Synaptic City
An Architectural Approach using an OSGI Infrastructure and GMaps API to Build a City Simulator

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Abstract: Big cities have noticeable problems resulting from poor management of urban services. Monitoring a city gives some parameters to evaluate the performance of urban services, allowing to identify their flaws, and elaborate strategic plains to correct them. Smart cities architectures are intended to propose Information and Communication Technologies (ICTs) solutions to increase service efectiveness. Considering that to establish a ICT infrastructure to support a smart city architecture is very expensive, once you have got the data and you know what urban service you will attend to, you can use a city simulator to test how the architecture will behave when facing the city's problems. In this context we propose the Synaptic City architecture, together with a city simulator, with which we modeled a Brazilian city, Recife, Pernambuco, in order to discuss its main problems.

1 INTRODUCTION

The literature offers several definitions of the term City, but the most accepted is described in Kuper (Kuper, 1995): a relatively large and permanent settlement. Usually, a big city has a high population density, with its citizens living constant interaction with industries, market and services. Under the operational viewpoint, cities are based on a set of basic infrastructure: energy, water, transportation, infrastructure, information and communication, leisure, home, citizens and public sanitation (Morvaj et al., 2011).

According to a UNESCO report released (Nations, 2007), in 1950, 30% of the world population lived in urban areas and in 2010 this percentage grew to 50%. It is estimated that by 2050 the percentage of people living in large urban centers will be 70%.

In the brazilian context, according to research conducted by the Brazilian Institute of Geography and Statistics (IBGE), published in the *Diario Oficial* (an official journal where the brazilian government publishes its actions, decisions and resolutions about the state) (de Geografia e Estatística (IBGE), 2012), in July, 2012, Brazil reached 193,946,886 inhabitants, representing an increase of approximately 1.65% in comparison to 2010. With the growth of both the population and the complexity of the issues that concern a city, there is a challenge in combining data from different sources with Information and Communication Technologies (ICTs) in order to promote better living conditions for citizens. This challenge, which in other words is how to make a city become a Smart City, has been widely discussed in the literature, from projects and initiatives with different views on the concept (Giffinger and Pichler-Milanović, 2007) (Su et al., 2011) (Kanter et al., 2009).

However, there is no consensus regarding the definition of this concept, nor as to the most appropriate environment to use it. In Kehua et. al. (Su et al., 2011), IBM defines smart cities as the use of information and communication technologies to capture, analyze and integrate relevant information into the core cities systems. At the same time, a smart city can make smart decisions for different types of needs, including daily aspects, environmental protection, public safety, city services and industrial and commercial activities.

In order to make better decisions that facilitate the citizens life, it is needed to constantly monitor the various environments that compose a city. Each environ-

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ment must be mapped with different types of sensors, such as temperature and presence (Hernández-Muñoz et al., 2011). The greater the variability of sensors, better the fidelity level of this mapping in relation to the real environment. This variability should be treated in relation to frequency of data sent, data type and variability of communication protocols (Filipponi et al., 2010) (Hernández-Muñoz et al., 2011) (Lee et al., 2011) (Zygiaris, 2012) (PlanIT, 2012) (Blackstock et al., 2010).

Thus, it is important to develop a central layer, that is able to attend several devices with different technologies. Additionally, this layer should be reliable to handle multiple simultaneous requests for information generated from the combination of several data sources (Filipponi et al., 2010) (Hernández-Muñoz et al., 2011).

Nevertheless, for testing and validating this central layer it is necessary to use several sensors. These sensors are difficult to be implemented in real environments, mainly due to high cost and some public policies (Sanchez et al., 2011). Therefore, the need to simulate the mapping of a real environment arises, with several different types of sensors sending information for an indefinite time. This simulator must be flexible enough to model any city, independently of cultural and demographic characteristics.

In this context, this work proposes a smart city architecture and validates it using a data simulator. Section 2 discusses related work in a minimally validated stage, found in literature. Section 3 describes the Synaptic City Architecture proposal divided in three layers. Each layer is presented and all technologies used for implementation are described. Section 4 presents the case study, describing the target city and all related scenarios. Finally, Section 6 concludes discussing results from the architecture and data simulator.

2 RELATED WORK

In order to have an updated snapshot of what is happening in an urban environment it is necessary to sense, keep track, of whatever is happening in its surroundings. Sensors allow computer systems to interpret a real world situation, based on raw data, that must to be related to a whole context to generate useful information.

Monitoring a city gives some parameters to evaluate the performance of urban services, allowing to identify their flaws, and elaborate strategic plans to correct them. Strictly speaking, sensors are usually capable of measuring physical quantities and convert it into a digital signal, that by its turn will become the raw data aforementioned. Adding some computational capabilities to the practical sensor concept, i.e., “smartening” a sensor, makes it able to act as a distributed, contextual and reconfigurable node in a highly dynamic, distributed and heterogeneous environment, collecting data, generating information, allowing implementation and support to pervasive computing environments (Lei, 2003)(Tan, 2010).

When we expand this behavior to a context where all objects are connected and acting as data sources - as sensors - applying to some common goal, we reach the Internet of Things (IoT) concept(Atzori et al., 2010). According to Tan and Wang (Tan, 2010), the Internet of Things is responsible for linking the physical and the information world.

Nowadays, as there are emerged projects in which “crowd sensing” is highly utilized, providing data from real world devices to developers create some value proposition using them.

One of these projects is described in (Cosm, 2012), where people are invited to connect their devices to the COSM platform and, developers and companies, besides connecting devices can integrate apps to securely store and exchange data. It offers real-time and scalable controlling, monitoring and analysis of the available data.

Additionally, the Magic Broker platform (Erbad et al., 2008) was adapted to smart cities, aiming to provide a consistent model and interfaces standardization for building Internet of Things applications. It addresses an architecture model driven by citizens engagement, to build and deploy application suited to their needs, exploiting the use of smart sensors, sensor web technologies and IoT technologies, such as Radio Frequency Identification (RFID). The project’s target is to compose a middleware, using OSGi bundles (i.e., software components) (Alliance, 2007), capable of supporting a wide range of devices and programming models to support wide area dynamic composition of devices and services.

The (Tecnic, 2012) presents a web centric sensing platform, called *WoTkit*, that facilitates the connection between real-world objects and the Internet, engaging users as “participatory sensors”, allowing developers to build “revolutionary services”, as they say. The focus is to help people to reduce costs through compelling services, enabling the development of mobile applications that sense and control the real-world.

Demand for smart cities that consolidate and deliver contextualized information about services of cities is latent and becomes stronger as cities grow and technologies emerge. Initiatives worth mentioning, such as the NYC BigApps (City, 2012) and

RioApps (Prefeitura do Rio de Janeiro, 2012) contests, where urban data is made available through software interfaces so people are encouraged and rewarded for creating outstanding applications using it, thus creating some value proposition to its citizens, improving urban daily life, resource usage, and quality of urban services.

Finally, our work aims to join the flexibility in coupling new devices to the architecture - as COSM does - but, instead of letting it be associated to user-defined subjects, we predefined some concerns covered by Synaptic City, standardizing the data that will be made available. Both flexibility and standardization will be achieved through a middleware capable of handling data from different devices, maintaining it uniformly. All these data will be provided to developers so they can build and compose useful services and applications in daily life of citizens, exploring new possibilities for urban services management based on crowdsourcing.

3 SYNAPTIC SMART CITY ARCHITECTURE PROPOSAL

One of the biggest concerns when creating a smart city software architecture is sharing responsibilities among the entities, keeping it consistent, guaranteeing extensibility and flexibility to the supported services. Thus, we divide the Synaptic Smart City architecture in three layers, as shown in 1: physical, middleware and application.

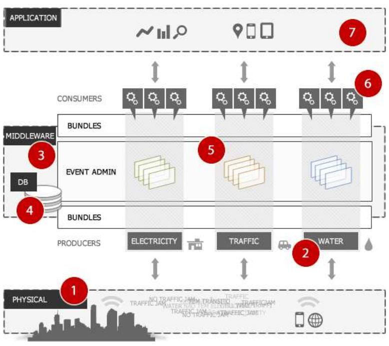


Figure 1: Synaptic City Architecture.

The physical layer (1) is responsible for hosting the sensors. In our test bed we had no proper physical sensors to use, so we decided to simulate them using a Mobile and a Web application. The former took the form of an Android traffic application consisted in a single button on the screen, which the user should press in case of facing a traffic jam; the latter consisted of a Web application that comprised a City Simulator. This layer has as responsibilities capturing raw data coming from different sensors - concerning to traffic or water/electricity consumption - and forwarding it to its specific producer bundle (2) at the middleware layer.

When the data reaches the middleware layer (3) it is saved in a database (4) with the purpose of maintaining historical data about the addressed concerns. Once saved, it is published in a message-oriented middleware under a specific message topic (5) from which the application - through the consumer bundles (6) - can retrieve the incoming data. As all the concerned topics are in this layer, contextualized information can be generated, or different concerns can be related, and a new topic with a new type of information will be available.

In the application layer (7), the data can be acquired through a subscription to a concerned topic in the message-oriented middleware. The interesting aspect of this layer is that an application can subscribe to different concerns and create its own contextual knowledge on the available data, increasing the richness of the information provided to the user.

For capturing useful information in the smart cities contexts it is necessary to involve citizens. Therefore, it is important to choose technologies that can encourage people to provide (layer 1) and consume (layer 7) data, without which this interaction is unpleasant. Thus, due to the increasing number of people with smartphones (Hall, 2012), we decided to create two applications for this type of device. The smartphone operating system chosen was Android, because of the facility in deploying new applications and the market share it holds. Our applications were built on the Froyo version (2.2), but they are compatible with newer Android versions.

By using the traffic application, one can identify through the map the traffic bottleneck and the amount of cars in every city area. The traffic application feeds the base providing location reports every 20 minutes. The second application is responsible for showing information about the sustainability level of a building, according to its reported water and energy consumption. Furthermore, some scenarios are designed to simulate a situation in which several people will be using these applications. These scenarios will be discussed throughout this work.

We deployed the discussed layers in the Amazon Web Services (AWS) infrastructure, that offers a highly reliable, elastic, scalable and low cost solution (Services, 2012). There was no special reason for that choice, we only wanted available infrastructure, able to give support to as much requests as possible, as well as a high number of connected sensors sending data constantly; in case of a increasing in one of these, it would scale automatically, without having to rethink about hardware or deployment issues.

3.1 Middleware: OSGI

The OSGi platform was chosen for developing the Middleware layer (2). According to OSGi reference (Alliance, 2007), “The OSGi technology is a set of specifications that define a dynamic component system for Java. These specifications enable a development model where applications are (dynamically) composed of many different (reusable) components”. OSGi reduces complexity by providing a modular architecture for large-scale distributed system, inhering some important advantages for smart cities architecture scenario, such as modularity, hot-deployment, scalability, and security. The OSGi component system was used to build some widely used projects like Eclipse, GlassFish, IBM Websphere, Oracle/BEA Weblogic, Jonas, JBoss, among other.

The OSGi advantages match with Synaptic City goals, mainly modularity for build new services. Thus, for implementation purposes we chose Equinox Bundles (Foundation, 2012) component, due to familirity with Eclipse enviroment and integration with Jetty Web Server.

For validation purposes, three services were created: traffic, water and energy consumption. For each service, a producer and a consumer bundle were built. The producer bundle is responsible for putting information about services on OSGi. Moreover, the consumer bundle is responsible for getting all information and making it available via REST interface. In Blackstock et al. (Blackstock et al., 2010) they proposed a platform called Magic Broker (MB2), which provides some basic abstractions, such as events, state, and content management services. Based on that, the producer-consumer communication is done via OSGi’s Event Admin component, an event-oriented communication architecture based on queue and topics, resembling a message-oriented middleware.

In the traffic service, the producer bundle puts information needed for traffic reports, such as latitude, longitude and report time. From this information, the consumer joins several reports and calculates a range of intense traffic around 200 meters. So, consumer makes available a block list of areas with traffic issues in the last 20 minutes.

In the case of water and energy services, the same informations was used. The producer bundle continuously sends the following information: the water/energy consumption, entity type and entity position (latitude and longitude), during an undefined period. The entity type must be residential, commercial or industrial. The consumer bundle makes available an average consumption on the last week, as well as a classification based on the population average consumption.

Table 1 summarizes the information to all bundles services interface. If more services need to be added, it is necessary just to create a producer and consumer bundles and plug them in architecture, thanks to OSGi hot deploy capability.

3.2 Physical: City Data Simulator

The simulator plays an important role in the Synaptic City architecture. Since we did not have any physical sensors available, we needed to create something to serve as data producer on the Physical layer (1), that could be attached to the architecture and act just like any other sensor was supposed to. That is why we implemented the City Simulator.

To make the simulation closer to the real world we created entities to represent some urban elements: residences, buildings, data center, cars, city hall, hotel, football stadium. Each one, except for cars, is identified uniquely from its geographical location. With this entities set it is possible to simulate several urban scenarios, with a geolocalized distribution represented with GMaps API. To validate the proposed architecture concept, we built some specific scenarios in Recife, Pernambuco, Brazil.

Furthermore, one can simulate any urban environment simply placing the map on the targeted city, selecting an entity and putting it in the most appropriate place. There is no restriction on the number and types of entities that can be added. Once this is done, it is possible to send the report of each entity manually or select the auto city simulator mode. In this mode, each entity periodically sends their information: in the case of cars, traffic reports are sent; for other entities, each report with water and energy consumption are sent.

For entities that provide water and energy information, the report values vary according to their consumption rate, based on real world values. For example, over a month, a data center should consume more water and energy than a city hall, mainly because the data center should be in operation all the time with a high and almost no variable consumption, while on weekends the city hall has a decrease on its consumption values. Therefore, consumption reports of the data center must have greater values than the ones measured in a city hall.

To utilize the data generated by the entities, we

Table 1: Information *vs.* bundles summary.

Service	Producer	Consumer
Traffic	latitude	Block List:
	longitude	-block latitude
	report time	-block longitude
		-amount of reports
Water	latitude	latitude
	longitude	longitude
	entity consumption	consumption rate
	entity type	consumption mean
Energy	latitude	latitude
	longitude	longitude
	entity consumption	consumption rate
	entity type	consumption mean

created some classification reports in which, according to the measured consumption, each entity is said to be sustainable or not.

4 CASE STUDY

The architecture efficiency is measured according to its behavior in real world scenarios. Specifically in smart cities architectures, the validation in real environments is difficult because often one needs infrastructure such as sensors network throughout the city and the availability of Internet connection. Moreover, government issues usually hamper this validation, mainly in aspects related to public areas.

From the simulator viewpoint, the efficacy is measured according to the similarity level between the simulated and the real environment. Therefore, this section aims to address the case study conducted to validate the Synaptic City architecture and the City Simulator. Starting with a contextualization of the city that the simulator aims to represent, we will describe the studied scenarios and how the needed information was captured and used.

4.1 Target City

The city chosen for the experiment was Recife, capital of Pernambuco, Brazil. According to statistics from Brazilian Institute of Geography and Statistics (IBGE) (de Geografia e Estatística (IBGE), 2012), the metropolis contains approximately 1.555.039 inhabitants, which places as the 8th most populated city in Brazil. From a sociological viewpoint this cluster of people implies in the occurrence of several problems that affect directly existing services, such as transportation, security, water and electricity supply/consumption, sanitation and natural resources utilization; from a technological viewpoint, this implies in several opportunities to turn problems into solutions to make life pleasurable living, through improvements and new ways for providing urban services.

Moreover, Recife is one of the host cities of the FIFA Confederations Cup 2013 and the FIFA World Cup 2014 with urban mobility demands. Focusing on traffic, the Recife city has about 600,000 registered vehicles. The city's road network is not ready for that amount of vehicles due to its narrow streets and few roadways as optional routes. On energy and water issues, citizens have no system that quantify the level of their consumption or even measure the quality of service in real time.

In the following subsection, we will analyze some scenarios chosen to represent these problems.

4.2 Scenarios

By using City Data Simulator it is possible simulates several urban scenarios, combining different entities. To validate the proposed architecture concept, we built some specific scenarios that mimic Recife's reality. Three scenarios were chosen to represent critical situations that occur frequently.

(a) Recife citizens are passionate about soccer and fanatics by the three top teams: Nautico, Sport and Santa Cruz. When there is a soccer game between these three great teams, several fans go to stadium to root and encourage their teams. Thus, the first scenario aims to illustrate this event, in which a soccer match between Sport and Nautico is held at Ilha do Retiro stadium. The avenues that give access to the stadium are narrow and are not prepared to meet that amount of cars. Fortunately, the stadium is located in a residential area and, from some buildings around the stadium, it is possible to watch the entire game.

(b) For being a coastal city, some periods of the year it rains a lot in the city of Recife. In turn, the main avenues that give access to the peripheral region does not have an effective drainage system, causing inconvenient traffic jams. Therefore, the second scenario aims to illustrate this situation, specifically highlighting Imbiribeira Avenue, which crosses the city and gives access to the International Airport of Recife/Guararapes and a major neighboring city, Jaboatão dos Guararapes.

(c) Some major events are held in Recife stadiums thanks to public policies to encourage art and culture. As an example, we can cite international artists concerts. The last scenario describes the situation in which a large event is held at the José Rego Maciel Stadium (known as Arruda) belonging to Santa Cruz Futebol Clube. Currently Arruda has capacity for 60,044 people, and there are several access routes to the stadium, some of them are narrow, with low flow of cars, and others wider, with a more intense flow.

5 RESULTS

Once the architecture design is completed and the producers and consumers bundles, as well as the simulator, are all created, the resulting information must be analyzed. Specifically in the Recife context, these results are interesting from a practical standpoint. Their analysys will be separated in two aspects: Synaptic City Architecture and data city simulator.

5.1 Synaptic City Architecture Results

Starting with the architecture results, the usage of the OSGi framework made the architecture well modularized and flexible, in terms of the amount of services provided. Additionally, each service can receive data from different sensors, as long as a new bundle producer is created and all the data are sent using the Event Admin topic concept. The architecture serves multiple client applications via JSON content provided by bundles consumers, as implemented in the web and as smartphone applications.

This applications variability is an important factor, because it increases the likelihood that citizens will be informed as soon as possible about any event in the city. By receiving this information, citizens can make the best decisions aiming their quality of life, taking advantage of improved urban services. In this first experiment, the types of applications are restricted to those only with Internet access.

Furthermore, the service composition is a requirement easily answered by that architecture organization. To compose various services, you just have to capture the data of the respective topics, combine them appropriately and make them available via web interface for any other application.

5.2 Data City Simulator Results

As the simulator, we highlight the possibility of creating different types of sensors. Considering that to establish an ICT infrastructure to support a smart city architecture is very expensive, once you have got the data and you know what urban service you will attend to, you can use a city simulator to test how the architecture will behave when facing the city you are trying to represent. Besides, different cities have different problems, and using a simulator makes it easy to model how these problems affect the performance of urban services and how they are related to each other. By knowing the input data and the output information, a simulator allows to create different scenarios to test the architecture effectiveness.

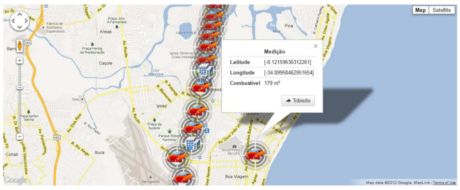
In the context of this work we should analyze the results obtained with the simulated scenarios of Recife. These scenarios represent everyday situations and should be analyzed, mainly, from the viewpoint of citizens welfare. Figure 2 illustrates the three scenarios. In all of them, the circles around each entity represents that, at the moment, consumption/traffic reports are being sent .

The scenario shown in Figure 2(a) represents the classic soccer match between Sport and Nautico. Analyzing this scenario, we can notice that the football stadium is sending reports constantly. Likewise, the buildings around the stadium are consuming enough water and energy. This probably means that people are watching the game at home increasing energy consumption. In turn, the traffic reports (represented by cars) are concentrated in the main access to the stadium, causing a heavy traffic jam. Figure 2(a) illustrates the information sent by the buildings.

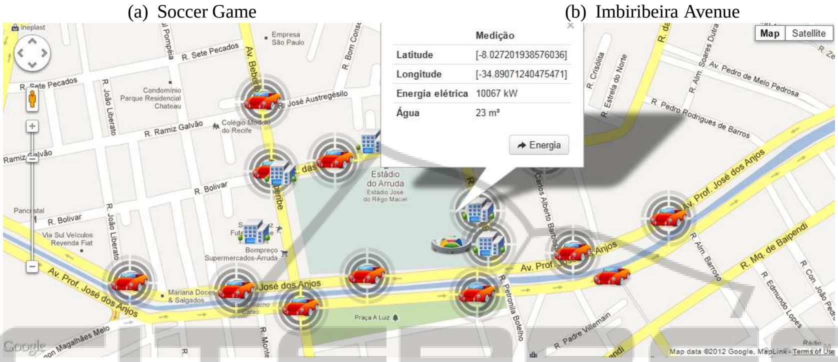
Regarding the scenario illustrated in Figure 2(b), a traffic jam can be noticed at the Imbiribeira Avenue, which gives access to important points in the city, such as the International Airport. Simultaneously, we notice an increase in both water and electricity consumption for buildings around, possibly due the measures being taken to mitigate the problems caused by traffic bottlenecks and flooding. Also in Figure 2(b) there is an illustration of the information sent by each traffic report.

Finally, the scenario shown in Figure 2(c), we can see that the main access to the stadium are congested,

(a) Soccer Game



(b) Imbiribeira Avenue



(c) Artists Concert

Figure 2: Results Three Recife scenarios.

but there are some alternatives roads that can minimize the time spent to get to the event. Moreover, we can observe changes of consumption in buildings around the stadium, possibly because of the opportunities created by the event, as parking lots and commerce. Finally, one can observe a bullet with the information that is sent from a stadium entity.

With this information acquired from the three scenarios, citizens can take some decisions to improve their quality of life, optimize their time and reduce the stress. Related to the first scenario 2(a) it is possible to choose going to the stadium before the scheduled time and pick the best path in real time. Considering the second scenario 2(b), it is possible to deviate routes to avoid flood points. The third scenario 2(c) can be mitigated choosing among different access routes to the international concert.

Besides this vision from the viewpoint of the citizen, one can analyze this information from the perspective of business opportunities. For example, in scenario 2(a) traders could exploit the brand of the teams in points with high concentration of people, and knowing the stadium and buildings consumption energy suppliers could work on optimizations, extracting consumption patterns from the scenarios, allowing to model and forecast some chaotic events, such as power outages or even consumption peaks for specific events, and determine the appropriate corrective/preventive actions.

6 CONCLUSIONS

Throughout this work, some aspects that an smart city architecture must meet were soon discussed. As a case study, we described the Synaptic City architecture. The Synaptic City constitutes a project with a proposal to build a modular, scalable and robust architecture, coupled with a wide simulator.

All results of this work were obtained from the use data simulator, in which no empirical experiment was conducted. Nevertheless, in this validation context, the architecture shown to be flexible, especially regarding the services composition aspect. This characteristic is very important because in a smart city context is important to combine information from different services.

At the end of this paper, we concluded that the architecture definition cannot be focused only on technological issues, but on issues related to daily lives of citizens and ways to make a participative action become a part of an effective solution to urban problems.

For future work, we will develop new topics in the Synaptic architecture with contextualized services, as well as model some local scenarios, such as companies, with sensors monitoring a more restricted scope, allowing to manage services in smaller domains. These federated solutions will stablish a new concept of smartness in a city, built from a collection of well managed subdomains, enabling more focused approaches to solve local problems based on a holistic view - in which each federation has its own topic from which other ones can get information - aiming to set up a high quality urban environment with very pleased citizens.

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