tracking history, perhaps removing outliers or some other desired refinement.

The third task is a rather classic problem in maritime navigation, but surprisingly this function has been and continues to be performed in a manual way (i.e. the ship captain or navigator manually choosing the route based on ice charts, local observations, and experience). It is also becoming increasingly important to find efficient paths through ice-covered waters due to the opening up of northern sea routes, as well as increased wintertime maritime transport in general (e.g. in the Baltic Sea). In terms of understanding the users needs, this capability means that if maritime conditions change such that the captain or navigator needs to alter its route, based on changing ice conditions or other factors, an "ice-aware" navigation system could automatically inform the ship's crew that a new route is recommended and even suggest the optimal route to the crew.

A plethora of other examples of the utility of context awareness could be given, even within the strict confines of navigation, but due to limitations in time, this thesis will only investigate the above three examples, which have been researched and published in separate publications and republished here for completeness.

1.3 Main Contributions

This research explores an important and previously under-examined link between machine learning and context awareness and exploits this link to demonstrate possible applications in the field of navigation. The author has developed a generic conceptual framework for the multi-step processing of raw sensor data into contextual information, which had been largely lacking in the literature.

Also, most earlier studies on context awareness either adopt a rather narrow view of context or do not provide any clear framework or mechanism of how to encode a situation or context in a systematic way. This thesis proposes and describes a simple but powerful framework for describing a context in terms of seven key questions, covered further in Chapter 2 and [P1]. Together, these two conceptual frameworks benefit the research community by making the abstract and ambiguous concepts "context" and "context awareness" more concrete and clearly defined and by providing a methodological skeleton on which to build context-aware systems.

In addition, this thesis examines three separate use case scenarios or applications of context awareness. These relate to the three tasks described in Section 1.2 above. The remainder of this section descibes the key contributions related to these use case scenarios.

Firstly, the thesis presents a probabilistic Location-Motion-Context (LoCoMo) model, combining location and motion context, used to detect human behavior (i.e. activities) in an indoor office environment. The sensors used to detect the human behavior include only sensors available in commercial-off-the-shelf (COTS) smartphones, as well as WLAN-based access points used for the positioning component. To our knowledge, this is the first study focused on detecting office-environment activities that utilizes only smartphone-based sensors and standard WLAN access points. This is significant because earlier studies mostly relied on installation of custom-designed sensors in the office environonement. As smartphones and WLAN access points are already widely present in office environments around the world, the results of this research has more potential for widespread application.

A problem related to the above topic is the determination of whether a smartphone user is indoors or outdoors. This is important contextual information because the optimal positioning systen differs depending on whether the user is indoors or outdoors. Another important benefit of this contextual information is that it can be used to conserve smartphone battery usage. Outdoor positioning systems, namely those based on Global Navigation Satellite Systems, are power intensive and can be turned off automatically when the user is indoors. The method described in this thesis for indoor-outdoor determination is, according to our knowledge, the first smartphone-based probabilistic indoor-outdoor method described in the literature.

Compared to earlier works on detecting activities in an office environment, the methods described in this thesis are more flexible and robust. For example, [8] relies on sensors installed in an office chair and multiple cameras installed in an office room to infer activity. By contrast, our method can be used anywhere within an office building where WLAN signals are present.

Next, this thesis includes a systematic evaluation of a large number of machine learning algorithms applied to the problem of detecting ”mobility contexts“, including consideration of the computational cost of the resulting classifiers, due to the intended use in mobile devices. The number of algorithms investigated and applied to this problem is larger than any other previous study, according to our knowledge. Also, most existing studies dealing with mobility context do not consider or evaluate the computation cost of classifiers, so our study is novel in this aspect.

Furthermore, our study is the first research on mobility context to utilize GNSS, accelerometers, and information from Geographic Information Systems (GIS) for the purposes of detecting mobility context[5]. In particular, GIS is an important source of information for detecting mobility context because it can be used to determine proximity to relevant landmarks, such as train stations and bus stops. Earlier studies did not consider this important source of semantic information, and our research provides strong evidence, as a result of feature selection, that such information improves the context recognition result.

Our research also studied the influence of parameter tuning for the RandomForest algorithm for this particular machine learning problem. After parameter tuning, we achieved an average recall rate of $>97.5\%$ for our test data. We are not aware of any other study achieving this level of performance for a comparable classification problem.

Lastly, for the purposes of developing an ”ice-aware“ maritime navigation system, we developed a novel method for route optimization. Compared to earlier works in this area, our method is the first to adopt a graph-based approach to the problem of route optimization through ice-covered waters. An earlier study tackling the same issue expressed the route optimization problem as a differential equation and used numerical methods to solve it, such as Powell's method [10]. Such methods, however, do not guarantee a global optimum. Due to the complex nature of ice fields, local minimums can be significantly worse than the global optimum.

The benefit of a graph-based approach is that shortest-path algorthms exist that can guarantee an optimal solution. The main novelty in our method is the design of a suitable graph structure that provides a reasonable trade-off between realistic modelling of ship motion and computational complexity. We employed the A* algorithm to find the optimal path. We are aware of only one previous study that investigated the use of the A* algorithm in a maritime setting, and this study focused exclusively on littoral (near-shore) navigation [11]. Furthermore, it did not consider

[5] This research was first published as a conference paper in 2013 (see [9]). The publication included in this thesis is an extended version of this earlier study.

ice-covered waters. Finally, we incorporated into our method an operational contraint related to ice breaker assistance, which was not considered in earlier studies.

1.4 Thesis Outline

The remainder of this thesis is organized as follows. Chapter 2 provides a theoretical and historical overview of the topic of context awareness. Chapter 3 provides an overview of machine learning. Chapter 4 summarizes and provides an overview of the included publications. Finally, Chapter 5 offers some conclusions that can be drawn from the author's overall work to date in context awareness and provides some suggestions for future areas of research and development.