SpatialServices: Self-adaptive On-the-fly Spatial Services for Open Smart Environments

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Abstract

Spatial services are a new generation of services. They exploits spatially distributed data, enable smart environments, or exploit Internet of Things (IoT) scenarios. This is a new category of decentralised services based on data propagation among mobile devices. These services are provided as the result of the collective interactions among multiple entities, involving processes and calculations. It takes place across several geographically distributed computational nodes. Moreover, research in the engineering of collective adaptive systems provides advances in the identification of bio-inspired self-organising mechanisms and their expression as design patterns. Fine-grained analysis of these mechanisms, when taken in isolation or combined with each other, and their sensitivity to parameters in relation with non-functional properties is still lacking. Dynamic composition of these mechanisms and providing reliable non-functional properties, through dynamic adaptation of parameters, is not yet considered in the literature. Spatial system services built on self-organising mechanisms are relevant in specific application contexts, particularly in open smart environment and for applications deployed over several nodes. Their performance depends on good calibration and some of them can be in competition for a specific application. The goal of this research project is to determine at run-time the most appropriate mechanism. Services should be well calibrated in dynamic situations to guarantee appropriate non-functional properties expressed as quality of service (QoS). It also intends to develop a model for on-the-fly creation of spatial services. These services are deployed over a geographic area and providing requested non-functional properties. In open smart environments, it is only at run-time that the need for a spatial user-service arises and it is through the collective interactions of existing spatial system services, sensors or other "Things" that the requested user-service is provided.

1 Introduction

Smart cities are urban areas which use technological innovations to manage their infrastructure, including the environment, mobility and critical services. It aims to improve quality of life and productivity of citizens, while creating a cleaner and more sustainable environment. In that context, new generation of services can be created, taking advantage of the distributed nodes network. These services, called spatial services, will be provided as the result of collective interactions among multiple entities, possibly spatially (geographically) distributed across several computational nodes. A spatial service is built dynamically through collaboration with other services. It is built and composed on-demand. For example, when users query to retrieve the closest vacant parking place in a smart city, sensors, connected objects, and services spontaneously collaborate to query the spatially distributed data and to provide the answer, going well beyond traditional location-based services requiring a central server gathering all data and providing the computation. Among spatial services, we distinguish on the one hand, spatial User services, and spatial system services, those services that implement spatial self-organisation mechanisms.

- Spatial System Services : they provide ready to use services that can be deployed on-demand over physical environments by higher-level services or applications. Spatial system services are based on self-organising mechanisms [9] (as shown in figure 1), they are time and space related, work on a decentralised and autonomous manner, and are naturally robust to some environmental perturbations, even though not to any perturbation or environmental change.

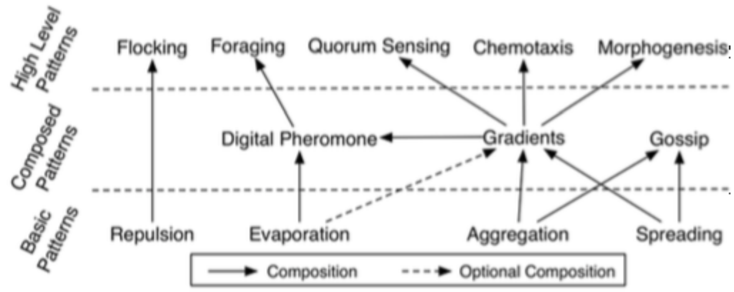

Figure 1: Self-organising mechanisms

- Spatial User Services : they are provided through dynamic selection of underlying spatial system services.

Spatial computing [14] and spatial services provide an opportunity to develop open smart environments, i.e. open ad-hoc physical infrastructures where anybody and anything can provide and consume services. Spatial services provide decentralised solutions well-suited to large-scale and dynamicity of such infrastructures. Research is still at its infancy in this topic. Spatial Services contributes advances, particularly in relation to non-functional aspects and on the creation on-demand of spatial user services.

2 Related works

1. **Non-functional aspects**
   Non-functional aspect of software, such as dependability, security or performance, are aspects that can be calibrated dynamically. Advanced techniques enabling adaptation at run-time based on dependability property include Chen et al. [4] who developed dependable Web Services overcoming different types of errors (e.g. non responsive or overloaded Web service). Non-functional aspects in micro-rules or chemical reactions. Kreyssig et al. [5] studies emergent control and how it differs from the traditional feedback loop control. They observe that emergence of control arises from both micro-rules at the level of the agents behaviour and additional "macro-to-micro feed forward controllers" which map high-level policies, constraints or requirements into modifiable parameters of the micro-structure, actually adapting those parameters at run-time. The optimum values of parameters can be identified manually (by the designer) or by other techniques more amenable for adaptation like evolution. Banâtre et al. [7] propose a decentralised approach based on chemical reactions for programming autonomic systems. They propose a high-order extension of the chemical programming language Gamma [8], and show how this extension can be used for the modelling and description of autonomic systems. The chemical reaction paradigm approach naturally models self-management and in particular dynamic reconfigurations. Indeed, policies for dynamic reconfigurations, such as "replace a server that is overloaded by another one" is easily modelled with a chemical reaction stating that if that server state is down, computing load is transferred to another server. Banâtre et al. [7] go a step further and propose a higher-order version of Gamma, where even the chemical reactions (considered as active molecules in this case) themselves can be dynamically changed as a result of the firing of a higher-order chemical reaction. Spatial services enhances self-organising mechanisms with non-functional aspects. It will build self-adaptive parameters, and underlying self-organising mechanisms. Services will select themselves, change and combined with each other to guarantee and maintain non-functional properties.

2. **Parameters adaptation for spatial system services**
   Spatial system services are used by self-organising systems to provide spatial user services ensuring not only functional requirements but also non-functional aspects. In order to handle environmental conditions, spatial system services have to adapt their parameters. For example, the spreading service could adapt the distance of spreading or the evaporation service, its evap-

oration frequency. Because of the environment's dynamics, the parameters need to be adapted at run-time. Several studies have been conducted on parameter adaptation in general (not especially on spatial system services). Most of these studies use optimisation techniques (see for example [2, 3] in agent-based simulation). Generally, those techniques are used before the system is deployed and not at run-time. Eiben et al. [1] reviews parameters adaptation in evolutionary algorithms and provides a taxonomy where parameters setting is either provided by: parameter tuning before the execution (e.g. identifying parameters values at design-time through simulations) or by parameter control during the execution, using one of three cases:

- deterministic rule changing the parameter without feedback from the evolutionary algorithm
- adaptive parameter control when the evolutionary algorithm provides some feedback from the search thus influencing the value of the parameter
- self-adaptive parameter control where the parameters themselves are encoded as "chromosomes" in the evolutionary algorithms, and thus undergo mutation and recombination. Gleizes [41] proposes to use a Multi-Agent System to adapt the parameters; each parameter is represented by an agent that adapts at run-time the value of the parameter depending on the interaction with the environment.

Recent work from the collective adaptive systems community addresses this aspect through a formal analysis point of view. Spatial services provides a detailed study of spatial services parameters and their relation with non-functional properties; and a run-time solution for self-adapting those parameters.

3. **On-the-fly spatial user services**
The static character of traditional composition approaches such as orchestration and choreography has been recently challenged by so-called dynamic service composition approaches, involving semantic relations [10], and/or AI planning techniques [13]. One of the main challenges of these approaches is their limited scalability and the strong requirements that they pose on the detail of service description. Evolutionary approaches such as those based on Genetic Algorithms have been proposed as well for service composition [6], motivated by the need of determining the services participating in a composition that satisfies certain Quality of Service constraints. In relation with non-functional properties, Cruz Torres et al. [12] propose to control composition of services aiming at maintaining a specified Quality of Service of the composition (end-to-end) despite any perturbance arising in the system. This approach uses ant colony optimisation to disseminate and retrieve QoS in an overlay network of available services, which then serve as a basis for selecting services in a composition. McKinley [11] proposes parameters adaptation by dynamic recomposition of software during its execution, such as switching behaviours and algorithms or adding on-the-fly new behaviour. Supporting technologies include aspect-orientation, computational reflection (introspection), and component-based design. Self-composition of spatial services inspired by chemical reactions has not gained much attention yet. Parameters and algorithms or behaviours adaptation on-the-fly have been applied in the context of evolutionary algorithms and for autonomic computing software. Only limited work is available yet for self-organising decentralised software or spatial services. Preliminary works concern chaining of services with no actual distributed deployment and no link with non-functional properties. Spatial services intends to develop a model for on-the-fly creation of spatial services deployed over a geographic area and providing requested non-functional properties.

3 Thesis statement

3.1 Gap in research

On-the-fly spatial services are a set of self-organising mechanisms provided as spatial system services and their relationships. Spatial services will study how spatial user services can be provided on-the-fly through the mobilisation of underlying spatial system services.
In the other hand, self-adaptive spatial services are a series of spatial system services. They dynamically adapt their parameters or dynamically select themselves to respond to a request for guaranteeing a requested non-functional property. Spatial services is particularly interested in understanding how

to guarantee non-functional properties at higher-levels, enforcing in turn QoS on lower-level services, exploiting dynamic adaptation of parameters of individual mechanisms, and seamless switching of underlying mechanisms at run-time to maintain acceptable QoS.

3.2 Research questions

1. What is the sensitivity to parameters of self-organising mechanisms, when taken in isolation (e.g. spreading, aggregation, evaporation or repulsion), when taken in combination with each other (e.g. gradient, gossip or chemotaxis), in both cases in relation with non-functional properties such as accessibility and availability of service, or accuracy and pertinence of provided results?
2. How can these parameters be dynamically adjusted for each of these mechanisms (in isolation or in composition), in order to guarantee a requested non-functional property (e.g. adapting communication range, spreading to a limited number of neighbours, etc)?
3. How to build actual spatial user services on-the-fly, mobilising the appropriate underlying spatial system services, addressing a user's need and guaranteeing non-functional properties?

4 Contributions and methodology

The main contribution of the project is to provide the adaptation of the spatial system services at run-time in order to guarantee and maintain QoS and provide on-the-fly user services. We will therefore proceed as follows:

- Detailed analysis of parameters and their impact to non-functional properties, done through extensive simulations involving a prototyping tool that combines both simulations (movements, communications, and large number of entities) and actual coordination middleware supporting spatial services running in the nodes.
- A self-adaptive model and corresponding algorithms for dynamic adaptation of parameters, depending on the interaction with the dynamic environment, providing the requested non-functional properties; this model will learn at run time how to adapt parameters of each self-organising mechanism in order to provide the requested non-functional properties.
- Model and algorithms for providing on-the-fly spatial user services, including dynamic selection of underlying spatial systems services through chemical reactions, mobilising geographically distributed computations and providing the requested functionality with the requested non-functional properties.
- Extension of a coordination model and corresponding middleware integrating the self-adaption of parameters and the on-the-fly creation of spatial user services.
- Evaluation and validation through both a prototyping tool and actual deployment (involving both simulations and the actual extended middleware).

5 Conclusion

The scientific results of spatial services consists in: enhancing self-organising systems, working as collective adaptive systems, with non-functional aspects and self-composition, using jointly self-adaption of parameters and on-the-fly creation of spatial services. Beyond scientific research, self-adaptive spatial services advances the state of the art of spatial computing and spatial services to be deployed on smart environments, opening the door to a new generation of services providing innovation capabilities for the software industry. Spatial services will then have an impact on the forthcoming Internet of Things and Smart Cities scenarios. Indeed, self-tuning on-the-fly spatial services, providing reliable non-functional properties, can be deployed on large variety of cases and will allow exploiting at its full capacity computational nodes geographically dispersed in a given area. Numerous models in energy, social behaviour, economy, ecology, or mechanics need to be tuned to be relevant in particular applications. This work is generally manually done and requires a huge amount of trials. We expect Spatial services to reduce drastically this time and provide an optimal adjustment at run-time.

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