Ad-Opera: Music-inspired Self-adaptive Systems

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ABSTRACT

These days, systems are emerging as agglomerations of software, hardware and people. They are highly distributed, heterogeneous, context-aware, mobile, and adaptive to resource availability and requirements evolution. New computing paradigms for such systems are required. AD-OPERA proposes radically new approaches to software engineering, based on investigation of, and inspiration derived from, a specific class of self-adaptive systems: adaptive music. In adaptive music, the interaction with the audience and with the environment plays an active role in the composition process. The musical work is fully defined only at execution time depending on context available resources, and only after appropriate user interaction. Nevertheless, the self-adaptation must ensure the character of the music desired by the artist, called style. The AD-OPERA approach proposes radically new approaches to software engineering, based on investigation of, and inspiration derived from, a specific class of self-adaptive systems: adaptive music. In adaptive music, the interaction with the audience and with the environment plays an active role in the composition process. The musical work is fully defined only at execution time depending on context available resources, and only after appropriate user interaction. Nevertheless, the self-adaptation must ensure the character of the music desired by the artist, called style. The AD-OPERA approach proposes radically new approaches to software engineering, based on investigation of, and inspiration derived from, a specific class of self-adaptive systems: adaptive music. In adaptive music, the interaction with the audience and with the environment plays an active role in the composition process. The musical work is fully defined only at execution time depending on context available resources, and only after appropriate user interaction. Nevertheless, the self-adaptation must ensure the character of the music desired by the artist, called style.

Categories and Subject Descriptors

D.2 [Software Engineering]: D.2.10 [Software Engineering]: Design—Methodologies; J.5 [Computer Applications]: Arts and Humanities—Music

General Terms
Design, Experimentation, Theory, Verification.

Keywords
Music-inspired research, Multi-disciplinary research, Self-adaptive systems, Ubiquitous computing.

1. INTRODUCTION

Ubiquitous computing, as envisioned by Mark Weiser [19], promotes the view of systems as pervasive agglomerations of software, hardware and people. We see applications enabled by ubiquitous computing replacing traditional systems which arose as the result of human activity (opera in the spirit of the Latin etymology “opus” of this word). The ubiquitous computing landscape has promoted interest in self-adaptive systems, and their potential diffusion has highlighted the challenge of their cost-effective engineering in the presence of predictable degrees of dependability. In the last few years the Software Engineering (SE) community has recognized the relevance of this challenge. The approaches proposed so far follow quite a traditional path by trying to extend and adapt established SE methodologies, notations, validation techniques and supporting infrastructure to this challenging domain. All these attempts show their limits and partially work only in specific application domains [9].

The approach proposed by the AD-OPERA project is to look at this challenge from a completely different perspective by studying a new form of producing pieces of art that is Adaptive Music (AM). AM systems represent a class of self-adaptive context-aware systems that we consider paradigmatic for visionary future systems. Adaptive music is performed by an integrated self-adaptive system that generates transformations of the musical form, of the sound parameters (tone, rhythm, pitch, and dynamics), and of the localization and movement of point sources. We expect that this innovative interpretation of music, thanks to its intrinsic creativity, will generate a broad-mindedness that will conduct to shape new theories and practices in SE. Looking at self-awareness and adaptation through music opens new perspectives and new scenarios in the software engineering foundations of ubiquitous systems. Among the fine arts, music is characterized by a rigorous structure that often offers mathematical interpretations. This makes it possible to establish a convergence with music that can widen the horizon of the entire ICT domain by giving opportunity of technological developments and providing social benefits.

More specifically, AM systems call for a radical change in the way that they are developed and executed. It is necessary to rethink the whole system lifecycle process, from design, to validation, to execution. The traditional divide among static phases and dynamic ones becomes blurred, thus requiring new specification formalisms, new computing paradigms, and new validation techniques. Current approaches assume that the environment in which applications operate is static (or changes slowly) and changes can be largely anticipated, so that the external context and the structure of the application, its components, and their relations and bindings can be defined at design time. Most of these assumptions are no longer true.
in the ubiquitous computing landscape. The usual closed-world- assumption used when developing and validating a system cannot be adopted for AD-OPERA. AD-OPERA systems are context-aware open systems whose definition only becomes complete at execution time, and they evolve by means of continuous adaptations throughout their lifetime. At design time, not everything can be defined, nor ought it to be. Parts of the system specification can be given at a high level of abstraction, which describes only the essential “need”. What remains, characterizes the portion of the composition that the composer leaves purposely under-specified. These parts will be supplemented at runtime by means of context-aware adaptation. The adaptation of the system must be performed by preserving the style, which becomes the key concept to define the boundaries of adaptiveness. This then means that a suitable engineering process has to explicitly take into account complex validation steps at runtime, when all the necessary pieces of information are available.

The paper is organized as follows: Section 2 introduces adaptive music by firstly providing a historical perspective and then presenting challenges in adaptive music. Section 3 explains the class of self-adaptive context-aware systems that is represented by AM systems. Section 4 presents the main parts composing the new computing paradigm proposed by AD-OPERA. Finally, the paper concludes in Section 5.

2. ADAPTIVE MUSIC

2.1 Historical perspective

In order to understand AM a historical digression is required. The process of music composition has been subjected to fundamental transformations in recent decades, since the attention of composers has widened from the mere writing of a score to the formalization of the process, which leads to the definition of one among many possible scores. To clarify this concept we can cite two musical works which belong to the classical tradition. The first one is Mozart’s *Musikalisches Würfelspiel* in which the number of potential combinations is so large, that any single instance of the waltz has probably never been heard. The other example is Stockhausen’s *Klavierstück XI* which is a piece composed of 19 fragments spread over a single, large page. The performer may start playing any fragment, and continue to any other, proceeding through the labyrinth until a fragment has been reached for the third time. The compositional intention has not focused on one predetermined version of the score, but rather on the rules of a process that lead to a definite outcome. The affirmation of computer music has led to a substantial widening of the idea of instrument and of the music generation. The general availability of powerful and automatic tools affects both the way in which sound is generated, and the rules and processes on which composition relies. The composer may leave parts of the composition “abstract”, by delegating their “concretizing” to the performer or the listener. Since the musical work is fully defined only at “runtime”, we speak of an interactive opera. The user is strongly involved since his intervention may affect one or more parameters of the sound generated. The composer may also decide to use environmental figures as input to his work, since the plurality of sensor devices and connections available today allows him to consider the brightness of the room, or traffic flow elsewhere, as relevant to his invention. No matter what the interaction with the context, the key fact is that it is still the composer who is in charge of defining the behaviour of the system over time, or, in other words, of defining the score. The score may possibly be non-linear, allowing for branches and diversions at certain places, but the key point is that the whole plot is predetermined by the composer at composition time. This leads us to discuss Adaptive Music.

2.2 Challenges in AM

In recent years the term Adaptive Music has appeared, with a meaning drawn from the entertainment domain, Interactive Music. Interactive Music in the gaming field has the main concerns to produce a musical outcome that preserves continuity and relevance. To this end, many implementations are built from a system that basically picks up musical fragments from a large database, arranges them according to the input received from the gaming engine, and finally synthesizes music. This approach becomes inadequate as soon as algorithmic composition, intended as generation of sonorous matters, becomes a basic need for the composer. The real challenge here is to perform the adaptation of the music to audience interaction and to environment changes as well as the generation of sonorous matters by necessarily preserving an expressive coherence, i.e. the self-adaptation must ensure the character of the music desired by the artist. To achieve this, a composer needs to make a set of choices regarding the sonorous matter and its temporal development, i.e. his own style. Style can be conceived as a distinctive and multidimensional quality of operas. Often, these different dimensions can be interrelated, and trade-offs among different dimensions are to be expected. Examples of such dimensions are time, the quantitative characterization of pitch, etc. We expect that the structure of the sound will become material for composition as the pitches, the rhythm, and the dynamics are. The composer, free from limitations of both performer and acoustic instruments, will put in scene a completely new and fascinating sonorous dramaturgy that is loaded of fresh sensations. Similarly to the revolution that experienced architecture with the use of new materials as glass and ferro-concrete, the discovery and use of new materials will promote in music the creation of previously unimaginable forms.

Figure 1 shows some previous attempts in the direction of producing adaptable works of art. Figure 1.A shows an installation called “Volumni adattivi”. It is composed of different electronic devices made out of different materials. The audience can interact by moving and touching the mobile parts of the installation. After a while, if the audience is not interacting, the installation initiates a different process of evolution, focused on sensing the environment instead of the mobile parts. Figure 1.B shows an installation called “Sorgenti nasoste”, which is inspired by continuous modulations of water. The four seasons cause four major musical mutations by means of changes in timbre, pitch and rhythm. Music evolution is influenced by the different climatic conditions and light.

3. RELATIONS BETWEEN AM AND ICT

In [1] a classification of modeling dimensions for self-adaptive systems is proposed. These dimensions are partitioned into four groups: dimensions regarding the goals of the system; dimensions regarding the causes of self-adaptations; dimensions regarding the change mechanisms of the system; dimensions regarding the effects of the adaptation upon the system. Referring to this classification, AM systems can have goals that change and evolve during the system’s lifetime, as well as goals that persist throughout the system’s lifetime, and these can be interrelated in various ways. Typically, a perpetual high level goal is to perform music under any weather conditions. On shorter timescales, the music played can vary during the system’s lifetime by changing the composition or the instrumental devices. The causes of change can be both internal and external, and can be of different kinds. For example, a device battery runs out of power (internal), or a spectator shouts
networks. In conclusion, such as service-oriented applications on the Internet or social networks, AM systems represent a significant class common to an increasingly important class of dynamic systems and consumers of content and services. This characteristic is user involvement should be predictable since adaptations should preserve the style (unplanned) context changes. The consequences of adaptation rather than the exception change is the norm.

Moreover, change is the norm rather than the exception since the music changes according to the (unplanned) context changes. The traditional divide among static phases and dynamic ones becomes blurred, thus requiring new specification formalisms, new computing paradigms, and new validation techniques.

4. AD-OPERA NOVELTY

Self-adaptive systems have been studied since decades within many different research communities both in terms of the basic self-adaptive mechanisms, like control loop, and of the application areas and technologies, like robotics and AI. The ubiquitous computing landscape has put forward the interest on context-aware self-adaptive systems and their potential diffusion has highlighted the challenge of their cost-effective engineering in presence of predictable degrees of dependability. Since few years the software engineering community has recognized the relevance of such challenge. The approaches proposed so far follow quite a traditional path by trying to extend/improve established software engineering methodologies, notations, validation techniques and supporting infrastructure to this challenging domain. All these attempts show their limits and partially work only in specific application domains and specific research areas: software architectures, middleware, component-based development, service-oriented systems, etc. Other work that aims at defining a formal framework for adaptability are the theoretical assume-guarantee framework to efficiently define conditions for adaptation at runtime, while preserving a desired invariant. [3] proposes a first-order logical modelling approach to describe evolvable computational systems. These are hierarchically composed of components which have associated supervisory processes which monitor and change the associated component as needed. Supervisory processes monitor and adapt their dependent components, enabling evolutionary behaviour to integral in system design.

The approach proposed by AD-OPERA is to look at this challenge from a completely different perspective by studying a new form of producing pieces of art that is adaptive music. In this setting adaptivity is the result of the system and environment sensing. Adaptivity needs to be expressive enough to produce highly variability in the composition but at the same time it needs to be properly controlled to allow a composer to create his own style by preserving an expressive coherence in the generated musical material. We believe that the study of a general framework and process that can be used to compose and execute adaptive music based on a formal notation to express the score and the style, will create, as outlined in Figure 2, fresh synergies and major breakthroughs in the following research areas:

- New life-cycle processes for AM systems: The software development and evolution process life cycle needs to be rethinked, breaking the traditional division among development phases, by moving some activities from design-time to deployment and runtime. Software architectures should play a central role during the entire process life cycle, enabling us to express and deal with characteristics that are crucial for AD-OPERA, i.e., QoS, resource awareness, evolution, reconfiguration, variability, and uncertainty. Moreover, the convergence between music and ICT suggests new dimensions that a life-cycle process needs to address. Traditional software systems have been mostly triggered by the needs of the business world. On the other hand, art-intensive system development is triggered by the evolving wishes of different stakeholders, like artists, the participating audience, political instances such as municipalities, and beyond that, citizens in the society. This shift from precise business needs to evolving wishes of different
stakeholders is an important trend that is typical not only of the interdisciplinary intersection between music and ICT, but also of other interdisciplinary settings. Even more contemporary life cycle process models, like Agile Methods [11] and OSS [15] based techniques need to be improved to meet the needs of interaction and adaptation in interdisciplinary domains at the intersection with ICT.

- **Formalisms to define the score and the style**: The score represents the description of the system, and the style represents constraints on how the execution of the system should be performed. The formalism used to express the score must allow parts of the specification to be left under-defined, and to enable “late specification” at runtime. The formalism to express the style must allow different musical qualities, including time, quantitative characterization of pitch, etc., to be taken into account and analyzed at runtime. Precise semantic relationships between the two formalisms must exist to ensure coherent specifications.

- **Adaptation theory**: Crucial to AM systems is the development of a framework for capturing, manipulating and reasoning about the appropriate abstractions that govern and characterize them. The different abstraction levels will be defined taking into consideration all the attributes that are commonly ascribed to music: high level ones such as style, duration, form; all the way down to low level ones, such as pitch, loudness and timbre. Invariants will characterize the “business as usual” of these levels. Runtime monitoring [4, 6] will supply information regarding the degree of conformance of the execution to the stated invariants. Assume-guarantee theory, introduced originally in the thesis of Cliff Jones [13] and subsequently developed by many others, including Amir Pnueli [17], will guide how the runtime information is evaluated for conformance to the invariants. The adaptation theory that will be investigated by AD-OPERA will be based on the general frameworks proposed in [12, 3].

- **Innovative techniques for modeling context sensing**: The context modeling must include both the environment (including user interaction), and system sensing (system resources and network). The context should be able to capture not only individual aspects of an adaptive and autonomous system, it should also be able to provide a unified view of the system’s parts, including all relevant relationships between those parts. A “good-enough” level of detail about the context will allow automated, intelligent and robust adaptation decisions to be made at runtime. The consequent reduction of human intervention will imply, on the one side, lower management costs, and on the other side, a more efficient use of resources.

- **Innovative execution monitoring**: Innovative monitoring techniques will enable the discovery in advance of situations in which the music execution is diverging from the style. This monitoring has to take into account the score, the environment and the audience interactions. Experience accumulated over the AD-OPERA lifetime could be taken into account with the aim of predicting and dealing with potentially risky situations (e.g., the likelihood of having noise in a crowded room is very high). The monitor could also trigger adaptation in response to security and reliability issues. For example, the AD-OPERA system could deactivate some devices or sensors in order to isolate potential attacks or other disturbances.

- **Novel sensor network design for adaptive music**: Wireless sensor networks will be used for body and environment sensing. New communication protocol stacks, capable of adapting to the audience and music will be proposed, with the focus on distributed operation with energy efficient, reliable, secure and timely communication. The cross-layer design paradigm will be considered to maximize the energy efficiency of the wireless sensor network, to offer seamless interaction by tiny and non-invasive nodes. Novel applications running on top of the protocol stack will be proposed to support audience interaction and adaptive music. Feature extraction applications for localization of the audience, spatialization, music and audience mood, etc., will be proposed and developed.

5. CONCLUSION

Even more than ever it emerges the notion of system as the systemic agglomeration of software-hardware-human beings. The ubiquitous environment strongly characterizes these applications. Adaptive music is performed by an integrated self-adaptive system that generates different pieces of music according to a defined score in response to context variations, for example sensing the people behavior or sensing the perturbation produced by a water fountain. All the music adaptations must be performed coherently to the style selected by the composer. Style selection is crucial to optimize the music adaptation with respect to environmental constraints such as availability of resources or user desired performance. The study of this application domain is particularly challenging in terms of the characterization of the context and of system adaptations. The latter being in response to context changes that must preserve a complex notion of invariance such as the above mentioned notion of style. The main objective of the AD-OPERA project is to propose, through the study of adaptive music, innovative software engineering principles and methodologies that span from modeling techniques to formal foundations, from verification and validation techniques to optimization techniques for the use of resources in the domain of self-adaptive systems.
6. REFERENCES


