ARCHITECTING DEPENDABLE CYBER-PHYSICAL SPACES

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We increasingly live in cyber-physical spaces – spaces that are both physical and computational, and where the two aspects are intertwined. Such spaces are software-intensive systems, as computational elements heavily interact with physical entities [1], especially with internet-of-things devices and along active human agents, where the physical space determines many of such interactions. This can be witnessed in a variety of settings, ranging from smart infrastructures based on sensors deployed on cities to visionary multi-functional living spaces that can be spatially re-organized in a dynamic way.

Cyber-physical spaces are much more dynamic than traditional –physical– spatial environments used to be. Humans, robots or devices moving around connected to networks are examples of entities dynamically performing actions while operating in a composite space. Such dynamics have to be considered in the design of systems operating within spatial environments, as certain dependability guarantees about their behaviour should be fulfilled [2]. Moreover, as for any other software-intensive system, maintaining a cyber-physical space which "operates" in a dynamic environment is faced with the manifold challenges that a self-adaptive system brings and demands for operational management to observe a constantly changing space and potentially react to environmental changes [7].

The current practice of designing space-intensive systems is weak in facing these emerging challenges, which appear in numerous contemporary applications. For example,

- How can a smart hospital be designed such that response of medical personnel is guaranteed [3]? In case of an emergency, after medical personnel are notified (i.e. through networked mobile devices), they should physically reach a location within a certain time.

- How can quality-of-service be maximized by a smart bike-sharing system in a smart city [4]? Utilization of bikes differs on time of day, location, riders' behaviour and exogenous events.

- How can assurances be obtained about a swarm of unmanned aerial vehicles providing autonomously emergency response in a city within a disaster scenario [2]? Challenges arise when non-human agents need to coordinate within an urban disaster setting – including limited connectivity, uncertainty and a constantly changing physical space.

In such challenging scenarios, the boundary between the physical and the computational aspects gets increasingly blurry. Design of systems operating within physical spaces is largely disconnected from the computational components enabling smart functionalities, a great concern especially in safety-critical applications dominated by mobile connectivity, active agents and complex dynamic behavior. As a consequence, dynamic space-dependent systems cannot be automatically – and formally – analyzed with respect to various qualitative or quantitative requirements. Moreover, runtime support to recognize and manage dynamic spatial changes in space, essentially some form of automated operational management based on systematic model-driven engineering, is largely missing.

An Emerging Research Agenda. This talk will show an avenue for research which can be characterized as rethinking cyber-physical spatial environments from a software engineering perspective. Specifically, we advocate that bridging architecture and urban planning with software systems engineering has significant potential for future living and urban spaces which should be dependable. Spatial environments are increasingly dynamic cyber-physical spaces, where the physical world and the computational world are heavily interwined and interacting with each other. Obtaining assurances of satisfaction of requirements concerning e.g., security [5], reliability [3] or safety [2] etc. becomes challenging, something which has to be considered during both design and operation.

In a walk through exemplar problems which have been tackled in the past [2, 3, 6], we will observe how CityGML or BIM descriptions can give rise to models amenable to automated analyses of dynamic behaviours on spaces populated with humans, robots, or mobile devices. Analysis amounts to assessing if some collective behaviour that is highly space-dependent, violates certain requirements that the overall system should exhibit. Requirements may state some behaviour that is about position of mobile entities in space, actions or state of internet-of-things devices, or roaming human agents.

Early results from experiments conducted based on prototypical implementations will be illustrated, showing potential benefits of our vision of supporting architects and system designers in the challenging task of reasoning on dynamic cyber-physical spaces adopting software engineering principles. This can be considered as a second happy marriage of two disciplines which, although apparently being far apart from each other, share a considerable amount of challenges and body of knowledge.

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