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Wi-Fi based indoor navigation in the context of mobile services

Master Thesis at the University of Ulm

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2013

“Wi-Fi based indoor navigation in the context of mobile services”
Typeset August 15, 2013

THANK YOU TO: My advisor Rüdiger Pryss, who helped me throughout the implementation of the application and the writing of this thesis. His ideas provided the initial spark of this project and helped make this implementation possible. I would also like to thank my girl friend Ann-Kathrin Rüger, who helped and supported me, even when the going was tough and at times frustrating. Her help and support during all times of day contributed in no small part that the work could be completed in time. I would also like to thank the Department V of the University of Ulm, that supplied the material without which the work would not have been possible. Especially I would like to thank Mr. Raubold for numbers and information related to the campus and Mr. Hausbeck for the architectural drawings of building O27. Another big thank you goes to everyone that has made the past years at this university such a pleasant experience. Last but not least I would like to thank my parents, Peter and Manuela, who made my choice of major possible and stood by my side each and every semester.

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Typeset: PDF-L^AT_EX 2_ε

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1 Motivation

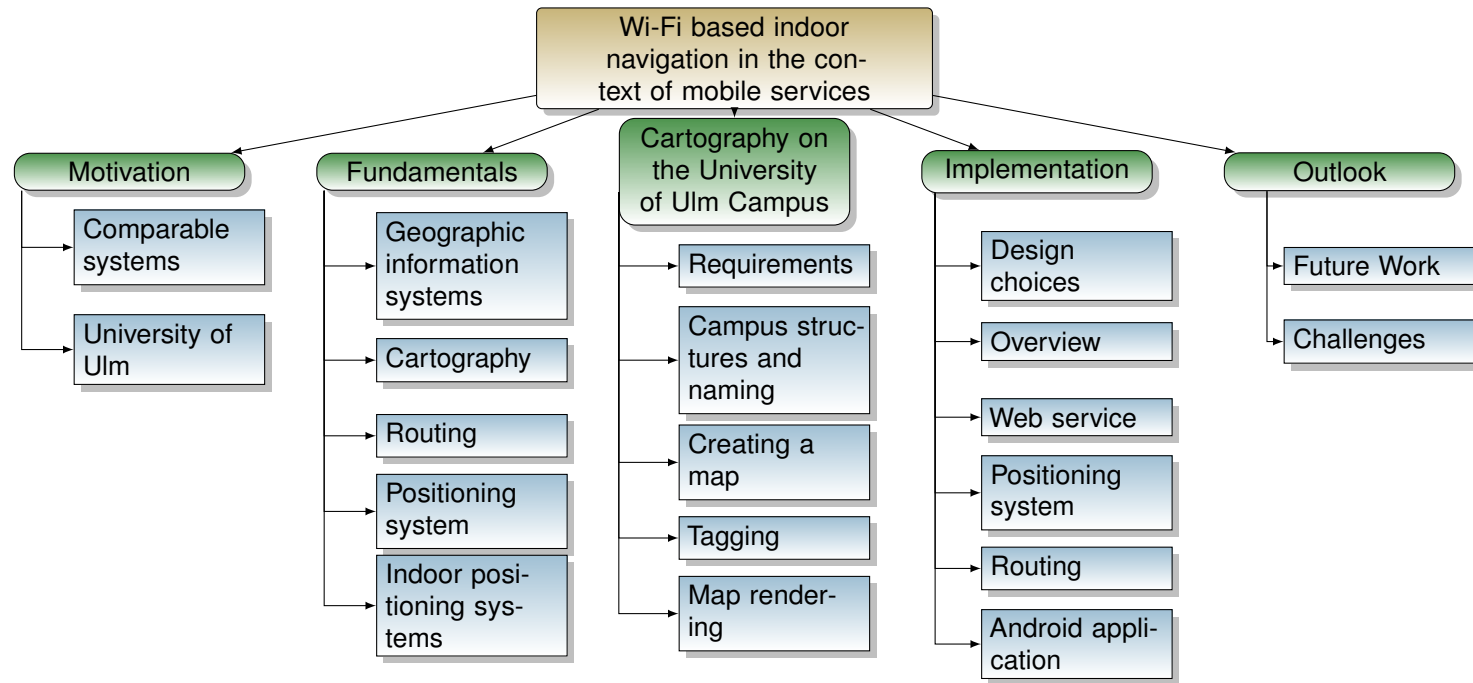
With the increased prevalence of smartphones and online mapping solutions like Google Maps, the next logical step is the mapping of indoor spaces. Especially in large public buildings like airports and shopping malls, people can profit from these systems. There are a large number of mapping solutions available on the market today. Some of the most popular being Google Maps [32], OpenStreetMap [48], Bing Maps [10] and MapQuest [41]. Google Maps and Bing Maps have both started offering indoor maps of a number of publicly accessible buildings, but these solutions are proprietary, and only data that is approved by these companies is accessible on their services.

The goal of the software and methods developed for this thesis is to provide a framework upon which an indoor mapping solution with the following properties can be developed:

- Indoor positioning
- Map of the indoor space
- Smartphone application that can access the map data and the position service
- A routing system that can give a user directions between rooms or from the users position to a room

The next page shows a graphical overview of the thesis as a whole and the topics covered by each chapter.

Overview



1.1 Comparable systems

Indoor navigation is by no means uncharted territory. Some of the biggest companies in the online mapping sector feature indoor mapping systems. Google added indoor maps to its system in 2011 with a focus on public buildings like airports and shopping malls [42]. Google Maps indoor maps also include positioning through Wi-Fi and the possibility to view different building levels.

1.2 University of Ulm

People who are unfamiliar with the naming and coordinate schema in use for rooms and buildings on the campus, are usually not able to find their way around without asking someone for help. New students as well as visitors are the primary target for this application, but even people already familiar can profit from an easier way to find the location of a room.

Another factor contributing to the problem of people getting lost is that the campus is spread out on a relatively large area with three separated parts:

1. Eastern campus
2. Western campus
3. Helmholtz institute

The eastern and western campus are also separated by the university's clinic, adding to the already somewhat confusing layout. Figure 1.1 gives an overview of the campus and separate parts of the campus. With a floor space of $121,601.28m^2$ for the eastern campus alone [1], an electronic aid for navigation provides a helpful tool. The application that was developed in this thesis has the goal of providing a mobile mapping and positioning solution for the campus of the University of Ulm. This way, anyone can find their position on the map inside buildings and get directions to any room on campus. The application is

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Figure 1.1: Overview of the University of Ulm campus

a prototypical implementation for this problem, providing a mapping solution for a single building on campus, which is built to be extendable to the whole campus.

2 Fundamentals

2.1 Geographic Information Systems

A geographic information system is defined as a “special-purpose digital database in which a common spatial coordinate system is the primary means of reference. ” by [18]. A broader interpretation of the term extends the system to include all systems that work with geographic information.

To create a mapping solution, the first step is to gather all information about the object to be mapped. A geographic information system provides specialized features to simplify working with geographic features. The heart of a geographic information system (GIS) is the database. A popular system of this kind is the PostgreSQL database extension *PostGIS*. The next section will explain the features of a specialized GIS database by the example of *PostGIS*.

2.1.1 PostGIS

PostGIS extends the PostgreSQL database by three features [46]:

spatial types Data types that represent geographic information, for example a line or polygon on the map.

spatial indexes Increase the speed with which the relationship between objects can be determined. This can include properties like objects within the same bounding box.

spatial functions Functions to query the properties of objects. For example the distance between two objects can be calculated by the database.

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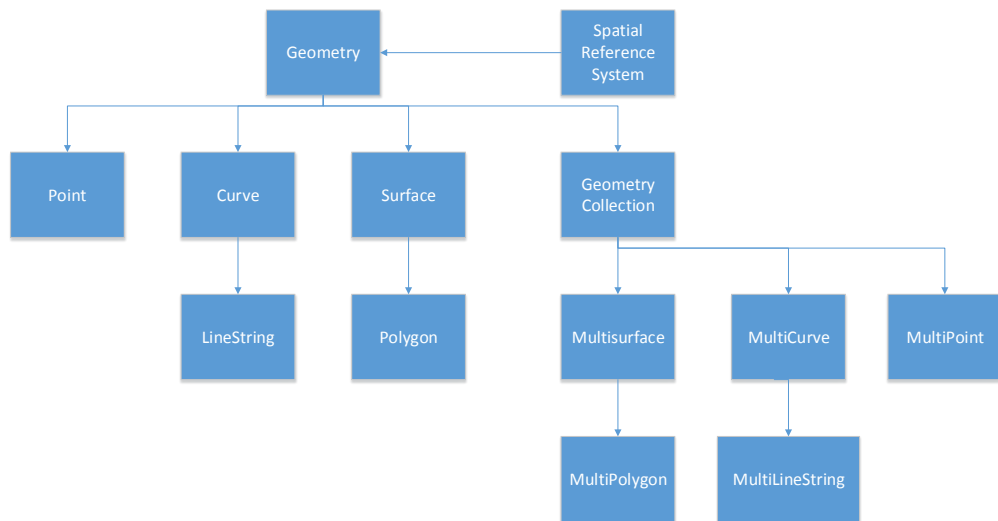


Figure 2.1: PostGIS Data hierarchy [46]

Data types These spatial features provide specific data types for geographic objects. Objects are represented using three different data types [46]:

1. points
2. lines
3. polygons

The need for these data types is explained in the PostGIS Documentation:

“An ordinary database has strings, numbers, and dates. A spatial database adds additional (spatial) types for representing geographic features. These spatial data types abstract and encapsulate spatial structures such as boundary and dimension. In many respects, spatial data types can be understood simply as shapes.” [46]

The full hierarchy of these shapes is shown in Figure 2.1.

Indexes In relational databases an index is used to speed up the access to data in a specific column [27]. Indexes in a spatial database can be used to perform geographic queries. Since geographic objects can overlap, a common operation in spatial databases is to find objects that are contained in a bounding box.

”A bounding box is the smallest rectangle – parallel to the coordinate axes – capable of containing a given feature.“ [46]

Spatial Functions Another feature offered by spatial databases like PostGIS are functions that can be performed on the geographic objects in the database. The functions can be grouped into five different categories [46]:

- Conversion: Functions that convert between geometries and external data formats.
- Management: Functions that manage information about spatial tables and PostGIS administration.
- Retrieval: Functions that retrieve properties and measurements of a geometry.
- Comparison: Functions that compare two geometries with respect to their spatial relation.
- Generation: Functions that generate new geometries from others.

Using these functions, operations on geographic data can be performed within the database.

2.2 Cartography

Cartography is defined as “the study and practice of making maps”[69]. The topic is one of the main aspects of this thesis, because the visual representation of the map is the main interface for a user of the application. The requirements for the map are centered around a correct visual representation. Different colors allow the user to better discern

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the features of a building. The mapping scheme is also based on colors in use on other mapping projects to provide a familiar look and feel of the application as a whole.

This chapter will give an introduction into the area of cartography, centered around the different map projections. The second part of this chapter focuses on the inner workings of the OpenStreetMap project and their implications for the work in this thesis.

2.2.1 The OpenStreetMap project

The OpenStreetMap project was founded in 2004 with the initial goal of mapping the United Kingdom [63]. In April 2006 the OpenStreetMap foundation was established to “encourage the growth, development and distribution of free geospatial data and provide this data for anyone to use and share.” [63]. In the beginning, already published data sets from the UK Government were used to build an open and easily accessible mapping solution. The concept of OpenStreetMap is similar to the Wikipedia project, where anyone can edit or add entries. On OpenStreetMap, anyone can edit maps and corrector errors or insert missing roads. Missing streets can be added by using GPS units and tracking an existing path or by tracing roads, mountains or other features on satellite imagery [59]. One of the building principles of the OpenStreetMap project is the free distribution of this information. As a direct result of which, all data is licensed under the “Open Data Commons Open Database License” [47] with the following conditions:

“You are free to copy, distribute, transmit and adapt our data, as long as you credit OpenStreetMap and its contributors. If you alter or build upon our data, you may distribute the result only under the same licence. The full legal code explains your rights and responsibilities.” [47]

Keeping with the goal of open data, all tools used in the development of OpenStreetMap are also licensed under various open source licenses:

“OpenStreetMap is not only open data, but it's built on open source software. The web interface software development, mapping engine, API, editors, and many other components of the slippy map are made possible by the work of volunteers.” [59]

2.2 Cartography

Because anyone can edit map data, OpenStreetMap can leverage the knowledge of people on location, who can add information about buildings, amenities or bus stops. This large amount of meta information allows for very detailed maps. Like other crowdsourced information, the quality and coverage of data can vary greatly. As an example of the detail of data in OSM, Figure 2.2 and Figure 2.3 show the same map segment from the University of Ulm Campus in Google Maps and in the online OSM map. The amount of data that is part of the OpenStreetMap project's database is 370 Gigabytes as of Jun 7th 2013. The data can be downloaded as the so called *planet file*.

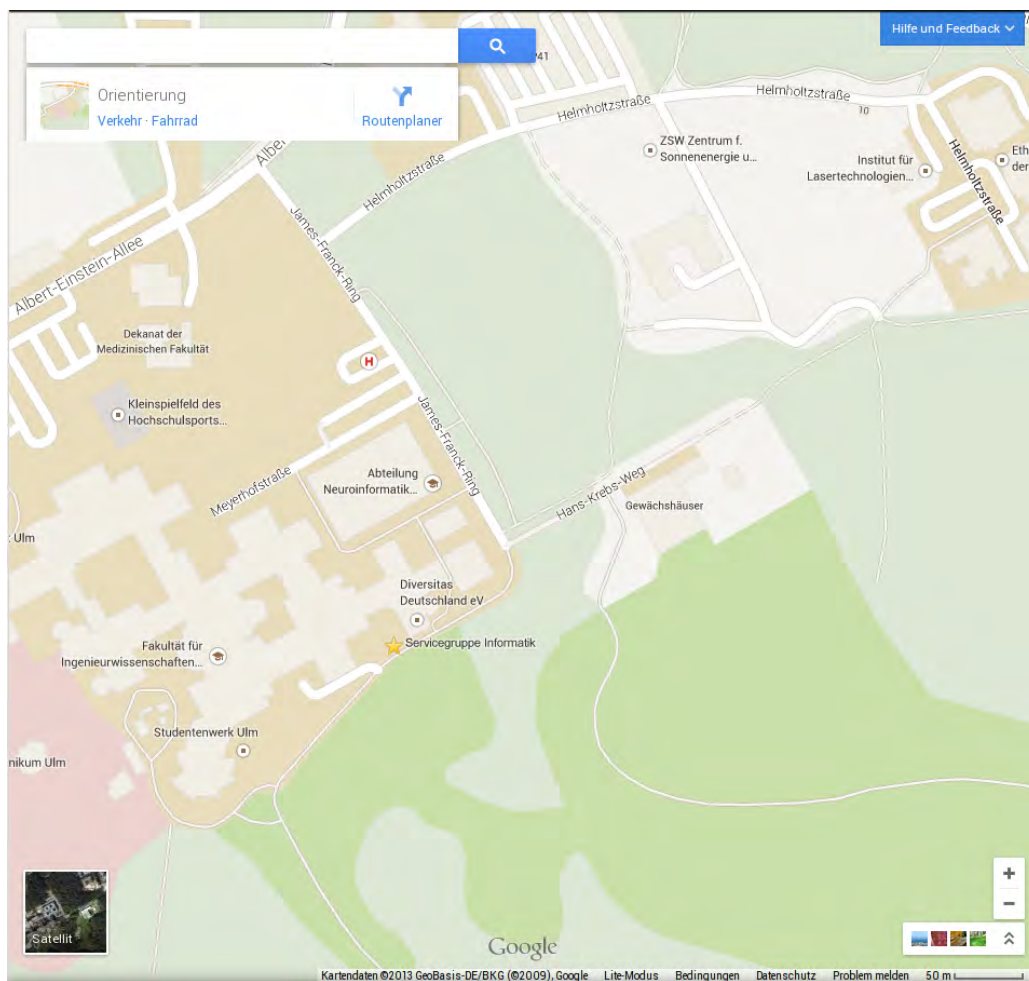


Figure 2.2: University of Ulm Campus: Google Maps [24]

2 Fundamentals

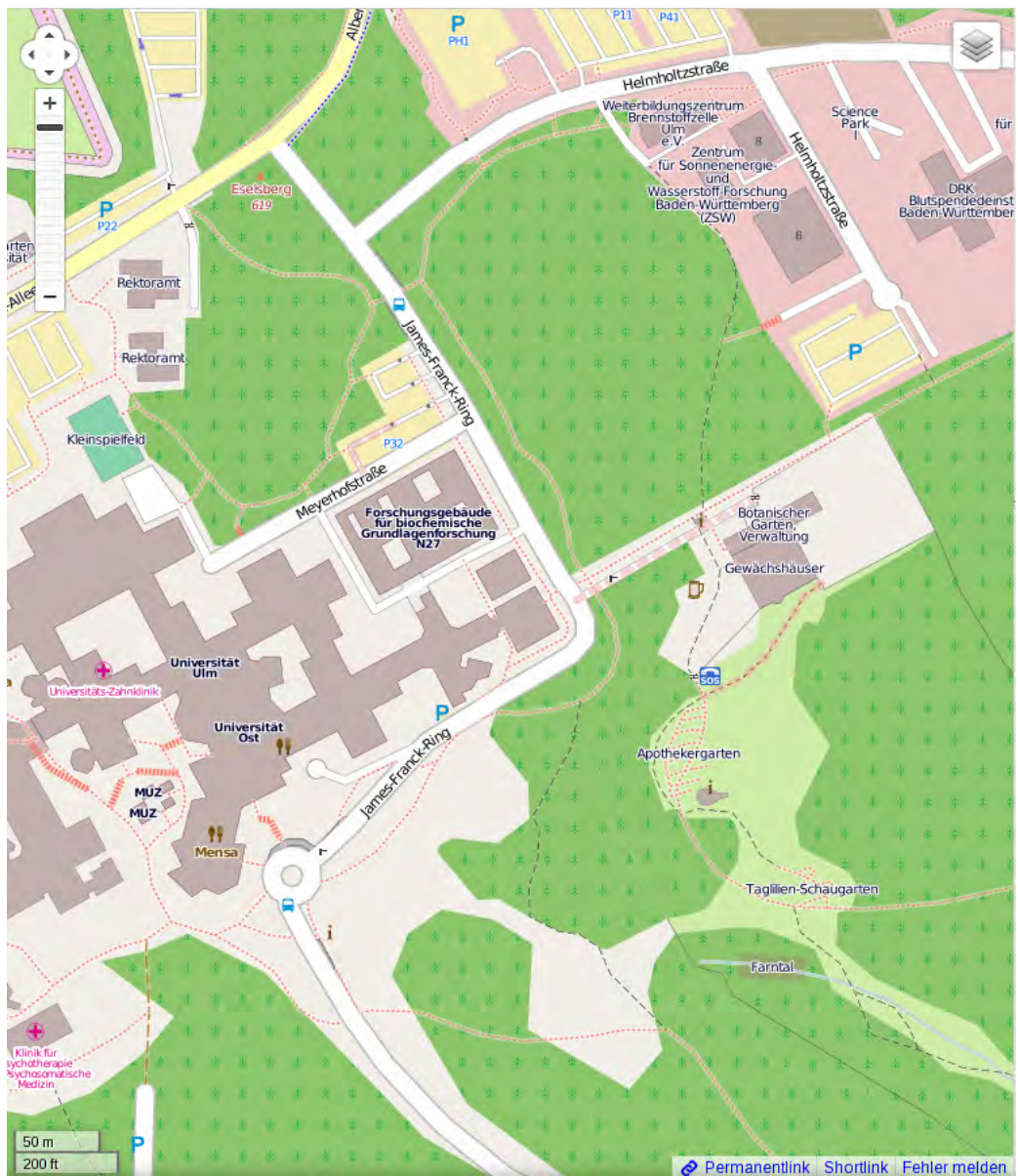


Figure 2.3: University of Ulm Campus: OpenSteetMap

2.2.2 OSM concepts

OSM uses a combination of a small number of different elements to represent objects in the database. Each of these elements can have attributes in the form of a *key/value* system.

Data elements

Three different data elements make up the geospatial information in the OpenStreetMap project [62]:

Node The simplest data element, a single data point, defined by a latitude and longitude. Shown in Figure 2.4.

Way A way “is an ordered list of between 2 and 2000 nodes” [62]. Ways are used to describe objects like buildings, roads or territorial boundaries.

Open polyline “An open Polyline is an ordered interconnection of between 2 and 2000 nodes describing a linear feature which does not share a first and last node. Many roads, streams and railway lines are described as open polylines.” [62] An example of a polyline object is shown in Figure 2.5.

Closed polyline “A closed polyline is a polyline where the last node of the way is shared with the first node.” [62]

Area An area is built using the same principles as a closed way. An area is not a data type in itself but defined using a tag or relation. Figure 2.6 is an example of such an area.

Relation “A relation is one of the core data elements that consists of one or more tags and also an ordered list of one or more nodes and/or ways as members which is used to define logical or geographic relationships between other elements. A member of a relation can optionally have a role which describe the part that a particular feature plays within a relation.” [52]



Figure 2.4: OpenStreetMap data element *node*

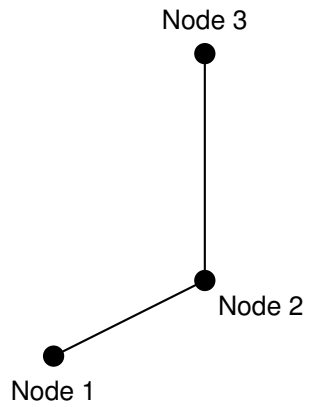


Figure 2.5: OpenStreetMap data element *way* with *open polyline*

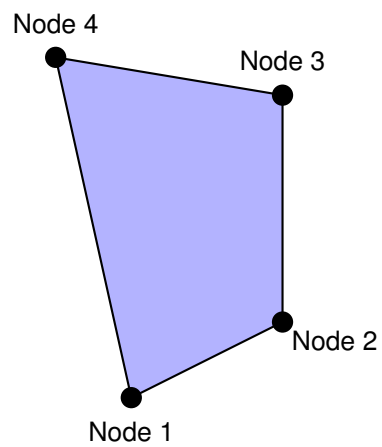


Figure 2.6: OpenStreetMap data element *way* with a closed polyline as *area*

Tags

Tags in OpenStreetMap are used to assign elements with metadata. The *tag* system consists of a key and value pair, which can be assigned to nodes, ways or relations [58]. There is no limit to the amount of tags that can be used. The key and value are both text fields and are usually used to describe the properties of an element. An example of this system is a road, which is represented using an open way in OSM. The way is marked using the pair *highway = motorway* which can be combined with additional information like *maxspeed = 60*. This tagging system is one of the greatest strengths of the project, since any kind of information can be included. For example, if the opening hours of stores are included in the tags, a map can be dynamically created showing all stores which are currently open. To ensure a coherent tagging schema, the OpenStreetMap Wiki provides a list of currently used tags and their usage [40]. For each item currently in use, an example of the tag, usually in combination with a picture, is provided. Table 2.1 provides a few examples of the range of information that can be saved using this system.

Key	Value	Description
shop	beauty	"A non-hairdresser beauty shop, spa, nail salon, etc. See also <i>shop = hairdresser</i> "
barrier	lift_gate	"A lift gate (boom barrier) is a bar, or pole pivoted in such a way as to allow the boom to block vehicular access through a controlled point. Combine with <i>access = *</i> where appropriate."
Restrictions		
emergency	yes	"Access permission for emergency motor vehicles; e.g., ambulance, fire truck, police car"
maxheight	height	"height limit - units other than metres should be explicit"
forestry	yes/no	"Access permission for forestry vehicles, e.g. tractors."

Table 2.1: Example of OSM tags in use [40]

2.2.3 Editing

Since OSM is a project primarily based on cloud sourcing, editing the map is one of the most important features. OSM has a choice of three different editor environments [60]:

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Potlatch A flash based editor, available as part of the online representation of the OpenStreetMap. It can be accessed directly from the *edit* tab of the map view.

JOSM An editor that is more powerful than Potlatch and is preferred by many experienced contributors but has a higher learning curve.

iD “Is the newest editor available from the edit tab, currently in beta status because it still has some minor issues. It is realized in html5/javascript (modern browser but no install required).”

Java OpenStreetMap Editor

The currently most powerful editor for OSM is the “Java OpenStreetMap Editor” (JOSM) [36]. Like most applications used in the OSM project, JOSM is also licensed under an open source license, the GNU General Public License [36]. JOSM features an extensive plugin system [36] which can change the interface or add features for specialized editing tasks, examples of which are plugins for tagging speed limits (*Maspeed tagging*), importing vector graphics (*ImportVec*), or aligning pictures (*PicLayer*) [37]

An example of the JOSM interface is shown in Figure 2.7. JOSM can also display imagery from other sources, for example MapQuest satellite imagery. Since Bing has licensed their imagery for use with the OSM project, their aerial imagery can be used to trace features like roads or buildings. This way new data can be imported into the OSM project, or already existing data can be corrected [61]. JOSM includes features to edit all aspects of OSM data, including tags and relations. JOSM can also directly upload data to OSM servers.

Figure 2.8 is an example of editing a *highway* tag of an intersection.

2.3 Routing

Part of this thesis is the implementation of routing functionality into an Android application. Routing and its associated algorithms are based on algorithms from graph theory.

2.3 Routing

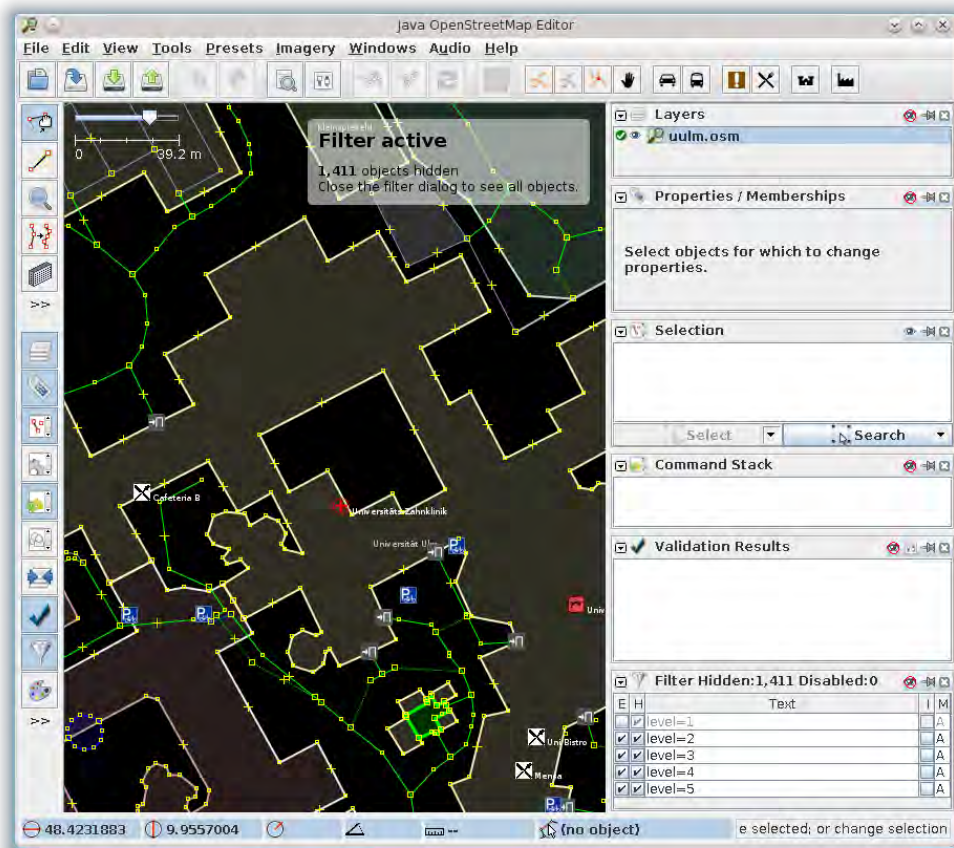


Figure 2.7: Example of the JOSM interface

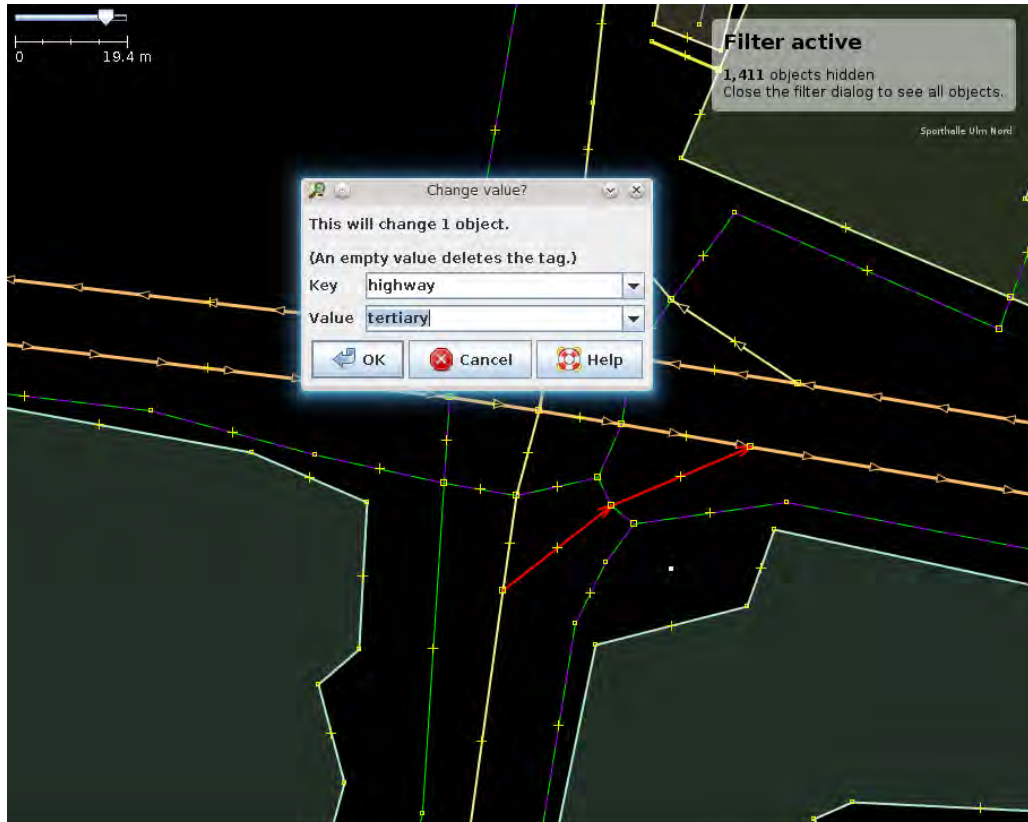


Figure 2.8: Editing an intersection in JOSM

Graph Theory

Graph theory is defined as "the study of graphs, which are mathematical structures used to model pairwise relations between objects." [70]. In the context of this thesis, the relations between objects are the paths that can be traveled by a user between two points.

The following elements are important in the context of graph theory [4]:

Graph A graph is composed of a set of vertices and edges

vertices A vertex could also be called a node or point and represents a single point on the graph.

edges An edge connects two vertices. As such it represents an ordered pair of vertices.

path A path is a sequence of vertices

The objective of a routing system is finding a path between two points, denoted as the start (S) and the end (E). Figure 2.9 shows the trivial case of routing between two points with only a single available path.



Figure 2.9: Trivial routing

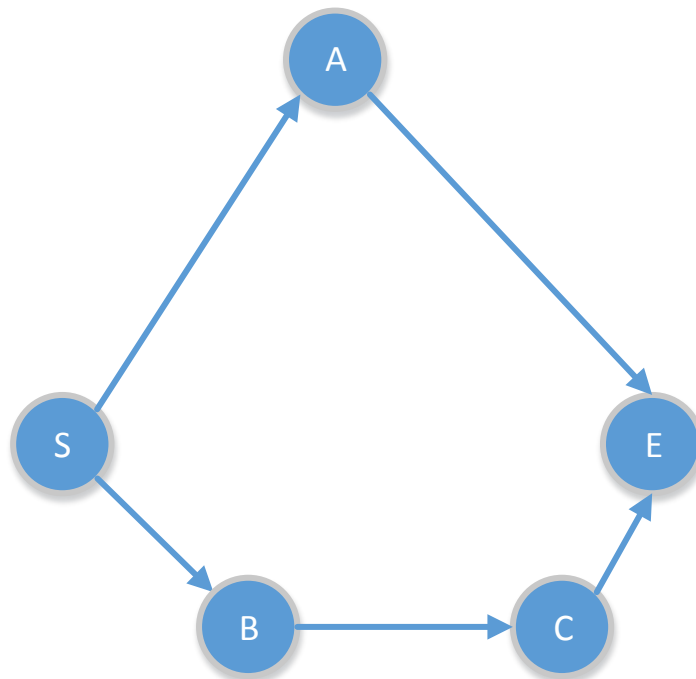


Figure 2.10: Complex routing

2.3.1 Routing algorithms: Shortest path problem

The trivial case isn't very realistic. Usually, there are multiple paths from the *start* to the *end* and not all paths will lead us to the destination. In Figure 2.10, there are two ways to get from the start to the end. The possible paths are:

1. $S \rightarrow A \rightarrow E$
2. $S \rightarrow B \rightarrow C \rightarrow E$

Either path is a possible route between the two points and would get a user from the start to the end.

The application of graph theory in this work is about navigation on a map. It is possible to provide users with a working route without finding the shortest path, but in terms of user acceptance it would provide a serious shortfall. To provide a correct routing algorithm, the shortest path needs to be found between two points.

Since the points on the graph are not separated equally in terms of the distance between them, a requirement of finding the shortest path is adding weights between two connected points. The resulting graph is known as a weighted graph. Figure 2.11 shows a weighted graph based on the example from Figure 2.10.

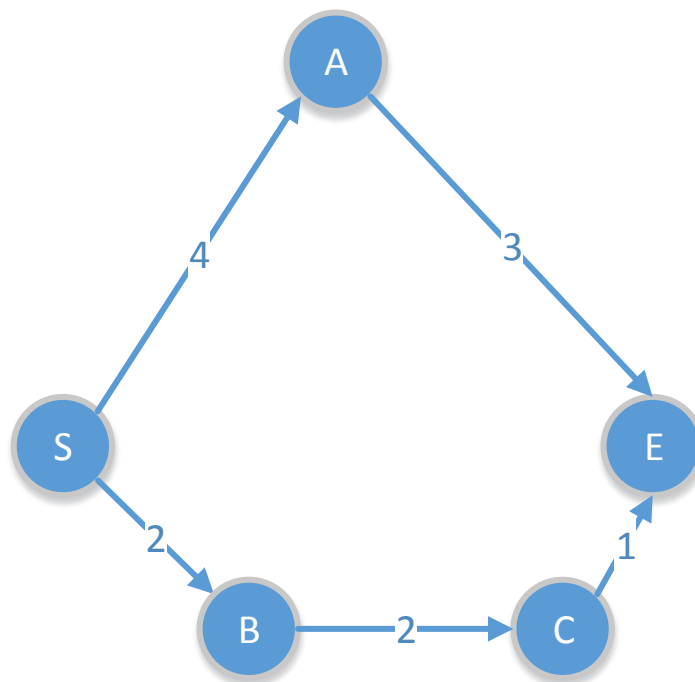


Figure 2.11: Weighted graph

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The connections between two points are now labeled with their corresponding weights, which would correlate to the distance between two points. The weights can now be used, to calculate the shortest path in Figure 2.11:

1. $S \xrightarrow{4} A \xrightarrow{3} E$, combined weights: 7

2. $S \xrightarrow{2} B \xrightarrow{2} C \xrightarrow{1} E$, combined weights: 5

The best resulting path is the second path.

In the problem of routing on a map, the weighted graph is constructed as follows:

vertices All nodes that can be traversed. For example all the houses on a street.

edges All paths that can be taken. To continue with the previous example, these would be the streets and side walks. The distance between two vertices are the weights on the graph. Accordingly, the geographic distance between two points equals the weight on the graph between two points.

The task of finding the shortest route thus equals the shortest path problem.

Comparison of shortest path algorithms

Dijkstra's Algorithm [15] has a running time of $O(n^2)$ when no further optimizations are considered [4]. A more popular algorithm for routing applications is the A^* algorithm [26]. Through the use of heuristics, A^* can achieve a faster running time. Considering the complexity of the algorithm, Dijkstra's algorithm was chosen for the implementation, since its implementation was achievable in considerably less time.

Dijkstra's algorithm The actual algorithm that was used to implement the routing algorithm in this thesis is Dijkstra's algorithm [15], published in 1959 by dutch computer scientist Edsgar Dijkstra. The algorithm can be classified as a Greedy-Algorithm [56]. The general hypothesis in this algorithm is, that by finding an optimal solution for a path to the element $n - 1$, the path to element n is equal to the previous path plus the optimal path from $n - 1$ to n .

The algorithms's pseudo code is shown in Algorithm 1 with the following definitions [56]:

V list of all vertices

u starting vertex

v all other vertices

$l(v)$ shortest length from u to v

$k(v)$ optimal edge to v

W list of unchecked vertices

F selection of edges, which form the shortest path from u to all other vertices

Algorithm 1 Dijkstra's algorithm in pseudo code [56]

```

for  $v \in V$  do
   $l(v) := \infty$ 
   $l(u) := 0$ 
   $W := V; F := \emptyset$ 
end for
for  $i := 1$  to  $|V|$  do
  find a vertex  $v \in W$  with a minimal  $l(v)$ 
   $W := W - \{v\}$ 
  if  $v \neq u$  then
     $F := F \cup \{k(v)\};$ 
  end if
  for  $v' \in Adj(v), v' \in W$  do
    if  $l(v) + w(v, v') < l(v')$  then
       $l(v') := l(v) + w(v, v')$ 
       $k(v') := (v, v')$ 
    end if
  end for
end for

```

2.4 Positioning system

Another fundamental part of the application developed is a positioning system. Without a positioning system, a user would have to find his position on the map manually. This time

2 Fundamentals

intensive and error-prone task should be handled by the application itself, resulting in a automated positioning and the displaying of the current user position on a map.

A number of methods can be used for this kind of positioning system.

2.4.1 Overview of positioning systems

A large selection of navigation systems are currently available. These can range from a compass and a map to systems that integrate a satellite based positioning system like GPS with an on screen display of a map as used in in-car navigation systems. Common to most of these systems is their reliance on radio waves as a positioning aid.

Manual positioning

A simple solution to the problem of showing the users current location on a map is relying on the user to position himself. If a user is given a complete map, he can use it to find his current location himself. This can only work if the user has a general idea of his current location. Given a map of a university campus, a user can use visual cues around him to accurately pinpoint his position on the map. This kind of process is labor and time intensive, and as previously discussed, error-prone and not very user-friendly. Considering the usability requirements of the application, a manual positioning system is not practical.

Global Positioning System

One of the most popular systems to determine a location in wide spread use are systems using satellites and trilateration. The best known system of this kind is the American Global Positioning System (GPS). As found in previous work of the author [9], GPS signals would provide an accuracy of at least seven meters. But since GPS requires a line of sight to at least four satellites, such accuracy is not feasible in an indoor environment. If a fix could be achieved at all, it could be very inaccurate and most of the time, a fix is not achievable at all. Another downside of GPS based systems is the time required to get a

fix. This time frame is known as the *time-to-first-fix* (TTFF) and can take more than 20 minutes, if the GPS equipment has no up to date information about satellite positioning, last position, or the date/time [45]. Through the usage of assistance technologies, it has been possible to reduce this time. AGPS for example can typically achieve a TTFF of 30 seconds [35].

2.5 Indoor positioning systems

The previous examples of positioning systems are not optimized for an indoor environment, and while they are sufficient in an outdoor environment, an indoor environment brings these technologies to their limit. This has led to the development of several different positioning systems for the indoor environment, a selection of which are presented in the following sections. The requirements and problems facing indoor positioning systems are [5]:

Accuracy The accuracy of an indoor positioning system is one of the most important metrics. The goal of any such system is the localization of a user in three dimensional space. A system with an accuracy of only 50 meters might be sufficient for some use cases, but in the context of indoor navigation, an accuracy of at least 10 meters is necessary.

Security Providing accurate information about the position of a user is needed for indoor navigation, but if an outside party is able to decrease the accuracy of the system, the result would be limited to a bad user experience. As such, the security requirement for the work of this thesis is not as strict as if the positioning system is for example used to navigate robotic vehicles.

2.5.1 Positioning principles

In general, the systems are using one or a combination of the following four principles: trilateration, triangulation, scene analysis, and proximity [5].

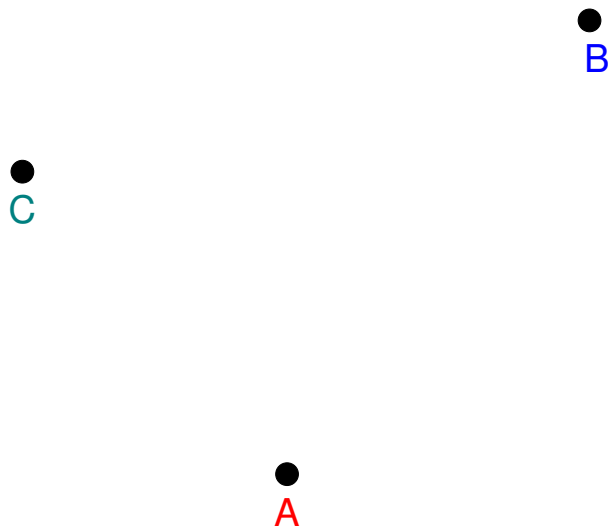


Figure 2.12: Trilateration: Three reference nodes

$A \longleftrightarrow X$	3
$B \longleftrightarrow X$	4.7
$C \longleftrightarrow X$	4

Table 2.2: Distance between X and reference nodes

Trilateration Uses the known location of three reference nodes and the distance from each node to the unknown location [14]. The calculated distance to each reference node can be visualized as a radius around each node. The intersection of all three radii should correspond with the current location. Trilateration is usually used in combination with radio/infrared radio systems, which can be used to get a reasonably good estimate about the distance to the reference locations. Figure 2.12 shows a scenario, where three reference nodes A , B , and C exist.

In this scenario, we are trying to find the current position, denoted as X . To perform trilateration, the distance between X and the three reference nodes is shown in Table 2.2

As shown in Figure 2.13, using these three distances as radii for each reference node, we can now determine the location of X as the intersection of all three.

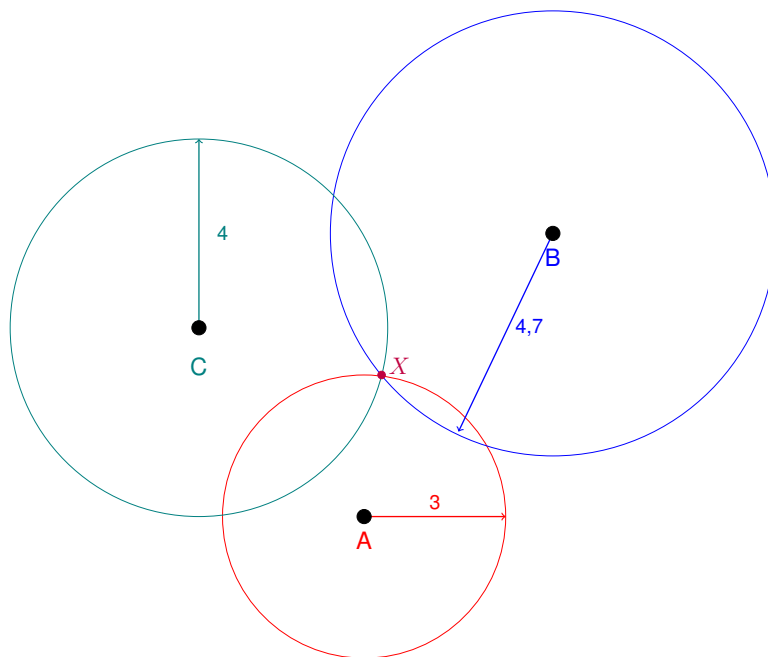


Figure 2.13: Trilateration: position is at intersection of three radii

Triangulation Works similar to trilateration, except that instead of being able to measure the distance to known points, measurements are based on angles. Unlike trilateration, triangulation requires only two reference nodes [14] in combination with the unknown third node. The required information is now the angle from the reference nodes to the unknown node. The intersection of the lines equals the location of the unknown node. Figure 2.14 shows an example of this scenario.

Scene Analysis In combination with radio waves is also known as fingerprinting [5]. "Location fingerprinting refers to techniques that match the fingerprint of some characteristic of a signal that is location dependent" [5]. The location is determined by comparing the received radio waves and their characteristics with a database of readings. This database is constructed during the offline phase by measuring signals at predetermined points at the location that will later be used for positioning. The actual location is determined by comparing these signal readings with the readings currently being received by a device. Using pattern recognition algorithms [5], a most likely location is calculated. An example

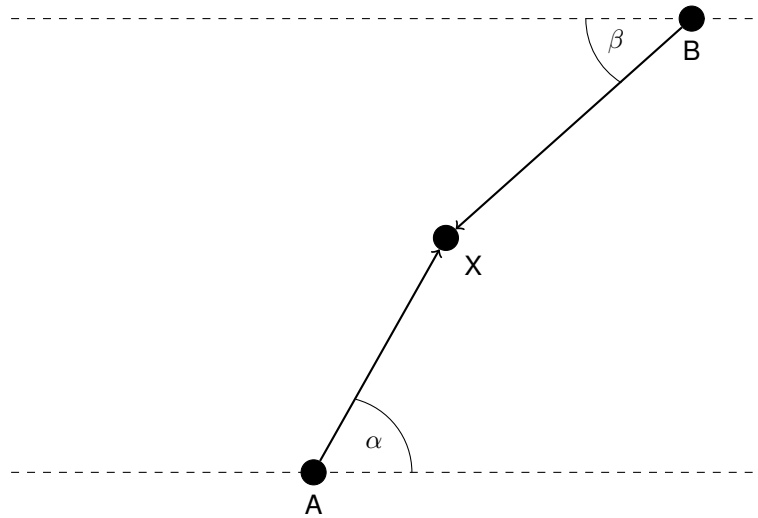


Figure 2.14: Example of triangulation

of this technique is the Wi-Fi fingerprinting system used in this thesis and described in more detail in Section 2.5.2.

2.5.2 Wi-Fi indoor positioning system

The positioning system used for this thesis is based on wireless fingerprinting. The factors that influenced this decision are explained in the following paragraphs:

Cost

Cost is one of the largest factors for this choice. The campus of the University of Ulm provides a campus wide network of Wi-Fi access points. Therefore, using wireless positioning does not require any additional infrastructure or changes to the existing services. To provide an offline database of reference nodes, a database can be stored on each client, minimizing the use of additional infrastructure. This also allows devices to position themselves without the requirement of an internet connection.

The second factor in terms of cost is the client that needs to be located. On the client side, wireless fingerprinting provides a cheap way to provide an indoor location system.

2.5 Indoor positioning systems

System/Solution	Wireless technologies	Positioning algorithm	Accuracy	Precision	Complexity	Scalability/Space dimension	Robustness	Cost
Microsoft RADAR	WLAN Received Signal Strength (RSS)	κ NN, Viterbi-like algorithm	3 ~ 5m	50% around 2.5m and 90%	Moderate	Good/2D, 3D	Good	Low
Horus	WLAN RSS	Probabilistic method	2m	90% within 2.1m	Moderate	Good/2D	Good	Low
DIT	WLAN RSS	MLP, SVM, etc.	3m	90% within 5.12m for SVM; 90% within 5.4m for MLP	Moderate	Good/2D, 3D	Good	Low
Ekahau	WLAN Received Signal Strength Indicator (RSSI)	Probabilistic method (Tracking-assistant)	1m	50% within 2m	Moderate	Good/2D	Good	Low
SnapTrack	Assisted GPS, TDOA		5m-50m	50% within 25m	High	Good/2D, 3D	Poor	Medium
WhereNet	UHF TDOA	Least square/RWGH	2-3m	50% within 3m	Moderate	Very good/2D, 3D	Good	Low
Ubisense	unidirectional UWB TDOA +AOA	Least square	15cm	99% within 0.3m	Real time response (1Hz-10Hz)	2-4 sensors per cell (100-1000m); 1 UbiTag per object/2D, 3D	Poor	Medium to High
Sapphire Dart	unidirectional UWB TDOA	Least square	< 0.3m	50% within 0.3m	response frequency (0.1Hz-1Hz)	Good/2D, 3D	Poor	Medium to High
Smart-LOCUS	WLAN RSS + Ultrasound (RTOF)	N/A	2-15m	50% within 15cm	Medium	Good/2D	Good	Medium to High
EIRIS	IR +UHF (RSS) +LF	Based on PD	< 1m	50% within 1m	Medium to High	Good/2D	Poor	Medium to High
SpotON	Active RFID RSS	Ad-Hoc lateration	Depends on cluster size	N/A	Medium	Cluster at least 2Tags/2D	Good	Low
LAND-MARC	Active RFID RSS	KNN	< 2m	50% within 1m	Medium	Nodes placed every 2-15m	Poor	Low
TOPAZ	Bluetooth (RSS) + IR	Based on PD	2m	95% within 2m	positioning delay 15-30s	Excellent/2D, 3D	Poor	Medium
MPS	QDMA	Ad-Hoc lateration	10m	50% within 10m	1s	Good/2D	Good	Medium
GPPS	DECT cellular system	Gaussian process (GP), κ NN	7.5m for GP, 7m for κ NN	50% within 7.3m	Medium	Good/2D	Good	Medium
Robot-based	WLAN RSS	Bayesian approach	1.5m	Over 50% within 1.5m	Medium	Good/2D	Good	Medium
MultiLoc	WLAN RSS	SMP	2.7m	50% within 2.7m	Low	Good/2D	Good	Medium
TIX	WLAN RSS	TIX	5.4m	50% within 5.4	Low	Good/2D	Good	Medium
PinPoint 3D-ID	UHF (40MHz) (RTOF)	Bayesian approach	1m	50% within 1m	5s	Good/2D, 3D	Good	Low
GSM fingerprinting	GSM cellular network	weighted κ NN	5m	80% within 10m	Medium	Excellent/2D, 3D	Good	Medium

Table 2.3: Wireless-based indoor positioning systems [5]

2 Fundamentals

Wireless receivers are broadly available and most of today's handheld devices like smart phones, tablets, or even laptops, provide all the needed hardware. Other indoor positioning systems rely on specialized hardware, that is not currently available on the campus of the university. The cost factor of installing specialized hardware for this purpose was also not feasible in the scope of this thesis.

Accuracy

As shown in Table 2.3, wireless fingerprint systems provide a degree of accuracy that is sufficient for the purpose of this thesis. While a position as accurate as possible is favorable, increased accuracy is only achievable with an increase in cost.

2.5.3 Euclidean distance based algorithm

To be able to estimate the position of a user, an algorithm needs to combine the Wi-Fi fingerprints in the database with the current signal landscape a device can receive. The algorithm is based on the research in [21] on the Euclidean distance algorithm. The basic idea of this algorithm is to compare the data measured by a device to the fingerprints in the data base. Based on the euclidean distances to matching *Signal/Nodes* in the database, the approximate position is calculated. The basic Euclidean distance algorithm is shown in Equation 2.1, where d is the distance, n is the number of access points being compared. $RSSI_{ci}$ is the *Received Signal Strength Indicator* of access point i during the calibration phase, and $RSSI_{pi}$ is the RSSI of the access point in the positioning phase [21]. RSSI uses the unit *dBm*, a logarithmic scale which uses an output signal of 1 milliwatt as 0 dB.

$$d = \sqrt{\sum_{i=1}^n (RSSI_{ci} - RSSI_{pi})^2} \quad (2.1)$$

This calculation is done for all matching fingerprints in the database, and the fingerprint with the smallest distance d should be the one closest to the actual position of the device in the positioning phase.

A problem that exists with the approach in Equation 2.1 is, that the number of base stations for a fingerprint can change because of the nature of radio waves. Especially inside building, external factors like moving subject, open or closed doors, change the signal strengths of the access points. An access point that was measured during the calibration phase might not be received during the positioning phase and vice versa.

To account for these changes in the environment, the Euclidean distance equation was adapted in [21] such that d is normalized by taking into account the varying number of access points that can be received. This change is represented by Equation 2.2, averaging the number of matching base stations m into the equation

$$d = \sqrt{\frac{1}{m} \sum_{i=1}^m (RSSI_{ci} - RSSI_{pi})^2} \quad (2.2)$$

If the signals from an access point are received neither in the positioning phase nor in the calibration phase, that access point is not considered for the calculation of the euclidean distance. The work in [21] proposes more changes to the algorithm to account for the effects of signal propagation. The changes are used to take into account the following problems that might occur:

Case 1: An access point is measured during the calibration phase but not in the positioning phase.

Case 2: An access point is measured in the positioning phase but not in the calibration phase.

Case 3: The number of matching access points between the positioning phase and the calibration phase for a fingerprint is too low. This value is set using a threshold parameter.

Case 4: RSSI-values (Received Signal Strength Indicator) of positioning and/or calibration tuple are too low.

To take these effects into account, the paper proposes the following threshold parameters:

2 Fundamentals

NBSmin The minimal number of matching access points required to perform a distance calculation.

TP1 Access points with a signal strength below this value are not used for the positioning algorithm. This includes access points from the positioning as well as the calibration phase.

TP2 If the RSSI-values from a matching access point from calibration and positioning phase are larger than TP1 but lower than TP2, the access point is not used for the calculation of d . This parameter is not used in the implementation of the positioning algorithm used in this thesis.

TP3 If the RSSI value of an access point during the positioning phase exceeds this value, and the access point is not part of the fingerprint, the fingerprint is excluded from the positioning calculation.

The algorithm used in the implementation enhances the positioning algorithm as described in 2.5.3 using the concept of weighted averages. The distances calculated from Equation 2.2 are averaged using their euclidean distance. The number of fingerprints used for this process is set using another parameter *neighbors*. A maximum of *neighbors* nodes are used for this calculation.

$$latitude = \frac{\sum_{i=1}^n \frac{latitude_{ci}}{d_{ci}}}{\sum_{i=1}^n \frac{1}{d_{ci}}} \quad \text{while } i \text{ is } < \text{neighbors} \quad (2.3)$$

$$longitude = \frac{\sum_{i=1}^n \frac{longitude_{ci}}{d_{ci}}}{\sum_{i=1}^n \frac{1}{d_{ci}}} \quad \text{while } i \text{ is } < \text{neighbors} \quad (2.4)$$

$$level = \frac{\sum_{i=1}^n \frac{level_{ci}}{d_{ci}}}{\sum_{i=1}^n \frac{1}{d_{ci}}} \quad \text{while } i \text{ is } < \text{neighbors} \quad (2.5)$$

To determine the position of a device in the positioning phase, three values are required: *latitude*, *longitude*, and the building *level*. Equation 2.4 and 2.5 show how these values are determined.

The details of the implementation are described in Section 4.4.

Conclusion

The fundamentals described in this chapter are used throughout the next chapters (Chapter 3 and Chapter 4). They cover the basics of the methods used to implement all parts of the system. The next chapter continues with the basics of the mapping system and how the objects on the campus are documented.

3 Cartography on the University of Ulm Campus

The following chapter will discuss the implementation of the mapping schema on the University of Ulm Campus. In the implementation part of this thesis, a prototypical map of a building on the campus of the University of Ulm was created using components from the OpenStreetMap project.

Part of this process is a definition of how elements are mapped.

3.1 Requirements

The requirements for the mapping schema are as follows:

- Well structured and documented tagging system. Tags are used to define building features and the tagging system needs to be documented, so that each item in the building uses the correct tags.
- Documented system for creating rooms. If rooms are not created using the same system of ways and tags, rooms might not be rendered consistently.
- Ability to differentiate between building levels. Since buildings feature multiple levels, levels need to be rendered separately and the user needs to be able to tell which level is shown.
- A system on which routing can be accomplished.
- Consistent naming schema for rooms and other building features.

3 Cartography on the University of Ulm Campus

- A rendering schema that differentiate between individual building features, as defined in the tags. This includes:
 - Distinct colors for rooms, auditorium, walls and stairways
- Geographical coordinate system. This ensures that future systems do not need to work on an unknown coordinate system, should they want to use the data created.

Without a documented approach to tagging and mapping, it would not be possible to provide a coherent map view. Since the data is not only used to render the map, but also to provide a point of interest (POI) database, as well as the basis for the navigation system, a strict approach to tagging and tracing features is required.

3.2 Campus structures and naming

The campus is divided into an eastern and a western part. The eastern part of the university uses a coordinate style naming schema with a combination of letters and numbers. Each building is labeled using a letter + number, for example “M 24”. Figure 3.1 is a schematical representation of the eastern campus.

The focus of this thesis is the building “O 27”, which houses the greater part of the computer science faculty. The position on the map is shown in Figure 3.2

3.3 Creating a map

One of the first tasks when creating a map is getting a reference grid. Since rooms and buildings need to be drawn on a map, a system of positioning these items needs to be implemented.

The choice was between the following two systems:

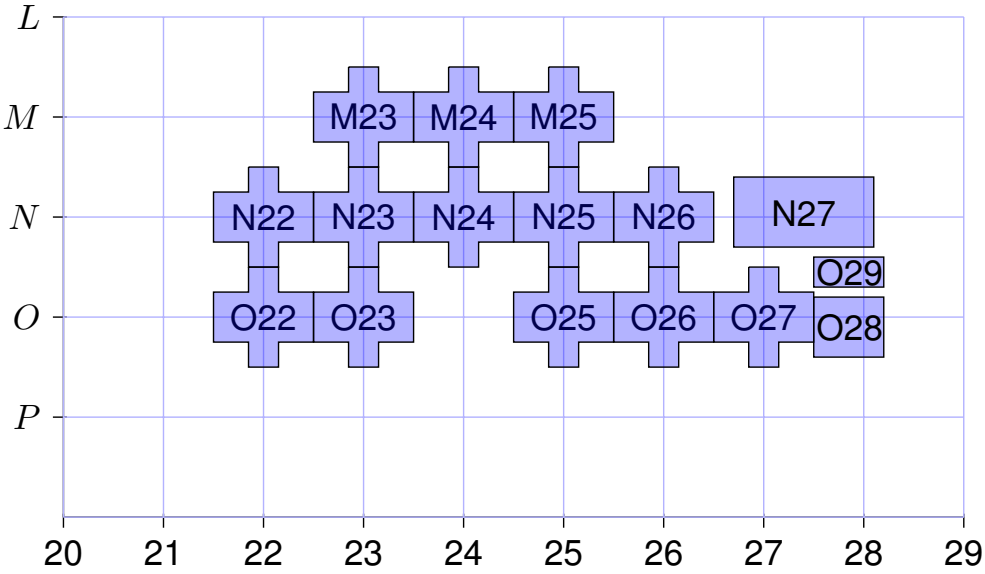


Figure 3.1: Schematical representation of the University of Ulm, eastern campus

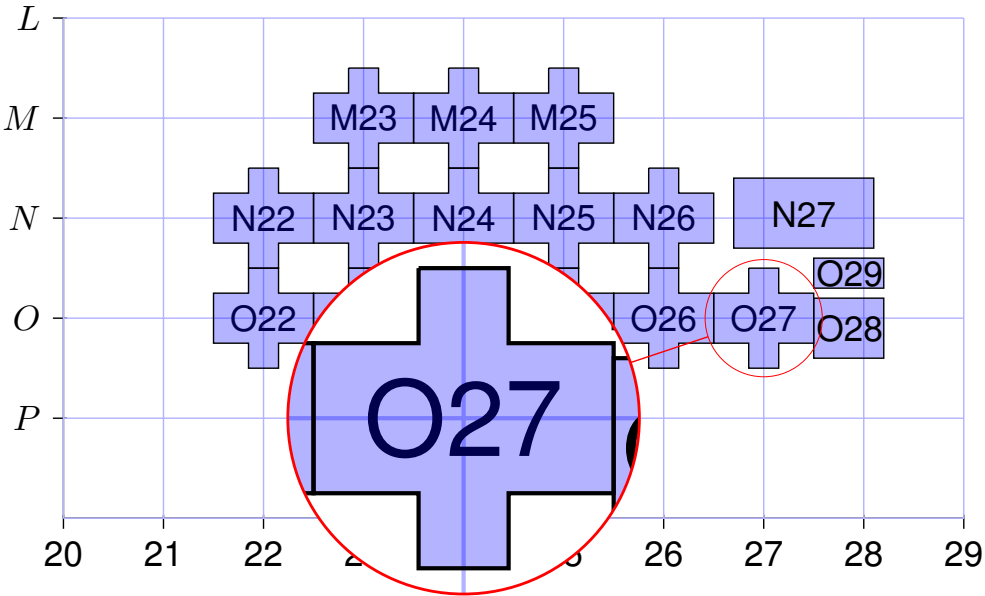


Figure 3.2: Position of Building O27 on the University of Ulm campus

3 Cartography on the University of Ulm Campus

1. Using a self created frame of reference, based on the existing coordinate system (O27, M24, etc.) with the addition of a number based grid for higher precision. For example: "O27.2534". The numbering system can be based on a unit of length, for example meters, or by creating a grid. An example of such a grid is shown in Figure 3.3
2. The buildings are drawn on a projection of the earth using latitude and longitude as coordinates. The usage of latitude and longitude allows for the usage of standard geographical tools and calculations. It also simplifies derivative work, since the coordinate system is standardized.

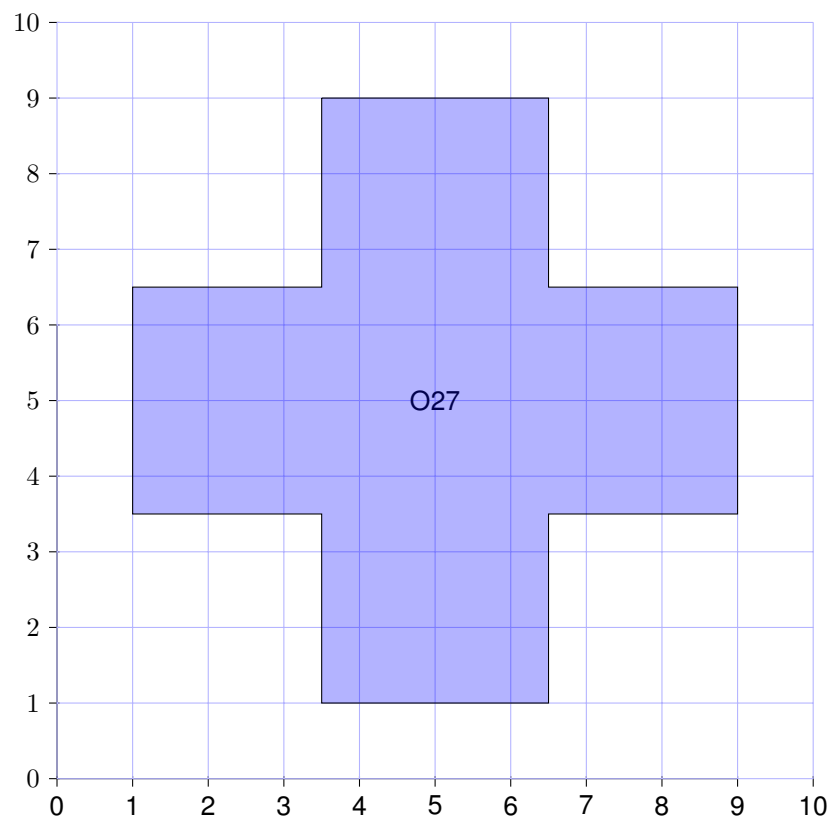


Figure 3.3: Example of a coordinate grid around a building

Since the second solution provides a set of standardized coordinates, it was chosen for the work in this thesis. It also allows for easier integration in the OpenStreetMap project,

whose tools are used throughout the thesis for work related to mapping and navigation. To provide additional structures outside of the buildings the area around the campus was imported from the OSM data. This way, the map does not only show the data created during the work of this thesis, which would be only the structure of the buildings and its rooms, but also the roads, paths and forests around the buildings. As a result of this, a user can also see the area outside of the buildings on the map's canvas.

3.3.1 Positioning elements

The architectural data used as the basis for the maps was provided by the university's department V5 in the form of PDFs, one PDF per building level. These architectural drawings are available in Appendix A.1. One of the challenges with a system based on a grid of latitude and longitude is the positioning of elements. This process is known as georeferencing. Since the available drawings do not provide any sort of positioning information on a map projection, the drawings need to be positioned on the map manually.

The JOSM Editor described in Section 2.2.3 offers the plugin "PicLayer".

PicLayer can be used to position elements on an OSM canvas. The plugin has support for various raster formats like *png* and *jpeg* but does not support the usage of PDFs. As a result, the PDFs needed to be converted into a raster format. For this task, the script in Listing D.1 was used.

After importing a picture into a picture layer, the process of georeferencing a building is described by [38] as:

1. Activate the layer
2. Click the green arrow button (*PicLayer Move point*) at the left toolbar
3. Select picture checkpoints (3 checkpoints needed for processing)
4. Click red arrow button (*PicLayer Transform point*) at the left toolbar

3 Cartography on the University of Ulm Campus

5. At this mode you can move checkpoints (you should point exactly in the circle at the point) and the image will transform

For the mapping work of this thesis, the already existing outline of buildings in the Open-StreetMap material was used as the reference for the images.

The process is shown in Figure 3.4, 3.5, and 3.4.

To verify the correct positioning, it is also possible to load satellite imagery into a layer. This has to be done for every building level, but once a single floor has been put into position, all other maps can be georeferenced on the floor already in position, using, for example, columns that lead through all floors of a building as reference points.



Figure 3.4: Setting three reference points on the picture

3.3 Creating a map



Figure 3.5: Two reference points are moved to the correct location on the map



Figure 3.6: All reference points are at their correct location

3.3.2 Errors

A possible point of failure in the process is that the existing map data could be offset from the correct position. The only possible way to perform exact georeferencing is by using high precision DGPS or similar equipment or by using data that already offers exact positioning information.

Once all needed floors are at their correct position on the mapping canvas, the rooms, corridors and other features need to be traced. To ensure a process of tagging and tracing, a schema was devised by which all features are traced and tagged.

3.4 Tagging

The maps created in this thesis use a defined schema of tags. These tags are used to provide a number of features:

- Rendering of rooms, outlines, corridors, auditoriums, and laboratories
- Paths used for navigation
- A database of rooms and points of interest
- Location of doors, elevators, and stairways
- Differentiate the building level a feature is on

Table 3.1 shows a list of all tags used to map the feature of the building O27. As far as possible, the tags are based on the existing usage of the OpenStreetMap project. This way other projects can work with a familiar system.

<i>Tag</i>	<i>Possible values</i>	<i>Description</i>	<i>Element</i>
level	<int>	Building level on the University of Ulm system	node, way
entrance	yes	Marks the entrance of a room or building	node
room	yes	Marks the outline of a room	area
	auditorium	An auditorium	area
	stairs	Area occupied by a staircase	area
	laboratory	A laboratory	area
laboratory	yes	Laboratory type not further specified	area
	computer	A computer laboratory	area
name	<string>	The room number/name fully qualified "O27 245"	node, way
highway	corridor	Used for all corridors	area
	elevator	An elevator	area
	steps	A stairway	way
incline	up down	The incline of a stairway	way
area	yes	Marks the area of a corridor	area
building	yes	Marks the shell of a building	closed way
amenity	toilets	Restroom	area

Table 3.1: Tags in use on the University of Ulm OSM schema. Loosely based on [40].

3.4.1 Tag usage

The following paragraphs describe all tags in use for the OSM schema of the University of Ulm. Tags are explained by using examples of building features. Chapter A.2 offers pictures of a number of these buildings features as additional examples.

3.4.2 Level definitions

The *level* tag is used to specify building level a feature is on. The University of Ulm uses a number based system to specify each building level. The levels range from 0 to 7, and the level tag uses the same system, as can be seen in Table 3.2.

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Level name	level=
Niveau 0	0
Niveau 1	1
Niveau 2	2
Niveau 3	3
Niveau 4	4
Niveau 5	5
Niveau 6	6
Niveau 7	7

Table 3.2: Mapping between University of Ulm schema and OSM schema

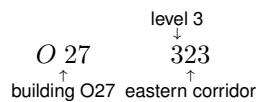


Figure 3.7: Explanation of numbering system

3.4.3 Rooms

The *room* tag is used to mark all kinds of indoor areas. Rooms on the University of Ulm are named using the following numbering system:

1. The first digit is the building level
2. The second digit is the direction inside the building from the center as follows:

North _1_

East _2_

South _3_

West _4_

Figure 3.7 is a full example of a room name and an explanation what each digit means.

The rooms are named without the building name, for example 245 and not O27 245.

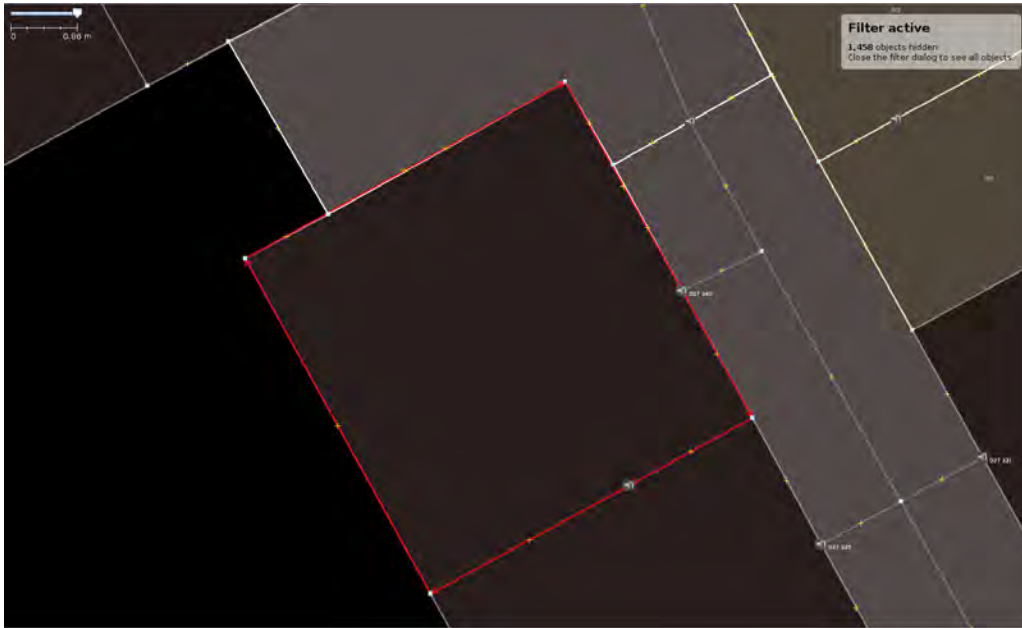


Figure 3.8: A room in JOSM

The `room = yes` tag is used to mark all rooms that do not match any of the more specific `room` tags. Examples of this tag usage include offices, class rooms, seminar rooms or closets. Figure 3.8 shows the layout of a room.

A room is composed of the following tags:

<i>Tag</i>	<i>Value</i>
level	<int>
room	yes
name	<room name>

Table 3.3: Tags of a room

Rooms also have a node which marks the position of doors.

3.4.4 Auditorium

Auditoriums are an important part of a university campus and as such have their own color schema in the rendered maps. The University of Ulm has a total of 22 auditoriums and unlike room names, the auditoriums all have a unique name, since each number is only assigned once on the whole campus. Building O27 has only one auditorium, H20.

Auditoriums are a special case of the room schema with the following tags:

<i>Tag</i>	<i>Value</i>
level	<int>
room	auditorium
name	<room name>

Table 3.4: Tags of an auditorium

3.4.5 Laboratory

A campus has a number of laboratories and in the OSM schema for the University of Ulm, laboratories are given their own tagging schema, as another special case of the room schema. There are a wide variety of laboratories on a campus, but in the case of O27, these are limited to computer laboratories. The tagging schema is similar to the room schema, but since there are a wide variety of laboratories, the *laboratory* tag is used to discern between different laboratory types. Examples of which are *computer*, *chemistry*, or *physics*. If the type can not be specified further, a *yes* tag can also be used.

<i>Tag</i>	<i>Value</i>
level	<int>
room	laboratory
laboratory	computer
name	<room name>

Table 3.5: Tags of a computer laboratory

3.4.6 Doors

Doors are needed to mark possible ways to enter a room. As such, they are also used for navigation, since a path to a room will end at its entrance. A room can have $0 \dots n$ doors. Rooms with 0 doors are possible, since there are cases where a cabinet does not have an actual door that can be accessed. The *name* tag of a door is used to store a fully qualified form of a rooms name, which is formed using the building a room is in along with the room number. An example of such an identifier is *O27 245*. A door has at least the following tags:

<i>Tag</i>	<i>Value</i>
entrance	yes
level	<int>
name	<fully qualified room name>

Table 3.6: Tags of a door

Figure 3.9 is an example of a room with two entrances.

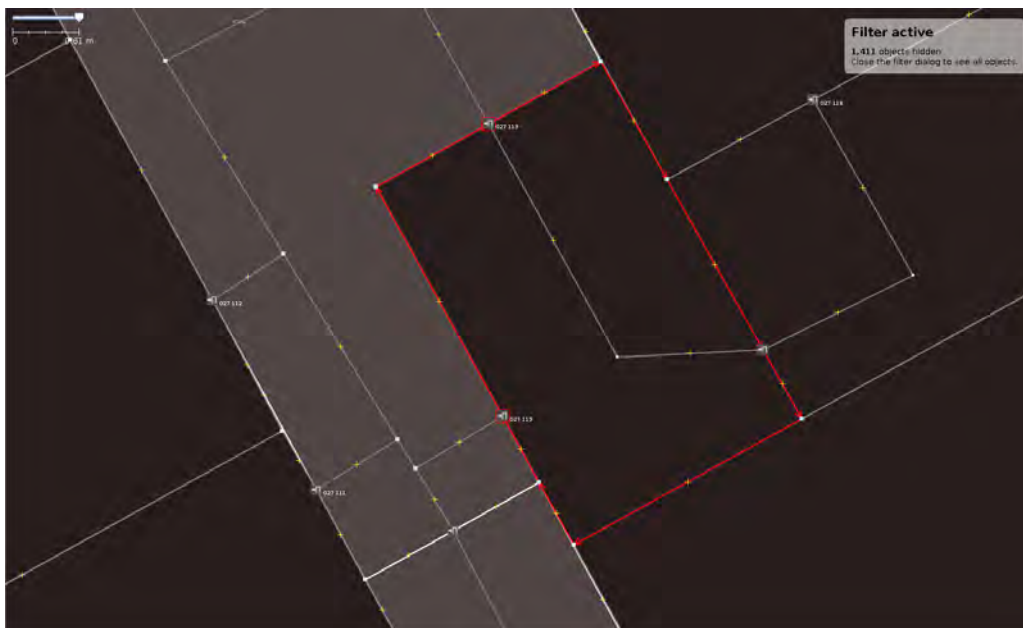


Figure 3.9: A room with two doors in JOSM

3.4.7 Corridors

Hallways inside of buildings are primarily marked using the *highway = corridor* tag. Corridors include all areas outside of rooms that are publicly accessible. Corridors are named using a *V* in front of the number, for example *V501*. An example of a corridor is shown in Figure 3.10.

A fully tagged corridor has the following tags:

<i>Tag</i>	<i>Value</i>
room	yes
highway	corridor
area	yes
level	<int>
name	<corridor name>

Table 3.7: Tags of a corridor

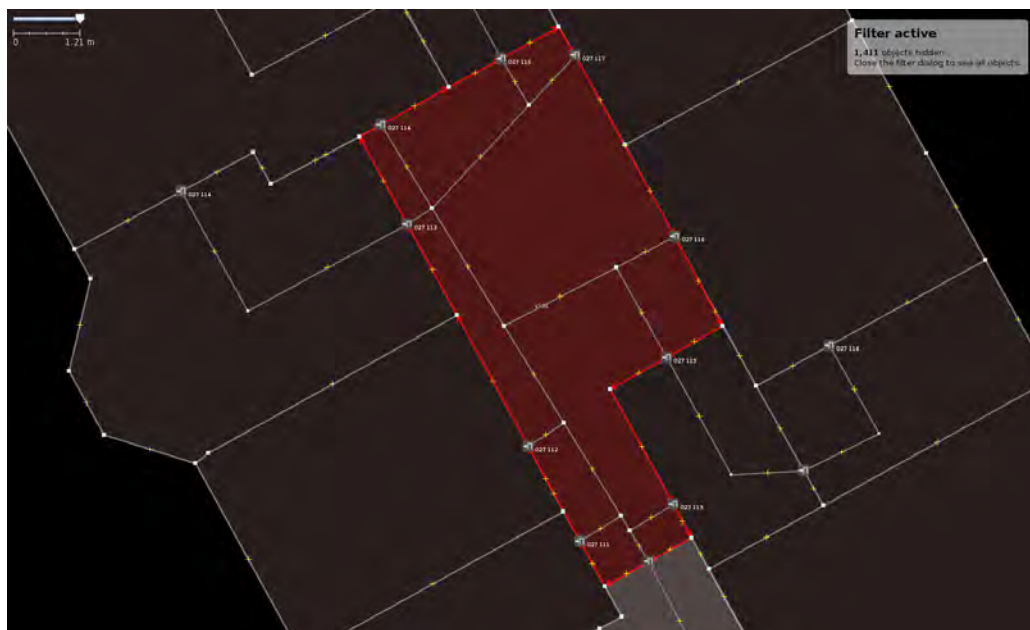


Figure 3.10: The red area marks a corridor

3.4.8 Stairways

Stairways are marked if they allow a person to move between building levels. A stairway is marked using an *area* as well as a *way*. The *area* element is used to render areas occupied by a stairway differently from a regular corridor. The *way* is used to mark the direction of a staircase as well as the incline from the current building level. An example of a stairway is shown in Figure 3.11.

The *area* occupied by a stairway has the following tags:

<i>Tag</i>	<i>Value</i>
area	yes
room	stairs
level	<int>
name	<corridor name>

Table 3.8: Tags of a stairway

Since stairways are used for navigation, a stairway is also marked using a *open way*, connecting two levels. Unlike other *way* or *area* elements, ways used for navigation have the following requirements:

- *Ways must not* be closed. Only open ways work.
- All *nodes* on a way used for navigation *must* have a *level* tag.

The connection between levels is created by connecting the open *way* with an upward incline to the open *way* with a downward incline from the *level* above the current one. The open way used for the stairway on Level 2 is shown in Figure 3.11 as a green line.

An open *way* of a stairway has the following tags:

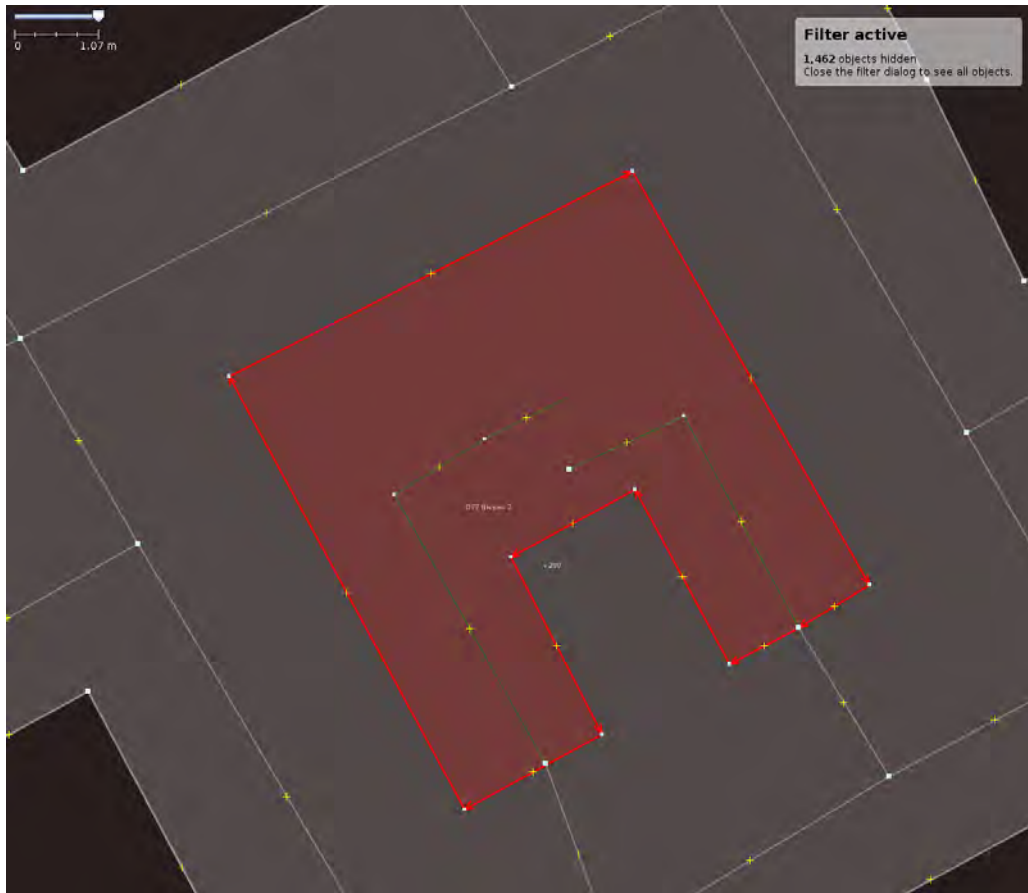


Figure 3.11: A stairway in JOSM; level 2 of building O27.

<i>Tag</i>	<i>Value</i>
highway	steps
incline	up down
level	<int>
wheelchair	no

Table 3.9: Tags of stairway *open way*

3.4.9 Elevators

Elevators are also tagged using a combination of the *room* and *highway* tag. Elevators share the same naming schema as corridors, using a *V* with a number as the identifier. It

has the same properties as a normal room, as it is formed using a closed way. Elevators are not used for navigation. Should such a feature be added in the future, a tag to specify all the levels that can be reached would have to be added.

Tags of an elevator are:

<i>Tag</i>	<i>Value</i>
room	yes
highway	elevator
level	<int>
name	<name>

Table 3.10: Tags of an elevator

3.4.10 Amenities

The only form of amenities currently used are restrooms. Restrooms are represented using their own color schema on the map. Restrooms share the common properties of all rooms, but add an *amenity* tag:

<i>Tag</i>	<i>Value</i>
level	<int>
room	yes
name	<room name>
amenity	toilets

Table 3.11: Tags for a restroom

3.5 Map rendering

Once all the required information is acquired and converted into the OSM format, the data needs to be rendered. Rendering is achieved by a special rendering server, that creates map tiles. A map view is generated by combining a number of smaller map tiles. Each tile

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is a square raster image, generated from a small segment of the map. The combination of these tiles is used to create a view, with newly rendered tiles for every zoom level.

The software stack that is used to achieve a rendered map consists of a number of different components. Figure 3.12 gives an overview of the server side components responsible to render a map.

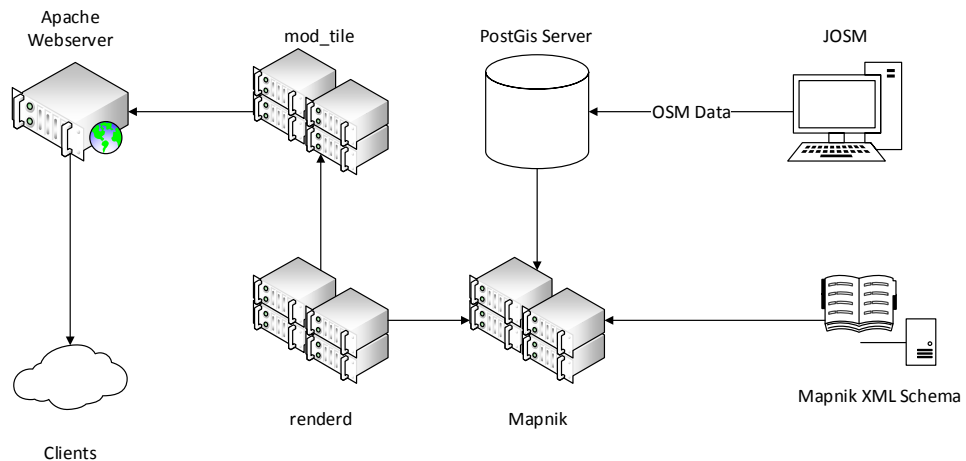


Figure 3.12: Rendering toolchain

The software pieces specific to the task of rendering the map on a server are:

mod_tile Is responsible for the caching and on the fly rendering of all map tiles [65].

renderd Renderd gets requests from mod_tile to render map tiles and saves these on the file system. It is also used to queue requests for map tiles.

Mapnik A toolkit for rendering maps. It uses XML style sheets as configuration [64].

PostGIS A geospatial extension for PostgreSQL database. A detailed explanation is available in Section 2.1.1.

3.5.1 Creating a database

Information created using JOSM is not directly used to render the map, since a database is used to store the information. The created data has to undergo a two step process, before it can be uploaded to the database:

1. Export OSM XML from JOSM
2. Upload data to database using *osm2pgsql*

3.5.2 osm2pgsql

Osm2pgsql is a command-line tool to convert OpenStreetMap data and upload this data into a PostGIS database [66]. The database is used by the Mapnik library to render the map tiles. Mapnik itself is explained in greater detail in Section 3.5.3. To change how *osm2pgsql* converts OSM XML into the PostGIS database format, a style file is used. The file uses a layout of four columns, with one entry per line. Each entry in the OSM XML file is checked for the features in the first two columns.

The column entries in order are explained on the OSM wiki as follows [66]:

OSM object type The OSM element to match on, as defined in Section 2.2.2: *node*, *way*, or both

Tag The OSM tag to match on

PostgreSQL data type specifies as what kind of PostGIS data element the data should be stored as.

Flag Flags separated by commas:

linear Import ways as lines, even when they are closed.

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polygon Closed ways with this tag are imported as polygons. Closed ways with *area = yes* are always imported as polygons.

delete The specified tag is not stored in the database.

phstore “Behaves like the polygon flag, but is used in hstore mode when you do not want to turn the tag into a separate PostgreSQL column” [66]

nocache Can be used for tags, that will not be part of a way.

The style file used in the thesis is based on the default style. An example of an entry as used in the thesis is shown Listing 3.1. It matches on all elements with a *room* tag and stores these as a polygon in the database. This way it is possible to have easy access to rooms in the rendering process.

Listing 3.1: *osm2pgsql* style for rooms

```
1 node, way    room    text polygon
```

The full *diff* to the default style can be seen in Listing 3.2.

To upload the data using *osm2pgsql* the command-line options seen in Listing 3.2 are used.

The description of these flags is described in Table 3.12.

<code>-slim</code>	Is used as an optimization. The flag permits the database to store temporary information in the database and not in random access memory.
<code>-C</code>	Specifies how much memory in MB may be used for caching nodes.
<code>-d</code>	Name of the database
<code>-H</code>	Hostname
<code>-W</code>	Interactive password entry
<code>-U</code>	Username
<code>-S</code>	Is used to specify a style sheet
<code>OsmConverter/uulm.osm</code>	The location of the OSM XML file that will be uploaded

Table 3.12: Command-line flags used for *osm2pgsql*

Listing 3.2: osm2pgsql command used to upload map data

```
1 #!/bin/sh
2 osm2pgsql --slim -d gis -C 2048 -H example.org
3 -W -U USERNAME -S wifinder.style OsmConverter/uulm.osm
```

3.5.3 Mapnik

Mapnik is the toolkit responsible for the actual rendering of map tiles. It uses a style sheet to render the elements in the database as map tiles. The style sheet allows for customization of all aspects of map rendering, including “data features, icons, fonts, colors, patterns and even certain effects such as pseudo-3d buildings and drop shadows” [64]. The style used by the official maps from the OSM project is known as the “OSM Standard Mapnik Style”.

Mapnik supports a large variety of data sources thanks to a plugin architecture [16]:

- *PostGIS*, the data source used for the rendering in this thesis
- *Shapefiles*, a common format for geographic data. Shapefiles are used to render additional aspects of the map not included in the PostGIS database, for example the landmasses or coastlines.
- *TIFF raster image*
- *OSM XML* There is also limited support to render raw OSM data, without the need for a database server.

3.5.4 Rendering Schema

Rendering of maps with Mapnik is based on the principle of layers, where each layer can use a different data source. A style defines how the objects in each layer are rendered [12]. These styles are defined using an XML schema with a combination of rules and

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filters. The order of rules and layers defines the order in which objects are rendered on the map canvas. Because XML files tend to be quite verbose, a different language was used to create the style sheets for this thesis: The CartoCSS language [11]. CartoCSS is a style sheet preprocessor, with a styling language very similar to the CSS language used for web page design.

TileMill & CartoCSS

TileMill is a tool developed by MapBox with the goal of simplifying the design process for mapping applications [34]:

“TileMill is not intended to be a general-purpose cartography tool, but rather focuses on streamlining and simplifying a narrow set of use cases.” [34]

TileMill is the software used to design the maps with the help of the CartoCSS language. It provides a live preview of the currently set map style, greatly enhancing the usability of the CartoCSS language. The actual rendering backend used by TileMill is the Mapnik library, which is also used for the rendering stack of the OSM project.

TileMill was used in the design phase of the maps rendering schema used for this thesis. The considerations that led to this choice are:

- Streamlined and simplified process compared to manually writing Mapnik XML style sheets
- Usage of variables in style sheets
- TileMill can export Mapnik XML style sheets
- Cross platform compatibility of TileMill
- Live preview of changes to rendering schema

TileMill uses the same concept of layers, each of which is based on a data source. The data source in use for the thesis is the *PostGIS database*, created from data that is edited with the *JOSM editor* and uploaded using the *osm2pgsql* tool.

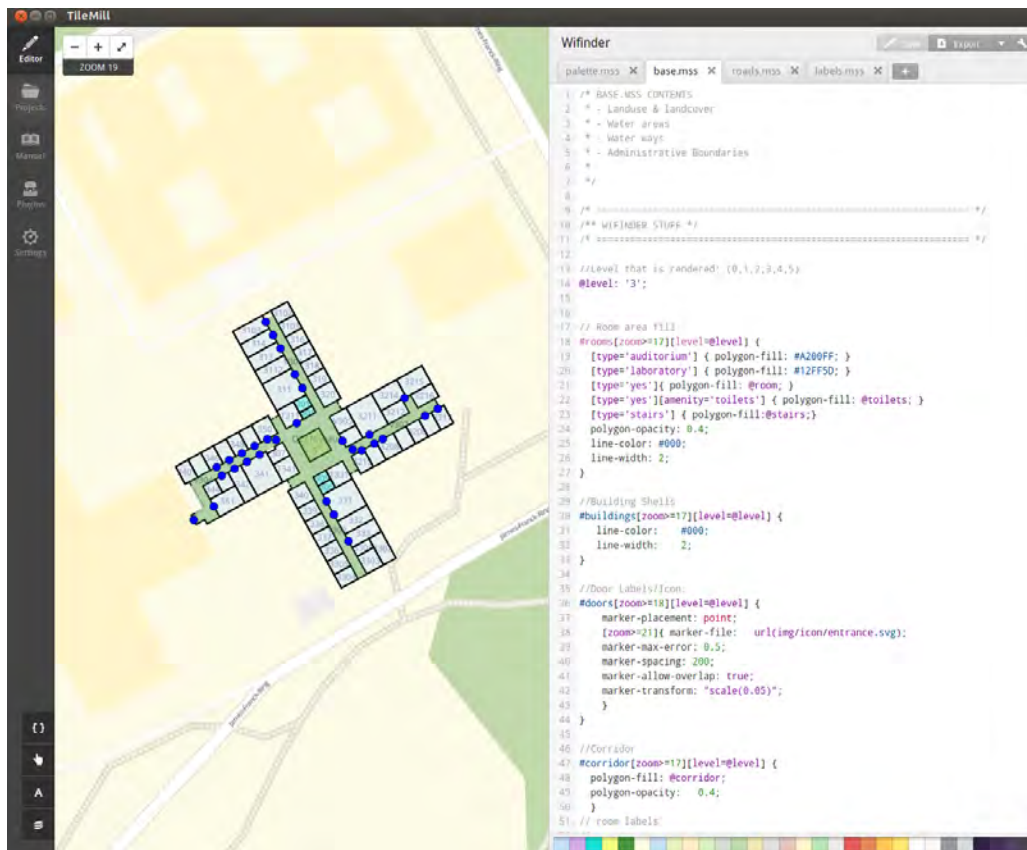


Figure 3.13: TileMill user interface, showing the map of Building O27, Level three

The mapping schema used was not built from scratch, as it is based on the *osm-bright* CartoCSS style available on GitHub [39]. To create the map style in use, the following new layers were created, while other layers were modified to achieve the desired results:

#doors Used to render doors on the map

#corridors Used to render the corridors

#rooms Used to render the maps

A building is split into several layers, and only one layer may be visible at a single time. Because the rendering of maps is not dynamic, but a collection of raster images, each layer needs to have its own style sheet. The usage of variables in CartoCSS is used to filter the indoor elements. This way, only elements that are on the desired layer are visible.

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Example: Rooms

The example of the room rendering is used to explain, how the available options are used.

A layer *#rooms* is created. Using the SQL query in Listing 3.3, the layer is used to filter all *ways* and *areas* from the database that match the criteria of having a *room* tag.

Listing 3.3: SQL query used to create the *#rooms* layer

```
1 (SELECT 'way', 'way_area' AS 'area', 'room' AS
2 'type', 'name', 'level', 'amenity'
3 FROM 'planet_osm_polygon' WHERE 'room' NOT IN ('0', 'false', 'no'))
4 AS 'data'
```

Defining a layer has no effect on the map, since a layer definition is akin to defining a data source and does not define how these objects are rendered. The actual operations that are performed using the layer need to be defined using the style sheet in the form of the CartoCSS language.

Rooms have a gray color as defined in the schema of Table 3.13. Through the usage of variables, color styles are defined in *palette.mss* file using hexadecimal RGB representation. Listing 3.4 is a part of the color definitions used for the map style. The *@room* variable can later be used to access the values from the color schema.

Listing 3.4: Color definitions used in the CartCSS style

```
1 /* ===== */
2 /* Wifinder: Styles
3 /* ===== */
4 // "normal rooms"
5 @room:          #C4Dff6; //gray
6 @room_auditorium: #A200FF;
7 @toilets:       #1BE0D6;
8
9 //Area marking a stairway
10 @stairs:        #F5FF82;
```

```

11
12 //Corridors:
13 @corridor:          #47943D;

```

The actual rules to render the rooms is shown in Listing 3.5. The `#room` tag is used to access the layer created from the SQL query. The values in the rules in the brackets are used to specify when the rule should be used. The `zoom` value is used to specify that the elements should only be rendered if the zoom level is above the level of 17. The zoom levels in OSM are defined using degrees, where zoom level 0 is relative to 360 degrees, which results in a view covering the whole area of the world. Zoom level 17 results in a view of 0.003 degrees.

The `level` is used to filter elements by the level tag assigned to them during the map creation process. Inside the braces, the actual options for the rendering process are defined. Through the usage of `[]` braces, rules can be applied for different types of rooms. The `type=` identifier is used to match the OSM value that was given for the `room` tag. For example an Auditorium tagged using `room = auditorium` is accessed using the rule `type='auditorium'`. The field is called `type`, because in the SQL query, the values of the `room` column are selected as `type`. The command `polygon-fill` specifies the color of the area as well as the fact that it is to be rendered as a polygon.

Listing 3.5: CartCSS style to fill the area of a room using

```

1 // Room area fill
2 #rooms [zoom>=17] [level=@level] {
3   [type='auditorium'] { polygon-fill: @room_auditorium; }
4   [type='laboratory'] { polygon-fill: #12FF5D; }
5   [type='yes'] { polygon-fill: @room; }
6   [type='yes'] [amenity='toilets'] { polygon-fill: @toilets; }
7   [type='stairs'] { polygon-fill: @stairs; }
8   polygon-opacity: 0.4;
9   line-color: #000;
10  line-width: 2;
11 }

```

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All the commands outside the more specific filter values like *polygon-opacity*, *line-color*, and *line-width* are set for all types filtered by the outside rule. Values specified using the additional rules, as for example the color for the auditorium, have precedence over the globally set values.

To use the CartoCSS style with Mapnik, the files need to be exported as a Mapnik XML schema. Because a schema is needed for every level, the *level* variable is changed for each level and the XML schema is exported. The resulting XML schemas are uploaded to the rendering server along with all the other resources needed for the rendering process. This includes shape files as well as images used to mark the position of doors.

Color definitions

The colors in use on the mapping style are defined in Table 3.13. This style is used throughout all maps and for each level.

An example of the end result is shown in Figure 3.14, and Appendix A.3 shows the map for every level of Building O27.







Element	Color	HEX value
Room		C4DFF6
Auditorium		A200FF
Laboratory		12FF5D
Toilets		1BE0D6
Stairs		F5FF82
Corridors		47943D

Table 3.13: Colors in use on the University of Ulm style

renderd & mod_tile

Renderd and *mod_tile* are the two components on the server side that are responsible for the process of creating tiles on demand. A part of this is a caching system, so that not all



Figure 3.14: Level 5 of Building O27

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tiles have to be created for every request. Because of the nature of an indoor mapping environment, a higher zoom level is required compared to regular maps. *Renderd* does not have a configuration option to specify a higher zoom level, the maximum zoom level is only a compile time option. Listing D.3 is a patch for the *render_config.h* file, to enable a zoom level of 22. The default configuration allows a maximum zoom level of 18, which is not high enough for an indoor map.

The configuration for *renderd* is used to configure the rendering system as well as the endpoints for map tile requests. Every building level needs its own endpoint as well as its own Mapnik XML schema. The URLs used for the map server are *osm_level<level number>/*, in the case of the test server with the hostname *example.org*, the full URL for map tiles from building Level 1 would be: *http://example.org/osm_level1*. The full configuration file is available in Listing D.4.

Conclusion

The documentation in this chapter does not cover all objects that may be encountered on the campus as a whole. As such the documentation will evolve further as more parts of the university are added. Some buildings will feature items, that need to be tagged and were simply not encountered during the mapping process of this building.

The next chapter describes, how the data created using the information and processes from this chapter, can be used to perform routing, displaying a map, and provide a database of point-of-interest information.

4 Implementation

This chapter covers the implementation of the server side components not directly related to mapping, as well as the client side application, in the form of an Android application. The code name for the application is *WiFinder* and the application as well as the web service carry this name.

Requirements

The following requirements exist on the server side:

- Server side hosting of Wi-Fi positioning system calibration data
- Server side computation of a users current position based on a scan of Wi-Fi signal strengths
- Calculation of a route between two rooms
- Calculation of a route between the users current location and a room
- A database of the position of all rooms
- Ability to query the position of a room

To fulfill this criteria, a RESTful web service [17] was implemented using the Python programming language [19].

The following requirements exist on the client side:

- Provide the user with an estimate of his current position including his current level
- Display the users position on a map view

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- User interface to show a route between two rooms
- User interface to show a route from the users current location to another room.

4.1 Overview

To get a better understanding of the implementation, Figure 4.1 shows an overview of the components and their connection within the implementation.

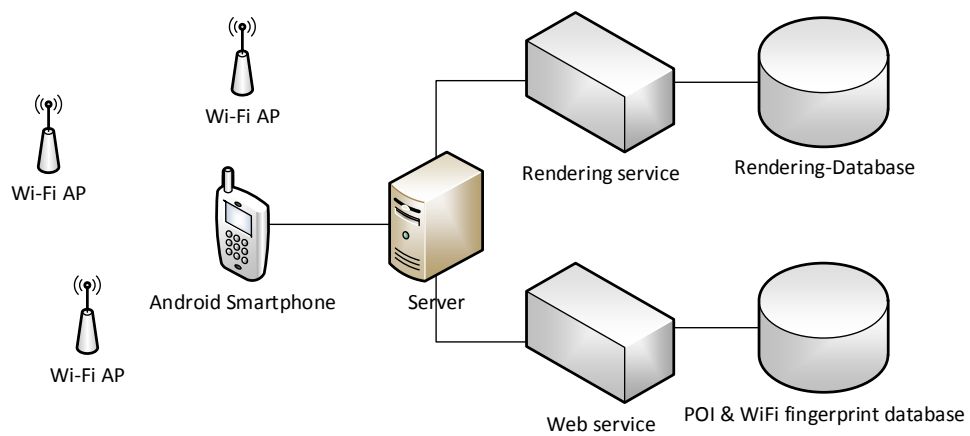


Figure 4.1: Overview of the infrastructure

The components fulfill the following purpose:

- Web service with a RESTful API
 - Route calculation
 - Wi-Fi fingerprint database
 - Calculation of smartphone position
 - Resources to access position of rooms

- Two PostGIS databases
 1. Database used to render the map
 2. Database for Wi-Fi fingerprints and map POIs
- Android application
 - Capture Wi-Fi fingerprints (*offline phase*)
 - Display Map
 - User interface for route calculation

4.2 Design choices

Considering the nature of this prototypical implementation, no caching of the information received from the web service is performed. In a later implementation that is meant for public consumption, caching should be implemented to reduce the server load as well as decrease the response time of the application. The server oriented architecture eliminates the problems of keeping the data in sync between the device and the server, and simplifies the maintenance of the code related to routing and positioning, since only the server side software needs to be changed.

4.3 Web service

The web services based on the RESTful architectures style was implemented. The implementation was done using a Python framework called *Flask* [54] in combination with a number of other Python modules, noteworthy being:

sqlalchemy A Python SQL Toolkit and Object Relational Mapper used for all database access [57]

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geoalchemy2 An extension of sqlalchemy for working with geospatial databases [22]

Flask

The implementation of the service was done using the flask microframework for Python. *Flask* simplifies the task of creating a web service while also giving the developer full control over all aspects of the application. Flask allows the developer control over all aspects of the application, while providing sensible defaults for these options.

RESTful Webservice

The API to provide all the features relies on the *RESTful pattern* along with *JSON* [13] as serialization format. The API developed provides the following endpoints:

4.4 Positioning system

The positioning system is implemented using the principle of Wi-Fi fingerprinting, also known as scene analysis. The explanation of how this system works is shown Section 2.4.

The system requires an offline and an online phase, where the offline phase is used to create a database of fingerprints. The online phase consists of devices trying to determine their location using the database.

The system works by using the map created from the campus in combination with an Android device. The requirement for the hardware of the android device is an internet connection as well as Wi-Fi module.

The software used for the offline as well as the online phase is the *Wi-Finder* Android application which was developed in this thesis.

URL	Method	Data Type	Description
/entries	GET	HTML	HTML view of all POI nodes in the database
/poi	GET	JSON	Request a JSON representation of a POI using name=<NAME> argument. If no name is given, all POIs are returned
/poi/names	GET	JSON	Get a list of all names in the database
/signalNodes/	GET	JSON	Retrieve all SignalNodes from the database
	POST	JSON	Submit a new SignalNode to the database
/signalNodes/<id:int>	GET	JSON	Retrieve the SignalNode with the given id
/getLocation	GET	JSON	List of Wi-Fi Signal scans, equivalent to SignalNodes
	POST	JSON	Returns the users approximate location given a signal scan
/route	GET	JSON	Needs a start and end URL parameter, calculates a route between two points, and returns the route as a JSON list of way-points
/nav	POST	JSON	Calculates a route based on the location given in the POST request to the room given as a start URL argument

Table 4.1: Endpoints provided by the Wi-Finder API [59]

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4.4.1 Data storage

The storage of the information from the positioning system is done using the web service's database. The data in the database consists of the data created using the fingerprinting system for positioning information as well as OpenStreetMap data. The OpenStreetMap data is based on the same raw data that is used for the map rendering system, but has to be held in two separate databases because of the differences in how the data is stored in the database.

Data for the rendering server is uploaded using the *osm2pgsql* tool while data for the POI service is created using the *osmosis* tool. The databases are separate, because OSM tags are stored using the key/value system provided through PostgreSQL's `HSTORE` functions. The rendering toolchain does not work with the `HSTORE` system.

Osmosis

Osmosis is a command-line utility in principle similar to *osm2pgsql* but with the ability to perform larger and more configurable operations [67]. The data that is uploaded to the database is the same raw data that is used to create the rendering database, but *osmosis* expects a cleaner format than *osm2pgsql*. All data (*nodes*, *ways*, *relations*) that is uploaded using *osmosis* need version information as well as timestamps. JOSM does not export OSM XML data with this information. To overcome this problem, an XML parser written in Python is used to add the missing information using dummy values. The source code for this parser is shown in Listing D.7. To automate the process of conversion and upload a small bash script is used, as shown in Listing D.8.

A fingerprint taken for the positioning system contains the following information:

- The position of the smartphone. This location is defined by the user performing the scan. The scan consists of latitude, longitude, and the building level.
- Signal strength of all Wi-Fi access points in range. The data captures for each signal includes:
 - Signal strength in dBm

- Frequency of the signal
- SSID of the access point
- MAC address of the access point
- The model of the smartphone
- A time stamp added by the web service when the node is uploaded

The data is transmitted from the smartphone using the *JavaScript Object Notation* (JSON) and saved in the database. Using the API, a JSON representation of a *SignalNode* can be retrieved. Listing 4.1 is an example of such a *SignalNode*, shortened to only two signals. The full representation of this node with the id 12 would have had 16 signals.

Listing 4.1: A shortened example of a Signal Node

```

1 {
2   "signalNodes": {
3     "level": 2,
4     "timestamp": "2013-04-03 15:05:49",
5     "longitude": 9.95694693177938,
6     "signals": [
7       {
8         "ap": {
9           "ssid": "eduroam",
10          "bssid": "00:1e:4a:54:f6:f0"
11        },
12        "signal_strength": -56,
13        "frequency": 2412,
14        "id": 157
15      },
16      {
17        "ap": {
18          "ssid": "eduroam",
19          "bssid": "00:1e:4a:57:76:a0"

```

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```
20     },
21     "signal_strength": -80,
22     "frequency": 5280,
23     "id": 158
24   },
25 ],
26 "device": "GT-I9100",
27 "latitude": 48.4231721291727,
28 "id": 12
29 }
30 }
```

The storage in the database is done using three tables with relationships between them. Figure 4.2 shows the schema and the relations between the tables in detail.

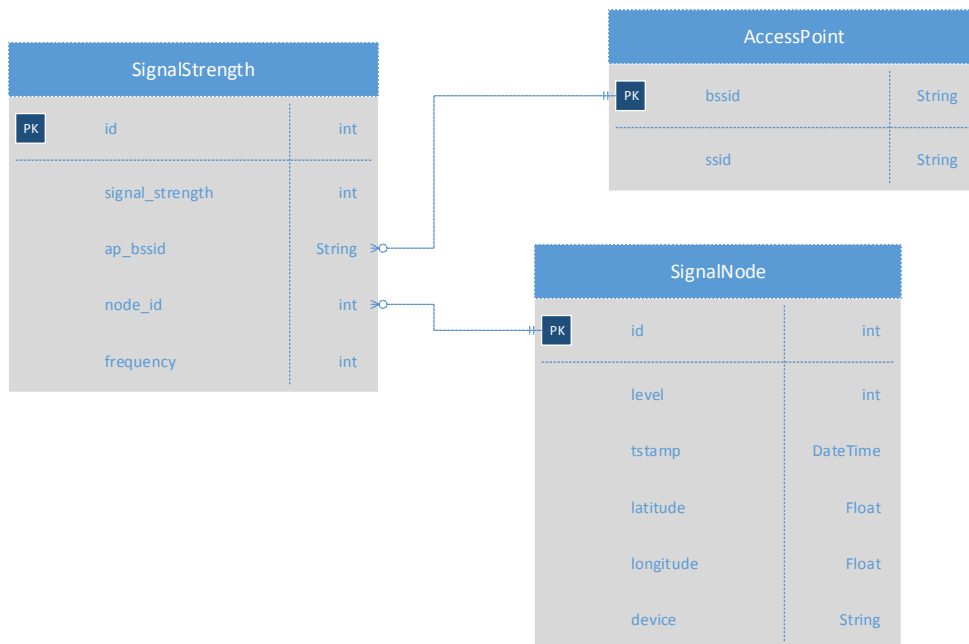


Figure 4.2: Wi-Fi fingerprints database schema

<i>Parameter</i>	<i>Value</i>	<i>Description</i>
TP1	-85	Minimal signal strength in <i>dBm</i> an access point needs to be used in the positioning algorithm
TP3	-70	If signal strength of an access point is $> TP3$ and the signal node is not in the calibration node, the calibration node is not used
apThreshold	3	If less than <i>apThreshold</i> APs match between the positioning scan and calibration node, calibration node is not used
neighbors	5	Number of <i>SignalNodes</i> at most averaged into the location

Table 4.2: Parameters in use for the positioning algorithm

4.4.2 Positioning algorithm

The algorithm used for the positioning system is based on the principle of Wi-Fi fingerprinting in combination with an euclidean distance based algorithm to determine the position. The algorithm used in the implementation is an implementation of Dijkstra's algorithm as described in Section 2.3.1. The algorithm adds the component of averaging the distance between the fingerprints, known as *SignalNodes* in the implementation.

Algorithm 2 is the first part of the process of calculating a position. The Euclidean distance is calculated to all *SignalNodes* that match the criteria as stated in Section 2.5.3. The implementation uses the parameters from Table 4.2 for the algorithm. The values are based on the work in [21] but were changed based on experimentation using the developed application.

The next step in the calculation of the position is the averaging of the weights which is shown in Algorithm 3. The resulting *level*, *latitude* and *longitude* are the best possible estimate of the users position.

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Algorithm 2 Part one of positioning algorithm in pseudo code

```

P is the position scan,
D is the database
for signal ∈ P do
  if signal > TP1 then
    mPosScan = mPosScan.append(signal)
  end if
end for
for AP in mPosScan do
  query = all SignalNodes in D which include AP
end for
for signalNode in query do
  ap_counter = 0
  distance_vector = 0
  for positionSignal in mPosScan do
    exists = True {Check if BS with signal_strength > TP3 exists in this calibrationNode}
    if positionSignal['signal_strength'] > TP3 then
      exists = False
      for calibrationSignal in calibrationNode.signals do
        if calibrationSignal.ap_bssid == positionSignal['ap']['bssid'] then
          exists = True
        end if
      end for
    end if
    if not exists then
      break {Signal strength is larger than TP3, calibration node is not used for locating}
    else
      for calibrationSignal in calibrationNode.signals do
        if positionSignal['ap']['bssid'] == calibrationSignal.ap_bssid then
          ap_counter = ap_counter + 1
          
$$distance = \sqrt{\frac{calibrationSignal.signal\_strength}{positionSignal['signal\_strength']}}$$

          distance = distance2
          distance_vector = distance + distance_vector
        end if
        ELSE:
          continue {no breaks encountered}
      end for
    end if
    Else:
      if ap_counter > apThreshold then
        
$$euclidian\_distance = \sqrt{\frac{distance\_vector}{ap\_counter}}$$

        tuple = euclidian_distance, calibrationNode
        add tuple to positionList
        continue
      end if
    end for
  end for
end for

```

Algorithm 3 Part two of positioning algorithm in pseudo code

Require: tuples of distance and signalNodes (*positionList*)
 sort *positionList* from smallest to largest distance *d*
 index, latitude, longitude, distances, level = 0
for *signalNode, distance* in *positionList* **do**
 if *index < neighbors* **then**
 index = index + 1
 distances = (1/distances) + distances
 latitude = (node.latitude/distance) + latitude
 longitude = (node.longitude/distance) + longitude
 level = (node.level/distance) + level
 end if
end for
latitude = latitude/distances
longitude = longitude/distances
level = level/distances

The position estimate is returned to the client using a JSON representation of the location, an example of which can be seen in Listing 4.2

Listing 4.2: Example of a position as returned by the web service

```

1 {
2   "latitude": 48.4231721291727,
3   "longitude": 9.95694693177938,
4   "level": 2
5 }
```

4.4.3 Accuracy

To determine the accuracy of the positioning system a test series was done on two levels of the building. On Level two the average deviation from the actual position was 3.84 meters. On Level three it was 6.76 meters. A total of 46 measurements were taken, five of these measurements returned the wrong building level compared to the actual location. The full test series is shown in Chapter B The accuracy that can be achieved varies throughout the building. Factors like open spaces can contribute larger error margins. The largest errors occur in stairways, where radio waves can travel mostly uninhibited between

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levels. As shown in the test series, the margin of error can be large enough such that the position is off by a building level.

4.5 Routing

The RESTful web service is also responsible for the calculation of routes between rooms or routes from the user's location to a room. Navigation to an arbitrary point on the map is not possible. The implementation of the routing algorithm uses the endpoints of the web service as defined in Table 4.1. The actual implementation is based on Dijkstra's algorithm, which is explained in detail in Section 2.3.1. The full source code of the implementation is shown in Listing D.6.

4.5.1 Implementation of a Dijkstra algorithm

To be able to calculate a route using a shortest path algorithm, a graph is needed. The graph is constructed using elements from the OpenStreetMap project. The graph is constructed with the JOSM in the form of *ways* with the tag *highway=corridor*. Because of how the routing algorithm works, all the nodes on these ways need to be tagged with a *level* tag. These paths are later used to construct the waypoints that are used for the route. The process of constructing this graph consists of connecting all nodes that are tagged with the *entrance = yes* with the ways. Since the ways are used for the routing process, the path that these ways take in the corridors must not be obstructed by walls or other obstacles. Figure 4.3 shows the ways that were constructed in building Level 1.



Figure 4.3: Routing paths of Building O27, Level one

4.5.2 Getting a route

The web service needs two parameters to be able to construct the route: a room number where the route starts and a room number where the route ends. These are transmitted in the URL of the request that is transmitted to the web service using URL parameters, for example `http://example.org/poi-service/route/?start=O27%20245&end=H20` represents the route from the office in room *O27 245* to the auditorium *H20*.

The web service returns a list of waypoints to the client requesting a route, an example of which is shown in Listing 4.3.

Listing 4.3: Example of a route from room *O27 245* to *O27 201*

```

1 {
2   "waypoints": [

```

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```
3   {
4     "latitude": 48.42282045409622,
5     "longitude": 9.956953558398476,
6     "level": "2"
7   },
8   {
9     "latitude": 48.422857374806135,
10    "longitude": 9.957059467154115,
11    "level": "2"
12  },
13  {
14    "latitude": 48.42282647162592,
15    "longitude": 9.957096769402563,
16    "level": "2"
17  },
18  {
19    "latitude": 48.422840172020194,
20    "longitude": 9.95714660380187,
21    "level": "2"
22  },
23  {
24    "latitude": 48.42284657089658,
25    "longitude": 9.957166790861855,
26    "level": "2"
27  },
28  {
29    "latitude": 48.42283814387136,
30    "longitude": 9.957175493101834,
31    "level": "2"
32  }
33 ]
34 }
```

Since the data type being returned is a list, no numbering of waypoints is required. The order is defined by the data type and as such by the order in which the items are returned. The data format is held as simple as possible and makes the usage through any other type of application which wants to perform routing functions inside the campus possible. This makes way for future projects that need a routing API on the campus. By drawing a line from the starting waypoint to the last item in the list, a route can be constructed.

4.5.3 Routing from the users current location

The second aspect of routing is using the information from the positioning system in combination with the routing system. The user transmits his current location to the web service using the endpoint `nav`. The web service computes a route using the same algorithms that are used when routing between two rooms. But because the starting point is usually not an already defined point, the process is more complex.

The routing process works by finding the point on the navigation grid as defined in Figure 4.3 that is closest to the starting point of the routing process. The process works by using *PostGIS* functions to determine the nearest neighbor that matches the characteristics of the routing grid nodes. Once such a point is determined, the routing process works exactly the same as routing between two rooms. The route is returned in the same JSON format as seen in Listing 4.3.

4.6 Android application

The component a user interacts with directly is a smartphone application developed for the Android platform.

4.6.1 Choosing a platform

In the planning stages of the project, the three largest smartphone platforms were considered for the development of the end user component. The results of other papers were

4 Implementation

also taken into consideration during the process of choosing the implementation platform [49], [53], and [55]. These platforms are:

- Apple's iOS [28]
- Microsoft's Windows Phone 7 [43]
- Google's Android [30]

The deciding factor for the choice of the platform was the possibility to access the devices information about Wi-Fi access points in range and their signal strength. Only the Android platform has an interface in its SDK which allows access to this information. *Windows Phone* and *iOS* only provide information about the connected networks or the network state, *Windows Phone* provides information about the SSID of the connected network [44], but not the signal strength or the MAC addresses [7] of the access points in range. As a result of this required feature, only the Android platform could be used to implement the positioning system as envisioned in the planning stages.

4.6.2 Android implementation

The Android implementation is built to be backwards compatible up to Android version 2.0. This backwards compatibility is needed because of the fragmentation of the Android smartphone market. The most prevalent version of Android is 2.3 with a market share of 36.4%. Building an application that is only compatible with versions starting from 4.0 would, at the time this application was developed, only work on 58.6% of devices. The full set of statistics that show the grade of fragmentation can be seen in Table 4.3.

4.6.3 Libraries

The following libraries are used for the Android application:

ActionBarSherlock A backport of the Android action bar pattern and fragments. The action bar is used to provide a standardized navigation interface for android applica-

<i>Version</i>	<i>Codename</i>	<i>API</i>	<i>Distribution</i>
1.6	Donut	4	0.1%
2.1	Eclair	7	1.5%
2.2	Froyo	8	3.2%
2.3 - 2.3.2	Gingerbread	9	0.1%
2.3.3 - 2.3.7	Gingerbread	10	36.4%
3.2	Honeycomb	13	0.1%
4.0.3 - 4.0.4	Ice Cream Sandwich	15	25.6%
4.1.x	Jelly Bean	16	29.0%
4.2.x	Jelly Bean	17	4.0%

Table 4.3: Android fragmentation on June 3, 2013 [31]

tions, but was only added with the Android API 13. *ActionBarSherlock* allows the usage of this pattern with Android versions 2.x and up [3]. Another feature provided by *ActionBarSherlock* is its own implementation of the Android fragment pattern

Google Play Services The Google play services library provides the Google Map View that is used to display the map tiles from the rendering server [25]. The Google Play Services SDK provides this in the form of the “Google Maps Android API v2” [33].

Gson or “Google-Gson” “ is a Java library that can be used to convert Java Objects into their JSON representation. It can also be used to convert a JSON string to an equivalent Java object.” [23]. The library is used to convert the data from the web service to Java objects.

4.6.4 Android implementation details

The Android implementation uses elements as suggested by the Android API guides when possible. The user interface is constructed using the action bar pattern for navigation and fragments to construct the individual views.

ActionBar

The action bar is a window on the upper edge of an application that provides a dedicated space for navigation purposes. Through the use of the action bar, a consistent navigation view can be provided across as many android applications as possible [2].

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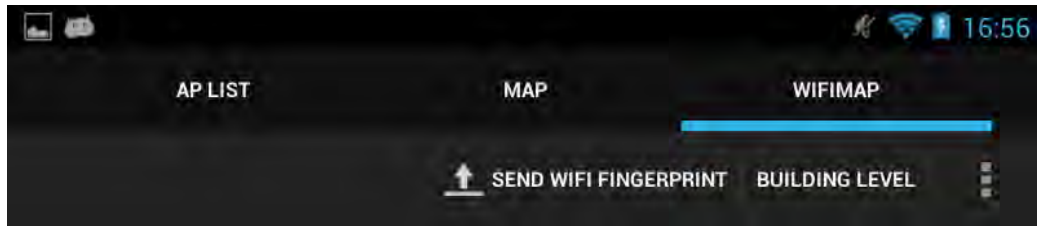


Figure 4.4: Action bar as used in the Wi-Finder application

The action bar as used in the Wi-Finder application is shown in Figure 4.4, the action bar provides three tabs to switch between the different views of the application. In the example shown, the action bar also provides three buttons to access features of the view currently being displayed as well as the so called “overflow” menu, accessed using the “☰” symbol.

The items shown in the action bar depend on the amount of screen real estate available on the device. The items that cannot be shown on screen are moved to the menu button, that is accessed using the menu key of the device.

Fragments

Fragments are components that hold the views being displayed. Fragments are primarily designed to “support more dynamic and flexible UI designs on large screens, such as tablets” [20]. The fragments implementation used in the application is the backported fragment from the ActionBarSherlock library.

4.6.5 Application views

This section provides a description of what features are provided by each of the available views and how these views are implemented.

The application has the following main views:

AP List A small view which displays a list of Wi-Fi access points currently in range along with metadata for every access point.



Figure 4.5: Smartphone screen of the Wifinder map view

4 Implementation

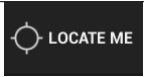
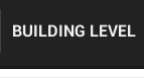
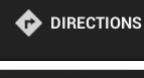
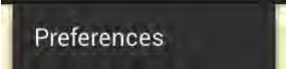
<i>Item</i>	<i>Description</i>
	Start the positioning system
	Switch the map view to a different building level
	Open the dialog to get directions
	Open the preferences screen

Table 4.4: Menu items in the map view

Map This is the default map view. It shows a map of the campus and provides features for locating the user as well as the routing functionality

Wi-Fi Map This map view is used to perform the fingerprinting phase of the Wi-Fi positioning system.

Map

The most important view in the application is the map view. Figure 4.5 shows how this view looks on a smartphone and Figure 4.6 shows the same view on an Android tablet. The map view combines all the information from the mapping process by displaying the map tiles as rendered by the server and can enable the positioning system. The menu items offered in this view along with a description of their functions can be seen in Table 4.4.

The view includes a widget to switch between building levels in the form of a menu item “BUILDING LEVEL”, the menu of which is shown in Figure 4.7.

Positioning system

The implementation consists of a specially crafted *SherlockMapFragment* based on Google’s Android Map API v2 and components of the *ActionBarSherlock* library. To display the map a `MapTools` class is used as a helper. It tailors the map view depending on

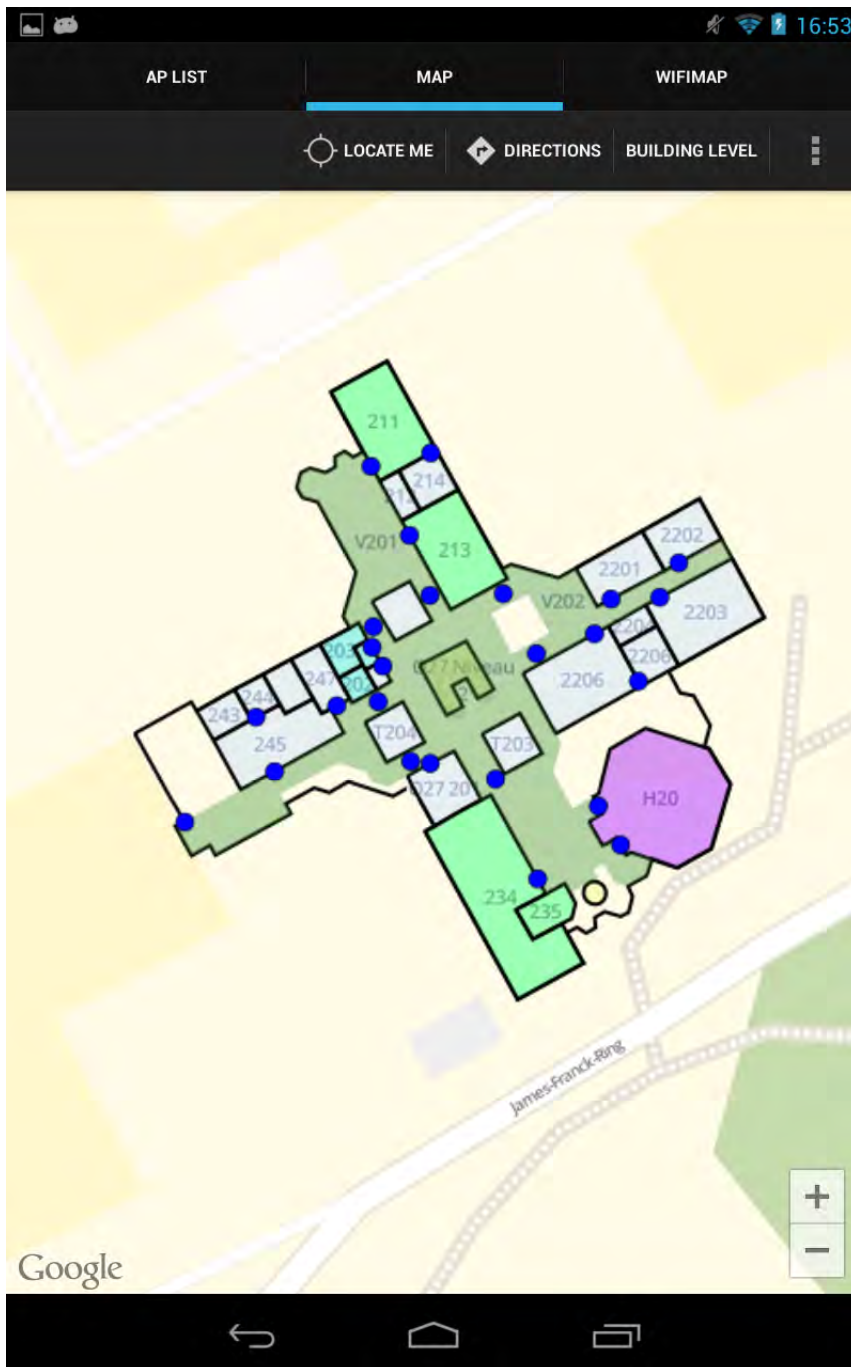


Figure 4.6: Screenshot of the map view of Level 1, Building O27

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Figure 4.7: Widget to switch between building levels

the required information and instantiates the maps canvas. It handles the display of a route and any other functions that need to draw items on the map. The *Locate Me* button starts the applications positioning system. It starts a service that is called when new position information is available. The specifics of this service are explained in detail later in this chapter. A marker is shown on the map once a position has been determined. This marker is shown in Figure 4.8 along with a pop up showing detailed information about the acquired position. Once a new location is determined, the marker is updated to reflect this change.

If the marker is not visible on the current map canvas, the canvas is updated so that the marker is centered on the screen. The map also changes the building level shown, based on the calculated position.

Routing

The map view includes the functionality required to query the web service for routes and display the returned route on the maps canvas. The calculated route is then displayed on the map canvas, so that a person can follow the path and reach their destination. To get the directions the user opens the *Get Directions* dialog enters a start and an end point of his route, as shown in Figure 4.9. The text fields need the unique identifiers of the rooms as set in Section 3.4.3. The text fields uses auto completion to show suggestions in a drop down list below the text box during text input (Figure 4.10). This simplifies the data entry process for the user, since all possible values are part of the auto complete function. The auto complete function is implemented by querying the web service for a list of all rooms. Besides the possibility to specify a starting and a end room, a check box can be used to specify that the current location should be used as the starting point of the route.

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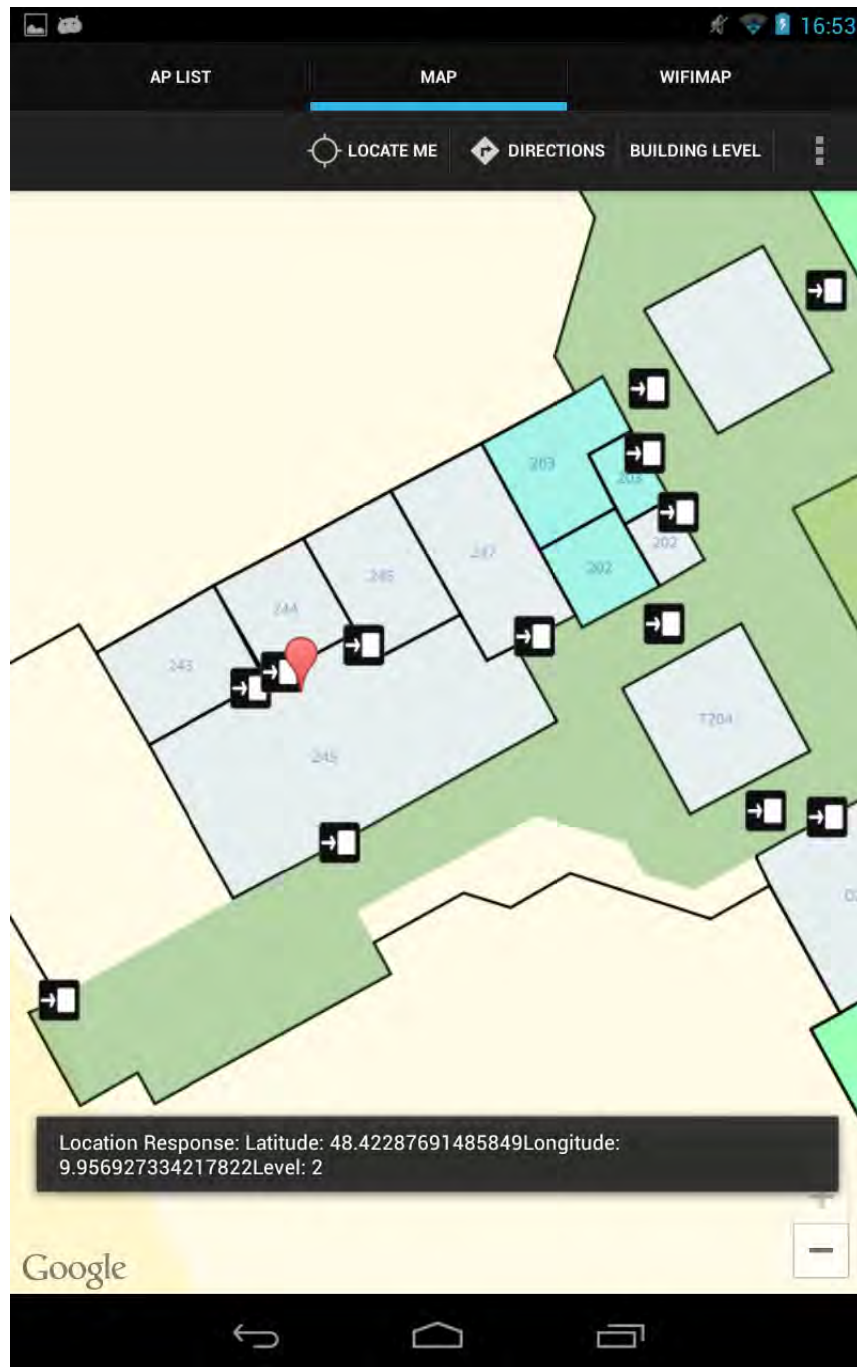


Figure 4.8: Marker showing the devices calculated position

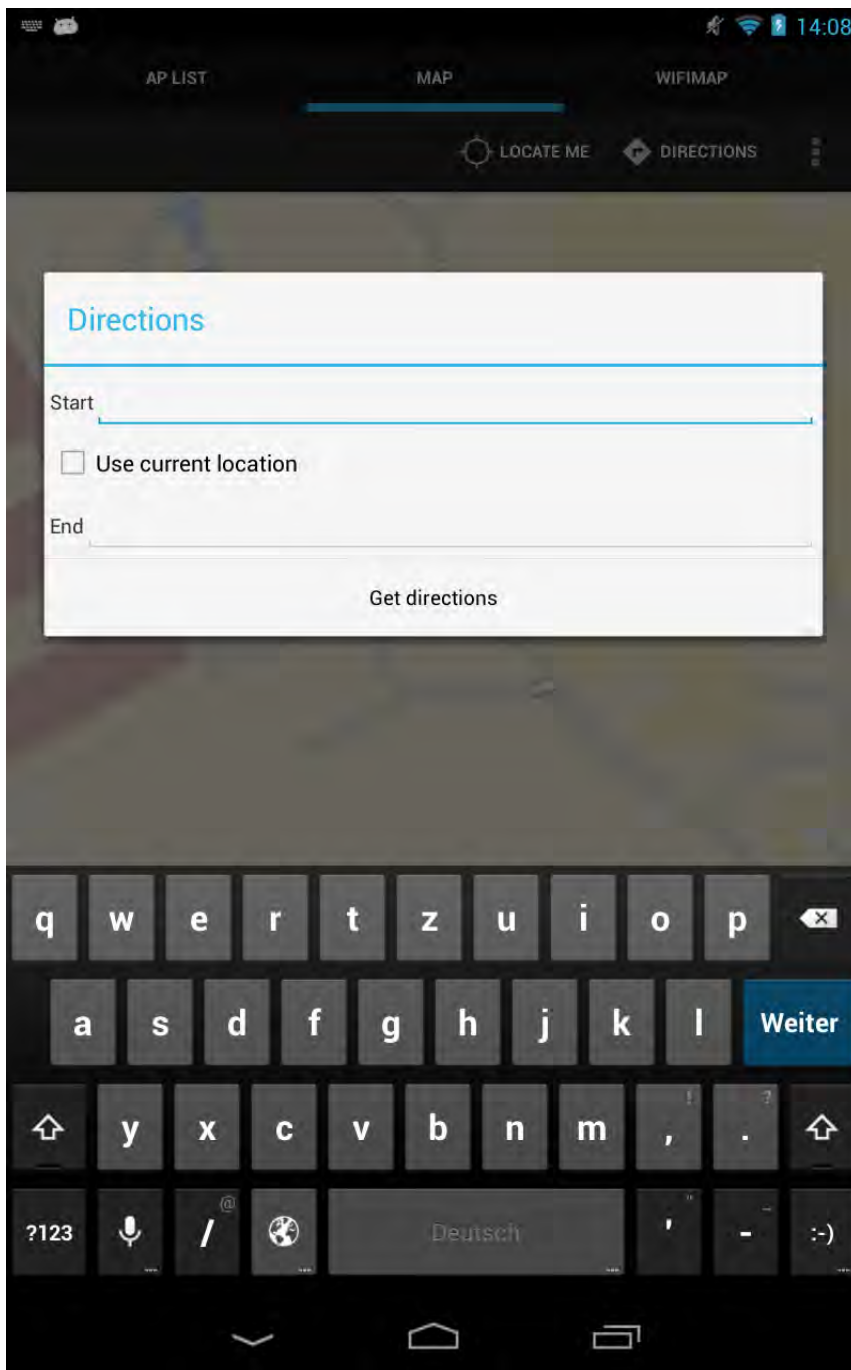


Figure 4.9: Dialog to request directions between two rooms

4 Implementation

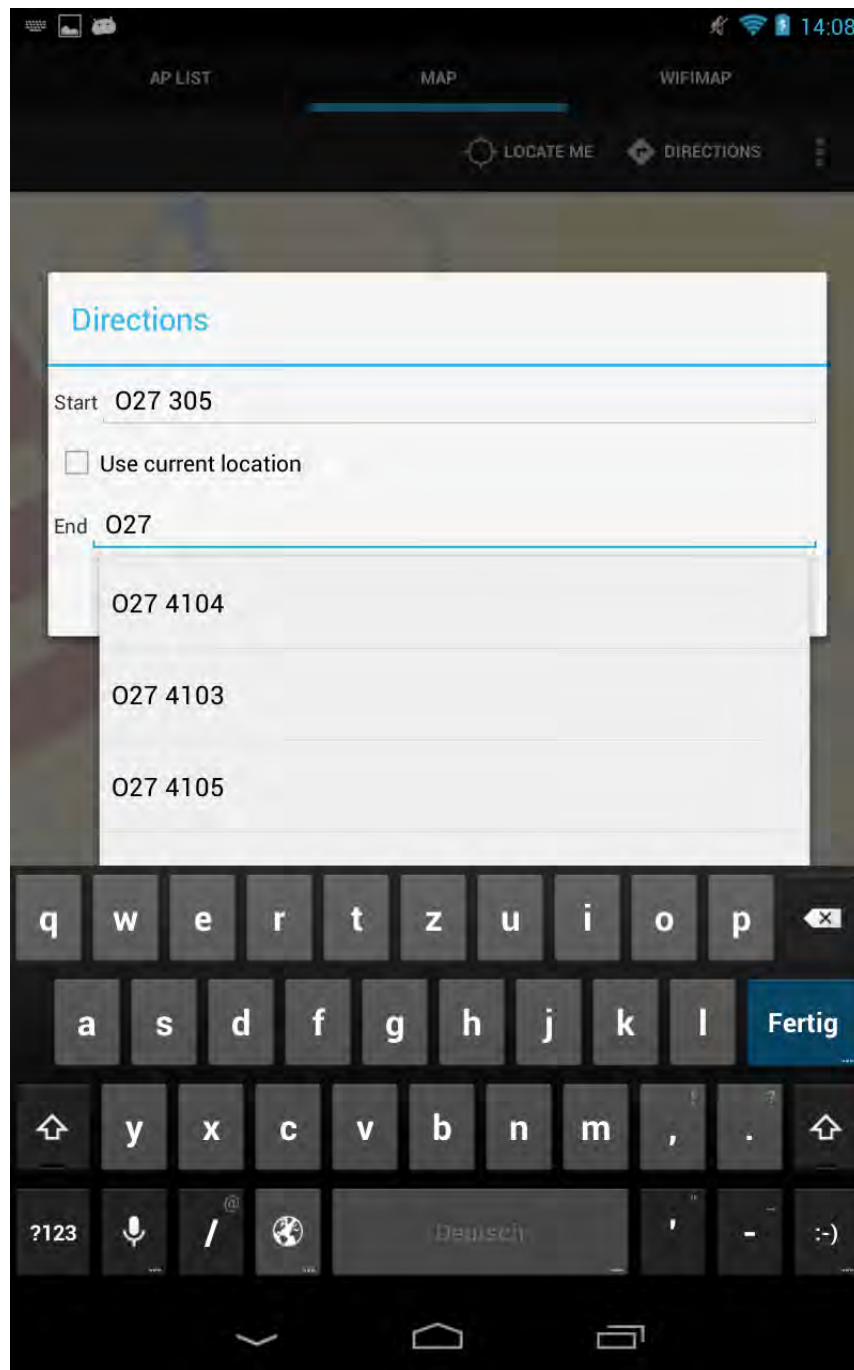


Figure 4.10: Auto completion function of the *Get Directions* dialog

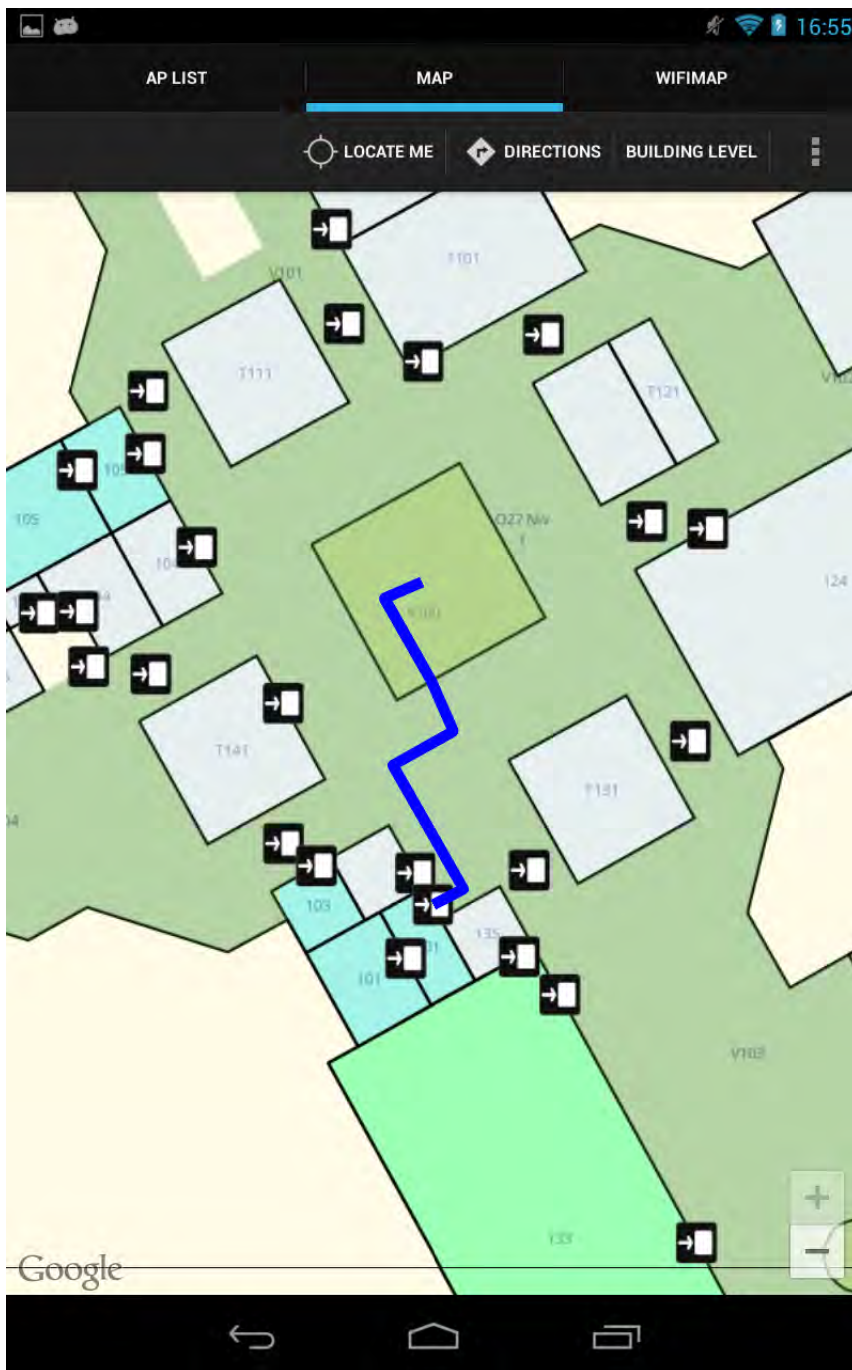


Figure 4.11: Example of a route as displayed on the canvas

4 Implementation

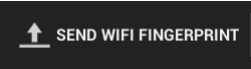
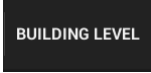
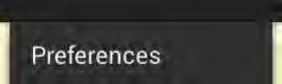
<i>Item</i>	<i>Description</i>
	Record a Wi-Fi fingerprint at the position indicated and send it to the web service
	Switch the map view to a different building level
	Open the preferences window

Table 4.5: Menu items in the *Wi-Fi Map* screen

Once the user has entered the required information and has clicked the *Get Directions* button, the route is calculated using the web services API and the result is then shown in the map canvas in the form of a blue line from the starting point to the end point. Figure 4.11 is an example of a route as it is displayed on the map's canvas.

WiFi Map

The WiFi Map uses the same tools to construct a map canvas as the *Map* screen, but serves an entirely different purpose. It can be seen as the development front end of the Wi-Fi positioning system. The map displayed is the same canvas as the *Map* view, but with some added features to help with the process of capturing Wi-Fi fingerprints. The first thing a users sees is that the canvas is overlayed with a grid with a mesh size of five meters. The grid is shown to have frame of reference when creating Wi-Fi fingerprints. Without such a grid it is not immediately apparent where fingerprints need to be placed. Another visible feature in this view are markers on the map. Each marker represents an existing Wi-Fi fingerprint. The Wi-Fi fingerprints are downloaded from the API service when the map view is loaded, so that the view always shows an up to date view of the fingerprints.

The view of the existing fingerprints makes it easier for a user to add missing fingerprints, since he can see where fingerprints were already taken. Another feature provided by the markers is the ability to delete fingerprints. This is useful, if a fingerprint was taken at the wrong location or fingerprints need to be updated. Because the device can provide

the needed functionality to change the fingerprints in the database, no other software is required to manage the fingerprints.

Fingerprinting

The main purpose of this view is to take fingerprints for the Wi-Fi positioning system. The process consists of the following steps:

1. The application on the device is started and the Wi-Fi fingerprint view is loaded.
2. The user selects the level he wants to take fingerprints on.
3. The user walks to the position where he wants to take the fingerprint at.
4. On the applications map canvas, the blue crosshairs are moved to the position the user is currently at, as seen in Figure 4.14.
5. The user presses the *SEND WIFI FINGERPRINT* button.
6. The dialog in Figure 4.15 is displayed. during the fingerprinting process. During this phase, the applications service queries the Wi-Fi radio and receives a callback when the results are available. Then the fingerprint is uploaded to the web service, where the fingerprint is stored in the database. Once this process is complete, the dialog is closed. The user must not move during this process, since otherwise the fingerprint will not be at the users current location.
7. A marker is shown on the map canvas at the location the fingerprint was created.

The process of deleting a fingerprint involves clicking that fingerprints marker. The dialog in Figure 4.15 is shown and once the user confirms the deletion, the fingerprint is deleted using the web service.

AP List

The AP list view was originally conceived as a test bed for parts of the application like the background service that queries the Wi-Fi module for access points. It has remained in

4 Implementation

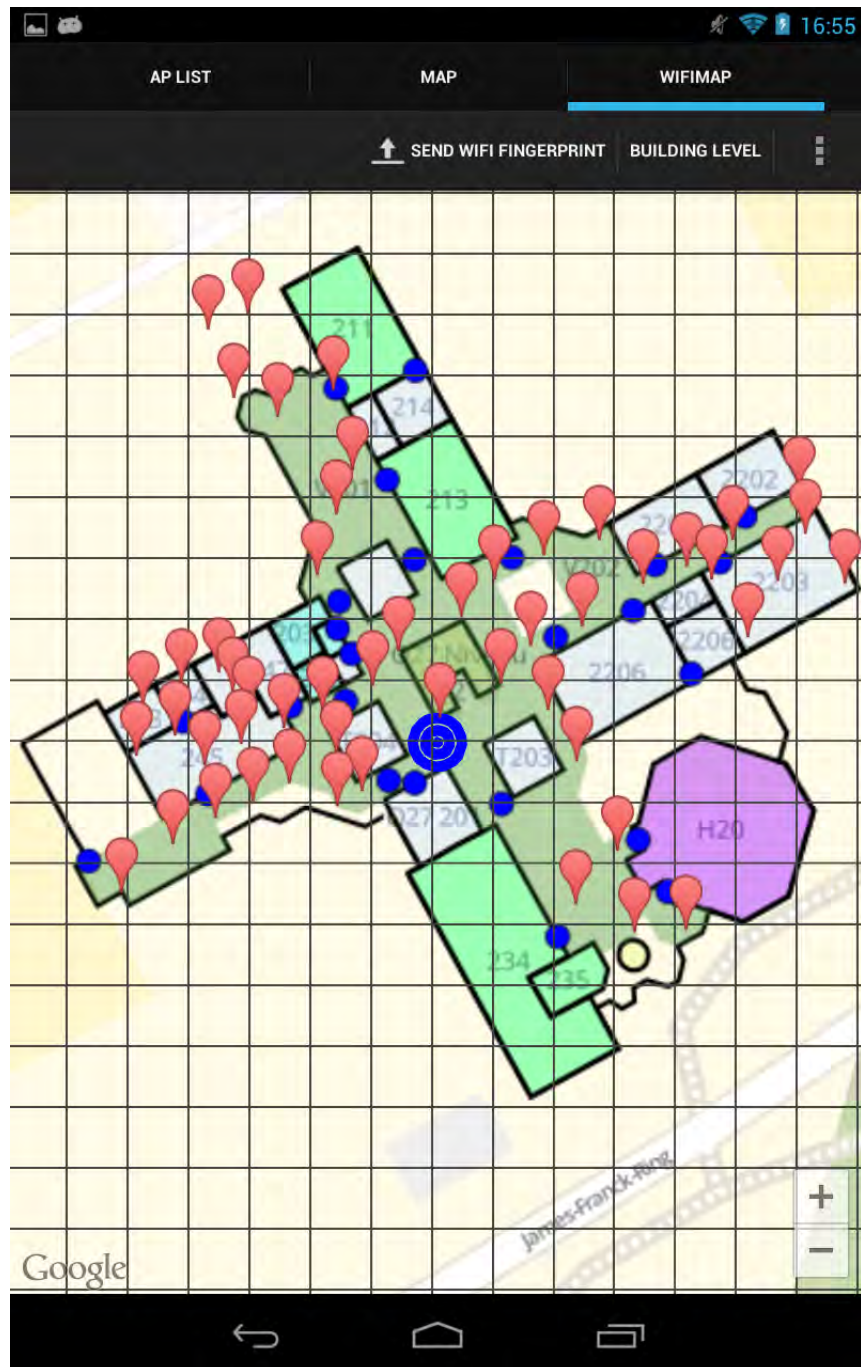


Figure 4.12: Mesh grid and existing fingerprints in the *Wifi Map* screen



Figure 4.13: Dialog asking for confirmation that a Wi-Fi fingerprinting node is to be deleted

4 Implementation

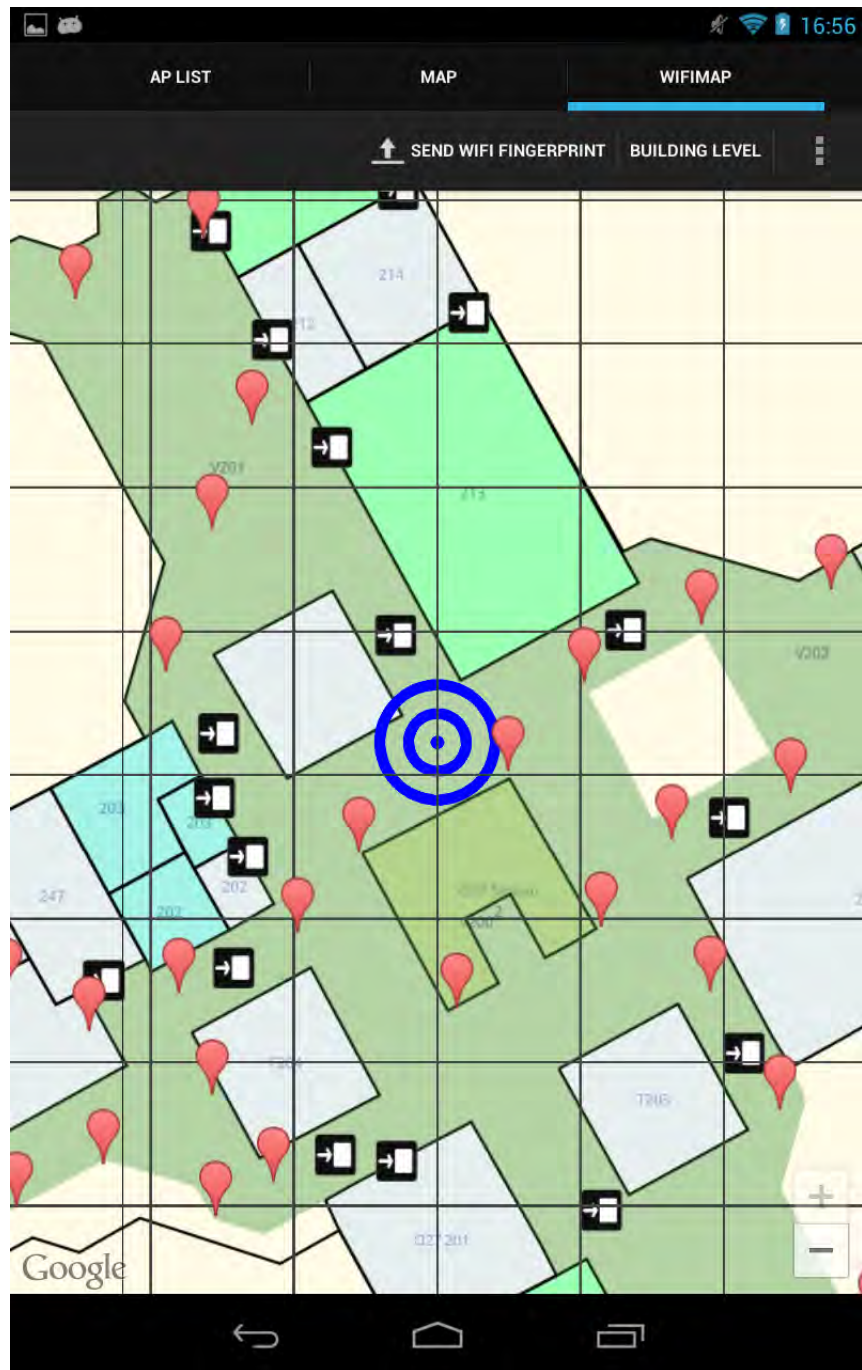


Figure 4.14: Crosshairs used to show the position of the fingerprint

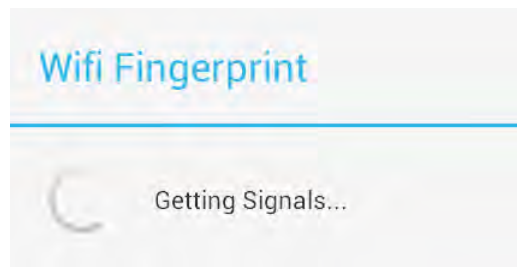


Figure 4.15: Dialog shown when a fingerprint is taken

the application since it is a valuable tool to check the Wi-Fi reception and the number of access points currently in range. It's functionality consists of querying the Wi-Fi service for access points and displaying them in a *ListFragment*, a fragment designed to display a list of items. An example of this view is shown in Figure 4.16, To get more information about an access point, it can be clicked. The information consists of all information available about the given access point, including signal strength and capabilities. Figure 4.17 is an example of the detailed view.



Figure 4.16: A list of access points in the AP List scanner view

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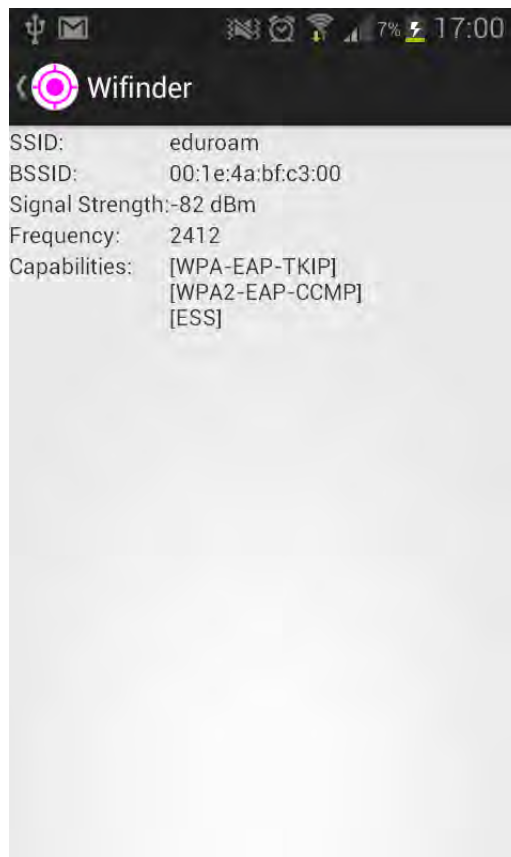


Figure 4.17: Detailed view of an access point in the AP list view

Preferences

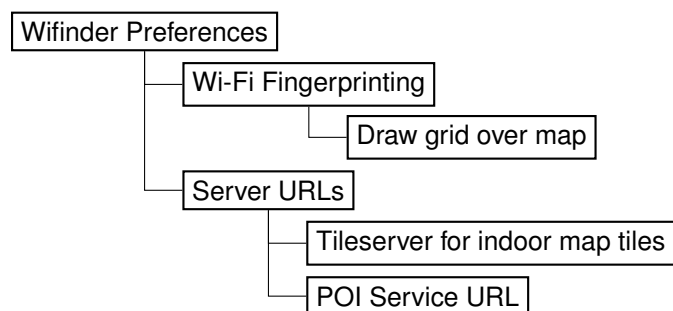


Figure 4.18: Structure of preferences

4.6 Android application

The application also features a preferences screen, where some settings can be influenced. The settings are mostly related to server URLs, since these were sometimes changed to reflect the usage of the debugging servers during the development phase. The preferences are split into two different preference screens, the *Wi-Fi Fingerprinting* preferences as well as the *Server URLs* preferences screen. The preferences can be accessed in any part of the application using the devices *Menu button* when available. The structure of the preferences can be seen in Figure 4.18. Figure 4.19 shows the actual preferences window in the application. The implementation is done using Android's preference management API [6].

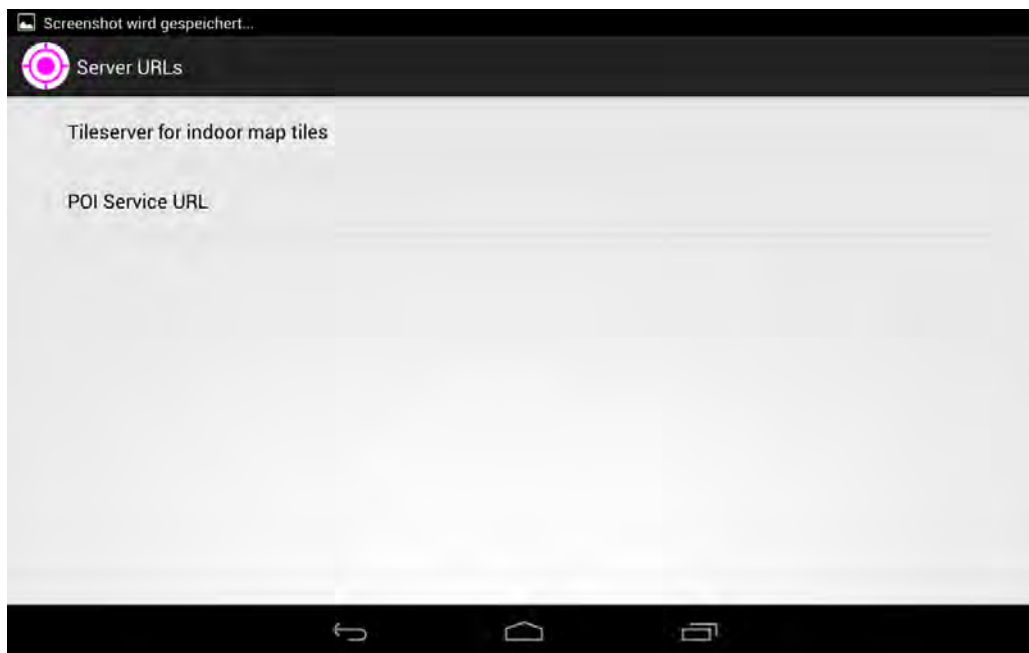


Figure 4.19: Preferences screen of the application

Server preferences

The preferences in this part allow the user to change the URL opened for the map tiles as well as the URL used for the calls to the web services. The URLs can be changed using a text field, when the corresponding entry is clicked in the preferences screen.

4 Implementation

Fingerprinting preferences

The fingerprinting preferences are used to enable or disable the mesh grid that is shown on the *Wi-FiMap* canvas.

Wi-Fi service

The implementation of the Wi-Fi service is responsible for the querying of the device's Wi-Fi radio and providing applications with the results. The system works through the usage of Androids concept of *System Services*. These service send broadcasts to registered receivers. A service can have a multiple broadcasts a receiver can subscribe to. In the case of the applications Wi-Fi receiver, the system service `WIFI_SERVICE` and its callback for new scan results is used. As an example of this usage, should a Wi-Fi fingerprint be created, a `BroadcastReceiver` is created and registered. Then the `WIFI_SERVICE` is instructed to scan for Wi-Fi signals and once this scan is complete, a callback interface is used to notify the application that new results are available.

Network tasks

The Android application relies heavily on calls to the web service and rendering server to perform its tasks. Without a network connection, the app has no functionality to speak of. The specifics of this design choices are in Section 4.2. All calls to the web services are handled in the background, which prevents the UI thread from freezing for the duration of these requests. The Android SDK provides a class called `AsyncTask`, which can handle these kind of background tasks.

“AsyncTask is designed to be a helper class around Thread and Handler and does not constitute a generic threading framework. AsyncTasks should ideally be used for short operations (a few seconds at the most.) If you need to keep threads running for long periods of time, it is highly recommended you use the various APIs provided by the `java.util.concurrent` package such as Executor, ThreadPoolExecutor and FutureTask.” [8]

4.6 Android application

The implementation uses these `AsyncTasks` to perform the background requests to the web service and callbacks are used to inform the UI of the finished request, so that the UI can update its screen as needed.

5 Outlook

The implementation in this work has succeeded in providing a system that can position a user on the campus of the university, display a map of the interior of the building with a high level of detail and provide directions to rooms in the building. The accuracy is high enough for a user to be able to find his position on the map and have a better understanding of his or her surroundings.

Requirements revisited

The following requirements for the client side were documented before the implementation phase of the project:

1. Provide the user with an estimate of his current position including his current level.
2. Display the users position on a map view.
3. User interface to calculate a route between two rooms.
4. User interface to calculate a route from the users current location to another room.

Table 5.1 shows a listing of these requirements and their corresponding solution. Using the implementation in this thesis, all requirements that were stated could be achieved. As such the implementation is successful in providing a mapping system for the Building O27 with the potential to expand the coverage across the whole campus.

5 Outlook

<i>Requirement</i>	<i>Fulfillment</i>
1	The positioning system created can provide the user with a position such that the user can see an estimate of his position inside the building. The position is not 100% accurate, but provides a best-effort solution to this requirement.
2	The map canvas in the Android application can use the data from the positioning system and show this position on the map.
3	A user interface to enter two rooms was implemented and the resulting route is shown by the Android application.

Table 5.1: Requirements and their fulfillment

5.1 Challenges

One of the challenges of this system was the creation of high quality mapping material. The process as outlined is highly manual and labor-intensive. The task of creating rooms and manually tagging them is also error-prone. Considering the size of for example, the campus of a university, the chances are high, that the maps will have errors. This can lead to maps that do not correctly portray the location of rooms or show areas that do not actually exist. These problems are not as serious as errors in the routing ways that are computed inside buildings. Errors in this grid of paths can lead to longer routes, errors in the routing algorithm, or rooms that can not be reached through navigation.

There are ways to reduce these errors. For example, an algorithm could be designed that checks the reachability of all POIs in the web service and reports such errors before new data is added to the database. Similar checks can be developed for other map data, which check if rooms have inconsistent tags. Both of these can eliminate errors. But these algorithms cannot decrease the amount of time needed to generate the map material. A way that has been devised during this thesis, but could not be tested because of time constraints, would be the automatic creation of map data from already existing schematics. Such data is usually available for buildings in the form of AutoCAD [29] or similar computer-aided-design software.

If a parser can be written that is able to produce map data for OSM, it can reduce errors in the material and either decrease the amount of time needed to create maps or, in the best case, automate the process as a whole. This would leave the Wi-Fi positioning system as

the last task that required a large amount of manual labor. But the advances in robotics might be able to automate even this process.

5.2 Future work

The way the application is designed is very modular as the system used for Wi-Fi positioning is separate from the components used to render the map. The POI service and Wi-Fi positioning both run on the same server, but can easily be separated from each other, since there are no interdependencies. The usage of OSM tools brings a framework of other software that can work with the created material. Through the usage of readily available components that work with OSM data, other systems can profit from this data.

One such example is the OpenStreetMap project called “Slippy Map” [68]. It provides a browser interface to map tiles. This interface was used to create a browser based map of O27, using the OSM material created for this thesis. This application can be seen in Figure 5.1. Such a map can be used throughout web sites of the campus to show the location of rooms or events.

Positioning system

The accuracy of the positioning system can be improved to increase its accuracy. Table 2.3 shows that accuracies in the range of two meters are possible using Wi-Fi based systems. Increasing the number of fingerprints is one way to increase the accuracy of these positioning systems. Another way to increase the accuracy is by taking four measurements at each fingerprint, in four different directions. This is used to reduce the impact on the received signals strengths caused by the person performing this scan.

Routing

The routing system currently uses Dijkstra’s algorithm to find the shortest path between two points. Using different algorithms, for example A^* , can decrease the time needed to calculate a route. Route calculation could also be performed on the device to decrease the reliance on a internet connection. Especially, a visitor might not always have the

5 Outlook

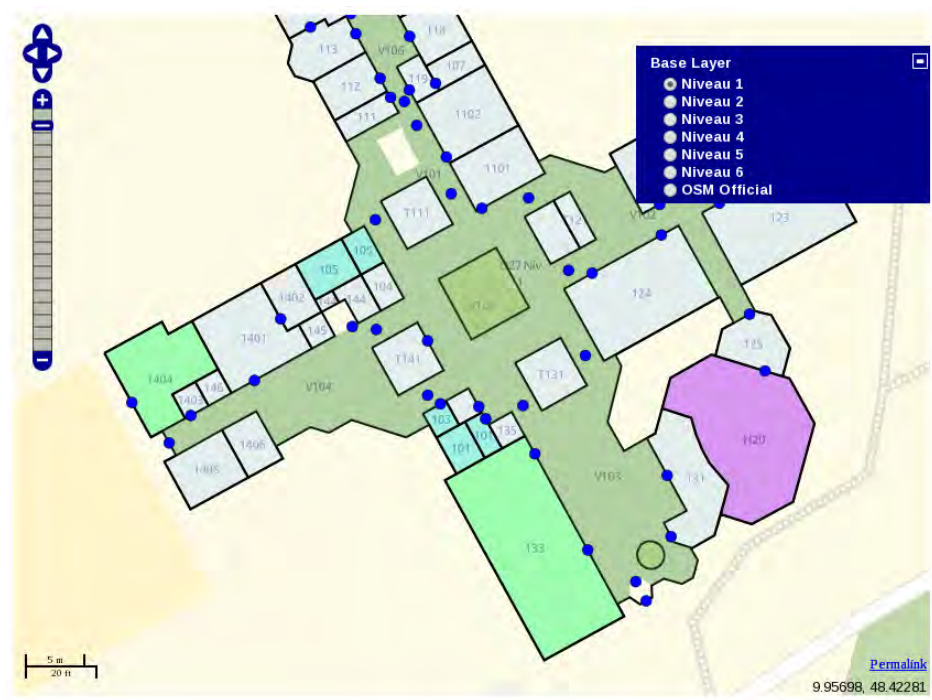


Figure 5.1: OSM Slippy Map of building O27

needed credentials to use the University's Wi-Fi system or even know of its existence. The reception from the cell phone network is not always reliable and especially in underground levels unreliable at best. Another possibility is the optimization of routes in the context of process management and mobile process management, examples that can profit from this work are [51] and [50].

App enhancements The functionality of the app can also be expanded to include more meta information. One idea that can be envisioned using the map material in combination with other data could be an extension of the map, where clicking on a office can show the occupants with phone numbers and other contact information. Clicking on an auditorium could show information about the usage for the current day and the maximum occupancy. Another possibility is the combination of the POI data with an augmented reality application. This app could show the location of all rooms or the location of some of the more important places on campus.

5.3 Conclusion

While the application leaves room for future enhancements, the application shows that using the technologies as described in this thesis provide a system that constitutes a full solution for indoor navigation. The concepts described in this system are fully transferable to almost any other indoor environment, especially considering the prevalence of Wi-Fi networks in most indoor environments.

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A Figures

A.1 Levels of Building O27

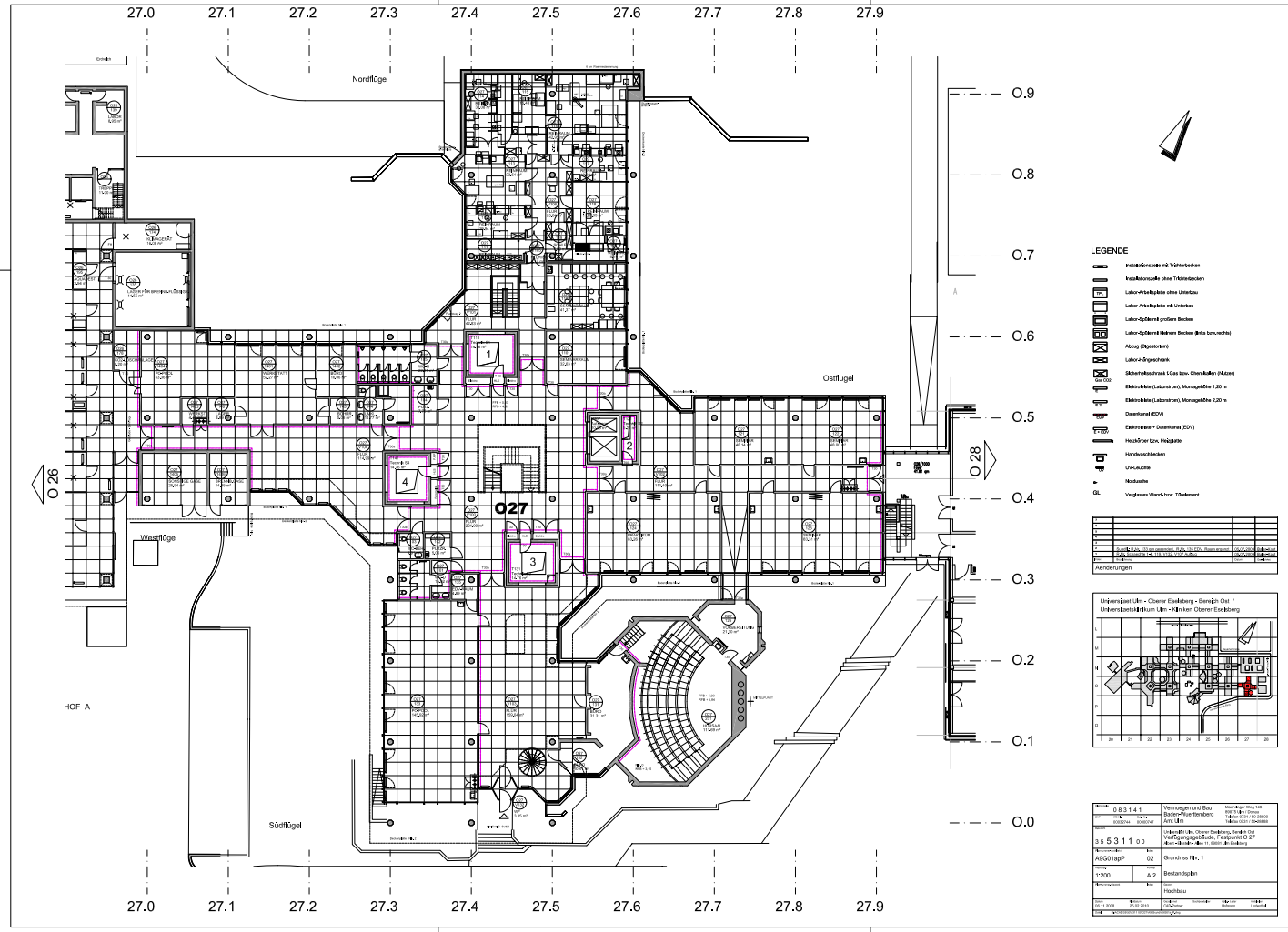


Figure A.1: Level one of Building O27

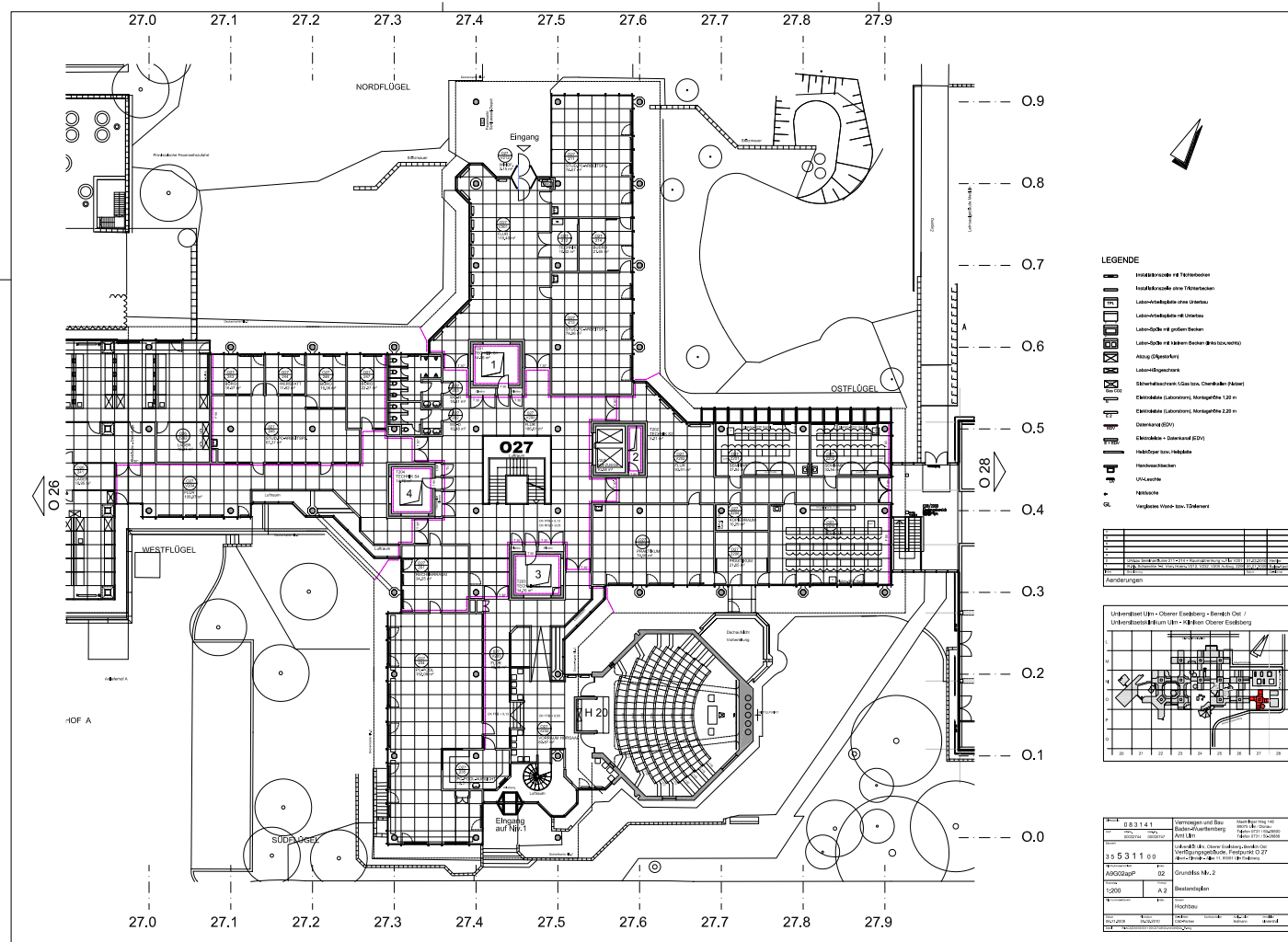


Figure A.2: Level two of Building O27



Figure A.3: Level three of Building O27



Figure A.5: Level five of Building O27

A.2 Examples of building features



Figure A.6: Building O27 on the eastern campus of the University of Ulm. Tagged using *building = yes.*

A Figures



Figure A.7: A computer laboratory in Building O27, tagged using *room = laboratory* and *laboratory = computer*.

A.2 Examples of building features



Figure A.8: A restroom as an example for the *amenity = toilets* tag.

A Figures



Figure A.9: An elevator on Level one of Building O27. Tagged using *highway = elevator*.

A.2 Examples of building features

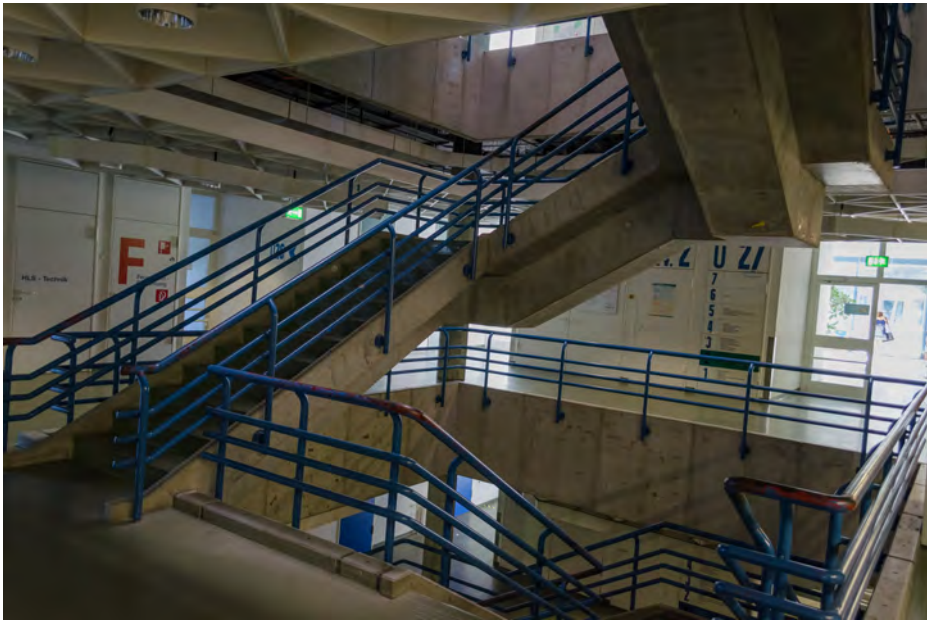


Figure A.10: Stairway on Level two of Building O27. The downward stairs lead to Level one, while the upward stairs lead to Level three. Tagged using *highway = steps*, *area = yes*.



Figure A.11: Auditorium “H20”, tagged using *room = auditorium*.

A.3 Building O27 rendered using the specified maps

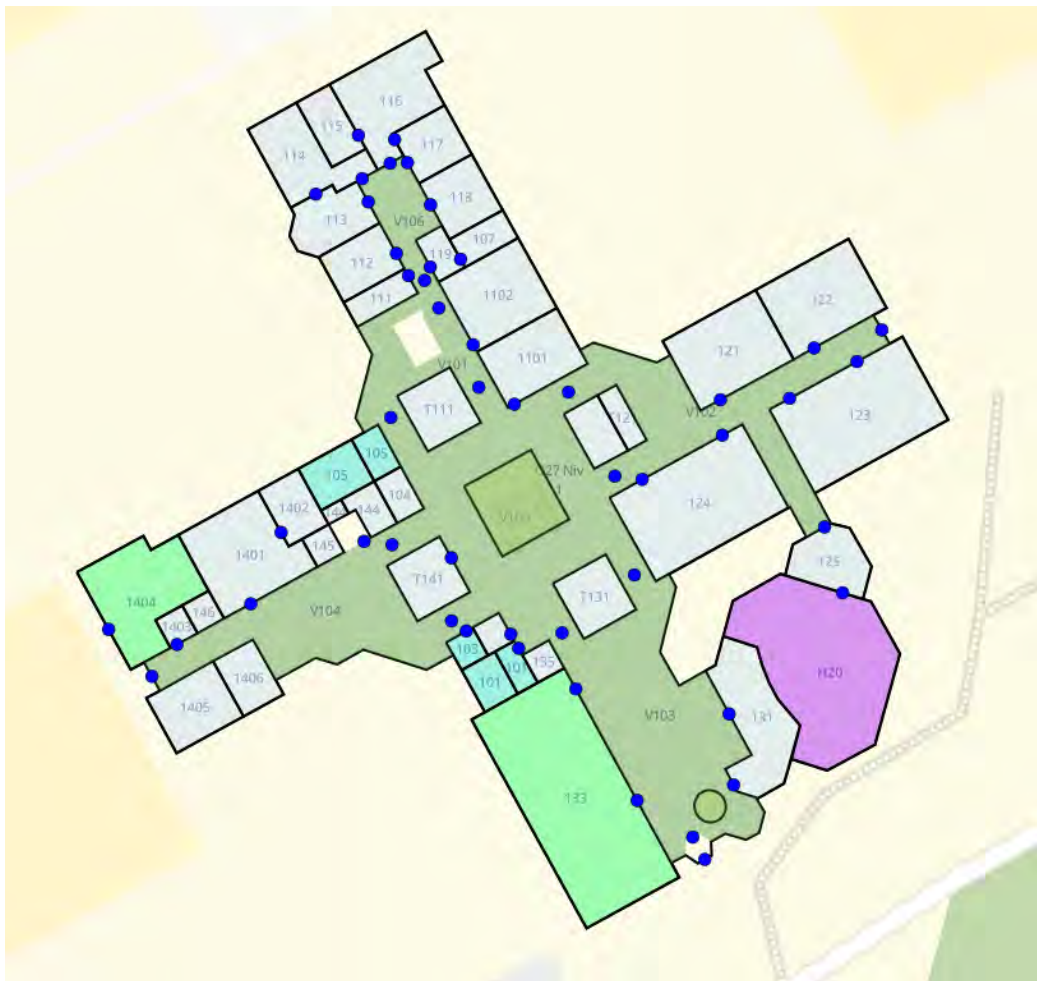


Figure A.12: Level one of Building O27

A.3 Building O27 rendered using the specified maps

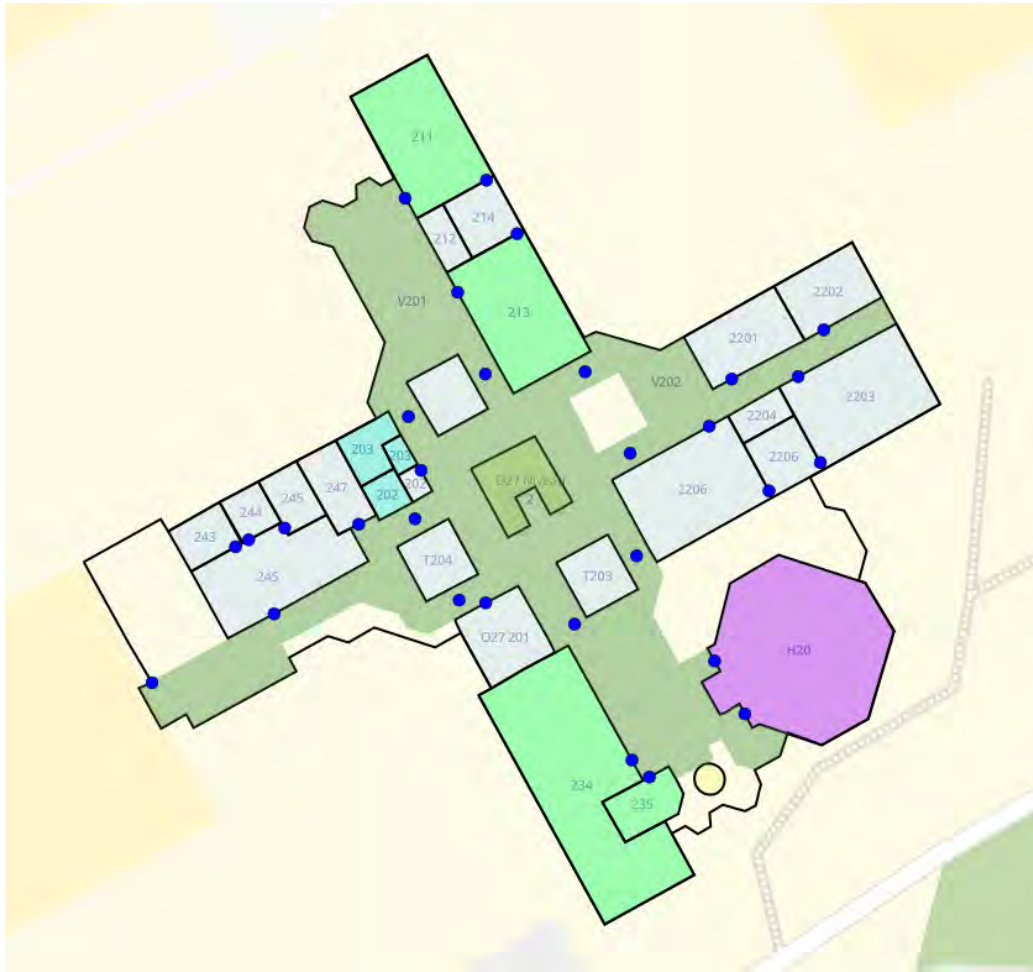


Figure A.13: Level two of Building O27

A Figures

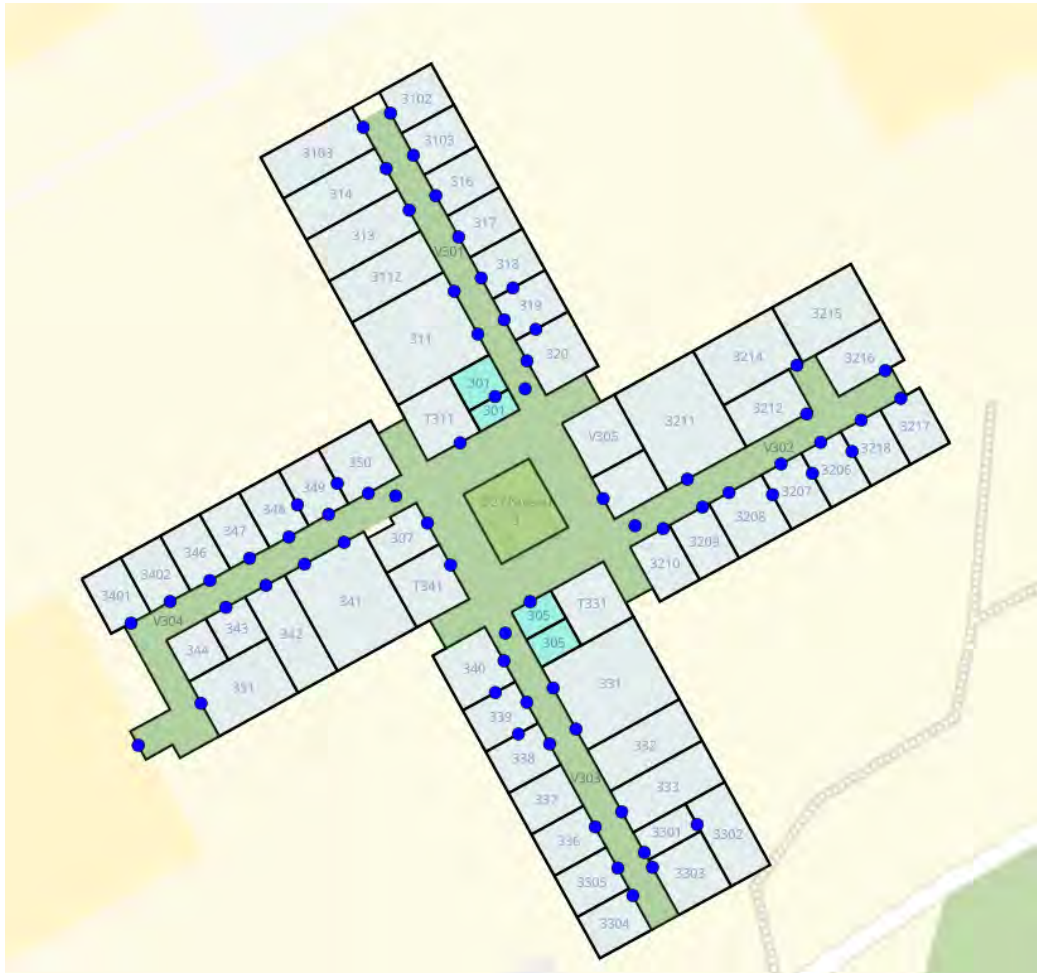


Figure A.14: Level three of Building O27

A.3 Building O27 rendered using the specified maps



Figure A.15: Level four of Building O27

A Figures



Figure A.16: Level five of Building O27

B Test series

The following test series was done using the positioning system developed in this thesis. The test consisted of measuring the distance from the actual location to the first two positions calculated by the positioning system. Position calculations that gave the wrong building level are also marked as such.

<i>Point</i>	<i>Distance A in m</i>	<i>level error</i>	<i>Distance B in m</i>	<i>level error</i>
A1	2.6	0	4.1	0
A2	7.4	0	10.7	0
A3	2.6	0	3.0	0
A4	1.5	0	2.2	0
A5	1.5	0	0.0	0
A6	0.0	0	2.2	0
A7	8.1	0	0.0	0
A8	1.5	0	1.1	0
A9	10.0	0	8.1	1
A10	2.6	0	10.4	0
A11	1.9	0	3.0	0
<i>Average:</i>	3.6		4.1	
<i>Combined average:</i>			3.84	
<i>Combined median:</i>			2.59	
<i>Combined variance:</i>			12.47	

Table B.1: Test series taken in Level two of Building O27

B Test series

<i>Point</i>	<i>Distance A in m</i>	<i>level error</i>	<i>Distance B in m</i>	<i>level error</i>
A1	9.3	0	11.7	0
A2	2.3	1	2.7	1
A3	3.7	0	2.0	0
A4	9.7	0	21.7	0
A5	5.0	0	10.0	1
A6	11.0	0	9.3	1
A7	0.0	0	0.0	0
A8	9.3	0	10.3	0
A9	2.3	0	2.3	0
A10	12.7	0	11.0	0
A11	2.7	0	2.0	0
A12	4.3	0	6.7	
<i>Average</i>	5.7		7.1	
<i>Combined average:</i>			6.76	
<i>Combined median:</i>			5.83	
<i>Combined variance:</i>			26.79	

Table B.2: Test series taken in Level three of Building O27

C Guides

C.1 Installation guide

This section is an installation guide for the database required for the POI service as well as the upgrade of the database to PostGIS 2.0

C.1.1 Geocoding

The pipeline consists of the following tools:

- Storage: JOSM(OSM XML) → osmosis(SQL) → PostgreSQL + PostGIS
- Retrieval: Request ("NAME") ↔ query key 'name' on nodes layer ↔ search PostgreSQL + PostGIS

Customizations compared to the normal process of exporting OSM data to a PostGIS database: JOSM does not export clean OSM XML, since the raw data is complemented by change set information, there are now configuration options to change this behavior, but through a small change in the sources of JOSM, the data exported is clean OSM XML data.

C.1.2 Compiling JOSM in Eclipse

The following steps are required to compile JOSM using the Eclipse IDE. Subversion is required to get the latest release from the JOSM project.

C Guides

1. Get JOSM Source:

```
$svn co http://josm.openstreetmap.de/svn/trunk josm
```

2. Install Eclipse JavaCC plugin from <http://eclipse-javacc.sourceforge.net/>

3. Import the project into Eclipse using the *existing project* wizard

4. Open `org.openstreetmap.josm.gui.mappoint.mapcss` in package explorer, right click `apCSSParser.jj` *Compile with JavaCC*

5. Create package

```
org.openstreetmap.josm.gui.mappoint.mapcss.parsergen
```

6. Move the files created by JavaCC into the new package

7. Modify `org.openstreetmap.josm.io.OsmExporter.java`

8. Execute *ant* in *JOSM* source path

9. The resulting binary in the form of a `.jar` can be found in the path:

```
dist/josm-custom.jar
```

Listing C.1: Original line of source code

```
1 OsmWriter w =  
2 OsmWriterFactory.createOsmWriter(new PrintWriter(writer), false,  
3 layer.data.getVersion());
```

Listing C.2: Modified line of source code

```
1 OsmWriter w =  
2 OsmWriterFactory.createOsmWriter(new PrintWriter(writer),  
3 true, layer.data.getVersion());
```


C.1.3 Database

The guide to install the PostGIS database is based on the official tutorial from http://wiki.openstreetmap.org/wiki/Osmosis/PostGIS_Setup. The database set up on a server running Ubuntu 12.04 was done using the following configuration. All commands are entered using a bash shell. Postgres 9.1 + PostGis 1.5 setup:

1. Dependencies: *postgis, postgresql, osmosis*
2. `#su postgres`
3. `$createdb osm`
4. `$createuser osm (yes superuser)`
5. `$psql osm --command "CREATE EXTENSION hstore;"`
6. `$psql --command "ALTER USER <username>
WITH ENCRYPTED PASSWORD 'osm'";`
7. `$psql -d osm -f
/usr/share/postgresql/9.1/contrib/postgis-1.5/postgis.sql`
8. `$psql -d osm -f
/usr/share/postgresql/9.1/contrib/postgis-1.5/
spatial_ref_sys.sql`
9. `$cd "/usr/share/doc/osmosis/examples"`
10. `$psql -d osm -f pgsnapshot_schema_0.6.sql`
11. `$psql -d osm -f pgsnapshot_schema_0.6_action.sql`
12. `$psql -d osm -f pgsnapshot_schema_0.6_bbox.sql`
13. `$psql -d osm -f pgsnapshot_schema_0.6_linestring.sql`

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14. If there are problems using peer authentication, the usage of a host name forces password authentication

Import osm file into database:

```
$osmosis --read-xml file="osm_output.xml"  
--write-pgsql user="osm" database="osm"  
password="PASSWORD" host="HOSTNAME"
```

Upgrade PostGIS database to version 2.0

To solve the closest neighbor problem using the geospatial database, an upgrade of PostGIS to version 2.0 was required.

1. Install *Ubuntu GIS stable PPA*:

```
# apt-add-repository ppa:ubuntugis/ppa && apt-get update  
&& apt-get dist-upgrade
```

2. Dump the old database:

```
#pg_dump -h localhost -p 5432 -U postgres  
-Fc -b -v -f "/somepath/olddb.backup" olddb
```

3. Rename the database to have a backup to return:

```
postgres=# ALTER DATABASE osm RENAME TO osm_backup;
```

4. Recreate the database:

```
a) #createdb osm  
  
b) psql osm: "create extension hstore;  
  
c) osm=# alter database osm OWNER to osm;
```

5. Restore backup:

```
#cd /usr/share/postgresql-9.1-postgis/utils  
# perl postgis_restore.pl
```

```
"/var/lib/postgresql/postgis_upgrade/osm.backup"  
|psql osm 2> /var/lib/postgresql/postgis_upgrade/errors.txt
```

6. Check PostGIS version:

a) `$psql osm=# SELECT postgis_full_version();`

b) Exepcted output:

```
POSTGIS="2.0.1 r9979" GEOS="3.3.3-CAPI-1.7.4"  
PROJ="Rel. 4.7.1, 23 September 2009"  
GDAL="GDAL 1.9.1, released 2012/05/15"  
LIBXML="2.7.8" RASTER
```

7. Install topology support:

```
osm=# CREATE EXTENSION postgis_topology;
```


D Sources

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Listing D.1: BASH script to convert PDF images to JPEG

```
1 #!/bin/sh
2 for file in `ls *.pdf`; do
3     convert -verbose -density 600 $file `echo $file |
4     sed 's/\.pdf$/\.jpg/'`
5     done
```

List of source code

Listing D.2: osm2pgsql style diff

```
1 --- /usr/share/osm2pgsql/default.style
2 +++ wifinder.style
3 @@ -69,7 +69,6 @@
4  node,way  motorcar    text          linear
5  node,way  name          text          linear
6  node,way  natural        text          polygon
7 -node,way  office          text          polygon
8  node,way  oneway          text          linear
9  node,way  operator        text          linear
10 node      poi            text
11 @@ -121,3 +120,12 @@
12 #node,way  osm_uid         text
13 #node,way  osm_version     text
14 #node,way  osm_timestamp  text
15 +#
16 +#
17 +#
18 ##### Wifinder Osm2Pgsql style
19 +node,way  room           text polygon
20 +node      entrance  text linear
21 +node,way  level           text ploygon
22 +node,way  incline      text polygon
23 +#node,way  highway      text polygon
```

D.1 Renderd & mod_tile

Listing D.3: Renderd patch to enable higher zoom levels

```
1 --- render_config.h 2011-12-04 21:57:22.000000000 +0100
2 +++ render_config.h.old 2013-06-18 16:03:17.740752121 +0200
3 @@ -1,7 +1,7 @@
```



```

4 #ifndef RENDER_CONFIG_H
5 #define RENDER_CONFIG_H
6
7 -#define MAX_ZOOM 18
8 +#define MAX_ZOOM 22
9
10 // MAX_SIZE is the biggest file which we will return to the user
11 #define MAX_SIZE (1 * 1024 * 1024)

```

Listing D.4: Configuration file used for renderd (*renderd.conf*)

```

1 [renderd]
2 socketname=/var/run/renderd/renderd.sock
3 num_threads=4
4 tile_dir=/var/lib/mod_tile ; DOES NOT WORK YET
5 stats_file=/var/run/renderd/renderd.stats
6
7 [mapnik]
8 plugins_dir=/usr/lib/mapnik/input
9 font_dir=/usr/share/fonts/truetype/ttf-dejavu
10 font_dir_recurse=0
11
12 [level1]
13 URI=/osm_level1/
14 XML=/etc/renderd/Wifinder_level1.xml
15 HOST=localhost
16 MAXZOOM=22
17 SERVER_ALIAS=http://example.org/
18
19 [level2]
20 URI=/osm_level2/
21 XML=/etc/renderd/Wifinder_level2.xml
22 HOST=localhost
23 MAXZOOM=22

```

List of source code

```
24 SERVER_ALIAS=http://example.org/
25
26 [level3]
27 URI=/osm_level3/
28 XML=/etc/renderd/Wifinder_level3.xml
29 HOST=localhost
30 MAXZOOM=22
31 SERVER_ALIAS=http://example.org/
32
33 [level4]
34 URI=/osm_level4/
35 XML=/etc/renderd/Wifinder_level4.xml
36 HOST=localhost
37 MAXZOOM=22
38 SERVER_ALIAS=http://example.org/
39
40 [level5]
41 URI=/osm_level5/
42 XML=/etc/renderd/Wifinder_level5.xml
43 HOST=localhost
44 MAXZOOM=22
45 SERVER_ALIAS=http://example.org/
```

D.2 Web service code

Listing D.5: Python code to calculate the position of a device

```
1 @app.route('/getLocation', methods=['GET', 'POST'])
2 def wifiPosition():
3     """
4     Calculate the approximate position of a device that transmits a signal
5     scan.
6
7     :return:
8     """
9
10    # Threshold Parameter:
11    TP1 = -85
12    TP2 = -80
13    TP3 = -70
14    apThreshold = 3
15    #of signalNodes averaged into location
16    neighbours = 5
17
18    if request.method == 'GET':
19        query = g.db.query(SignalNode)
20        query = query.all()
```

```
21
22     if app.config['DEBUG']:
23         print('List of wifi signals %s' % query[0])
24
25     return jsonify(miau=query[0].to_dict())
26
27 if request.method == 'POST':
28     js = request.json
29
30     posScan = js['position_scan']
31
32     # Values for location heuristic
33     lastLatitude = posScan['last_latitude']
34     lastLongitude = posScan['last_longitude']
35     last_level = posScan['last_level']
36
37     mPosScan = []
38
39     print('Delete APs with signal strength lower %s ' % TP1)
40     # remove Signals < threshold 1
41     for signal in posScan['signals']:
42         if signal['frequency'] > 5000:
43             wifi5 = True
```

```

44         if signal['signal_strength'] > TP1:
45             mPosScan.append(signal)
46
47         #5GhZ results available
48         wifi5 = False
49
50         aps = []
51         for signal in mPosScan:
52             print(('add signal {} with signal strength {} to positioning signal').format(
53                 signal['ap']['bssid'],
54                 signal['signal_strength']))
55             aps.append(signal['ap']['bssid'])
56
57
58
59
60         ## Get all SignalNodes with the found APs
61         query = g.db.query(SignalNode)
62         query = query.filter(Signal.ap_bssid.in_(aps)).all()
63
64         positionList = []
65
66         #calculate euclidean distance:

```

```
67
68     #iterate over all found calibration nodes
69     for calibrationNode in query:
70
71
72         ap_counter = 0
73         distance_vector = 0
74         print(('Checking Calibration Node {}'.format(calibrationNode.to_dict())))
75
76         # iterate over position scan signals
77         for positionSignal in mPosScan:
78
79             #Check if BS with signal strength > TP3 exists in this calibrationNode
80             exists = True
81             if positionSignal['signal_strength'] > TP3:
82                 exists = False
83                 for calibrationSignal in calibrationNode.signals:
84                     if calibrationSignal.ap_bssid == positionSignal['ap']['bssid']:
85                         exists = True
86
87             if not exists:
88                 # no check if 5GHZ
89                 #if positionSignal['frequency'] > 5 and not wifi5:
```

```
90         # pass
91         #Signal strength is larger then TP3, calibration node ist
92         # not used for locating
93         print(('AP {} with signal strength {} is above TP3 of {}'.format(
94             positionSignal['ap'],
95             positionSignal['signal_strength'],
96             TP3))
97         break
98
99     else:
100         for calibrationSignal in calibrationNode.signals:
101             if positionSignal['ap']['bssid'] == calibrationSignal.ap_bssid:
102                 print(
103                     ('adding positionSignal of {} to distance_vector').format(
104                         positionSignal['ap']['bssid']))
105                 ap_counter = ap_counter + 1
106                 distance = calibrationSignal.signal_strength\
107                     -positionSignal['signal_strength']
108                 distance = math.pow(distance, 2)
109                 distance_vector = distance + distance_vector
110
111             else:
112                 #no breaks encountered
113                 continue
```

```
113         break
114     else:
115         if ap_counter > apThreshold:
116             euclidian_distance = math.sqrt(distance_vector / ap_counter)
117             print('Euclidian Distance: %s' % euclidian_distance)
118             tuple = euclidian_distance, calibrationNode
119             positionList.append(tuple)
120         continue
121
122
123     ##TODO: correct message if list too small
124     if len(positionList) < 1:
125         response = Response(status=500)
126         return response
127
128     positionList.sort()
129     if True:
130         for k, v in positionList:
131             print('Distance {} for Node {}'.format(k, v.to_dict()))
132
133     distance, bestSignalNode = positionList[0]
134
135
```



```

136
137     location = [['latitude', bestSignalNode.latitude],
138                 ['longitude', bestSignalNode.longitude],
139                 ['level', bestSignalNode.level]]
140     print(('Location of best signal node: {}'.format(location))
141
142     #initialize counting variables
143     index = 0
144     latitude = 0
145     longitude = 0
146     distances = 0
147     level = 0
148     level_sum = 0
149
150     for distance, node in positionList:
151         if index >= neighbours:
152             break
153
154         index = index + 1
155         distances = (1 / distance) + distances
156         latitude = (node.latitude / distance) + latitude
157         longitude = (node.longitude / distance) + longitude
158         level = (node.level / distance) + level

```

```
159         latitude = latitude / distances
160         longitude = longitude / distances
161         level = level / distances
162         print(('average level {}'.format(level))
163         level = round(level, 0)
164
165
166         location = [['latitude', latitude], ['longitude', longitude], ['level', level]]
167
168         print('Average location: {} ').format(location)
169
170         return jsonify(location)
171
172
173         # TODO: Return a URL to the uploaded object
174     resp = Response(status=200)
175     return resp
```

Listing D.6: Python implementation of Dijkstra's algorithm

```
1 from sqlalchemy import *
2 from sqlalchemy.dialects.postgresql import array
3 from sqlalchemy.types import BigInteger
```

```

4 from sqlalchemy import func
5
6 from shapely.geometry import Point
7
8 from geoalchemy2.elements import WKTElement
9
10 from uulm_find.database import db_session
11 from uulm_find.models.osm import *
12 from uulm_find import app
13 from itertools import chain
14
15
16 __author__ = 'Alexander Bachmeier'
17
18
19 class Routing:
20     def init(self, g):
21         #Get the g object from the current flask request (allows us to perform database queries)
22         #self.g = g
23         self.db = g.db
24         self.metadata = MetaData()
25
26     pass

```

```
27
28
29 def getWays(self, level):
30     query = db.query(Ways).filter(
31         and_(Ways.tags['level'] == level, Ways.tags['highway'] == 'corridor'))
32
33     return query
34
35
36 def get_neighbour_nodes(self, nodeId):
37     """
38     Returns a list of nodes with the id of all neighbours of the given node
39     :param node:
40     :return: list of node ids
41     """
42     if app.config['DEBUG']:
43         print("getNeighbourNodes Start")
44
45     ## Get all ways the starting node is on:
46     ## select * from ways where nodes @> '-710'::bigint[];
47
48     ways_with_node = self.db.query(Ways).filter(
49         and_(Ways.nodes.contains(array([cast(nodeId, BigInteger)])),
```

```

50         or_(Ways.tags['highway'] == 'corridor', Ways.tags['highway'] == 'steps'),
51         not_(Ways.tags.has_key('area')))).all()
52
53     neighbour_ids = []
54
55     #Traverse ways with nodes
56     for way in ways_with_node:
57         if app.config['DEBUG']:
58             print(
59                 ("Getting neighbour nodes of {0} on way with id: {1}").format(nodeId,
60                                                                                   way.id))
61
62                 #get seq# of "node" on current way:
63     way_node = self.db.query(WayNodes).filter(
64         and_(WayNodes.way_id == way.id, WayNodes.node_id == nodeId)).one()
65     node_seq = way_node.sequence_id
66
67     #get all nodes on way
68     all_way_nodes = self.db.query(WayNodes).filter(
69         WayNodes.way_id == way.id).all()
70
71     ##check if nodes are -1 or +1 in seq from "node"
72     for way_node in all_way_nodes:
73         if way_node.sequence_id == (node_seq + 1) or way_node.sequence_id == (

```

```
73         node_seq - 1):
74         neighbour_ids.append(int(way_node.node_id))
75
76     if app.config['DEBUG']:
77         print(
78             ("List of neighbours of node with id {0}: {1}").format(nodeId, neighbour_ids))
79         print("getNeighbourNodes END")
80
81     return neighbour_ids
82
83
84     def getDistance(self, node1_id, node2_id):
85         """
86             Calculate the distance between two nodes
87             :param node1_id: id of the first node
88             :param node2_id: id of the second node
89             :return: distance as a geom object between the two nodes
90         """
91         node1 = self.db.query(Nodes).get(node1_id)
92         node2 = self.db.query(Nodes).get(node2_id)
93
94         query = self.db.query(func.ST_DISTANCE(node1.geom, node2.geom)).one()
95         if app.config['DEBUG']:
```

```

96         print(
97             ("distance between node {0} and node {1}: {2}").format(node1_id, node2_id,
98                                                                     query))
99
100     return query[0]
101
102
103     def dijkstra(self, startNode, endNode):
104         """
105             Dijkstra algorithm that returns the shortest path from startNode to endNode
106             :param startNode: uulm_find.models.osm.Node object
107             :param endNode: uulm_find.models.osm.Node object
108         """
109
110         distance = {}          #distance
111         best_prev_node = {}
112
113         distance[startNode.id] = 0 ##distance to start node = 0
114
115         #add starting nodes to queue
116         queue = []
117         queue.append(startNode.id)
118

```

```
119     #the algorithm itself only uses the ID of the nodes,  
120     #not the actual representation of the node!  
121  
122     #while loop counter  
123     count = 0  
124     #make sure code doesn't run forever  
125     max_count = 100000  
126  
127     while count < max_count:  
128         if app.config['DEBUG']:  
129             print(('While counter : {0}').format(count))  
130         count = count + 1  
131  
132         try:  
133             current_node = queue.pop(0)  
134         except IndexError:  
135             print("IndexError")  
136             break  
137  
138         if current_node == endNode.id:  
139             ##our endNode has been found ==> shortest path found  
140             print("Found End Node!")  
141             return best_prev_node, distance
```



```
142
143     #"usual" case of find neighbours and calculating their distance
144
145     neighbors = self.get_neighbour_nodes(current_node)
146     if app.config['DEBUG']:
147         print("Node {0} has {1} Neighbours".format(current_node, len(neighbors)))
148
149     for nodeId in neighbors:
150         #append new neighbors to the queue
151         if nodeId not in distance:
152             queue.append(nodeId) ##TODO: might lead to longer routes!
153
154         dist = distance[current_node] + self.getDistance(current_node, nodeId)
155
156         if nodeId in distance:
157             if dist < distance[nodeId]:
158                 ##shorter path found, update!
159                 distance[nodeId] = dist
160                 best_prev_node[nodeId] = current_node
161         else:
162             distance[nodeId] = dist
163             best_prev_node[nodeId] = current_node
164
```

```
165
166 def getRoute(self, startNode, endNode):
167     print("Start Node ID {0}: \n {1}".format(startNode.id, startNode.to_dict()))
168     print("End Node ID {0}: \n {1}".format(endNode.id, endNode.to_dict()))
169
170     print('Neighbors of EndNode: {0}'.format(self.get_neighbour_nodes(endNode.id)))
171
172     best_prev_node, distance = self.dijkstra(startNode, endNode)
173
174     route = []
175     loop_node_id = endNode.id
176     while 1:
177         #route complete if previous node is start node:
178         node = self.db.query(Nodes).get(loop_node_id)
179         #
180         # if node.tags['highway'] is 'steps':
181         #     steps = True
182         # else:
183         #     steps = False
184         node_dict = node.to_dict()
185         waypoint = {
186             'latitude': node_dict['latitude'],
187             'longitude': node_dict['longitude'],
```

```

188         'level': node_dict['level'],
189         'steps': False,
190     }
191
192     route.insert(0, waypoint)
193     if (best_prev_node[loop_node_id] == int(startNode.id)):
194         break
195     loop_node_id = best_prev_node[loop_node_id]
196
197     ##close database collection
198     #db.close()
199
200     print('Finished Route:')
201     for waypoint in route:
202         print(waypoint)
203
204     #Return a route, represented by a list of waypoints.
205     #Starting from the StartNode to the EndNode
206     return route
207
208
209 def getNextWayNode(self, location):
210

```

```
211
212     # Create a geometry point; arguments are lon, lat
213     point = 'Point(%0.8f %0.8f)' % (location['longitude'], location['latitude'])
214
215     # transform into a wkt element
216     wkt_point = WKTElement(
217         'Point({0} {1})'.format(location['longitude'], location['latitude']),
218         srid=4326)
219
220     #get a list of all way nodes
221     listOfNodes = self.db.query(Ways.nodes).filter(
222         and_(Ways.tags['highway'] == 'corridor',
223 %       Ways.tags['level'] == str(location['level'])).order_by(
224         Ways.bbox.distance_box(wkt_point)).all()
225
226
227     #flatten list of lists of lists:
228     node_ids = list(chain.from_iterable((chain.from_iterable(listOfNodes))))
229
230     best_node = self.db.query(Nodes).filter(Nodes.id.in_(node_ids)).order_by(
231         Nodes.geom.distance_box(wkt_point)).first()
232
233
```

```
234     return best_node
235
236
237 if __name__ == '__main__':
238     db = db_session()
239
240     routing = Routing()
241     routing.db = db
242     #routing.getRoute(node1, node2)
243     current_location = {'latitude': 48.4228724245706, 'longitude': 9.95691005140543,
244                        'level': 2}
245
246     routing.getNextWayNode(current_location)
247
248
249
250     #g.db.close()
```

D.3 OsmConverter

These tools are used to upload OSM data into the webservice's database. The data is used for POI services as well as routing.

Listing D.7: OsmConvert.py, used to add missing information from OSM XML data

```
1  #!/usr/bin/env python2
2
3  __author__ = 'Alexander Bachmeier'
4  # add missing version attribute from JOSM osm exports
5  import xml.etree.ElementTree as ET
6  from datetime import datetime
7
8
9  INPUT_FILE = 'uulm.osm'
10 OUTPUT_FILE = 'osm_output.xml'
11
12
13 #get input file using ElementTree parser
14 tree = ET.parse(INPUT_FILE)
15 root = tree.getroot()
16
17 #timestamp format: timestamp="2012-06-04T21:25:04Z"
18 now = datetime.datetime.now()
19 timestamp = now.strftime("%Y-%m-%dT%H:%M:%SZ")
20
21 #traverse children
22 for child in root:
23     #add required version attribute
24     if child.tag == 'node' or child.tag == 'way' or \
25         child.tag == 'relation' \
26         and 'version' not in child.attrib:
27         child.set('version', '0')
```

```

28     #add required timestamp attribute
29     if child.tag == 'node' or child.tag == 'way' or \
30         child.tag == 'relation' \
31         and 'timestamp' not in child.attrib:
32         child.set('timestamp', timestamp)
33
34 tree.write(OUTPUT_FILE)

```

Listing D.8: Tool to automate process

```

1  #!/bin/bash
2
3
4  ./OsmConvert.py
5  #Truncate Database before import
6  osmosis --tp user="osm" database="osm" \
7  password="$PASSWORD" \
8  host="example.org" \
9
10
11 osmosis --read-xml file="osm_output.xml" \
12 --write-pgsql user="USER" database="osm" \
13 password="$PASSWORD" host="example.org"

```


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Erklärung

Ich erkläre, dass ich die Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

Ulm, den

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