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Visualization Summit 2007: ten research goals for 2010

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Abstract

At the first international Visualization Summit, more than 100 international researchers and practitioners defined and assessed nine original and important research goals in the context of Visualization Science, and proposed methods for achieving these goals by 2010. The synthesis of the whole event is presented in the 10th research goal. This article contributes a building block for systemizing visualization research by proposing mutually elaborated research goals with defined milestones. Such a consensus on where to go together is only one step toward establishing visualization science in the long-term perspective as a discipline with comparable relevance to chemistry, mathematics, language, or history. First, this article introduces the conference setting. Second, it describes the research goals and findings from the nine workshops. Third, a survey among 62 participants about the originality and importance of each research goal is presented and discussed. Finally, the article presents a synthesis of the nine research goals in the form of a 10th research goal, namely 'Visualizing Future Cities'. The article is relevant for visualization researchers, trend scouts, research programme directors who define the topics that get funds.
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Keywords: Visualization science; visualization summit; information visualization; knowledge visualization; future cities; research goals

Introduction: the visualization summit

At the first Visualization Summit, more than 100 international researchers and practitioners defined and assessed nine original and important research goals in the context of Visualization Science and proposed methods for achieving these goals by 2010. The synthesis of the whole event is presented in the 10th research goal.

The Visualization Summit was a 1-day event that took place on the 3rd of July 2007 at ETH Zurich in Switzerland. The visualization summit was initiated by the author and organized by a group of people (Remo

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Burkhard, Silke Lang, Michael Meier, Gerhard Schmitt and Andrew Vande Moere) associated with the chair for information architecture (http://www.ia.arch.ethz.ch) at ETH Zurich who organized pre- and post-event activities, published the 'call for workshops', prepared briefings of the workshop leaders, and organized the reviewing process. In this reviewing process, various experts (Gennady Andrienko, Natalia Andrienko, Ebad Banissi, Katy Börner, Dominique Brodbeck, Gerhard Buurman, Chaomei Chen, Jason Dykes, Martin Eppler, Felice Frankel, Michael Granitzer, Markus Gross, Dennis Groth, Urs Hirschberg, Jeffrey Huang, Alex Ivanov, Wolfang Kienreich, Carsten Mapel, Jonathan Roberts, Ben Shneiderman, Liz Stuart and Wibke Weber) reviewed the submitted proposals and helped to sharpen the workshops. From the 14 proposed workshops 10 were chosen, whereas one of the accepted workshops was pulled back by the workshop leader in the preparation phase. The preparation phase of each workshop was managed by the workshop leader and lasted more than 6 months. It included the submission of detailed documents, compiling a list of workshop attendees, and organizing online discussions with the attendees beforehand.

The term 'Visualization Science' is used in this article in a generic way and incorporates all fields that investigate how to exploit the social, emotional, and cognitive benefits of visual representations for science, business, and society. Examples of such fields are information visualization, geographic information systems (GIS), computer-aided design (CAD), concept mapping, story telling, graphic design, knowledge visualization, imaging techniques, and many more.

The Visualization Summit started with a power breakfast and keynote speech by Professor Dr. Olaf Kuebler from ETH Zurich on how the emerging visualization science can contribute to a sustainable future. Then, the nine parallel workshops started to work. In each of the nine parallel workshops, the respective leaders discussed and elaborated with their peers one research goal that can be achieved by 2010. The requirements for the research goals were that they be new, achievable, and of the highest relevance to science, business, and society. Each of the nine new research goals was presented to the audience before lunch and evaluated by them with a questionnaire. The afternoon started with a keynote lecture by the artist Ursus Wehrli about 'Tidying up art'. It conveyed the message that it is necessary and possible to structure the isolated visualization fields and to think beyond current classifications. Then, the participants of the workshop continued to discuss how to achieve their respective goal by 2010. This particular year was chosen because 3 years is a manageable planning horizon and because it is an even number. The findings of the afternoon session were captured on posters that were presented to the attendees, who were able to browse the results of the different groups. Then, the keynote lecture by Professor Dr. Gerhard Schmitt from ETH Zurich illustrated how ETH Zurich combined the different visualization techniques to design, communicate, and implement the strategic project Science City ETH (http://www.sciencecity.ethz.ch).

Figure 1 Impression from the exhibition: Visualizing Knowledge.

The visualization summit ended with the official opening of the exhibition 'Visualizing Knowledge' (Figure 1) which showed a variety of examples of the different visualization processes structured according to the Knowledge Visualization Framework,[1,2] such as envisioning, sketching, diagramming, expressing, mapping, materializing, and exploring.

Results from the nine workshops

In this section, written by the respective workshop leaders, the authors introduce their workshop and answer the following questions:

- What is the most promising topic found by your workshop?
- What is the background of the participants?
- What is your new research goal that can be achieved by 2010?
- What compelling evidences and arguments do you have?
- Why is this research goal important?
- Why is this research goal original?
- How can you achieve this goal by 2010?

Workshop 1: the architectural image and the computer

Author: Alexander Koutamanis (Delft University of Technology)

Introduction: Architecture is a highly visual discipline. It depends on visual representations in practically all stages and for most aspects of designing – from ideation and specification to analysis and communication. This follows our predominantly visual interaction with the built environment (most buildings are known by sight and not by, for e.g. taste or touch, even though smell plays an important role) but also indicates the capacity of visual representations with respect to integration and interaction. Computerization has given new impetus to matters visual in architecture, from systems that automatically generate architectural designs to means for visualizing aspects previously expressed mostly by rules of thumb or crude analogue reproductions, for example, daylight and air flow simulation.

The popularization of the computer is one of the big technological transitions that could change the form and the role of the architectural image, comparable to typography and other forms of mechanical reproduction. The workshop focused on the relationship between the architectural image and the computer by exploring two main questions:

1. How do architectural images change with computerization.
2. How do computers support the production and use of architectural images.

The first question refers to computer generation of images, especially the ones that seem impossible or uneconomical with analogue media, for example, simulation, virtual reality, dynamic visualization. The second question stresses the role of architectural images as information and related issues such as interaction and recognition. It is noteworthy that computer production of architectural images currently dominates academic research and education, as well as commercial research and development, arguably at the cost of a deeper understanding of the effects of computerization on architectural thinking and representation.

Further development requires firstly a comprehensive and reliable framework that integrates the new digital world in architectural theory and practice and secondly advanced research areas that promise radical change and rapid development. This claim is not without precedents:

- Technological changes may alter the form and role of existing representations and information. For example, typography facilitated the spread of the Renaissance throughout Europe. Palladio's ideas became widely known and influential mostly thanks to his books.
- Understanding of how a technology works and what effects it has on information and representation is essential to its application. For example, Palladio's illustrations were intentionally simplified to meet the spatial resolution of the book and reach a wide readership.
- Effective use of a technology requires general and domain theories that explain applicability and guide usability on the basis of transparent criteria and convincing, insightful examples and demonstrations. Once again, Palladio exemplifies how the humanistic ideals of the Renaissance combined with the practical necessities of building to form a persuasive framework for the revitalization of architecture in Western Europe.

What is the most promising topic found by your workshop? Despite the extent of architectural computerization, architectural design remains a mixed environment that combines analogue and digital tools, even for the same tasks. Moreover, we have good cognitive and practical reasons to assume that it will remain mixed even when more advanced computer tools become available and popular. Rather than trying to shift the balance in one or another direction we accept the situation as a quintessential characteristic of architectural creativity, as well as an indication of the true priorities in the design, construction and use of the built environment: regardless of tools used in designing, the main issue is the performance of buildings with respect to the accommodation of human activities, cost, and environmental impact.

Architecture and building are generally approached as small business domains but if we examine them closely we realize that they represent a huge part of our society and economy:

- 30% of the life income of the average Dutch person is spent on housing.
- 24% of CO_2 emissions come from buildings (excluding indirect influences on e.g. transportation).
- 25% of the GDP of most developed countries is spent on the built environment.

Such numbers show the cumulative importance of the built environment and stress the significance of architectural performance. This makes architecture not only a priority in the development of the new working environments we require to improve performance but also a responsive application area for the other specializations present in the Visualization Summit.

What is the background of the participants? The 11 participants (Workshop leaders: Alexander Koutamanis; Attendees: André Brown, Nancy Yen-wen Cheng, Ellen Yi-Luen Do, Gabriela Goldschmidt, Mark D. Gross, Gilles Halin, Thomas Kvan, Earl Mark, Bob Martens, Gerhard Schmitt) of the workshop have a background in architecture (theory and practice) and computer-aided architectural design (CAAD).

What is your new research goal that can be achieved by 2010? By 2010 we will have articulated the fusion of the analogue and digital (physical and virtual) developed hybrid representations to support the multiple interpretations of design and management of the built environment towards a new, interactive and dynamic working environment which brings together valuable existing domain knowledge and requires new and existing visualizations.

The main characteristic of this environment is that it changes the role of visualization from passive output concerning the form of architectural designs or some aspect of behaviour and performance to a central, active component in the architect's thinking and actions. It seamlessly links geometric description, programmatic and other requirements, environmental relations and human interaction with a building into a virtual prototype that accommodates the actions and transactions of all parties involved in the design process – from architects and engineers to clients and users.

What compelling evidences and arguments do you have? The proposed approach and goals are on the one hand a clear necessity for the improvement of architecture and building. The current incremental improvement of their practices by means of simple technology transfer (i.e. readily available tools from related disciplines) does not appear to suffice for the development of new solutions. A comparison between a building designed and constructed 60 years ago, in the aftermath of the Second World War, and a building recently completed usually reveals few changes in terms of spatial articulation, building technology, behaviour, and performance. However, a comparison between a motor car or an aeroplane of the 1940s and their recent counterparts shows a tremendous improvement in practically every aspect. In order to achieve similar leaps forward, we need major changes in mentality and means. Promising theoretical and methodical developments in the architectural domain have yet to find appropriate implementation means that allow extensive impact on practice. Such major changes are not without historical precedent. We have already mentioned the Renaissance and the deep, far-reaching cultural impact it had through the work of luminaries like Palladio. A more recent example concerns the changes brought on by Modernism in the reconstruction period following the Second World War. These changes were not only at the aesthetic, morphological level but also included engineering and performance issues such as the integration of services in the organization and structure of a building, resulting in improvements not only in construction but also in hygiene. Computerization promises a similar major improvement in overall performance and offers moreover vehicles like visualization that deliver this promise in a transparent and comprehensive manner.

Why is this research goal important? Performance improvement in architecture and building are of paramount importance for the economical and environmental reasons already mentioned. Any major improvement in the built environment but perhaps even more in the way we approach it as designers and decision takers has extensive repercussions for the rest of human society. Another reason why this goal is important is that it utilizes and integrates existing knowledge, both from the architectural domain and from related areas including visualization and information design. Architecture is a demanding but also responsive application area that can absorb the products of many other areas returning direct and challenging results.

Why is this research goal original? The originality of the research goal does not derive from its building blocks (most of which are already known or even established) but from the complexity and potential of their integration. It does not take place in isolation from the real world, in a laboratory or other artificial environment but in relation to real problems and real working conditions. The research does not attempt to simplify reality but accepts its multiple levels of abstraction, points of view and intricate relationships and proposes that there are ways of handling it without losing overview and purpose.

How can you achieve this goal by 2010? The first step towards the set goal is to develop a common framework and a platform for it among architects and other specialists, that is, the domain workers and the external contributions that will shape the future of the area. This can be achieved through the usual cooperation networks we can establish in the framework of our daily activities but efficiency and effectiveness can be increased in a spectacular manner through the existence of physical environments that stimulate and support high focus and cooperation, for example, centres of research excellence where we can work together free from our daily activities.

Workshop 2: geovisualization

Authors: Gennady Andrienko and Natalia Andrienko (Fraunhofer Institute Intelligent Analysis and Information Systems), Jason Dykes (City University, London)

Introduction: Among the data the modern society has to deal with, a great part involves a geographical (or, more generally, spatial) component. Visualization of such data (further referred to as 'spatial data') traditionally belongs to the research area known as geographic visualization, or geovisualization. Very often, spatial data also have a temporal component. Hence, spatial data have a complex structure involving space, time, and a number of thematic attributes, which poses significant challenges to the visualization.[3] The visualization of spatial data requires the use of maps or 3D displays where at least two display dimensions are utilised to represent the physical space, which is different from information visualization dealing with abstract data spaces. This restricts the possibilities for the representation of the temporal and thematic components of the data. In modern geovisualization software, such data are represented using both traditional cartographic techniques based on the use of colours, textures, symbols, and diagrams; and using computer-enabled techniques such as map animation and interactive 3D views. Moreover, maps are used in combination with non-geographic visualization techniques such as scatterplots or parallel coordinates. The use of multiple interactively linked views providing different perspectives into the data has become a kind of standard in geovisualization. However, a number of problems have yet to be solved, such as the scalability of geovisualization tools and their usability.

What is the most promising topic found by your workshop? In order to prepare the workshop, all participants were asked to introduce themselves by addressing the following three core questions: (1) What topics of GeoVis you are working on now? (2) What are, in your opinion, the major difficulties that prevent wide use of geovisualizations? (3) In which areas of GeoVis do you expect major progress in the coming years? (What are the outstanding research questions in GeoVis?) Analysis of 15 detailed answers that we received allowed us to indicate that some geovisualization-related applications are widely accepted and used: Open online mapping tools, GoogleEarth and GoogleMaps, Weather forecasts, Navigation and routing tools, GeoVis in geoscientific community, GIS-generated maps (at least by GIS students). On the other hand, some tools that have been developed in our community still have limited acceptance: Collaborative GeoVis, GeoVis of multivariate data, GeoVis of temporal data, Visual data mining, GeoVis for non-geographic data.

This situation can be explained by the following factors: (1) undeveloped terminology (e.g., how does GeoVis differ from cartography?); (2) the general public has a poor understanding of the additional value of interactivity; (3) the focus on exploration in geovisualization limits potential users to experts; (4) tools are designed for expert users and are too complex; (5) tools do not exactly address users' needs; (6) the ignorance of potential users about the strength of GeoVis; (7) the lack of success stories about solving real-world problems; (8) the lack of education and training in using GeoVis; (9) low trust of domain specialists in visual approaches, and a bias towards numbers, formulas, and texts; (10) the lack of support for documenting insights and knowledge gained; (11) the fact that visualization produces no material results; (12) the lack of support for spatial and spatio-temporal reasoning; (13) the lack of ready-to-use software; (14) the lack of advanced GeoVis functions in GIS; (15) the limited functionality of non-commercial tools (focus on particular techniques and data types); (16) limited infrastructural (data model) basis; (17) the lack of interoperability of data, systems, and tools/methods; (18) the lack of scalability with respect to data size, device characteristics, and other factors; (19) the gap between existing theory and technological opportunities.

The major challenges that geovisualization should address are the following:

- handle huge data volumes,
- handle complex and heterogeneous information,
- handle dynamic phenomena and processes,
- support time-critical analysis and decision making,
- support externalization of insights and synthesis of knowledge,
- embrace new hardware and technologies,
- increase the use of GeoVis, extend the user community and application scope,
- develop adequate theory and methodology.

An important finding is that the majority of these challenges are not specific to geovisualization but are common to many areas of information visualization.[4] Moreover, the scientific visualization community also faces similar problems.

What is the background of the participants? The 16 participants (Jurgen Dollner, Doris Dransch, Sara Fabrikant, Nick Hedley, Lorenz Hurni (corresponding participation), William Cartwright, Bernhard Jenny, Mikael Jern, Daniel Keim, Jorn Kohlhammer, Boris Kovalerchuk, Menno-Jan Kraak, Jochen Schiewe, Andre Skupin (corresponding participation), Kirsi Virrantaus, Monica Wachowicz) of this workshop formed a multidisciplinary team with backgrounds in computer science, geoinformatics, cartography, and cognitive science.

What is your new research goal that can be achieved by 2010? Challenge: Purpose-driven GeoVis in Appropriate Domains. By 2010 we will know more about the relationship between the purposes of GeoVis, the people that use GeoVis, and the methods and tools of GeoVis. In particular, we need to address the multiple purposes of GeoVis such as data analysis, decision support, communication, and education. Comprehensive analysis and grounded justifiable decision making requires special mechanisms that reflect the nature of problems in their geospatial and temporal context. One sound approach involves complementing the power and efficiency of computational methods with the human subject's background knowledge, flexible thinking, and experience, which often involves intangible preferences and intuition, as proposed by the geovisual analytics research agenda.[5] This new research direction emphasizes the importance of visualization and interactive visual interfaces for analytical reasoning in spatial and temporal applications, and links with the emerging research discipline of Visual Analytics.[6]

The goals of Geovisual Analytics are consistent with the goals of Visual Analytics as a more generic research field. Within this broader research area, Geovisual Analytics pays special attention to handling the complexities of the geographical or, more generally, physical space; to supporting the work of multiple actors with diverse roles, expertise, capabilities, and interests; and to integrating innovative computational technologies into the established human practices of problem solving and decision making.

What compelling evidences and arguments do you have? First, numerous geovisualization techniques and systems have already been developed over recent decades and demonstrated their potential and importance. In parallel, industry is working on developing a solid technological basis for geovis (Google, Microsoft, ESRI). Third, actively used applications (e.g. Google Earth) improve public awareness about the value of geovisualization and create good opportunities for broad use of geovis tools and methods in the future.

Why is this research goal important? First, because analysis of the state of the art has revealed a need in concerted cross-disciplinary efforts to achieve substantial progress in supporting space- and time-related problem solving and decision making. Second, because the size and complexity of real-life problems together with their ill-defined nature call for a true synergy between the power of computational techniques and the human capability to analyse, envision, reason, and deliberate. Existing methods and tools are still far from enabling this synergy.

Why is this research goal original? Appropriate methods can only appear as the result of a focused research based on achievements in several scientific disciplines.

How can you achieve this goal by 2010? We need research in multidisciplinary teams (including cartography and GeoVis, information visualization, visual analytics, data mining, statistics, databases, HCI, cognitive sciences) for solving real-life spatio-temporal problems characterized by huge volumes of complex data in tight cooperation with domain experts.

Workshop 3: challenges in architectural and geospatial visualization

Author: Wolfgang Kienreich (Know-Center, Graz)

Introduction: Methods of information and knowledge visualization enable knowledge discovery in large, complex knowledge spaces. In many cases, the visual means employed to represent a given knowledge space are based on real-world metaphors taken from geography or architecture. Users find the resulting visualizations effective to navigate and intuitive to understand. In reverse, it is tempting to represent knowledge spaces formed by geospatial and artefact data exclusively through assertive real-world metaphors. According approaches, however, tend to undervalue key aspects of spatio-temporal reasoning because of their implicit focus on the current, visual appearance of knowledge entities. Several disciplines have independently encountered this problem and proposed solutions in the form of visual abstractions supplementing real-world metaphors. Illustrations can be found in the field of the architectural heritage, where the analysis of an artefact requires an understanding of the artefact's evolution over time, based on partial and questionable information; and in the area of geography, where an increasing amount of knowledge-based relationships between geospatial entities has to be integrated into visual representations. It is essential to foster awareness of this problem in the various application domains as well as in the visualization area providing the methods and tools in order to develop architectural and geospatial visualization beyond pretty renderings.

What is the most promising topic found by your workshop? The workshop investigated the borderline between visualization approaches based on real-world models and the abstract graphical representations provided by methods of classical information visualization. Participants discussed methodological challenges in visually representing evolving topological and artefact knowledge comprised of abstract structures and semantics as well as real-world data. The most promising topic encountered was how to integrate approaches from various research areas while retaining context-dependent peculiarities related to application environments.

What is the background of the participants? The nine participants (Workshop leaders: Jean-Yves Blaise, Wolfgang Kienreich; Attendees: Iwona Dudek, Alberto Sdegno, Vedran Sabol, Livio De Luca, Stefan Wrona, Krzysztof Koszewski, Jan Slyk) of this workshop came from the area of information and knowledge visualization as well as from the architectural domain. Many participants had already encountered the problem stated in the introduction either from the application side or from the research aspect.

What is your new research goal that can be achieved by 2010? By 2010 we will be able to combine abstract and figurative graphical practices to understand spatial dynamics and emphasize uncertainties. We will employ such combined practices in the architectural and geospatial domain to demonstrate the validity of our approach.

What compelling evidences and arguments do you have? First, architectural and geospatial information is most often exclusively represented through assertive real-world models or metaphors, in particular when delivering 3D graphics. However, there is much more to an artefact than its visible, physical properties. In fact, real-world models and metaphors are ill-suited to convey many important aspects, for example changes over time or semantic relationships. Second, there are well-developed visualization methods for such aspects. However, they mostly stem from fields unrelated to the architectural and geospatial domain and have to be adapted and integrated to become useful in the context. Third, because of the investment needed, and of the lack of sustainability of existing solutions, researchers dealing with spatio-temporal artefacts do not necessarily see visualization at the centre of their activity. Applying and evaluating best-practice rules can help the community to save time and money by making efficient graphics, and define a common methodological background for spatio-temporal reasoning at various scales.

Why is this research goal important? The development of combined practices in abstract and figurative graphical representations is important because the problem discussed above is likely to become more dominant in the future. The amount of information available globally is rapidly increasing, and large portions of this new information are of an architectural or geospatial nature, exhibiting the spatio-temporal dynamics and uncertainty requiring combined practices for visual representation.

Why is this research goal original? The workshop investigated the borderline between visualization approaches based on real-world models (as used by architects and geographers) and the abstract graphical representations provided by methods of classical information visualization. This contrasts the focus on computer graphics and rendering which has been the classical interface between architecture, geography, and computer science.

How can you achieve this goal by 2010? Following the workshop, participants will first address issues of common language and interpretation of technical terms across the fields of architectural and information visualization to create an environment for further discussions of the final research goal. In this environment, a catalogue (potentially a semantic description) of both information properties found in the application domains and visualizations available will be compiled. A preliminary set of best-practice rules and metrics for combining information properties and visualization elements will be identified. Practical experiments will be proposed by participants in order to verify the efficiency of these tools across fields of application. Discussion threads as well as results of this process will be collected in a virtual platform. By 2010, we hope that such a platform will contain a solid repository of visualization elements and rules on how to apply them in various application contexts to address aspects of spatio-temporal dynamics and uncertainty of information.

Workshop 4: visualizing strategy – exploring graphical roadmap forms

Authors: Robert Phaal (University of Cambridge), Alan Blackwell (University of Cambridge), Martin Eppler (University of Lugano)

Introduction: Roadmapping techniques are widely used in industry and government to support innovation, strategy, and policy development. Improved communication is a key benefit, both during the development of the roadmap and afterwards to support alignment of strategy between functions and organizations. Graphical roadmaps are particularly important, enabling the evolution of complex systems to be represented in a relatively simple way that supports understanding and dissemination. The concept of roadmapping in the context of strategic planning can be traced back to the 1940s,[7] although Motorola is widely credited with establishing the modern approach as a core part of their business processes, to align technology and product development with market outcomes in a single visual chart.[8] The approach was adopted (and adapted) initially in the consumer electronics, aerospace and defence sectors, and then at the sector level with the creation of the public domain International Technology Roadmap for Semiconductors in the 1990s (http://public.itrs.net/), which was the catalyst for the widespread take up of the concept by industry, trade associations, government agencies, and other organizations. Visual representation is an important aspect of roadmapping, in terms of both the development and dissemination of strategy and policy, and probably the aspect of the approach that is most attractive to practitioners, but current practice and theory in this area is not mature. Research is needed to develop frameworks and guidance to support industry and government to more effectively explore and communicate complex strategic issues.

What is the background of the participants? Apart from the three workshop leaders, a total of 12 participants (Workshop leaders: Alan Blackwell, Martin Eppler, Robert Phaal; Attendees: Brock Craft, Elke den Ouden, Mike Ferril, Clive Goodchild, Elizabeth Harvey, Ralph Lengler, Steve Mann, Andreas Neus, Dominic Oughton, Paul Palmer, Clive Richards, Masayoshi Wanatabe, Colin Winfield) were invited to the workshop, 10 of whom have extensive experience in the application of roadmapping techniques to industry and government, together with two experts in design and visual science. The aims of the workshop were to develop a better understanding of the types of visual representations used for strategy and policy and to identify research challenges.

Workshop approach and outputs (This workshop followed a individual and differing workshop agenda and has therefore another structure). More than 900 public-domain roadmap documents have been collected (www.ifm.eng.cam.ac.uk/ctm/trm/documents/published_roadmaps.pdf), from which 450 examples of visual roadmap representations have been extracted, providing a rich, diverse and unique resource to support research in this area. Participants initially formed into three groups, each selecting a set of 20 varied roadmaps on the basis of three criteria: (1) purpose of the roadmap, (2) good visual structure and (3) design pitfalls. Duplicate sets were extracted from a second collection of the roadmaps, enabling participants to work in rotating pairs to undertake a series of card sorting activities, so that each person had the opportunity to sort each set into categories of their own choosing, based on perceived similarity. Cluster analysis enabled dendrograms to be constructed for each theme, the branches of which were then labelled in a separate activity in three groups. Research challenges were identified and clustered (Figure 2), and the dendrograms were tested by using the emerging structure to support the rapid development of 'meta roadmaps' (roadmaps of roadmapping research), based on a discussion of purpose and good visual structure, taking into account the identified design pitfalls (Figure 3).

Summary and conclusions. The workshop provided a valuable opportunity to bring together participants from the roadmapping and visual science communities, to explore how strategy and policy issues can be visually represented, an area where there has been very limited research in the past. The key outputs from the workshop were:

- A preliminary structure for the visual representation of strategy and policy that will be developed and tested, with the eventual aim of developing practical guidance for creating such representations.
- A framework of roadmapping research challenges (Figure 2) that can be used to guide further efforts in this area.

A novel card-sorting workshop methodology that can be repeated with different communities to build confidence about the underlying structures in the corpus of roadmap specimens, and potentially for other visual representations.

By 2010, the overall goal is to develop a coherent 'visual language for charting the future', to support the development and communication of strategy and policy, which could have a significant impact on society's ability to deal with the challenges of globalization and environmental change.[9]

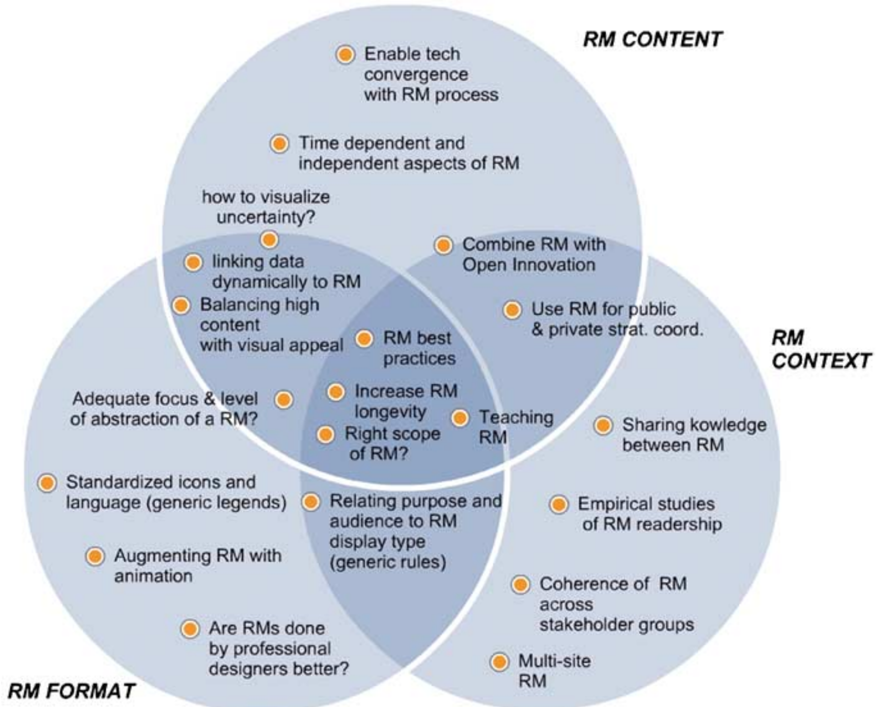


Figure 2 Roadmapping research challenges, clustered in terms of roadmap context, format and content.

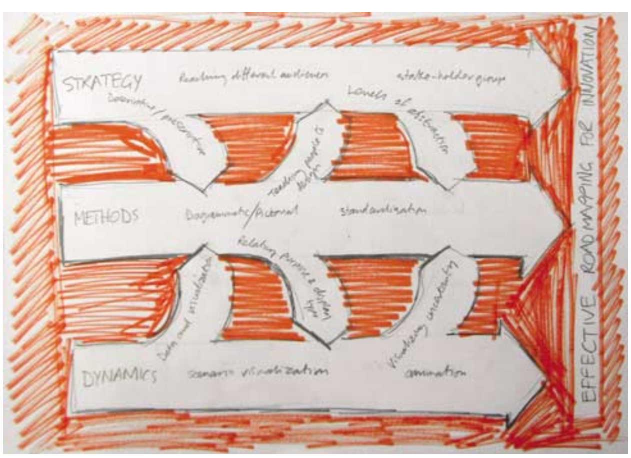


Figure 3 Example meta-roadmap developed to test the dendrograms (roadmap of roadmapping research), created by Clive Richards.

Workshop 5: workplace 2010

Authors: Mark Meagher, Jeffrey Huang (both EPFL Lausanne, Switzerland)

Introduction: The phenomenon of nomadic work and nomadic living was a primary preoccupation of the architectural *avante garde* from the early 20th century, inspiring early explorations of the open plan. This relation between spatial setting and spontaneity or freedom of choice was one way in which Modern architecture anticipated and accommodated new modes of living and working. Nomadic and spontaneous work practices are now a necessity for many knowledge workers, and present specific challenges for designers of spaces, devices, and software to support the needs of the nomadic workforce.

Our workshop focused on the relation between spatial setting ('Where do you work?') and the specific needs of nomadic workers ('What are the limitations of the places where you work?'). We proposed that one way to meet the needs of nomadic workers is through (information) visualization: the creation of an 'information environment' that recreates selected affordances of the traditional office space. The purpose of the workshop was to collect design guidelines for the creation of such an environment, and to make several initial proposals. The focus was on goals that could be achieved in the immediate future – the workplace of 2010.

We first conducted a survey of the workshop participants to identify the spatial settings where work is taking place, collecting over a hundred photographs of workplaces – cubicles, conference rooms, trains, cars, airports, living rooms, and open plan offices. Using the physical, tectonic detail contained in these images as a starting point, we began our discussion by asking what are the affordances offered by each work environment, and what are the problems or limitations encountered. Issues that arose from this discussion included the tension between territoriality and nomadic spontaneity; the need to maintain a degree of privacy when working in public settings; and the demands of a 24/7, 'always on' work ethic.

What is the most promising topic found by your workshop? The primary idea which emerged from our discussion was the importance of (information) visualization as an enabler of distributed work, and in particular as a tool for the creation of a consistent information environment within the constantly changing physical environment of the nomadic worker.

What is the background of the participants? The 18 participants (Workshop leaders: Jeffrey Huang, Silke Lang, Alvise Simondetti, Mark Meagher, Isabelle Bentz, Nicolas Nova; Attendees: Francesco Cara, Hans-Peter Fischer, Joanna Chopard, Marco Molteni, Andreas Kunz, Roberto Vitalini, Yasmine Abbas, Deanne Beckwith, Frederik Kaplan, Martin Kuechler, Martin Rudolph, Marc Schmit (Playze)) have transdisciplinary backgrounds. We were first concerned to select workshop participants who were themselves nomadic workers; we also sought participants with complementary backgrounds including architecture, graphic design, product design, design management, and business management.

What is your new research goal that can be achieved by 2010? Our workshop focused on the role of design in addressing the needs of nomadic workers, and we chose to use design as a tool to identify the most important topics and to propose potential solutions. As a result of the workshop, we have two research goals for 2010. First, we assert the need for more ethnographic study of the varied phenomena associated with nomadic work. Second, we propose that this ethnographic study should be accompanied by the design of a travelling information environment for nomadic workers, an environment which will most likely involve software, hardware, and space design. This information environment should take into account the importance of privacy, territoriality, of collective grounding and of selective connectivity (the primary 'pain points' for nomadic workers that were identified in the workshop).

What compelling evidences and arguments do you have? The short ethnographic study we conducted among the workshop participants revealed a number of 'pain points' which should be addressed in future design work, and also re-affirmed the importance of using design as a tool in foresight research. Prior to the workshop, we collected over 100 images of the places where the workshop participants conduct their work, and even this limited sample provided a valuable springboard from which we were able to make a number of general design proposals. Future design work should both clarify the nature of the problem ('what do we mean when we talk about nomadic work'), and identify potential futures.

Why is this research goal important? A large proportion of knowledge workers are either compelled to or choose to leave the familiar territory of the cubicle behind to work in unfamiliar settings; and, there are clear indications that these workers are not entirely content with their working conditions. Issues of privacy, territoriality, and connectivity urgently need to be addressed as a means of improving the working conditions of nomadic workers.

Why is this research goal original? Although there has been much discussion of nomadic work in recent years, we believe that this phenomenon has not been adequately studied in the field. The use of information visualization as a tool for supporting nomadic workers is particularly in need of investigation. It is also the case that many products, spaces, and software packages designed for nomadic work have not taken into account the actual needs of nomadic workers.

How can you achieve this goal by 2010? Our workshop focused on goals that could be realized immediately, and although three years is probably not sufficient time to reach a definitive solution, both the ethnographic and the design components of our goal can be seriously addressed within this timeframe.

Workshop 6: large scale city modelling

Authors: Armin Grün, Silke Lang (both ETH Zurich, Switzerland)

Introduction: City modelling has evolved over the years and gains currently in importance not only in architecture and urban planning, but also in virtual reality, car and other navigation systems, climate and air quality investigations, fire propagation, public safety studies, security and defence, location-based services (LBS), game and movie industry, infotainment and other areas. Commercial users include phone, gas, electric, communication, real estate, and tourism and travel companies. Most of these users are primarily interested in models of buildings and other man-made structures like bridges, traffic networks and supply facilities, but also in terrain and vegetation. These are extended into facility management applications, where also the interiors of buildings have to be modelled. It should be noted that the term 'city models' is used here in a generic way, encompassing not only models of cities but also of suburban and rural areas. A very special category of users comes from the Cultural Heritage field, where models of very high accuracy and resolution are usually required. Computer technology, computer graphics, CAD and Spatial Information System (SIS) technology now offer powerful tools for storing, analysing, and visualizing digital models of cities. We distinguish reality-based and generic city models. All the aforementioned applications need reality-based models, very often by combining geometry and texture. Increasingly, the data is supported by attribute information and integrated into Spatial Information Systems.

What is the most promising topic found by your workshop? The first big challenge is the development of dynamic city models that are able to adapt to the rapidly growing and changing cities, including the realistic modelling of dynamic activities of people in cities. The second challenge is the efficient and automatic (or semi-automatic) generation of large reality-based 3D city models, which can be used in a great variety of diverse applications.

What is the background of the participants? Most of the 12 participants (Workshop Leaders: Armin Grün, Roland Siegwart, Silke Lang; Attendees: Stefan Gächter, Simon Haegler, Dirk Helbing, Alexandre Kapellos, Olaf Kübler, Christian Plagemann, Frank Schweitzer, Alex Schmid, Rudolph Triebel) of this workshop have a background in digital design and modelling, with specialization in computer vision, photogrammetry, system design and robotics.

What is your new research goal that can be achieved by 2010? We aim at the automatic generation of 3D city models with up to 10–20 cm resolution with the inclusion of semantics, dynamics, and human interaction.

What compelling evidences and arguments do you have? Google Earth (http://earth.google.com/), Microsoft Virtual Earth (http://www.microsoft.com/virtualearth/default.mspx), and NASA Worldwind are providing worldwide for land- and cityscapes 3D real-time visualization solutions. However, the resolution of the data is currently limited, both in terms of geometry and texture. An ever-increasing user community will ask for better resolutions. Also, the use of textured truly 3D models is just in an infant state in those systems. So there is an urgent need for procedures and techniques that allow us to generate even larger data sets very quickly and with high precision and reliability.

There are worldwide many groups in research labs that are putting efforts into the improvement of reality-based city modelling techniques. Engineering companies and governmental agencies are generating large numbers of city models for practical applications.

Using data from photogrammetry or airborne laser scanners in combination with 3D Digital Terrain Models (DTM) it is possible to generate 3D city models relatively cost-efficiently. Textured with high resolution aerial and terrestrial images, users can freely navigate in virtual 3D scenes.

Autonomous vehicles of terrestrial and/or aerial type are increasingly being investigated and developed. For navigation purposes these devices are equipped with sensors that allow real-time positioning. The need for 3D models of our environment for navigation is obvious. At the same time the collected data can be used to update the models and to generate new ones. Areas which are not visible from the air can now be filled by data derived from terrestrial sensors.

Why is this research goal important? 3D models and 3D landmarks have many applications. Among these urban planning is one of the most relevant. Especially in the decision-making processes in reconstruction projects of old town areas, investment projects or new road construction 3D models are becoming more and more an important tool. 3D city models in combination with DTM also serve as a basis in risk analysis and disaster control. For example, flood simulations visualize which part of a city will be affected as well as the impact on buildings. A prominent engineering application could be the maintenance and simulation of a city sewer system. Structures, connecting sewers, street names, proposed construction sites, and 3D buildings are included in geo-referenced 3D computer environments. Also the simulation of traffic noise from several sources and contaminants in the air of large cities requires detailed 3D city models. Photorealistic 3D models are also used by real estate companies and the government in marketing processes to acquire and recruit investors and vendees. 3D city models are on the one hand used by tourists who are planning their holidays, on the other hand the hotel and restaurant industries use them to present their products and their services. Further application fields are homeland security and navigation systems, and the entertainment industry with their applications in TV, movies, and computer games.

Applications in urban planning, disaster control, and engineering have the potential for mastering the spatial problems of emerging mega-cities worldwide, especially in developing countries. Prognoses state that 90% of the global population growth will be in cities between now and 2030. Therefore, infrastructures and the environment have to be adapted to the changing demands and new urban development strategies have to be developed. The big challenge is the development of dynamic city models that are able to adapt to the rapidly growing and changing cities.

Cities are extremely complex systems and unique par excellence. The challenge we are facing today in urban planning is forecasting and modelling the dynamics of mega-cities and growth-limited cities as well as considering the wide range of influencing parameters and forces. For the most part vast growths of population as well as flows of migration bring out serious challenges for a positive economical, environmental, and social development. Consequently, we have to find methods for the society of tomorrow living in mega cities which are able to manage this new form of cityscape ecologically, sociopolitically, and economically. To face this challenge capable and innovative infrastructure solutions as well as new approaches to metropolitan governance have to be developed. Already in 1951 Isaac Asimov described in his original Foundation trilogy the vision of an urban gigantism. He predicted the end of the fictive planet Trantor because of mega urbanization. In order to avoid this fate we have to work on strategies for achieving long-term ecologically balanced urban settlements.

Why is this research goal original? Firstly, because the big picture of generic mechanisms of the underlying spatial dynamics of urban growth is still missing. Secondly, the automated reality-based generation of high-quality landscape and city models is one of the great and enduring problems of the imaging sciences. And thirdly, we combine the expertise of several disciplines in achieving our goals and we are looking at the challenges from a transdisciplinary point of view.

How can you achieve this goal by 2010? We must make clear that the road to full automation in object modelling from sensor data is an open-ended one. There will not be a final solution, but intermediate results will always be subject to improvement. It is in the nature of humanity that the request for better data and more detailed information will always run ahead of possible realizations.

As the performance of the sensors and the processing techniques improve over time, so do the expectations of the user communities. Our goals shall be achieved by bundling forces with a transdisciplinary concept, establishing a focused research programme, and making full use of the various expertises that are available at our school and beyond.

In Fundamental Research, we have isolated the following research goals of high priority:

- Investigate how to handle uncertainties and to propagate them through the different levels of abstractions and across different modalities.
- Establish a shape grammar that allows parameterized modelling based on real data.
- Develop methods of relational learning for analyses of functions of buildings/environments/structures (context understanding).
- Develop advanced image- and pointcloud understanding algorithms, with particular emphasis on the understanding of semantics.
- Dynamics in data sets. Study how to identify and consistently update static and dynamic elements at different time scales.
- Develop automated texture generation algorithms based on real images including the alignment of geometry and texture across different resolutions.
- Study the interaction of people with model cities and environments.
- Model realistically the dynamic activities of people in cities (simplified models of people, sensor data e.g. from surveillance cameras, traffic information)

With regard to integration, we have isolated the following research goals of high priority:

- Selection of appropriate sensor combinations in order to generate particular models (sensor fusion).
- Development of quality control systems and benchmarks.
- Development and optimization of system architectures and data structures for visualization and analyses of information.

Workshop 7: basic narratives in visualization

Authors: Daniel Perrin (Zurich University of Applied Sciences Winterthur), Wibke Weber (Stuttgart Media University)

Introduction: Narratives are a basic aspect of our everyday life, because they provide the initial and continuing means for shaping our experience. Narratives help us to make sense of the world and to create individual and cultural identity. They evoke emotions and have a strong cognitive and motivational impact. The analysis of narratives shows that any particular narrative can be taken as a concretization and variation of a basic narrative.

Basic narratives (John Campbell calls them monomyths) are universal semiotic patterns with prototypical constellations of actors and actions, scenes, perspectives and combinations of dramaturgical elements like conflicts, plot points, and key frames. They are the traces of cultural and societal construction of meaning, so they are deeply rooted in cultures, societies, communities. Examples of basic narratives are: good guy *vs* bad guy; rise leads to fall; trouble on earth *vs* being saved in paradise; small and clever can win over mighty and clumsy (David and Goliath).

Meanwhile, several disciplines, for example, literary studies, linguistics, anthropology, sociology, psychology, and even economics, have recognized the significance that narratives might have. In spite of the growing interest in narratives and storytelling, so far no approach has combined narratology and visualization science. Therefore, the goal of the workshop was to link the two disciplines and to start a strand of interdisciplinary narrative research, that is, to transfer the knowledge and findings of narrative research to visualization science.

Visualization experts and computer scientists define visualization, especially information visualization, as a specific technology for charting complex data sets. They use visual elements like lists, tables, and graphs: elements that are often sterile and abstract, unemotional and bare of any links to everyday experience – an experience that is framed by basic narratives, as mentioned above. Shaping visuals along basic narratives could improve their emotional appeal and, in the end, the impact of visualization. The idea of the workshop was to discuss the relation between basic narratives and visualization – of story elements framing all human communication, whether verbal or non-verbal. It is time for a narrative turn.

Which were the key questions of the workshop? Both stories and visuals have authors and directors. They are not a one-to-one-copy of reality, but reconstructions based on rules and regularities. Both contain certain continual patterns. The key questions discussed were: What are the basic narratives framing visualizations? What turns a visual into a narrative visual? How can storytelling theory be connected to visualization theory? And how can visualization be optimized with storytelling practice?

What is the background of the participants? The four participants (Workshop leaders: Daniel Perrin, Wibke Weber; Workshop attendees: Andreas Bechtold, Mike Sips) of this workshop have a background in communication design, information design, journalism, media and communication sciences, and computer sciences.

What is your new research goal that can be achieved by 2010? By 2010, we expect to achieve the following new main research goal: to develop a theoretical framework and best practice for identifying and applying basic narratives in visualization, for visuals with the potential to affect recipients and evoke emotional and cognitive involvement and, therefore, a deeper understanding by the target audience.

What compelling evidence and arguments do you have? First, narrative elements allow visualization to convey information in an effective and intuitive way. Second, narrative elements are more appealing than a bulleted list of facts. Third, narrative elements facilitate cognitive storage and retrieval of information by activating the (mighty) episodic memory.

Why is this research goal important? This research goal is important in order to make visualizations more affective and effective – for improved understanding on the part of the target audience.

Why is this research goal original? This goal connects humanities to engineering and computer sciences; it connects the world of stories to the world of data; and the world of emotions to the world of facts.

How can you achieve this goal by 2010? By December 2008, the first papers on the key questions will have been accepted for publication. By December 2009, a first research project proposal will be submitted to EU funding agencies. By 2010, we expect to achieve the following research goal: to develop a theoretical framework and best practice for identifying and applying basic narratives in visualization, for visuals with the potential to affect recipients and evoke emotional and cognitive involvement and, therefore, a deeper understanding by the target audience.

Workshop 8: information aesthetics

Author: Andrew Vande Moere (The University of Sydney)

Introduction: The information visualization community is challenged to develop novel techniques that are capable of amplifying human cognition to enable insight in abstract, complex data sets. Owing to the focus on making visualizations purposeful for valuable and usable applications, the typical design rationale of an information visualization application has shifted towards optimizing effectiveness, the accuracy and completeness with which users achieve specific tasks, and efficiency, the resources expended in relation to the effectiveness criterion, such as the required time or computational power, measures. As a result, most visual metaphors are based on scientific insights that model the qualitative correlations between human cognition and visual perception, such as from visual cognitive sciences, visual Gestalt Laws or general information design guidelines.

In recent years, a stream of mainly young and self-motivated people is experimenting to visualize fashionable real-world data sets in 'artistic' ways.[10–12] Independent from institutional or commercial pressure, their visualizations demonstrate the initiative, enthusiasm, interest and skill to tackle complex issues that were previously reserved for the expert visualization researcher or developer. Captured in the relatively limited fame of online weblogs, galleries or museum exhibitions, their contributions seem to be ignored by the academic world. This emergent movement is driven by a combination of contemporary social phenomena, including the current seductiveness of the 'information society', novel software tools specialized in the creation of visual artefacts that are specifically developed for designers, the cross-fertilization of computer science knowledge in design schools (and vice versa, the inclusion of design methods in computer science course units), and the online creation and sharing of complex, but socially interesting data sets.

Therefore, this workshop aimed to identify 'information aesthetics' as an emerging research direction in information visualization and aesthetic computing in general,[13] to identify its unique characteristics and potential for future research.

What is the background of the participants? The 10 participants (Workshop leader. Andrew Vande Moere; Attendees: Roger Clarke, Robert Erbacher, Paul Fishwick, Daniele Galiffa, Urs Hirschberg, Robert Kosara, Warren Sack, Markus Schaefer, Andres Ramirez Gaviria) of this workshop varied widely both in national origin as in personal backgrounds. They included academics from computer science, art theory, information design and architecture, visualization-inspired artists and independent information design practitioners. Despite the disparate backgrounds of the workshop participants, still a strong consensus emerged of the meaning and purpose of information aesthetics. All participants expressed their willingness to closely collaborate in order to demonstrate the potential of information aesthetics to enrich good practice in future information visualization research.

What is your new research goal that can be achieved by 2010? We formulated the goal to have established, by 2010, a broad discourse between art, design and information science about the criteria of aesthetics, including aspects such as emotion, affection, persuasion, impact, perception, criticism, style, culture, the body and user engagement.

What compelling evidence and arguments do you have? Currently, hundreds of aesthetic visualizations exist, hidden on websites, in magazines, in galleries, but most admired by an audience that is larger than the user base of the typical information visualization application. Based on previous research on the aesthetics of interface design,[14] discovering what make these visualizations so attractive can have a positive influence on the effectiveness of existing visualizations, opening the pathway for more cross-disciplinary approaches, and making the information visualization field significant for a broader application area.

Why is this research goal important? Chen[4] recently listed the 'investigation of aesthetics to increase insight' as one of the 10 most important problems in the field of information visualization, which is based on the assumption that, based on previous research in interface design, the effectiveness and efficiency of visual insight and aesthetic judgment might be tightly linked. However, recent empirical research has shown how this phenomenon is valid for static information visualizations for task performance and task abandonment,[14] which is especially relevant for information visualizations for lay persons that aim to communicate phenomena and tendencies that 'underlie' occurring data sets and any patterns they contain. However, a precise description, critical evaluation or theoretical discourse of the characteristics and the value of aesthetics for information visualization is still missing from academic literature. Currently, few collaborations between artists and visualization researchers exist.

Why is this research goal original? Research on aesthetics has a long tradition in the Arts, however has not been explored in the field of information visualization before. It takes a positive and open view on research, by deliberately encouraging people from disparate fields and backgrounds to consider the potential influence of emotional and creative factors on an otherwise purely quantitative-driven research direction.

How can you achieve this goal by 2010? In 2010, we will have engaged in a broad discourse between art, design, and information visualization scientists about the significance and purpose of aesthetic. We have planned to initiate a community of people from cross-disciplinary backgrounds, including design, art, science, theory and industry, interested in the subject of merging creativity, art and computer science in the context of information representation. Potential avenues include a special issue academic journal, workshops, specialized book issues, dedicated conferences, art galleries, or exhibitions. Each of these initiatives should be specifically designed to encourage people from different backgrounds and disciplines to actively participate in a process of dissemination, exploration, discovery, and discussion about the value of aesthetics in the current age of information addiction and data eroticism. We well realize that the currently existing structure of academic journals and conference presentations is probably not well suited to accomplish our goals, so that a creative (and aesthetic) approach is required to encourage people from different backgrounds to come together with the goal of enriching each one of the participating fields.

Workshop 9: information visualization software infrastructures

Authors: Katy Börner (Indiana University), Bruce Herr (Indiana University), Jean-Daniel Fekete (INRIA, Université Paris-Sud)

Introduction: Information visualization software has matured to the point that we should start thinking of standards for interoperation.

There exists a rich diversity of software specifications, APIs, applications, and cyberinfrastructures (CIs) that can be employed by InfoVis researchers to design effective visualizations. Some efforts support the plug-and-play of diverse algorithms, others support snap-together visualizations, while others provide a rich API for creating custom visualization programs. These efforts help to reduce re-implementation of existing algorithms.

This workshop brought together major experts in visualization software architecture design to promote interoperability of visualization software at the application, algorithm, and visualization level; to avoid fragmentation; and to improve collaboration towards widely used and usable InfoVis software.

In 2004, two of the workshop leaders organized a workshop on the same topic at IEEE InfoVis. The 2004 workshop was an impressive showcase of the diversity of different approaches to modularize information visualization software at the algorithmic and at the interface level. Working solutions to modularization at the algorithmic level have been achieved by APIs such as Prefuse, Jung, VTK, Piccolo, Boost Graph Library (BGL), TouchGraph and tools such as R, Cytoscape, Tulip, InfoVis Cyberinfrastructure, the Universal Visualization Platform, GeoVISTA Studio, Snap-Together Visualization, WilmaScope, VisMine, etc. Modularization at the interface level appears to be more complex as a rich solution space of data to visual element mappings needs to be supported. Plus, many applications require the coupling of different visualizations or data views. Much of the effort for modularization at the interface level has gone into APIs. However, non-programmer users have a hard time to use APIs for the intelligent selection and customization of the about 200 visualization algorithms available today. There was also an impressive diversity of data exchange formats and software couplings. The latter ranged from very rigid 'all algorithms work on the very same data structure' to very loose mash-up like couplings where anything goes that serves a user's need.

Since 2004, many new algorithms have been developed and there are more efforts to bundle the best algorithms and techniques. Examples of the latter are Prefuse, Jung, Pajek, Tableau software, Many-Eyes, Improvise, ILOG Discovery, IV Toolkit, Network Workbench Tool, CommonGIS, etc. Industrial and open-source software in the last couple of years has moved to a more decoupled model. Web services, Open Services Gateway Initiative (OSGi), service and component-oriented architectures, and open standards have allowed code reuse on a large scale. When considering how best to interoperate, we as a community should look to the software industry for inspiration.

Given modularity at the algorithm and visualization level, new applications and tools can be easily assembled by plugging and playing exactly those data sets and algorithms that address a specific information need. Obviously, there will be pre-filled applications and tools for different research communities and tasks. Data exchange with third-party tools needs to be easy. New combinations of visualization techniques will be possible since they can be mixed and matched regardless of their implementation. We will see a surge in visualization development since we will no longer have to re-implement and re-invent. Finally, due to the ease of use and re-use we will likely see more visualization algorithms integrated into popular programs such as Excel, SPSS, and other products that currently have comparatively limited visualization capabilities. IV software infrastructures are envisioned as a bridge that supports the transfer of the best IV algorithms from theory to practice.

What is the background of the participants? The 15 participants (Workshop leaders: Katy Börner, Bruce Herr, Jean-Daniel Fekete; Attendees: Georges Grinstein, André Skupin, Christopher Mueller, Gabor Csardi, Benno Schwikowski, Vladimir Batagelj, Jonathan C. Roberts, Mike Smoot, Ghislain Bidaut, Chris Weaver, Anton Heijs, Xia Lin, Benno Schwikowski, Liz Stuart, Yuk Lap Yip.) of this workshop have backgrounds in network analysis, information science, biomedical applications, engineering, computer graphics, computer science, and of course information visualization. Almost all of them have developed or managed the development of major software packages and all have a deep interest in modular and scalable software architecture design.

What are the most promising topics found by your workshop? The main needs are a data model for data analysis, a reference model for visualization design, a communication model for linking different visualizations, and an interaction model for interactivity design. The software architecture model needs to have a specification that is implementation independent, an open-source 'prototype implementation', and bindings for Java, C#, C++, and Web services. Specification and prototype implementations need to be reviewed for speed, timing, memory usage, and stability by different research groups. The software architecture model should consist of core architecture and plugin components. The core architecture will support the plug and play of plugin components in a highly decoupled manner – replacement of plugin components should be easy. Plugin components that deal with large-scale data sets or highly interactive coordinated views need to be coupled more tightly to support highly interactive, incremental loops and tightly coupled windows.

What is your new research goal? By 2010 we will have a sound architectural model for Information Visualization and open-source implementations to quickly build visualization applications suited to a wide variety of users and domains.

What compelling evidences and arguments do you have? There are about 200 general visualization algorithms available today. There are about 100 visualization APIs, tools, and CIs available today. Many of the existing visualization algorithms have been re-implemented more than 10 times and are still not available in an easy to use format for general, open-source use.

Why is this research goal important? The proposed work will help to reduce re-implementation of existing algorithms, support algorithm comparison, and facilitate more efficient design of visualizations and tools.

Why is this research goal original? We envision software that supports the: (1) Easy reuse of highly usable code on many levels, for example, the application, algorithm, and visualization levels. (2) Balance between the ability to innovate and the convenience of reusing code in a variety of customizable software environments. (3) Modularity at the algorithm and visualization level in support of easy assembly of new applications and tools by plugging and playing exactly those data sets and algorithms that are needed to address a specific information need. Obviously, there will be pre-filled applications and tools for different research communities and tasks. (4) Easy data exchange with third-party tools.

New combinations of visualization techniques will be possible since they can be mixed and matched regardless of their implementation. We will see a surge in visualization development since we will no longer have to re-implement and re-invent. Finally, due to the ease of use and re-use we will likely see more visualization algorithms integrated into popular programs such as Excel, SPSS, and other products that currently have comparatively limited visualization capabilities. IV software infrastructures are envisioned as a bridge that supports the transfer of the best IV algorithms from theory to practice.

How can you achieve this goal by 2010? Workshop participants decided to (1) Form a working group of 4–5 people with one FTE/group to develop software specification and open-source prototype implementations. (2) Develop language neutral specification in IDL that is reviewed by anybody interested. (3) Aim for quarterly software releases of open-source prototype implementations. (4) Keep track of resources and progress via a shared wiki at https://nwb.slis.indiana.edu/events/ivsi2007.

The individual sections were written by the workshop leaders and present their view on the items. The next section will present a survey on the originality and importance of the proposed goals.

Discussion: survey on the originality and importance of the nine research goals

The proposed nine goals have been assessed with a small evaluation. This section presents and discusses the results.

Methodology

During the event, a survey on the originality and importance of the respective goals was conducted. Each workshop leader presented the elaborated goal from the respective workshop to the audience. The participants of the summit listened to the explanations and asked questions. This approach guaranteed that people understood the research question correctly and in the right context. Then, they had time to assess the goal by filling in a paper-based questionnaire with two questions for each research goal. The first question addressed the originality, the second question the importance of the proposed research goal. The two questions to assess the respective workshop were: (1) How original is the proposed research goal? (2) How important is the proposed research goal. For both questions the participants could mark their assessment with a pen on an horizontal line with four labelled divisions (i.e., 'not original', 'somewhat original', 'original', and 'very original' or rather 'not important', 'somewhat important', 'important', 'very important'). Then, the questionnaires were collected and processed manually by measuring the distance and filling in the correct position

Table 1 Background of the participants, who participated in the survey

Australia	2
Austria	3
Finland	1
France	3
Germany	11
Italy	2
Netherlands	2
Slovenja	1
Switzerland	18
UK	2
USA	10
no answer	7

into a database. The findings were then presented at the end of the summit with the help of an interactive visual application (http://www.ia.arch.ethz.ch/summit.htm). In this application, each circle represented one of the nine workshop goals. The position of the circle is defined by the means of the two questions and positioned on a two-dimensional axis. Clicking on a circle (research goal) resulted in additional points that appear which represent all the assessments of the individuals who handed in a questionnaire. Finally, the application allowed to point out people who think similarly. However, this feature and the corresponding social map was removed from the application for privacy reasons.

Participants

The participants are all attendees from the visualization summit. In total, 62 peopled handed in a questionnaire. The participants from the workshop Visualizing Strategy did not participate, because they were engaged in their workshop, which had an own schedule.

Twenty-two of the participants are professors, 19 have a Ph.D. degree (additional to the professors from whom most of them also have a Ph.D. degree), 21 have no academic title. Professional backgrounds: nine attendees work in the industry, 53 in universities or research centres. The educational backgrounds of the participants are in one or more of the following fields: Architecture, Cartography, Computer Science, Computational Biology, Design, Teaching, Software Design, Business.

The country in which they stay and work are listed in Table 1.

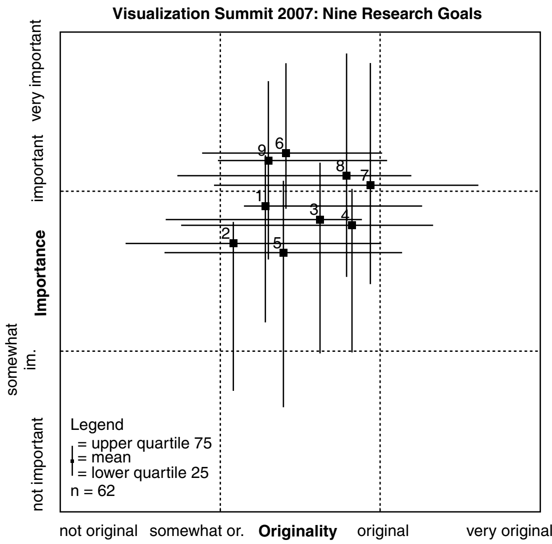
Survey

The results of the evaluation are presented in Figure 4. In this figure, each research goal is represented on a two-dimensional coordinate system. The position of the rectangle is defined by the mean of all 62 ratings with regard to the two questions. The end of the line represents the upper and lower quartile.

Discussion

Discussion of the three most important research goals:

- *Large-scale city modelling* (*Workshop 6*): 'By 2010 we will hopefully have the automatic generation of 3D city models with 10–20 cm resolution with the inclusion of semantics, dynamics and human interaction.'
  Today, urban planning and city planning still rely mainly on static representations (maps, conceptual drawings, key visuals, physical models). There have been relatively few projects that visualize dynamic data or simulate different scenarios. The automatic and semi-automatic generation of 3D city models in high resolution can be helpful for analysing, designing, managing, maintaining, and redeveloping future urban and rural areas. Semi-automatic generative simulations help to visualize and discuss scenarios, such as new high-density housing areas. The creation of such scenarios with today's CAAD software is too expensive. With regard to the implementation, hopefully the researchers from this group will soon get in contact with the software industry that develops tools for the practitioners (planners, architects, facility managers, etc.) to guarantee that their precise models are also supported by the tools (export, import, modification) the planners work with. Then, copyright issues need to be clarified. Ideally, the 3D city models will be free. Additionally, synergies with the GIS and CAAD communities should not be neglected. The researchers probably will also have to take an active role in educating architects and planners how to use the new tools. Then, there is a chance that the planners and architects will use these tools.
- *Information visualization software infrastructures* (*Workshop 9*): 'By 2010 we will have a sound architectural model for Information Visualization and open source implementations to quickly build visualization applications suited to a wide variety of users and domains.'
  Achieving this goal would be a major breakthrough in Information Visualization. However, one of the key challenges did not receive sufficient attention, namely the cost-benefit ratio for precisely defined user groups compared to the techniques they already use (e.g., statistics). Then, the tools cannot be simple enough! The author was involved in the development of a very easy-to-use TreeMap implementation (Jointly developed with Macrofocus GmbH and available at www.macrofocus.com). It was developed and customized for non-expert users that regularly play with their data in Excel. We introduced the tool in executive trainings, and limited the functionalities to make it as simple as possible to use. Nevertheless, it seems that the tool is still too complicated for everyday use by the typical manager. In addition, the importance of communicating knowledge should not be neglected, because it automatically follows as the next step after using the Information Visualization tools. For more than 5 years the author has encouraged companies in



1 **The Architectural Image and the Computer:** By 2010 we will have articulated the fusion of the analogue and digital (physical and virtual) developed hybrid representations to support the multiple interpretations of design and management of the built environment towards a new, interactive and dynamic working environment which requires new and existing visualizations.
2 **GeoVisualization: Use of Geovisualization?** Challenge: Purpose-driven GeoVis in Appropriate Domains. By 2010 we will know more about the relationships between purposes, people, and methods
3 **Challenges in Architectural and Geospatial Visualization:** By 2010 we will be able to combine abstract and figurative graphical practices to understand spatial dynamics and emphasize uncertainties.
4 **Visualizing Strategy: Exploring Graphical Roadmap Forms:** By 2010 we will have a visual language to chart the future.
5 **Workplace 2010:** By 2010 we will develop a travelling box for the nomadic worker that provides selective connectivity and collective grounding.
6 **Large Scale City Modeling:** By 2010 we will hopefully have the automatic generation of 3D city models with 10-20 cm resolution with the inclusion of semantics, dynamics and human interaction.
7 **Basic Narratives in Visualization:** By 2010 we will develop a theoretical framework and best practice for identifying and applying basic narratives in visualization: for visuals with the potential to evoke emotional and cognitive envolvement and engagement and therefore, a deeper understanding by a broader audience (lay people, interdisciplinary communication, students…).
8 **Information Aesthetics:** By 2010 we will have established a broad discourse between art, design and information science about the criteria of aesthetics, including emotion, perception, style, culture, the body, engagement, …
9 **Information Visualization Software Infrastructures:** By 2010 we will have a sound architectural model for Information Visualization and open source implementations to quickly build visualization applications suited to a wide variety of users and domains.

Figure 4 Each research goal is represented with a rectangle, which represents the mean from 62 assessments on two questions (originality and importance). The end of the lines represent the respective upper and lower quartiles.

today's business world to introduce Information Visualization tools. However, until today it was, at least in Switzerland, very difficult to convince the industry to invest in Information Visualization tools. It is not that they do not see the advantage, it is that other issues (than exploring data) seem more important to them, namely the ability to quickly and clearly communicate their messages and insights to different stakeholders. The group should therefore not neglect that the average small and large companies from all sectors search for better ways to communicate insights (alternatives to PowerPoint) and ways to reduce complexity, rather than analysing their data and searching for patterns in their data. Additionally, one should also not forget that large organizations have a lot of restrictions when it comes to installing new software. Finally, the group might also consider making online courses available to educate professionals in science, business, and society, how, why and when to use an algorithm. The structure of the framework needs attention. A value creation chain such as: collecting data, exploring data, communicating insights might be more sustainable than a technical structure or structure that follows the research terminology (i.e., focus + context, etc.).

- *Information Aesthetics* (*Workshop 8*): 'By 2010 we will have established a broad discourse between art, design and information science about the criteria of aesthetics, including emotion, perception, style, culture, the body, engagement.'
  When you communicate a telephone number or send an invoice the need for aesthetic and emotional information design is not as important as when you write a love letter, create a brochure for your company, or design the wallpaper for your headquarters. Depending on the situation and goal, aesthetic and emotional information design can leverage or even make the success of a product campaign. It can also support heavily the implementation of a business strategy, process, or project. Today, we possess a rich vocabulary for describing whether and why something is aesthetic or emotional. However, we have largely neglected the development of techniques to measure the value of creativity, of aesthetics, of emotional visualization, etc. A measurement system would help to convince companies to invest more in the aesthetic design of documents, screen designs, interior design, architecture, etc. Findings that would be helpful are scientifically proven data and arguments for the key questions of business decision makers: how can aesthetics lead to more sales, less expenses, or faster implementation of projects/process? Maybe the group can even concentrate on the cost/benefit ratio of aesthetics. Everyone agrees on the importance of aesthetics in architecture, product design and information design, but the point of discussion is how much to pay for it. Today, no one systematically measures the impact of aesthetics in science and business, both on a micro-level (e.g., aesthetic brochure) and on a macro-level (e.g., contribution of aesthetics to the success of a product, such as Apple's I-Pod).

Discussion on the three most original research goals:

- *Basic narratives in visualization* (*Workshop 7*): 'By 2010 we will develop a theoretical framework and best practice for identifying and applying basic narratives in visualization: for visuals with the potential to evoke emotional and cognitive involvement and engagement and therefore, a deeper understanding by a broader audience (lay people, interdisciplinary communication, students…).'

The research is very important because it addresses an important topic in business, science, and society, namely to improve communication by using stories or figurative narratives. The research should refer to and learn from the existing research on the power of visual metaphors. The research group might also collect typical communication situations where communicators often fail and try to propose narratives for specific situations. It should also address the topic of science communication, such as the communication of scientific data, insights to non-experts and the use of narratives to make the academic profession more attractive for the next generation of talents.

- *Visualizing strategy*: *Exploring graphical roadmap forms* (*Workshop 4*): 'By 2010 we will have a visual language to chart the future.'
  Today, it sometimes seems like the ones that complain the most about PowerPoint presentations are the ones that use the PowerPoint presentations most extensively. Why? Often they do not know alternatives or if they know them they are too shy to use proven alternatives, such as mapping techniques. Maybe they assume that digital mapping techniques are too expensive and hand drawn maps belong to the kindergarten, rather than to the board room. Both assumptions are wrong. Today, visually illiterate managers can create digital maps with a variety of tools. And various companies are successful in the communication of their strategies with hand drawn maps. Success factors for such maps are: They capture attention, evoke emotions, provoke discussions, create a mutual framework, and contribute to a shared vision. In conclusion, the research goal is very specific and original. Furthermore, it is a promising direction for future research because it is successfully embedded in a transdisciplinary scientific discourse and in a close interaction with practitioners from different fields, nationalities, and backgrounds.
- *Information aesthetics* (*Workshop 8*): 'By 2010 we will have established a broad discourse between art, design and information science about the criteria of aesthetics, including emotion, perception, style, culture, the body, engagement, ...'
  This research goal is not only important but also original because it limits the scope to the aesthetics of information, not architecture, product design, etc. There is a danger to stay in an abstract or experimental discourse within a closed group without comparing the benefits of the new approaches with existing approaches. Of course, the exploratory and artistic approach is a key of this group and this is important. However, it could become dangerous to experiment and discuss without constantly asking how the benefits and impact for real-world situations can be measured. The field has a potential for significant impact in science and business!

The discussion above represents a critical discussion of the proposed goals by the main author. It is next complemented with a personal impression from the domain expert Dominique Brodbeck who is an information visualization expert. His role at the summit was to watch for emerging trends. He is well known in the information and knowledge visualization community and is the founder of a company (Marcofocus GmbH, http://www.macrofocus.com) that develops customized information visualization solutions. Dominique Brodbeck: 'As both a researcher and practitioner I was interested to see if there are any common themes or trends that emerge from the nine workshops. In order to get an overview, I deconstructed the nine statements about the research goals, and put them back together in a few categories. Since the task for the working groups was to come up with research goals that can be achieved by 2010, I chose rather pragmatic categories, such as what are they going to deliver? What can it be used for? Who benefits? The result can be seen in Figure 5.

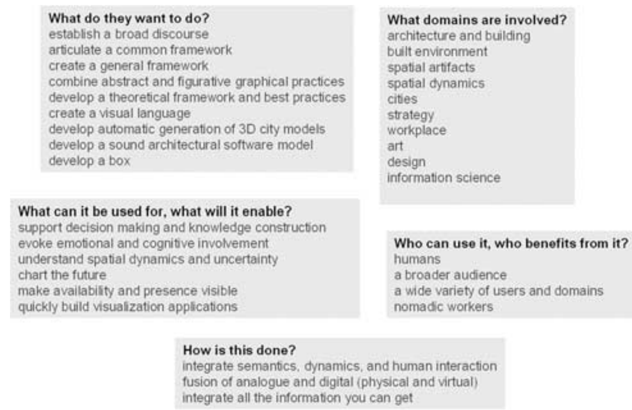


Figure 5 A deconstruction of the ten research goals for 2010. Author: Dominique Brodbeck.

We can see that most of the groups want to create some kind of framework for the benefit of humans in general. Considering that 2010 is only 2.5 years away, this might be an ambitious undertaking.

One common theme that is visible, is a concern for the built environment, architecture, and spatial dynamics. It is obvious that our growing cities and the dynamic flows of people, material, and information through them are complex systems. Trying to answer questions about these systems is a perfect example of what has become known more recently as Visual Analytics. Funnily enough, a buzzword that was prominently absent from the discussions at the Summit.

This could be due to the fact that the participants were mostly of European origin. The term Visual Analytics was coined in the USA in the context of applications focused on homeland security and anti-terrorism intelligence, a topic that does not get quite the same exposure in Europe. Also, the term is less than two years old, and it is not clear yet if it will become a separate discipline, will be used as a more general term by the various disciplines related to visualization, or will simply remain in its current niche.

One is probably well advised though to not pay too much attention to these labelling issues.

So we might conclude this little meta analysis with the insight that the spatial dynamics and information structures of the built environment is where Geo-Information, and Knowledge-Visualization meet, complement, and fertilize each other. As for a common megatrend that spans all fields of visualization, the workshop setup was probably not systematic enough to reveal it, if it should exist.

Synthesis: visualizing future cities – the 10th research goal.

A lot of persons asked for a one-sentence summary of the whole event, in other words the research direction that emerges from the nine goals. The author proposes as a synthesizing 10th research goal, namely 'Visualizing Future Cities'. The term 'Future City' relates to both city and mega-cities (such as Zurich, or Tokyo) but also for urban, suburban structures and rural areas. 'Visualizing' includes computer-aided research fields such as city modelling, computer graphics, CAD, Geovisualization, Spatial Information Systems (SIS), Information Visualization and non-primarily computer-based research fields such as architecture, urban planning, communication science, film industry, etc. All fields have in common that they create analogue or digital, static or dynamic visual representations for purposes such as analysis, monitoring, communication, planning, or decision making.

What are evidences that support the importance and originality of this 10th research goal? Generally speaking, almost all research workshops relate to this overall research goal. Five of the nine workshops directly deal with the analysis, design, or communication of a built environment (namely the workshops 'Architectural Image and the Computer', 'Geovisualization', 'Challenges in architectural and geospatial visualization', 'Workplace 2010', 'Large-scale city modelling'). Strategic Road Maps from the workshop 'Strategy Visualization' can be seen as a method that can be used for the planning of future cities or infrastructures. The link between the workshop 'Information Visualization Software Infrastructures' and 'Visualizing Future Cities' is not as obvious but existing. Currently an important application area of Information Visualization is the field entitled Visual Analytics which investigates the use of complementary visualization techniques in the context of homeland security, thus guaranteeing safety for cities or a country. The two workshops 'Information Aesthetics' and 'Basic Narratives in Visualization' do not directly address the topic Visualizing Future Cities. However, they strive for general insights that can easily be linked to 'Visualizing Future Cities', especially when it comes to communication tasks and city marketing matters.

More specifically, the workshop Large-Scale City Modeling pointed directly to the challenges of the rapidly growing cities in Asia. According to the workshop leaders' argumentation, cities like Shanghai, Beijing and Chongqing are rapidly growing. According to them, prognoses state that 90% of global population growth will be in cities between now and 2030. Therefore, infrastructures and the environment have to be adapted to the changing demands and new urban development strategies have to be elaborated. They conclude that the big challenge is the development of dynamic city models that are able to adapt to rapidly growing and changing cities all over the world such as Shanghai, Jakarta, Mumbai and Mexico City. They state that in the middle of 2007, for the very first time more people lived in cities than in the countryside, and that until 2015 the number of cities with a population in excess of 10 million people will grow from 300 up to 560 so that 350 million people will live in mega-cities. One main reason that they mention for this above average growth lies in the economic attractiveness of metropolitan regions.

Based on this argumentation it should be easy to show the importance of the field in one case study. The author has chosen Singapore to hypothetically reflect the value of the proposed solutions of each group. He has chosen Singapore because of a recent study trip to Singapore.

Singapore strives for growth: From its current 4.5 million inhabitants to 6 million in the mid-term future. Consequently, Singapore has to design new buildings and infrastructures to enable living, working, and relaxing in a healthy and sustainable city-state. With limited land resources ($699.1\,km^2$) the question is where to build the next buildings and infrastructures and how to design them sustainably. In such a sustainable future city, the neighbourhoods should be healthy and safe, buildings should be zero energy buildings (or low energy buildings) and healthy for their users, clean water and energy need to be guaranteed by smart systems, and amenities for the highest quality of living, working, and relaxing should constantly spring up like mushrooms to guarantee constant global attention. This is important to attract the leading pioneers in science, art, and economy.

Now, how can visualizations support the design and implementation of the sustainable future city of Singapore? To design and implement such a sustainable future city the stakeholders (e.g., individual urban planners, national planning authorities, investors, the general public, local neighbourhoods, the domestic creative industry, the international press) can exploit the benefits of visual representation techniques. The starting point is proven and existing static illustrations and maps of the concept plan and the wooden model of the whole city-state in the gallery of the Urban Redevelopment Authorities. This physical model gives an overview. However, the model does not adequately permit the representation of existing infrastructures (e.g., water systems, transportation systems), and buildings are abstracted. Here the proposed precise reality-based model would complement the static model: for purposes such as analysis, design, management, marketing, surveillance and many more. The next step is the question of how to visualize dynamic structures (e.g., traffic) or related data (e.g., demographic data, safety data, water systems). Here the know-how from the workshops 'GeoVisualization' and 'Challenges in architectural and geospatial Visualization' is needed. If we are able to visualize dynamic systems and also simulate scenarios (e.g. traffic, the behaviour of people in a city, energy use of a building or city, security issues) the next question is how to simulate and visualize future scenarios of living or scenarios for growth. In this context the tools from the workshop 'Information Visualization Software Infrastructures' are needed. We also look forward for results from the workshop 'Large Scale City Modeling', because they not only create reality-based models, but tools that allow one to simulate and visualize scenarios describing what future districts could look like. Such tools need a set of defined rules (e.g. construction details for novel high-density housing, or principles of new working paradigms) and use the computer to semi-automatically produce visual examples of buildings, cities, or neighbourhoods. The quality of the simulations correlates with the quality of the rules. Such results could be derived from the workshop 'Workplace 2010'. We all know that such generative design tools are powerful to simulate scenarios based on a set of predefined rules. However, they neither represent reality nor replace the planner and the architect. They can become powerful building blocks for discussing scenarios. That is why we must also pay attention to the risks of using such visual representations. This is exactly what is being investigated in the workshop 'The architectural image and the computer'. Here we can learn from past research on the representation of architecture in general, and more specifically related to the computer generated visualizations. Finally, what is often neglected in the design of the future city is the aspect of communication for the collaborative design and sustainable implementation of a future city. To build a sustainable city, we must first co-create it with different stakeholders. That is why the research goals 'Strategy Visualization' is of importance. Secondly, we have to win the hearts of the inhabitants (foreign investors and tourists). This can only happen through focused, transparent, and emotional communication with easy to understand stories and key visuals. Both have to create strong mental pictures. The drivers for such visualizations are the research from the groups 'Basic narratives in Visualization' and 'Information Aesthetics'. Finally, smart visual approaches to navigate in a city are needed. Here the findings from the workshops 'GeoVisualization', 'Challenges in architectural and geospatial Visualization', and 'Workplace 2010' are needed.

Conclusion

We live in cities. And we need to plan the space we live in. Designing future cities means more than designing buildings. Key questions are the design of supporting structures such as water systems, smart transportation concepts, wireless network systems, ecological systems, etc. For each field visual representations help for various purposes such as analysis, design, planning, management, surveillance, or maintenance. But a future city can only become vibrant if people live in it and bring life to it. Therefore communication is a key topic. Communication in the collaborative design processes with diverse groups of stakeholders, communication to explain the importance of respect for cultural heritage, communication to market new city regions across the globe, and communication to provide orientation within the city and city districts, through signs and interactive panels.

'Visualizing future cities' can therefore be seen as one generic field of research, grounded in the fact that many cities are currently being planned, constructed or redeveloped, be it in Asia, UAE or other emerging markets.

Of course, the presented synthetical 10th research goal reduces the various aspects of the proposed nine individual goals and applies them to the design of future cities, which can become misleading. Therefore, each research goal and workshop needs to be studied carefully and without reference to the proposed 10th goal to get a full understanding of the whole depth of the individual research goal. Nevertheless, the 'umbrella' goal 'Visualizing Future Cities' is necessary. First, because it incorporates the nine goals. Second, because, the design of future cities remains a key challenge and the research from the nine workshops helps a lot to create sustainable future cities. Third, because it helps as a new term to launch new research programmes. Such programme are economically justified if we consider that 30% of the life income of the average Dutch person is spent on housing; 24% of CO_2 emissions come from buildings (excluding indirect influences on e.g. transportation); and 25% of the GDP of most developed countries is spent on the built environment.

It is important to understand that 'Visualizing Future Cities' means more than GIS, CAAD, reality-based modelling and simulation. Just as important are visions and social or economical scenarios for future cities, new approaches for the implementation of future cities (e.g. Strategy visualization for future cities), and innovative communication strategies (e.g., Basic narratives for visualizing future cities), for example to market mega cities or to win heterogenous stakeholders in cooperative city planning processes. Thus, it is a truly transdisciplinary challenge, where many different skills are needed: Computer Science, Environmental Studies, Sociology, Design, Communication, Urban Planning, Strategic Management, Architecture, and Aesthetics, plus feedback from the general public.

That is why 'Visualizing Future Cities' should become a key area of research and should receive serious research funding for transdisciplinary work, both in basic and applied research.

Summary

This article proposed nine research goals that can be achieved by 2010. First, it introduced the conference setting. Second, the goals and findings from the nine workshops were described. Third, a survey among 62 participants about the originality and importance is presented and complemented with a personal response from a domain expert and a discussion. Finally, a 10th research goal is presented that is a synthesis of the whole event. It proposes ‘Visualizing Future Cities’ as a key area of research.

The article is relevant for visualization researchers, trend scouts, and research programme.

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