Viable Computer Systems: A Cybernetic Approach to Autonomic Computing

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Abstract - **Autonomic Computing has the potential to deliver self-managing systems, based upon the principles of the human autonomic nervous system. Since its inception, significant advancement has been made in realising the objectives of the genre; however, scope for progression still exists. The authors present innovative research, applying a cybernetic approach to the development of Autonomic Computing systems. The basis of this research is a set-theory oriented, atomically-derived, emergent model. This reflects first-stage, functional, decomposition of Beer's recursive Viable System Model (VSM). Although the scope of the existing VSM is that of human organizations, our research has provided a context-shift towards the field of Autonomic computing. The model provides integrated management of all elements promoting each sub-system as an autonomous whole within a closed meta-boundary. By endorsing autonomy versus governance, our research presents a formalism that can be used to represent self-aware systems, seeking inherent learning and control through communicative system-environment interplay.**

Keywords: Autonomic Computing, Viable System Model, Cybernetics.

I. INTRODUCTION

An imperative of the industry today is to resolve the growing problem of software system complexity [1]. Autonomic Computing has been mooted as a possible solution, yet this paper seeks to advance the boundaries of the state of the art via extending existing biological and cybernetic metaphors. By fusing a mathematical analogue with the underpinning functionality of Beer's Viable System Model (VSM) [2], we have developed a set-theory blueprint as the basis of a design grammar model. Focusing on the externally-facing, future-oriented, System Four (S_4) of the architecture, the ultimate research vision is to represent this via a software demonstrator. This paper presents a fundamental building block towards its realization in the form of a context free design grammar. The evolving system, currently in development, will be realized as a *Viable Computer System (VCS),* able to retain its viability through self-organization and emergence, so managing complexity. The VCS will operate in an intrinsic, reactive, forecasting mode, ready to respond to environmental stimulus post t^{n-1}. A referential *self* model of the internal capabilities of the system i.e. the status quo t^n and a model of the wider systemic environment, dictating the required world situation t^{n+1}, will be employed. Symbiosis between these past, present and future events will be accommodated via transposing the sensor/effector principles from the VSM. Feedback control will thus be core to the final prototype.

Our research aims to facilitate change, whilst satisfying the imperative of a self-organizing system to continuously emerge. We thus work towards a model that will manage this. By offering such proof of concept, we will surpass the existing margin of the Autonomic Computing genre through the principles of homeostasis [3], and autopoiesis [4, 5]. The adoption of this approach, seeks to reduce redundancy and so complexity, by generating timely models, referenced and responded-to by the system. The research objective is to ultimately reflect the real world and autonomically address environmental requirements via the VCS.

Our current work reformulates the existing recursivity present within the VSM architecture, via algebraic set theory. At this stage, a context-free design grammar appears to offer not only the potential for modelling a dynamic system by providing an internal representation but also a topology imbuing the system with self-awareness. The self/non-self dichotomy [6] is thus important to the research. Our primary goal is to progress Autonomic Computing towards the development of Viable Computing Systems, so extending the concept to correspond with the way that human autonomic systems are subsumed by cognitive systems. This research will produce a VCS to at least a prototypical level, achieved via the construction of the design grammar model. The work also serves to significantly extend and reformulate the existing recursivity within a previously published cybernetic architecture for Autonomic Computing [7].

The remainder of the paper is structured as follows: Section II considers the state of the art within Autonomic Computing with respect to the relationship between Autonomic Computing and Cybernetics. Section III reviews Beer's Viable System Model and its cybernetic governance. Section IV considers how Management Cybernetics and the VSM can be combined to form the basis for a VCS, by translating the VSM context into that of the VCS. Section V describes the design grammar, providing examples and Section VI draws conclusions from the research to date.

II. AUTONOMIC COMPUTING

The term *Autonomic Computing* dates back to March 2001, with the inception of the IBM initiative [1]. Horn highlighted the growing problems of complexity in today's computer systems in terms of managing size, maintainability, and implicitly the legacy system syndrome [8].

The basis of Autonomic Computing is that systems are able to self-manage, adapting their behaviour at runtime to respond dynamically to change. Analogous to the self-governance of the human body such as a person's heart beating with them having to neither consider, nor understand the rudiments of that action, thereby promoting autonomy versus governance.

Circa 1999, Laws et al. drew a parallel between the cybernetic properties of Beer's VSM and the complexity reduction requirements of the software industry [9]. In applying the VSM to problems that were later identified as pertinent to the then Autonomic Computing ideal, the fusion subsequently produced the 2001 J-Reference Model [7]. Displaying the existing cybernetic topology, it united with both Bratman et al.'s IRMA architecture [10] and the Beliefs, Desires, Intentions (BDI) framework, whilst employing the Ashbian systemic variety [11] concept to the endogenous complexity proliferation pre-millennium [8]. The BDI framework application, however, introduced recognised problems from Artificial Intelligence; successful application of a real-time, isomorphic model [12], depends upon a real-time BDI complete model, necessitating context-sensitivity. Laws et al's research continued [7, 13-15] however, later running concurrent, yet significantly unparalleled, to others drawing biological homeostatic analogies such as IBM's Horn [1], Kephart and Chess [16]. Contemporaries including Herring [17] and latterly Stoyanov [18], applied the VSM blueprint to their Autonomic Computing research. Stoyanov proposed that the abstraction of observable variety and a managed Communication Channel was core to development of viable, Autonomic Computer systems, whilst outlining the importance of the runtime capability verification of interacting components. Espejo's collaboration with Harnden [19], applied a cybernetic slant to the modelling of agent communities.

None, however, have fused these requirements and principles with a mathematical analogy to the VSM. Our work advances to multi-agent self-organization of software technology, a context-digression from the human-oriented Management Cybernetics. Blending Beerian concepts and Autonomic Computing innovates a model-based system and formalism, circumventing previous approaches.

III. VIABLE SYSTEM MODEL

Fig. 1., represents Beer's VSM, as a five-system, autopoeitic, top-down recursive, emergent model, with one sub-system, named System Three Star, or S_{3^*}. It mainly comprises inter-communicative homeostatic loops, exhibiting interaction of system operations and its environment. Viability becomes an emergent property.

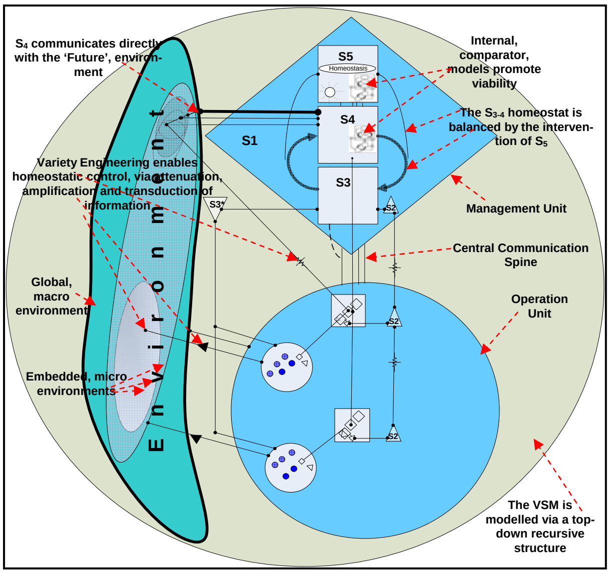

Fig. 1. Simplistic VSM representation.

Originally applied to the human organization, the VSM is set in the context of Management Cybernetics [20]. It is unique within the field due to its use of Variety Engineering [2], a process controlling systemic complexity. Organizationally and operationally closed, yet informationally open, it encompasses the three elements of Management unit, Operation and Environment*.*

Operation contains the primary activities and is the locus of recursion within the topology. The Management unit or Metasystem ensures integration of the Operational units. The Environment incorporates external elements directly relevant to the system. Three key environmental levels encompass the micro, the macro, (or global, in-which these are embedded) and the future, forecasting level. Two internal models promote viability via mapping between the internal capabilities of the system and a changing environment. The central, vertical spine encompasses four communicative channels and one intermittent algedonic or alarm channel, carrying and transducing data amid the system-environment alliance. S_4 promotes viability by mapping to the future environment, so identifying benefits and threats. The Beerian model parts constitute:-

- *System One (S_1), Implementation*: Comprised of a management and operation unit, S_1 is nested within a higher parent S_1. It is autopoietic, via its ability to self-produce lower-level recursions within a recommended range of one to seven S_1's per recursive level. The primary systemic activities are executed by S_1, an autonomous homeostat. Interacting directly with the environment, S_1 assumes primacy within the systemic federation, as it consists itself, of viable systems.
- *System Two (S_2), Co-ordination*: The local regulatory system particular to each S_1, S_2 is a standardizing anti-oscillatory body. Coordinating and facilitating S_3 in its objective of integrative function, S_2 is thus the locus of systemic homeostasis.

- *System Three (S_3), Control*: The controlling facility within the model, S_3 regulates, optimises and stabilises internal activity. Assisted by S_2, S_3 provides overall structure, integrating cohesive activities of the S_1's.
- *System Three-Star (S_{3*}), Audit*: Sporadic auditing system, S_{3*} acts as a backup inspection facility to the validity and functionality of S_1 and S_3 respectively.
- *System Four (S_4), Intelligence*: Unique in directly connecting to all of the wider environments. Each recursive S_4 links directly to its parent and subordinate counterparts, promoting inter-recursive cohesion.
- *System Five (S_5), Policy*: Providing ultimate authority, S_5 is the policy maker, homeostatically controlling systemic complexity. S_5 thinks about what the system does. Providing logical closure to the system, S_5 monitors the $S_{3\text{-}4}$ homeostat.
- *Metasystem Homeostat ($S_{3\text{-}4\text{-}5}$)*: The metaphorical head of the system [2], comprised of S_3, S_4 and S_5. The metasystem is the composite management vortex masterminded by S_5. Presiding over and beyond the $S_{3\text{-}2\text{-}1}$ homeostat, of lower logical order, yet not necessarily of higher authority.
- *Environment*: The highest recursive level of the metasystem, part of the triadic alliance of management, operation and its particular environment. The VSM is viable only because it can maintain a separate existence within its embedded environment. Management is thus the regulator of operations and vice-versa.
- *Central Vertical Communication Channels*: The spine of the system, characterising viability via flows of information within the system and between its environments. Comprised of four bidirectional, principal channels named Accountability, Resource Bargain, Command and Legal and Corporate Requirements, there exists one Algedonic or alarm tributary. Each operates in a reactive, feedback controlled mode.
- *Variety Engineering*: Unique to Management Cybernetics, this process regulates systemic complexity. Feedback control is key to viability, empowering the homeostatic loops with a common endeavour to attenuate the variety emanating from the parent S_1, yet amplifying the variety in terms of its environments. In attaining requisite variety, the location of the command centre is determined by the data available to a concatenation of systems. This dictates the relevant elements and systems in real time, promoting self-organization.

IV. Translating The VSM Context Into VCS

The Beerian model is a black box system, with merely the inputs and outputs being defined, without explanation of the internal systemic processes that lead to each operation. The functionality i.e. scanning of the environment is executed by human agents. The observer views the resultant actions, rather than additional aspects supplied by those people. S_4 of the VSM is the primary sensor for complexity, uniquely linking directly to the open environment it produces an attenuated model upon which decisions are made. Applying this metaphor to Viable Computing, we focus on determining *what* the system should sense, the embodiment of such properties posing a significant research challenge.

The VCS advances the natural milieu of the VSM from the human organization to computing, via the design grammar. Development of an algebraic set theory model, informed by the VSM, reflects fractal-type recursive geometry [21], inherent within the topology. Beer's architecture appears ripe to support a potentially context-free design-grammar, germane to diverse computing scenarios. An internal representation will be incorporated, imbuing the system with aspects of a *self/non-self* distinction, maintaining viability via recognising environmental changes, whilst seeking to combine atomic elements to gain specific emergent properties. Fusing principles of Autonomic Computing with the VSM and mathematical set theory, the algebraic design grammar is the main modelling formalism that will realize the VCS specification. Previous research has focused on *what* the requirements are; conversely, this study addresses *how* to achieve the goal, so progressing the development of a J-Reference Model II as shown in Fig.3.

A. *VSM Topology Post-Application of Algebraic Design Grammar*

Fig. 2. shows the modification of the VSM's topology, to satisfy the specification for complexity reduction within the system-in-focus. Changes also address the long-term, ongoing research intention to produce a J-Reference Model II, to be discussed in subsequent publications, possibly incorporating a temporal control function, to represent the design grammar's aspired forecasting capability. Our research has led to the incorporation of S_{3*} into S_3. Similarly, the highest-level S_2 has been omitted from Beer's highest-level S_0, to devolve central governance to self-governing lower-recursion S_1's. A model of the viable system in focus is incorporated within S_4 and S_5. Rather than an isomorphic mapping of the environment [12] we will assume the lossy data compression approach [22] reflecting an homomorphic depiction [12]. By fulfilling specific systemic requirements, complexity will be reduced.

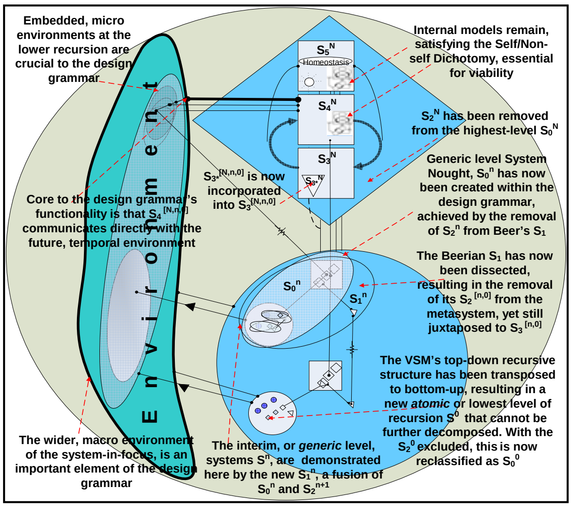

Fig. 2. VSM topology, post-application of Design Grammar.

Our research has led to the incorporation of S_{3*} into S_3. Similarly, the highest-level S_2 has been omitted from Beer's highest-level S_0, to devolve central governance to self-governing lower-recursion S_1's. A model of the viable system in focus is incorporated within S4 and S_5. Assuming the lossy data compression approach [22], there will not be an isomorphic mapping of the environment [12] but an homomorphic depiction [12] to satisfy particular requirements of the system. As the VSM's top-down recursive structure has been transposed to bottom-up within the design grammar, Beer's highest-level systems represent the design grammar's lowest-level systems and vice-versa.

V. DESIGN GRAMMAR

Construction of a first-stage, system-wide context-free design grammar is currently in progress. The formal algebraic representation incorporates production rules and a set of symbols encompassing a vocabulary comprised of atomic elements of the language. Immediate future research will expand the grammar to allow systemic configuration via deletion and insertion of topological parts. Narrowing the focus by delineating the models' system-environment ecology, the design grammar will apply Sommerhoff's coenetic variable principles [23], permitting modelling of variables to affect both the system-in-focus and its environment.

A. *Relevance of Design Grammar Formalism*

The design grammar has been applied as a formal representation, characterizing a set of rules dictating how the VCS elements may be put together. The design grammar model will be capable of automating the design process and rules generated by emerging requirements. It can be applied to both the analysis and synthesis of the VCS design. The former is useful for determining the design legality, the latter facilitates discovery of faults, indicating reformulation.

B. *Instantiation via VSM*

Atomic decomposition of Beer's model incorporates dissection of the conventional S_1 into two distinct parts. S_2, removed from the metasystem and re-positioned still adjacent to S_3, facilitating enclosure by the new S_1's, boundary. Similarly, the same management and operation units without that S_2 are re-classified as System Nought, S_0.

C. *Modelling of System-Environment Ecology*

The design grammar reflects the system-environment unity. Concluding that where *S* is a system and *E* incorporates the environment of *S*, it follows that $S \wedge E \rightarrow S \cup E$. Also, where S_1 is equal to S_0 in union with S_2, E_1 will thus be equal to E_0 in union with E_2. System-environment interplay is crucial to support the models, emergence and viability per se.

A research challenge is defining the semantics of addition, or *union*, and any future *subtraction*, *multiplication* and *division*, operators. Understanding what lies behind the concatenation of compositions of elements is context dependant, due to the range of different elements able to be added/subtracted. Future work will comprehend how this interconnection of two separate things is achieved.

Our utilisation of a mathematical analogy is purely a vehicle for expressing research concepts and ideas.

D. *Recursivity*

The design grammar echoes the VSM's indefinite recursivity, at a post-atomic level, having no specific starting point or initial conditions. Aspirant to produce a VCS that reduces human agent intervention, it reflects Horn's self-CHOP benchmark [24]. Our research concludes that three levels of recursion require definition. These encompass the lowest (atomic) level of recursion nought, or S_0, with all higher levels, to the penultimate, infinite recursion, defined as generic, or S^n. Exceptionally, the highest level of recursion, defined as S^N, is distinct by its lack of S_2; terminating autopoiesis and production of further recursions at this point. Recursion reflects stability in the chain of operations, as constant values maintain their structure or function when operations are repeatedly performed upon them. The identity pursues its indefinite recursive chain, promoting self-stabilisation through homeostasis. As with the generic level, the particular local, future and macro environments, are each incorporated into an identity. At the atomic point, S_0^0 consists of non-decomposable elements, yet must nonetheless autopoietically spawn higher levels, enabling emergence of a viable system.

E. *Proposed Model of S_4*

As demonstrated in Fig. 3., the mode of S_4 scanning is undetermined, yet a long-term objective is for the VCS to inspect the wider, open, environment. The demonstrator will initially be implemented in an intermittently open and closed environment.

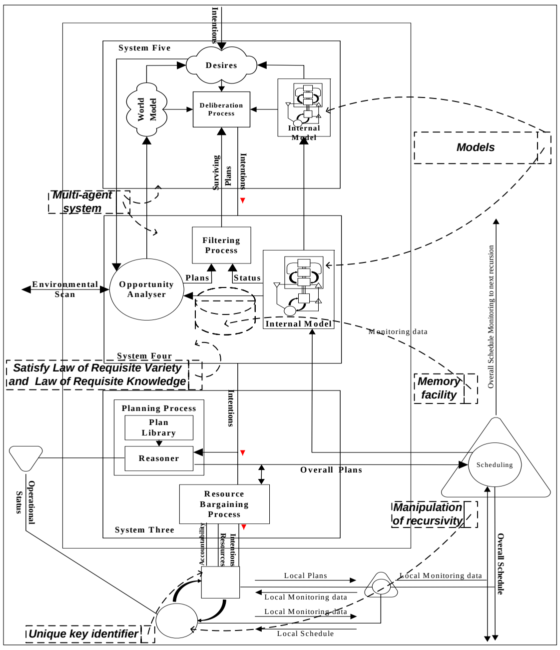

Fig. 3. Proposed model of System Four.

Experience-driven, building and improvement of models of the local, global and future environments will be continuous. Modelling and contrasting internal systemic capabilities with lossy data models of scanned environments, S$_4$ may enable the observation, diagnosis and storage of systemic risks and benefits, so promoting reinforcement learning. A memory capacity possibly will exist, allowing identity storage, thus enabling the VCS to profit from environmental challenge and opportunity will result in emergence. The multi-agent system, populated by autonomous learning agents could assume a reward and punishment scheme. Through the employment of algedonic regulation, achieved via manipulation of inherent design grammar recursivity, novelty and creativity [25] may be promoted.

S$_4$ will aspire to comply with Ashby's Law of Requisite Variety [11], ensuring that for each environmental action there must be an equal and appropriate response and Aulin's Law of Requisite Knowledge [26], dictating that the VCS must *know* which actions to select to control perturbations. Incorporating a default hierarchy of a multi-level structure, classifiers could become more general as the top level is ascended. Each rule will respond to a set of environmental messages, research aiming for minimal rules covering all possible states of a partially open environment. We consider this indicative of a *learning* capability.

F. Design Grammar Identities Syntax Examples

There follow key examples from the design grammar model, that represent the proposed VCS.

A : the set $\{a_1,a_2,a_3,a_4,\ldots_i\}$| a_i is atomic
M : *Management unit*
O :*Operation*
E : *Environment*
t : *CurrentTime*| $t+1$: *FutureTime* | $t-1$: *PastTime*

- *System Nought (S$_0$):* Comprised of the management and operation unit, the latter being the focus of recursivity within the whole.

$$S^0_{0,i\le7}\to A$$

$$S^n_{0,i\le7}\to\left(M^n_{0,i\le7}\cup O^n_{0,i\le7}\cup E^n_{0,i\le7}\cup\begin{pmatrix}\left(E_4^{n(t)}\cup E_4^{n(t+1)}\right)\\-\left(E_4^{n(t)}\cap E_4^{n(t+1)}\right)\end{pmatrix}\right)$$

$$S^N_{0,i\le7}\to\left(M^N_{0,i\le7}\cup O^N_{0,i\le7}\cup E^N_{0,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)$$

- *System One (S$_1$):* The union of S$_0$, with S$_2$, this directional system is a self-governing autopoeitic, recursive, homeostat.

$$S^0_{1,i\le7}\to A$$

$$S^n_{1,i\le7}\to\begin{pmatrix}S^n_{0,i\le7}\cup E^n_{0,i\le7}\cup S^n_{2,i\le7}\cup E^n_{2,i\le7}\cup E^n_{1,i\le7}\cup\\\left(\left(E_4^{n(t)}\cup E_4^{n(t+1)}\right)-\left(E_4^{n(t)}\cap E_4^{n(t+1)}\right)\right)\end{pmatrix}$$

$$\wedge\supset\left(S^n_{3,i\le7}\cup E^n_{3,i\le7}\right)$$

$$S^N_{1,i\le7}\to\begin{pmatrix}\left(M^N_{1,i\le7}\cup O^N_{1,i\le7}\cup E^N_{1,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)\\\supset\left(S^N_{3,i\le7}\cup S^N_{2,i\le7}\cup S^N_{1,i\le7}\right)\end{pmatrix}$$

- *System Two (S$_2$):* Co-ordinating, anti-oscillatory, local-regulatory S$_1$ element. Unites S$_1$ with its S$_0$.

$$S^0_{2,i\le7}\to A$$

$$S^n_{2,i\le7}\subseteq\left(\left(S^n_{2,i\le7}\cup E^n_{2,i\le7}\right)\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)\subset S^n_{1,i\le7}$$

$$S^N_{2,i\le7}\to\phi$$

$$S^N_{2,i\le7}\neg\supset S^n_{2,i\le7}$$

$$S^n_{2,i\le7}\subset S^{N-1}_{2,i\le7}$$

- *System Three (S$_3$):* Cohesive, strategic, planning force. Enabling concatenation of the fellow metasystemic union and the higher, autonomic, directional, S$_2$, S$_1$ and S$_{3*}$.

$$S^0_{3,i\le7}\to A$$

$$S^n_{3,i\le7}\to S^n_{3*,i\le7}\cup E^n_{3,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\subset\left(S^n_{3,i\le7}\cup S^n_{2,i\le7}\cup S^n_{1,i\le7}\right)$$

$$S^N_{3,i\le7}\to\left(S^N_{3*,i\le7}\cup E^N_{3,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)\subset\left(S^N_{3,i\le7}\cup S^N_{1,i\le7}\right)$$

- *System Three Star (S$_{3*}$):* Sporadic auditing system, assimilated into S$_3$ [N,n,0] Transposing the VSM into a VCS obviates the intermittency of this element, which could be instantiated as a constituent if required.

$$S^0_{3*,i\le7}\to A$$

$$S^n_{3*,i\le7}\subset\left(S^n_{3*,i\le7}\cup S^n_{3,i\le7}\right)$$

$$S^N_{3*,i\le7}\subset\left(S^N_{3*,i\le7}\cup S^N_{3,i\le7}\right)$$

$$S^N_{3*,i\le7}\subset S^N_{3,i\le7}$$

- *System Three-Four-Five (S$_{3\text{-}4\text{-}5}$) Homeostat:* The homeostatic force within the system, containing models of the extra-systemic environment and the internal systemic capabilities.

$$\left(S^0_{3,i\le7}\cup S^0_{4,i\le7}\cup S^0_{5,i\le7}\right)\to A$$

$$\left(S^n_{3,i\le7}\cup S^n_{4,i\le7}\cup S^n_{5,i\le7}\right)$$

$$\to\left(S^n_{3,i\le7}\cup S^n_{3*,i\le7}\cup E^n_{3,i\le7}\right)\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}$$

$$\subset\left(S^n_{3,i\le7}\cup S^n_{2,i\le7}\cup S^n_{1,i\le7}\right)$$

$$S^n_{4,i\le7}\supset\begin{pmatrix}\left(S^n_{1,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)\\\supset\left(S^n_{3,i\le7}\cup S^n_{4,i\le7}\cup S^n_{5,i\le7}\right)\end{pmatrix}\wedge$$

$$S^n_{5,i\le7}\supset\begin{pmatrix}\left(S^n_{3,i\le7}\cup S^n_{4,i\le7}\cup S^n_{5,i\le7}\right)\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\\\cup E^n_{5,i\le7}\cup E^n_{3,i\le7}\end{pmatrix}$$

$$\subset\left(S^n_{3,i\le7}\cup S^n_{2,i\le7}\cup S^n_{1,i\le7}\right)$$

$$\left(S^N_{3,i\le7}\wedge S^N_{4,i\le7}\wedge S^N_{5,i\le7}\right)$$

$$\to\begin{pmatrix}\left(S^N_{3*,i\le7}\cup E^N_{3,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)\\\subset\left(S^N_{3,i\le7}\cup S^N_{1,i\le7}\right)\end{pmatrix}\wedge$$

$$S^{N(t)}_{4,i\le7}\supset\begin{pmatrix}\left(S^N_{1,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t)}\right)\end{pmatrix}\right)\\\supset\left(S^N_{3,i\le7}\cup\left(S^{N(t+1)}_{4,i\le}\cup S^{N(t+1)}_{4,i\le}\right)\cup S^{N(t)}_{5,i\le7}\right)\end{pmatrix}$$

$$S^{N(t+1)}_{4,i\le7}\to\begin{pmatrix}\left(S^N_{1,i\le7}\cup\begin{pmatrix}\left(E_4^{N(t)}\cup E_4^{N(t+1)}\right)\\-\left(E_4^{N(t)}\cap E_4^{N(t+1)}\right)\end{pmatrix}\right)\\\supset\left(S^N_{3,i\le7}\cup\left(S^{N(t)}_{4,i\le}\cup S^{N(t+1)}_{4,i\le}\right)\cup S^{N(t)}_{5,i\le7}\right)\end{pmatrix}\wedge$$

$$S_{4,i\le 7}^{N(t)} \supset \left(S_{1,i\le 7}^{N} \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t)}\right) \end{pmatrix} \right)$$

$$\supset \left(S_{3,i\le 7}^{N} \cup \left(S_{4,i\le}^{N(t+1)} \cup S_{4,i\le}^{N(t+1)}\right) \cup S_{5,i\le 7}^{N(t)}\right)$$

$$S_{4,i\le 7}^{N(t+1)} \to \begin{pmatrix} \left(S_{1,i\le 7}^{N} \cup \left(\left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) - \left(E_4^{N(t)} \cap E_4^{N(t+1)}\right)\right)\right) \\ \supset \left(S_{3,i\le 7}^{N} \cup \left(S_{4,i\le}^{N(t)} \cup S_{4,i\le}^{N(t+1)}\right) \cup S_{5,i\le 7}^{N(t)}\right) \end{pmatrix} \wedge$$

$$S_{5,i\le 7}^{N} \supset \begin{pmatrix} S_{3,i\le 7}^{N} \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t+1)}\right) \end{pmatrix} \\ \cup S_{5,i\le 7}^{N(t)} \cup \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \cup E_{5,i\le 7}^{N(t)} \end{pmatrix} \subset \left(S_{1,i\le 7}^{N} \cup S_{3,i\le 7}^{N}\right)$$

- *System Four (S_4):* Enabling self-reference and development planning, by embedding a model of the internal systemic capabilities. Unique in communicating directly with the local, future and global environments, S4 represents system intelligence.

$$S_{4,i\le 7}^{0} \to A$$

$$S_{4,i\le 7}^{n} \supset \left(\left(S_{1,i\le 7}^{n} \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t+1)}\right) \end{pmatrix} \right) \supset \left(S_{3,i\le 7}^{n} \cup S_{4,i\le 7}^{n} \cup S_{5,i\le 7}^{n}\right) \right)$$

$$S_{4,i\le 7}^{N(t)} \supset \left(\left(S_{1,i\le 7}^{N} \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t+1)}\right) \end{pmatrix} \right) \supset \begin{pmatrix} S_{3,i\le 7}^{N} \cup \left(S_{4,i\le}^{N(t+1)} \cup S_{4,i\le}^{N(t+1)}\right) \\ \cup S_{5,i\le 7}^{N(t)} \end{pmatrix} \right)$$

$$S_{4,i\le 7}^{N(t+1)} \to \begin{pmatrix} \left(S_{i,i\le 7}^{N} \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t+1)}\right) \end{pmatrix} \right) \supset \\ \left(S_{3,i\le 7}^{N} \cup \left(S_{4,i\le}^{N(t)} \cup S_{4,i\le}^{N(t+1)}\right) \cup S_{5,i\le 7}^{N(t)}\right) \end{pmatrix} \quad S_{4,i\le 7}^{0(t+1)} \supset S_{4,i\le 7}^{0(t)}$$

$$S_{4,i\le 7}^{n(t+1)} \subset S_{4,i\le 7}^{n(t)}$$

$$S_{4,i\le 7}^{N(t)} \subset S_{4,i\le 7}^{N(t+1)}$$

- *System Five (S_5):* Member of the $S_{3\text{-}4\text{-}5}$ metasystem homeostat. The policy maker within the whole, procuring normative planning.

$$S_{5,i\le 7}^{0} \to A$$

$$S_{5,i\le 7}^{n} \supset \begin{pmatrix} \left(S_{3,i\le 7}^{n} \cup S_{4,i\le 7}^{n} \cup S_{5,i\le 7}^{n}\right) \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t+1)}\right) \end{pmatrix} \\ \cup E_{5,i\le 7}^{n} \cup E_{3,i\le 7}^{n} \end{pmatrix}$$

$$\subset \left(S_{3,i\le 7}^{n} \cup S_{2,i\le 7}^{n} \cup S_{1,i\le 7}^{n}\right)$$

$$S_{5,i\le 7}^{N} \supset \begin{pmatrix} S_{3,i\le 7}^{N} \cup \begin{pmatrix} \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \\ -\left(E_4^{N(t)} \cap E_4^{N(t+1)}\right) \end{pmatrix} \\ \cup S_{5,i\le 7}^{N(t)} \cup \left(E_4^{N(t)} \cup E_4^{N(t+1)}\right) \cup E_{5,i\le 7}^{N(t)} \end{pmatrix} \subset \left(S_{1,i\le 7}^{N} \cup S_{3,i\le 7}^{N}\right)$$

VI. CONCLUSION

Having novelly addressed a gap in the genre, our research has sought to further Autonomic Computing through the inception of *Viable Computer Systems*. Immediate future research will expand the design grammar model, investigating how the future configuration of any realizable system may be enabled via articulating the semantics of the operators. The long-term goal is to narrow the research focus, producing an expansive design grammar for S_4. This modelling of S_4's system-environment interdependence will produce a J-Reference Model II, and so a working VCS prototype. Discerning itself and its environment by embracing an algorithmic approach to countering external perturbations, the highly reductive model will be ultrastable [27] - thereby proving our research concept.

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