9 Recommendations

Governments, businesses, research institutes, and people themselves are collecting and hoarding large amounts of data, which are presently often not utilised in the best possible way for solving the world's pressing problems. We need better and more usable solutions to extract information and ultimately knowledge from these rich data resources. Our ultimate goal as a research community is to provide visual analytics methodologies, tools, and infrastructure that will benefit society in general. The international research initiatives in the area of visual analytics including the European VisMaster project have acted as a catalyst in instigating better collaboration between leading institutes and universities working on various aspects of visual analytics. The successful collaboration and interaction of different communities enables us for the first time to identify common challenges and problems across many disciplines. This book is a stepping stone towards our goal and lays down the path to a shared solution.

Each of the chapters has described the specific challenges and opportunities within the specific domain. This chapter summarises the challenges according to what we believe to be the main entities of visual analytics and then consolidates the recommendations presented in the individual chapters into higher level recommendations for enabling successful visual analytics research. The challenges and recommendations highlight the interdisciplinary nature of visual analytics and the importance of working together. While many initiatives have been started in different countries including many EU member states, only under a worldwide and EU-wide umbrella can significant overlap be avoided, and continued strong collaboration between the research groups be fostered.

9.1 The Challenges

Visual analytics is concerned with data, users, and designing a technology that enables the user to make sense of the data in order to extract information and augment their knowledge. Each of the chapters in this book has identified challenges associated with visual analytics with respect to its particular domain, but many challenges are common to more than one domain.

This section presents a summary of the challenges, organised into four entities:

- **Data:** the challenge of dealing with very large, diverse, variable quality datasets.
- **Users:** the challenge of meeting the needs of the users.

- **Design:** the challenge of assisting designers of visual analytic systems.
- **Technology:** the challenge of providing the necessary infrastructure.

9.1.1 Data

An obvious challenge is dealing with very large datasets, whether this is in terms of storage, retrieval, transmission (as with distributed databases or Cloud storage), algorithm processing time, and scalability of visualisations. It is also apparent that many analytic applications use in-memory storage rather than a database approach, as traditional databases cannot meet the challenging functionality required by visual analytics.

Data is often heterogeneous and can be of poor quality with, missing, incomplete, or erroneous values. This adds to the complexity of integrating data from many sources. In addition, data often requires transformation of some sort (e.g., scaling and mapping) or requires specialised data types, which are seldom provided by current database systems.

Streaming data presents many challenges – coping with very large amounts of data arriving in bursts or continuously (as with analysing financial transactions or Internet traffic), tackling the difficulties of indexing and aggregation in real-time, identifying trends and detecting unexpected behaviour when the dataset is changing dynamically.

Semantic management (managing metadata) is currently not well catered for, which is surprising, given the wealth of information contained in rich metadata. In addition, we can also add further meaningful information gathered during the analysis and visualisation phases.

9.1.2 Users

There are many challenges related to system usability and process understanding. For users to have confidence in the data they should be aware (or be able to discover) where the data comes from, and also what transformations have been applied on its way through the process pipeline (e.g., data cleansing, analysis and visualisation). Furthermore, a clear understanding of the uncertainties in the data and results of the analysis can help minimise cognitive and perceptual biases, which without attention can significantly affect the interpretation of the results.

Another challenging aspect is using visual analytics to simplify the models and patterns extracted by advanced data mining techniques, so called 'visual data mining'. Existing methods are largely non-intuitive and require significant expertise. Similar efforts are required to assist users in understanding visualisation models, such as the level of abstraction (actual data or aggregated view) and visual metaphors (how the data is represented on the screen). Expert analysts require this flexibility and so do the more naive users, who in addition, require guidance in, for instance, choosing appropriate analysis tools and visualisation methods for the task at hand. Users often wish or need to collaborate in order to

share, or work cooperatively on, the data, results of analysis, visualisations and perhaps workflows. Providing the necessary distribution infrastructure as well as the user interface is a challenging task.

The degree of interactivity is important for all users. Rapid feedback is critical in visual interfaces and this presents challenges to many of the domains associated with visual analytics. Evaluating visual analytics applications is particularly difficult due to the complexity of human interaction with multiple processes (e.g., analysis and visualisation). The question of how to classify success or decide what is a good solution is problematic when dealing with exploratory tasks, which are typically ill-defined or open-ended.

9.1.3 Design

One of main challenges is to utilise our existing theoretical and practical knowledge by making it readily available to designers of visual analytics systems, possibly in the form of design guidelines. For instance, there is a wealth of experimental results in the field of visual perception and cognition that would be of considerable benefit to interaction designers, if it were organised appropriately. In general, we have a host of technology, but for a given task, the challenge is to provide guidance on what to use (e.g., method of analysis, type of visualisation), how to use it and how to decide if it was a good choice. We need to find ways of making appropriate test datasets, tools, and results of evaluation studies available to the community.

Designing and implementing visual analytics applications would be faster and potentially more reliable and flexible, if a unified architectural model was used. Designing a suitable component-based framework is certainly a challenge.

9.1.4 Technology

Various challenges have been identified regarding more technical aspects of visual analytics. One is in relation to the duration of the analysis phase, which tends to be much longer than traditional transactions dealt with by a standard database management system. Therefore, methods are required not only to support long commit phases, but also to furnish partial results from the analysis. Providing this 'progressive analysis' would give the analyst a rapid overview and hence, a basis for steering the analysis in a particular direction, from which details could be sought. This interactive functionality requires notification services – current database management systems utilise a trigger mechanism that is not suitable for visual analytics, especially when the trigger for recalculation comes from the visualisation sub-system rather than from the analysis.

Providing multi-scale analysis is a particular challenge identified by the geospatial visualisation community. For example, the analyst may wish to look for

patterns over a long period of time, months or even years, as well as patterns in daily activity.

Finally, we need to devise a methodology for providing basic visualisation functions, such as linking and brushing, which can be used to coordinate different views of the data. These connection mechanisms ought to be incorporated in the next generation of lightweight web-based visualisation tools, in order to facilitate the analysis of data to a wider audience.

9.2 Meeting the Challenges

Our recommendations consolidate the recommendations from the individual chapters (under the 'Next Steps' section) and put forward higher level recommendations for enabling successful visual analytics research under the following areas:

- International, European, and national funding agencies
- Visual analytics research community
- Broader research community
- Industry and other potential users

9.2.1 International, European, and National Funding Agencies

These recommendations are aimed at the funding agencies throughout the world, including the US and Canada as well as the EC and the national funding agencies. Some EU countries have already started initiatives in this direction.

Recommendation 1: Need for Continuing Support

National and international agencies should endeavour to continue support for visual analytics

VisMaster considers it of great importance that a parallel effort, both at the international and national level, is extended. The national funding agencies have the opportunity to step in earlier (while more time is needed at the international level) and provide additional support for visual analytics research. The umbrella, under which the various efforts in the EU can be integrated, has to be further entrenched by the EC. Within the FET area of ICT, this could be established through a FET Proactive Topic that funds several projects in visual analytics, implementing the vision that this research roadmap lays down. Such open basic research schemes or comparable national instruments will support pilot projects in visual analytics as a next step.

Recommendation 2: Appreciate Visual Analytics in Related Research Areas

The European Commission, as well as the main national funding agencies, should assess their existing programs and identify possibilities to acknowledge the consideration of visual analytics questions in related interdisciplinary research projects. Visual analytics is not just a 'user interface' for research prototypes; it is a different approach all together, fully integrating the human expertise in the human-machine dialogue. We recommend that funding agencies and their units start to think in new ways about an interdisciplinary integration of visual analytics components in the context of existing programmes. A first example can be seen in the Objective ICT-2011.4.4 Intelligent Information Management, target outcome b).

Consider integrating visual analytics into existing research projects

Recommendation 3: Foster Interdisciplinary Research Projects

The fastest path to new solutions to highly complex problems is the promotion of interdisciplinary research projects where heterogeneous teams address real-world problems and develop visual analytics methods and tools that help in investigating and solving these problems.

Promote interdisciplinary research projects, addressing real-world problems

Interdisciplinary PhD programs and summer schools that support young researchers in travelling to other universities and research institutions are a perfect way of exchanging knowledge about complementary disciplines and doing transdisciplinary research.

Recommendation 4: Avoid Redundant Development

Visual analytics, not only its visualisation part, is relevant to many areas of current research projects. The development and sharing of open-source analysis and visualisation tools should be fostered by and for the visual analytics community. Building and publicising repositories of visual analytics techniques will enable the rapid implementation of effective and efficient visual analytic solutions and help to avoid costly redundant development effort.

Develop repositories of visual analytic, tools, techniques, guidelines and datasets to accelerate the implementation of appropriate applications

Potential users and other research areas need guidelines on what visual analytics technology to adopt, how to apply it in order to solve their problems, and how to evaluate their effectiveness. Guidelines, tutorials, handbooks, etc., which are useful and understandable have to be developed for the targeted audience, and be grounded in results from the scientific community as well as real world practice and experience.

The evaluation of visual analytic techniques, including software tools, models and theories is very important for the continued growth of the discipline. This can be performed much more effectively and efficiently if central repositories are set up and maintained to provide relevant material. Such repositories

Promote the evaluation of all aspects of visual analytic solutions

could provide datasets at various levels of detail for a variety of applications, together with data generation tools, analysis tools, results of evaluations and libraries.

9.2.2 Visual Analytics Community

The following recommendations address the visual analytics research community. Most, if not all of the research institutions active in visual analytics within the EU have been involved in VisMaster. Through this collaboration, the project identified recommendations for each institute that should help the community to strengthen visual analytics research throughout and outside the EU.

Recommendation 5: Spread the Word Within Academia

Continue and expand upon interdisciplinary workshops and support visual analytics within education

Visual analytics technologies should be presented at data management, data mining and human-computer interaction conferences. This can be achieved by organising special sessions, panel discussions and dedicated workshops or by publishing related success stories. In addition, educational curricula ought to be updated to reflect the increasing prominence of visual analytics, and educators should engage in related interdisciplinary teaching efforts.

Interdisciplinary scientific workshops like VAKD (in conjunction with ICDM), INTERACT-VA, or GeoVA(T) should be continued as they give researchers from different disciplines, the opportunity to discuss the research problems in visual analytics and establish contacts for further interdisciplinary cooperation in solving these problems. The working groups of VisMaster have been successful in organising such workshops, drawing together different communities.

Support the annual EuroVA Symposium

VisMaster successfully organised the EuroVAST symposium on visual analytics in June 2010 in Bordeaux, France, which attracted over 70 scientists and researchers from all over the world. EuroVAST 2010 will not be a singular event; it will continue as the EuroVA Symposium in cooperation with EuroVis, with the next taking place in 2011 in Bergen, Norway. This symposium should be established as the European event where researchers can submit their visual analytics research work, in addition to IEEE VAST in the US.

Collaboration should be continued with agencies outside the EU

Further collaboration should be continued on an international level beyond the EU with NVAC, the Purdue Center of Excellence and the DHS (all in the US), as well as other initiatives in Canada, Australia and elsewhere.

Recommendation 6: Spread the Word Within Industry and Governmental Agencies

Publicise work of the visual analytics community in dealing with real-world problems

The VisMaster Industry Day has shown the existing interest in visual analytics from areas such as business intelligence, finance, security, and media technologies. The visual analytics community should publicise their work within both their industry and application domains, and show the hands-on benefits of using visual analytics technologies to solve some of the most pressing problems facing industry.

The effective use of visual analytics in exploring government data should be encouraged

Politicians and policy makers should use visual analytics to explore data collected by their statistical departments in order to increase their understanding of the needs and desires of their constituencies. In addition, their constituents could evaluate their policy decisions, thus helping to strengthen and legitimise democratic institutions.

Demonstrate the possibilities and benefits of visual analytics to a wide audience

The outside world has to be made more aware of the possibilities and advantages of visual analytics. The collection and dissemination of showcases, including successful evaluation approaches, is important in demonstrating the possibilities and the benefits of visual analytics. Potential users and decision makers must easily recognise the novel and valuable insights, which only visual analytics can enable, as well as the reduced costs of obtaining the insights.

Recommendation 7: Build a Visual Analytics Infrastructure

Stimulate the design of conceptual and software architectures for visual analytics

Researchers in databases, analytics, visualisation and communication should be given incentives to work together to iterate on the design of a conceptual architecture for visual analytics applications. This will avoid an explosion of partial solutions to the overall infrastructure problem with issues of interoperability and also situations in which specialists in one domain implement another domain's modules. Applied-research projects are required to design and experiment with software architectures, again to promote interoperability and compatibility across domains, and thought needs to be given to managing and promoting the specifications of the resulting architectures at an international level.

Recommendation 8: Understand and Reach Out to Users

Encourage research on evaluation methods for visual analytics

Research on evaluation methodologies for visual analytics should be encouraged. We expect that methodologies for evaluation can be improved significantly, and this will provide a means to obtain more insight with visual analytics technologies. In addition, scientifically verified best practices will reduce the cost of implementing high-quality tools and provide convincing arguments for their adoption.

The understanding of human perceptual and cognitive processes in dealing with spatial and temporal information should be improved as well as the

Develop design guidelines based on visual perception and cognition research

understanding of visual displays of and interaction with such information. On this basis, appropriate design rules and guidelines should be developed for interactive displays of information, with particular focus on non-expert users of visual analytics systems.

Support the visual analytics process for personal as well as professional analysts

Furthermore, a new generation of lightweight accessible dynamic visual analytics tools should be developed to support a range of personal and professional analysts in the best possible way. Effective solutions for training both specialist and non-specialist users interested in adopting these visual analytics tools are also necessary.

9.2.3 Broader Research Community

Visual analytics is a highly interdisciplinary topic. While VisMaster approached specific related research communities to start or enhance collaboration, there are more topics and fields of research that relate to visual analytics. Certain communities feel that there should be an integration of research efforts, rather than just an exchange of views.

Recommendation 9: Integrate Visual Analytics and Related Research Areas

Build a new integrated research community

Our investigation and analysis show that there is a widely recognised need for an integration of visual analytics and related research areas for building a new integrated research community. This is especially true for the area of knowledge discovery and data mining (KDD). For many years, KDD and visualisation research have been complementary. With the rise of the field of visual analytics, the need to integrate these two disciplines becomes more apparent. The experience from the IEEE VAST conference and the VAKD workshop held at SIGKDD suggest that we should bring the integration of these topics to a new level to enable its full potential.

Recommendation 10: Organise Interdisciplinary Events

Organise interdisciplinary events

The VisMaster project has demonstrated the success of jointly organising and implementing interdisciplinary events in enabling researchers to discuss common problems and establish future contacts. Such events are more beneficial if one finds mediators that can translate between communities, as achieved at the INTERACT workshop by inviting experts from areas of cognitive science, HCI, and visualisation. Invited lectures and seminars by prominent researchers in universities and research organisations are also ideal for the dissemination of knowledge and experience.

9.2.4 Industry and Potential Users of Visual Analytics Technology

The following recommendation targets the industry users and all other potential users of visual analytics technology. Through many research projects and presentations, the VisMaster partners saw that industry, policy makers, governments, social scientists, and individuals from many other areas are in need of visual analytics tools. Many of them highly appreciate visual analytics solutions since they recognise the limits of purely analytical or purely visual solutions. We invite our potential users to be open to new approaches and to help us understand their needs.

Recommendation 11: Evaluate and Express the Need for Visual Analytics

Industry users should explore possible uses of visual analytics

Drawing on the examples of successful prototypes, industrial users should evaluate their potential need for visual analytics technology, possibly with the assistance of knowledgeable researchers and developers, and communicate this need through the appropriate channels. It is advisable to focus on small, incremental improvements and use case studies of successful pilot projects to generate broader support for and acceptance of visual analytics in the organisation.

9.3 Future Directions

An interesting observation is that all grand challenge problems of the 21th century, such as the climate change, energy, financial, health or security crisis, require the exploration and analysis of very large and complex data sets which can neither be done by the computer nor the human alone. Making scientific discoveries and solving complex problems require a tight integration of human intelligence and intuition with the storage and processing power of today's computers. Visual analytics will therefore likely develop into a general science of problem solving and interactive discovery. It will change the way we approach large complex datasets and the unsolved grand challenge problems associated with them. This research roadmap is designed to pave the way for visual analytics to become such a tool of scientific discovery. It is also designed to help the readers to recognise the potential of visual analytics and encourage them to engage in the next steps towards this goal.