1. INTRODUCTION

We are currently witnessing an era of technological convergence that rivals some of the great technological upheavals of modern history. The steam engine, the electric lamp, the transistor, the jetliner, the artificial satellite—it is in this same revered company that we can place the technological revolution we are now undergoing. According to authors Erik Brynjolfsson and Andrew McAfee, we are living in a "second machine age" (where the first machine age began with James Watt's steam engine), which they describe as "an inflection point in the history of our economies and societies because of digitization." (p. 11). Brynjolfsson and McAfee define digitization as converting things into bits that can be stored on a computer and sent over a network" (p. 10). They further define "digital technologies" as "those that have computer hardware, software, and networks at their core" (p. 9).

The category of digital technologies, however, can be further narrowed to a set of a few key technologies that are driving this revolution. Accordingly, this thesis focuses on a few of these technologies and looks at how they have impacted a particular application area, namely navigation. In particular, we focus on four major technologies, whose convergence[1] has taken place over the course of a few decades: (1) mobile telecommunication devices, (2) the Internet, (3) positioning technologies, and (4) a wide range of inexpensive yet highly capable sensors, namely microelectromechanical systems (MEMS). All of these technologies came to a technological crossroads in the late 20th century and early 21st century. The first major manifestation of this convergence, especially with respect to consumer markets, is the so-called "smartphone", of which there were already more than one billion in use worldwide in 2012, according to Strategy Analytics. This number is likely to surpass two billion in 2015. These devices allow their users to stay "connected" virtually everywhere they go, and consequently anyone can connect to these one billion plus users from any networked device, including desktop computers and "land-line" phones–no matter where the user is located or travelling to. Ironically, in many technologically advanced societies, it is now considered a societal and/or behavioral challenge for one to go "off the grid" or "disconnected" for any extended period of time.

[1]By convergence, we mean these technologies have undergone simultaneous rapid advances and thus been available for technological update in combinatorial ways.

It is the author's view that the smartphone is only the first manifestation of this technological revolution. Many other so-called "smart" devices are soon to follow: "smartwatches" and the use of various wearable sensors may soon become a mainstay consumer habit. In addition, the same technologies that have made smartphones possible and popular are quickly making their way into existing everyday devices, including cars, home appliances, and even toothbrushes. Furthermore, it is not just consumer markets that are being transformed but also many industrial markets, ranging from manufacturing to commercial shipping. It would be naïve to speculate exactly how this revolution will play out in the coming decades, but is clear is that it is already changing the lifestyles, habits, and possibilities of people living in the early 21st century, especially those who can afford these (currently) "high-end" consumer devices.

Aside from being a convergence of new digital technologies, is there any unifying concept or principle that is underlying this technological revolution? Some would argue that it is the increased levels of *mobility* that these technologies provide. Others have rallied under the banner of *ubiquitous computing* or *pervasive computing*, which describes the fact that computing devices can now be found nearly everywhere one looks. Certainly these are two important characteristics giving wind to this revolution, but we argue in this thesis towards another underlying principle that provides a common thread and deep insight into how our relationship to these computing devices is changing.

One common development, of course, is the increasing ability of computing devices to fulfil various user desires, e.g. download large amounts of data at high speeds, capture or render various high-quality multimedia content, store and edit content in various ways, etc. What is not advancing or expanding—at least, not at any considerable rate—is the patience or attention span of the users themselves. Therefore, users are expecting (consciously or not) that their devices will "do more" with essentially the same total quantity and quality of human input. Fortunately, however, these devices are rapidly advancing in their ability to know what their users want or need—without the user having to explicitly formulate and express these desires to the computer. This is the goal under which this thesis is motivated and focused—to improve our understanding of how computing devices can better understand us and our needs.

We are not there yet. In many ways, smartphones, for example, are not yet "smart". They have the "braun" and not the brains, in the sense that they are powerful and capable but deficient in understanding the user's needs. This thesis aims to improve the state-of-the-art in a computer's ability to understand situations or contexts that humans find themselves in. Mobile computing researchers have adopted the term *context awareness* to refer to this ability. In other domains, such as aviation, maritime, and military domains, the term used is situational awareness (or situation awareness)[2]. In particular, this thesis will focus on how machine learning can be utilized for building context or situation awareness, in order to solve problems in navigation. According to Tom Mitchell, "machine learning research seeks to develop computer systems that automatically improve their performance through experience". In many ways, machine learning has become the preferred set of techniques used to build up systems that exhibit—or attempt to exhibit—artificial intelligence. Artificial intelligence has been an allusive goal of computer science researchers ever since John McCarthy first coined the term in 1956. Although computers have not yet replicated human intelligence in a general sense, there are many tasks of increasing complexity that computers can already perform equally well or even better than the most gifted well-trained humans. As Brynjolfsson and McAfee detail in their book *The Second Machine Age*, computers have been programmed to beat even the best human players of the game-show *Jeopardy!*, to write corporate earnings previews for *Forbes.com* that are indistinguishable from ones written by humans, and to diagnose breast cancer from images of tissue as good as or even better than pathologists could otherwise do[3].

In this thesis, we focus on two tasks related to context awareness that are relevant to the field of navigation: (1) to recognize the mode of motion that a smartphone user is undergoing and (2) to determine the optimal path of a ship travelling through ice-covered waters. These tasks are very different from one another, demonstrating the breadth of problems encompassed by the topic of context awareness and showing how machine learning can be a powerful tool in a wide range of different problems. The first task is important for navigation because a navigation system can adapt and improve its performance based on the motion mode in which it is used, but it would be easier to use if the user did not have to manually change the modes of the navigation system when he or she transitions, e.g. from walking to driving. The second task is a rather classic problem in maritime navigation but one that 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

[2]For consistency, in this thesis we primarily use the term context awareness, although it can be considered synonymous with the term situation(al) awareness.

[3]To be precise, what Brynjolfsson and McAfee describe is a system, known as C-Path, that helped to diagnose breast cancer and also identified new features of breast cancer tissue that were shown to be good features for predicting survival.

maritime transport in general (e.g. in the Baltic Sea).

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 covers the first of the two tasks described above, that of recognizing the mobility context of smartphone users. Chapter 5 covers the second task, that of “ice-aware” maritime route optimization. Finally, Chapter 6 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.