A Survey on Autonomic Computing Research

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Abstract

Autonomic computing is a new technology to solve crisis of software complexity which means to hide the complexity of system management from human users by means of technologies managing technologies, to establish guidable, state-aware, and self-adaptive computer systems. According to the analysis of domestic and foreign representative literature, this paper makes an overview on concept of autonomic computing and presents autonomic computing properties and sampling applications. Then the important theories and technologies for autonomic computing system models are given. Finally, the research problems and future directions of autonomic computing are discussed.

I. INTRODUCTION

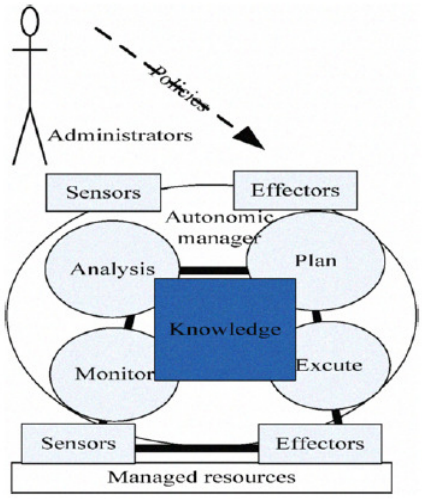
With the permeation expansion of Internet to every comer of society and the emergence of new application models such as grid computing, pervasive computing, the size and complexity of software are increasing. Autonomic computing [1] technology is an emerging research topic to solve the software complexity crisis. It is inspired by the function of the human nervous system and is aimed at designing and building systems that are self-managing. Its thoughts is to make systems manage their own under the guidance of management strategies developed by IT managers, through the technologies managing technologies to hide the system complexity. As a result, the system can realize self-configuration, self-optimization, self-healing and self-protection. According to the self-adjustment mechanism of autonomic nervous system and the existing theory and technology (including service-oriented computing, adaptive control theory, optimization theory, policy-based management, multi-agent technology, etc.), autonomic computing is to build autonomic computing system. Therefore, it makes the information system achieve self-management in holistic. The realization of autonomic computing is an evolution process. According to the maturity autonomy, it can be divided into five levels [I]: basic level, management level, predict level, adaptation level, and full autonomic level.

II. CONCEPT

In 2001, IBM first proposed the concept of autonomic computing [2]. In the manifesto, complex computing systems are compared to the human body, which has an autonomic nervous system that takes care of most bodily functions, thus removing us from the task of coordinating all our bodily functions. Then IBM pointed that complex computing systems should have four properties to achieve self-management, that is, self-configuration, self-optimization, self-healing, and self-protection.

To meet self-management, systems should be designed with components that contain an autonomic manager. IBM presented a reference model of autonomic control loop in 2003[3] , which is known as MAPE-K. Fig. 1 shows an autonomic element (AE) which is comprised of managed resources and an autonomic manager (AM).The Control loop with sensors and effectors together with Monitor, Analysis, Plan, Execute, Knowledge components makes the autonomic element to be self-manage. The managed resources can be software or hardware resource that is given autonomic behavior in accord with an autonomic manager. Thus, the managed resources can be operating systems, wired or wireless network, CPU, database, servers, routers, application modules, Web service or virtual machine and so on. Autonomic manager consists of monitoring component, analysis component, planning component, and execution component and knowledge repository. The monitoring component provides the ability of self-awareness and detects the external environment. The analysis

component then carries out autonomic decision-making and decides the adaptive goal of system; planning and execution components achieve the adaptive function when the system state departures from the expected goal. The operation of four components is supported by the knowledge repository.



The reference model of autonomic element

As we know, the autonomic computing is inspired by the human body's autonomic nervous system [4]. In autonomic nervous systems, the constraints information to guide system behavior arises from a variety of emotional state in the cerebral cortex, as well as the various parameters of the body (such as cardiac rhythm, blood pressure, blood glucose level, etc.). Many of the decisions made by autonomic elements in the body are non-conscious, while autonomic elements in autonomic computing systems make decisions based on the constraints information which is management strategies developed by administrators. Some scholars further developed the concept of autonomic computing. From the basic connotation of autonomic computing and based on the above jobs, Liao further clarified the concept and stressed the important characteristics of the guidance and overall adaptive about autonomic computing .

So far, although the concept of autonomic computing is still in the development process, but its basic content has been clear. That is, the information system whose properties are similar to that of the autonomic nervous system in the human body is established for reducing the workload on the system administrators, improving reliability, availability and fault tolerance of system.

III. AUTONOMIC COMPUTING PROPERTIES AND APPLICATIONS

There have been a number of research efforts in both academia and industry to develop the properties and applications. A brief description of the properties and a sampling of these applications are presented below.

A. Self-configuration

An autonomic computing system configures itself based on the needs of the platform or a strategy provided by IT professionals to adapt to changing environment. Dearle builds a framework for deployment and implementation of self-management on component-based distributed application [5]. A Constraint Solver is used to find high-level goals which are desired and automatically deploys. Jann presents the dynamic configuration of autonomic computing using the basic building blocks method for the IBM pSeries Servers .This method can guarantee to insert a new software or delete some software during the normal operation of the system.

B. Self-healing

An autonomic computing system detects, diagnoses abnormalities and makes the appropriate repair measures. Self-healing component can detect system failure and in the case of uninterrupted service, it initiates repair measures automatically based on pre-specified strategy by IT professionals.

Back door is a well-known system architecture which can be used to monitor the status of the target machine's software and computing system, instead of using processor and system resources of the target machine. Bohra researches the application of the back door for remote monitoring control, and for self-healing of system failure [6]. He also uses specific example to illustrate that the method has fast system response and small consumption in self-healing. Huang discusses the Cheap Recovery, which is based on the restart repair strategy. Cheap Recovery is fast, and has moderate effects for system performance and availability, so the method has good manageability.

C. *Self-protection*

An autonomic computing system predicts, identifies and prevents the threat which is from

anywhere. Self-protection component can detect hostile acts and take appropriate measures to ensure stability of the system.

For a wide range of network attacks, Qu presents a framework for online monitoring and analysis for self-protection. They use the main software to monitor and control a number of system attributes online, and the states of all network and computing resources are marked as normality, uncertainty, and abnormality. When the main software once determines that some service or a network device is in abnormal state, it implements the restoration mechanism.

D. Self-optimization

An autonomic computing system automatically optimizes managed resources, and the optimization component adjusts itself to meet the needs of their end-user and business needs.

Sadjadi researches how to design adaptive middleware to support the autonomic computing in pervasive computing environment .The research focus is that when mobile users interact with a variety devices in wireless network environment, how to change the network connection. The goal is to make best change, and the core application code should be transparent.

IV. IMPORTANT THEORIES AND TECHNOLOGIES FOR AUTONOMIC COMPUTING SYSTEM MODELS

Autonomic computing is to promote self-manage goal of various components to the whole system. Autonomic computing system involves service-oriented technology, Agent technology, adaptive control theory, machine learning, and optimization theory and so on. It also depends on the maturity of self-manage techniques about the various components resources (such as networks, databases, storage devices and middleware, etc.) The realization of autonomic computing system will result in a significant improvement in system management efficiency.

A. Adaptive Control Theory

Adaptive control is one of the most dynamic branches in the modem control theory . Adaptive control system based on dynamic object and the environment, by measuring the input /output information, obtains the dynamic characteristics of the managed object and systematic errors in time. According to the change and a certain design method, it makes decisions and modifies the controller parameters autonomously to adapt control signal to meet the changes of object and disturbance, to maintain optimal control performance of system. Feedback control analyses the implementation result of the previous work which is compared with the control standards, for finding bias. And then it identifies the reasons and formulates corrective measures, which can prevent the development or the continued existence of bias.

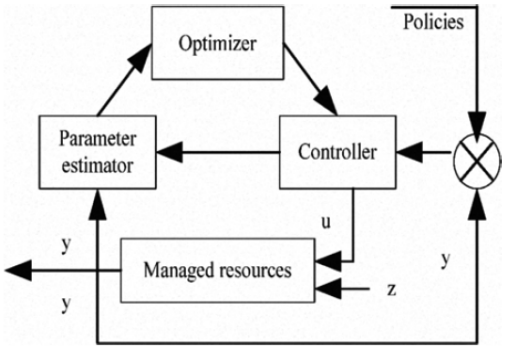


Fig. Autonomic Element Based on Adaptive Control Theory

Therefore, through the appropriate expansion, adaptive control *theory* and feedback control *theory* can be used to establish autonomic computing system, especially the optimization system. The working principle model of autonomic element based on adaptive control *theory* is depicted in Figure above.

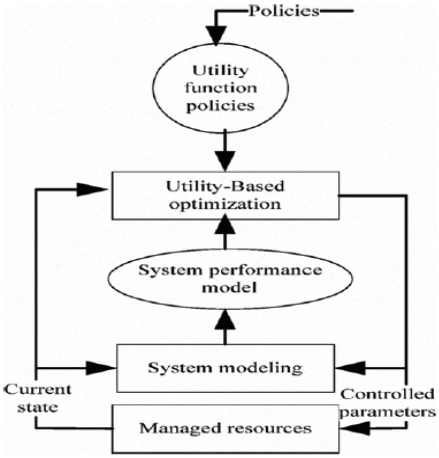
B. Agent Technology

Agent called intelligent agent has the properties of reactivity, autonomy and social. It can sense the environment to make a reaction (Reaction Agent) or to achieve the goal-oriented behavior (Deliberative Agent) by plan. Also, agent has been widely known as the key technology which supports the large-scale, open and distributed information systems to achieve dynamic service integration and teamwork. Web Service is a new branch of Web applications, which has the advantages of platform independence, inter-operability and so on. Semantic Web technology makes computer understand the meaning of information and complete the intelligent agent function like the human brain. Therefore, based on Agent technology and policy-based management approach, and combined with Web

service and Semantic Web technology, we can create a variety of autonomic computing systems. Liao introduced two main methods for building autonomic computing system . One is autonomic element based on Reaction Agent, the other based on Deliberative Agent.

C. *Utility Function*

Utility is one of the most commonly used concepts in economics. In autonomic computing, utility function maps each possible state (system performance) of the entity (autonomic element) to a real number, for showing the value which corresponds to system performance (such as reaction time, delay, throughput, etc.). Autonomic computing system uses utility function to show management strategies. Based on the current system performance model, through the maximization of utility, autonomic computing system gets the desired system state and the values of corresponding adjustable system parameters. At last, autonomic computing system adjusts system parameters, making the system achieve the desired state in order to achieve optimization. The autonomic element model of autonomic computing system based on the principle is shown in Fig. 3. Especially in distributed autonomic computing system, utility function provides a favorable framework for self-optimization. In a dynamic complex environment, utility function can make autonomic element optimize computing resources continuously. Kephart provides a specific example for realization of autonomic computing system. Utility function strategy used to reflect a high-level goal establishes a resource self-management and distribution model for a prototype data center.



Autonomic element based on utility function

There is a strong need for combining with other emerging fields such as pervasive computing and communications for building autonomic systems. Sterritt discusses the combination between soft computing and hard computing to achieve autonomy. Not only the capacity of soft computing which can deal with the imprecision, uncertainty is used, but also the highly predictable solutions and lower computational complexity of hard computing are obtained. Franke proposes the idea that autonomic computing, grid computing and virtualization technology are combined to create autonomic business grid. At present, some researchers have applied model-driven idea to adaptive research and proposed a model-driven self-management approach.

v. AUTONOMIC COMPUTING RESEARCH PROBLEMS AND FUTURE DIRECTIONS

At present, some problems of autonomic computing have been studied at home and abroad. However, the research of theory, method and techniques on this new computing model is far from being systematically carried out. There are many problems that have not yet discovered and have to be resolved. Key research problems and future directions are presented as follows.

A. Autonomic Computing System Architecture

Autonomic computing system itself must be the organizational structure, and the combination and interactive collaboration of autonomic element should be limited. However, current research that autonomic computing system should be what kind of architecture to support its elements effectively for self-management and its elements should be what kind of organizational structure to achieve self-configuration, self-healing, self-optimization , self-protection are not yet ripe. Therefore, the research of generic architecture and prototype for autonomic computing system will remain active.

B. Software Engineering Tools for Autonomic Computing System

The development methodology for autonomic computing system is the key point which achieves a blueprint for autonomic computing. We need more powerful software engineering tools for the analysis, design, development, testing and

deployment on autonomic computing system. However, there are a small number of tools which have kinds of different problems. Bigus describes the learning environment ABLE for the development of autonomic computing system. However, ABLE is an agent generation environment based on component reuse. It lacks clear structure, agent deployment and operation management environment. The elements themselves also have no clear self-management support. Thus, with the depth research of autonomic computing, software engineering tools will be a research hot spot.

C. *Strategies for Autonomic Computing*

The research of autonomic computing strategy in theory and in engineering is still in the initial stage. The main problems are as follows: Understanding for the role of strategy in autonomic computing is not deep enough; there is no powerful specification language, as well as strategic planning methods; there is no systematic strategy implement engineering approach; the strategy position on the life cycle of software systems has not been clear. Therefore, some scholars have presented that strategies for autonomic computing will also be focused on.

VI. CONCLUSIONS

With the promotion of researchers and practitioners, autonomic computing research has infiltrated into pervasive computing, grid computing, software architecture and other fields. It has achieved fruitful research results. However, it remains a relatively immature topic. In this paper, we give an introduction to autonomic computing, and point out that the current research problems and research prospects hoping to provide a useful reference for the further study of autonomic computing.

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