Autonomic Computing: the natural fusion of Soft Computing and Hard Computing

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Abstract - *Autonomic Computing is emerging as a significant new approach in the design of computing systems. Its overall goal is the creation of Self-Managing Systems. In order to achieve this, Hard and Soft Computing are required. The benefits from utilizing Soft Computing include their ability to handle imprecision, uncertainty and partial truth that is inherently present in any complex real world problem accompanied by the practicable benefits of Hard Computing namely the stability of highly predictable solutions and typically low computational burden. This paper motivates the proposition that the successful creation of Autonomic Systems requires a fusion of Soft Computing and Hard Computing.*

Keywords: Soft Computing, Hard Computing, Fusion, Autonomic Computing, Self-Managing Systems

1 Introduction

Soft Computing differs from *Hard Computing*, often known as conventional computing, in that it is tolerant of imprecision, uncertainty and partial truth [1]. In general, Soft Computing aims to exploit these properties to achieve tractability, robustness and low cost in computing systems.

Currently, Soft Computing comprises of *neural network theory*, *fuzzy logic*, *probabilistic reasoning* (incorporating belief networks), *genetic algorithms*, *chaos theory* and sections of *learning theory*. It is an expanding field, for example *immune network theory* [2], however a consensus as to the exact scope of the subject has not been reached [3].

Soft Computing offers a toolbox of techniques that can be used in combination to address problems in computer-based systems [4]. With this perspective, the task is to find the complementary techniques that best fit each specific application [5].

Hard Computing techniques [6] are typically easier to apply. Also the stability of resulting solutions is highly predictable and the computational burden of practical algorithms is typically low [7]. Just as Soft Computing brought together related techniques for greater benefit [8], taking a broader perspective, in effect finding a fusion [9], can bring further gain [10]. The purpose of this paper is to consider the combined use of Hard Computing and Soft Computing techniques in relation to the emerging area of Autonomic Computing (AC).

2 Autonomic Computing

Autonomic Computing is emerging as a significant new initiative to encourage a *self-managing* design approach to computing based systems. To achieve this overall goal of creating self-managing systems the belief is that such attributes as self-configuring, self-healing, self-protecting and self-optimizing must effectively be addressed. See Figure 1 and [12] for a fuller discussion of its properties.

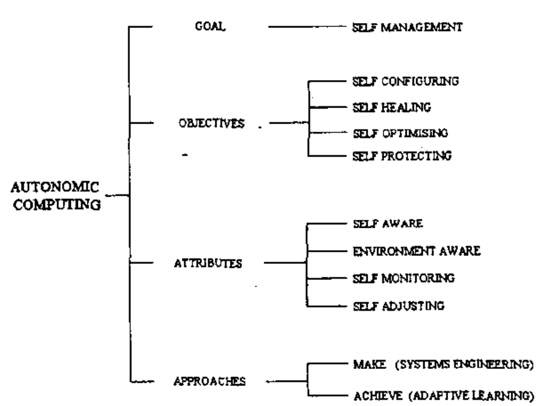

Figure 1 AC Tree [12]

Just as Soft Computing has a biological analogy – of the mind and offers ambiguity in human thinking with real life uncertainty, Autonomic Computing is grounded, as the name suggests, in the analogy with the human body's Autonomic Nervous System (ANS). The ANS regulates vital bodily functions such as the control of heart rate, the body's temperature and blood flow—all without conscious effort. The aim is to bring this level of unconscious 'self' effort to systems.

Autonomic Computing may first appear as existing efforts with a new 'brand' or marketing image. For instance the desire for automation and effective robust systems is not new; in fact this may be considered an aspect of best practice software engineering (the engineering of Hard Computing). Similarly, the desires for systems self-awareness, awareness of the external environment, and the ability to adapt, are also not new, being major goals of several fields within artificial intelligence (AI) research for many years. What may be considered new in Autonomic Computing is its overall breadth of vision and scope [11]. A vision that may best be addressed with a true fusion of Hard and Soft Computing.

Research in Autonomic Computing will see a greater collaboration between the intelligence research and software engineering fields. The creation of Autonomic Computing Systems, or methods of enabling computer-based systems to respond to problems, recover from outages and repair faults, all on their own without human intervention, is a major challenge.

There are two perceived approaches for Autonomic Computing to become a reality [11]:

- Making Autonomic Computing
- Achieving Autonomic Computing

'Making Autonomic Computing' has an implied Systems and/or Software Engineering view – to engineer autonomic function into the individual systems. 'Achieving Autonomic Computing' has an implied AI, evolutionary computing and adaptive learning view – to utilize algorithms and processes to achieve autonomic behavior. Yet both approaches rely on each other to be able to achieve the objectives set out in Automatic Computing. As such Autonomic Computing may prove to require a natural fusion between Soft Computing and Hard Computing. This paper will explore these fusions or potential through discussion of early applications in the literature.

3 Fusion of Soft Computing and Hard Computing

The Autonomic Computing initiative concepts of effective system configuration; fault prevention, tolerance, removal and prediction; protection and optimization traditionally reside in the Hard (conventional) Computing domain - with stability resulting from highly predictable solutions and low computational burden of Hard practical algorithms. Increasingly, Soft Computing has been applied in these areas to provide tolerance of imprecision, uncertainty and partial truth that is inherently present in any complex real world problem.

Also the autonomic concepts of self awareness, environment awareness, self adjustment and autonomous behavior all reside within AI of which Soft Computing has emerged as a collection of methodologies that are particularly tolerant of imprecision, uncertainty and partial truth.

The successful fusion can be made not only at the algorithm level but also at the higher system level [9]. This fits with the goal of an Autonomic System - that there should be no failure at the system level, components of the system will fail but self-management is used to ensure minimal disruption [25].

4 Brief Review of Emerging Autonomic Computing Applications

It has been highlighted that meeting the grand challenge of Autonomic Computing systems will involve researchers in a diverse array of fields, including systems management, distributed computing, networking, operations research, software development, storage, artificial intelligence, and control theory, as well as others [13]. This section will discuss the early reports in the literature of efforts underway in AC seeking early signs of approaches that would benefit from such a fusion.

The AC initiative launched in 2001 is now starting to see special issues, conferences and workshops on the topic such as [15]-[20]. The papers in [15] generally cover Hard Computing topics such as mirroring and replication of servers, software hot swapping and DB query optimization, yet these could generally benefit from Soft Computing.

Machine Design

An interesting paper in [15] discusses affect and machine design [22]. Essentially it supports those psychologists and AI researchers that hold the view that affect is essential for intelligent behavior. It proposes three levels for the design of systems:

1. Reaction – lowest level where no learning occurs but immediate response to state information coming from sensory systems.

2. Routine – middle level where largely routine evaluation and planning behaviors take place. It receives input from sensors as well as from the reaction level and reflection level. This level assessment results in three dimensions of affect and emotion values: positive affect, negative affect and (energetic) arousal.

3. Reflection – top level receives no sensory input or has no motor output, it receives input from below. Reflection, a meta-process, where the mind deliberates about itself. Essentially operations at this level look at the systems representations of its experiences, its current behavior, its current environment etc.

Although not described in such terms this approach to intelligent design may offer a framework for the fusion of Hard and Soft Computing. Essentially the reaction level sits within the hard domain, monitoring current state of both the machine and its environment with rapid reaction to changing circumstances. The reflection level may reside within Soft Computing utilizing its techniques to consider the behavior of the system and learn new strategies. The routine level may be a cooperative mixture of both. The affect and emotion values could then provide an effective mechanism to maximize the fusion between the Soft and Hard Computing within the system.

Prediction and Optimization

Clockwork, a method for providing predictive autonomicity – regulating its behavior in anticipation of need, using statistical modeling, tracking and forecasting methods [23] is being expanded to include real-time model selection techniques to fulfill the self-configuration element of Autonomic Computing [24]. This work, already containing probabilistic reasoning, could benefit from a fusion of Hard and Soft Computing for instance in utilizing a genetic algorithm for the model selection.

Bayesian networks are central as a technique in research into autonomic algorithm selection. The system uses the approach along with self-training and self-optimizing to find the best algorithm [33].

The breath and scope of the autonomic vision is highlighted by work that is using AI techniques (machine learning, Tabu search, statistical reasoning and clustering analysis) for controlling the detection of the need for re-optimization of enterprise business objectives [34].

An autonomic application – 'Smart Doorplates' seeks to assist visitors to a building in locating an individual who is presently not in their office. A module in the architecture utilizes probabilistic reasoning to predict the next location of the individual which is reported along with their current location.

Knowledge Capture and Representation

A vital issue to the success of Autonomic Computing is the ability to transfer knowledge about the system management and configuration from human experts to the software managing the system. Fundamentally this is a knowledge acquisition problem [27]. One current research approach is to automatically capture the expert's actions (keyboard and mouse movements etc) when performing on a live system and dynamically builds a procedure model that can execute on a new system to repeat the same task [27]. Building up a collection of traces over time should allow the approach to develop a generic and adaptive model.

The Tivoli management environment approaches this problem by capturing the key characteristics of a managed resource in its resource model [28]. This approach is being extended to capture the best practices information into the common information model (CIM) through descriptive logics at both design phase and deployment phase of the development lifecycle [29]. In effect, the approach captures system knowledge from the creators ultimately to perform automated reasoning when managing the system.

Monitoring and Root Cause Analysis

Event correlation, rule development and root cause analysis are important areas for the autonomic environment [30]. Early versions of tools or autonomic functionality updates to existing tools and software suites in this area have recently been released by IBM [25] through their AlphaWorks Autonomic Zone website [21].

- The generic Log and Trace Tool correlates event logs from legacy systems to identify patterns. These can be used to facilitate automation or help debugging [25].

- The Tivoli Autonomic Monitoring Engine essentially provides server level correlation of multiple IT systems to assist with root cause analysis and automated corrective action [25].

- The ABLE rules engine can be used for more complex analysis. In effect it is an agent building learning environment that includes time series analysis and Bayes classification among others. It correlates events and invokes the necessary action policy [25].

- A policy-based management tool sets out to reduce the complexity of product and system management by providing uniform cross-product policy definition and management infrastructure [25].

It has been highlighted that correlation, rule discovery and root cause analysis activity can benefit from a fusion of Hard and Soft Computing incorporating Bayesian Belief Networks [26] either in the rule discovery process or in the actual model learning.

Large-scale server management and control has also received similar treatment. Event logs from a 250 node large-scale server were analyzed through applying a number of machine learning algorithms and AI techniques to establish time-series methods, rule-based classification and Bayesian network algorithms for a self-management and control system [32].

Costs are another area that is being added to the autonomic system and self-healing equation. One approach utilizes naive Bayes for cost-sensitive classification and a feedback approach based on Markov decision process for failure remediation [35]. The argument is easily made that the autonomic system involves decisions and decisions involve costs [36]. This naturally leads to work with agents, incentives, costs and competition for resource allocation and extensions thereof [36] [40].

Agents will obviously play a large role in Autonomic Computing [37]-[40]. The potential contribution of a fusion to the use of agents may come from learning environments for the rules and norms or agent monitoring systems.

Legacy Systems and Autonomic Environments

Autonomic Computing is widely believed to be a promising approach to developing new systems. Yet organizations continue to have to deal with the reality of legacy systems or build 'systems of systems' comprising new and legacy components involving disparate technologies from numerous vendors [41]. Work is currently underway to add autonomic capabilities to legacy systems, in areas such as instant messaging, spam detection, load balancing and middleware [41].

Generally engineering autonomic capability into legacy systems involves providing an environment that monitors sensors to the system and provides adjustment through effectors thus creating a control loop.

One such infrastructure is KX (Kinesthetics eXtreme) which runs a lightweight decentralized easily integral collection of active middleware components tied together via a publish-subscribe (content-based messaging) event system [41]. Astrolabe may be used to automate self-configuration, monitoring and to control adaptation [42].

DIOS provides mechanisms to directly enhance traditional computational objects/components with sensors, actuators, rules, a control network, management of distributed sensors and actuators, interrogation, monitoring and manipulation of components at runtime through a distributed rule-engine [43].

5 Conclusions

In this short discussion paper, we have presented the concept that the successful creation of Autonomic Systems will require a fusion of Soft Computing and Hard Computing.

Individual components or tools may not necessary require the fusion but the overall system requires the real world tolerance of imprecision, uncertainty and partial truth from Soft Computing along with the stability resulting from highly predictable solutions and low computational burden of hard practical algorithms of Hard Computing.

The paper focused on a brief review of emerging autonomic applications that either show the first signs of containing a Hard and Soft Computing fusion or would benefit from such. At this stage probabilistic reasoning is receiving the greatest attention while fuzzy logic does not explicitly appear to be utilized in early autonomic developments. Yet the inclination is that it would certainty benefit for instance self-healing

In the future Autonomic Computing may not only benefit from a fusion but also become the approach for Hard and Soft Computing fusion applications to manage themselves and adapt to their changing circumstances.

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