Autonomic Systems

Engineering Self-Management into Computer-Based Systems

Kumulativ Dissertation

zur Erlangung des Grades eines

Doktor der Ingenieurwissenschaften

der Technische Universität Dortmund
an der Fakultät für Informatik

von

Roy Sterritt

Dortmund

2025

Tag der mündlichen Prüfung:	03.03.2025
Dekan:	Prof. Dr. Jens Teubner
Gutachter:	Prof. Dr. Bernhard Steffen – TU Dortmund
Gutachter:	Prof. Dr. Mike Hinchey – University of Limerick
Gutachter:	Prof. Dr. Martin Wirsing – Ludwig-Maximilians-Universität München

Fakultät für Informatik
Technische Universität Dortmund
Dortmund, Deutschland

Acknowledgement

Special Thanks to …

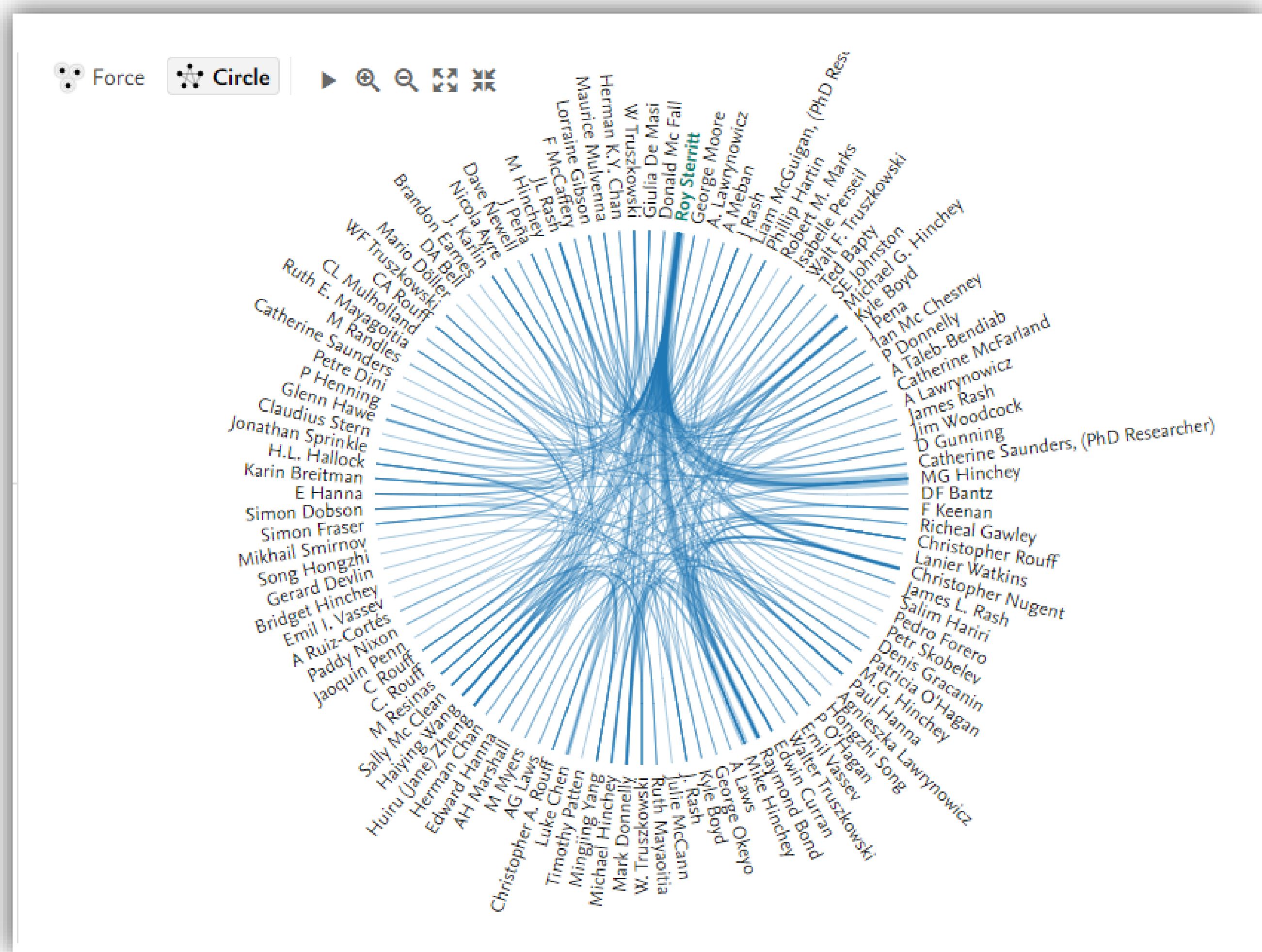
Where to start with special thanks on a Cumulative PhD thesis that spans, if not quite a career, but 20+ years' timeline of Autonomic Computing! Firstly, I would like to thank my supervisors Prof. Bernhard Steffen at the TU Dortmund University and Prof. Mike Hinchey at the University of Limerick, for the encouragement and opportunity to make this happen at last! Also the PhD Commission who have spared their valuable time to review this work.

As a member of Faculty at Ulster University, I had the gracious opportunity to connect with esteemed researchers worldwide, whom I'd like to extend my thanks to all my Co-Authors over the years (not all fitted into the image below!).

Extra special thanks must go to my wife, Donna, and son, Robbie, who have been incredibly supportive of me throughout the stages of my academic career, as they have been in everything else.

And of course, my mum who shaped the direction of my life without ever realising. If I hadn't received a ZX Spectrum for Christmas one year from "Santa", or been allowed to go age 11 to the US for the 8 week summer to stay with an unknown Irish-American family (Children of "the Troubles" / Project Children scheme) and there introduced to a "home PC" and wider awakening of professional ambition, none of this would have happened.

Co-Authors



Abstract

The complexity of today's and tomorrows' computer-based/cyber-physical systems-of-systems, consisting of very large numbers of elements, must be increasingly autonomous in order to carry out their complex tasks without constant human input. To reach those increasing levels of autonomy, the elements themselves must have the capability to self-manage, that being; self-configure, self-heal, self-optimise and self-protect through the abilities of self-awareness, self-situation (context and environment-awareness), self-monitoring and self-adjusting. This self-management specialisation of Autonomy, is Autonomicity, or the field of Autonomic Computing.

The accumulative contribution of this thesis is several-fold;

- adding to IBM's Autonomic Computing initiative by specifying the self-* properties as an Autonomic Computing quality tree and redefining the Autonomic Element and Architecture with these self-* properties and tighter scoping engineering rules;.
- by engineering dynamics within autonomic responses and multiple loops of control, such as reflex reactions among the autonomic managers and architecture through "Pulse Monitoring" and the associated artifact Pulse Monitor (PBM) to provide that autonomic reflex reaction;
- engineering such developments to Autonomic Personal Computing;
- engineering such to NASA and their future (SWARM based) concept missions;
- engineering such to Autonomic Communications;
- 'Inventing' the field of Apoptotic Computing, inspired by biological cellular pre-programmed 'self-destruct' behaviour, as the ultimate security/trust mechanism for Autonomic Systems.

All of these have added to the "<u>vision</u>" of Autonomic Computing, as assessed by IBM and the field's top-cited researcher.

This mix of Autonomic Computing, Autonomic Communications and Apoptotic Computing leads to a more general umbrella term of Autonomic Systems. Sterritt's 20+ years of Autonomic Computing research with academia and industry has led to more 'Engineering Self-Management into Computer-Based Systems' than can be covered in this cumulative thesis, such as; Autonomic Robotics, Apoptotic Robotics, Autonomic Cloud, Autonomic Swarms, Autonomic Cybersecurity, Autonomic Ambient Assisted Living, Autonomic Grid, Autonomic Business Grid, Autonomic Analytics… so much so that *Autonomic-** becomes the norm with a

hypothesis that ‘all Computer-Based Systems Should be Autonomic’. This view results in many future paths for this research, both in improving the paradigm itself and applying/engineering it to other fields. That said, the last 20+ years of Autonomic Systems (AS) has been mostly an (Software and Systems) Engineering accomplishment. As a field, its next level future growth may be part of the latest A.I. incarnation – Generative AI, as it evolves towards Artificial General Intelligence (AGI). Essentially, AS may be considered advanced automation. Gen-AI AS may provide accelerated AI automation in the next decade performing domain-bounded tasks that exhibit three fundamental characteristics: autonomy, learning, and agency and have an equivalent level of industrial success as Gen-AI.

Attached Publications

Parts of this dissertation were already published in cooperation with other scientists. These publications with comments on my participation are listed below.

Autonomic Computing

1. R. Sterritt, "Autonomic Computing". In: *Innovations of Systems and Software Engineering: A NASA Journal*, **1**, pp79–88, 2005.

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: *IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems)*. 36(3), pp. 304-314, May 2006.
Sterritt's contribution was Pulse Monitoring, to provide a biological inspired reflex reaction in autonomic/self-managing architectures, to Dave Bantz's (IBM TJ Watson Center) vision of Autonomic Personal Computing.

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: *Science of Computer Programming.* 61(1), pp. 48-57, Jun 2006.
The presented ideas were discussed amongst all authors. Sterritt's contribution was expertise in Autonomic Computing, added to the NASA computer scientists' expertise in engineering the Space missions.

Autonomic Communications

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: *Engineering Applications of Artificial Intelligence.* 17, 7, p. 727-739, Oct 2004.

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: *Advanced Engineering Informatics*. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015
The presented ideas were discussed amongst all authors. Sterritt held a BT Research Fellowship in 2003, and his contribution was Autonomic Computing and Pulse Monitoring

added to the BT engineers (Gunning & Henning) expertise on BT's Unified Fault Management (UFM) architecture.

Apoptotic Computing

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: *Computer.* 44(1), pp. 59-65, Jan 2011.

Autonomic Systems

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: *Journal of the British Interplanetary Society.* 73, 11, p. 397-408, Nov 2020.

This is a "big picture" paper summarising some of Sterritt's supervised PhD researchers (Saunders, Doran, Gama, McGuigan), work on Autonomic Systems {AComp, AComms, ApopC} related to NASA original work with co-supervisors (Wilkie, Hawe).

Abbreviations

AC	Autonomic Computing
AComp	Autonomic Computing
AComms	Autonomic Communications
ACF	Autonomic Communications Forum
AE	Autonomic Element (AE = AM+MC)
AGI	Artificial General Intelligence
AI	Artificial Intelligence
AM	Autonomic Manager
ANTS	Autonomous Nano-Technology Swarm
APC	Autonomic Personal Computing
ApopC	Apoptotic Computing
AS	Autonomic Systems
BT	British Telecom
DS1	Deep Space 1
FTC	Fault Tolerant Computing
Gen-AI	Generative AI
GSFC	NASA Goddard Space Flight Center
HBM	Heart-Beat Monitor
IBM	Industrial Business Machines
I.T.	Information Technology
I/T	Information Technology [sic]
LARA	NASA ANTS concept Lander Amorphous Rover Antenna (LARA)
MAPE	Monitor, Analyse, Plan and Execute
MAPE-K	Monitor, Analyse, Plan and Execute / Knowledge
MC	Managed Component
NASA	National Aeronautics and Space Administration
OGSA	Open Grid Services Architecture
PAC	Personal Autonomic Computing
PAM	NASA ANTS concept Prospecting Asteroid Mission
PBM	Pulse Monitor (extension of HBM)
SARA	NASA ANTS concept Saturn Autonomous Ring Array
Self-*	Self-properties, often meaning beyond self-chop
Self-CHOP	Self-Configuring; Healing; Optimizing; Protecting (IBM's AC vision)
Self-Star	*See Self-**
Selfware	Self-managing software / hardware.
SEL	NASA Software Engineering Laboratory
TC-AAS	IEEE Technical Committee on Autonomous & Autonomic Systems
TF-AAS	IEEE Task Force on Autonomous & Autonomic Systems
UFM	BT's Unified Fault Management architecture

Contents

Table of Contents

Table of Figures

1. Introduction

In 2001, IBM Senior Research Vice President Paul Horn set forth the idea of Autonomic Computing (AC) in a keynote to the National Academy of Engineers [1] at Harvard University. The Autonomic Computing Manifesto was released immediately afterwards ("Autonomic Computing: IBM's Perspective on the State of Information Technology") and white papers followed [2].

Figure 1-1 IBM's Call to Industry & Academia - Autonomic Computing

"The Information Technology (I/T) [sic] industry loves to prove the impossible possible. We obliterate barriers and set records with astonishing regularity. But now we face a problem springing from the very core of our success – and too few of us are focused on solving it."
"More than any other I/T [sic] problem, this one – if it remains unsolved – will actually prevent us from moving to the next era of computing. Interestingly enough, it has little to do with the usual barriers that preoccupy us."

"It's not about keeping pace with Moore's Law, but rather dealing with the consequences of its decades-long reign. It's not directly related to how many bits we can squeeze into a square inch, or how thinly we can etch lines in silicon. In fact, a continued obsession with the smaller/faster/cheaper triumvirate is really a distraction."

"It's not a barrier of "machine intelligence," either, that threatens our progress. It has less to do with building "thinking machines" that embody the popular conception of artificial intelligence (AI) than automating the day-to-day functioning of computing systems. It may sound odd coming from the creators of Deep Blue, but we don't really need a better chess-playing supercomputer – or sentient machines and androids programmed to love and laugh – to overcome the largest obstacle standing in our way."

"The obstacle is complexity. Dealing with it is the single most important challenge facing the I/T industry. ***It is our next Grand Challenge.***" [1].

Clearly almost 25 years later we have not suffered the I/T melt-down predicted by IBM, was it Autonomic Computing that derailed this? Further detail on the Autonomic Computing vision and field will be presented in Chapter 2 including the author contributions beyond that initial IBM vision.

1.1 Scientific Contributions

Sterritt's scientific contributions covered in this dissertation

- Adding to the vision of Autonomic Computing.
- Autonomic Computing quality tree and alternative Autonomic Element and Architecture with these *self** properties from the AC tree, including better scoping refinement.
- Dynamics within autonomic responses and multiple loops of control, such as reflex reactions among the autonomic managers and architecture.
- Pulse Monitoring and the associated artifact (PBM) to provide that reflex reaction.
- Applying this to Autonomic Personal Computing.
- Applying this to NASA and their future (swarm-based) concept missions.
- Applying such to Autonomic Communications, in particular PBM.
- 'Inventing' Apoptotic Computing, inspired by biological cellular 'self-destruct' behaviour.

Sterritt's contributions have inspired other scientists to work on related research and to further explore the potential. Most notable are probably Sterritt's supervised PhD researchers which are briefly highlighted at the end of Chapter 3 and in Chapter 7, with research on Autonomic and Apoptotic Robotics, Autonomic and Apoptotic CubeSat Capability Model and further developments on the Autonomic-ANTS swarm concept mission. Kephart, the author of the most cited publication in the AC field, notes Sterritt's contributions in his 2011 Keynote assessment of the first decade of AC [17]. Research collaboration with NASA, IBM, BT, Core Systems and others, have further inspired them in their developments within and beyond the AC field.

As [103] expresses;

"What is "scientific contribution"? Perhaps the most popular understanding is: (1) the added scientific value of the published researcher's results and (2) its impact on obtaining new

scientific results registered by corresponded citations. It is very difficult to measure the added scientific value. Because of this, in recent years it became very popular to measure the second part – the citations".

This thesis attempts to do the former concerning the attached publications, but resorts to the latter at times due to this difficulty.

1.2 Overview

Chapter 2 reviews the Autonomic Computing Initiative both from IBM's perspective [1][2] and Sterritt's additions to it [3], concluding with some perspective from IBM's Kephart [17].

Chapter 3 presents Sterritt's Autonomic Pulse Monitoring and the PBM construct, as a means to add a biologically-inspired reflex reaction to the AC architecture / toolkit, along with a review of work with IBM T.J. Watson Center's Bantz on Autonomic Personal Computing [4].

Chapter 4 reviews work with NASA's Software Engineering Lab and in particular adding Autonomicity to the NASA ANTS (Autonomous Nano-Technology Swarms) concept mission.

Chapter 5 reviews Autonomic Communications, in particular work with British Telecom (BT) adding Autonomicity via pulse monitoring to their Unified Fault Management architecture.

Chapter 6 reviews the invention of a specialized field "Apoptotic Computing", inspired by the biological cellular apoptosis pre-programmed self-destruct mechanism, where Sterritt's vision is this self-destruct mechanism is part of the Autonomic Systems (Computing and Communications) toolkit.

Chapter 7 concludes with briefly reviewing further research expanding on these concepts including by Sterritt's PhD researchers; Autonomic and Apoptotic Robotics, CubeSat Craft and further development on Autonomic-ANTS concept mission.

2. Autonomic Computing

2.1 IBM's Autonomic Computing Initiative

It is undeniable that Autonomic Computing was IBM's vision – launched as a call to industry and academia, with the hope that "It is our (I/T industry) [sic] next Grand Challenge" to deal with complexity. Where Sterritt adds to this vision in [3] will be reflected upon in this chapter.

"Autonomic computing (AC), as the name suggests, is a metaphor based on biology. The autonomic nervous system within the body is central to a substantial amount of nonconscious activity that allows us as individuals to proceed with higher level activity in our daily lives" [1]. Typical examples that have been highlighted are heartbeat rate, breathing rate, reflex reactions upon touching a sharp or hot object and so on [10]-[12]. The aim of using this metaphor is to express the vision to enable something similar to be achieved in computing, in other words, to create the self-management of a substantial amount of computing function to relieve users of low-level management activities, allowing them to place emphases on the higher-level concerns of running their business, their experiments or their entertainment.

The need and justification for AC is based on the ever-increasing complexity in today's systems. It has been expressed that the information technology (IT) industry's single focus has been on improving hardware performance, with software burgeoning with additional features to maximise on this additional capacity, at the neglect of other vital criteria. This has created a trillion-dollar industry with consumers consenting to the hardware–software upgrade cycle. Its legacy, though, is a mass of complexity within systems-of-systems, resulting in an increasing financial burden per computer (often measured as the TCO: total cost of ownership).

In addition to the TCO implications of complexity, complexity in itself is a blocking force to achieving dependability [13]. Dependability, a long-standing desirable property of all computer-based systems, integrates such attributes as reliability, availability, safety, security, survivability and maintainability [14]. Dependability was identified by both US and UK Computer Science Grand Research Challenges; "Build systems you can count on", "Conquer system complexity" [15] and "Dependable systems (build and evolution)" [16].

The autonomic initiatives offer a means to achieve dependability while coping with complexity [13].

Initial reaction by some to the autonomic initiative was “is there anything new?”, and to some extent, this question can be justified as artificial intelligence (AI) and fault tolerant computing (FTC), among other research disciplines, in which many of the envisaged issues within AC have been researched for many years. For instance, the desire for automation and effective robust systems is not new; in fact, this may be considered an aspect of best-practice systems and software engineering.

Similarly, the desires for system self-awareness, awareness of the external environment, and the ability to adapt are also not new, being major goals of several fields within AI research. What is new is AC’s holistic aim of bringing all the relevant areas together to create a change in the industry’s direction; *self-ware* instead of the hardware and software feature upgrade cycle of the past that created the complexity and TCO quagmire. Yet, a danger lies in that the self-* properties may just become the next marketing cycle of features–*autonomics inside*, and ultimately, AC would fall prey to the public impression of not meeting perceived expectations.

As such, it must be kept in the foreground that this is a long-term strategic initiative with evolutionary deliverables enroute.”

2.2 Sterritt’s Contributions to the Autonomic Computing Initiative

Upon reflection of [3] from 2005, the first commentary that stands out is “Yet, a danger lies in that the self-* properties may just become the next marketing cycle of features – *autonomics inside*, and ultimately, AC would fall prey to the public impression of not meeting perceived expectations … this is a long-term strategic initiative …” Could be considered from a 20+ years later perspective, that this did indeed come true – and damaged ACs development as a field, but perhaps that’s best left to bigger picture conclusions, and focus here specifically should remain on Sterritt’s scientific contributions.

Even in this introduction to AC in [3], there is a difference in emphasis from IBM. Instead of AC just being presented as the solution to Complexity, Sterritt presents it, perhaps with more academic foundations, as a means to achieving Dependability, based on Randell’s research. This was explored in the cited 2003 conference paper “Autonomic Computing - a means of achieving dependability?” [13], which from Kephart’s first decade 2011 keynote

[17], was the fourth most cited 2003 paper on AC (sixth in AC two decades on, 2021 data [18]).

This difference with or refinement of IBM's vision follows ("What is Autonomic Computing?" in [3])."IBM, upon launching the call to the industry, voiced the state of the industry's concerns as complexity and TCO. They presented the solution to be AC, expressed as comprising eight elements [1];

– Possess system identity—detailed knowledge of components
– Self-configure and reconfigure—adaptive algorithms
– Optimise operations—adaptive algorithms
– Recover—no impact on data or delay on processing
– Self-protection
– Be aware of environment and adapt
– Function in a heterogeneous world
– Hide complexity

These eight elements can be expressed in terms of properties that a system should have to constitute Autonomicity [13]."

Sterritt, realising that these 8 elements are a mixture of aims and solutions (the *what's* and *how's*), had re-presented this as an "Autonomic Computing properties tree", also first published in 'AC-a means of achieving dependability?" [13]. Interestingly, this AC Tree has been spotted in publications attributed to IBM and not Sterritt.

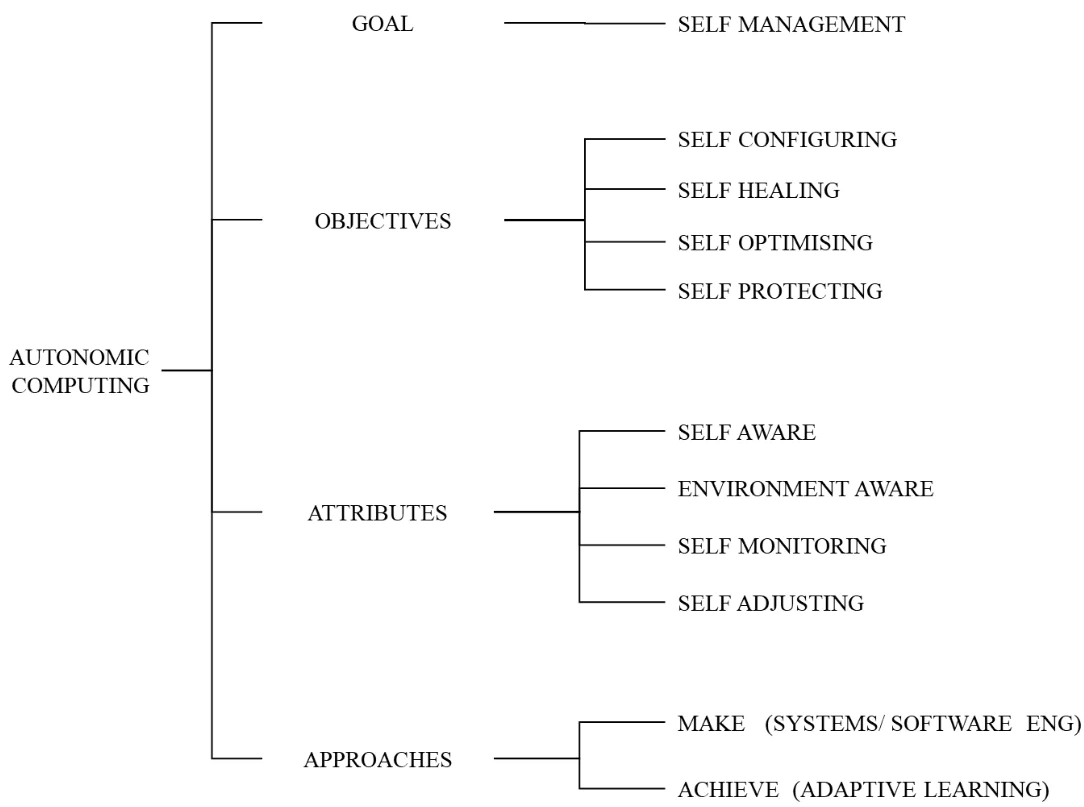


Figure 2-1 Sterritt's Autonomic Computing Tree [13][3]

See [3] for a fuller discussion on the properties in Figure 2-1.

IBM in their white paper [2] had presented a closed feedback control loop "Autonomic Element" (AE) as a MAPE or MAPE-K loop, so named after the elements in the Autonomic Managers control loop; Monitor, Analyse, Plan and Execute / Knowledge (Figure 2-2). Sterritt, although unashamedly inspired by IBM's AE, had spotted some issues from a Software Engineering perspective. Firstly, scoping rules. The AE manages its "element" through the MAPE-K – all good as its within its responsibility. Yet, the AE with its sensor and effectors into the External Environment implies that it also has *effect* (control, domain, scope) in the general case over other elements what should be beyond its management control (i.e., responsibility of other AEs).

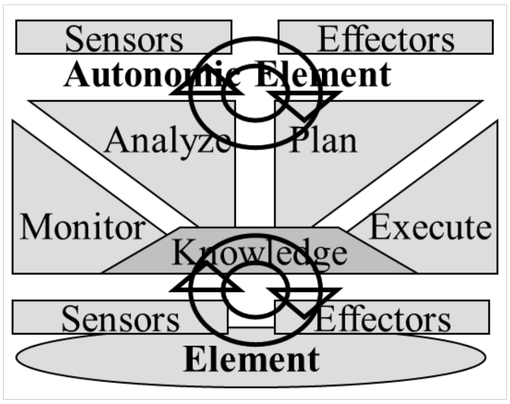


Figure 2-2 IBM's Autonomic Element containing an Autonomic Manager, with the MAPE-K feedback control loop self-managing the Manged Component (Element) and External Environment (via Sensors and Effectors).

The AC paradigm has a leaning more to a peer-to-peer paradigm (even if practically, often a client-server hierarchical paradigm is implemented), where each element has its own AE (as opposed to, say, a FTC approach of a 'watch dog' single manager having domain over many elements). In this approach, the autonomic elements co-operate together to achieve self-management of the system (note Autonomic Communications channel in Figure 2-3).

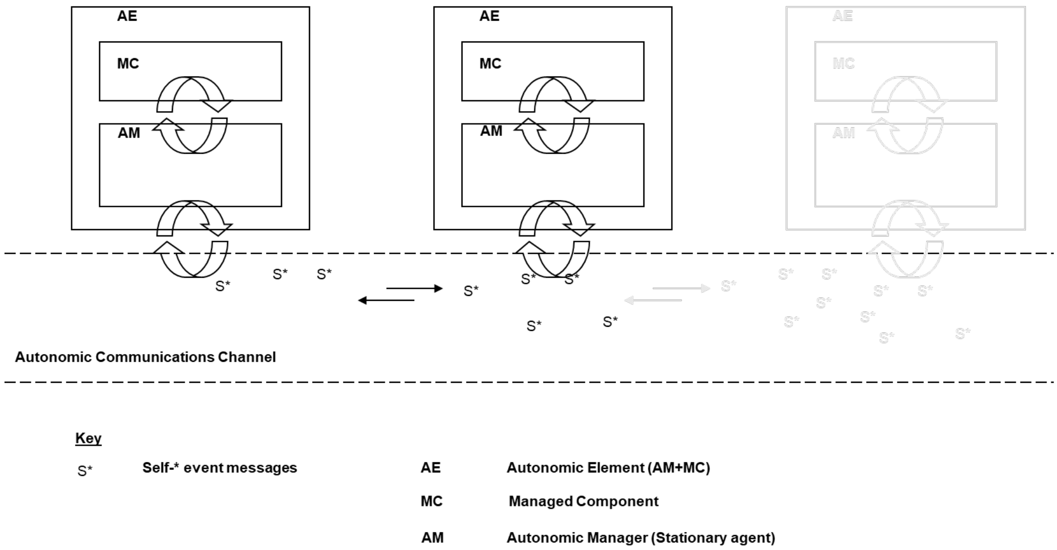


Figure 2-3 The Autonomic Environment, incorporating cooperating Autonomic Elements to achieve self-management.

As such, the implied sensors and effectors control loop in the MAPE-K into the external environment should be beyond the scope of that AE to make *effects.* At most it should only communicate with the AE that does have ownership (or, if unknown, broadcast the issue), a.k.a. co-operation between many AEs to achieve self-management of the system (Figure 2-3).

Therefore, a distinction in Sterritt's architecture view of the AE from IBM's (Figure 2-4) is that the control loop terms follow those of the Autonomic Tree (instead of "MAPE"), and make explicit that the only effect the AM can have on the External Environment is AM to AM communications (enforcing scoping/ownership/control rules).

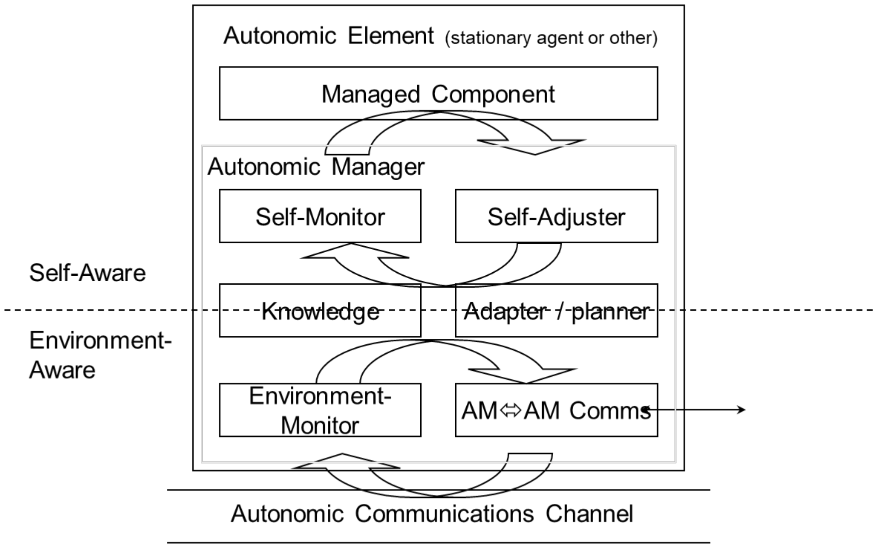


Figure 2-4 Sterritt's version of the Autonomic Element (AE) consisting of an Autonomic Manager (AM) and managed component (MC)

Another distinction in Sterritt's architectural view of the AE from IBM's, was the introduction of speeds of response – . that is, a literal biological inspiration from an "autonomic response" – a reflex reaction. "The autonomic environment requires that autonomic elements and, in particular, autonomic managers communicate with one another concerning self-* activities to ensure the robustness of the environment. Figure 2-4 and Figure 2-5 views an AE with the additional concept of a pulse monitor—PBM (an extension of the embedded system's heart-beat monitor (HBM), which safeguards vital processes through the emission of a regular 'I am alive' signal to another process) with the capability to encode health and urgency signals as a pulse [19], "I am healthy" in Figure 2-5. Together with the standard event messages on the autonomic communications channel, this provides dynamics within autonomic responses and multiple loops of control, such as reflex reactions among the autonomic managers [21].".

Pulse monitoring and the PBM was first proposed by Sterritt in 2003 at conferences, in [20] as part of an Autonomic Computing Environment, and in [19] as a part of the Autonomic Grid, and then added to the wider AC contributions in [3]. This was developed further and will re-appear in other contexts as scientific contributions in later chapters.

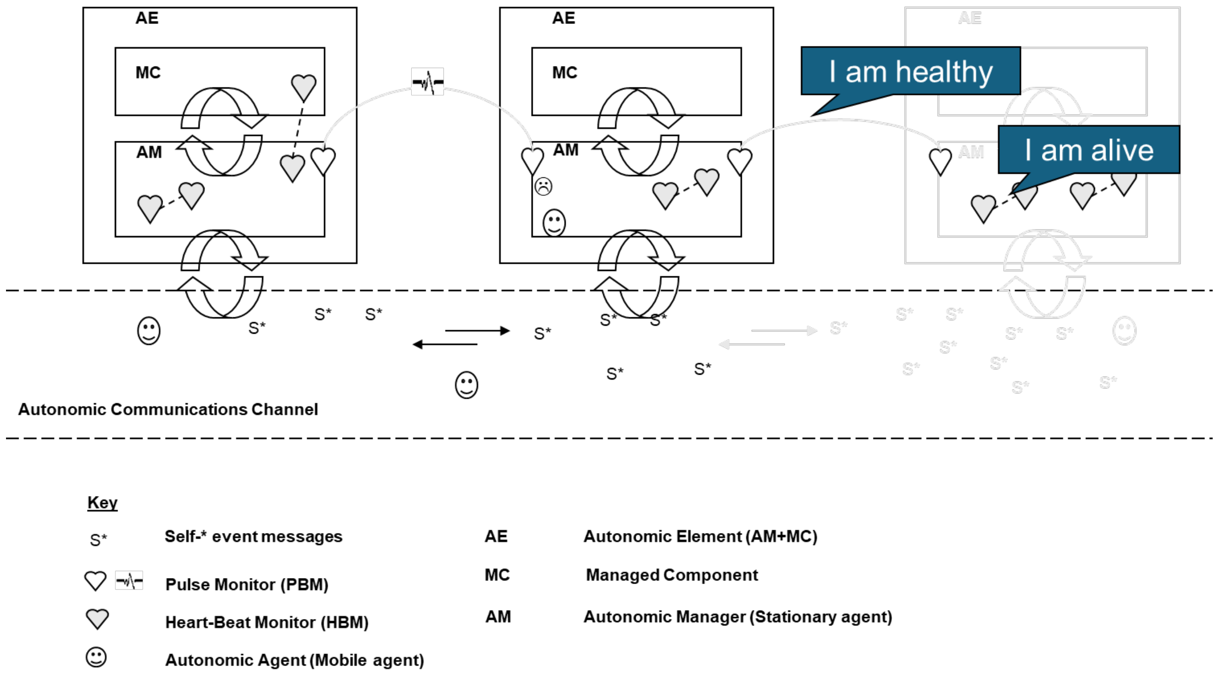


Figure 2-5 Sterritt's logical view of the Autonomic Environment, incorporating cooperating different dynamics of autonomic responses via pulse monitoring.

2.3 Sterritt's Contribution to the Autonomic Computing *Vision*

In 2011, IBM's Jeff Kephart, the co-author of the most widely cited article in the field of autonomic computing, gave a keynote "Autonomic Computing: the first decade" [17]. In this Keynote, several relevant points to the work report here were made and a summary follows.

This chapter's journal publication [3], had cited contributing conference submissions [12], [13],[19], [20] from the first and second years of AC, namely 2002 & 2003. These were cited in Kephart's keynote 1st decade data that;

- [12] "Towards autonomic computing: effective event management" ranked 4th in 2002's papers with 84 citations.
- [13] "Autonomic Computing - a means of achieving dependability?" ranked 4th in 2003's publications with 108 citations.
- [20] "Towards an autonomic computing environment" closely followed [13], ranked 7th in 2003 with 104 citations.
- [19] "Pulse monitoring: extending the health-check for the autonomic grid", was ranked 28th in 2003's publications with 47 citations.

Sterritt updated Kephart's 2011 analysis in 2021 [18] with two decades of AC data, and found that; [20] was 10th, [13] 27th and [12] 35th in the top 1000 Autonomic Computing publications.

The 'Autonomic Computing' NASA ISSE journal paper, summarised in this chapter [3], was ranked 5th in the top 1000 AC publications for the first two decades of the field with 126 citations. It may be an interesting debate, beyond this thesis, if citations or indeed ranks (via [22], the method employed by Kephart in [17]) are a good measure of a scientific contribution, but they are a measure [103]. Undoubtedly though, this early work in the emerging field of Autonomic Computing, led Kephart in his keynote to cite *Sterritt* as being one of 5 teams of researchers that contributed to the Vision of Autonomic Computing (Figure 2-6 and Figure 2-7).

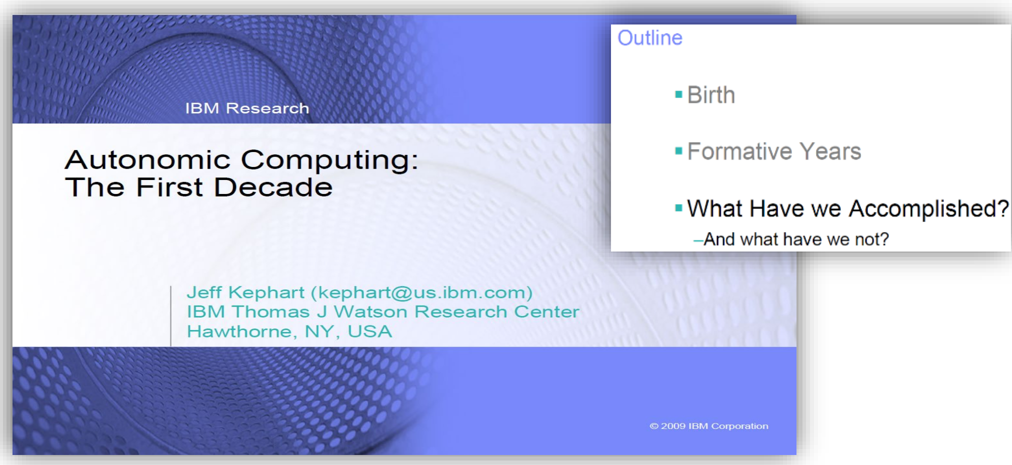


Figure 2-6 Jeff Kephart, "Autonomic Computing: The First Decade" ICAC 2011 Keynote June 15, 2011 [17]

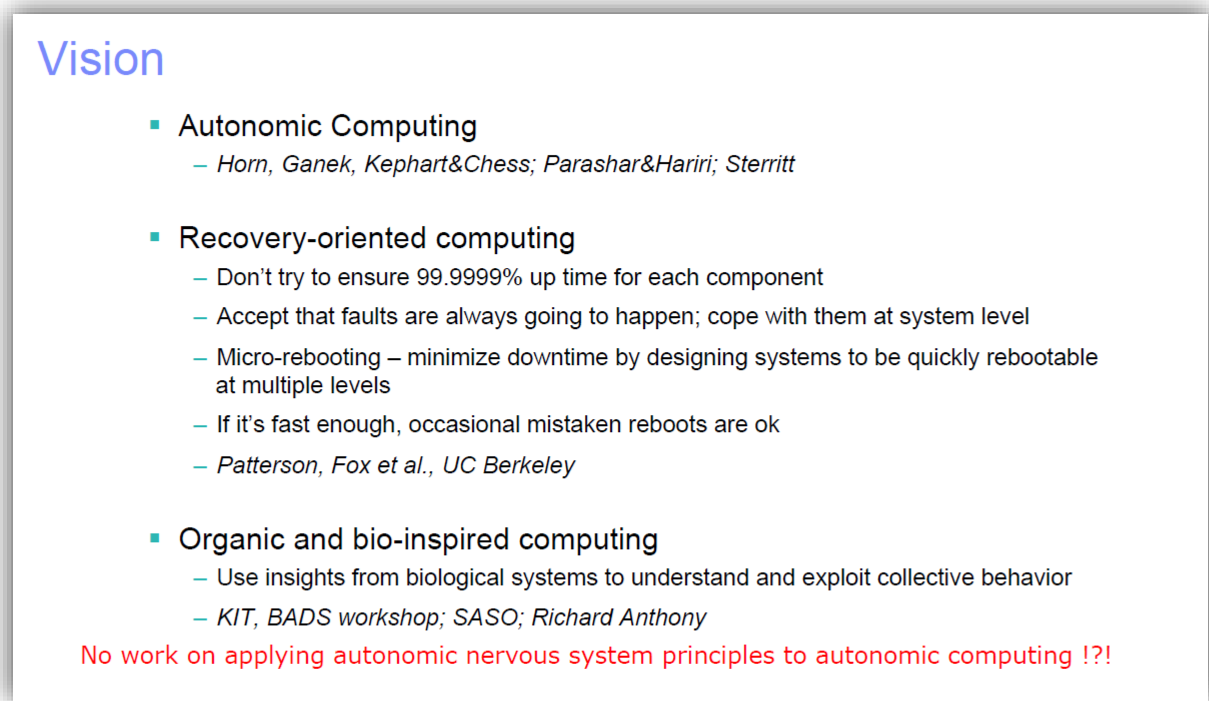


*Figure 2-7 Kephart's "Autonomic Computing: The First Decade" ICAC 2011 Keynote June 15, 2011 - **"Vision" contributions** [17]*

3. Pulse Monitoring, engineering a biological inspired reflex reaction

This chapter continues to focus on Sterritt's evolving scientific contribution to Autonomic Computing, but within a sub-context of "Autonomic Personal Computing" (APC), with Dave Bantz of IBM TJ Watson Center. The APC context gives the opportunity to further explore Sterritt's contribution of Pulse Monitoring, to engineer a biologically-inspired reflex reaction in autonomic/self-managing architectures. The attached IEEE Trans SMC-C journal publication [4] is co-authored with Bantz, and expanded on the conference papers [23][24];

3.1 Autonomic Personal Computing

The overall goal of the research reported in [4] was to improve the self-awareness and environment-awareness aspect of Personal Autonomic Computing (PAC) / Autonomic Personal Computing [25], to facilitate self-managing capabilities such as self-healing.

Personal computing offers unique challenges for self-management due to its multi-equipment, multi-situation, and multi-user nature. The aim is to develop a support architecture for multi-platform working, based on autonomic computing concepts and techniques. Of particular interest is collaboration among personal systems to take a shared responsibility for self-awareness and environment awareness.

Concepts mirroring human mechanisms, such as reflex reactions and the use of vital signs to assess operational health, are used in designing and implementing the PAC architecture. As proof of concept, this was implemented as a self-healing tool utilizing a pulse monitor and a vital signs health monitor within the autonomic manager. This type of functionality opens new opportunities to provide self-configuring, self-optimizing, and self-protecting, as well as self-healing autonomic capabilities to personal computing.

PAC shares the goals of personal computing—responsiveness, ease of use, and flexibility—with those of AC—simplicity, availability, and security [26]. Personal computing also creates some problems for the implementation of autonomic principles. In particular [25]; personal computing users are often, of necessity, system administrators for the equipment they use. Most are amateurs without formal training, who perform system operations infrequently. This reduces their effectiveness and typically requires them to consult with others to resolve difficulties.

Specifically, in terms of PCs used for client versus server applications, Table 1 highlights typical differences in the way an organization uses them, resulting in different management requirements for the two domains. As such it is not just the case that PAC is AC implemented on a PC—there are many other considerations related to the way these PCs are used. Added to this, personal computing is not just the PC—consider the pervasiveness of all manners of personal devices with such future directions toward wearable computing and smart homes.

Table 1 SERVER VERSUS CLIENT DIFFERENCES [4]

Servers	**Personal computers**
Hundreds	Thousands
Small set of applications	Open-ended set of applications
Controlled, stable configuration	Less-controlled, dynamic configuration
Fault tolerance through redundancy	Hardware redundancy not affordable
Multiple OS instances through virtualization	One OS instance
Dedicated service processor	All management via main processor
Trained managers	Manager/users
Fixed location	Transportable or mobile
Stable networking environment	Dynamic and intermittent when mobile

As such, the flexibility of the biological inspired autonomic nervous system *reflex reaction* pulse monitor was needed and utilized in this research for autonomic personal computing. The technical detail of the Autonomic Self-Healing Tool implementation including a Pulse Monitor (PBM), its design and results can be read in original papers [4][24], but as Sterritt's PBM construct is key not only to this (personal computing) application of the AC research, but to others that will follow, it is worth considering specifically it in more detail.

3.2 Autonomic Reflex Reactions via Pulse Monitoring and the Pulse Monitor (PBM)

Embedded System's *Heartbeat Monitoring (HBM)*

System management is typically based on events that are generated by a process when fault or problem conditions occur in that process. In embedded systems, the opposite is typically the case—a management action is taken when an independent process detects that an expected event has not occurred. An example is the fault tolerant mechanism of a heartbeat monitor (HBM); through a combination of the hardware (the timer) and software (the heartbeat generator) an "I am alive" signal is generated periodically to indicate all is well [27]. The absence of this signal indicates a fault or problem. Some embedded processors have a hardware timer which, if not periodically reset by software, causes a reset/restart. This allows a particularly blunt, though effective, recovery from a software hang. It may cause a perceptible outage in the system's function and may even cause lost data.

The approach of independent process monitoring offers the advantage that through continuous monitoring problem determination becomes a pro-active rather than a reactive process. Around the time AC 'came on the scene' the HBM was being adopted in system management architectures. In Grid Computing, the Open Grid Services Architecture (OGSA) has a facility referred to as the Globus HBM which is designed to detect and report whether registered processes are still alive or not [28], by detecting the absence of an heartbeat. The HBM may be considered a specific type of environment awareness, since from a system perspective these heartbeats provide awareness of the individual functioning elements [20] (Figure 3-1).

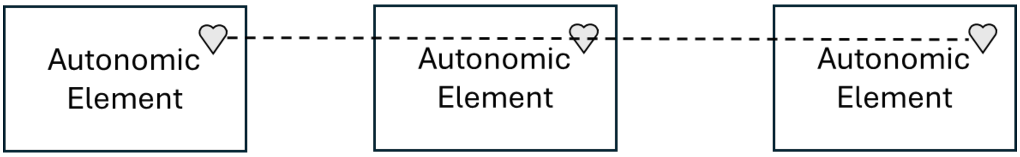


Figure 3-1 Heart-beat monitoring ("I am alive" signals).

NASA's *Beacon Monitoring*

Deep Space 1 (DS1) [29][31] was launched in July 1998 by the National Aeronautics and Space Administration (NASA). The beacon monitor was one of the twelve new technologies used in DS1. Its goal was to decrease the total volume of engineering telemetry, through reducing the frequency of use of the downlink Table 2 NASA BEACON TONE and the volume of data received per pass [30]. With beacon monitoring, the spacecraft assesses its own health and transmits one of four subcarrier frequency tones to inform the ground how urgent it is to track the spacecraft for telemetry [31]. Table 2 summarizes the tone definitions.

Table 2 NASA BEACON TONE

Tone	**Description**
Nominal	All functions as expected. No Need to downlink.
Interesting	Interesting – non-urgent event. Establish communications when convenient.
Important	Communications need to take place within timeframe or else state could deteriorate.
Urgent	Emergency. A critical component has failed. Cannot recover autonomously and intervention is necessary immediately.
No Tone	Beacon mode is not operating.

The two primary flight software innovations implemented through the beacon monitor were on-board engineering data summarization and beacon tone selection [30]. The tone selector module maps fault protection messages to beacon tone states. Transforms and adaptive alarm thresholds are the components to create top-level summary statistics, episode data, low-resolution “snapshot” telemetry, and user-defined data. These two components aim to minimize the number of false alarms. These approaches influenced Sterritt’s extended Autonomic Computing architecture, and initially adopted the taxonomy of urgency that they define.

Sterritt’s *Pulse Monitoring*

Figure 3-2 Pulse monitoring (“I am/am not healthy” signals).

A hybrid approach for the autonomic environment [12] is to use the urgency concept of the beacon monitor to turn the HBM into a pulse monitor—so instead of just checking the presence of a beat, the rate is also measured (Figure 3-2). The concept of the pulse monitor is based on extending the HBM construct (and as such the acronym is PBM not PM, to indicate this extension to the HBM – and indeed HBM functionality is still included in the PBM). The HBM itself provides a means to ensure a vital process may be safeguarded. The lack of a heartbeat will alert the designated remote HBM that the process has died (or indeed the communications themselves have failed). This relatively instant alert to the fact a process is no longer functioning enables immediate actions such as restarting the process and, as such, minimizing disruption.

Essentially, the HBM provides a vital construct, without which the system is relying on another process noticing that the process has died with no guarantee on how much time will have lapsed before this occurs, if it occurs at all.

Yet, vital as it is, essentially the HBM only informs if a process is alive or dead (assuming communications are working), not the processes’ actual health or state of being. Taking the biological analogy, the rate of the heartbeat indicates the current conditions within which the biological system is operating and determines strategies for components within the system (for example, increased heart rate may indicate increased blood flow through the body due to the individual changing from walking to running). Choosing the right rate for the pulses is key, since if they are too frequent, resources are consumed unnecessarily; if too infrequent, the latency of detection is too long and damage may propagate.

An important point to note from the HBM, and also from the Beacon Monitor, is the minimization of data sent, essentially only a signal is transmitted. Any move towards sending more information must not compromise this reflex reaction. As such, the tone or the beat must contain within it the urgency level.

This effectively may be used to provide a reflex reaction within the autonomic environment and adds the dual approach of reflex and healing, sharing responsibility for self-monitoring and environment monitoring among peers.

The pulse monitor has been recommended as an extension of the HBM for Grid computing [19], as a construct within an AM [12][20], and a reflex mechanism within a telecommunications fault management architecture [21], which will be explored later. The research reported here is utilizing the pulse monitor as a construct within the PAC architecture which specifically demonstrates self-healing. The demonstration self-healing tool operates in a P2P mode without any additional environment on top of the Windows OS.

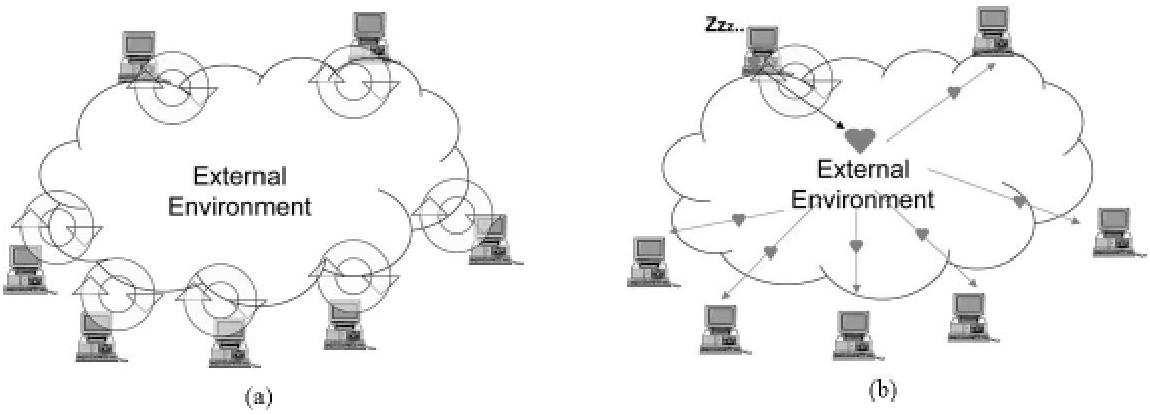


Figure 3-3 Reflex environment awareness

Reflex Self-Awareness

The PBM monitor may be used as a means to quickly (a reflex reaction) communicate the state of the individual self to other AMs (peers), i.e., through internal monitoring of a managed component vital signs (e.g., failing processes) give an indicator to the state of health and used to bring about a change in pulse being emitted from the self. This information could then be used in various ways - for instance, to enable remote recovery strategies or avoid allocation of workload to that element experiencing difficulties.

Reflex Environment Awareness

The PBM may also be used for environment awareness. In this scenario, the pulse becomes a shared value of environment health as opposed to an individual's health value (Figure 3-3). From Figure 2-4 it is clear each machine (the managed component) must have its own internal monitoring but it is also clear that each AM needs to monitor the external environment (at least two logical control loops per AE). In a local P2P network in many circumstances it may be assumed (or defined) that the environment the peers are all monitoring is the same environment, resulting in a waste of resources through duplication [Figure 3-3 (a)].

To reduce this duplication, an individual peer or group of peers (e.g., the least busy PC or assigned PCs) may take on the monitoring role for the group [Figure 3-3 (b)]. Again, taking into account the required flexibility of personal computing, other peers must be ready to take on monitoring responsibilities should circumstances change (e.g., a laptop is removed from the peer group by the user departing the office). The role of the PBM in these circumstances is to provide a reflex reaction from the environment monitoring (external monitoring) peer to the non-environment monitoring peers to alert them to an environment situation.

The PBM utilized for environment awareness should be considered in addition to the self-awareness pulse mechanism, i.e., utilized to create a shared dynamic group environment awareness as well as individual self-protection.

See attached paper for the detail on the proof of concept PAC self-healing tool based on these principles.

3.3 Wider Context and Discussion

In terms of scientific contribution, pulse monitoring and the PBM construct still remain a relevant strategy for providing a reflex reaction in architectural and systems design. PBM will feature to some degree in each chapter in this thesis.

As highlighted by Kephart's 2011 keynote [17], a 2003 Sterritt PBM paper for extending the Autonomic Grid [19] was the first publication on the topic and one of the highest cited Autonomic papers of that year within the AC field. Then in Chapter 2 *Autonomic Computing*, as part Sterritt's contribution in [3] extensions to IBM's view, *Figure 2-5 Sterritt's logical view of the Autonomic Environment, incorporating cooperating different dynamics of autonomic responses via pulse monitoring.*

In Chapter 5 *Autonomic Communications*, pulse monitoring is utilized again, this time for Autonomic Communications with BT's communications architecture (*Figure 5-2 Autonomic*

Reflex Reaction via Pulse Monitoring, proposed additions to BT's UFM system architecture [7].). Pulse doesn't feature heavily in the next chapter with the NASA related attached publication [5] beyond a mention, but this was featured in other co-research patents/publications with NASA.

So how does Pulse monitoring fare for Autonomic Personal Computing? The self-healing tool itself for Personal Computing hasn't fared well timewise, but it was a proof-of-concept, so it was never intended it should. It highlighted the need for standards, for autonomic signals, communications, and for checkpointing to take place not only at the level of AM to processes running on the managed component, but also at the level of AM to AM. Allowing standard "autonomic signal" routes into processes would raise security issues if handled at the application level—yet this will need to be a part of the self-protection autonomic property.

On the other hand, Windows and Linux processes have a standard kill function and this is not considered a security issue. Basically, the infrastructure being considered is OS-like and therefore trusted. This implies all processes and OSes need to be designed with Autonomicity and self-managing capabilities in mind, i.e., capable of taking direction from the external environment. This not only raises issues of standards to achieve this but raises questions as to whether the current design and development tools meet the needs for developing process of this type. Recursive micro-rebooting is a promising non-expensive approach for self-healing [32][27], which fits directly with the concepts in this PAC reflex and healing research. It seeks to create software components (at various levels of granularity) that are "crash only," that is, self-healing is to reboot them, and to do so at as low a level as feasible so the user does not see the physical impact of an application restarting. Within a matter of years the Personal Computing Operating Systems were doing what the proof-of-concept attempted, automated recovery with proper checkpointing (just not calling it Autonomic!).

The contribution in pulse monitoring research is a way for AMs to share data and management decisions in a non-hierarchical way, even in an ad hoc manner. It permits one AM to monitor the health of other AMs without necessarily controlling them and even to reach decisions based on consensus. It opens up opportunities for the collaboration of AMs in a way that is less rigid than in current AC architectures. This style of AC is much more appropriate to personal and embedded computing because it supports the dynamic self-centred style exhibited by this type of computing. The reflex reaction notion is based on the need for a system to respond more quickly than it can respond after detailed analysis and planning of a comprehensive response.

Often, the first part of a comprehensive response can be pre-planned: in the case of virus infections the first step is to disconnect from the network. It has been observed that failures sometimes occur in recovery from virus infections, where the OS is reinstalled and is reinfected during the installation process itself. Recovery actions when connected to a network hosting a virulent virus infection have to be performed in less time than it takes to get infected.

Also, since comprehensive analysis in preparation for response may involve contacting neighbours and servers and waiting in their queues, the time to do this comprehensive analysis may be long. To address this requires research into the dynamics of infection, analysis, and recovery in order to supply bounds on the amount of time that a system can take before it starts to take action.

Obviously this body of work is Sterritt utilizing his own 'invention', autonomic inspired evolution of HBM+Beacon monitoring design / pattern, across his own research work in different applications / industries (and not all are covered above, for instance with IBM in 2012 for Cloud Computing [33] or Core Systems for biometric prison security systems [34]), but when discussing contribution, has there been an uptake of Pulse Monitoring beyond Sterritt?

This is hard to tell from citation data on Pulse Monitoring specifically, which is a degree of magnitude lower than that of the contributing publication featured Chapter 2 *Autonomic Computing* [3], although reader/download data is over 1k when combining IEEE and Sterritt's Institute repository (Pure) data. So is pulse too specialised (for instance cited here in "Personal Autonomic Desktop Manager with a Circulatory Computing Approach" [35]) to be a general construct of an autonomic environment? The sense Sterritt has from Autonomic conference presentations and publications he has seen over the years, is that researchers describe their use of this construct as heart-beats and not make the distinction from the extended pulse, and even when they do refer to it as pulse monitoring they don't cite this body of work, for instance [36] "*to facilitate the proactive monitoring, the individual spacecraft units exchange on a regular basis the so-called pulsebeat messages carrying useful information including the current health status of the sender. For example, each worker sends, on a regular basis, pulsebeat messages to the ruler of its group*".

Whether this is due to the fact Sterritt was so prolific, and chair of the IEEE Technical Committee on Autonomous & Autonomic Systems (TC-AAS) in those early years advocating *Autonomicity,* that this approach became synonymous with IBM's original AC vision or even NASA's ANTS and not Sterritt's research is not clear (mind you in this highlighted case, neither IBM or NASA ANTS researchers are cited either – probably shortage of paper space!).

Further contribution-wise, one of Sterritt's graduated PhD researchers, Dr Liam McGuigan (2023), extended pulse monitoring with his thesis "Autonomic Pulse Communications for Adaptive Transmission Range and Data Transfer in Decentralised Robot Swarms". The work in McGuigan's thesis makes a contribution to Autonomic Pulse Monitoring by considering a different use, where the pulse reports the position of a robot in a swarm, enabling a local swarm density to be calculated. Measuring the swarm density may then be used for adaptively adjusting the transmission range for local communication – assisting with autonomic self-managing properties such as self-configuring and self-optimising.

The External Examiner report on the work states "*This research investigates how principles of autonomic computing can be applied to swarm robotics, along with the development of a new communications protocol to enable the swarm to cooperate and adapt appropriately to perform various tasks effectively in a range of circumstances, and support the design and management of scientific missions, as demonstrated by applications to the foraging problem, subswarm formation and an interesting application to the NASA Prospecting Asteroid Mission, as well as some issues related to reduction in communication quality and robot loss. This is an extremely exciting area of research with potentially enormous long-term engineering significance, and it is a huge testament to the candidate's, his supervisors', and the School of Computing's abilities that they are so deeply engaged in research of this kind at the highest international levels.*" This is perhaps a case of quality over quantity engineering artifact contribution.

4. Autonomicity for future NASA exploration missions

This chapter focuses on the application of and further development of Autonomic Computing to and with some NASA exploration missions, through the NASA Software Engineering Laboratory (SEL) at Goddard Space Flight Center (GSFC), Maryland. For the purpose of this thesis, the attached publication for this chapter is [5] "Next generation system and software architectures: Challenges from future NASA exploration missions", published in Science of Computer Programming.

Future NASA missions will push the limits of current system and software architectures. Planned and concept NASA missions represent some of the largest, most ambitious, most challenging, and expensive software projects to date (at that stage in 2004/2005, estimates for the software component of the mission to Mars exceeded US$48 billion, which would make it the most expensive software project ever to be undertaken). These missions will exploit emerging concepts such as intelligent swarms, whereby large numbers of (relatively) heterogeneous and simple components will act in unison, analogous to swarms in nature, producing complex behaviours that could not be achieved without their emergent behaviour.

These missions must not only support fully autonomous behaviour, in order to exploit the benefits of this emergence, they must be survivable in deep space, which requires that they also exhibit autonomic properties. Current system and software architectures fail to meet the needs of such missions.

The major point that is brought out in this research [5] is the need for next generation system and software architectures, in which architectural components are, for instance, autonomous agents, in contrast to the majority of the current assumptions that the interactions of such components are relatively predictable, and that they communicate with one another in a predetermined way [5].

4.1 Self* in NASA missions

The term *selfware* has been coined to refer to the growing set of self-properties that are emerging in the Autonomic Computing and other related self-managing systems initiatives.

The initial set of properties defined by [1][38]—namely self-configuration, self-healing, self-optimization and self-protection (objectives: what is to be achieved) through self-awareness, self-monitoring and self-adjusting (attributes: how it is to be achieved)—has been expanded, and further properties are expected to be added to this ever-growing list. Additional monitoring constructs, such as pulse monitoring [19] and heart-beat monitoring, have also been proposed, along with biologically-inspired metaphors such as apoptosis and self-destruction [11][39] (this will be covered later in Chapter 6 *Apoptotic Computing*).

The autonomic computing initiative has firmly placed the goals of self-managing systems on the map through *self-** properties, yet a lot of the objectives were already emerging or residing in the field of autonomous systems prior to the 2001 launch of the initiative. In fact, one definition of "autonomous" is "autonomic" [40]. What the initiative brings to the fore is that every system should exhibit these self-* properties in order to cope with the ever-rising complexity and total cost of ownership, and not just be a specialized autonomous domain. This is in addition to a focus on self-management (*Autonomicity*) as opposed to self-governance (*autonomy*).

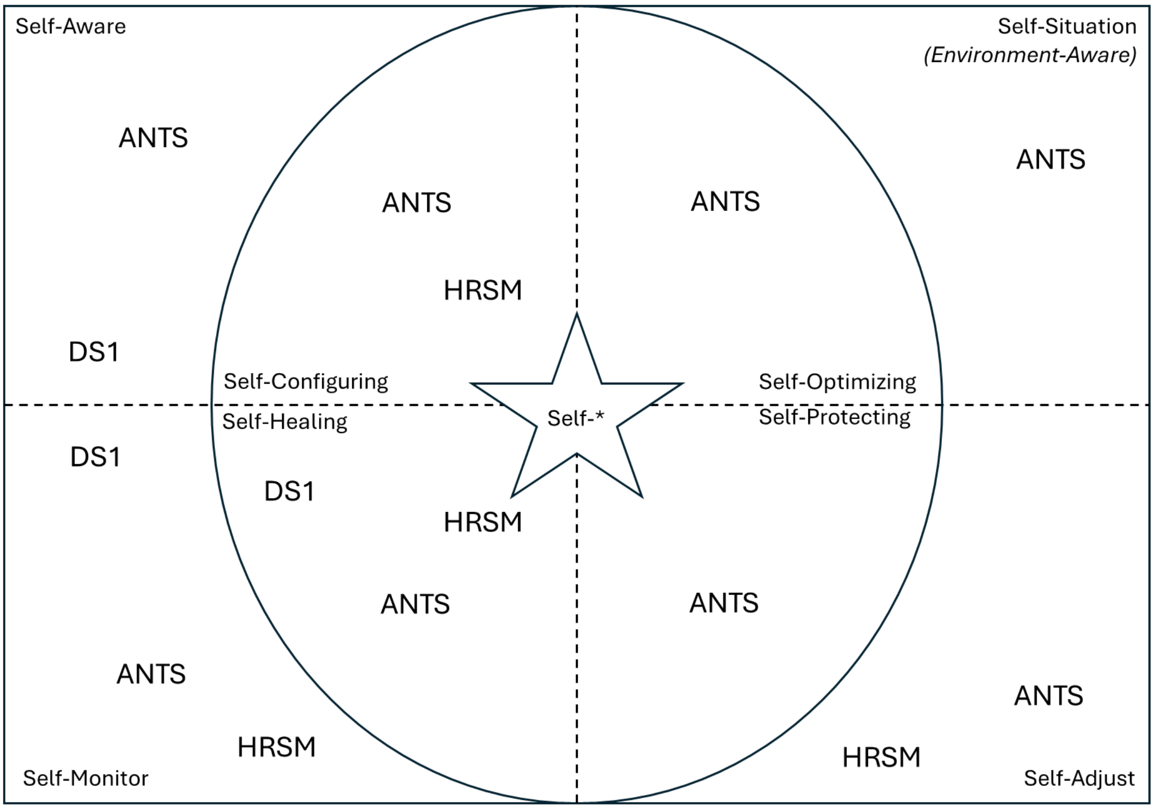


Figure 4-1 Evolution of self- properties in missions [5]*

NASA, addressing the realities of increasing deep space exploration and the goal of more versatile and cheaper missions, has been researching autonomy for some time now. This paper illustrates some of these self-* properties with reference to NASA missions (Figure 4-1). The challenge is to provide a suitable architecture for these in a cohesive, generic, and integrated fashion.

For more details on the missions in Figure 4-1 see the [5] and indeed [41]. The ANTS concept mission though became the defacto case study for Sterritt, and colleagues in NASA working on this Autonomic Computing research, as it offered a future (*some said Sci.Fi.*) that allowed the full exploration of Autonomicity and Autonomy. As such it is worth considering further.

4.2 The Autonomous Nano-Technology Swarm (ANTS) concept mission

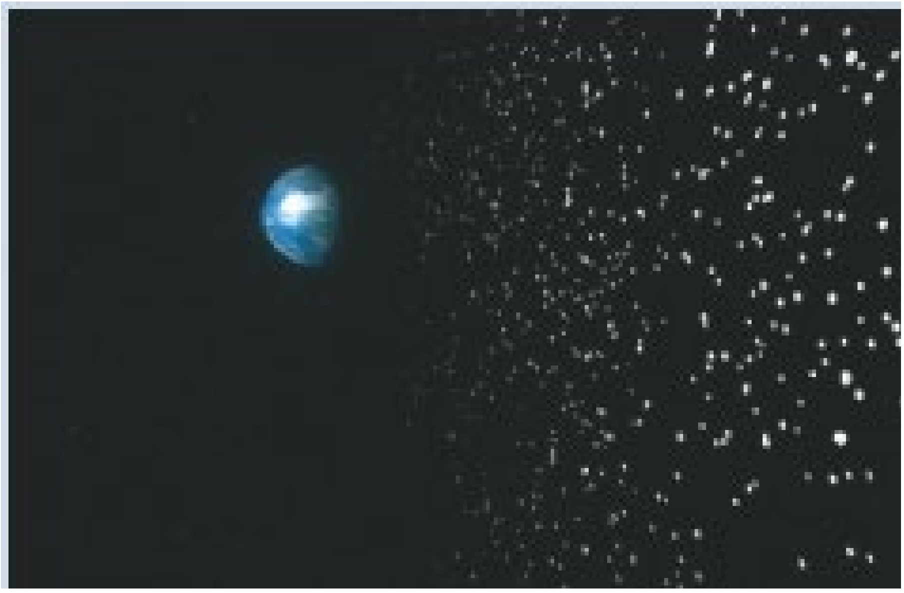


Figure 4-2 NASA's new space exploration paradigm calls for missions involving thousands of small spacecraft rather than a single large craft. Image courtesy of NASA.

Space exploration missions by necessity have become increasingly autonomous and adaptable. To develop more self-sustainable exploration systems, NASA is investigating the use of biologically-inspired swarm technologies [11]. As Figure 4-2 shows, the idea is that swarms of small spacecraft offer greater redundancy (and, consequently, greater protection of assets), lower costs and risks, and the ability to explore more remote regions of space than a single large craft.

The Autonomous NanoTechnology Swarm (ANTS) concept mission (originally at http://ants.gsfc.nasa.gov) was a collaboration between NASA's Goddard Space Flight Center and its Langley Research Center. It exploits swarm technologies and AI techniques to develop revolutionary architectures for both space craft and surface-based rovers.

ANTS [42]-[44] is a NASA *concept* mission; *a concept mission in NASA terms was 20-30 years in the future.* The concept involves the launch of a swarm of autonomous pico-class (approximately 1 kg) spacecraft that will explore, for instance, the asteroid belt for asteroids with certain characteristics (PAM sub-mission – Prospecting Asteroid Mission) [45].

ANTS consists of several concept sub-missions:

•The Saturn Autonomous Ring Array (SARA) consists of a swarm of 1,000 pico-class spacecraft, organized as 10 subswarms with specialized instruments, to perform in situ exploration of Saturn’s rings to better understand their constitution and how they were formed. SARA will require self-configuring structures for nuclear propulsion and control as well as autonomous operation for both maneuvering around Saturn’s rings and collision avoidance.

•The Prospecting Asteroid Mission (PAM) also involves 1,000 pico-class spacecraft but with the aim of exploring the asteroid belt and collecting data on particular asteroids of interest for potential future mining operations.

•The Lander Amorphous Rover Antenna (LARA) will implement new NASA-developed technologies in the field of miniaturized robotics, which could form the basis of remote lunar landers launched from remote sites, as well as offering innovative techniques to allow rovers to move in an amoeboid fashion over the moon’s uneven terrain.

The ANTS architecture emulates the successful division of labor exhibited by low-level social-insect colonies. In such colonies, with sufficiently efficient social interaction and coordination, a group of specialists usually outperforms a group of generalists. To accomplish their specific mission goals, ANTS systems likewise rely on large numbers of small, autonomous, reconfigurable, and redundant worker craft that act as independent or collective agents [42]. The architecture is self-similar in that ANTS system elements and sub elements can be structured recursively [44], and it has been proposed by Sterritt et.al to be autonomic / self-managing, with at least one AM per ANTS craft.

Figure 4-3 gives an overview of the ANTS PAM mission [46]. In this mission, a transport ship, launched from Earth, will travel to a point in space where gravitational forces on small objects (such as pico-class spacecraft) are all but negligible. From this point, termed a Lagrangian point (specifically L1), 1000 spacecraft, that have been assembled, will be launched towards the asteroid belt. Since each spacecraft has only solar sails to provide thrust for manoeuvring, collisions between spacecraft or with asteroids during operations are likely, and 60% to 70% of them are expected to be lost over the duration of the mission. Because of their small size, each spacecraft will carry just one specialized instrument for collecting a specific type of data from asteroids in the belt. As a result, spacecraft must cooperate and coordinate using a hierarchical social behaviour analogous to colonies or swarms of insects, with some spacecraft directing others.

To implement this mission, a heuristic approach was being considered that provides for a social structure to the spacecraft based on a hierarchy. Artificial intelligence technologies, such as genetic algorithms, neural nets, fuzzy logic, and on-board planners, were being investigated to assist the mission to maintain a high level of autonomy.

Crucial to the mission will be the ability to modify its operations autonomously to reflect the changing goals of the mission and the large delay and low bandwidth of communications links with Earth. Approximately 80% of the spacecraft will be workers that will carry the specialized instruments (e.g., a magnetometer or an x-ray, gamma-ray, visible/IR, or neutral mass spectrometer) and will obtain specific types of data. Some will be coordinators (called leaders) that have rules that decide the types of asteroids and data the mission is interested in and that will coordinate the efforts of the workers. The third type of spacecraft are messengers that will coordinate communication between the rulers and workers, and communications with the Earth ground station.

Once the swarm has reached the asteroid belt (2.5 years later) it will form sub-swarms under the control of a ruler, which contains models of the types of science that it wants to perform. The ruler will coordinate workers each of which uses its individual instrument to collect data on specific asteroids and feeds this information back to the ruler, which will determine which asteroids are worth examining further. If the data matches the profile of a type of asteroid that is of interest, an imaging spacecraft will be sent to the asteroid to ascertain the exact location and to create a rough model to be used by other spacecraft for manoeuvring around the asteroid. Other teams of spacecraft will then coordinate to finish the mapping of the asteroid to form a complete model [45].

In terms of self-* properties, the ANTS mission will exhibit almost total autonomy, and will also exhibit many of the properties required of an autonomic system [47] (see Figure 4-1 Evolution of self-* properties in missions). This section presents some examples of these properties, utilized independently and in cooperation, to achieve *selfware* [48].

Self-Configuring: The resources of ANTS must be fully configurable to support concurrent exploration and examination of hundreds of asteroids. Resources must be configured at both the swarm and team (sub-swarm) levels, in order to coordinate science operations while simultaneously maximizing resource utilization.

Self-Optimizing: Rulers self-optimize primarily through learning, and improving their ability to identify asteroids that will be of interest. Messengers self-optimize through positioning themselves appropriately. Workers self-optimize through learning and experience. Self-optimization at the system level propagates up from the self-optimization of individuals.

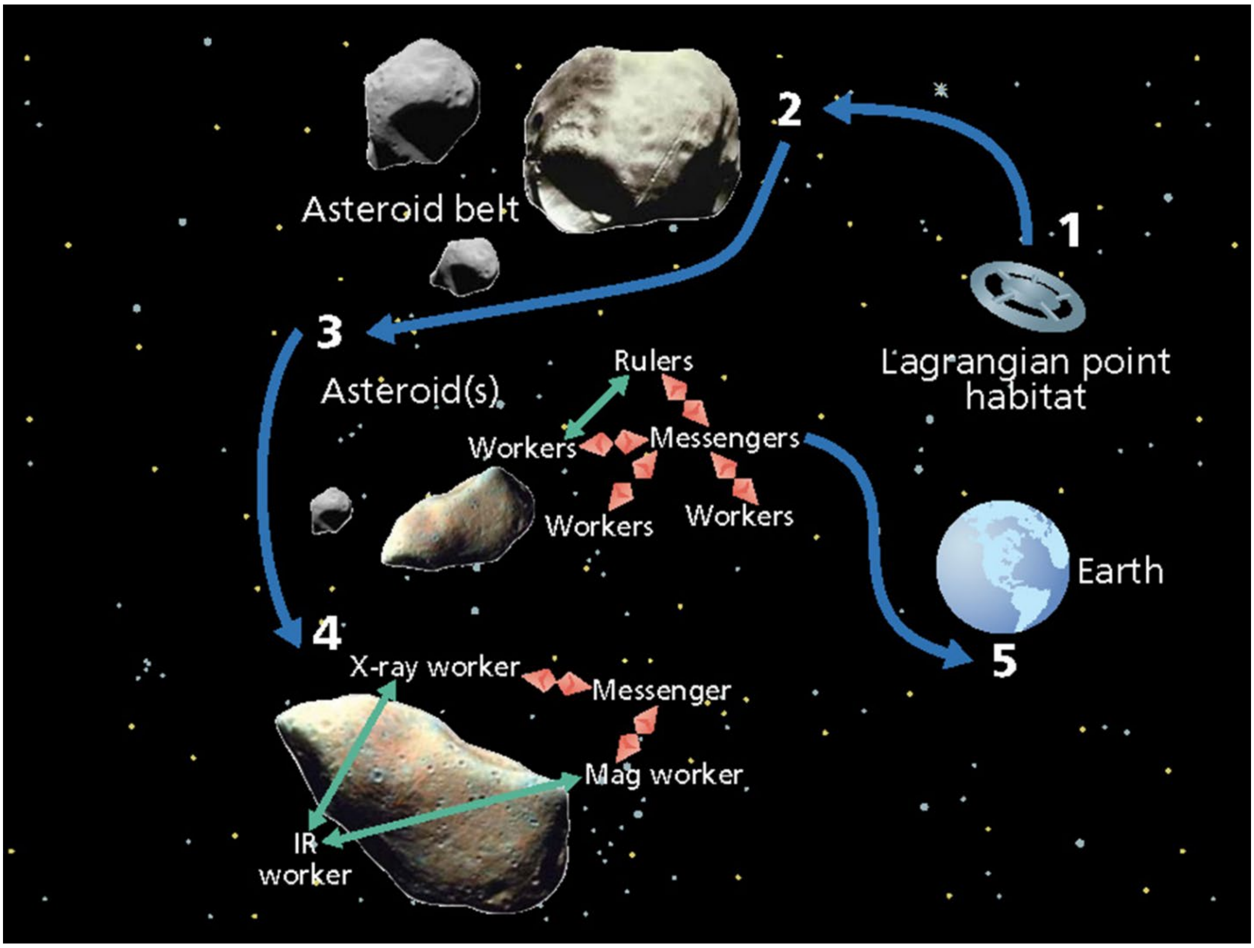


Figure 4-3 NASA ANTS mission concept

Self-Healing: ANTS must self-heal to recover from damage due either to solar storms or (possibly) to collision with asteroids or with other ANTS spacecraft. Loss of a ruler or messenger may involve a worker being “upgraded” to fulfil that role. Additionally, loss of power may require a worker to be killed off.

Self-Protecting: In addition to protection from collision with asteroids and other spacecraft, ANTS teams must protect themselves from solar storms, where charged particles can degrade sensors and electronic components, and destroy solar sails (the ANTS spacecrafts’ sole source of power). ANTS teams must re-plan their trajectories, or, in worst-case scenarios, must go into “sleep” mode to protect their sails.

ANTS must have these properties. The long duration of the exploration, the high radiation levels, and other risks to humans, mean that the mission must be unmanned. If the individual ANTS spacecraft were to be controlled by mission control, there would constantly have to be a human-in-the-loop, which would increase costs and limit the scope of future missions.

Moreover, there is a 15 to 30 minute delay between sending messages from mission control and their receipt by the spacecraft. Therefore, instructions from Earth could not be received in time to avoid collisions with asteroids or other spacecraft. Analogous constraints are exhibited by real-time mission critical systems in the commercial world.

Self-protecting/self-healing: Self-protection and self-healing are inextricably linked. Consider the human body: self-protection necessitates being self-healing. When the skin is cut, cells are displaced, and the body reacts (in time) using cell division to cause scabbing to protect the area until it fully heals via the growth of new cells [39].

Self-protection in ANTS occurs at both the macro (swarm) level and micro (individual spacecraft) level. A great problem for ANTS is potential damage to solar sails or instruments or other subsystems caused by solar storms.

Fortunately, advance warning of such activity can be given either by mission control, or by a spacecraft in the mission that constantly watches the solar disc for signs of an impending storm. Upon receiving such a warning, individual spacecraft will take appropriate action—selectively powering down subsystems and reorienting solar panels (which supply power to recharge batteries)—in an attempt to avoid damage.

In addition, individual spacecraft will protect themselves by attempting to avoid collisions with other spacecraft and with asteroids in the asteroid belt. Clearly this will not always be possible, and it is anticipated that spacecraft will regularly be damaged and even completely destroyed while engaged in asteroid observations.

Self-protection at the swarm level is required precisely because of this damage. Protecting the entire swarm, and ensuring that the mission continues, necessitates a form of self-healing. When spacecraft are damaged or lost, other spacecraft may take over their roles. For example, if a messenger, used for intra-swarm communication and for communication with mission control back on Earth, is destroyed, another spacecraft may take over that role. If a leader is destroyed, another spacecraft may be promoted to fulfil its role.

Collection of science data requires the use of specialized instruments (x-ray, mass spectrometer, magnetometer, etc.), as shown in Figure 4-4. Clearly if these are no longer available in the swarm, another spacecraft cannot simply be promoted to cover the loss. Autonomic behaviour at the swarm level would involve self-healing to avoid failure of the mission when losses of particular capabilities reaches a danger point. Swarm-level intelligence and self-awareness and environmental awareness will result in planning and action to cause the factory ship to assemble new spacecraft in a timely manner to compensate for losses.

Self-healing/self-configuring: Healing, too, requires a certain degree of self-configuration or self-reconfiguration. Again, consider the human body, and damage from a cut. As the skin heals, there is a certain degree of reconfiguration of the various layers, and in particular of the surface layers. Depending on how well this is performed by the body (and on how significant the damage was to start with), a certain degree of scarring may result.

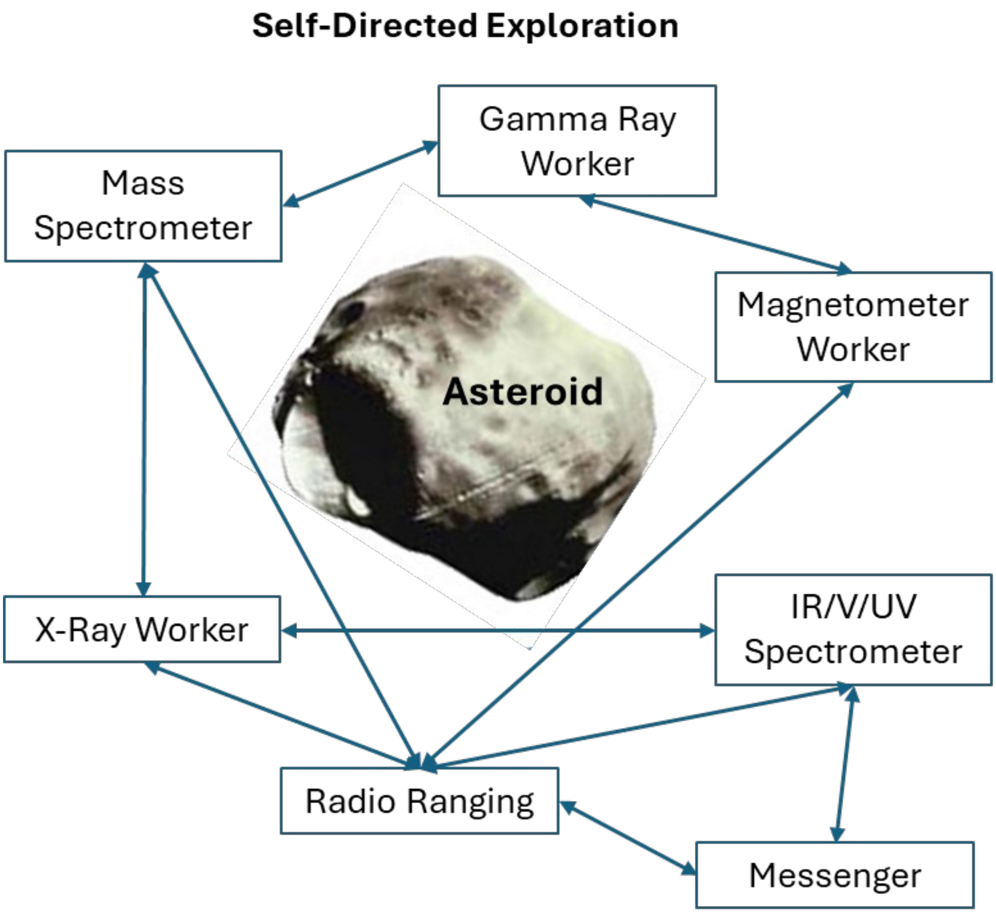


Figure 4-4 ANTS coordination and cooperation

Healing in ANTS, as has been described, may necessitate a spacecraft taking over the role of another. This clearly requires a certain degree of self-configuration of the spacecraft, as it must alter the way it behaves and the work that it must do. For example, a worker that was supposed to assist in making x-ray observations of various asteroids of interest, may be required to take over the role of a messenger. Now its role changes from orbiting a particular asteroid in coordination with other spacecraft equipped with the necessary instruments, to just positioning itself close to the sub-swarm and relaying appropriate messages between the workers and leader, and between the leader and mission control.

Self-reconfiguration may also be required when a spacecraft has been replaced by another. This could be either another from the swarm, which would have to self-reconfigure as described above, or a new craft. In the latter case, the entire sub-swarm would have to self-reconfigure in order to make allowance for the new spacecraft in its orbit, and to allow for it in the leader's decision making.

Self-configuring/self-optimizing: After self-configuration, or self-reconfiguration, a certain degree of self-optimization is not strictly essential, but is certainly desirable. Once again, consider the human body. Damage to skin can result in its becoming rougher and tougher following healing. This is a form of primitive self-optimization that follows the self-configuration of the surface layers. This optimization makes the skin more resilient in anticipation of future possible damage. Similarly, following a haircut, or trim, the hair eventually grows back longer, and both stronger and thicker. The latter is self-optimization.

In ANTS, self-optimization after self-configuration is desirable, both at the individual level and the (sub-)swarm level. At the individual level, this may involve optimizing use of an instrument, or optimizing the spacecraft's orbit around an asteroid of interest and in relation to other workers in the swarm. At the sub-swarm level, optimization may involve a redistribution of duties, as appropriate, or realignment of workers to ensure sufficient coverage of instrument roles.

Self- summary*: We see that self-healing actions can be the result of self-protecting actions. The self-healing actions then may cause self-configuration, which in turn may trigger self-optimization. From the analysis of ANTS in terms of the four properties of autonomic systems, we see significant overlap in the scenarios. In particular, self-healing is often likely to require self-configuration. Clearly, this will not always be the case—a system where one component is replaced by a homogeneous component will likely not need to be reconfigured.

In another example, where a worker loses so many of its sensors that it can no longer make science observations, the ruler may give it the goal to take the role of a communications node (messenger agent), and this would entail a degree of self-reconfiguration (and possibly self-re-optimization) by the ANTS team. Similarly, self-protection may require the addition of components (whether or not they are identical to other components in the system) or replacement of components with others that have better protection mechanisms. This will likely require some degree of re-configuration (in the case of an autonomic system, this will be performed autonomously by the system itself), and possibly some degree of optimization to take advantage of the new components and to ensure that all resources are being used effectively. In the class of systems we are discussing, these actions would represent self-configuration and self-optimization. This may be considered to confirm a view that the Autonomic Systems initiative is concerned with the interaction and interfacing between such self-* properties in contrast to distinct emerging fields such as self-healing systems.

Although the research described in the attached publication [5] is at a relatively high level concerning Autonomicity in NASA missions and didn't cover pulse monitoring beyond mentioning its role in the AC architecture, there was other research and patents/publications with NASA that does feature its use – for instance as part of the autonomic/self-managing software architecture for ANTS (note the familiar pattern!) in Figure 4-5 Reflex environment awareness for NASA ANTS Sub-Swarm analysing an Asteroid. and Figure 4-6 Autonomic Agents (redundantly) running on ANTS crafts in the sub-swarm.

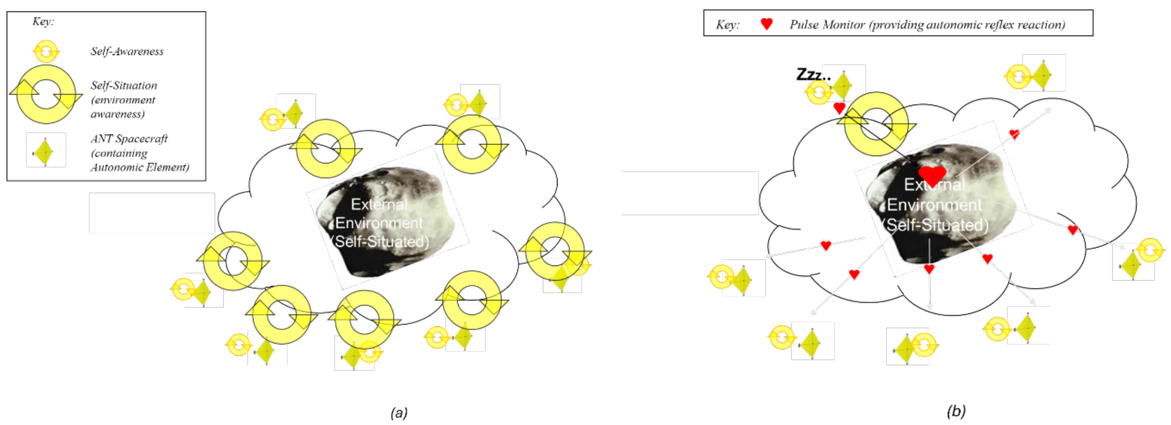


Figure 4-5 Reflex environment awareness for NASA ANTS Sub-Swarm analysing an Asteroid.

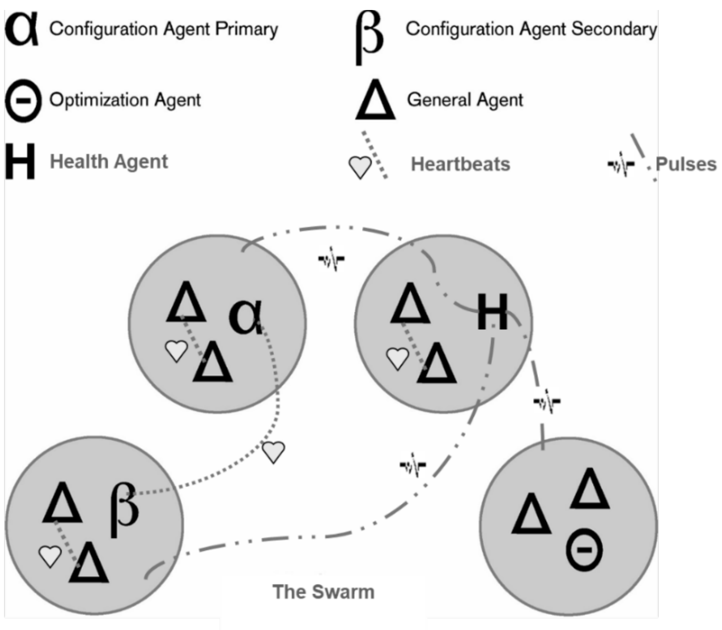


Figure 4-6 Autonomic Agents (redundantly) running on ANTS crafts in the sub-swarm.

4.3 Contributions to NASA and Discussion

Sterritt's contribution to Autonomic Computing at/with NASA involved a decade as a visiting researcher, with 16 patents and 70+ publications as outputs, including a book in the NASA monographs in System and Software Engineering series with Springer, on "Autonomous and Autonomic Systems: With Applications to NASA Intelligent Spacecraft operations and Exploration Systems". Sterritt used this book and many of the publications from 2005 until last year (2023) as part of teaching on his MSc modules; (COM834) Autonomic Computing & Communications; (COM760) Autonomic Computing & Robotics. So, with a wealth of material why this representative publication [5]?

NASA missions represent some of the most extreme examples of the need for survivable systems that cannot rely on support and direction from humans while accomplishing complex objectives under dynamic and difficult environmental conditions. Future missions will embody greater needs for longevity in the face of significant constraints, in terms of cost and the safety of human life. Future missions also will have increasing needs for autonomous behaviour not only to reduce operations costs and overcome practical communications limitations (signal propagation delays and low data rates), but also to overcome the inability of humans to perform long-term missions in space. There is an increasing realization that future missions must be not only autonomous, but also exhibit the properties of autonomic systems for the survivability of both individuals and systems.

This research [5] illustrated the need for self-* properties with reference to ANTS, a NASA concept mission. These illustrations with relevance to ANTS highlight that these properties are, in general, interrelated. The paper also illustrated the high level software architecture for such futuristic swarm based self-directed and self-managing systems.

This was quite a general paper from Sterritt and the NASA team, reflecting on the wider NASA ANTS concept PAM sub-mission and how it required more than Autonomy, a.k.a. Autonomicity. Essentially, this is a summation of some of the work that had gone into conference papers and was being drafted for the NASA book which wasn't published until 2009-2010 [41] and the Chinese edition in 2012.

It was interesting how at this time the distinction between Autonomicity and Autonomy was forming. At this stage Sterritt was chair of the newly formed IEEE Task Force on Autonomous and Autonomic Computing, so his role of championing Autonomic Computing was forming – presenting (and representing) Autonomic Computing to communities that hadn't already heard about it, not just his Autonomic Systems fellow researchers – and of course everyone wants to hear what NASA are doing/planning. This probably resulted in too many Sterritt et al Autonomic / NASA papers.

So what makes this one stand out amongst all those papers apart from a nice Journal (Science of Computer Programming) especially when it wasn't one of the papers that had a patent attached? Probably the high level and general application of Autonomic Computing to an engaging future(istic) space mission, rather than a deeply technical specialised niche area (for instance Apoptotic Computing that will be covered later in Chapter 6). And ANTS generated more interest than, say, the applications of applying Autonomic Computing to utilize spare processing and storage capacity on NASA office PCs as a cheap(er) approach than expensive HPC or Storage Arrays for processing and storing satellite data! (which was also worked on during these years).

It was also interesting to see other non-NASA connected researchers in the field start to publish about ANTS as the most Autonomic application possible (and often not cite this body of work as the source! But there lies an aspect of being an Autonomic Evangelist!). This was so much so that at the IEEE TF/TC level Sterritt and Hinchey, considered making ANTS a common case study for researchers in the field to study and report back annually showing their developments (much like RoboCup for Autonomous Robots). So, the paper marked a point in time of the NASA work that contributed to the community understanding (and excitement) of Autonomicity. The work on ANTS later become a main stay of Sterritt's MSc modules, and PhD researchers' work through the 2010s and into the 2020s. This was literally taking to heart, that Autonomic Computing was a 20-30 year initiative and the ANTS "Concept" Mission classification meant 30+ years!

5. Autonomic Communications

This chapter will focus on Sterritt's scientific contribution to "Autonomic Communications", a field inspired by Autonomic Computing, supported by work with Nortel [6] and British Telecom (BT) [7].

5.1 "Autonomic Communications" & Self-Healing

As the size and complexity of networks and communications have continuously grown, there has been a challenge of achieving a level of service with successful operations upon which users can place even more reliance. Sterritt (2004) [6] considered that key emerging strategies for meeting this demand was 'autonomic networks' and 'autonomic communications', concepts inspired by, and similar, to the autonomic computing initiative while specific to the communications field.

Interestingly, upon launch of the Autonomic initiative, IBM highlighted the growing complexity crisis in the IT industry, comparing it with telephony in the 1920s. There, the rapid increase in use of the telephone led to estimates that by the 1980s half of the population of the USA would have to be employed as telephone operators to meet the demand [1]. The implementation of automated switching and other technological developments avoided this crisis. By analogy, IBM was predicting that the full working population of the US would be needed to manage the global complex IT systems of systems within the next 10-20 years, and thus was expecting autonomic system implementations to achieve similar productivity gains. It was anticipated, however, that significant research and development would be required to achieve that goal.

As has been highlighted previously, the envisaged goal of autonomic computing is the production of systems that are self-managing in four main respects: self-configuring, self-healing, self-protecting and self-optimizing (self-CHOP). Yet, some of the prerequisites for autonomic computing include complete visibility of the managed platform, complete control of that platform without undesirable side effects, and complete knowledge of how to relate visible situations to concrete actions.

Most importantly is the ability to capture and represent both enterprise and personal policy (rules). Because of the need for differing levels of human involvement, autonomic computing maturity and sophistication has been categorized into five ''stages of adoption'' [26][49]: Basic, Managed, Predictive, Adaptive, and Autonomic. These prerequisites are priorities in the work reported in this paper [6] while evolving along the autonomic computing maturity stages.

As was depicted in the Autonomic Computing properties tree (Figure 2-1), there are two strategies for introducing autonomic behavior. The first is to engineer it into systems and the second is to achieve it through adaptive learning. The first approach could be progressed immediately, with human experts generating or overseeing the generation of rules for autonomic functions. Over time, this could be increasingly supplemented with self-learning processes [12].

Sterritt [6] focused on the 'self-healing' aspect of autonomic networks, examining, in particular, techniques for event correlation to aid fault identification. A three-tier rule discovery framework and associated support and analysis tools are described in [6]. These tools assist with the development, management and maintenance of correlation rules and beliefs (Figure 5-1 Three-tier alarm event correlation rule discovery process [6].).

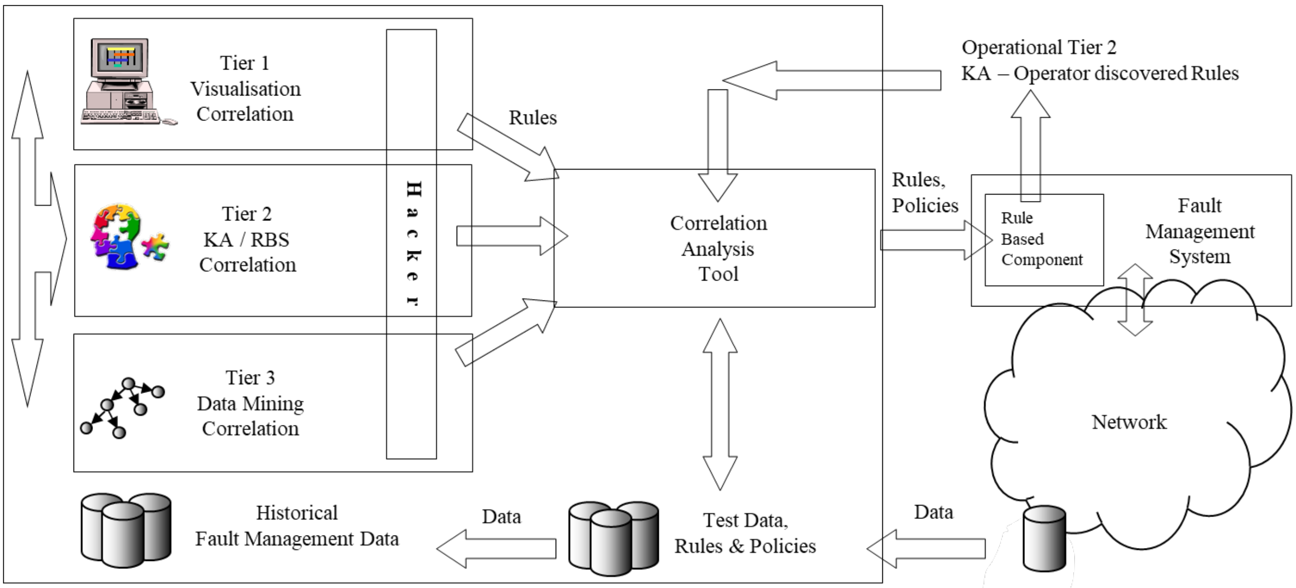


Figure 5-1 Three-tier alarm event correlation rule discovery process [6].

The origin of this work lies in research that predates the Autonomic Computing initiative (1996-2002) performed with Nortel Networks on Intelligent Fault Management for SDH/Sonet networks, e.g., [50],[51] and then continued with a BT Exact Research Fellowship "xACT: Autonomic Computing and Telecommunications" (2003); the findings confirmed and motivated the research in this publication [6].

The Autonomic initiative is about much more than faults and self-healing, yet it is a critical area to address considering that it has been estimated that companies spend 33–50% of their total cost of ownership recovering from or preparing against failures [52].

IBM concurred with this assessment that root cause analysis in complex systems is key to achieving Autonomicity. In their white paper 'Autonomic problem determination: A first step towards self-healing computing systems' (October 2003) they stated that in effect complexity in problem determination is diluting the effectiveness of computing in the corporate environment [53]. The same can be said for communications and networks. As has been mentioned, it has been estimated that companies then spent from one third to one half of their total cost of ownership recovering from or preparing against failures, yet many of these outages, with some estimates at 40%, are caused by operators themselves [52].

These typical TCO costs was perhaps the motivation that sparked BT's interest in the work Sterritt had originally undertaken with Nortel [54]. They developed their own internal (not published) version of the discovery tools based on this work, marking a more industrial contribution / impact from Sterritt's research than the academic citation metrics as the contribution in previous chapters.

5.2 "Autonomic Communications" & Autonomic Reflex Reaction via PBM.

The starting point of the BT Research Fellowship may have been the Intelligent Fault Management research with Nortel, but once underway, Sterritt's access to BT and their fault management systems allowed for a more autonomic architectural analysis, in particular that speeds of response concept – a reflex reaction and pulse monitoring (PBM) as highlighted as contributions in Section 3.2 Autonomic Reflex Reactions via Pulse Monitoring and the Pulse Monitor (PBM)", was proposed to resolve an issue.

Event correlation through many layers of protocols and managers (Ethernet, IP, ATM, PDH, all being multiplexed and carried on fiber optical high speed networks via SDH) naturally takes time. So much so that customers were aware of major issues in the network and reporting them before the 'network' had reported them (northbound) to the service level. This timeframe could be up to 15 minutes later (sensitivity at the time only allowed a 10 minute figure to be published [7][17]). Adding an autonomic reflex reaction to the Unified Fault Management (UFM) architecture allows for immediate alerting of the Service level of potential major incidents in the network via Pulse Monitors (PBMs) based on a significant increase in alarming events or severe alarms, etc. (Figure 5-2).

Of course, the specific fault managers may resolve the issues at any level prior to the service level, and effectively the PBM will have sent a false positive to the service level – but it was seen that false positives (if minimum impact and learnt from) would be better than ignorance of real incidents and having customers inform BT first (Figure 5-3). The fuller concept of Autonomic Communications implementation would have the AEs self-learn and adapt to counter these false positives.

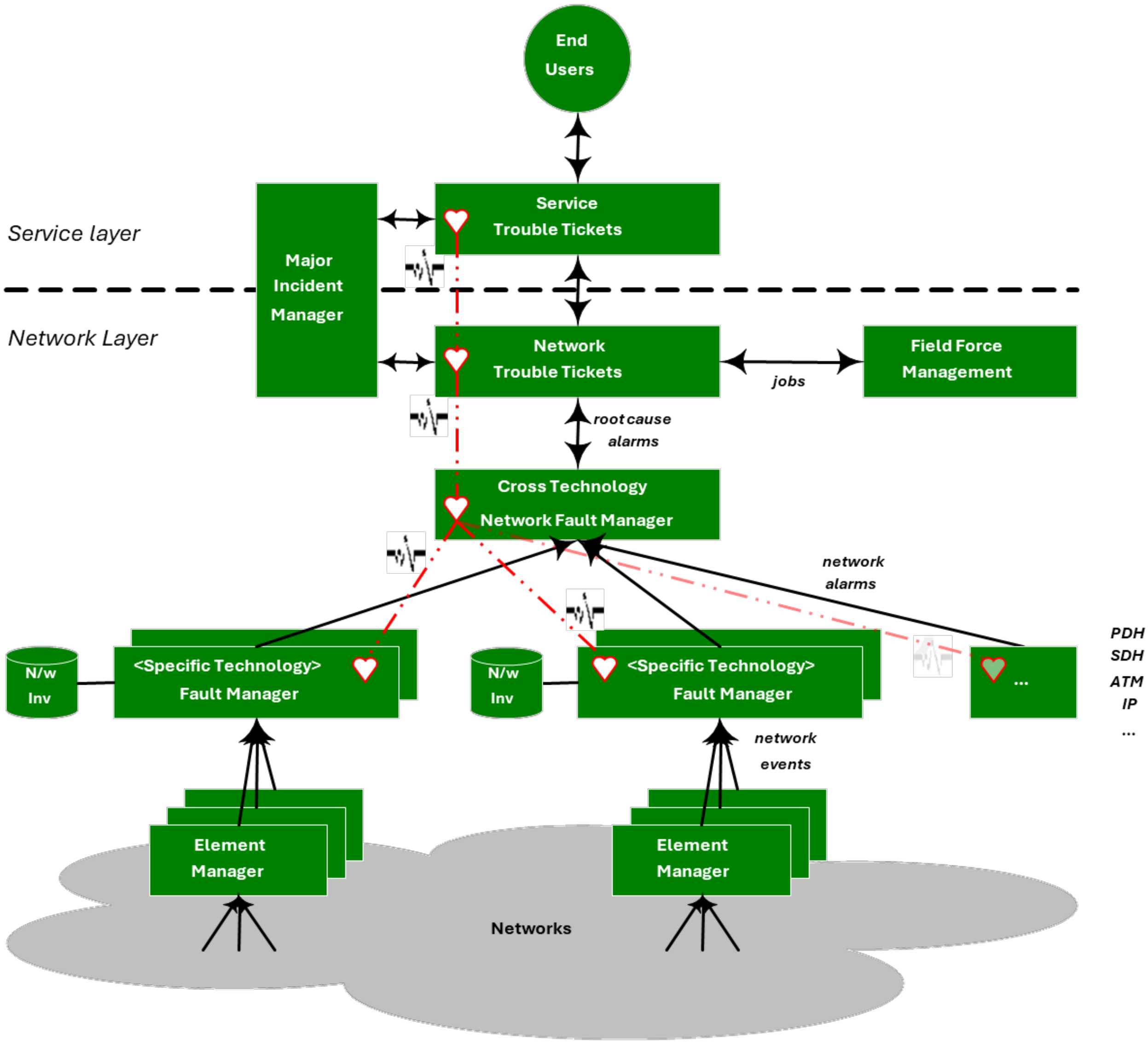


Figure 5-2 Autonomic Reflex Reaction via Pulse Monitoring, proposed additions to BT's UFM system architecture [7].[17]

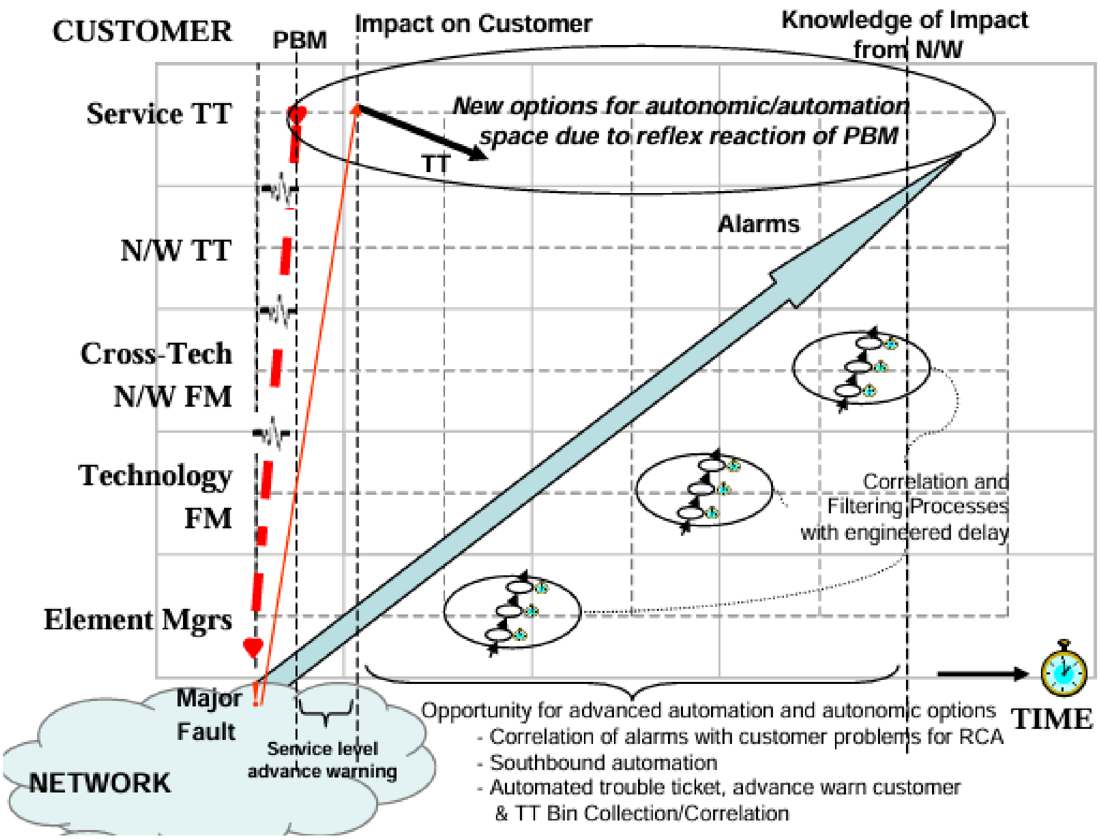


Figure 5-3 Dual timelines- introducing reflex reaction via PBM into architecture [7] .

Apart from this work making Autonomic Computing/Communications more widely known back in 2003 within BT, and a solid published case study on Sterritt's Autonomic Pulse Monitoring pattern/construct for Autonomic Communications, debate surrounded the feasibility of retrospectively adding Autonomic PBM into the UFM. From memory the <Specific Technology> FM team where in favor, while the Cross-Tech N/W FM team weren't (it could have been the other way around! IP sensitivity meant this aspect was not published at the time) as it was seen as too complex to retrofit. As such it went forward as recommendations into the next generation BT networks programme, *21st Century Network (21CN)*, that were being designed at that time, marking another more industrial contribution / impact from Sterritt's research.

Interestingly, a decade and a half later, in late 2017, a BT Ireland Innovation Centre (BTIIC) was established at Ulster University with one of the research streams being Adaptive and Autonomic Systems. It seems Sterritt and the BT UFM team were ahead of their time!

5.3 Wider Context and Discussion

In a wider context, an EU brainstorming workshop in July 2003 discussed novel communication paradigms for 2020 and identified 'Autonomic Communications' as an important area for future research and development [55] [56].

This can be interpreted as further work on nonconventional networking (self-organizing networks, ad hoc, sensor, peer-to-peer, group communications, active networks, and so on) but was undoubtedly a reflection of the growing influence of IBM's Autonomic Computing initiative launched in 2001 [1]. In effect, autonomic communications [57] has the same motivators as the autonomic computing concept with particular focus on the communications research and development community. Hence Autonomic Communications is dependent on a successful Autonomic Networking infrastructure [58].

At a follow-up meeting (March 2004), Autonomic Communications had become the main focus, with a follow-on at the First International IFIP Workshop on Autonomic Communications organized by Mikael Smirnov (Fraunhofer) in Berlin, in which Sterritt was involved. This set an agenda and subsequent EU funding call and programme on Situated and Autonomic Communications (SAC) 2005-2007 in Framework VI. Ulster University was a partner in one of the funded projects. By this stage, Sterritt had been invited by IEEE Computer Society TAB (Technical Activities Board) in 2005 to establish and chair a Task Force on Autonomous and Autonomic System (Autonomous included to reach wider than Autonomic for more inclusivity), which then having proved itself became a Technical Committee in 2007 with Sterritt as founding chair.

The TF-AAS / TC-AAS chair position involved the promotion of Autonomic Systems as a research field to both the US / IBM et al. oriented *Autonomic Computing* community as well as the EU *Autonomic Communications* community and beyond. For instance, reaching out to the A.I. community at IJCAI 2005 with a workshop on "AI & Autonomic Communications" [59]. Both communities cross-pollinated each other and grew beyond their initial memberships. Then it became more an IEEE CS versus ACM academic issue, and then economic issues into the 2010s following the financial crisis that started in 2008 – but that's another story beyond this thesis.

The Autonomic Communications Forum (ACF) was established in Oct. 2007 to move the Autonomic Research towards standards for the industry. Chaired by John Strassner

(Autonomic Networking Director at Motorola[1]). ACF Founding Members included, from Industry Fujitsu, Hewlett-Packard, Hitachi, IBM, Intel, Motorola, Telefonica, Whitestein Technologies. From Academia Postech, Rutgers University, Trinity College Dublin, Universitat Politecnica De Catalunya, Universite d'Evry, University College Dublin, University of Ulster, University of Waterloo, Waterford Institute of Technology. And others: Fraunhofer-FOKUS. On the ACF Board, Sterritt held the SDO (Standards Developing Organization) Liaison Co-Chair position. The ACF effectively ceased to exist from 2009-10 when Motorola dissolved, due to economic conditions, its Autonomic Networking Research Lab laying off its staff and the Autonomic Networking Director John Strassner, the ACF chair. The research side (more than standards angle) continued, notably through the FAME (Federated Autonomic Management of End-to-end Communications services) project in the Republic of Ireland, which Sterritt was a Scientific Advisor to.

These are wider AComp/AComms field/community contributions/impacts, that cannot be attributed to a single publication for a PhD by Publication/Cumulative thesis but undoubtedly the likes of this research with Nortel then BT and that with NASA directly contributed to the invite from IEEE to establish and chair the TF/TC in the first place.

[1] the fact there was a such a position at Motorola demonstrates how the field had progressed so quickly!

6. Apoptotic Computing

This chapter focuses on the creation of “Apoptotic Computing” as a specialized area, and in one view, an extension to Autonomic Computing [8]. Inspired by the cellular pre-programmed self-destruct mechanisms in biological apoptosis, Apoptotic Computing offers a promising specialized engineering construct, to assist with developing self-managing computer-based systems.

6.1 Apoptotic Computing

At the 2009 International Joint Conference on Artificial Intelligence (IJCAI), researchers warned that the nightmare scenarios depicted in sci-fi films such as *2001: A Space Odyssey*, the *Terminator* and *Matrix* series, *Minority Report*, and *I, Robot* could come true. “Scientists fear a revolt by killer robots” proclaimed the UK’s Sunday Times [60], which highlighted alarming findings at the conference that mankind might lose control of computer-based systems that carry out a growing share of society’s workload, from chatting on the phone to waging war, and have already reached a level of indestructibility comparable with the cockroach.

For instance, unmanned predator drones, which can seek out and kill human targets, have already moved out of the movie theatre and into the theatre of war in Afghanistan and Iraq (and many wars since…). While currently controlled by human operators, these drones are moving toward more autonomous control. Similar devices may also soon appear above city streets to carry out domestic surveillance. Samsung, the South Korean electronics giant, has developed autonomous sentry robots with “shoot to kill” capability to serve as armed border guards [60].

To provide for this future, the Apoptotic Computing project has been working since 2002 toward the long-term goal of programmed death by default for computer-based systems [11][39] [61]-[63]. Motivated by the apoptosis mechanisms in multi-cellular organisms, apoptotic computing can be considered a subarea of bio-inspired computing, natural computing, or autonomic systems. Two example applications are autonomic agent-based environments and swarm space exploration systems.

Biological Apoptosis

Developing a self-managing computer system is the vision of autonomic computing [38][64][65]. As the “Autonomic System Properties” (Chapter 2 *Autonomic Computing;* Figure 2-1, Figure 2-4 & Figure 2-5), an autonomic computing system is analogous to the biological nervous system, which automatically maintains homeostasis (metabolic equilibrium) and controls responsiveness to external stimuli. For example, most of the time you are not consciously aware of your breathing rate or how fast your heart is beating, while touching a sharp knife with your finger results in a reflex reaction to move the finger out of danger [66].

If you cut yourself and start bleeding, you treat the wound and carry on without thinking about it, although pain receptors will induce self-protection and self-configuration to use the other hand. Yet, often the cut will have caused skin cells to be displaced down into muscle tissue [67]. If the cells survive and divide, they have the potential to grow into a tumor. The body’s solution to this situation is cell self-destruction (with mounting evidence that some forms of cancer are the result of cells not dying fast enough, rather than multiplying out of control, as previously thought).

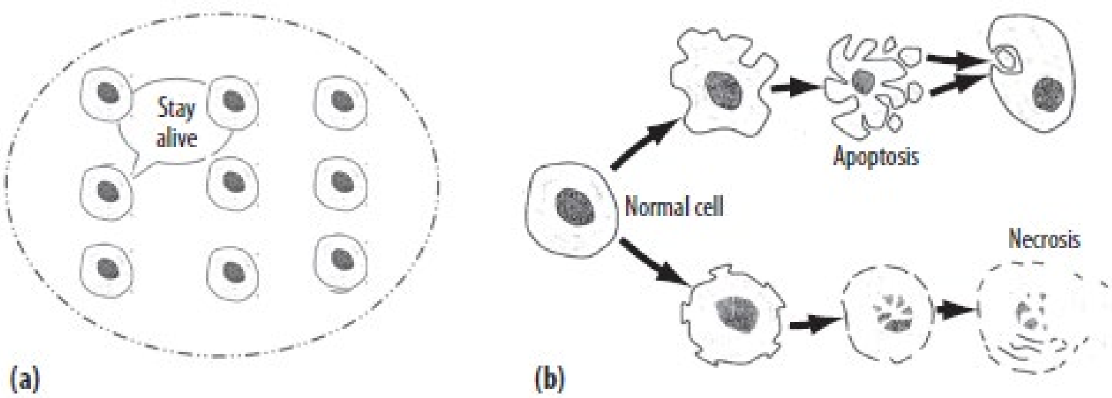


Figure 6-1 Biological apoptosis. (a) A cell’s constant receipt of “stay alive” signals turns off its programmed self-destruct sequence. (b) Apoptosis versus necrosis due to injury.

Biologists believe that cells are programmed to commit suicide through a controlled process known as apoptosis [68]. The term is derived from the Greek word for “to fall off,” in reference to dead leaves falling from trees in autumn; likewise, cells “fall off” the living organism and die. As Figure 6-1(a) shows, a cell’s constant receipt of “stay alive” signals turns off the self-destruct sequence [11]. When these signals cease, the cell starts to shrink, internal structures decompose, and all internal proteins degrade; thereafter, the cell breaks into small, membrane-wrapped fragments to be engulfed by phagocytic cells for recycling Figure 6-1(b) contrasts apoptosis, also known as “death by default”, [67] with necrosis, the unprogrammed death of a cell due to injury—inflammation and the accumulation of toxic substances [69].

Recent research indicates that cells receive orders to kill themselves when they divide [68]. The reason appears to be self-protection. An organism relies on cell division for maintenance and growth, but the process is also dangerous: if just one of the billions of cells in a human body locks into division, the result is a tumor. The suicide and reprieve controls can be likened to the dual keys of a nuclear missile: the suicide signal (first key) turns on cell growth but at the same time activates a sequence that leads to self-destruction, while the reprieve signal (second key) overrides the self-destruct sequence [70].

Autonomic Agents

Autonomic computing depends on many disciplines for its success; not least of these is research in agent technologies. There are no assumptions that an autonomic architecture must use agents, but agent properties—adaptability, autonomy, cooperation, and so on—complement the paradigm’s objectives. In addition, there are arguments for designing complex systems with multiple agents [71], providing such systems with inbuilt redundancy and greater robustness [72], and for retrofitting legacy systems with autonomic capabilities that may benefit from an agent-based approach [73].

Figure 2-4 shows a basic autonomic element (AE), which consists of a managed component (MC) and an autonomic manager (AM) [20]. The AM can be a stationary agent—for instance, a self-managing cell [74] that contains functionality for measurement and event correlation and provides support for policy-based control. AMs communicate via means such as self-* event messages.

Mobile agents can also play a role in autonomic systems. Their ability to reduce network load, overcome network latency, encapsulate protocols, execute asynchronously and autonomously, adapt dynamically, reflect natural heterogeneity, and maintain robustness and fault tolerance can make it easier for AMs within different systems to cooperate.

Apoptosis in Agent-based Autonomic Environments

Michael S. Greenberg and colleagues first proposed agent destruction to facilitate security in mobile-agent systems [75]. They described an event in which network operators decommissioned a computer named omega.univ.edu and moved its work to other machines. A few years later, the operators assigned a new computer the old name and, to everyone’s surprise, e-mail arrived, much of it three years old; the mail had survived “pending” on Internet relays waiting for omega.univ.edu to come back up. Greenberg’s team considered a similar scenario in which mobile agents—not rogue agents but ones carrying proper authenticated credentials—carried out work that was out of context rather than the result of abnormal procedures or system failure. In this circumstance, the mobile agents could cause substantial damage—for example, deliver an archaic upgrade to part of the network operating system, bringing down the entire network.

Misuse involving mobile agents can occur in several forms. Agents can accidentally or unintentionally misuse hosts due to, say, race conditions or unexpected emergent behavior in those agents. In addition, external bodies acting upon agents, either deliberately or accidentally, can lead to their misuse by hosts or other agents—for example, due to damage, breaches of privacy, harassment, social engineering, event-triggered attacks, or compound attacks.

Encryption can prevent situations in which portions of an agent's binary image—monetary certificates, keys, information, and so on—could be copied when visiting a host. However, agent execution requires decryption, which provides a window of vulnerability [75]. This situation is analogous to the body's vulnerability during cell division [11].

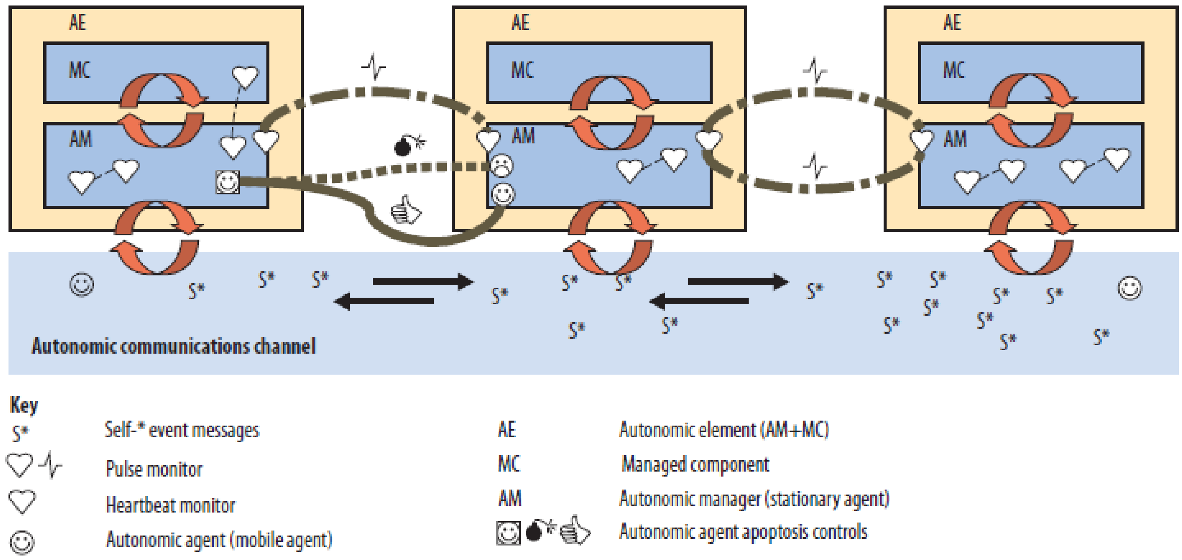


Figure 6-2 Simple autonomic environment consisting of AEs with autonomic agents (stationary and mobile), heartbeat monitors ("I am alive"), pulse monitors ("I am un/healthy"), and apoptosis controls ("stay alive/self-destruct").

Figure 6-2 extends Figure 2-3 and Figure 2-5's Autonomic Environment with agent based Autonomicity and apoptosis. The following will recap some of what has already been covered in Chapter 2 *Autonomic Computing* and *3.2 Autonomic Reflex Reactions via Pulse Monitoring and the Pulse Monitor (PBM)*, as part of the logical view to introduce agents and apoptosis into the Autonomic Environment.

Figure 6-2 shows a high-level view of a simple autonomic environment with three AEs (a typical system would have hundreds, thousands, or even millions of AEs). Each AE is an abstract view of Figure 2-4, and in this case the MCs represent self-managing computer systems. These AEs can have many other lower-level AEs—for example, an autonomic manager for the disk drive—while at the same time residing within the scope of a higher-level AM such as a system-wide local area network domain's AE.

Within each AM, heartbeat monitors (HBMs) send "I am alive" signals to ensure the continued operation of vital processes in the MC and to immediately indicate if any fail. The AM has a control loop that continually monitors and adjusts, if necessary, metrics within the MC, yet vital processes in the MC can also be safeguarded by an HBM that emits a heartbeat signal as opposed to its being polled by the AM, avoiding lost time (time to next poll) by the AM to notice a failure (note in Figure 6-2 that the left-hand AE has an HBM between the AM and a process on the MC).

Because each AM is aware of its MC's health via the continuous control loop, it can share this information by sending a pulse signal ("I am un/healthy") to another AM—in Figure 6-2, for example, from the left-hand AE to the middle AE. This not only allows self-managing options if the machines are, say, sharing workload as a cluster but protects the AM itself as the pulse signal also acts as an HBM signal from one AM to another. Thus, if an AE's vital process fails, the neighboring AM will immediately become aware of it and, for example, try to restart the failed AE or initiate a failover to another AM. This pulse signal can also act as a reflex signal between AMs warning of an immediate incident—a more direct solution than the AM's processing numerous event messages to eventually determine an urgent situation (*3.2 Autonomic Reflex Reactions via Pulse Monitoring and the Pulse Monitor (PBM)*).

Because AMs also monitor the external environment (the second control loop), they have a view of their local environment's health. They can encode such information into the pulse signal along with self-health data (just as our hearts have a double beat). The double-pulse signals between the right-hand and center AEs in Figure 6-2 represent this situation.

AMs can dispatch mobile agents to work on their behalf—for example, to update a set of policies. To help provide self-protection in these situations, AMs can send apoptosis signals ("stay alive/self-destruct") to such agents by either authorizing continued operation or by withdrawing such authorization—for example, if the policies become out of date. Figure 6-2 depicts both scenarios.

Sterritt referred to the absence of a "stay alive" signal resulting in agent self-destruction as strong apoptotic computing, or programmed death by default, while weak apoptotic computing involves an explicit self-destruct signal—similar in principle to the garbage collection method first used by Lisp and by many languages since or the destructor method in object orientation. The differences in these approaches are subtle but important.

Only a built-in default death can guarantee true system safety. For example, you would never rely on a self-destruct signal getting through to an agent containing system password updates in a hostile environment. Likewise, a robot with adaptive capabilities could learn to ignore such a signal. That said, clearly not all circumstances require a death-by-default mechanism. However, Sterritt believed that many researchers using programmed death under the apoptosis descriptor should be using programmed death-by-default.

There is a concern that denial-of-service (DoS) attacks could prevent "stay alive" signals from reaching their target and thereby induce unintentional agent self-destruction. DoS attacks could likewise interrupt terminate signals, resulting in potentially dangerous scenarios. DoS-immune architectures are thus a critical part of next-generation self-managing systems.

Swarm Space Exploration Systems

NASA missions such as ANTS (4.2 The Autonomous Nano-Technology Swarm (ANTS) concept mission) provide a trusted private environment, eliminating many agent security issues and enabling system designers to focus on ensuring that agents are operating in the correct context and exhibiting emergent behavior within acceptable parameters.

In considering the role of the self-destruct property inspired by apoptosis, suppose one of the worker craft in the ANTS mission was operating incorrectly and, when coexisting with other workers, was causing undesirable emergent behavior and failing to self-heal correctly. That emergent behavior could put the mission in danger, and ultimately the ruler would withdraw the "stay alive" signal [11].

Likewise, if a worker or its instrument was damaged, either by colliding with another worker or (more likely) an asteroid, or during a solar storm, the ruler would withdraw the "stay alive" signal and request a replacement worker. Another worker would then self-configure to take on the role of the lost worker to ensure optimal balanced coverage of tasks to meet the scientific goals. If a ruler or messenger was similarly damaged, its ruler would withdraw the "stay alive" signal and promote a worker to play its role.

6.2 Wider Context and Conclusions

Promising apoptotic computing applications have been developed for data objects, highly distributed systems, services, agent systems, and swarm systems. However, more applied work is needed in other areas, and researchers must address the challenges around trust—until then, users are not likely to embrace a system with self-destruct capabilities.

The case has been made that all computer-based systems should be autonomic [48]. Likewise, there is a compelling argument that all such systems should be apoptotic, especially as computing becomes increasingly pervasive and ubiquitous. Apoptotic controls should cover all levels of human-computer interaction from data, to services, to agents, to robotics. With constant news headline incidents of credit card and personal data losses by organizations and governments, and scenarios once relegated to science fiction becoming increasingly possible, programmed death-by-default is a necessity.

We are rapidly approaching the time when new autonomous computer-based systems and robots should undergo tests, similar to ethical and clinical trials for new drugs, before they can be introduced. Emerging research from apoptotic computing could guide the safe deployment of such systems.

Regarding contribution, Apoptotic Computing is perhaps the most untapped potential discussed in this thesis. It was probably the foundational link with Sterritt collaborating with NASA Goddard. Although Sterritt's link to NASA started with a presentation that introduced Goddard folk to Autonomic Computing back in 2002 [12] at the NASA Software Engineering Lab's (SEL) annual Software Engineering Workshop (SEW). Then Sterritt encouraging SEL key researchers to apply Autonomic Computing to ANTS for his organized EASe (Engineering of Autonomic Systems) workshop at IEEE ECBS (2003) and subsequent edited special issue journal on Autonomic Computing of IEEE Transactions on SMC-C (2004), but this may all have just remained research community contacts if it hadn't been for Apoptotic Computing (ApopC).

The background to ApopC was that having been inspired by IBM's success with biological inspired computing for Autonomic, Sterritt and his researchers/MSc students had then also returned to biology seeking further inspiration. The heart-beat monitor (HBM) and "I am alive" signals, extending to pulse monitoring (PBM) and "I am healthy" signals, and (re-) 'discovering' "stay alive" signals in the body via hormones at the cellular level aka apoptosis. Sterritt and students had been looking at agents for AC, and Greenberg's [75] issue with persistent internet messages akin to agent security highlighted to Sterritt the need for apoptosis for "autonomic agents". Yet the idea of introducing a pre-programmed self-destruct (self-suicide) into a system was highlighted as *a dream for hackers* by Sterritt's then Professor of Software Engineering and mentor, Prof. Dave Bustard, so the concept never even got out of Ulster.

So, when Sterritt attended NASA's 27th SEW in 2002 for his own presentation on Autonomic Computing, saw their FAST (Formal Approaches for Swarm Technologies) projects for ANTS – aha – Sterritt had a solution without an application (due to security concerns) and NASA had a concept application with concerns about adaptability (and thus the security of the future missions). So, this led Sterritt to discussions (and ultimately long-term collaboration) with

Prof. Mike Hinchey, then director of NASA's SEL. *[Interesting side note; both Profs Bustard and Hinchey were supervised (years apart) by Prof Tony Hoare (Sir Charles Antony Richard Hoare FRS FREng, also known by his initials C. A. R. Hoare) the computer scientist who made foundational contributions to programming languages, algorithms, operating systems, formal verification, and concurrent computing].*

That collaboration began with writing a paper on Apoptosis for ANTS [11] which then was held up in the approval process by NASA's IP/Patent department. So that work became Sterritt & Hinchey's first NASA patent application before it was published. This may all seem a personal career contribution for Sterritt, than a contribution to the research community – but it was that link, due to ApopC, that solidified a collaboration between Sterritt and Hinchey, that lead to much wider contributions to AC.

Although not necessarily referred to under the Apoptotic Computing tag, many popular software-based applications have emerged over the last decade utilizing an apoptotic mechanism. One class of applications provides self-destruct text message services, such as SnapChat, iDelete, and Apple providing it for iMessage. These are growing beyond social networking and increasingly finding ground in the security arena not just for messages but self-destructing data in general, for instance self-deleting phones if an incorrect password is entered repeatedly. Wickr is one such that focus on the security aspect, and allows users to text, send images, videos and pdfs to individuals or groups and time limit access to those communications. Wickr allows the sender to set the self-destruct time from between one second and five days. Wickr uses forensic deletion techniques to ensure that messages and other media are irrecoverable once they have self-destructed. This self-destructor has also moved into the digital rental application; where on apps such as BBC iPlayer and Sky Go digital content viewers, programmes can be downloaded that automatically delete after a time period [76]. Hardware-wise, Amazon has patented a self-destructing drone (2017).

ApopC is undoubtedly much more specialized than AC, but these applications such as SnapChat's self-deleting messages, may all be considered "Apoptotic Computing". ApopC has a role to play in the concerns over internet privacy, including EU rulings on *right to be forgotten*, and the current concerns over trustworthy AI, for instance explored in Sterritt's Keynote in 2020, "Achieving Trustworthy Autonomous Systems through Autonomic and Apoptotic Computing" [77]. Untapped, in that it could be investigated to act as a guard rail around AI (much as first proposed for the concerns over adaptivity in NASA's ANTS mission). With the recent concerns/interest in *Trust in AI*, even at highest political levels, for instance the 2023 testimonies at Capitol Hill, where Constitutional AI was discussed, that being where AI is trained in some set of ethics/values/regulations/policies etc. to watch Gen-AI, and if it doesn’t comply it regenerates until it does comply. Apoptotic Computing should fit in nicely here as part of that guard rail, as that ultimate safe-guard – pre-programmed self-destruct if the Gen-AI doesn’t comply – with potentially Autonomic Computing providing that control layer.

7. Autonomic Systems Conclusions

This chapter concludes the Cumulative dissertation/PhD by Publication with some thought drawn from what has been presented in the thesis, and [18] "Keynote: 20 Years of Autonomic Computing", Roy Sterritt, June 2021, at *17th International Conference on Autonomic and Autonomous Systems*. It also includes a brief high-level focus on extending the previously-covered Autonomic Systems (AS) research through Sterritt's supervision of PhD researchers, with the attached publication [9]. Please excuse some of the non-Scientific Contribution career angle that follows as it provides context around that overall contribution to Autonomic Systems and leads to possible future work.

Sterritt's 23 years as a Faculty member, (his start happened to coincide with Autonomic Computing launch!), lecturing and researching, means he has quite a bit of "marking/grading" experience, including at the post-graduate supervision level. He marks himself a 2.1 (2nd class upper) on the career contribution to AC which highlights are partially reflected in this thesis. This is probably one of the main reasons this thesis has not been written until now. A belief that there was always more to do, more to achieve.

When many of his colleagues moved on from the AC scene to other newer (and more fundable) emerging topics, he doggedly stayed. Really believing it was a 20-30 year initiative (and NASA's *concept* mission the same if not a longer timeframe). Ironically, Sterritt reflects his career may map Gartner's Hype Cycle zones (Figure 7-1) – AC was the Tech Trigger in 2001, 2000s fast rise (probably too fast with burn out) including visiting researcher at NASA and foundation of IEEE TC-AAS, 2010s decline with sunsetting of TC (although AC was doing well within Cloud, that has skipped Sterritt by with an initial attempt at the Autonomic Cloud with SAP and separately with HP not leading further), and now the 2020s into the slope of enlightenment. Danager is that by the time of the 'Plateau of Productivity', Sterritt should be retired!

The glass half empty or half full idioms which are meant to contrast a pessimistic and optimistic outlook on a specific situation or on the world at large never quite worked for Sterritt on this as he saw both – the excellence (and excitement) in what was achieved by himself and the community, and the frustration of the potential that was missed out on – so much more could have been achieved. And this was perhaps expressed most in [18] and briefly covered here in 7.2 Sterritt's Contributions to the AS Community. Sterritt, perhaps expressing his Irishness and love for Guinness, would joke its half full and empty – order me another one! And that's perhaps where the community now stands – time for another round on the Hype Curve (7.4 Autonomic Systems' Future is A.I. ?!).

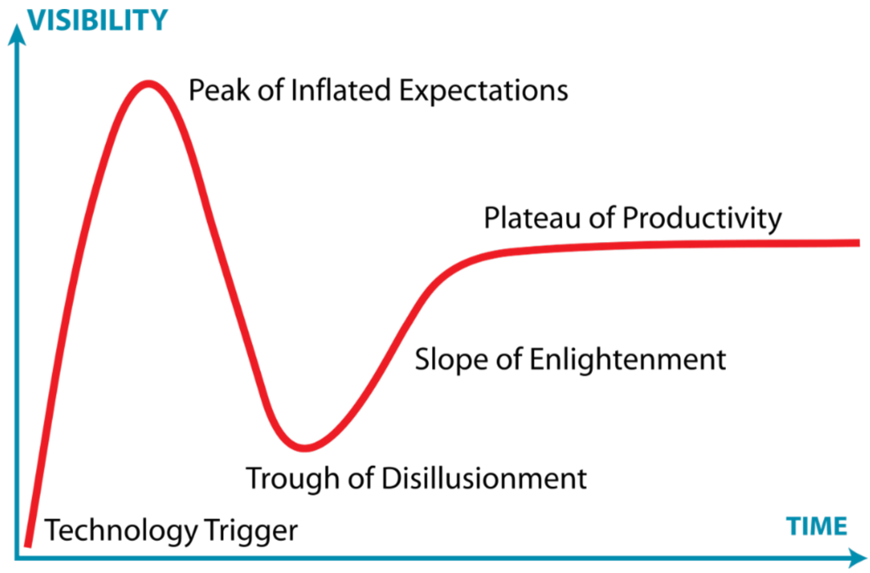


Figure 7-1 Gartner's Hype Cycle "zones"

Interestingly regarding evidence of impact/contribution based on citations (which briefly framed Chapter 2, but has been a weak measure for the rest of the contributions), and the mentioned marking/grading; Sterritt had as part of the coursework in COM834 / COM760 MSc Autonomic Computing modules, a literature review of any field/area/system/system of systems etc. that Autonomic Computing had been or could be applied to. With the University focus on plagiarism, and instructing the students not to automatically cite Wikipedia – go back to the source, it became very noticeable Sterritt was recognizing his own research not cited to him in these literature review coursework submissions. And then often to find it wasn't the students fault – their source had not cited Sterritt… So as a community of researchers we may not be helping each other! With 125+ publications in AC, Sterritt himself is guilty of self-plagiarism as there is only so many ways you can re-describe AC! And this leads to a lot of self-citations! Okay, moving on before downgraded to a 2.2!

Intriguingly, re-researching for this thesis write-up, Sterritt came across ScholarGPS, where it publishes *"Highly Ranked Scholars™ aka the most productive authors (by number of publications) whose works demonstrate exceptional impact (citations) and outstanding quality (h-index). These scholars hold a ScholarGPS® Rank within the top 0.05% in any given Field, Discipline, or Specialty*".

ScholarGPS has ranked Sterritt 2nd (Kephart 1st) in the world amongst 10,000 scholars participating in Autonomic Computing research [104];


ScholarGPS®

POWERING SCHOLARLY ANALYTICS

Roy Sterritt

is honored as a

2025

Highly Ranked Scholar - Lifetime

in the Specialty of

Autonomic computing

as conferred by ScholarGPS in recognition of exceptional productivity, noteworthy impact and quality of scholarly work in the top 0.05% of scholars in the Specialty worldwide.

Amir Faghri
PRESIDENT AND CEO, ScholarGPS

Perhaps the analytical algorithms behind ScholarGPS are less self-critical than the author!

7.1 Sterritt's Contributions via AS Publications

This cumulative dissertation/PhD by Publication thesis has presented where a number of Sterritt's publications have made a contribution to Autonomic Systems;

- To the vision of Autonomic Computing through the NASA/Springer ISSE journal publication [3] and the prior conference publications that contributed to such. Evidence provided by way of Jeff Kephart's 1st decade of AC keynote [17], both making reference to the citations of those early AC Sterritt publications and also naming Sterritt as one of five main contributors to the AC vision.
- To Autonomic Personal Computing, with IBM T.J. Watson Center with publication [4]. Probably the term with the least longevity, but the principles apply to "newer" / similar sub-fields; pervasive computing, edge computing, IoT, mobile computing, CPS … all still need AC [48] with that more flexible twist.
- Via the design pattern/construct of Pulse Monitor (PBM) & Pulse Monitoring, used as part of the AC environment, and highlighted across the chapter themes; APC, within NASA ANTS, within Autonomic Comms and PhD projects.
- To Autonomic Computing at NASA, with 70+ publications and 16 patents, a focus on a more general self-* to NASA missions was considered in the publication [5]. The NASA

interest in AC undoubtably generated more interest in AC in the wider, and wider than, Computer Science field.

- To Autonomic Communications utilizing prior to AC work with Nortel Networks and new AC design options (inc. pulse monitoring) with British Telecom (BT) in publication [6], [7] and beyond. How this extended into an initially EU led field, and for a time a standards organization (ACF).
- To the "invention"* of Apoptotic Computing, envisaged through AC (although does not have to be so), a pre-programmed death to ensure ultimate self-protection; across autonomic agents within the self-managing system/environment, data and privacy, to 'Apoptotic' added to the Autonomic Robots/Drones/Space Craft. (Term "invention" used due to Apoptotic patents with NASA).

7.2 Sterritt's Contributions to the AS Community

The nature of a Cumulative dissertation/PhD by Publication is obviously to consider contributions via publications and not contributions to the community, yet the extent of the publishing activity* undoubtedly led to "contributions" / invites for Sterritt to partake in AC community activity, more contributions through contributions. *[Quick count of "autonomic" in the 256 publications in Appendix A: Roy Sterritt – Publications (1997 – 2024) returns 175 instances of Autonomic. Obviously some papers with Autonomic in the title also have Autonomic in the conference/publication name, and some Autonomic related publications may have neither – but a quick guestimate would be at least half of these are Autonomic papers].

The most notable community activity would be the formation of the IEEE Technical Committee on Autonomous and Autonomic Systems (TC-AAS) via a Task Force on AAS (TF-AAS). As it happens the second part of Sterritt's 20 years of AC keynote focused on this – so there is a "publication" link [18]. Some reflection on this may be appropriate at this concluding and discussion stage.

Interestingly the keynote took place during the COVID period and "working from home" via online was the norm for those that could. Sterritt provides the following "small print" in the published presentation; *"Please accept the intent is just to reflect and provide insight into history (his-story, her-story, their-story, not always facts, personal reflections and the mind often revises, but not intending to be "alternative facts") and in no way intended as whistle blowing nor accusations against anyone or any organization; my memories may not be fully accurate, nor my understanding correct at the time from the positions I held."* Reflection was a side effect for many during the COVID period! To read more about Sterritt's reflections on impact of the TC and ultimately its sunsetting see [18] [Keynote: 20 Years of Autonomic Computing : https://www.iaria.org/conferences2021/filesICAS21/RoySterritt_Keynote_20Years.pdf].

It covers Sterritt's personal journey and community contributions. The long and the short of it is Sterritt believes the TC-AAS sunsetting had more to do with politics (with a small p) and finances (the 2008+ Western banking crisis – for instance led IEEE CS to attempt to sell off its Washington DC HQ etc. and begin a process of sunsetting many TCs, workshops, conferences and activities to reign in the spending), than AAS not being deserving of TC status. Yet the lack of a TC since 2013 has probably caused the demise of AC as a technical field to a niche/sub-field or at least much slower growth and less visibility.

7.3 Sterritt's Contributions to AS via PhD Supervision

This chapter concludes Sterritt's scientific contributions to Autonomicity, by simply considering Autonomic Systems being made from the set of Autonomic Computing + Autonomic Communications + Apoptotic Computing. That is evident in Sterritt's supervision of PhD researchers during the 2010s and into the 2020s. The section takes a brief focus on extending the previously-covered Autonomic Systems research through Sterritt's supervision of PhD researchers, with the attached publication; [9]. It is a shorter treatment than the other attached papers, as Sterritt is not claiming the individual researchers' work but general directions he supervised those researchers towards.

This contributing paper [9] for this thesis, introduces at a high level the concept of Autonomic Robotics based on the Autonomic Computing paradigm with the aim to achieve a systematic means to obtain self-managing and autonomous robotic craft software for future space missions. It briefly reflects on the Sterritt's research that took place in the noughties with NASA GSFC (and covered here in Chapter 4, in particular on the *4.2 The Autonomous Nano-Technology Swarm (ANTS) concept mission* Autonomic Computing research stream), before briefly highlighting Sterritt's PhD researchers' streams in the twenty-tens and into the twenty-twenties moving towards NewSpace or Space 2.0. Three specific streams of research within this area are summarized; cooperation between the autonomic robotic craft, an autonomic robotic architecture (and case-studies to derive such) and the development of an Autonomic Systems capability model for CubeSats.

This paper was for the Journal of the British Interplanetary Society, with the material originally presented at their Reinventing Space Conference (RISpace) 2019 [78]. The contributing detail is beyond this chapter and resides in the PhD researchers' theses and publications. Indeed the journal [9] and presentation [78] for and to the UK Space community, was really pointers at the original work and PhD researchers' work, for that community – in particular with the conference having 'traveled' to Belfast in Northern Ireland.

Some of the key directions in the work was utilizing the AC paradigm for robotics – "Autonomic Robotics";

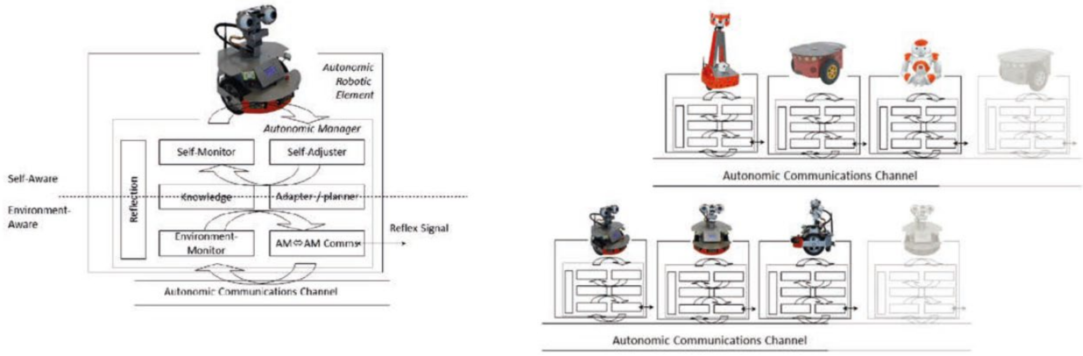


Figure 7-2 Autonomic Robotic Element (left-hand side) & "Autonomic Robotics" Environment (right-hand side).

Figure 7-2 Autonomic Robotic Element (left-hand side) & "Autonomic Robotics" Environment (right-hand side). should at this stage be easily recognized as the autonomic designs applied to robotics, where the robot is now the "managed component (MC)". This took two major paths, one external autonomic cooperation between the robots/craft and one internal, recognizing self-management issues and *self** work arounds. The two paths of research could be considered akin to the two logical control loops prevenient in the AE pattern – *Self-awareness* and *Environment-awareness* (*self-situation*).

With the external or environment-awareness path, autonomic cooperation, some of the PhD researchers contributions have already been reflected upon in Chapter 3 *Pulse Monitoring, engineering a biological inspired reflex reaction* and specifically *3.3 Wider Context* and section. More detail about this research stream can be found in [79] - [90] ([81] & [84] won best paper awards).

With the internal or self-awareness, this also included a further examination into Sterritt's high-level logical hierarchy from the days of the formation of the TC-AAS, where Autonomicity / Self-ware / Autonomy was proposed as a general architecture, and supported by the Intelligent Machine Design (IMD) (Figure 7-3).

This view combined and Figure 7-4 'Autonomic Robotics Architecture high-level conceptual 3xA's of Awareness, Analysis and Adjustment was derived [91]. More detail to [91], and this research stream can be found in [92]-[95].

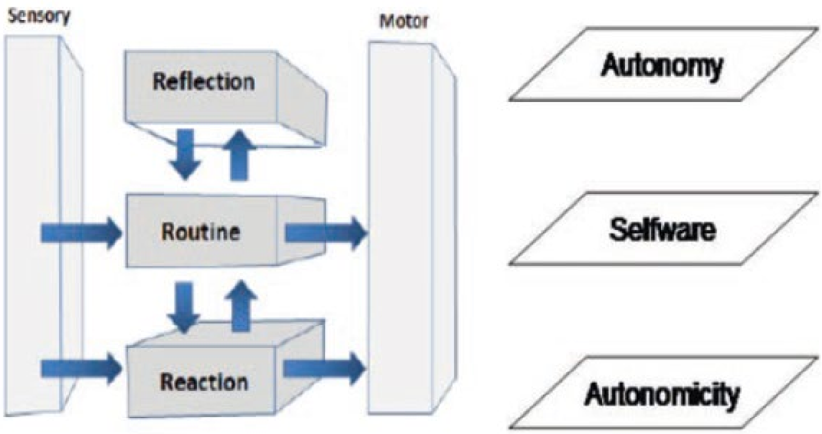


Figure 7-3 Comparing intelligent machine design and system level

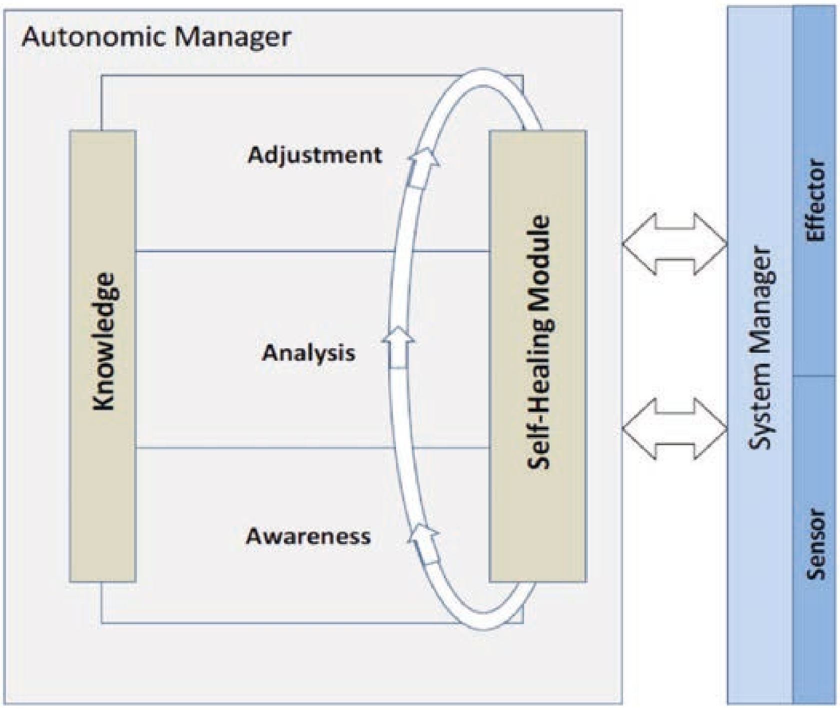


Figure 7-4 Autonomic Robotics Architecture high-level conceptual 3xA's

Another direction was applying AC to the new emerging CubeSat technology (Figure 7-5), with proof of concepts on autonomic and apoptotic (pre-programmed self-destruct) [96] and later the research moved towards defining a CubeSat Autonomicity Capability Model (CACM) as a roadmap for future autonomic CubeSat development and an exemplar "killswitch" (Apoptotic Computing) application to prevent the CubeSat becoming space debris/junk (Figure 7-6). More detail about this research stream can be found in [97]-[99].

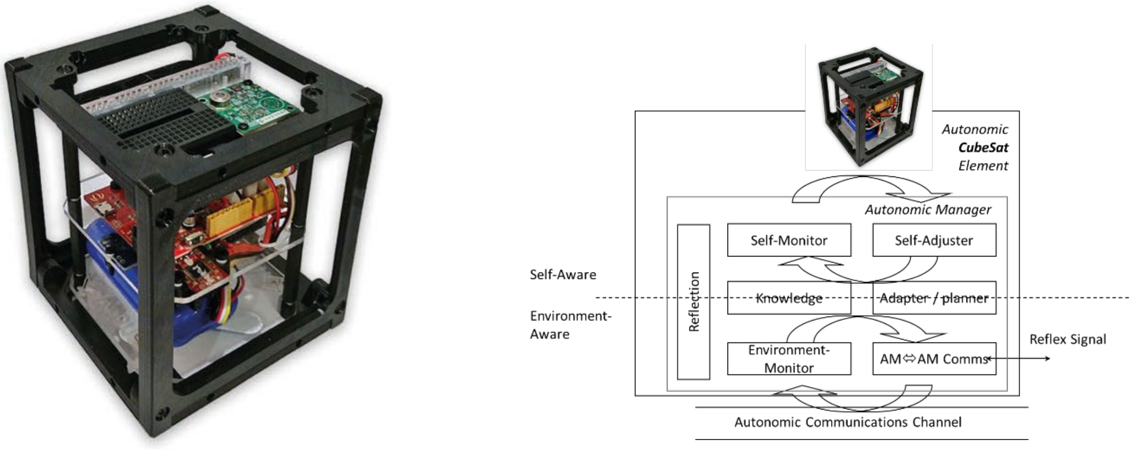


Figure 7-5 CubeSats (ArduSat DemoSat equipment) & Autonomic CubeSat Element

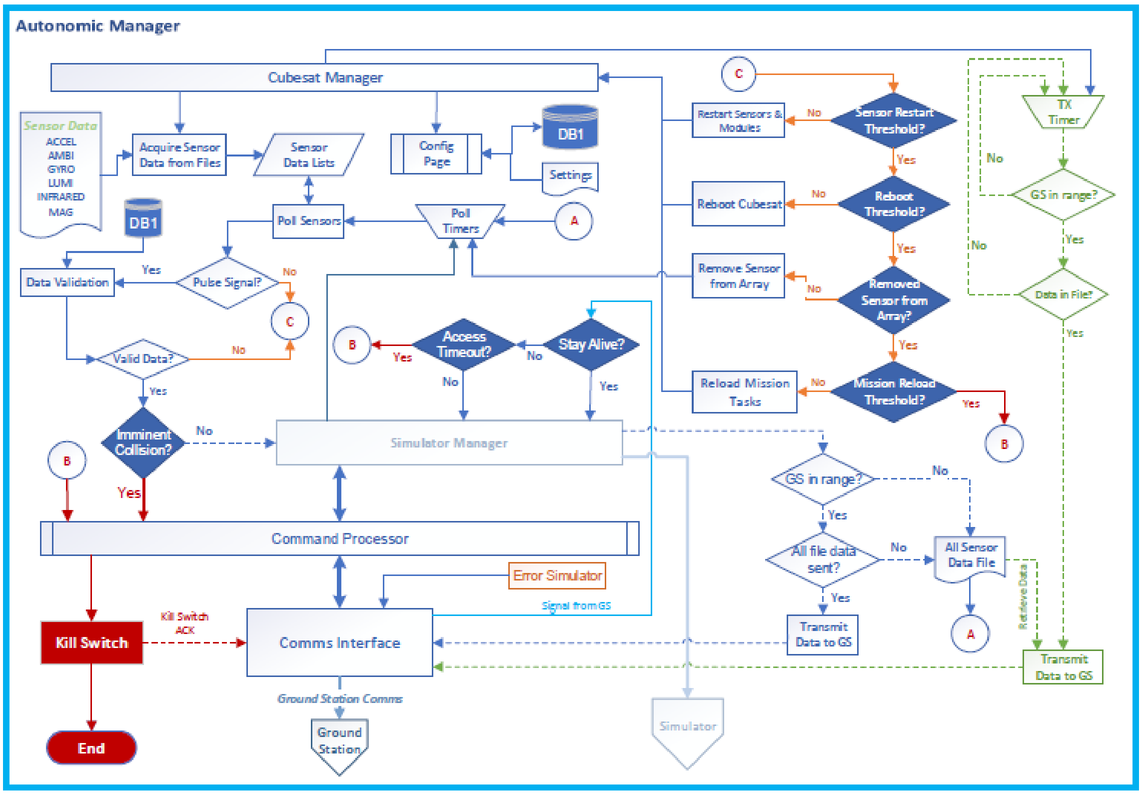


Figure 7-6 CubeSat Autonomic Capability Model Level 3

ANTS – Autonomous NanoTechnology Swarm – was classed as a concept mission, where "concept" meant framing the mission 30 years prior to launch. The ANTS concept movie, visualizing the Prospecting Asteroid Mission (PAM), was often dismissed as "science fiction" by skeptical audiences when shown at conferences. Twenty+ years later, not only has the technology moved closer to realizing such a vision, but the actual shape of the space industry has changed beyond recognition. One can now envisage CubeSats acting as those ANTS craft, the envisaged robotic factory at a Lagrange point could now be supplemented with 3D printers and the headache of autonomously managing thousands of craft can be significantly supported by autonomic and apoptotic software indicated here.

Regarding contribution, while this paper cannot stand on its citations (at the moment 1!), but interestingly the downloads (from the authors' institute's repository) are a magnitude of order or two, larger than the downloads for some other publications discussed here (currently standing at 1135 downloads), it highlights that the initial contributions to Autonomic Systems made during the 2000s have continued through PhD researchers. Ultimately the continued contributions to AC from this work now stands, with Sterritt's thanks, on the shoulders of the doctoral researchers themselves, their publications and theses.

7.4 Autonomic Systems' Future is A.I. ?

Sterritt's AC publications citations aren't that high compared with many of his non-AC colleagues in Computer Science, giving some healthy self-doubt concerning should this Cumulative dissertation/PhD by Publication even be submitted! Yet the data in [17][18][2] indicate that these are relatively high for the "field" of Autonomic Computing. This may indicate the "field" despite the original hype, has essentially settled as a niche sub-field of Software Engineering, Systems Engineering or Cloud Computing depending on the field/context one is working from. That said, that doesn't mean it won't re-emerge, for instance, benefiting from or as part of the latest A.I. incarnation – Generative AI, as it moves towards Artificial General Intelligence (AGI).

Indeed Gartner's Hype Curve for Emerging Tech 2022 has Autonomic Systems (re-) appearing (Figure 7-7) [100] 20 years later;
"***Autonomic systems*** *are examples of accelerated AI automation. They are self-managing physical or software systems, performing domain-bounded tasks that exhibit three fundamental characteristics: autonomy, learning and agency. When traditional AI techniques aren't able to achieve business adaptability, flexibility and agility, autonomic systems can be successful in helping with implementation. Autonomic systems will take five to ten years until mainstream adoption but will be transformational to organizations.*"

and on the 2023 (and again on the 2024) Hype Curve for AI (Figure 7-8) [101][102];
"*... Innovation Trigger, so for example on this year's Hype Cycle we* have ***Autonomic Systems*** *which is more around actual evolution of AI into systems which can take actions and decide or plans the tasks to accomplish, and to achieve, and can achieve some of those things in an*

autonomous kind of way as well, and then we also have multi-agents systems, which are kind of related to Autonomic Systems as well, where we have different AI agents collaborating together in order to achieve a particular outcome. …" [101] *(podcast 15mins 08secs in).*

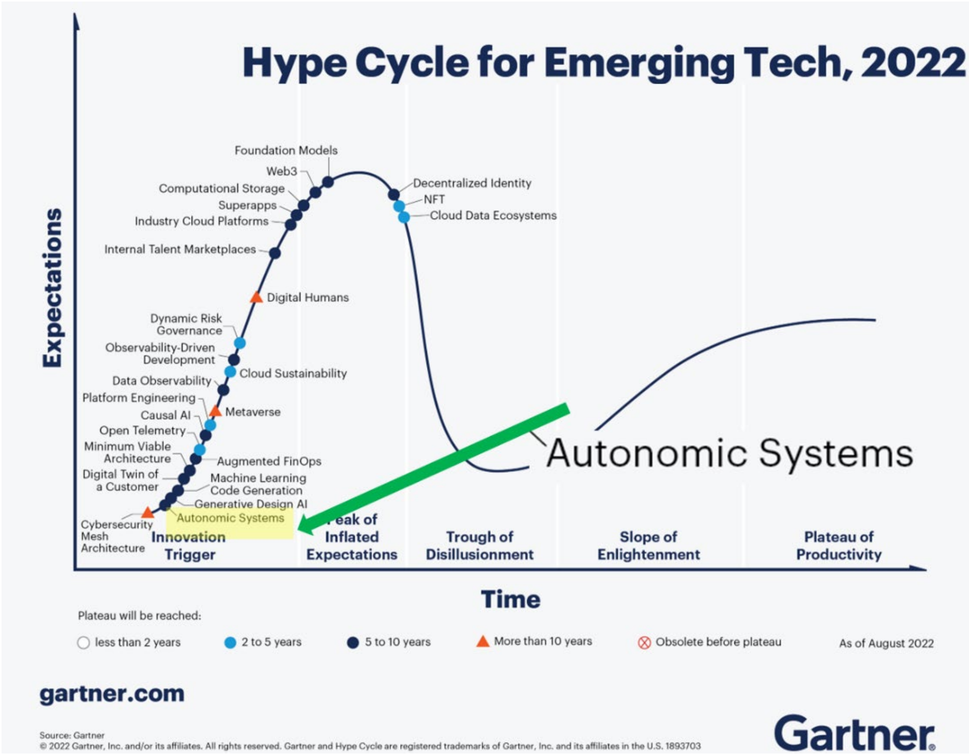


Figure 7-7 Gartner's Hype Cycle for Emerging Tech 2022 has Autonomic Systems on the curve (5-10 years to reach plateau)

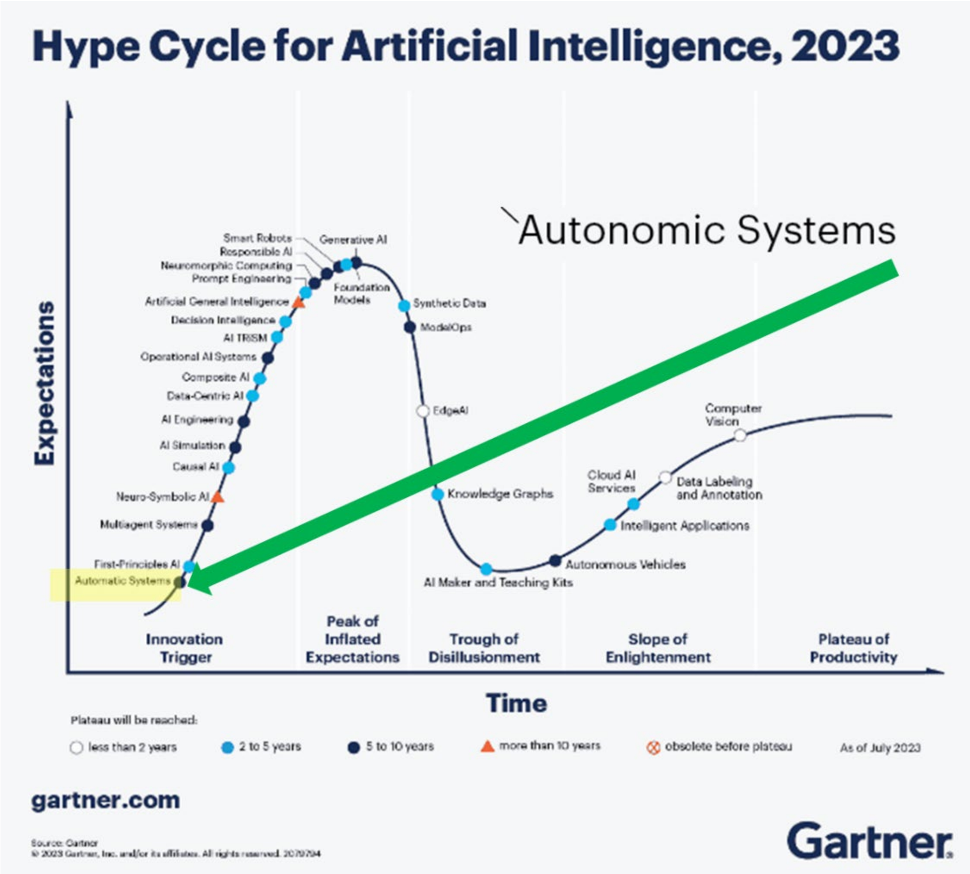


Figure 7-8 Gartner's Hype Cycle for A.I 2023 has Autonomic Systems on the curve (5-10 years to reach plateau)

Interestingly, back in 2003 Sterritt had two “approaches” for AC on Figure 2-1 Sterritt's Autonomic Computing Tree [13][3] “Make (systems/software engineering)” and “Achieve (AI/Adaptive Learning”). In an earlier version the approaches were “Engineer” & “Learn”. In 2003 & 2005 the emerging AC community reached out to the A.I. community through running workshops at IJCAI (the top AI conference) e.g. [59], but found they (AC) were really just talking to themselves. The first two decades of AC have been very much more Software Engineering / Systems Engineering. Perhaps now in its third decade, Autonomic Systems will see its full (or fuller) realization through A.I. building on its Engineered first two decades.

References

[1] P. Horn, (2001) "Autonomic computing: IBM perspective on the state of information technology", IBM T.J. Watson Labs, NY, 15th October 2001. Presented at AGENDA 2001, Scotsdale, AR. (originally available http://www.research.ibm.com/autonomic/), (Web archive: https://web.archive.org/web/20110916160342/http:/www.research.ibm.com/autonomic/manifesto/autonomic_computing.pdf)

[2] IBM (2001) "Autonomic computing concepts." White Paper, IBM.

[3] R. Sterritt, (2005), "Autonomic computing". *Innovations Syst Softw Eng: A NASA Journal,* 1, 79–88 (2005). doi:10.1007/s11334-005-0001-5

[4] R. Sterritt, and D.F. Bantz, (2006), "Personal Autonomic Computing Reflex Reactions and Self-Healing", IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems), 36(3), 304-314. https://doi.org/10.1109/TSMCC.2006.871592

[5] R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, and W. Truszkowski, (2006), "Next generation system and software architectures: Challenges from future NASA exploration missions", Science of Computer Programming, 61(1), 48-57. https://doi.org/10.1016/j.scico.2005.11.005

[6] R. Sterritt, (2004), "Autonomic networks: engineering the self-healing property", Engineering Applications of Artificial Intelligence, 17(7), 727-739. https://doi.org/10.1016/S0952-1976(04)00111-3

[7] R. Sterritt, D.W. Bustard, Gunning, D. and Henning, P. (2005), "Autonomic Communications and the Reflex Unified Fault Management Architecture", Jul 2005, In: Advanced Engineering Informatics. 19, 3, p. 189-198

[8] R. Sterritt, (2011), "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", Computer, 44(1), 59-5. https://doi.org/10.1109/MC.2011.5

[9] R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, and L. McGuigan, (2020), "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", Journal of the British Interplanetary Society, 73(11), 397-408, https://bis-space.com/shop/product/inspiration-for-space-2-0-from-autonomous-nanotechnology-swarms-concept-mission-towards-autonomic-robotic-craft/

[10] A.G. Ganek, T.A. Corbi (2003), "The dawning of the autonomic computing Era", IBM Sys J 42(1):5–18.

[11] R. Sterritt, M. Hinchey, (2004), "Apoptosis and self-destruct: a contribution to autonomic agents?", In: Proceedings of Third NASA-Goddard / IEEE workshop on formal approaches to agent-based systems (FAABS III), Washington 26–27 April, in Lecture notes in computer science 3228. Springer-Verlag, Berlin Heidelberg New York, pp 269–278

[12] R. Sterritt, (2002), "Towards autonomic computing: effective event management," *27th Annual NASA Goddard/IEEE Software Engineering Workshop, 2002. Proceedings.*, 2002, pp. 40-47, doi: 10.1109/SEW.2002.1199448.

[13] R. Sterritt and D. Bustard,(2003), "Autonomic Computing - a means of achieving dependability?," *10th IEEE International Conference and Workshop on the Engineering of Computer-Based Systems, 2003. Proceedings.*, 2003, pp. 247-251, doi: 10.1109/ECBS.2003.1194805.

[14] A. Avizienis, J-C. Laprie, B. Randell, C. Landwehr, (2004), "Basic concepts and taxonomy of dependable and secure computing", IEEE Transactions on Dependable and Secure Computing, 1(1), Jan–Mar.

[15] USA Computing Research Association, (2002), "Grand research challenges", Available via http://www.cra.org/reports/gc.systems.pdf

[16] "UK grand challenges for computing research", (2002), Was originally available at: http://www.nesc.ac.uk/esi/events/Grand Challenges/

[17] J. Kephart, "Autonomic Computing: The First Decade" ICAC 2011 Keynote June 15, 2011

[18] R. Sterritt, (2021) "Keynote: 20 Years of Autonomic Computing", *17th International Conference on Autonomic and Autonomous Systems,* Valencia, Spain and Online. June 2021.

[19] R. Sterritt, (2003), "Pulse monitoring: extending the health-check for the autonomic grid," *IEEE International Conference on Industrial Informatics, 2003. INDIN 2003. Proceedings.*, 2003, pp. 433-440, doi: 10.1109/INDIN.2003.1300375.
[20] R. Sterritt and D.W. Bustard, (2003), "Towards an autonomic computing environment," *14th International Workshop on Database and Expert Systems Applications (DEXA), Proceedings.*, 2003, pp. 694-698, doi: 10.1109/DEXA.2003.1232103.
[21] R. Sterritt, D. Gunning, A. Meban, P. Henning, (2004), "Exploring autonomic options in an unified fault management architecture through reflex reactions via pulse monitoring", In: Proceedings of IEEE workshop on the engineering of autonomic systems (EASe 2004) at the 11th annual IEEE international conference and workshop on the engineering of computer based systems (ECBS 2004), Brno, Czech Republic, 24–27 May. pp 449–455
[22] R. Harzing,(2007), "Publish or Perish" Software Tool, https://harzing.com/resources/publish-or-perish, 2007
[23] R. Sterritt, and D.F. Bantz, (2004) "PAC-MEN: Personal Autonomic Computing Monitoring Environments". In: IEEE DEXA 2004 Workshops - 2nd International Workshop on Self-Adaptive and Autonomic Computing Systems (SAACS 04), Zaragoza, Spain. IEEE. 5 pp.
[24] R. Sterritt, and S. Chung, (2004) "Personal Autonomic Computing Self-Healing Tool", In: IEEE Workshop on the Engineering of Autonomic Systems (EASe 2004) at 11th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2004), Brno, Czech Republic. IEEE. 8 pp.
[25] D. F. Bantz, C. Bisdikian, D. Challener, J. P. Karidis, S. Mastrianni, A. Mohindra, D. G. Shea, and M. Vanover, "Autonomic personal computing," IBM Syst. J., vol. 42, no. 1, pp. 165–176, 2003.
[26] D.F. Bantz and D. Frank, 2003. "Challenges in autonomic personal computing, with some new results in automatic configuration management". Proceedings of IEEE Workshop on Autonomic Computing Principles and Architectures (AUCOPA 2003) at INDIN 2003, Banff, Alberta, Canada, 22–23 August, pp. 451–456.
[27] P. Stelling, I. Foster, C. Kesselman, C. Lee, and G. V. Laszewski, "A fault detection service for wide area distributed computations," in Proc. 7th IEEE Symp. High Performance Distributed Computing, Jul. 28–31, 1998, pp. 268–278.
[28] The Globus Heartbeat Monitor Specification v1.0. [Online]. Originally Available at: http://www-fp.globus.org/hbm/heartbeat spec.html
[29] D. DeCoste, S. G. Finley, H. B. Hotz, G. E. Lanyi, A. P. Schlutsmeyer, R. L. Sherwood, M. K. Sue, J. Szijjarto, and E. J.Wyatt, "Beacon monitor operations experiment DS1 technology validation report," Jet Propulsion Lab, California Inst. Technol., Pasadena, CA, 2000.
[30] E. J. Wyatt, M. Foster, A. Schlutsmeyer, R. Sherwood, and M. K. Sue, "An overview of the beacon monitor operations technology," presented at the Int. Symp. Artificial Intelligence, Robotics, and Automation in Space, Tokyo, Japan, 1997.
[31] E. J. Wyatt, H. Hotz, R. Sherwood, J. Szijjarto, and M. Sue, "Beacon monitor operations on the deep space ONE mission," presented at the 5th Int. Symp. AI, Robotics and Automation in Space, Tokyo, Japan, 1998.
[32] G. Candea, S. Kawamoto, Y. Fujiki, G. Friedman, and A. Fox, "Microreboot-A technique for cheap recovery," in Proc. 6th Symp. Operating Systems Design and Implementation (OSDI), San Francisco, CA, Dec. 2004.
[33] T. Lorimer and R. Sterritt, 'Autonomic Management of Cloud Neighborhoods through Pulse Monitoring', in 2012 IEEE Fifth International Conference on Utility and Cloud Computing, Chicago, IL, USA: IEEE, Nov. 2012, pp. 295–302. doi: 10.1109/UCC.2012.60.
[34] R. Sterritt, E. Hanna, and P. O'Hagan, 'Autonomic Agents for Survivable Security Systems', in Embedded and Ubiquitous Computing – EUC 2005 Workshops, T. Enokido, L. Yan, B. Xiao, D. Kim, Y. Dai, and L. T. Yang, Eds., in Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2005, pp. 1235–1244. doi: 10.1007/11596042_125.
[35] A. A. Kopiler, I. D. C. Dutra, and F. M. G. França, 'Personal Autonomic Desktop Manager with a Circulatory Computing Approach', in Fifth IEEE Workshop on Engineering of Autonomic and Autonomous Systems (EASe 2008), Mar. 2008, pp. 119–127. doi: 10.1109/EASe.2008.20.
[36] E. Vassev and M. Hinchey, 'Self-Awareness in Autonomous Nano-Technology Swarm Missions', in 2011 Fifth IEEE Conference on Self-Adaptive and Self-Organizing Systems Workshops, Ann Arbor, MI, USA: IEEE, Oct. 2011, pp. 133–136. doi: 10.1109/SASOW.2011.8.

[37] R. Sterritt, D.W. Bustard, Gunning, D. and Henning, P. (2005), “Autonomic Communications and the Reflex Unified Fault Management Architecture”, Jul 2005, In: Advanced Engineering Informatics. 19, 3, p. 189-198
[38] J. O. Kephart and D. M. Chess, "The vision of autonomic computing", Computer, vol. 36, no. 1, pp. 41-50, Jan. 2003, doi: 10.1109/MC.2003.1160055.
[39] R. Sterritt, M. Hinchey, Engineering ultimate self-protection in autonomic agents for space exploration missions, in: Proceedings EASe 2005, 2nd IEEE Workshop on Engineering Autonomic Systems, at ECBS 2005, 12th IEEE International Conference on Engineering of Computer Based Systems, Greenbelt, MD, 4–7 April, IEEE Computer Society Press, 2005, pp. 506–511.
[40] R. Sterritt, M. Hinchey, Autonomic computing — Panacea or Poppycock? in: Proceedings EASe 2005, 2nd IEEE Workshop on Engineering Autonomic Systems, at ECBS 2005, 12th IEEE International Conference on Engineering of Computer Based Systems, Greenbelt, MD, 4–7 April, IEEE Computer Society Press, 2005, pp. 535–539.
[41] W. Truszkowski, H.L. Hallock, C. Rouff, J. Karlin, J. Rash, M.G. Hinchey, and R. Sterritt, (2009), “Autonomous and Autonomic Systems With Applications to NASA Intelligent Spacecraft Operations and Exploration Systems”. Springer-Verlag. 289 pp ISBN 978-1-84628-232-4 [NASA Monographs in Systems and Software Engineering]
[42] P.E. Clark et al., “ANTS: A New Concept for Very Remote Exploration with Intelligent Software Agents,” Eos, Trans., American Geophysical Union, vol. 82, no. 47, 2001
[43] P.E. Clark, S.A. Curtis, M.L. Rilee, (2002), “ANTS: Applying a new paradigm to lunar and planetary exploration”, in: Proceedings Solar System Remote Sensing Symposium, Pittsburgh, 2002.
[44] S.A. Curtis, J. Mica, J. Nuth, G. Marr, M. Rilee, M. Bhat, (2000), “ANTS (Autonomous nano-technology swarm): An artificial intelligence approach to asteroid belt resource exploration”, in: Proceedings International Astronautical Federation, 51st Congress, October, 2000.
[45] S. Curtis, W. Truszkowski, M. Rilee, P. Clark, (2003), “ANTS for the human exploration and development of space”, in: Proceedings IEEE Aerospace Conference, 2003.
[46] G. Marr, S. Cooley, C. Roithmayr, L. Kay-Bunnell, T. Williams, (2004), “Autonomous NanoTechnology Swarm (ANTS) Prospecting Asteroid Mission (PAM), Asteroid Proximity Operations”, International Aeronautics Congress, Vancouver, British Columbia, Canada, October 2004.
[47] W.F. Truszkowski, J.L. Rash, C.A. Rouff, M.G. Hinchey, (2004), “Asteroid exploration with autonomic systems”, in: Proceedings of IEEE Workshop on the Engineering of Autonomic Systems (EASe 2004) at the 11th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems, ECBS 2004, Brno, Czech Republic, 24–27 May, 2004, pp. 484–490.
[48] R. Sterritt and M. Hinchey, (2005), “Why computer-based systems should be autonomic”, in: Proceedings ECBS 2005, 12th IEEE International Conference on Engineering of Computer-Based Systems, Greenbelt, MD, 4–7 April, IEEE Computer Society Press, 2005, pp. 406–412.
[49] IBM, (2003), “An Architectural Blueprint for Autonomic Computing, April, revised October, 2003.
[50] R. Sterritt and D.W. Bustard (2002), “Practical Intelligent Support for Rule Discovery in Fault Management Systems”, Cybernetics and Systems, 33:6, 579-601, DOI:10.1080/01969720290040768
[51] R. Sterritt, and D.W. Bustard, (2002), “Fusing Hard and Soft Computing for Fault Management in Telecommunications Systems”, In: IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews. 32, 2, p. 92-98. DOI: 10.1109/TSMCC.2002.801725
[52] D.A. Patterson, A. Brown, P. Broadwell, G. Candea, M. Chen, J. Cutler, P. Enriquez, A. Fox, E. Kiciman, M. Merzbacher, D. Oppenhiemer, N. Sastry, W. Tetzlaff, J. Traupman, N. Treuhaft, (2002), “Recovery-oriented computing (ROC): motivation, definition, techniques, and case studies”, UC Berkeley Computer Science Technical Report, UCB//CSD-02-1175, University of California, Berkeley, March 15.
[53] IBM, (2003), “Autonomic Problem Determination: A First Step Towards Self-healing Computing Systems”, White Paper, October, 2003.
[54] R. Sterritt, (2002), “Facing Fault Management as It Is, Aiming for What You Would Like It to Be”. In Proceedings of Soft-ware 2002: Computing in an Imperfect World, Belfast, N. Ireland. LNCS Springer, Berlin, pp. 31-45, DOI: 10.1007/3-540-46019-5_3
[55] EU IST FET, (2003), “New Communication Paradigms for 2020”, Brain Storming Meeting July 2003, Brussels, Belgium, (report published September 2003).

[56] M. Smirnov, R. Popescu-Zeletin, (2003), "Autonomic communication", Presentation at the EU IST FET Brainstorming Meeting on Communication Paradigms for 2020, Brussels, Belgium, July 2003.
[57] D. Clark, C. Partridge, J.C. Ramming, J.T. Wroclawski, (2003), "A knowledge plane for the internet", Proceedings of the Applications, Technologies, Architectures, and Protocols for Computer Communication, ACM SIGCOMM 2003, Karlsruhe.
[58] J.M. Agosta, S. Crosby, (2003), "Network integrity by inference in distributed systems", NIPS 2003 Workshop on Robust Communication Dynamics in Complex Networks, Whistler, Canada, December 12–13.
[59] R. Sterritt, S. Dobson, M. Smirnov, IJCAI 2005 Proceedings of the AI and Autonomic Communications workshop available as IEEE Technical Notes of the Computer Society for Autonomous and Autonomic Systems TC: http://tab.computer.org/aas/TNCS-AAS/ijcai-2005-acai-proceedings.pdf
[60] J. Arlidge, "Scientists Fear a Revolt by Killer Robots," The Sunday Times, 2 Aug. 2009; Originally available at; http://technology.timesonline.co.uk/tol/news/tech_and_web/article6736130.ece.
[61] R. Sterritt and M. Hinchey, "SPAACE IV: Self-Properties for an Autonomous and Autonomic Computing Environment—Part IV: A Newish Hope," Proc. 7th IEEE Int'l Conf. and Workshops Eng. of Autonomic and Autonomous Systems (EASe 10), IEEE CS Press, 2010, pp. 119-125.
[62] R. Sterritt and M. Hinchey, "From Here to Autonomicity: Self-Managing Agents and the Biological Metaphors That Inspire Them," Proc. 8th Int'l Conf. Integrated Design and Process Technology (IDPT 05), Soc. for Design and Process Science, 2005, pp. 143-150.
[63] R. Sterritt and M.G. Hinchey, "Biologically-Inspired Concepts for Autonomic Self-Protection in Multiagent Systems," M. Barley et al., eds., Safety and Security in Multi-Agent Systems: Research Results from 2004-2006, LNCS 4324, Springer, 2009, pp. 330-341
[64] M.G. Hinchey and R. Sterritt, "Self-Managing Software," Computer, Feb. 2006, pp. 107-109.
[65] S. Dobson, R. Sterritt, P. Nixon, and M. Hinchey, (2010) "Fulfilling the Vision of Autonomic Computing", IEEE Computer, 43 (1). pp. 35-41.
[66] R.A. Lockshin and Z. Zakeri, "Programmed Cell Death and Apoptosis: Origins of the Theory," Nature Reviews Molecular Cell Biology, July 2001, pp. 542-550.
[67] Y. Ishizaki et al., "Programmed Cell Death by Default in Embryonic Cells, Fibroblasts, and Cancer Cells," Molecular Biology of the Cell, Nov. 1995, pp. 1443-1458.
[68] J. Klefstrom, E.W. Verschuren, and G. Evan, "c-Myc Aug ments the Apoptotic Activity of Cytosolic Death Receptor Signaling Proteins by Engaging the Mitochondrial Apop totic Pathway," J. Biological Chemistry, 8 Nov. 2002, pp. 43224-43232.
[69] M. Sluyser, ed., Apoptosis in Normal Development and Cancer, Taylor & Francis, 1996.
[70] J. Newell, "Dying to Live: Why Our Cells Self-Destruct," Focus, Dec. 1994; http://members.fortunecity.com/ templarseries/Yahoo/Omegaman/apoptosi.html.
[71] N.R. Jennings and M. Wooldridge, "Agent-Oriented Soft ware Engineering," J. Bradshaw, ed., Handbook of Agent Technology, AAAI/MIT Press, 2000.
[72] M.N. Huhns, V.T. Holderfield, and R.L.Z. Gutierrez, "Robust Software via Agent-Based Redundancy," Proc. 2nd Int'l Joint Conf. Autonomous Agents and Multiagent Systems (AAMAS 03), ACM Press, 2003, pp. 1018-1019
[73] G. Kaiser et al., "Kinesthetics eXtreme: An External In frastructure for Monitoring Distributed Legacy Systems," Proc. Autonomic Computing Workshop—5th Ann. Int'l Workshop Active Middleware Services (AMS 03), IEEE Press, 2003, pp. 22-30.
[74] E. Lupu et al., "AMUSE: Autonomic Management of Ubiqui tous Systems for e-Health," Concurrency and Computation: Practice and Experience, Mar. 2003, pp. 277-295.
[75] M.S. Greenberg et al., "Mobile Agents and Security," IEEE Comm. Magazine, July 1998, pp. 76-85.
[76] R. Sterritt, and M. Hinchey, (2018), Apoptotic Computing: Programmed Death by Default for Software Technologies, in Software Technology: 10 Years of Innovation in IEEE Computer. Hinchey, M. (ed.). First ed. John Wiley & Sons, Inc., p. 93-106, DOI:10.1002/9781119174240.ch5
[77] R. Sterritt, (2020), "Keynote: Achieving Trustworthy Autonomous Systems through Autonomic and Apoptotic Computing", Lisbon, Portugal, p. 53-58 ICAS 2020, The Sixteenth International Conference on Autonomic and Autonomous Systems, [Available Online: ThinkMind(TM) Digital Library].

[78] R. Sterritt, G. Wilkie, C. Saunders, M. Doran. C. Gama, G. Hawe, and L. McGuigan, (2019), “Inspiration for Space 2.0 from Autonomic-ANTS (Autonomous NanoTechnology Swarms) Concept missions”, 17th Reinventing Space Conference, Belfast, 2019.
[79] C. Saunders, R. Sterritt, and G. Wilkie, (2014) The Utility of Robot Sensory Devices in a Collaborative Autonomic Environment. In: 11th IEEE International Conference and Workshops on the Engineering of Autonomic and Autonomous , APL, Laurel, Maryland, USA. 8 pp.
[80] C. Saunders, R. Sterritt, and G. Wilkie, (2015) Computer Vision Techniques for Autonomic Collaboration between Mobile Robots. In: 7th International Conference on Adaptive and Self-Adaptive Systems and Applications, Nice, France. IARIA. 7 pp
[81] C. Saunders, R. Sterritt, and G. Wilkie, (2016). Autonomic Cooperation Strategies for Robot Swarms. Adaptive 2016: The Eighth International Conference on Adaptive and Self-Adaptive Systems and Applications - Rome, Italy, Mar 2016
[82] C. Saunders, R. Sterritt, and G. Wilkie, (2019). Collective Communication Strategies for Space Exploration, BIS Reinventing Space Conference, Belfast, Northern Ireland, Nov. 2019. (BIS-RS-2019-06)
[83] C. Saunders, R. Sterritt, and G. Wilkie, (2020). Collective Communication Strategies for Space Exploration. Journal of the British Interplanetary Society, 72(12), 416.
[84] L. McGuigan, C. Saunders, R. Sterritt, and G. Wilkie, (2020). Cooperation Strategies in a Time-Stepped Simulation of Foraging Robots, Adaptive 2020, The Twelfth International Conference on Adaptive and Self-Adaptive Systems and Applications - Nice, France, pp 135-142, 25-29 Oct 2020.
[85] L. McGuigan, R. Sterritt, and G. Wilkie, (2021), Centralised Autonomic Self-Adaptation in a Foraging Robot Swarm, ICAS 2021, The Seventeenth International Conference on Autonomic and Autonomous Systems. Sterritt, R. and Balas, M. J. (eds.). pp. 11-17, 30 May 2021.
[86] L. McGuigan, C. Saunders, R. Sterritt, and G. Wilkie, (2022), “Cooperation Strategies for Swarms of Collaborating Robots: Analysis of Time-Stepped and Multi-Threaded Simulations”, In: International Journal on Advances in Systems and Measurements. 14, 1, p. 44-58, 31 Jan 2022.
[87] L. McGuigan, R. Sterritt, G. Wilkie, and G. Hawe, (2022) “Decentralised Autonomic Self-Adaptation in a Foraging Robot Swarm” In: International Journal On Advances in Intelligent Systems. 15, 1&2, p. 12-23 15 Jul 2022
[88] L. McGuigan, R. Sterritt, and G. Hawe, (2023). “Autonomic Pulse Communications for Adaptive Transmission Range in Decentralised Robot Swarms.” In Proceedings of EMERGING 2023, The Fifteenth International Conference on Emerging Networks and Systems Intelligence (pp. 15-21). IARIA. Pp 15-21, Sept. 2023.
[89] L. McGuigan, R. Sterritt, and G. Hawe, (2023). “Autonomic Pulse Communications for Adaptive Transmission Range and Data Transfer in Deep Space Decentralised Robot Swarms”. Poster session presented at UK SPACE Conference 2023, Belfast, Northern Ireland. Nov. 2023.
[90] L. McGuigan, “Autonomic pulse communications for adaptive transmission range and data transfer in decentralised robot swarms”, Doctoral Thesis, Supervisors: R. Sterritt, G. Wilkie, G. Hawe. Jul 2023
[91] M. Doran, R. Sterritt, and G. Wilkie, (2020), Autonomic architecture for fault handling in mobile robots In: Innovations in Systems and Software Engineering. A NASA Journal. 16, 3-4, p. 263-288 26 p., ISSE-D-19-00010R1. Dec. 2020.
[92] M. Doran, R. Sterritt, and G. Wilkie, (Mar 2016), Autonomic Self-Adaptive Robot Wheel Alignment, in Adaptive 2016: The Eighth International Conference on Adaptive and Self-Adaptive Systems and Applications, p. 27-33.
[93] M. Doran, R. Sterritt, and G. Wilkie, (Mar 2017), Autonomic Sonar Sensor Fault Manager for Mobile Robots, in ICACCE 2017 : 19th International Conference on Autonomic Computing and Computer Engineering - London, 8 p
[94] M. Doran, R. Sterritt, and G. Wilkie, (May 2018), Autonomic Management for Mobile Robot Battery Degradation, ICACCE 2018 : 20th International Conference on Autonomic Computing and Computer Engineering - London, UK, 7p.
[95] M. Doran, (2020), “Developing a Generic Architecture for Autonomic Fault Handling in Mobile Robots”, Doctoral Thesis, Supervisors: R. Sterritt and G. Wilkie. May 2020.
[96] R. Palmer, and R. Sterritt, (2019), Autonomic and Apoptotic Computing Prototype; Providing Pre-Programmed Death of Cubesats for Avoiding Space Junk, Proceedings 2019 IEEE International

Conference on Space Mission Challenges for Information Technology, SMC-IT 2019. IEEE Computer Society, p. 78-86
[97] C. Gama, R. Sterritt, G. Wilkie, and G. Hawe, (2017). Towards a Cubesat Autonomic Capability Model (CACM): A Road Map. At 2017 6th International Conference on Space Mission Challenges for Information Technology (SMC-IT 2017), Alcala de Henares, Sept. 2017.
[98] C. Gama, R. Sterritt, G. Wilkie, and G. Hawe, (2018). Towards a Cubesat Autonomicity Capability Model A Roadmap for Autonomicity in Cubesats. Proc. The Tenth International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE 2018).
[99] C. Gama, R. Sterritt, G. Wilkie, and G. Hawe, (2021). Cubesat Autonomicity: A Paradigm Shift in Cubesat Autonomicity. Proc. 18th British Interplanetary Society Reinventing Space, London, 28-30 Jun 2021 (RISpace 2021).
[100] L. Perri, "What's New in the 2022 Gartner Hype Cycle for Emerging Technologies", Gartner, Online: https://www.gartner.com/en/articles/what-s-new-in-the-2022-gartner-hype-cycle-for-emerging-technologies, August 10, 2022.
[101] N. Arya, "Gartner Hype Cycle for AI in 2023", KDnuggets, https://www.kdnuggets.com/gartner-hype-cycle-for-ai-in-2023, September 25, 2023.
[102] A. Jaffri, "The AI Hype Cycle 2023: New Technologies on the Innovation Trigger", https://www.gartner.com/en/podcasts/thinkcast/the-ai-hype-cycle-2023-new-technologies-on-the-innovation-trigger
[103] K. Markov, K.B. Ivanova, and V. Velychko, (2013). "EVALUATION OF SCIENTIFIC CONTRIBUTION." https://www.researchgate.net/publication/331546435_EVALUATION_OF_SCIENTIFIC_CONTRIBUTION/citations (Last accessed: 3/8/24).
[104] ScholarGPS (2025), Highly Ranked Scholars – Autonomic Computing – Lifetime All, https://scholargps.com/highly-ranked-scholars?year=2025&ranking_duration=LIFETIME_ALL&specialty=Autonomic+computing

</End of Main Body Thesis>

Attached Paper 1 “Autonomic Computing”

1. R. Sterritt, “Autonomic Computing”. *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p79 removed for online version. Please access at publishers site.

DOI: 10.1007/s11334-005-0001-5 | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p80 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p81 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p82 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p83 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p84 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, “Autonomic Computing”. *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p85 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p86 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p87 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

1. R. Sterritt, "Autonomic Computing". *Innovations of Systems and Software Engineering: A NASA Journal,* **1,** pp79–88, 2005.

p88 removed for online version. Please access at publishers site.

DOI | *Springer* | *Pure*

Attached Paper 2. "Personal Autonomic Computing Reflex Reactions and Self-Healing"

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p304 removed for online version. Please access at publishers site.

DOI: 10.1109/TSMCC.2006.871592 | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p305 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p306 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p307 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p308 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p309 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p310 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p311 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p312 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p313 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

2. R. Sterritt, and D.F. Bantz, "Personal Autonomic Computing Reflex Reactions and Self-Healing", In: IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems). 36(3), pp. 304-314, May 2006.

p314 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

Attached Paper 3. "Next generation system and software architectures: Challenges from future NASA exploration missions"

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P48 removed for online version. Please access at publishers site.

DOI: 10.1016/j.scico.2005.11.005 | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P49 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P50 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P51 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P52 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P53 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P54 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P55 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P56 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

3. R. Sterritt, C.A. Rouff, M.G. Hinchey, J.L. Rash, & W. Truszkowski, "Next generation system and software architectures: Challenges from future NASA exploration missions", In: Science of Computer Programming. 61(1), pp. 48-57, Jun 2006.

P57 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

Attached Paper 4 “Autonomic networks: engineering the self-healing property”

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P727 removed for online version. Please access at publishers site.

DOI 10.1016/S0952-1976(04)00111-3 | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P728 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P729 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P730 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P731 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P732 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P733 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P734 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P735 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P736 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P737 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P738 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

4. R. Sterritt, Autonomic networks: engineering the self-healing property, In: Engineering Applications of Artificial Intelligence. 17, 7, p. 727-739, Oct 2004.

P739 removed for online version. Please access at publishers site.

DOI | *Elsevier* | *Pure*

Attached Paper 5 "Autonomic Communications and the Reflex Unified Fault Management Architecture"

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P189 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P190 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P191 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P192 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P193 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P194 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P195 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P196 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P197 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

5. R. Sterritt, D.W. Bustard, D. Gunning, & P. Henning, "Autonomic Communications and the Reflex Unified Fault Management Architecture", In: Advanced Engineering Informatics. 19, 3, pp. 189-198, Jul 2005. doi:10.1016/j.aei.2005.05.015

P198 removed for online version. Please access at publishers site.

DOI 10.1016/j.aei.2005.05.015 | *Elsevier* | *Pure*

Attached Paper 6 "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems"

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: Computer. 44(1), pp. 59-65, Jan 2011.

P59 removed for online version. Please access at publishers site.

DOI 10.1109/MC.2011.5 | *IEEE* | *Pure*

6. R. Sterritt, “Apoptotic Computing: Programmed Death by Default for Computer-Based Systems”, In: Computer. 44(1), pp. 59-65, Jan 2011.

P60 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: Computer. 44(1), pp. 59-65, Jan 2011.

P61 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: Computer. 44(1), pp. 59-65, Jan 2011.

P62 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: Computer. 44(1), pp. 59-65, Jan 2011.

P63 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: Computer. 44(1), pp. 59-65, Jan 2011.

P64 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

6. R. Sterritt, "Apoptotic Computing: Programmed Death by Default for Computer-Based Systems", In: Computer. 44(1), pp. 59-65, Jan 2011.

P65 removed for online version. Please access at publishers site.

DOI | *IEEE* | *Pure*

Attached Paper 7 "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft"

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

JBIS Cover removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P397 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P398 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P399 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P400 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P401 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P402 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P403 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P404 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P405 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P406 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P407 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

7. R. Sterritt, G. Wilkie, C. Saunders, M. Doran, C. Gama, G. Hawe, & L. McGuigan, "Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft", In: Journal of the British Interplanetary Society. 73, 11, p. 397-408, Nov 2020.

P408 removed for online version. Please access at publishers site.

British Interplanetary Society | *Pure*

Appendix A: Roy Sterritt – Publications – *“The First Byte”* (1997 – 2025)

1. Sterritt, R. (2025). AI and Autonomic Computing. Paper presented at The Twenty First International Conference on Autonomic and Autonomous Systems, Lisbon, Portugal, March 2025. https://pure.ulster.ac.uk/en/publications/ai-and-autonomic-computing/

2. Saunders, C., Sterritt, R., Nicholl, P., & McChesney, I. (2025). Synthetic Data Generation for Autonomic Computing. pp1-7. Paper presented at The Twenty First International Conference on Autonomic and Autonomous Systems, Lisbon, Portugal, March 2025. https://www.thinkmind.org/library/ICAS/ICAS_2025/icas_2025_1_10_20014.html

3. McLean, A., & Sterritt, R. (2025). Hard Disk Drive Reliability: A Comparative Study of Supervised Machine Learning Algorithms for Predicting Drive Failure. pp8-14. Paper presented at The Twenty First International Conference on Autonomic and Autonomous Systems, Lisbon, Portugal, March 2025. https://www.thinkmind.org/library/ICAS/ICAS_2025/icas_2025_1_20_28002.html

4. Bennett, J., & Sterritt, R. (2024). Autonomic Computing in Total Achievement of Quality. pp35-40. Paper presented at The Twentieth International Conference on Autonomic and Autonomous Systems, Athens, Greece. https://www.thinkmind.org/index.php?view=article&articleid=icas_2024_1_60_20032

5. Michler, O., & Sterritt, R. (Eds.) (2024). Proceedings of the Twentieth International Conference on Autonomic and Autonomous Systems: ICAS 2024. The Twentieth International Conference on Autonomic and Autonomous Systems, Athens, Greece. https://www.thinkmind.org/index.php?view=instance&instance=ICAS+2024

6. Schmidt, A., Weimer, J., Rajhans, A., & Sterritt, R., (Eds.) (2024), Proceedings of 2024 International Conference on Assured Autonomy (ICAA), Nashville, Tennessee, United States. 123p., Oct. 2024. https://doi.org/10.1109/ICAA64256.2024.

7. McGuigan, L., Sterritt, R., & Hawe, G. (2023). Autonomic Pulse Communications for Adaptive Transmission Range and Data Transfer in Deep Space Decentralised Robot Swarms. Poster session presented at UK SPACE Conference 2023, Belfast, Northern Ireland.

8. Merwick, F., & Sterritt, R. (2023). AC/DC: Autonomic Computing to Maintain Drone Fleet Continuity. 73. Paper presented at The 2023 IARIA Annual Congress on Frontiers in Science, Technology, Services, and Applications, Valencia, Spain. https://www.thinkmind.org/index.php?view=article&articleid=iaria_congress_2023_1_140_50131

9. Russell, G., & Sterritt, R. (2023). An Autonomic Approach to Security Incident Response and Prevention in Cloud Computing. 65. Paper presented at The 2023 IARIA Annual Congress on Frontiers in Science, Technology, Services, and Applications, Valencia, Spain. https://www.thinkmind.org/index.php?view=article&articleid=iaria_congress_2023_1_130_50129

10. Martin, A., & Sterritt, R. (2023). Autonomic Computing for Autonomous Vehicles. 83. Paper presented at The 2023 IARIA Annual Congress on Frontiers in Science, Technology, Services, and Applications, Valencia, Spain. https://www.thinkmind.org/index.php?view=article&articleid=iaria_congress_2023_1_160_50136

11. McLean, A., & Sterritt, R. (2023). Autonomic Computing in the Cloud: An Overview of Past, Present and Future Trends. 77. Paper presented at The 2023 IARIA Annual Congress on Frontiers in Science, Technology, Services, and Applications, Valencia, Spain. https://www.thinkmind.org/index.php?view=article&articleid=iaria_congress_2023_1_150_50133

12. Sehring, H.-W., Chan, S., Caicedo-Castro, I., Zhukov, A., & Sterritt, R. (Eds.) (2023). Proceedings of 2023 IARIA Annual Congress on Frontiers in Science, Technology, Services, and Applications:

"Technical Advances and Human Consequences". 1. The 2023 IARIA Annual Congress on Frontiers in Science, Technology, Services, and Applications, Valencia, Spain. https://www.thinkmind.org/index.php?view=instance&instance=IARIA+Congress+2023

13. McGuigan, L., Sterritt, R., & Hawe, G. (2023). Autonomic Pulse Communications for Adaptive Transmission Range in Decentralised Robot Swarms. In Proceedings of EMERGING 2023, The Fifteenth International Conference on Emerging Networks and Systems Intelligence (pp. 15-21). International Academy, Research, and Industry Association. Advance online publication. https://www.thinkmind.org/index.php?view=article&articleid=emerging_2023_1_30_50021

14. Cai, X., Bi, Y., Nicholl, P., & Sterritt, R. (2023). Revisiting the Encoding of Satellite Image Time Series. In Revisiting the Encoding of Satellite Image Time Series British Machine Vision Association.

15. Karsai, Gabor; Watkins, Lanier; Dubey, Abhishek & Sterritt, Roy,(Eds.), Proceedings 2023 IEEE International Conference on Assured Autonomy (ICAA). Maryland, United States.161 p., June 2023. https://doi.org/10.1109/ICAA58325.2023

16. McGuigan, L., Sterritt, R., Wilkie, G., & Hawe, G. (2022). Decentralised Autonomic Self-Adaptation in a Foraging Robot Swarm. International Journal On Advances in Intelligent Systems, 15(1&2), 12-23. Article 14054.

17. McGuigan, L., Saunders, C., Sterritt, R., & Wilkie, G. (2022). Cooperation Strategies for Swarms of Collaborating Robots: Analysis of Time-Stepped and Multi-Threaded Simulations. International Journal on Advances in Systems and Measurements, 14(1), 44-58. http://www.iariajournals.org/systems_and_measurements/tocv14n12.html

18. Rouff, C., Watkins, L., Sterritt, R., & Hariri, S. (2021). SoK: Autonomic Cybersecurity - Securing Future Disruptive Technologies. Paper presented at IEEE Int. Conf. Cyber Security and Resilience.

19. Gama, C., Sterritt, R., Wilkie, G., & Hawe, G. (2021). Cubesat Autonomicity: A Paradigm Shift in Cubesat Autonomy. Paper presented at British Interplanetary Society Reinventing Space, London, United Kingdom.

20. Sterritt, R., & Balas, M. J. (Eds.) (2021). Proceedings of the 17th Int. Conf. of Autonomic and Autonomous Systems (ICAS 2021). International Conference on Autonomic and Autonomous Systems, Valencia, Spain.

21. McGuigan, L., Sterritt, R., & Wilkie, FG. (2021). Centralised Autonomic Self-Adaptation in a Foraging Robot Swarm. In R. Sterritt, & M. J. Balas (Eds.), ICAS 2021, The Seventeenth International Conference on Autonomic and Autonomous Systems (pp. 11-17)

22. Doran, M., Sterritt, R. & Wilkie, FG., (Dec 2020), Autonomic architecture for fault handling in mobile robots In: Innovations in Systems and Software Engineering. A NASA Journal. 16, 3-4, p. 263-288 26 p., ISSE-D-19-00010R1.

23. Sterritt, R., Wilkie, G., Saunders, C., Doran, M., Gama, C., Hawe, G. & McGuigan, L., (Nov 2020), Inspiration for Space 2.0 from Autonomous NanoTechnology Swarms Concept missions towards Autonomic Robotic Craft
In: Journal of the British Interplanetary Society. 73, 11, p. 397-408

24. McGuigan, L., Saunders, C., Sterritt, R. & Wilkie, G., (Oct 2020), Cooperation Strategies in a Time-Stepped Simulation of Foraging Robots
The Twelfth International Conference on Adaptive and Self-Adaptive Systems and Applications, 25 Oct 2020 → 29 Oct 2020 p. 135-142 [BEST PAPER AWARD]

25. Sterritt, R., (Sep 2020), Achieving Trustworthy Autonomous Systems through Autonomic and Apoptotic Computing. Lisbon, Portugal, p. 53-58 ICAS 2020, The Sixteenth International Conference on Autonomic and Autonomous Systems

26. Panel: Autonomy Control at Work: Cars, Robots, Drones and Satellites
Sterritt, R., Skobelev, P., Döller, M., Dini, IARIA., Stern, C., De Masi, G., Patten, T. & Forero, P., ICAS 2020, The Sixteenth International Conference on Autonomic and Autonomous Systems, - Lisbon, Portugal, Sep. 2020.

27. Saunders, C., Sterritt, R. & Wilkie, FG., (Feb 2020), Collective Communication Strategies for Space Exploration In: Journal of the British Interplanetary Society. 72, 12, p. 416-430

28. Sterritt, R., Wilkie, G., Saunders, C., Doran, M., Gama, C., Hawe, G. & McGuigan, L., (Nov 2019), Inspiration for Space 2.0 from Autonomic-ANTS Concept missions, Proceedings of the 17th BIS Reinventing Space Conference. British Interplanetary Society, BIS-RS-2019-39

29. Saunders, C., Sterritt, R. & Wilkie, G., (Nov 2019), Collective Communication Strategies for Space Exploration, Proceedings of the 17th BIS Reinventing Space Conference. British Interplanetary Society, Vol. 72. 18 p. BIS-RS-2019-06

30. Palmer, R. & Sterritt, R., (Jul 2019), AUTONOMIC & APOPTOTIC COMPUTING PROTOTYPE; Providing Pre-Programmed Death of Cubesats for Avoiding Space JUNK, Proceedings - 2019 IEEE International Conference on Space Mission Challenges for Information Technology, SMC-IT 2019. IEEE Computer Society, p. 78-86

31. Sterritt, R. & Hinchey, M., (Sep 2018), Apoptotic Computing: Programmed Death by Default for Software Technologies, in Software Technology: 10 Years of Innovation in IEEE Computer. Hinchey, M. (ed.). First ed. John Wiley & Sons, Inc., p. 93-106 14 p. 10.1002/9781119174240.ch5

32. Doran, M., Sterritt, R. & Wilkie, G., (May 2018), Autonomic Management for Mobile Robot Battery Degradation, ICACCE 2018 : 20th International Conference on Autonomic Computing and Computer Engineering - London, UK, 7 p.

33. Gama, C., Sterritt, R., Wilkie, G. & Hawe, G., (Feb 2018), Towards a Cubesat Autonomicity Capability Model A Roadmap for Autonomicity in Cubesats, The Tenth International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE 2018) - Barcelona, Spain, p. 34-43

34. Doran, M., Sterritt, R. & Wilkie, G., (Mar 2017), Autonomic Sonar Sensor Fault Manager for Mobile Robots, in ICACCE 2017 : 19th International Conference on Autonomic Computing and Computer Engineering - London, 8 p

35. Curran, E. & Sterritt, R., (Jan 2017), GIVING STUDENTS EMPLOYMENT INTERVIEW PRACTICE IN AN EFFICIENT MANNER, in INTED 2017 11th annual International Technology, Education and Development Conference, 10 p.

36. Sterritt, R., Curran, E., Ayre, N., McChesney, I. & Hanna, (May 2016), Placement Employability: Challenge & Change in an Evolving Landscape, in Employability Challenge and Change in an Evolving Landscape Conference 2016

37. Ayre, N., McChesney, I. & Sterritt, R., (Mar 2016), EMBEDDING EMPLOYABILITY IN THE CURRICULUM - THE AWARE FRAMEWORK, in INTED 2016: 10th annual International Technology, Education and Development Conference, p. 2596-2598

38. Doran, M., Sterritt, R. & Wilkie, G., (Mar 2016), Autonomic Self-Adaptive Robot Wheel Alignment, in Adaptive 2016: The Eighth International Conference on Adaptive and Self-Adaptive Systems and Applications, p. 27-33.

39. Saunders, C., Sterritt, R. & Wilkie, G., (Mar 2016), Autonomic Cooperation Strategies for Robot Swarms, in Adaptive 2016: he Eighth International Conference on Adaptive and Self-Adaptive Systems and Applications, p. 20-27. [BEST PAPER AWARD]

40. Brady, G., Sterritt, R. & Wilkie, G., (Dec 2015), Mobile Robots and Autonomic Ambient Assisted Living In: Paladyn, Journal of Behavioral Robotics. 6, 1, p. 205-217

41. Hinchey, M. G., Vassev, E. I., Hinchey, B. & Sterritt, R., (Oct 2015), Power provision based on self-sacrificing craft, Patent No. 13/606174, Priority date 27 Oct 2015, NASA, Priority No. United States Patent 9171266

42. Sterritt, R., Wilkie, G., Brady, G., Saunders, C. & Doran, M., (May 2015), AUTONOMIC ROBOTICS FOR FUTURE SPACE MISSIONS, in 13th Symposium on Advanced Space Technologies in Robotics and Automation (ASTRA 2015) - ESA/ESTEC, Noordwijk, the Netherlands, European Space Agency, 7 p.

43. Curran, E., Sterritt, R. & Curran, M., (May 2015), Helping students on their journey from undergraduate to IT professionals, in Employability in Action: Opportunities for Developing the Student Experience.

44. Ayre, N., McChesney, I. & Sterritt, R., (May 2015), The AWARE framework - A progressive approach to employability, in Employability in Action: Opportunities for Developing the Student Experience.

45. Saunders, C., Sterritt, R. & Wilkie, G., (Mar 2015), Computer Vision Techniques for Autonomic Collaboration between Mobile Robots, in 7th International Conference on Adaptive and Self-Adaptive Systems and Applications - Nice, France, p. 51-57.

46. Campbell, Julie, Sterritt, Roy, Moore, George, Bond, Raymond, Fraser, Simon, Trombino, Giuseppe, Cleland, Brian and Hanna, Paul (Mar. 2015) INSPIRING COMPUTER SCIENCE EDUCATION IN A WIDENING ACCESS CONTEXT WITH TECHNOLOGY. In: INTED2015 - 9th International Technology, Education and Development Conference, Madrid, Spain. IATED. 8 pp.

47. Sterritt, Roy, Hanna, Paul and Campbell, Julie (Mar. 2015) REINTRODUCING PROGRAMMING TO THE SCHOOL ENVIRONMENT. In: INTED 2015 - 9th International Technology, Education and Development Conference, Madrid, Spain. IATED. 2 pp.

48. Boyd, K., Nugent, C., Donnelly, M., Sterritt, R., Bond, R. & Lavery-Bowen, L., (Jan 2015), EasiSocial: An Innovative Way of Increasing Adoption of Social Media in Older People, in Smart Homes and Health Telematics – Denver, Lecture Notes in Computer Science. Springer, Vol. 8456. p. 21-28.

49. Saunders, Catherine, Sterritt, Roy and Wilkie, George (2014) The Utility of Robot Sensory Devices in a Collaborative Autonomic Environment. In: 11th IEEE International Conference and Workshops on the Engineering of Autonomic & Autonomous , APL, Laurel, Maryland, USA. IEEE CS. 8 pp.

50. Doran, Martin, Sterritt, Roy and Wilkie, George (2014) Autonomic Wheel Alignment for Mobile Robots. In: 11th IEEE International Conference and Workshops on the Engineering of Autonomic & Autonomous , APL, Laurel, Maryland, USA. IEEE CS. 6 pp.

51. McFarland, Catherine, Sterritt, Roy, Bustard, David, McClean, Sally and O'Hagan, Patricia (2014) AARCTIC: Autonomic Analytics Research for Corrections Technology, Institutional and in the Community. In: 11th IEEE International Conference and Workshops on the Engineering of Autonomic & Autonomous , APL, Laurel, Maryland, USA. IEEE CS. 6 pp.

52. Sterritt, Roy (2014) Autonomic Analytics. In: 11th IEEE International Conference and Workshops on the Engineering of Autonomic & Autonomous , APL, Laurel, Maryland, USA. IEEE CS. 4 pp.

53. Boyd, Kyle, Nugent, CD, Donnelly, M, Bond, RR and Sterritt, R (2014) Opportunities and Challenges for Supporting People with Vascular Dementia Through the Use of Common Web 2.0 Services. In: Rare Diseases in the Age of Health 2.0. Springer , Berlin Heidelberg, pp. 241-261. ISBN 978-3-642-38643-5

54. Boyd, Kyle, Nugent, Chris, Donnelly, Mark, Bond, Raymond, Sterritt, Roy and Hartin, Phillip (2014) An investigation into the usability of the STAR training and re-skilling website for carers of persons with dementia. In: 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Chicago. IEEE. 3 pp.

55. Boyd, Kyle, Nugent, Chris, Donnelly, Mark, Bond, RR, Sterritt, R and Gibson, Lorraine (2014) Investigating Methods for Increasing the Adoption of Social Media amongst Carers for the Elderly. In: XIII Mediterranean Conference on Medical and Biological Engineering and Computing , Spain. Springer. Vol 41 4 pp.

56. Okeyo, George, Chen, Liming, Wang, Hui and Sterritt, Roy (2014) Dynamic sensor data segmentation for real-time knowledge-driven activity recognition. Pervasive and Mobile Computing , 10 ((2014)). pp. 155-172.

57. Sterritt, Roy, Campbell, Julie, Bond, Raymond, Moore, George, Trombino, Giuseppe, Fraser, Simon, Cleland, Brian and Hanna, Paul (2014) Technology Enhanced Learning for Computer Science Education: A regional STEM Widening Access Case Study. In: 2014 International Conference on Frontiers in Education: Computer Science and Computer Engineering, Las Vegas, USA. FECS. 8 pp.

58. Sterritt, Roy, Campbell, Julie, Bond, Raymond, Moore, George, Trombino, Giuseppe, Fraser, Simon, Cleland, Brian and Hanna, Paul (2014) Technology Enhanced Learning for Computer Science Education: A regional STEM Widening Access Case Study. In: The 2014 International Conference on Frontiers in Education: Computer Science and Computer Engineering (FECS'14). CSREA Press. 7 pp.

59. Boyd, Kyle, Nugent, Chris, Donnelly, Mark, Bond, Raymond, Sterritt, Roy and Gibson, Lorraine (2013) Methods of Increasing Adoption of Social Media Among Elderly Carers. In: Medicine 2.0 Congress, London. Medicine 2.0. 1 pp.

60. Brady, Guanitta, Sterritt, Roy and Wilkie, George (2013) An Investigation into the Viability of a Mobile Ultrasonic Array as a Sensor Substitute in an Autonomic Intelligent Environment. In: IEEE INTERNATIONAL CONFERENCE ON SYSTEMS, MAN, AND CYBERNETICS, Manchester, UK. IEEE. 6 pp.

61. Chan, Herman, Yang, Mingjing, Wang, Haiying, Zheng, Huiru, McClean, Sally, Sterritt, Roy and Mayagoitia, Ruth E. (2013) Assessing Gait Patterns of Healthy Adults Climbing Stairs Employing Machine Learning Techniques. International Journal of Intelligent Systems, 28 (3). p. 257.

62. Marks, Robert M. and Sterritt, Roy (2013) A Metadata Driven Approach to Performing Complex Heterogeneous Database Schema Migrations. NASA Innovations in Systems and Software Engineering, 9 (3). pp. 179-190.

63. Sterritt, Roy (2013) Special Issue: Engineering of Computer-Based Systems. Innovations in Systems and Software Engineering. A NASA Journal, 9 (3). p. 133.

64. Sterritt, Roy (2013) Forward to Autonomic Computing Principles, Design and Implementation. In: Autonomic Computing Principles, Design and Implementation. Springer, V-VI. ISBN 978-1-4471-5006-0

65. Boyd, Kyle, Nugent, Chris D, Donnelly, Mark, Sterritt, Roy and Bond, Raymond R. (2012) A Usability Protocol for Evaluating Online Social Networks. In: International Conference On Smart homes and health Telematics. Springer. Vol 7251 4 pp.

66. Hinchey, Mike, Rash, James L., Truszkowski, Walt F., Rouff, Christopher A. and Sterritt, Roy (2012) You Can't Get There from Here! Large Problems and Potential Solutions in Developing New Classes of Complex Computer Systems. In: Conquering Complexity. Springer, pp. 159-176. ISBN 978-1-4471-2296-8

67. Hinchey, Mike and Sterritt, Roy (2012) 99% (Biological) Inspiration…. In: Conquering Complexity. Springer, pp. 177-190. ISBN 978-1-4471-2296-8

68. Lorimer, Trevor and Sterritt, Roy (2012) Autonomic Management of Cloud Neighbourhoods through Pulse Monitoring. In: The 2nd International Workshop on Intelligent Techniques and Architectures for Autonomic Clouds (ITAAC) at the 5th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2012), Chicago, Illinois, USA. IEEE Computer Society. 8 pp.

69. Okeyo, George, Chen, Liming, Wang, Hui and Sterritt, Roy (2012) Dynamic sensor data segmentation for real-time knowledge-driven activity recognition. International Journal of Pervasive and Mobile Computing, Elsevier, pp, DOI: 10.1016/j.pmcj.2012.11.004

70. Okeyo, George, Chen, Liming, Wang, Hui and Sterritt, Roy (2012) A Knowledge-driven Approach to Composite Activity Recognition in Smart Environments. In: Ubiquitous Computing and Ambient Intelligence, Lecture Notes in Computer Science. Springer, pp. 322-329. ISBN 978-3-642-35376-5

71. Okeyo, George, Chen, Liming, Wang, Hui and Sterritt, Roy (2012) A Hybrid Ontological and Temporal Approach for Composite Activity Modelling. In: The 12th IEEE International Conference on Ubiquitous Computing and Communications (IUCC 2012), Liverpool, Britain. IEEE Computer Society. 8 pp.

72. Panousopoulou, Athanasia, Sterritt, Roy and Tzes, Anthony (2012) Localised Transmission Power Adjustment for Relative Connectivity Awareness in Wireless Ad-hoc & Sensor Networks. In: 2012 American Control Conference (ACC), Montréal, Canada. IEEE Control Society. 6 pp.

73. Truszkowski, W., Hallock, H.L., Rouff, C., Karlin, J., Rash, J., Hinchey, M.G. and Sterritt, Roy (2012) Autonomous and Autonomic Systems With Applications to NASA Intelligent Spacecraft Operations and Exploration Systems -- Chinese edition. National Defense Industry Press. 249 pp ISBN 978-7-118-07709-4

74. Vassev, Emil, Sterritt, Roy, Rouff, Christopher and Hinchey, Mike (2012) Swarm Technology at NASA: Building Reslient Systems. IT Professional, 14 (2). pp. 36-42.

75. Chan, Herman, Yang, Mingjing, Zheng, Huiru, Wang, Haiying, Sterritt, Roy, McClean, Sally and Mayaoitia, Ruth (2011) Machine learning and statistical approaches to assessing gait patterns of younger and older healthy adults climbing stairs. In: 2011 Seventh International Conference on Natural Computation (ICNC), Shanghai, China. IEEE Computer Science Society. 5 pp.

76. Chan, Herman K.Y., Zheng, Huiru, Wang, HY, Gawley, Richeal, Yang, Mingjing and Sterritt, Roy (2011) Feasibility study on iPhone accelerometer for gait detection. In: Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on, Dublin. IEEE. 4 pp.

77. Chen, Liming, Okeyo, George, Wang, Hui, Sterritt, Roy and Nugent, CD (2011) A Systematic Approach to Adaptive Activity Modeling and Discovery in Smart Homes. In: The 8th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD'11) , Shanghai, China. IEEE . 5 pp.

78. Okeyo , George, Chen, Liming, Wang, Hui and Sterritt, Roy (2011) Time Handling for Real-time Progressive Activity Recognition. In: The 2011 international workshop on Situation activity & goal awareness, in conjunction with Ubiquitous Computing 2011. ACM Digital Library. 8 pp.

79. Okeyo, George, Chen, Liming, Wang, H and Sterritt, Roy (2011) Ontology-based Learning Framework for Activity Assistance in an Adaptive Smart Home. In: Activity Recognition in Pervasive Intelligent Environments, Atlantis Ambient and Pervasive Intelligence. (Eds: Chen, Liming, Nugent, CD, Biswas, Jit and Hoey, Jesse), Atlantis Press, pp. 237-262. ISBN 9789078677352

80. Sterritt, Roy (2011) Apoptotic Robotics: Programmed Death by Default. In: 2011 Eighth IEEE International Conference and Workshops on Engineering of Autonomic and Autonomous Systems, Las Vegas, Nevada USA. IEEE Computer Society. 7 pp.

81. Sprinkle, Jonathan, Sterritt, Roy and Breitman , Karin, eds. (2011) Proceedings of 2011 18th IEEE International Conference and Workshops on Engineering of Computer-Based Systems. 294 pp. IEEE Computer Society. ISBN 978-0-7695-4379-6

82. Perseil, Isabelle, Breitman, Karin and Sterritt, Roy, eds. (2011) Proceedings of the 2011 16th IEEE International Conference on Engineering of Complex Computer Systems. 374 pp. IEEE Computer Society. ISBN 978-0-7695-4381-9

83. Sterritt, Roy, ed. (2011) Proceedings of the 2011 Eighth IEEE International Conference and Workshops on Engineering of Autonomic and Autonomous Systems. 116 pp. IEEE Computer Society. ISBN 978-0-7695-4380-2

84. Sterritt, Roy (2011) Autonomic Software Systems. AIAA JOURNAL OF AEROSPACE COMPUTING, INFORMATION, AND COMMUNICATIO, 8 . p. 86.

85. Sterritt, Roy (2011) Next Generation Autonomic System Environment. AIAA JOURNAL OF AEROSPACE COMPUTING, INFORMATION, AND COMMUNICATION, 8 (4). pp. 115-126.

86. Sterritt, Roy (2011) Autonomic and Apoptotic Systems for Distributed Dynamic Data. NSF & eSci.

87. Sterritt, Roy (2011) Apoptotic Computing: Programmed Death by Default for Computer-Based Systems. Computer, January 2011 . pp. 37-43.

88. Dobson, Simon, Sterritt, Roy, Nixon, Paddy and Hinchey, Mike (2010) Fulfilling the Vision of Autonomic Computing. IEEE Computer, 43 (1). pp. 35-41.

89. NASA, Hinchey, Sterritt (2010) System and method of self-properties for an autonomous and automatic computer environment. [Patent]

90. McCann, Julie and Sterritt, Roy (2010) Autonomic Pervasive Networks (APNs). In: AA-SES-IV: 4th IEEE International Workshop on Autonomic and Autonomous Space Exploration Systems (at SMC-IT), Pasadena, CA, USA. IEEE Computer Society. 4 pp.

91. McFarland, Catherine, Sterritt, Roy, O'Hagan, Patricia and Hanna, Edward (2010) Interfacing with Next Generation Tagging and Tracking Systems for Prisons and Correctional Facilities. In: Seventh IEEE International Conference and Workshops on Engineering of Autonomic & Autonomous Systems, Oxford, England. IEEE Computer Society. 8 pp.

92. O'Hagan, Patricia, Hanna, Edward and Sterritt, Roy (2010) Addressing the Corrections Crisis with Software Technology. Computer, 43 (2). pp. 90-93.

93. Okeyo, George, Chen, Liming, Wang, Hui and Sterritt, Roy (2010) Ontology-Enabled Activity Learning and Model Evolution in Smart Homes. In: The 7th International Conference on Ubiquitous Intelligence and Computing (UIC 2010), Xian China. Springer-Verlag. Vol 6406 6 pp.

94. Sterritt, R (2010) Keynote: Autonomous and Autonomic Systems: Paradigm for Engineering Effective Software Based Systems. In: 33rd Annual IEEE Software Engineering Workshop 2009, Skövde, Sweden. IEEE. 1 pp.

95. Sterritt, Roy and Bustard, David W. (2010) Autonomic Systems. In: Encyclopedia of Software Engineering. Taylor & Francis, pp. 111-117. ISBN 1-4200-5977-7

96. Sterritt, Roy and Hinchey, Mike (2010) SPAACE IV: Self-Properties for an Autonomous & Autonomic Computing Environment – Part IV A Newish Hope. In: AA-SES-IV: 4th IEEE International Workshop on Autonomic and Autonomous Space Exploration Systems (at SMC-IT), Pasadena, CA, USA. IEEE Computer Society. 7 pp.

97. Sterritt, Roy, Hinchey, Mike and Vassev, Emil (2010) Self-Managing Software. In: Encyclopedia of Software Engineering. (Eds: Laplante, Phillip A.), Taylor & Francis, pp. 1072-1081. ISBN 1-4200-5977-7

98. Sterritt, Roy and Nugent, Chris (2010) Autonomic Computing and Ambient Assisted Living. In: AA-SES-IV: 4th IEEE International Workshop on Autonomic and Autonomous Space Exploration Systems (at SMC-IT), Pasadena, CA, USA. IEEE Computer Society. 3 pp.

99. Sterritt, Roy and McCann, Julie, eds. (2010) Engineering of Autonomic & Autonomous Systems, Proceedings of Seventh IEEE International Conference and Workshops on. 163 pp. IEEE Computer Society. ISBN 978-0-7695-4004-7

100. Sterritt, Roy, Eames, Brandon and Sprinkle, Jonathan, eds. (2010) Engineering of Computer Based Systems, The 17th Annual IEEE International Conference and Workshop on the (ecbs 2010). 437 pp. IEEE Computer Society. ISBN 978-0-7695-4005-4

101. Hinchey, MG, Rash, JL, Truszkowski, W, Rouff, CA and Sterritt, R (2009) Vous ne pouvez aller la a partir d'ici! Problemes et solutions potentielles dans le developpement de nouvelles classes de systemes complexes. Genie Logiciel, March 2009 (88). pp. 14-25.

102. Hinchey, Michael G., Sterritt, Roy and Rouff, Christopher A. (2009) Sustainable space exploration missions. Futures, 41 (8). pp. 572-574.

103. Sterritt, R (2009) Keynote: Autonomous and Autonomic Systems: Paradigm for Engineering Effective Computer-Based Systems. In: 1st IEEE Eastern European Regional Conference on the Engineering of Computer Based Systems, Novi Sad, Serbia. IEEE Computer Society . 1 pp.

104. Sterritt, R and Hinchey, MG (2009) Adaptive reflex Autonomicity for real-time systems. Innovations in Systems and Software Engineering, 5 (2). pp. 107-115.

105. Sterritt, R and Hinchey, MG (2009) Organic Computing and Model-Driven Development in Embedded Systems. In: 12th IEEE Symposium on Objects/components/services-oriented Real-time distributed Computing (ISORC 2009), Tokyo, Japan. IEEE. 2 pp.

106. Sterritt, Roy and Hinchey, Mike (2009) Biologically-Inspired Concepts for Autonomic Self-Protection in Multiagent Systems. In: Safety and Security in Multiagent Systems. Springer-Verlag, pp. 330-341. ISBN 978-3-642-04878-4

107. Truszkowski, W., Hallock, H.L., Rouff, C., Karlin, J., Rash, J., Hinchey, M.G. and Sterritt, Roy (2009) Autonomous and Autonomic Systems With Applications to NASA Intelligent Spacecraft Operations and Exploration Systems. Springer-Verlag. 289 pp ISBN 978-1-84628-232-4

108. Bustard, David W. and Sterritt, Roy (2008) A Two-Level Robustness Model for Self-Managing Software Systems. In: Robust Intelligent Systems. Springer-Verlag, pp. 43-60. ISBN 10.1007/978-1-84800-261-6_3

109. Hinchey, MG, Rash, J, Truszkowski, W, Rouff, C and Sterritt, R (2008) You Can’t Get There From Here! Problems and Potential Solutions in Developing New Classes of Computer Systems. In: International Multiconference on Computer Science and Information Technology, Wisla, Poland. IEEE. 9 pp.

110. Mulholland, CL, Sterritt, R, O'Hagan, P and Hanna, E (2008) Tagging and Tracking System for Prisons and Correctional Facilities – A Design Roadmap. In: Fifth IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (ease 2008), Belfast, Northern Ireland. IEEE Computer Society. 9 pp.

111. Bustard, David W. and Sterritt, Roy, eds. (2008) Engineering of Computer Based Systems, The 15th Annual IEEE International Conference and Workshop on the (ecbs 2008). 506 pp. IEEE Computer Society. ISBN 978-0-7695-3141-0

112. Sterritt, Roy, Bustard, David W., Lewis, Dave and Fleck, Joel J., eds. (2008) Engineering of Autonomic & Autonomous Systems, Proceedings of Fifth IEEE International Workshop on. 210 pp. IEEE CS Press. ISBN 0-7695-3139-3

113. Breitman, Karin, Woodcock, Jim, Sterritt, Roy and Hinchey, Michael G., eds. (2008) Engineering of Complex Computer Systems, Proceedings of the 13th IEEE International Conference on. 302 pp. IEEE CS Press. ISBN 0-7695-3139-3

114. Sterritt, R and Hinchey, MG (2008) Towards Self-Managing Real-Time System. In: International Workshop on Real Time Software (RTS'08), Wisla, Poland. IEEE . 6 pp.

115. Strassner, J, O'Sullivan, D, van, de Meer S, Breitman, K, Dobson, S and Sterritt, R (2008) Engineering Semantic Mappings for Autonomic Management. In: Joint ACF, AUTOI, EMANICS Workshop on Autonomic Management in the Future Internet, Barcelona. EU. 2 pp.

116. Sterritt, R (2007) Panel: Autonomic Computing impact on Network Operations & Management. In: the 2nd IEEE Latin American Autonomic Computing Symposium (LAACS), Petropolis, RJ, Brazil.

117. Sterritt, R (2007) Keynote: Autonomous and Autonomic Systems :: Paradigm for Engineering Effective Systems. In: the 2nd IEEE Latin American Autonomic Computing Symposium (LAACS), Petropolis, RJ, Brazil.

118. Hinchey, MG, Sterritt, Roy and Rouff, C (2007) Swarms and Swarm Intelligence. IEEE Computer, 40 (4). pp. 111-113.

119. NASA, Hinchey, Sterritt (2007) Systems, methods, and apparatus for otoacoustic protection of autonomic systems. [Patent]

120. NASA, Hinchey, Sterritt (2007) Systems, methods, and apparatus for otoacoustic protection of autonomic systems. [Patent]

121. Hinchey, MG and Sterritt, R (2007) Keynote: 99% (Biological) Inspiration. In: First IEEE International Conference on Self-Adaptive and Self-Organizing Systems, MIT, Boston, Mass., USA.

122. Sterritt, R, Johnston, SE, O'Hagan, P and Hanna, E (2007) The Imminent Complexity Quagmire in Pervasive Computing - Autonomic Agents a Solution? In: 12th IEEE International Conference on Engineering of Complex Computer Systems (ICECCS 2007), Auckland, New Zealand. IEEE CS Press.

123. Johnston, SE, Sterritt, R, Hanna, E and O'Hagan, P (2007) Reflex Autonomicity in an Agent-Based Security System :: The Autonomic Access Control System. In: Fourth IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (EASe'07), Tucson, AZ, USA. IEEE CS Press. 10 pp.

124. Peña, J, Hinchey, MG, Resinas, M, Sterritt, R and Rash, J (2007) Designing and managing evolving systems using a MAS product line approach. Science of Computer Programming, 66 (1). pp. 71-86.

125. Peña, J, Hinchey, MG, Sterritt, R and Ruiz-Cortés, A (2007) Building and implementing policies in autonomous and autonomic systems using MaCMAS. Innovations in Systems and Software Engineering, 3 (1). pp. 17-31.

126. Pena, J, Hinchey, MG, Resinas, M, Sterritt, R and Rash, JL (2007) Designing and managing evolving systems using a MAS product line approach. Science of Computer Programming, 66 (1). pp. 71-86.

127. Wakid, S and Sterritt, R (2007) Virtualization the Enabler for the Autonomic Business Grid. In: 31st Annual IEEE/NASA Software Engineering Workshop (SEW-31), Loyola College, Baltimore, MD, USA. IEEE CS Press. 5 pp.

128. Hinchey, MG and Sterritt, R (2007) 99% (Biological) Inspiration... In: Fourth IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (EASe'07), Tucson, AZ, USA.

129. Franke, C, Theilmann, W, Zhang, Y and Sterritt, R (2007) Towards the Autonomic Business Grid. In: Fourth IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (EASe'07), Tucson, AZ, USA.

130. Sterritt, R, Hinchey, MG, Bapty, T ed. (2007) Proceedings of the fourth IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (EASe 2007). Los Alamitos, CA, USA. IEEE Computer Society. ISBN 0-7695-2809-0

131. O'Hagan, P, Hanna, E, Sterritt, R and McKay, P (2007) Engineering Vertical Orchestration: From Biometric Trace Events to Incident Reporting. In: 14th Annual IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS'07), Tucson, AZ, USA. IEEE CS Press.

132. Hinchey, M.G. and Sterritt, R (2006) Self-managing software. Computer, 39 (2). pp. 107-109.

133. Sterritt, R and Hinchey, MG (2006) Radical Concepts for Self-Managing Ubiquitous and Pervasive Computing Environments. In: 2nd NASA/IEEE Workshop on Radical Agent Concepts (WRAC 2005), NASA GSFC, Maryland, USA. Springer.

134. Sterritt, R, etal, ed. (2006) Innovative Concepts for Agent and Autonomic Based Systems - Second International Workshop on Radical Agent Concepts, WRAC 2005 (LNAI 3825). Springer. ISBN 978-3-540-69265-2

135. Sterritt, R, Garrity, G, Hanna, E and O'Hagan, P (2006) Survivable Security Systems through Autonomicity. In: 2nd NASA/IEEE Workshop on Radical Agent Concepts (WRAC 2005), NASA GSFC, Maryland, USA. Springer.

136. Sterritt, R (2006) Panel: Bio-inspired Network Management: a viable alternative or a pipe dream?? In: 1st IEEE International Workshop on Modelling Autonomic Communications Environments (MACE 2006), Dublin, Ireland.

137. Peña, J, Hinchey, MG, Sterritt, R, Ruiz-Cortés, A and Resinas, M (2006) A Model-Driven Architecture Approach for Modeling, Specifying and Deploying Policies in Autonomous and Autonomic Systems. In: The 2nd IEEE International Symposium on Dependable, Autonomic and Secure Computing (DASC'06), Indianapolis. IEEE Computer Society Press.

138. NASA, Hinchey, Sterritt (2006) Systems, methods, and apparatus for otoacoustic protection of autonomic systems. [Patent]

139. NASA, Hinchey, Sterritt (2006) Systems, methods, and apparatus for otoacoustic protection of autonomic systems. [Patent]

140. NASA, Hinchey, Sterritt (2006) Systems, methods, and apparatus for otoacoustic protection of autonomic systems. [Patent]

141. NASA, Hinchey, Sterritt (2006) Systems, methods and apparatus for quiescence of autonomic systems with self action. [Patent]

142. NASA, Hinchey, Penn, Sterritt (2006) Systems, methods and apparatus for modeling, specifying and deploying policies in autonomous and autonomic systems using agent-oriented software engineering. [Patent]

143. NASA, Hinchey, Sterritt (2006) Otoacoustic protection in biologically-inspired systems. [Patent]

144. NASA, Hinchey, Sterritt (2006) Systems, methods and apparatus for quiescence of autonomic safety devices with self action. [Patent]

145. Hinchey, MG and Sterritt, R (2006) Keynote: 99% (Biological) Inspiration. In: IFIP Conference on Biologically Inspired Cooperative Computing (BICC 2006) at 19th IFIP WCC 2006, Santiago, Chile.

146. Sterritt, R and Hinchey, MG (2006) Biologically-Inspired Concepts for Self-Management of Complexity. In: 11th IEEE International Conference on Engineering of Complex Computer Systems (ICECCS 2006), Stanford University, CA, USA. IEEE CS Press.

147. Sterritt, R and Hinchey, MG (2006) SPAACE: Self-Properties for an Autonomous and Autonomic Computing Environment - Part II. In: Autonomic & Autonomous Space Exploration Systems (A&A-SES-02), Pasadena, California, USA. NASA.

148. Sterritt, R, Hinchey, MG, Rouff, C, Rash, J and Truszkowski, W (2006) Sustainable and Autonomic Space Exploration Missions. In: Second IEEE International Conference on Space Mission Challenges for Information Technology (SMC-IT 2006), Pasadena, California, USA.

149. Peña, J, Hinchey, MG and Sterritt, R (2006) Towards Modeling, Specifying and Deploying Policies in Autonomous and Autonomic Systems using an AOSE Methodology. In: 3rd IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (EASe 2006), Potsdam, Germany. IEEE Computer Society. 10 pp.

150. Sterritt, R and Bantz, DF (2006) Personal Autonomic Computing Reflex Reactions and Self-Healing. IEEE Transactions on Systems, Man and Cybernetics - PART C: Applications and Reviews (Special Issue on the Engineering of Autonomic Systems), 36 (3). pp. 304-314.

151. Sterritt, R and Hinchey, MG (2006) Biologically-Inspired Concepts for Autonomic Self-Protection in Multiagent Systems. In: 3rd International Workshop on Safety and Security in Multi-Agent Systems (SASEMAS 2006) at AAMAS 2006, Hakodate, Japan.

152. Hinchey, MG, Sterritt, R, Peña, J and Rouff, CA (2006) Software Engineering and Swarm-Based Systems. In: ICSE 2006 Workshop on Software Engineering for Adaptive and Self-Managing Systems (SEAMS'06), Shanghai, China.

153. Sterritt, R, Hanna, E, O'Hagan, P and Garrity, G (2006) Targeting Prediction Engineering a Distributed Event Processor for an Autonomic Biometric System. In: 30th NASA/IEEE Software Engineering Workshop (SEW-30), Columbia, Maryland, USA.

154. Sterritt, R and Bustard, DW (2006) A Health-Check Model for Autonomic Systems Based on a Pulse Monitor. The Knowledge Engineering Review, 21 (3). pp. 195-204.

155. Sterritt, R, Rouff, CA, Hinchey, MG, Rash, JL and Truszkowski, W (2006) Next generation system and software architectures: Challenges from future NASA exploration missions. Science of Computer Programming, 61 (1). pp. 48-57.

156. Pena, J, Hinchey, MG, Resinas, M, Sterritt, R and Rash, J (2006) Managing the Evolution of an Enterprise Architecture Using a MAS-Product-Line Approach. In: The 2006 International Conference on Software Engineering Research and Practice (SERP 2006), Las Vegas, Nevada, USA.

157. Rash, J, Sterritt, R and Hinchey, MG (2006) Autonomic Communication for Space: The Next Frontier? In: Integrated Design & Process Technology Symposium (IDPT 2006), San Diego, California.

158. Bustard, David, Sterritt, Roy, Taleb-Bendiab, A, Laws, A, Randles, M and Keenan, F (2005) Towards a systemic approach to autonomic systems engineering. In: Engineering of Computer-Based Systems, 2005. ECBS '05. 12th IEEE International Conference and Workshops on the . IEEE. 8 pp.

159. Sterritt, Roy, Hinchey, Mike and Bapty, Ted, eds. (2006) Proceedings of the third IEEE International Workshop on Engineering of Autonomic and Autonomous Systems (EASe 2006). Los Alamitos, CA, USA. 165 pp. IEEE Computer Society. ISBN 0-7695-2544-X

160. Sterritt, R (2005) Panel: Agents and Grids: A fruitful marriage? In: 2005 International Conference on Self-Organization and Adaptation of Multi-agent and Grid Systems (SOAS'2005), Paisley, Scotland.

161. Sterritt, R (2005) Keynote: Autonomous and Autonomic Systems. In: 2005 International Conference onSelf-Organization and Adaptation of Multi-agent and Grid Systems (SOAS'2005), Paisley, Scotland.

162. Hinchey, MG, Rash, JL, Truszkowski, WF, Rouff, CA and Sterritt, R (2005) YOU CAN'T GET THERE FROM HERE! PROBLEMS AND SOME POTENTIAL SOLUTIONS IN DEVELOPING NEW CLASSES OF COMPLEX SYSTEMS. Journal of Integrated Design and Process Science, 9 (1). pp. 1-16.

163. NASA, Sterritt et al (2005) Systems, methods and apparatus for generation and verification of policies in autonomic computing systems. [Patent]

164. Sterritt, R, Garrity, G, Hanna, E and O'Hagan, P (2005) Autonomic Agents for Survivable Security Systems. In: 1st IFIP Workshop on Trusted and Autonomic Ubiquitous and Embedded Systems (TAUES 2005) at EUC'05, Nagasaki, Japan. Springer.

165. Sterritt, R, Hinchey, MG, Rash, JL, Truszkowski, W, Rouff, CA and Gracanin, D (2005) Towards Formal Specification and Generation of Autonomic Policies. In: 1st IFIP Workshop on Trusted and Autonomic Ubiquitous and Embedded Systems (TAUES 2005) at EUC'05, Nagasaki, Japan,. Springer.

166. NASA, Hinchey, Sterritt (2005) Swarm autonomic agents with self-destruct capability. [Patent]

167. Marshall, AH and Sterritt, Roy (2005) Clustering Gene Expression Data using Continuous Markov Models. In: IEEE Computational Systems Bioinformatics (CSB 2005) Workshops, Stanford, CA. IEEE. 8 pp.

168. Hinchey, MG, Rash, J, Truszkowski, W, Rouff, C and Sterritt, R (2005) You Can't Get There From Here! Problems and Potential Solutions in Developing New Classes of Systems. In: Integrated Design & Process Technology Symposium (IDPT 2005), Beijing, China.

169. McCaffery, F, McFall, D, Donnelly, P, Wilkie, George and Sterritt, Roy (2005) A software process improvement lifecycle framework for the medical device industry. In: Engineering of Computer-Based Systems, 2005. ECBS '05. 12th IEEE International Conference and Workshops on the . IEEE. 8 pp.

170. Rouff, C, Hinchey, M, Rash, J, Truszkowski, W and Sterritt, Roy (2005) Autonomicity of NASA Missions. In: Autonomic Computing, 2005. ICAC 2005. Proceedings. Second International Conference on , Seattle, WA. IEEE. 2 pp.

171. Sterritt, R (2005) Autonomic Computing. Innovations in Systems and Software Engineering, 1 (1). pp. 79-88.

172. Sterritt, R, Bustard, DW, Gunning, D and Henning, P (2005) Autonomic Communications and the Reflex Unified Fault Management Architecture. Advanced Engineering Informatics, 19 (3). pp. 189-198.

173. Sterritt, R and Marshall, AH (2005) Dynamic Bayesian Networks: a contribution to Autonomic Communications and the Knowledge Plane? In: IJCAI'05 Workshop on AI & Autonomic Communications, Edinburgh, Scotland.

174. Sterritt, R and Bustard, DW (2005) Reflex Unified Fault Management Architecture – Lessons for the Knowledge Plane? In: IJCAI'05 Workshop on AI & Autonomic Communications, Edinburgh, Scotland.

175. Sterritt, R, Dobson, S, Smirnov, M, ed. (2005) Proceedings of the 2005 IJCAI Workshop on AI and Autonomic Communications. .

176. Hinchey, MG, Rash, JL, Truszkowski, WF, Rouff, CA and Sterritt, R (2005) Challenges of Developing New Classes of NASA Self-Managing Missions. In: Workshop on Reliability and Autonomic Management in Parallel and Distributed Systems (RAMPDS-05) at ICPADS-2005, Fukuoka, Japan.

177. Rouff, CA, Hinchey, MG, Rash, JL, Truszkowski, WF and Sterritt, R (2005) Towards Autonomic Management of NASA Missions. In: Workshop on Reliability and Autonomic Management in Parallel and Distributed Systems (RAMPDS-05) at ICPADS-2005, Fukuoka, Japan.

178. Truszkowski, WF, Hinchey, MG and Sterritt, R (2005) Towards an Autonomic Cluster Management System (ACMS) with Reflex Autonomicity. In: Workshop on Reliability and Autonomic Management in Parallel and Distributed Systems (RAMPDS-05) at ICPADS-2005, Fukuoka, Japan.

179. Sterritt, R, Mulvenna, MD and Lawrynowicz, A (2005) Dynamic and Contextualised Behavioural Knowledge in Autonomic Communications. In: First International IFIP Workshop, WAC 2004, Berlin. Springer-Verlag, Lecture Notes in Computing Science.

180. Sterritt, R, Rouff, CA, Rash, JL, Truszkowski, WF and Hinchey, MG (2005) Self-* Properties in NASA Missions. In: International Workshop on Systems/Software Architectures (IWSSA'05) at 2005 International Conference on Software Engineering Research and Practice (SERP'05), Las Vegas. CSREA.

181. Hinchey, MG, Rash, JL, Truszkowski, WF, Rouff, CA and Sterritt, R (2005) Autonomous and Autonomic Swarms. In: Autonomic & Autonomous Space Exploration Systems (A&A-SES-1) at 2005 International Conference on Software Engineering Research and Practice (SERP'05), Las Vegas.

182. Sterritt, R and Hinchey, MG (2005) SPAACE :: Self- Properties for an Autonomous & Autonomic Computing Environment. In: Autonomic & Autonomous Space Exploration Systems (A&A-SES-1) at 2005 International Conference on Software Engineering Research and Practice (SERP'05), Las Vegas. CSREA Press.

183. Sterritt, R and Hinchey, MG (2005) Biologically Inspired: The Autonomic Computing Initiative. THE EASST NEWSLETTER, 11 (December). pp. 36-41.

184. Sterritt, R and Hinchey, MG (2005) From Here to Autonomicity: Self-Managing Agents and the Biological Metaphors that Inspire Them. In: Integrated Design & Process Technology Symposium (IDPT 2005), Beijing, China. Society for Design and Process Science. 8 pp.

185. Sterritt, R and Hinchey, MG (2005) Birds of a Feather Session: “Autonomic Computing: Panacea or Poppycock?”. In: IEEE Workshop on the Engineering of Autonomic Systems (EASe 2005) at 12th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2005), Greenbelt, MD, USA. IEEE. 6 pp.

186. Sterritt, R and Hinchey, MG (2005) Engineering Ultimate Self-Protection in Autonomic Agents for Space Exploration Missions. In: IEEE Workshop on the Engineering of Autonomic

Systems (EASe 2005) at 12th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2005), Greenbelt, MD, USA. IEEE Computer Society. 6 pp.

187. Sterritt, R and Hinchey, MG (2005) Why Computer-Based Systems Should be Autonomic. In: of 12th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2005), Greenbelt, MD, USA. IEEE Computer Society. 7 pp.

188. Sterritt, R, Parashar, M, Tianfield, H and Unland, R (2005) A Concise Introduction to Autonomic Computing. Advanced Engineering Informatics, 19 (3). pp. 181-187.

189. Sterritt, Roy and Hinchey, MH (2005) Autonomicity – An Antidote for Complexity? In: IEEE Computational Systems Bioinformatics (CSB 2005) Workshops, Stanford, CA. IEEE. 8 pp.

190. Sterritt, Roy, Symth, B and Bradley, M (2005) PACT: Personal Autonomic Computing Tools. In: of IEEE Workshop on the Engineering of Autonomic Systems (EASe 2005) at 12th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2005), Greenbelt, MD, USA. IEEE. 9 pp.

191. Hinchey, MG, Rash, J, Truszkowski, W, Rouff, C and Sterritt, R (2005) Plenary: You Can't Get There From Here! Problems and Potential Solutions in Developing New Classes of Systems. In: 10th Lucent Software Symposium, Naperville, IL.

192. Taleb-Bendiab, A, Bustard, DW, Sterritt, Roy, Laws, AG and Keenan, F (2005) Model-Based Self-Managing Systems Engineering. In: Database and Expert Systems Applications, 2005. Proceedings. Sixteenth International Workshop on . IEEE. 5 pp.

193. Hinchey, MG, Rash, JL, Truszkowski, WF, Rouff, CA and Sterritt, R (2005) Autonomous and Autonomic Swarms. In: 8th Biennial Conference on Real Time in Sweden (RTiS) 2005, Skovde, Sweden. SNART.

194. Sterritt, R and Hinchey, MG (2005) Autonomic Computing for Real-Time Systems Tutorial. In: ARTES Summer School 2006, Skovde, Sweden.

195. NASA, Hinchey, Sterritt (2004) Swarm autonomic agents with self-destruct capability. [Patent]

196. Mulvenna, Maurice, Sterritt, Roy, Lawrynowicz, Agnieszka and Devlin, Gerard (2004) Service Delivery Platforms: Servicing Real-World mobile Ubiquitous Computing Applications. 200 pp [Internet publication]

197. Sterritt, R and Hinchey, MG (2004) Apoptosis and Self-Destruct: A Contribution to Autonomic Agents? In: Third NASA-Goddard/IEEE Workshop on Formal Approaches to Agent-Based Systems (FAABS III), Washington DC. Springer-Verlag.

198. Sterritt, R (2004) Autonomic Networks: Engineering the Self-Healing Property. Engineering Applications of Artificial Intelligence, 17 (7). pp. 727-739.

199. Sterritt, R, Mulvenna, MD and Lawrynowicz, A (2004) A Role for Contextualised Knowledge in Autonomic Communications. In: 1st IFIP TC6 WG6.6 International Workshop on Autonomic Communication (WAC 2004), Berlin, Germany.

200. Sterritt, Roy and Bantz, DF (2004) PAC-MEN: Personal Autonomic Computing Monitoring Environments. In: IEEE DEXA 2004 Workshops - 2nd International Workshop on Self-Adaptive and Autonomic Computing Systems (SAACS 04), Zaragoza, Spain. IEEE. 5 pp.

201. Sterritt, Roy and Chung, S (2004) Personal Autonomic Computing Self-Healing Tool. In: IEEE Workshop on the Engineering of Autonomic Systems (EASe 2004) at 11th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2004), Brno, Czech Republic. IEEE. 8 pp.

202. Sterritt, Roy, Gunning, D, Meban, A and Henning, P (2004) Exploring Autonomic Options in an Unified Fault Management Architecture through Reflex Reactions via Pulse Monitoring. In: IEEE Workshop on the Engineering of Autonomic Systems (EASe 2004) at the 11th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2004), Brno, Czech Republic. IEEE. 7 pp.

203. Sterritt, Roy, Mulvenna, Maurice and Lawrynowicz, A (2004) A Role for Contextualised Knowledge in Autonomic Communications. In: First IFIP WG6.6 International Workshop on Autonomic Communication (WAC-2004), Berlin, Germany. IFIP. 13 pp.

204. Sterritt, Roy, Mulvenna, Maurice and Lawrynowicz, A. (2004) Dynamic and contextualised behavioural knowledge in autonomic communications. In: Autonomic Communication. (Eds: Smirnov, M.), Springer-Verlag Berlin, Berlin, GERMANY, pp. 217-228. ISBN 3-540-27417-0

205. McFall, D, Wilkie, FG, McCaffery, F, Lester, NG and Sterritt, R (2003) Software processes and process improvement in Northern Ireland. In: 16th Int. Conf. SOFTWARE & SYSTEMS ENGINEERING and their Applications (ICSSEA 2003), CNAM — Paris, France. ICSSEA. 6 pp.

206. Sterritt, R (2003) Autonomic Computing: the natural fusion of Soft Computing and Hard Computing. In: 2003 IEEE International Conference on Systems, Man & Cybernetics, Washington, D.C., USA.. IEEE. 6 pp.

207. Sterritt, R (2003) Pulse Monitoring: Extending the Health-check for the Autonomic GRID. In: IEEE Workshop on Autonomic Computing Principles and Architectures (AUCOPA 2003) at INDIN 2003, Banff, Alberta, Canada. IEEE. 8 pp.

208. Sterritt, R and Bustard, DW (2003) Towards an Autonomic Computing Environment. In: IEEE DEXA 2003 Workshops - 1st International Workshop on Autonomic Computing Systems, Prague, Czech Republic. IEEE Computer Society. 5 pp.

209. Sterritt, R and Bustard, DW (2003) Autonomic Computing-a Means of Achieving Dependability? In: IEEE International Conference on the Engineering of Computer Based Systems (ECBS'03), Huntsville, Alabama, USA. IEEE CS Press. 5 pp.

210. Sterritt, R, Bustard, DW and McCrea, A (2003) Autonomic Computing Correlation for Fault Management System Evolution. In: IEEE International Conference Industrial Informatics (INDIN 2003), Banff, Alberta, Canada. IEEE. 8 pp.

211. Myers, M, Sterritt, Roy, Curran, Edwin and Song, Hongzhi (2002) Exploring Visualization of Complex Telecommunications Systems Network Data. In: 2002 IEEE International Conference on Systems, Management and Cybernetics. IEEE. 6 pp.

212. Song, Hongzhi, Curran, Edwin and Sterritt, Roy (2002) FlexTree: visualising large quantities of hierarchical information. In: Systems, Man and Cybernetics, 2002 IEEE International Conference on . IEEE. Vol 7 6 pp.

213. Sterritt, R (2002) Towards Autonomic Computing: Effective Event Management. In: 27th Annual IEEE/NASA Software Engineering Workshop (SEW), Maryland, USA. IEEE Computer Society. 8 pp.

214. Sterritt, R and Bustard, DW (2002) Practical Intelligent Support for Rule Discovery in Fault Management Systems. Cybernetics & Systems: An International Journal, 33 (6). pp. 579-601.

215. Sterritt, Roy and Bustard, DW (2002) Fusing Hard and Soft Computing for Fault Management in Telecommunications Systems. IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews, 32 (2). pp. 92-98.

216. Sterritt, Roy, Curran, Edwin and Hongzhi, Song (2002) HACKER: Human And Computer Knowledge discovered Event Rules for Telecommnuications Fault Management. In: 2002 IEEE

International Conference on Systems, Man and Cybernetics, Hammamet, Tunisia. IEEE. Vol 7 6 pp.

217. Sterritt, R (2002) Fault Identification from Uncertain Symptoms. In: Conference on Applied Statistics in Ireland (CASI), Ballycastle.

218. Marshall, AH, Sterritt, R and Bell, DA (2002) Developing Bayesian Belief Networks to Model the Relationships Between Dietary Intake and Pregnancy Outcome. In: Conference on Applied Statistics in Ireland (CASI), Ballycastle.

219. Bustard, David, Liu, Weiru and Sterritt, Roy, eds. (2002) Soft-Ware 2002: Computing in an Imperfect World. (First International Conference, Soft-Ware 2002 Belfast, Northern Ireland, April 8–10, 2002 Proceedings). 357 pp. Springer. ISBN 978-3-540-43481-8

220. Marshall, AH, Bell, DA and Sterritt, R (2002) Handling Uncertainty in a Medical Study of Dietary Intake during Pregnancy. In: Soft-Ware 2002: Computing in an Imperfect World, Belfast, Northern Ireland. Springer-Verlag. 11 pp.

221. Sterritt, R (2002) Facing Fault Management as It Is, Aiming for What You Would Like It to Be. In: Soft-Ware 2002: Computing in an Imperfect World, Belfast, Northern Ireland. Springer-Verlag. 15 pp.

222. Sterritt, R (2002) The Jigsaw Project: Knowledge management - a piece of the puzzle. In: IEE & BTexact Advances in Systems Integration, Adastral Park, Martlesham, Ipswich, UK.

223. Sterritt, R and Liu, W (2001) Constructing Bayesian Belief Networks for Fault Management in Telecommunications Systems. In: 1st European Workshop on Computational Intelligence in Telecommunications and Multimedia at EUNITE 2001, Tenerife, Spain.

224. Sterritt, R (2001) Soft Computing and Fault Management. In: Fourth International Symposium Soft Computing and Intelligent Systems for Industry, Paisley, Scotland.

225. Sterritt, R (2001) Discovering Rules for Fault Management. In: IEEE International Conference on the Engineering of Computer-Based Systems (ECBS), Washington DC, USA. IEEE. 7 pp.

226. Schuster, A, Sterritt, Roy, Adamson, Kenneth, Curran, Edwin and Shapcott, CM (2000) Towards a Decision Support System for Automated Testing of Complex Telecommunication Networks. In: IEEE International Conference on Systems, Man and Cybernetics, Nashville, Tennessee, USA. IEEE. Vol (Volume III) 5 pp.

227. Sterritt, R, Marshall, AH, Shapcott, CM and McClean, SI (2000) Exploring Dynamic Belief Networks for Telecommunications Fault Management. In: IEEE International Conference on Systems, Man and Cybernetics, Nashville, Tennessee, USA. IEEE. 7 pp.

228. Sterritt, Roy, Adamson, Kenneth, Curran, Edwin and Shapcott, CM (2000) Probabilistic Networks for Verifying Automated Testing of High Speed Telecommunication Equipment through the Development Lifecycle. In: IEEE International Conference on Systems, Man and Cybernetics, Nashville, Tennessee, USA. IEEE. Vol (Volume I) 6 pp.

229. Sterritt, Roy, Marshall, AH, Shapcott, CM and McClean, Sally (2000) Exploring Dynamic Belief Networks for Telecommunications Fault Management. In: IEEE International Conference on Systems, Man and Cybernetics, Nashville, Tennessee, USA. IEEE. Vol (Volume V) 5 pp.

230. Sterritt, R, Shapcott, CM, Adamson, Kenneth and Curran, Edwin (2000) High Speed Network First-Stage Alarm Correlator. In: IASTED International Conference Intelligent Systems and Control (ISC 2000), Honolulu, Hawaii, USA.

231. Schuster, A, Seguí, Prieto M, Sterritt, R, Adamson, Kenneth, Curran, Edwin and Shapcott, CM (2000) Data Mining of Automated Testing Telecommunication Networks Data. In: Fourth

World Multiconference on Systemics, Cybernetics and Informatics, and the 6th International Conference on Information Systems, Analysis and Synthesis ISAS 2000, Orlando, USA.

232. Palmer, FL, Sterritt, R, Shapcott, CM, Curran, Edwin and Adamson, Kenneth (2000) Exploring Dynamic Belief Network Visualisation. In: , Third IASTED International Conference Artificial Intelligence and Soft Computing (ASC'2000), Banff, Alberta, Canada.

233. Sterritt, R, Schuster, A, Curran, Edwin, Adamson, Kenneth and Shapcott, CM (2000) An Application of Case-Based Reasoning for Development Verification Testing of SDH Equipment. In: Fourth World Multiconference on Systemics, Cybernetics and Informatics, Orlando, Florida, USA.

234. Sterritt, R, Schuster, A, Adamson, Kenneth, Shapcott, CM, Curran, Edwin, Houston, P and Johnson, R (2000) A Proposal for End-to-End Automated Testing for the Development Life-Cycle of High Speed Telecommunication Equipment. In: Fourth World Multiconference on Systemics, Cybernetics and Informatics, Orlando, Florida, USA.

235. Sterritt, R, Curran, Edwin, Adamson, Kenneth and Shapcott, CM (2000) Visualisation for Data Mining Telecommunications Network Data. In: Second International Conference on DATA MINING 2000, Cambridge University, UK. WIT Press.

236. Sterritt, R, Adamson, Kenneth, Shapcott, CM and Curran, Edwin (2000) Data Mining Telecommunications Network Data for Fault Management and Development Testing. In: Second International Conference on DATA MINING 2000, Cambridge University, UK,. WIT Press.

237. McBride, S, Sterritt, R, Curran, EP, Adamson, Kenneth and Shapcott, CM (2000) Maypole: Visualising Contingency Tables. In: International Conference On Artificial Intelligence (IC-AI'2000), Monte Carlo Resort, Las Vegas, Nevada, USA.

238. Sterritt, R, Adamson, Kenneth, Curran, Edwin, Shapcott, CM, Johnson, R and Calvert, W (2000) Towards Intelligent Automated Testing In The Development Lifecycle Of High Speed Telecommunication Equipment. In: The International. Conference On Artificial Intelligence (IC-AI'2000), Monte Carlo Resort, Las Vegas, Nevada, USA,.

239. Sterritt, R, Adamson, Kenneth, Shapcott, CM and Curran, Edwin (2000) Parallel Data Mining of Bayesian Networks from Telecommunications Data. In: Third Workshop on High Performance Data Mining 2000, IEEE International Parallel and Distributed Processing Symposium (IPDPS), Cancun, Mexico. Springer.

240. Shapcott, CM, Sterritt, R, Adamson, Kenneth and Curran, Edwin (2000) NETEXTRACT - Extracting Belief Networks in Telecommunications Data. In: of the ERUDIT Workshop on Application of Computational Intelligence Techniques in Telecommunication, Imperial College, London, UK.

241. Schuster, A, Sterritt, R, Adamson, Kenneth, Shapcott, CM and Curran, Edwin (1999) Case-base Reasoning for Complex Telecommunication Systems. In: the ERUDIT Workshop on Application of Computational Intelligence Techniques in Telecommunication, Imperial College, London, UK.

242. Sterritt, R, Adamson, Kenneth, Curran, Edwin and Shapcott, CM (1999) Visualisation And Context Of Telecommunications Data. In: the 17th International IASTED Conference on Applied Informatics, Innsbruck, Austria.

243. Sterritt, R, Curran, Edwin, Adamson, Kenneth and Shapcott, CM (1998) Applications of AI for Automated Testing in Complex Telecommunication Systems. In: Expersys-98 Artificial Intelligence Applications, Virginia, USA. I.I.T.T. International.

244. Sterritt, R, Adamson, Kenneth and Curran, Edwin (1998) Geometrical Visualisation Interfaces For Complex Telecommunication Systems. In: the NIMES 98 Conference on Complex Systems, Intelligent Systems and Interfaces, Nimes, France.

245. Sterritt, R, Adamson, Kenneth and Curran, Edwin (1998) Case-Based Reasoning For Complex Telecommunication Systems. In: the NIMES 98 Conference on Complex Systems, Intelligent Systems and Interfaces, Nimes, France.

246. Sterritt, R, Adamson, Kenneth and Curran, Edwin (1998) A Graphical And Real-Time Network Emulation Toolset. In: the NIMES 98 Conference on Complex Systems, Intelligent Systems and Interfaces, Nimes, France.

247. Sterritt, R, Adamson, Kenneth, Shapcott, CM and Curran, Edwin (1998) Adapting An Architecture For Knowledge Discovery In Complex Telecommunication Systems For Testing Assurance. In: the NIMES 98 Conference on Complex Systems, Intelligent Systems and Interfaces, NIMES, France.

248. Gilmour, G, Sterritt, R, Adamson, Kenneth and Curran, Edwin (1998) A Monitor For An SDH Simulation On A Transputer Network. In: the 16th IASTED International Conference on Applied Informatics, Garmisch-Partenkirchen, Germany.

249. Sterritt, R, Curran, Edwin, Adamson, Kenneth and Houston, P (1998) Towards An Intelligent GUI For An SDH Simulation On A Transputer Network. In: the 16th IASTED International Conference on Applied Informatics, Garmisch-Partenkirchen, Germany.

250. Sterritt, R, Adamson, Kenneth, Shapcott, CM, Wells, N, Bell, DA and Liu, W (1997) A Parallel Genetic Algorithm For Cause And Effect Networks. In: The IASTED International Conference On Artificial Intelligence And Soft Computing (in co-operation with AAAI), Banff, Canada.

251. Sterritt, R, Adamson, Kenneth, Shapcott, CM, Bell, DA and McErlean, F (1997) Using A.I. For The Analysis Of Complex Systems. In: IASTED International Conference On Artificial Intelligence And Soft Computing (in co-operation with AAAI), Banff, Canada.

252. Sterritt, R, Livingstone, N, Adamson, Kenneth and Curran, Edwin (1997) SSM Model: Synchronous Status Messaging Emulation Model. In: The Third EPSRC Annual Conference On Architectures For Integrated Knowledge-Manipulation Systems, London, England.

253. Sterritt, R, Livingstone, N, Curran, Edwin and Adamson, Kenneth (1997) Garnet: Graphical And Real-time Network Emulation Tool, Presented. In: The Third EPSRC Annual Conference On Architectures For Integrated Knowledge-Manipulation Systems, London, England.

254. Sterritt, R, Bell, DA, Adamson, Kenneth and Shapcott, CM (1997) NetExtract. In: The Third EPSRC Annual Conference On Architectures For Integrated Knowledge-Manipulation Systems, London, England.

255. Adamson, Kenneth, Bell, DA, Shapcott, CM and Sterritt, R (1997) An Architecture For The Extraction Of Cause And Effect Networks From Complex Systems. In: The Third EPSRC Annual Conference On Architectures For Integrated Knowledge-Manipulation Systems, London, England.

256. Sterritt, R, Daly, M, Adamson, Kenneth, Shapcott, CM, Bell, DA and McErlean, F (1997) Netextract: An Architecture For The Extraction Of Cause And Effect Networks From Complex Systems. In: 15th IASTED International Conference On Applied Informatics, Austria.

Figure 0-1 A Cartoon that accompanied a feature on Sterritt's work on Autonomic Computing with BT in 2003 in the UK's Times Higher Education newspaper ([Self-help is key to healthy computers]).

Sterritt's first, but not last, embarrassment at how the press edits out "citations" so quotes that should have been accredited to IBM were written up as "Sterritt said". The cartoon though was used extensively throughout Sterritt's AC presentations over the last 20+ years usually with the words "But there is only so much we can achieve… any questions?", and seems appropriate to end this thesis with.

</End of Appendices>