Bicycle Path Network Designing and Exploitation Simulation as a Microservice Architecture

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Abstract. Simulation is recognized as a suitable tool for sociotechnical systems research. But the variety and complexity of sociotechnical systems often leads to the need for distributed simulation solutions to understand them. Models that are built for infrastructure planning are typical examples. They combine different domains and involve variety of simulation approaches. This article proposes an easy management environment that is used for VeloRouter software – a multi agent-based bicycle path network and exploitation simulator that is built as a microservice architecture where each domain simulation is executed as a different microservice.

Keywords: Sociotechnical systems simulation · Bicycle path network planning · Easy Communication Environment

1 Introduction

Within FP7 FLAG-ERA FuturICT 2.0 project "Large scale experiments and simulations for the second generation of FuturICT" (2017–2020) the authors of this article worked on a sub-topic "Intermodal bicycles network as efficient kind of urban green transport (VeloRouter 2.0)". That included development of prototype of intermodal bicycle network modeling tool, called VeloRouter, to be used both by policy planners and decision makers, as well as cyclists for bicycle infrastructure improvement and everyday route planning. Article presents its solution as a microservice architecture.

Rapid technological development has brought changes to many realms of life. With that, also the notion of sociotechnical systems has become widely accepted in many domains as sociotechnical factors are at the foundation of nearly all forms of contemporary human activity. Education, healthcare, entertainment and social media are among the many current, and frequently intersecting, examples of complex sociotechnical systems [1]. Transportation system is no exception. In fact, Schmitt argues that cities are the largest, most complex and most dynamic man-made systems [2].

E. Ginters et al. (Eds.): ICTE ToL 2019, LNITI, pp. 344–351, 2020.
https://doi.org/10.1007/978-3-030-39688-6_43

Socio-technical approach enables us to systematically identify, describe, and study the more obscure, non-linear effects of multiple, dynamically shifting interactions among large collections of socio-technical system components [1]. Hettinger et al. conclude that sociotechnical approach can drive improvements in system performance and safety [1] therefore this approach fits the needs of a research focusing on transportation and planning issues in cities.

The next section of this article introduces the underlying assumptions and understanding of VeloRouter. The authors argue how introduction of sociotechnical approach, participatory planning methods and simulation modeling can lead to better results. The third section describes the main functionality of VeloRouter. And finally, the fourth section of this article outlines the building blocks and communication mechanisms of VeloRouter as a microservice architecture.

2 Sociotechnical Approach to Urban Planning

According to the World Bank data urban population in the world exceeds 50% since 2007 [3] and for more than ten years more than half of the world's population live in cities. With growing cities and increasing environmental and climate challenges urban planning is more important than ever before. For policy planners, decision makers and engaged citizens technology development has enabled large scale data collecting, excessive computation abilities and also direct citizen participation. Rapidly spreading and evolving technologies led to development of fields like urban informatics and participatory planning etc.

At the same time research points out that traditional methods of planning and managing large cities have reached their limits and need a radical re-thinking. On the computational side, this necessitates the integration of new methods and instruments. On the planning and design side, this requires an involvement of stakeholders and decision makers much earlier than usually done in the past [2].

Architect and urban design consultant Gehl [4] has defined four key objectives in urban planning – lively cities, safety, sustainability, and health. All four objectives can be strengthened by increasing the concern for pedestrians, cyclists, and city life in general:

- Lively cities are promoted when more and more people are invited to walk, bike and stay in city space;
- Safe cities are promoted when more people move about and stay in city space;
- Sustainable cities are promoted if a large part of the transport system can take place as what Gehl calls "green mobility", that is travel by foot, bike or public transport;
- Healthy city is strengthened dramatically if walking or biking can be a natural part of the pattern of daily activities.

In other words, there is a need for diversified infrastructure, that is aimed at diverse needs within the society and leads to vivid, secure, sustainable cities and healthy societies. In particular, cycling should be viewed among the pivotal nodes of diversified transportation infrastructure. Cycling promotes healthy lifestyle, reduces CO2 emissions, improves urban public space and cyclers infrastructure can also be used at least partly by skaters, skateboarders, scooter drivers, etc. Cycling should be encouraged by municipalities – by building infrastructure that corresponds to the needs of society, by enabling cyclists to participate in planning process, etc.

For cycling to become a fully integrated element within a multimodal transport system and not just a type of tourism, an appropriate infrastructure is necessary – cycling routes, lighting, bike rental, parking, repair services, as well as alignment with other types of transport. Cyclists need route planning tools, information about road surface quality, relief, and usage patterns during different weather conditions and over different days of the week [5].

But cities lack instruments to gather and analyze rapidly changing trends and to plan and build the necessary infrastructure in an effective manner. Decision makers and policy planners have to respond to the actual needs, make data driven projections, adjust the society's habits according to strategic vision of the city. This aim can not be achieved without appropriate tools. It is necessary to combine modern instruments and methods or to invent new ones to allow for the simulation of successful scenarios for sustainable future cities [6]. Special care must be taken to incorporate the local stakeholders, the legislative authorities, politics and economy, as well as the geographic, social and environmental context in the process [2].

At the same time the citizens lack instruments to interact with the decision makers and express their needs in an easy, inclusive way (without "red tape" burden), to give feedback about existing infrastructure, to submit their own proposals and to plan their routes based on distance, terrain, weather conditions, etc. Available tools – like petitions.net for participation and bikemap.net or mapmyride.com for bicycle route planning – focus on these things separately and usually on a different scale. Petitioning tools are meant for any type of policy proposals and need additional filtering, but route planners usually calculate the shortest distance without taking into account other factors and these. No existing tools incorporate both – route planning and functionality necessary for municipalities [15].

The authors of this article view VeloRouter as a viable sophisticated alternative for municipal decision making, besides it provides higher level of citizen involvement in local infrastructure development. End-user involvement in early planning phases gives much higher acceptance of end result and can be an important instrument for democratic governance.

3 VeloRouter – Bicycle Path Network Design and Exploitation

VeloRouter is a web-based tool for participatory urban planning that integrates live-data based services and simulation modeling and allows stakeholder interaction. Previous research concluded that existing products aimed at cycling routes design mainly offer the capabilities of planning and publishing the routes, but do not provide functionality necessary for municipalities to build justified bicycle path network [5]. Three main groups of stakeholders or target audiences for VeloRouter are: decision makers, infrastructure developers and cyclists. Their main benefits are as follows:

- Decision makers (municipalities) can determine the most popular routes, receive feedback and communicate with infrastructure users, analyze different possible bicycle route infrastructure projects and compare them, if needed also against a fixed budget;
- Infrastructure developers maintain the bicycle infrastructures digital twin in VeloRouter in order to update the information about the actual state of the infrastructure, keep track of real-life situation and plan maintenance works;
- Cyclists can plan their routes, find out the potential occupancy of it and participate in infrastructure development by submitting their own projects and giving feedback for other submitted projects and plan their trips.

There are four main services that are integrated in VeloRouter and provide its wide functionality: weather service, bicycle usage service, traffic service and infrastructure service. Weather service provides forecast for each given date and time. This information is used for simulation and user bicycle path navigation. Bicycle usage service calculates how many cyclists will be riding on each given time. This information is used for simulation and user bicycle path navigation. Traffic service provides prediction on traffic load on the streets, this information is critical for low level bicycle infrastructure parts of the route. Infrastructure service has all the information about the actual state of each edge of the route. This information is used for simulation and user bicycle path navigation.

Simulation modeling is widely accepted as a method for sociotechnical systems research [1]. In addition, Lawson et al. point out that computer-based simulation modeling is an effective tool for helping to address the challenges associated with managing visitor use in wilderness settings [7]. Their study shows, how simulation modeling can be used as a tool for understanding existing visitor use patterns within a specific area, estimating the impact of increasing visitor use levels on management objectives, and evaluating the effects of alternative policy decisions.

VeloRouter is a multi agent-based bicycle path network and exploitation simulator. It is, in fact, a multi-model simulation system that contains several sub-models. Each sub-model is built with domain specific technologies and simulation approach. For example – multi agent-based bicycle path network and exploitation simulator. It is designed in the Repast Symphony environment and it uses OpenStreetMap spatial data. Multi-model simulation systems are built as multi service applications. VeloRouter technological infrastructure enables simulation services to communicate among each other and also provides information services – allowing different services to co-exist in one communication environment.

4 Communication Architecture

As mentioned in previous section, VeloRouter consists of several services that comprise microservice architecture. Microservice architecture is an approach to developing a single application as a suite of small services, each running in its own process and communicating with lightweight mechanisms, i.e. AMPQ. These services are built around business capabilities and independently deployed and developed. As for the key benefits of such architecture scalability (relatively easy to duplicate services to gain more computing power), availability/resiliency (if one service breaks down, general application can still provide functionality) and independency (each service can be built with the tools and technologies that suits the best for each case, regardless of technologies used for other services) can be mentioned [8].

Communication among such independent deployable components thus becomes crucial. Authors have developed Easy Communication Environment (ECE) for VeloRouter sub-model communication [9]. ECE architecture can be divided into four levels of abstraction (see Fig. 1).

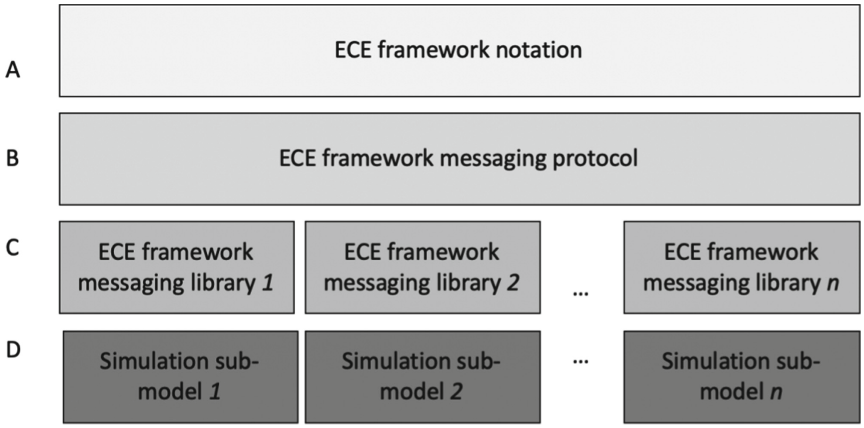

Fig. 1. Easy Communication Environment architecture abstraction layers.

D – Simulation Sub-model. Sub-model is any program or algorithm that consumes or produces any data. Distributed simulation approach highly depends on intercommunication among sub-modules [9]. In such approach sub-models are distributed by various reasons, i.e. by domain specific, to manage load balance, to parallelize simulation process, etc. In any case communication is crucial to maintain distributed simulation and achieve main simulation purpose.

In VeloRouter use-case, sub-module communication is used in many cases, for example, between bicycle usage simulation service and weather forecast service, between route infrastructure service and bicycle usage simulation service. Each of the service may publish several information endpoints for other sub-modules to use. For example, route service is responsible for the route calculations and may have such endpoints as – *closes_path*, *best_path*, *less_occupied_path*, etc. It is up to simulation designer to decide what information should be public and used by other simulation sub-models. ECE by itself does not put any limitations on it.

B – ECE Framework Messaging Protocol. Messaging protocol consists of two functional parts – message transportation and message carrier format.

For message transportation ECE uses AMQP (Advanced Message Queuing Protocol) protocol. It is an open standard application layer protocol for message-oriented middleware. The defining features of AMQP are message orientation, queuing, routing (including point-to-point and publish-and-subscribe) and reliability [10]. Reliability is one of the core features of AMQP, and it offers two preliminary levels of Quality of Service (QoS) for delivery of messages – At most once and At least once [11].

At most once service level guarantees a best-effort delivery. There is no guarantee of delivery. The recipient does not acknowledge receipt of the message and the message is not stored and re-transmitted by the sender. QoS level 0 is often called "fire and forget" and provides the same guarantee as the underlying TCP protocol [12].

At least once service level guarantees that a message is delivered at least one time to the receiver. The sender stores the message until it gets a PUBACK packet from the receiver that acknowledges receipt of the message. It is possible for a message to be sent or delivered multiple times [12].

And for the message carrier, ECE uses JSON (JavaScript Object Notation) data format. JSON is an open-standard file format that uses human-readable text to transmit data objects consisting of attribute–value pairs and array data types (or any other serializable value). It is a very common data format, with a diverse applicability [13].

All to gather, ECE combines both of these technologies to deliver sophisticated communication architecture that is highly reliable and easy maintainable [14]. AMQP ensures that message is delivered to the right client/subscriber (and resilience) and JSON allows to transmit complicated data that can be parsed and understood by most of the programming languages [13].

A – ECE Framework Notation Level. Notation level is the highest level in ECE communication architecture. This level ensures that each node (sub-model) understands each other and speaks the same language. ECE notation is based on JSON data format, which is used to format the message, the notation defines mandatory fields in each communication part and communication behavior. ECE communications consist of three communications events – request, response, acknowledgment (see Fig. 2, see Fig. 3).

Communication pattern is described in Fig. 2, the first action is a request that is made by Sub-module A with message that is formed according to ECE communication notation (see Fig. 3 as a request example).

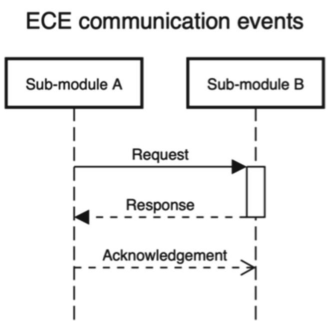

Fig. 2. ECE communication events.

This process is asynchronous, when the Sub-module B is ready to respond, it sends back the response message. Afterwards Sub-module A sends back the acknowledgment message to notify Sub-module B, that the response is received and understood.

```
{
    "type": "request",
    "request_guid": "2fbec59a-7686-4f96-9686-88aaff7ef3a5",
    "service_guid": "9b0ae71b-aeb6-42db-bbcf-2875cafb0a39",
    "service_endpoint": "closes_path",
    "payload": {
        "location_node_start": 847584,
        "location_node_end": 234903
    }
}
```

Fig. 3. ECE request example.

Figure 4 gives example on how ECE architecture abstraction layers are represented in communication between two sub-models. In this figure one can see all the main parts that are required to deliver a message from one entity to another. In such case message is constructed affirmative with ECE notations and encoded in JSON format. Sub-module has a library for its specific programming language that provides AMQP communication. AMQP requires message broker for communication consistency it ensures that messages are delivered at the right recipient in the right order.

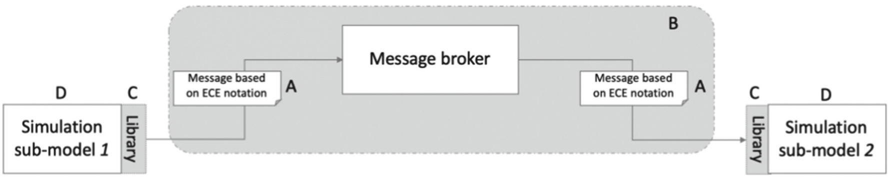

Fig. 4. ECE communication example between two sub-modules.

5 Conclusion

Development of a diversified and inclusive transport scheme that corresponds to the needs of all stakeholders is a challenge in many modern cities. Socio technical approach used in VeloRouter addresses many of those challenges.

VeloRouter combines functionality meant for decision makers, infrastructure developers and cyclists, that ensures up-to date and comprehensive information exchange among stakeholders. For such operability VeloRouter consists of several services or microservices. Microservice approach is beneficial for this kind of system as it enables to separate different functions, it is easier to maintain and they are reusable. The communication among the microservices has to be defined to be simple and universal at the same time. The authors propose Easy Communication Environment based on JSON and AMQP to ensure simplicity and resilience. Further development of ECE will focus on time advancement in such simulation environment.

Acknowledgements. The article publication is initiated by FP7 FLAG-ERA FuturICT 2.0 (2017–2020) "Large scale experiments and simulations for the second generation of FuturICT" STIMUL project "Intermodal bicycles network as efficient kind of urban green transport (VeloRouter 2.0)".

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