Spatial Representation of
Public Displays Networks

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Professor Doutor Adriano Moreira

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“Dictionary is the only place that success comes before work.

Hard work is the price we must pay for success.

I think you can accomplish anything if you’re willing to pay the price.”

Vince Lombard

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Firstly, I would like to express my deepest gratitude to my family. Without their love and support, all of this would not have been possible. Also a special thank to the Proença/Rocha family for all the support over these years.

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Thank you all!

Representação espacial de redes de ecrãs públicos

Resumo

Este trabalho faz parte do projeto Europeu Pd-Net e tem como objectivo identificar e abordar os desafios tecnológicos e de investigação relacionados com a criação de redes, em larga escala, de ecrãs públicos e sensores associados.

O aparecimento das redes de larga escala de ecrãs públicos irá representar uma mudança significativa no modo como pensamos sobre a disseminação de informação em espaços públicos e criará uma nova área de investigação, as bases para um novo meio de comunicação e novas oportunidades de negócio. De igual modo, é esperada uma mudança nos espaços públicos para espaços inteligentes que podem ser ajustados para refletir as esperanças, aspirações e interesses dos ocupantes que utilizam o conteúdo e as aplicações criadas em qualquer parte da rede.

Um dos pontos-chave da rede de ecrãs públicos é a possibilidade de endereçar a rede como um todo e focar nas relações espaciais entre os ecrãs.

Spatial representation of public displays networks

Abstract

This work is part of Pd-Net, a European project that aims to explore the scientific challenges and new technologies required to enable the emergence of large scale networks of pervasive public displays and associated sensors that are open to applications and content from many sources. The emergence of such pervasive display networks would represent a radical transformation in the way we think about information dissemination in public spaces and will create a new research area, provide the foundations for a new communication medium and new business opportunities. In the same way, it is expected a change from public spaces – from today's environments in which information is pushed to passers-by in the form of adverts – to spaces that can utilise ambient intelligence to be tailored to reflect the hopes, aspirations and interests of its occupants using content and applications created anywhere in a global network.

One of the interesting features of pervasive displays networks is the possibility to address the network as a whole and to focus on the spatial relations between displays.

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1. Introduction

The debate over large-scale networks of pervasive public displays is earning a considerable attention, but in fact it is still an area in its infancy. In comparison to static signage, pervasive displays have more advantages as they can be used with different purposes.

Typically static signage has only one purpose and in order to change or update the information that is being given, new signage has to be created and deployed. However, it takes some time to firstly, identify when a static signage needs to be updated or created and secondly, to place or replace it. During that time, incorrect, incomplete, ambiguous, or even no information is given. Furthermore, the way in which the static signage is placed has a strong impact in the information quality, as it is desirable that the information is given in a clear and unambiguous way. Another issue is related to temporary events, given that new and specific signage has to be created and placed to provide information or directions about the event. But when the event ends, all the created signage has to be removed. However, since it is time consuming and it represents significant costs, in most cases the signage is not removed and stays visible presenting wrong and unusable information. Despite of this, static signage is still widely used.

At the same time a public display entails dynamic solutions that allow presenting, varying and updating the available information without involving any infrastructure costs. When there is the need to modify or update the information being displayed this can be done almost immediately, and consequently the most up to date and accurate information is always provided. This capability represents an advantage over static signage and it can be even more important in emergency scenarios, where updated and precise instructions/information can be given to help people in a more effective way. Moreover, when a specific event takes place the displays can be used during that period to provide information and/or give guidance to the event. When the event ends the displays can be used to display other information. Public displays, unlike static signage, can be used to serve multiple purposes e.g. personalized navigation, shopping assistance, advertising, context aware, emergency scenarios etc.

Nevertheless, to enable this dynamic solution a public network of displays has to be set up to provide a service infrastructure. The information showed on the display needs to be adjusted to new conditions and to the surrounding environment. The display's location and orientation has to be known and so a suitable and generic spatial location model has to be developed. The emergence of such possibility will definitely represent a huge change in the way we all think and see the information propagation in public spaces. The European project (Pd-Net) intends to explore the scientific challenges and technologies that will be needed to enable pervasive display networks and associated sensors. This will represent several new opportunities at different levels of research.

1.1. Contributions

The main purpose of this thesis is to specify a suitable, simple and generic spatial model to associate the display medium within its spatial location. A spatial model will enable the displays on a public network to spontaneously support applications that require knowledge about the location and orientation of the display. It will be generic without limiting any application or system to get the information needed about the displays. It should allow the inclusion of any sensor technology already available or that will be available in the future. Therefore, the main goals of this thesis are the following:

- Identify the spatial requirements that are imposed not only to the spatial model but also to the characterization of the displays;
- Develop a spatial model that enables spatial relations between displays and their physical location (location within an indoor space);
- Develop a mobile application to perform the display's registration, i.e. generate and collect the display's spatial information;
- Develop a solution that enables applications to understand the geometric and spatial relations between displays in order to achieve their goals;
- Build up a test environment to test the pervasive displays network.

1.2. Motivating scenarios

The following scenarios show how spatial representation of public displays networks can be used in real-world applications. The scenarios share the need for a spatial model that associates the display medium and its spatial placement, enabling the displays on a pervasive network to spontaneously support applications that require some knowledge about the specific placement and orientation of the display. The scenarios are the following:

- *Locally Sourced Emergency Information - Missing Child Alerts*

Sue realizes she has lost her daughter Millie in the local shopping centre. She immediately calls the local police who ask her to send them a recent photo from her mobile phone. Within seconds all of the displays in the shopping centre are showing a photograph of Millie together with a number to call. As the minutes pass the photographs spread over an ever-increasing area – reflecting how far away Millie might be. Five minutes after the first call Millie and her mum are reunited after being found by a fellow shopper who recognized her photo from the screen.

- *Emergency Evacuation – Responding to a Terrorist Incident*

Imagine the Emergency Services are handling a suspected terrorist incident involving an explosion in a major city. The local command centre selects the epicentre of the incident and initiates evacuation of the area. Immediately all of the public displays in the city – not just those owned by the council but all displays - fall under the control of the command centre. Displays seen as people travel toward the emergency warn them to turn away whereas displays seen while travelling away provide helpful navigation instructions to safe areas.

- *Interactive Applications – Information in an Unfamiliar City*

Brian has not been to Bulgaria before, but the flight was certainly cheap, and since he knows they joined the European Union he feels sure they must speak English. It was with some surprise then that Brian found he was almost entirely unable to read the Bulgarian signs. Fortunately, since 2011 Sofia has joined many of its municipal displays to a global network. Brian walks up to one of these and immediately it recognises that he's foreign, switches to English and offers him helpful advice about nearby hotels and attractions. He can see notes and reviews from other tourists. He sets the "Casa Ferrari B&B" as his destination and now gets additional guidance as he passes further displays reassuring him that he's on the right track. Brian is beginning to feel more confident in this unusual but beautiful country.

1.3. Thesis outline

This thesis is divided in eight chapters.

Chapter 1 introduces the motivation, the main contributions and the motivating scenarios of this research project.

Chapter 2 presents the fundamental location concepts related and used throughout this work.

In the Chapter 3 a selected number of publications from the location modelling and public displays are described and related to our work.

The Chapter 4 presents the identified display's usage patterns and the spatial requirements that are imposed to the display's categorization.

In the Chapter 5 the system architecture, the assumptions made in this work and the modules of our proposed solution are presented.

The Chapter 6 presents how the application to collect the required display's spatial information was implemented.

Chapter 7 reports the obtained results and evaluates them in light of the initially proposed objectives.

Finally the Chapter 8 concludes the document by revisiting the thesis statement, providing a list of published papers and suggesting future developments.

2. Location concepts

Before we review the related work we need to introduce some basic concepts that will be used throughout this work. The title of this thesis – Spatial representation of public displays network – highlights two key areas of interest: spatial location concepts and spatial model. This chapter starts with an overview over the three location-sensing techniques that are used to determine the location of a given object (section 2.1). Since the location of the display can be defined in the form of geometric or symbolic coordinates, the properties of both coordinates are presented (section 2.2). Then an overview over absolute/relative location systems (section 2.3), accuracy (section 2.4) and precision (section 2.5) is presented. The last section of this chapter presents the features of the location models, i.e. the queries that a location model should be able to reply.

2.1. Location Sensing Techniques

In order to identify the objects' location, at least one location sensing technique has to be used. The three main location-sensing techniques are: triangulation/trilateration, proximity and scene analysis. These techniques can be used individually (the location of the object is estimated through just one technique) or combined (location-sensing techniques are combined to estimate the objects' location).

2.1.1. Triangulation/trilateration

The triangulation sensing technique calculates the object's location through the geometry properties of triangles. Depending on how the calculation is performed – if through distances or angles – the triangulation is divided into two sub-categories, lateration and angulation. In **lateration** the object is located by measuring its distance relatively to multiple reference points. If the location is calculated in two dimensions (2D), three non-collinear points are required to guarantee that there is only one point where the circumferences – formed in each point – intercept each other and then the object's location is identified (see Figure 2-1). On the other hand, if the location is calculated in three dimensions (3D), four non-coplanar reference points are required.

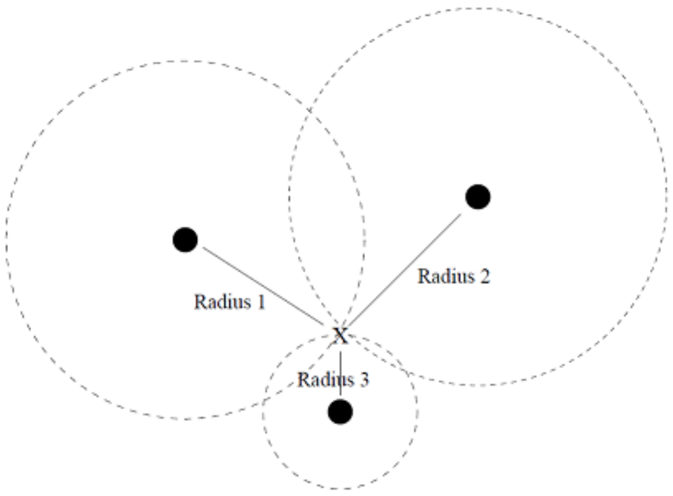


Figure 2-1: Lateration [Hightower J. *et al.* (2001)].

In **angulation,** the object's location is not determined by distances measurements but rather by angles. If the location is calculated in two dimensions (2D), two angles and the distance between the two points where the angles are formed are required. If the location is calculated in three dimensions (3D) then one length, one azimuth and two angles measurements are required to achieve a precise object's location. Some implementations of angulation define a constant reference vector as 0º. In the Figure 2-2 it is possible to observe an implementation of 2D angulation with a constant reference vector.

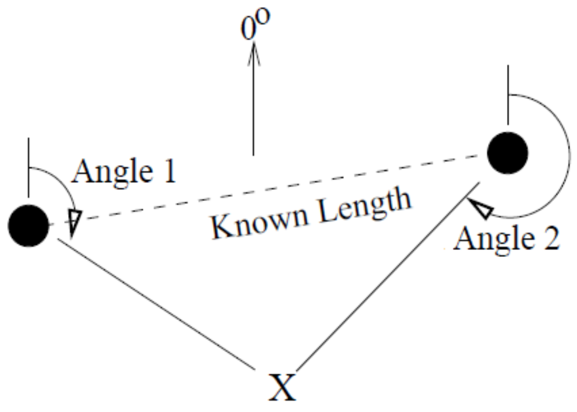


Figure 2-2: Angulation [Hightower J. *et al.* (2001)].

2.1.2. Proximity

In proximity sensing techniques the objects' location is determined through the proximity of the object to known locations. The proximity is sensed through some sort of physical phenomenon, typically with short range to sense the object in a more precise way. However, if multiple objects are sensed then an identification mechanism is required to identify each one. The three major proximity-sensing techniques are: physical contact, monitoring wireless access points and observing automatic ID systems.

Physical contact is one of the most basic proximity-sensing techniques, in which the object is located through the physical contact between the object and the sensor. Since the sensors' location is known, the object's location is inferred when the physical contact occurs.

Monitoring wireless access points detects the object when it is within the range of one or more access points. The location of the access points as well as the signal power at that location, are known. Thus, the object is located through the variation of the signal's power, as the distance between the object and the access points increases, the weaker the signal's power becomes.

Observing automatic ID systems determines the objects' location through automatic identification systems - such as credit cards point-of-sale, computer logins histories, landline telephone records, etc. – that are able to scan the object. Since the location of these automatic identification systems is known, the objects' location is inferred.

2.1.3. Scene analysis

In scene analysis, the characteristics of the scene being observed through a vantage observation point are used to identify the location of the object. The scene being observed is usually simplified to obtain features that are easier to represent and compare. Scene analysis is divided into two sub-categories: static scene analysis and differential scene analysis.

In ***static scene analysis,*** the scene being observed is compared with a predefined reference observation of that scene. This predefined observation is recorded in a database and any difference between the predefined and the current observation indicates the object's location.

In ***differential scene analysis,*** successive scenes are observed and compared to identify any difference between them. The difference between the scenes indicates the location of the object and the objects movement.

2.2. Geometric and symbolic coordinates

In the previous section it was presented how the location of an object can be determined, in this section it will be presented how it can be defined. Two types of coordinates can be used to define the object's location: geometric and symbolic.

In **geometric coordinates** the object's location is defined as a set of coordinates relatively to a specific coordinate system. Geometric coordinates can be divided in global and local physical coordinates. ***Global coordinates*** are able to determine the location of an object worldwide as the **G**lobal **P**ositioning **S**ystem (GPS) uses a global reference system (WGS84) On the contrary, ***local coordinates*** entail a local solution with limited range, such a room or building where the system is implemented. In this case the object's location is only achieved within that space.

Geometric coordinates properties:

- Fine-grained location information;
- Allow distance calculation between two points;
- Allow to determine if different areas overlap, touch or contain each other;
- Allow simple spatial reasoning.

In ***symbolic coordinates,*** the object's location is defined as a set of abstracts symbols or ideas of where the object is. For instance, the symbolic information of an object can be defined as *"University of Minho, School of Engineering, Laboratory 3"*.

Symbolic coordinates properties:

- Coarse-grained location information;
- Distance calculation between two coordinates is not achieved directly;
- To determine if different areas overlap, touch or contain each other, further information is required.

2.3. Absolute location systems

In absolute location systems, a shared reference for all objects being located is used. This means that all objects in the same location will report the same or much approximated location information. The GPS is an example of an absolute location system, since two different GPS receivers achieve the same or much approximated location information if they are at the same location.

2.4. Relative location systems

In relative location systems, each object can have its own reference. For example, in an emergency scenario each hand-held computer of each rescue team element is able to determine the location of the victims relatively to it. This means that each computer has its own relative location system.

2.5. Accuracy

Accuracy is the average difference between the object's real location and the location achieved by the location system. If this difference is small, then the system is accurate (fine-grained). As the difference increases the system starts to lose accuracy (becoming coarse-grained). A system that provides a difference of 1 meter is more accurate than the one that provides a difference of 5 meters.

2.6. Precision

Precision represents how often a certain level of accuracy is expected. This means that, it is the percentage of times that a system is able to provide – overtime – the same or much approximated location information of an object in the same location. A system that provides 99% of the times the same location information to the same object's location is more precise than a system that provides 70%.

2.7. Features of location models

Depending on the application type and requirements, a set of queries and tasks are imposed, which will lead to the location model that has to be used. Hence, these queries and tasks have to be defined and considered before assessing the functional requirements for the location models.

2.7.1. Location queries

Every location-based and context-aware system requires the location of objects, thus a location query is mandatory. Hence, all models have to be able to answer this query despite the fact that each model defines the objects' location differently, by using different coordinate reference systems – global or local – and different coordinates – geometric or symbolic.

2.7.2. Nearest neighbour queries

Nearest neighbour queries search and retrieve the objects that are closest to a given location. In order to identify which is/are the nearest object(s), a distance function is required to compare the distances and identify the nearest objects. If it is true that calculating the distance between geometric coordinates is relatively simple – just perform some calculations – the same is not valid for symbolic coordinates (i.e. additionally information is required).

2.7.3. Navigation

Navigation systems require a location model to find /identify the paths between two locations. To calculate the path it is mandatory to know how the different locations are connected, thus a “connected to” relation has to be modelled. This relation enables the navigation query to calculate and determine the path between the two given locations. Different paths can be calculated depending on the requirements that are specified, it can be the *fastest path*, *shortest path*, *most suitable path* (e.g. handicap users) among others. Therefore, additional information like the distance between locations and the type of connection between locations are required.

2.7.4. Range queries

Range query return all objects that are within a certain range of a given location. If geometric coordinates are used, finding the objects that are within a specified range is straightforward, because it just needs to verify if the distance to the objects is less or equal than the specified range to the given location. In contrast, if symbolic coordinates are used, the topological “contains” relation has to be explicitly defined.

2.7.5. Key properties

Through the previous queries and tasks it is possible to achieve the following key properties for the locations model. Nonetheless, it is important to notice that not all of these properties have to be fulfilled at the same time, unless it is truly demanded by the system/application. Therefore, it is important to identify which are the properties needed by the system/application, and based on that, select the most suitable model. To support the location, nearest neighbour and range queries, a location model should provide:

1. **Object's location** defines the location of the objects in the form of symbolic or geometric coordinates, in accordance with the coordinate reference system used, which can be global or local.

2. **Distance function** models the distance between spatial objects. The distance can correspond to the length of the path that connects two locations (e.g. a corridor) thus, in these cases it corresponds to the distance a user has to travel.

3. **Topological relations** define the spatial containment and spatially connected relations. The spatial containment relation enables range queries, while the spatially connected relation enables and is used for navigation.

4. **Orientation** defines the vertical and/or horizontal dimensions, as well as, landscape and/or portrait orientation.

Even though the previous requirements are important and in some cases crucial to the systems/applications, they should not be achieved through high modelling effort. The modelling effort is defined via the accuracy, level of detail and scope elements.

Accuracy defines how accurate the model describes the world, how the model is created and updated and the dynamics of the objects being modelled. The dynamic of the objects indicates how frequently their information needs to be updated.

Level of detail describes the precision or granularity of the model, which can be fine-grained or coarse-grained.

Scope defines the area covered by the model, which can be local or global. The level of detail and the scope are related, since a model that provides a high level of detail usually has a local scope, otherwise the modelling effort is high or very high. On the other hand, when the scope is global the level of detail is usually low.

2.8. Chapter Summary

In this chapter we presented the basic terms and concepts that will be used throughout this work. We first introduced fundamentals location concepts to determine the objects' location through triangulation, proximity or scene analysis. The two different types of coordinates, symbolic or geometric, were presented as well as the relative and absolute location systems. In this context we also presented the main difference between accuracy and precision of the location information.

Furthermore, we presented the features of location models that had to be taken into account when selecting the location model. The features presented were the location queries, nearest neighbour queries, navigation, range queries and key properties.

3. Related work

In this chapter we perform a review over the work related with this thesis' topic. The two main topics of this work are: the public displays and their spatial representation. Therefore, this chapter is divided in two sections: Locations models (section 3.1) and Public displays (sections 3.2). In the first section we intend to identify the different types of location models along with their advantages and disadvantages in order to select the approach that is going to be followed in this work. Afterwards, a review over the literature that uses public displays was performed to perceive how the displays are used, the goals of such uses, which services use the displays and if such uses impose any spatial requirement.

3.1. Location models

Location models (also known as world models or space models) became a crucial topic in ubiquitous computing. They represent the state of the world, i.e. contain the information regarding places, people, objects and the relations between them. Based on the features defined in the previous section a location model should provide: the object's location (regardless if it is defined in geometric/symbolic coordinates and in a local/global coordinate system), the distance between objects and the topological relations of containment, interception and connection. In the ubiquitous computing scope, the location models play an important role in tracking people/objects and identifying the most suitable devices to perform the interactions with the different context-aware applications.

Based on Becker and Dürr *et al., (2005)* and Domnitcheva *et al.,* 2001, the locations models can be classified in: geometric, symbolic and hybrid location models. However, some authors make the distinction between topological (Brumitt and Shafer *et al., 2001*) or semantic (Pradhan *et al., 2000*) world models and metric models.

3.1.1. Geometric location models

Geometric location models define the locations as geometric figures and contain points, lines and polygons that are characterized by metric and non-metric attributes. If multiple coordinate systems are used (e.g. a global coordinate system is combined with multiple local coordinate systems), the location and orientation information has to be defined in a way that enables the translation between the multiple systems. The <<*containment in*>> relation and the distance between locations are inferred through mathematical calculations. However, the <<*connected to*>> relation cannot be achieved through mathematical calculations, hence it has to be defined explicitly.

The EasyLiving project presented by Brumitt *et al.,* (2000) implements a geometric location model for indoor spaces to provide a location-based context and it is focused in developing an architecture and technologies for intelligent environments. The project's main goal is to identify and track the devices within a given space in order to make the interaction between the user and the devices easier. To perform the interaction, it is not required that the user knows the exact name of the device(s), instead the user just needs to know the device's type and location. To attain the necessary information a set of sensors is spread around the space.

3.1.2. Symbolic location models

Symbolic location models represent the location of the objects and things as abstract ideas or symbols. According to Becker and Dürr *et al., (2005)* the symbolic location models can be divided in: set-based, hierarchical, graph-based and a combination of graph and set-based.

The set-based model relies on a set L of symbolic coordinates. Locations containing several symbolic coordinates are defined by subsets of the set L. For example, the set L of the second floor represented in the Figure 3-1 can be defined as L_{Floor2} = [2.002, …, 2.075], additionally subsets of L_{Floor2} can be created as required, e.g. LocationA = [2.002, 2.003]. The <<*overlapping*>> relation is determined through the interception between sets, i.e. if $L_A \cap L_B = \emptyset$ it means that the set L_A and the set L_B do not overlap, whereas if $L_A \cap L_B \neq \emptyset$ it means they overlap. The <<*containment*>> relation is also determined through the interception between the sets, i.e. if $L_A \cap L_B = L_A$ it means that L_B contains L_A. This model only supports a qualitative notion of distance that is achieved by modelling sets of "neighbouring" symbolic coordinates, quantitative notion of distance is not supported. Therefore, this model offers a limited support for queries related with spatial distances (such as the nearest neighbour and navigation queries).

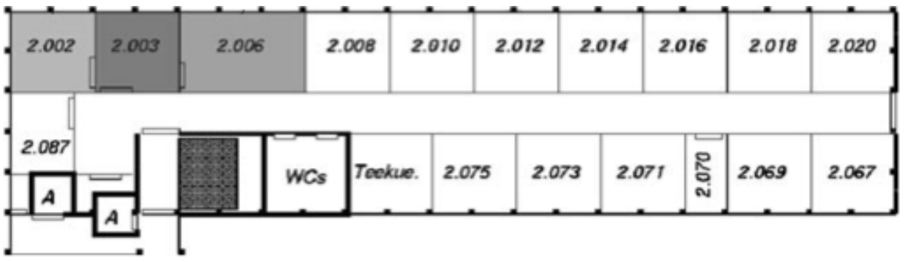


Figure 3-1: Set-based model [Becker C. *et al.* (2005)].

Hierarchical model consist on a set L of symbolic coordinates ordered according to their <<*spatial containment*>> relation. If a location L_B is spatially contained in L_A it means that L_A is an ancestor of L_B ($L_A > L_B$, i.e. L_A contains L_B). The <<*overlapping*>> relation defines two subtypes of hierarchical model: the lattice-based model (when the overlapping locations are to be modelled) and the tree-based model (when the locations do not overlap). In the Figure 3-2 it is possible to observe a lattice-based model in which the interceptions are modelled as separate locations with more than one parent location. Once the <<*containment*>> relation is the basis of this model (i.e. the descendants of a given location define the locations that are in range of that location), range queries are naturally supported. The overlapping locations are defined trough the interception of sets and simple qualitative notion of distance is supported. However, it is not possible to model the connections between locations therefore, the <<*interconnection*>> relation is not supported.

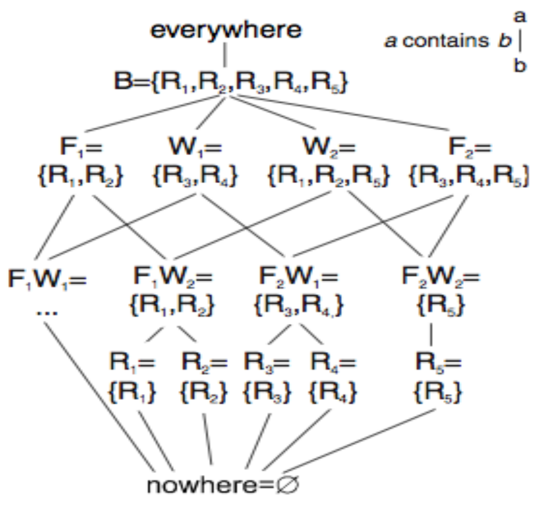


Figure 3-2: Hierarchical lattice-based model [Becker C. *et al.* (2005)].

In the graph-based model G = (V, E), symbolic coordinates define the vertices V and the edge E defines – if exists – a direct connection between two locations. The Figure 3-3 presents a graph-based model. The distance between locations can be either achieved by weighing the edges or the vertices, or by counting the number of hops between the locations. Since the edges defines whenever a connection between locations exits, the <<*connected to*>> relation is fully supported. By combining the <<*connected to*>> relation with the distance between locations this model is capable of answering the nearest neighbour queries. One limitation of this model is the fact that is not possible to explicitly define bigger locations comprehending several small locations, e.g. define all the locations within a given floor.

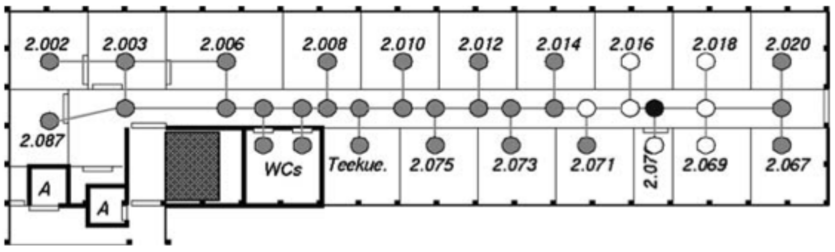


Figure 3-3: Graph-based model *source* [Becker C. *et al.* (2005)].

If the graph and set-based models are combined an improved model is attained, particularly in the range queries (see Figure 3-4). The model uses the same set L of symbolic coordinates and defines locations within that set L as subsets like in the set-based model, whereas the graph-based model is used to define the <<*connection*>> relation between locations. The distance between locations is inferred through the weight of the edges or vertices, which enables the range queries. Since the edges define whenever two locations are directly connected, the <<*connected*>> relation is fully supported. By combining the distance and the <<*connected*>> relation information, the nearest neighbour query is supported. This model provides the necessary means to define fine-grained information – e.g. define every room in a certain building – or coarse-grained information – e.g. define the connection between different floors of a certain building or the connections between different buildings, as it is possible to observe in the Figure 3-5.

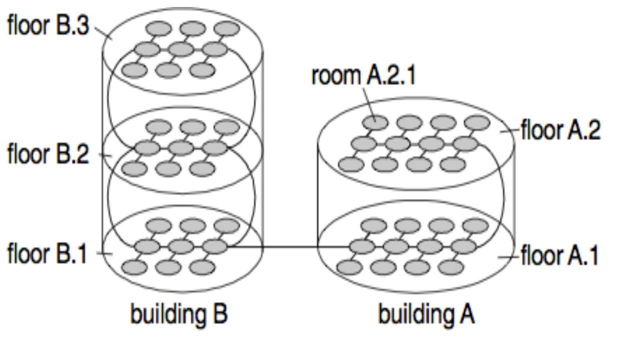


Figure 3-4: Combined symbolic model [Becker C. *et al.* (2005)].

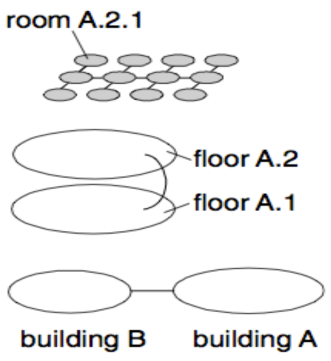


Figure 3-5: Levels of details [Becker C. *et al.* (2005)].

Satoh et al., (2008) presents a location-aware communication approach for smart home environments based on a symbolic location model. The model represents the <<*containment*>> relation between physical objects, computing devices and places. The unique feature of this model is that unlike others it not only shapes the physical objects, but also the location of computing devices and services. The virtual counterpart component *(VC)* defines the physical objects, e.g. a car carrying one person is mapped in two VCs: one VC is the car and the other is the person. The proxy component *(PC)* executes the services located in a VC, maintains the model's sub tree and bridges the model and computing devices. The service component *(SC)* defines the specific services that are available on certain physical entities or places. The framework presented is able to determine available services and execute them in accordance to the space in which the user is located. Objects that do not possess any computational resources or network interfaces are also supported and listed in the framework.

Kolodziej and Danado *et al.,* (2004) proposed a hierarchical model that can be decomposed to the required level of detail. This model enables relative positions inside an existing hierarchy and discovery of adjacency spaces. However, due to the lack of absolute location and distance information to other spaces, the precision of the model is reduced.

Baras *et al.,* (2001) presented a symbolic model in which the edges of the vertices (graph-based) are used to represent generic relations between objects. The relations can be complemented with a set of attributes to enrich the description and facilitates inference processes. Some of the relations implemented are: "Is_In" (defines containment and is attained through the model's hierarchy), "Is_Accessible_From" (defines connectedness) and "Is_Next_To" (defines adjacency and enables the support for pedestrian/navigation applications).

3.1.3. Hybrid location models

Hybrid location models combine geometric and symbolic models, which provides two major advantages. The first one is the gain of accuracy and precision of every distance-related query. The second advantage is the use of arbitrary figures to define ranges for the nearest neighbour queries. This way, one of the biggest disadvantages of the symbolic models is overcome, i.e. the lack of support for distance-related queries. According to Becker and Dürr *et al., (2005)* two types of hybrid location models can be defined: the subspaces and the partial subspaces.

The basis of this subspaces model is a symbolic model in which additional geometric information of every location is modelled and stored (see Figure 3-6). This information can be either achieved through a global or local reference system. Embedding a coordinate system into another coordinate system forms the subspace.

Therefore, the position and orientation information has to be defined in a way that is possible to translate and compare the coordinates between the different coordinate systems. The graph part of the model defines the interconnection and the distance between locations, which enables the <<*containment*>> relation.

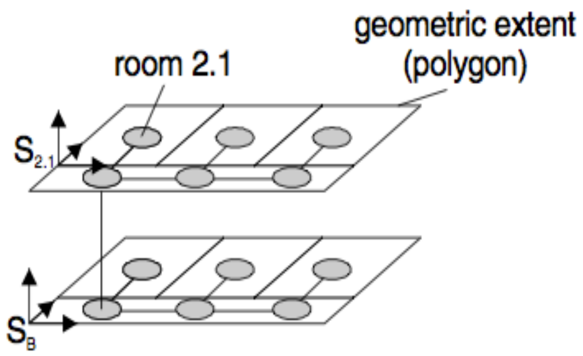


Figure 3-6: Subspaces model [Becker C. *et al.* (2005)].

Contrarily to the subspaces, where it is assumed that geometric information is modelled to every location, in partial subspaces only some locations are geometrically extended (see Figure 3-7). For instance, the geometric information might be used to model the outdoor domain of the building while the indoor domain is modelled through symbolic models. This way the symbolic models can be integrated with the global geometric model. The geometric information enables the range and spatially containment queries, but the <<*connected to*>> relation cannot be determined through geometric information therefore; it has to be explicitly modelled.

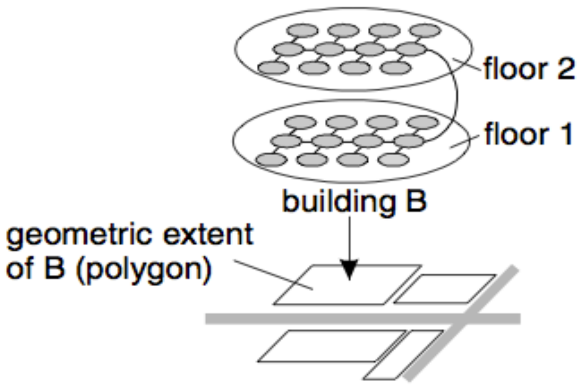


Figure 3-7: Partial subspaces model [Becker C. *et al.* (2005)].

The RAUM is a hybrid location model presented by Beigl *et al.* (2002) that describes the location of everyday objects (called as artefacts) in the surrounding environment. The model combines symbolic names with geometric information and describes a location tree (each path of the tree defines the location of a specific object). The RAUM model is divided in two main parts: the LRM part defines how the location information is represented, stored and communicated, while the CM part defines how the information is used in the artefacts communication. Since the model is able to detect the current location and any change that occur to the objects, it is a dynamic model.

The CMU Aura system is a hybrid location model presented by Hsieh *et al.,* (2004) which combines hierarchical symbolic names with geographic coordinates. This model defines five primitives on the ALI (Aura Location Identifier) that are able to compute the distance, containment, within, super and sub relations. A model to compute the distance and the time required to move between two locations is presented by the authors.

After being presented in 2002 the AURA system was improved and presented by Miller and Steenkiste *et al.,* (2007) with the same hybrid location model but with new extensions. These extensions were: connectivity between locations, support for both outside and inside spaces and additional information concerning the spaces. The hierarchical model was augmented to support that each space in the hierarchy could use different coordinates systems to specify points or areas within that space. The locations are represented using ALIs, which can represent a physical space (e.g. a room), an exact point (e.g. a printer location), an arbitrary area (e.g. Wi-Fi coverage area) or a collection of spaces (e.g. a floor with multiples offices). The information regarding spaces has to be available for all the applications regardless their goals (e.g. infer the properties of the space(s), i.e. calculate distances, optimization, i.e. indicate the shortest path and effective communication with the users, i.e. indicate a path).

Hu and Lee *et al.* (2004) present a hybrid location model based in a relational model for constrained environments. The model contains heterogeneous entities that are defined as they are in the world (e.g. buildings, rooms, corridors, etc.) with arbitrary number of different attributes (e.g. temperature, ZIP code, room's capacity, etc.). Although the number of attributes can be arbitrary there are two mandatory attributes: the *Id* (that uniquely identifies the entity) and the location (that defines the geographic location information of the entity). The location model is composed through two hierarchies: the location and the exit hierarchy. The exit hierarchy can be derived from maps/floor plans to model the <<*connection*>> relation and the distances between places. The authors present their own new definitions of topological relations on path; lemmas, proofs and algorithms regarding the topological relations; and a complete example of modelling an indoor office area.

A hybrid location model that combines lattice and graph based representation is presented by Ye *et al.* (2007) for more complex environments (e.g. city plan, forest, etc.). According to the authors the model provides flexible, expressive and powerful spatial representation along with a new data structure in order to express comprehensive spatial relations. The lattice based describes the containment, disjointness and overlapping, while the graph based describes the adjacency and <<*connection*>> relation.

3.2. Public displays

The deployment and use of public displays is increasing in the major public spaces, such as: airports, hospitals, shopping malls, universities etc. The displays are used to perform multiple and different tasks, while some tasks require the display's spatial information, the others do not require it.

Kray *et al.,* (2008) presented an indoor navigation system that uses public displays to present dynamic signage. The navigation information is presented in the display in text or arrows form when the user is approaching the display. This system was implement in two floors of the InfoLab21 at the Lancaster University, where a 7" colour touchscreen display was placed in each office door. The displays were placed at specific locations within the InfoLab21 and with specific orientation (the display's orientation has a strong impact in the navigation service).

Kray *et al.,* (2005) presented a public navigation (Gaudi) system that uses adaptive displays as directional signs. The GAUDI system was a prototype of a pervasive way finding that is dynamic, adaptive and embedded in the building environment. Each Gaudi display presents information regarding the name of the event/destination, the direction the user has to follow and distance estimation between the display and the destination. The key advantages of GAUDI are: support for temporary events and capability that each display has to detect its new location and orientation. The two main parts that compose the Gaudi system are: the navigation server (manages navigation information and publishes it in the displays) and the arbitrary number of autonomous displays.

Hamhoum *et al.,* (2012) introduced a prototype dynamical system in a realist setting to support pilgrims in navigating one particular area. The goal was to investigate how public displays can be used to reduce the crowdedness during the Tawaf ritual, by helping the pilgrims remember how many times they have circled around the Ka'bah. Due to the religious nature of the scenario the author presented three key requirements: be usable by a large number of pilgrims, easy to learn and not interferer with the spiritual task. After an initial proposal, an enhance solution was presented where the display presents a single large circle that is subdivided into coloured wedges and a central smaller circle. The wedges correspond to a group of people in specific areas and have different colours facilitate recognition and differentiation.

Stahl *et al.,* (2005) presented the REAL project that is focused in two particular tasks: navigation and shopping in an airport scenario through public displays. In the shopping task, the goal was to help the user achieve the best buying decision within a limited time. The navigation assists the user to reach the desirable destination (macro navigation) or focus the user attention to a given spot within the user perimeter (micro navigation).

Hamhoum *et al.,* (2008) investigated augmented signage as a mean to provide personal navigation support for large crowds. The approach proposed in this work was based on a spatial partitioning and a mapping of destinations to visual codes. The two visual codes presented by the authors were: add coloured circles to items shown on signs, and a combine symbols and colours (e.g. red heart). A study with 18 participants was conducted to perceive which of the two solutions versus the traditional arrow symbol was the most suitable. The parameters to perform the test were: timing, usability, satisfaction, errors/disorientation, ease to use, learnability and workload. In the end the participants were asked to rank which of the three designs they prefer and the choice was: the colour one. Despite the good results attained, the authors pointed two limitations: the lack of realism and crowdedness of the test environment.

Ojala *et al.,* (2012) deployed 12 multi-propose interactive displays in 2009 at six outdoor and six indoor spaces around Oulu, Finland. The work's goal was to understand how the users interact and derive value from the interactive displays that provide real services based on real content during an extended period of time. The authors believe that a long-term test enhances the value of any system comparatively to a short-term test with predefined task and users. The displays deployed can be used in passive broadcast or interactive mode. In passive mode the display's screen is totally used by the UBI channel to present videos, animations and photos. The interactive mode is triggered when a user touches the screen and the display slips its content between the UBI channel and a customizable UBI portal. The portal contained 25 different services divided in 7 categories: *news, services, city, third party, fun & games, multimedia* and *new cool stuff*.

3.3. Chapter summary

In this chapter we presented the different types of location models available in the literature. Based on this research we conclude that the type of coordinate used will influence the choice of the location model, i.e. geometric coordinates impose a geometric model, symbolic impose a symbolic model and the combination of both coordinates impose a hybrid location model. Regarding the displays, we identified the different uses of the displays in the literature along with the spatial requirements that such uses impose. For example, we identified that some uses need the location, orientation and the surrounding information of the display. Therefore, we identified the need of a spatial model to characterize the spatial information of the displays. In the following chapter we present in detail the spatial requirements and the display's usage patterns.

4. Requirements

In this chapter we gather and identify the different types of public displays' usage patterns. Each usage pattern clearly identifies how the displays are used to perform a certain task, and how they relate with the others displays as well their surroundings. Firstly, we start to describe the process that was followed to identify the usage patterns and then each usage pattern is presented (section 4.1). Afterwards, based on these patterns we identify the spatial requirements that were imposed not only to the spatial model but also to the characterization of the displays (section 4.2). Each spatial requirement is then described and possible solutions to attain the required information are presented. Finally, based on the pros and cons of each of the proposed solution, the solution that is going to be used in this work is presented.

4.1. Usage patterns

During the literature review one aim was to identify and gather the scenarios in which the displays were used with some knowledge regarding their location, the location of the others displays and the status of their surroundings, i.e. spatial knowledge. Nevertheless, even though there were more scenarios, they were not considered in this work as the displays were used without any spatial knowledge. After gathering all the scenarios, we started to categorize the services that were using the displays in terms of: how each type of service exploited the displays; which spatial requirements were imposed; and how the displays related with the others displays/surroundings. Based on this knowledge the different scenarios were arranged in different groups. However, for this task to be completed, two intermediate steps were performed. In the first step, we grouped the scenarios in a more embracing way, i.e. the groups were merely formed based on how the displays were used by the services without establishing any relation between the groups/services. The result was a vast number of different groups. Still, after a careful look into the groups, it was perceived that among the different groups the displays were in fact used in the same or similar manner while imposing the same or very similar spatial requirements. These groups were merged into one group. Regarding the groups in which the displays usage was identified as a particular case of another group, they were added as a subtype of that group. The groups resulting from the first arrangement were the following:

1. Content oriented
   1.1 Content's scheduling
2. Spatially coordinated displays
   2.1 Coordinated behaviour
3. Location based display discovery
4. Context aware
5. Position aware
6. Spatial interaction
7. Navigation assistance
   7.1 Shopping assistance
   7.2 Support crowds
   7.3 Dynamic solution

Nonetheless, after this first arrangement it was perceived that a second arrangement would be needed because, despite the displays were used by different services we identified that they were used in the same way to attain the same goals while imposing the same spatial requirements. So, in the second step we decided that these groups would be merged into one group. One good example of this arrangement is the *shopping assistance* group, because apart from the shopping assistance that helps the users in their buying decisions (which does not imposes any spatial requirement) the displays were used to provide navigation assistance to reach the product's location. Hence, the *shopping assistance* group is just a particular case of the navigation and so it was merged into the *navigation* group. The same standard was followed in the others groups that were merged. The final groups are (✓ are the final groups, and ✗ are the groups that were merged):

- ✓ Location based displays
  - ✗ Content oriented
  - ✗ Content's scheduling
  - ✗ Context aware
- ✓ Spatial coordinated displays
  - ✗ Spatially coordinated displays
  - ✗ Coordinated behaviour
- ✓ Navigation
  - ✗ Shopping assistance
  - ✗ Support crowds
  - ✗ Dynamic solution
- ✓ Spatial aware displays
  - ✗ Position aware
  - ✗ Spatial interaction

These were the final four groups that clearly identify the different types of displays' usage patterns. Moreover, each usage pattern clearly identifies how the displays are used to perform a certain task (e.g. the *navigation* usage pattern clearly identifies the displays that are used to provide navigation assistance). In the following sections each usage patterns is presented and described in detail.

4.1.1. Location based displays

Location based displays, is the usage pattern that clearly identify the displays that are used to disseminate content based on the displays' location. This content can be disseminated separately in time or space (José R. et al. (2006)) and it can be generated in arbitrary or specific way (Storz O. et al. (2008)). When the content is separated in time, it means that each display presents the content for a certain period of time that can be synchronized among the displays involved. On the other hand, when the content is separated in space, it means that the content is presented in the displays that are at certain locations. The content's generation can be performed in an arbitrary way (i.e. the content is generated regardless who is passing near the display) or in a specific way (i.e. the content is specifically generated to match its target personal interests). In the latter case, based on the identity and/or location of the user (Madeira R. et al. (2010)) the system generates specific content that matches the user' interests. The process that controls how the content is presented – separated in time or space – and how it is generated – in a specific or an arbitrary way – can be performed through a central entity (typical broadcast model, one-to-many) or locally by the display (José R. et al. (2006)). The displays are able to personalize themselves based on their current location, how they are being used and based on the user's location and identity (Ward A. et al. (2002)). If the system is able to identify the user, the displays can be used to present coded messages when the user is at certain locations or performing certain actions (Strohbach M. et al. (2009)). Sign oriented displays (José R. et al. (2006)) besides presenting traditional sign information are also used to present occasional location-based announcements. The content can be schedule to be presented based on the location of the displays and when the scheduling requirements are fulfilled. An example of this is a store that, at the end of the day, wants to sell its surplus at lower prices. To increase the number of people that knows about this price reduction, a scheduling application can be used to schedule the time at which this information is presented and to select the displays (based on their location) that will present this information. Additionally, the displays can provide navigational assistance to reach the store.

4.1.2. *Spatially coordinated displays*

Spatially coordinated displays is the usage pattern that clearly identifies all the displays that are used to present the content in coordinated ways (Storz O. et al. (2008)). Contrarily to the previous usage pattern that only required the location of the displays, in this case the location of the displays relatively to the location of the other displays is required. The displays involved in the coordinated interaction can be used in a sequential or simultaneous way. If the displays are simultaneously used, it means that they are used at the same time to present the content, e.g. in an emergency scenario the displays are simultaneously used to present the emergency information at the same time. Contrarily, if the displays are sequentially used, it means that different displays are used at different times to present the content, e.g. during a navigation service, the displays are used in sequence as the navigation information is only presented in the display that is near the user. Based on the display's location the system is able to interact and integrate the displays in a coordinate manner. Even though some displays are able to control their integration level to operate in isolation, if required (José R. et al. (2006)), it is assumed that the system is able to suppress their integration control level to integrate them in the coordinated interaction if required. Besides being used to present content in coordinated ways, the displays can also be used to collectively process the surrounding information and to act as a more user-friendly front-end service (Strohbach M. et al. (2009)).

4.1.3. *Navigation*

Navigation is the usage pattern that defines all the displays that are used to assist the users in their search for a suitable path to reach their destination (Kray C. et al. (2008)). The challenge is to provide an effective navigation at indoor spaces, such as airports (Stahl C. et al. (2005)), universities, hospitals and office buildings (Kray C. et al. (2005)). When the user types the destination, the service immediately starts to calculate the most suitable path. The path calculation is performed through way-findings algorithms that are supported by the location model (Kray C. et al. (2008)). During the path's calculation any special requirement is taken into account, e.g. if a user cannot use stairs (e.g. handicap user), a path with elevator or ramp is provided. When the path is calculated, the information is presented in the display near the user or in the user's Smartphone (Strohbach M. et al. (2009)). If the Smartphone is used, firstly it needs to synchronize with the system (Strohbach M. et al. (2009)). Furthermore, if during the path the system or the user identifies any change or issue in the surroundings (e.g. locked door) an alternative path is automatically and dynamically calculated and provided. Besides requiring the display's location and the location of the other displays as the previous usages patterns, this usage pattern requires the displays' surroundings status. This status enables the display to perceive its surroundings and adapt the navigational information if required (e.g. if a path is blocked, an alternative one is provided).

Gaudi (Kray C. et al. (2005)) is an example of a navigation system, which purpose is to assist the visitors, students and staff in their navigation around the Lancaster University campus. Each Gaudi display, besides presenting directional information, provides information regarding the destination or event. Sign oriented displays (José R. et al. (2006)) present short pieces of information, such as directions to a given destination.

Shopping assistance is a particular case of *navigation,* because apart from assisting the users to achieve the best buying decision (Stahl C. et al. (2005)), the displays are used to provide navigation. If the user pretends to see a product, he can activate the navigation service to reach that product‘s location. The navigation stops when the user reaches it (Strohbach M. et al. (2009)), or when he reaches a checkout point or manually by the user.

Support crowds' is another particular case of *navigation,* which the goal is to provide assistance and useful information to everyone in crowed situations. In these situations it is crucial to keep everyone calm, safe and ensure that everyone follows the same orders, with the aim of avoiding disorder. At Ka'ba (Hamhoum F. et al. (2012)) the displays are used to help the pilgrims to keep on track the number of rounds they have performed around Ka'ba. Each pilgrim has to perform seven complete rounds and with the help of the displays, the pilgrims know exactly how many rounds they have performed. Therefore, no unnecessary rounds are performed.

4.1.4. Spatially aware displays

Spatial aware displays is the usage pattern that defines the displays that are aware of what is happening in their surroundings, are able to identify when their location and orientation changes (Kray C. et al. (2005)), tune their content base on how the passers-by are reacting to the content (Schilit B. et al. (1993)), and are aware of the state of the surroundings (José R. et al. (2006)). To perceive how the passer-by reacts to the content being presented, the display monitors a few discrete proxemics zones in its surroundings. Within this proxemics zone the display detects the presence or absence of users and the distance and orientation of the user relatively to the display. Based on this, the content is generated or adapted. Proactive applications adapt their behaviour and content to match the environment where the user and the display are located [10]. The display also detects whenever its location and orientation changes and updates it to its current location and orientation. This aspect is very important for the services that provide directional information, given that even a slightly change in the display's location and orientation implies that the information has to be adapted (Kray C. et al. (2005)). Additionally, the displays perceive the status of their surrounding facilities, e.g. the availability of a certain meeting room.

4.2. Spatial requirements

Based on the usage patterns described in the previous section, it was possible to identify the imposed spatial requirements. In the Table 4-1 it is possible to identify which spatial requirements are imposed by each usage pattern. Afterwards, a description of each spatial requirement is presented along with possible solutions to attain the required information. At the end, the solution that is going to be used in this work is presented.

	Location based displays	Spatially coordinated displays	Navigation	Spatially aware displays
Absolute location	X	X	X	X
Relative location	X	X	X	
Topological information		X	X	
Orientation		X	X	X
Surroundings			X	X
Attributes and status	X	X	X	X

Table 4-1: Scenarios and spatial requirements.

4.2.1. Absolute location

The absolute location defines the displays' location through absolute values (e.g. WGS84[1] latitude, longitude and elevation) and references (e.g. street name, building name, address, etc.). Due to the variety of different services' types and needs, different levels of accuracy, precision and resolution are imposed and required. To certain services it might be enough to know that a display is located in a certain street (*low resolution*), while other services require the exact location in that street (*high resolution*). For example, the navigation service requires a high level of accuracy and precision, because an error of a few meters in the display's location might be enough to provide incorrect navigational information. On the contrary, to other services, the same few meters error is not critical and the information being provided is still correct. Therefore, the absolute location has to be generated and provided in a way that matches the different requests of the different services.

To define the absolute location, three types of coordinates can be used: geometric, symbolic or hybrid coordinates. Through the geometric coordinates it is possible to attain fine-grained location information, directly calculate the distance between locations and establish relations – interception, overlapping and containment – between areas. The location is defined as a set of coordinate values that are defined in the coordinate referential system (can be either global or local) being used. Contrarily, symbolic coordinates provide coarse-grained location information and the distance between locations along with the relation between areas cannot be determined without further information. The location is defined as an address (e.g. a street or building name) or as a set of abstract ideas; in this case no coordinate referential system is required. Hybrid coordinates combine both geographic and symbolic coordinates. The location can be either defined by using both coordinates (e.g. the display is in the *street w* at *latitude x and longitude y*) or just by using one of the coordinates (e.g. the most suitable). When both coordinates are used, a mechanism to translate between geographic and symbolic coordinates is required. An example of such translation mechanism is the one used by the navigational systems - such as NDrive, Tomtom and Google Maps – in which the address typed is translated to its corresponding set of geographic coordinates in order to perform the path calculation. Since the display's

[1] World Geodetic System – dating from 1984 and last revised in 2004
[2] Quick Response Code
[3] Near Field Communication

location can change, the system and/or the display have to identify that change and update it to the new location of the display.

Given the capability to provide high levels of location accuracy and precision, along with its worldwide availability, the GPS is one of the proposed solutions to define the display’s absolute location through geographic coordinates. The GPS uses the WGS84 global coordinate referential system where the latitude, longitude and elevation values define the display’s location. Nonetheless, the GPS has a huge drawback as it can only be used at outdoor spaces where the GPS receiver is able to connect with the satellites. Since the displays can be placed at indoor spaces, the GPS alone is not a feasible solution. Therefore, to achieve the display’s location at indoor spaces through geographic coordinates, an alternative solution is a digital representation of the floor/building plan in a local coordinate referential system (e.g. 2D or 3D model of the floor/building). However, this approach is very complex and time consuming, because it is necessary to create and maintain the digital representation of the floors/building plans. Another possible solution is through the *Wi-Fi* and/or *mobile networks*. The Google’s location service uses the Wi-Fi and/or mobile network cells *Ids* and signal power to perform calculations and determine the location. Therefore, by using the Google Maps API it is possible to retrieve the WGS84 geographic coordinates, visualize the computed location in the map and manually adjust the location if required. The disadvantage of this approach is that requires connection to the Internet (either through the mobile or Wi-Fi network), and the computed location is, sometimes, far from the actual location. However, nowadays, it is possible to connect to the Internet almost anywhere and if the computed location is not correct the user can manually adjust it to the correct location. The advantages of this approach are: it can be used in both outdoor and indoor spaces because it just requires a connection to the Internet rather than a connection to the satellites; the calculations are promptly performed and it is possible to translate between geographic and symbolic coordinates.

The symbolic coordinates defines the location as an address (e.g. the display is at the street *s*, building *x*, 4th floor) and it can be either used at indoor and outdoor spaces. The symbolic approach has the advantage of being easier for the user to memorize and specify an address rather than a set of geographic coordinates. But the accuracy, precision and resolution are inferior comparatively to the previous proposed solutions. The symbolic information may be attained through the Google Places, Foursquare, Facebook, etc. APIs. These systems have in their databases millions of places that are linked with their corresponding geometric location's information. Therefore, by using their APIs a geometric coordinate is translated to its corresponding space name (if there is a space in that coordinate). Another approach is to use/define/implement a symbolic world model that stores the spaces where the display can be located. Contrarily to the previous system, the symbolic model detailed information of the space is also defined (i.e. the number of floor, rooms, areas, etc.).

In summary, it is possible to conclude that if the display is at an outdoor space, its location can be effectively defined either by geographic coordinates (GPS and Wi-Fi and/or Cellular network) or by symbolic coordinates (an address). At indoor spaces the display's location can be effectively defined through symbolic coordinates, by combining the street name, the name and/or door number of the indoor space and the location within that indoor space (e.g. building's floor, wings). Since the focus of this work is to define a unique solution that is suitable for both indoor and outdoor spaces, the solution that is going to be used defines the display absolute location through hybrid coordinates, i.e. combines the geographic and symbolic coordinates. The display's geographic coordinates are acquired through the Wi-Fi and mobile data network (Google's location service) and the Google Maps API is used to retrieve the latitude and longitude values, presents them in the map and enables the user to adjust the location. The symbolic coordinates regarding the indoor space are attained through the Baras K. *et al.* (2001) symbolic world model (as presented in the Chapter 3).

4.2.2. Relative location

The relative location defines the display's location by establishing relations between the display and the surrounding key elements. For example, the relative location of a display can be defined as being at the *left of room x, right of room y, front of room z*, *back of the exit*. While the left, right, front and back are the relations, the rooms and the exit are the surrounding key elements. At outdoor spaces it is possible to automatically determine some of the surrounding key elements through the POI (points of interests available in the digital maps). However, it might be required to manually define some key elements that are not considered as POI or are not available in the POI list. On the other hand, at indoor spaces the system might be able to identify and provide all the key elements that are mandatory and/or near to the display, otherwise they have to be manually defined. Depending on the type/importance of the key elements, some are defined as mandatory while others are defined as optional. The ones defined as mandatory, have to be obligatorily defined during the display's registration (e.g. at indoor spaces, an *exit* and *emergency* exit are examples of mandatory elements). The near key elements are complementary, in the sense that they are not obligatory but they should be defined to enrich the spatial model (e.g. the rooms that are close to the display). To define the relations between the key elements and the displays, there are two possible approaches that can be followed. One is performed automatically, i.e. the system is able to identify the display's location relatively to the location of the key elements thus the relations are automatically established. For example, at outdoor spaces through the digital map and geographic coordinates the system is able to perform calculations and determine the relations. At indoor spaces, if the system has a 2D or 3D digital representation of the space, the relations between the display and the key elements can be established automatically. If a display is placed in the same or much approximated location of a known display, the relations of this new display can be inferred. The other approach is to manually establish the relations between the elements and the display.

Despite being better, the automatically approach has a huge drawback because it requires a digital representation of the space to establish the relations. If it is true that at outdoor spaces there is such representation (digital map), the same is not valid for all the indoor spaces. Therefore, since the goal is to define a solution that is suitable for both indoor and outdoor spaces, the solution that is going to be used is the manual one.

4.2.3. Topological information for the display's environment

The topological information retrieves not only the displays that are at a given direction relatively to the location of a given display but also the displays that are located around of a given display. For example, a display might want to know which displays are around him (i.e. at its front, back, left, right, top, bottom, etc.). Through this information the display can interact in novel ways with the other displays. An example of such interaction is a set of displays that are being used to advertise a new Tennis ball and the goal is to pass the ball between the displays in a coordinated manner. In other words, if the ball moves to the right of the display, then the ball is passed to the display that is at the right of that display. Therefore, all the involved displays need to know the direction of the others displays relatively to its location, in order to know to which display the ball has to be passed.

To attain this information two possible approaches can be followed: one is automatically through calculations, and the other is manually. By performing calculations over the geometric coordinates, the direction in which a given display is relatively to another display is determined. The result of the calculations determines not only the direction between the displays, but also the distance between them. Contrarily, in the manual approach the directions are manually defined. A display is selected and then the directions of the other displays are defined. Additionally a notion of distance between the displays can also be defined. For example, a display that has three displays in its surroundings generates the following information *"display x, right, 5meters", "display y, left, 7meters"* and *"display z, front, 9 meters"*. However, as more and more displays are added and these relations are established, the system will be able to establish some relations automatically. For instance, if the relations between two displays are defined and if a new display is placed between them, the system is able to automatically establish the relations between the three displays. Since the location of the displays can change, when that occurs the relations need to be redefined or recalculated.

4.2.4. Display orientation

The display's orientation provides the orientation and the direction in which the display is faced. By knowing this information, it is possible to determine if the content being presented is or is not visible by its target. For example, let's consider a display that is located in a corridor that instead of being faced to the inside it is faced to the outside (a corridor with glass walls). Despite being located in the corridor, this display cannot be used to present content to the people passing in the corridor, because only the people in the outside will be able to see the content. For this reason, this information has a strong impact in how the content is generated and in the display(s)'s selection to present the content. Therefore, this information is crucial to identify in which direction the display is faced, and based on that, decide if that display can be used to present the content, i.e. if it is visible to its target. The display's orientation defines if the display is horizontally, vertically, landscape, portrait, etc. orientated. This information is required because depending on how the display is oriented the content might need to be adjusted before being presented. For example, some applications adapt their content depending on how the display is oriented, i.e. if it is in portrait or landscape orientation. The display's orientation can be attained through a manual approach where a set of different orientation stages is presented and the user selects the correct one. For instance, it is presented a set of buttons, each one defining an orientation stage and the user just needs to press the one that corresponds to the display's orientation. An automatic approach that relies on the sensors of any mobile device can also be used. Nowadays, almost every mobile device is equipped with sensors that are able to determine the orientation of the device, examples of such sensor are the: accelerometer, gyroscope and magnetometer. The accelerometer measures the acceleration force in m/s^2 that is applied to a device on all three physical axes (x, y, and z), including the force of gravity. The magnetometer measures the ambient geomagnetic field for all three physical axes (x, y, z) in μT. The gyroscope measures a device's rate of rotation in rad/s around each of the three physical axes (x, y, and z). Therefore, if the user places the mobile devices in the display orientated in the same way as the display is, the display's orientation is inferred through the mobile device.

The manual approach has the advantage of being easy to use and easy to implement. However, it also presents some limitations: restricts the number of orientation stages, requires a management of the orientation stages (i.e. add or remove orientation stages), and the interpretation of the stages might differ from user to user. On the other hand, the automatic approach has the advantage of attaining the orientation automatically, no user interaction is required, and so the orientation is always correctly determined. But this approach is more difficult to implement because it requires programming the sensors and processing the returned values. After analysing the advantages and disadvantages of each approach, we are going to follow the automatic approach in this work. Further, the sensor that we are going to use to infer the display's orientation is the accelerometer sensor, because it is the most commonly sensor available in almost every mobile device.

4.2.5. Display surroundings

The surrounding information translates the state of the world to the display(s) and system. Within this proxemics zone the display and the system detect the state of the display's surroundings, i.e. is aware of what is occurring in the proximities of the display. For example, when a display identifies that the state of its surroundings changed to an emergency condition, it proactively generates and presents specific emergency content. Another example, in a navigation service if the display perceives a change in the path (e.g. a door that now is locked) it adapts the navigational content, i.e. provides an alternative path. Therefore, based on this information the display and the system are able to generate specific content, adapt de content being presented and choose how the information is provided. For example, at noisy places the display can choose to provide the information in text form rather than in audio form, since it is most likely that the user will not hear it. Furthermore, the surrounding information can also be used for others purposes, for instance, the display can choose to turn off the screen or reduce its brightness if there is no activity occurring or there is no one in the surroundings.

To sense the surroundings, it is required an infrastructure of sensors that are continuously sensing. The type and number of sensors that are required to effectively perform this task is out of the scope of this work. However, a low delay should be guaranteed between what is happening in the surroundings and when the sensor senses it and the display/system perceives it.

4.2.6. Display attributes and status

It is most likely that the network possesses different displays with diverse attributes. Therefore, it is important to identify the specific attributes of each display in order to better adapt and generate the content to match the display's attributes, as well as to provide a better user experience. Such attributes consist on the: screen size, connectivity interfaces, sound capability, input methods, etc. These attributes are defined when the display is added to the network. However, if the attributes are associated with the display brand and model when an equal display (same brand and model) is added to the network, the attributes can be automatically loaded. On the contrary, the status translates the display's real state i.e. if the display is turned on/off, if the display encounters any error/bug situation, the display's load level along with other relevant status information. If it is true that the attributes of the display are static - they do not change overtime - the same is not valid for the status information. For instance, when the display encounters an error situation its status changes to ***ErrorStatus***(e.g.) and when the error is solved its status changes to ***OkStatus***(e.g.).

4.3. Chapter summary

In this chapter we identified four types of display usage patterns: *Location based displays*, *Spatially coordinated displays*, *Navigation* and *Spatially aware displays*. Besides identifying how the displays are used to perform their task, it was also provided the information to identify the required spatial information. The Table 4-1 presented the spatial information that each usage pattern imposed. The identified spatial requirements were: *absolute location*, *relative location*, *topological information for the displays environment*, *display's orientation*, *display's surroundings,* and *display's attributes and status*. The absolute location defines the display's location by combining the geometric and symbolic coordinates while the relative location defines the location of the surrounding key elements relatively to the display location. The topological information retrieves the displays that are at a given direction relatively to the location of a given display. The orientation information defines if the display is horizontally, vertically landscape or vertically portrait oriented, whereas the attribute and status information provide the display's status, i.e. if they are working correctly. Though these spatial requirements we are able to identify the modules needed by our solution to collect that information.

5. System architecture

Before presenting the solution developed to generate and gather the spatial information required to perform the display's registration, the assumptions and the modules of that solution are presented. The assumptions were made due to the complexity of this work and to the lack of time to implement everything required by our solution. For each assumed part, a description of its role and required functionalities is performed (section 5.1). However, despite being assumed, some of these parts were in fact implemented in order to evaluate our solution. Afterwards, based on the spatial requirements gathered in the chapter 4 we identified the needed modules for our solution (section 5.2.). Each module is responsible to generate specific spatial information, but together these modules gather all the required spatial information to perform a successful registration. At the end, a summary of this chapter is presented (section 5.3).

5.1. Assumptions

The solution developed in this work assumes that the network infrastructure, the back-office (BO), the database (DB) and the spatial model server are already setup, configured and running. The Figure 5-1 presents the system's architecture.

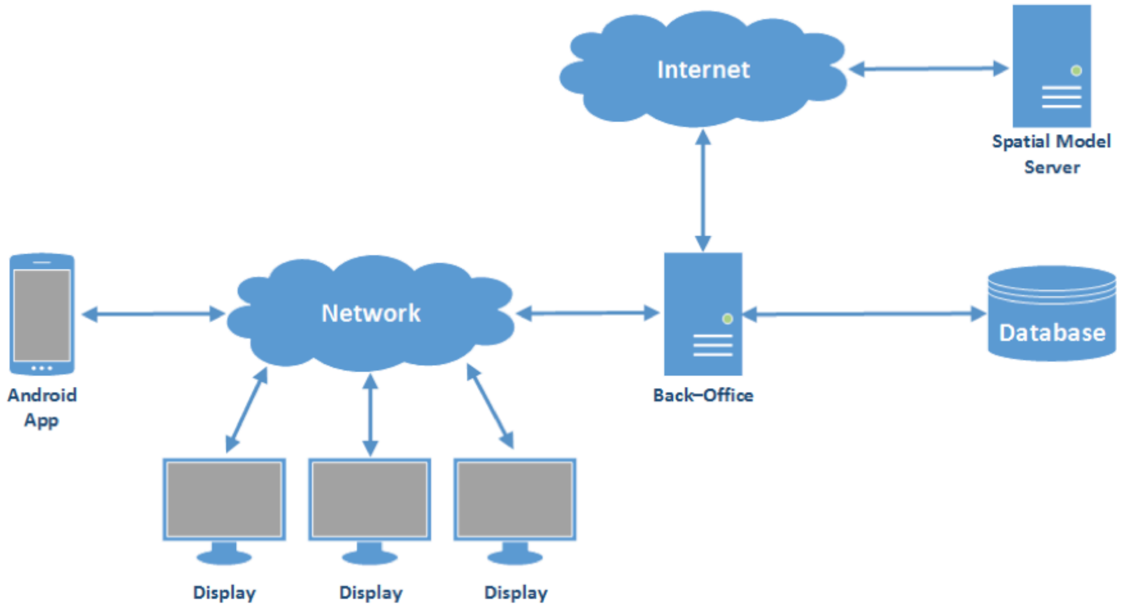


Figure 5-1: System architecture.

5.1.1. Network

The network connects the application and the displays (that belongs to that network) with the BO, providing the required communication medium. The content that is generated by the BO is sent to the displays over the network, and the application's requests along with the BO's replies to those requests are also performed through the network. Due to the variety of possible solutions to design the network, we do not present details regarding the network topology and how the displays should be connected to the network (e.g. through a RJ45, wireless or any other type of connection). The only constraint that our solution imposes is the need of a wireless interface for the application to connect to the network/BO. This is required because the application developed is to be used in a smartphone and so, it relies in the device's wireless interface to establish the connection.

5.1.2. Back Office

The BO is the central entity that processes all the application's requests, accesses to the DB to store/consult the spatial information, accesses to the spatial model server to get the required symbolic information and manages everything related with the displays.

Regarding the displays, we assumed that when a display is connected to the network an automatic procedure is triggered in the BO. This procedure identifies the display (e.g. through its serial number, Mac address, etc.) and determines (e.g. by inquiring a DB) if it is a new/unregistered or known/registered display. If the display is known, it means that it was reconnected to the network; if it is a new display it is assumed that the BO generates a unique *Id* for the display. These *Ids* guarantee that each display is clearly and undoubtedly identified, and for that reason they are used by the application in the association step (explained further). These *Ids* can be automatically generated by the BO (e.g. a random name) or manually by an admin (e.g. to establish a relation between the *Id* and the display's location, *"Main_Entrance_Display"*, *"Lab3_Display"*). In both cases (i.e. new or know display) the *Id* is presented in the display, and in this work we propose that the *Ids* are presented as a QRCode or plain text (see Figure 5-2).

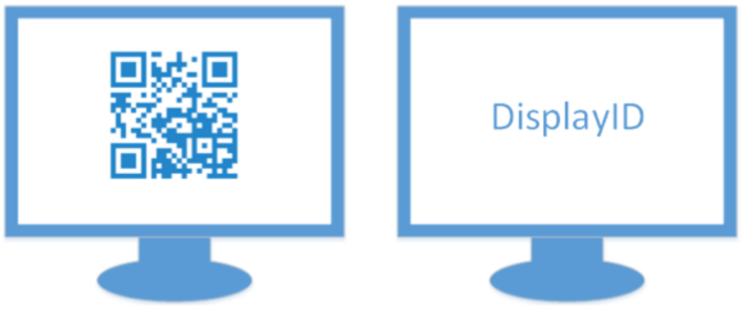


Figure 5-2: QRCode and plain text *Ids*.

The QRCode[2] is one of the proposed solutions because it is easy to generate, it has the capacity to store 4.296 alphanumeric characters, it has a good error correction (30%) and any device with camera is able to read it. Since the QRCode is read through the camera and processed directly by the application, this approach has the advantage of being immune to typing errors and is performed faster than a manual approach. The disadvantage is that a device without or with a broken camera is not able to read the

[2] Quick Response Code

code. The plain text is the most traditional approach where the *Id* is presented as regular text. Contrarily to the QRCode, this approach is not immune to typing errors and it requires more time to be performed (depending on how fast the user types the *Id*), but it has the advantage that it can be performed in any device with or without a camera. However, other approaches can be used to identify the display (e.g. NFC[3]). The BO manages the displays' status. The status indicates whenever a display is working properly or encountered an error, and this information is crucial to identify the displays that are working properly and in conditions to present the content, or need to be fixed/replaced.

The BO also manages the displays' spatial information that is stored in the DB (i.e. inserts the generated spatial information into the DB) and consults/retrieves the spatial information when required. Likewise, it is the BO that attains the symbolic information from the spatial model server. Once this server is hosted at the University of Minho, it is accessed over the Internet through a HTTP connection. When the application requires any information from symbolic world model, the requests are performed through the BO, i.e. the application sends a request to the BO then the BO inquires the spatial model server and returns the result to the application. Therefore, the BO has to follow the API[4] defined by the application developed in this work (explained further). The API defines how the application and the BO interact with each other, i.e. defines the type of requests that the application can perform and how the BO has to reply to those requests. Hence, regardless how the BO is implemented in each solution, the only thing that has to be ensured is that fallows the application's API.

Despite being one of the assumed parts, we developed a BO in order to evaluate the application. The BO was implemented in Java but only with the functionalities required to interact with the application (i.e. follows it's API), DB and spatial model server. The procedures to identify and generate the *Ids* for the displays, control their status and generate/send the content to the displays were not implemented (it is assumed that they are already implemented).

[3] Near Field Communication
[4] Application Programming Interface

5.1.3. Database

A database is required given that the spatial information generated by the application has to be stored. This information is mandatory to validate if the application is correctly generating the spatial information and to perform an evaluation over this information's level of detail (Chapter 7). Once more, despite being one of the assumed parts, we implemented a DB in order to evaluate the application. The Figure 5-3 presents the entity-relationship diagram of the database used in this work. The database was then implemented in MySQL.

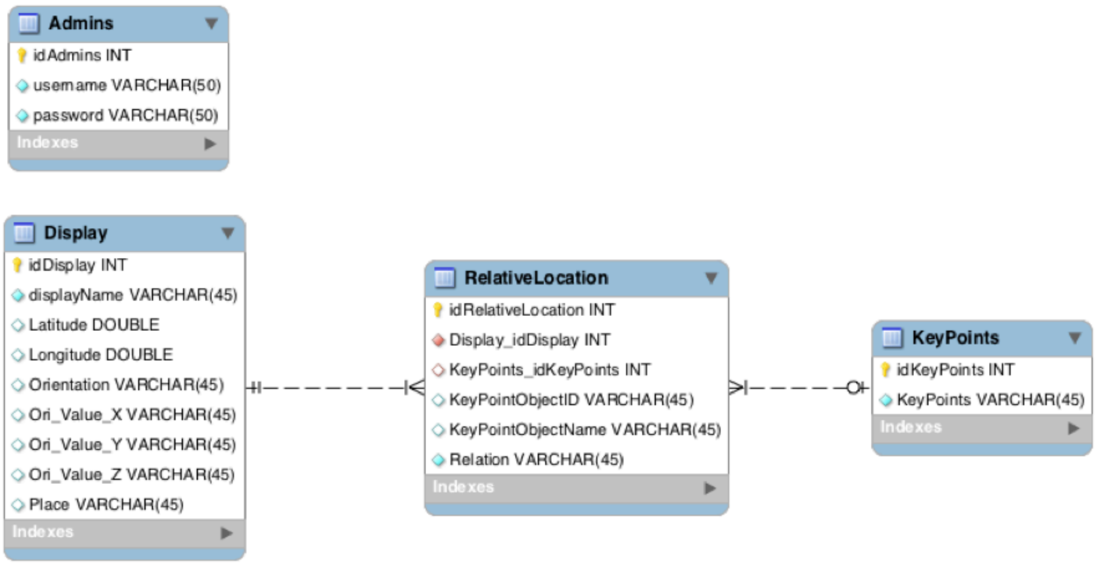


Figure 5-3: Database ER model.

This database is simple because our goals were to store and provide access to the display's spatial information and to define the users that are authorized to register/update a display. However, depending on the requirements of each system, the database can be more complex.

The *Admins* table contains all the users that are authorized to perform operations over the displays and has two attributes: the *username* and the *password*. For security reasons, we decided not to store the password in plain text, but a MD5 hash instead. While the user is performing the authentication, the application sends the username and a MD5 hast of the password to the BO, and the BO consults this table to validate if the user's authentication is correct.

The *Display* table contains all the spatial information of the displays. The *latitude* and *longitude* attributes contain the displays geometric coordinates values. The *orientation* attribute contains the display's orientation state and the *Ori_Value_X*, *Ori_Value_Y* and *Ori_Value_Z* contain the accelerometer values for the attained display's orientation. The *Place* attribute contains the *Id* of the space where the display is located (this *Id* is attained from the spatial model server). As in our application it is not mandatory to define all spatial information at once, these attributes were defined in a way that can be *null*. For example, the user is able to just define the orientation information and later define the rest of the spatial information.

The *KeyPoints* table contains a set of mandatory key elements (e.g. emergency exit and regular exit). These elements are considered mandatory because every indoor space has at least one of them and so the location of these elements relatively to the location of the display has to be defined. However, some spaces define their own key elements in the spatial model and in these cases, those key elements are used instead of the ones defined in this table. Therefore, the elements in this table are only used when the space does not define any key element.

The *RelativeLocation* table is where the location of the display relative to the location of the key elements is defined. The elements can be either attained through the *KeyPoints* table or through the spatial model. If the elements are attained through the *KeyPoints* table, then the *KeyPoints_idKeyPoints* attribute is used and contains the primary key of the defined element. Otherwise, the *KeyPointObjectID* and the *KeyPointObjectName* attributes are used. The first one contains the *Id* of the element defined in the symbolic world model and the second one contains the name of the key element defined in the symbolic world model. The *Relation* attribute contains the direction (e.g. right, left, front, back, etc.) in which the key element is located relative to the display's location.

5.1.4. Spatial model server

The indoor spaces where the display can be located and their corresponding key elements are defined in the symbolic world model. To access the information in the symbolic world model the spatial model server is inquired. The spatial model server (Symbolic Contextualizer) consists of four components: query interface, query processor/reasoner, database access module and database. The query interface is a Java servlet interface that accepts and validates requests for query, insert, update, and remove operations over the data in the database, and the reply is in XML format. The query processor/reasoner is a Java class that processes the query interface, requests and generates the corresponding XML responses. In this module, all the algorithms and the methods for retrieving the information from the URLs stored in the object attribute values are implemented. The database access module is where the SQL statements that allow the querying and the editing of the model are implemented (it abstracts the access to the database). Lastly, the database contains the symbolic world model and in the version used in this work a MySQL database managements system was used. The spatial model server is accessible through the following link: http://local.dsi.uminho.pt:8080/sc2/SCTX and the three types of queries and their respective operations are the following:

- Get
    - an object by its name;
    - an object by its Id;
    - an object by the value of one of its attributes;
    - an object by its type;
    - all the existing types of objects and their frequencies;
    - all objects having a given relation;
    - all objects having the same author.

- Insert
    - an object;
    - an attribute;
    - a relation;
    - a relation attribute.

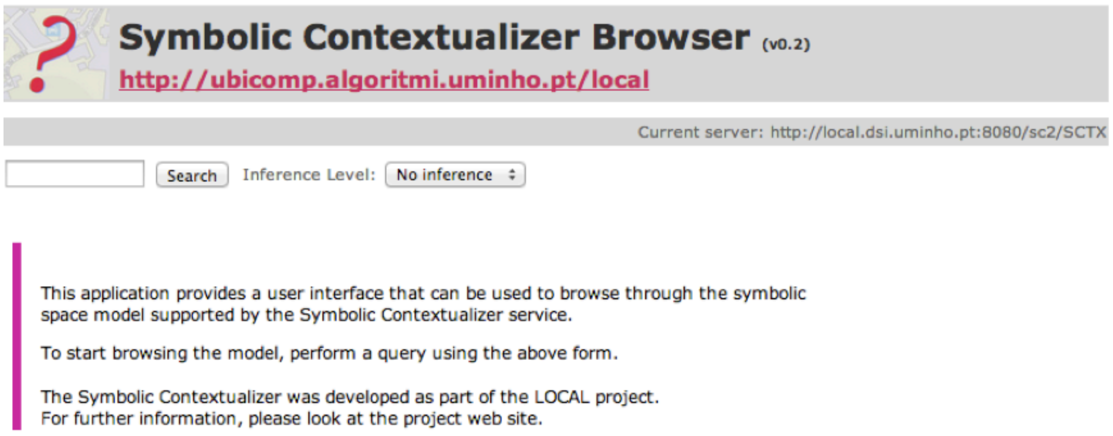
- Delete
    - one relation;
    - all relation attributes of a relation.

There is an additional parameter, *infer*, that takes values 0 to 3 that indicates the query's level of inference.

- infer=0: no inference;

- infer=1: inference concerning relations with their type attribute set to transitive;
- infer=2: inference concerning relations with their type attribute set to symmetric;
- infer=3: inference concerning both, relations with their type attribute set to transitive and those with their type set to symmetric.

The browser to search for objects in the symbolic world model is accessible through the link: http://local.dsi.uminho.pt:8080/scb2/index.html (see Figure 5-4)


Symbolic Contextualizer Browser (v0.2)
http://ubicomp.algoritmi.uminho.pt/local
Current server: http://local.dsi.uminho.pt:8080/sc2/SCTX
Search Inference Level: No inference

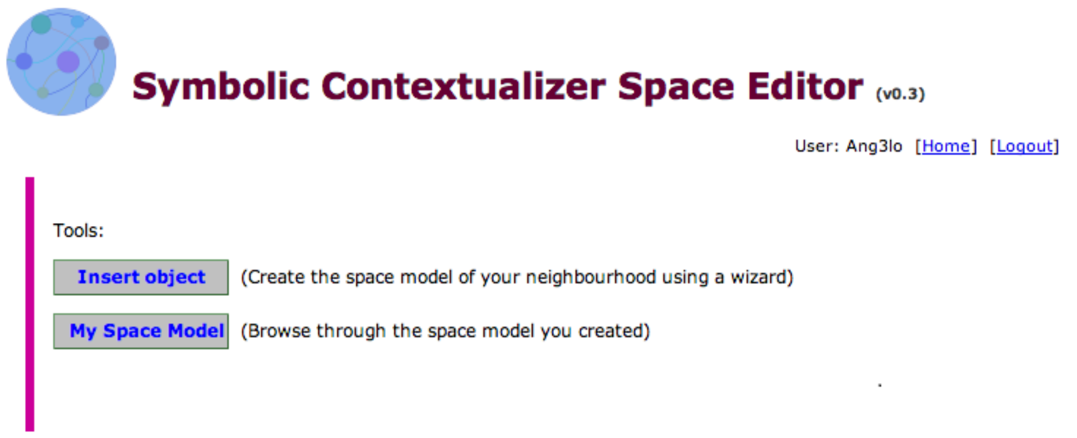
This application provides a user interface that can be used to browse through the symbolic space model supported by the Symbolic Contextualizer service.

To start browsing the model, perform a query using the above form.

The Symbolic Contextualizer was developed as part of the LOCAL project.
For further information, please look at the project web site.

Figure 5-4: Symbolic contextualizer browser.

The editor to create spaces in the symbolic world models is accessible through the link: http://local.dsi.uminho.pt:8080/scse2/index.html (see Figure 5-5).


Symbolic Contextualizer Space Editor (v0.3)
User: Ang3lo [Home] [Logout]

Tools:
Insert object (Create the space model of your neighbourhood using a wizard)
My Space Model (Browse through the space model you created)

Figure 5-5: Symbolic contextualizer space editor.

Contrarily to the BO and DB (that were implemented in this work) this server was already implemented, therefore we just used it to evaluate the application.

5.2. Solution modules

Based in the spatial requirements identified and gathered in the section 4.2 we propose a solution that is composed by six modules (see Figure 5-6). Each module is responsible to attain a certain and specific spatial information of the display. As presented in that section, the display's orientation, absolute location (which is divided in geometric and symbolic coordinates) and relative location are required. The display's orientation is inferred in the *Orientation* module. The display's absolute location is attained by two different modules: the *Location* module that obtains the geometric information and the *Space* module that obtains the symbolic information. Lastly, the display's relative location is attained through the *Surrounding* module. However, our solution presents two more modules that were not mentioned, the *Association* and the *Authentication*. Although these modules are not directly related with the displays' spatial requirements they are required in our solution. The *Association* module establishes a relation between the display and the network and the *Authentication* module authenticates the user that intends to perform a registration. In the following sections each module is explained in detail.

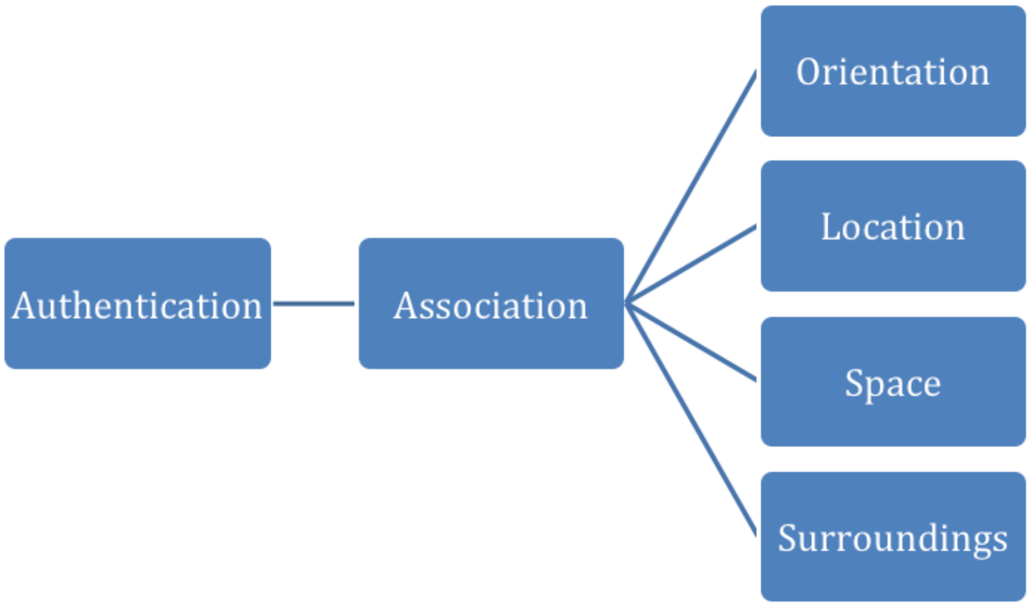


Figure 5-6: Application modules.

5.2.1. Authentication

As the displays are intended to be placed at some critical spaces (such as airports, hospitals, schools, universities, offices, etc.) it is crucial to guarantee that only authorized and capable users can perform the displays' registration. Otherwise, unauthorized displays or displays with incorrect/inaccurate spatial information might be registered in those spaces. To avoid or at least to mitigate these issues we propose this *authentication* module in which the user has to provide his credentials (i.e. his username and password) before starting the display's registration. If the credentials are correct the user can register and collect the display's spatial information, if they are not the user is not able to perform the registration and new credentials are requested. In summary, only after this module is successfully performed the user can start to collect the spatial information of the display.

5.2.2. Association

In the *Association* module the display (that is going to be registered) and the network (in which the display is connected) are associated. This association ensures that the correct display is registered in the correct network and for this reason it is mandatory, i.e. the other modules are not executed until the association is successfully performed. The display is identified through the *Id* generated by the back-office when it is connected to the network and the network is identified through the back-office IP address. Since each back-office manages a specific network, its IP address can be used to identify the network. Both of these *Ids* guarantee that each display and each network are clearly and undoubtedly identified. However, these two *Ids* are requested in two different phases. In the first phase the network's *Id* is requested to validate the BO, i.e. to confirm if it is the correct network and BO to where the information has to be sent. To validate the network our solution relies on the network domain information. When the connection with the BO is established the BO returns the network domain information and so, the network is validated. If it is the correct network, the second phase starts and the display's *Id* is requested. As presented in the section 5.1.2, we propose two approaches to present the display's *Id*, which were the QRCode and the plain text. Therefore, our solution provides the required methods to identify the display in both approaches. When the network and the display are correctly identified and validated, the association module is completed and so the user can start to generate and gather the spatial information of the displays.

5.2.3. Orientation

The *orientation* module determines, as presented in the section 4.2.4, the display's orientation and the direction in which the display is faced. Regarding the orientation, in this work it was define that the displays can be horizontally, vertically landscape or vertically portrait orientated (see Figure 5-7).

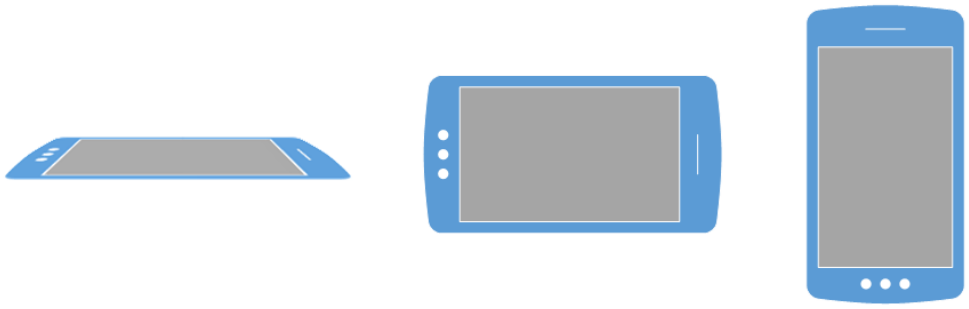


Figure 5-7: Horizontally, vertically landscape and vertically portrait orientation.

Based on how the display is oriented the content might need to be adjusted or properly generated before being presented. For example, some applications in our mobile devices change their layout/content based on the orientation of the device, especially between the vertically landscape and vertically portrait orientation. Moreover, the orientation is required during the display's registration, particularly at the *Surroundings* module. In that module the directions of the surroundings key elements relatively to the display's location are defined, but the directions change based on how the display is oriented. For example, the *"Front"* direction of a horizontal oriented display corresponds to the *"Up"* direction of a vertical oriented display (see Figure 5-8).

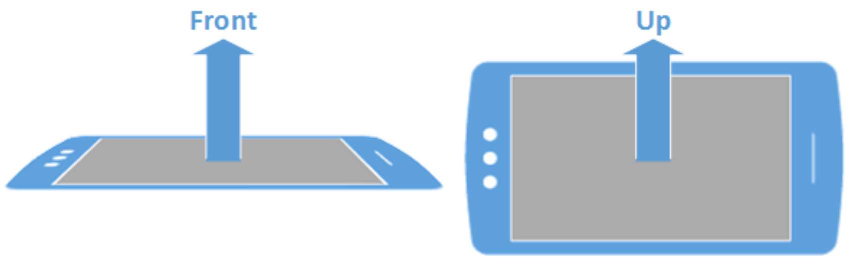


Figure 5-8: Relations and orientation.

In this work, the direction in which the display is faced can be inferred through the relations defined in the *Surrounding* module. However, we did not explore this point in much detail and we think that a proper and better solution should be attained in the future. Examples of such solutions are: using the digital magnetic compass information or by defining a specific relation. If the digital compass is used, the direction in which the display is faced is determined in the form of cardinal points (e.g. the display is faced *North, South*) and by combining this information with the location model it is possible to determine from where the display is visible. A relation (e.g. *is_visible_from*) that relies on the elements of the location model to define the display's visibility can also be used.

5.2.4. Location

As presented in the section 4.2.1 the displays' location is defined by combining the geometric and symbolic information. In our solution we defined two modules to attain each of the spatial information. In the *Location* module the display's location is defined in the form of geometric coordinates, i.e. latitude and longitude values.

5.2.5. Space

Although the previous module defines the display's location as geometric coordinates that do not provide any information regarding the space where the display is located (e.g. the name of the indoor space). For that reason, the *Space* module was created to define the display's symbolic information. Since this module relies on a location model to attain the symbolic information, the level of detail of the information will depend on how the space was defined in the model. The information can present a coarse-grained level of detail (e.g. if just the name of the space is defined) or fined-grained level of detail (e.g. if information regarding the floor, wings, areas, rooms within the space are defined). For example, if a space is just defined as "Engineering School" without any more information, it presents a coarse-level of detail, but if floors, areas, rooms, etc. are defined within that space, then it presents a fined-grained level of detail.

5.2.6. Surroundings

In the *Surroundings* module the directions of the surrounding key elements relatively to the display's location are defined. The key elements are achieved either through the location model or the database. If the space where the display is located defines its key elements in the location model, then this module uses those key elements. Otherwise, the elements defined in the database (*KeyPoints* table) are used.

5.3. Chapter summary

In this chapter we presented the assumptions in which our solution relies, that were the *network*, *back-office*, *database* and *spatial model server*. The spatial model server was the only assumption that was already implemented. The indoor spaces needed throughout this work were added to the symbolic world model therefore, when the application requires information regarding those indoor spaces this server has to be consulted. To obtain the information from the symbolic world model our solution had to follow the API defined by the spatial model server. On the other hand, all the other assumptions were implemented in this work. The database was implemented in MySQL, the BO in Java and an ad-hoc network was created to connect the application and the BO. Others systems might use a different architecture with different assumptions, but we believe that these are the minimum and recommended parts.

Based in the spatial requirements identified in the section 4.2 we also presented the modules of our solution. Each of these modules attains and gathers specific spatial information and in our opinion, together these modules gathered all the information need to perform a successfully display's registration.

6. Application

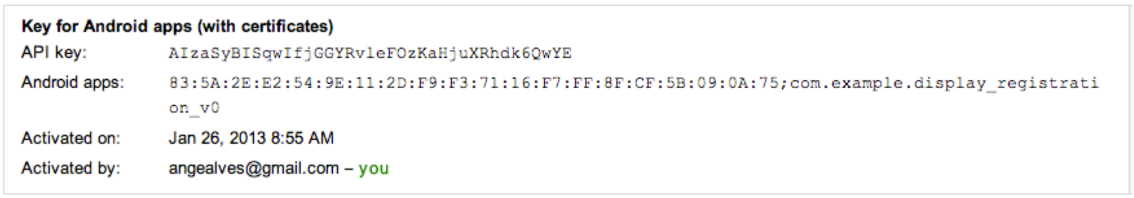
So far we presented the spatial requirements that are needed to register a display (Chapter 4), and the assumptions and the modules of our proposed solution (Chapter 5). In this chapter we explain how our solution was implemented in order to generate and gather those spatial requirements. From the beginning of this work we intended to develop a mobile application, i.e. an application to be used in a smartphone. This decision was made due to the highly smartphones' proliferation, their increasing processing power capability, their sensors, their interfaces (e.g. Wi-Fi and GPS), their mobility, etc. In summary, nowadays smartphones are like portable mini computers. Currently, there are two major operating systems in the smartphone's world, Android OS (Google) and IOS (Apple). We selected the Android OS to implement our solution because some of the previous work developed in our working-group was already developed in Android. The Android programming language is Java based and so, it uses objects and follows the same Java good programming practices. This chapter starts with the dependencies implied by our application in order to work as expected (section 6.1), how the connection with the server is performed (section 6.2) and the permissions that are required (section 6.3). The following section presents how each module (presented in the section 5.2) was implemented. In the end of the chapter a summary is presented (section 6.9).

6.1. Dependencies

The application developed has four dependencies, which have to be verified in order to start the application. If any of the dependencies is not verified then a list with the missing dependency(s) is presented to the user to fix it. After fixing it, the user re-launches the application and if everything was correctly fixed, the application starts. Next, we will present the four dependencies.

6.1.1. Google Play Services

The Google Maps API v2 requires both Google Play Services APK and Google Play Services client library. The client library is added to the project and then to the application when it is compiled, but the Google Play Services APK needs to be installed and updated in the device where the application is executed. Through the client library, we can get authorization from the user to gain access to individual Google services, by using the user's credentials. It also provides the required APIs to resolve any issue at runtime, such as: a missing, disabled or out-of-date Google Play services APK. The Google Play services APK contains the Google services and runs as a background service in the Android OS. The interaction with this background service is performed through the client library and the service performs the required actions. Because the Google Play services APK is delivered through the Google Play Store, updates to the services are not dependent on the carrier or OEM system image. This is an advantage because it allows us to always use the newest APIs available in Google Play services. Therefore, our application only initializes if the Google Play Services APK is installed and updated. The Google Maps API v2 also requires a Google Maps Mobile SDK Key that is generated at: https://code.google.com/apis/console. The Figure 6-1 presents the key generated and the project allowed the use of that key.



Key for Android apps (with certificates)

API key:	AIzaSyBISqwIfjGGYRvleFOzKaHjuXRhdk6QwYE
Android apps:	83:5A:2E:E2:54:9E:11:2D:F9:F3:71:16:F7:FF:8F:CF:5B:09:0A:75;com.example.display_registration_v0
Activated on:	Jan 26, 2013 8:55 AM
Activated by:	angealves@gmail.com – you

Figure 6-1: Google maps mobile SDK Key.

The key was then added to the project, more specifically at the *AndroidManifest.xml*, as presented in the Figure 6-2.

```
<meta-data
      android:name="com.google.android.maps.v2.API_KEY"
      android:value="AIzaSyBISqwIfjGGYRvleFOzKaHjuXRhdk6QwYE"
/>
```

Figure 6-2: Google maps mobile SDK Key added to the project (AndroidManifest.xml).

The Google Maps API v2 provides the required methods to add maps (based on Google Maps) to the application, the required methods to achieve the geometric coordinates and access to all the Google Maps functionalities. To evaluate the status of the Google Play Services APK the following method was used (see Figure 6-3).

```
GooglePlayServicesUtil.isGooglePlayServicesAvailable(Context)
```

Figure 6-3: Method that evaluates the Google Play Service status.

This method returns one the following status:

- SERVICE_MISSING
- SERVICE_VERSION_UPDATE_REQUIRED
- SERVICE_DISABLED
- NULL

The first status indicates that the Google Play Services is not installed, the second that the current version requires an update and the third that the service is disabled. If the method returns *Null* it means that Google Play Service is correctly running in the device.

6.1.2. Google Maps

The Google Maps APK provides the maps of any place in the world. The Google Maps API requires the Google Maps APK to add maps to the application and to present the result of the methods invoked by the application. By presenting the results, particularly the result of the methods that computes the location, it is easier for the user to validate in the map if the result is correct or needs to be adjusted. The application verifies if the device has the Google Maps installed, through the following method (see

Figure 6-4). If the method throws an exception it means the Google Maps is not installed, otherwise it is installed and running as expected.

```
getPackageManager().getApplicationInfo("com.google.android.apps.maps", 0)
```

Figure 6-4: Method that evaluates the Google Maps status.

6.1.3. Wi-Fi & mobile network location

The Wi-Fi & mobile network location is an option of the Android OS, which enables the application to use the Google's location service to estimate the location of the device. This information is anonymously collected and sent to Google. The application also relies on the GPS information, but this approach presents some limitations at indoor spaces. Since nowadays any smartphone is able connect to the Internet (either through Wi-Fi or mobile network data) the location can always be attained through the Google's location service, regardless the space where the device is. However, if the GPS location information is available the application compares the location information with the one attained through Google's location service and uses the most accurate. The following method (see Figure 6-5) returns *true* if the option is enabled or *false* otherwise.

```
LocationManager locationManager = (LocationManager)
getSystemService(LOCATION_SERVICE)

locationManager.isProviderEnabled(LocationManager.NETWORK_PROVIDER)
```

Figure 6-5: Method that evaluates the Wi-Fi & mobile network location option status.

6.1.4. Internet connection

Lastly, the application verifies if the device is connected to the Internet through any of its interfaces, e.g. wireless or mobile network data. The application requires the Internet connection (i.e. Internet to access the Google's location service) to estimate the device's location. The application uses the following method (see Figure 6-6) to evaluate if the device is or not connected to the Internet. If the *netinfo* variable is not *null* it means that the device is connected or is connecting to the Internet.

```
ConnectivityManager connectivity= (ConnectivityManager)
getSystemService(Context.CONNECTIVITY_SERVICE);

NetworkInfo netInfo= connectivity.getActiveNetworkInfo();
```

Figure 6-6: Method that evaluates the Internet connection status.

The Figure 6-7 presents an example of a device that was not connected to the Internet and did not have the Wi-Fi & mobile network location option enabled. By pressing the dependency, the application gives hints or information regarding that dependency. The Figure 6-8 presents the information that the application gave when the user pressed the Internet Connection dependency.

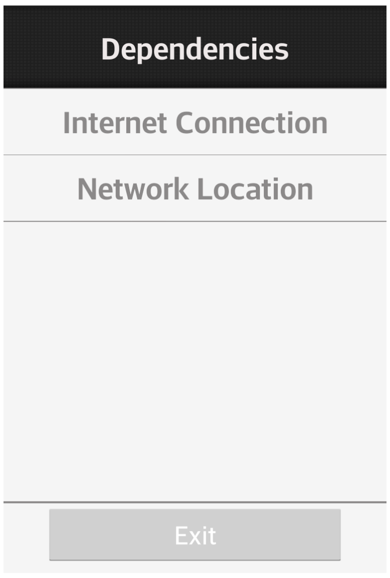
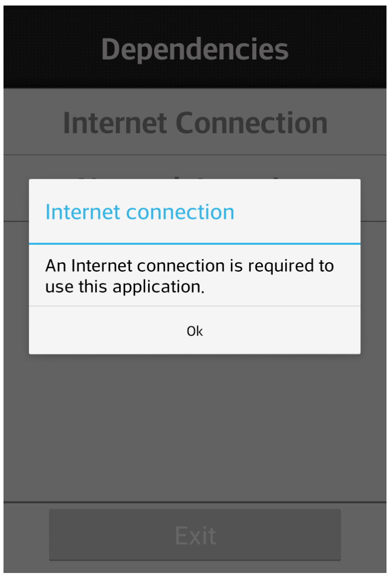


Figure 6-7: Dependencies error list.



Internet connection

An Internet connection is required to use this application.

Ok

Figure 6-8: Internet dependency information.

6.2. Server connection

The connection between the application and the BO is established through a client socket. The socket is implemented at the *SocketSingleton* class, which contrarily to the other classes of the application is a singleton. The singleton pattern restricts the instantiation of a class to just one object across the whole application. Therefore, it guarantees that there is just one object of this class and so, there is just one client socket. This way the same socket (the one who established the connection with the BO) is used throughout the whole application to send and receive messages. The application uses the *getInstance()* method (see Figure 6-9) to evaluate if an object of this class was or not instantiated. If the class was already instantiated the method returns that instance/object, otherwise a new instance/object is created. When the application instantiates this class the socket is also created and so, the connection is established.

```
public static SocketSingleton getInstance() {

        if (instance == null) {

            synchronized (SocketSingleton.class){
                if (instance == null) {
                    instance = new SocketSingleton();
                }
            }
        }
        return instance;
}
```

Figure 6-9: getInstance method.

Sometimes the connection was not established at the first try and for that reason the *retryCreatSocket()* method was implemented. This method performs a maximum of five extra attempts to establish a connection. If after this method the connection is not established, the application presents a connection error message to the user. The data exchanged between the application and the BO are objects, the methods *sendMessage(Object message)* sends an object to the BO and the method *receiveMessage()* receives an object from the BO.

6.3. Permissions

In order to access to the required functionalities and information, the application has to request for permissions. These permissions are defined at the *AndroidManifest.xml* and when the user installs the application the permissions are presented. This way the user knows exactly which permissions the application requires and only installs the application, which he agrees with. If the permissions are not defined the application will not be able to access to the required functionalities/information. This is imposed by the Android programming language, and this application requires the following permissions (see Figure 6-10).

```
android:name="android.permission.ACCESS_COARSE_LOCATION"
android:name="android.permission.ACCESS_FINE_LOCATION"
android:name="android.permission.ACCESS_WIFI_STATE"
android:name="android.permission.ACCESS_NETWORK_STATE"
android:name="android.permission.INTERNET"
android:name="android.permission.WRITE_EXTERNAL_STORAGE"
android:name="com.google.android.providers.gsf.permission.READ_GSERVICES"
```

Figure 6-10: Required permissions.

The first permission allows the Google Maps API v2 to use Wi-Fi or mobile cell data (or both) to determine the device's location. The second permission allows the Google Maps API v2 to use the Global Positioning System (GPS) to determine the device's location. The third permission is to access the state of the Wi-Fi interface to determine if is turned-on or turned-off. The fourth permission allows the Google Maps API v2 to check the connection's status to determine whether the required data can be downloaded. The fifth permission is to determine if the device is connected to the Internet (through any of the available interfaces) and is used by the Google Maps API v2 to download map files from Google Maps servers. The sixth permission allows the Google Maps API v2 to cache map file data in the device's external storage area. The seventh permission allows the Google Maps API v2 to access the Google web-based services.

6.4. Association/Authentication

As presented in the section 5.2.1, the association is the application's module where the network and the display are associated. To perform this association two phases are required: one to identify the network and the other to identify the display. In the first phase the BO's IP is required to identify the network and in the second phase the display's *Id* is required to identify the display. Therefore, when the application starts firstly it requests an IP address to establish a connection with the BO (see Figure 6-11) through a client socket (as explained in the section 6.2). If the connection is established, the BO returns the network domain information and the application presents it to the user to validate it (see Figure 6-12).

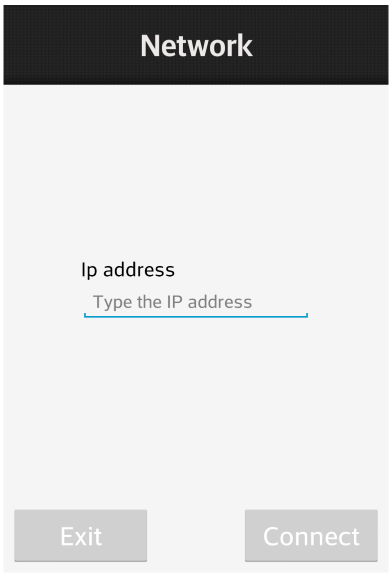
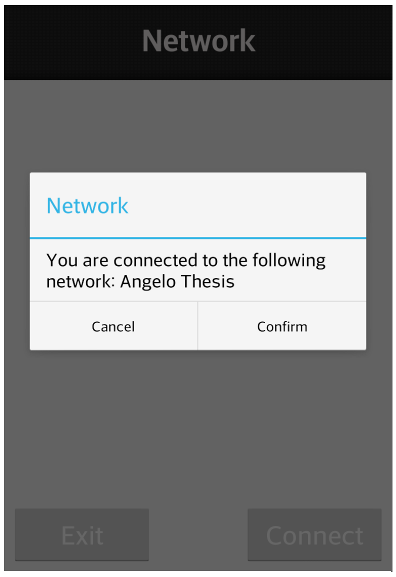


Figure 6-11: Application requesting an IP address.



You are connected to the following network: Angelo Thesis

Figure 6-12: Network domain information.

The network domain information is a String that contains the name of the network (e.g. SSID) or the name of the domain (e.g. uminho.pt). Through this information the user is able to validate if the application is connected to the correct network. If the user presses the *Cancel* button (meaning that is not connected to the correct network) the application requests a new IP address and establishes a new connection. But, if the user presses the *Confirm* button (meaning that is connected to the correct network), the application requests a *username* and *password* to perform the authentication (see Figure 6-13). Before sending the authentication information to the BO the application calculates the MD5 hash of the password. The application uses the *AuthenticationObject* to send the authentication information (i.e. the username and the MD5 hash of the password) to the BO. When the BO receives this object it knows that an authentication is being performed and so, it verifies if the authentication information is correct. To do so, the BO consults the database (*Admins* table) and after consulting and validating the authentication it sends the feedback to the application. If the authentication is valid the BO sends the message *"authenticationSuccess"* and the application presents the available input methods to identify the display (see Figure 6-14). On the other hand, if the authentication is not valid the BO sends the message *"authenticationInvalid"* and the application requests new credentials and no further step is performed until the user is authenticated.

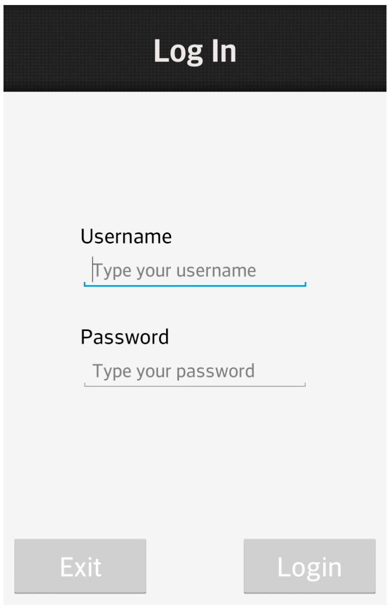


Figure 6-13: User's authentication.

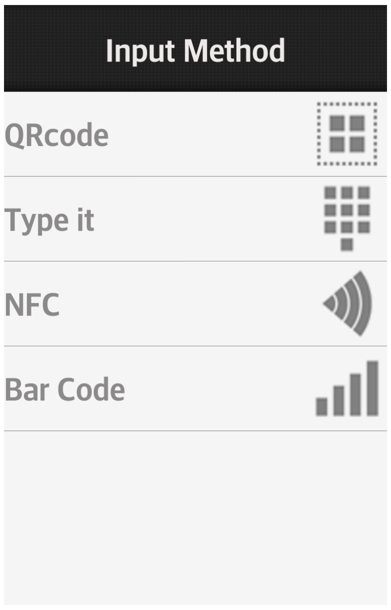
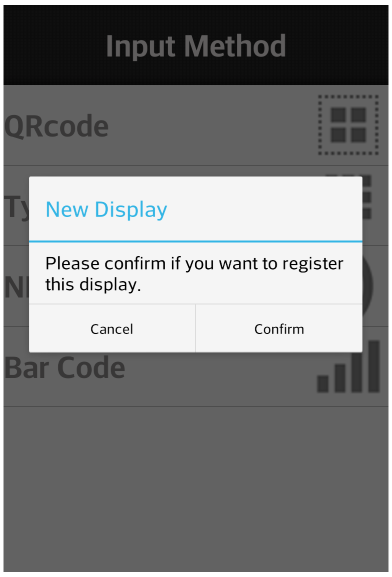


Figure 6-14: Input method's list.

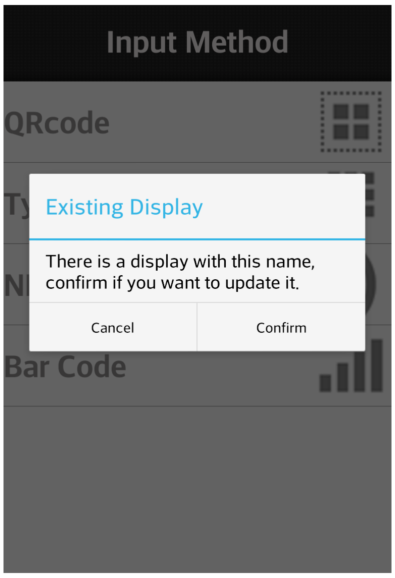
The user then selects the most suitable method to identify the display. As presented in the section 5.1.2 the display's *Id* can be provided in the form of a QR Code or plain text. The QRCode input method relies on the ZXing (Zebra Crossing) open-source library to process the QRCode images, which uses the camera of the device. Therefore if the user selects this input method the application verifies if the ZXing is installed in the device, and if it is not installed, the application automatically redirects the user to the Google Play Store to download and install it. This approach has the advantage that is immune to typing errors, because the *Id* is automatically attained from the QR Code. On the other hand, if the *Id* is provided in the form of plain text the user selects the *Type It* input method and uses the keyboard of the device to manually type the *Id*. The advantage of this approach is that does not present any dependency, but is vulnerable to typing errors. The others two input methods, NFC and Bar Code, were not implemented in this current version of the application (future work). When the *Id* is attained the application sends it to the BO through the object: DisplayIdObject. When the BO receives this object it knows that has to verify if it is a new or known display. To do so, the BO uses the *Id* contained in the object and consults the database (*Display* table). If the display is new the BO sends the message "newDisplay" otherwise sends "updateDisplay". Based in this messages the application presents the following feedback to the user, the Figure 6-15 presents an example of an unregistered/new display, while the Figure 6-16 presents a registered/known display.



New Display

Please confirm if you want to register this display.

Figure 6-15: New display.



Existing Display

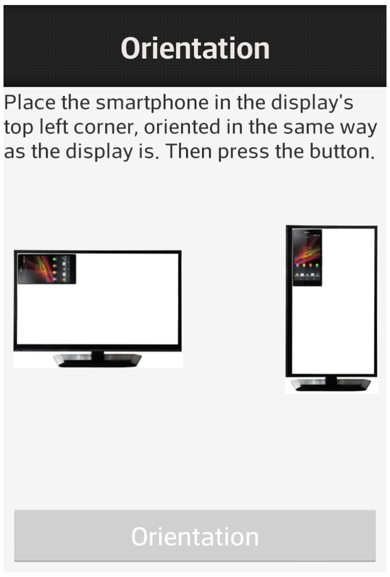
There is a display with this name, confirm if you want to update it.

Figure 6-16: Known display.

The user confirms or not the feedback sent from the BO, i.e. if in fact it is a new/unregistered or known/registered display. The association is completed when the user confirms this feedback. At this point, the network and the display are associated, and the user is authenticated, therefore the spatial information of the display can be collected.

6.5. Orientation

The orientation module determines if the display is horizontally, vertically portrait or vertically landscape orientated (as presented in the section 5.2.1). To determine the orientation the device that is running the application has to be placed at the top left corner of the display, orientated in same way as the display (see Figure 6-17). When the device is correctly positioned the user press the *Orientation* button and then the application start the calculations to determine the orientation. The calculations are performed over the values retrieved by the accelerometer sensor of the device (as stated in the section 4.2.4). The accelerometer framework uses a standard 3-axis coordinate system to express the sensor's values (see Figure 6-18).



Orientation

Place the smartphone in the display's top left corner, oriented in the same way as the display is. Then press the button.

Figure 6-17: Orientation.

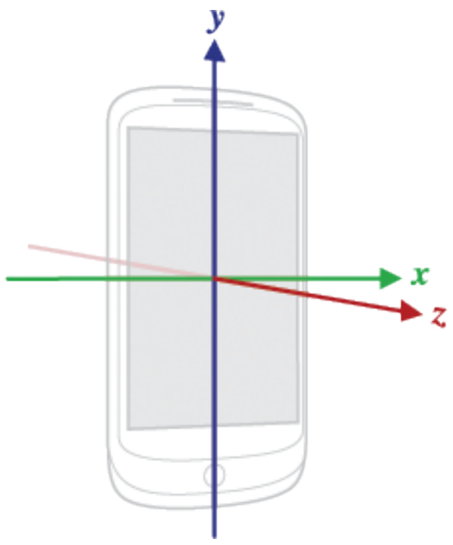


Figure 6-18: Accelerometer 3-axis coordinate system.

The X-axis is defined as the vector product Y*Z, it is tangential to the ground at the device's current location and points approximately east. The Y-axis is tangential to the ground at the device's current location and points toward the geomagnetic North Pole. The Z-axis points toward the sky and is perpendicular to the ground plane. Therefore to determine the orientation the application compares the magnitude of the values of each axis. If the X-axis presents the highest value the orientation is *Vertical Landscape*, if it is the Y-axis the orientation is *Vertical Portrait* and if it is the Z-axis the orientation is *Horizontal*.

However, to ensure that the orientation is correctly determined, the application performs five consecutive readings of the sensor in order to confirm that the magnitude of the values is the same between readings. If the values are consistent the orientation is determined, otherwise the application continues reading the sensor until the values stabilize. After determining the orientation the application presents the result to the user to validate it, if the user validates it the application sends the orientation state and the sensor values (i.e. the X-axis, Y-axis and Z-axis values) to the BO through the DisplayOrientationObject. In its turn, the BO registers the orientation information in the DB by associating it with the display being registered. After registering the orientation the BO sends the message *"success"* to the application confirming it was successfully registered.

6.6. Location

The *Location* module determines the location of the display in the form of geometric coordinates. As presented in the section 4.2.1, the Google Maps API v2 is used in this work to determine the display's location. This solution is used because it provides the required methods to compute the location either by resorting to satellites (GPS receiver) or to an Internet connection and so, it can be used in both indoor and outdoor spaces. Therefore, the application relies on the Google Maps API v2 and the Google Maps APK to compute and to present the location. Since it takes some time to compute the location (in some cases several minutes), the location starts to be computed in background as soon as the application starts. This way when this step is reached the application rapidly determines which location is more accurate (i.e. if it is the location attained through the GPS or through the Internet) and presents it in the map through a blue marker (see Figure 6-19).

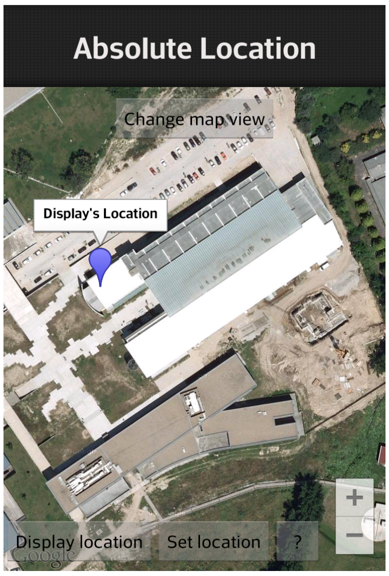


Figure 6-19: Display's location.

If the computed location is not correct or accurate enough, the user can drag-and-drop the marker at the right location or long press at the exact location to place the marker at that location. When the location is correctly set, the user press the *SetLocation* button and the application sends the latitude and longitude values of the marker to the BO through the DisplayGlobalLocationObject. The BO receives this object and inserts the geometric information in the DB. If the information is correctly inserted the BO sends the message *"success"* to the application or *"error"* otherwise. The application also enables the user to change the map type/view (between normal, satellite, hybrid), zoom in /out and use the 3D features.

6.7. Space

In the *Space* module the indoor space where the display is located is defined. The information regarding the indoor spaces is defined in the symbolic world model and to attain that information the application has to inquire the spatial model server. However, the application does not inquire it directly, instead it sends a request to the BO and it is the BO who inquires the spatial model server. The server replies in XML format, the BO parses the XML to extract the information needed and sends the result to the application. The application could perform the request directly to the spatial model server but this approach was followed instead due to the following reasons. Firstly, if a different system uses a different spatial model, or if the current system starts to use a different spatial model, the application does not need to be changed because the BO follows the API defined by the application, i.e. the API defines that the spaces names and spaces *Ids* have to be placed in two *ArrayList* and this information has to be sent through the GetSpaces object. So, it is the BO who needs to accommodate any change in the spatial model. The other reason is related with the processing power, time and battery consumption of the device. Although the smartphones presents high processing capacity, which enables them to easily parse a XML, they still presents low battery performance. Since the XML can have large information to be parsed and since the user can perform several searches, this step might requires a substantial processing power and in consequence a substantial battery consumption. By taking this into account we decided to let the BO do all the work and free the application. This way the application just has to extract the information from GetSpaces object, which is a much lighter operation, and the system is free to use any spatial model.

When the user searches for a space it is more natural for the user to start the search from the more generic information and then navigate through the more specific information. For example, it is easier to search for the Engineering School, then select one of the 3 floors, and then select one of the areas/rooms within that floor (see Figure 6-20). However, in the symbolic world model used in this work there is only one relation that allow this type of search is: *“Is_Accessible_From (bidirectional)”* all the others relations just enables the search in the opposite direction, i.e. from the more specific to the more generic. For that reason, all the relations within a given space have to be defined as: *"Is_Accessible_From (bideractional)"*. Therefore, through this relation it is possible to retrieve the objects within a given object, e.g. for the *"Floor 1"* this relation retrieves the *"Areas 1,2,3"* and the *"Engineering School"* (see Figure 6-20). However, at this point the user already knows the *"Engineering School"* and so it makes no sense to present that information again. For that reason, we defined that the objects have to contain the attribute *Level* to set the level of the object (see Figure 6-20). The *"Engineering School"* is the most generic object so it has the *"Level 1"* attribute, the floors of the building *"Floor 1, Floor 2* and *Floor 3"* are above the previous level and so, they have the attribute *"Level 2"*, and the areas are above the *"Level 2"* have the attribute *"Level 3"*. This information enables the BO to identify which information is required, i.e. if it is the information from the next, previous or current level.

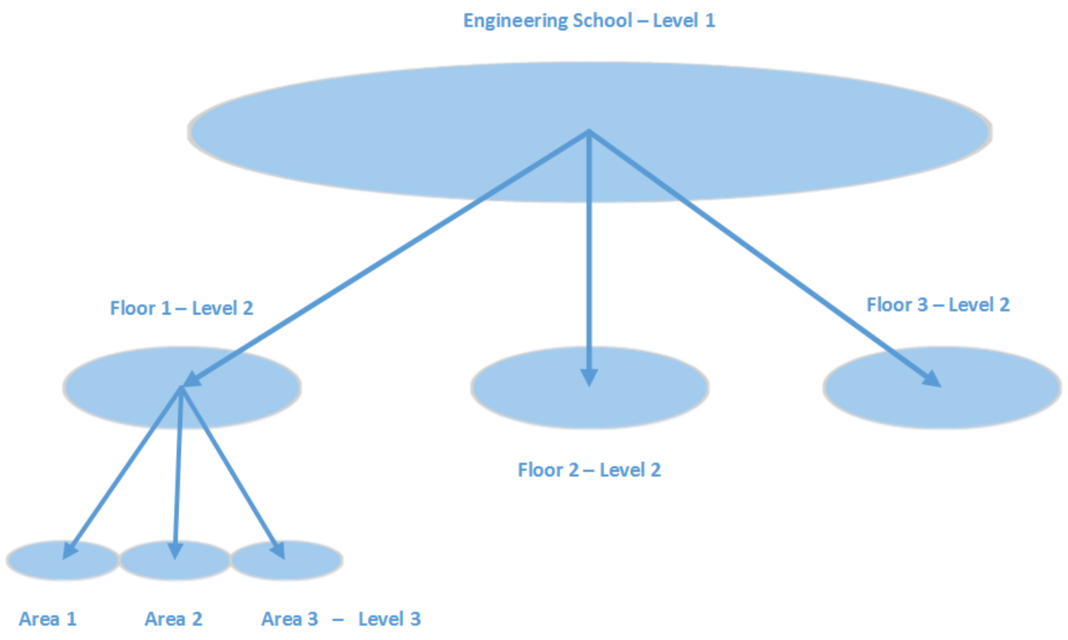


Figure 6-20: Level attribute.

6.8. Relative Location

Lastly, in the *Relative Location* module the location of the display relative to the location of the surrounding key elements is defined. However, this module cannot start until the space and orientation information is defined. The information regarding the space is required to infer if that space has key elements defined in the spatial model. If the space does not have key elements defined in the model, the key elements defined in the DB (*KeyPoints* tables) are used. The orientation is required to determine which directions are presented, because the information of the directions change based on the display's orientation. The Figure 6-21 presents the directions of a vertically oriented display, whereas the Figure 6-22 presents the directions of a horizontally oriented display.

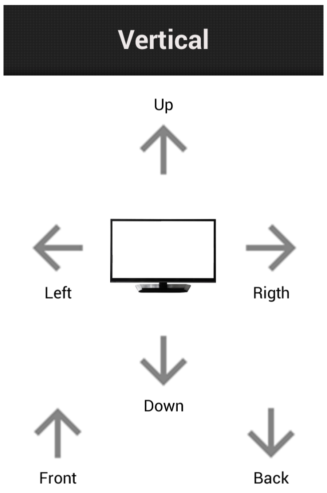


Figure 6-21: Vertical oriented.

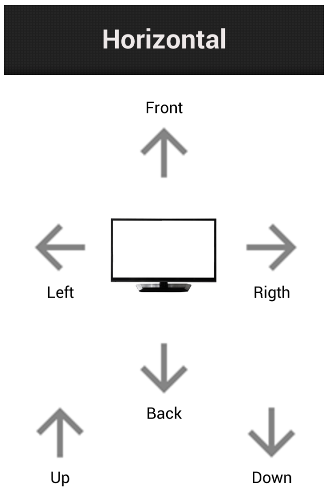


Figure 6-22: Horizontal oriented.

When this step starts the application sends the *Id* of the space where the display is located to the BO and the BO searches for key elements. The search is performed over all objects that are in the same level because if they are in the same level then the key elements are accessible in some way. For example, if the display is located at the *"Area 1"* the BO searches for key elements in all objects that are under the *"Floor 1"* but only the ones with the attribute *"Level 3"* (see Figure 6-20). Therefore, the key element(s) can be at the *"Area 1, 2* or *3"*, if no key element is defined in those areas the key elements in the DB are used instead. However, the BO needs some sort of tag to distinguish the key elements from any other element/object (e.g. a room), and for that reason we decided that the object type of the key elements has to be defined as: *"KeyElement"*. So, when this operation is being performed the objects defined with that type are searched. When the BO determines the key elements, it sends them one-by-one to the application. The first key element is sent to the application and when the user defines the direction, the application sends that information to the BO. The BO registers that information in the DB and sends the next key element. This procedure is followed until all key elements are defined. To define the directions the user performing this task has to be at the display's front and looking forward to the display.

6.9. Chapter summary

In this chapter we presented how the application developed in this work to perform the display's registration was implemented. Firstly, we presented the application's dependencies and the reason why they are imposed. The dependencies are: Google play services, Google maps, Wi-Fi & Mobile network location and an Internet connection. Afterwards, it was presented how the connection between the application and the BO is performed and the particularity of our solution is that it follows the singleton pattern. Lastly, we presented how each module identified in the section 5.2 was implemented and how the respective spatial information is attained. During the implementation, each module was exhaustively tested and only when the module passed the test we started to implement the following module. At the end, the entire modules were tested together as well as the interactions with the BO, DB and the spatial model. After performing these exhaustive tests we validate that our application was working as expected (at least at a controlled and virtual environment) as well as the interactions with the other parts.

7. Discussion

This chapter starts with a demonstration of a display's registration (section 7.1), where all the steps to perform a successfully registration are presented. Through this registration it was possible to evaluate not only if the application was working as expected, but also the information attained from the spatial model server and the interactions with the BO and DB. Following the application's performance assessment, two tests were performed to evaluate the collected spatial information. These tests were based on the motivating scenarios described in section 1.2. The first test was based in the "Missing Child Alerts" (section 7.2) and the second test on the "Responding to a Terrorist Incident" (section 7.3). At the end of this chapter, a summary of the obtained results is presented (section 7.4).

7.1. Display's registration

This section aims to present a demonstration of the application conducting a complete display's registration. This demonstration also intends to evaluate how the application performs a registration of a real display at a real indoor space (so far the tests were performed in a controlled and virtual environment) and to identify any issue or areas of improvement in the application. Before starting the demonstration we had to create a network to connect the application and the BO, as presented in system's architecture (section 5.1). The domain name of the network was: *"Angelo Thesis"* and the BO's IP address was: *192.168.43.226*. As a result, the application had to connect to that IP address and the network was validated through its domain name. The indoor space used in this test was the Engineering School at the University of Minho Azurém campus. The building in question has three floors, the shape of an *H* and the first floor was divided into twelve different areas (see Figure 7-1). These areas were created to be easier to identify the display's location within the first floor. In this demonstration the display was placed in the *Area 1* (see Figure 7-1).

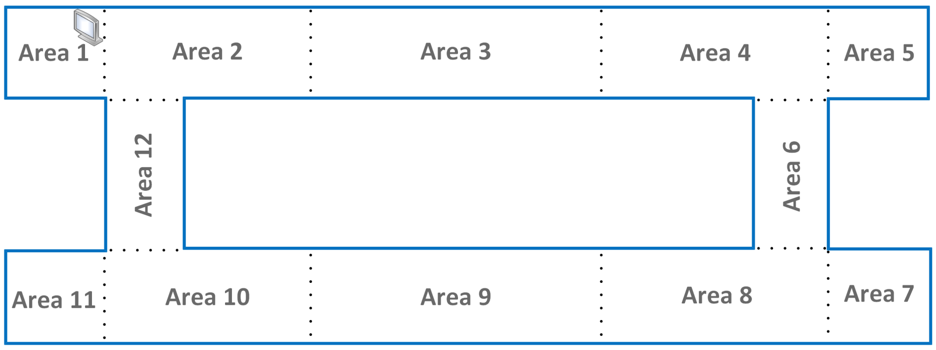


Figure 7-1: Engineering school first floor plan.

This space was registered in the symbolic world model through the editor[5]. Firstly, we created the Engineering School object with the attribute *Level* equals to 1, because it is the most generic object. Subsequently, three objects, one for each floor (EE_Floor_1, EE_Floor_2 and EE_Floor_3), were created. As they are within the Engineering School the attribute *Level* had the value 2 and the relations between those objects and the Engineering School were defined as: *"Is_Accessible_From (bidirectional)"*. Lastly, the twelve areas (EE_Floor1_Area1, …, EE_Floor1_Area12) were created, each one with

[5] http://local.dsi.uminho.pt:8080/scse2/index.html

the attribute *Level* equals to 3, as they are within the first floor. The relations between the twelve areas and the first floor were also defined as: *"Is_Accessible_From (bidirectional)"*.

Afterwards the application was installed in a smartphone, for this test we used the *LG Maximo GE975* with the Android OS v4.1 (Jelly Bean). Once the application was installed, we started it and, as expected, the application requested an IP address. As noted above, the BO's IP address was *192.168.43.226,* hence we typed this IP address (see Figure 7-2). The application used this IP to create a client socket and tried to establish a connection with the BO. Once the connection was successfully established, the BO returned the domain information of the network (see Figure 7-3). Otherwise, (i.e. if the connection was not established), an error message would be presented and a new IP address would be requested.

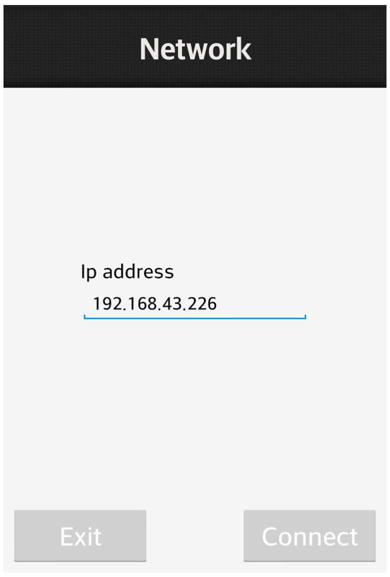
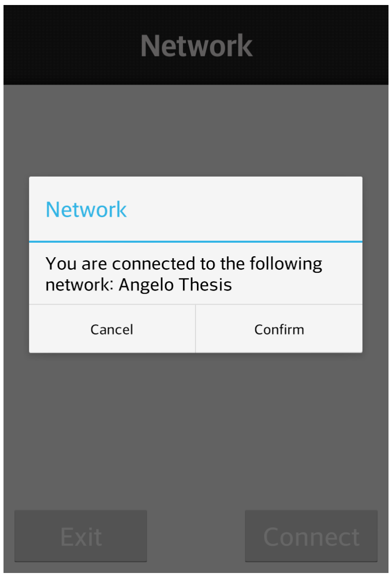


Figure 7-2: BO IP address.



You are connected to the following network: Angelo Thesis

Figure 7-3: Domain information.

In view of the fact that the domain information was the same as the one we defined in our test network, i.e. *"Angelo Thesis"*, it was possible to validate that the application was connected to the correct network. Thus, we pressed the *Confirm* button and after that the application requested the username and password. In this demonstration both username and password of the authorized user were: *"Angelo"* (see Figure 7-4). The application then sent the username and the MD5 hash of the password to the BO to be validated. This information was sent to the BO through the *AuthenticationObject*. When the BO received this object it knew that an authentication was being carried out and so, it consulted the DB (*Admins* table) to validate the respective credentials.

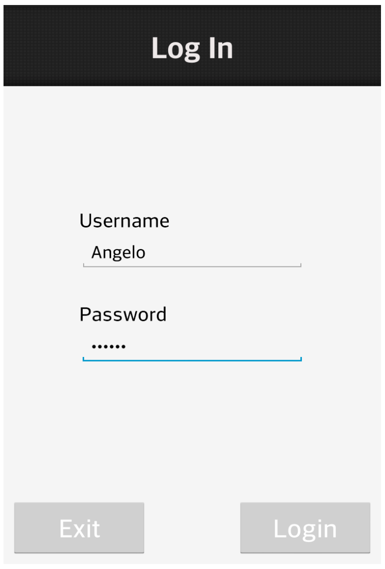
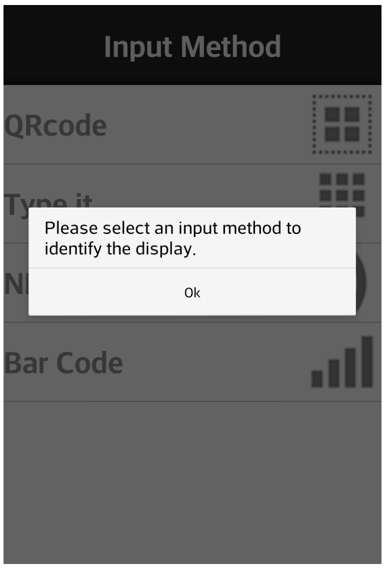


Figure 7-4: User authentication.



Please select an input method to identify the display.

Figure 7-5: Spatial information.

Once the credentials were correct, the application presented the available input methods to identify the display (see Figure 7-5). If the credentials were not correct, an error message would be presented and new credentials would be requested, which was not the case. As previously mentioned, it was assumed that when a display is connected to the network, the BO automatically generates an *Id* and this *Id* is presented in the display. In this demonstration, we assumed that the generated *Id* was *"DisplayTest"*. To identify the display, the input method *"Type it"* was selected (see Figure 7-6).

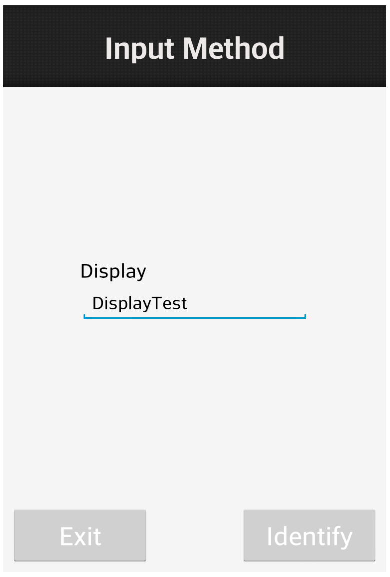
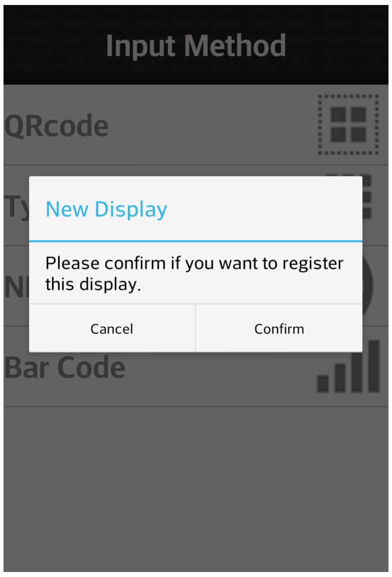


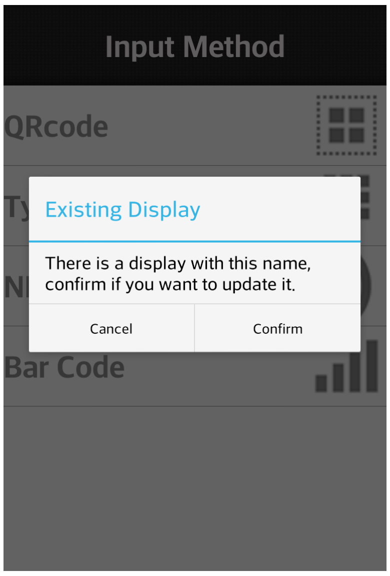
Figure 7-6: Display's *Id.*



Please confirm if you want to register this display.

Figure 7-7: New display.

Afterwards, the *Id* was sent to the BO through the *DisplayIdObject*, and the BO consulted the DB (*Display* table) to determine if that *Id* was a new/unregistered or a known/registered display. It determined that it was a new display and so, that feedback was sent to the application, which was presented to us (see Figure 7-7). Since this was the expected feedback, we confirmed it (Note: only after this confirmation, the BO created an entry with this *Id* in the DB). In order to certify that the BO was executing the validation correctly we retyped the display's *Id* and as expected the BO's feedback was different, i.e. now this *Id* was known (see Figure 7-8).

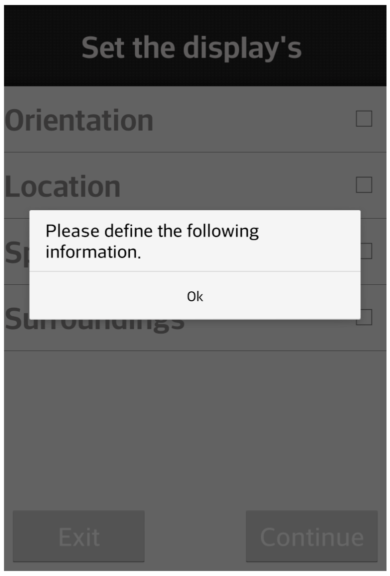


Existing Display

There is a display with this name, confirm if you want to update it.

Cancel Confirm

Figure 7-8: Existing display.



Please define the following information.

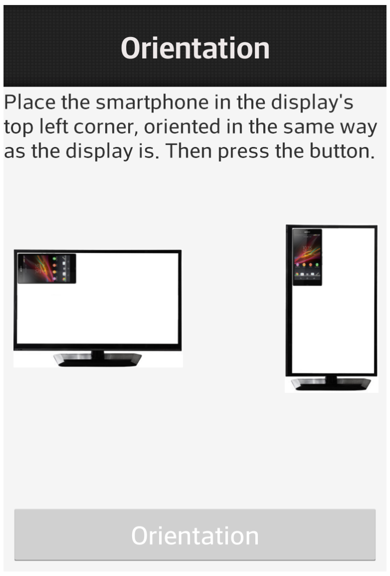
Ok

Figure 7-9: Main menu.

After confirming the first feedback, the application presented the list of the spatial information that had to be defined (see Figure 7-9). In summary we had to define the orientation, the location, the space and the surroundings of the display. One of the key points of this application is that it allows the user to defined this information in any order, the only constraint is that the surroundings information cannot be defined until the orientation and the space of the display are defined (as explained before). At the same time as we define the spatial information the application places a *tick* in the line of the information defined. Through this *tick* it was possible to check which spatial information was already defined and the ones that were not.

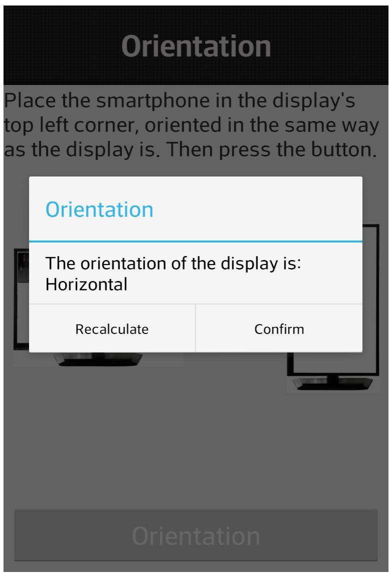
Firstly, we start to define the display's orientation. As stated in the section 6.5, to infer the display's orientation the device executing the application has to be placed at the top left corner of the display, orientated in the same way as the display (see Figure 7-10).

When the device was correctly placed, we pressed the *Orientation* button. Within a few seconds the application determined the orientation and the result was presented to be validated (see Figure 7-11).



Place the smartphone in the display's top left corner, oriented in the same way as the display is. Then press the button.

Figure 7-10: Display's orientation.

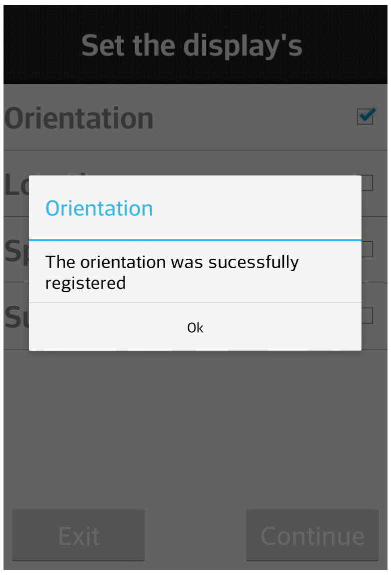


Place the smartphone in the display's top left corner, oriented in the same way as the display is. Then press the button.

The orientation of the display is: Horizontal

Figure 7-11: Display's orientation result.

Once the result was presented the application also provided an option to recalculate the orientation. If for some reason the orientation was not correctly determined the user is able to perform a recalculation by pressing the *Recalculate* button. Consequently, the application re-initializes the accelerometer sensor and performs new calculations to determine the device's orientation. Nevertheless, in our test the orientation was correctly determined, (i.e. in our test display was horizontally orientated) and, for that reason, we pressed the *Confirm* button to validate the result. Afterwards, the application sent the orientation state and the values of the accelerometer sensor to the BO through the object: *DisplayOrientationObject*. When the BO received this object it registered the orientation in the DB (*Display* table) and sent a confirmation to the application indicating that the orientation was successfully inserted in the DB. After receiving the confirmation, the application presented it to the user (see Figure 7-12) and once the user confirms it, the application placed a *tick* in the orientation line (see Figure 7-13). At this time the display's orientation was defined.



Orientation

The orientation was sucessfully registered

Figure 7-12: Orientation defined.

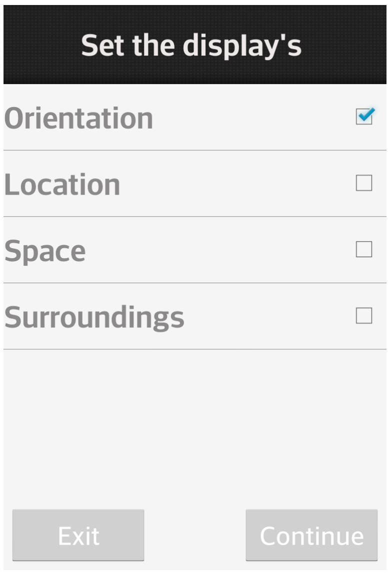


Figure 7-13: Orientation defined.

The next step consisted on defining the display's location in the format of geometric coordinates, i.e. latitude and longitude values. As soon as this step started the application automatically estimated the location of the device and placed a marker in the map to signalize it. This estimation was calculated by only relying in the *Wi-Fi or data access over mobile network* information (the *GPS* was not used in this test). Therefore, it was not by surprise that the marker's location (that indicates the location of the display) was not very accurate. In order to adjust it we drag and drop the marker to the correct location (see Figure 7-14). By pressing the *"?"* button the application presented a set of useful information (see Figure 7-15).

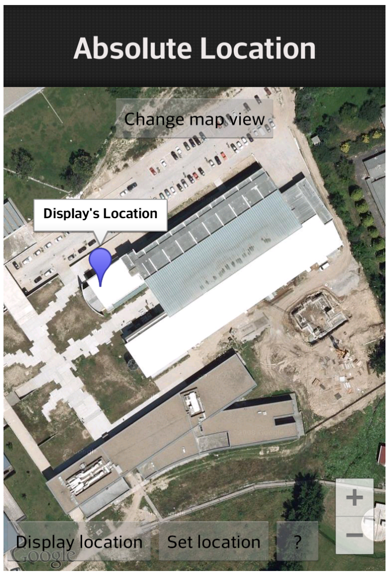
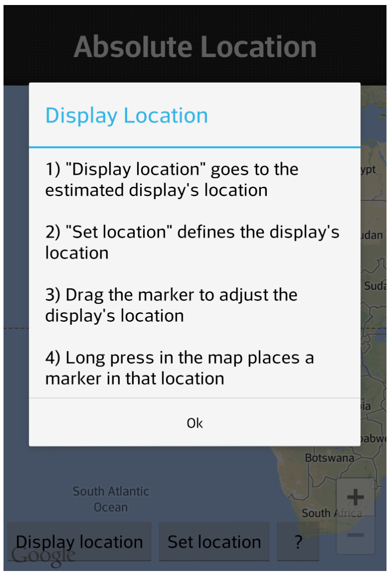


Figure 7-14: Display's location.



Display Location

1) "Display location" goes to the estimated display's location

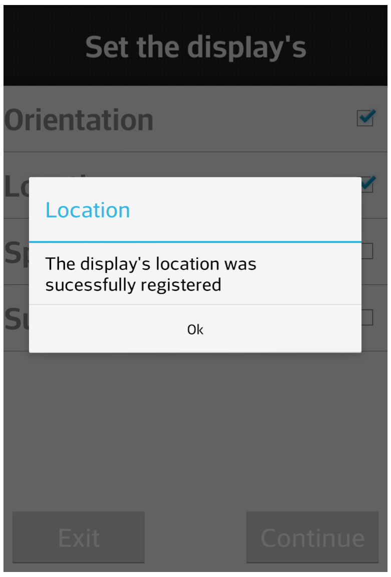
2) "Set location" defines the display's location

3) Drag the marker to adjust the display's location

4) Long press in the map places a marker in that location

Figure 7-15: Useful information.

After placing the marker in the correct location, we pressed the *"Set Location"* button to register the location in the DB. When this button was pressed the application collected the latitude and longitude values of the marker and sent them to the BO through the DisplayGlobalLocationObject. The BO inserted those values in the DB (*Display* table) and after successfully inserting them it sent a confirmation to the application. The application informed us that the coordinates were successfully registered (see Figure 7-16) and when we confirmed it, the application placed a *tick* in the location line (see Figure 7-17). At this point the orientation and location of the display were already defined.



Location

The display's location was sucessfully registered

Ok

Figure 7-16: Location defined.

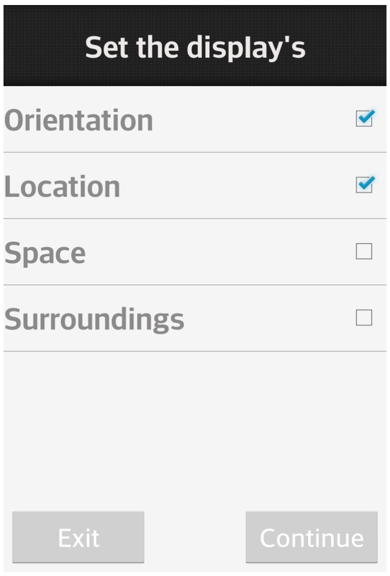
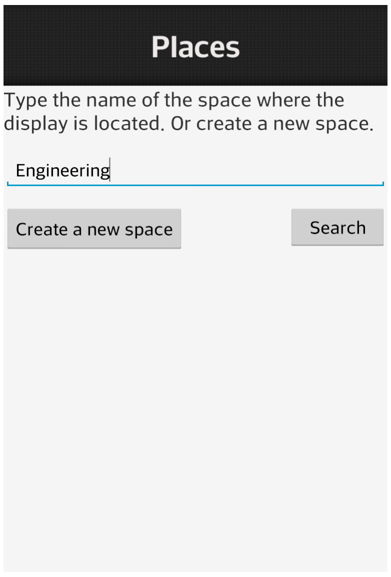


Figure 7-17: Location defined.

We then moved to the space step up to define the indoor space where the display was located. As previously stated, the display was located at the Engineering School, for that reason we searched for a space with *"Engineering"* in its name (see Figure 7-18). When we hit the *Search* button the application sent the *"Engineering"* to the BO through the *GetSpaces* object. Once the BO received this object it knew that had to inquire the spatial model server and so, it performed a connection over the Internet, using the following query:

http://local.dsi.uminho.pt:8080/sc2/SCTX?function=f2_1&objname=Engineering

The *function=f2_1* indicates that the search was performed through the name of the object (i.e. this function searched for spaces that had a specific word in its name), in this case *Engineering*. The spaces that were found were returned to the BO in the form of a XML file, after performing the parse of the XML file the BO sent the attained spaces to the application. In its turn the application presented the result to us. In this test the returned spaces were: *"Engineering School"* and *"Engineering_School"*(see Figure 7-19).



Places
Type the name of the space where the display is located. Or create a new space.
Engineering
Create a new space
Search

Figure 7-18: Search for Engineering.

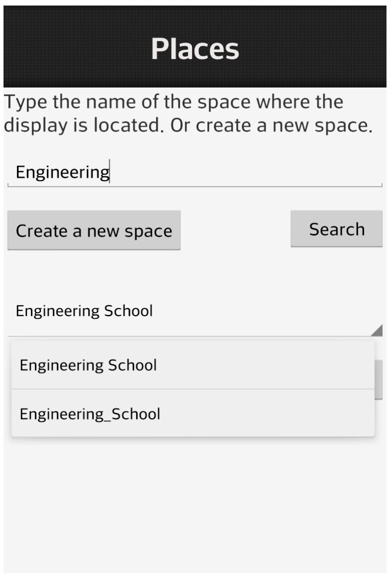
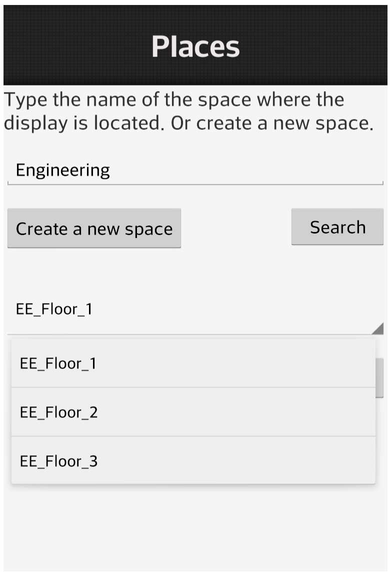


Figure 7-19: Search's result.

We then selected the correct space where the display was located, which in this test was *"Engineering_School"*. By selecting it the application sent the information about that space to the BO through the same *GetSpaces* object. As the variable step's value was set with the value 2 the BO knew that it had to search for spaces related with the selected space. Therefore, at this time the BO used the following link:

http://local.dsi.uminho.pt:8080/sc2/SCTX?function=f2_3&objid=193&infer=2

Contrarily to the previous search, this search was performed through the function=f2_3, which looks up for an object with the *Id=193* (*Id* of the selected space). The *infer=2* indicated that the spaces that were related with this one had to be as well returned. Thus, the three floors of the Engineering School were returned (see Figure 7-20).


Places

Type the name of the space where the display is located. Or create a new space.

Engineering

Create a new space | Search

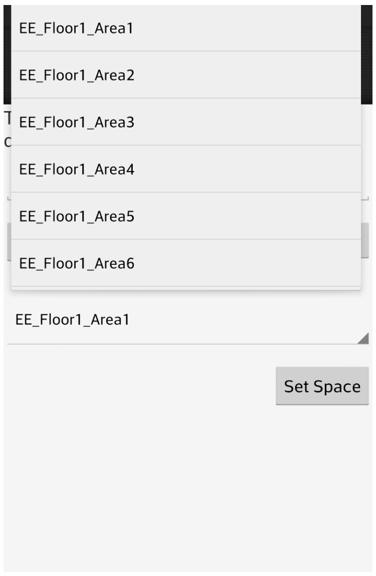
EE_Floor_1

EE_Floor_1

EE_Floor_2

EE_Floor_3

Figure 7-20: Space's floors.


EE_Floor1_Area1

EE_Floor1_Area2

EE_Floor1_Area3

EE_Floor1_Area4

EE_Floor1_Area5

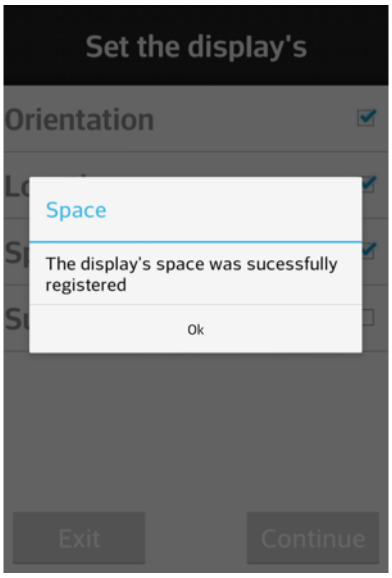
EE_Floor1_Area6

EE_Floor1_Area1

Set Space

Figure 7-21: First floor's areas.

Since we knew that the display was located in the first floor, we selected the space *"EE_Floor_1"*. The previous procedure was again followed, i.e. the BO used the *Id* of the selected space to attain the related spaces. The attained spaces were the twelve areas within the first floor (see Figure 7-21). Since the display was located in the Area 1 we selected the *"EE_Floor1_Area1"* space. The BO registered this space in the DB and sent the feedback to the application, as there were no spaces related with this one. Afterwards, the application informed us that the space was successfully registered (see Figure 7-22) and placed a *tick* in the space line (see Figure 7-23).


Set the display's

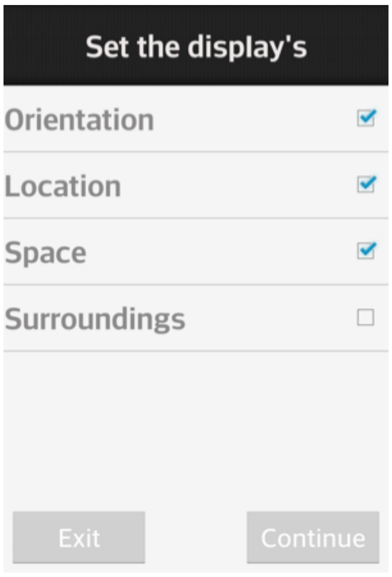
Space

The display's space was sucessfully registered

Ok

Exit | Continue

Figure 7-22: Space defined.


Set the display's

Orientation ✓

Location ✓

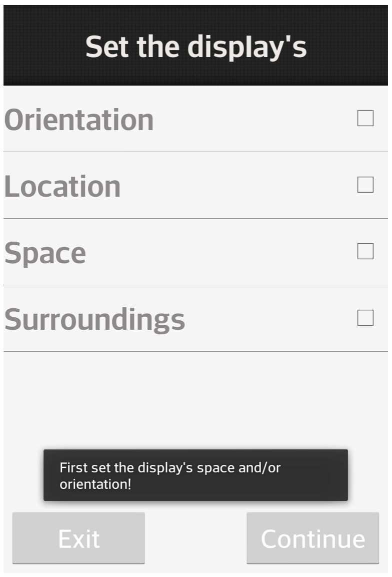
Space ✓

Surroundings ☐

Exit | Continue

Figure 7-23: Space defined.

At this moment the only missing information regards the surroundings of the display. As we stated before, until the orientation and the space of the display are defined this step cannot be performed (see Figure 7-24). By starting this step, the application sent a request to the BO to identify the surrounding key elements of the space where the display was located. The BO firstly went to the DB to get the space's *Id* where the display was located and secondly searched for key elements. This search is just performed within the related spaces and those that had the attribute *Level* with the same value. Even though this floor has 4 emergency exits and 2 exits, for this test just one emergency exit and one exit were considered. One by one, it was defined the direction of them in relation to the location of the display (see Figure 7-25). If no key element had been found the key elements defined in the DB (*KeyPoints* table) would be used.



First set the display's space and/or orientation!

Figure 7-24: Surrounding step.

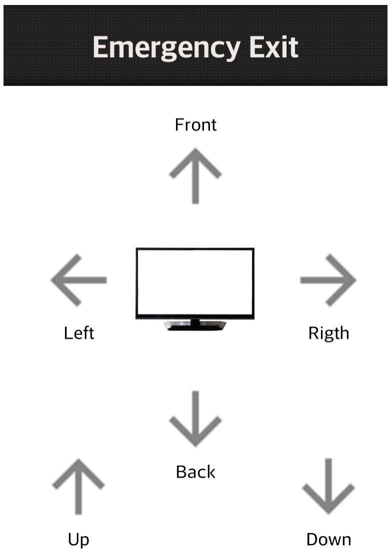


Figure 7-25: Emergency Exit key element.

As soon as the relation of all key elements was defined, the application presented that information to us (see Figure 7-26). When we confirmed it, the application placed the last *tick* in the surroundings line (see Figure 7-27). At this time, display's spatial information was all successfully collected and registered in the DB, and for that reason, we pressed the *"Continue"* button.

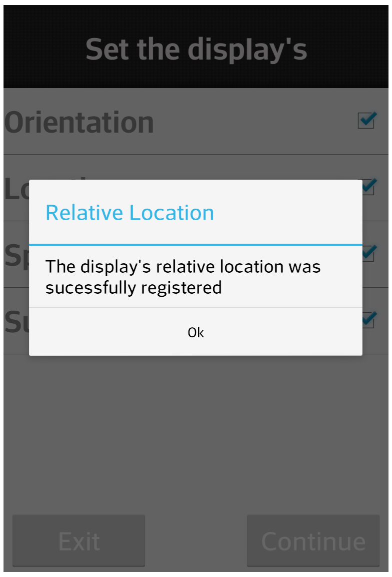


Figure 7-26: Surroundings defined.

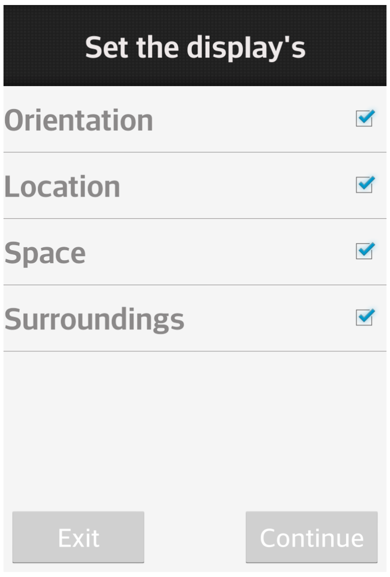
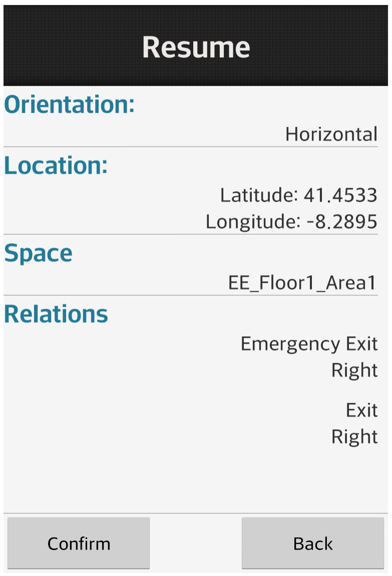


Figure 7-27: Surroundings defined.

The application then presented an overview of the spatial information that was collected during this demonstration (see Figure 7-28). After confirming the information, we concluded that the display's spatial information was correct so, we pressed the *"Confirm"* button. Afterwards, the application presented the menu in which we could select the suitable input method to identify the display, this way we could perform another registration. On the other hand, if any of the spatial information were incorrect we would press the *"Back"* button in order to go back to the previous menu and fix the incorrect spatial information.


Resume

Orientation:
Horizontal

Location:
Latitude: 41.4533
Longitude: -8.2895

Space
EE_Floor1_Area1

Relations
Emergency Exit
Right
Exit
Right

Figure 7-28: Information's resume.

7.2. Missing Child

The missing child scenario (described in section 1.2) was one of the scenarios used to evaluate the generated displays' spatial information. As described before, in this scenario until the child is found the content has to be spread over an increasing area as time passes by. To attain the increasing area, the geometric and/or symbolic information are required. Through the geometric information it is possible to calculate the distance between the displays and so, the increasing area can be attained. For example, if we consider a random display as the first one to present the content, after sometime the displays that are within a five meters range from this display start to present the same content, then the displays that are in a ten meters range also show the same content, and so on and so forth. However, this approach alone presents a limitation when the space has multiple floors (as explained before). So, the symbolic information can also be used to compute the increasing area. However, in this case it will depend on how the symbolic information is defined in the location model, i.e. if it allows us to determine the topology and the relations between the spaces/floors/areas/rooms/objects/etc. For example, if we consider a display that is at a given area as the first display to present the content, after some time the displays in the following areas also start to present the content, then the displays in the following floors, and so on. Since this test was performed at an indoor space and our location model enabled us to attain the topology of the indoor space, our approach just relied in the symbolic information. The indoor space used to perform this test was once again the Engineering School, where we registered eight displays: four in the first floor (see Figure 7-29) and two in the second and third floor.

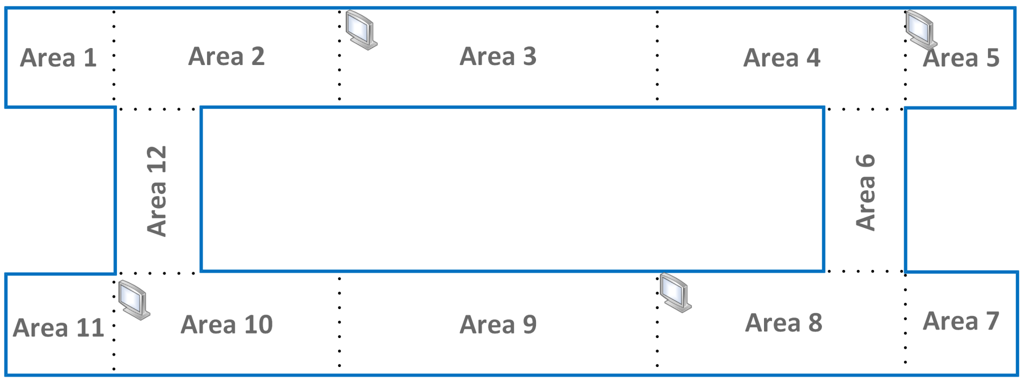


Figure 7-29: Engineering school floor plan.

Once all the displays were registered, we started the test. To perform this test we developed an application in Java language that uses the spatial information defined in the DB and in the spatial model server to compute the increasing area. To start the test the application requested the *Id* of the initial display, which was the first to present the content and, consequently used as a reference to compute the increasing area. Based on the space's *Id* where this initial display was located, the application searched for the near spaces and to each space attained it searched for displays within those spaces.

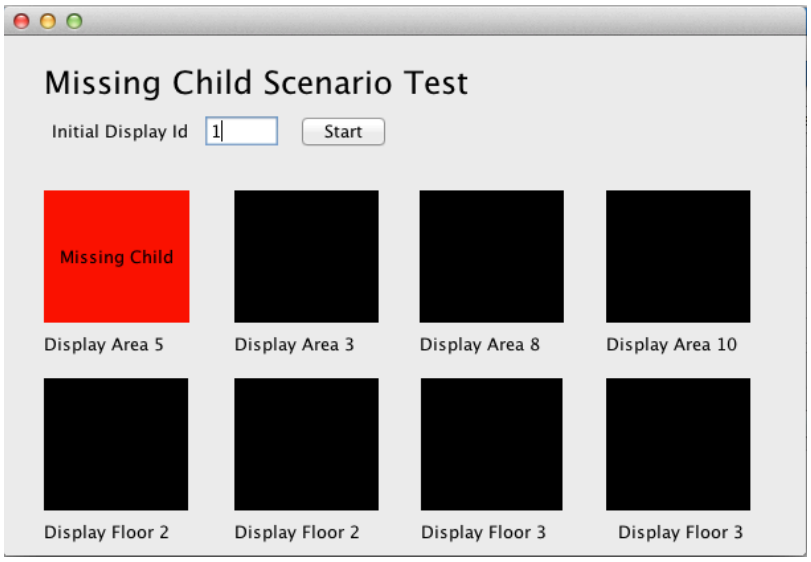


Figure 7-30: Missing child first step.

In our test we selected the display in the *Area 5* (display with the *Id*=1) to be the initial display (see Figure 7-30). The application immediately sent an instruction to that display to present the missing child content. Afterwards, the application consulted the DB to obtain the *Id* of the space where that display was located, i.e. the *Id* of the Area 5. Through this *Id* the application inquired the spatial model server to attain the areas related with the Area 5 (i.e. the Area 4 and Area 6), and then searched in the DB for displays in those areas. However, no display was defined in those areas, and after some time (five seconds) the application inquired again the spatial model server to attain the areas related with the Areas 4 and 6, i.e. the Area 3, 7 and 8. By searching for displays in those areas the application found a display in the Area 8 and so, it sent the instruction to that display to present the missing child content (see Figure 7-31).

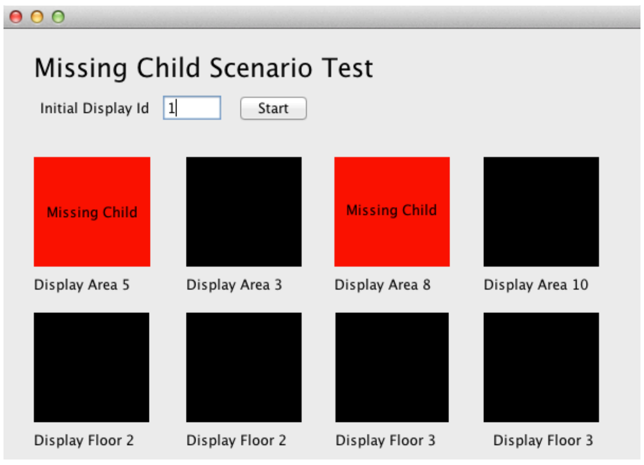


Figure 7-31: Missing child second step.

The application continued the search in the following areas of this floor and found two more displays, one in the Area 3 (see Figure 7-32) and other in the Area 10 (see Figure 7-33). For each display the instruction to present the missing child content was sent.

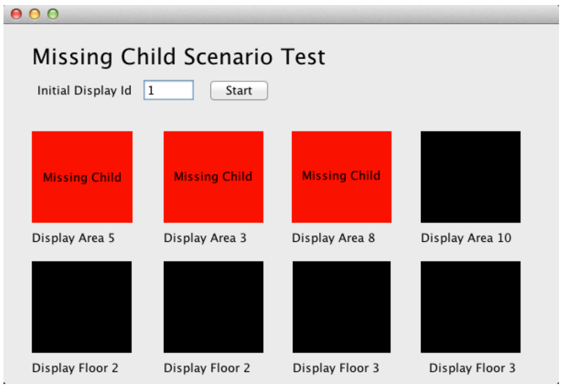


Figure 7-32: Missing child third step.

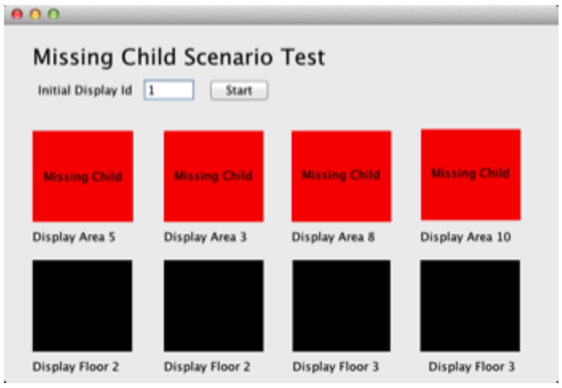


Figure 7-33: Missing child fourth step.

At this point the application searched in all first floor areas. Therefore, all the displays in this floor were presenting the missing child content. However, the child was still missing and for that reason the application extended the search to the following floors of the building, i.e. Engineering School's second and third floor. By following the topology of the building the application firstly search for displays in the second floor and as a result two displays were found. The instruction with the missing child content was sent to those displays (see Figure 7-34).

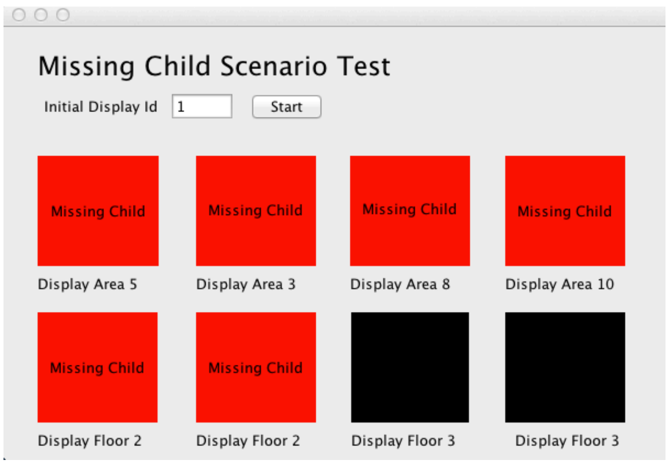


Figure 7-34: Missing child fifth step.

Then the application searched for displays in the third floor and as a result it found two more displays. The same instruction was sent to those displays and they also presented the content (see Figure 7-35).

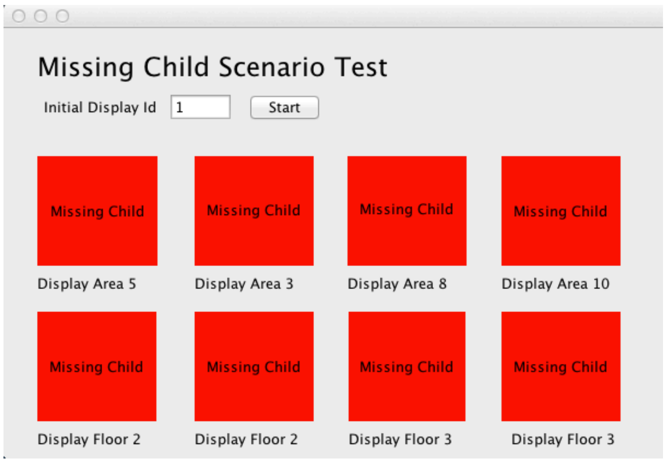


Figure 7-35: Missing child sixth step.

In the meantime the child was found, consequently the application stopped the search for more displays and the current displays stopped presenting the missing child content. If the search would continue the application would search for more displays outside the building.

7.3. Emergency evacuation

The emergency evacuation scenario, described in the section 1.2, was also used to evaluate the displays' spatial information. The goal of this scenario was to provide navigational information to people, for them to reach a safe area. However, the test performed in this work was slightly different from the one described in the scenario, as it was not only performed at an indoor space, but also the safe areas were emergency exits. To provide the directional information to reach the nearest emergency exit, the information defined during the surrounding step was required as it was in that step that the emergency exits directions (i.e. the surrounding key elements) in relation to the display's location were defined. To find the displays and the emergency exits that were defined within that indoor space, the symbolic information was also required. To perform this test we created an indoor space with three emergency exits and three displays (see Figure 7-36). This indoor space was divided into eight different areas, the displays were registered in the Areas 2, 4, and 7 and the emergency exits were registered in the Areas 1, 5 and 7. This space and the key elements were registered in the symbolic world model.

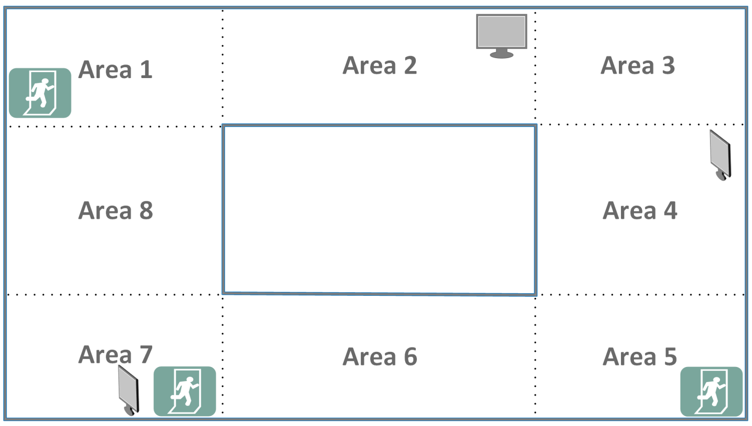


Figure 7-36: Space floor plan.

Display	Emergency Exit Area 1	Emergency Exit Area 5	Emergency Exit Area 7
Area 2	Left	Right	Left
Area 4	Left	Right	Right
Area 7	Left	Back	Back

Table 7-1: Emergency exit directions relatively to the display's location.

The Table 7-1 presents the directions of each emergency exit relatively to each display. This table will be used to validate the results.

To perform this test we developed an application in Java. When we initialized the application it requested the spaces' *Id* where the emergency situation was occurring, in this case the *Id* was 295 (see Figure 7-37).

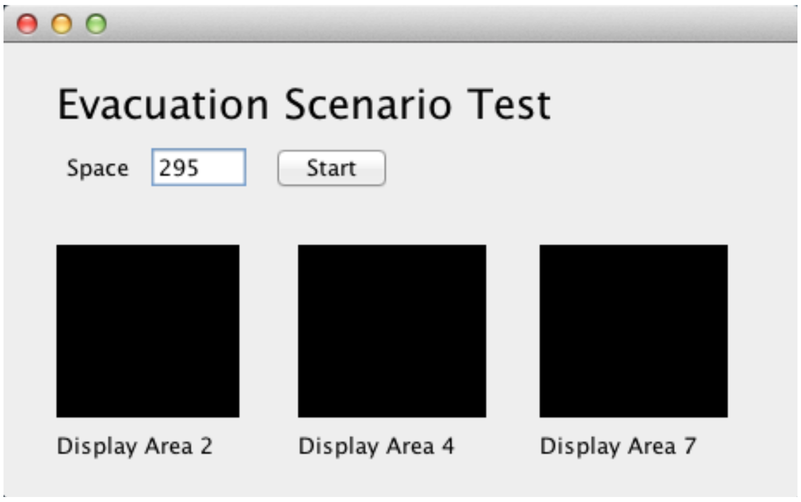


Figure 7-37: Evactuation first step.

Using this *Id,* the application inquired the spatial model server to attain all the areas within that indoor space. The returned areas were the Areas 1 through 8. For each of these areas, the application searched for objects related with them. However, only the object's *Ids* defined as *"KeyElement"* and with *"Emergency Exit"* in its name were considered and stored (1). Besides this, the *Ids* of the areas where those key elements were defined were also stored. At the same time, the application searched for displays in those areas and the result were the displays in the Areas 2, 4 and 7. Then, for each display the application searched for the nearest emergency exit. To do so, the application started to get the *Id* of the area where the display was located and inquired the spatial model server in order to attain the *Ids* of the areas immediately followed. From the attained areas the application checked if the *Ids* of those areas matched the ones with emergency exits (that were stored in (1)). If one of those areas had an emergency exit, then the application through the *Id* of the display, as well as the *Id* of the emergency exit consulted the DB (*KeyPoints*table) and got the direction's information. Otherwise, the application continued searching in the subsequent areas. When this procedure was performed to all of the displays, the application sent an instruction to each display with the direction information that had to present. In our test the nearest emergency for the display in the Area 2 was the one in the Area 1, for the one in the Area 4 was the display in the Area 5 and finally, for the display in the Area 7 was the one in the same area. By consulting the Table 7-1 we can conclude that each display had to present the following direction information: *Left, Right, Back*. Which was the result attained (see Figure 7-38).

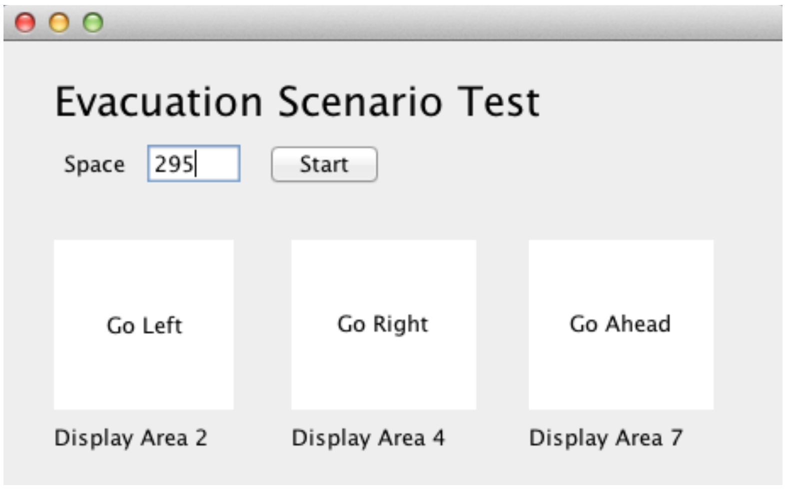


Figure 7-38: Evacuation second step.

To test the resilience of the spatial information we intentionally blocked one of the path/areas that lead to an emergency exit. So the application had to find an alternative way, i.e. a path to an accessible emergency exit. The blocked area was the Area 1 (marked with red dots in the Figure 7-39) so its emergency exit was inaccessible. Therefore, the display in the Area 2 could not rely in that emergency exit anymore.

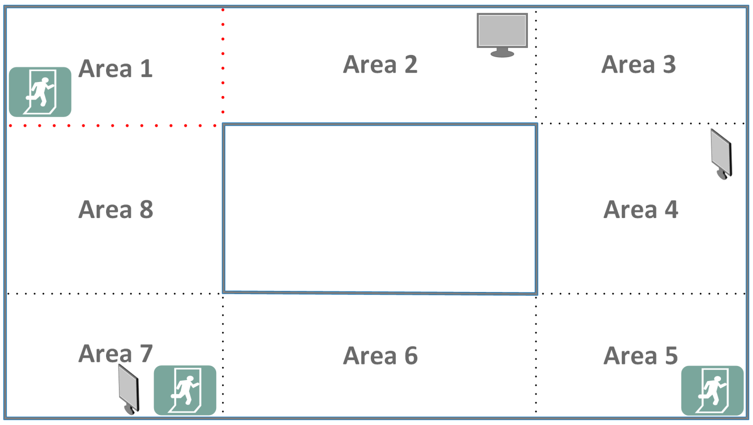


Figure 7-39: Blocked path.

The application used the same procedure described above but the only difference was that any path that contained the Area's 1 *Id* was not considered. Therefore, the display in the Area 2 presented new direction information: *Right*. The others displays continued to rely in the previous emergency exits and for that reason their content stayed unchanged (see Figure 7-40).

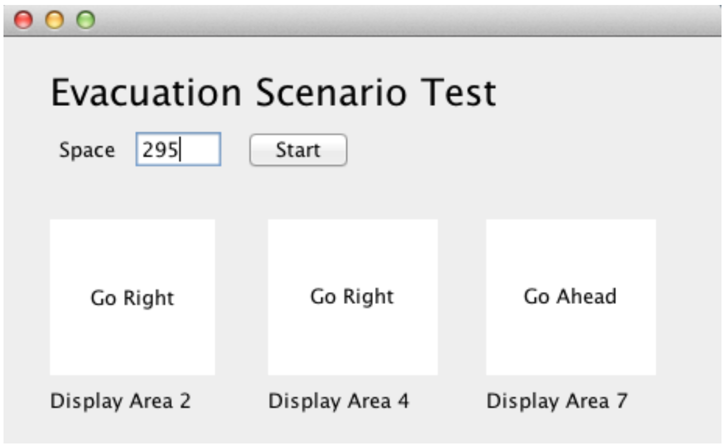


Figure 7-40: Evacuation third step.

We then restored the Area 1 (i.e. it was again accessible) and we blocked the Area 5, marked with red dots in the Figure 7-41.

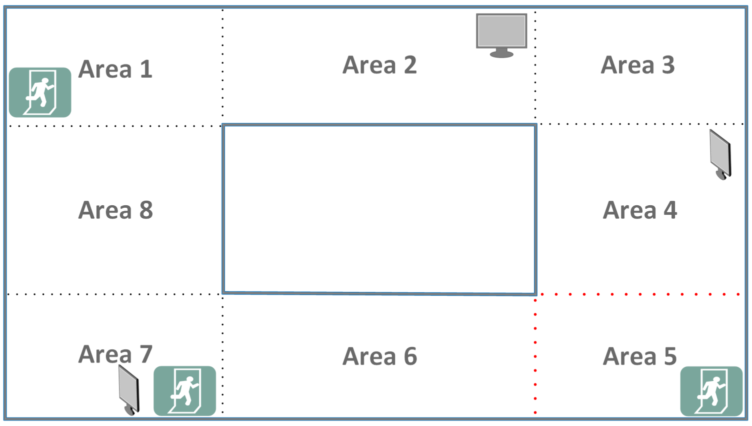


Figure 7-41: Blocked path.

At that moment, the emergency exit in the Area 5 was inaccessible and so, the display in the Area 4 could not rely in the emergency exit anymore. The application followed the same procedure except that any path that contained the Area 5 was not considered. Hence, the content of the display in the Area 4 changed. The content of the display in the Area 2 also changed because its nearest emergency exit was accessible again, i.e. the emergency exit in the Area 1. The content of the display in the Area 7 remained unchanged. In conclusion, the display in the Area 2 presented the direction *Left*, the display in the area 4 presented the direction *Left* and the display in the Area 7 presented the direction *Back* (see Figure 7-42). This information can be verified in the Table 7-1.

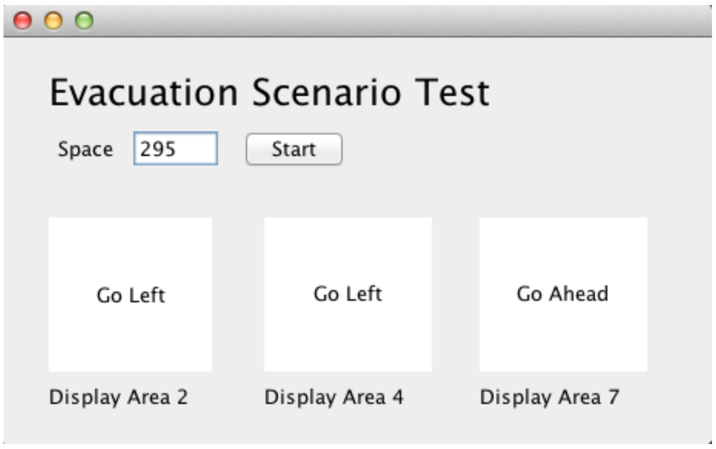


Figure 7-42: Evacuation fourth step.

7.4. Chapter summary

In this chapter, we proposed to perform three tests: (1) evaluate the application developed to register the displays; (2) evaluate the generated spatial information; and (3) test the application in a real set up, i.e. perform a registration of a real display in a real indoor space. Even though the application had been tested during its implementation, we felt the need to perform the later test. Its goals were to not only identify any issues or improvement aspects that could be added to the application but also to test the interactions between the application, BO, DB and spatial model server. After performing multiple registrations we found some minor issues in the application that were promptly fixed, as well as we added some improvements to the application. The association step was successfully performed, as the application was able to identify the network, connect with the BO and identify the display. Regarding the spatial information, the application successfully used the accelerometer sensor to infer the display's orientation, and the Google Maps API to infer the displays' geometric coordinates. The information regarding the indoor space where the displays were located and the surroundings key elements within that space were successfully attained from the spatial model server. This meant that the interactions between the application, BO and spatial model server were performed as expected. When the registrations were completed we validated that the spatial information had been correctly stored in the DB.

The second and third tests allowed us to evaluate if the displays' spatial information was generated with the required level of detail to fulfil the spatial needs of those scenarios. More precisely, the goal of the second test was to disseminate the content over an increasing area. Using the symbolic information it was possible to determine the displays that were near to a given display and so, the increasing area was achieved. As previously explained, once this test was performed at an indoor space with multiple floors we could have not relied in the geometric information. The missing child content was successfully spread over the displays in the first floor of the Engineering School and then over the displays in the second and third floors. Regarding the third test, its goal was to provide assistance in an emergency situation by indicating the direction of the near emergency exit. To attain the required information, we relied in the information of the space where the displays were located, as well as in the surrounding key elements of that space. The space's information was required to identify the displays and the emergency exits within that space, while the surrounding information was required to attain the direction that the displays had to present to its nearest emergency exit. Through the results attained, we validated that all the displays presented the correct direction information to their nearest emergency exit. We then blocked some paths/areas to evaluate if the application would be able to compute an alternative path, i.e. a path that lead to an accessible emergency exit. The application was able to compute an alternative way just by relying in the available spatial information of the displays.

In summary, based on these results we can conclude that the application is working as expected and the spatial information is being generated with the required level of detail.

8. Conclusion and outlook

This final chapter presents the main conclusions of this work. At this point, all the work developed in this thesis and the basis in which this work accents were presented. Moreover, multiple tests over the application and the generated spatial information were performed. We start to present the remarks of this work (section 8.1) and then we introduce some possible developments and challenges (section 8.2).

8.1. Concluding remarks

The main outcome of this thesis is a fully functional Android application to register public displays at any indoor space. This application generates and collects the required spatial information (i.e. the orientation, location, space and surrounding information) to perform the display's registration. These spatial requirements were identified based on the ones imposed by the display's usage patterns (section 4).

This application is to be used at any smartphone running the Android OS. We decided to rely on the smartphone's accelerometer sensor to attain the orientation information and the Google services to attain the location information. These automatic approaches were followed because the collected information is more accurate and immune to errors during the registration. Contrarily, the information regarding the indoor space and the surroundings key elements are manually defined. This information is stored at the location model. We used the symbolic world model developed by Baras K. *et al.* (2001) as it provides all the spatial needs of our solution.

The system's architecture required by our application is composed by: a back-office, database, location model and a network (section 5). In order to work as expected, we assume that these elements are already implemented and running. However, we did not impose how they should be developed. The only constraint is the back-office since it has to strictly follow the application's API, in order to perform the interactions with the application. Even though we used the spatial model server developed by Baras K. *et al.* (2001), we developed and implemented the back-office (Java), database (MySQL) and the network (Wireless Ad-Hoc network).

Once the application and all the elements of the system's architecture were fully implemented, we performed exhaustive tests to the whole system. The main goals of these tests were to evaluate the application's behaviour and to identify any area of improvement in the application. This first phase of tests was conducted at a virtual and controlled environment but afterwards, we tested it in a real set-up, i.e. performing a registration of a real display at a real indoor space. To perform this second test, we created a Wi-Fi Ad Hoc network to connect the application and the back-office and we registered the Engineering School and their key elements (such as: exits and emergency exits) in the symbolic world model. After performing the registration, we concluded that the application was working as expected and the spatial information was successfully generated, collected and stored.

To evaluate if the spatial information was generated with the required level of detail to match the spatial needs of the display's usage patterns, we built two tests environments. To do so, we developed two applications in Java, one to simulate the missing child scenario and the other to simulate an emergency evacuation scenario. Both of these applications just used the spatial information generated by the application and stored it in the database to present the appropriate content in the displays. We concluded that the spatial information was generated with the required level of detail as the spatial requirements of these two tests were successfully attained.

8.2. Future research and challenges

Further extensions and/or improvements can be considered, some are described below.

Regarding the location model, it would be interesting to improve the used model or develop a new one with more relations. The current model only allows using one of the available relations, which was the *"Is_Accessible_From (bidirectional)"*.

In the domain of the space, we would like to expand the registration to outdoor spaces and perform tests at such spaces.

In the application scope, we intent to use the Foursquare/Facebook API to attain the name of the places through the geometric coordinates, and also to perform registration of displays at outdoor spaces.

Lastly, a study to evaluate how random users use our application to perform the registration could be exploited. Through this study we could identify how random users use the application, which complications they encounter and what they think about the application. Through this feedback, further improvements could be performed.

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