Preface

In every sense of the word, movement is a central and fundamental aspect of life. Indeed, being able to move still figures prominently in most definitions of animal life in biology. Movement has also been a central element in the evolution of species and their conquering the planet and in the development of our society. In those parts of human history that we know about, movement of individuals and civilizations has helped shape our societies and culture. Arguably, however, the most revolutionary changes brought about by movement to the lives we know today have been happening in the past 150 years: with a particular kind of movement that we call traffic. Beginning with the first railway connections, followed by the invention of the automobile and the first airplanes, moving people and goods from one place to another has become easier and faster not by one, but by several orders of magnitude. Consequently, the capacity of an economy for movement, often referred to as mobility, is now considered to be a crucial enabler for industrial development and prosperity.

Not surprisingly, many of the important planning decisions in society and business depend on proper knowledge about and a correct understanding of movement. Should a region or a country invest billions of euros into a new airport or into a new train station? Where can wind parks for power generation be placed without affecting ship traffic and the movement of animals? How should urban quarters or shopping malls be structured so that the needs of pedestrians can perfectly be met? How should national parks be laid out to best protect animals and their movements? Where should new stores and logistics centers be set up to best reach customers and minimize cost? How do diseases spread, which may put lives in danger? How can a stadium or large building be evacuated quickly and safely?

The above are just a few examples of the scientific, societal, and commercial questions that relate to movement, and none of them can be answered without deep and well-structured knowledge of the movement patterns of people and objects. Yet, surprisingly, until very recently, many of those decisions were made based on common sense knowledge only, often relying on general rules of thumb and prior beliefs about how people and objects would be moving. Empirical studies were extremely expensive, and the tools for their analysis complex, resulting in limited availability of precise knowledge and as a result, in many costly decisions that did not bring the intended benefit or even worsened an existing situation.

Fortunately, recent technological advances have completely changed the game of knowing about location and finding out about movement. The technical foundations were created quite a while ago, with Global Positioning System (GPS), cellular mobile telephony, and Radio-frequency identification tags (RFID). In the GPS, the receiver can localize itself and record its position with high precision based on the system's satellite signals. A cell-based mobile phone can be localized in its individual cell or even more precisely by measuring its radio signals. RFID are so cheap that they can be placed on objects which can then be recognized when passing stationary receivers. In addition, wireless networks today can be used to localize objects very precisely, and small sensors are available for special purposes such as tracking animals.

The true revolution, however, has been in the extremely widespread adoption of such technology as it has been brought about by mobile phones. With several billion mobile phones in use today, most people today possess the technology necessary to localize themselves and record the movement if they so wish. RFID and other technologies are so widely deployed now that unsurprisingly, location and mobility data are considered to be the fastest-growing type of data today. According to a recent study by the McKinsey Global Institute (Manyika et al. 2011), the amount of mobility data available in 2009 was estimated to be one petabyte, and it is safe to assume that today, we are rather looking at exabytes or maybe zetabytes of mobility data.

While this deluge of data promises to contain the needed information to arrive at empirically well-founded models and decisions about mobility and movement, current practice shows that working with the available data often does not lead to insight, but rather to confusion and frustration. Since when talking about movement and mobility, we usually are not interested in the historical whereabouts of a single individual or object, the large data volumes by themselves only make us fail to see the forest for the trees. Moreover, simple classical means of visually inspecting movement data fail catastrophically when used with extremely large data volumes without further changes, since even the highest resolution displays cannot show millions or even billions of movements at the same time without completely cluttering the display. Algorithmic approaches to processing movement data are thus sorely needed to reduce the data volume by aggregation and selection, and to bring out the important properties. At the same time, due to the very nature of such algorithmic methods, they can be used to ensure the privacy of individual movement, since detail about individual movement is not needed in the condensed model and thus stripped away. Such algorithmic methods, however, have turned out to be difficult to control for analysts if used in isolation.

What is needed, therefore, are new methods of visualization and new methods of algorithmic data analysis that are combined in such a way that they tightly integrate and complement each other to allow end-users and analysts alike to work with extremely large volumes of movement data in as simple a way as they would have with simpler models of the past. And this is exactly where this book comes in. The book is concerned with the science, technology, and the software of doing *visual analytics* for movement data, i.e., using visual and algorithmic approaches

in an integrated and interactive fashion. The science of visual analytics has been developing rapidly over the past years, and the paradigm of tightly intertwining visualization and algorithmic analysis has proven a breakthrough for many data analysis tasks. As this book shows, visual analytics techniques today are ready to even tackle the enormous challenges brought about by movement data, and there is technology and software available for use right at this moment.

This book is about the exciting possibilities created by visual analytics for anyone interested in understanding movement, analyzing movement, or simply make decisions that are influenced by the way people, animals, and objects move. We start out with an introduction that illustrates the different kinds of data that are available to describe movement, from single trajectories of single objects to multiple trajectories of many objects, and then proceed to a conceptual framework, which provides the basis for a fundamental understanding of movement data. The book then moves on to more practical and technical aspects, focusing on how exactly to transform movement data to make it more useful, and on the infrastructure necessary for performing visual analytics in practice. We then illustrate that visual analytics of movement data can bring exciting insights into the behavior of moving *persons and objects*, but can also lead to an understanding of the *events* that happen when things move. Indeed, visual analytics techniques can be used to even turn around the analytical questions in order to derive characteristics of the underlying *space* or characteristics of *time* from movement data. Throughout the book, we use application examples from various domains to show what can be done in practice, and always illustrate the examples with graphical depictions of the interactive displays and the analysis results.

In summary, we hope that the book will make a useful and entertaining reading for anyone interested in movement and the possibilities of visual analytics in this field. Researchers will find the necessary scientific precision, software technologists will find the necessary information on algorithms and systems, and practitioners will find readily accessible examples with detailed illustrations for practical purposes. Enjoy!

Reference

Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., Hung, A. (2011). *Big data: The next frontier for innovation, competition, and productivity*. McKinsey Global Institute.

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