POLICY-BASED MANAGERS COORDINATION FOR SELF-ADAPTIVE SOFTWARE APPROACH

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To

My Parents

My Wife, Hana

My Mother-in-Law

My Sons, Ghassan and Safwan

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ABSTRACT

Due to the complexity and rapidly changing environment, it is crucial for a software system to be adaptable. One of the key approaches to achieve adaptability is policy-based management. Policy-based management has been acknowledged mostly as a methodology that provides flexibility, scalability, adaptability, and support to assign system resources, control, quality of service, and security by considering administratively specified rules. The promotion of policy-based management was to commit to these features at runtime because of changeable concurrent system conditions ensuing from the interactions of users' applications and existing resources. This thesis proposes an adaptive policy-based management approach called Policy-based Manager Coordination (PobMC) based on Event-Condition-Action (ECA). The aim of PobMC approach is to deal with the critical nature of avoiding the policy conflict problem. This approach facilitates policy conflict avoidance and static analysis to address the inconsistencies of multiple manager and modality conflicts when two or more policies are enforced simultaneously. The PobMC will also coordinate managerial tasks when multiple rules are simultaneously triggered. The mobility of devices and applications in complex system complicates policy design. Rules must be added or revoked when the composition of a system changes. Static and dynamic analysis algorithms are proposed; moreover, the need for these algorithms on various complex systems and their performance evaluation is demonstrated. In this thesis, a modelling of PobMC based on an ECA framework is presented. The proposed modelling is to address the main concerns inherent in concurrent systems including coordination and scalability. An actor-based language called Rebecca has been incorporated to model and analyze PobMC. Experiments using a Smart Mall System (SMALLS) case study show that the PobMC approach leads to effective policy-based management and is a feasible approach. Additionally, PobMC has the ability to enhance the existing approaches to support software adaptation. PobMC enables the coordination among system managers in order to adapt to system changes and avoid the potential conflicts thereby providing the main contribution of this research.

ABSTRAK

Kekompleksan dan perubahan persekitaran yang pantas telah menuntut supaya sistem perisian menjadi lebih mudah disesuaikan. Pengurusan berasaskan polisi merupakan salah satu pendekatan utama untuk mencapai kebolehsuaian. Pendekatan ini telah dikenali sebagai metodologi yang menyediakan ciri-ciri kebolehlenturan, kebolehskalaan, kebolehsuaian dan menyokong pengagihan sumber sistem, kawalan, kualiti perkhidmatan dan keselamatan dengan mempertimbangkan peraturan yang telah ditetapkan. Pengenalan pengurusan berasaskan polisi dikatakan mampu menyediakan ciri-ciri ini semasa pelaksanaan oleh sebab keadaan sistem yang boleh diubah kesan interaksi antara pelbagai aplikasi dan sumber sistem. Tesis ini mencadangkan pendekatan pengurusan berasaskan polisi mudah suai yang dikenali sebagai Penyelarasan Pengurus berasaskan Polisi (PobMC) berdasarkan Peristiwa-Keadaan-Tindakan (ECA). Matlamat pendekatan PobMC adalah untuk menyelesaikan masalah kritikal dalam mengelakkan masalah konflik polisi. Pendekatan ini membantu penghindaran konflik polisi dan membuat penganalisisan statik untuk menyelesaikan ketidakseragaman antara kepelbagaian pengurus dan konflik modaliti apabila dua atau lebih polisi dikuatkuasakan serentak. PobMC juga menyelaras tugas pengurusan apabila beberapa peraturan dicetuskan. Mobiliti peranti dan aplikasi dalam sistem yang kompleks menjadikan reka bentuk polisi lebih sukar. Peraturan perlu ditambah atau dibatalkan apabila komposisi sistem berubah. Algoritma untuk analisis statik dan dinamik telah dicadangkan. Sementara itu keperluan kepada algoritma oleh pelbagai sistem yang kompleks dan penilaian prestasi algorithma tersebut telah dibuat. Dalam tesis ini permodelan PobMC berasaskan pendekatan ECA diperjelaskan. Permodelan yang dicadangkan akan menyelesaikan masalah utama dalam sistem serentak termasuklah penyelarasan dan kebolehskalaan. Bahasa berasaskan aktor, iaitu Rebecca, telah digabungkan untuk memodelkan dan menganalisis PobMC. Uji kaji menggunakan kajian kes Sistem Pusat Membeli Belah Pintar (SMALLS) menunjukkan bahawa pendekatan PobMC merupakan pengurusan berasaskan polisi yang efektif dan pendekatan yang boleh dilaksanakan. PobMC juga mempunyai kelebihan untuk menambah baik pendekatan sedia ada bagi menyokong penyesuaian perisian. PobMC membolehkan penyelarasan antara pengurus-pengurus sistem bagi menyesuaikan perubahan sistem dan mengelakkan konflik.

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LIST OF ABBREVIATIONS

ADL	-	Architecture Definition Language
AP	-	Access Point
ECA	-	Event Condition Action
GPS	-	Global Positioning System
ISP	-	Internet Service Provider
IETF	-	Internet Engineering Task Force
KaOS	-	Policy and Domain Services
KB	-	A knowledge base
LOS	-	Line-Of-Sight
LTL	-	Linear Temporal Logic
MOP	-	Meta-Object Protocol
Mngr	-	Manager
NLOS	-	Non Line-Of-Sight
PDL	-	Policy Description Language
PDP	-	Policy Decision Point
PEPs	-	Policy Enforcement Points
PS	-	Policy Server
P3P	-	The Platform for Privacy Preferences Project
QoS	-	Quality of Service

RSSI	-	Receive Signal Strength Indicator
Rebeca	-	REactive objECts lAnguage
SHOUSE	-	Smart House
SMALLS	-	Smart MALL System
TCP	-	Transmission Control Protocol
UTMC	-	Universiti Teknologi Malaysia Campus
XACML	-	eXtensible Access Control Markup Language
xADL	-	eXtensible Architecture Description Language
WSPL	-	Web Services Policy Language
2D	-	Two Dimensions
3D	-	Three Dimensions

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CHAPTER 1

INTRODUCTION

This chapter introduces the current research with the background of the problem described first. After that, the problem statement, objective, scope, and importance of the study are described respectively.

1.1 Background of the Problem

The complexity of current software systems has led engineers to find innovative approaches for building, running, and managing software systems and services. In adaptive software, available information about environmental changes is used to simplify system complexity and improve behavior. Self-adaptation systems that are able to adjust runtime behavior have become a hot topic within the software engineering community. Although self-adaptation has been studied in a wide range of disciplines, only recently did the research community recognize its key role in enabling the development of future software systems that are able to self-adapt to changes that may occur in the system, its requirements, or the environment in which it is deployed (Cheng and Giese, 2009). However, the appropriate realization of the self-adaptation functionality remains a significant intellectual challenge and only recently have the first attempts in building self-adaptive systems emerged within specific application domains (Cheng *et al.*, 2009). Policy-based management knowledge-based are some of the approaches recognized as an enabler of such a view.

In a large system, policies are often used as a means of management in a hierarchical fashion. A high-level policy guides a manager who may achieve goals by making lower-level policies that apply to other administrators lower in the hierarchy. However, the main challenge limits the development of such systems is the policy conflict. Conflicts may arise in the set of policies and during the refinement process between the high-level goals and the implementable policies (Lupu *et al*., 2007). The system must be able to handle conflicts including exceptions to normal authorization policies. For instance, in a large system there will be multiple human administrators specifying policies stored on distributed policy servers.

Policy conflicts can arise when multiple policies control the system behavior. A conflict occurs when an event triggers multiple actions that cannot occur together as specified by the system administrator. Human error is one obstacle to accurate access-control policies because the authors who assign and maintain these policies are prone to making specification errors that lead to incorrect policies. Access-control policies consist of a set of rules that dictate the conditions under which users will be allowed access to resources. These rules may conflict with each other. For example, an obligation policy may define an action that must be performed but there is no authorization policy to permit the manager to perform this activity. Conflict detection between management policies can be performed statically for a set of policies in a server as part of the policy specification process or at runtime (Michael *et al*., 1993; Sibley *et al.*, 1993).

Obviously, there is a limitation in developing approaches that do not provide support for detecting and resolving conflicts. While a considerable attempt at static conflict detection has been presented (Lupu and Sloman, 1999), the very complex and crucial issue of dynamic conflict detection in a policy-based management has gone largely unresolved. Moreover, current research revealed that there is still a large class of policy conflict that cannot be determined statically. Static conflicts are used to detect specification errors and to reduce runtime conflicts that occur among rules whose event and condition parts can be statically matched. It may not be able to evaluate policy constraints because conflicts may depend on the runtime state of the system (Shiva *et al.*, 2005).

1.2 Statement of the Problem

While policies have been successfully applied to manage various simple systems, the complexity and dynamism of active spaces pose several novel challenges. Though this thesis addresses these challenges in the context of self-adaptive software, the challenges and approach presented are applicable in the wider context of complex systems. This section presents the policy-related problems caused by the dynamism of systems.

In all systems, both subjects and target objects are represented as sets of objects called domains (Sloman and Twidle, 1994). The overlap relationship between domains is crucial to the discussion of policy conflicts as it is the contention of this work. There are several possibilities for overlap among policies corresponding to various combinations of overlap between objects in the subject and target object sets that are discussed in certain references (Lupu and Sloman, 1997; Lupu and Sloman, 1999). Overlap of some kind is of course the prerequisite for many kinds of relationships between policies that do not involve conflict.

According to the definition of conflicts (Dunlop *et al.*, 2002; Charalambides *et al.*, 2009; Davy *et al.*, 2009), and the above-mentioned cases, to avoid the potential conflicts some information is necessary to define each type of conflicts (Khakpour *et al.*, 2010). This section will introduce classification of various expected conflicts among system policies.

First, conflicts are expected when there is a triple overlap between the set of subjects' targets and actions of two or more policies with modality of opposite signs to the same subjects' actions and targets (Flegkas *et al.*, 2009). For instance, “the subjects are authorized and forbidden to perform the action on the target objects.” Another example includes “the subjects are forbidden but required to perform the actions on the object.”

Secondly, contradiction occurs due to omission errors or conflicting requirements of the manager that enforces the policies (Lupu and Sloman, 1997; Lee,

2010). For instance, “an obligation policy defines an activity that must be performed but there is no authorization policy to perform the activity.” As an example, “the same subject cannot authorize the user and offer the resource.”

Thirdly, overlapping of domains (Sloman and Twidle, 1994; Simmons *et al.*, 2006) relates to sharing of resources such as a gateway between two networks or a service between two or more applications. Overlapping leads to conflicts between policies when managers can be responsible for an object or that multiple policies apply to the object (Lupu and Sloman, 1999; Thebaut *et al.*, 1999). In some situations, overlap is prevented by creating a new domain with an independent manager and all objects from the overlapping set are moved into this domain.

This work aims to provide an approach for building an adaptive-software system to support behavioral changes adaptation. Furthermore, this approach concentrates on the coordination between the system managers by developing a medium layer that includes some information about managers. The problem statement brings about the main research problem that is:

“How to enable the coordination between system managers to avoid the potential policy conflicts using appropriate technique in behavioral adaptation approach?”

To answer this question there is a set of related questions. Each constitutes a part or aspect of the main question that must be answered in order to find all the aspects of the proposed approach. These questions include:

(i) What are the important approaches to develop a self-adaptive system?
(ii) What are the main adaptive features to enable the proposed approach to be adapted to behavioral changes?
(iii) What does the management mean and include and what are the managed events in the proposed approach?
(iv) How could managers govern and manage policies to direct the system behavior?

(v) What are the requirements to make the proposed approach easy to use and development?

(vi) How to verify correctness of adaptation approaches in the context of a message communication application?

1.3 Objectives of the Study

The research objectives are mentioned based on the problem statement as follows:

(i) To develop and specify an adaptive architectural approach that may avoid the potential policy conflicts.

(ii) To specify the algorithm that supports the proposed architectural approach.

(iii) To evaluate the applicability of the proposed approach through application of the approach using a case study and conducting a synthetic environment experiment.

1.4 Scope of the Study

The study is divided into three research directions by researches in adaptation policy-based management and coordination. The above directions have been considered as the scope of the research.

Firstly, the term adaptation in the software context refers to changes that happen during its lifetime involving “planned activities” and “unplanned phenomena”(Reiss, 2005). The systems are considered high assurance since errors during execution could result in high cost if adaptation is not carefully planned. Furthermore, systems must continue to evolve to correct defects, additions, or removals of functional behaviors and adaptation to the operating environment. Ideally, adaptation should occur without the need to interrupt system operations.

Secondly, current approaches have been acknowledged most often as a methodology that provides adaptability. Therefore, this coordination approach (Wang *et al.*, 2005) makes easy adaptation of new rules and system resource changes, thus enabling dynamic system management according to the alteration of system rules. Additionally, user experiences and expertise, as well as other heuristics can be encoded into policies to help or guide resource management. Furthermore, it is one of the key approaches that is recognized as an enabler or connector of self-management properties for telecommunications networks (Loyola, 2007). Employing policies as a paradigm to modify self-adaptive systems was given considerable attention recently.

Thirdly, coordination is the harmonious adjustment or interaction of different things to achieve a goal or effect (Canal *et al.*, 2005). Coordination languages and models are being developed to address the problem of managing the interactions among concurrent and distributed processes (De Vries *et al.*, 2009). The underlying principle is the separation of computations by components and their interactions (Colman and Han, 2005; Gesbert *et al.*, 2007). To achieve correct coordination (Zhu, 2008) , rather than only considering dependency relations between multiple adaptations, this approach further focuses on dependency relations between managers at runtime. This work considers a number of features including specification to identify and measure achievement of managerial goals to insure that the modelling provides mechanisms for structuring or modularising coordination activities and to verify that coordinated managers do not have any explicit action that may affect the coordination (Nogueira *et al.*, 2012; Wang *et al.*, 2012).

1.5 Significance of the Study

Currently, software systems increasingly rely on dynamically adaptive programs to respond to changes in their physical environment. Examples include ecosystem monitoring and disaster relief systems. These systems are considered high assurance because errors during execution could result in injury, loss of life, environmental impact, and financial loss. Furthermore, systems must continue to

evolve to correct defects, addition, or removal of functional behaviors, and adaptation to the operating environment. Ideally, the evolution should occur without the need to interrupt system operation(Wang *et al.*, 2006). However, evolution occurs with high cost if it is not carefully planned.

Static and dynamic conflicts were considered as two distinct classes that need to be understood and independently managed (Dunlop *et al.*, 2002). The distinction between these two classes is important because detecting and resolving conflict can be computationally intensive, time consuming, costly, and is most preferably done at compile-time. However, dynamic conflict is quite unpredictable because it may or may not proceed to a state of realized conflict. This class of conflict must be detected at runtime.

The considerable attempt at static conflict detection, the very complex and crucial issue of dynamic conflict detection in a policy-based management, has gone largely unresolved. Moreover, current research has revealed a large class of policy conflict that cannot be determined statically.

Existing works in developing adaptive systems have several challenges that must be addressed appropriately. The most fundamental challenge is to verify whether the system is operating as required (Khakpour *et al.*, 2010). Furthermore, existing policy-based systems do not provide any techniques to uncover such conflicts. The initiated rules are assumed to execute without any failures because there are no mechanisms to monitor and verify rule enforcement. According to the knowledge of these authors, existing systems do not reason about concurrent rule enforcement, define enforcement ordering, or investigate the effects of different policies.

Consequently, providing a guideline to avoid policy conflicts between different domain configurations and resolve the conflicts during implementation time is very important in order to simplify software evolution tasks and minimize evolution efforts.

1.6 Structure of the Thesis

This Thesis is composed by eight Chapters and four Appendixes. Chapter 1 introduces the Thesis providing a general outline of policy-based management and the policy conflict problem. We also state the motivations of the Thesis and its main contributions to the state of the art.

Chapter 2: presents some background material that constitutes the foundations of the Thesis. Concretely, we present some crucial material on policy, self adaptive software. Moreover, we present a comparative evaluation on the approaches to develop self adaptive system. In this chapter, we provide a systematic litriture review on self adaptive approaches. Finally, we conclude the weaknesses of the previous approaches.

Chapter 3: Provides the research methodology that describes research design and formulation of research problems and validation considerations. This chapter describes research design and procedure that is utilized in this research work. It also describes the case studies that are applied to evaluate PobMC as well as describes the evaluation process that is conducted in this research. Moreover, it explains some research assumptions and limitations.

Chapter 4: This Chapter provides analysis of the case study. Some examples are provided in the analysis to illustrate the development of the proposed approach. Some policy examples are provided clarifying the management of the system. The adaptability of the case studies is using the criteria in chapter 2 is discussed in this chapter.

Chapter 5: In this chapter the system architecture of the proposed approach is presented in details, the evaluation of the algorithm is discussed. Furthermore, the modelling of PobMC is provided using the actor based language Rebeca. This chapter also specifies the adaptation behaviour of PobMC approach.

Chapter 6: This chapter presents static analyses to address the inconsistencies; multiple managers' conflicts and modality conflict, when there are two or more policies are enforced simultaneously. Moreover, the chapter presents a classification of policy conflicts, and then provides temporal patterns to avoid each class of policy conflicts, and to ensure that policies are enforced correctly.

Chapter 7: This chapter describes the evaluation results of PobMC as well as its relevant discussions. It contains the results of the case study and the experiment. Then, each result is furnished with sufficient discussions about the specific condition found in each case. Finally, results of the investigative evaluation are described.

The Summary Conclusions of the thesis are provided in Chapter 8. We review the contributions of the Thesis, provide additional discussion of relevant issues of the Thesis and provide some directions for future work.

Appendix A references the author's publications related to this Thesis. Appendix B includes the modelling of case studies using Rebeca language. Appendix C presents the actor based language Rebeca. Finally, Appendix D includes the list of policies that used in the implementation of the proposed approach in this thesis.

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