Final Draft Version

Towards a framework for creating design support environments for adaptive systems

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Abstract

This paper proposes and discusses the development of a methodological framework for the analysis, development and creation of design support environments for adaptive systems.

1 Introduction

Design and development of adaptive systems is currently a strong research theme which results from the dynamically changing requirements and preferences of the participants in interactive systems and may refer to various types of customisation and personalisation.
This paper presents a view of the role of adaptivity in interactive systems design and in particular it discusses the necessity of acknowledging and containing the notion of adaptivity, conceptually as well as functionally, in any design support environment. This proposal adopts an abstract approach for the analysis of preferences and requirements in interactive systems. The main result of this is the general ability of the designed system to "grow" from a very simple and implementable structure, to a complex environment.
Research areas such as agents and multiagent systems, profiles, active decision support systems, accessibility, usability, machine learning, and adaptive help systems have been investigated towards a definition of a framework for creating design support environments. Such a framework thus defined follows a systems theory approach, so the adaptive systems are considered to consist of sub-systems, of their characteristics, of their relationships and of a holistic behaviour. These parts compose systems that are characterised as dynamic, massively entangled, scale independent, transformative and emergent. Hence a framework as such should warrant that the resultant adaptive systems should have attributes such as self-maintenance, adaptability, information preservation and spontaneous increase in complexity.
This paper begins with a review of research work related to the investigation of adaptivity, seen from the systemic point of view, as well as to relevant methodologies, and to tried and tested relevant technologies. Then follows a presentation of a set of requirements and characteristics of adaptive systems which the proposed framework should ensure are included in the resultant adaptive systems.

2 Adaptivity in natural and artificial systems

Evolution is one of the obvious properties of natural systems, i.e. systems whose structure is changing over time. When this restructuring is combined with organisation preservation, then the system can be said to be experiencing adaptive evolution. Natural selection was the first attempt to explain the mechanism used by natural systems in order to adapt to their environments. It considered evolution as an irreversible fact, in spite of classical Newtonian reversibility. Although this mechanism has been enriched with other theories, its whole concept of adaptation still has its basis in the mere existence of environmental factors, which appeared to contradict with findings supporting the theory that the relaxation of selection works in favour of an increase in system variety, i.e. an increase in its capability for adaptive behaviour (Bausch, 2001). Natural selection was not an adequate mechanism to explain all the non-physics features of life and this was strengthened by the introduction of non-linear dynamics and self-dissipative structures (Nikolis & Prigogine, 1977). Based on these, matter presents a spontaneous activity, or else, an emergent adaptive behaviour. From the perspective of far-from-equilibrium conditions, there is a strong need for adaptive behaviour as the natural system acts in a dynamic irreversible framework. In the theory of dissipative structures, a natural system is an open dynamic system, which, when pushed far-from-equilibrium, results in emergent novel structures. In this instance, adaptive evolution is based on the system's dynamics. This capability for autonomous, self-adaptation to a changing environment is called self-organisation. Two main principles of self-organizing and adaptive systems indicate the need of a systemic and interaction-oriented framework for adaptivity. "The principle of self-organisation", (Ashby, 1952) argues that a self-adaptive evolutionary system, always tends to evolve towards a state of temporary equilibrium (attractor). Consequently, the system reduces its uncertainty, expands its variety and its knowledge of available options and adapts to the environment. The "order from noise" principle (von Foerster, 1960), states that the larger the random perturbations ("noise") that affect a system, the more quickly it will self-organize (inner emergence, production of "order"). Having in mind that non-linear systems have in general several attractors, it is the interaction between system and environment that makes adaptation both necessary and possible. Moreover, system's adaptation is characterised by its *fitness* to the environment. Holland (1975) suggests that the structure of a given self-organising system has the ability to fit in different environments if it has the ability to perform "well" under them. In that case, adaptations to the environment are persistent properties of the sequence of structures generated by the adaptive system. There are two theories of evolution which expand these principles and embed them in a functional framework: The component-systems theory (Csanyi & Kampis, 1991) and the theory of autopoiesis (Maturana & Varela, 1980).

The first is based on the idea that the law of energy conservation and non-reversible dynamics express the necessary but not sufficient conditions for explaining the functionality of evolutionary and complex adaptive systems. Some components have abilities that influence and modify other components of the system with which they are related. These functions are the means of a system's organisation (Bausch, 2001).

The theory of autopoiesis gives a phenomenological description of life from the viewpoint of a living organism. It describes the way living systems address and engage with the domains in which they operate. Autopoiesis states that in order a system to be adaptive it must be *structure-determined*. This means that the actual changes a system undergoes depend on the structure itself. Additionally, autopoietic systems are *organisationally closed* as the product of their organisation is that very organisation itself. The fact that an autopoietic system interacts with its environment through its structure but simultaneously is organisationally closed leads to the conclusion that there is no "direct mapping" between the environment and the system itself. Thus, the environment is only able to trigger the system's structure and in no way determines or specifies the behaviour of the system (*structural coupling*). The theory of autopoiesis offers an evolutionary framework, as it suggests that an organism undergoes a *history* of perturbations from its environment, which trigger its own state trajectories. If these triggers result in attractor changes that involve structural changes, then there is adaptation. The usefulness of the descriptive theory of autopoiesis has made it appropriate as a theory of evolution in the cognitive and social domain also. These domains are characterised by the participation of higher-order systems, which, apart from their self-organizing aspects at the level of biological adaptation, have a need of goal-driven adaptation. In this context, information is not the transportation of mere messages that will change the structure of a cognitive system, but perturbations which are classified into the system's structure. An adaptive cognitive system is able to structurally determine its behaviour to perform "well" in terms of the respective message. When it wants to proceed to communicate its response, the interaction becomes a socio-communicative one, resulting in a dynamic co-adaptation. It is clear that "adaptations" arise in a dynamic internal way as the system evolves.

The systemic and phenomenological epistemology of autopoiesis has as its central idea that "knowing is doing and doing is knowing". According to this and having in mind that a system is "intelligent" if it has a large internal variety of behaviours, its adaptability should be proportional to its variety and its ability/intelligence to manage its variety in its interaction with other systems. Like physical systems, artificial systems have to employ a mechanism for observing their changing requirements, and to track behaviour of the interacting systems.

One of the first attempts in building an adaptive system has been based on the view that adaptive behaviour is the result of assigning the system's variety in abstract symbols, which should then, depending on the environmental perturbations, be manipulated based on rules that have been externally imposed (Newell, 1980). There is no need for self-organisation of the system, and all its variety is externally selected. This has been followed by "knowledge-based AI", which has emphasised a top-down approach by building systems that possess a certain amount of knowledge about a certain problem domain and then tries to model high-level cognitive capacities. In contrast, "behaviour-based" AI follows a bottom-up approach, in which adaptation is taken to be a biological system's capacity to interact with its environment, rather to represent it internally (Ziemke, 1998). Additionally, AI also studies intelligent behaviour as a result of adaptation at the cognitive and social level (Mataric, 2001). The main idea here is to start with the design of simple modules with multiple interaction capabilities, while expecting complex adaptive behaviour to emerge from their interaction (Brooks, 1989). Although a system's adaptivity emerges from the interaction of the individual behavioural modules in a self-organised manner, its variety is externally imposed, as each module's behaviour is pre-programmed in an algorithmic manner. Neural networks are being used on the same rationale, but with advanced capabilities in searching a whole static or dynamic landscape. In this case, the system tries to recognise and adapt to a static or dynamic environment (connectionist approach). The emphasis is given in the development of learning behaviours which are usually based on a direct mapping between the system's inputs and outputs.

Another approach uses techniques inspired by natural selection. These techniques give the possibility to make a large number of individuals evolves, each representing an adaptive behaviour. Evolutionary algorithms can exhibit high adaptivity where no reinforcement learning is available (Mitchell, 1996). On the other side of computation, one finds dynamic approaches to adaptive behaviour. An adaptive system consists of a number of processes running in parallel and being represented by means of differential equations establishing a relationship between a set of quantities. Self-organisation is emphasised, but the role of the environment is disguised.

3 Towards the framework: requirements and characteristics

The framework proposed here should ensure that the produced support environments consider the basic characteristics of adaptive systems in an abstract level such that could be both theoretically and practically approached. According to this framework, designers of adaptive systems should address the following characteristics:

1. **Self-maintenance:** This means that the system acts in order to create itself. Aiming to avoid its disappearance, because of the continuous entropy increase, the system has to continuously reconstruct itself, by collecting material from its environment and by setting a border with it.
2. Adaptivity: The system not only should be able to preserve its internal equilibrium in a constant environment but also should be able to adapt/reconfigure itself to its environment so that its existence will be ensured.
3. Information preservation: Information that determines the system should be preserved so that its survival would not depend on the existence of every component. The roles and the relation of those components as well as their preservation are what determine the preservation of the system.
4. Spontaneous increase in complexity: The most important attribute is the ability of the system to increase its internal complexity. Thus it is possible that there could be continuous increased internal parts, more complex relations between those parts, more complex behaviour of those, etc.
A system with these characteristics could be characterised as dynamic, massively entangled, scale independent, transformative and emergent.
These characteristics are the basic factors considered by a designer for analysis of a system in order to design its adaptability. They are the basic criteria for the design space analysis, the space where the designer has to take design decisions for creating adaptivity.
The notion of "adaptivity measurement" is introduced in this framework in terms of the necessary complexity, variety and sustainability that the system should maintain in order to correspond to the designer's requirements regarding adaptability.

4 Summary and Conclusions

In this paper, a way towards a definition of a framework for the creation of design support environments for adaptive systems has been discussed. Initially, predefined rules which control systems evolution have been tested but new ways of systems thinking are now being tested (Arnellos, Spyrou & Darzentas, 2003). The aim is to create a library of tools useful for the designers of adaptive systems.
Various methodologies and technologies have and are being investigated in order to create and evaluate parts of the proposed framework.
Methodologies used for designing systems and especially adaptive ones are crucial to a framework. After a long period of classical methodologies that were predictive rather than adaptive, and process oriented rather than people-oriented, several methodologies such as SSM (Checkland, P & Holwell, S., 1993), UML (G. Booch, 1990)), as well as new lighter weight methodologies emerged, such as: XP (Extreme Programming) (K. Beck, 1999); Crystal Family (A. Cockburn, 2000) Adaptive Software Development (J. Highsmith, 1997); Feature Driven Development (FDD), (Abrahamsson et al., 2002); Dynamic System Development Method (DSDM) (DSDM, 2002): USERfit (Poulson, et.al., 1996).
Technologies assessed for the proposed framework, include web-based environments, as the need for adaptivity becomes more critical for systems to be used by users with diverse characteristics cultures and access technologies. Amongst the environments considered, have been: Jetspeed (Apache, 2003) a portal that offers a coherent front end application for end-users. It is a hub from which users can locate all their commonly used web content. It makes use of user profiling to offer customisation and personalisation, as well as multi-device adaptation; Cocoon2 (Apache, 2003) an open source frameworks targeting personalisation and device independent publishing; DELI (Mark H. Butler, 2002) is an open-source library that allows Java Servlets to resolve HTTP requests containing CC/PP information. The CC/PP (Composite, 2002) specification describes two protocols for transmitting the device profile from the client to the server.

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