A TRIAD-BASED CONTEXTUALISATION APPROACH FOR UNDERSTANDING A CRITICAL ISSUE

by

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ABSTRAK

Dalam bidang kejuruteraan perisian, terdapat suatu masalah yang telah lama wujud iaitu pihak berkepentingan tidak dapat memahami keperluan perisian dengan betul dan juga menyampaikan penyelesaian yang betul untuk menangani isu-isu kritikal. Masalah ini berlaku kerana konteks yang berkenaan dengan isu-isu kritikal sentiasa diabaikan, diandaikan terlebih dahulu, atau tidak tepat. Oleh itu, objektif penyelidikan ini ialah untuk mencadangkan satu kaedah pembentukan konteks yang berasaskan tiga serangkai bagi membantu pihak berkepentingan untuk memahami suatu isu kritikal. Kaedah pembentukan konteks yang dicadangkan terdiri daripada tiga proses iaitu pencirian konteks, perwakilan konteks, dan pentafsiran konteks. Dalam satu kitaran proses, suatu konteks dicirikan oleh satu set kriteria yang ditentukan oleh pihak berkepentingan. Set kriteria yang telah dipilih akan ditukar kepada satu set tiga serangkai di mana pihak berkepentingan itu perlu menjawab soalan-soalan untuk membentuk perhubungan tiga serangkai bagi perwakilan konteks. Setelah melalui proses intepretasi dan proses penyesuaian mengikut keperluan individu, hasil daripada satu kitaran pemprosesan adalah satu set tiga serangkai dengan hubungan yang konsisten untuk mewakili konteks dalam memahami suatu isu kritikal dan satu set tiga serangkai dengan hubungan yang tidak konsisten untuk pertimbangan konteks pada masa depan. Tidak seperti pendekatan perwakilan konteks sedia ada yang hanya menumpu kepada hasil yang positif, kaedah pembentukan konteks yang dicadangkan merangkumi kedua-dua hasil positif

dan negatif. Peringkat pengesanan ketidakkonsistenan logikal dalam proses soal-jawab dibuktikan sebagai peringkat yang berupaya untuk mewakili pelbagai model mental daripada pihak berkepentingan agar memperoleh suatu konteks yang betul untuk memahami suatu isu kritikal. Di samping itu, penemuan baru dalam penyelidikan ini adalah penghasilan keadaan dalam setiap konteks yang dinyatakan dalam bentuk perhubungan antara kriteria dan bukan kriteria bebas yang digunakan dalam kaedah pembentukan konteks yang lain.

Kata kunci: isu kritikal, konteks, pengesanan ketidakkonsistenan logikal, perhubungan tiga serangkai

A TRIAD-BASED CONTEXTUALISATION APPROACH FOR UNDERSTANDING A CRITICAL ISSUE

ABSTRACT

In software engineering field, there is a long-standing problem whereby the stakeholders were unable to correctly understand the software requirements and deliver the right solutions to resolve critical issues. This problem occurred because the contexts that were associated with the critical issues were often omitted, being presume preliminarily, or inaccurate. In this regard, the objective of this research is to propose a triad-based contextualisation approach that could assist the stakeholder to understand critical issue. The proposed contextualisation approach comprises three processes namely the context characterisation, context representation, and context interpretation. In a contextualisation process cycle, a context is first characterised by a set of stakeholder-driven criteria. The chosen set of criteria is then converted to a set of triads whereby a stakeholder is required to answer questions to form triad-based relationships for context representation. After undergoing the interpretation and personalisation processes, the outcomes of a contextualisation process cycle are a set of consistent triad relationships for representing a context to understand the critical issue and a set of inconsistent triad relationships for future contextualisation process deliberation. Unlike the existing context representation approaches which only focused on the positive outcomes, the proposed triad-based contextualisation approach covered both the positive and negative outcomes. The logical inconsistency detection stage in the question-answering process is proven to be a viable stage to depict various mental models of the stakeholder in order to acquire the right context

for understanding the critical issue. On the other hand, the novelty of this research goes to the established conditions in each context are expressed in terms of relationships among the criteria and not merely the independent criteria as adopted by other existing contextualisation approaches.

Keywords: context, critical issue, logical inconsistency detection, triad relationships

CHAPTER 1 INTRODUCTION

1.1 Research Background

Generally, a critical issue could be referred to a primary issue that is being critically reviewed by a certain party. Basically, different fields have their own definition and interpretation of the critical issues involved. For example, Zakaria et al. (2011) from software engineering field regarded critical issue to the issue that could make software project failed. The critical issues could also be found in many other fields such as business strategic planning (AARM (2014) and Falque (2012)); education development (Pathways (2014) and Dewitt (2014)); transportation development (TRB, 2013); health care development (Sharfstein et al., 2013), community neighbourhood's environmental support (I'DGO, 2008); customer-friendly design for Stonehenge World Heritage Site (Veverka, 2014); and many other fields.

This research looks into contextualisation of a critical and complex issue which refers to a process for searching some situation(s), setting(s), qualifier(s) or context(s) through which the critical problem can become more meaningful to the stakeholders. According to O'Callaghan (2011), it was hard to imagine the eventualities of a critical issue which was completely devoid of a context. On the other hand, Gascoigne (2012) also commented that without a context, one tends to jump to the conclusion prematurely based on the first few words that one heard.

The use of contexts to qualify critical situations were also important in e-Commence, business intelligence, and discourse analysis. For example, Achtenhagen

and Welter (2005) used contexts to reflect the micro and macro environments of the entrepreneurs whereas Woods (2013) utilised context to pose the right questions to assemble the right data faster in analytical environments. In addition, Nagara (2015) who was a senior fellow at the Institute of Strategic and International Studies (ISIS) Malaysia also commented that it was crucial to put the issues in the news in their proper context.

According to Batchelder and Alexander (2012), there may be more than one context for the same issue where the various characteristic of an issue could be used to admit several possible problem representations. A context may be either implicit in the background or explicit in the foreground of a critical issue. On the other hand, a context might be right for an issue *A*, but wrong for another issue *B*.

Based on the findings from the research background study, an approach for contextualisation support is important and should be exploited for assisting the relevant stakeholders to better understand a critical issue prior to any decision making process. In addition, this research also attempted to utilise human mental models to integrate deductive reasoning as proposed in Johnson-Laird and Khemlani (2014) for context derivation. Several social psychology researchers such as Khemlani and Johnson-Laird (2013), Ragni et al. (2013) and Johnson-Laird (2010) had discovered that individuals did not only adjust their beliefs but also formulated an explanation to justify any detected inconsistencies. In this research, the inconsistency detection process was proposed as a means to inspire the stakeholders to self-evaluate their understanding of the vision, missions, and objectives of a critical issue. From a different perspective, in the processes of criteria comparison

and logical inconsistency detection, some unexpected and less-structured elements would be discovered to derive the right context for better understanding the critical issue.

1.2 Research Problem Statement

According to Larrucea et al. (2013) and Cole (2013), human safety was increasingly dependent on software-intensive systems. Based on the findings from RISKworld (2009), different safety-critical software had also been developed to support or resolve critical issues in many fields such as aeronautics, medicine, railway sector, automotive, nuclear, and others. However, the critical issues were always resolved inaccurately because the contexts which played a role for understanding the issues to be resolved by the software system were always assumed to be irrelevant, being omitted, or presumed preliminarily.

The long-standing problem in a typical software development life cycle (SDLC) could be illustrated by using a tree-swing development process as shown in Figure 1.1. It is shown that the customer, the project leader, the engineer and the programmer produced different version of tree-swing in a development lifecycle. In one situation, the engineer might tend to relate the development requirements with no regard to the thinking of the programmers. Eventually, the wrong tree-swing was produced due to the omission of a proper context. Therefore, contextualisation support in SDLC for critical issue solving is important and should not be forbidden.

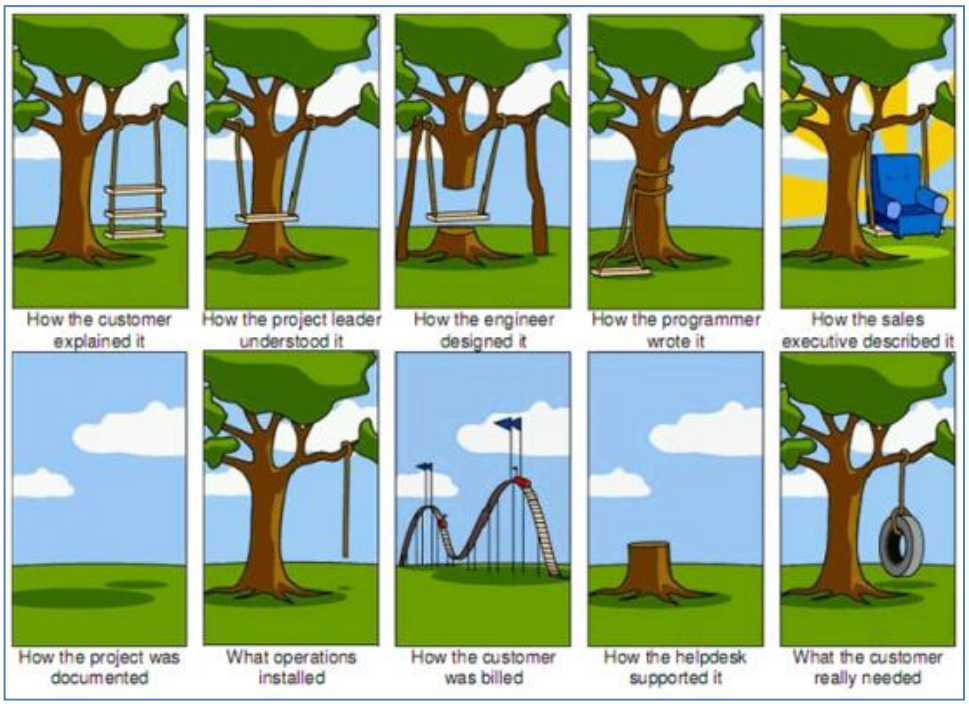


Figure 1.1 A tree-swing development cycle to illustrate SDLC problem (cavdar.net (2011)

Despite many contextualisation approaches had been proposed by various researchers such as Lapouchnian (2011), Gross (2011), Wang (2010), and Winbladh (2010), the existing contextualisation approaches consisted various limitations such as the stakeholder was not allowed to characterise the attributes for the unique context representation, the linear relationship among the attributes in the existing context representation methods was not able to represent more than one human mental model, and there was no personalisation support to enable the stakeholder to derive the right set of context representation output for critical issue deliberation. Therefore, the problem statement of this research goes to there is lacking of a contextualisation approach that is capable of supporting stakeholder to characterise the context attributes, representing the context in non-linear relationships, and allowing the stakeholder to personalise the right context for a critical issue.

From the study of Larrucea et al. (2013) and Ali (2010), it was found that the contexts associated with the software were always assumed to be irrelevant or presumed preliminarily. This situation happened because the software developers expressed or defined the software attributes in their own terms with no regard for the right thinking of the stakeholder. In consequence, the non-stakeholder characterised attributes could not fully represented a context accurately for different stakeholders' needs. Therefore, it is necessary to have a mechanism that allows the stakeholder to personally characterise a set of attributes that will be used to represent the context of critical issue under study.

On the other hand, based on the research conducted by Ciccconi (2010), Dzung and Ohnishi (2009), Dutoit et al. (2006), and Öztürk et al. (2003), the researchers assumed that there was only a structured and fixed context with linear attributes relationship representation in a contextualisation process. In fact, Ivanenko and Mikhalevich (2008) found that different attributes and relationship levels might be elicited and refined from different complex mental models due to different degrees of uncertainty faced by the stakeholders in a decision-making process. Therefore, non-linear attributes relationships should be explored as a new context representation method to enhance the contextualisation support's capability.

From the other perspective, the study from ChangingMinds (2012) discovered that the mental model of a stakeholder could be changed from time to time during a contextualisation process cycle. It could happen that the stakeholder only crystalised his or her mind at the later stage of the contextualisation process to add on or remove certain attributes or the relationships of some attributes for a right

context representation. Unfortunately, the existing contextualisation approaches such as those mentioned earlier could not support context interpretation and personalisation. Therefore, it is also necessary to look into this aspect for more robust contextualisation support.

1.3 Research Questions

This research attempts to resolve two major research challenges. The first challenge is to satisfy the need for providing contextualisation support before a critical issue is processed by any existing decision support systems or expert systems. The second challenge is to derive a means for supporting human reasoning derivation from logical inconsistency detection process. In order to resolve the above mentioned research challenges, there are several research questions to be answered such as:

(i) What is the method used for characterising a context?

(ii) What are the components and techniques used for validating the criteria or attributes of a context?

(iii) How to represent a context?

(iv) How to present a context for ease of visualisation?

(v) How to personalise and interpret a context?

(vi) How to associate a right context with a critical issue?

1.4 Research Objectives

The ultimate objective of this research is to propose a contextualisation approach that could assist the stakeholder to understand a critical issue prior to decision-making deliberations. In order to realise the proposed contextualisation approach, three sub-research objectives have to be fulfilled in this research. The sub-objectives include:

(i) To establish a method for characterising a context

(ii) To represent a context with a set of triad-based relationships

(iii) To personalise and interpret a set of triad-based relationships as the context for a critical issue

In particularly, the sub-objective (i) is corresponded to research question (i) for establishing a stakeholder-driven context characterisation method; The sub-objective (ii) is corresponded to research question (ii) to (iv) for proposing a new triad-based context representation method which is able to support non-linear attributes relationships; The sub-objective (iii) is corresponded to research question (v) and (vi) for deriving the context interpretation and personalisation phases within contextualisation process, with reference to the research questions from Section 1.3.

1.5 Research Scope

The purpose of this research is to propose an approach which could help the stakeholders to identify, characterise, represent, personalise and interpret the context(s) to understand a critical issue. At any stage of the research process, the

research scope is confined to only one critical and complex issue. In a processing cycle, the focus is only on one set of criteria, one set of triads and one context. The entire processing only involves one individual at a time.

1.6 Significance of Research

The significance of this research goes to the capability of the proposed contextualisation approach to assist a stakeholder to understand a critical issue through the representation of a context in a set of triad relationships. The logical inconsistency detection stage in the criteria comparison question-answering process is claimed as a viable stage to segregate different human mental models as the contexts of a critical issue. In an individual level, this research helped the stakeholder to recall what he/she already knew as well as what he/she did not previously know about a critical issue through the exploration and interpretation of criteria comparison and triad relationships.

1.7 Thesis Organisation

This thesis presents the proposed triad-based contextualisation approach in six chapters. In **Chapter 1**, the research background of the proposed contextualisation approach is given. With reference to the identified research problem statement, the research objectives, research questions, and scope of research are also stated. The significance of research is also included in this chapter.

In **Chapter 2**, the three important aspects of contextualisation namely the context characterisation, representation, and interpretation are studied. The strengths and weaknesses of the existing contextualisation methods were critically reviewed to identify the research gaps for proposing a new triad-based contextualisation approach in this research.

In **Chapter 3**, the preliminary study of the research is discussed before the research procedures and the research framework are derived. This chapter also discussed the justifications of the new contextualisation research, the research design, and the limitation of research.

In **Chapter 4**, the proposed triad-based contextualisation approach is presented in detail. Firstly, the roadmap of the proposed contextualisation approach is presented. Subsequently, the three major processes in terms of context characterisation, context representation, and context interpretation are elaborated in the sub-sections with the relevant algorithms, rules, procedures, formulae, figures, and tables. The expected research outcomes of the proposed approach are also been discussed. In addition, there is also a justification section to explain various concerns in the derivation of the contextualisation approach.

In **Chapter 5**, quantitative and qualitative evaluations have been conducted to evaluate different aspects of the proposed triad-based contextualisation approach. Among the evaluation methods are simulation test, experiments, case study, and comparative analysis.

In **Chapter 6**, the research objectives and the contributions of the research have been revisited. The novelty and originality of the research have also been identified. Finally, the possible future works for this study are suggested for any interested research parties.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter contains the findings of the literature review areas that are relevant to this research. Firstly, the overview of context is described in Section 2.2. Since this research focuses on contextualisation support, the three important aspects of contextualisation such as context characterisation, context representation, and context interpretation are critically reviewed and discussed from Section 2.3 to Section 2.5. In addition, the background study of triad-based contextualisation approach is presented in sub-section 2.4.3. The findings of this chapter path the way for the derivation of a triad-based contextualisation approach.

2.2 Critical Issues

With reference to businessdictionary.com (2014), a critical issue could be referred to the primary issue that is considered extremely important by the relevant party which may determine its survival and/or success. Basically, different fields have their own definition and interpretation of the critical issues involved. For example, in software engineering field, Zakaria et al. (2011) regarded critical issue to the issue that could make software project failed. As in the I'DGO (2008) research for community neighbourhood's environmental support, the critical issue was identified as the key factor that was needed to be addressed from their research findings, which was related both to environment and to personal circumstances that affect that utilisation of the neighbourhood environment, in order to facilitate people's outdoor activities and neighbourhood experience. Veverka (2014)

commented that for the entity like Stonehenge World Heritage Site, the critical issue was defined as the topic related to the safety of the visitors that deal with resource problems and their need for solutions at the resource site, as well as the resource protection and management issue that the public needs to be alerted.

There are also different methods to identify and interpret the critical issues as proposed by different researchers such as the identification matrix for modelling critical issue by Hamilton (2013), the ten-step procedures to organise the critical issues found in school improvement area by Pathways (2014), rule of thumbs, and as well as the SWOT analysis.

According to Veverka (2014), there were two types of critical issues to be resolved by the relevant party. The first type of critical issues referred to the new problems that arise from the evolving and changing environment. The second type of critical issues referred to the old or recurrent problems that other previous strategies failed to manage and resolve. Different strategies had to be adopted to handle the two different types of critical issues. For the new critical issues, the relevant party had to investigate about the root causes of the problems in such that what have happened and changed in the surroundings and environment that made the problems or issues to become critical at present. As for the old or recurrent type of critical issues, the relevant party had to investigate on why the previous applied strategies or methods failed to resolve the issues entirely before making new plans to handle the critical issues.

Critical issues could be found in almost every field and industry. According to Zakaria et al. (2011) and Hussain et al. (2007), one of the critical issues/problems that could lead to software project failure was the ill-managed software project requirements. The other critical issues for poor software project requirement engineering (RE) outcomes also included continuous changes in scope, incomplete and ambiguous requirements, poor software project management, unrealistic expectations, and wrong software development process model's adoption. As for business critical issues, it could be found in AARM International Report (2014) and the BearingPoint Institute Report which was written by Falque (2012). In education field, the critical issues were identified and compiled in Pathways (2014) and DeWitt (2014). The critical issues for sustainable development were researched and presented in RIO+20, the United Nations Conference on Sustainable Development and reported in UNCSD (2012). Meanwhile, the critical issues for transportation development and U.S. health care were reported in TRB (2013) and Sharfstein et al. (2013) separately.

From the critical issue review study, it could be concluded that it is necessary to have contextualisation support for understanding and deliberating critical issues and problems. According to Gascoigne (2012), without a context, one tended to jump to the conclusion prematurely based on the first few words that one heard. On the other hand, there might be more than one context that could represent a critical issue. Moreover, the critical issue may be resolved in the wrong way/context to fulfil the wrong needs of the stakeholders if each stakeholder preserved different contexts at the same time to resolve a critical issue.

In addition, according to Woods (2013) and Achtenhagen and Welter (2005), the use of contexts to qualify critical situations was also important in e-Commence, business intelligence, and discourse analysis whereby contexts were used to reflect the micro and macro environments of the entrepreneurs and to pose the right questions to assemble the right data faster in analytical environments. In short, it is strongly believed that contextualisation support could make critical issue management more effective.

2.3 An Overview of Contexts

According to Dey (2001), a context can be defined as "*any information that can be used to characterise the situation of an entity*" whereby an entity can be referred to a person, a place, or an object that is considered relevant to an interaction between a user and an application which includes the users and the applications themselves. A broader definition of a context given by O'Callaghan (2011) covered all aspects regardless of it being conscious, subconscious, observable, non-observable, central, or even ancillary. According to Rudy (2009), a context was composed by "*a set of concurrent independent component features that potentially can be sampled by an individual*". Among the properties of the features that were used to define a particular context include 1) the features must be stable whereby the relationships among different features must be existed, and 2) the features should be subjected to "component variation" whereby the components could be removed or readjusted in the existed relationships.

Basically, there were two categories of researchers who defined context differently. The first category (category 1) of researchers defined context with specific entities such as location or object whereas the second category (category 2) of researchers defined context from more conceptual viewpoint and focussed on the relationships and structures of the contextual information. Different definitions of context are listed in Table 2.1.

Table 2.1 Different definitions of context

Researchers	Definition	Category
Schilit B. N. and M (1994)	- the first researcher to use the term "context-aware" - focussed on location as the primary part of context - also included a notion of the identity of nearby people and objects	1
Brown P. J. et al. (1997)	- defined context as location - also retrieved the identity of nearby people and the time of day	1
Ryan N. et al. (1998)	- viewed context as location, environment, identity, and time	1
Schmidt A. et al. (1999)	- defined context as "*knowledge about the user's and IT device's state*"	2
Dey (2000; 2001)	- most widely cited definition - defined context as "*any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.*"	1 and 2
Mikalsen and Kofod-Petersen (2004)	- defined context as "*the set of suitable environmental states and settings concerning a user, which are relevant for a situation sensitive application in the process of adapting the services and information offered to the user.*"	2

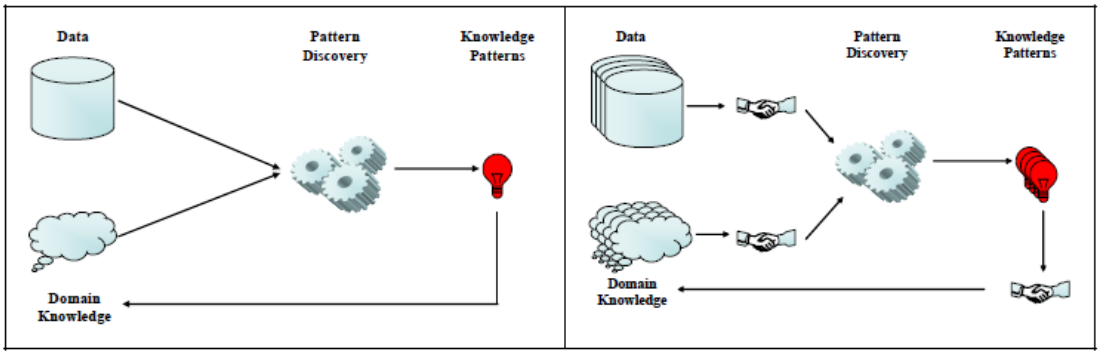
In the discourse of defining context, despite Morse et al. (2000) had looked into answering the "*who, when, where, what and how*" questions that addressed potential challenges in the context-awareness aspect, the researchers Perttunen et al.

(2009) and Mikalsen and Kofod-Petersen (2004) also commented that the conceptual description of context was still not properly defined. Mikalsen and Kofod-Petersen (2004) highlighted that context was often defined *ad hoc* from project to project. On the other hand, Perttunen et al. (2009) also stated that the realisation of context-awareness fell into difficulty due to poor context definition which was caused by two identified problems as follow: The first problem was the difficulty to select and adopt a proper approach for context definition in terms of abstract concept or technically represented context information. The second problem was about the identification of the sources of the context's definition and adaptation rules as well as the dilemma to choose and adapt a proper approach to redefine the context upon context changes.

According to the findings from Brézillon and Pomerol (1997), the lacking of explicit context representation in Artificial Intelligence was one of the reasons that many Knowledge-Based Systems failed. In a survey which was conducted by Brézillon (1999) to point out the existence of different types of context along knowledge representation and the mechanisms of reasoning on the knowledge, it was mentioned that the modelling, representation and the use of context appeared to be challenging for the following years in 2000s when people faced with very complex problems, large knowledge bases and multimedia.

The contextualisation research continued to develop after the year 2000. In Büchner (2004) which explored context mediation that was concerned with information interchange across different environment (hereby refers to the different human mental models and thinking contexts), context mediation was said to be a

better approach for knowledge pattern discovery in comparison with traditional knowledge discovery processes as illustrated in Figure 2.1.



(a) traditional (b) context-mediated

Figure 2.1 The comparison of traditional and context-mediated knowledge discovery process (Source: Büchner (2004))

Follows on, Rosemann, Recker and Flender (2008) found that context provided the drivers for flexibility in a business process. Rudy (2009) also commented that contextualisation research has becoming more popular especially in the field of neuroscience whereby neurobiologists and psychologists were interested in contextualising brain systems. Wurm et al. (2012) also discovered that in recent years, context played an important role in requirements acquisition and consideration, the derivation of alternatives in software analyses and designs, and the assessment of the quality of each alternative/criterion. According to Eckerson (2014), without context, we may get different responses or answers to the same question because the respondents defined the terms differently under different context.

In short, it is necessary to have contextual support for deliberating problems and issues correctly. The importance of context was recognised by Rudy (2009) whereby context played a special role in recalling of episodes. Besides playing a

major role in various fundamental faculties such as philosophy, psychology, cognitive science, artificial intelligence, linguistics, and others, the theory of context was also introduced to support object refinement process in rational decision making.

2.4 Context Characterisation

Many attributes could be used to characterise a context such as people, place, time, requirements, criteria, and factors. Table 2.2 shows different types of contextual attributes used in various criteria/requirements refinement and refactoring methods such as design factors, software requirements, and safety requirements.

Table 2.2 Review of context characterisation attributes in different approaches

Method / tool	**Types of context characterisation attributes**	**Refinement and refactoring methods**
Contextual-supported ontology for design factor derivation (Zisko, 2008)	Tall building design factors	• Building Information Modelling (BIM) • Knowledge-based model
A method to early detect and identify the defects of requirements (Onabajo, 2009)	Software confidentiality requirements	Annotations of the natural language sources
Interactive model-based approach with a specification technique (Winbladh, 2010)	Software requirements	• A semi-formal language - Preusa to express narrative requirements • Integrated Model-based Use-case and Storytelling Environment – iMuse
Intentional Architecture Language (IAL) (Gross, 2011)	Software architecture elements like intents, concept, decisions	• Intentional and organisational modelling • Analysis concepts
Construction safety documents management framework (Wang, 2010)	Construction safety requirements	1. Reasoning-supported computer interpretable model 2. Context-supported semantically-rich model 3. A reasoning mechanism to integrate the findings from (1) and (2)

Table 2.2 Continued.

Method / tool	Types of context characterisation attributes	Refinement and refactoring methods
Requirements-driven approach for adaptive and customisable software systems' development (Lapouchnian, 2011)	Software requirements	• Requirements goal models • Contextual based model

Besides the contextualisation approach as proposed by Winbladh (2010) supported user interaction to derive a right set of software requirements, all other contextualisation approaches as shown in Table 2.2 were not personalisable for characterising a context. The characterised attributes were mostly derived by the relevant experts only. In addition, the attributes were not adjustable in the past contextualisation approaches. Therefore, more flexible context characterisation methods should be researched into.

2.5 Context Representation

Context representation refers to the method used to qualify or quantify requirements, attributes or metrics in different decision units for describing a context. Perttunen et al. (2009) commented that contextual study in terms of contextual requirements representation has become essential in software system developments with the emerging of computing paradigms such as ambient, pervasive, and as well as ubiquitous computing. Ali (2010) and Wurm et al. (2012) also claimed that there was a strong relationship between context and requirements whereby context played an important role in requirements determination and consideration, the derivations of

the alternatives that the system can adopt for the software systems, as well as the assessment of the quality of each alternative.

Over the years, contextualisation support had been adopted in various application domains such as artificial intelligence (AI) related domain, databases and ontology, communication, and vision. According to Brézillon (1999), the main role of context in databases and ontology research was to provide humans with a much greater control over knowledge stored in databases and ontology whereby contexts served as adjustable filters to provide the right meaning in the current situation/scenario. This was especially important for the building and the usage of large and reliable knowledge systems. The examples of contextual support database applications are Context-SQL (C-SQL) by Sciore et al. (1992), PROTEGE-II system - with a context-definition language call MODEL by Walther et al. (1992), as well as the Oracle7 ConText Option by Oracle (1996).

Context was also an important factor in different applications in the vision area such as character recognition by Toussaint (1978), target recognition by Forman et al. (1984), and image recognition by Mohr and Masini (1979). Desvignes et al. (1989) identified that the roles of the context in vision systems included guiding the research, solving ambiguities, filling gaps, correcting errors, and learning. Context was also considered for change detection in Burlina et al. (1995), mapping of image events sequences to performed actions in Kjeldsen and Kender (1995) and frames tracking in Bobick and Pinhanez (1995) and Intille and Bobick (1995).

2.5.1 Contextual Representation's Requirements and Formalism

In Perttunen et al. (2009), the researchers compiled and proposed a list of requirements for context representation modelling as shown in Table 2.3a. On the other hand, the researchers Serafini and Homola (2011) commented that well-designed contextual representation formalism should support the requirements as shown in Table 2.3b.

Table 2.3 Requirements for context representation modelling

(a) Requirements proposed by Perttunen et al. (2009)

Requirement	**Purpose**
Unique identifiers	To uniquely identify different contexts and enable the reuse of the representations without conflicts
Validation	To ensure that the data in context is at least consistent with its schema before performing any processing with it
Expressiveness	To allow the representation of complex entities and relations
Uncertainty and incomplete information	To enable the inclusion of contextual data collected and measured from the real world through imprecise sensors
Simplicity, reuse, and expandability	To promote reuse and expandability
Generality	To enable the encoding of context information at different levels of complexity

(b) Requirements proposed by Serafini and Homola (2011)

Requirement	**Purpose**
Explicitly represent and reason the knowledge about context	To be able to explicitly represent and reason the knowledge about contexts such as contextual dimensions and relations between contexts
Include local contextually bounded facts	To be able to state facts with local effect that does not necessarily propagate everywhere
Reuse/Lifting of facts	To be able to include all the information contained in more specific contexts "automatically"

Table 2.3(b) Continued.

Requirement	**Purpose**
Overlapping and varying domains	To support objects so that they can be present in multiple contexts, but not necessarily in all contexts
Inconsistency tolerance	To tolerate or accommodate the possibility that two contexts may contain contradicting facts
Complexity invariance	To ensure that the qualification of knowledge by context would not increase the complexity of knowledge interpretation outcomes

On the other hand, the context could also be represented differently in two different viewpoints such as the cognitive science's practical viewpoint and engineering theoretical viewpoint. In the cognitive science view, the context was used to model the interactions and situations in infinite world whereby the human behaviour is the key for model extraction. As for the engineering view, the context was used to represent and reason about a restricted state space in resolving a problem.

2.5.2 Current Context Representation Methods

Basically, a context was built up with sets of concepts (also refer to schemas, frames, or structures) that described the basic terms used to encode knowledge in the ontology and a set of constraints that restricted the manner in which instances of these concepts may be created and combined. In year 2008, Gronau et al. (2008) proposed an integrated contextual representation whereby a bound representation could be formed by the identity-related ("semantic") and location-related ("spatial") contextual knowledge. Eventually, context simplified the knowledge base construction by imposing requirements on the representation language.

Contexts could also be represented through logic-based and rule-based models for knowledge engineering process. For logic-based representation of context, the contexts were formalised as first class objects (formal objects) and the basic relation was *ist(c,p)*. It asserted that the proposition *p* is true in the context *c*, where *c* is meant to capture all that is not explicit in *p* that is required to make *p* a meaningful statement representing what it is intended to state. The example of a logic-based context representation application is a Lisp-based software architecture called ATMB for an intelligent design support which was proposed by Tang (1995). As for rule-based representation of context, the contexts may be expressed on the basis of either the knowledge structures (if explicitly represented) or the functionalities of the chosen representation formalism. For a representation at the rule level, the well-known example of screening clause is the rule in MYCIN (Clancey (1983) and Clancey (1993)).

According to Perttunen et al. (2009), context representation and reasoning was at the middle layer of a three-layer context information processing as shown in Figure 2.2. The other two layers included activity and context recognition at the bottom layer, and application and adaptation rules in the top layer. The existing context representation methods and techniques included conceptual models, logic programming, databases and queries, procedural programming, as well as representation and reasoning methods which were ontology-based, rule-based and case-based.

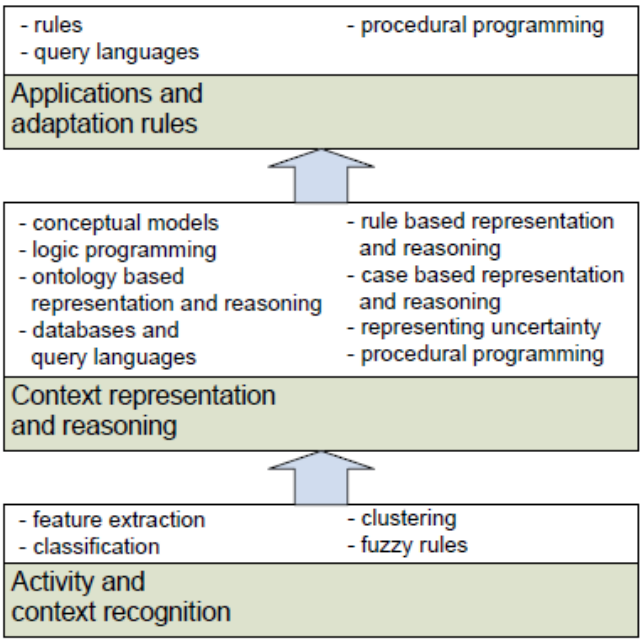


Figure 2.2 Three layers of context information processing

(Source: Perttunen et al. (2009))

Among the various context representation methods and approaches, Gómez-Romero et al. (2011) commented that formal ontology was a remarkable context representation method in the last decade. According to the definition of ontology from Gruber (2009), ontology referred to "*an explicit and formal specification of a conceptualisation*". The ontological modelling was originated from the philosophy domain and was widely adopted in research efforts in the artificial intelligence and computer science domain in the recent two decades. Zisko (2008) described that ontologies were generally constructed as conceptual taxonomic trees with general and domain-independent at the top levels to increasingly domain-specific further down the hierarchy. Besides, Gómez-Romero et al. (2011) also commented that ontology was still a popular contextual representation due to its advantages of strong underpinnings in descriptive logics and the capability to promote knowledge exchange and reusability within the characterised attributes. An example of