FIT Fukuoka Institute of Technology 福岡工業大学

FUKUOKA INSTITUTE OF TECHNOLOGY

GRADUATE SCHOOL OF ENGINEERING

A Generic Context Processing Algorithm for the Delivery of Personalised Services in Context-Aware Systems

by

Philip T Moore

Adviser: Prof. Leonard Barolli

2013

Contents

List of Figures

Acknowledgements

This thesis submitted to the Fukuoka Institute of Technology, Japan forms part of my research. I wish to express my gratitude to the Fukuoka Institute of Technology for the opportunity to submit this thesis.

I would wish to express my grateful thanks and appreciation to Prof. Fatos Xhafa and Prof. Leonard Barolli who have over time given much support, sage advice, and feedback on the research documented in this thesis and in the published work. Their input and feedback has been very important to me and has informed and illuminated the research with many insightful observations from which I, on a personal level, and the research, have benefited.

My thanks go to Dr. Bin Hu who supervised my Masters Degree and is responsible for my initial foray into publishing and conference activities which has led to the submission of this thesis. He was instrumental in my interest in context and personalisation and his support in those early days encouraged me to consider undertaking this study.

Reflecting on the study I am reminded of the essentially solitary nature of the research and the need for support, encouragement, and honest appraisal during the course of the work. Thinking about my support network there have been of a number of friends and colleagues who have been central to the research. It is a pleasure to convey my gratitude to all of them and I extend my appreciation of their support and encouragement during the good times and bad along with their input and feedback during the research and in the completion of this thesis.

Abstract

The concept of personalization (the Delivery of Personalised Services: DPS) in its many forms has gained traction driven by the demands of computer mediated interactions. Such interactions are generally characterised by inherent complexity and uncertainty given their dynamic and constant change together with the lack of *a priori* knowledge related to the participants and their diverse service demands. Personalization requires the identification and selection recipients based on a defined profile which describes their current state (a *context*).

The implementation of a context requires the processing of data (contextual information); a broad and diverse range of contextual information may be used to define and describe context. Additionally, systemic requirements for context-aware systems include the need to: (1) implement predictable decision support, (2) effectively address constraint satisfaction and preference compliance (CS), and (3) implement data processing under uncertainty given that (generally) there is very little or no *a priori* knowledge relating to the matching of inputs (e.g., a resource) to outputs (a potential recipient for personalisation).

This thesis addresses *personalisation* with the DPS. Personalisation requires the processing of contextual information to arrive at a Boolean decision identifying an individual as a suitably qualified recipient for DPS based on context. We posit that the generic Context Processing Algorithm (CPA) presented in this thesis implemented with Ontology-Based Context Modelling (OBCM) provides an effective basis upon which the dynamics and complexity of context-aware systems can be managed. Intelligent data processing is achieved while retaining predictable decision support and the ability to address (or at least mitigate) violations of CS.

Chapter 1

Introduction

1.1 Background

There has been a communications revolution with far reaching developments in computing and mobile technologies. This has provided a platform upon which individuals and organisations can generate data and information at an ever increasing rate. Concomitant with the exponential growth in the volume of data and information generated is the increasing ability to store and distribute the data and information. This phenomenon has been termed Information Overload [1] the impact of which is felt by individuals, industry, and academia alike.

Personalisation and personalised service provision has the potential to mitigate information overload by increasing the relevance of service provision based on users current needs while accommodating constraint satisfaction and preference compliance (CS) [2]. There is a large body of documented research addressing personlalisation; the focus being (generally) on accommodating user preferences to enable: personalised service provision, service mediation, and content adaptation based on user-specific information and preferences.

Research addressing personalisation has addressed a broad range of domains and systems [1][3][4] including: Recommender Systems, Collaborative Computing, Health Monitoring, e-learning, and financial systems. Current approaches to enable personalisation are generally implemented in context-aware systems (generally pervasive systems) based on an individuals *context*; a context, also termed a situated role [5], describes a users prevailing personal, environmental, proximate, and social situation [6].

1.2 Context and Context-Aware Systems

Context is highly domain and application specific [7][8]; a context is also potentially highly dynamic and must reflect a users prevailing dynamic state (or *context*)[8]. The issue historically for context-aware systems has been the relatively limited use of the available data (contextual information); the general usage being limited to location, identity, and possibly proximate information [8]. A broad and diverse range of context factors combine to form a context definition [8][9][10]; in fact, almost any (generally sensor derived and/or user entered) information available at the time of an interaction that can be codified and digitised it can be considered to be contextual information; this is exemplified in the range of domains in which context-awareness has been applied to enable personalised service provision [6][10]. Current research is attempting to extend the range and scope of contextual information utilised; the issues lie not in the capture of the data but principally in the difficulty in processing such information. This issue is arguably due to the inherent complexity of context [11] and the processing of contextual information whilst accommodating CS [2].

Effective implementation of personalisation in context-aware systems requires that systemic requirements are accommodated including: the need to implement predictable decision support, effectively address constraint satisfaction and preference compliance (CS), and implement data processing under uncertainty given that (generally) there is very little or no a priori knowledge relating to the matching of inputs (e.g., a resource) to outputs (a potential solution for the personalised services). A discussion on context and its application can be found in [6][7][12][13][14][15] and in Chapter 2.

An essential function within context-aware systems is the data structure. Context processing relies on data (contextual information) which relates to specific entities with their attributes, preferences, and constraints defined in a suitable data structure which incorporates the metadata, context properties, and their (frequently multiple) literal values. In identifying a suitable approach to enable the creation of a suitable data structure (a context model) a design aim is to address these issues and provide a basis upon which the *Context Processing Algorithm* (CPA) can be easily extended to accommodate the diversity and domain specific nature of context and manage its inherent complexity. Research has identified *Ontology-Based Context Modelling* (OBCM) [16] as the optimal approach to realise the goals identified. The development of the ontology is presented in Chapter 3 where the design requirements and potential approaches to the modeling of context is discussed. The developed ontology is presented in Chapter 5.

1.3 Thesis Aim and Contribution

This thesis targets personalisation in service provision in context-aware systems. In essence, our aim is to enable effective targeted provision of services predicated on an approach in which an *input* context is matched to an *output* context to arrive at a predictable Boolean decision which identifies the suitability of an entity for service provision. In summary our contribution(s) can be summarized as follows:

- The design and development of a generic approach to enable the processing of contextual information under dynamic uncertainty.
- The design and development of a generic context processing algorithm capable of realising context processing with predictable decision support.
- The creation of a flexible and extensible human and machine readable data structure capable of managing both *in memory* and *persistent* data storage with effective context modelling.
- An evaluation of the context processing algorithm using a prototypical application predicated on a tertiary education domain.

The aim of this thesis is to illuminate the process of personalisation and targeted service provision in context-aware systems with accommodation of CS. This thesis posits that the CPA implemented with OBCM provides an effective basis upon which the dynamics and complexity of context-aware systems can be managed. The posited approach provides effective and predictable decision support under uncertainty in pervasive context-aware systems with the ability to address (or at least mitigate) violations of CS.

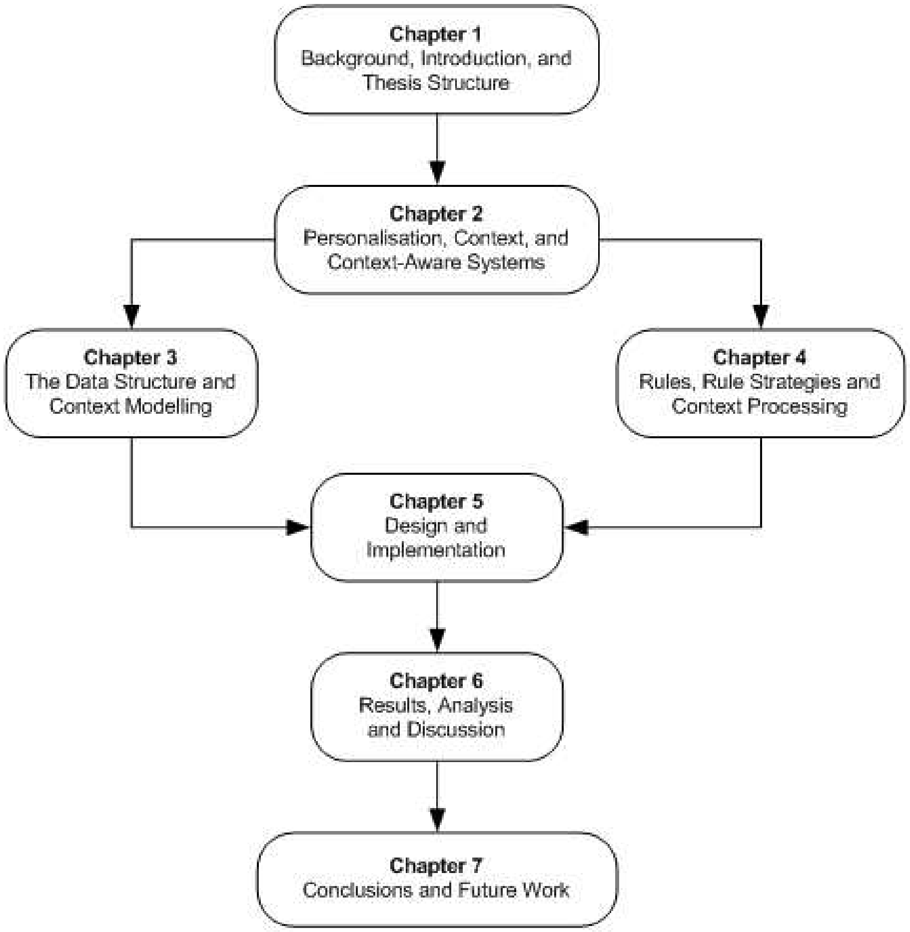

Figure 1.1: Thesis structure.

1.4 Thesis Outline

This thesis consists of 7 chapters; the structure is shown in Fig. 1.1. In Chapter 1 we present the background, the purpose, contribution, and the outline structure of the thesis.

In Chapter 2, we present an overview of the literature as it relates to information systems and personalisation with an overview of uncertainty and the complexity of context. Context, contextual information, and the application of context are discussed with an overview of the domains in which context has been applied. The chapter closes with concluding observations.

In Chapter 3, we expand on the discussion on context in Chapter 2 to consider the creation of a context definition with related design considerations. The approaches to the modeling of context and contextual information (context modeling) are considered with a reflection and conclusions.

In Chapter 4, we address context-processing. Following an overview of context processing and the system architecture the algorithm design is addressed including consideration of rule-based systems, rules, and rule strategies. The CPA is presented with an illustrative example implementation to evaluate the algorithm and provide proof-of concept. The chapter closes with reflections and conclusions.

In Chapter 5, we discuss the design and implementation of the CPA and the data structure (the Semantic Context Modelling Ontology: SCMO). The design of the membership function and related considerations is addressed with a discussion around crisp and heuristic decision boundaries (thresholds). An analysis is set out with conclusions.

In Chapter 6, we presents a discussion relating to the implementation of the CPA with results, an analysis of the CPA in operation, a discussion around conclusions supported as they relate to design considerations. The chapter closes with concluding remarks and observations.

In Chapter 7, we present a discussion around the research set out in this thesis with consideration of the issues and challenges identified and related open research questions. Finally, the chapter closes with consideration of future directions for research and concluding observations.

Chapter 2

Context and Personalisation

This chapter considers the literature related to information systems, personalisation, context, and context-aware systems. The nature of context and contextual information is discussed with an overview of the domains and applications to which context has been applied. The chapter concludes with a reflection and concluding observations.

2.1 Information Systems and Personalisation

An important driver for the growing interest in and take-up of the Delivery of Personalised Services (DPS) in Information Systems (IS) is information overload [1], an issue impacting academia, industry, and individuals alike. In presenting a framework for information overload research in organisations Eppler & Mengis [1] and observe that in general usage of the term information overload is frequently used in relation to *too much information*. Within the research community this everyday use of the term has led to various constructs, synonyms and related terms [17][18][19][20]. Information overload has been applied to a broad and diverse range of domains [21][22][23][24][25][26]. The diverse range of domains addressed support the observation that information overload represents a significant issue [1]. It is clear that information overload is not a new phenomenon however, the advent of the Internet which empowers the exponential growth in the ability to create and store data and information merely serves to exacerbate the issue.

Concomitant with the issue of information overload is the related challenge of information processing and the issue of relevance. In general usage information processing refers to computer-based operations comprising locating and capturing information which is subsequently processed into a desired format. Checkland & Holwell [27] define information as data processed. In discussing information systems this definition has been extended to include an intermediate stage termed: "*CAPTA*" [27]. CAPTA is defined as: *data selected, created, or to which attention is paid* and involves the selection (or creation) of relevant data for processing into information that is relevant and useful to the user. Clearly, if a proportion of the information is relevant a proportion will be irrelevant. The literature identifies information overload and the related issue of relevance as a significant challenge however an effective solution remains largely unrealised.

Personalisation in information systems has its genesis in research into early adaptive user-interfaces, personal assistants/agents, and adaptive information retrieval [28][29]. Currently, personalisation in computerised systems (generally) falls into two types of application [7]: collaborative filtering, and recommender systems. The focus of the personalisation research has been principally on accommodating user preferences [30][31][32] to enable DPS, service mediation and content adaptation using user-specific information and preferences [33][34][35]. Adomavicius & Tuzhilin [36] observe that: *personalisation enables the tailoring of information, services, products and offerings by providers to consumers based on knowledge about them (such as their current needs, situation and preferences) with certain goals in mind.* The reference by Adomavicius & Tuzhilin [36] to the *current needs, situation, and preferences* has a clear correlation with user profiling and the creation of a context.

2.1.1 Uncertainty in Information Systems

The IS are intimately connected with the concept of uncertainty. A fundamental factor in this connection is that uncertainty [in a problem solving situation] results from some information deficiency [37] (pp. 245-247), this is exemplified in the foregoing discussion addressing the membership function and its design. Information (related to a model within which a situation is conceptualised) may be incomplete, imprecise, fragmentary, vague, or contradictory, or deficient [37]. In general, these various information deficiencies may result in differing types of uncertainty [37]. There are three types of uncertainty (as it relates to information): (1) nonspecificity (or imprecision) which relates to sizes (cardinalities) of relevant sets of alternatives, (2) fuzziness (or vagueness) which is a result of imprecise boundaries of fuzzy sets, and (3) strife (or discord) which expresses conflict(s) amongst various sets of alternatives. Context processing and the CPA has a clear connection with fuzziness [9][14][38][39] in that it produces a resultant value (rv) which represents the *degree* to which an output context is a qualified match for an input context.

2.1.2 The Complexity of Context

Context and context-aware systems [across a broad and diverse range of domains] are characterized by inherent complexity [11] and uncertainty [14][38][39]. This is to the lack of a-priori knowledge related to the *input*(s) [in the case of resource allocation the resource (the input) being distributed] and the potential recipient(s) (the *output*) [in the case of resource distribution and collaboration activities]. A discussion on this aspect of context-aware systems can be found in [14].

Complexity theory addresses the study of complex systems and how order, pattern, and structure can arise from them. Complexity theory argues that processes and systems having a large number of seemingly independent agents can be ordered into a coherent system. Research has investigated a diverse range of domains of interest related to context; for example Akman & Surav [40] have extended the concept of *Situation Theory* [41] to model context with situation types which are ordinary situations and thus first-class objects of situation theory. This research not only demonstrates the diversity of context but importantly points to its inherent complexity.

To illustrate the highly complex nature of context and context-aware systems a hospital setting where context(s) must relate to individuals (patients / staff) and resources (e.g., X-Ray facilities: availability, workload, scheduling, etc). From this perspective there are a number of dynamic issues and challenges including: (1) a hospitalized patient is generally very ill and there may be unexpected change in a patients state (or context in computational terms), and (2) there is a high probability that the number of patients may change as in, for example, an influx of emergence cases in the accident and emergency department which can disrupt scheduled and planned medical procedures [10][39]. The hospital environment is therefore typically subject to consistent dynamic complexity and uncertainty [42][43][44].

It is clear that patient management in hospital environments requires the provision of *real-time* contextual information relating to patients in terms of their *numbers* with the current prevailing *locations* and *states*. These demands can be viewed in terms of complexity theory (the processing of a large number of seemingly independent but inter-related entities in an integrated system) where the context-aware system is attempting to mitigate the impact of the dynamic change under uncertainty.

Additionally, there are potential issues for context-aware systems where the scale and scope of the system is subject to constant change. This relates to the number and type of entities that must be accommodated in the realization of a comprehensive context definition. Such a definition entails the capture and processing of a very broad and diverse range of related contextual information [as discussed below] in a system designed to achieve predictable decision support whilst accommodating constraint satisfaction and preference compliance as discussed in [9][10][11][14].

2.2 Context and Context-Aware Systems

Context and context-awareness began to be investigated along with pervasive / ubiquitous computing in distributed systems with the emergence of mobile computing components in the early 1990's and led to the desire to support computer usage in diverse physical environments [9][45][46]. Context-awareness describes a computing paradigm in which the profile (or context) of an entity is used to target the provision of information and resources and match users in interactive systems based on location, preferences and current need [9][46]. A system is context-aware if it can extract, interpret and use context information and adapt its functionality to meet the demands of individual current context(s).

2.2.1 What is Context?

According to Merriam-Webster's Online Dictionary [47] context is defined as: *interrelated conditions in which something exists or occurs.* Context, when viewed from a computing perspective, has been defined in the Dictionary of Computing [48] as: *that which surrounds and gives meaning to something else.* The concept of context is widely understood in the pervasive computing research community, context in computer science referring to physical and social situations in which computational devices are used [49]. While the concept of context is generally agreed a common definition for the term is not [50], considerable confusion surrounding the notion of context, its meaning, and the role it plays in interactive systems [51]. The literature contains many definitions for context; however one of the earliest, broadest, and most comprehensive definitions of context has been proposed by [52]: *Context encompasses more than just the users location, because other things of interest are also mobile and changing. Context includes lighting, noise level, network connectivity, communication costs, communication bandwidth and even the social situation, e.g., whether you are with your manager or with a co-worker.*

A broad range of context factors combine to form a context definition; context-awareness describing a concept in which the profile of an entity [10][15][50]. Context-awareness employs context to identify individuals and implement DPS. Context is highly domain and application specific requiring the identification of domain specific function(s) and properties [13] and therefore must reflect a user's current dynamic state [7][8]. Location is central to context; context however includes more than just location [6][7][10][54]. A broad and diverse range of context factors combine to form a context definition, in fact, almost any information available at the time of an interaction can be viewed as contextual information including:

- The variable tasks demanded by users with their preferences, and constraints.
- The diverse range of mobile devices and the associated service infrastructure(s) and availability.
- Resource availability (connectivity, battery condition, display, network, and bandwidth, etc).
- Nearby resources (accessible devices and hosts including I/O devices).
- The physical (environmental) situation (temperature, air quality, light, and noise level etc).
- The social situation (who you are with, people nearby - proximate information).
- Spatial information including orientation, speed and acceleration.
- Temporal information including time of the day, date, and season of the year.
- Physiological measurements (blood pressure, heart function - *Electrocardiography* (ECG or EKG from the German *Elektrokardiogramm*), cognitive functions

related to brain activity (EEG from Electroencephalography), respiration, galvanic skin response, and motor functions including muscle activity).

- Cognitive and abstract contextual information such as an individuals emotional responses, intuition, feelings, and sensibilities expressed in terms of semantic terminology, this may include *Electromyography* (EMG) which records the electrical activity produced by skeletal muscles [10][55].

The range of potential combinations of these factors demonstrates the difficulty in defining and measuring context as demonstrated in [52][53][54][55][56]. The factors cited, whilst not comprehensive, effectively demonstrate the inherent complexity of context, its domain specific nature and the difficulty in defining and measuring it.

2.3 The Application of Context

There exists a large body of documented research addressing context and context-aware systems dating from the early 1990s [6]. The first use of context in computer systems runs concurrently with developments in pervasive computing as envision by Paul Weiser [57] and the emergence of mobile computing components in the early 1990's. These developments led to the desire to support computer usage in a diverse range of environments, and domains [45]. Context-aware systems have been developed for a broad and diverse range of domains and systems as discussed in [6] where a review of the application of context is presented..

2.3.1 Early Developments

Early developments in the field mainly addressed office-based systems. The research conducted at the Olivetti Research Laboratory was significant and led to the development of the *Active Badge System* [58][59], the *PARCTab* system [60], and work in this area carried out at *Xerox PARC* with the ubiquitous computing experiment which led to the early work in the field of mobile context-aware computing [52]. As part of the PARCTab experiment Lancaster University developed a prototype context-aware system termed *FLUMP* (Flexible Ubiquitous Monitor Project) [61].

2.3.2 Tourist Guides

Tourist Guides represent a prolific area of research. An early example of a *Tour Guide* is the Chameleon project [62], this project methods to enable palmtop computers to identify their location and orientation and provide information about physical objects and their environment. Similar systems include: (1) Cyberguide [63], (2) Guide [64], and (3) The *PALIO* Project [65][66]. As with the *early developments*, the usage of contextual information is limited to spatio-temporal and identity based data. There is also a corollary in the use of sensor derived data.

2.3.3 Context-Aware Field Tools

Context-aware field tools are a variation on the concept of tourist guides. A research project at the University of Canterbury targeted the development of a number of *context-aware fieldwork tools*, these are: an archaeological assistant tool [67], a giraffe observation tool [68], and a rhino observation tool [69]. These tools enable the users to make location dependent notes based on GPS location technologies with a limited capability to apply personalisation and preferences. The restricted use of contextual information to spatio-temporal data remains a limiting factor in these applications.

2.3.4 Memory Aids

Human users generally associate situational information with current contexts; for example when, where, and with whom events occurred. Examples of research projects that have investigated the use of context to build computerised *memory aids* include: Forget-Me-Not [70] and Remembrance Agent [71].

2.3.5 Sensing and Monitoring Systems

A broad and diverse range of contextual information may be utilised to define a context [14][10]. *Sensing and monitoring* of users current state can involve processing a broad range of contextual information. Examples of research in which sensing and monitoring forms a focus for the investigation include: Smart Sight [72] Startle-Cam [73], recent sensor-based motion tracking research including for example [74][75][76][77][78][79], and research addressing Health care Monitoring systems including[80][81][82].

Sensor-based motion tracking research has been the focus of a number of research projects. Clay *et al* [74] report two case studies addressing motion tracking for music with mobile systems technologies; two wearable systems for mobile music making, one simple and one complex.

The first study is *China Gates* which is a work for hand held [music] instruments (for example gongs, claves etc.) and a custom-built GPS device, the *Wrist-Conductor* [76]. The second study is *GoingPublik* [74] which investigates a distributed [music] ensemble; wearable computing using a sensor network consisting of GPS and 3-D Compass is employed. The core premise is a strategy of mobility where content is dependent upon the movement and behaviour of the players; the electronic score allows players to conduct themselves in that it permits improvisational elements within a compositional structure based on activity.

Related *Sensing* and *monitoring* research has investigated Tai Chi and the related health benefits [78][79][80]. This research shares with the case studies identified [74][75] the use of wearable sensors and computing technologies to utilise the sensor derived data. Given that where data can be codified and digitised it can be viewed as contextual information following processing the systems discussed [74][77][78][79][80] can be considered to be context-aware systems and support the observations relating to the diverse nature of contextual information, the inherent complexity of context, and the broad range of domains to which context-aware systems can be effectively utilised.

2.3.6 Georgia Institute of Technology Projects

Georgia Institute of Technology (GeorgiaTech) has investigated a number of different aspects of context-awareness, examples include: In/Out board, Information Display, the *Dynamic Ubiquitous Mobile Meeting Board* (DUMMBO) [83], *Conference Assistant* [84][50], and *Cyberguide* [63]. The projects were developed using the Context Toolkit [50] and are prototypical applications tested and evaluated in a laboratory environment.

2.3.7 Personalisation and Adaptation

Generally applied to mobile systems, adaptation has mainly addressed user interfaces and visualization adaptable to meet the restrictions imposed by mobile, handheld, and wearable devices. Context-aware systems research in this area generally has as its underlying aim the needs of personalisation in its many forms.

There is a large body of research in the literature addressing personalisation and adaptability in mobile systems; significant examples of such work include:the *PALIO Project* [66][67] which targeted location-based services with a focus on support for extensive adaptation in a pervasive context-aware environment. Other relevant research is: the Pocket PiCoMap [86], the Mobile Adaptation with Multiple Representation Approach as Educational Pedagogy [35], and the *Cognitive Trait Model* for Persistent Student Modelling [87].

2.3.8 Ad-hoc Wireless Networks

Ad-hoc wireless networks are networks built using wireless connectivity with mobile devices which are generally established between devices situated in a certain logical or physical locations [88][89]. Ad-hoc networks are (generally) established dynamically by mobile and wearable devices and are maintained by them to realise their communication needs [89]. The mobile devices act as network nodes routing the traffic with no additional infrastructure required as the nodes can come on-line and go off-line resulting in dynamic changes in the network topology [88][89].

Contextual information can be on a number of levels including: establishing a network, establishing and managing the routing mechanisms, and on an application level [90][91].

An issue in ad-hoc networks is their relative complexity, ad-hoc networks may utilise physical proximity, device identity, liability of a node, different characteristics of a node (mobile device) including bandwidth capacity, owner, and cost to use of the node. To achieve these functions the contextual information required must include spatio-temporal data, service infrastructure data, identity data and proximate data (for the mobile device and therefore its user) [88][89][90][91].

In identifying the characteristics of wireless ad-hoc networks, the observation that ad-hoc networks are by their very nature inherently context-aware is supported; this is shown by the increasing usage in a broad range of domains and systems as evidenced by the range of applications identified in this thesis.

2.4 Conclusions

This chapter has considered information systems and personalisation, uncertainty, context and context-awareness, ad-hoc networks [a central feature of many context-aware pervasive systems], and adaptation. An analysis of the research reviewed has resulted in a number of observations and conclusions relating to context and its usage in *real-world* and research conditions.

Information overload and addressing relevance has been identified as an outstanding challenge. Uncertainty is a feature of context and context-aware systems. The documented research demonstrates that the broad range and diversity of potential contextual information is generally known and its usefulness and efficacy as a facilitator of personalisation understood. However, in practice context-aware information systems research dating from the early 1990s to the present day has predominantly used spatio-temporal and identity contextual information in location-based applications providing limited personalisation functionality. This limitation is exemplified in the majority of commercial applications which are essentially information systems targeting tourist, travel information or news distribution applications. This is arguably the result of the inherent complexity of context and the difficulty of context processing. While there is a clear desire to extend the range of contextual information processed to realise a more rounded and comprehensive context that reflects users complex (and dynamically changing) context(s) such work is at an experimental stage. The research projects which have investigated the enhanced range of contextual information are generally developed as prototype systems in research laboratories and academia.

Recent research into context and context-aware systems includes: the sharing and management of context data between smart spaces and the creation of new smart spaces [92], the Context-Aware Smart Space: Reference Model [93], a Quality Aware Context Information Aggregation System for Pervasive Environments is proposed in [94], and a Context Matchmaking for Fast Context-aware Computing is presented by Noh *et al* in [95].

The extension to the usage of contextual information is exemplified by its application in a context-aware tunneling system; in a paper entitled *Predicting Intelligence using Hybrid Artificial Neural Networks in Context-Aware Tunneling Systems under Risk and Uncertain Geological Environment* [15] context-awareness is employed to predict Tunnel Boring Machine (TBM) performance both at the design stage and during the execution of a contract. The proposed approach has been evaluated in experiments using data series from tunnel projects in Japan and Asian countries. To validate the research the results are compared with conventional statistical methods in terms of TBM performance evaluation. Experimental results show that the proposed approach performs better than other current methods under uncertain geological environments.

Current research has begun to use a broader range of contextual information including abstract terms; this is exemplified in the use of Kansei words [96]. In intelligent context-aware systems, contexts are dynamically influent by user intuitions and preferences. An appropriate method called *Kansei* Engineering [96][97] has been developed as a methodology to deal with human feelings, demands, and impressions. An example of this diversity is the use of *Kansei* words in quantifying trader sensibilities about trading decisions under market conditions with uncertain risks in a Context-Aware Group Decision Making [97]. By aggregating user preferences and selecting alternatives, a group of individuals enhances potentially optimal solutions based on contextual information. This research shows that if data can be captured, measured, codified, and digitized it can be considered to be contextual information.

An interesting development is the use of ontology and *Ontology-Based Context Modeling* (OBCM) [91] and the aggregation of evolving contextual information [94]. In proposing a shared view of resources and services over a number of devices Smirnov & Kashevnik [93] provide a model based on the application of such technologies as profiling and context management and Noh *et al* [95] propose a hybrid matchmaking approach for context.

In the field of health monitoring the SOAPD ontology developed by Ann. C. Hurley *et al* [98] the information used relates to the *behavioural and Psychological Symptoms of Dementia* (BPSD) and models the measurement of observed agitation in patients with dementia of the Alzheimer type; this information can be viewed in terms of contextual data as it relates directly to a patients current prevailing context. This research further extends the use of contextual information to include the BPSD, an accepted approach to the evaluation of patients with dementia. There are similarities between Health Care Monitoring Systems and other context-aware systems using wireless wearable computing devices used in conjunction with sensors physically attached to a users person.

Much of the research-based work has used sensor derived contextual data; this is exemplified in the early work, the context-aware sensing and monitoring systems, and health monitoring systems. In fact, sensors have traditionally formed a pivotal function in context research dating back to the early work at XeroxParc. There are significant similarities of approach between Health Care Monitoring Systems and other context-aware systems using wireless wearable computing devices used in conjunction with sensors physically attached to a users person of which the work conducted at ETH Zurich in for example [77][75][76][79][80] are interesting cases. Research has addressed context and sensor networks to create *smart spaces* for health monitoring; this is exemplified by the research documented in [81][82]. The research has a synergy with the development of the SOAPD ontology [98] and while interesting, is in general limited in its scope both in terms of the data processing capability and the failure to fully grasp the systemic requirements for the monitoring of patients with dementia.

Mobile systems using ad-hoc networks are the predominant type of application applying context, indeed we have argued that ad-hoc networks are inherently context-aware. As observed, ad-hoc mobile networked systems and the applications designed to run on them remain reliant upon spatio-temporal, device, and proximate contextual information.

While historically there have been limitations in the technologies available to capture, process, and store contextual data this is now no longer a significant problem as all the basic hardware technologies and mobile devises with the related service infrastructures exist [99]. While this observation is generally true for location-based services; where specialist sensing is required in for example dynamic patient monitoring in health monitoring systems, there remain open research questions relating to non-invasive sensor technologies.

Context-awareness forms a central plank in pervasive computing systems and the literature addressing context and context-aware systems support the conclusion that realising effective personalisation in context-aware systems is essentially a software problem within which there are currently significant open research questions [9][14][10].

Chapter 3 expands the discussion on the literature review set out in this chapter and considers context as it is relates to the problem this research is designed to address and the approach proposed in this thesis with consideration of context modeling an overview of ontologies. Chapter 4 presents a discussion on context processing and introduces the CPA with an evaluation and proof-of-concept. Implementation is addressed in Chapter 5 with the results presented in Chapter 6.

Chapter 3

Context Modelling

Context has been shown to be an effective means to realise personalisation and target service provision. Effective context modelling requires that a number of principal design parameters are addressed including: (1) *in memory* and *persistent* storage of data (contextual information) using a suitable data structure in machine, and ideally human readable, formalism, and (2) dynamic accessing and updating of contextual information to reflect a current context. This chapter considers the approaches to context modeling with a comparative analysis, reflections, and conclusions related to the optimal approach to context modeling.

3.1 Evaluation Methodology

The evaluation of the approaches to context modeling is viewed from the perspective of their efficacy in addressing a number of criteria. Six criteria are used; the criteria being derived from the survey of approaches to context modeling by [100]; these are as follows.

Distributed Composition (**dc**): pervasive context-aware computing is (generally) implemented in dynamic distributed systems, often in ad-hoc networks.

Partial Validation (**pv**): given the potential for errors in defining contextual relationships between entities a desirable characteristic of any context modeling approach is the ability to partially validate contextual knowledge against a context model.

Richness and Quality of Performance (**qua**): sensor derived data is qualitatively and qualitatively variable; context processing and modeling must support quality and richness indication.

Incompleteness and Ambiguity (**inc**): contextual information may suffer from incompleteness and ambiguity. Context models must incorporate the capability to handle this issue by interpolation of incomplete data on an instance level.

Level of Formality (**for**): the description of facts and interrelationships in a precise and traceable manner represents a significant challenge. It is desirable therefore that (in an interactive scenario) each party shares a common understanding and interpretation of the contextual data exchanged.

Applicability to Existing Environments (adaptability) (**app**): a context model will ideally be adaptable for use in existing domains, systems and infrastructures that utilise contextual information to effectively implement personalisation.

The evaluation that follows considers the positive and negative aspects that characterise each context modeling approach. The results are summarised in parametric evaluation matrix set out in tabulated form in Figure 3.1.

Context Modelling Approaches	Parameters					
	dc	**pv**	**qua**	**inc**	**for**	**app**
Key-Value Models (KVM)	-	-	-	-	-	+
Markup Scheme Models (MSM)	+	+	-	-	+	++
Graphical Models (GM)	--	-	+	-	+	+
Object Oriented Models (OOM)	++	+	+	+	+	+
Logic Based Models (LBM)	++	-	-	-	++	-
Ontology Based Models (OBM)	++	++	+	+	++	+
Machine Learning (MLM)	+	+	-	++	++	--

Figure 3.1: Parametric Evaluation Matrix.

3.2 Approaches to Context Modelling

There are a number of methods of classifying modeling approaches [16]. Historically a variety of essentially bespoke modeling approaches have been used, generally addressing one specific application or application class [100], such modeling approaches target users current situation while others model physical environments. Context models are classified under 7 headings [16]. Strang & Linnhoff-Popien [100] classify the context modeling approaches under 6 headings:

1. Key-Value Models (KVM)
2. Markup Scheme Models (MSM)
3. Graphical Models (GM)
4. Object-Oriented Models (OOM)
5. Logic-Based Models (LBM)
6. Ontology-Based Models (OBM)

This list is however not comprehensive, there being modeling approaches using machine learning techniques [16], accordingly an additional *Machine Learning Models* (MLM) classification has been created. The context modeling approaches will be considered under these classifications.

3.2.1 Key-Value Models

KVM use a simple data structure and employ key-words and key-value pairs to represent data to define and implement context properties [51][60] [101][102][103]. The KVM approach is frequently used in distributed service frameworks [100] where services are (generally) described using a list of simple attributes with a service discovery process such as employed in Jini [103].

There are significant advantages in the use of the KVM approach including: (1) ease of management, (2) the ability to implement such approaches using relatively simple programming in traditional high-level programming languages, (3) given the use of a common standard (such as vCARD) there is a capability to implement a degree of adaptability in the transfer of information between different applications and/or systems.

These advantages are however offset by a number of difficulties including [100]: developing structures to enable the effective realisation of context and retrieval algorithms in systems capable of efficient context processing, and (2) the restricted ability to describe complex contextual information.

3.2.2 Markup Scheme Models

MSM markup languages which combine text with additional descriptive information [100] which includes for example describing the presentation structure for the text expressed using markup intermingled with the primary text. The best-known markup languages are the HyperText Markup Language (HTML) and the Extensible Markup Language (XML). MSM are characterised by an hierarchical data structure using a combination of tags with attributes and content with markup tag(s) defined recursively in a nested structure.

The strengths of the MSM approach to context modeling lie in: (1) modeling on a structural level with the capability to enable (pv), (2) the ability to realise scheme definitions, and (3) type checking including complex types. Range checking is also possible to some degree for numerical values (additional constraints can be accommodated when OWL is used) however (inc) has to be handled on an application level. Accommodating the (dc) requirement tends to be approach specific with restricted overriding and merging mechanisms. While there are uses which attempt to addresses this limitation by providing greater flexibility in the overriding and merging capability Indulska *et al* [104] and Butler [105] have reported negative experiences of MSM context models due to constraints imposed by the XML serialisation (also a feature of RDF). Additional issues include: (1) the method of updating values, and (2) the absence of relational constraints issues identified in [104][105]. Applicability to existing environments (app) is a feature of MSM, applicability to existing markup-centric infrastructures of context-aware computing environments being a strength of this context modeling approach.

3.2.3 Graphical Models

GM fall into two (general) areas (1) diagrammatic modeling using (for example) the Unified Modelling Language (UML), and (2) entity relationship diagrams (ERD) [104]. Representative examples of GM approaches are documented in [106][107][108].

An issue with ERD when considering contextual information and the modeling of facts is that ERD contain more than one information construct; hence the need for designers to know when to encode a fact as: (1) a relationship, or (2) an attribute of an entity an issue in relational database design identified in [109]. While (pv) is possible (inc) are (seemingly) not addressed by Bauer [106] but are addressed by Henricksen & Indulska [110] in a revision of the original model presented in Henricksen *et al* [107].

The majority of the extensions to the ORM approach are quality labels to enable quality meta-information to be considered and be an intrinsic component in the approach [110]. The level of computer evaluable formality is (generally) relatively low for any graphical model, GM being mainly used for human structuring and modeling purposes at the design stage. Viewed from the perspective of the approach proposed in this thesis, a GM offers significant benefits in modeling OO class-based systems on a conceptual and design level however the approach fails to meet the needs of the approach postulated in this thesis.

3.2.4 Object-Oriented Models

In considering OOM there is a corollary between the GM and OOM approaches (at least in respect of UML) in that they are both predicated on the principle of Object-Orientation (OO). A common feature of OOM approaches is the aim of achieving the (principal) benefits of OO which are (1) encapsulation and (2) reusability [111] to cover issues arising from the dynamics of context in ubiquitous environments. Context processing is encapsulated on an object level with access to contextual information provided through specified interfaces. Examples of OOM research include: [112][113][114][115].

A strength of the OOM approach is compliance with the (dc) requirement and (pv) is possible [45][112][113]; this is also useful in handling (inc) correctly. Applicability to existing OO context-aware OO computing (runtime) environments is high however OOM may impose significant additional computational overhead.

Considered in the light of the posited approach presented in this thesis there is a correlation between OOM and OWL which is predicated on OO with classes forming a wrapper for context properties and their literal values upon which OBM (discussed in a subsequent section) is based. Thus, while OOM alone fails to address fully the requirements of the posited approach it does form a useful component when taken with OBM.

3.2.5 Logic-Based Models

LBM refer to the conditions under which a concluding expression or facts may be derived from a set of expressions of facts to enable such reasoning and inference rules in formal systems. In logic-based context models a context is defined, added, and updated using facts implemented using logical expressions and rules to describe and define relationships and constraints. A characteristic of logic-based systems is a high-degree of formalism.

Exemplars of LBM approaches include: [87][116][117][118][41][119][120]. LBM incorporates a high level of formality and the ability to be composed in a (dc) arrangement, however (pv) is difficult which represents a significant issue for the posited approach. LBM fails to meet (inc) requirements and adaptability (app) appears to be a major issue. The failure to adhere to common standards also negatively effects (app).

3.2.6 Ontology-Based Models

The preceding context modeling approaches: KVM, MSM, GM, OOM, and LBM, are all precursors to OBM which incorporate many of the concepts that characterise the other modeling approaches discussed. Ontologies represent a potentially useful option to specify concepts and relationships [100]; ontologies being an effective approach in which to represent contextual information in machine-readable formalism in a data structure such as RDF/S with OWL. Examples of research using OBM include: [121][122][123][124][125][126][127][128][129].

Due to the similarities between the modeling elements of ontologies *concepts* and *facts* and objects *classes* and *instances*, OBM approaches share with OOM approaches strength in meeting the (dc) requirement. Partial validation (pv) is enabled with a comprehensive range of (usually GUI based) design and validation tools such as Protege. Applicability (app) and adaptability to existing environments is reached in the ASC model [128], achieved by the adoption of the integration elements of CoOL [128] such as scheme extensions.

3.2.7 Machine Learning Models

MLM are not strictly context modeling approaches, they do however target similar objectives in personalisation and adaptation as discussed in [130]. There are a number of projects in the literature which can be characterised as MLM including: [131][132][133][134]. Flanagan [130] cites Chen *et al* [129], Wang *et al* [135], and Lassila & Khushraj [136] in discussing the MLM approach.

The ability to assimilate and manage data derived from distributed sources (such as ad-hoc networks in mobile systems) is a positive advantage. MLM approaches also confer positive traits in realising (pv) due to the ability to apply formality to the processing and management of contextual information. In assessing ML against (inc) parameters the MLM approach offers positive attributes in that validation algorithms using rule based approaches can define rules to check for problems in meeting the (inc) evaluation criteria. An issue with MLM is the need to experience a context at least once before it is recognised.

MLM approaches incorporate advantages when considered against the (dc) criteria; MLM approaches also confer positive traits in realising partial validation (pv) due to the ability to apply formality to the processing and management of contextual information. MLM approaches using statistical methods fail to meet the (inc) criteria; however, the use of threshold values can enable ML approaches to apply degrees of checking for (pv).

Two areas where MLM's fail are in the (qua) and (app) in existing environments. In assessing MLM against (qua) criteria there is a failure to support diverse data types in supervised learning approaches and in the case of unsupervised learning classification can be achieved often at the expense of issues related to tractability in real-world systems. The (app) criteria is a significant issue, the nature of ML approaches seriously mitigates against achieving adaptability in a diverse range of technologies and systems in the real-world.

3.3 Evaluation

The review of context modelling has considered a range of approaches identified in the literature [100] with an additional ML approach identified in [16]. Clearly the context modelling approaches are not mutually exclusive, as such context modeling approaches are not independent; there is a significant degree of interdependence. For example, in developing systems using ontologies, OBM may be used to model the relationships and constraints that exist between entities; OBM however inherits elements from LBM, OOM, GM and MSM. In classifying the modelling approaches on a structural level based on the data structures used the need to accommodate the processing of contextual information is addressed, such information (generally) being expressed in a textual format, this format when used with the Semantic Web technologies accommodating varying levels of granularity and relatively simple specification of constraints and relationships.

In considering context modeling design there is a clear similarity between the GM and OOM approaches including: (1) the use of graphical symbols in the representation of the domain, (2) the ease with which human users (and designers) can read and interpret the graphical models (e.g. UML diagrams), and (3) the ability to model design solutions and analyse specific issues at differing levels of granularity relating to a modelled situation or specific design problem (e.g. the range of diagrammatic possibilities within UML combined with ER diagrams and data flow diagrams).

Comparing the needs of context modelling and database design with their modelling needs there is a clear synergy between the data structures (essentially tree-based) used to describe for example an address, person or company [137] with the data structure that characterises RDF/S [138] and its text-based attribute (context factors) representation. Context modelling, which arguably functions on the basis of facts (attributes/context properties etc.) about entities and the relationship between entities, the GM approach provides (at least on a conceptual level) a basis upon which effective modelling of entities can be represented. However, GM and OOM approaches while providing an excellent graphical representation understandable to human designers (as an aid to conceptualisation) fail to adequately encompass the demands of semantic context definitions and the recursive nested nature of markup languages that predominate in context-aware applications as evidenced in Indulska *et al* [104]; this demands additional extensions to the GM/OOM approach to effectively model context(s) in intelligent context-aware systems (discussed elsewhere in this thesis).

The LBM techniques as exemplified in [87][116][117][118][41][119][120] and Akman & Surav [40] arguably provide a basis upon which intelligent context-aware systems can be realised however the LBM approach fails to provide a complete answer, a hybrid approach to the modelling of context is being required. The use of markup languages (e.g., RDFS) is a feature of a number of approaches including MLM and OOM where OWL may be serialised in XML/RDF. For example, in developing systems using ontologies, OBM may be used to model the relationships and constraints that exist between entities. OBM however inherits elements from LBM, OOM, GM and MSM. Space restricts a detailed analysis of the context modelling approaches listed however in summary the review set out in [16] supports the following conclusions.

When viewed from a data structures perspective, classifying the context modelling approaches points to the need to accommodate the processing of contextual information (generally) expressed in a textual format. Such a format when used with the Semantic Web technologies accommodates the varying levels of granularity with relatively simple specification of constraints and relationships.

Context is generally entity-based resulting in ontologies which incorporate the ability to function as a simple data structure (see the discussion in chapter 7 relating to the issues identified in achieving persistent data storage in context-aware systems) with, where required, the capability to implement reasoning which represents the dominant approach to the issue of context recognition in mobile environments.

Flanagan [130] cites [129][135][136] in observing that the characterisation of real-world entities is a complex information processing task on real world information sources such as sensor signals. This complexity can severely restrict the ability to realize effective personalisation. In considering OBM Flanagan [130] notes that *it is not surprising the most dominant approach to the problem of context recognition in the mobile environment is based on ontologies*; this is arguably the result of the immediate availability of an ontology. This trait addresses the systemic requirements of a context-aware system are the persistent storage of contextual information. OBM enables persistence using ontologies and the related data (literal values) with the ability to store, update and retrieve contextual data and information on demand.

3.4 Conclusions

The evaluation of the approaches to context modelling supports the conclusion that OBM currently represents the optimal approach to context modeling providing an extensible and flexible solution to the creation of a data structure for domain specific context-aware applications and systems. Additionally, it provides a cross-platform basis upon which the posited generic CPA can be implemented in a broad range of applications and systems.

Context is generally entity-based resulting in ontologies which incorporate the ability to function as a simple data structure, see the discussion in Chapter 6, or where required, provide the capability to implement inference and reasoning[130][133].

In summary, the analysis and evaluation of the identified approaches to the modeling of context points strongly to the use of OBM as the optimal approach to provide the basis upon which context modeling for the posited approach can be realised [16].

Chapter 4

Context Processing

This chapter addresses the processing of contextual information. Context processing is discussed with consideration of rule-based systems and fuzzy theory as they relate to the posited approach. The CPA is presented with an evaluation and proof-of-concept. The chapter closes with a reflection and conclusions. The implementation is addressed in Chapter 5 with results of testing presented in Chapter 6.

4.1 Context Processing

The CP addresses the creation accessing and updating of a stored context definition(s); a context can be viewed as a state with transitional states [7][9][13][14][15], Figure 4.1 presents the context process model (CPM) which commences with a stored context (current Context [A]) and terminates with the replacement of the initial stored context (current Context [A]) with the Implemented (updated Context [D]). The process is cyclic with a back-up context always retained to address issues such as a systems failure. Notes (1 to 6) (see Figure 4.1) are discussed and expanded in the notes below. The CPA is designed to implement the CPM.

Note 1: The initial stored Current Context [A] is created in the first instance default values will be used to create an initial current context [A].

Note 2: Upon an event triggering the system the sensory input data is processed and the Updated Context [B] created to reflect the new situated role.

Note 3: Based on context processing rules if no further context processing is required the Updated Context [B] will replace the initial stored Current Context [A]. The initial Current Context [A] is stored in a back-up system.

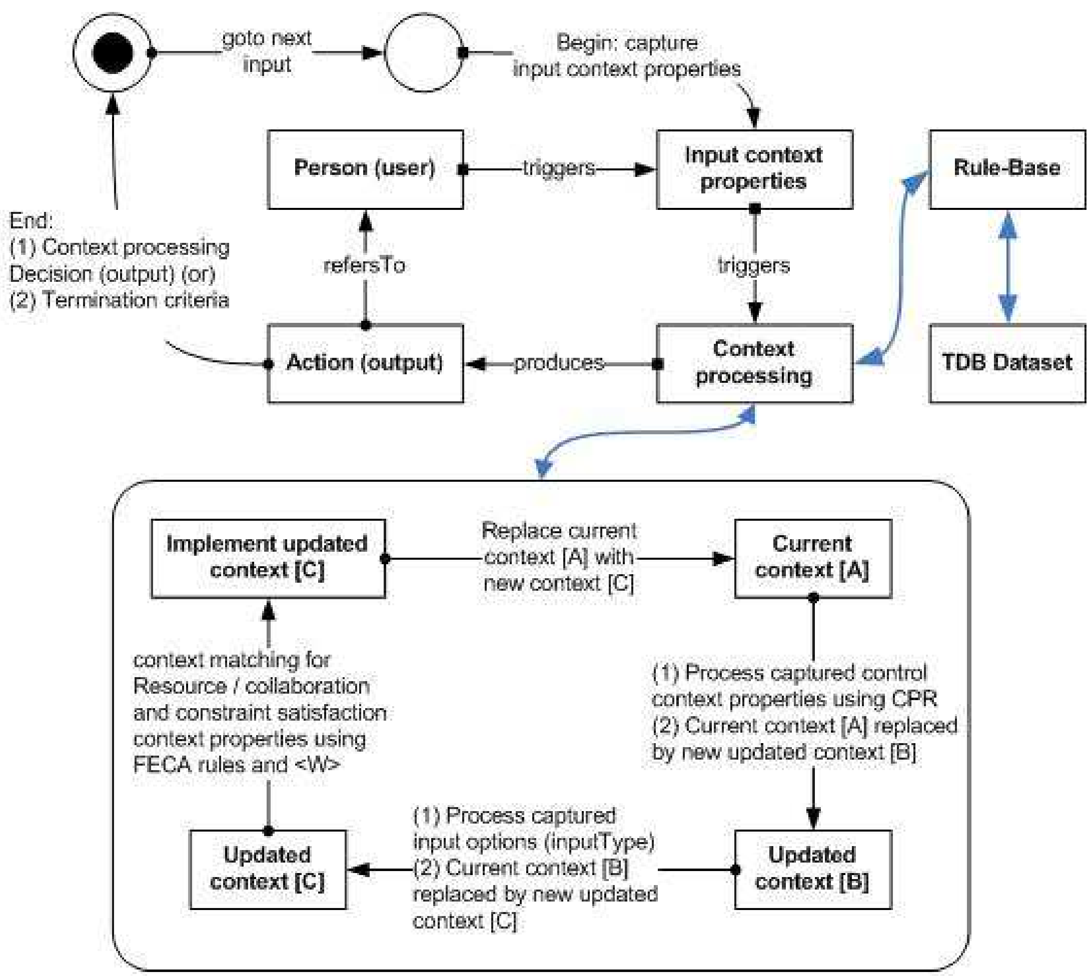

Figure 4.1: The context process model.

Note 4: In situations where context-processing rules dictate the Updated Context [B] will be replaced by the Updated Context [C] (following context processing) to reflect the changing state or context.

Note 5: The Updated Context [C] is implemented and the Updated Context [C] becomes the Implemented Context [D].

Note 6: Finally the Implemented Context [D] replaces the Current Context [A]. The initial Current Context [A] is stored in a back-up system.

A central function within CP is *Context Matching* (CM) which is a process designed to access the input and output context definitions and determine if the output context forms an acceptable match with the input context. Essentially CM produces a Boolean decision as to the suitability of a specific individual [for service provision] based on the context. CM involves the matching of context properties and their related literal values that describes the input and output contexts. Given that a perfect match is highly unlikely the context matching process must accommodate Partial Patching (PM) with a high degree of predictability at a predetermined level. Figure 4.3 graphically models the CM process, PM, and the decision boundary (threshold). Note: The proposed approach enables multiple thresholds [19][14] in for example context-aware health monitoring systems [139] where multiple decisions to reflect differing prognoses must be accommodated.

4.2 The System Architecture

The system architecture, graphically modelled in Figure 4.2, represents the principal component technologies and processes that combine to create an event-driven rule-based context-aware decision-support system. This is the conceptual structure, identified is the data structure and the approach adopted to handle contextual data, the context management component which manages the context matching function, and the rule-base which implements CPA along with the CP and CM functions (see Figure 4.1). The modules identified are relatively simple to understand; however a brief explanatory note regarding the Context Definitions Repository will be useful; this effectively models the *context-space* [9][13][14] which is a conceptual space in which the input context and the output context (s) are held for use in CM process. The proposed general rules architecture employs a paradigm in which there is an association (a process of subscription) between a specific event and a specific rule (or rule set) as discussed in relation to: *Logical Events and ECA Rules* [137]. The advantage gained using this approach is a reduction in the computational overhead due to the reduction and possible elimination in relation to the searching of inappropriate rules or rule sets not applicable to a specific event type.

4.3 Algorithm Design

The design of the CPA is predicated on *Rule-Based Systems* (RBS) and the principles espoused in *Fuzzy-Set Theory* to provide a basis upon which conditional relationships can be achieved with the capability of implementing PM (degrees of membership of a set as modelled in Figure 4.3) in CP and CM.

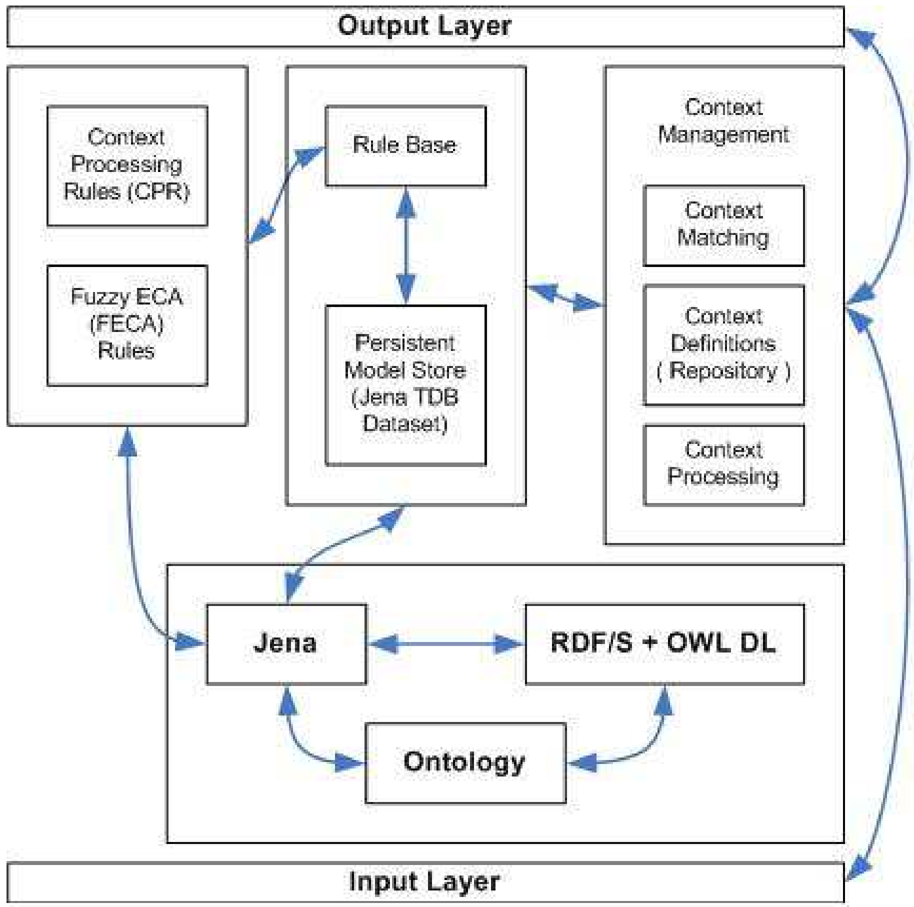

Figure 4.2: The system architecture.

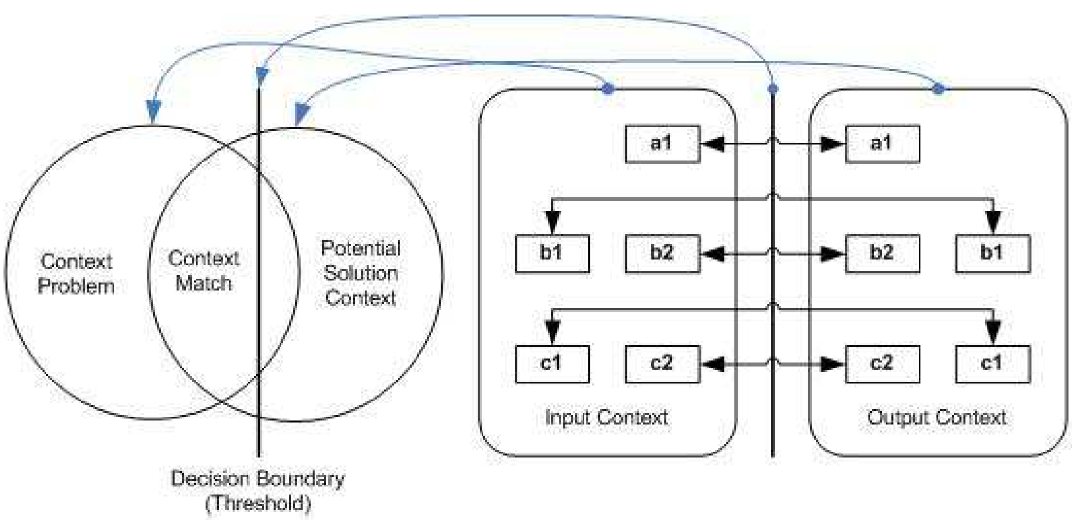

Figure 4.3: Context matching model.

4.3.1 Approaches to Rule-Based Systems

The proposed approach to CP is predicated on the use of an rule-based approaches in an event driven systems [9][12][14]. There is a large body of documented research into rule-based systems addressing a broad and diverse range of approaches [141][142][143] including database systems [137][140], data mining and warehousing [144], fuzzy logic [145][146], decision trees (DT) [147][148][149], and logical reasoning and inference [150][151] which generally applies subsumption and entailment.

There are examples of research projects that investigate rule-based systems from the perspective of the W3C Semantic Web technologies such as: the *RDF Triggering Language* [145] and a research project which integrates an ECA rules strategy with fuzzy extensions to derive conclusions [143]. This research, while relevant to the proposed approach is limited in its scope, CP with CS representing a significantly more complex and challenging task than the research addresses. Notwithstanding the reservations expressed, the research documented in [145][152] is interesting as the reported results confirm the intuition that fuzzy rule-based systems represent a potentially good solution to the inherent complexity and challenging nature of context and context-aware systems.

The use of rules with fuzzy logic with the associated defuzzification [146] based on a predetermined threshold provides the basis for PM and enables effective CP and CM [9][14]. $\{IF - THEN\}$ rules have been shown to be an effective solution to arrive at binary decisions in decision-centric systems using: (1) approaches implementing Event:Condition:Action (ECA) rules [146], and (2) approaches applying fuzzy extensions [146]. Rule-based approaches in the construction of DT's have been shown to be effective in decision support systems. While DT's represent a potentially usable solution where such decision support is required they do not form part of the posited approach; the rationale is considered in Chapter 7. The research into logical reasoning and inference (generally) addresses the defining of complex relationships (frequently based on family or work-based P2P relationships). This aspect of the research will be considered in this chapter with a discussion on the topic in Chapter 7.

This brief overview of research investigating rule-based systems is extended and its relationship to the approach proposed in this study is considered in this chapter where rules and rule strategies, conditional relationships, conventional and fuzzy systems, and the relationship to the proposed approach are discussed. The overview of the literature relating to RBS supports a number of conclusions: (1) CM (a fundamental concept in the CPA) represents a concept that we have not identified in the literature, and (2) the CPA represents an effective approach to enable personalisation and the DPS in context aware systems.

4.3.2 Rules and Rule Strategies

Rules are generally conditional specifications that instruct, permit, trigger, and inhibit processes, functions, and actions [9][14]. Many approaches have emerged to organize RBS; the approaches however share certain key properties [141] including: (1) the capability to incorporate practical human knowledge in conditional $\{IF - THEN\}$ rule strategies, (2) the capacity to solve diverse and complex problems, and (3) the ability to determine the best execution sequence.

Rules fall into two general types [9][14]: (1) Reasoning and Inference rules which are generally used where inference is drawn to identify conditional relationships such as familial or P2P relationships, and (2) Trigger rules which generally implement actions either in the form of a Boolean decision or the firing of another rule. Four rule strategies have been identified in [154]: (1) Derivation or Deduction rules, (2) Integrity Constraints (3) Transformation rules, and (4) Reaction or Event Condition Action (ECA) rules.

Derivation rules: Generally express conditional relationships; for example, $\{IF\}$ one set of statements is true $\{THEN\}$ a second set of statements is also true. *Integrity Constraints*: In general use this rule type relates to validation checking predicated on truth by negation ($\{IF\}$ it is not true $\{THEN\}$ conclude it is an error). *Transformation* rules: These rules relate to truth in for example one knowledge base or ontology with truth in another. For example, in a modified form (when used in combination with integrity constraints) transformation rules have been used in the matching and merging of ontologies [155]. *Reaction* rules: These rules relate to the notion of $\langle action \rangle$ where the $\{IF\}$ component evaluates the rule $\langle condition \rangle$ resulting in an $\langle action \rangle$. The outcome can be either: (1) a Boolean decision, or (2) the firing of another rule. The four rule strategies are based on the $\{IF - THEN\}$ logic structure in the form: $\{IF < condition > THEN < action >\}$

The CPA employs a rules strategy is based on the ECA rule strategy using the $\{IF - THEN\}$ logic structure. In actuality, RBS generally utilize a number of rule strategies. Viewed from a context processing perspective, the final output is a Boolean decision; this clearly calls for a trigger rule type with a reaction rule strategy. However, CS [2][9][14] requires validation using integrity constraints to address, for example, implementation of security and access control policies. Where context modelling utilizes OBCM [18] transformation or derivation rules strategies may be used.

RBS using the ECA rule strategy with the $\{IF - THEN\}$ logic structure have been employed in diverse domains [7][9][14] including *Fuzzy Rule-Based Systems* (FRBS) as discussed in [146]. There are 5 principal fuzzy rule composition strategies [146]: (1) Competitive rules, (2) Weighted rules, (3) Prioritized rules (4) Hierarchical rules, and (5) Adaptive rules. Given the inherent complexity of context [11] and the demands of CS [2][14] no single fuzzy rule composition strategy fulfills the demands of CP and CS. The ECA rules strategy implemented in the CPA [14] employs strategic functions drawn from a number of fuzzy rule composition strategies; e.g., thresholds (competitive rules), and weighting (weighted rules). It is therefore clear that to address the domain specific demands of RBS no one rule strategy is capable of addressing all RBS, each problem requiring a domain and problem specific rules strategy based on the use of conventional logic with fuzzy set theory to reflect the need to address cases where conventional logic is not an adequate solution.

4.3.3 Rules

The rules employ the principles espoused in fuzzy set theory to address the requirements of CP with PM and accommodate CS with predictable decidability in context-aware decision-support systems. The *Context Processing Rules* (CPR) are based on a binary structure (similar to a Horn Clause); both simple and complex rule structures (using multiple conditions) to address cases where multiple (complex) conditions apply can be implemented. CP and CM implemented in the CPA requires logic functions implemented in the $\langle condition \rangle$ component of the rule. The logic operators considered for inclusion are: (1) $\{IF\}$, (2) $\{THEN\}$, (3) $\{AND\}$, (4) $\{OR\}$, and (5) $\{NOT\}$.

The context process model and the system architecture (see Figures 4.1 and 4.2 respectively) with the rule assignment paradigm [146] are predicated on the use of the CPR implemented in the CPA which is predicated on an event-driven rule-based system to enable both the CP and context management. The CPR rules are based on the ECA rule structure using the $\{IF - THEN\}$ logic functions in the form: $\{ON\ \langle event\rangle\ IF\ \langle condition\rangle\ THEN\ \langle action\rangle\}$.

The ⟨*event*⟩ component of the rules can be either a system input or the result of an ⟨*action*⟩ generated in the firing of a preceding rule which triggers a subsequent rule or rule set. The ⟨*condition*⟩ (the antecedent) component in the rule compares one *input* context property with the corresponding *output* context property to determine if the *input* and *output* properties are a *true* match; this process is repeated for every context property. In operation, the ⟨*condition*⟩ component executes a conditional comparison of the *input* and *output* Literal Values to arrive at a Boolean result. The result can be either: (1) a decision (based on the result derived from the ⟨*condition*⟩, or (2) the triggering (firing) of a related rule, or (3) the implementation of built-in stopping criteria defining termination and/or CS issues.

4.3.4 Fuzzy Set Theory

Conventional logic is generally characterized by notions based on a clear numerical bound (the crisp case) [37] in which an element is defined as a member of a set based on numerical parameters in the discrete range $\{0, 1\}$, a *bivalent condition* [146]. Traditionally, conventional logic (also referred to as Boolean logic) consists of three elements [146]: (1) truth values, (2) linguistic connectors, and (3) reasoning types. In Boolean logic truth values are in the discrete range $\{0, 1\}$ (true/false); in fuzzy logic truth is a matter of degree with truth values in the continuous range [1...0] [37][146]. Fuzzy set theory however enables a variable measure of membership of a set (expressed in terms of degrees of membership) defined using a membership function based on continuous values in the range [1...0]; an element that maps to a (normalised) value of [0.80] has a partial degree of membership in proportion to the mapping value; Figure 4.3 graphically models these mapping assumptions which are central to the implementation of the CPA.

In CP the likelihood of a perfect match between the input and corresponding output context property values is highly unlikely; this introduces the need for PM where a matched context mapped to a normalised value of, for example [0.80], has a defined degree of membership. CP with PM imposes issues similar to those encountered in decision support under uncertainty, which is possibly the most important category of decision problem and represents a fundamental issue for decision-support. Uncertainty is associated with vagueness [37] and is considered in relation to rule-based

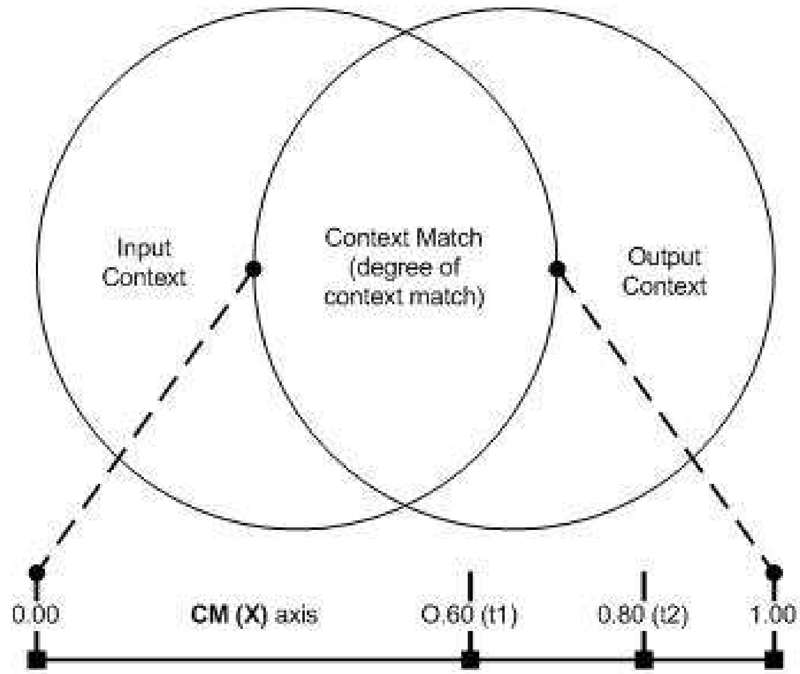

Figure 4.4: Decision boundary model.

systems in [146] where fuzzy logic as it applies to decision support is discussed. A detailed exploration of fuzzy sets and fuzzy logic can be found in [37][146]; a comprehensive discussion on fuzzy system design principles can be found in [146] where a number of classes of decision problem are identified and discussed.

4.3.5 Membership Function (Defuzzification)

The result of step 6 in the CPA is a normalised measure of the degree to which a specific entity (the output context) is a qualified recipient for DPS; this measure is the resultant value (rv) which, when converted into a semantic representation in step 7, represents a measure of the degree of *qualifiedness* when considered in terms of everyday natural language. The semantic classifications are: LQ (a low quality CM), GQ (a good quality CM, and HQ (a high quality CM); these semantic measures of context matches are used to identify the match and apply stopping criteria within CP.

While the degree to which an output context is a match for an input context is interesting, it is not in itself useful when used in a decision-support system; this is addressed in the final step in the CPA which implements *defuzzification* using a distribution function, more generally referred to in the literature as a membership function as discussed in [146]. The result derived from defuzzification is a Boolean decision identifying a specific user as a qualified recipient for service provision. A discussion on membership function design is set out in chapter 5.

4.4 Context Processing Algorithm

The CPA and the related parameters are set out below along with an illustrative implementation and proof-of-concept. To illustrate the thresholds introduced below see Figure 4.4. The CPA parameters and the algorithm are as follows:

$\mathbf{e} \equiv \{0, 1\}$ - a Boolean evaluation of the input/output context property match for each context property $\{true = 1\}$ or $\{false = 0\}$.

$\mathbf{w} \equiv \{0 > \mathbf{w} \leq 1.0\}$ a weight applied to each context property to reflect its relative priority.

$\mathbf{av} \equiv \prod (\mathbf{e} * \mathbf{w})$ the Actual Value (av) for each context property match in the range [0.00...1.00] following the application of the weight (**w**).

$\mathbf{sav} \equiv \sum (\mathbf{av}\,(a1...an))$ - the sum of the Actual Values (**av**).

$\mathbf{mpv} \equiv \sum (\mathbf{av}\,(a1...an))$ - the Maximum potential Value (**mpv**). This parameter represents a state in which all context property matches $\sum (\mathbf{av}\,(a1...an))$ are true [1]. The **mpv** assumes that a perfect context match has been identified.

rv ≡ (**sav** / **mpv** - the resultant value (**rv**) represents the degree to which the overall context match is true in the range [0.00...1.00]. The (**rv**) value is computed in step 6 and used in step 7 to test if (**rv**) is greater than (**t1**, **t2**). (note: in actuality the value for **rv** will be: (**rv** + **xc**) for the X(CM) axis).

xc ≡ the *Euclidean distance* - [0.01] (1% of the normalized context match (**rv**).

q ≡ the resultant semantic value representing the degree of the *qualifiedness* of the CM.

t1 ≡ {0.60} the *lower* bound for a good quality *GQ* context-match on the X(CM) axis as shown in Figure 4.4.

t2 ≡ {0.80} the *upper* bound for a good quality *GQ* context-match and the *lower*bound for a *HQ* context match on the X(CM) axis as shown in Figure 4.4.

t3 ≡ the *upper* bound for the high quality *HQ* context-match-match on the **CM** axis as shown in Figure 4.4. Note: **t3** is a special case as no **rv** value can ever exceed [1.00].

Applying the these functions the CPA is as follows:

step 1: Evaluate the context match $\{1.0\}$ for each individual context property:

IF $(\mathbf{a1}\,(input))$ $.equalTo$ $(\mathbf{a1}\,(output))$ THEN $(\mathbf{e}) = [1]$
IF $(\mathbf{a1}\,(input))$ $.notEqualTo$ $(\mathbf{a1}\,(output))$ THEN $(\mathbf{e}) = [0]$

step 2: Obtain the pre-defined property weighting $(\mathbf{w})$ for each context property in the range $\equiv \{0 > \mathbf{w} \leq 1.0\}$:

$(\mathbf{w}) = (\mathbf{a1}\,\{0 > \mathbf{w} \leq 1.0\})$

step 3: Apply the weighting $(\mathbf{w})$ to the value as derived from step 2 (note: the **w** is applied irrespective of the value of **e**. Thus retaining the result for **e**):

IF $(\mathbf{e}\,(a1)) = \{0, 1\}\,THEN\,(\mathbf{av} = (\mathbf{e} * \mathbf{w}))$

step 4: Sum the values derived from the CM process:
$\mathbf{sav} = \sum(\mathbf{av}\,(a1)) + (\mathbf{av}\,(b1)) + (\mathbf{av}\,(b2)) + (\mathbf{av}\,(c1)) + (\mathbf{av}\,(c1))$
step 5: Compute the potential maximum value (**mpv**) for the context properties a1, b1, b2, c1, c2:
$\mathbf{mpv} = \sum(\mathbf{w}\,(a1)) + (\mathbf{w}\,(b1)) + (\mathbf{w}\,(b2)) + (\mathbf{w}\,(c1)) + (\mathbf{w}\,(c1))$
step 6: Compute the resultant value (**rv**) for testing against threshold value (**t**):
rv = (**sav** / **mpv**)
step 7: Using the threshold values (t1, t2, t3) determine if the output context definition is a suitably qualified match with the input context. Derive the semantic measures of the degrees of *qualifiedness*: (LQ, GQ, HQ). The value of **rv** is (**rv** + **xc**) - the **rv** result is compared to the threshold(s) **t1** / **t2** / **t3**.

IF $((\mathbf{t1}) < (\mathbf{rv} + \mathbf{xc}))$ $\{THEN\}$ $\mathbf{q}$ $(qualifiedness) = LQ$ (Low Qualifiedness))
IF $((\mathbf{t1}) \geq (\mathbf{rv} + \mathbf{xc}))$ $\{THEN\}$ $\mathbf{q}$ $(qualifiedness) = GQ$ (Good Qualifiedness))
IF $((\mathbf{t2}) \geq (\mathbf{rv} + \mathbf{xc}))$ $\{THEN\}$ $\mathbf{q}$ $(qualifiedness) = HQ$ (High Qualifiedness))

step 8: Taking the output (**q**) derived from **step 7** implement the context match.

4.4.1 Evaluation

We present an illustrative implementation to evaluate the CPA; an evaluation of CPA with a dataset evaluation can be found in [13]. Applying the CPA using the indicative context properties shown in Figure 4.3 where the values for (w(a1 ...c2)) are set out in (1), and the values for (**e**(a1...c2)) are set out in (2), and the threshold value (**t**) is defined in (3) results in a computation as follows:

1. **w**(a1) = 0.7, **w**(b1) = 0.8, **w**(b2) = 0.7, **w**(c1) = 1.0, **w**(c2) = 0.9,
2. **e**(a1) = [1], **e**(b1) = [0], **e**(b2) = [1], **e**(c2) = [1],
3. **t** = [0.75]

$\mathbf{sv} = \sum((av\,(a1)) = ([1] * 0.7) = 0.70) + ((av\,(a1)) = ([1] * 0.7) = 0.70) +$
$((av\,(a1)) = ([1] * 0.7) = 0.70) + ((av\,(a1)) = ([1] * 0.7) = 0.70) +$
$((av\,(a1)) = ([1] * 0.7) = 0.70)$ $\mathbf{sv} = 3.30$

$\mathbf{mv} = (\mathbf{w}1...\mathbf{w}n) \Rightarrow \mathbf{mv} = 4.10$ $\mathbf{rv} = (\mathbf{sv}/\mathbf{mv}) \Rightarrow (\mathbf{rv} = 3.30/4.10) \Rightarrow \mathbf{rv} = 0.80$

Applying step 7 and applying the following rules:

IF $((\mathbf{t1}) > (\mathbf{rv} + \mathbf{xc}) <)$ THEN $\mathbf{q} = LQ$
IF $((\mathbf{t1}) \leq (\mathbf{rv} + \mathbf{xc}) < (\mathbf{t2}))$ THEN $\mathbf{q} = GQ$
IF $((\mathbf{t2}) \leq (\mathbf{rv} + \mathbf{xc}) \leq (\mathbf{t3}))$ THEN $\mathbf{q} = HQ$

Applying the semantic membership function LQ, emphGQ, HQ the ($\mathbf{rv} + \mathbf{xc}$) (to two decimal places) 0.80 results in $\mathbf{rv} + \mathbf{xc}) \geq (\mathbf{t2})$. The result is (0.80 + 0.01 = 0.81) = HQ. This results in a semantic measure of *qualifiedness* of *HQ* which is a *true* context match.

The CPA is designed to realise effective CP with predictable decision support while accommodating CS. An analysis of the CPA and the illustrative implementation demonstrates that a number of important attributes incorporated into the CPA address some important issues, design goals, and open research questions as identified in [6][19][14]. Additionally, a number of significant conclusions can be supported.

The evaluation of the context properties (step 1) and their respective values initially results in a Boolean result in the range $\{(e) = [1, 0]\}$. The truth or falsity $[1, 0]$ is retained when the weight (**w**) is applied (step 3) of the CPA.

The CPA has been designed to be generic and accommodate the ability to implement single / multiple thresholds (decision boundaries). For example, in a health monitoring the use of multiple thresholds relecting a patients prognoses is an important attribute.

Personalisation in context-aware systems is characterised by inherent complexity and uncertainty as the *input* context (e.g., a resource being distributed of a collaboration request) and *output* context(s) (a potential recipient for DPS drawn from a set of potential recipients) are generally *a-priori* unknown [9][14]. The CPA is posited as a solution to CP under uncertainty with the capability to manage the inherent complexity of context-aware systems with predictable decision support.

The quantitative result (rv) while interesting is not useful in a decision support system as it is a fuzzy variable. The implementation of the *semantic* conversion in step 7 of the CPA resolves this issue and produces a crisp value useful in personalisation and DPS.

The weight (**w**) applied in step 3 of the CPA provides a basis upon which CS can be achieved. The result of step 7 is a semantic conversion of the (rv) metric to one of: LQ, GQ, and HQ. The semantic measures GQ and HQ are (albeit loosely) related to the well understood precision and recall metrics. A user may opt for a lower level of CM (higher recall) and specify: GP (general precision) which relates to the GQ metric. Similarly, the HP (high precision) preference relates to the HQ level in the CM process, see Figure 4.5 which sets out the relationship between the CM result (LQ, GQ, and HQ) and the user expressed preference level (GP and HP). In the CPA the results utilize the semantic metrics for the degrees of *qualifiedness*.

	LQ	GQ	HQ
GP	[0]	[1]	[1]
HP	[0]	[0]	[1]

Figure 4.5: User preferences and context matching relationships.

We argue that identifying the data points and the DB(s) on the X(CM) axis, while enabling defuzzification and providing a basis upon which predictable decision support can be realized, raises a significant issue. Consider, for example, a normalized context match of 0.595; this degree of membership when tested against the lower bound for the semantic measure GQ (the 0.60 DB) fails. It is arguable that this is not a logical decision given the very small difference (0.5% of the overall solution space, and as discussed below 0.834% of the LQ solution space). Whilst ultimately in any decision-support system the final result will be a Boolean decision, in systems predicated on a fuzzy rule-based approach the solution should at the very least attempt to mitigate such anomalies. To this end the concept of *Euclidean distance* [157] has been investigated. This issue is discussed in Chapter 5 however in summary the CPA in enabling the use of *Euclidean distance* provides a basis upon which this issue may be at least mitigated.

4.5 Conclusions

In developing the CPA there are issues and challenges addressed relate to: (1) identifying the value(s) for the decision boundaries, and (2) the decision boundary proximity issue (DBPI). These issues are addressed in chapter 5 where the design of the membership function is considered with a discussion and a proposed solution to address the DBPI is set out with consideration of the process of defuzzification as discussed in [146]. Chapter 5 presents the design and implementation of the CPA, the testing strategy, and an analysis and conclusions.

Currently the CPA utilizes the X(CM) axis as shown in Figure 4.4. Investigations are ongoing to extend the CPA to include the Y(UC) axis as shown in Figure 7.1 [38] (and possibly later the Z axis) offers significant potential to increase the granularity of the results obtained in context processing. This represents future work and is discussed in section 7.1.1.

Chapter 5

CPA Implementation

This chapter addresses the implementation of the CPA. The data structure is introduced with the testing strategy and datasets; the results derived from the testing are set out in Chapter 6. The *Membership Function* is discussed with the design, an analysis, and consideration of related topics. the chapter closes with reflections and concluding observations.

5.1 Data Structure

A central component in context-aware systems is the data structure used to hold the context. As discussed in Chapter 3 the optimal approach to the creation of the data structure (which in actuality is a context model) is OBCM. In this study a *Semantic Context Modelling Ontology* (SCMO) (see Figure 5.1) has been developed using the *Ontology Web Language*(OWL). For an exposition of the OWL Language vocabulary and constructs see [158][159]. In the SCMO instances are created to hold the context for a *Person*. Context properties with their related literal values are asserted for each Person object. Each *Class* holds the properties (slots in Protege terminology) that define and describe that Class with the datatypes, functional and non-functional object property definitions, and the data values (in Protege terms literal values).

The SCMO is constructed using a combination of Core Concepts with Domain Specific Concepts. The core concepts are designed to be generic; the domain specific concepts are designed to address the prototypical tertiary education application used to evaluate the CPA. The SCMO defines the metadata and provides a the means by

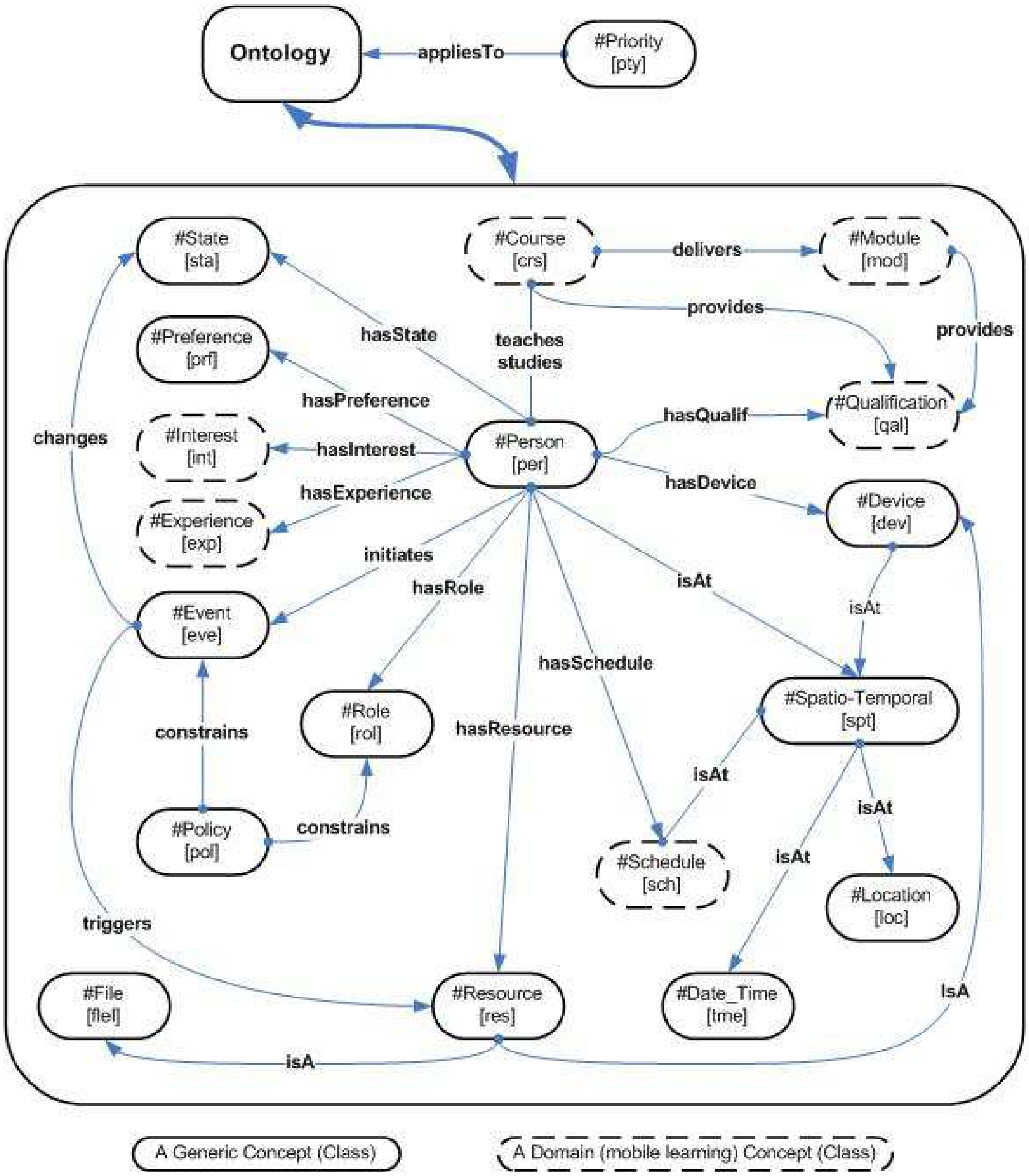

Figure 5.1: The Semantic Context Modelling Ontology (SCMO).

which the Literal Values are defined along with property constraints which typically include: (1) if a property is functional or non-functional property (restricted to a single value), (2) the data type (derived from the XML data type), and (3) the number (cardinality) and allowed terms to be used in the input and output context definitions and utilized in CP. The SCOM relies on class naming conventions which follow the *unique names assumption* which is also a common feature of datasets persistently stored in relational database systems (RDMS). The naming convention used in the following discussion may use shorthand for the class naming used in the actual ontology. Observations on the data structure are set out in chapter 7 where the positive and negative aspects of the approach derived from the research are discussed with potential solutions to the challenges identified.

An important challenge in implementing context is the issue of persistent storage of the SCMO; this is addressed in Chapter 7 where the nature of the challenge and the open research questions relating to the storage of data in context-aware systems is discussed. In summary the processing of data and persistent storag uses the functionality built into the Jena 2 Java API [150]. Jena 2 provides three approaches for persisting RDF and OWL data:

1. Persistent Ontology: an approach to achieve persistence in a SQL backend database;

2. TDB: a non-transactional high-performance, native persistence engine using custom indexing and storage. TDB employs file-based persistent storage (an SQL database is not required);

3. SDB: a transactional persistence layer that uses an SQL database and supports full ACID transactions [150].

The issue with the Jena Persistent Ontology approach is that SPARQL/update is not supported; both TDB and SDB support SPARQL and SPARQL/update however TDB better suited to large datasets [150] and accordingly this approach has been adopted. SPARQL is (generally) based on the Structured Query Language (SQL) however SPARQL search and update strings (Query Strings) are significantly more complex than equivalent SQL search String. SPARQL is discussed in [160][161] and for examples of SPARQL and SPARQL/update search strings see [162][163][164].

5.2 Testing Strategy and Test Datasets

Context-aware systems are domain specific [14]; this characteristic relates directly to the data structure used to model a context in a domain of interest. Accordingly, in this research we are using a prototypical learning application in the domain of tertiary education (PLS) modelled in the SCMO to enable testing and evaluation of the CPA. Investigations have failed to identify a suitable benchmark dataset suitable for the testing and evaluating the CPA, therefore a bespoke test dataset(s) for the *input* and *output* contexts has been developed. The aim of the testing strategy is to evaluate the CPA and not exhaustively evaluate the SCMO which is based on the PLS upon which the evaluation of the CPA is based.

In considering complexity, for the input dataset there are ***2n*** combinations of *true* and *false* results for each context property where ***n*** relates to the number of context properties in the input context, see Figure 5.2. This produces not only an exponential growth in the number of test scenarios but also results in multiple test scenarios for which the Boolean result derived from the context matching process is intuitively either *true* or *false*. To address the complexity an approach using *equality partitions* (EP) [165][166] has been implemented. The EP are predicated on the assumption that testing one instance of a use-case is representative of similar use-cases in a dataset [165][166]. In summary the test scenarios can be restricted to produce a representative testing strategy for the evaluation of the CPA.

The following assumptions have been made when compiling the test datasets and relate to: (1) the classification of students and resources using a numerical system based on integer classification which identifies the suitability of an individual to receive a resource or collaboration request. As we will show the FHEQ will form a parameter in the operation the CPA to implement constraints and stopping criteria. There are 3 student classifications in the output test dataset, the classification being predicated on the *Framework for Higher Education Qualifications* (FHEQ) [167]. The classifications used are: (1) Under Graduate students (UG): (FHEQ level: 6), (2) Post Graduate students (PG) (FHEQ level: 7), and (3) Post Graduate (Research) students (PGR): (FHEQ level: 8). The faculty, course and module structure is as shown in Figure 5.1.

5.2.1 The *output* Test Dataset

The *output* dataset is predicated on the following assumptions. There are 2 Faculties (defined as C1 and C2 in the ontology). Each Faculty has 2 UG courses (each course having 2 modules), 2 PG courses (each course having 2 modules), and 2 PGR research courses (each Faculty having 2 PGR subject areas). Each UG and PG student is enrolled on 1 course and is registered for 1 module from the 2 available modules. Each PGR student undertakes research addressing 1 subject area from the available 2 subject areas from 1 Course. Each UG and PG student is enrolled on

1 course and is registered for 1 module from the 2 available modules. Each PGR student undertakes research addressing 1 subject area from the available 2 subject areas from 1 Course. Each module is assumed to have 1 tutor therefore for a course having 2 modules the course will have at least 2 tutors (tutors may teach more than 1 course and more than 1 module). Each PGR student will have 2 supervisors and each PGR subject area will have 2 supervisors.

Based on the above assumptions there are in total 20 student instances and 24 tutor instances resulting in a total of 44 instances of individuals to enable exhaustive testing for every combination of course and module within the output test set. However, using EP in which testing one instance of a specific use-case (e.g., a PG student) is assumed to be representative of all use-cases for a PG student; therefore, as discussed above the numbers of students and tutors can be reduced to 1 UG student instance, 1 PG student instance, and 1 PGR student instance. In respect of tutors and supervisors the number of instances can be reduced to 1 UG course tutor, 1 PG course tutor, and 2 PGR supervisors. The resulting instances are: 3 students, 2 tutors, and 2 supervisors giving a (minimum) total of 7 individuals in the output test set. The input contexts are matched with the output contexts in context processing; in actuality the matching uses conditional relationship between the input and output literal values. In implementing *Context matching* it has been assumed that all results (rv) which are less than 0.60 will fail.

5.2.2 The *input* Test Dataset

The *input* dataset relates to: (1) control events (2) location change events (3) resource input events and (4) resource distribution events. *Control* events: these properties include: event_Type, location, location_Type (derived from the ontology using the location context property), login_Action, registered (a Boolean value that identifies a user as registered on the system), and academic_Policy (a parameter to define access rights and permissions, also used in CP and CM to match the academic level (FHEQ) of a resource to that of a potential recipient). The function is to direct the program flow to an appropriate rule or rule set and the catch errors and exceptions. *Location change* events: these properties relate to the initial context processing where an individuals current location is identified and is subsequently used in CP *Resource input* events: these events relate to login_Actions entered by individual users of the system. A resource can be: (1) a file, document, or URL/URI

	Context Property	CM	Options	No of Options	No of Scenarios
1	#course	T	F	2	$2^1 = 2$
2	#module	T	F	2	$2^2 = 4$
3	#acadInt	T	F	2	$2^3 = 8$
4	#vocInt	T	F	2	$2^4 = 16$
5	#acadExp	T	F	2	$2^5 = 32$
6	#vocExp	T	F	2	$2^6 = 64$
7	#acadQual	T	F	2	$2^7 = 128$
8	#vocQual	T	F	2	$2^8 = 256$
9	#acadLevel	T	F	2	$2^9 = 512$

Figure 5.2: Context properties and complexity.

		0.60 DB					**0.80 DB**										
	Context Properties	Test Cases (Scenario)					Test Cases (Scenario)										
		0	1	2	3	0	0	1	2	3	4	5	6	7	8	9	0
1	#course	**T**	**T**	**T**	**F**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**F**	**F**
2	#module	**T**	**T**	**T**	**F**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**F**	**T**	**F**
3	#acadInt	**T**	**T**	**T**	**F**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**F**	**T**	**T**	**F**
4	#vocInt	**T**	**T**	**F**	**T**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**F**	**T**	**T**	**T**	**F**
5	#acadExp	**T**	**T**	**F**	**T**	**F**	**T**	**T**	**T**	**T**	**T**	**F**	**T**	**T**	**T**	**T**	**F**
6	#vocExp	**T**	**T**	**F**	**T**	**F**	**T**	**T**	**T**	**T**	**F**	**T**	**T**	**T**	**T**	**T**	**F**
7	#acadQual	**T**	**F**	**T**	**T**	**F**	**T**	**T**	**T**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**F**
8	#vocQual	**T**	**F**	**T**	**T**	**F**	**T**	**T**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**F**
9	#acadLevel	**T**	**F**	**T**	**T**	**F**	**T**	**F**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**F**

Figure 5.3: Analysis of the test case scenarios for the 0.60 DB and 0.80 DB.

link to be distributed to suitably qualified individuals, or (2) a collaboration query entered with the aim of identifying suitably qualified available (making contact based on the user-defined preferences and constraints) advisors.

The sets of context properties (reflected in the input context scenarios) are shown in Fig 5.2 which identifies the complexity of exhaustive testing (discussed in section 5.2.3) and 5.3 which identifies the *true* or *false* combinations representing the potential number of scenarios shown in Fig 5.2. The results of the testing are set out in Chapter 6 with a discussion; concluding observations and comments set out in Chapter 7 where the positive and negative aspects of the approach derived from the research are discussed with potential alternative approaches and solutions to the challenges identified.

5.2.3 Dataset Analysis

An analysis of the tabulated sets of context properties set out in Fig 5.3 identifies the following characteristics: (1) where all context matches are *true* it is clear that in all such cases the result will be *true*, and (2) where all context matches are *false* it is clear that in all such cases the result will be *false*. The lowest number of true (T) context matches that may produce a true overall context matching result will be: (1) for the 0.60 DB all scenarios with 3 or more false (F) context matches can be discounted as they are bound to fail the lower bound for a context match, and (2) for the 0.80 DB all scenarios with 1 or more false (F) context matches can be discounted as they are also bound to fail the lower bound for a context match. The disparity identified between the number of false (F) context property matches in the scenarios is explained by the % contribution each context property makes to the overall context match as discussed in Section 5.3 which addresses the design of the membership function and the related analysis.

As discussed in Section 5.3 the design of the membership function has identified three crisp DB(s) (t1, t2, and t3); the values are: *t1*(0.60), *t2*(0.80), and *t3*(1.00). Note: the t3 DB is a special case as it represents the limit of the solution space as no context match can ever exceed a normalised value of [1.00]. The DB(s) are implemented in the CPA, (see Chapter 4); the solution space and the DB's are modelled in Figure 4.4. Based on the analysis in Section 5.3 and using the context properties shown in Fig 5.3 there are [excluding the test cases (scenarios) where all context matches are either all *true* or all *false*] 3 and 9 testing scenarios for the 0.60 and 0.80 thresholds respectively

Returning to the observations regarding use of EP and the scenarios as tabulated in Fig 5.3; the actual number of test cases are: (1) there are (3) test cases for a 0.60 DB and (9) test cases for a 0.80 DB. There are therefore (3 + 9 = 16) test cases excluding all test cases where all Boolean values are either *true* or *false* which will in all cases result in a *true* and *false* result in CM respectively. In practice the design of a suitable test set will be dependent on the number of context properties that make up an overall context; from the analysis a number of conclusions can be supported.

Given the domain specific nature of context the number of context properties that combine to make up a context will be variable and therefore unpredictable. Accordingly. The design of the test set will be domain specific based on the context being tested. The weighting of context properties using the $\langle w \rangle$ parameter adds additional complexity into the potential context matching result(s); this is however an unknown prior to context processing. A discussion on this topic is presented in Chapter 7. Notwithstanding these observation the EP approach remains valid and provides additional benefits: (1) in this testing approach there will be cases where the highly weighted property will be set to false (F) with the lowly weighted properties are set to true (T), and (2) there will be cases where the reverse is the case. The testing strategy discussed will accommodate these factors; thus the 16 scenarios with their (T) and (F) matches represent a representative input context test set.

5.2.4 Scenario-Based Evaluation

The scenario-based evaluation builds on the evaluation of the CPA as set out in Chapter 4. The results of the testing is set out in a tabular format; an example of scenario template for (software) control testing is shown in Fig 5.4; the results can be found in Chapter 6. To evaluate the software there are 10 test cases to evaluate the effectiveness of the control context properties (for example to test if a user is a registered member of a system or to catch exceptions such as invalid input values).

Based on the analyses set out above each of the 16 input test cases will be matched to 7 output test cases (instances / individuals in OWL). To evaluate the CM against the 0.60 DB there will be (3 (outputs) x 7 (inputs) = 21) tests and for the 0.80 DB there will be (9 (outputs) x 9 (inputs) = 81) tests. This results in 102 test sets.

Additionally there are a further 2 test sets in which all context matches are true and false. Thus for this phase of the testing there are 104 test sets. In addition to the control testing based on a single DB(s) there are 22 test sets with randomly generated values in the range $[0, 1]$ (false and true respectively). Thus, the total number of tests documented in the appendix is: 104 + 22 giving a total of 126 test sets evaluated.

Control Context Processing Scenario: C_CP_8

Context Properties	Data Type	Functional Property	Literal Value	Validity
#event_Type	Integer	True	[2]	True
#action_Type	Integer	True	[1]	True
#user_Id	String	True		True
#user_Policy	Integer	True	[2]	False
#res_Type	Integer	True	[1, 2]	True

Exceptions Caught:	Invalid: #user_Policy
Anticipated (design) result:	False: in this scenario the user policy only permits a collaboration query input therefore the system terminates the context processing
Actual (experimental) result:	False: the anticipated design result is validated
Scenario testing result:	Correct
Design action:	Terminate context processing + error message
Actual action:	Terminate context processing + error message
Action result:	Correct

Notes:

- #event_Type [2] == a user input such as a resource or a collaboration query
- #action_Type [1] == a resource (file) input
- #user_Policy [1, 2] == an academic policy. [1] allows both a resource or collaboration input, [2] is a restricted level of rights and only allows collaboration queries
- The #user_Policy property is derived using a Sparql query using the #user_Id
- #res_Type [1, 2] == a type of resource input. [1] relates to a file input while [2] relates to a link input. Different context properties are used for a file and a link.

Figure 5.4: Scenario Template for a Control Test

5.3 Membership Function

Central to the implementation of CPA is the design of the *distribution function*, more generally referred to in the literature as a *membership function* (MF) [146] which implements *defuzzification* [14][146]. The result of step 6 in the CPA is the *resultant value* (rv); this, while interesting, is not in itself useful when used in a decision-support system. This is addressed in step 7 in the CPA where the MF is applied to implement defuzzification [14][146] to arrive at a Boolean result.

5.3.1 Design of Membership Function

The membership function and the related fuzzy variable(s) are domain specific requiring domain specific design; a feature shared with context-aware systems. Threshold(s) (DB's) forms an element in fuzzy variable development and is a parameter in the CPA. Identifying the datapoints (and therefore the DB's) in the solution space on the X(CM) axis is achieved using a partitioning technique as discussed in [14][144]. In its simplest form, partitioning is an attempt to find a datapoint(s) for a DB(s) between (at least two) data points on a solution space. Figure 5.5 graphically models the partitioning of the solution space; shown are the notional (crisp) DB(s), the heuristically defined DB(s), and the partitioning process using Linear Extension Surfaces [146].

Implementation of the CPA is predicated on the principles espoused in fuzzy set theory (in which there are degrees of membership of a set) [40] in the range [0.0...1.0] and defuzzification as discussed in [144] to arrive at a Boolean decision in the range $\{1, 0\}$. In operation the CPA results in a solution space with a lower bound of [0.00] and an upper bound of [1.00] as shown in Figures 4.4 and 5.5. The lower and upper bounds of the solution space represent crisp data points on the X(CM) axis and represent the only known *a priori* data points and information relating to the solution space.

The solution space is initially partitioned to into two partitions each with defined data points (thresholds) on the X(CM) axis (t1) and (t2); as observed (t3) is a special case as it represents the limit of the solution space as no context match can ever exceed a normalised value of [1.00]. There are two partitioning cases: (1) partitioning based on crisp data, and (2) partitioning based on (at least two) crisp data points identified with fuzzy data points [146]. Given that there is no *a priori* knowledge relating to the probability of a context match being achieved the partitioning utilizes the available (normalized) data range [0.00...1.00]. In (1): identifying data points (and therefore the thresholds) requires merely linear extension surfaces, the result being a defined (crisp) data points (DBs) [144]. In (2): heuristically defined (fuzzy) data points are identified using available knowledge; this approach employs heuristic interpolation predicated on: (a) the results published in the literature relating to the success of recommender systems, and (b) the data points and thresholds identified using the partitioning approach as discussed in this section. The heuristic interpolation employs a number of factors:

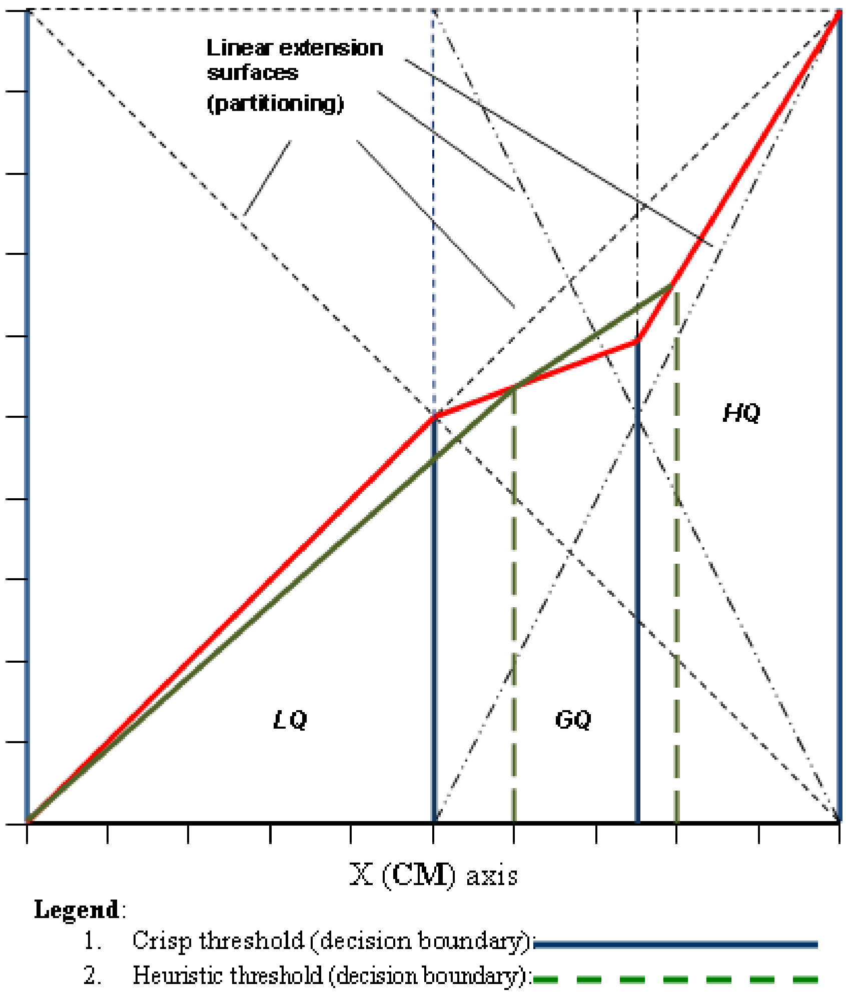

Figure 5.5: The Membership Function with Decision Boundaries

1. The literature addressing recommender systems has identified success rates (generally predicated on the precision and recall metrics) [39] in a normalized range: 0.48 to 0.710 (48% to 71% respectively)

2. The only *a priori* known crisp data points are the upper and lower bounds of the solution space [0.00] and [1.00] (t3); there being no a priori knowledge relating to intermediate crisp points upon which to base partitioning of the solution space.

3. The contribution made by each context property (which combine to create an overall context) is variable in direct proportion to the number of context properties that make up a context. For example: for 5 context properties

each property contributes 0.20 (5 x 0.20 = 1.00) and 9 context properties each property contributes 0.111(9 x 0.111 = 0.999). Both cases result in a normalized value of [1.00] (the upper bound of the solution space).

Considering point 3, for (9) context properties as shown in Fig 5.3 each property [match] contributes 0.111 (to 3 decimal places) to the overall context (0.111 x 9 = 1.00). Now consider a context comprising 9 context properties and it's relationship to a threshold set at a value of 0.60; all scenarios with less than 6 true matches will be false (e.g., 5 x 0.111 = 0.555) and as 0.555 is less than the 0.60 DB the CM fails. Further, consider a DB set at a normalised value of 0.80 all scenarios with less than 8 true matches will be false (e.g., 7 x 0.111 = 0.777) and as 0.777 is less than the threshold the CM fails.

Based on the points 1-3 and the following analysis of the partitioning of the solution space has been developed. There are 3 decision boundaries identified for the context processing: (a) the lower bound (t1), (b) the upper bound (t3), and (c) the intermediate bound (t2) as shown in Figure 4.4.

Considering point 3 above and the following analysis of the partitioning and (rv) adjustment, the following conclusions are supported. A context match where less than 7 context properties are *true* matches would not be a very good match. For example where there are 9 context properties in a set of context properties (a context definition) it is unlikely that a context match with 5 or less true matches will be acceptable as 5 properties equate to: (5 x 0.11 = 0.55), 7 properties equate to: (7 x 0.11 = 0.77), and 9 properties equate to: (9 x 0.11 = 0.99). Based on these assumptions the heuristics applied to set the data points on the X(CM) axis are: 6 context properties (maximum 6 x 0.11 = 0.66 degree of membership) will be used for the t1 DB, 7 context properties (7 x 0.11 = 0.77 degree of membership) will identify the t2 DB, and clearly 1.0 will be used for the t3 DB.

The heuristically defined intermediate bounds are (t1) and (t2) (0.60 and 0.80 respectively); these relate to the semantic metrics: LQ, GQ, and HQ as discussed in chapter 4 and this chapter. Thus, in the presence of fuzzy data between (at least two) crisp points on a solution space, equidistance partitioning (a result of the first approach) can be modified to accommodate the desired boundaries by asymmetric (as opposed to symmetric) functions. The approach adopted for this study employs linear extension surfaces as shown in Figure 5.5 to identify a defined location for the initial decision boundaries; then the interpolation technique is applied to arrive at a set of heuristically defined DB(s).

Identifying the crisp data points on the continuous solution space is based on the assumptions set out above. In Figure 5.5 the crisp data points obtained using the partitioning technique are 50% (or 0.50 normalized) and 75% (or 0.75 normalized) for the lower bounds for the GQ match(s) and for the HQ match(s). The heuristically defined DB(s) derived using the heuristic approach (as shown Figure 5.5 are: (t1) 60% (0.60 normalized) and (t2) 80% (0.80 normalized).

5.3.2 Decision Boundary Proximity Issue

Identifying the data points on the X(CM) axis of the solution space with the DB(s), while enabling defuzzification and providing a basis upon which predictable decision support can be realized, raises a significant issue. Consider, for example, a normalized context match of 0.595; this degree of membership when tested against the lower bound for the semantic measure GQ (the 0.60 DB) fails. It is arguable that this is not a logical decision given the very small difference (0.5% of the overall solution space, and as discussed below 0.834% of the LQ solution space). Whilst ultimately in any decision-support system the final result will be a Boolean decision, in fuzzy systems the solution should at the very least attempt to mitigate such anomalies. To this end the concept of *Euclidean distance* (ED) [157] has been investigated. ED applies to a threshold(s) and the (rv) metric computed in step 7 of the CPA and as discussed below can enable (where required) both *promotion* and *relegation* of a context matching result (rv) prior to the semantic conversion.

We have intuitively identified that ED implemented in the CPA provides a basis upon which the use of ED can be extended to other relationships between DB(s) and context match(s) (rv values) including accommodating the relationship between the rv value and the DB's located on on the Y(UC) axis as shown in Figure 7.1. For a discussion on uncertainty see chapters 2 and 7 where the location of the uncertainty decision boundary is discussed.

In practice, as shown in the following analysis the actual % adjustment reduces as the value for the rv metric increases; for the t1 DB a 1% adjustment (0.01) equates to 1.67% and for the t2 DB a 1% adjustment (0.01) equates to 1.25% , see Fig 5.8. Thus, with increasing degrees of confidence in the context matching the adjustment effectively reduces in direct proportion as shown in the analysis presented in the

Properties	1	2	3	4	5	6	7	8	9	10	11	12
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Contribution	1.000	0.500	0.333	0.250	0.200	0.167	0.143	0.125	0.111	0.100	0.091	0.083
1	1.00											
2	0.50	1.00										
3	0.33	0.67	1.00									
4	0.25	0.50	0.75	1.00								
5	0.20	0.40	0.60	0.80	1.00							
6	0.17	0.33	0.50	0.67	0.83	1.00						
7	0.14	0.29	0.43	0.57	0.71	0.86	1.00					
8	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00				
9	0.11	0.22	0.33	0.44	0.56	0.67	0.78	0.89	1.00			
10	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00		
11	0.09	0.18	0.27	0.36	0.45	0.55	0.64	0.73	0.82	0.91	1.00	
12	0.08	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.83	0.92	1.00

Figure 5.6: Context property contributions for 1 to 12 context properties.

following section. It can be seen from the above that within restricted parameters this rule when implemented in the CPA provides a basis for mitigating the potential anomaly identified.

5.3.3 Partitioning and Resultant Value Analysis

The following analysis attempts to identify a logical foundation upon which: (1) the partitioning of a solution space on the X(CM) axis (see Figure 4.4), and (2) the identification of suitable (rv) adjustment values can be achieved.

Figures 5.6 and 5.8 with Figure 5.7 set out: (a) the relationship(s) between the number of context properties (in a set of context properties), and (b) the contribution made by each context property to the normalised context matching total [1.00]. The analysis considers the trends in the data under two headings: (1) the identification of the data points (see Figure 5.6 with Figures 5.5 and 5.9) and (2) the relative changes in the % adjustment (to the rv value) used to address the *Decision Boundary Proximity Issue*(DBPI).

Figure 5.7 sets out the contribution made by context properties to the overall context for 1 to 12 context properties (i.e., the number of context properties that make up an overall context). Figure 5.7 models the contribution made by each context property to an overall context, the relative error related to the increasing

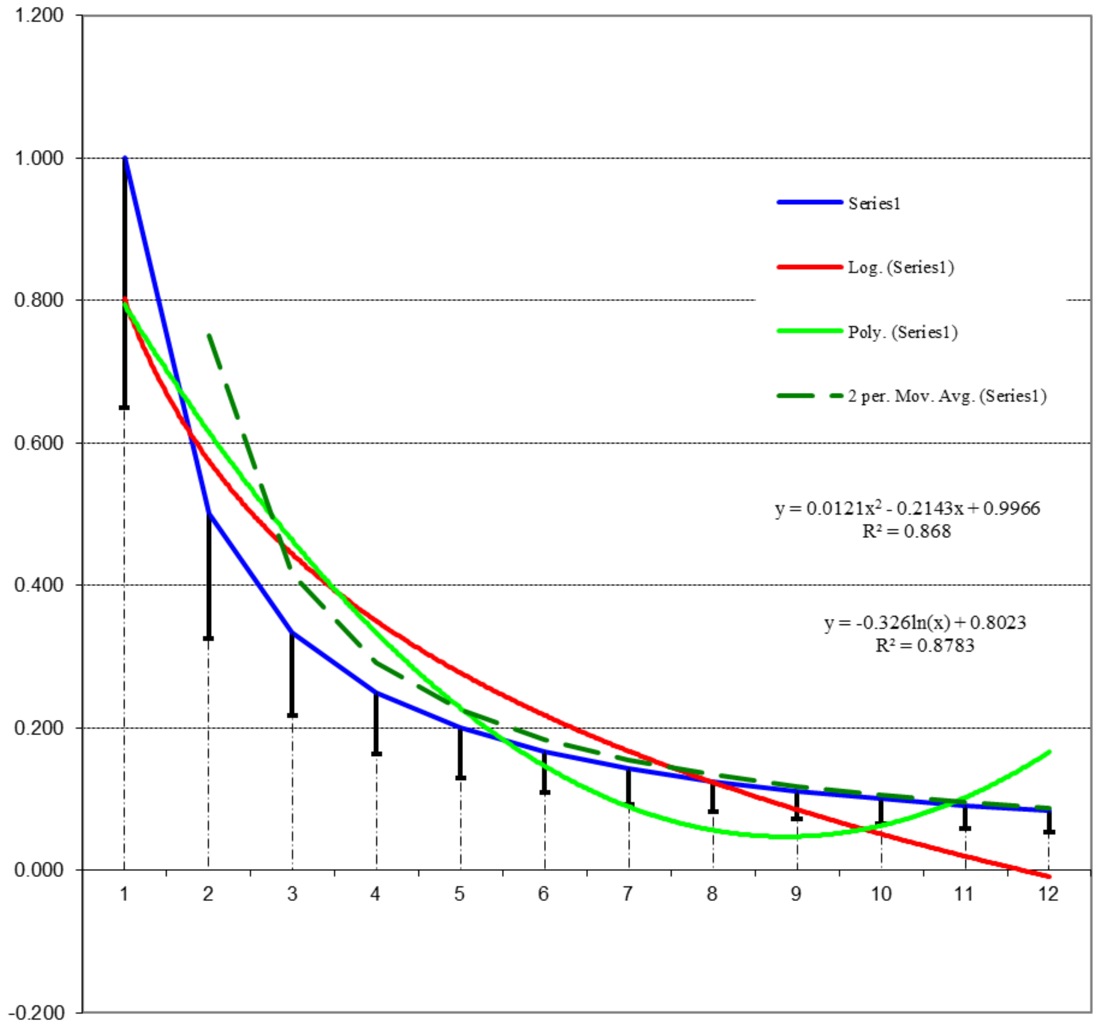

Figure 5.7: Context property contributions, data trends, and relative error.

DB	rv (DB) value	Confidence Level	adj (0.01)	adj (0.02)	adj (0.03)	adj (0.05)
	0.00	0.00%	0.00%	0.00%	0.00%	0.00%
	0.10	10.00%	10.00%	20.00%	30.00%	50.00%
	0.20	20.00%	5.00%	10.00%	15.00%	25.00%
	0.30	30.00%	3.33%	6.67%	10.00%	16.67%
	0.40	40.00%	2.50%	5.00%	7.50%	12.50%
	0.50	50.00%	2.00%	4.00%	6.00%	10.00%
T1	0.60	60.00%	1.67%	3.33%	5.00%	8.33%
	0.70	70.00%	1.43%	2.86%	4.29%	7.14%
T2	0.80	80.00%	1.25%	2.50%	3.75%	6.25%
	0.90	90.00%	1.11%	2.22%	3.33%	5.56%
T3	1.00	100.00%	1.00%	2.00%	3.00%	5.00%

Figure 5.8: Relative adjustments related to potential DB values.

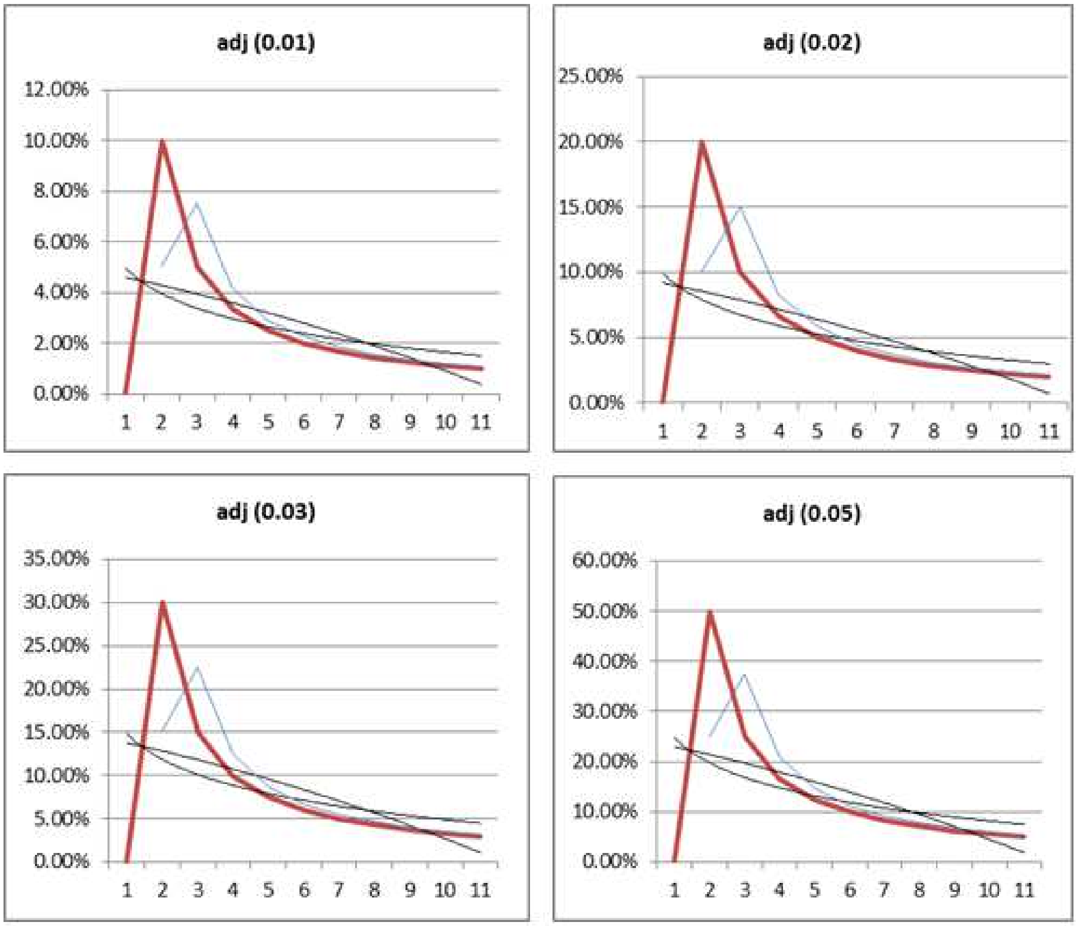

Figure 5.9: The Trends in the Adjustments for a Range of Context Properties.

number of context properties and the trends in the data (the error is based on 35% error[1]). Shown are the data plots with moving average (MA), logarithmic (LT) and polynomial (PT) trends in the data. Figures 5.7 and 5.9 identify trends in the data relative to the number of context properties in a context.

Figure 5.8 sets out the relative quantitative adjustments to the (rv) value, Figure 5.9 models graphically the relative adjustments related to the range of context properties in a context. Shown are the *data plots* with MA, LT, and PT trends in the data. The calculation to arrive at the % adjustment value is, for example: for an ($adj(0.01)$) the adjustment to the (rv) is: $|(0.01/0.60) * 100|$.

[1]The term *error* in the context of this analysis relates to the impact of the weight $\langle w \rangle$. Based on an assumption that $\langle w \rangle$ Literal Values will be in the range [0.30...1.00] the median Literal Value is [0.65]; this results in an *error* of [0.35] or 35%.

5.3.4 Analysis

Considering the analysis set out in Figure 5.6 with Figures 5.7 and 5.9 an analysis of the trends in the data and the convergence [in the data plots] provide supporting evidence for a number of conclusions, principal amongst which are: (1) a context property set with less than 5 constituent properties provides low confidence levels relating to a context match; this provides evidence that based on the % contribution a lower bound (t1) of 0.60 is logically appropriate, and (2) the setting of the upper bound (t2) at 0.80 is supported by the converging trends in the data around a point on the X(CM) axis which approximates to 80% of the solution space. This conclusion is also supported by the trends in the data when taken with the increasing level of confidence in the context processing.

From Figure 5.7 it can be seen that: (1) the error is directly proportional the the contribution made by each context property; the error reducing as the number of context properties that make up an overall context increases, (2) as the number of context properties increase the effect of the weight $\langle w \rangle$ applied to each property as it applies to the overall context match reduces. However, as the confidence levels of the context match increases the $\langle w \rangle$ factor becomes increasingly relevant as the granularity of the context matching (the rv value) and the number of context properties (and therefore the number and range of the $\langle w \rangle$ values) increases number and range of the$\langle w \rangle$ values) increases.

Additionally, in considering the error as shown on Figure 5.7, the error is always negative. The error is influenced by the promotion of a context match (e.g., LQ to GQ) when the CPA as it applies to the DBPI is implemented. In actuality, there is never a situation (for the prototype PMLS) in which the context match will be relegated (e.g., GQ to LQ). However, the domain specific nature of context makes both the *promotion* and *relegation* of a context match probable; accordingly, the CPA has been designed to be generic and the has the capability to address both *promotion* and *relegation* of a context match around a data point or threshold. Notwithstanding these observations the analysis which states that the error has a direct relationship to the number of context properties (in a context) remains valid.

Shown in Figure 5.8 are: the thresholds, the (rv) value, and the % values for adj(0.01), adj(0.02), adj(0.03), adj(0.05). The adjustment values are modeled in Figure 5.9. From an analysis of Figures 5.6 and 5.8 when taken with Figure 5.9 it can be seen that there are clear similarities in the trends in the data and visual analysis confirms this. Further, considering the MA, LT, and PT trends in the data as they relate to the logical identification of a partition there are convergences in the trends around potential datapoints (thresholds) that relate to 5 and 8 context properties, this supports the observation that 0.60 (DB) and 0.80 (DB) represent suitable approximations for data points on the X(CM) axis and the related DB(s). The conclusions drawn relating to converging trends in the data provide supporting evidence that the partition (threshold) values of 0.60 for DB (t1) and 0.80 for DB (t2) are based on a logical foundation.

5.3.5 Conclusions

This chapter has addressed the implementation of the posited approach. The testing strategy with the development of the test datasets have been addressed along with the data structure (the SCMO) and data storage. Central to the implementation of context processing and the CPA is the design of the membership function used in the defuzzification process; this has been discussed with consideration of the design parameters, the known *a priori* knowledge, assumptions used in the partitioning of the solution space, and the DBPI. An analysis with closing observations has been presented. The overall conclusions to be drawn from the analysis set out above can be summarised are as follows.

While the % contribution made by a context property to a context (the set of context properties) provides a logical foundation for the identification of the crisp and heuristic setting of the data points and the related DB(s) there is little discernable statistical evidence upon which the location of the DBs can be determined. Notwithstanding this observation a visual analysis of the trends in the data supports the overall concluson that thresholds set at 0.60 and 0.80 represent realistic options. And, as shown in Figures 5.7 and 5.9 a set of context properties with less than 5 properties arguably fails to provide a high degree of confidence in the overall context match.

From a design perspective the impact of the prioritising bias (the weight $\langle w \rangle$ is arguably greater than the location [on the X(CM) axis of the solution space] of the thresholds. This is demonstrated by considering the effects in context matching of high priority $\langle w \rangle = 1.00$ properties and low priority $\langle w \rangle = 0.300$ when implemented in the CPA as shown in the implementation and proof-of concept set out in Chapter 4 and in the results presented in Chapter 6. Thus, for a set of 5 context properties the range for the (rv) value may be in the range: [0.56...0.80] this demonstrates the scope for a context match to be from LQ to HQ classifications and supports the observations that: when designing a membership function and identifying suitable threshold data points the $\langle w \rangle$ property has a significant effect on the performance of an intelligent context matching system, (2) the designation of the $\langle w \rangle$ Literal Values along with the DB(s) are closely connected and interconnected, and (3) the error as discussed in the foregoing section forms an important factor in the identification of data points and the related DB(s).

In considering context processing the design of a membership function must include both the partitioning technique (used to locate the threshold data points) and the setting of the weight(s) as applied to the context properties (as discussed in this chapter, Chapter 6, and Chapter 7 where issues and challenges identified in the research are considered. Further, considering the discussion and analysis set out in this chapter relating to the DBPI there there is little supporting statistical evidence in the data to justify the selection of a specific % adjustment value to be applied to the (rv) metric. In practice, this will be derived based on *a priori* knowledge obtained from domain specific research in which *tacit* and *explicit* expert knowledge derived from knowledge engineering using surveys and investigations which will form a central factor in the design of the membership function. This conclusion applies to both the data points (thresholds) and the weight $\langle w \rangle$ value applied to each context property.

We argue that the posited approach to the design of the membership function when implemented using domain specific knowledge when used in combination with the known crisp data points as discussed above provides a basis for the realisation of effective defuzzification for fuzzy rule-based systems. Chapter 6 presents a discussion on the implementation with results derived from the testing process; Chapter 7 sets out a discussion with identified challenges, the accommodation of uncertainty, and open research questions.

Chapter 6

Results and Evaluation

This chapter presents the results derived from the testing of the CPA with an analysis and evaluation. The testing strategy is set out in Chapter 5 and the testing with the related results are considered under two headings: (1) Structured test cases, and (2) Un-structured (randomly generated) test cases. The analysis and evaluation considers the operation of the CPA, the output, and the impact on the $\langle w \rangle$ parameter. The chapter closes with a discussion around context-aware systems design and closing remarks.

6.1 Structured Test Results

The structured test sets relate to the pre-defined test sets and fall into a number of scenarios: (1) *Context processing* (CP) control scenarios, and (2) *Context-Matching* (CM) test scenarios including testing where all input / output literal value conditional relationships are either *true* or *false* $\{1, 0\}$.

6.1.1 Control Functions

Figure 5.4 (see Chapter 5, Section 5.2.4) presents an example of a scenario to test a control function. The scenario template shows the inputs, the anticipated and actual results, the actions taken within the software, and descriptive notes. The results show that the invalid #user_Policy exception is caught and the appropriate actions implemented. The results validate the software, demonstrate the capability to manage the rule assignment [153][6], implement stopping criteria, and catch exceptions.

Input Test Set 1 – 0.60(t)

Property	Test Cases (all **true** Literal Values)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
coSub	CUG1	**CPG1**	CPGR1	CUG1	CPG1	CPGR1	CPGR1
modSub	M1CUG1	**M1CPG1**	M1CPGR1	M1CUG1	M1CPG1	M1CPGR1	M1CPGR1
acadQual	AQ1	**AQ1**	AQ1	AQ1	AQ1	AQ1	AQ1
vocQual	VQ1	**VQ1**	VQ1	VQ1	VQ1	VQ1	VQ1
acadExp	AE1	**AE1**	AE1	AE1	AE1	AE1	AE1
vocExp	VE1	**VE1**	VE1	VE1	VE1	VE1	VE1
acadInt	AI1	**AI1**	AI1	AI1	AI1	AI1	AI1
vocInt	VI1	**VI1**	VI1	VI1	VI1	VI1	VI1
FHEQ	6	**7**	8	8	8	8	8

Figure 6.1: Test set for 0.60(t) Threshold.

Input Test Set – 0.80(t)

Property	Test Cases (true Literal Values)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
coSub	CUG1	CPG1	CPGR1	CUG1	CPG1	CPGR1	CPGR1	CUG2	CPG2
modSub	M1CUG1	M1CPG1	M1CPGR1	M1CUG1	M1CPG1	M1CPGR1	M1CPGR1	M1CUG2	M2CPG2
acadQual	AQ1	AQ1	AQ1	AQ1	AQ1	AQ1	AQ1	AQ1	AQ1
vocQual	VQ1	VQ1	VQ1	VQ1	VQ1	VQ1	VQ1	VQ1	VQ1
acadExp	AE1	AE1	AE1	AE1	AE1	AE1	AE1	AE1	AE1
vocExp	VE1	VE1	VE1	VE1	VE1	VE1	VE1	VE1	VE1
acadInt	AI2	AI2	AI12	AI12	AI12	AI12	AI12	AI2	AI2
vocInt	VI2	VI2	VI2	VI2	VI2	VI2	VI2	VI2	VI2
FHEQ	6	7	8	8	8	8	8	6	7

Figure 6.2: Test set for 0.80(t) Threshold.

6.1.2 Context Matching

This section addresses CP with the implementation of CM; demonstrated is the implementation of the CPA for the structured test cases. Shown in Figure 6.1 is the test set for the $[0.60\,(t)]$, Figure 6.2 shows the test set for the $[0.80\,(t)]$ threshold. Program runs are shown in Figure 6.3 for test cases where all Boolean Literal values are *true* and *false*. For the test sets cases (1/1) and (8/1/1) the output the output is shown in Figure 6.4.

The CPA is implemented in Java. The output shown is the result of actual program run(s) with the resultant Boolean decision. The program output(s) demonstrate the use of the Java String functions: #StringTokenizer, #Trim, and #ToLowerCase Java methods to ensure correct and consistent representation of the literal

Test set all True Literal Values

```
run:
Begin Program Run
 INFO [main] (SetupTDB.java:678) - Statistics-based BGP
optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cpg1 (oCS): cpg1
*(e): 1 *(W): 0.9 *(av): 0.9 *(sv): 0.9 *(mv): 0.9
*eval_MoSub(iMS): m1cpg1 (oMS): m1cpg1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 1.7 *(mv): 1.7
*eval_AcadQual(iAQ): aq1 (oAQ): aq1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 2.5 *(mv): 2.5
*eval_VocQual(iVQ): vq1 (oVQ): vq1
*(e): 1 *(W): 0.5 *(av): 0.5 *(sv): 3.0 *(mv): 3.0
*eval_AcadExp(iAE): ae1 (oAE): ae1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 3.7 *(mv): 3.7
*eval_VocExp(iVE): ve1 (oVE): ve1
*(e): 1 *(W): 0.6 *(av): 0.6 *(sv): 4.3 *(mv): 4.3
*eval_AcadInt(iAI): ai1 (oAI): ai1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 5.0 *(mv): 5.0
*eval_VocInt(iVI): vi1 (oVI): vi1
*(e): 1 *(W): 0.4 *(av): 0.4 *(sv): 5.4 *(mv): 5.4
*eval_FHEQ(resFHEQ): 7 (outFHEQ): 7
*(e): 1 *(W): 1.0 *(av): 1.0 *(sv): 6.4 *(mv): 6.4
*getResultantValue (sv / mv): 1.0
*semanticMatch.outPrecision: GQ
*semanticMatch: 1.0
*semanticMatch (q): 0.01
*semanticMatch: HQ
*applyPrecision(semPrec)(outPrec): HQ : GQ
*CM result: true
BUILD SUCCESSFUL (total time: 3 seconds)
```

Test set all False Literal Values

```
run:
Begin Program Run
 INFO [main] (SetupTDB.java:678) - Statistics-based BGP
optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cpg2 (oCS): cpg1
*(e): 0 *(W): 0.9 *(av): 0.0 *(sv): 0.0 *(mv): 0.9
*eval_MoSub(iMS): m1cpg2 (oMS): m1cpg1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 0.0 *(mv): 1.7
*eval_AcadQual(iAQ): aq2 (oAQ): aq1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 0.0 *(mv): 2.5
*eval_VocQual(iVQ): vq2 (oVQ): vq1
*(e): 0 *(W): 0.5 *(av): 0.0 *(sv): 0.0 *(mv): 3.0
*eval_AcadExp(iAE): ae2 (oAE): ae1
*(e): 0 *(W): 0.7 *(av): 0.0 *(sv): 0.0 *(mv): 3.7
*eval_VocExp(iVE): ve2 (oVE): ve1
*(e): 0 *(W): 0.6 *(av): 0.0 *(sv): 0.0 *(mv): 4.3
*eval_AcadInt(iAI): ai2 (oAI): ai1
*(e): 0 *(W): 0.7 *(av): 0.0 *(sv): 0.0 *(mv): 5.0
*eval_VocInt(iVI): vi2 (oVI): vi1
*(e): 0 *(W): 0.4 *(av): 0.0 *(sv): 0.0 *(mv): 5.4
*eval_FHEQ(resFHEQ): 8 (outFHEQ): 7
*(e): 0 *(W): 1.0 *(av): 0.0 *(sv): 0.0 *(mv): 6.4
*getResultantValue (sv / mv): 0.0
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.0
*semanticMatch (q): 0.01
*semanticMatch: LQ
*applyPrecision(semPrec)(outPrec): LQ : GQ
*CM result: false
BUILD SUCCESSFUL (total time: 3 seconds)
```

Figure 6.3: Test set all true and false literal values.

values and to catch: (1) exceptions generated by errors in data entry when compared to the literal values in the ontology, and (2) noise in the literal values generated by the TDB output from the Sparql queries such as commas in the comma separated lists, white space, and String characters such as (_).

6.2 Unstructured Test Results

The un-structured test cases utilise randomly generated Boolean Literal Value conditional relationships $\{1, 0\}$ (*true* or *false* respectively) for each context property. In the un-structured test cases there is no distinction drawn between the 0.60 DB and 0.80 threshold parameters.

Presented is a set of results for the un-structured test sets. Figure 6.5 presents the random generation of Boolean values $\{1, 0\}$ for the Literal values for use in test sets 1 and 6, the context properties used in the test with the randomly generated

Test Set (1/1)

```
run:
Begin Program Run
 INFO [main] (SetupTDB.java:678) - Statistics-based BGP
optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cug1 (oCS): cug1
*(e): 1 *(W): 0.9 *(av): 0.9 *(sv): 0.9 *(mv): 0.9
*eval_MoSub(iMS): m1cug1 (oMS): m1cug1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 1.7 *(mv): 1.7
*eval_AcadQual(iAQ): aq1 (oAQ): aq1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 2.5 *(mv): 2.5
*eval_VocQual(iVQ): vq1 (oVQ): vq1
*(e): 1 *(W): 0.5 *(av): 0.5 *(sv): 3.0 *(mv): 3.0
*eval_AcadExp(iAE): ae1 (oAE): ae1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 3.7 *(mv): 3.7
*eval_VocExp(iVE): ve1 (oVE): ve1
*(e): 1 *(W): 0.6 *(av): 0.6 *(sv): 4.3 *(mv): 4.3
*eval_AcadInt(iAI): ai2 (oAI): ai1
*(e): 0 *(W): 0.7 *(av): 0.0 *(sv): 4.3 *(mv): 5.0
*eval_VocInt(iVI): vi2 (oVI): vi1
*(e): 0 *(W): 0.4 *(av): 0.0 *(sv): 4.3 *(mv): 5.4
*eval_FHEQ(resFHEQ): 8 (outFHEQ): 6
*(e): 0 *(W): 1.0 *(av): 0.0 *(sv): 4.3 *(mv): 6.4
*getResultantValue (sv / mv): 0.6718749999999999
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.6718749999999999
*semanticMatch (q): 0.01
*semanticMatch: GQ
*applyPrecision(semPrec)(outPrec): GQ : GQ
*CM result: true
BUILD SUCCESSFUL (total time: 3 seconds)
```

Test Set (8/1/1)

```
run:
Begin Program Run
 INFO [main] (SetupTDB.java:678) - Statistics-based BGP
optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cug1 (oCS): cug1
*(e): 1 *(W): 0.9 *(av): 0.9 *(sv): 0.9 *(mv): 0.9
*eval_MoSub(iMS): m1cug1 (oMS): m1cug1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 1.7 *(mv): 1.7
*eval_AcadQual(iAQ): aq1 (oAQ): aq1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 2.5 *(mv): 2.5
*eval_VocQual(iVQ): vq1 (oVQ): vq1
*(e): 1 *(W): 0.5 *(av): 0.5 *(sv): 3.0 *(mv): 3.0
*eval_AcadExp(iAE): ae1 (oAE): ae1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 3.7 *(mv): 3.7
*eval_VocExp(iVE): ve1 (oVE): ve1
*(e): 1 *(W): 0.6 *(av): 0.6 *(sv): 4.3 *(mv): 4.3
*eval_AcadInt(iAI): ai1 (oAI): ai1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 5.0 *(mv): 5.0
*eval_VocInt(iVI): vi1 (oVI): vi1
*(e): 1 *(W): 0.4 *(av): 0.4 *(sv): 5.4 *(mv): 5.4
*eval_FHEQ(resFHEQ): 8 (outFHEQ): 6
*(e): 0 *(W): 1.0 *(av): 0.0 *(sv): 5.4 *(mv): 6.4
*getResultantValue (sv / mv): 0.84375
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.84375
*semanticMatch (q): 0.01
*semanticMatch: HQ
*applyPrecision(semPrec)(outPrec): HQ : GQ
*CM result: true
BUILD SUCCESSFUL (total time: 2 seconds)
```

Figure 6.4: Test sets: (1/1) and)(8/1/1).

Boolean Values are set out in Figure 6.6. The output generated in the running of the CPA using the test sets 1 and 6 is presented in Figure 6.7. Figure 6.8 presents the random generation of Boolean values $\{1, 0\}$ for the Literal values for use in test sets 17 and 19, the context properties used in the test with the randomly generated Boolean Values are set out in Figure 6.9. The output generated in the running of the CPA using the test sets 17 and 19 is presented in Figure 6.10.

The Boolean results generated in the program runs are: for test sets (1/1) and (8/1/1) the results are *true* and *false* respectively, and for test sets (17) and (19) are *true* and *false* respectively. The results confirm the anticipated results and the semantic conversions are achieved correctly.

6.2.1 CPA Output

As discussed in Chapter 5 the testing strategy employed an approach using *Equality partitions* [157]; this resulted in 126 test cases to evaluate the CPA in operation.

Random Test Set: 1

```
run:
Generating true [1] / false [0])
test boolean values for
9 context properties:
context property value : 1
context property value : 1
context property value : 0
context property value : 1
context property value : 1
context property value : 1
context property value : 0
context property value : 1
context property value : 1
BUILD SUCCESSFUL (total time: 0 seconds)
```

Random Test Set: 6

```
run:
Generating true [1] / false [0])
test boolean values for
9 context properties:
context property value : 1
context property value : 0
context property value : 1
context property value : 1
context property value : 1
context property value : 0
context property value : 0
context property value : 0
context property value : 1
BUILD SUCCESSFUL (total time: 0 seconds)
```

Figure 6.5: Random test sets 1 and 6: generation of random Boolean values.

Random Test Set: 1

property	test value [1] / [0]	true / false
coSub	1	true
modSub	1	true
acadQual	0	false
vocQual	1	true
acadExp	1	true
vocExp	1	true
acadInt	0	false
vocInt	1	true
resFHEQ	1	true

Random Test Set: 6

property	test value [1] / [0]	true / false
coSub	1	true
modSub	0	true
acadQual	1	false
vocQual	1	true
acadExp	1	true
vocExp	0	true
acadInt	0	false
vocInt	0	true
resFHEQ	1	true

Figure 6.6: Random test sets 1 and 6: context properties and Boolean values.

Full documentation of the results is beyond the scope of this thesis however the example test results when taken with the proof-of-concept (see chapter 4 demonstrate the effectiveness of the CPA. In practice the results generated in the testing process demonstrated 100% predictability and correctness of outcome (both in the (rv) metric and in the Boolean result derived from the semantic conversion and its implementation in the MF. The output from program run(s) shows that: (1) the CPA (as discussed in chapter 4 in action and demonstrates that it performs as anticipated at the design and development stage, and (2) the results, which in operation, match the evaluation and proof-of-context presented in chapter 4.

The output from the program run(s) shows the results from the conditional relationship. The output identifies: (1) two control properties: the *inputReseouceType* [2] and the *loginAction* [2], and (2) The (9) context matching properties, each show-

Random Test Set: 1

```
run:
INFO [main] (SetupTDB.java:678) - Statistics-based BGP optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cug1 (oCS): cug1
*(e): 1 *(W): 0.9 *(av): 0.9 *(sv): 0.9 *(mv): 0.9
*eval_MoSub(iMS): m1cug1 (oMS): m1cug1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 1.7 *(mv): 1.7
*eval_AcadQual(iAQ): aq2 (oAQ): aq1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 1.7 *(mv): 2.5
*eval_VocQual(iVQ): vq1 (oVQ): vq1
*(e): 1 *(W): 0.5 *(av): 0.5 *(sv): 2.2 *(mv): 3.0
*eval_AcadExp(iAE): ae1 (oAE): ae1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 2.9 *(mv): 3.7
*eval_VocExp(iVE): ve1 (oVE): ve1
*(e): 1 *(W): 0.6 *(av): 0.6 *(sv): 3.5 *(mv): 4.3
*eval_AcadInt(iAI): ai2 (oAI): ai1
*(e): 0 *(W): 0.7 *(av): 0.0 *(sv): 3.5 *(mv): 5.0
*eval_VocInt(iVI): vi1 (oVI): vi1
*(e): 1 *(W): 0.4 *(av): 0.4 *(sv): 3.9 *(mv): 5.4
*eval_FHEQ(resFHEQ): 6 (outFHEQ): 6
*(e): 1 *(W): 1.0 *(av): 1.0 *(sv): 4.9 *(mv): 6.4
*getResultantValue (sv / mv): 0.765625
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.765625
*semanticMatch (q): 0.01
*semanticMatch: GQ
*applyPrecision(semPrec)(outPrec): GQ : GQ
*CM result: true
BUILD SUCCESSFUL (total time: 3 seconds)
```

Random Test Set: 6

```
Run
INFO [main] (SetupTDB.java:678) - Statistics-based BGP optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cug1 (oCS): cug1
*(e): 1 *(W): 0.9 *(av): 0.9 *(sv): 0.9 *(mv): 0.9
*eval_MoSub(iMS): m1cug2 (oMS): m1cug1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 0.9 *(mv): 1.7
*eval_AcadQual(iAQ): aq1 (oAQ): aq1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 1.7 *(mv): 2.5
*eval_VocQual(iVQ): vq1 (oVQ): vq1
*(e): 1 *(W): 0.5 *(av): 0.5 *(sv): 2.2 *(mv): 3.0
*eval_AcadExp(iAE): ae1 (oAE): ae1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 2.9 *(mv): 3.7
*eval_VocExp(iVE): ve2 (oVE): ve1
*(e): 0 *(W): 0.6 *(av): 0.0 *(sv): 2.9 *(mv): 4.3
*eval_AcadInt(iAI): ai2 (oAI): ai1
*(e): 0 *(W): 0.7 *(av): 0.0 *(sv): 2.9 *(mv): 5.0
*eval_VocInt(iVI): vi2 (oVI): vi1
*(e): 0 *(W): 0.4 *(av): 0.0 *(sv): 2.9 *(mv): 5.4
*eval_FHEQ(resFHEQ): 6 (outFHEQ): 6
*(e): 1 *(W): 1.0 *(av): 1.0 *(sv): 3.9 *(mv): 6.4
*getResultantValue (sv / mv): 0.609375
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.609375
*semanticMatch (q): 0.01
*semanticMatch: GQ
*applyPrecision(semPrec)(outPrec): GQ : GQ
*CM result: true
BUILD SUCCESSFUL (total time: 2 seconds)
```

Figure 6.7: Random test sets 1 and 6: random program runs.

ing: the Boolean evaluation (e) $\{1,0\}$(*true* or *false* respectively), the weight (W), the aggregate value (av): (e * w), the sum value (sv): the incrementing total of the (av), the maximum potential value (mpv): value if all values for (e) are *true*, the resultant value (rv): (sv / mv), the decision boundary adjustment metric: (q), the semantic conversion (rv * q), the overall CM result $\{1,0\}$ (*true* or *false*). Additionally the run time in seconds (including the build time) is shown.

6.2.2 Operation of the CPA

The operation of the CPA has been evaluated in Chapter 4 with the proof-of-concept. In the evaluation of the CPA implemented in the posited approach the (LQ) semantic measure will always result in a *false* [0] context match. However, given the domain specific nature of context this will not be the case as the classification of the (LQ)

Random Test Set: 17
run:
Generating true [1] / false [0])
test boolean values for
9 context properties:
context property value : 1
context property value : 0
context property value : 1
context property value : 0
context property value : 0
context property value : 1
context property value : 1
context property value : 0
context property value : 1
BUILD SUCCESSFUL (total time: 0 seconds)

Random Test Set: 19
run:
Generating true [1] / false [0])
test boolean values for
9 context properties:
context property value : 0
context property value : 0
context property value : 0
context property value : 1
context property value : 1
context property value : 1
context property value : 1
context property value : 0
context property value : 0
BUILD SUCCESSFUL (total time: 0 seconds)

Figure 6.8: Random test sets 17 and 19: generation of random Boolean values.

Random Test Set: 17

property	test value [1] / [0]	true / false
coSub	1	true
modSub	0	false
acadQual	1	true
vocQual	0	false
acadExp	0	false
vocExp	1	true
acadInt	1	true
vocInt	0	false
resFHEQ	1	true

Random Test Set: 19

property	test value [1] / [0]	true / false
coSub	0	false
modSub	0	false
acadQual	0	false
vocQual	1	true
acadExp	1	true
vocExp	1	true
acadInt	1	true
vocInt	0	false
resFHEQ	0	false

Figure 6.9: Random test sets 17 and 19: context properties and Boolean values.

semantic measure may in other domains be viewed as simply a measure of context matching.

The evaluation and proof-of-concept articulated in Chapter 4 supports the conclusion that the running of the CPA results in a predictable decision. he tests confirm this intuition with the results obtained demonstrating 100% predictability where the input and output literal values are known *a-priori*. This is reflected in the relationship between the anticipated outcome and the actual results derived from the running of the [structured and unstructured] test sets which are in all cases correct. This supports the conclusion that the CPA provides a high level of predictability for decision support systems.

```
Random Test Set: 17
run:
Begin Program Run
 INFO [main] (SetupTDB.java:678) - Statistics-
based BGP optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cug1 (oCS): cug1
*(e): 1 *(W): 0.9 *(av): 0.9 *(sv): 0.9 *(mv): 0.9
*eval_MoSub(iMS): m1cug2 (oMS): m1cug1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 0.9 *(mv): 1.7
*eval_AcadQual(iAQ): aq1 (oAQ): aq1
*(e): 1 *(W): 0.8 *(av): 0.8 *(sv): 1.7 *(mv): 2.5
*eval_VocQual(iVQ): vq2 (oVQ): vq1
*(e): 0 *(W): 0.5 *(av): 0.0 *(sv): 1.7 *(mv): 3.0
*eval_AcadExp(iAE): ae2 (oAE): ae1
*(e): 0 *(W): 0.7 *(av): 0.0 *(sv): 1.7 *(mv): 3.7
*eval_VocExp(iVE): ve1 (oVE): ve1
*(e): 1 *(W): 0.6 *(av): 0.6 *(sv): 2.3 *(mv): 4.3
*eval_AcadInt(iAI): ai1 (oAI): ai1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 3.0 *(mv): 5.0
*eval_VocInt(iVI): vi2 (oVI): vi1
*(e): 0 *(W): 0.4 *(av): 0.0 *(sv): 3.0 *(mv): 5.4
*eval_FHEQ(resFHEQ): 6 (outFHEQ): 6
*(e): 1 *(W): 1.0 *(av): 1.0 *(sv): 4.0 *(mv): 6.4
*getResultantValue (sv / mv): 0.625
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.625
*semanticMatch (q): 0.01
*semanticMatch: GQ
*applyPrecision(semPrec)(outPrec): GQ : GQ
*CM result: true
BUILD SUCCESSFUL (total time: 1 second)
```

```
Random Test Set: 19
run:
Begin Program Run
 INFO [main] (SetupTDB.java:678) - Statistics-
based BGP optimizer
Error: null
InData.inResType: 2
*loginAction: 2
cp_R4: 2
*begin context matching
*eval_CoSub(iCS): cug2 (oCS): cug1
*(e): 0 *(W): 0.9 *(av): 0.0 *(sv): 0.0 *(mv): 0.9
*eval_MoSub(iMS): m1cug2 (oMS): m1cug1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 0.0 *(mv): 1.7
*eval_AcadQual(iAQ): aq2 (oAQ): aq1
*(e): 0 *(W): 0.8 *(av): 0.0 *(sv): 0.0 *(mv): 2.5
*eval_VocQual(iVQ): vq1 (oVQ): vq1
*(e): 1 *(W): 0.5 *(av): 0.5 *(sv): 0.5 *(mv): 3.0
*eval_AcadExp(iAE): ae1 (oAE): ae1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 1.2 *(mv): 3.7
*eval_VocExp(iVE): ve1 (oVE): ve1
*(e): 1 *(W): 0.6 *(av): 0.6 *(sv): 1.8 *(mv): 4.3
*eval_AcadInt(iAI): ai1 (oAI): ai1
*(e): 1 *(W): 0.7 *(av): 0.7 *(sv): 2.5 *(mv): 5.0
*eval_VocInt(iVI): vi2 (oVI): vi1
*(e): 0 *(W): 0.4 *(av): 0.0 *(sv): 2.5 *(mv): 5.4
*eval_FHEQ(resFHEQ): 7 (outFHEQ): 6
*(e): 0 *(W): 1.0 *(av): 0.0 *(sv): 2.5 *(mv): 6.4
*getResultantValue (sv / mv): 0.390625
*semanticMatch.outPrecision: GQ
*semanticMatch: 0.390625
*semanticMatch (q): 0.01
*semanticMatch: LQ
*applyPrecision(semPrec)(outPrec): LQ : GQ
*CM result: false
BUILD SUCCESSFUL (total time: 1 second)
```

Figure 6.10: Random test sets 17 and 19: random program runs.

In real-world operation the CPA when implemented in context-aware systems would generally have no *a priori* knowledge of the inputs and potential outputs. However, based on the test results there is a high level of confidence that real-world results will exceed the performance of recommender systems [which generally perform at an accuracy of between 60% to 80%]. Additionally, the CPA will complete in a search of the potential solutions in polynomial time where the term polynomial is a synonym for predictable tractability as defined in the Alan Cobham thesis cited in [168].

6.2.3 Accuracy of Outcomes

The evaluation and proof-of-concept articulated in Chapter 4 supports the conclusion that the running of the CPA results in a predictable decision. The tests confirm this intuition with the results obtained demonstrating 100% predictability where the input and output literal values are known *a-priori*. This is reflected in the relationship between the anticipated outcome and the actual results derived from the running of the test sets (structured and unstructured) which were in all cases correct. This supports the conclusion that the CPA provides a high level of predictability for decision support systems.

There are important considerations relating to the CPA and the design of the membership function and identification of the location of the decision boundaries on the X(CM) axis of the solution space. This is reflected in the design considerations as discussed in Chapter 5 however, it is important to note that the decision boundaries are not independent of the number of properties in a context (a set of properties and their literal values) and the prioritizing weights $\langle w \rangle$. In operation, the number of properties and the weights $\langle w \rangle$ are central to the design of a fully functioning system. These factors are considered in the following section.

6.2.4 Impact on Design of Membership Function

The impact on the design (in respect of the crisp data points and heuristics) of the membership function and the location of the decision boundary(s) on the CM (X) axis of the solution space of (a) the decision boundary proximity issue metric (q) in (rv + xc), (b) the number of properties in a context property set, and (c) the impact of the weight $\langle w \rangle$ prioritizing bias metric is significant given that these parameters are not independent but are closely interconnected and interdependent. Prior to considering points (a), (b), and (c) above it will be useful if the context matching solution space is considered. Shown in Figures 4.4 and 7.1 are graphical representations of the context-matching problem overlaid onto the solution space with the DBs and the semantic classifications identified. The thresholds are defined using both crisp and heuristic design criteria ad discussed in Chapter 5 where the intuitive conclusions relating to points (a), (b), and (c) are discussed. The test results derived from the testing process has illuminated the discussion; this is considered in the following sub-sections.

Membership Function and Test Results

Central to the implementation of the context matching algorithm is the design of the membership function used in the defuzzification process, the final step where the fuzzy result is converted into a crisp Boolean result; the decision as to a users qualifiedness for DPS. This has been discussed in Chapter 5 with consideration of the design parameters, the known *a priori* knowledge, the crisp and heuristic assumptions used in the partitioning of the solution space as modelled in Figure 4.4, and an analysis with conclusions and observations. The test results provide support the following conclusions:

1. The conclusion drawn relating to the number of properties in a set of properties used to define and describe a context is that this parameter is very important. This is the result of the contribution made by each property to the normalised context match; the contribution varying in direct proportion to the number of properties in a set of properties.

2. As discussed below, the setting of the literal value(s) for the weighting parameter $\langle w \rangle$ and the literal value for the adjustment for the decision boundary proximity issue (xc) assumes a critically important element in systems design.

3. The aim of the design of the membership function is to identify the location of the DBs on the X(CM) axis as shown in Figure 7.1. Given the domain specific nature of context-aware systems there may be a single DB or multiple DBs based on the requirements specification and systemic design needs. The CPA enables single or multiple BDs with decisions in relationship to DBs achieved using simple of complex rules incorporating the logic functions as discussed in Chapter 4 (Section 4.3.3). The relationship between the semantic degree of *qualifiedness* and a DB is implemented in step 7 of the CP

6.2.5 Implementation of DBPI

The decision DBPI has been introduced in Chapter 4 with an expanded discussed set out in Chapter 5 (Section 5.3.2) with an analysis. Considering the DBPI, the adjustment metric (xc) implemented in step 7 of the CPA clearly has an important function for the conversion of the (rv) context matching metric to the semantic measure of *qualifiedness* (q). This value clearly is dependent of the domain specific nature of context-aware systems and will require domain specific heuristics to identify a suitable value.

In actuality, the use of the adjustment is optional in the CPA; the rule-based approach enables flexibility in the implementation of CM which addresses the domain specific nature of context and the domain specific design requirements. Additionally, the CPA as implemented in this thesis only applies the (xc) to increase the context match; the inbuilt flexibility inherent in the CPA provides the capability to apply the adjustment to either side of the DB should the domain specific nature of context-aware systems design requirements call for such an approach.

6.2.6 Impact of Weight parameter

The weights $\langle w \rangle$ used to implement the prioritising bias forms a vitally important element in systems design of the CPA. In considering the test results the application of the weights $\langle w \rangle$ has been shown to perform as anticipated in the design of the CPA. This is demonstrated in the example test sets presented in this chapter. There is however an observable relationship which has a direct impact on the system design in that with the reducing influence imparted by each property [as the number of properties in a set of properties increases] (see Chapter 5 for discussion on this topic) the ability to mitigate violations of constraint satisfaction is reduced; this may nullify the intended result.

To address this issue it is necessary to consider very carefully at the systems design stage the value for the $\langle w \rangle$ metric for high, medium, and low priority properties. Testing of a real world system must also include the analysis of the $\langle w \rangle$ parameter to *tune* the weights to achieve a satisfactory result in CM. In the testing process initially a low priority weight $\langle w \rangle$ value of 0.30 was tried. This demonstrated that such a value was too small and the influence was negligible on the overall result; accordingly the low priority weight was increased to 0.40 which increased the influence of properties to which this weight was applied. The testing supported the observations made on the setting of the $\langle w \rangle$ parameter.

6.2.7 Context-Aware System Design

Context is inherently complex and domain specific which presents challenges for context-aware systems design. The CPA incorporates the ability to handle this domain specificity and complexity with predictable decision support. The identification of the appropriate context properties are domain specific requiring domain specific design. Identification of the context properties in context-aware systems requires domain investigations (knowledge engineering) to identify the appropriate tacit and explicit knowledge and the methodology used in data capture.

There are important considerations relating to the CPA and the design of the MF and identification of the location of the thresholds on the X(CM) axis of the solution space, implementing the DBPI, and the design considerations relating to the $\langle w \rangle$ parameter. These considerations are addressed in chapter 5 however it is important to note that MF parameters, the DBPI parameters, and the weight $\langle w \rangle$ prioritization parameter are not independent but are interconnected and closely integrated as discussed in Chapter 5.

Context and context-aware systems are characterised by uncertainty and partial matching in the context matching process. The test results support the conclusion that the approach presented in this thesis is in using the CPA, which is predicated on fuzzy set theory, provides an effective basis upon which personalisation and the DPS under uncertainty can be realised.

6.3 Conclusions

This chapter has presented examples of the test results derived from the test data. Consideration has been given to the test results and conclusions have been drawn based supporting evidence from the testing process and on an analysis of the results. Context-aware systems design has been introduced with observation based on the analysis of the test results. Chapter 7 presents a discussion addressing the research presented in this thesis with consideration of the issues and challenges identified and related open research questions.

Chapter 7

Conclusions

In this thesis, we have addressed *personalisation and delivery of personalised services* (DPS). We argue that context implemented in context-aware systems provides a basis for personalisation and DPD. To implement context we postulate that *context processing* (CP) achieved using the CPA (see Chapter 4) implemented with OBCM (see Chapters 3 and 5) enables effective DPS with predictable decision support while retaining the ability to address (or at least mitigate) violations of constraint satisfaction and Preference compliance.

Chapter 1 has considered the motivation for the study, Chapter 2 addressing personalization, context, context-aware systems. Chapter 3 has expanded on the discussion in Chapter 2 and introduces context modelling. Chapter 4 addresses CP, considers rules and rule strategies, and presents the CPA with an analysis, evaluation, and proof-of-context. Central to the thesis is the creation of a data structure capable of achieving both in *memory* and *persistent* storage of contextual information; this is discussed in chapter 5 which addresses the design and implementation of the CPA; the context modelling ontology is presented with a discussion on the testing strategy and the development of the MF (an essential element in the implementation of the CPA to enable defuzzification) and consideration of related design issues. The testing strategy is presented in Chapter 5 with the results derived from the testing and evaluation of the CPA being presented in Chapter 6. The research has provided the following contributions and has resulted in a number of conclusions:

- Context provides an effective approach to realise personalisation in service provision across a broad and diverse range of domains and systems. We posit that the approach presented in this thesis has the potential to increasing the effectiveness of personalisation context-aware systems.

- *Ontology-Based Modeling* (OBM), see chapter 3, has been identified as the optimal approach to the modelling of context. OBM is the approach adopted to create the data structure (the *Semantic Context Modelling Ontology* (SCMO) (see Figure 5.1) used in the implementation of the CPA. This approach provides a cross platform approach to the creation of a data structure for context-aware systems which is flexible and extensible and may be shared. Additionally, if required in other applications, the SCMO has the capability to implement inference and reasoning using entailment and subsumption.

- Context has been characterised by uncertainty; this is a result of: (1) the broad and diverse range of data which can be viewed as contextual information, (2) the diversity in the domains to which context applies, and (3) the general lack of *a priori* knowledge in context processing. We postulate that the CPA presented in this thesis provides an effective approach to implement personalisation under uncertainty whilst accommodating the diversity of contextual information and enabling (or at least mitigating violations of) constraint satisfaction / preference compliance with robust and predictable decision support in a range of domains and systems.

- Context is domain specific, a feature shared with the *Membership Function* (MF) which occupies a central role in the implementation of the CPA. The MF provides an approach to *defuzzification* which is flexible and the design parameters identified and implemented in the CPA may be applied to a broad and diverse range of domains and system in which context-awareness is utilised to design crisp and heuristically defined thresholds in defuzzification..

7.1 Future Work

The research conducted has identified solutions however additional issues and challenges have been identified which include the following areas as discussed below.

The range of contextual data used in context-aware systems has traditionally focused on location, identity, and proximate factors. A goal is to extend the range of data used including integrating emotional response. This extension in the range and scope of data used may be very beneficial in health monitoring and in e-Learning where engagement may be better measured. The issues lie less in the processing of the data than in clearly identifying the data points and in non-invasive data capture; work in this area represents a fertile direction for research.

This research has identified a number of critical parameters used in the design of the MF. There is a need for a formalized approach to the optimization of the parameters used to locate the data points on the solution space. This remains an open research question.

In context-aware systems the development of a suitable data structure represents a challenging task; contextual data in such systems being characterized by a dataset which requires both *in-memory* and *persistently* stored data. Additionally, data is (generally) dense, may evolve either rapidly or slowly, and has few, if any, null values. Developing a database schema to accommodate these potentially conflicting requirements is a challenging task [54][138][169]. The OBCM approach, while effective, is recognised as a sub-optimal solution.

An investigation into the development of an improved data structure for context-aware systems using a relational database approach by Agrawal *et al* has been documented in [169]. The approach presented in [169] converts the data storage from a novel vertical structure into a horizontal representation to construct a view for searching; the process then reverts the horizontal presentation into the original vertical structure for persistent storage. The algorithm used by Agrawal *et al* [169], while providing a functional approach, resulted in significant computational overhead and is not considered to be an effective solution for context-aware systems.

Context is application specific and Objects represent entities [50] and concepts from an application environment. An alternative to the development of a data structure for context-aware systems currently under consideration is the use of an *Object-Oriented* database solution implemented in a relational database management system (e.g., Oracle). This forms an interesting direction for research as *Object Relational Database Management Systems* (ORDMS) build on the well established relational data model by adding object oriented concepts such as: Objects, methods, , constructors, arrays of objects, and nested tables. An ORDMS approach has potential benefits but there are possible issues around complexity and increased computational cost. Notwithstanding the potential issues identified, the use of an

ORDMS remains a promising approach, however the development of an optimal solution requires more research and remains an open research question.

Data description relates to the representation of user input to enable effective context matching. The generally adopted approach to user input is the use of *keywords* related to terms expressed in ontologies. There are however issues relating to the keyword corpus, investigations having failed to locate a suitable corpus. Given the need for domain specific design the development of a suitable corpus remains. Data entry using natural language is a desirable aim, NLP is however very challenging, computationally expensive, and remains an open research question.

The weighting $\langle w \rangle$ parameter requires careful design and testing to optimize the effectiveness in context processing. Currently, the Literal Value for the $\langle w \rangle$ is set manually; however ideally the $\langle w \rangle$ parameter would be initially set manually and updated dynamically to arrive at optimal values. There are however potential negative side effects of dynamic updating including the induction of emergent dynamic change to the design priorities. The side effects may impact the ability to enable CS with predictability and consistency. Identifying solutions represents a significant challenge and is an open research question.

A recognized issue in context-aware systems is the potential for anomalies and ambiguities. This poses a problem for context-aware systems; the prioritization approach proposed in this thesis may offer a solution which may mitigate such anomalies however the discussion regarding the setting of the $\langle w \rangle$ parameter presents further issues in disambiguation of anomalies. Addressing this potential issue represents an open research question.

7.1.1 Extensions to Context Processing Algorithm

Currently the CPA utilizes the X(CM) axis as shown in Figure 4.4. Extending the CPA to include the Y(UC) axis as shown in Figure 7.1 [38] (and possibly later the Z axis offers) significant potential to increase the granularity of the results obtained in context processing. The rule-based approach provides the basis for this extension with the addition of an additional step (step: 8) as shown below for the Y(UC) axis. The extended solution space is modelled graphically in Fig 7.1; shown is the Y(UC) axis with the (t4) threshold (having a 0.70 data point) and the related semantic conversions for the (rv) metric.

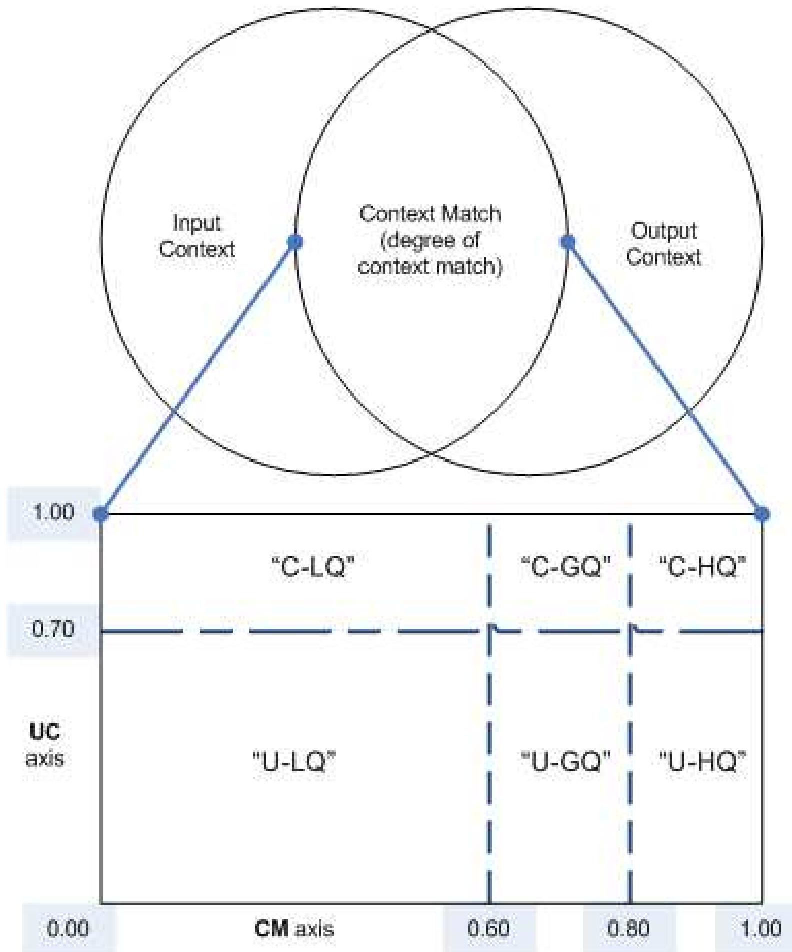

Figure 7.1: The extended CP solution space.

The result of step 7 is a semantic conversion of the (rv) metric to one of: (LQ) (GQ) (HQ). There is a direct relationship between these semantic metrics and an expressed user preference relating to the degree of membership derived from CM the user is happy with (see Figure 4.5), the semantic measures (GP) (HP) defined in the SCMO.

Step 8 identifies the context match as a positive (+) or negative (-) condition relative to the uncertainty boundary (t4) (see Fig 4.4). Note that the posited approach enables multiple uncertainty boundaries thus introducing increased granularity in the classification of uncertainty. Fig 7.1 expands on Fig 4.4 and shows the DBs and the UB with the semantic classifications $(U - LQ)$ $(U - GQ)$ $(U - HQ)$ $(C - LQ)$ $(C - GQ)$ $(C - HQ)$ where (U) and (C) represent uncertainty and certainty respectively.

In step 8 we adjust uncertain environmental conditions to adapt with context matching and compute the relationship to the uncertainty boundary where $\{f1, f2...fn\}$ is a be a set of ECA rules which represent domain specific uncertainty in environmental conditions. Note: (uc) := the relationship of (rv) to the uncertainty boundary; i.e., (positive) (+) or (negative) (-) is defined using (rv + xc) where: $((t4) \geq uc\,(+))\,AND\,((t4) > uc\,(-))$

IF $((t4) \geq uc\,(+)\,AND\,((t4) > uc\,(-)))$: rule: (f1):

$\{\langle con_1\rangle\, AND\, \langle con_2\rangle\, AND\, \langle con_n\rangle\, THEN\, \langle action\rangle\, uc(+)\}$

Else If: $((t4) < (rv)\,AND\,\langle event\rangle)$: rule: (f2):

$\{\langle con_1\rangle\, AND\, \langle con_2\rangle\, OR\, \langle con_n\rangle\, THEN\, \langle action\rangle\, uc(-)\}$

ELSE: $((0.70) \geq rv\,(t4)\,\langle event\rangle)$: rule: (fn):

$\{\langle con_1\rangle\, AND\, \langle con_2\rangle\, AND\, \langle con_n\rangle\, THEN\, \langle action\rangle\, uc(+)\}$

7.2 Conclusions

The extension to the CPA is current ongoing work and we feel that implementation is realistic. The remaining 6 research areas introduced above are not considered to be trivial and represent significant challenges. They do however represent interesting and potentially profitable directions for future work where the goal is personalisation and the DPS to entities in a broad range of domains, applications, and systems. Realizing solutions to the issues and challenges identified holds significant potential for the application of context intelligence in real-world context-aware applications and systems.

References

[1] M. J. Eppler and J. Mengis, “A Framework for Information Overload Research in Organizations”, Insights from Organization Science, Accounting, Marketing, MIS. Paper #1/2003 Universit della Svizzera Italiana, 2003.

[2] P. Moore, M. Jackson and B. Hu, “Constraint Satisfaction in Intelligent Context-Aware Systems”, *In Proceedings of the Fourth International Conference on Complex, Intelligent and Software Intensive Systems* (ARES/CISIS 2010), Krakow, Poland, February 15-18, 2010, pp. 75-80, 2010.

[3] C. R. Hildreth, “On-line Library Catalogues as IR Systems: what can we learn from research?”, In P.A. Yates Mercer (ed), Future Trends in Information Science and Technology, pp. 9-25,Taylor Graham, LA, USA. Hong, J.Yi, Suh, E.Ho, & Kim, J.K. (2008). Context-aware systems: A literature review and classification, Elsevier, doi:10.1016/j.eswa.2008.10.071, 1998.

[4] S. Alter, “Defining Information Systems as Work Systems: Implications for the IS Field”. *European Journal of Information Systems*, 17(5), pp. 448-469, 2008.

[5] P. Moore, B. Hu and J. Wan, “Smart-Context: A Context Ontology for Pervasive Mobile Computing”. *The Computer Journal*, Vol. 53(2), pp. 191-207. ISSN: 0010-4620 (print), 1460-2067 (online). doi: 10.1093/comjnl/bxm104. Available: http://comjnl.oxfordjournals.org/cgi/reprint/53/2/191.pdf, 2010.

[6] P. Moore, B. Hu, and J. Wan, “Intelligent Context for Personalised Mobile Learning”, *In Architectures for Distributed and Complex M-Learning Systems: Applying Intelligent Technologies*, (Eds) S. Caballe; F. Xhafa; T. Daradoumis; A. A. Juan, Hershey, PA, USA, IGI Global, pp. 236-270, 2010.

[7] P. Moore, B. Hu and J. Wan, "Smart-Context: A Context Ontology for Pervasive Mobile Computing". *The Computer Journal*, Vol. 53(2), pp. 191-207. ISSN: 0010-4620 (print), 1460-2067 (online). doi: 10.1093/comjnl/bxm104. Available: http://comjnl.oxfordjournals.org/cgi/reprint/53/2/191.pdf, 2010.

[8] P. Moore, B. Hu, and J. Wan, "Intelligent Context for Personalised Mobile Learning", *In Architectures for Distributed and Complex M-Learning Systems: Applying Intelligent Technologies*, (Eds) S. Caballe; F. Xhafa; T. Daradoumis; A. A. Juan, Hershey, PA, USA, IGI Global, pp. 236-270, 2010.

[9] P. Moore, B. Hu and M. Jackson, "Rule Strategies for Intelligent Context-Aware Systems: The Application of Conditional Relationships in Decision-Support", *In Proceedings of the International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS-2011). Korean Bible University (KBU), Seoul, Korea, June 30 July 2, 2011, pp. 9-16, 2011.

[10] P. Moore, C. Evans, and H. V. Pham, "Towards Implementing Emotion into Intelligent Context", The 13th International Conference on Web Information Systems Engineering (WISE 2012), *In Proc of The International Workshop on Advanced Reasoning Technology for e-Science* (ART2012), November 28th, 2012, Paphos, Cyprus, in LNCS 7652, Springer, pp. 27-40, 2013.

[11] P. Moore, "The complexity of context in mobile information systems", *In Proceedings of the 12th International Conference on Network-Based Information Systems* (NBiS 2009), *1st International Workshop on Heterogeneous Environments and Technologies for Grid and P2P Systems* (HETGP'2009). 19-21 August 2009, Indianapolis, Indiana, USA, pp. 91-96, 2009.

[12] P. Moore, "Anytime-Anywhere Personalised Time-Management in Networking for e-Learning", *eLC Research Paper Series*, 3, pp. 48-59, 2011.

[13] P. Moore, B. Hu and M. Jackson, "Fuzzy ECA Rules for Pervasive Decision-Centric Personalized Mobile Learning", *In Computational Intelligence for Technology Enhanced Learning*. (Eds) Fatos Xhafa, Santi Caballe, Ajith Abraham, Thanis Dardoumis, Angel Juan. Springer-Verlag, Studies in Computational Intelligence, Vol. 273, ISBN: 978-3-642-11223-2, http://dx.doi.org/10.1007/978-3-642-11224-9, 2010.

[14] P. Moore and H. V. Pham, "Personalization and Rule Strategies in Human-Centric Data Intensive Intelligent Context-Aware Systems", Accepted to Appear in *The Knowledge Engineering Review*, Cambridge University Press, UK, 2013.

[15] P. Moore and H. V. Pham, "Predicting Intelligence using Hybrid Artificial Neural Networks in Context-Aware Tunnelling Systems under Risk and Uncertain Geological Environment", *Second International Workshop on Intelligent Context-Aware Systems* (ICAS 2012), *In Proceedings of the 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 989-994, 2012.

[16] P. Moore, B. Hu. X. Zhu, W. Campbell and M. Ratcliffe, "A Survey of Context Modelling for Pervasive Cooperative Learning", *In Proceedings of the First International Symposium on Information Technologies and Applications in Education* (ISITAE 07). Kunming, Yuan, P.R, China, November 23-25, 2007, K5-1-K5-6, 2007.

[17] T. E. Vollmann, "Cutting the Gordian Knot of Misguided Performance Measurement", *Industrial Management & Data Systems*, Vol. 1, pp. 24-26, 1991.

[18] Z. Libowski, "Sensory and information inputs overload: Behavioral effects", *Comprehensive Psychiatry*, Vol. 16, pp. 199-221, 1975.

[19] R. E. Hunt and R. G. Newman, "Medical knowledge overload: A disturbing trend for physicians", *Health Care Management Review*, Vol. 22, pp. 70-75, 1997.

[20] R. S. Wurman, "Information Anxiety 2". *Macmillan Publishing,* Indiana, USA, 2001.

[21] R. Simnet, "The effect of information selection, information processing and task complexity on predictive accuracy of auditors", *Accounting, Organizations and Society*, Vol. 21, pp. 699-719, 1996.

[22] P. R. Sparrow, "Strategy and cognition: Understanding the role of management knowledge structures, organizational memory and information overload", *Creativity and Innovation Management*, Vol. 8, pp. 140-149, 1999.

[23] M. T. Hansen and M. R. Haas, "Competing for Attention in Knowledge Markets: Electronic Document Dissemination in a Management Consulting Company", *Administrative Science Quarterly*, Vol. 46, pp. 1-28, 2001.

[24] M. L. Grise and R. B. Gallupe, "Information Overload: Addressing the Productivity Paradox in Face-to-Face Electronic Meetings", *Journal of Management Information Systems*, Vol. 16(3) (Winter, 1999/2000), pp. 157-185, 1999.

[25] J. Jacoby, D.E. Speller and C.A. Kohn, "A. Brand choice behavior as a function of information load", *Journal of Marketing Research*, 1974, Vol. 11(l), pp. 63-69, 1974.

[26] B. M Friedman, "Optimal expectations and the extreme information assumptions of rational expectations", *Journal of Monetary Economics*, Vol 5(1), January 1979, pp. 23-41, http://dx.doi.org/10.1016/0304-3932(79)90022-9, 1979.

[27] P. Checkland and F. Holwell, "Information, systems and information systems: making sense of the field", *John Wiley and Sons*, 1998.

[28] T. Blechschmidt, T. Wieland, C. Kuhmunch and L. Mehrmann, "Personalization of End User Software on Mobile Devices", *In Proceedings of the The Second IEEE International Workshop on Mobile Commerce and Services, 2005* (WMCS '05). July 18-19, 2005, Munich, Germany, pp. 130-137, 2005.

[29] R. J. Keeble and R. D. Macredie, "Software agents and issues in personalisation: Technology to accommodate individual users", *Personal Technologies*, Vol. (2), pp. 131-140, DOI: 10.1007/BF01321171, 1998.

[30] I. Cingil, A. Dogac and A. Azgin, "A broader approach to personalization", *Communications of the ACM*, Vol. 43(8), pp. 136141, 2000.

[31] C. Y. Kim, J. K. Lee, Y. H. Ch and D. H. Kim, "Viscors: a visual content recommender for the mobile web", *IEEE Intelligent Systems*, Vol. 19(6), pp. 3239, 2004.

[32] J. W. Kim, H. J. Lee and S. J. Park, "Intelligent knowledge recommendation methods for R&D knowledge portals", *Journal of Electronic Science and Technology of China*, Vol.2(3), September 2004, pp. 80-85, 2004.

[33] A. Held, S. Buchholz and A Schill, "Modeling of context information for pervasive computing applications", *In Proc. of the 6th World Multiconference on Systemics, Cybernetics and Informatics* (SCI200), [online], Retrieved from: http://citeseer.ist.psu.edu/held02modeling.html, 2002.

[34] L. Barkhuus and A. K. Dey, "Location-based services for mobile telephony: a study of users' privacy concerns", *Proceedings of INTERACT 2003, 9th IFIP TC13International Conference on Human-Computer Interaction*, Vol. 2003, pp. 709-712. 2003.

[35] Kinshuk and T. T. Goh, "Mobile adaptation with multiple representation as educational pedagogy", In W. Uhr, W. Esswein & E. Schoop (Eds.), Wirtschaftsinformatik 2003-Medien-Markte-Mobilita, pp. 747-763, 2003.

[36] G. Adomavicius and A. Tuzhilin, "Toward the next generation of recommender systems: a survey of the state-of-the-art and possible extensions", *IEEE Transactions on Knowledge and Data Engineering*, June 2005, Vol. 17(6), pp. 734-749, 2005.

[37] G. K. Klir and Bo. Yuan, "Fuzzy sets and fuzzy logic: theory and applications", Prentice Hall, NJ, USA, 1995.

[38] P. Moore and Hai. V. Pham, "Intelligent Context with Decision Support under Uncertainty", *In the Second International Workshop on Intelligent Context-Aware Systems* (ICAS 2012), *In Proc of The 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 977-982, 2012.

[39] P. Moore, "Intelligent Context: the realization of decision support under uncertainty", *In Inter-Cooperative Collective Intelligence: Techniques and Applications*, Eds: Fatos Xhafa,Nik Bessis, To appear in Studies in Computational Intelligence, Springer (2013).

[40] V. Akman and M. Surav, "The use of situation theory in context modeling", *Computational Intelligence* Vol. 1(3), 1997, pp. 427438, 1997.

[41] J. Barwise and J. Perry, "Situations and Attitudes", MIT Press, USA, 1993.

[42] A. Thomas, P. Moore, F. Xhafa and L. Barolli, “Smart Care Spaces: Pervasive Sensing Technologies for At-Home Care”, Accepted, *Int. J. Space-Based and Situated Computing*, 2013.

[43] Philip. Moore, Andrew Thomas, George Tadros, Fatos Xhafa, Leonard Barolli, “Detection of the Onset of Agitation in Patients with Dementia: Real-Time Monitoring and the Application of Big Data Solutions”, Accepted, *Int. J. Space-Based and Situated Computing*, 2013.

[44] P. Moore, A. Thomas, G. Tadros, L. Barolli and H. V. Pham, “Situation Awareness for Enhanced Patient Management”, *The Third International Workshop on Intelligent Context-Aware Systems* (ICAS 2013), *In Proc of the 7th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), July 2-6, Taichung, Taiwan, pp. 493-498, 2013.

[45] A. Schmidt, U. Karlsruhe and K. Van Laerhoven, “How to Build Smart Appliances”, *IEEE Personal Communications*, Vol. 8(4), August, pp. 66-71, 2001.

[46] P Lonsdale, C. Barber, M. Sharples and T. N. Arvanitis, “A context awareness architecture for facilitating mobile learning”, *In Proceedings of Learning with mobile devices: Research and development (MLEARN 2004*, London, UK, pp. 79-85, 2004.

[47] “Merriam-Webster Online Dictionary”, [online], retrieved from: http://www.merriam-webster.com/dictionary/context, 2013.

[48] “The Dictionary of Computing”, [online], retrieved from: http://foldoc.org/context, 2013.

[49] T. P. Moran and P. Dourish, “Context-Aware Computing”, *Special Issue of Human-Computer Interaction*, Vol. 16, pp. 1-8, 2001.

[50] A. K Dey and G. D. Abowd. G.D, “Towards a better understanding of context and context-awareness”, *(GVU Tech. Rep. GIT-GVU-99-22), Georgia: College of Computing, Georgia Institute of Technology*, 1999.

[51] P. Dourish, “What we talk about when we talk about context”, *Personal and Ubiquitous Computing*, Vol. 8, pp. 19-30, 2004.

[52] B. N. Schilit, N. I. Adams and R. Want, "Context-aware computing applications", *In Proceedings of the Workshop on Mobile Computing Systems and Applications*, IEEE Computer Society, pp. 85-90, 1994

[53] E. Kaasinen, "User needs for location-aware mobile services", *Personal and Ubiquitous Computing*, Vol. 7, pp. 70-79, 2003.

[54] A. Sheth and C. Ramakrishnan, "Semantic (Web) technology in action: Ontology driven information systems for search, integration, and analysis". In U. Dayal, H. Kuno & K. Wilkinson (Eds.), *IEEE data engineering bulletin, special issue on making the Semantic Web*, Vol. 26(4), pp. 40-48, 2003.

[55] H. J. Hermens, B. Freriks, C. Disselhorst-Klug, and G. Rau, "Development of recommendations for SEMG sensors and sensor placement procedures", *Journal of electromyography and Kinesiology*, Vol. 10(5), pp. 361-374, 2000.

[56] P. Coppola and M. A. Della, "The concept of relevance in mobile and ubiquitous access", *Mobile and Ubiquitous Info* 2003, LNCS 2954, pp. 1-10, 2004.

[57] M. Weiser, "The computer for the 21st century", *Scientific American*, pp. 94-104, 1991, Reprinted in *IEEE Pervasive Computing*, Jan.-Mar. 2002, pp. 19-25, 2002.

[58] R. Want, A. Hopper, V. Falcao, and J. Gibbons, "The active badge location system", *ACM Transactions on Information Systems*, Vol. 10(1), pp. 91-102, 1992.

[59] A. Ward, A. Jones, and A. Hopper, "A new location technique for the active office", *IEEE Personal Communications*, Vol. 4(5), pp. 42-47, 1997.

[60] R. Want, W. N. .Schilit, N. I. Adams, R. Gold, K. Peterssen, D. Goldberg, J. R. Ellis and M Weiser, "An overview of the PARCTAB ubiquitous computing environment", *IEEE Personal Communications*, Vol. 2(6), pp. 28-43, 1995.

[61] J. Finney, S. Wade, N. Davies and A. Fridal, "FLUMP: The flexible ubiquitous monitor project", (Tech. Rep.). Distributed Multimedia Research Group, Department of Computing, Lancaster University, Lancaster, UK [online]. retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.53.2268, 1996.

[62] G. W. Fitzmaurice, "Situated information spaces and spatially aware palmtop computers", *In Proceedings of CACM*, Vol. 36(7), pp. 39-48, 1993.

[63] S. Long, R. Kooper, G. D. Abowd and C. Atkeson, "Rapid Prototyping of Mobile Context-aware Applications: The Cyberguide Case Study", *In Proceedings of the 2nd ACM International Conference on Mobile Computing and Networking* (MobiCom'96), November 10-12, pp. 97-107, 1996.

[64] N. Davies, K. Mitchell, K. Cheverest and G. Blair, "Developing a context sensitive tourist guide", *In First Workshop on Human Computer Interaction with Mobile Devices*, GIST Technical Report, G98-1, 1998.

[65] V. Zarikas, G. Papatzanis and C. Stephanidis, "An architecture for a self adapting information system for tourists", *In Procof the 2001 Workshop on Multiple User Interfaces over the Internet* (HCI-IHM2001), 10-14 September 2001, Lille, France, 2001.

[66] A. Andreadis, G. Benelli, A. Bianchi, P. Fedele and G. Giambene, "Universal access to personalised information services", (Tech. Rep.). Siena, Italy: Dipartimento di Ingegneria dellInformazione, Universita di Siena. IST-PALIO project, 2001.

[67] N. Ryan, J. Pascoe and D. Morse, "Enhanced reality fieldwork: The context-aware archaeological assistant", In Gaffney, Leusen & Exxon (Eds.), *Computer applications in archaeology.* Oxford, UK: British Archaeological Reports, 1997.

[68]) J. Pascoe, "Adding Generic Contextual Capabilities to Wearable Computers", In Wearable Computers, Digest of Papers, *In Proc of the 2nd International Symposium on Wearable Computers* (ISWC 1998), pp. 9299, 1998.

[69] J. Pascoe, N.S. Ryan and D. R. Morse, "Issues in developing context-aware computing", *In Proceedings of the International Symposium on Handheld and Ubiquitous Computing*, Karlsruhe, Germany, pp. 208-221, 1999.

[70] M. Lamming, and M. Flynn, "Forget-me-not: Intimate computing in support of human memory", In Proceedings of FRIEND21 _94, the International Symposium on Next Generation Human Interface, Magufo Jagoen, Japan, p. 4, 1994.

[71] B. J. Rhodes, "The wearable remembrance agent: a system for augmented memory", *In Proc of the 1st International Symposium on Wearable Computers*, Cambridge, Massachusetts, October 13-14, 1997, pp. 123-128, 1997.

[72] Jie Yang, Y. Weiyi, M. Denecke and A. Waibel, "Smart sight: A tourist assistant system", *In Proceedings of the 3rd International Symposium on Wearable Computers*, San Francisco, CA, pp. 73-78, 1999.

[73] J. Healey and R. W. Picard, "Startlecam: A cybernetic wearable camera", *In Proceedings of the 2nd International Symposium on Wearable Computers*, Pittsburgh, PA, pp. 42-49, 1998.

[74] A. Clay, T. Frey, J. Gutknecht and D. Majoe,.D. (2006). "Motion Tracking Music with Mobile-Media Technology in Two Case Studies", *In Proceedings of the 1st International Symposium on Pervasive Computing and Applications 2006* (SPCA06), 3-5 Aug. 2006, pp. 358-363, 2006.

[75] A. Clay and D. Majoe. D, "GPS Interface for Public Use", *In Proc of SIGGRAPH '06 ACM SIGGRAPH 2006*. Research posters. Article No. 105, ISBN:1-59593-364-6, doi¿10.1145/1179622.1179744, 2006.

[76] A. Clay and D. Majoe. D, "The wrist-conductor", *In Proc of the 7th international conference on New interfaces for musical expression* (NIME07). pp. 242-245, 2007.

[77] K. Kunze, P. Lukowicz, H. Junker and G. Troster, "Where am I: Recognizing On-body Positions of Wearable Sensors. Location and Context-Awareness", *Lecture Notes in Computer Science,* 2005, Vol. 3479/2005, pp. 257-268, DOI: 10.1007/11426646_25, 2005.

[78] K. Kunze, B. Michael, E. A. Heinz, P. Lukowicz, M. Dennis and J. Gutknecht, "Towards Recognizing Tai Chi An Initial Experiment Using Wearable Sensors", *In Proc of Institute for Computer Systems and Networks* (CSN), UMIT, Hall in Tyrol, Austria, 15-16 March 2006, pp. 1-6, 2006.

[79] D. Majoe, I. Kulka and J. Gutknecht, "Qi energy flow visualisation using wearable computing", *In Proceedings of the 2nd International Conference on Pervasive Computing and Applications, 2007* (ICPCA 2007), 26-27 July 2007, pp. 285290, 2007.

[80] D. Majoe, M. Estermann, N. Ranieri and J. Gutknecht, "Ergonomic low cost motion capture for every day health exercise", *In Proceedings of the Third International Conference on Pervasive Computing and Applications* (ICPCA08), Alexandria, Egypt, pp. 627-632, 2008.

[81] J. Biswas, M. Jayachandran, P. V. Thang, V. F. S. Fook, T. S. Choo, Q. Quiang, S. Takahashi, E. H. Jianzhong, C. J. Feng and P.Y. Lin Kiat, "Agitation monitoring of persons with dementia based on acoustic sensors, pressure sensors and ultrasound sensors: a feasibility study", *In Proceedings of the International Conference on Aging, Disability and Independence*, St. Petersburg, Amsterdam, pp. 3-15. 2006.

[82] J. Biswas, V. Foo, S. Fook, Q. Qiang, M. Jayachandran, A. P. Wai, P. V. Thang, T. M. Htwe, L. B. iong, and P. Yap, "Data Collection and Feature Extraction for a Smart Ward Application", *In Proc of the 11 IEEE Conference on Emerging Technologies and Factory Automation* (EFTS06). 20-22 September 2006. pp. 110-115, 2006.

[83] D. Salber, A. K. Dey, and G. D. Abowd, "The context toolkit: Aiding the development of context-enabled applications", *In Proceedings of the ACM CHI 99 Human Factors in Computing Systems Conference* (CHI 99), Pittsburgh, PA, pp. 343-441, 1999.

[84] A. K. Dey, D. Salber, G. D. Abowd and M. Futakawa, "The conference assistant: Combining context-awareness with wearable computing", *In Proceedings of the 3rd International Symposium on Wearable Computers*, San Francisco, CA, October 18-19, pp. 21-28, 1999.

[85] A. K. Dey, "Understanding and using context", *Personal and Ubiquitous Computing*, Special issue on Situated Interaction and Ubiquitous Computing, Vol. 5(1), pp. 4-7, 2001.

[86] K. Luchini, M. Curtis, C. Quintana and E. Soloway, "Supporting learning in context: Extending learner-centered design to the development of handheld educational software", In M. Milrad, H.U. Hoppe & Kinshuk (Eds.), *IEEE International Workshop on Wireless and Mobile Technologies in Education 2002*, pp. 107-111, 2002.

[87] T. Lin, Kinshuk and A. Pate. A, “Cognitive trait model for persistent student modelling”, In D. Lasser & C. McNaught (Eds.), EdMedia 2003, pp. 2114-2147, Norfolk, USA: AACE, 2003.

[88] D. B. Johnson, and D. A. Maltz, “Dynamic source routing in ad hoc wireless networks”, *In The International Series in Engineering and Computer Science*, Vol. 353, pp. 151-181, Springer, 1996.

[89] O. K. Tonguz and G. Ferrari, “Ad-Hoc Wireless Networks: A Communication-Theoretic Perspective”, John Wiley & Sons, Ltd. ISBN: 0-470-09110-X. DOI: 10.1002/0470091126.fmatter, pp. i-xvi, 2006.

[90] W. Beer, V. Christian, A. Ferscha and L. Mehrmann, “Modeling Context-aware Behavior by Interpreted ECA Rules”, *In Proceedings of the International Conference on Parallel and Distributed Computing* (EUROPAR03), Klagenfurt, Austria, August 26-29, 2003, Springer Verlag, LNCS 2790, pp. 1064-1073, 2003.

[91] A. Ferscha, H. Clemens and S. Oppl, “Context awareness for group interaction support”, *In Proceedings of MobiWac04*, Philadelphia, PA, pp. 8897, 2004.

[92] G. Hynes, V. Reynolds and M. Hauswirth, “Enabling mobility between context-aware smart spaces”, *In proc of The 5th International Symposium on Web and Mobile Information Services, IEEE Workshop at IEEE international conference on advanced information networking and applications* (WAINA’09), Bradford, England, pp. 255-260, 2009.

[93] A. Smirnov, A. Kashevnik, N. Shilov, S. Oliver and S. Boldyrev, “Smart Spaces and Next Generation Wired / Wireless Networking. Anonymous Agent Coordination in Smart Spaces: State-of-the-Art”, LNCS, 5764, pp. 42-51. DOI: 10.1007/978-3-642-04190-7_5, 2009.

[94] A. Manzour, Hong-Linh. Truong and S. Dustdar, “Quality Aware Context Information Aggregation System for Pervasive Environments”, *In Proc of Advanced Information Networking and Applications Workshops, 2009* (WAINA ’09), Bradford, England, 26-29 May 2009, pp. 266-271, 2009.

[95] E. S. Noh, C. Hoon Lyu and H. Yong Youn, "Hybrid Context Matchmaking for Fast Context-Aware Computing", *In Proc of Advanced Information Networking and Applications Workshops, 2009* (WAINA '09), Bradford, England, 26-29 May 2009, pp. 272-277, 2009.

[96] B. Salem, R. Nakatsu and M. Rauterberg, "Kansei experience: aesthetic, emotions and inner balance", *Int. J. of Cognitive Informatics and Natural Intelligence*, Vol. 3, pp. 5464, 2009.

[97] Hai. V. Pham, C. Thang, I. Nakaoka, E. W. Cooper and K. Kamei, "A Proposal of Hybrid Kansei-SOM Model for Stock Market Investment", *Int. J. Innovative Computing, Information and Control*, vol.7(5)(B), pp. 2863-2880, 2011.

[98] Ann C. Hurley, et al, "Measurement of Observed Agitation in Patients with Dementia of the Alzheimer Type", *Journal of Mental Health and Aging*, Vol. 5(2), pp. 117-134, 1999.

[99] D. Saha and A. Mukherjee, "Pervasive computing: A paradigm for the 21st century", *IEEE Computer*, Vol. 36(3), pp. 2531, 2003.

[100] T. Strang and C. Linnhoff-Popien, "A Context Modeling Survey", *In Proc. UbiComp 2004*, Nottingham, UK, September 710, ACM Press, USA, pp. 34-41, 2004.

[101] M. Samulowitz, F. Michahelles and C. Linnhoff-Popien, "Capeus: An architecture for context-aware selection and execution of services", *In Proc of New developments in distributed applications and interoperable systems*, Krakow, Poland, September 17-19 2001, Kluwer Academic Publishers, pp. 2339, 2001.

[102] T. Strang, "Service Interoperability in Ubiquitous Computing Environments", PhD thesis, Ludwig-Maximilians-University Munich, October. 2003.

[103] J. Wald, "The Jini architecture for network-centric computing", emphCommunications of the ACM, Vol. 42(7), July 1999, pp. 76-82, 1999.

[104] J. Indulska, R. Robinsona, A. Rakotonirainy, and K. Henricksen, "Experiences in using cc/pp in context-aware systems", *In LNCS 2574: Proceedings of the 4th International Conference on Mobile Data Management* (MDM2003),

(Melbourne/Australia, January 2003). In, M.-S. Chen, P. K. Chrysanthis, M. Sloman, and A. Zaslavsky, Eds., Springer, pp. 247-261, 2003.

[105] M. H. Butler, "CC/PP and UAProf: Issues, improvements and future directions", *In Proceedings of W3C Delivery Context Workshop* (DIWS 2002), Sophia-Antipolis/France, March 2002, 2002.

[106] J. Bauer, "Identification and Modeling of Contexts for Different Information Scenarios in Air Traffic", *Technische Universitt Berlin, Diplomarbeit*, 2003.

[107] K. Henricksen, J. Indulska and Rakotonirainy, "Generating Context Management Infrastructure from High-Level Context Models", *Industrial Track, Proceedings of the 4th International Conference on Mobile Data Management* (MDM2003), Melbourne, Australia, January 2003, p. 16, 2003.

[108] T. Halpin, "Information Modeling and Relational Databases: From Conceptual Analysis to Logical Design", Morgan Kaufman Publishers, San Francisco, 2001.

[109] G. Nijssen and T. A. Halpin, "Conceptual Schema and Relational Database Design: A Fact Oriented Approach", Prentice Hall, Australia, 1989.

[110] K. Henricksen and J. Indulska, "Modelling and Using Imperfect Context Information", *In Workshop Proceedings of the 2nd IEEE Conference on Pervasive Computing and Communications* (PerCom2004), Orlando, FL, USA, March 2004, pp. 33-37, 2004.

[111] P. Stevens and R. Pooley, "Using UML, Software Engineering with Objects and Components", London: Addison-Wesley, 2000.

[112] H. W. Gellersen, A. Schmidt and M. Beigl, "Adding Some Smartness to Devices and Everyday Things", *In Proc of The Third IEEE Workshop on Mobile Computing Systems and Applications 2000* (WMCSA00), Dec. 2000, Monterey, USA, IEEE Press, pp. 3-10, 2000.

[113] A. Schmidt, M. Beigl and H. W. Gellersen, "There is more to context than location", *Computers and Graphics*, Vol. 23(6), pp. 893-901, 1999.

[114] K. Cheverst, K. Mitchell and N. Davies, "Design of an object model for a context sensitive tourist GUIDE", *Computers & Graphics*, Vol. 23(6), pp. 883-891, 1999.

[115] B. Bouzy and T. Cazenave. "Using the object oriented paradigm to model context in computer go" *In Proceedings of the First International and Interdisciplinary Conference on Modeling and Using Context* (Context97), Rio, Brazil, pp. 279-289, 1997.

[116] J. McCarthy, "Notes on formalizing contexts", *In Proceedings of the Thirteenth International Joint Conference on Artificial Intelligence, San Mateo, California, 1993*, R. Bajcsy, Ed., Morgan Kaufmann, pp. 555-560, 1993.

[117] F. Giunchigli, "Contextual reasoning", *Epistemologica - Special Issue on I Linguaggi e le Macchine* Vol. 16, 1993, pp. 345-364, 1993.

[118] C. Ghindi and F. Giunchiglia, "Local models semantics, or contextual reasoning = locality + compatibility", *Artificial Intelligence* , Vol. 127(2), pp. 221-259, 2001.

[119] P. Gray and D. Salber, "Modelling and Using Sensed Context Information in the design of Interactive Applications", *In LNCS 2254: Proceedings of 8th IFIP International Conference on Engineering for Human-Computer Interaction* (EHCI 2001), Toronto, Canada, May 2001, M. R. Little and L. Nigay, Eds., Springer, pp. 317-335, 2001.

[120] J. Bacon. J,J. Bates and D. Halls, "Location-oriented multimedia", *IEEE Personal Communications*, Vol. 4(5), pp. 48-57, 1997.

[121] M. Uschold and M. Gruninger, "Ontologies: Principles, methods, and applications", *Knowledge Engineering Review*, Vol. 11(2), 1996, pp. 93-155, 1996.

[122] T. R. Gruber, "Toward principles for the design of ontologies used for knowledge sharing", *International Journal of Human-Computer Studies*, Vol. 43(5-6), pp. 907-928, 1993.

[123] T. R. Gruber, "A translation approach to portable ontologies", *Knowledge Acquisition*, Vol. 5(2), pp. 199-220, 1993.

[124] I. Horrocks, P. F. Patel-Schneider and F. Van-Harmelen, "From SHIQ and RDF to OWL: The making of the ontology Web language", *Journal of Web Semantics*, Vol. 1(1), pp. 7-26, 2003.

[125] I. Horrocks and U. Sattler, "A Tableau Decision Procedure for SHOIQ", *Journal of Automated Reasoning*, Vol. 39(3), pp 249-276, 2007.

[126] P. Otzturk and A. Aamodt, "Towards a model of context for case-based diagnostic problem solving", *In Context-97; Proceedings of the interdisciplinary conference on modeling and using context*, Rio de Janeiro, February 1997, pp. 198208, 1997.

[127] T. Strang, C. Linhoff-Popien and K. Frank, "CoOL: A Context Ontology Language to enable Contextual Interoperability", *In LNCS 2893: Proceedings of 4th IFIP WG 6.1 International Conference on Distributed Applications and Interoperable Systems* (DAIS2003) (Paris/France, November 2003). In J.-B. Stefani, I. Dameure, and D. Hagimont, Eds., LNCS. vol. 2893, Springer, pp. 236247, 2003.

[128] J. De Bruijn, "Using Ontologies Enabling Knowledge Sharing and Reuse on the Semantic Web". *Tech. Rep. Technical Report DERI-2003-10-29, Digital Enterprise Research Institute* (DERI), Austria, October, 2003.

[129] H. Chen, T. Finin and A. Joshi, "An ontology for context-aware pervasive computing environments", *Special Issue on Ontologies for Distributed Systems, Knowledge Engineering Review*, Vol. 18(3), pp. 197207, 2003.

[130] J. A. Flanagan, "Context awareness in a mobile device: Ontologies vs. unsupervised / supervised learning", [online]. retrieved from: http://www.cis.hut.fi/AKRR05/papers/akrr05flanagan.pdf, 2005.

[131] O. Brdiczka, P. Reignier and J. L. Crowley, "Supervised learning of an abstract context model for an intelligent environment", *In Proceedings of the 2005 Joint Conference on Smart Objects and Ambient Intelligence: Innovative Context-aware Services: Usages and Technologies*, Grenoble, France, SESSION: Context-aware Systems, pp. 259-264, 2005.

[132] H. Chen, T. Finin and A. Joshi, "The SOUPA Ontology for Pervasive Computing", *Ontologies for Agents: Theory and Experiences, Whitestein Series in Software Agent Technologies and Autonomic Computing*, 2005, pp. 233-258, DOI: 10.1007/3-7643-7361-X_10, 2005.

[133] J. A. Flanagan, J. M. Mantyjarvi and J. Himberg, "Unsupervised clustering of symbol strings and context recognition", *In Proceedings of the IEEE Int. Conf. Data Mining* (ICDM02), 2002, pp. 171-178, 2002.

[134] J. Himberg, A. Hyvarinen and F. Esposito, "Validating the independent components of neuroimaging time series via clustering and visualization", *NeuroImage*, Vol. 22(3), July 2004, pp. 1214-1222, 2003.

[135] X. H. Wang, D. Q. Zhang, T. Gu and H. K. Pung, "Ontology Based Context Modeling and Reasoning using OWL", *In Workshop Proceedings of the 2nd IEEE Conference on Pervasive Computing and Communications* (PerCom2004), Orlando, FL, USA, March 2004, pp. 1822, 2004.

[136] O. Lassila and K. Deepali Khushraj, "Contextualizing applications via semantic middleware". *In Proc of the Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services, 2005*, (MobiQuitous 2005), pp. 183-189, 2005.

[137] R. Elmasari and S. B. Navathi, "Fundamentals of database design 2nd ed", Redwood City, CA: Benjamin/Cummins, 1994.

[138] W3C, "W3C Semantic Web Activity", [online], retreived from: http://www.w3.org/2001/sw/, 2011.

[139] R. Ashford, P. Moore, B. Hu, M. Jackson and J. Wan, "Translational Research and Context in Health Monitoring Systems", *In Proceedings of the Fourth International Conference on Complex, Intelligent and Software Intensive Systems* (ARES/CISIS 2010). Krakow, Poland, February 15-18, 2010, pp. 81-86, 2010.

[140] M. Berndtsson and J. Hansson, "Issues in active real-time databases", *In Proceedings of the 1st International Workshop on Active and Real-Time Database Systems* (ARTDB-95), Skovde, Sweden, Workshops in Computing, London: Springer Verlag, pp.142-157, 1995.

[141] F. Hayes-Roth, "Rule-based systems", *Communications of the ACM*, Vol. 28(9), pp. 921-932, 1985.

[142] A. J. Gonzales and D. D. Dankel, "The engineering of knowledge-based systems theory and practice", Prentice-Hall, NJ, 1993.

[143] T. Mitchell, "Machine learning", McGraw-Hill, Singapore, 1997.

[144] R.J. Roiger, C. Azarbod and R. R. Sant, "A majority rules approach to data mining", *In Proceedings of the 1997 IASTED International Conference on Intelligent Information Systems*(Iis97), Grand Bahamia Island, Bahamas, pp. 100-107, 1997.

[145] M. Alvarado and M. Vazquez, "Decision making automation based on fuzzy event-condition-action rules", [online]. retreived from http://delta.cs.cinvestav.mx/ matias/PDF/, 2004.

[146] R. C. Berkan and S. L. Trubatch, "Fuzzy systems design principles: Building fuzzy IF-THEN rule bases". IEEE Press, Piscataway, NJ, 1997.

[147] G. Cerkveinik, "Decision trees and automatic learning in medical decision making", *In Proc of the 1997 IASTED International Conference on Intelligent Information Systems* (Iis97), Grand Bahamia Island, Bahamas, pp. 8-10 and 37-45, 2007.

[148] J. Basak and R. Krishnapuram, "Interpretable hierarchical clustering by constructing an unsupervised decision tree", *IEEE Transactions on Knowledge and Data Engineering*, Vol. 17(1), pp. 121-132, 2005.

[149] H. Berger, D. Merkl and M. Dittenbach, "Exploiting partial decision trees for feature subset selection in e-mail categorisation", *In Proceedings of the 2006 ACM Symposium on Applied Computing*, Dijon, France. SESSION: Information Access and Retrieval (IAR), pp. 11051109, 2006.

[150] Jena, "Apache Jena", [online], retreived form: http://jena.apache.org/, 2012.

[151] I. Horrocks, P. F. Patel-Schneider, H. Boley, S. Tabet, B. Grosof and M. Dean, "SWRL: A Semantic Web rule language combining OWL and RuleML", [online], retreived from: http://www.w3.org/Submission/SWRL/, 2004.

[152] G. Papamarkos, A. Poulovassilis and P. Y. Wood, "RDFTL : An Event-Condition-Action Language for RDF", [online], retreived from: http://www.dcs.bbk.ac.uk/selene/reports/webDyn3.pdf, 2004.

[153] M. Berndtsson and B Lings, "Logical events and ECA rules". *(Tech. Rep. HS-IDA-TR-95-004). University of Skovde*, [online]. retreived from: http://citeseerx.ist.psu.edu/legacymapper?did=77063, 1995.

[154] W3C, "Comparing Rule-Based Systems", [online], retreived from: http://www.w3.org/2000/10/swap/doc/rule-systems, 2013.

[155] I. Lera, C. Juiz and R. Puigjaner, "OWL-M Extension for Semantic Representations of Ontology Alignments", *In Proc of the Complex, Intelligent and Software Intensive Systems* (ARES/CISIS 2010), Krakow, Poland, February 15-18, pp. 956-961, 2010.

[156] L. A. Zadeh, "Fuzzy sets", *Information and Control* Vol. 8(3), pp. 338-353, 1965.

[157] J. C. Gower, "Euclidean Distance Geometry", *Mathematical Scientist*, Vol. 7(1), PP. 1-14, 1982.

[158] W3C OWL, "OWL Web ontology language reference W3C recommendation", [online], Retrieved from http://www.w3.org/TR/owl-ref/, 2009.

[159] G. Antoniou and F. G. van Harmelen, "Web ontology language: OWL", In S. Staab & R. Struder (Eds.), Handbook on ontologies. Germany: Springer, 2003.

[160] E. F. Codd, "A Relational Model of Data for Large Shared Data Banks", *Communications of the ACM*, Vol. 13(6), pp. 377387, 1970.

[161] D. Chamberlin and R. F. Boyce, "SEQUEL: A Structured English Query Language", *In Proceedings of the 1974 ACM SIGFIDET Workshop on Data Description, Access and Control*, pp. 249264, 1974.

[162] W3C SPARQL, "Main Page: SPARQL Working Group Wiki", [online]. Retrieved from: http://www.w3.org/2009/sparql/wiki/Main_Page, 2012.

[163] SPARQL, "W3C SPARQL 1.1 Update", [online], retreived from: http://www.w3.org/TR/2011/WD-sparql11-update-20110512/, 2011.

[164] Cambridge Semantics, "SPARQL by EXAMPLE", [online], retreived from: http://www.cambridgesemantics.com/en_GB/semantic-university/sparql-by-example, 2012.

[165] B. Alpern, M. N. Wegman and F.K. Zadeck, "Detecting equality of variables in programs", *In Conference Record of the Fifteenth ACM Symposium on Principles of Programming Languages*, pp. 1-11, San Diego, 1988.

[166] H. J. Greenberg, "The use of the optimal partition in a linear programming solution for postoptimal analysis", *Operations Research Letters*, Vol. 15, pp. 179-185, 1994.

[167] FHEQ, "QAA", [online]. retreived from: http://www.qaa.ac.uk/Pages/default.aspx, 2012.

[168] S. Homer and A. L. Selman, "Complexity theory", Department of Computer Science, State University of New York at Buffalo, 1991.

[169] R. Agrawal, A. S. Somani, and Y. Xu, "Storage and querying of e-commerce data", *In Proceedings of the International Conference on Very Large Data Bases*, vol. 11, pp. 149-158. 2001.

[170] K. Wilkinson, C. Sayers, H. Kuno and D. Reynolds, "Efficient RDF storage and retrieval in Jena2", TechRep, HP Laboratories, , HPL-2003-266, 2003.

List of Papers

Journal Articles

1. P. Moore, B. Hu and J. Wan, "Smart-Context: A Context Ontology for Pervasive Mobile Computing". *The Computer Journal*, Vol. 53(2), pp. 191-207. ISSN: 0010-4620 (print), 1460-2067 (online). doi: 10.1093/comjnl/bxm104. Available: http://comjnl.oxfordjournals.org/cgi/reprint/53/2/191.pdf, 2010.

2. P. Moore, "Anytime-Anywhere Personalised Time-Management in Networking for e-Learning", *eLC Research Paper Series*, Vol. 3, pp 48-.59, 2011.

3. B. Hu, D. Majoe, M. Ratcliffe, Y. Qi, Q. Zhao, H. Peng, D. Fan, M. Jackson and P. Moore, "EEG-Based Cognitive Interfaces for Ubiquitous Applications: Developments and Challenges". *IEEE Intelligent Systems - Brain Informatics*, September / October 2011, Vol. 26(5), pp. 46-53, 2011.

4. X. Zhang, B. Hu, P. Moore, J. Chen and L. Zhou, "Emotiono: an ontology with rule-based reasoning for emotion recognition", *Neural Information Processing*, 2011, pp. 89-98, 2011.

5. X. Zhang, D. Cao, P. Moore, J. Chen, L. Zhou, Y. Zhou, et al, "A Bayesian Network (BN) Based Probabilistic Solution to Enhance Emotional Ontology", *In Human Centric Technology and Service in Smart Space*, ed: Springer, pp. 181-190, Springer, Netherlands, 2012.

6. X. Zhang, B. Hu, J. Chen, and P. Moore, "Ontology-based Context Modeling for Emotion Recognition in an Intelligent Web", *World Wide Web*, September 2012, doi 10.1007/s11280-012-0181-5, Springer Link, September 2012, pp. 1-17, 2012.

7. P. Moore and Hai. V. Pham, "Personalization and Rule Strategies in Human-Centric Data Intensive Intelligent Context-Aware Systems", To appear in *The Knowledge Engineering Review*, Cambridge University Press, UK, 2013.

8. A. Thomas, H. Shah, P. Moore, C. Evans, M. Sharma, S. Mount, Hai V. Pham, K. Osman, A. J. Wilcox, P. Rayson, C. Chapman, P. Chima, C. Athwal and D. While, "Challenges and Opportunities for the Future of iCampuses", *Computer Science*, North America, 14, mar. 2013. Available at: http:journals.agh.edu.pl/csci/article/view/105/53.

9. A. Thomas, P. Moore, H. Shah, C. Evans, M. Sharma, F. Xhafa, S. Mount, Hai V. Pham, A. J. Wilcox, A. Patel, C. Chapman and P. Chima, "Smart Care Spaces: Needs for Intelligent At-Home Care", *Int. J. Space-Based and Situated Computing*, Vol. 3(1), 2013, pp 35-44, 2013.

10. A. Thomas, P. Moore, F. Xhafa and L. Barolli, "Smart Care Spaces: Pervasive Sensing Technologies for At-Home Care", Accepted, *Int. J. Space-Based and Situated Computing*, 2013.

11. Philip Moore*, Andrew Thomas, George Tadros, Fatos Xhafa, Leonard Barolli, "Detection of the Onset of Agitation in Patients with Dementia: Real-Time Monitoring and the Application of Big Data Solutions", Accepted, *Int. J. Space-Based and Situated Computing*, 2013.

International Conference Papers

1. J. Wan, B. Hu, P. Moore and R. Ashford, "Intelligent Mobile Computing to Assist in the Treatment of Depression", *In the IEEE Proc of The Third International Conference on Pervasive Computing and Applications* (ICPCA2008), 06-08 October, Alexandria, Egypt, pp. 650-655, 2008.

2. P. Moore, B. Hu, M. Jackson and J. Wan, "Intelligent Context for Personalised mlearning", *In Proc of the International Conference on Complex, Intelligent and Software Intensive Systems* (CISIS 2009), Fukuoka, Japan, March, pp 16-19, Fukuoka, Japan, March 16-19, pp. 247-254, 2009.

3. P. Moore, "The complexity of context in mobile information systems", *In Proc of the 12th International Conference on Network-Based Information Systems*

(NbiS 2009), *1st International Workshop on Heterogeneous Environments and Technologies for Grid and P2P Systems* (HETGP'2009), 19-21 August 2009, Indianapolis, Indiana, USA, pp. 91-96, 2009.

4. P. Moore, M. Jackson and B. Hu, "Constraint Satisfaction in Intelligent Context-Aware Systems", *In Proc of the Fourth International Conference on Complex, Intelligent and Software Intensive Systems* (ARES/CISIS 2010). Krakow, Poland, February 15-18, pp. 75-80, 2010.

5. R. Ashford, P. Moore, B. Hu, M. Jackson and J. Wan, "Translational Research and Context in Health Monitoring Systems", *In Proc of the Fourth International Conference on Complex, Intelligent and Software Intensive Systems* (ARES/CISIS 2010). Krakow, Poland, February 15-18, pp. 81-86, 2010.

6. P. Moore, B. Hu and M. Jackson, "Rule Strategies for Intelligent Context-Aware Systems: The Application of Conditional Relationships in Decision-Support", *In Proc of the International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS-2011). Korean Bible University (KBU), Seoul, Korea, June 30 July 2, 2011, pp. 9-16, 2011.

7. X. Li, B. Hu, W. Campbell, P. Moore and H. Peng, "An EEG Approach to Attention Recognition", *In Proc of The 6th International Conference on Pervasive Computing and Application* (ICPCA) and the 3rd International Symposium of Web Society (SWS) (ICPCA/SWS2011), Port Elizabeth, South Africa, 2-28 October 2011, 2011.

8. H. Peng, B. Hu, Q. Liu, Q. Dong, Q. Zhao, and P. Moore, "User-centered Depression Prevention: An EEG Approach to pervasive healthcare", *In Proc of the 5th International Conference on Pervasive Computing Technologies for Healthcare*(PervasiveHealth), 2011. 23-26 May 2011, Dublin, Ireland, pp. 325-330, 2011.

9. X. Zhang, B. Hu, P. Moore, J. Chen and L. Zhou, "Emotiono: An Ontology with Rule-Based Reasoning for Emotion Recognition", *In Proc of the 2011 International Conference on Neural Information Processing* (ICONIP 2011), Shanghai, China, 14-17 November 2011. Neural Information Processing, *Lec-*

ture Notes in Computer Science, 2011, Volume 7063/2011, pp. 89-98, DOI: 10.1007/978-3-642-24958-7_11, 2011.

10. B. Hu, C. Mao, W. Campbell, P. Moore, L. Liu and G. Zhao, "A pervasive EEG-based biometric system", *In Proc of 2011 international workshop on Ubiquitous affective awareness and intelligent interaction*, Beijing, China, September 17-21, pp. 17-24, 2011.

11. P. Moore and Hai. V. Pham, "Predicting Intelligence using Hybrid Artificial Neural Networks in Context-Aware Tunnelling Systems under Risk and Uncertain Geological Environment", *Second International Workshop on Intelligent Context-Aware Systems* (ICAS 2012), *In Proc of The 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 989-994, 2012.

12. P. Moore and Hai. V. Pham, "Intelligent Context with Decision Support under Uncertainty", *Second International Workshop on Intelligent Context-Aware Systems* (ICAS 2012), *In Proc of The 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 977-982, 2012.

13. P. Moore and Hai. V. Pham, "Personalized Intelligent Context-Aware e-Learning On Demand", *Second International Workshop on Intelligent Context-Aware Systems* (ICAS 2012), *In Proc of The 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 965-970, 2012.

14. A. M. Thomas, H. Shah, P. Moore, P. Rayson, A. J. Wilcox, K. Osman, C. Evans, C.Chapman, C. Athwal, D. While, D, Hai.V. Pham and S. Mount, "E-education 3.0 Challenges and Opportunities for the Future of iCampuses", *Second International Workshop on Intelligent Context-Aware Systems* (ICAS 2012), *In Proc The 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 953-958, 2012.

15. C. Evans, P. Moore and A. M. Thomas, "An Intelligent Mobile Advertising System (iMAS): Location-Based Advertising to Individuals and Business",

Second International Workshop on Intelligent Context-Aware Systems (ICAS 2012), *In Proc of The 6th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), 4-6 July 2012, Palermo, Italy, pp. 959-964, 2012.

16. X. Zhang., B. Hu, L. Zhou, P. Moore and J. Chen, "A Pervasive EEG Based Analysis to Detect Depression in Females", *In Proc of the 7th International Conference on Pervasive Computing and Application* (ICPCA) and *the 4th International Symposium of Web Society* (SWS). Istanbul, Turkey, from 28 November to 30 November 2012, In *Pervasive Computing and the Networked World*, LNCS 7719, pp. 848-861, 2013.

17. P. Moore, C. Evans and Hai V. Pham, "Towards Implementing Emotion into Intelligent Context", The 13th International Conference on Web Information Systems Engineering (WISE 2012), *In Proc of The International Workshop on Advanced Reasoning Technology for e-Science* (ART2012), November 28th, 2012, Paphos, Cyprus, in LNCS 7652, Springer, pp. 27-40, 2013.

18. P. Moore, C. Evans and G. Tadros, "Towards Independent Assisted Living: The Application of Intelligent Context-Aware Systems", *The First International Workshop on Informatics for Intelligent Context-Aware Enterprise Systems* (ICAES 2013), *In proc of the 27th IEEE International Conference on Advanced Information Networking and Applications* (AINA-2013), March 25-28, Barcelona, Spain, pp. 1180-1185, 2013.

19. A. M. Thomas, C. Evans, P. Moore, M. Sharma, A. Patel, H. Shah, P. Chima,S. Abu Rmeileh, G. Dubb and R. Bhana, "eMonitoring for eHealth: Research Projects for Assisted Living", *The First International Workshop on Informatics for Intelligent Context-Aware Enterprise Systems* (ICAES 2013), *In proc of the 27th IEEE International Conference on Advanced Information Networking and Applications* (AINA-2013), March 25-28, Barcelona, Spain, pp. 1180-1185, 2013.

20. C. Evans, P. Moore, A. M. Thomas and O. Pavlemko, "iMAS: an Intelligent Mobile Advertising System Development and Implementation", *The First International Workshop on Informatics for Intelligent Context-Aware Enterprise Systems* (ICAES 2013), *In proc of the 27th IEEE International Conference on*

Advanced Information Networking and Applications (AINA-2013), March 25-28, Barcelona, Spain, pp. 1192-1196, 2013.

21. P. Moore, A. Thomas, G. Tadros, L. Barolli and H. V. Pham, "Situation Awareness for Enhanced Patient Management", *The Third International Workshop on Intelligent Context-Aware Systems* (ICAS 2013), *In Proc of the 7th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), July 2-6, Taichung, Taiwan, pp. 493-498, 2013.

22. A. Thomas, P. Moore, C. Evans, M. Sharma, P. Chima, V. Vijay and S. Abu Rmeileh, "Emotive Sensors for Intelligent Care Systems", *The Third International Workshop on Intelligent Context-Aware Systems* (ICAS 2013), *In Proc of the 7th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), July 2-6, Taichung, Taiwan, pp. 499-504, 2013.

23. J. Chen, B. Hu, Na. LI, C. Mao and Moore, P, "A Multimodal Emotion-Focused E-health Monitoring Support System", *The Third International Workshop on Intelligent Context-Aware Systems* (ICAS 2013). *In Proc of the 7th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), July 2-6, Taichung, Taiwan, pp. 505-510, 2013.

24. R. Austin, D. Newell, M. Sharma and P. Moore, "Situated Computing and Virtual Learning Environments e-Learning and the Benefits to the Students Learning", *The Third International Workshop on Intelligent Context-Aware Systems* (ICAS 2013). *In Proc of the 7th International Conference on Complex, Intelligent, and Software Intensive Systems* (CISIS 2012), July 2-6, Taichung, Taiwan, pp. 523-528, 2013.

25. P. Moore, F. Xhafa, L. Barolli and M. Sharma, "Context and the Cloud: Situational Awareness in Mobile Systems", *The 4th International Workshop on Heterogeneous Networking Environments and Technologies* (HETNET-2013). *In Proc of the 16th International Conference on Network-Based Information Systems* (NBiS). Gwangju, South Korea. 4-6 September, pp. 551-558, 2013.

26. P. Moore, A. Thomas, F. Xhafa and L. Barolli, "Context and the Virtual Campus: Collaboration in Tertiary Education", *In Proc of the 5th Interna-*

tional Conference on Intelligent Networking and networking Systems (INCoS). Xi'an, China, 9-11 September, pp. 266-272, 2013.

27. P. Moore, F. Xhafa, L. Barolli and A. Thomas, "Detection of Agitation in Dementia: Real-Time Health Monitoring and Big-Data Solutions", *In Proc of the 8th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing* (3PGCIC-2013), October 28-30, 2013, University of Technology of Compiegne, France, 2013, Accepted.

28. A.M. Thomas, J. Parkinson, P.T. Moore, A. Goodman, F. Xhafa, and L. Barolli. "Nudging Through Technology: Ethical choice architectures and the mobile information revolution", *In Proc of the 8th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing* (3PGCIC-2013), October 28-30, 2013, University of Technology of Compiegne, France, 2013, Accepted.

Books

1. P. Moore and B. Hu, "A Context Framework with Ontology for Personalised and Cooperative Mobile Learning", *Computer Supported Cooperative Work in Design III. LNCS 4402*, 10th International Conference, CSCWD 2006, Nanjing, China, May 2006 , Revised Selected Papers, (Eds) Weiming Shen, Junzhou Luo, Zongkai Lin, Jean-Paul A. Barthes, pp. 727-738, Springer-Verlag, Berlin, Germany, 2007.

2. B. Hu and P. Moore, "SmartContext: An Ontology Based Context Model for Cooperative Mobile Learning", *Computer Supported Cooperative Work in Design III. LNCS 4402*, 10th International Conference, CSCWD 2006, Nanjing, China, May 2006 , Revised Selected Papers, (Eds) Weiming Shen, Junzhou Luo, Zongkai Lin, Jean-Paul A. Barthes, pp. 716-726, Springer-Verlag, Berlin, Germany, 2007.

3. P. Moore, B. Hu and J. Wan, "Intelligent Context for Personalised Mobile Learning", *In Architectures for Distributed and Complex M-Learning Systems: Applying Intelligent Technologies*, (Eds) S. Caballe; F. Xhafa; T. Daradoumis; A. A. Juan, Hershey, PA, USA, IGI Global, pp. 236-270, 2010.

4. P. Moore, B. Hu and M. Jackson, "Fuzzy ECA Rules for Pervasive Decision-Centric Personalized Mobile Learning", *In Computational Intelligence for Tech-*

nology Enhanced Learning, (Eds) Fatos Xhafa, Santi Caballe, Ajith Abraham, Thanis Dardoumis, Angel Juan. Springer-Verlag, *Studies in Computational Intelligence*, Vol 273, ISBN: 978-3-642-11223-2, http://dx.doi.org/10.1007/978-3-642-11224-9, 2010.

5. P. Moore, "Intelligent Context: the realization of decision support under uncertainty", Eds: Fatos Xhafa, Nik Bessis, To appear in *Studies in Computational Intelligence*, Springer, 2013.