which proceed within and between nurses and patients. The Structure, Process and Outcome (SPO) model devised by Donabedian (1988) continues to underline studies which explore how nursing interventions affect patient outcomes (Jennings, Staggers, & Brosch, 1999). The SPO literature is almost devoid of process domain semantics because semantics describing nursing processes are difficult to acquire. The difficulty acquiring semantics in the process domain means that many studies have bypassed the process domain in favour of developing ‘easier’ structure to outcome associations that are readily available. The proliferation of structural and outcome studies has shifted the research spotlight towards studies that acquire process semantics (Doran, 2011).

Nursing studies exploring nursing’s contribution to patient care tend to populate the SPO with small data collection metrics called Nurse Sensitive Indicators (NSIs). When NSIs are connected across the SPO, causal relationships between nurses and patients can be mapped. This thesis exploits the similarity between mapped nursing NSIs and graph architecture; the architecture which underpins semantic technology such as ontologies. An ontology is a computer-readable document that conceptualises concepts and their relationships, called ‘semantics’, which exist in some ‘domain of interest’. A domain of interest is a ‘snapshot’ of activity which exists in the ‘real world’ (Bizer, Heath, & Berners-Lee, 2009). This similarity between studies using NSIs connected across Donabedian’s framework Donabedian (1988) and graph architecture is built upon in this thesis to enable the acquisition and analysis of semantics in the nursing process domain. However, the challenge facing the development of ontologies is how to acquire ‘first hand’ process semantics from front-line nurses.

1.2 The problem this thesis addresses

1.2.1 Acquiring semantics from front-line nurses

This thesis addresses the lack of nursing process domain semantics by using ontologies. Ontologies can reflect Donabedian’s SPO domains Donabedian (1988) which include the process domain. The problem with ontologies, in the main, is that their construction language is difficult to write and understand. Consequently, front-line nurses who perform the domain processes have not constructed them.

1.3 Research question

The research question this thesis asks is: ‘Can nurse domain experts produce node-arc-node graphs containing semantics describing their process domain and can semantics be evaluated?’

1.4 Research aims

Figure 1 depicts the aim of this thesis which is to acquire nursing process semantics from ontologically unskilled nursing domain experts using graphs. Ontologies are constructed from graphs. Graphs and ontologies are evaluated separately as per the two following sub-aims:

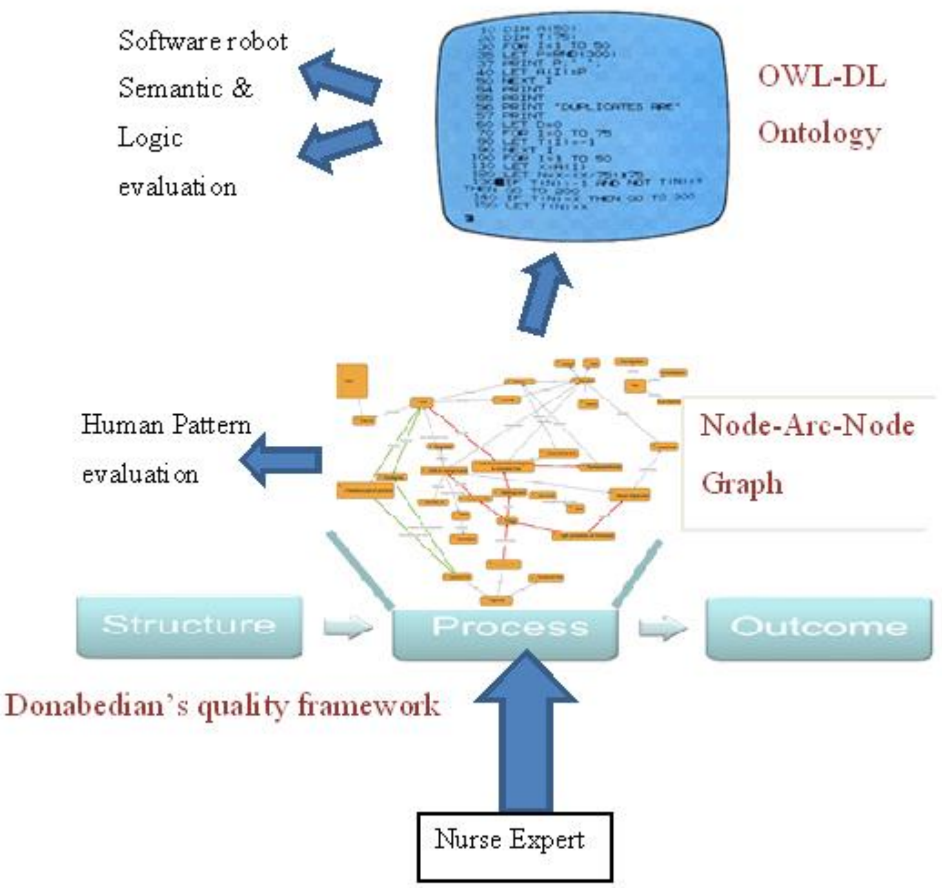
Human (graph) evaluation:

- Determine graph patterns such as the number of nursing ‘roles’ and the number of ‘clusters’
- Evaluate the usability of graph software.

Robot (ontology) evaluation:

- Rank the ‘closeness’ of terms across ontologies
- Determine each ontology’s logic consistency.

Figure 1: A conceptual diagram showing the relationship between the nurse expert, graphs and OWL-DL ontology



1.5 Significance

Evidence in the form of semantics provided by graphs and ontologies have implications in terms of enhancing understanding of nursing processes. Semantics from front-line nurses present ‘undiluted’ nursing processes in a technological form that both humans and robots can visualise and analyse. This is important, because it allows nursing experts, who are masters of semantics, and are unfamiliar with ontologies, to directly input their understanding of the nursing process domain into a robot/human-readable form.

1.6 Methodology

1.6.1 The study framework

This thesis utilises the design science framework of Peffers, Tuunanen, Gengler et al. (2006) to construct ontologies from graphs and evaluate both the graphs and ontologies. The methodology has a usability study component to ascertain the usability of the VUE graph software and its application in nursing.

The study must be considered as a pilot due to the ‘newness’ of the technological features of emerging semantic technologies and their limited application.

1.6.2 The study population

A purposive sample of nursing domain experts (participants) was recruited from different specialities, namely, transitional care, triage, administration and surgical within one organisation. Participants were currently working in their specialities and had practiced in their relevant areas for over 15 years.

1.6.3 Semantics collection methods

The participants were each given a ‘blank’ graph containing three nursing process roles, which were modelled from sources in the literature. Participants were instructed to reflect on their process domain. That is, they were encouraged to think about their everyday roles in terms of concepts they interact with each day and how they related to them. Participants drew graphs and connected their concepts to the three supplied nursing roles. The student researcher converted graphs into OWL-DL ontologies using the Protégé software development platform (Protege, 2011).

1.6.4 Semantics analysis

The participants’ graphs were analysed by counting the number of nursing roles and node ‘clusters’ in each graph. The number of connections from the three supplied nursing process roles to the participants’ concepts was counted in each graph to determine the ‘role focus’ of their process domain. In addition, participants filled out a survey informed by Nielsen (1994) which rates graphs' usability and 'fit for purpose' for nursing science and practice. Machine-readable ontologies were analysed by two software 'robots', which examined the ontologies for semantic 'closeness' and logic consistency.

1.7 The thesis' outputs

Outputs of the study:

- Findings of graph patterns generated by the participants
- Findings of a usability survey
- Ranking of semantic 'closeness' and logic consistency

1.8 Overview of the thesis

This thesis proceeds in six chapters:

1) **Introduction:** Chapter One introduces the thesis and identifies gaps in the literature and the methodology.
2) **Literature review:** Chapter Two provides an in-depth review of nurse-related 'semantic' studies that have been published between 1996 and 2014. The chapter provides the nursing perspective/frameworks that underpin the methodology of this thesis.
3) **Framework:** Chapter Three provides a description of the study's semantic framework. The chapter provides a detailed 'bottom-up' discussion of the Resource Description Framework (RDF) in which the methodology is embedded. The chapter commences by describing triples, the basic elements that enable the Linking Of Data and concludes with a description of the Semantic Web and ontologies.
4) **Methodology:** Chapter Four details the design science methodology, which includes a usability testing study used to evaluate the usefulness of the graph software. Graphs produced by participants are used to construct OWL-DL ontologies. Graph patterns are evaluated and software robots are used to compare terms and test logic consistency of the ontologies.
5) **Results:** Chapter Five details the results of the graph and ontology evaluations.
6) **Discussion/Conclusion:** Chapter Six discusses the research outcomes in light of nursing practice and policy implications. The chapter presents the conclusion of the thesis, limitations and potential directions for future research.

1.9 Glossary

Architecture

In the semantic web context, ‘architecture’ is a collection of specifications built on the W3C's Resource Description Framework (RDF). It is often illustrated as a ‘stack’ of specifications, each building on its predecessor. The stack includes: URIs, RDF and OWL. How specifications are connected is determined by the Linking Of Data specification (LOD).

Attributes

Attributes are the personal data that identify an individual; they ‘fill in’ the personal details laid out by a constraint. For example: a constraint may state that a nurse must have an education level; the attribute for an individual nurse may be ‘bachelor of nursing’.

Class

A class is a group of similar concepts in an ontology that exist in the ‘real world’. They are similar because they conform to the same conditions of class membership (see Constraints).

Concept

An ontology is built by joining concepts through common semantic logical relationships. Concepts within an ontology are representations of concrete or abstract things one might expect to encounter in the ‘real world’ (see Domain of interest). For example, a health domain of interest may contain ‘concrete’ concepts such as doctors, nurses and patients. Abstract concepts may be ‘nursing care’.

Constraints

Constraints are ‘rules of class membership’ which describe the scope of an individual. Constraints help classify individuals into their correct classes. A software ‘reasoner’ will make logical inferences based on various conditions. For example, a reasoner will compare an individual’s attributes against its class constraints to see if they are logical, that is, the reasoner asks: “Does this individual have the necessary attributes to belong in this class?”

Types of constraints:

- *Necessary constraints* are basic rules that individuals must hold to be a member of a particular class. It allows individuals from different classes to be members of multiple classes. For example, nurses and doctor individuals have necessary conditions to belong to class employee. A nurse individual may not fulfil the conditions to be a member of doctor but both doctors and nurses fulfil requirements to be an employee (Protege, 2011).
- *Necessary and sufficient constraints* are such that an individual must hold those conditions to be recognised as a member of a particular class. For example, nursing practice registration is a requirement; a necessary and sufficient condition to be a member of class 'nurse' in this thesis (Protege, 2011).
- *Disjoint from constraints* will guarantee that a class of individuals is exclusive. A member of one class cannot simultaneously be a member of another class. For example, a domain expert has placed a 'disjoint from' constraint between the nurse and doctor classes. Therefore, the nurse and doctor individuals cannot exist in the other's class—as far as the reasoner is concerned, a nurse cannot be a doctor and vice-versa (Baader and Sattler, 2001). With a disjoint constraint in place, the reasoner will report a logic inconsistency if it detects a doctor in a nurse class; it declares, 'your ontology is inconsistent!' (Meditskos and Bassiliades, 2010). This thesis has disjoint constraints between patient, nurse and doctor classes.

Data

Data published on the Semantic Web are machine-readable formats such as CSV, XML, RDF triples and URIs. See Linking Of Data and Semantics.

Domain expert

This thesis uses the common design science term 'domain expert'. Keeney, McKenna, and Hasson (2010) define domain expert as a practitioner in their field who has a working knowledge regarding their specific domain of interest.

Description Logics

Description Logics (DL) is a sub-class of first order logic. DL is a family of knowledge representation languages with varying and adjustable expressivity. A reasoner uses DL's

Boolean arithmetic to compare individuals' attributes to class constraints. A reasoner uses 'If then' statements and 'and, or, not' conditions to compare attributes to constraints.

Domain

See Domain of interest

Domain of interest

The domain of interest is the part of subjective human reality the ontology represents. The domain of interest is constructed of concepts representing objects (physical or logical) and relationships between them. Concepts are most likely to be nouns and relationships are verbs in sentences that describe the domain (Noy and McGuinness, 2001). The domain of interest in this thesis is nursing's process domain.

Explicit

In the context of this thesis, 'explicit' means knowledge that is provided by a nurse expert; 'implicit' knowledge is inferred by a software reasoner (from explicit knowledge).

Framework

Coiera (2003) described frameworks as having two main purposes. Just like an image produced by a camera, it is a representation of reality. Frameworks are an abstraction of the 'real world'. Secondly, frameworks act as templates where new ideas are built upon and tested.

Graph

Node-arc-node graphs are a visual representation of Resource Description Framework (RDF) triples, the basic element of the Linking Of Data specification. It is a natural language for translating RDF triples into a form that can then be viewed by using standard graph visualisation tools such as Visual Understanding Environment (VUE). Graphs are constructed like a simple sentence: Object (node), Predicate (Arc), Subject (Node). For example, the 'Bob knows Alice' triple can be drawn as a graph. Hayes, Saavedra, and Reichherzer (2003) suggest it is natural to display ontology in a node-arc-node graphical format, which is the architecture used in the OWL-DL specification.

Implicit

In the context of this thesis, ‘implicit’ means knowledge that is inferred by a software reasoner from explicit knowledge provided by a nurse expert.

Individual

An individual is a concept normally representing a human. It is an instance of an ontology’s class and therefore inherits constraints from the class. For example, a nurse individual may have constraints that declare that a nurse has a registration, education level and role. Each constraint must be ‘filled in’ with individual attributes for the nurse to be considered a member of the class.

Inference

Inference is the process of using a reasoner to derive logical conclusions from a set of starting logic assumptions called constraints. Inference is one of the outputs of the reasoner, which uses DL to deduce new relationships between concepts.

Linking Of Data (LOD)

LOD is the W3C specification that supports connectivity in semantic technologies such as ontologies and the Semantic Web. It connects resources using Uniform Resource Indicators (URIs). LOD typically uses three URIs organised in a simple sentence called a ‘triple’. The basic rules for Linked Data according to Berners-Lee (2006) are:

- Use URIs as names for things
- Use URIs so that people can look up those names
- When someone looks up a URI, provide useful information, using W3C standards.

Nurse Sensitive Indicator (NSI)

The Nurse Sensitive Indicator is an evidence-based metric which reflects the effectiveness of nursing processes on the improvement of patient function and care (Naylor, 2007). (Plural is represented as NSIs in this thesis.)

Ontology

Ontology is a document containing a formal representation of knowledge for a specific domain of interest in the ‘real world’. An ontology defines the common terms that may describe concepts used to describe and represent a domain of interest. In doing so, it 'paints a semantic picture' of the domain that machines can read and analyse.

This thesis uses 'ontology' in its design science context and adopts the most commonly accepted definition proposed by Gruber (2004): *'a formal, explicit specification of a shared conceptualisation.'* This basically means an ontology uses explicit, defined semantics to conceptualise a shareable robot-readable abstract of some 'real world' domain of interest.

OWL

The Web Ontology Language (OWL) is a family of knowledge representation and vocabulary description languages for authoring ontologies. It is based on the LOD specification and standardised by the W3C.

OWL-DL

OWL-DL is a knowledge representation and vocabulary description language based on Description Logics (hence the suffix DL). This flavour of OWL makes it possible for a software reasoner to automatically compute logical inferences and check for inconsistencies in an OWL-DL's structure.

Participants

In this thesis, participants are nursing domain experts. Participants represent four areas of nursing speciality, namely: transitional care, emergency triage, surgical nursing and administrative nursing.

Patient outcomes

Patient outcomes are any reports or metrics coming directly from patients about how they function or feel in relation to a health condition and its therapy. Outcomes are not an interpretation of the patient's responses by a clinician.

Predicate

A predicate is the middle term (the linkage, or 'verb') in a triple. For example, in the triple 'Alice knows Bob', 'knows' is the predicate that connects 'Alice' (the subject of the triple) to 'Bob' (the object of the triple).

Reasoning

Reasoning is the process of forming logical conclusions about relationships between concepts, from a set of constraints.

Reasoner

A reasoner is a software logic engine. One of the main tasks of a reasoner is to test whether or not an individual conforms to logic constraints set down by their class. By performing such tests on all individuals and classes in an ontology, it is possible for a reasoner to compute the inferred ontology class hierarchy. Another standard service offered by reasoners is consistency checking. Based on the constraints of a class, the reasoner can check whether or not it is possible for the class to have any individuals or if the individuals conform to their constraints. A class is deemed to be inconsistent if it cannot possibly have any individuals. Reasoners are sometimes also known as classifiers.

Resource

A resource is data on the Web that LOD links to. Resources are addressed by three Unified Resource Identifiers (URIs) that constitute a ‘triple’ (see RDF).

RDF

The Resource Description Framework (RDF) is not a language per se, but a framework for organising triples pointing to resources in an ontology. RDF encodes as a set of Universal Resource Indicators (URIs) statements called triples, pointing to resources that expand that concept.

RDF graph

See Graph.

RDF triple

See Triple**.**

Robot

‘Robot’ is the term used in this thesis for ‘software agent’. Robots, for the purpose of this thesis, are goal-directed software programs which can accommodate problem-solving tasks using a ‘rule-set’. Two robots used in this thesis are the reasoner, FaCT++ and the semantic classification robot OnAGUI.

Semantic

Authors Euzenat, Mocan, and Scharffe (2007) and Giunchiglia and Shvaiko (2003) use the term ‘semantic’ for a combination of terms, relationships and descriptions which describe concepts through an ontology’s layered structure. This means that semantics in this thesis are the concepts, the relationships that connect them, and descriptions of their functions, in the context of a nursing process domain.

Semantic Network

A semantic network, or frame network, is a network representing concepts, and relationships between concepts, in multiple domains of interest. This is often used as a form of knowledge representation for a ‘universe of discourse’ such as the Semantic Web.

Semantic technologies

The broad set of technologies that relate to the extraction, representation, storage, retrieval and analysis of machine-readable semantics. Examples are: ontologies, graphs and triples.

Semantic Web (SW)

The Semantic Web, or web of data, is a machine-readable evolution of the World Wide Web. The SW consists of billions of semantically linked data elements connecting simple files up to expansive ontologies representing multiple domains of interest. Berners-Lee (2011) described the Semantic Web as an extension of the current World Wide Web in which resources are given well-defined meaning, better enabling computers and people to work in cooperation.

Software robot

See robot

Term

A term in the context of this thesis is a label of a concept in a graph. A term can be a single word or a group of words.

Triple

A triple is the smallest bit of semantics in the LOD specification. It is often likened to a three-word sentence with object, predicate and subject. For example, ‘Bob knows Alice’ is a triple describing the relationship between three resources, Bob, Alice and ‘knows’. In an ontology, triples are three Uniform Resource Indicators (URIs) which point to descriptions of Bob, Alice and ‘knows’ on the Semantic Web. For example:

<http://myHospital.org.au/Emergency/people#**Bob**>

<http://foaf:**knows**>

<http://myHospital.org.au/Surgical/people#**Alice**>

Multiple triples describing some domain of interest are organised as per the Resource Description Framework (RDF), which ensures the rigid and predictable construction of ontologies, and ultimately, the Semantic Web.

Universal Resource Identifier (URI)

A URI is a global identifier of which the WWW URL address is a member. It is standardised by joint action of the World Wide Web Consortium and Internet Engineering Task Force. URIs play a key role in enabling LOD. Triples consist of three URIs that uniquely identify virtually any resource on the Semantic Web; including an individual or more abstract concepts.

Visual Understanding Environment (VUE)

Node-arc-node graph software such as VUE[1] is a visual tool that evolved from concept mapping software. This thesis uses VUE graph mapping software to record domain knowledge provided by the participants in a human readable form that can be later translated into OWL-DL (Musen, Shahar, & Shortliffe, 2001).

Because of their simplicity, VUE and its counterpart, Concept map (Cmap)[2], have been used successfully as a knowledge-acquisition methodology in Artificial Intelligence research where it is used and as an input modality for knowledge-acquiring software such as Protégé (Novak and Gowin, 2002).

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[1] http://vue.tufts.edu/resources/

[2] http://cmap.ihmc.us/

Vocabulary

A vocabulary in the Semantic Web context contains agreed upon definitions of ‘terms’ that are used to represent data. Linking your data to a vocabulary makes data self-descriptive and enables Linked Data applications to understand and integrate data across the Semantic Web (Heath and Bizer, 2011). For example, the ‘Friend Of A Friend’ (FOAF) vocabulary provides standard predicates which are used to describe human relationships (Bizer et al., 2009).

The FOAF[3] project provides a collection of basic terms that can be used in RDF/OWL triples to describe people’s activities. The ‘knows’ predicate in the ‘Bob knows Alice’ Triple, <http://foaf:**knows**>, points to the FOAF ‘knows’ property in the vocabulary which is defined in the following specification:

Property: foaf:knows

knows - A person known by this person (indicating some level of reciprocated interaction between the parties).

Status: stable

Domain: having this property implies being a Person

Range: every value of this property is a Person (FOAF, 2013)

[3] http://www.foaf-project.org/

CHAPTER TWO: Evidence of nurses using process semantics to construct ontologies

2.0 Introduction to the chapter

This chapter summarises key literature that addresses how nurses have employed semantics to develop ontologies. The first section summarises literature concerning the use of nurses to provide semantics for ontology development. The second section reviews nursing studies that link concepts by their relationships. Finally, a conclusion is made based on the application of lessons learnt in the literature, for this thesis' methodology.

2.1 Evidence of nurse process semantics to construct ontologies

An 'all resources' title search was conducted; Victoria Universities' on-line 'all resources' search includes hundreds of data bases, containing journals and e-books. The following filters were added between 1996 and 2015.

Table 1: Ontology in nursing search results

Search string	Number of results returned
Nursing node-arc-node graphs	0
Nursing LOD ontology	1
Nursing ontology	80
Nursing linked data	0
Nursing Linking of data	0
Linking of health data	10
Nursing in the semantic web	0
Health care in the semantic web	0
Clinical data on the semantic web	1
Nursing computer ontology	3

As seen in Table 1, there were 80 hits returned by the term ‘nursing ontology’ but after review of the articles, none were related to the design science methodology used in this thesis. These journal articles did not discuss computer ontologies, but were concerned with the traditional philosophical definition of ontology as it pertains to the nature of being and reality. The philosophical approach to ontology has dominated nursing literature because nursing science is concerned with different world-views that may help build nursing knowledge. There was no evidence of a computer ontology concerned with linking semantics to describe a nursing process domain. No papers mentioned nurses’ directly inputting domain semantics into the construction of an ontology.

One explanation for the lack of nursing input into the construction of process domain semantics may be that ontologies are an emerging technology, which in the main, have a difficult construction language. The language is difficult because ontologies are a complex amalgam of information technology, logic and knowledge acquisition technologies (Gruber, 2004). This may explain why ontologies have not been constructed by front-line nurses who actually perform the processes.

The review showed that computer ontologies were largely built by design and computer science experts, who failed to incorporate nurses’ interpretations. Thus, it is noted that the computer ontologies developed to date are built from so-called ‘third person’ nursing semantics, nevertheless, computer science experts have gained semantic information from other sources such as documentation (Abidi and Chen, 2006), literature synthesis (Becker, Heine, Herrler et al., 2003; Din, Abidi, & Jafarpour, 2010; Gooch and Roudsari, 2011; Hurley and Abidi, 2007; Ye, Jiang, Diao et al., 2009) or survey focus groups (Daniyal, Abidi, & Abidi, 2009).

The use of ‘third party’ nursing semantics by computer design experts has considerable limitations. Gurupur and Tanik (2012), and Anand and Verma (2010) observed that computer science researchers are usually not clinicians and clinicians are not computer science researchers. Therefore, semantic meaning developed by computer science researchers may be ‘lost in translation’ and more than likely not be a ‘true’ reflection of the semantic information. In fact, Dimitrova et al. (2008) note that nursing ontologies constructed by design and computer science experts have not delved into the process domain with sufficient granularity; rather, there is a tendency towards the capture of nursing semantics at a very superficial level.

Peace (2008) argued that nursing knowledge and practice may benefit from the use of rule and logic ontologies (OWL-DL) because they enable nurses to draw inferences from their semantics which describe patient care. Essentially, Peace (2008) used nursing clinical guidelines as a ‘knowledge-base’ for logic software ‘reasoner’ (robot) software. A reasoner compared patients against their clinical guidelines and inferred knowledge by logical deduction. Peace (2008) used a reasoner to compare semantics in the Family Health History Ontology (FHHO) and enabled logic reasoning of 21 families and their health histories. The reasoner identified 55 persons who required heightened screening regimes.

Within this review, studies have mentioned ‘benefits’ that ontologies may bring to nurses and the nursing discipline. Feigenbaum, Herman, Hongsermeier et al. (2007) suggested the implementation of semantic technologies may ‘free up’ nurses to do nursing work. An example is an ontology called ‘SAPPHIRE’[4] which integrated emergency room cases, descriptions of patients' self-reported symptoms, updated electronic health records, and clinicians' notes from eight hospitals that account for more than 30 per cent of Houston's (USA) emergency room visits. SAPPHIRE integrated the preceding information into a single view of current health conditions across the area. SAPPHIRE relieved nine nurses from doing such work manually so they were allocated for active nursing.

As no nursing ontologies were found in the literature (as summarised in the preceding section); the next section reviews nursing studies that link concepts by their relationships in a manner which is similar to the Linking Of Data specification used in ontologies. The section highlights the preponderance of structure-outcome studies which bypass the process domain.

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[4] https://www.w3.org/2001/sw/sweo/public/UseCases/UniTexas/

2.2 Linking Nurse Sensitive Indicators (NSIs) with relationships across a framework

As direct nursing input into the construction of an ontology is the goal of this thesis, conceptual relationships already established in current literature are important for knowing how a representation of a nursing domain ontology can be achieved.

2.2.1 Donabedian's conceptual framework

Many nursing studies reviewed in this thesis measure the effect of nursing activities on patient outcomes through linked NSIs across the structure-process-outcome (SPO). The SPO devised by Donabedian (1988) (Figure 2) is the dominant framework for most nursing quality studies. Donabedian (1988) believed that good structure increases the likelihood of good process, and that good process increases the likelihood of a good outcome. The SPO model continues to underline how nursing's role in patient outcomes are viewed (Health, 2010).

Figure 2: Donabedian's framework

However, the sequential progression from structure to process to outcome has been criticized by Mitchell, Ferketich, and Jennings (1998) as too linear and consequently provides limited utility for recognising how the three domains influence and interact with each other. Coyle and Battles (1999) suggest the framework fails to incorporate antecedent patient and environmental characteristics which are important precursors for evaluating quality care. Despite its detractors, Donabedian's SPO framework (Donabedian, 1988) has become the touchstone for nursing quality studies.

Donabedian's SPO framework (Donabedian, 1988) is a useful model to assist with understanding where key connections can be built in an architecture of semantic technology, and in particular, graph architecture. That is, the studies connect Nursing Sensitive Indicators (NSIs) by relationships across the SPO.

2.2.2 Definition of NSIs

NSIs are unambiguous evidence-based metrics which reflect the effectiveness of nursing care on patient outcomes (Needleman et al., 2007). The effect of nursing care processes on patient care has been until recently, difficult to measure. Efforts to systematically collect nursing quality process NSIs did not commence until the 1970s in the United States. During the pre-development phase of the International Classification of Nursing Practice (INCP), Clark and Lang (1992) introduced their case for the introduction of NSIs by stating: "If we cannot name it, we cannot control it, finance it, teach it, research it, or put it into public policy" (p.109). Recently, studies tend to place 'specialised' NSIs in each SPO domain; NSIs, therefore, may be categorised by their place in a domain.

2.2.3 NSIs in the structural domain

Structural NSIs such as 'nurse skill mix', which measure the educational levels or experience of nurses, have been criticised for being used as 'proxy' measures that fail to measure the effectiveness of nursing processes. As explained by Needleman et al. (2007), structural NSIs were often generated from hospital databases which were appealing to researchers for their ease of procurement and expedience. Also, Naylor (2007) reasoned that, because many structural measures had been sourced from administrative databases, they may be budgetary in nature not patient focussed. Naylor (2007) concluded structural NSIs sourced from administrative databases may have limited use compared to indicators generated from patient records.

2.2.4 NSIs in the process domain

Donabedian (1988) defined 'processes' as a set of activities which proceed between practitioners and patients. Unlike structural indicators, nursing process NSIs are generally not available in administrative databases. Instead, process indicators are often sourced from clinical documentation, chart audit (Doran, Harrison., Laschinger et al., 2006) and protocols and procedures (Hannah, White, Nagle et al., 2009).

Process NSIs are difficult to use as standardised measures because of differences in documentation and standards of collection from one hospital to another, and even from one unit to another (Doran, Mildon, & Clarke, 2011). Process indicators have proven elusive in the sense that they may contain ‘hidden’ processes. Needleman et al. (2007) noted many ‘hidden’ or unrecorded processes of daily nursing care are unaccounted for. In a systematic review of literature which aimed to compare and contrast available quality indicator tools, (Savitz et al., 2010) found little or no evidence of research activity identifying ‘hidden’ nursing process and their impact on patient outcome. The lack of NSIs that capture processes has become an important area identified in the recommendations of nursing bodies such as the American National Quality Forum (NQF) (2011). The NQF recommend the development of nursing process indicators with empirical-based theoretical frameworks and models. Particularly, the NQF noted, research should be undertaken to determine the relationship between patient outcomes and process indicators and that additional research should be undertaken to address a broad range of important nursing clinical processes for which no indicators exist.

Needleman et al. (2007) also noted the lack of indicators for nursing clinical processes. The researchers stated: “developing effective performance measurement systems will enable healthcare stakeholders to better understand and monitor the degree to which nursing care influences patient safety and health care quality” (p.28).

2.2.5 NSIs in the outcome domain

Like structural indicators, outcome indicators such as ‘patient mortality’ and ‘nurse burnout’, can be easily procured from ‘administrative’ databases (Doran, 2011). Consequently, outcome indicators reporting on adverse patient outcomes such as rates of nosocomial infection, falls, pressure ulcers and failure to rescue, routinely appear in the literature (Alexander, 2007). As a result, outcome indicators have been criticised for their narrow focus on adverse patient events, which may not provide a true picture of nursing outcomes that could result from nursing processes of actual care delivered.

The difficulty of acquiring NSIs from the process domain has meant a proliferation of studies that bypass the process domain in favour of structure to outcome pairings. The following studies are typical Structure-Outcome pairings.

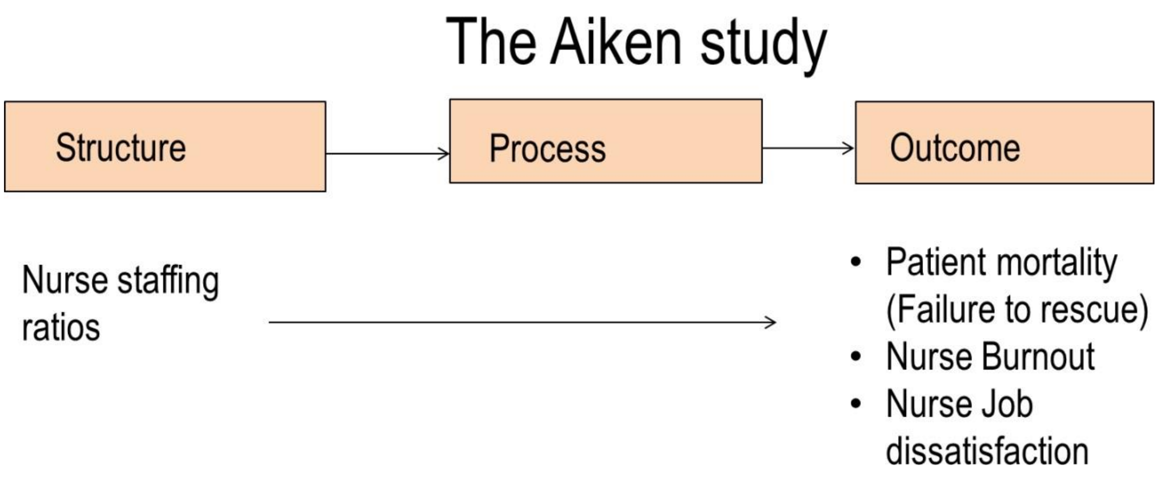
2.3 Nursing structure to outcome studies

NSIs and the SPO framework (Donabedian, 1988), described in the previous section provides a background to studies discussed in this section. This section commences with the Aiken, Clarke, Sloane et al. (2002) study and concludes with the Nursing Role Effectiveness Model (NREM) which is one of the few studies that connect all of the SPO domains. The NREM is a good 'fit' for the semantic technology used in this thesis. All studies connect NSIs in the SPO using a similar structure to graph architecture, which underpins ontology construction in this thesis. Also, these studies underline the difficulty of capturing process semantics.

2.3.1 The Aiken study

Aiken, Clarke, Sloane et al. (2002) provided the first of many studies to link NSIs between Donabedian's SPO structure (Donabedian, 1988) and outcome domains. Their cross-sectional study of administrative data included 168 non-federal adult general hospitals in Pennsylvania U.S.A. Their sample comprised 10,184 staff and 232,342 patients discharged from hospital in 1999. The study concluded that NSIs measuring nurse staffing ratios in the structure domain were linked to measures of the outcome of nurse dissatisfaction, nurse burnout and patient mortality in the outcome domain. Figure 3 illustrates NSIs and their links in the structure to outcome study by Aiken et al. (2002). To bypass the process domain, this study controlled 132 confounding variables.

Figure 3: Representation of the Aiken et al. (2002) study

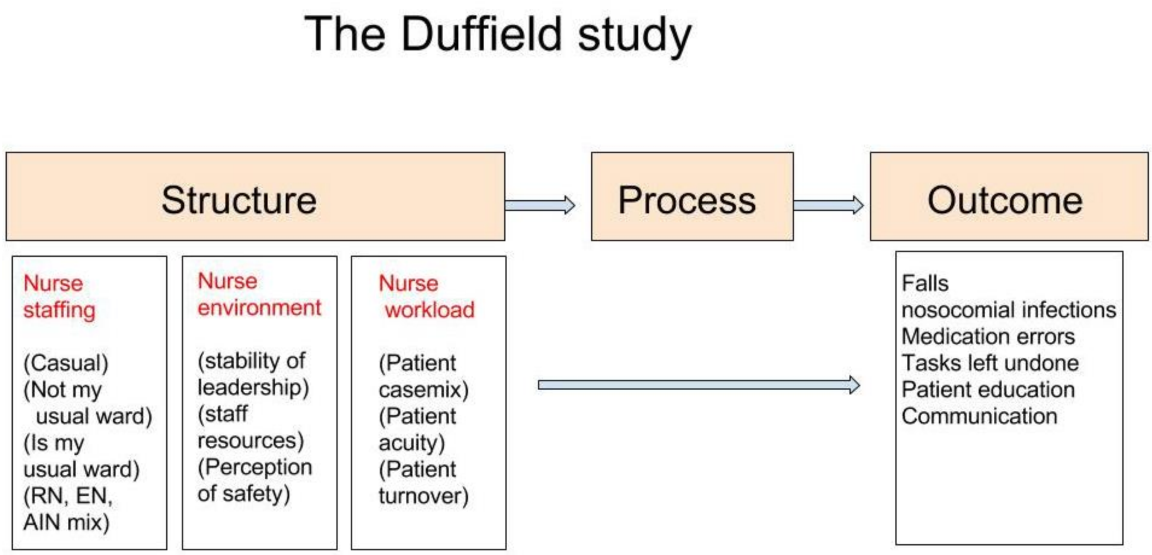


Many studies have since replicated the original approach developed by Aiken et al. (2002). Consequently, the literature is dominated by studies focussed on structure-outcome pairings. For example, impacts of various structural attributes such as nurse skill mix (Crisp, 2001), workload (Al-Kandari and Thomas, 2008), education, system design (Cheung, Aiken, Clarke et al., 2008) and operational constraints (Mark, Sayler, & Smith, 1996) on nurse and patient outcomes have been examined extensively. In a critical review of 58 studies, Hearld, Alexander, Fraser et al. (2008) found a preponderance (63%) of structure-outcome pairings. Hearld et al. (2008) concluded that overall, structure and outcome NSIs are easily obtainable from administrative databases and may account for their overuse.

2.3.2 The Duffield study

Commissioned by The Australian New South Wales (NSW) Health Department, Duffield, Diers, O'Brien-Pallas et al. (2011) conducted a longitudinal and cross-sectional study aimed at identifying strategies to improve the effectiveness of nurse staffing in hospitals. Duffield et al. (2011) suggested that Aiken et al. (2002)’s nurse staffing ratio NSI was possibly superficial and instead, proposed the measure be expanded to encompass an amalgam of staffing, environmental and workload factors. This new composite structural NSI recorded, amongst other things, staffing, leadership and safety. The study by Duffield et al. (2011) is presented in Figure 4, and shows the division of the structure domain into three categories; nurse staffing, environment and workload. Data from 80 randomly selected nursing units in 19 hospitals in New South Wales were analysed. The study compared the relationship of nurse staffing and workload at unit level to patient outcomes by examining five years of administrative data. Figure 4 illustrates the expanded structural concepts and richer semantics in the study. The study concluded that a higher number of Registered Nurses (RNs) involved with nursing care were associated with lower levels of adverse events.

Figure 4: Representation of the Duffield et al. (2011) study showing terms, concepts and links

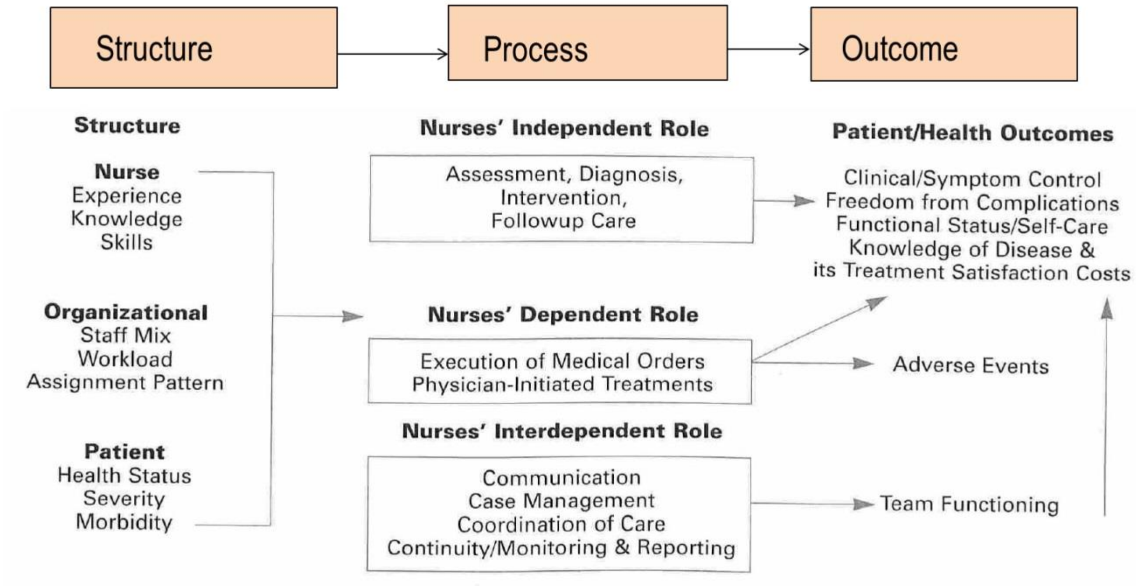


2.3.3 Irvine (Doran)'s Nursing Role Effectiveness Model

The Nursing Role Effectiveness Model (NREM) is one of the few models that describes the nursing process domain. Irvine, Sidani, and McGillis-Hall (1998) suggested that the previous structure-outcome studies failed to take into account nursing processes and suggested the NREM represents the multidimensional nature of a nursing process domain. The NREM is discussed because it provides a vital function in this thesis; it provides a 'focus' for participants when they describe their own process domain via graph drawings. Figure 5 shows the SPO with the NREM process domain. The NREM elucidates the process domain as three nursing 'roles' which are:

- *the independent role* involving processes in which a nurse acts autonomously;
- *the dependent role* which encompasses actions requiring a physician's order, and
- *the interdependent role* which covers tasks in which the nurse liaises with allied health.

Figure 5: Representation of the Nursing Role Effectiveness Model



Specific relationships across the SPO link structural-process-outcome NSIs. The NREM can be used to guide investigations of mechanisms that underlie nursing processes. Irvine et al. (1998) reasoned that the process domain provided understanding about what caused a favourable or unfavourable outcome when it is connected to factors in the structural domain. The NREM is considered as a good 'fit' for this study because of its 'graph-like' architecture, which connects NSIs by their relationships to each other. NREM roles are used in this thesis to 'focus' participant's graphs.

2.3.4 The NREM in a 'real' nursing process domain

Doran, Sidani, Keatings et al. (2002) investigated the propositions of the NREM in a real nursing process domain. Nurse and patient structural variables were expected to influence nurse processes, which in turn were expected to affect patient outcomes. Their cross-sectional study collected NSI data using chart audit from nursing documentation. Three hundred and seventy two patients and 254 nurses from 26 general medical-surgical units in a tertiary care hospital participated in the study. Using Structural Equation Modelling (SEM), they confirmed a correlation between hypothesised NSI links with 'real world' NSI links obtained from the chart audit (Doran et al., 2002).

Acquiring process semantics through chart audit is difficult. Numerous studies have proven that semantics gathered through chart audit and nursing documentation were not only costly and but also burdensome (Butler et al., 2006; Duffield et al., 2011; Sarre and

Cooke, 2009). For example, in a study aimed to identify strategies for improving the effectiveness and efficiency of nurse staffing in hospitals, Duffield et al. (2011) concluded a one year/researcher expenditure of time and effort would be required for producing process semantics.

The literature revealed nursing studies that attempted to alleviate the burden of semantic acquisition. The following section reviews nursing studies which explore manual and automated approaches that map the 'closeness' of terms from disparate sources. The reasoning is that global vocabularies can be constructed if enough 'close' terms are identified. Nursing studies generally focus on the construction of vocabularies called Nursing Minimum Data Sets (NMDS). NMDS are defined as a repository which holds the minimum set of NSIs with standardised definitions concerning a specific dimension of nursing which meets the interoperability needs of multiple data users (Werley, Devine, Zorn et al., 1991). The following studies are reviewed because they contain insights into mapping the 'closeness' of terms which is an aim of this thesis.

2.4 Manual and automated extraction of terms by comparing their 'closeness'

Goossen, Epping, Feuth et al. (1998) suggested in a review of NMDS, that the 'visibility' of nursing processes would be improved by linking similar semantics. Butler et al. (2006) constructed a NMDS of patient problems, nursing interventions and nursing outcomes for Ireland. Nursing and allied health notes were used as an authoritative source of semantics. To extract the semantics, 59 nurse experts in 11 nursing focus groups, cross-referenced patient problems, nursing interventions and outcomes discerned from nursing and allied health notes. Nurses acted as abstractors who manually acquired semantics from clinical notes that addressed patient problems, nursing diagnoses, treatments and interventions for the entire episode of nursing care. As a result, Butler et al. (2006) identified several new types of NSIs by mapping similar semantics found in existing NMDS.

Similarly, Sarre et al. (2009) used workshops to acquire semantics from a purposive sample of nine primary care nurse experts who participated in a nominal group questionnaire. The questionnaire was circulated prior to the meeting, and analysis of the responses formed the basis for structured discussion. The study was successful in generating a set of agreed NSIs considered relevant to primary care.

2.4.1 Fully automated 'rule sets' to compare semantics

To overcome the burdensome overhead of manually collecting semantics, Hardiker (2001) utilised a software 'rule set' called a 'metathesaurus' which contained rules of linguistics. The study was a completely automated attempt to map similar semantics between three data sets. A key motivation behind this work was to use the metathesaurus to produce a 'new' version of the International Classification for Nursing Practice (ICNP). To achieve this goal, the metathesaurus identified and linked similar semantics between the Nursing Intervention Classification (NIC, 2013), the Omaha System (Martin and Scheet, 1992) and the Home Health Care Classification (Saba, 1997).

The metathesaurus produced a 'new' ICNP that included 350 common NSIs mapped between the three data sets; approximately 10% of NSI had no links from the source data sets. The fully automated metathesaurus developed by Hardiker (2001) was shown to be inadequate because human intervention was required to check semantics selected by the metathesaurus. Critics of fully automated classification such as Stoilos, Stamou, and Kollias (2005) and Klein (2001) assert that fully automated classification of semantics is beyond our current knowledge acquisition technology. Consequently, many researchers attest that mapping process will stay semi-automated for the foreseeable future with domain experts eventually completing any automated classification.

The implication for this thesis is that the 'metathesaurus' is replaced by automated logic 'reasoner' software.

2.4.2 Semi-automated NSI acquisition studies

Hardiker (2003) reasoned that semi-automated semantic acquisition would proceed more efficiently if semantics were split into labels (terms) and their definitions. Hardiker (2003) employed 23 nursing abstractors and a rule set, to produce two data sets from the Nurse Intervention Classification (NIC). One data set was derived from NSI terms, and the other from their definitions. Hardiker (2003) hoped a comprehensive set of NSIs would be produced due to the relative richness of the definitions. This hope was never realised because nursing reviewers had differences of agreement about the meanings of the definitions of the NSIs. The data set was discarded.

For the data set based on terms, Hardiker (2003) initially feared the simplicity and abstract nature of terms would result in fewer NSIs. In fact, the use of terms had resulted in a more robust organisation of NSI relationships and greater coherence. For this thesis, this discovery highlighted the importance of splitting terms and their definitions. The separation of terms, relationships and definitions (annotations) reflects the logical 'semantic' structure of an ontology.

Goossen (2006) also employed a semi-automated abstractor/rule-set methodology which used an ISO specification as a rule-set. Goossen (2006) utilised nurse abstractors and the ISO 18104 (ISO, 2003) standard 'rule-set' to aid mapping of similar NSI terms between three heterogeneous data sets. Twenty four diagnostic NSIs selected in the Nursing Minimum Data Set of the Netherlands (NMDSN) were linked to 20 equivalent NSI terms from the International Classification of Functioning, Disability and Health ICF (2013) and the International Classification of Nursing Practice (ICNP, 2013). Goossen (2006) concluded that equivalent NSIs could be linked between structurally different (heterogeneous) data sets by using the ISO (2003) standard as a rule-set. The rule-set provided semantic 'rules' for splitting terms and their definitions, which enabled the linkages.

This thesis employs a semi-automated methodology that uses nurse abstractors to draw their process semantics in a graph that can be used to construct an ontology.

2.5 Chapter Two summary

This chapter has reviewed the literature which has revealed that current evidence is extremely limited in terms of any reporting of how nurses have directly inputted process semantics to construct ontologies. Although many studies in nursing care quality have applied the Structure-Process-Outcome (SPO) framework devised by Donabedian (1988), the studies frequently bypass the process domain in favour of 'easier' structure to outcome pairings.

Clearly, there have been considerable hurdles that have posed difficulties for researchers around the acquisition process semantics. The studies reviewed in this chapter have informed the development of nursing process acquisition approaches used in this thesis. One key learning from the nursing studies reviewed in this chapter was information gained about the current methodological approaches that have been applied to help understand relationships across the SPO framework. For instance, the Nursing Role Effectiveness Model (NREM) provides detail about nursing roles in the process domain. The chapter identifies the Nursing Role Effectiveness Model (NREM) as key to understanding the elements of the nursing process domain. Consequently, the NREM is a good ‘fit’ for semantic technology as the three roles form the ‘base’ to focus participants’ process domain construction. As this thesis is concerned with building knowledge about nursing processes, the NREM has been chosen to support the development of the graph architecture pivotal to the methodology of this thesis. As well, the review of nurse-related data acquisition studies reveals several salient features that have helped to decide on the use of graphs to acquire nurse processes, and software robots to rank the ‘closeness’ of terms. The next chapter details the Resource Description Framework (RDF), which underpins the structure of semantic technology including graphs and ontologies.

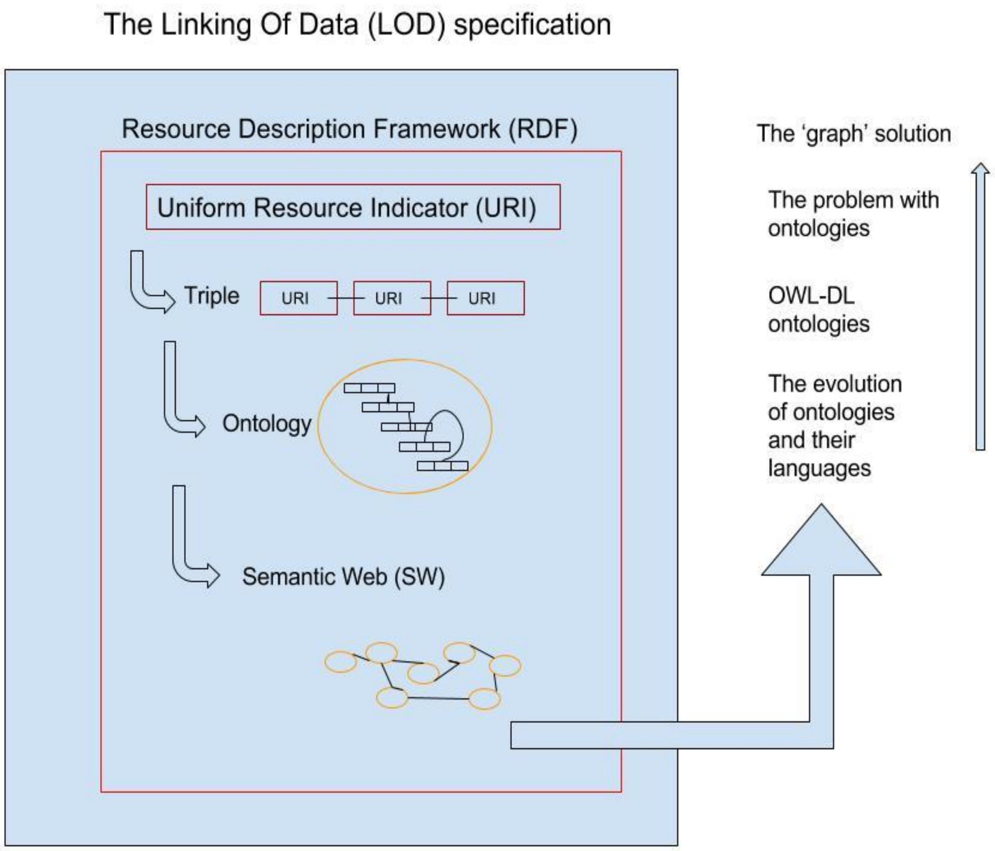
CHAPTER THREE: The Resource Description Framework (RDF)

3.0 Introduction to the chapter

This chapter describes the framework that underpins semantic technology. It describes variables and patterns that make up the Linking Of Data (LOD) specification possible. The LOD specification is described from the 'bottom up', that is, the specification is described from the smallest Uniform Resource Indicator (URI), three of which make a triple. The chapter describes how ontologies are constructed of triples and the Semantic Web is constructed of linked ontologies. This chapter discusses the evolution of ontologies and their languages and concludes with a description of graph architecture.

This thesis draws upon complex concepts that have largely been generated in the field of design science. As this study is directed to nursing audiences and not a mathematical/computer science one, the technical features are expounded to ensure access by nurses. The future of nurse-led informatics lies in the ability of nurses to integrate and utilise the technology. Also, an understanding of the technology is important so that nurses are players in the development of knowledge acquisition systems (IOM, 2011). Figure 6 is an organisational diagram of the chapter. It shows the progression of the chapter through the LOD specification.

Figure 6: Organisational diagram of Chapter 3



3.1 The Linking Of Data (LOD) specification

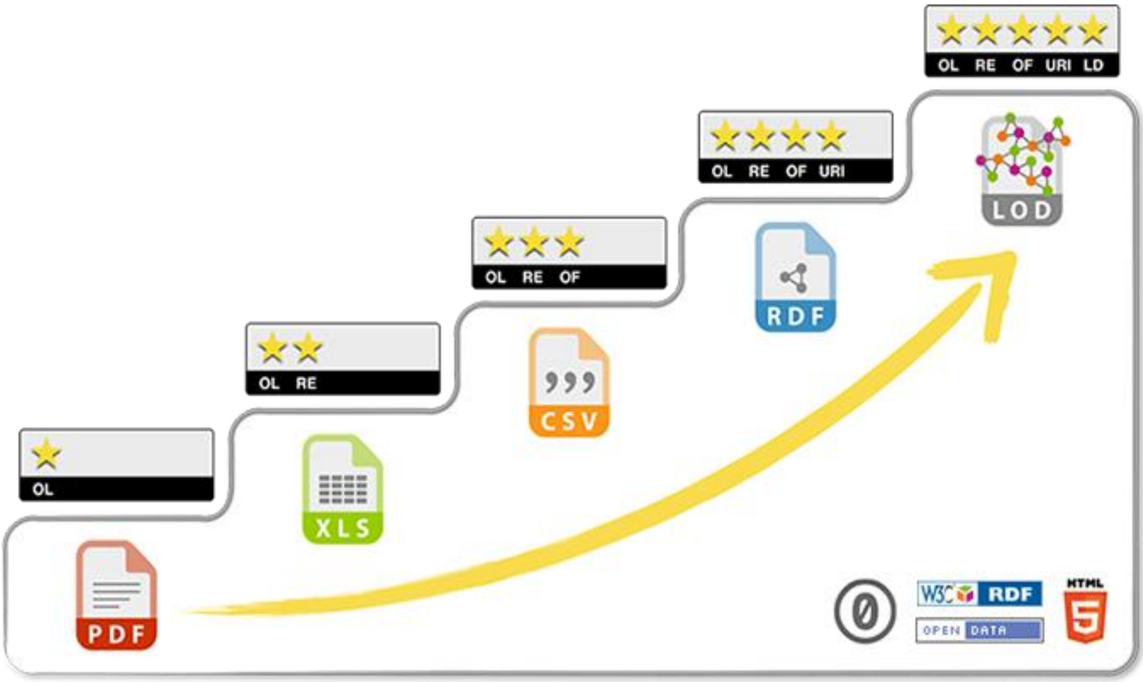
The Linking of Data (LOD) specification comprises a number of data connection specifications. The specification describes the connection of concepts using common relationships. The assumption behind LOD is that the value and usefulness of data increases knowledge when it is linked and built upon by 'better' data (Berners-Lee, 2006). The 'spine' on which all of the LOD components hang is a rigid and predictable Resource Description Framework (RDF).

3.1.1 The Resource Description Framework (RDF)

RDF is not a language per se but an organisational framework. RDF is a family of World Wide Web (WWW) Consortium (W3C) data connection specifications originally designed as a metadata data model. Basically, RDF provides the 'rules of grammar and syntax' used to organise the structure of semantic technologies.

As depicted in Figure 7, Tim Berners-Lee (2011)'s 'five stars of data connectivity' shows where RDF is positioned in a pyramid compared to other data conceptualisations.

Figure 7: Tim Berners-Lee (2011) data rating diagram



The RDF framework facilitates machine-readability by providing pre-determined, predictable LOD variables and patterns (Berners-Lee, 2011). LOD variables and patterns are discussed in the next section.

3.1.2 Uniform Resource Identifier (URI)

The smallest unit of connectivity in the LOD specification is the Uniform Resource Identifier (URI). A URI is the 'address' that points to any resource on the WWW. A resource is any document that is accessible on the WWW. The familiar Uniform Resource Locator (URL) address found in the navigation bar of any WWW browser is a form of URI (Heath et al., 2011). However, URIs serve an expanded purpose compared to their simpler WWW URL counterpart. The Semantic Web Technical Architecture Group (TAG, 2012) note that URIs serve three purposes in LOD:

- URIs provide a simple way to create globally unique names of resources
- URIs are a pointer to some resource on the Web
- URIs are a means of determining relationships between resources.

The four ‘golden rules’ of LOD coined by Sir Tim Berners-Lee (2006) are listed below:

- Use URIs as names for things
- Use URIs so that people can look up those names
- When someone looks up a URI, provide useful information, using the RDF standard
- Include links to other URIs so that they can discover more things.

In order to facilitate the connection of data to other data, RDF organises groups of three URIs into a ‘triple’.

3.1.3 The triple

A triple is the smallest ‘semantic’ unit in RDF; it represents a relationship between two concepts. Three connected URIs represent a simple sentence containing the subject (a concept), predicate (relationship) and object (another concept) (Noy, Fergerson, & Musen, 2000). Concepts can be anything that exist in a domain of interest. The domain of interest in this study is the nurses’ process domain. The nurses’ process domain may have concrete things like people, or abstract things like ‘nursing care’. For example, Bob works in an Emergency unit at a hospital and knows Alice who works in the surgical unit in the same hospital. The ‘Bob knows Alice’ triple can point to knowledge about Bob and Alice and describe their relationship. The ‘Bob knows Alice’ triple written in RDF may look like this:

<http://myHospital.org.au/Emergency/people#**Bob**> (Subject)

<http://foaf:**knows**> (Predicate)

<http://myHospital.org.au/Surgical/people#**Alice**> (Object)

Triples delineate the explicit relationship between Bob and Alice and link resources that provide more information about Bob and Alice and their relationship. The preceding triple may be linked to resources that include Bob and Alice’s addresses, employment histories or roles in a hospital (Euzenat, Mocan, et al., 2007). Triples may be almost infinitely connected to other triples to describe a nursing process domain.

The predicate URI in the preceding triple contains the word ‘knows’, which delineates Bob and Alice’s relationship. How does a computer ‘understand’ what the predicate 'knows' means? The word 'knows' is a *standard* in a vocabulary of human relationship predicates.

3.1.4 The Friend-Of-A-Friend (FOAF) vocabulary

The FOAF vocabulary provides standard predicates which are used to describe human relationships (Bizer et al., 2009). The FOAF[5] vocabulary provides a collection of basic predicates that can be used in triples to describe people's activities. For example, the 'knows' predicate in the 'Bob knows Alice' triple points to the 'knows' standard in the FOAF vocabulary which is defined in the following specification:

Property: foaf:knows

knows - A person known by this person (indicating some level of reciprocated interaction between the parties).

Status: Stable

Domain: Having this property implies being a person

Range: Every value of this property is a person (FOAF, 2013)

Vocabularies are a solution to interoperability on the Semantic Web. In the Semantic Web context, interoperability is defined as an agreement between the sender and receiver (usually two dissimilar systems), that any communications between them is understood by both parties (van Harmelen, 2008). Predicate vocabularies provide predicates whose meaning have reached consensus, and so, facilitate interoperability by ensuring that predicates are self-descriptive, understandable and standardised to both parties (Heath et al., 2011). An ontology designer may invent his/her own 'in house' predicate vocabulary or use standard predicates in a global vocabulary. Either way, using a vocabulary's predicates in a triple ensures that it is linked to a standard peer reviewed specification.

As mentioned earlier, triples may be connected to an infinite number of other triples; each new connection will serve to enhance and clarify a picture of the process domain. Ultimately, hundreds of linked triples may be used to describe a domain of interest in an 'ontology'.

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[5] http://www.foaf-project.org/

3.1.5 Definition of ontology

An ontology is a document which contains shareable standardised semantics. Semantics in the design science context are information contained in triples. That is, they contain concept names (terms), the logical relationship between concepts, and definitions (annotations) of concepts and relationships. This thesis adopts the most commonly accepted definition of an ontology: ‘a *formal, explicit specification of a shared conceptualisation’* (Gruber, 2004). The word 'formal' refers to the fact that an ontology is readable by a software agent (robot-readable), and so, excludes natural (human) language. The word 'explicit' means concepts and their relationships used to describe things in the domain and their relationships are explicitly defined. ‘Shared' reflects the notion that an ontology uses standardised semantics which are not private to some individual, but accepted by a group. ‘Conceptualisation’ refers to a concept of some phenomenon in the world (Studer, Benjamins, & Fensel, 1998). Coiera (2003) likened a concept to a photograph; it is not ‘reality’ per se, but rather a representation of reality. So basically, the definition means that an ontology is a document which specifies robot-readable, shareable, agreed-upon semantics, that represent logical concepts and relationships in some domain of interest that exists in the world (Noy et al., 2001). The ‘robot-readable’ ontologies in this thesis are constructed by triples organised in the RDF. Triples also connect ontologies to other ontologies and documents to form a global semantic network called the ‘Semantic Web’.

3.1.6 The ‘Semantic Web’

Sir Tim Berners-Lee (2006) theorised that a new web of linked data could be built using the same specifications as the WWW. The Semantic Web (SW) would seamlessly cohabit with the existing WWW by sharing ‘tried and true’ transport mechanisms such as Hyper Text Transfer Protocol (HTTP). The SW is defined by Feigenbaum, Herman, Hongsermeier et al. (2007) as a web of linked documents providing a machine-readable intelligence that would come from using standardised semantics. Machine readable intelligence, such as software robots, or ‘agents’, make inferences on semantics that go beyond the simple linguistic analysis performed by today’s search engines. Although the WWW and SW share many similarities, they differ in one respect. The WWW encapsulates the world as a collection of human-readable documents linked together in ad-hoc relationships. In contrast, the SW is a highly structured computer-readable web of data connected by standardised semantics. Computer-readability in the SW is facilitated by LOD's variables and patterns organised in the RDF's rigid specification which determine exactly how resources are related to each other (Noy et al., 2001).

Since 2006, the SW has evolved from a theory to a robust network linking billions of data by their relationships and has now become a realistic option for a world-wide information infrastructure (Heath et al., 2011). The SW maintains rigor through various working groups that regulate its core framework standards. The development of SW standards is led by the WWW Consortium (W3C)[6], which has specialist sub-groups, some of which are listed below.

The Semantic Web Best Practices and Deployment Working Group[7] provides hands-on support for developers of SW applications. This working group assists application developers by providing them with best practices in various forms including: engineering guidelines, ontology /vocabulary repositories, and educational material.

The RDF Working Group[8] updates the RDF recommendations, extending RDF to include features desirable and important for interoperability.

The Semantic Web Health Care and Life Sciences (HCLS) Interest Group[9] develops, advocates for, and supports the use of SW technologies across healthcare domains of life sciences, clinical research and translational medicine. These domains stand to gain tremendous benefit from intra and inter-domain application of SW technologies. In particular, the interoperability of information between disciplines offers an alternative to legacy applications that have been developed in isolation.

The Semantic Web Interest Group[10] **(SWIG)** provides a forum to support developers and users of SW technologies. The group helps developers create vocabularies and

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[6] http://www.w3.org/2001/sw/

[7] http://www.w3.org/2001/sw/BestPractices/

[8] http://www.w3.org/2011/rdf-wg/wiki/Main_Page

[9] http://www.w3.org/blog/hcls/

[10] http://www.w3.org/2001/sw/interest/

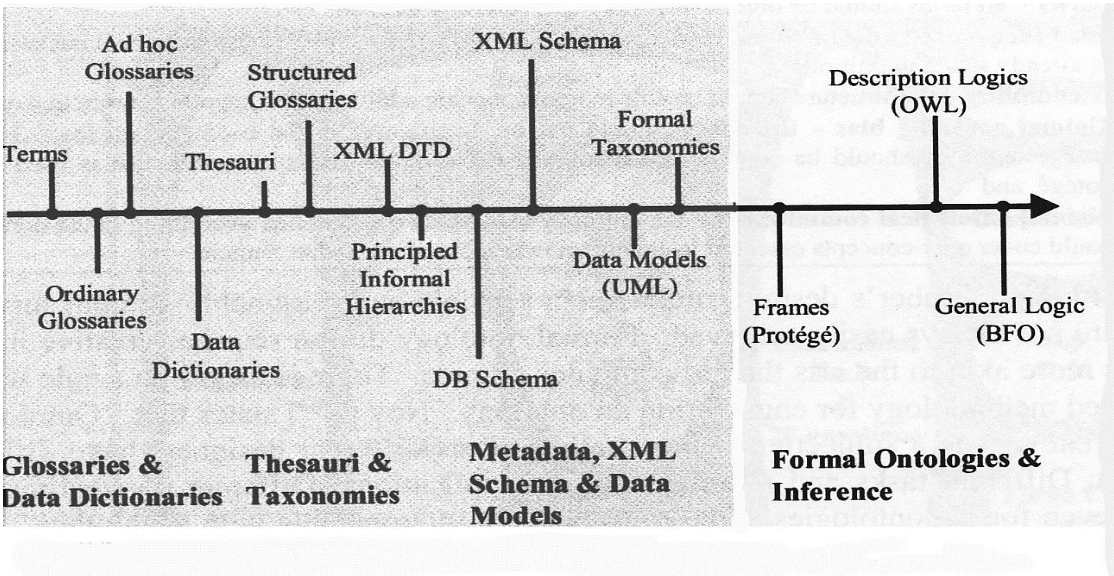
applications to support a Web data marketplace. The marketplace harvests and syndicates metadata and Web Service techniques.

This study aimed to produce domain-level OWL ontologies because they are shareable, standardised and 'robot-readable' and thus have the ability to link within the Semantic Web. The next section details the evolution of ontologies and their construction languages. The section concludes with a description of the OWL-DL ontology used in this thesis and the distribution of knowledge that defines it.

3.2 Ontology 'types' and languages

Until 1998, the definition of an ontology included anything in the shaded area of Figure 8 because, it was reasoned, each type provided some extent of data explication and, therefore, was an 'ontology'.

Figure 8: Ontology types (Madsen, 2010) adapted from (Rector, Rogers, & Bittner, 2006)



Studer et al. (1998) observed that defining an ontology by the extent of data explication was 'diluted' in the sense that so called 'light weight' representations in the shaded area of Figure 8 were considered to be ontologies. Consequently, Studer et al. (1998) proposed that ontologies should differ from such representations in at least two respects:

- ontologies have richer internal structure
- ontologies reflect some degree of consensus about their semantics which describe concepts and relationships within the domain of interest.

Guarino (1998) further differentiated ontologies from other representations by defining an ontology according to three operational levels; each level focusses on a particular task or point of view:

- Top Level: an ontology that contains general ‘event data’ which are independent of a particular problem or domain
- Domain Level: are ontologies which describe data and their relationships in a particular domain of interest
- Application Level: is an ontology that is a description of data concerning a particular task. These concepts are often specific and correspond to one role. The process of taking a blood pressure is an example.

Gómez-Pérez, Fernández-López, and Corcho (2004) further modified the Guarino (1998) classification into two levels:

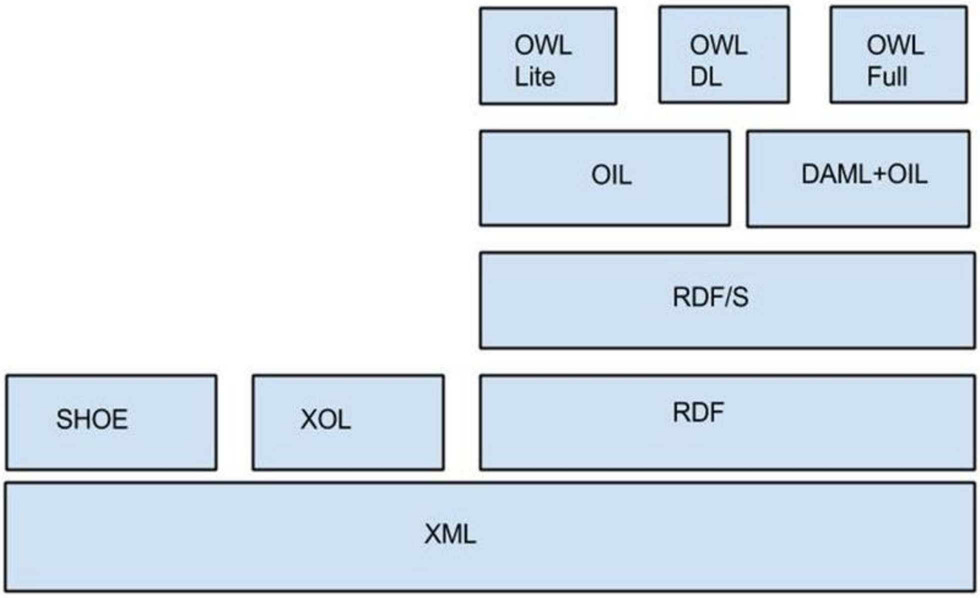
- Upper Level: an ontology which describes general data as a template for other ontologies and provides general relationships under which all data link to
- Domain Level: an ontology which can be linked to vocabularies describing standardised semantics within a domain of interest. Domain level ontologies contain axioms and constraints that determine the scope of individuals within the domain.

The knowledge represented in a domain level ontology is structured in a precise robot-readable syntax that conserves the original semantics. As ontologies developed, ontology construction languages progressed to accommodate greater expressivity and logical inference. Expressivity and inference is present in the now dominant Web Ontology Language (OWL)**.** Basically, expressivity and inference pertain to an OWL ontology’s mixture of semantics and rules of logic. That is, logic can be applied to semantics to produce ‘new’ inferred knowledge. Figure 9 illustrates the evolution of ontology languages culminating in OWL.

3.2.1 The evolution of ontology languages

The pyramid depicted in Figure 9 shows the least expressive language at the base and the most expressive (OWL) language at the top. Each language builds on its predecessor.

Figure 9: The hierarchy/evolution of WWW based ontology languages



3.2.2. The base layer: Extensible Mark-up Language (XML) is a class of objects used to describe data on the web. It was developed by an XML Working Group formed under the auspices of the World Wide Web Consortium (W3C) in 1996. Each XML document has both a logical and a physical structure. Physically, the document is composed of units called entities, which are a set of instructions that guide software to perform a certain task. Logically, the document is composed of declarations, elements, comments, character references, and processing instructions, all of which are indicated in the document by the explicit mark-up language (W3C, 2015).

3.2.3 The second layer: The Simple HTML Ontology Extensions (SHOE) is one of the first data-and-logic based languages that offered HTML annotations which described concepts in a domain of interest (Gómez-Pérez et al., 2004).

The XML-based Ontology Language (XOL) introduced a subset of language elements based on the Open Knowledge Base Connectivity (OKBC) protocol—an Application

Programming Interface (API) for accessing databases. It was developed for exchanging formal ontologies in bioinformatics and was influenced by early structure-based (XML) representation languages (Rebstock, Fengel, & Paulheim, 2008). The Resource Description Framework (RDF), as its name suggests, is not a language per se, but a framework to organise resource pointers or triples. As described previously, triples are resource pointers on the WWW describing concepts and their relationships (Berners-Lee, Hendler, & Lassila, 2001).

3.2.4 The third layer: RDF Schema (RDF/S) evolved from RDF[11]. Eventually the '/S' was discarded from the acronym after becoming a W3C standard. RDF is suitable for the construction of ontologies (Stuckenschmidt and Van Harmelen, 2005). RDF underpins a family of specifications for organising concepts which may describe people, physical objects, abstract entities or an entire domain of interest (Manola, Miller, & McBride, 2004).

3.2.5 The fourth layer: This layer contains two similar languages. Developed by the United States Defence Advanced Research Projects Agency (DARPA), the Agent Mark-up Language (DAML) is a communication language between software applications. DAML was later combined with the Ontology Inference Layer (OIL) (Hesse, 2005). OIL is an ontology language containing formal semantics derived from data and uses extensive logical deduction capabilities (Rebstock et al., 2008). DAML was combined with OIL, and together, the so-called DAML+OIL forms the basis for developing the current semantic-logic OWL language.

3.2.6 The top layer: The top layer contains three variants of OWL. The W3C approved OWL as the ontology standard in 2009, which resulted in the bulk of ontologies now being developed in OWL. OWL is a synergy of two different areas of research, knowledge acquisition and logic. Consequently OWL is often referred to as a 'frame-rule' language.

An OWL ontology's hierarchy, the structural 'skeleton', is constructed of classes, subclasses and individuals placed there by a domain expert. The expert may develop rules of class membership (constraints) which an individual must adhere to. When

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[11] http://www.w3.org/RDF/

individuals are ‘made’ (abstracted) they inherit constraints according to the ‘Frame’ theory proposed by Minsky (1974). The core of this theory is that the top-most classes called ‘Frames’ in the hierarchy contain explicit knowledge (contained in constraints). Constraints are similar to a ‘template’ or a ‘snapshot’ that is inherited by an individual when they are abstracted. An individual is ‘born’ with the constraints intact. The individual’s attributes are ‘filled in’ as the individual experiences new situations. For example, a nursing class may contain constraints that assert that a nurse individual must have a nursing registration and educational level. A new nurse is abstracted with the constraints in place; the individual may then build on its knowledge by acquiring new educational requirements and registrations (attributes) that fulfil the constraints.

OWL is called a ‘frame-rule’ language because it contains both semantic and logic components. A logic ‘reasoner’ uses rules of logic to compare class constraints against an individual’s attributes to see if they are ‘logically consistent’. That is, it checks that individuals fulfil their constraints. The reasoner may deduce implicit knowledge about the individual. For example, an individual’s details may not logically address the constraints. In each case, the reasoner ‘draws up’ a new inferred ontology with its own recommended alterations. With the amalgamation of Frame Theory and logic, OWL has become a true ‘frame-rule’ language (McGuinness and Van Harmelen, 2004).

The top level of Figure 8 shows that OWL provides three increasingly expressive sublanguages designed for use by specific communities; each of these sublanguages is an extension of its simpler predecessor.

3.2.7 OWL-Lite supports users requiring a semantic classification hierarchy with simple constraints. It provides a quick migration path from thesauri and taxonomies to ontologies.

3.2.8 OWL-DL is a ‘frame-rule’ language. Description Logics (DL) is a subset of formal logic. A software ‘reasoner’ uses DL to compare attributes against constraints to check for inconsistencies and infer new knowledge (Madsen, 2010). OWL-DL guarantees maximum semantic expressiveness while retaining logical computational rigor (Obitko, 2012) .

3.2.9 OWL-FULL is used to construct mostly informal ontologies. OWL-FULL has maximum explicit semantic expressiveness with limited logical computational inference.

It is used to semantically describe a domain where inference is not a major concern (W3C, 2013).

3.2.10 How did OWL derive its name?

The Web Ontology Language (OWL) is not abbreviated as 'WOL' as one would expect. The name is in recognition of Owl, the elder of the forest in A.A. Milne's 'Pooh' children's books. Owl can annotate semantics and is often consulted by Pooh because Owl is wise and able to read, write, and spell his own name, 'WOL'. Pooh assumes Owl to be always semantically correct as Owl is 'very good at long words'.

3.2.11 OWL ontologies are defined by knowledge content

Rebstock et al. (2008) recognised that so-called 'frame-rule' ontologies, such as OWL, can be defined by the balance between explicit knowledge placed in the hierarchy by a human and the implicit knowledge inferred by a logic software reasoner. They concluded that 'frame-rule' ontologies may be defined by the 'balance' between explicit and implicit knowledge. Guarino (1998) observed that if the ontology contains mostly explicit knowledge, it is said to be 'informal'. If the ontology contains mostly implicit knowledge, it is said to be a 'formal' ontology. Historically, Studer et al. (1998) noted that almost all ontologies were informal because they modelled explicit human knowledge.

Recently, with the advent of OWL-DL ontologies, a new 'semiformal' classification has emerged. Gruber (2004) observed that all practical ontologies are 'semiformal' and may contain a 'sweet spot' balance between formal and informal elements. Gruber (2004) described the 'sweet spot' as the perfect balance between the formal elements which facilitate logic reasoning and the informal elements which are the domain expert's well-written hierarchy. The ontologies produced in this thesis are OWL-DL semiformal domain ontologies.

Kalfoglou and Schorlemmer (2003) described the formal and informal elements of an OWL-DL ontology as the ratio O = (S:A), where S is explicit semantics and A are 'axioms' (constraints) specifying logical implicit inference.

Critics have observed that the vast majority of ontologies to date are often used to 'just link semantics together'. Eric Little (2009) challenged this notion and argued that ontologies are capable of depicting more traditional philosophical aspects of reality, that is, a nurses perception of reality. Eric Little (2009) argued that a major theoretical problem that informatics research must address is that of providing an accurate, comprehensive and consistent description of our world that computers can understand. Ontologies produced in this study are constructed from semantics describing a nurse's *perception* of his/her process domain.

In summary, OWL-DL ontologies contain explicit knowledge in the form of semantics placed in the ontology's frame-based hierarchy by a domain expert. Implicit knowledge is inferred by a logic reasoner. OWL-DL ontologies are often considered to be 'semiformal' as they have a balance between explicit (human) and implicit (inferred) knowledge.

Given the complexity of OWL-DL ontologies, it is obvious that clinicians such as nurses cannot be expected to learn LOD, OWL and RDF to construct an ontology of their process domain. The next section details the solution, which enables nurses to input their semantics which describe their process domain into the construction of ontologies.

3.3 Constructing ontologies

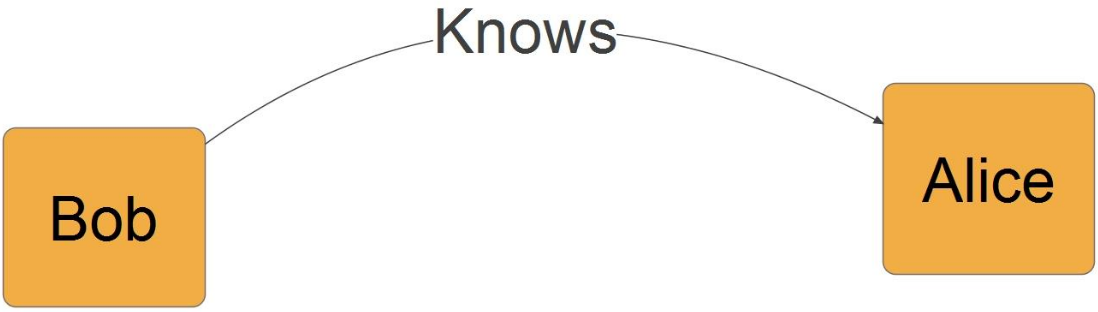
RDF triples are hard to read and write, so historically, nursing professionals have had little direct input into ontology construction that describes their process domain. Consequently, ontologies are generally written by computer science experts, who often find nursing processes and terminology impenetrable. This problem is succinctly put by Gurupur et al. (2012) and Anand et al. (2010) who observed that computer science experts are usually not clinicians and clinicians are usually not computer science experts. As a consequence, 'third person' nursing data are acquired by computer researchers from nurses and interpreted from various sources. Often the data are acquired through document interpretation (Abidi et al., 2006) , literature synthesis (Becker et al., 2003; Din et al., 2010; Gooch et al., 2011; Hurley et al., 2007; Ye et al., 2009) or surveying focus groups (Daniyal, Abidi, & Abidi, 2009; Zhen, Li, Hai-yan et al., 2009). As a result, some studies do not delve into the nurses' process domain with sufficient granularity, or only capture nursing processes on a superficial level (Dimitrova, Denaux, Hart et al., 2008).

Nurses cannot be expected to write 1000 lines of triples in RDF to describe their process domain. However, nurses can help construct ontologies by inputting their knowledge 'first hand' in a visual 'graph' language that is understood by nurses and can be used to construct an ontology.

3.3.1 Node-Arc-Node graphs

RDF is a framework for creating statements in a form of triples. Graphs are a visual representation of triples. That is, RDF triples can be made human-readable and visualised as a ‘graph’ which consists of two nodes connected by a binary relation called an arc (Hepp, 1983). Tim Berners-Lee (2007) noted that the SW is essentially a very large ‘graph’ of connected concepts and relationships. Figure 10 illustrates a graph representation of the ‘Bob Knows Alice’ triple used previously.

Figure 10: The ‘Bob knows Alice’ triple depicted as a graph



Spivak (2007) noted a graph can be made ‘semantic’ if the nodes and arcs are defined, that is, annotations may be added to describe the concepts. Using concept mapping software to import visual graphs as RDF triples into an ontology, this study enabled nursing domain experts with no knowledge of triples, RDF or ontology construction, to directly produce process domain semantics for an ontology.

3.3.2 Concept mapping Graph software

The Visual Understanding Environment (VUE[12]) is an open source concept and content mapping application developed by Tufts University. The VUE project is focused on creating simple flexible tools for visualising and integrating digital resources. VUE provides a flexible visual graph environment for structuring, presenting, and sharing ontological information. Using a simple set of tools, and a basic visual grammar consisting of nodes and arcs, nursing domain experts construct their process domain using nodes, arcs and annotations that can be imported into an ontology. Domain experts

[12] http://vue.tufts.edu/

using graphs are pivotal to this study's strategy of maintaining the integrity of nursing semantics by ensuring the direct input of semantics from front-line nurses.

3.4 Chapter Three summary

This chapter placed the study within the context of RDF, the framework that permeates the thesis. A detailed description of RDF was provided which discussed SW standards used in the construction of ontology and linking of data in this study. The chapter highlighted the problem of the loss of nursing semantic meaning caused by computer researchers constructing ontologies using 'third party' nursing semantics. The chapter describes node-arc-node graphs which nursing experts use to describe their process domain. Graphs have the added advantage in the sense that they can be used to construct an ontology.

CHAPTER FOUR: Methodology

4.0 Introduction to the chapter

This chapter describes the methodology applied to achieve the aim of this thesis: 'to acquire nursing process semantics from ontologically unskilled nursing domain experts using graphs'. The chapter describes the methodology, which draws upon design science. The chapter also details how nurse experts describe their process domain using graphs drawn in the VUE software. A usability survey is completed by the participants. Graphs are converted into ontologies which are evaluated by software 'robots'.

4.1 Justification of design science for ontology construction

Debate continues regarding the best methodologies for ontology construction. Fernández-López (1999) concluded a systematic review by stating that ontologies have no widely accepted design methodologies. Strassner, O'Sullivan, and Lewis (2007) explain the lack of an accepted methodology for ontology construction is possibly because an ontology draws from two scientific disciplines, knowledge acquisition and information systems. Consequently, Strassner et al. (2007) suggest that design science is an approach which is particularly appropriate for ontology construction because it has its roots in information technology design. Hevner, March, Park et al. (2010) and March and Storey (2008) trace the intellectual origins of design science to Herbert Simon's study of the 'Sciences of the Artificial'(Simon, 1996). March and Smith (1995) observe that design science as an approach which may facilitate abstract systems design, such as ontology. The design science approach was chosen for this thesis because:

- Researchers such as Hevner (2007) contend that disciplines which grapple with questions of design, such as information technology and medicine, benefit from a design science approach because it is essentially pragmatic in nature, due to its emphasis on usability and relevance

- Design science has its philosophical roots in ‘critical realism’.

4.1.1 The critical realism philosophical perspective

Design science is underpinned by a philosophical approach known as ‘critical realism’. Critical realism's philosophical perspective in information systems research has been advocated by a number of authors; (Dobson, 2001; Mingers, 2004; Smith, 2006) and Carlsson (2006) have all identified critical realism as having a particularly good application with design science.

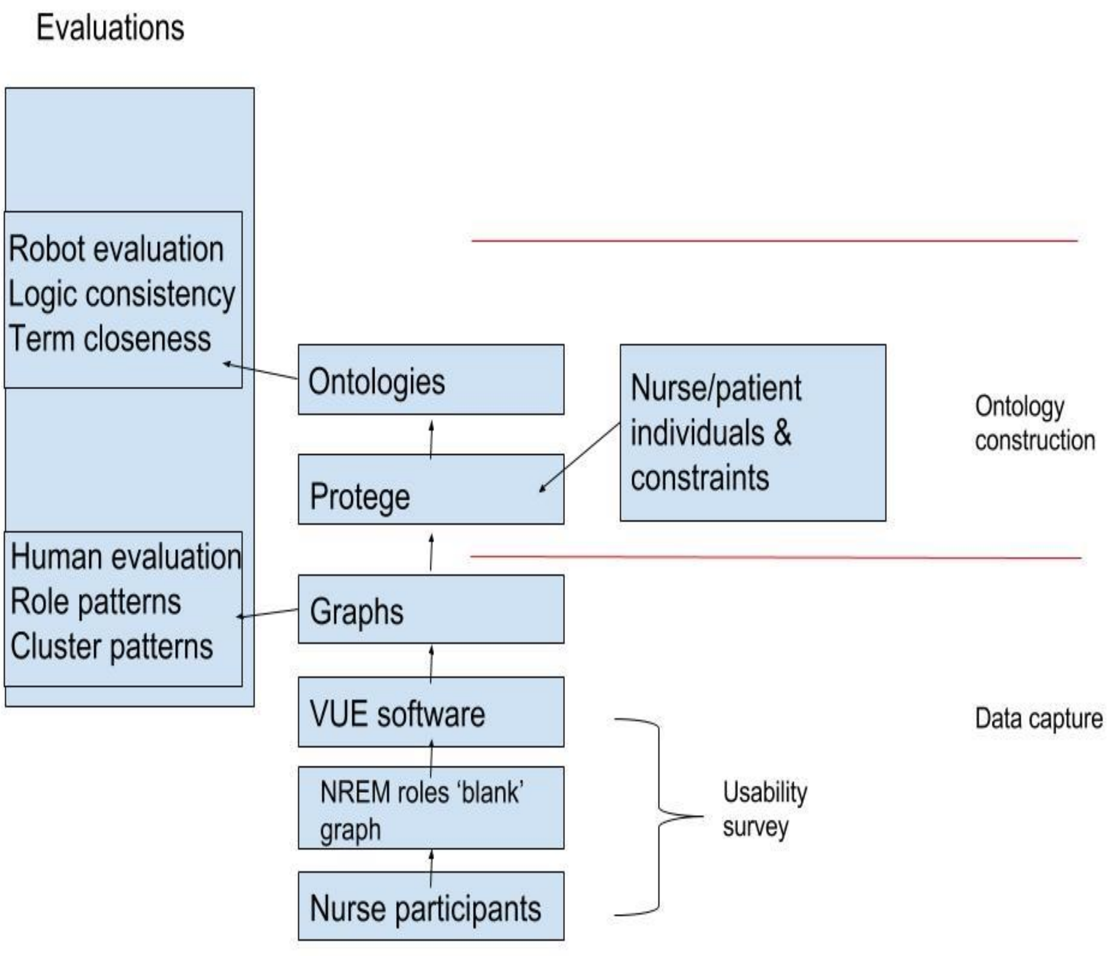
Broadly speaking, critical realism argues that there is a ‘real world,’ that is, objects exist independently from our perception of them. This idea fits well with ontology, which is not reality, but a representation of it. Critical realism is a very useful perspective in the context of this thesis because it allows for the study of abstract phenomena and their interrelationships as represented in an ontology (Bhaskar and Norrie, 1998). Critical realism also underpins the usability survey used in the thesis. The usability survey measures the user’s ‘perception’ of how well graphs represent their human reality in the form of a process domain.

4.2 Overview of the methodology

The student researcher counts patterns from graphs constructed by nursing domain experts. Patterns are the number of arcs connecting roles to participants’ concepts and the numbers of ‘clusters’ are also counted in each graph. Participants complete a usability survey to determine VUE software usability. Graphs are then used to construct ontologies that are subject to software robot analysis. Software robot analysis determines the ‘closeness of terms’ across ontologies and logic consistency of each ontology.

Figure 11 is a conceptual overview of the design science methodology applied to this thesis.

Figure 11: Conceptual overview of the design science methodology



4.2.1 The usability survey

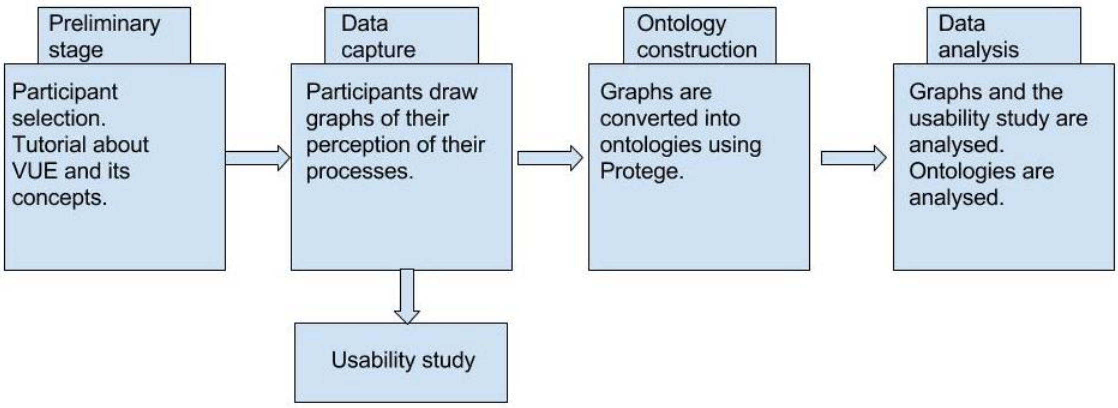
Jacob Nielsen (1994)'s usability survey has been modified for this thesis to include elements of the 'usability' of the software and an evaluation of the utility of the software to reflect the nursing process domain. Usability surveys typically determine the participants' perceptions of the software under test. This includes elements such as the flexibility and efficiency of use, the match between the system's outputs and the 'real world', and benefits to nursing. The usability survey is presented in Appendix 1.

The usability survey is a component of design science and one of the basic 'usability' evaluations of a system under test.

4.3 Detailed description of the methodology

The methodology illustrated in Figure 12 underpins the thesis' aim to acquire nursing process semantics from ontologically unskilled nursing domain experts to construct an ontology. To this end, the methodology proceeds in four logical sections. The approach reflects the design science logical flow from a preliminary stage through to data capture, ontology construction and data evaluation suggested by (Peffers et al., 2006).

Figure 12: Logical flow in design science framework (Peffers et al., 2006).



4.4 The preliminary stage

The purpose of the preliminary stage was to select and educate participants about knowledge extraction using the VUE software. Participants attended a one-hour tutorial presented by the student researcher explaining the basics of the study including aspects of knowledge acquisition, graphs and the acquisition software.

4.4.1 Participants

Prior to commencing the study, ethical clearance was sought from Victoria University Ethics Committee (Appendix 6). Purposive samples of four nurse domain experts (the participants) from different acute nursing specialities were selected. Nielsen (1994) recommends a sample of not more than five people, because he observes there is no point continuing with a large sample if there is a possibility of an inherent problem in the software being studied. The nurse domain experts were chosen by the student researcher to represent a broad spectrum of nursing expertise across emergency, transitional care, administrative and surgical specialities. The four selection criteria were:

- Participants have a minimum of 15 years nursing experience in their particular speciality
- Participants are currently working in their speciality
- Participants expressed an interest in knowledge acquisition techniques but have no working knowledge of it
- Participants have no previous experience with VUE software.

4.4.2 Setting

The setting was a quiet, convenient location in the participant's facility. VUE software was loaded onto computers and demonstrated by the student researcher. Appendix 2 is the outline of the day's knowledge acquisition for nurses' program which included two handouts. The first (Appendix 3) was a data visualisation handout and the second (Appendix 4) an introduction to the VUE software. The student researcher explained that VUE provides a simple 'point and click' flexible visual environment for structuring, presenting, and sharing knowledge. The student researcher had no input in the graphs other than to guide the participant through software issues.

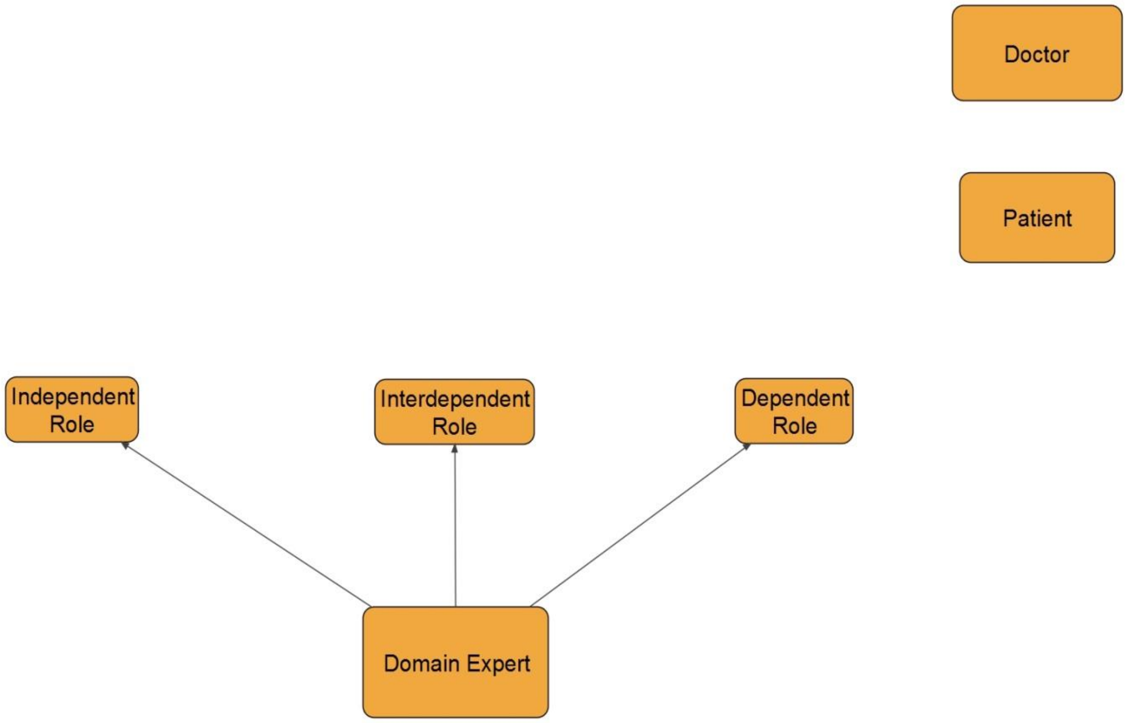
4.4.3 The 'starting point' graph

An identical base-line graph (Figure 13) was given to each participant. The graph was a common 'starting point' which contained three 'nursing roles', and a 'doctor' and 'patient' node. The nursing roles were derived from the Nursing Role Effectiveness Model (NREM) (Doran et al., 2006):

- Independent: roles in which nurses act independently
- Interdependent: roles in which nurses consult with allied health
- Dependent: roles in which nurses follow a doctor's orders.

The nursing roles provided a process domain 'focus' for the graph and a common 'base' from which the experts linked their own nodes.

Figure 13: The empty 'starting point' graph



4.5 The data capture stage

Each participant constructed one graph representing his/her perspective of the process domain. At the conclusion, a usability survey was conducted. The data capture stage proceeded in the following four steps:

- The participants constructed graphs using the VUE software
- Graphs were checked and de-personalised by the student researcher
- Graphs were checked by their authors and changed if necessary
- Participants completed a usability survey.

4.5.1 Graph construction by participants

Participants with no previous experience of knowledge acquisition and node-arc-node graphs were asked to consider their roles in their process domain. That is, they were asked to consider concepts they interact with and their relationships to the concepts. They were informed that concepts in the process domain could be concrete objects such as doctors and patients or abstract concepts such as 'nursing care'.

Participants used the VUE graph software to draw one process domain, each containing multiple node-arc-nodes. Node-arc-nodes consist of two concepts (nodes), connected by a relationship (arc). Participants placed annotations that explained the nodes and relationships in the node-arc-node. Participants provided the labels for nodes and arcs. The participants then connected arcs from their concepts to three NREM roles supplied in the graph.

4.5.2 Instruments

- Computers which were accessible to the participants
- Visual Understanding Environment (VUE[13]) node-arc-node graph acquisition software
- A usability survey questionnaire (Appendix 1).

4.5.3 Types of data obtained from VUE

VUE software captures domain semantics comprised of:

- Nodes: nodes represent concepts
- Arcs: arcs represent relationships
- Annotations: plain language descriptions explaining the functions of each node and arc
- Terms: labels of concepts.

4.5.4 The usability survey

The usability survey in Appendix 1 is informed by Nielsen (1994). The survey encompasses the following topics.

- Representation of the actual work environment, that is, how closely does the graph represent real-world conventions?
- Suitability for the task—is the interface suitable for the task and the user's skill level? Is it easy to use? In an interface that is suitable for the task, the user is enabled to focus on the task itself rather than the technology chosen to perform that task.

[13] http://vue.tufts.edu/

- Suitability for learning—does the interface support learning? Does the interface give the user an insight into their work environment?

Outputs from this stage are:

- VUE and starting graph loaded into laptops
- Completed graphs
- Completed usability surveys.

4.6 The ontology construction stage

The purpose of this stage was to construct OWL-DL ontologies from graphs. The stage proceeded in four steps:

- The student researcher exported participants' graphs as RDF into the Protégé development platform
- The Protégé ontology development platform was used to construct OWL-DL ontologies
- The student researcher added identical fictitious 'test' individual nurses and patients and their class/individual constraints to each ontology
- The student researcher concluded a manual 'double-check' of semantics between graphs to ontologies.

4.6.1 Instruments

- The VUE software
- Protégé 4.0 ontology development platform
- Individuals and constraints.

4.6.2 Exporting four graphs into Protégé

The student researcher exported each of the participants' graphs from VUE software into the Protégé ontology development program. Protégé produces OWL-DL ontologies which are equivalent to the participants' graphs. Each node-arc-node in each graph was checked manually against its equivalent in the ontology to detect any semantic errors which may have occurred as a result of the graphs being exported into Protégé.

4.6.3 Adding fictitious ‘test’ nurses, patients and their constraints

Identical class constraints and fictitious ‘test’ nurses, patients and their attributes were added to each ontology by the student researcher. The purpose of individuals and their attributes is to simulate a ‘real world’ nursing unit which may contain people. The logic ‘reasoner’ robot compares individual’s constraints and attributes against their class constraints to ascertain the ontology’s logic consistency. Class constraints, four ‘test’ patients and three ‘test’ nurses were added. Individuals were given attributes to fulfil their constraints.

4.6.4 Class constraints for fictitious ‘test’ patients

Table 2 shows the constraints for the patient class. Universal constraints mean a patient *must* have this constraint. An asymmetric constraint is optional.

Table 2: Class constraints for a patient

Subject	Predicate	Object	Constraint type
Patient	Has	Diagnosis	Universal
Patient	Has	Medication	Asymmetric

4.6.5 Class constraints for the fictitious ‘test’ nurses

Table 3 shows nurses *must* have education levels, designations and a registration.

Table 3: Class constraints for a nurse

Subject	Predicate	Object	Constraint type
Nurse	Has	Nurse designation	Universal
Nurse	Has	Nurse education level	Universal
Nurse	Has	Registration	Universal

4.6.6 The nurse and patient individuals

Nurse and patient classes were populated with ‘test’ nurse and patient individuals in Tables 4 and 5. Random attributes were added to ‘fulfil’ their constraints. Although it may seem flippant, names of individuals were selected from Douglas Adams’ book ‘Hitchhiker’s Guide to the Galaxy’. Characters from contemporary literature are commonly used placeholder names. They are normally used in fields such as cryptography, game theory and physics (Schneider, 1996). Basically, the names are used for convenience. The names of Douglas Adam’s characters are convenient for demonstrating linking to external resources from an ontology.

Table 4: Constraints and attributes for four individual ‘test’ patients

Patient name	**Class constraint**	**Attribute**
Gag Halfrunt	Has medication	Salbutamol
	Has diagnosis	Insufficient gas exchange
Gogrilla Mincefriend	Has medication	Colchicine
	Has diagnosis	Gout
Googleplex Starthinker	Has medication	Esomeprazole
	Has diagnosis	Gastric reflux
Mavis Garkbit	Has medication	Enalapril

Likewise, in Table 5, nurses have random attributes to ‘fulfil’ their constraints.

Table 5: Constraints and attributes for three individual ‘test’ nurses

Nurse name	**Class constraint**	**Attribute**
Jane Arkleseizure	Has a nurse education level	Bachelor of nursing
	Has a nurse designation	Clinical nurse specialist
	Has registration	Yes
Zaphod Beebelbrox	Has a nurse education level	PhD
	Has a nurse designation	Nurse researcher
	Has registration	Yes
Slarty Bartfast	Has a nurse education level	Bachelor of nursing
	Has a nurse designation	Nurse educator
	Has registration	Yes

The result of the preceding tables was that identical class constraints, ‘test’ patients, nurses and their attributes were in-place in each ontology to facilitate a logic consistency check by the software reasoning robot during the data evaluation phase.

4.7 Data evaluation

Instruments used for data evaluation were:

- The participants' graphs
- The FaCT++ logic reasoner
- The OnAGui semantic comparison robot.

Data evaluation falls into these two categories, human (graph) and robot (ontology), described in the following sections.

4.7.1 Human evaluation

Human evaluation involved identifying and recording patterns concerning NREM roles and identifying and recording the types of 'clusters' in each graph.

4.7.2 Pattern of NREM roles

The number of arcs from each role represents the role 'focus' of the graph. The role focus is the mixture of dependent, independent and interdependent arcs the graph contains. Hence, the numbers of arcs related to the three NREM roles in the graph were counted to ascertain the pattern of process 'dependency'.

4.7.3 Pattern of the number of clusters in each graph

Clusters in the context of this study are defined as four or more nodes surrounding a central node. The numbers of clusters in the graph were counted to indicate areas of increased nursing activity.

4.7.4 Robot evaluation

Two robots were used to evaluate the closeness of terms and logic consistency of the ontologies.

4.7.5 Term 'closeness' ranking

Terms are the labels which participants place on their nodes. Terms are compared across each of the four ontologies using the OnAGUI semantic robot which ranks term 'closeness' (Charlet, 2012). If similar terms appeared across the ontologies, a 'global' vocabulary of nursing terms may be constructed. The 'closeness' decimal is calculated by an I-Sub algorithm which measures the number of edits required to make two terms identical (Hu and Qu, 2008). A number '1' is an exact match. OnAGUI was set to reject term matches lower than 0.7 as per recommendations made by Euzenat and Shvaiko (2007).Terms supplied in the 'blank' graph, such as NREM role names and the term 'Patient' and 'Doctor', are discounted in the comparison. This is because the terms were supplied in the 'blank' graphs and consequently would obviously appear in each graph.

OnAGUI produced the following results:

- Terms which ranked above 0.7 across all four ontologies
- Tables showing each ontologies common and unique terms compared to other ontologies
- A matrix diagram showing identical terms as possible ontology connection points.

4.7.6 Logic reasoning

The description logic reasoner FaCT++[14] was bundled in the Protégé development platform. The reasoner checks each ontology's logic consistency and each ontology is either consistent or inconsistent. The robot scans to see if each individual has the correct attributes for their constraints and that each class has individuals that comply with constraints. As part of the scan, the robot checks each ontology's hierarchy for classes that may have 'faulty' constraints. For example, classes may contain constraints where it is not possible to have individuals or there may be 'orphan' individuals that cannot be a member of any class.

4.7.7 Chapter summary

In this chapter, design science has been explained as the overarching methodology employed to achieve the thesis' aim. Given the lack of development in ontology development to support nurses' processes of care, design science offers a useful approach to achieve developing knowledge in this field. Each stage of the methodology, that is the preliminary stage, data capture stage, ontology construction stage, and data evaluation stage has been described in detail. The next chapter provides results of the graph and ontology evaluation.

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[14] http://owl.cs.manchester.ac.uk/tools/fact/

CHAPTER FIVE: Results

5.0 Introduction to the chapter

Results are presented in four main sections:

- The participants' graphs
- Patterns in graphs
- Participants' usability survey
- The robot (ontology) evaluation.

The first section in this chapter commences by presenting each graph in turn. In the second section, two patterns in each graph are presented. The first pattern is the number of NREM arcs, and the second, the number of clusters in each graph. In the third section, the results of the usability study are presented and the final section includes the robot evaluation. The robot evaluation consists of the ranking of terms 'closeness' between the ontologies followed by tables showing terms which are unique and common across the ontologies.

5.1 The participants' graphs

The following section shows four process domain graphs. The arcs connected to NREM roles are shown in different colours for clarity as follows:

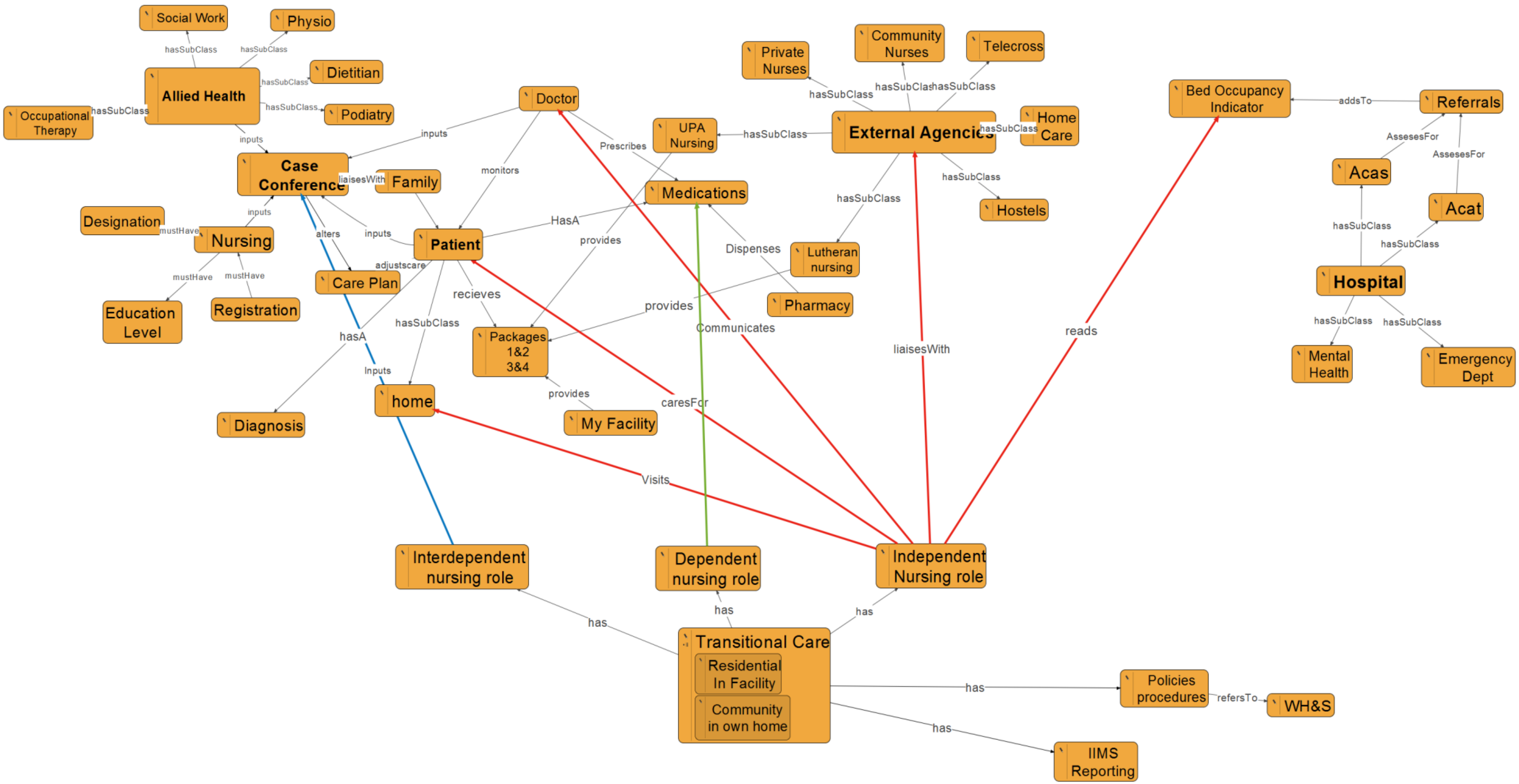
- Independent (things nurses do autonomously) (Red)
- Dependent (things nurses do ordered by a doctor) (Green)
- Interdependent (things nurses do with other health disciplines) (Blue).

In each graph, the coloured arcs denote the participants' perception of how their processes 'fit in' with the previously supplied NREM roles.

5.1.1 The process domain graph from the transitional nursing care perspective

Figure 14 depicts the transitional care process domain graph. The transitional care participant identified five arcs from the independent role, one arc from the dependent role, and one arc from the interdependent role. Clusters appear around nodes denoted as the ‘allied health’, ‘case conference’, ‘patient’ and ‘external agencies’.

Figure 14: Transitional nurse graph showing links to NREM roles[15]

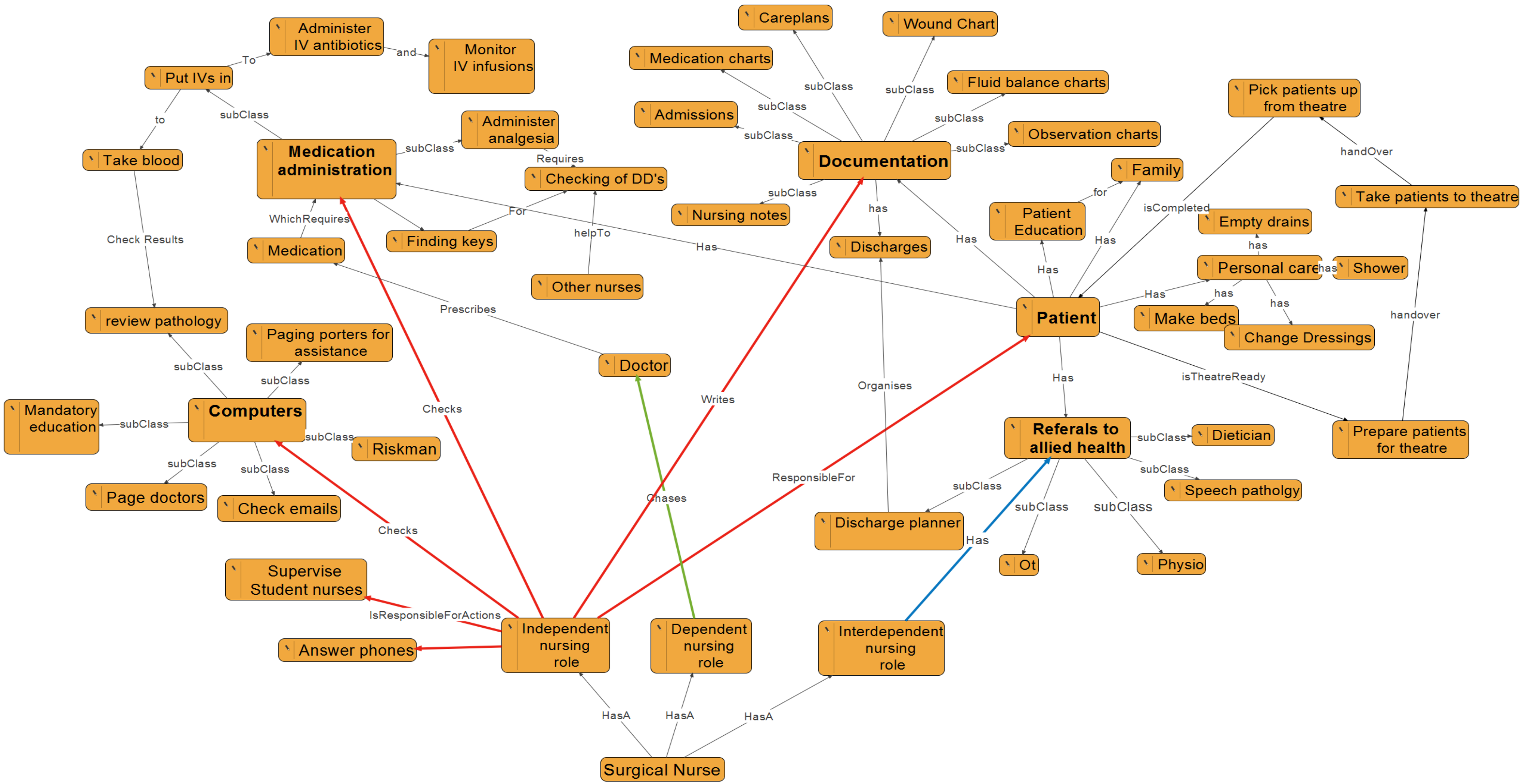


15 http://philshields.altervista.org/transitional/transitional_nurse.html

5.1.2 The process domain graph from the surgical nursing care perspective

Figure 15 is the surgical process domain graph. The surgical participant identified six arcs from the independent role, one arc from the dependent role, and one arc from the interdependent role. In comparison to the previous transitional care and following administrative and triage graphs, this surgical graph contains the most arcs radiating from the independent role and the most clusters. Five clusters in this graph are: 'computers', 'medication administration', 'documentation', 'patient' and 'referrals to allied health'.

Figure 15: Surgical nurse graph showing links to NREM roles[16]



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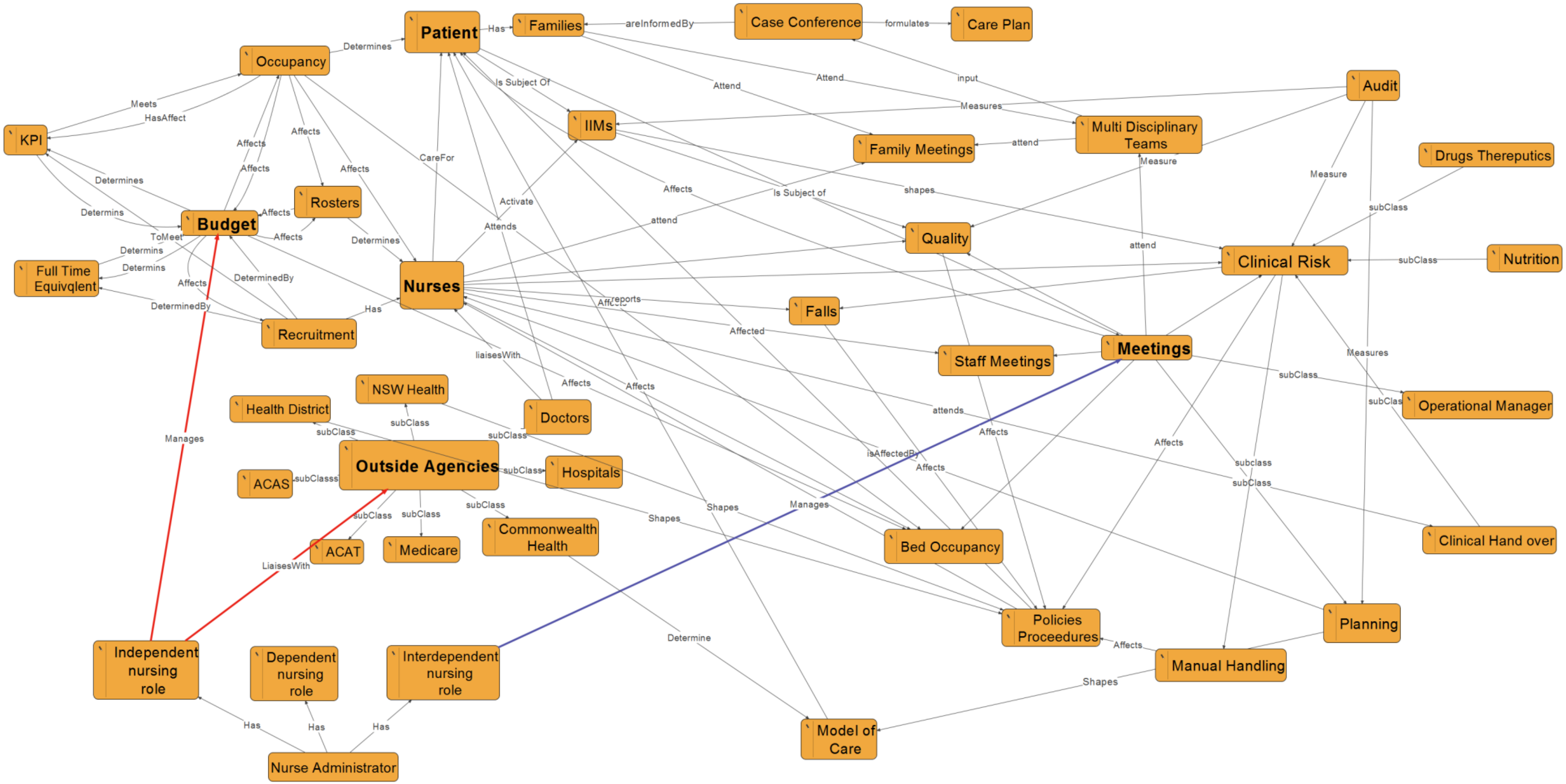
[16] http://philshields.altervista.org/surgical/surgical_nurse.html

5.1.3 The process domain graph from the administrative nursing care perspective

Figure 16 is the administrative process domain graph. The administrative participant identified two arcs from the independent role, no arcs from the dependent role, and one arc from the interdependent role. Five clusters can be seen in the graph: ‘budget’, ‘nurses’, ‘patient’, ‘outside agencies’ and ‘meetings’.

Figure 16: Administrative nurse graph showing links to NREM roles[17]

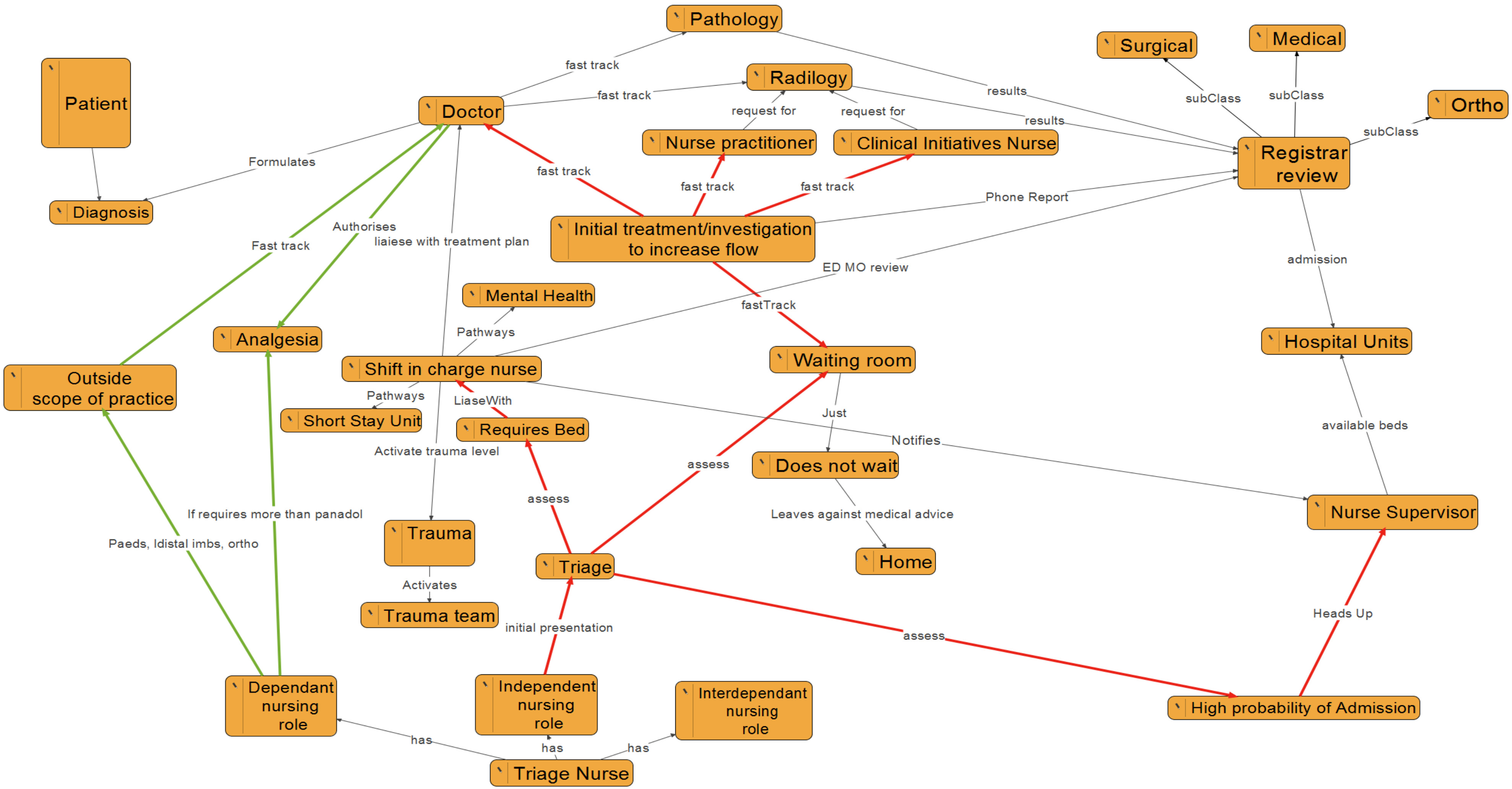


[17] http://philshields.altervista.org/administration/administrative_nurse.html

5.1.4 The process domain graph from the triage nursing care perspective

Figure 17 is the graph of the triage process domain. The participant identified one arc from the independent role and two arcs from the dependent role. There are no interdependent roles marked. This graph is different from the previous three graphs in that the participant identified no clusters. Also, many arcs terminate at other staff members such as doctor, nurse practitioner, shift in charge nurse and nurse supervisor. The patient was placed off to the side of the graph because: ‘the patient concept would encompass the entire graph’ as commented by the participant and the graph would lose readability. It is beyond the scope of the thesis to theorise on the nurse’s perception of the patient’s position in the graph.

Figure 17: Triage nurse graph showing links to NREM roles[18]



[18] http://philshields.altervista.org/triage/triage_nurse.html

5.2 Patterns in graphs

This section displays in table format the number of NREM arcs in each graph as well as the number and type of clusters in each graph.

5.2.1 The number of NREM arcs in each graph

Table 6 shows the number of dependent, independent and interdependent roles in each graph.

Table 6: The number of arcs connected to NREM roles in each individual graph

NREM roles	Transitional graph	Surgical graph	Administrative graph	Triage graph
Independent	5	6	2	1
Dependent	1	1	0	2
Interdependent	1	1	1	0

5.2.2 The number of 'clusters' in each individual graph

Each graph may contain visually identifiable clusters. The cluster name and the number of clusters in each graph appear in Table 7.

Table 7: The number of clusters in each graph

Transitional graph clusters (4)	Surgical graph clusters (5)	Administrative graph clusters (5)	Triage graph clusters (0)
Case conference	Medication administration	Budget	
External agencies	Computers	Outside agencies	
Patient	Documentation	Meetings	
Allied health	Patient	Patient	
	Referrals to allied health	Nurses	

5.3 Participants' usability survey

The survey gauged participants' perceptions of the ease of use, usefulness and application of VUE software for representing the nursing process domain. The results of the survey are presented in Table 8.

Table 8: Usability survey results

Participant	**Participant's years in nursing**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
Triage	15	8	9	7	7	9	9
Surgical	20	7	4	6	8	8	9
Administration	41	10	5	9	10	10	10
Transitional	38	10	4	1	10	10	10
Mean	28.5	8.75	5.5	5.75	8.75	9.25	9.5

The survey form is displayed in Appendix 1. As a guide to Table 8, questions 1-6 are presented below. Each question was presented as a 0-10 Likert scale with 0 representing least and 10 most.

Q1: Representation of your actual work environment.

How close did the completed graph represent your real-world work environment?

Q2: User skill level.

How would you rate your computer skill level?

Q3: How would you rate the usability of the software for your skill level?

That is, how easy was the software to use?

Q4: Suitability for learning.

Do you think the process of drawing graphs would be a useful teaching tool?

Q5: Fit for purpose.

Do you think the graph tool would be useful in analysing your clinical environment?

Q6: Workplace insight.

Did the process of drawing a graph give you better insight into your workplace?

5.4 The robot evaluation of ontologies

The previous graphs (Figures 13 to 16) were imported into the Protégé development platform and four OWL-DL ontologies were constructed. Each graph has a corresponding ontology based upon the semantics, that is the terms, or names of concepts, and constraints.

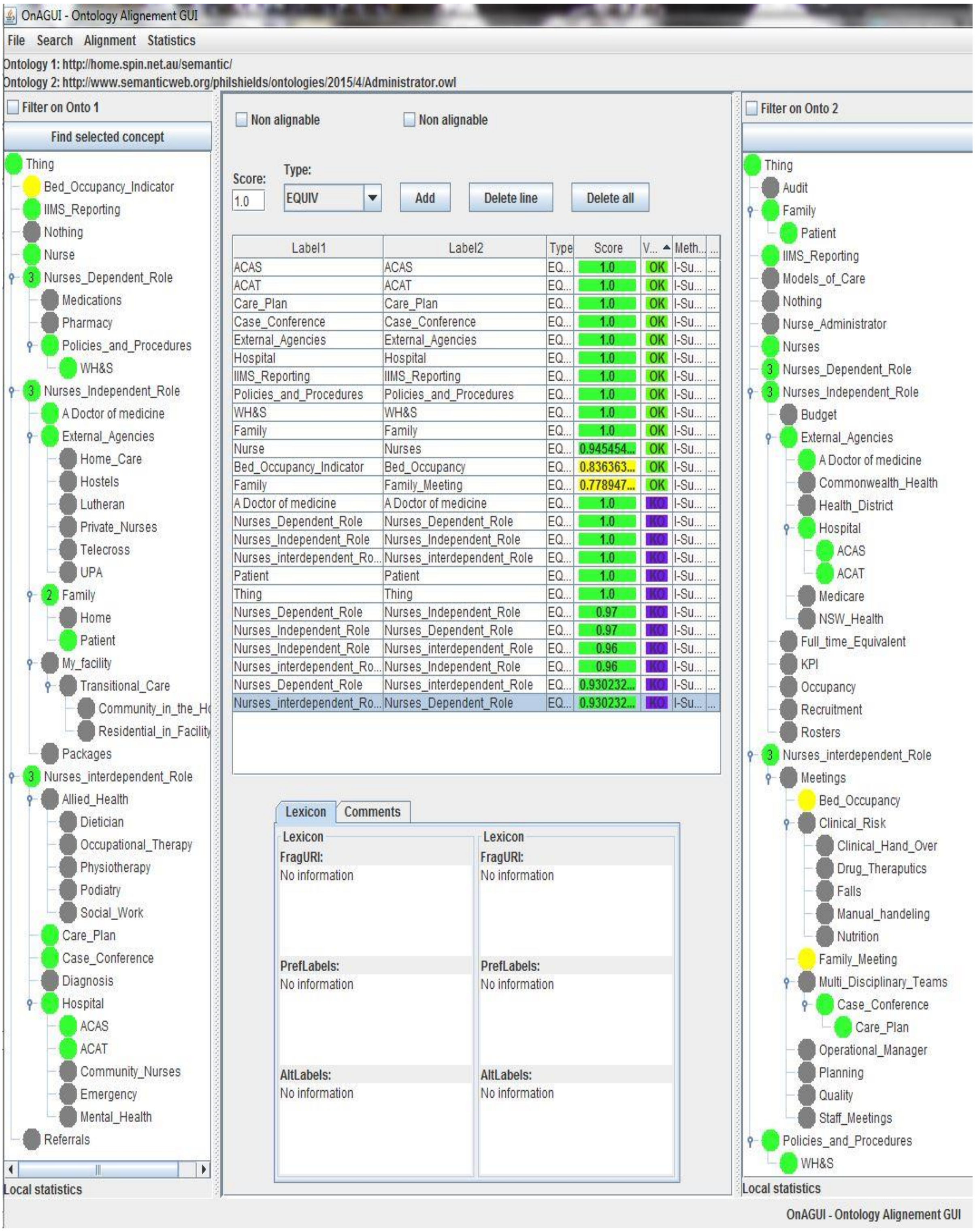
This section presents the results of comparison of terms and their ranking and logic consistency by the OnAGUI textual ranking robot and FaCT++ logic reasoning robot respectively.

5.4.1 Ranking of terms by the OnAGUI robot

As mentioned in Chapter Four, ranking of terms, in the context of this dissertation, is about using the OnAGUI robot's 'I-Sub' algorithm to compare textual 'closeness' between two terms in different ontologies. An I-Sub number of '1' indicates an exact match between two terms. A decimal below '1' indicates a decreasing match. The I-Sub algorithm was set to 'cut-out' and ignore any match below 0.7 as per the recommendation by Euzenat and Shvaiko (2007).

Figure 18 is a screen-shot example of the OnAGUI ranking of terms between the transitional care and the administrative ontologies. The scanned transitional care ontology is shown in the left column, the centre column displays the ranking results, and the scanned administrative ontology is in the right column. Terms marked with purple squares in the centre column are 'invalid' because they were terms given to the participants at the start of the study describing nursing roles, doctor and patient.

Figure 18: OnAGUI textual ranking screen-shot.



Tables 9 to 14 contain results of the ranking of terms, two ontologies per table. OnAGUI tries to match 'similar' terms in each ontology. One term from each ontology appears in the first two columns and the last column contains the I-Sub 'closeness' number for each term match.

Table 9: Term ranking between transitional care and administrator ontologies

Transitional care terms	Administrator terms	I-Sub Number
Family	Family_Meeting	0.778
Bed_Occupancy_Indicator	Bed_Occupancy	0.836
Nurse	Nurses	.945
Aged Care Assessment Services (ACAS)	Aged Care Assessment Services (ACAS)	1.0
Aged Care Assessment Team (ACAT)	Aged Care Assessment Team (ACAT)	1.0
Care_Plan	Care_Plan	1.0
Case_Conference	Case_Conference	1.0
External_Agencies	External_Agencies	1.0
Hospital	Hospital	1.0
Incident Information Management System (IIMS) Reporting	Incident Information Management System (IIMS) Reporting	1.0
Policies_and_Procedures	Policies_and_Procedures	1.0
Work Health and Safety (WH&S)	Work Health and Safety (WH&S)	1.0
Family	Family	1.0

Table 10: Term ranking between transitional care and triage ontologies

Transitional care terms	Triage terms	I-sub number
Home_Care	Home	0.8
Hospital	Hospital_Units	0.857
Mental_Health	Mental_Health_Team	0.914
Nurse	Nurse	1.0
Diagnosis	Diagnosis	1.0
Home	Home	1.0

Table 11: Term ranking between transitional care and surgical ontologies

Transitional care terms	**Surgical terms**	**I-Sub number**
Patient	Patient_Education	0.765
Physiotherapy	Physio	0.778
Medications	Medication_Charts	0.800
Medications	Medication	0.971
Care_Plan	Care_Plan	1.0
Nurse	Nurse	1.0
Dietician	Dietician	1.0
Family	Family	1.0

Table 12: Term ranking between administrator and triage ontologies

Administrator terms	**Triage terms**	**I-Sub number**
Medicare	Medical	0.831
Hospital	Hospital_Units	0.857
Nurses	Nurse	.945

Table 13: Term ranking between administrator and surgical ontologies

Administrator terms	**Surgical terms**	**I-Sub number**
Patient	Patient_Education	0.765
Family_Meeting	Family	0.778
Nurses	Nurse	.945
Care_Plan	Care_Plan	1.0
Family	Family	1.0

Table 14: Term ranking between triage and surgical ontologies

Triage terms	**Surgical terms**	**I-Sub Number**
Pathology	Review_Pathology	0.75
Pathology	Speech_Pathology	0.75
Medical	Medication	0.751
Patient	Patient_Education	0.765
Nurse	Nurse	1.0

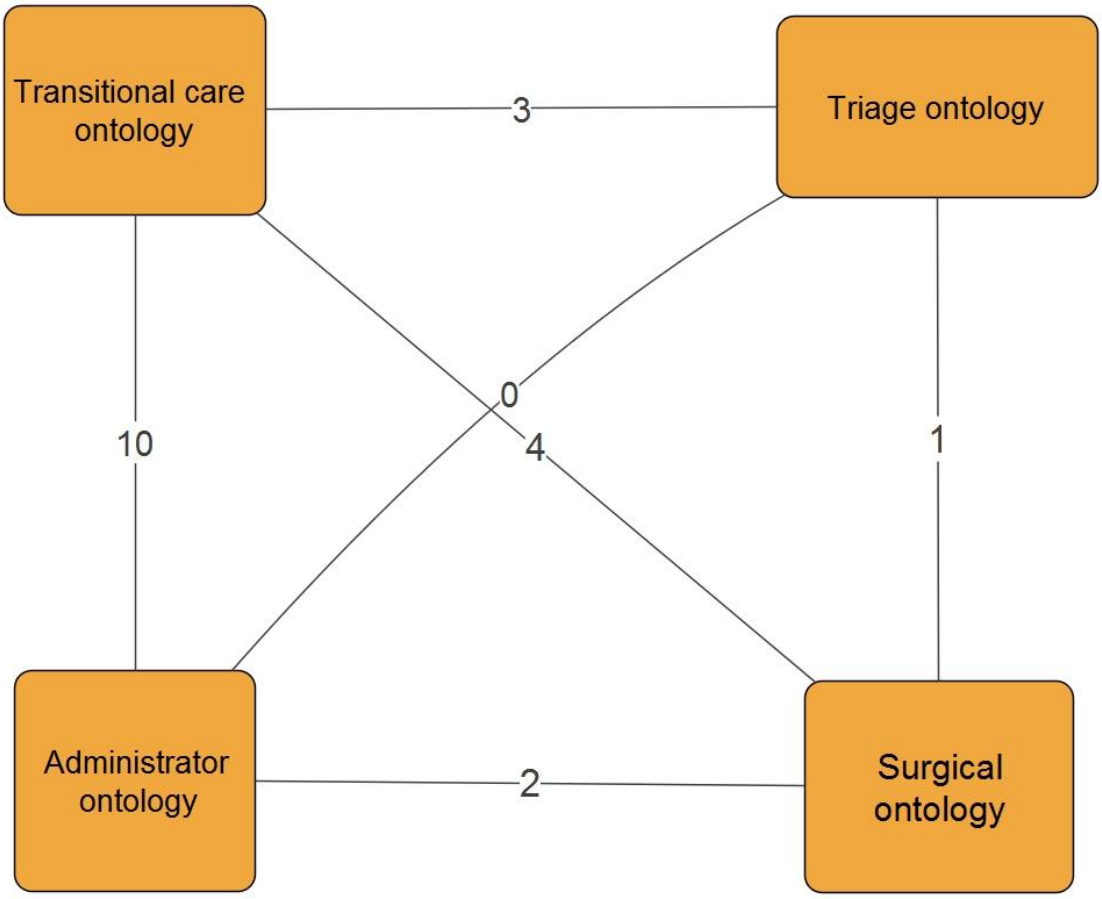
OnAGUI found no identical terms occurred in all four ontologies. However, three identical terms occurred in three ontologies, these were:

- *Care plan* used in surgical, administration, transitional care
- *Family* used in surgical, administration, transitional care
- *Nurse* used in transitional care, triage, and surgical.

5.4.2 OnAGUI term matching matrix diagram

Figure 19 is a matrix diagram that shows OnAGUIs' scan 'paths' between the four ontologies. The number of identical terms is indicated on the path connecting two ontologies. It can be seen that the most frequent number of identical terms occurred between the transitional care and administrative ontologies and the least between the administrator and triage ontologies.

Figure 19: A simple matrix diagram showing the number of identical terms between the divergent ontologies



As OnAGUI scanned each ontology, the following Tables 15-18, containing unique/common terms, were produced. It was anticipated that a ‘global’ vocabulary of common terms across the ontologies would emerge.

5.4.3 Terms and annotations produced from each ontology

The following tables show all of the common and unique terms and annotations for each ontology. Terms in the first column show identical terms in another ontology. Terms in the second column are unique to the ontology denoted by the table. The third column displays the term’s’ annotation. A screen-shot of each ontology (in Protégé), which the table pertains to, is shown after each table for reference.

5.4.4 Terms and annotations of the transitional care ontology

The transitional care Table 15 is derived from the OnAGUI scan of the transitional care ontology in Figure 20. The table shows 22 unique terms out of 35 in total, that is, OnAGUI found the transitional care ontology has 62.8% unique terms.

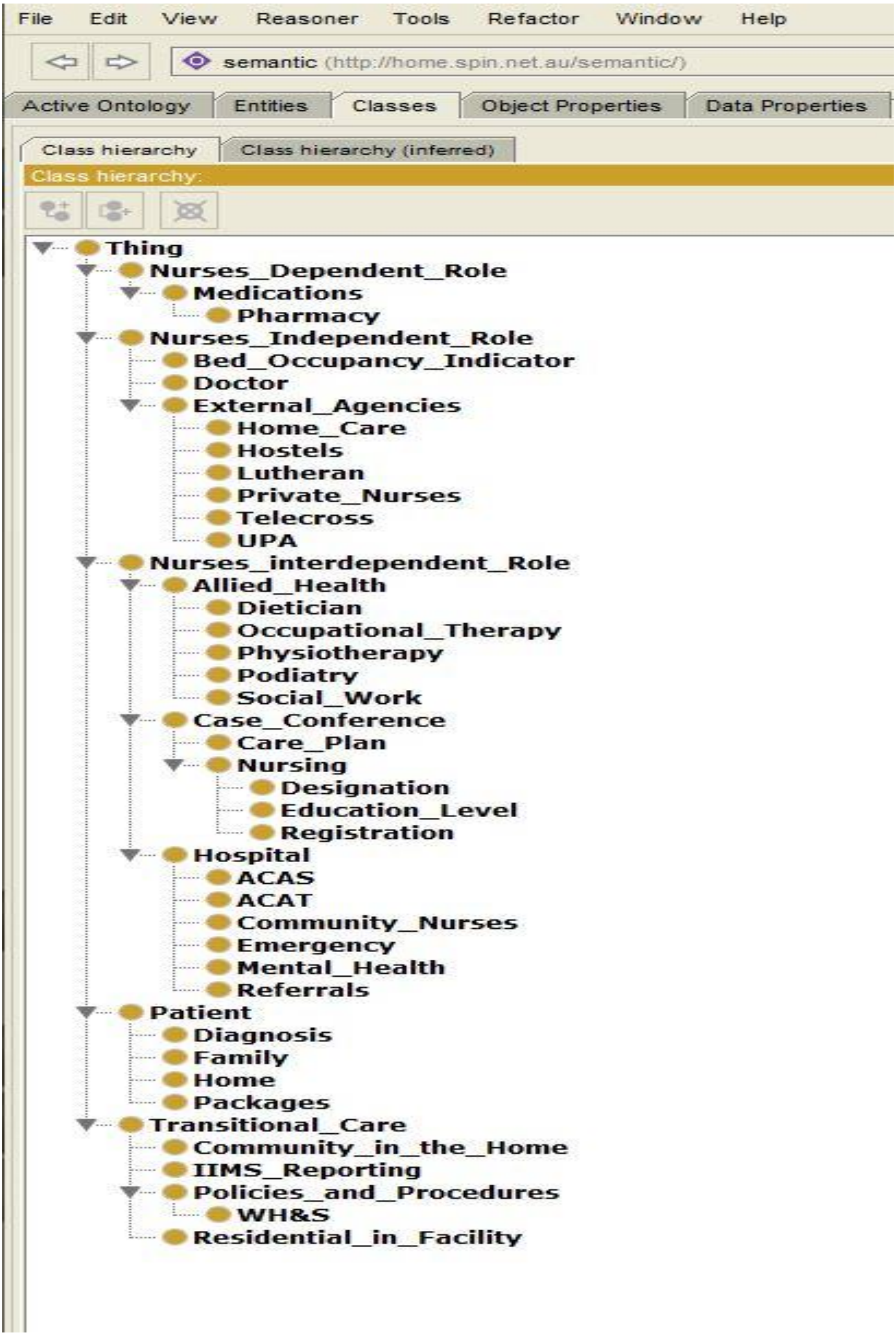
Table 15: Transitional ontology identical and unique terms

Identical terms	**Unique terms in the transitional care ontology**	**Annotation**
	Allied health	Medical professionals other than nurses and doctors
	Bed occupancy indicator	A metric that counts the number of patients in beds in the facility in a time period
	Community in the home	Transitional care nurse caring for patients who have been discharged home
	Community nurses	Community nurses who treat non-veterans in their homes
	Emergency department	Emergency department in the external hospital
	Home care	A service that cleans the patient's house
	Hostels	Temporary accommodation for the homeless
	Lutheran	Aged Care facility run by the Lutheran church
	Mental health	Mental health department in the external hospital
	My facility	The facility that the transitional care participant works in
	Packages	A 'Package' of patient services provided by some external or internal agency
	Pharmacy	Dispenses medications and can be an internal facility or external agency
	Physiotherapy	Assesses the patient's musculoskeletal functioning
	Podiatry	Assesses the patient's ambulation
	Private nurses	Private home nursing company who usually treat Veterans Affairs patients

	Referrals	When a patient is assessed and fits the criteria to be admitted to a facility and/or services
	Residential in facility	Transitional care nurses caring for patients in a bed in the facility
	Social work	Assesses the patient's social networks and support
	Telecross	A branch of Red Cross that calls on the patient's phone too check their safety
	Transitional care	Nurse planning team for transition back into the home or a facility
	UPA	United Presbyterian Association is an aged care facility
ACAS (Admin)		The Aged Care Assessment Service. Frail aged assessment body for the state of Victoria
ACAT (Admin)		Aged Care Assessment Team. Frail aged assessment body for the state of NSW/ACT
Care plan (Surgical) (Admin)		The plan of patient's care determined at the case conference
Case conference (Admin)		A meeting of all stakeholders about changes to care
Diagnosis (Triage)		A professional description of the patient's malady
Dietician (Surgical)		Assesses the patient's swallowing and diet
External agencies (Admin)		Agencies external to the facility which provide goods and services for the patient
Family (Surgical) (Admin)		Relatives identified by the patient
Home (Triage)		The normal residence of the patient
Hospital (Admin)		An external hospital
IIMS reporting (Admin)		Incident Information Management System. Computerised adverse event reporting system in the facility
Medication		A medication is a drug prescribed by a

(Surgical)		doctor for a patient
Nurse (Triage) (Surgical)		A nurse cares for a patient in this facility
	Occupational therapy	Assesses the patient's environmental functioning
Policies and procedures (Admin)		Policies and procedures governing the operation of the facility
WH&S (Admin)		Work Health and Safety procedures and auditing

Figure 20: A screen-shot of the transitional care ontology in the Protégé software



5.4.5 Surgical ontology identical and unique terms

The following surgical Table 16 is derived from the OnAGUI scan of the surgical ontology in Figure 21. The table shows 40 unique terms out of 45 in total, that is, OnAGUI found the triage ontology has 88.0% unique terms.

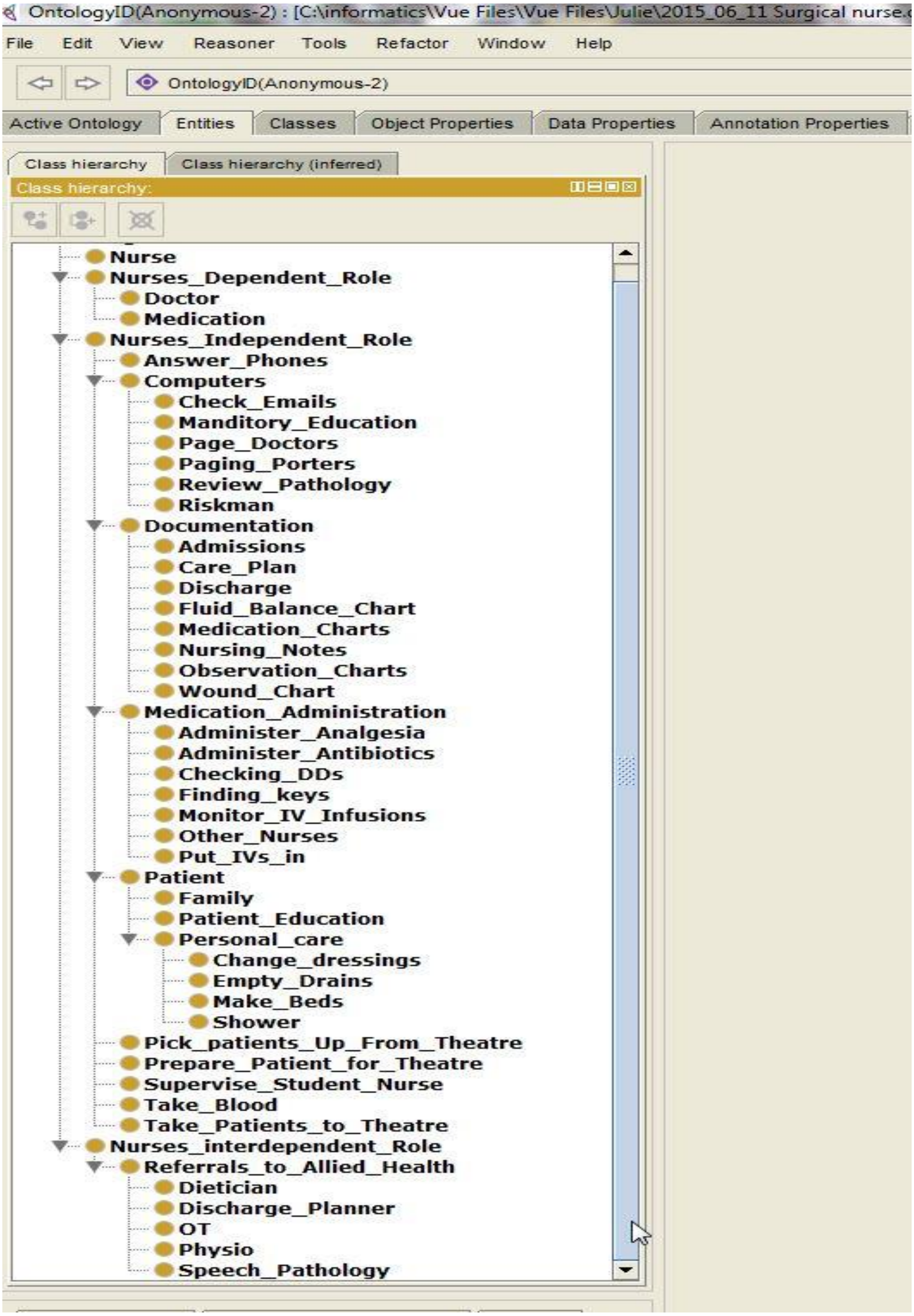
Table 16: Surgical ontology identical and unique terms

Identical terms	Unique terms in the transitional care ontology	Annotation
	Administer analgesia	Pain killing drugs
	Administer antibiotics	Antibiotics are often administered through the IV line
	Admissions	Documentation required to admit a patient to the facility
	Answer phones	Phone calls are often received from the family of patients asking about their condition and calls from theatre
	Change dressings	Wound dressings are checked and changed, recorded on wound chart
	Check emails	Emails are a communication from the facility
	Checking DD	Dangerous drugs have to be checked out of a safe with two registered nurses using a government register
	Computers	A nurses’ station computer
	Discharge	Documentation necessary for the discharge of a patient from the surgical unit
	Discharge planner	Organises the discharge of a patient
	Documentation	Paperwork that has to be filled out regarding the patient’s care
	Empty Drains	Wounds drain into bags which have to be recorded and changed
	Finding keys	Keys to the locked dangerous drugs safe have to be located
	Fluid balance chart	A chart documenting the ratio of how much fluid is expelled and ingested resulting in the total fluid left remaining in the patient
	Make beds	Change sheets and make beds

	Mandatory education	Mandatory nursing education is delivered by computer which has to be undertaken when there is time
	Medication administration	Checking dose, route, time, amount, type, identification of patients and drugs
	Medication charts	Documentation dictating the dosage, type, route and time for a patient's medication
	Monitor IV infusions	Intravenous infusions have to be monitored for rate of flow and blockage/s
	Nursing notes	A written running record documenting the day's care for a patient
	Observation charts	Line graphs and histograms detailing the patient's vital signs over time. Includes blood pressure, pulse, temperature and respirations
	OT	Occupational Therapy, environmental functioning of the patient
	Other nurses	Other nurses help with checking and advice
	Page doctors	Doctors are paged to make decisions about the patient's care and medications after a nurse's summation
	Page porters	Porters help move patients and their belongings around the facility
	Patient education	Educating patients and families about pending surgery, medications and what is generally going on about them
	Personal care	Personal hygiene the patient cannot do autonomously
	Physio	Physiotherapy is concerned with structural mobility and movement of the patient
	Pick up patients from theatre	Hand over patients from surgery to surgical ward
	Prepare patients for theatre	The patient's paperwork, identification, fasting and gowning is prepared prior to surgery
	Put IVs in	A cannula has to be inserted in a patient's arm

	Referrals to allied health	A patient can be referred to allied health; other health professionals with specialised disciplines
	Review pathology	Pathology is mainly results of blood tests which appear on the computer after being analysed
	Riskman	The computerised risk management system which adverse events are entered into. Similar to IIMS in other domains
	Shower patients	Patient is showered if unable to do it themselves
	Speech pathology	Concerned with muscles used for swallowing and the upper airway
	Supervise student nurse	Student nurses are assisted and supervised by the nurse as they learn procedures
	Take blood	Blood is taken from a cannula in the patient for analysis
	Take patients to theatre	Handover patients from surgical ward to surgery
	Wound chart	Charts the healing progression of a wound. Records area, colour, exudate temperature, moisture
Care Plan (Trans Care) (Admin)		A plan of care dictating what has to be done to improve the patient's condition
Dietician (Trans Care)		Responsible for nutrition
Family (Trans care) (Admin)		The patient’s family
Medication (Trans Care)		Medications prescribed by a doctor
Nurse (Triage) (Trans Care)		A nurse cares for a patient in this facility

Figure 21: A screen-shot of the surgical ontology in the Protégé software



5.4.6 Administrative ontology identical and unique terms

The administrator Table 17 is derived from the OnAGUI scan of the administrator ontology in Figure 22. The table comprises 28 unique terms out of 38 in total, that is, OnAGUI found the triage ontology has 73.68% unique terms.

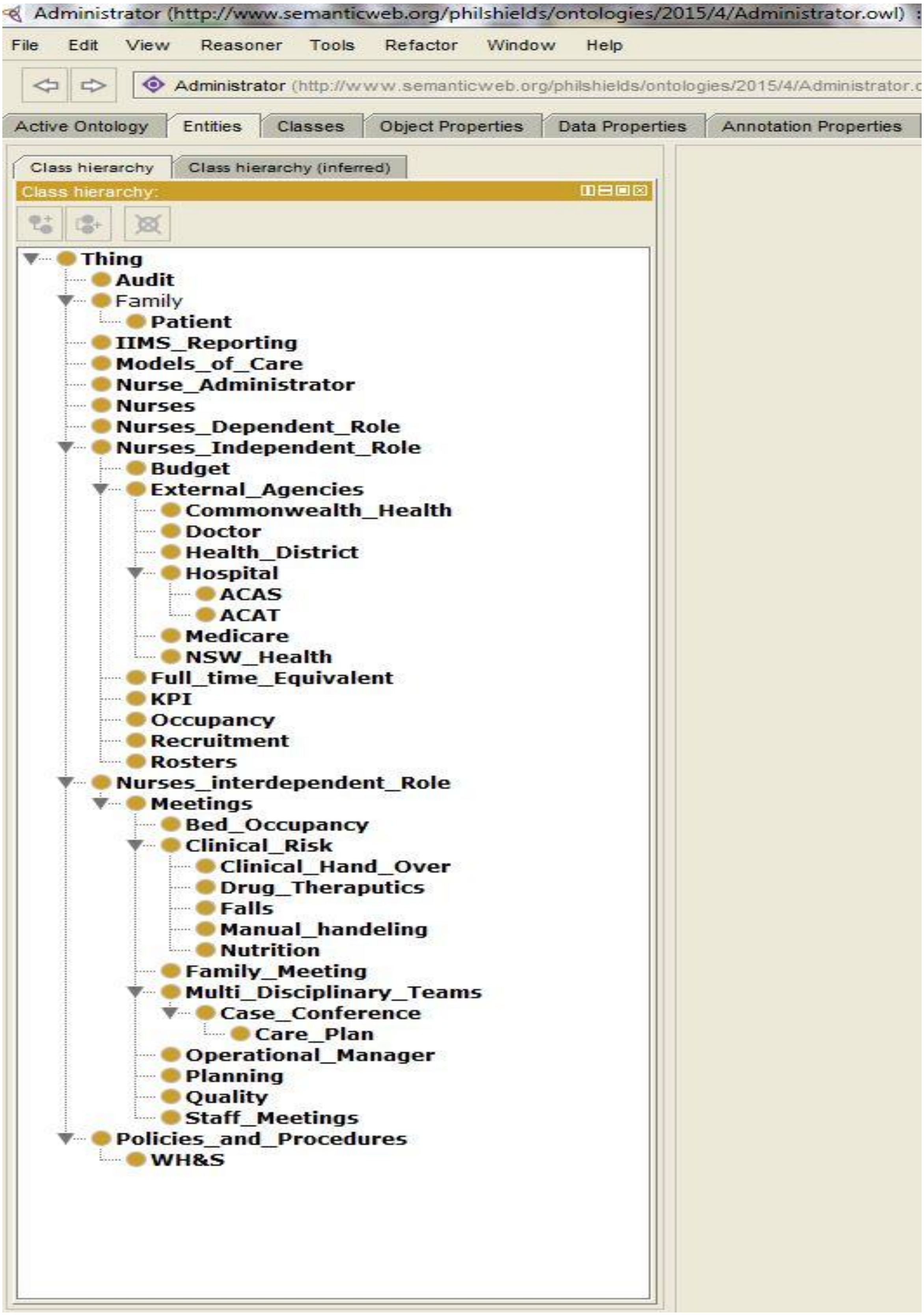
Table 17: Administrative ontology identical and unique terms

Identical terms	**Unique terms in the transitional care ontology**	**Annotation**
	Audit	An external audit of key aspects of facility operation
	Bed occupancy	The number flow of patients in and out of the facility
	Budget	The amount of money allocated to various aspects of facility operation
	Clinical hand over	The handing over of personal patient clinical information from the preceding shift to the next
	Clinical risk	Identifying risk factors associated with patient and staff safety
	Commonwealth	National Health agencies which provide (amongst other things) Key Performance Indicators linked to funding
	Drug therapeutics	Concerned with patient’s medications
	Falls	Patient falls prevention
	Family meeting	A meeting with the patient's family to discuss treatment and the care plan
	Full time equivalent	Full-time equivalence (FTE) is a measure of the amount of time an individual works. Consider an organisation where a full-time employee is required to work 40 hours a week. An individual working 40 hours has an FTE of 1.0.
	KPI	Key Performance Indicators (KPIs) are linked to federal and state funding. The facility also has its own KPIs linked to occupancy funding
	Manual handling	Safe patient lifting and moving within the facility

	Medicare	Provide indirect funding to the facility after receiving patient admission and discharge data.
	Meetings	Meetings with key stakeholders of patient care in the facility
	Model of care	Commonwealth patient demographics data concerned with sufficiently addressing catchment patient base
	Multi disciplinary teams	Prioritises admission and discharge and appropriate care
	My health district	A geographic district of hospitals and other medical facilities
	NSW health	Supplies state funding linked to Key Performance Indicators
	Nurse administrator	The nurse in this graph
	Nurses	Nurses working in this facility
	Nutrition	Patient meals
	Occupancy	The number of patients in beds + admissions -discharges
	Operational manager	Next level of nursing up, senior planning meeting
	Planning	Facility forward operational requirements planning
	Quality	KPI planning meeting linked to quality
	Recruitment	Interview panels and recruitment of nurses
	Rosters	The time and date dictating a nurse's working shift
	Staff meeting	Meeting to exchange information for nursing staff
ACAS (Trans Care)		The Aged Care Assessment Service. Frail aged assessment body for the state of Victoria
ACAT (Trans Care)		Aged Care Assessment Team. Frail aged assessment body for the state of NSW/ACT
Care plan (Trans Care) (Surgical)		The plan of patient's care determined at the case conference

Case conference (Trans Care)	A meeting of all stakeholders about changes to care
External agencies (Trans Care)	Agencies external to the facility which provide goods and services for the patient
Family (Trans care) (Surgical)	Relatives identified by the patient
Hospital (Trans Care)	External hospitals
IIMS reporting (Trans Care)	Incident Information Management System. Computerised adverse event reporting system in the facility
Policies & procedures (Trans Care)	Policies and procedures governing the operation of the facility
WH&S (Trans Care)	Work health and safety

Figure 22: A screen-shot of the administrative ontology in the Protégé software



5.4.7 Terms and annotations of the triage ontology

The triage Table 18 is derived from the OnAGUI scan of the triage ontology in Figure 23. Out of a total 27 terms, there are 24 unique terms. In other words, the triage ontology has 88.0% unique terms.

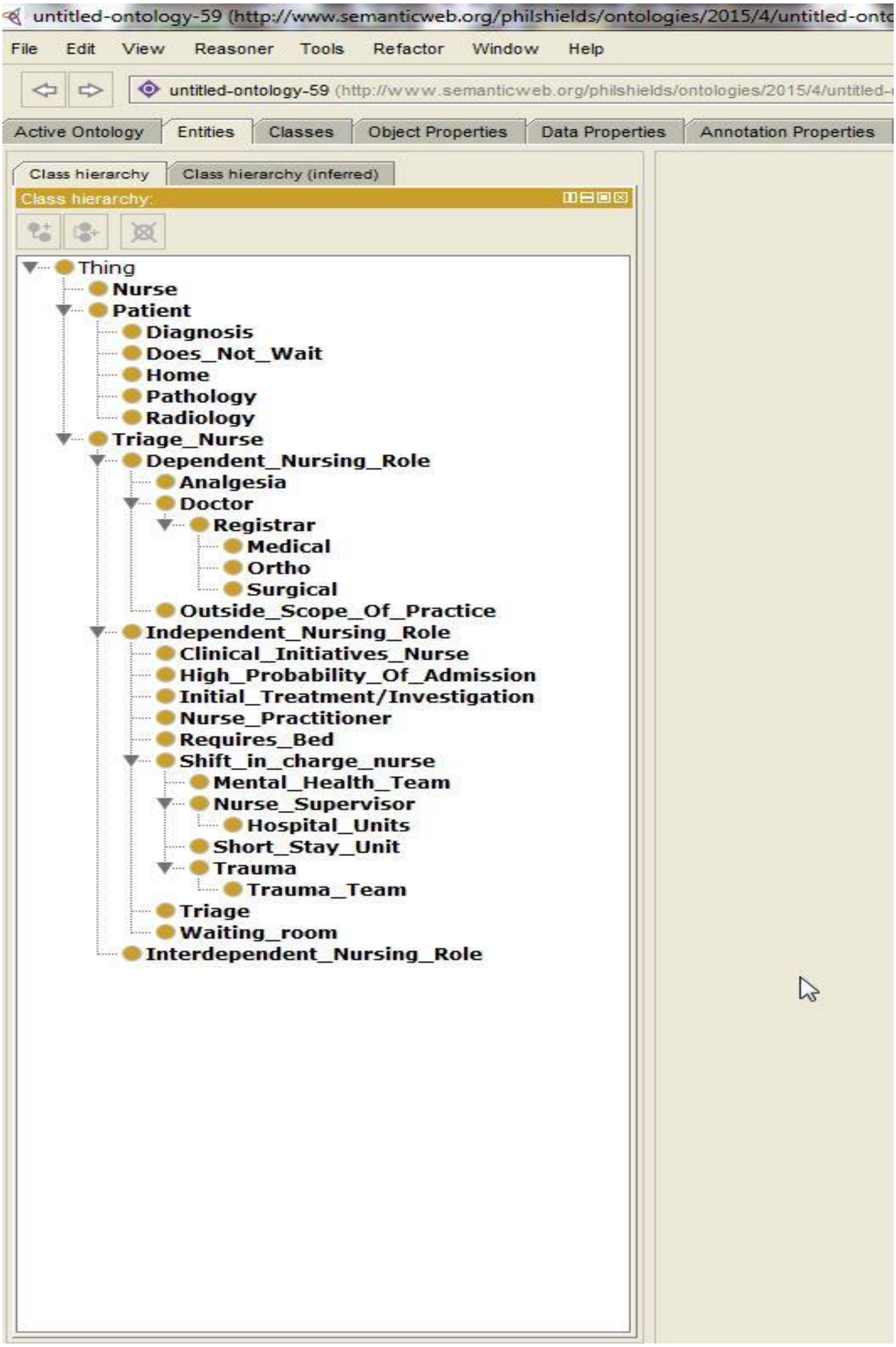
Table 18: Triage ontology identical and unique terms

Identical terms	Unique terms in the triage ontology	Annotation
	Analgesia	Alleviates pain
	Clinical initiatives nurse	Initiates treatment and care within guidelines to expediate treatment and patient flow
	Does not wait	Patient leaves the emergency department before medical intervention
	High probability of admission	A patient who has a presentation such as chest pain that has a high likelihood of admission. This includes many factors and clinical judgment based on age, duration, extensiveness and co-morbidities for example
	Initial treatment/investigation	Pathology, xray or pain relief
	Medical registrar	Assesses and admits patients who are deemed to have medical issues- cardiac issues etc
	Nurse practitioner	Initiates care, treatment and referral of patients with assistance of doctors to provide a very high level of care and treatment within the guidelines
	Nurse supervisor	In charge of hospital, controls all beds on all wards. Allocates admitted patients to the wards
	Ortho registrar	Assesses and admits patients who are deemed to have orthopaedic issues- broken bones etc
	Outside scope of practice	A patient's treatment that is deemed outside the practice scope of the nurse, such as distal limb damage, paediatrics and ortho
	Radiology	Xrays, CT

	Registrar	Specialist team medical representative who assesses and admits for each specialist team
	Requires bed	The patient will be admitted
	Shift in charge nurse	Senior nurse who is in charge of all nursing staff and directs all flow incoming and out going patient flow
	Short stay unit	Patient deemed likely to go home post simple results such as blood tests or treatable illnesses such as migraine—the end result means discharge
	Surgical registrar	Assesses and admits patients who are deemed to have surgical issues- i.e. require surgery
	Trauma	Multi system issues/damage to the body that requires a team approach such as car accident
	Trauma team	Specialist team made up of surgical, anaesthetic, ED and ICU doctors as well as senior nurse resuscitation team
	Triage	A scale based on the priorities of life and limb (Cat 1,2,3,4,5) that require the patient to be seen within a given time frame
	Triage nurse	Assess ALL patients who present to emergency to give them a number from Cat 1 (immediate intervention) to Cat 5 (seen within 2 hours), assesses on the basis of the priorities of life airway, breathing, circulation and limb
	Waiting room	Area outside of the emergency department where people wait to be seen by a doctor or triaged
Diagnosis (Trans Care)		A label given to set of symptoms that require treatment.
Home (Trans Care)		Place of residence
	Hospital units	Specialist areas of care for specific presentations under specialist teams i.e. medical team, surgical team, orthopaedic team

	Mental health team	Mental health specialist nurses who assess risk and direct care and admission
Nurse (Trans Care) (Surgical)		A nurse who works in the emergency department
	Pathology	Blood tests

Figure 23: A screen-shot of the triage ontology in the Protégé software



5.4.8 Evaluation of consistency in each ontology

This subsection describes the results of the FaCT++ logic reasoner's scan of each ontology. To re-cap, individual nurses and patients were added by the student researcher to test the reasoner's logic functions after the graphs were produced. The logic reasoner compares each individual's attributes against the class constraints to see if they 'fit' (consistency). If they do not fit, the reasoner suggests a new inferred hierarchy.

The 'consistency' of each ontology is examined by the FaCT++ logic reasoning robot with a special focus on the following aspects:

- Each individual nurse has attributes which state education requirement, registration and designation
- Each individual patient has attributes which state a diagnosis and possibly an optional medication
- Patients and nurses are separate and in their respective classes (disjoint)
- Each nurse class contains nurse individuals who conform to class constraints
- Each patient class contains individuals who conform to patient constraints
- Each class is capable of containing at least one individual
- There are no 'orphaned' individuals who do not have a class.

Individual nurses and patients, their attributes and class constraints were displayed in Chapter Four. Figure 24 is an example of how class constraints of 'nursing' are displayed in the Protégé development program. Class constraints for the class 'nursing' can be seen in the blue 'annotation' pane in the top right hand corner. The class 'nursing' is defined by designation, education level and registration.

Figure 24: Class constraints for 'nursing' in the transitional care ontology

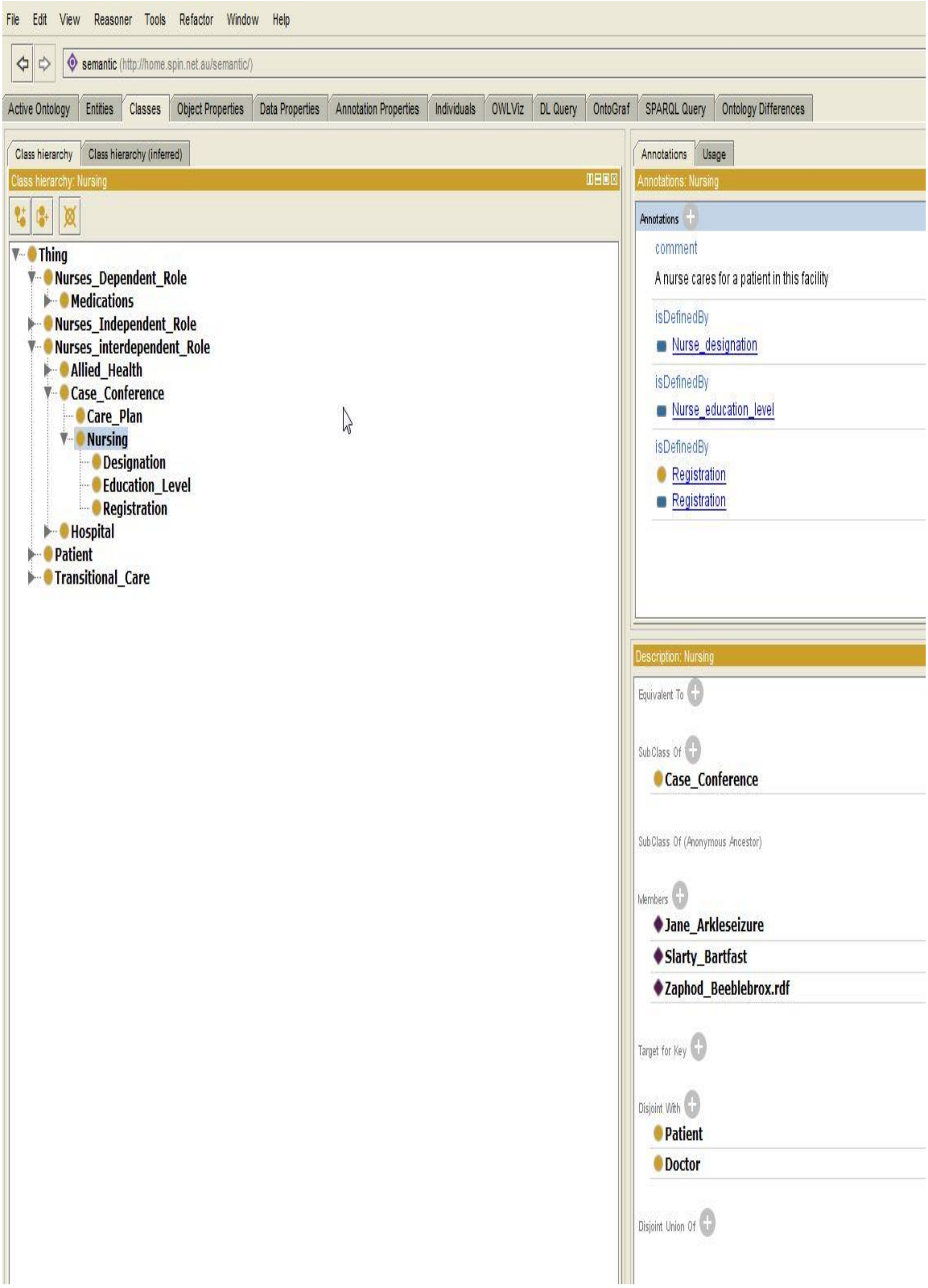
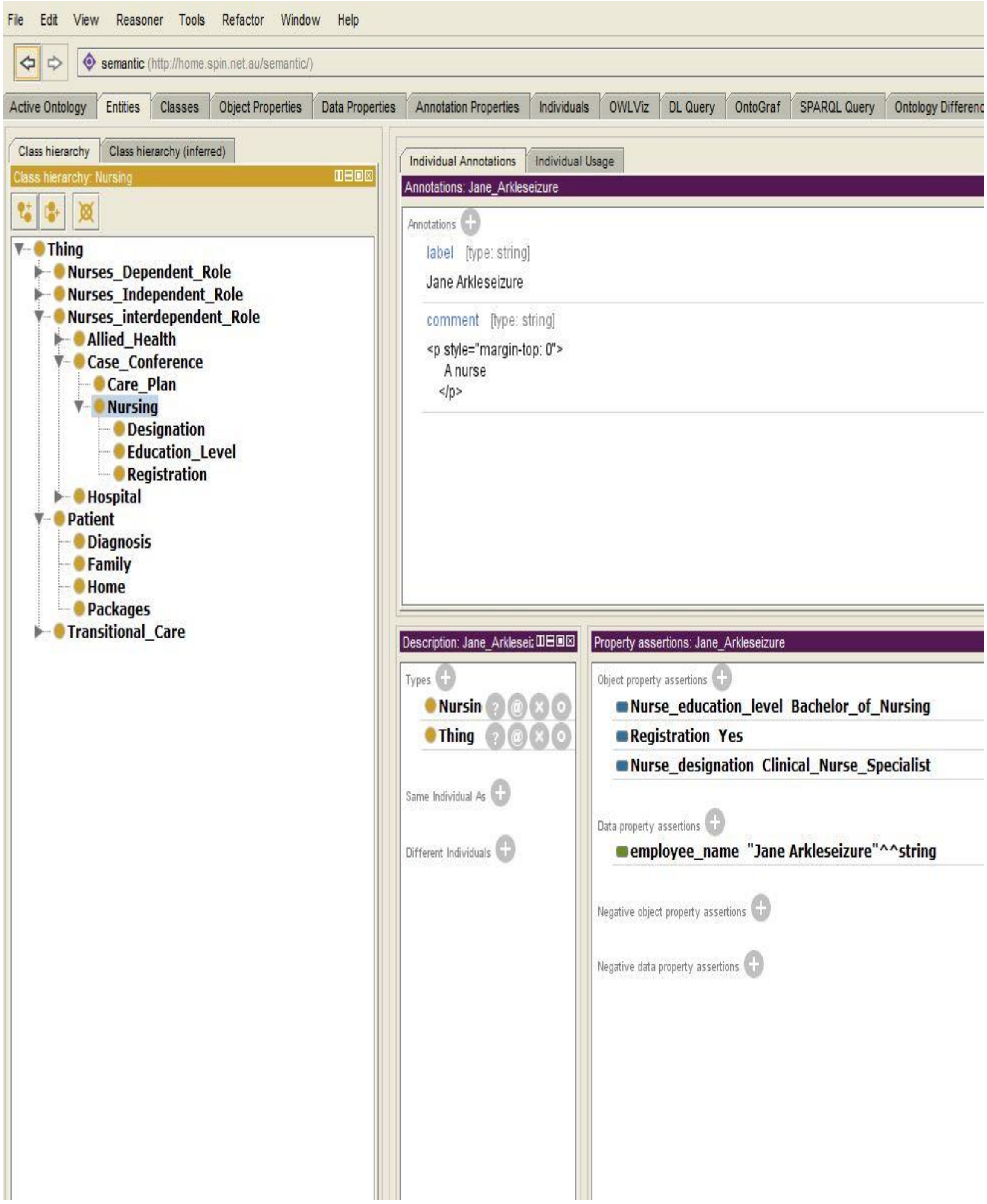


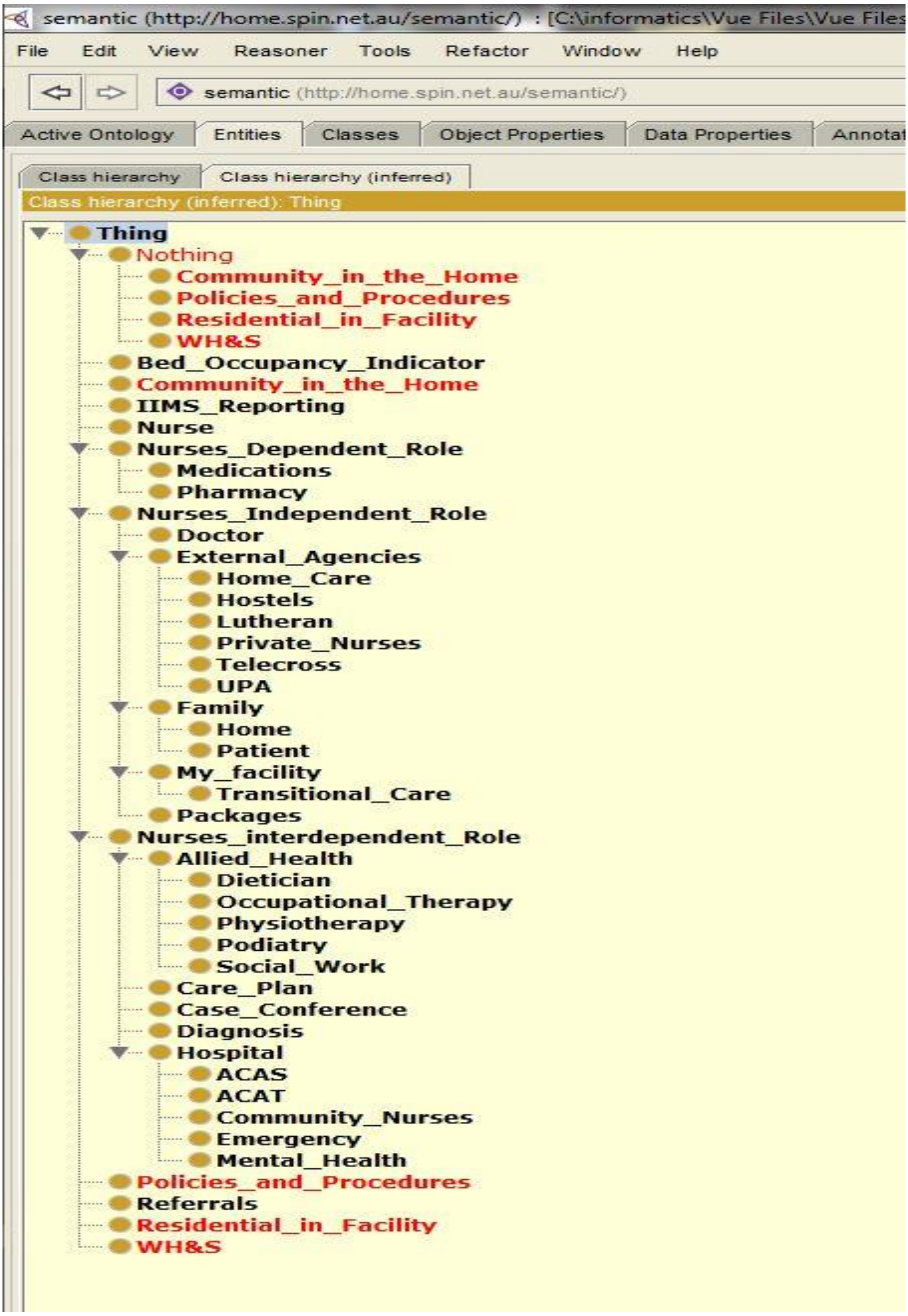
Figure 25 is an example showing nurse Jane Arkleseizure's attributes. The attributes are the 'answers' to class constraints. As shown in the 'property assertions' panel, nurse Jane fulfils the requirements of being a member of the class 'nursing' in the transitional care ontology. That is, she has a designation, education level and a registration.

Figure 25: Nurse 'Jane Arklesiezure's' attributes in in the transitional care ontology



The logic reasoner checked each ontology’s structure. The reasoner analysis showed that the administrative, surgical and triage ontologies were logically consistent. That is, all of the patient and nurse individuals’ attributes were consistent with their class constraints. However, the transitional care ontology was inconsistent. The reasoner found that nurse and patient individuals exist (or are linked) in the same class contrary to a ‘disjoint’ constraint. A disjoint constraint means that these individuals cannot exist in the same class, that is, nurses cannot be patients. As a result, the reasoner inferred a ‘new’ transitional care ontology as shown in Figure 26.The inferred ontology suggests possible culprit classes which the reasoner deems inconsistent (unsatisfiable) and places them in the ‘nothing’ class.

Figure 26: The reasoner's inferred transitional care ontology in Protege



5.5 Chapter summary

This chapter presents the results as per the methodologies' stages presented in figure 12, namely, data capture, Ontology construction and data analysis.

Data capture

The participants' transitional care, triage, surgical and administrative graphs were presented.

The usability survey gauged participants' perceptions of the ease of use of the VUE graph software and showed that participants agreed that the graph tool was useful in analysing their process domain and provided insights into processes.

Ontology construction

Four ontologies were constructed from the four graphs using the ontology development platform Protégé. Each ontology was populated with fictitious patients and nurses each with individual attributes and constraints. Nurses and patients were used to test Protégés' logic reasoning capability.

Data Analysis

Graph patterns, namely, the number of arcs from NREM roles, and the number of 'clusters' were counted. The 'role mix' in each graph suggests the degree of autonomy each nurse possesses. Arcs connecting the independent NREM roles to participants' concepts predominated in the graphs. Clusters may indicate focussed areas of responsibility. Clusters of transitional care, surgical and administrative nurse participants' graphs all contained clusters. However, the triage graph did not contain defined clusters.

Ontologies were subject to assessment by two robots. The first robot, OnAGUI, ranked the 'closeness' of terms across the four ontologies. OnAGUI found that most of the terms contained in the ontologies were unique to that ontology. Additionally, OnAGUI found that no identical terms occurred in all four ontologies, however, three identical terms occurred in three ontologies which were:

- *Care plan* used in surgical, administration, transitional care
- *Family* used in surgical, administration, transitional care
- *Nurse* used in Transitional care, triage, and surgical.

The second robot, FaCT++ logic consistency reasoner, uncovered an inconsistency in the transitional care ontology. Nurses and patients breached a disjoint constraint, that is, nurses and patients existed together in the same class. The reasoner produced a ‘new’ inferred ontology, which highlighted possible classes where the inconsistency may have occurred. The next chapter discusses these results in detail, draws conclusions and concludes the thesis.

CHAPTER SIX: Discussion and conclusion

6.0 Introduction to the chapter

Computer-based technology has become an increasingly important part of contemporary healthcare. However, the full benefit of rapidly evolving computer-based technology may never be realised unless a better understanding of how healthcare and computer technologies can be made to 'mesh' for mutual benefit of stakeholders. This thesis is a first step to merge nursing science with semantic technologies to address the lack of nursing processes semantics.

Capturing nursing process semantics has been regarded as one of the most difficult topics. This study found that it is possible for nurses with no knowledge of ontology construction to use graph software to capture process semantics of a real process domain. Graphs revealed potential patterns of the process domain including potential clusters or 'hot spots' of nursing processes, the nursing role 'focus' of the graph and 'hidden' processes. Graphs revealed 'hidden' processes; the capture of hidden processes has been elusive in previous studies. This study showed that nurse-constructed graphs could be converted into 'robot-readable' ontologies and robots could 'scan' ontologies for similar terms and determine the logic consistency of an ontology's structure.

This chapter presents a discussion of findings related to graph patterns, the outcome of the usability survey and textual 'closeness'/logic consistency of ontologies. This chapter discusses the thesis' significance, answers the thesis' research question and discusses the thesis' strengths and weaknesses. The thesis concludes with a discussion of further research.

6.1 The evaluation of patterns in participants' graphs

Four nurse domain expert participants, with no previous experience of knowledge acquisition and node-arc-node graphs, were asked to consider their roles in their process domain as part of the data analysis phase of the methodology depicted in figure 12. That is, they were asked to consider their process domain as concepts (nodes) and relationships (arcs) between nodes. The participants used VUE software to connect arcs from their own nodes to three Nursing Role Effectiveness Model (NREM) roles supplied in the graph. The purpose of the pattern evaluation of NREM roles and clusters is to determine ‘role focuses’ and nursing ‘focus’. Role focus may suggest the amount of autonomy the participant has making decisions and the number and type of cluster may suggest areas of responsibility of the participant.

The following discussion pertains to participants’ process domain graphs (which appear in Figures 13 to 16 in Chapter Five).

6.1.1 The transitional care nurse process domain graph

As shown in Figure 13, the ‘transitional care’ node is divided into two sections, ‘community in own home’ and ‘residential in facility’. The two sections are different models of care. ‘Community in own home’ extends into the community and ‘residential in facility’ is a more hospital-based model. Both sections in the transitional care node share the same infrastructure in the transitional care graph. The transitional care graph contains four ‘clusters’; case conference, external agencies, allied health and patient. The largest cluster in this graph is the case conference. The case conference cluster connects to allied health, nursing, the patient, and family nodes. The output of the case conference is a written care plan that modulates the patient’s ongoing plan of care. The case conference cluster is one of two clusters that are the main focus of the graph. The other large cluster, external agencies, act as providers of patient assistance ‘packages’ and patient assessment/referrals. Interestingly, the transitional care graph shares a ‘bed occupancy’ NSI with the administrative graph in Figure 15. Bed occupancy is a structural NSI that measures the number of incoming patients referred from the external hospital. Why the NSI was included in the process domain is unclear; it is possibly because funding for services is tied to the number of patients admitted to the facility.

6.1.2 Transitional care NREM roles

As mentioned earlier, nodes and arcs in Figure 13 can be seen to reach beyond the transitional care node into the wider community and surrounding hospitals. In this way, nodes and arcs extending to the patient’s home and the wider community may suggest a ‘horizontal’ care structure. That is, patient pathways transcend organisational boundaries and connect community-based stakeholders. On the other hand, there is evidence of a more traditional vertical ‘medical model’ structure. In the medical model, the physician assumes an authoritative position, because of his/her specific expertise, in relation to the patient’s care. In the transitional care graph, the dependent nursing role extends to the ‘medication’ node, which is prescribed by the doctor through a pharmacy. This is the only graph, out of the four graphs, where both horizontal and vertical models seem to exist.

The transitional care node was connected to all three NREM roles by arcs but independent arcs form the majority (5). Independent roles are connected to patient, home, doctor, external agencies and the bed occupancy NSI. The interdependent role links directly with the case conference which links to allied health, the patient and nursing. This may suggest that all stakeholders including the patient are ‘equal’ by virtue of having access to the case conference and its decisions; this may reinforce the notion of a horizontal care structure.

6.1.3 The surgical nurse process domain graph

The surgical nurse graph in Figure 14 has the most number of clusters (5) out of the four graphs. The clusters are medication administration, computers, documentation, the patient, and referrals to allied health. The surgical nurse is connected to all clusters that the patient is connected to. This may suggest that the surgical nurse is involved in the majority (if not all) aspects of patient care. The only cluster the patient is not connected to is the computer cluster.

The surgical nurse graph is the only graph with a computer cluster. This cluster may suggest that computers play a large role in non-direct patient logistics such as paging doctors, searching for pathology results, paging porters, emails, mandatory education and risk reporting. Surprisingly, although Electrical Health Records (EHR) had been introduced into this facility, the graph shows no connection between the documentation cluster and computer cluster. The absence of an arc may suggest that the connection has not been made between documentation and computers at the surgical nurse level. The medication administration cluster is the largest and most connected of the clusters in the surgical process domain graph. The ‘medication administration’ and ‘patient’ clusters contain some connected nodes that may be termed ‘hidden’ processes.

Hidden processes were described in Chapter Two as being elusive and not normally captured in other studies. It was found that there is little or no evidence of research activity identifying ‘hidden’ nursing process. Examples of ‘hidden’ processes in this surgical graph are:

- Checking Dangerous Drugs (DDs)
- Finding keys to the drug room
- Other nurses to help check drugs
- Answering phones
- Supervising student nurses
- Making beds.

It is possible that time may be taken from face-to-face patient care when dealing with the many unrecorded ‘hidden’ processes that are connected to the medication administration cluster and the computer cluster.

6.1.4 Surgical NREM roles

Like the transitional care graph, the surgical graph has all three NREM roles connected by arcs to the participant’s nodes. The surgical nurse participant has the most independent roles out of the four graphs, six in total. Independent roles terminate at all of the clusters except the referrals to allied health cluster, which is connected to the interdependent role. The sole dependent role is connected to the doctor who prescribes medication. This may suggest that the surgical nurse is mostly autonomous and is concerned with almost every aspect involved with direct patient care.

6.1.5 The administrative nurse graph

The administrative nurse graph has the most interlinked nodes of the four graphs. Many interlinked nodes may suggest complex interactions between the budget, nursing staff and the various meetings. A couple of observations can be made from the graph:

- The graph shows that the administrative nurse has no direct connection to the nursing staff or the patient
- Indirect connections to staff and patients may occur as a result of outcomes of meetings and the regulation of the budget.

The meeting cluster, (the largest cluster of nodes) is surrounded by many interconnected meeting nodes. Patients are indirectly connected to the meeting cluster through the planning node. The ‘planning’ node suggests that it is modulated by the ‘models of care’ node, which is ultimately dictated by the ‘Commonwealth’ node. Meetings are connected to every node in the graph except the external agencies cluster. The external agencies cluster is the least connected cluster in the graph. Nodes connected to the external agencies cluster may suggest that it serves a regulatory function, that is, it ensures compliance with state and federal regulations.

The budget cluster links with most nodes in the administrative graph except the external agencies node. Nurses are connected to the budget through rosters, recruitment and bed occupancy nodes. Patients are connected to the budget node through a bed occupancy NSI. It is clear from the administrative graph that the major drivers of the graph are the budget and meeting nodes. The budget may be influenced by bed occupancy numbers, which is most likely a primary source of income for the facility. It can be seen in the administrative graph that the bed occupancy node is the sole connection between the meeting cluster and the budget cluster. The administrative graph was useful in displaying the complex web of interactions. For example, the administrative participant was under the impression that the administrative role had a stronger connection with patients and nurses, however, the graph showed that the administrator had indirect connections to patients and nurses through the budget and meeting nodes. The administrative participant expressed surprise about the indirect arcs in the graph.

The policies and procedures node is connected to the external agencies, staff, and meeting nodes. The policies and procedures node is connected to quality, clinical risk, falls and manual handling meeting nodes, all indirectly linked to patient care. This may suggest that policies and procedures are not only shaped by external state and Commonwealth factors but internal clinical risk and quality meeting outcomes.

6.1.6 Administrative NREM roles

The administrative nurse graph contains no dependent roles and may suggest that the nurse administrator is probably autonomous with regard to decisions concerning the budget, implementation of meeting outcomes and external agency liaison. The administrative graph has few interactions with outside community nodes except for liaison with external agencies that determine models of care and policies/procedures. It is interesting that the administrator does not have a ‘higher’ nurse authority to refer to. Instead, there are state and Commonwealth bodies that dictate care models and policy. This may also suggest a high degree of autonomy.

6.1.7 The triage nurse process domain graph

Compared to the other three graphs, the triage graph is the only graph without 'clusters'. There are no clusters because the triage participant's arcs either terminate at a person who effects the actual care, or a location in the Emergency Department (ED). The pattern of arcs terminating at other people or locations in the ED suggests an underlying strict procedural structure that may govern the placement and ranking of patients. The 'clusterless' graph structure may also facilitate care as quickly as possible—as suggested by the arcs labelled 'fast track' and 'assess'. These arcs terminate at a node of someone or something that continues patient care.

The graph may suggest patient 'load sharing' where patients are allocated equally to care providers. Nodes connected to a node called 'initial treatment/investigation to increase flow' may suggest patient 'load sharing'. This node may increase patient flow through the process domain by distributing the patient load between the doctor, clinical initiative nurse and nurse practitioner nodes.

The 'shift in charge nurse' node is a central figure in the graph that is connected to mental health, short stay unit, trauma, doctor and supervisor nodes. This may suggest that the shift in charge nurse has an 'overall view' of triage and may escalate patient care if the need arises. The triage nurse's view for the process domain shows that the shift charge nurse is the only person who activates the trauma team in response to a trauma. The shift in charge nurse node may act as a 'buffer' between the triage nurse and the rest of the ED. This may indicate a fair degree of isolation of the triage nurse from the wider ED and hospital. This 'isolation' may have been illustrated by the textual ranking robot OnAGUI, which identified triage as having the most exclusive language.

The triage nurse view of the process domain does not include 'the ambulance'. This is logical because ambulance patients are triaged on their entry into the ED by another team. The shift supervisor node is directly connected to the nurse supervisor. The graph suggests that the nurse supervisor acts as an 'interface' between the ED and the wider hospital.

6.1.8 Triage NREM roles

The triage participant did not add any interdependent roles to the graph. The lack of these arcs may suggest that the triage nurse has little interaction with allied health. On the other hand, independent roles are dominant in the graph and show clear pathways to nodes that further the care of the patient.

Dependent roles are minimal for the triage nurse. The only two dependent roles are 'analgesia' (because the triage nurse requires a doctor to fill out a medication chart) and a larger concept called 'outside the scope of practice' which is everything else that requires a doctor's order. The previous section discussed patterns within graphs. The next two sections discuss the participant's perceptions of the usability of the VUE software to produce graphs. As mentioned earlier, graphs display semantics as nodes, arcs and annotations. The discussion of VUE usability is followed by a discussion of automated evaluations of 'terms'. Terms are concept labels, which are a small (but important) component of semantics in an ontology.

6.2 The VUE software usability survey results

On average, participants rated their computer skills as 5.5 out of 10—this result suggests the participants rated their computer literacy as 'average'. Participants were not selected on their computer literacy because computer literacy was inferred due to the participants holding senior positions in the organisation. Participants remarked that the software itself was not difficult to operate. The problem participants encountered lay in thinking about their process environment and translating those concepts into nodes and arcs in the VUE software. Participants noted the screen quickly became cluttered with nodes and arcs. Participants found that placing nodes in no particular order in the VUE software, then moving nodes about on the screen into rough clusters and adding terms or labels worked well. Once the clusters were in place, connecting arcs were drawn. The participants found that NREM nodes, which were provided in the original 'blank' graph, were beneficial for focussing the graph, and categorising their processes. Finally, participants added attributes to describe, in plain English, the function of each node.

The triage nurse had high computer literacy (9/10) but found the graph process difficult (7/10). The participant remarked that thinking about the process domain in terms of being 'concrete or abstract' was difficult. The difficulty the triage nurse encountered was due to identifying abstract concepts the participant interacts with. The triage nurse commented that the triage process was 'straight forward' and protocol driven, leaving little latitude for 'abstract' concepts.

All participants agreed that the most difficult part of graphing their process domain was thinking about concepts as concrete or abstract entities. More emphasis on determining the difference between concrete and abstract concepts, possibly as a VUE exercise, may be useful to develop in the initial training tutorial. However, all of the participants managed to draw their perception of a process domain using VUE, once they became accustomed to VUE's operation. The time it took to complete a graph varied. Some participants completed the graph in one sitting of about an hour. Other participants saved the graph and continued later. Once the participants started their graph, all seemed to be engrossed in the task. The participants' focus resulted in a much more detailed graph than expected. Participants remarked that the extra detail provided a clearer picture of the process domain. The process of drawing graphs clearly caused the participants to think about their various roles in the process domain and how they interacted with concepts.

Participants agreed (average 9.5/10) that the process of drawing a graph gave them insight into their nursing processes and that the graph tool would be useful for analysing their clinical process domain (average 9.25/10). Participants agreed that graphs might be a useful teaching tool (average 8.75/10). That is, participants remarked that a graph would be useful when explaining the various processes and roles in their process domain. One participant suggested that graphs would be particularly useful to explain processes to new nurses, nursing students and non-clinicians. Participants believed graphs closely represented their real-world process domain (average 8.75/10).

6.3 The robot (ontology) evaluation

This section presents a discussion about the results derived from the two software robots' ranking of terms and logic consistency of ontologies.

6.3.1 Ranking terms across ontologies

The OnAGUI robot ranked terms across four ontologies to ascertain identical terms or their 'closeness'. If enough identical terms exist across the ontologies, a single 'global' vocabulary of terms may emerge. Also, if identical terms are identified in different ontologies these may be used to connect ontologies together. Conversely, the ranking robot may find no identical terms in ontologies, which may suggest 'siloing'. That is, independent 'silos' of nursing speciality with no common language, resulting in poor communications between specialities.

The OnAGUI (Charlet, 2012) linguistic comparison robot compared terms in ontologies by scanning two ontologies at a time. The robot ranked each term with a number. An 'I-Sub' number of '1' indicated an identical match between two terms. A decimal less than '1' indicated the degree of textual 'closeness' of two terms. The robot was told to disregard any terms ranked lower than 0.75. The robot also disregarded the original terms supplied in the empty graphs at the start of the thesis, namely, NREM role names, 'patient' term and 'doctor' term; these were not ranked because they would obviously occur across the ontologies.

The robot found the number of identical terms across the four ontologies was minimal. The robot found that there were not enough identical terms to construct one overarching vocabulary. Still, the robot produced four individual tables, one from each ontology, and only three terms were common across the four ontologies. Only the terms 'care plan', 'family', and 'nurse' were present in all four ontologies. That is, three terms out of 145 terms ranked by the OnAGUI robot were used in all four ontologies. The lack of similar terms may suggest 'siloing'. The silo effect refers to a lack of information flowing between nursing specialities. Siloing is an analogy describing the effect of silos on a farm in which the silos prevent different grains from mixing. In healthcare, the silo effect may limit interactions between nursing specialities, leading to reduced patient care. The term comparison robot, OnAGUI, may identify silos that may be removed to foster innovation, and increase productivity, by unlocking the information needed for collaboration.

6.3.2 Tables of terms produced from each ontology

The OnAGUI robot compared and ranked terms across the four ontologies. The robot produced a table containing terms and annotations from each ontology. Also, terms that occurred in other ontologies were identified in the tables and participants provided annotations to explain the meanings of the terms. Tables of terms and annotations are presented in Chapter Five (Tables 15 to 18).

A comparison of terms across the four ontologies found, on average, 78.12% exclusive language. There were only three identical terms that appeared in three ontologies while there was no identical term that appeared in all four ontologies. The transitional care ontology table shared the most number of identical terms with other ontology tables. Transitional care displayed eleven identical terms with the administrator, four identical terms with surgical, and three with triage. Transitional care's relatively high number of identical terms with other ontologies may reinforce the notion of transitional care having a ‘horizontal’ care structure which expands out into the wider community and other nursing process domains (as identified earlier in this chapter).

Conversely, the triage ontology table had the least number of identical terms when compared with other ontology tables. Triage had no common terms with the administrator, one common term with surgical and three with transitional care. An explanation for the lack of common terms may be due to the triage nurse not having direct contact with the wider hospital as previously discussed in this chapter. The nursing supervisor/in charge nurse in the triage graph may act as ‘buffers’ between the triage nurse and the wider hospital.

6.3.3 Logic consistency in each ontology

Identical ‘test’ patients, nurses and their constraints were placed in each ontology by the student researcher to simulate a hospital unit. The constraints of patients and nurses were:

- Each nurse must have an education requirement, registration and designation
- Each patient must have a diagnosis and an optional medication
- Patients and nurses are separate (disjoint) from each other, that is, a nurse cannot be a patient and vice versa.

The FaCT++ logic reasoner (Tsarkov and Horrocks, 2006) checked that each ontology’s individual patients and nurses were in the correct class with appropriate constraints.

The FaCT++ logic reasoner checked each ontology complied with the following conditions:

- Each individual nurse had an education requirement, registration and designation
- Each individual patient had a diagnosis and possibly an optional medication
- Patients and nurses are separate and cannot exist in the same class (disjoint constraint)—nurses are not patients and patients are not nurses
- Each nurse class contained nurse individuals that conformed to the class constraints (the rules of membership)
- Each patient class contained individuals who conformed to the patient constraints
- Each class was capable of containing at least one individual
- There were no ‘orphaned’ individuals who did not have a class.

The reasoner declared that the administrative, surgical and triage ontologies were logically consistent. However, the transitional care ontology had ‘unsatisfiable’ classes. The reasoner scans the ontology and ‘infers’, or constructs, a new ontology using rules of logic. The reasoner compares the original ontology’s individuals against their constraints; the inferred ontology is shown in Figure 19. It can be seen in Figure 19 that the inferred transitional care ontology has four ‘unsatisfiable’ classes in red. The reasoner grouped these classes under the ‘nothing’ class on the top of the hierarchy. The inconsistencies were caused by ‘disjoint’ individuals, who cannot exist in the same class, being brought together. Basically, nurses and patients existed in the ‘unsatisfiable’ classes contrary to the disjoint constraint applied to them.

6.4 Answering the research question

This thesis answered the question: ‘Can nurse domain experts produce node-arc-node graphs containing semantics describing their process domain and can semantics be evaluated?’ The thesis found that nursing domain experts can describe their process domain using the VUE graph software. Semantics in graphs can be evaluated because they contain human-readable patterns. Semantics in graphs may form node ‘clusters’ which could suggest areas of increased processes. Arcs from NREM roles may determine the ‘role focus’, that is, if the process domain contains more dependent, independent or interdependent roles. The results show that graphs containing nursing semantics can be used to construct ontologies. Software robots can evaluate ontologies containing nursing semantics and provide useful results.

6.5 The thesis’ significance

The thesis provided one way of overcoming contemporary limitations of ontology construction. Prior to this study, nurses have not been used to construct complex ontologies. Graphs in nursing are innovative because the approach developed in this study may facilitate a clearer and more faithful representation of the process domain, which to date has been elusive. More importantly, the approach may be generalised and be applied to industries other than nursing to provide evidence of nursing’s contribution to patient care; all of which may improve understanding between nurses, policy makers and computer science researchers and ultimately translate into improved patient outcomes.

6.6 Strengths and limitations of the thesis

6.6.1 Thesis weaknesses

The thesis was limited by the small number of participants and was constrained by the fact that only four graphs were produced. I did not know at the outset if ontologies constructed from graphs drawn by nurses would work; let alone be able to be analysed. We were guided by Nielsen (1994)'s recommends that a sample of not more than five people, be used in the evaluation of new technology, because he observes, there is no point continuing with a large sample if there is a possibility of an inherent problem in the technology being assessed. The weakness of having too few participants doing a 'once off' graph is we do not know whether nurse domain experts could produce node-arc-node graphs containing semantics describing their process domain in a reliable and quality manner in a longitudinal/cross-sectional study. However, the study is essentially a pilot for future studies to expand on.

The study was also constrained by the limitations of the technology, particularly, the semi-manual process of converting RDF to OWL-DL which could introduce conversion errors. Still, this dissertation has made inroads into understanding nursing processes by giving a more accurate picture of them.

6.6.2 Thesis strengths

This thesis was concerned with working out how new semantic technologies can be linked to nursing models that denote areas of nursing processes or activity. The key strengths of the thesis were:

- Graphs provided a way for front-line nurses to describe their process domain with semantics. Nurse-constructed graphs containing semantics could be converted into ontologies.
- Graphs and ontologies provided valuable insights into nursing processes. Patterns such as 'clusters' and nursing 'roles' in graphs can be evaluated. Ontologies can be evaluated by software 'robots'.

6.7 Observations about the nursing process domain

Graphs and their resulting ontologies in this thesis provided some interesting insights into the nursing process domain. The participants produced very detailed graphs after less than an hour of training in the use of VUE. This was despite most participants ranking their computer expertise low on the usability survey. Also, this was impressive considering that the participants struggled with the notion of nodes being ‘concrete’ or ‘abstract’.

The thesis showed that graphs could provide an insight into ‘what nurses do’. For example, the administrative nurse provided patient care by regulating the budget and implementing the outcome of planning meetings. This is in contrast to the surgical nurse graph where the nurse was directly involved in just about every process connected with patient care.

The transitional, surgical and administrative participants found it easier to group nodes into clusters and they did this naturally when organising the layout of the graph. Interestingly, the triage graph had no clusters because it could be assumed that every process was a ‘straight line’ to another nurse or doctor who effected the care. Clusters may be useful in identifying areas of increased process activity.

The surgical graph had two large clusters, the ‘medication administration’ and ‘computer’ cluster. It may be argued that the computer cluster has too much prominence in the surgical graph and may ‘take the nurse away’ from direct patient care. The surgical graph also showed auxiliary and ‘hidden’ processes. The graph suggested that many of these processes, while necessary, could be time consuming. The large medication administration cluster in the surgical graph is understandable because pain relief and antibiotic administration is a large part of the role of the surgical nurse.

Nurse participants’ graphs showed that the participants’ roles in the process domain were mostly independent. This was not surprising because the participants have been in their roles for an average of 15 years. All of the participants remarked that they found the NREM nodes useful as they organised the graphs; in particular, the roles were useful when it came to categorising their processes.

The OnAGUI robot found the terms used by participants to label their nodes were approximately 85% unique to each ontology. In fact, there were only three terms that were identical in just three ontologies and no terms were identical in all four ontologies. All three ontologies in this study had a large amount of unique terms, which may suggest ‘siloing’. A larger study may confirm siloing which may suggest poor intercommunications between nursing specialities. The identification of ‘siloing’ through a high number of unique terms, with the inherent loss of communication, could have implications for patient care.

The least ‘siloed’ ontology was transitional care, which had the most common terms with other ontologies. An explanation for common terms may be found in the transitional care graph. Transitional care seemed to be a mixture of traditional vertical ‘medical model’ and horizontal ‘community’ model. Transitional care arcs reach out to the wider community and other hospitals. Looking at transitional care from different perspectives (graph and ontology) may be one way to explain the lower count of unique terms in transitional care.

The FaCT++ robot did pick up errors in the transitional care ontology. Patients and nurses coexisted through some classes. This was contrary to the ‘disjoint’ constraint placed on them. The disjoint constraint means that nurses cannot be patients and vice versa. Logic reasoners like FaCT++ can check a process domain for logic inconsistencies.

In this thesis, the graphs provided by the participants were their *perception* of their process domain. Who is to say that another nurse working in the unit would not produce a totally different graph of the same domain? Surely, if every nurse in the domain produced a graph, there would be some common processes and semantics? Searching for common processes and semantics in the same domain may be the basis for future research.

6.8 Further research

Process domain graphs generated by nurses in the same unit may render common terms and semantics, which may suggest ‘common points’ in different perspectives. It would be realistic to say that the graphs, and the subsequent ontologies produced from them, in this thesis, can only be considered as a ‘beginning picture’ of nursing process knowledge acquisition. In future studies, the number of participants may be increased significantly. Future research should increase the sample size so that common processes and semantics in the same domain may be identified. That is, it would be interesting to obtain graphs from nurses working in the same role in a unit. The question may be ‘do nurses have the same perspective of the process domain?’ Also, future research may employ a panel of nursing experts to arrive at consensus on ontology constraints describing International Classification for Nursing Practice concepts such as ‘falls’. That is, what are the conditions (rules) that describe a fall? Knowing this, a reasoner may scan domains to identify patients who have a high probability of a fall.

6.9 Conclusion

The motivation for the thesis was to find a way for nurses, who are not experts in RDF, OWL and LOD, to impart process semantics that could be used to construct an ontology. Underpinning this thesis is the notion that process semantics will be more ‘accurate’ if they are sourced directly from nurses.

This thesis set out to investigate why there was an absence of studies that describe nursing process semantics and to find a way of capturing and analysing the semantics. The thesis found that there was an absence of nursing process semantics because the studies that used Donabedian’s Structure-Process-Outcome (SPO) framework to link Nurse Sensitive Indicators (NSI), frequently bypassed the process domain in favor of linking the ‘easier’ structure domain directly to the outcome domain. The reason frequently cited for this was that process semantics are hard to capture because they are often ‘hidden’ in documentation or described by ‘impenetrable’ medical terminology. Ontologies are ideal to capture semantics but ontologies are hard to construct. There is a good reason why non-clinicians construct ontologies; the language used to construct ontologies is complex. The thesis found that semantics can be captured in ‘graphs’, which are a visual representation of the ontology’s construction language, and graphs can be used to construct ontologies. Semantics in graphs and ontologies can be evaluated and may produce useful information.

The thesis ventured into unexplored territory between nursing and semantic technology and is one of the first nursing studies to draw upon techniques from both realms. Nursing tools-of-trade for this thesis are semantics and nursing frameworks. Semantic technology provided knowledge acquisition frameworks, both are a means to an end, that is, to achieve the best possible patient outcomes.

The literature describing nurse-constructed ontologies, was inconclusive. However, the literature did provide insights into several vital aspects which were used to steer the thesis towards semantic technology as an evaluation platform. In particular, nursing studies used methodologies similar to graph architecture to link NSIs across Donabedian’s SPO. Also, the literature described the Nursing Role Effectiveness Model (NREM), which contained three nursing process roles. Because of NREM’s similarities to graph architecture, the thesis found that the NREM was a good ‘fit’, and was useful as a ‘base’ to focus participants’ graphs.

The thesis found that simple graph software such as VUE negated the need to know complicated ontology languages. Participants agreed that by constructing their process domain in VUE they gained a better insight into processes.

Graphs and ontologies open the way for two different types of evaluation; firstly, the patterns of ‘clusters’ and ‘nurse roles’ in graphs, and secondly, the use of software robots for ranking of terms and checking the logical structure in ontologies.

6.9.1 Participants’ process domain graphs

The graphical visualisation of the nurses’ process domain, and its analysis, provide insights which will assist policy makers to improve patient outcomes through a clearer picture of what ‘nurses do’. Results show that semantic technologies can be used to perform analysis of a nurse’s process domain using semantics provided by nurses. Graphs contained a network of relationships between concepts showing clear semantics. These detailed graphs are significant. The significance lies in their detailed visual representation of the nursing process domain. The detail of the graphs may be a product of the participants who mentally ‘walk through’ their process domain on the VUE platform. Benner (1982) suggested that knowledge is embedded in practice, that is, more knowledge may be elicited by thinking and drawing a graph than by merely talking about what one does in the process domain. Node-arc-node graphs place nurses at the centre of process data collection; participants remarked that drawing the graph gave them better insight into their workplace processes.

6.9.2 Ontologies constructed from the participants’ graphs

The literature mostly concentrated on ontologies’ basic functions such as linking data to build ‘better’ data. Studies describing ontologies that depict a human domain of interest are rare. This thesis positions itself squarely in the depiction of a human ‘reality’, that is, through ontology construction of a relatively elusive process of nurses’ roles. Ontologies produced from four graphs in this thesis represented the participants’ ‘reality’, that is, their perception, of the process domain. The thesis used software robots to evaluate ontologies. This is important, because it opens the way for automated auditing of process domains by software robots.

Because graphs were used to construct ontologies, and they both contain the same semantics, it was possible to refer to graphs for a possible explanation of results in the ontology. For example, FaCT++ results show that the transitional care ontology had the least exclusive terminology of the four ontologies. An explanation may be found in the transitional care graph which showed processes being extended to external facilities, and the community, in a 'horizontal' care structure. This may suggest that exposure to the wider community made the language more 'accessible'.

On the other hand, the triage ontology contained the most exclusive terminology of the four ontologies. The triage graph revealed that the triage nurse had little interaction with the wider hospital and community. The graph showed that the triage nurse was surrounded by nurses who may act as 'buffers', effectively separating the triage nurse from the wider hospital.

Non-clinicians are often frustrated by 'impenetrable' terminology when they attempt to construct nursing process ontologies. This study may serve as a 'stepping stone' or act as a useful 'bridge' to enable non-clinicians to have a better understanding of nursing processes.

For example, in this study, all concepts and relationships were annotated in 'plain English' by nurse participants. Annotations enable non-clinicians to follow the flow of processes through the ontology.

Another problem for researchers is capturing 'hidden' processes. The surgical graph contained many 'hidden' and possibly time-consuming processes which occurred around the computing and medication clusters. These processes may be well known to nurses but are seldom captured in a graph.

The thesis' results suggest that:

- Nurses can supply semantics in graphs that describe their process domain
- Graphs contain patterns inherent to the nursing process domain
- Graph patterns can provide useful information about the nurse process domain
- Graphs can be imported into a development platform such as Protégé and used to construct an OWL-DL process domain ontology
- Software robots can evaluate process domain ontologies for textual 'closeness' and logic consistency.

Ultimately, the fusion of nursing and design science in this thesis may shed light on the development of human/computerised formats used to support understandings of the nurse's process domain. This thesis is a step towards understanding some of the complicated and interconnected processes a nurse undertakes each day—ultimately the goal of this thesis, and all nursing research, is improved patient care.

APPENDICES

Appendix 1: The usability survey

Graph software usability survey

Instructions: Please read the question and place an 'X' on the line.

Q1: Representation of your actual work environment

How close did the completed graph represent your real-world work environment?

1 2 3 4 5 6 7 8 9 10

Not at all — Exactly

Q2: User skill level

How would you rate your computer skill level?

1 2 3 4 5 6 7 8 9 10

Non-existent — Expert

Q3: How would you rate the usability of the software for your skill level?

That is, how easy was the software to use?

1 2 3 4 5 6 7 8 9 10

Easy — Hard

Q4: Suitability for learning

Do you think the process of drawing graphs would be a useful teaching tool?

1 2 3 4 5 6 7 8 9 10

Not useful — Useful

Q5: Fit for purpose

Do you thing the graph tool would be useful in analysing your clinical environment?

1 2 3 4 5 6 7 8 9 10

Not useful — Useful

Q6: Workplace insight

Did the process of drawing a graph give you better insight into your workplace?

1 2 3 4 5 6 7 8 9 10

None at all — Greatly

Appendix 2: Knowledge acquisition for nurses program

Knowledge acquisition for nurses.

Introduction to knowledge acquisition.

- Knowledge is all around embedded in processes. Benner stated that knowledge is embedded in practice
- Tangible knowledge that you can consume at a glance is difficult to acquire
- If we can consume tangible knowledge we can:
    1. Share the knowledge
    2. Understand other aspects of nursing processes
    3. Train people faster
    4. Represent processes in a formal way
    5. Prevent ‘knowledge drain’ as people leave
    6. Capture and store nursing’s contribution to patient health
    7. Capture and store a hospitals’ ‘corporate memory’.

Knowledge models

- The Visual Understanding Environment (VUE)
- The nurse practice environment
- Concrete and abstract concepts in the environment
- Graphs arcs and nodes
- Annotations.
- A quick introduction to ontology.

Vue practice

- Thinking about who or what you interact with in your practice environment
- Getting your head around abstract vs concrete concepts and their relationship to you.

Appendix 3: Data visualisation handout

7 things you should know about...

Data Visualization II

Scenario

One requirement of Vera's master's program in sociology is a thesis, which includes a presentation of findings before her peers for review, discussion, and recommendations. In addition to her own clinical project, which traces correlations between environmental factors and learning disabilities in the United States, Vera gathers 12 years of data on learning disabilities from organizations in the United States, Canada, New Zealand, the Netherlands, South Africa, Australia, and Great Britain. As she begins looking over the paper with an eye toward presentation, she becomes convinced that her statistics, alone, will not clearly articulate the implications of her research to an audience of listeners, so she starts looking for ways to present the information visually.

She begins by using the Visual Understanding Environment, a concept-mapping tool to create a simple knowledge map that illustrates how complex clusters of symptoms characterize specific disabilities. Then she visits IBM's Many Eyes site, searching for examples in her field and ideas for presenting her statistics visually. There she finds a chart correlating a central auditory processing disorder with exposure to heavy metals. She initiates an online discussion with the creator of that chart, who makes suggestions about how she might clearly present her findings. Soon she has a map of the United States showing clusters of learning disabilities that have been associated with environmental toxicity.

For her conclusion, she hopes to convey her concerns about under-diagnosis of key disabilities. She enters the data she collected into a Google Spreadsheet and exports it into Google Motion Chart. The result is an animated chart that Vera runs several times during her presentation to contrast the extremely low number of dyspraxia diagnoses in the United States compared to the number in the six other countries in her data set.

In discussions with her classmates after the presentation, Vera learns that the charts, maps, and animations helped the audience understand the research and findings. What surprises her, however, is the extent to which working with various visual mapping tools to illustrate the data had clarified for her just what the data meant, further advancing her understanding of what was going on in the field.

1 What is it?

Data visualization is the use of tools to represent data in the form of charts, maps, tag clouds, animations, or any graphical means that make content easier to understand. The past two years has seen a blossoming of visualization applications, as well as of technologies and infrastructure to support increasingly sophisticated visual representations of data. The greatest change, however, may be in access to data. Electronic sensors, for example, have made weather information available on a previously unimaginable scale. While geographic information systems (GIS) have for years allowed individuals to gather, transform, and analyze data, new tools have become widely available that easily create unique mashups of disparate sources of data, as evidenced by the increasing number of applications that employ Google Earth and Google Maps. Growing access to information from education, government, astronomy, geology, medicine, and news offers an increasingly widening pool of data that can be combined to create impressive visuals ranging from cartography to cartoons.

2 Who's doing it?

Data visualization tools are popular among those who use social networking sites—on Facebook, for instance, users can create "friend maps" (digital ball-and-stick representations that show networks of friends), while a Flickr mapping function lets photographers easily show where they took photos. Twitter users can post from visual decks like Twittervision, where tweets appear on a world map, or they can use tools such as Stweet, a mashup of Twitter with Google Street View that shows a photo of the street from which the tweet is sent.

In academe, some users have turned to VUE (Visual Understanding Environment), a concept-mapping tool designed at Tufts University that facilitates creation of knowledge maps. At Columbia University, Professor Peter Eisenberger encourages students in his interdisciplinary course, The Earth/Human System, to use VUE to create maps linking the complex problems of sustainability to issues in their own fields of biology, physics, and social sciences. More widely known is the IBM project Many Eyes, which provides both a suite of visualization tools and a public forum for people to share the data visualizations they create. Google Maps and Google Earth have made their way into classes and other places where association of data with geography is valuable, as when

more

EDUCAUSE Learning Initiative

www.educause.edu/eli

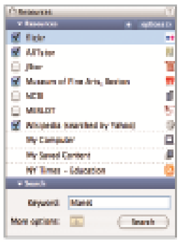
Appendix 4: An introduction to VUE

VISUAL UNDERSTANDING ENVIRONMENT
search • organize • present

VUE is open source and free
http://vue.tufts.edu

Search

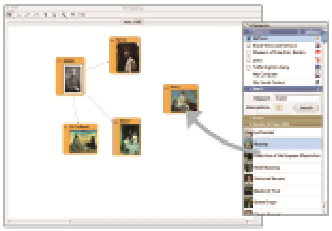
Through VUE's interface, repositories of digital information can be searched via the Resources window. VUE also supports federated searching across digital libraries and repositories.



- ArtStor
- Encyclopedia Britanica
- Fedora
- Flickr
- Merlot
- NY Times Archives
- PubMed
- RSS
- Sakai
- Wikipedia
- and more...

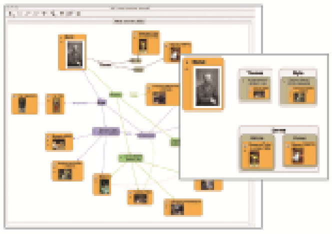
Collect

Digital content such as images, urls, videos and documents can be added to VUE maps, allowing authors to create meaningful content maps.



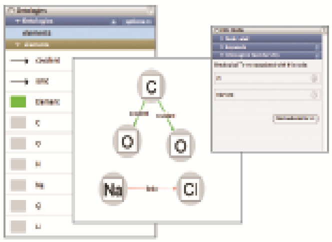
Organize

By way of semantic linking, grouping and nesting, content can be orgazined and contextualized to create meaningful collections.



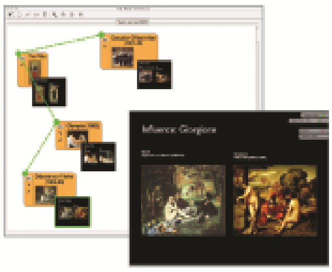
Analyze

The "Merge Maps" tool can merge multiple maps into a new one. The "Ontologies" tool provides additional semantic meaning. The "Connectivity Analysis" tool generates a connectivity matrix which can be imported into other statistical packages.



Present

VUE's interactive zoom and pathways tools allow presenters to deliver linear and non-linear presentations while maintaining information context.



A user guide is available at http://vue.tufts.edu/help
Contact: vue@elist.tufts.edu

Appendix 5: Step-wise methodology

Step	Operation	Equipment	Description	People	Result
Step 1	Select the participants	Invitation to participants flyer	Select participants according to criteria	Student researcher	Participants selected
Step 2	Tutorial and software installation	Laptops and venue	A one hour tutorial about knowledge acquisition and the software is conducted	Participants and student researcher	Software installed and tutorial completed
Step 3	Construct graphs	Vue graph software	The experts are given a graph containing three NREM roles, a patient and doctor class which they fill-in with their work environment	Participants One student researcher	Four graphs are produced
Step 4	Check for confidentiality	Vue graph software	The student checks the graphs and depersonalises where necessary	One student researcher	Semantics are depersonalised
Step 5	Return of the graph to participants	Graphs	The student returns the graph to the participant.	Participants and student researcher	Graphs are checked ok
Step 6	Import graphs into Protege	Protégé 4.3.0	Graphs are imported	One student researcher	Ontologies are constructed from graphs
Step 7	Add constraints and annotations from the graph	Protégé 4.3.0	Constraints and annotations from the graphs are added to the classes	One student researcher	Constraints and annotations in place
Step 8	Add individuals	Protégé 4.3.0	Individuals and their personal constraints are added	One student researcher	Individuals and their constraints are added
Step 9	Compare semantics	OnAGui (I-Sub) robot	OnaGui compares terms in all four ontologies and determines closeness	One student researcher	Four tables containing ranked terms
Step 10	Calculate how similar and different the four ontologies are from each other	OnAGUI Robot	Terms are counted and a percentage closeness is calculated	One student researcher	The percentage of closeness and difference is calculated
Step 11	Calculate the number of arcs from NREM roles	graphs	Nodes are counted attached to each role in each graph	One student researcher	A visual representation of the importance of each role is produced for each speciality
Step 12	Validate logic	Protégé 4.3.0 and the description logic reasoner, FaCT++	The ontology's logic is tested	One student researcher	All four ontologies have been scanned for logic inconsistencies

Appendix 6: The ethics approval

quest.noreply@vu.edu.au

Liza.Heslop@vu.edu.au;l.lu@vu.edu.au;Philip Shields; Tue 1/12/2015 3:20 PM

Deleted Items

Dear DR LIZA HESLOP,

Your ethics application has been formally reviewed and finalised.

» Application ID: HRE15-266

» Chief Investigator: DR LIZA HESLOP

» Other Investigators: MR Philip Shields, MR Philip Shields, DR LUCY LU

» Application Title: Representing the nurse practice environment on the Semantic Web: A usability study to acquire nursing domain semantics.

» Form Version: 13-07

The application has been accepted and deemed to meet the requirements of the National Health and Medical Research Council (NHMRC) 'National Statement on Ethical Conduct in Human Research (2007)' by the Victoria University Human Research Ethics Committee. Approval has been granted for two (2) years from the approval date; 01/12/2015.

Continued approval of this research project by the Victoria University Human Research Ethics Committee (VUHREC) is conditional upon the provision of a report within 12 months of the above approval date or upon the completion of the project (if earlier). A report proforma may be downloaded from the Office for Research website at: http://research.vu.edu.au/hrec.php.

Please note that the Human Research Ethics Committee must be informed of the following: any changes to the approved research protocol, project timelines, any serious events or adverse and/or unforeseen events that may affect continued ethical acceptability of the project. In these unlikely events, researchers must immediately cease all data collection until the Committee has approved the changes. Researchers are also reminded of the need to notify the approving HREC of changes to personnel in research projects via a request for a minor amendment. It should also be noted that it is the Chief Investigators' responsibility to ensure the research project is conducted in line with the recommendations outlined in the National Health and Medical Research Council (NHMRC) 'National Statement on Ethical Conduct in Human Research (2007).'

On behalf of the Committee, I wish you all the best for the conduct of the project.

Secretary, Human Research Ethics Committee

Phone: 9919 4781 or 9919 4461

Email: researchethics@vu.edu.au

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