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DATA MODEL FOR HYBRID INDOOR POSITIONING SYSTEMS

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Abstract. Indoor Positioning Systems have gained attention over the last decade. Despite of numerous attempts and solutions, there is no common standard indoor positioning system such as the GPS for outdoor environment. Smart phones seem to be a good candidate for mobile devices of indoor positioning systems due to their low cost and incidence. The sensor sets of the most popular mobile platforms are analyzed from the point of view of indoor positioning and a formal data model has been created in this paper. The presented model allows the development of hybrid indoor positioning algorithms. The data model is used to design and implement a Java library which will be used to create an indoor location and navigation framework.

Keywords: indoor positioning, mobile platforms

1. Introduction

Location based services became the part of our life. Global Navigation Satellite Systems [1, 2] are essential in transportation, logistics, military, aviation, etc. Augmented reality has become a hot topic in the last years. Smart phones, –watches and glasses– are possible candidates to make augmented reality available to the masses. Google Indoor Maps makes it possible to share the map of buildings on Google Maps, moreover big airports, railway stations, malls and other public areas already have been modeled.

Despite of the numerous efforts to create indoor positioning system [3, 4], there is no single commonly used solution on the market. These systems have different complexity, installation and maintenance costs, performance and requirements. Developers usually have to make a trade–offs between performance and costs. For example a system with high accuracy usually requires special hardware and infrastructure thus its cost is high. Moreover the special hardware requirements limit the usage and the spread of the system. The systems which use the already established infrastructure have low installation cost but they have lower accuracy and precision than the special–purpose systems. Hence the smart phones seem to be good possible candidates for client of indoor positioning systems due to their availability, easy programmability and wide sensor set.

The analysis of the widely available sensors is necessary to design the data model for indoor positioning systems [5]. The three dominant mobile platform were analyzed in this work. The analysis of the sensor sets makes it possible to create a mathematical description and a formal data model for hybrid indoor positioning methods. The presented data model was implemented in Java. The library supports JSON serialization which is essential for web applications with multi–platform mobile clients.

2. Mobile Platforms

Smart phones are excellent candidates for client devices of indoor positioning system due to their availability, popularity and wide range of built–in sensors. The smart phones became popular in the early 2000's and these days hundreds of them are produced by four major producers. According to the statista.com [6], the smart phone market was shared between the Google, Apple, Microsoft and Blackberry in the United States. Google's Android operation system has slightly more than half of the market. The Apple's iOS system is the second dominant and owns approximately 40% of the market. Microsoft have acquired only 5% of the market over the years. The Blackberry produces devices for Enterprises so they have less potential customers than the previous producers.

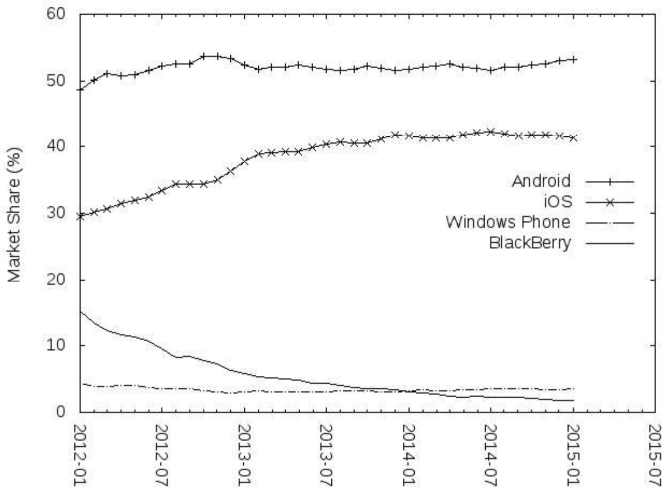

Figure 1. Market Share of Mobile Platforms

Android is the most popular and most widely used mobile platform. Numerous manufacturers offer huge range of devices so that there is huge variety in hardware, computational capabilities and performance of Android devices. Applications have to be implemented in this heterogeneous hardware which is standardized by the Android operation system. Although the API allows to implement the same application on various Android devices, but precision and accuracy of the mobile sensors depend on the quality of the device. Thus the mobile device affects on the measurement due to the heterogeneity of the Android platform.

Although iOS can be run on only iPhone and iPad devices Apple still has about 40% of the market share in the United States. The limitation of the possible architectures allows to optimize the operation system and applications to the supported ones. Moreover this limitation increases the robustness and quality of applications and simplifies the development. On the other hand, the iOS development has special requirements for the developers such as specific operation system which limits its applicability in research projects.

Both Windows Phone and BalckBerry have only 5% of the market of smart phones so they are not leading but they are relevant. Windows Phone has joined the most recently to the market of smart phones. Microsoft provides efficient tools for developers. Moreover Windows Phones can be programed in C# and .Net Libraries are also available for the developers. Blackberry produces smart phones for enterprises thus these products are bought by companies. Moreover Blackberry provides various services to handle and manage the devices remotely and other producers do not have similar services.

3. Sensors

Most of the available sensors are detailed and evaluated from the point of view of indoor positioning in this section. These sensors are categorized based on their purpose so motion, environment and radio frequency sensors are discussed. The applicability for indoor positioning was the main selection criteria. Availability, platform support, incidence are also important features.

3.1. Motion

Motion sensors measure the movement of the device. Numerous popular applications are built on the usage of these sensors such as step counters, fitness application or simulators [7]. From the point of view of indoor positioning these sensors can be used for tracking devices [8]. Calibration is required for these systems which limits the applicability of these sensors in real life situations. On the other hand, motion sensors based measurements can support positioning systems and can be applied in tracking services.

Accelerometer measures the acceleration of the device in a three dimensional space. Equation 3.1 shows the calculation of acceleration vector $\overline{a}$ where $\overline{g}$ stands for gravity, $\overline{F}$ denotes the forces acting upon the device and m is the mass of the device.

$$\overline{a} = -\overline{g} - \frac{\sum \overline{F}}{m} \tag{3.1}$$

Gyroscope and Rotation Vector give data about the spinning of the device via three axes. However these values could be applied to determine the orientation of the device, but they are not related to positioning directly. Proximity sensor determines the distance of the device from other objects. Its result can be given in centimeter or logical value. Proximity sensor is not suit for indoor positioning tasks. Thus our data model is based on neither gyroscope nor proximity sensors.

3.2. Ambient Environment

The characteristics of the environment can be used to determine the location. Location and their functions are often recognized by their characteristics and signs. For example a lecture hall can be recognized based on the organization and it can be identified by its number. Temperature and humidity also can suggest the function of place. There are systems that creates unique environment characteristics for mobile devices. For examples the Active badges [9] uses infrared sensors which are installed at entrances. Visible light communication based indoor positioning offers high accuracy [10] but it requires a specific infrastructure thus its installation cost is high. Ultrasonic signals are also widely used [11, 12].

The usage of magnetic field for indoor positioning was suggested by various researchers [13, 14]. Mobile platforms provide interface for the measurement of the magnetic field. Android has a built–in model to convert the results of magnetometer into GPS coordinates and vice-versa. This model was created by the United States National Geospatial-Intelligence Agency and it was valid until 2015. The indoor environment affects on the magnetic fields. Electronic devices and large metal objects can generate noise for the magnetometer.

Smart phones usually have numerous built–in sensors to measure the environment such as temperature, relative humidity, or pressure. These sensors are meant to give information about the environment for further processing. Temperature sensor can be used to warn the user about the possible overheating of the device. These kind of measurement can vary in the building but their values can be used to distinguish certain positions or functionality. For example an ice–room can be identified by its temperature and a greenhouse has unique relative humidity parameters. But generally, these parameters do not change within a building. Moreover, in industrial facilities like an electronic product line these parameters are fixed or limited. Hence these sensors are not included in the proposed model.

3.3. Radio Frequency Signals

Radio frequency signals are widely used in wireless communication solutions. Short–range wireless protocols such as WLAN [15, 16, 17], RFID [18, 19, 20] and Bluetooth [21] are used for indoor positioning so only these sensors will be discussed. Moreover WLAN and Bluetooth are supported by all of the dominant platforms and RFID readers also became available in the modern smartphones.

Bluetooth is a short ranged communication protocol. Its range is typically less than 10 meters in mobile devices. Bluetooth modules has unique identifiers which can be used for tracking objects. Both three major mobile platform provides API for Bluetooth programming. The Received Signal Strength Indication of Bluetooth devices were used to create a triangulation based indoor positioning method [21]. Two mobile devices can communicate via Bluetooth, if they supports the same protocol and they are within the range. Equation 3.2 shows the formal description of Bluetooth scan with a protocol version v.

$$B_v = \{id_0, id_1, \ldots, id_n\} \tag{3.2}$$

RFID tags are widely used in industrial environment, logistics and security systems. Near Field Communication is a subcategory of RFID technology which allow short range wireless data exchange among devices. Due to the popularity gain of NFC technology, the recent smart phones have built–in RFID readers. Typical range of NFC is less than 10 cm which limits its applicability. However the current built–in NFC sensors are not capable for indoor positioning, hand–held RFID readers can be connected via Bluetooth. Landmark [20] and SpotOn [18, 19] are RFID based indoor positioning systems. The RFID readers detect the tags that are within a given range. The range depends on the setup of the reader and tags. Thus the result of an RFID measurements can be described as Equation 3.3:

$$RFID = \{tag_0, tag_1, \ldots, tag_n\} \tag{3.3}$$

WiFi Card is a common interface of mobile devices. The first fingerprinting based Indoor Positioning System, RADAR [15], was based on the Received Signal Strength Indication of WLAN Access Points. Experiments on the Horus system showed that the RSSI values fluctuate, so the usage of RSSI vector instead of a single value was proposed [16, 17]. The measurements of a WiFi RSSI can be formalized as a set of access points and RSSI values which is shown by Equation 3.4 where ap stand for the SSID of an Access Point and $rssi \in R$.

$$WiFi = \{(ap, rssi)\} \tag{3.4}$$

4. Formal Model

The analysis of the available sensor set allowed to create a formal data model for hybrid indoor positioning methods. The position is also included into the formal model because it is required for fingerprinting based methods. The presented data model is used in the development of the ILONA (Indoor LOcation and NAvigation) system.

4.1. Selected Sensors

Table 1 gives a brief summary of different sensors on various platforms. The main selection criteria were the applicability for indoor positioning, availability and platform support. Bluetooth, GPS, magnetometer, RFID reader and WLAN network interface card were selected because they are vital components of smart phones. RFID reader was chosen because it is integrated into modern Android devices and the RFID technology is significant in the research of indoor positioning systems.

Table 1. Commonly Available Mobile Sensors

Sensor	Android	iPhone	Windows Phone	Chosen
Accelerometer	✓	✓	✓	
Bluetooth	✓	✓	✓	✓
Camera	✓	✓	✓	
Gravity	✓			
GPS	✓	✓	✓	✓
Gyroscope	✓	✓	✓	
Light	✓	✓	✓	
Magnetic Field	✓	✓		✓
Microphone	✓	✓	✓	
Orientation	✓		✓	
Pressure	✓			
Proximity	✓	✓	✓	
Relative humidity	✓			
RFID				✓
Rotation Vector	✓			
Temperature	✓			
WiFi Card	✓	✓	✓	✓

4.2. Mathematical Description

The measurements of the selected sensors can be modeled formally as a tuple which is shown in Equation 4.1. Measurement $\mathcal{M}$ consists of data that is read from the selected sensors ($\mathcal{S}$) and a time stamp which is used to distinguish measurements and a position ($\mathcal{P}$) which is set by the user. The timestamps and the position together determine a measurement because it is possible to perform multiple measurements in the same location.

$$\mathcal{M} = \langle \mathcal{S}, timestamp, \mathcal{P} \rangle \tag{4.1}$$

Let $\mathcal{S}$ be a tuple of the read sensor data and given in Equation 4.2. Missing values are allowed in $\mathcal{S}$ due to the variety of the mobile devices. Moreover the existing indoor positioning systems usually rely on a single sensor. The

$\{bt_{tags}\}$ represents the set of available Bluetooth devices. GPS coordinate is unavailable in indoor environment but it can be used in campuses and hospitals which contain many buildings. The magnetometer returns with a vector (x, y, z) which point the North. It can be used to determine orientation of the user. The sensed RFID tags are represented as set in the model. Finally, the WLAN interface can be used to scan available access points. The measurement yield key–value pairs where the key is the SSID of the access point and the value is the measured RSSI.

$$\mathcal{S} = \langle \{bt_{tags}\}, (lat, lon, alt), (x, y, z), \{rfid_{tags}\}, \{(ssid, rss)\} \rangle \tag{4.2}$$

Position can refer to either a symbolic zone of the building or relative coordinates. Zones are considered as well defined disjunct parts of the building. Thus zone can denote a room, a corridor or even a part of the building. Zones are used by symbolic or room level positioning methods. The relative coordinates denotes the distance from a fixed point which is the origin of the coordinate system. Absolute positioning methods use the relative coordinates and the GPS coordinates can be calculated.

$$\mathcal{P} = \langle zone, (x, y, z) \rangle \tag{4.3}$$

This mathematical description allows to handle the measurements formally and create operations among them. However this abstract model cannot be used directly by indoor positioning systems because technical details have been omitted. For example, the mathematical model do not define data types nor constrains.

4.3. Data model

Entity-Relationship model has been created based on the mathematical description in order to simplify the implementation of the formal model. Figure 2 shows the entity–relationship model which describes the measurements and the positions. The data model contains unique identifiers for both measurements, positions. Zone identifier was created because the name of the zone is not necessarily unique. For example there are ground floor in every building or each floor could have the same room numbering. Because either the zone and the coordinate can be unknown the position identifier has to be defined. In the mathematical model, a measurement could be identified by the position and the time stamp but also a unique identifier has been defined for each measurement, due to the following reasons: Firstly, the positions also identified by identifier. Secondly, the position is unknown during the positioning and the identification of measurements is necessary to monitor the positioning algorithm.

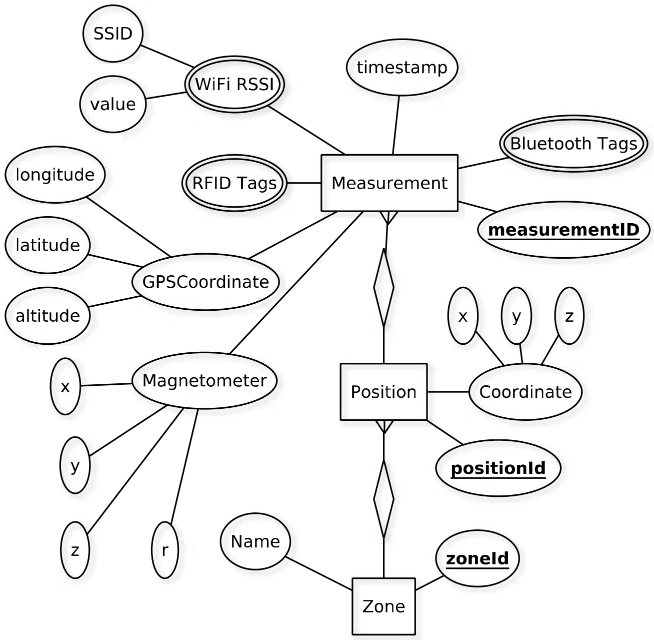

Figure 2. ER model of Measurements

5. Implementation

The above detailed model has been implemented in Java. Maven was used to build the component and to manage its dependencies. JUnit and EasyMock were used for testing and Jackson JSON Processor Library was used to serialize and deserialize objects.

The classes of the components are shown in Figure 3. The `Measurement` class is used to wrap the values of the sensor. The measurements of the selected sensors are represented by corresponding classes such as BluetoothTags, `Magnetometer` and `WiFiRSSI`. These classes were implemented as beans because this was required for Jackson.

The instantiation of `Measurement` object is difficult because it is a wrapper class. The number of the possible valid constructors is the combination of the wrapped types. So the number of the constructors grows rapidly. The Builder pattern [22] was used to simplify the instantiation of `Measurement` objects.

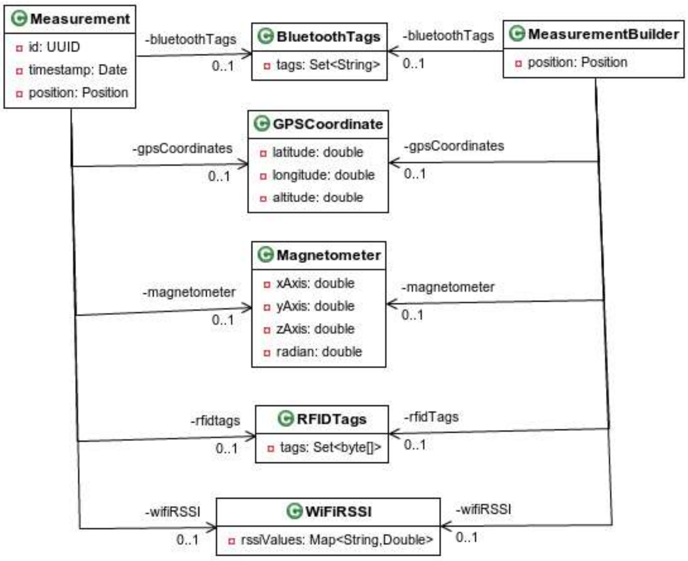

Figure 3. Measurement Implementation

Due to its protected constructor, `Measurement` objects can be instantiated only from its package and the `MeasurementBuilder` can be used to create them.

5.1. Serialization

Jackson JSON Processor was used to serialize the objects. The JSON format was chosen due to its readability and compactness. Moreover, REST based web application are popular nowadays and JSON format is required by them. Restful web applications communicate via HTTP protocol and send object in JSON format. So that platform-independent, widely available, reusable, component based web applications can be developed rapidly.


```
{
"coordinate":{"x":0.0,"y":0.0,"z":0.0},
"zone":{
  "id":"47aa248b-5852-43a6-af34-21b9771517c8",
  "name":"Lab 115"},
"uuid":"a014dee1-ea28-4c66-b160-87a58becf9ff"
}
```


Figure 4. Position JSON

The `Position` objects can be represented by coordinates, a `Zone` object or both of them. Figure 4 shows the JSON format of a `Position` object. The coordinate consists of zeros because it was created during the tests. The zone element shows the structure of the `Zone` objects which have an identifier and a name. Development of a refined zone model could be necessary for navigation services.


```
{
"bluetoothTags":null,
"gpsCoordinates":null,
"id":"99631985-b254-4598-886a-33033521d4b8",
"magnetometer":{
  "xAxis":0.34035778045654297,
  "yAxis":-0.04757712036371231,
  "zAxis":0.0158716831356287},
"position":{
  "coordinate":null,
  "zone":{
    "id":"47aa248b-5852-43a6-af34-21b9771517c8",
    "name":"Lab 115"},
  "uuid":"a014dee1-ea28-4c66-b160-87a58becf9ff"},
"rfidtags":null,
"timestamp":1444932266450,
"wifiRSSI":{
  "rssiValues":{
    "TP-LINK_517E90":-90.0,
    "teszt":-78.0
    }
  }
}
```


Figure 5. Measurement JSON

Figure 5 shows the serialized form of a `Measurement` object which contains a time stamp, an identifier, magnetometer and WiFi RSSI measurements. The time stamp is serialized as a long number which is the standard form of UNIX times stamp. The magnetometer contains a vector which points to North. The WiFi RSSI contains a set of key value pairs, where the key is SSID of the access point, and the value is the RSSI value.

6. Conclusion

Formal model for hybrid indoor positioning systems have been proposed. Analysis of the sensor sets of the popular mobile platforms was performed to select the widely available, relevant and useful sensors for indoor positioning. The existing indoor positioning systems were reviewed from the point of view of their applied technologies. Mathematical description were given for the measurements which can be used to develop positioning algorithms. A data model has been created based on the mathematical model which introduces domain constrains for the measurements which would be hard to define in the mathematical model. Based on the data model a Java Library was designed and implemented. The implementation support JSON serialization due to the increasing popularity of restful web applications. The presented library is used in the development of a indoor location and navigation system which performs the positioning calculations on the server and communicate with the client via HTTP.

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REFERENCES

[1] Lechner, W. and Baumann, S.: Global navigation satellite systems. *Computers and Electronics in Agriculture*, **25**(1), (2000), 67–85.

[2] Hofmann-Wellenhof, B., Lichtenegger, H., and Wasle, E.: *GNSS–global navigation satellite systems: GPS, GLONASS, Galileo, and more*. Springer Science & Business Media, 2007.

[3] Liu, H., Darabi, H., Banerjee, P., and Liu, J.: Survey of wireless indoor positioning techniques and systems. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, **37**(6), (2007), 1067–1080.

[4] Deak, G., Curran, K., and Condell, J.: A survey of active and passive indoor localisation systems. *Computer Communications*, **35**(16), (2012), 1939–1954.

[5] Kaemarungsi, K.: Design of indoor positioning systems based on location fingerprinting technique, 2005, URL `http://d-scholarship.pitt.edu/6395/`.

[6] Statista.com: Market share held by smartphone platforms in the united states from january 2012 to january 2015. URL `http://www.statista.com/statistics/266572/market-share-held-by-smartphone-platforms-in-the-united-states/`.

[7] Kecső, D.: Okostelefonnal vezérelhető repülőgép szimulátor. 2014.

[8] TAJTI, T.: Indoor localization with mobile phone. In *Proceedings of the 1st International Conference on Future RFID Technologies*, 2014.

[9] WANT, R. and HOPPER, A.: Active badges and personal interactive computing objects. *Consumer Electronics, IEEE Transactions on*, **38**(1), (1992), 10–20.

[10] ZHOU, Z., KAVEHRAD, M., and DENG, P.: Indoor positioning algorithm using light-emitting diode visible light communications. *Optical Engineering*, **51**(8), (2012), 085009–1.

[11] WARD, A., JONES, A., and HOPPER, A.: A new location technique for the active office. *Personal Communications, IEEE*, **4**(5), (1997), 42–47.

[12] BORRIELLO, G., LIU, A., OFFER, T., PALISTRANT, C., and SHARP, R.: Walrus: wireless acoustic location with room-level resolution using ultrasound. In *Proceedings of the 3rd international conference on Mobile systems, applications, and services*, ACM, 2005, pp. 191–203.

[13] BRACHMANN, F., JENAK, I., HORVATH, Z., WU, T., XUAN, C., BARANYI, A., and JENE, S.: The effects of hardware and software-based signal distortion in multi-platform indoor positioning systems. In G. Gartner and H. Huang (eds.), *Proceedings of the 11th International Symposium on Location-Based Services*, ISBN 978-1-907075-07-0, 2014.

[14] LI, B., GALLAGHER, T., DEMPSTER, A. G., and RIZOS, C.: How feasible is the use of magnetic field alone for indoor positioning? In *Indoor Positioning and Indoor Navigation (IPIN), 2012 International Conference on*, IEEE, 2012, pp. 1–9.

[15] BAHL, P. and PADMANABHAN, V. N.: Radar: An in-building rf-based user location and tracking system. In *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 2, Ieee, 2000, pp. 775–784.

[16] YOUSSEF, M. and AGRAWALA, A.: Handling samples correlation in the horus system. In *INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies*, vol. 2, IEEE, 2004, pp. 1023–1031.

[17] YOUSSEF, M. and AGRAWALA, A.: The horus wlan location determination system. In *Proceedings of the 3rd international conference on Mobile systems, applications, and services*, ACM, 2005, pp. 205–218.

[18] HIGHTOWER, J., WANT, R., and BORRIELLO, G.: Spoton: An indoor 3d location sensing technology based on rf signal strength. *UW CSE 00-02-02, University of Washington, Department of Computer Science and Engineering, Seattle, WA*, **1**.

[19] HIGHTOWER, J., VAKILI, C., BORRIELLO, G., and WANT, R.: Design and calibration of the spoton ad-hoc location sensing system. *unpublished, August.*

[20] NI, L. M., LIU, Y., LAU, Y. C., and PATIL, A. P.: Landmarc: indoor location sensing using active rfid. *Wireless networks*, **10**(6), (2004), 701–710.

[21] Feldmann, S., Kyamakya, K., Zapater, A., and Lue, Z.: An indoor bluetooth-based positioning system: Concept, implementation and experimental evaluation. In *International Conference on Wireless Networks*, 2003, pp. 109–113.

[22] Gamma, E., Helm, R., Johnson, R., and Vlissides, J.: *Design patterns: elements of reusable object-oriented software*. Pearson Education, 1994.