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A Survey on the Challenges in Autonomic Computing

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***Abstract*—** With the advancement in technology, the emerging complexity of the systems require the development of a more intelligent system that can tackle the requirements of system/ software architectures in an efficient manner. The term 'autonomic computing' refers to the computing system that operates on its own or with the involvement of minimum human activity and paved the way for the system designers and system developers to develop such intelligent systems that can have adjusting capability. It completely revolutionized the area of research in the context of computing technologies. The goal of this paper is to provide insight overview of autonomic computing, followed by the challenges involved in its realization, and then applications and future application scope is discussed with the addressing of key issues.

Keywords- Autonomic computing, Smart Grid, Optimal Grid, ANS, DSI

I. INTRODUCTION

The ever-growing upbringing of Internet over the last couple of years leads to improvement in the computing equipments as well as in computing systems but on the other side this advancement and enhancement brought a challenge-complexity. By looking at the prevailing scenarios there is a need for the revolution or a solution that can manage these complexity issues and as a result, now we have autonomic computing systems. The evolution in the field of computing technology can be traced back in 2001 when IBM took the initiative for building such intelligent systems that have the capability to self-manage i.e. without involving anyone else, so as to get rid of the existing and upcoming complexity issues [1]. This idea was introduced by Paul Horn, in a careful manner by relating this to an autonomic nervous system which manages the controlling functions like heart rate and body temperature and some other important functions of the body [2]. Therefore, reduces the burden of brain to a great extent by managing all these body related functions. Thus, autonomic systems can be realized in such a way that controls the vital functions of the system and hence, reduces the burden of humans to manage each and every aspect of the system. Therefore, self management in the large computing systems in which high-level guidance is provided by humans and is one of the biggest challenges as the technology is gearing up. A framework is also required that is capable enough to realize the aims of autonomic computing. Firstly, autonomic computing system should be able to explain the interfaces in an external way and the requirement for making an individual component, self-managing. Secondly, to make an autonomous system that works as a whole in self managing way by utilizing the autonomic components that are identified earlier [3].

A. Foundations and Concepts: Control loops and Architectural Foundation

Control system form the basis for autonomic computing systems in which several components work together to achieve the best desired results that are close to specifications [2]. In Open-loop control systems, the output is not affected with the given input as it is never compared with the given conditions while in Closed-loop control systems, output is affected with the given input as feedback is involved within the system. Human Autonomic Nervous System (ANS) comprises of two divisions called the parasympathetic and sympathetic nervous system for handling normal and abnormal situations, similarly normal and abnormal situations are to be separated by controlling loops that might works well for autonomic software systems.

The architectural foundation is laid down by IBM researchers as represented in Figure 1 which has autonomic element as its key component [4]. Control loop is present at the core of an autonomic element that provides integration of autonomic manager to managed element. The resource management is done by autonomic manager which is part of autonomic element. The purpose of managed element is that to provide execution environment to the application and it consists of sensors and effectors for providing internal state and functional behavior corresponding to changes in environment. Knowledge is required in order to maintain the

autonomous management of managed elements. Elicitation of knowledge is done using sensors that are part of managed elements and then gathered data is analyzed. Effectors also affect the managed elements by the previous results. In order to maintain the managed elements, Monitor-Analyze-Plan-Execute (MAPE) loop is used [4].

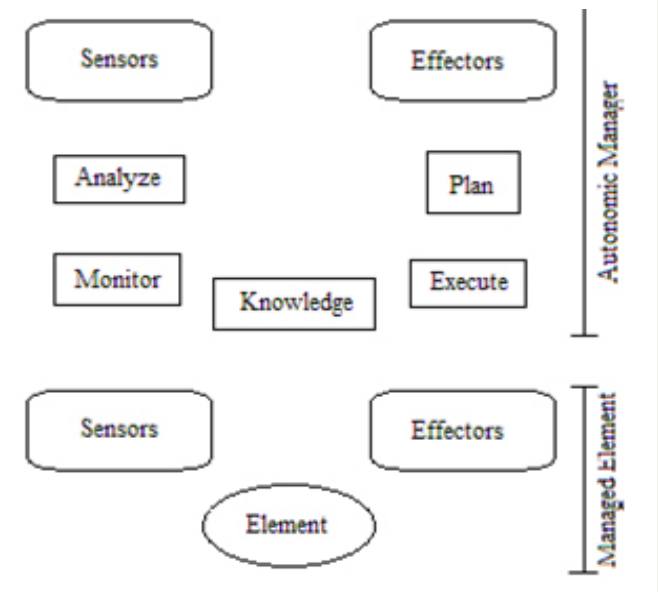

Figure1. Architecture of Autonomic element [adapted from [4]]

In this intelligent loop starting from monitor phase, that monitors the managed elements for gathering information, then in analyze phase by analyzing the monitored information, prediction is done related to coming situations and trends, then on the basis of analysis further planning of future action is done, at the last is execution phase in which autonomic manager is responsible for changing the behaviors of managed elements as required. Like autonomic elements, autonomic manager also has sensors and effectors that are used for facilitating communication with other autonomic elements in response to changing environment.

This paper reviews the basic terminology, evolution of intelligent computing technology i.e. autonomic computing and how it is useful in realizing the computing systems that can tackle the complex task of managing complexity in existing and upcoming systems. It starts with the foundations and concepts then followed by characteristics of autonomic computing systems in Section II. Section III represents the challenges being faced by autonomic computing systems. Section IV is the related work with respect to challenges by classifying them into the most suited category. Section V proceeds with the applications of autonomic computing in various directions and Section VI has the future application scope with the addressing of key autonomic issues.

II. CHARACTERISTICS OF AUTONOMIC COMPUTING

This section describes the major characteristics as represented in Figure 2 and minor characteristics as represented in Figure 3 of the autonomic computing systems [2][5-7].

A. Major Characteristics

1) Self-configuration is one of the key properties that belong to autonomic systems. In case of large and complex systems, the process of installing, configuring and then integrating components consumes a lot of time. Moreover, a team of expert programmers for merging the systems which involves the incorporation of different databases, different platforms, and different vendors is required in order to facilitate this task like in installing an e-commerce application –SAP. But with autonomic systems, configuration takes place automatically as per the directions of high-level policies that basically depict business-level objectives. It follows the approach of specification in which what is required is mentioned but how that can be achieved is not mentioned i.e. the procedure is not mentioned. Whenever a new component is incorporated into the existing system either component will learn the behaviour of system in terms of configuration and composition of system or other components of system can change appropriately so as to use its functionality. The general intention is to free the system administrators or developers by reducing their burden for operating and maintaining the system. Thus, users are provided with 24/7 service via machine. It is all possible with autonomic systems that are continuously monitoring its working and thus capable enough to self manage on their own. Whenever it finds a vital upgrade that is required for system that gets installed and again configured and re-configured to make it happen and even on error detection it goes back to the previous version and maintains the system integrity.

2) In order to achieve *self-optimization,* different parameters of the system like database system or other technology need to be tuned so as to achieve optimality in performance of the system. In this regard, autonomic computing systems continuously put their efforts in order to find some ways that can improve the performance of system in terms of cost and also involves optimize use of resources for overall enhancing the performance of system. To achieve this, they get configured, re-configured many times for incorporating the latest updates.

3) *Self-healing* implies the capability of autonomic systems in terms of software and hardware to detect and repair the errors or failures. In earlier computing systems it was quite difficult to detect and then fix the problem and it also involves a team of expert programmers as resources and time spent even in months for diagnosing and fixing the issue.

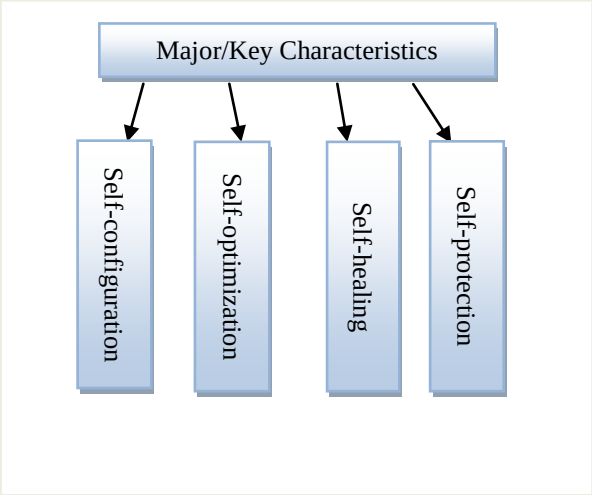

Figure 2. Major Characteristics of Autonomic Computing Systems

4) In order to provide security to the system, an autonomic computing system must be *self-protecting* in nature. It must be able to detect the internal and external attacks that can be even some form of malicious attacks and should always leave the system in secured state. Autonomic computing systems must be capable enough to deal with the attacks that can come from anywhere. The problems that occurs at large scale cannot be handled by self-healing property measures. Therefore, there must be some self-protection mechanism that is capable of handling the worst scenarios such as malicious attacks when takes place at large scale, and cascading failures that are not handled by self-healing measures. For handling large-scale attacks, the system's autonomic components must collaborate themselves so as to defend against attack as a whole. In order to protect the accessing of resources, the limit to be put on the access by user to all the shared resources and even on its own resources. There is even need to protect the communication media from the obstacles like traffic analysis that is usually done by intruders in order to gather the sensitive data. The technologies like Access Control List (ACL), Secure Socket Layer (SSL) can be integrated with the prevailing scenario.

B. Minor Characteristics

The additional properties that must be possessed by autonomic computing systems are as follows:

1) *Self-awareness* in autonomic computing systems refers to the awareness of its state and behaviour that is required for its self management as well as for interacting and collaborating with other systems.

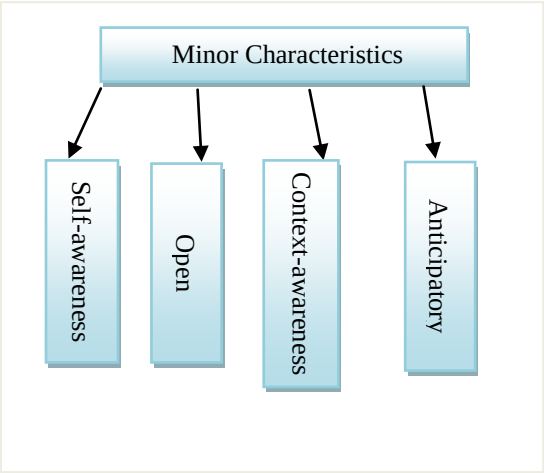

Figure3. Minor Characteristics of Autonomic Computing Systems

2) The *open* property refers to the capability of autonomic computing systems to work in a heterogeneous environment in terms of equipments/devices, databases, etc and to get implemented in cross-platform scenarios.

3) In *context-awareness* feature, execution environment must be known to autonomic computing systems so that they can well respond to the changes if required like in case of incorporation of new business policies.

4) The *anticipatory* characteristic refers to the autonomic computing system that will predict the resource optimization requirement and make a check on complexity details so that they cannot be revealed. It basically makes self-managing property proactive in nature.

III. CHALLENGES IN AUTONOMIC COMPUTING

There are still some challenges that are being faced by autonomic computing paradigm. These come out to be the future direction as well for the existing and upcoming researchers in order to realize its full potential. Following are discussed some of the challenges that might not be yet addressed or been partially addressed [2][5-6].

A. The objective behind the emergence of autonomic computing is to reduce the burden of system administrators or system developers from operating and maintaining the system but to realize this aspect the key requirement is to have new techniques that can analyse the working of autonomic elements and must be able to decide on the key factors like affected performance with the incurred cost, security aspects and reliability.

B. The evaluation of major and minor characteristics is required so as to reduce the gap between them and the associated quality factors as represented in Figure 4.

C. There must be standardization in the designing of autonomic elements as these elements are to be shared by other autonomic elements in system. Moreover, autonomic elements may be having different perspective like it may represent some business aspect or scientific objective, etc. Lack of standards is also impacting the involvement of autonomic components and systems in I/T industry.

D. The algorithms that are used in autonomic computing in order to determine the problem and then provide automatic correction to that problem involve the usage of learning algorithms. These algorithms are quite different from the traditional ones as it explores different aspects like how coordination can be handled between different autonomic elements, etc. still a challenge.

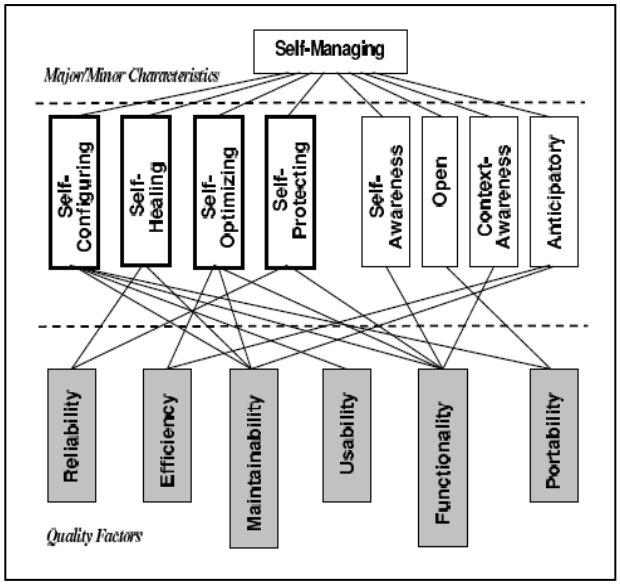

Figure 4. Major and Minor Characteristics with their impact on Quality factors [adapted from [6]]

E. Service delivery protocols or service utilization protocols can be used in order to share the services and this can be done by autonomously observe the services and then shared between the existing autonomic elements and utilization of parameters for providing standardization between different autonomic elements as they work in an unpredictable environment where optimize use of resources is required and this can be achieved if existing autonomic elements are aware of other autonomic elements and external environment.

F. The implementation of autonomic computing systems involves the coordination between large number of processes that are working in different autonomic elements which are in turn having different purpose and utilize different criteria of optimization.

G. This leads to the making of autonomic computing system when different autonomic elements collaborate with each other but the core component that is required in realizing this scenario is the standardized policies. Efforts are under way for implementing standardization but the realization is not taking place until and unless successful negotiation, enforcing and reasoning about the policies are lacking.

H. Autonomic elements must be able to detect the attacks and then protect themselves against those attacks as information is also exchanged in an autonomous manner.

I. There are numerous techniques available for supporting the autonomic systems started from designing till their maintenance and to choose the relevant one is quite a challenging task.

J. In order to translate business policies into I/T policies there is requirement of an interface that is capable of determining the mutually independent components. Though high-level approaches and engineering methods are moving in this direction but it is very critical to determine and requires much more work to be done in this direction.

K. Virtually, it is not feasible to make the test systems that can gain insight of the realistic system about its size and complexity and workloads.

L. Autonomic computing systems are facing security, privacy issues like authentication, encryption, identity masking, etc. that need to be addressed by formulating the security policies in an understandable and careful way. When the autonomic systems or elements are involved in multiple administrative domains then these issues become more prevalent as to match up with different legal requirements of different states and countries.

M. The form of attacks that are enough capable that they can manipulate the high-level policies, thus attacker can easily intrude into the system than in non-autonomic systems. So these systems must be robust in nature despite of the uncertainty and dynamic behaviour of the system. Therefore, the middleware used must possess robustness, reliability and scalability in order to realize the autonomic behaviour of systems.

N. Optimization is also one of the challenges like learning in autonomic systems as autonomic elements are changing their behaviour be exchanging information , therefore, sometimes it leads to instability in the system. The optimization techniques to be used in such an environment must be dynamic in nature and need to be changed with the changing requirements.

O. The application development challenge is to make applications that are capable of managing the key characteristics that is self-optimizing, self-configuration, self-healing and self-protection themselves. This requires the formulation of frameworks, middleware services that support the dynamism of the autonomic elements and systems.

IV. RELATED WORK

In this section, focus is to provide categorisation to challenges like Management challenge, Quality of Service, Standardization, coordination of processes, etc so that they can be easily tackled.

Table 1. Represents Challenge and Category of Challenge

Challenge	Category of Challenge
A	Management
B	Quality of Service
C,G	Standardization
D	Learning Algorithms
E	Sharing of Services
F	Process Coordination
H,L,M	Attack Detection
I,K	Design, Test, Verify
J	Interface for Translation
M	Middleware
N	Optimization
O	Application development

It is giving a quick overview regarding the challenges mentioned above (III) with their corresponding category to which they are most suited. This highlight will surely helps the researchers in moving to the direction according to their interest.

V. APPLICATIONS OF AUTONOMIC COMPUTING

The following Table 2 represents some of the applications with their description.

Table 2. Applications of Autonomic Computing with their description [5-6]

Sr. No	Application	Description
1	Autonomic Computing Toolkit	It comprises of Autonomic manager engine which depicts the MAPE process, Log and Trace Analyzer that depicts monitoring, analyzing with partial implementation of control loops, Generic log adapter makes the transition of log files into a common format that can easily be recognized by autonomic systems and Resource Model Builder helps in making special resources using common resource model.
2	Dynamic Systems Initiative (DSI)	It is an initiative by Microsoft in order to overcome the challenge of system complexity by reducing it to certain level. The approach used in DSI is to define a common schema so that other software can be made into its operating system. As a consequence, this model is then utilized in system runtime and enables the autonomous management of system.
3	OceanStore	As the name implies, it is a data storage system that utilizes introspection layer for improving performance and fault-tolerance ability of system while analyzing the network information.
4	Optimal Grid	It provides solution to the implementation of large-scale applications by making performance optimization.
5	Smart DB2	It reduces the cost involved for DB2 by incorporating self-managing capabilities and thus reduces the complexity and enhances the quality of service.

The other applications in Industry-Oriented and Academic-Oriented Projects includes Oceano by IBM, AutoAdmin by Microsoft, N1 by Sun, The Adaptive Enterprise by HP, AntHill by University of Bologna, Recovery-Oriented Computing by UC Berkeley/Stanford, Autonomia by University of Arizona, eBiquity by University of Baltimore County, Software Rejuvenation by Duke University [6]. Each of these projects has specific application in autonomic computing systems.

VI. FUTURE APPLICATION SCOPE OF AUTONOMIC COMPUTING

The Table 3 is showing the benefits and future application scope of autonomic computing systems in the existing systems with the addressing of major autonomic issues with respect to the specified system. Some of the key autonomic issues are addressed by S.K. Chauhan, A. Sharma in their research paper titled "AUTONOMIC COMPUTING: A LONG TERM VISION IN COMPUTING" and some are proposed in this survey paper by analysing the details corresponding to the system.

Table3. Represents Future Application Scope in existing systems with the addressing of key autonomic issues

System	Application	Key autonomic issues addressed
Electricity Transmission System [8]	Sensors can be used to monitor the environmental factors like temperature, speed of wind, etc , and thus provide the required power, short-circuit detection, load forecasting facility	Self-optimization, Self-healing (proposed)
Train Route Management System [8]	Speed in decision making in scheduling of trains, security against attacks	Self-configuration, Self-healing (proposed), Self-protection (proposed), Self-management (proposed)
Multiprocessor Systems [8]	Manage processor load autonomously	Self-management, Self-configuration
Traffic Management [8]	Current traffic scenario	Self-configuration, Self-healing (proposed)
Travel Guide [8]	GPS systems can be used in order to track user's location	Self-management (proposed), Self-configuration (proposed)

VII. CONCLUSION and Future Scope

This paper provides an insightful study towards the autonomic computing system that is basically derived from the human autonomic nervous system. The main contribution of this review lies in representing challenges and applications so that researchers can focus on their respective area and full potential of the paradigm can be explored. It's being widely used in the projects like Smart Grid, Optimal Grid, etc. The key aspect of autonomic computing is working autonomously in an effective way so that human intervention can be reduced to certain extent. The significant properties of autonomic elements like self-protection for managing attacks on its own, etc which forms the base for autonomic framework makes it worthwhile in its existence. The technology that has positive impact on the field areas also has another side that represents its negative impact in terms of challenges that are being faced by researchers, user community, businesses, etc. that should be addressed. The further research will definitely give promising results in this direction as it is the coming future in almost each and every aspect.

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