10461 Abstracts Collection
Schematization in Cartography, Visualization, and Computational Geometry
— Dagstuhl Seminar —

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Abstract. The Dagstuhl Seminar 10461 "Schematization in Cartography, Visualization, and Computational Geometry" was held November 14–19, 2010 in Schloss Dagstuhl – Leibniz Center for Informatics.

The seminar brought together experts from the areas graph drawing, information visualization, geographic information science, computational geometry, very-large-scale integrated circuit (VLSI) layout, and underground mining. The aim was to discuss problems that arise when computing the layout of complex networks under angular restrictions (that govern the way in which the network edges are drawn).

This collection consists of abstracts of three different types of contributions that reflect the different stages of the seminar; (a) survey talks about the role of schematization in the various communities represented at the seminar, (b) talks in the open problem and open mic sessions, and (c) introductory talks.

Keywords. Information visualization, geo-visualization, geographic information systems, cartography, graph drawing, VLSI layout, underground mining, cartographic generalization, schematization, building simplification, orthogonal graph drawing, octilinear layout, schematic maps, Steiner trees, minimum Manhattan networks, boundary labeling.

1   Summary of the Seminar

Motivation. In this seminar, we were interested in computing the layout of complex networks under *angular* restrictions. We refer to this problem as *angular schematization* and subsume under it also the combined effort of network construction and layout. It is striking that edge directions are being restricted in networks of very different nature and that these networks are constructed in very different communities: graph drawing, information visualization, geographic information science, computational geometry, very-large-scale-integrated circuit (VLSI) layout, and underground mining. In some of these communities (such as graph drawing or VLSI layout), rectilinear connections have a long history, but recently octilinear connections have moved into the spotlight, bringing with them completely new problems and challenges. In other fields of application such as underground mining, it is not the number of slopes that is restricted, but there is an upper bound on the maximum slope.

We believed that it was high time for these communities to meet and to exchange problems and ideas. For example, the drawing of subway maps has been discussed independently in graph drawing, information visualization, and GIS. Manhattan networks are constructed by operations researchers and computational geometers. Octilinear connections are used when drawing subway maps, but also in the new X-architecture in VLSI layout.

We wanted to bring together researchers from different communities that all have to do with (angular) schematization but have little overlap otherwise. These communities have different backgrounds, literature, and histories. Therefore, we needed a forum where we could spend time learning from each other, transferring knowledge and developing common or at least translatable language. This was a difficult process and took time, but Dagstuhl provided an excellent environment for this kind of activity.

Seminar schedule. In order to ignite this process, we started the seminar with a morning of very short (3-minute 2-slide) introductory talks of all participants. These were followed, in the afternoon and the next morning, by a number of survey talks about the role of schematization in different communities: Max Roberts, a cognitive psychologist, talked about "Underground Maps: Design Challenges and Challenging Designs", William Mackaness investigated "Context, Meaning and Schematisation", Jack van Wijk gave a short overview over "Information Visualization and Visual Analytics", Martin Nöllenburg introduced us to "Schematization in Graph Drawing", Heiko Schilling gave us an idea about the potential use of schematization in car navigation, Matthias Müller-Hannemann talked about schematization in the areas VLSI design and underground mining, and Stefan Felsner gave a crash course on "Schnyder Woods and Applications".

Next, we had an open-problem session where some participants introduced their favorite schematization-related problems. We made a list of these problems:

1. Lombardi Metro Maps
2. Dynamic Layout – Remove / Add Edges

3. Geographic Hypergraphs
4. Hexagonal / Octagonal Cartograms
5. Skeletons for Bundled Graph Layout
6. Steiner Trees in Optimal Network Design
7. Which Way is Up?
8. Layout of Alternative Routes
9. Combining Boundary Labeling and Graph Drawing with High Vertex Resolution

Then we asked each participant to select a problem he or she wanted to work on. Various working groups formed and walked off into different corners of the castle. The group structure changed somewhat over the remaining days of the seminar, but many participants simply stuck to their group.

In order to keep discussions lively, we set up an 'open mic' session each morning where participants could present their own software or point to interesting projects, not necessarily related to schematization. Presenters had to sign up for 10-minute slots beforehand; the slots filled quickly.

On Friday morning, we had a progress-report session where all groups reported back to the plenum. The results varied from group to group. Some groups had already very concrete ideas about publications, whereas others had just arrived at the point were they thought they were beginning to ask the right questions. We asked each group to nominate a group member responsible for stimulating the discussion after the end of the seminar.

Conclusion. One of the key workshop objectives was to "develop a common language" across communities. This is difficult to achieve, and even the identification of "open problems" and the use of a problem-led approach drew attention to the different approaches and expectations of groups from the participating disciplines.

The beauty of Dagstuhl is that it provided a means of enabling colleagues from different disciplines and with different backgrounds and expectations to communicate and share perspectives: whether in an "open problem" description, an "open mic" demonstration of work in progress, or during a game of table tennis!

Lots of knowledge about how the different groups operate was shared. . . along with many suggestions of work relating to some of the approaches and open problems. The Dagstuhl library proved to be an excellent source of information to support this activity.

In summary, we did manage to get people from different communities to contribute to the groups in which open problems were discussed. . . certainly in some cases. Those with backgrounds in disciplines that do not have a tradition of working in this way tended to move between groups – meaning that groups were able to both focus on the problem in hand and benefit from a range of perspectives, whilst these individuals were able to sample the scope of problems being addressed and apply their knowledge in diverse contexts.

There was some "retreat" in a few cases, where participants with shared background focused on known and specific problems. But even here some sharing of

knowledge, approaches and understanding took place, particularly through the intermittent participation of "floating" group members, the stimulating "open mic" sessions, informal discussion during the very useful breaks and the plenary reporting. And some of this intra-disciplinary effort may be beneficial to the wider community – involving, for example, members of a single discipline identifying the need to describe and communicate established knowledge within their domain more widely.

Undeniably, those who participated in the meeting acquired valuable knowledge, new perspectives and insights into the ways in which domains relating to their own discipline operate. New and lasting contacts were forged as ideas were shared and understanding of the similarities and differences between subject areas and their associated approaches were established.

Proceedings. This abstract collection reflects the structure we chose for the seminar; we just changed the order. We start with the survey talks (Section 2), move on to the contributions to the open mic and open problem sessions (Section 3), and finish with abstracts of the Monday morning introductory talks (Section 4).

Exhibition. The seminar was accompanied and inspired by Max Roberts' exhibition "Underground Maps Unravelled" which was opened by Prof. Dr. Reinhard Wilhelm, the scientific director of Schloss Dagstuhl, during the seminar week, on Tuesday night. The exhibition showed underground maps from all over the world; historic maps, official maps and Max Roberts' own creations. The exhibition was a perfect match with the topic of the seminar. Thanks, Max!

The organizers

Postscriptum: Four of Max' underground maps will stay in Dagstuhl; three were donated by participants of this seminar, one by the participants of seminar 10482.

2   Survey Talks

Context, Meaning and Schematisation

William Mackaness (University of Edinburgh, GB)

There is a close coupling between art, schematisation, abstraction and generalisation. Art in design is reflected in ideas of the aesthetic; that the familiar is more readily cognitively digested. That the power of maps lie in their capacity to abstract – to selectively represent entities of the real world together with a subset of their attributes. Generalisation is the methodological pathway by which we achieve that abstraction. A schematic map is a form of abstraction [RF10] – in which the sacrosanct variables x and y are annealed in the interests of visual clarity such that they no longer precisely represent geographical location. The other quality of schematic maps is their emphasis in conveying connectivity between things, whether it be a street network, or global airline destinations. All forms of abstraction (of which schematics are just one) can usefully be viewed as models – with assumptions, seeking to emphasise and convey a subset of all possible relationships. The automatic generation of schematics must take into account the complexity of the data, the nature of the phenomenon being visualised, the expectations of the user, and their prior exposures to using maps. Only then can we convey meaning [Kri89]. Most importantly, in annealing x and y, the geography cannot afford to become so distorted from the ground truth, that it befuddles the user. This presentation explores how such cartographic considerations have always governed design, and argues that the parameterisation of automated schematisation algorithms must take account of both the task (ambition of the user), and the context of use.

Schematic maps in the context of geography are very different from schematic maps in the context of circuit board design, or architectural layouts. This is because geography is inherently hierarchical in nature – its associations, patterns and functions are mereologically nested in the landscape [MST99, BS03]. The challenge in automated schematisation is in providing sufficient underlying geography to support the creation of schematic maps that find the right balance between simplicity and truth.

References

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Underground Maps: Design Challenges and Challenging Designs

Maxwell J. Roberts (University of Essex, GB)

As urban rail networks around the world grow and develop, so the challenge to create attractive usable maps increases. Generally, designers begin with rules first used for the Berlin S-Bahn in 1931, and by Henry Beck for the London Underground in 1933, also known as octolinearity (horizontal and vertical lines and 45 degree diagonals). From the perspective of cognitive psychology, what are the requirements for a well-designed map versus a poorly designed one? Why might octolinearity assist usability? Is this really the optimum means of achieving the best possible design? Can objectives be better achieved if this constraint is relaxed? It is concluded that different networks have different underlying properties, and that these suit different rules.

Keywords: Cognitive psychology, schematic maps, transport networks

Overview Information Visualization

Jack Van Wijk (TU Eindhoven, NL)

In this talk a short overview of information visualization and visual analytics is given. InfoVis concerns the visual analysis of abstract data using interactive computer graphics. The visualization pipeline is presented: From raw data via selection and filtering to processed data, which are mapped into geometric objects, color and texture, which are finally displayed as still images or animations. The user can interact with all stages, and adapt the selection, presentation and view on the data.

Typical examples of abstract data are hierarchical data, networks, and tables. All these are studied separately (tree visualization, graph visualization, multivariate visualization), but in practice often a combination has to be used. One key problem in InfoVis is scalability: Typically there is too much data to show at once. Solutions are interactive selection; clustering; the use of dense visualization (where all pixels are used); the use o large diplays; and interactive viewing. Shneiderman's mantra (overview first, zoom and filter, details on demand) is a very useful guideline for interaction. Other relevant terms here are semantic zooming, focus and context.

Visual analytics is a more recent and more ambitious develoment. Key concepts here are the integration of other data analysis methodologies, such as statistics and machine learning; handling of heterogenous data, ranging from tables via documents to multimedia data; and support for the complete knowledge discovery process, from collection of data to presentation. Visual analytics

started in the US, driven by the late Jim Thomas, recently VisMaster, a European Union supported consortium, has presented a roadmap for visual analytics research in Europe.

Keywords: Overview, infovis, visual analytics

Schematization in Graph Drawing

Martin Nöllenburg (KIT - Karlsruhe Institute of Technology, DE)

In this survey talk we give a quick overview of important concepts in graph drawing, in particular, a generic formulation of the graph layout problem in terms of drawing conventions, aesthetics, and local constraints. After a brief introduction to the current state of graph drawing as a research field and its history, schematization in graph drawing is (narrowly) defined as the question of how to draw graphs with angular restrictions on the edge slopes.

The best studied subarea is that of orthogonal graph drawing, where only horizontal and vertical edge segments are allowed. Orthogonal layouts are used in many applications and popular drawing styles in graph drawing software. We report several results in orthogonal graph drawing that deal with the question of minimizing the number of bends for polyline drawings both globally and per edge [Tam87, GT01, BK98]. Orthogonal layout has also been used to redraw graph sketches [BEKW03] or for drawing certain graphs on a given set of points using Manhattan-geodesic edges [KKRW10].

A generalization of orthogonal layouts are octilinear layouts, in which the two main diagonals are added as possible slopes. This style is most prominently used for drawing metro maps [HMdN06, SRMOW10, NW10] or schematic road maps [CdBvK05].

Finally, $\mathcal{C}$-oriented layouts generalize the previous styles even further by defining a fixed set $\mathcal{C}$ of admissible edge slopes. We present results on $\mathcal{C}$-oriented path simplification [Ney99, MG07] and drawing $\mathcal{C}$-oriented route sketches [DGNP10, BP09, GNPR11].

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Schematization: Steiner Trees, VLSI Design, and Mining

Matthias Müller-Hannemann (Martin-Luther-Universität Halle-Wittenberg, DE)

The purpose of this talk is to survey fundamental results about Steiner trees and to relate it to angular schematization. While schematization typically deals with a given network structure and tries to find a well-comprehensible, clear and aesthetically pleasant drawing or embedding of it, the situation in most applications

of geometric network design is different. Here, the main task is to construct the network such that it is functional. Roughly speaking, this means to optimize one or several criteria subject to technical side constraints.

We give a brief overview about applications in VLSI design (rectilinear and octilinear Steiner trees, group Steiner trees, Steiner tree packing, Steiner trees in the presence of obstacles) and in the mining industry where the slope of edges is restricted by some maximum gradient.

Keywords: Geometric network design, Steiner trees, fixed orientation metrics

Crash Course: Schnyder Woods and Applications

Stefan Felsner (TU Berlin, DE)

Schnyder woods are a combinatorial structure on planar triangulations defined by Walter Schnyder in the late 1980s. Schnyder used them for his characterization of planar graphs in terms of order dimension [Sch89] and for compact straight line drawings of planar graphs [Sch90].

In recent years, Schnyder woods have found numerous applications in graphs drawing [BR06, BFM07] but also in areas where it would be less expected, e.g., counting of planar structures [PS06], resolution of monomial ideals [Mil02], and greedy routing [Dha08]. Generalizations of Schnyder woods and related structures have also been investigated. Most prominaent examples are Schnyder woods for 3-connected planar graphs [Fel01] and separating decompositions of quadrangulations [dO01, FHKO]. They found a similarly broad range of applications.

In this survey talk, we give a quick overview of structural concepts related to Schnyder woods, e.g., tree decomposition. regions of a vertex, angle labelings. We show how these properties can be used in graph drawing applications. Then we focus on orthogonal surfaces and their connection with Schnyder woods [FK08, FZ08]. This connection is directly linked to problems concerning the representation of planar graphs as contact graphs of homothetic triangles. We describe an experimental algorithms to generate this kind of contact representation and close with some open problems.

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[Sch89]   Walter Schnyder. Planar graphs and poset dimension. *Order*, 5:323–343, 1989.

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3   Open Problem and Open Mic Sessions

On two days of the seminar, participants were invited to present dynamic demonstrations at the start of the day to stimulate creative thinking in advance of groupwork. Contributions were open to all participants by simply chalking a title on the blackboard in the lecture room in advance of the Open Mic sessions. Demos were presented in 10-minute slots with the audience invited to ask questions and discuss the presentations during the second half of each demonstration. This provided an excellent opportunity to present, discuss and explore ideas before morning coffee.

Area-Preserving Subdivision Schematization

Wouter Meulemans (TU Eindhoven, NL)

I have briefly explained our ongoing research on subdivision schematization using the four main orientations and shown some schematizations using the explained iterative approach in an interactive demonstration.

London Schematics by QuickMap

Jason Dykes (City University – London, GB)

QuickMap (http://www.quickmap.com) is a small cartographic design company producing innovative paper and digital cartography with a transportation theme from their headquarters in Luton, North London. Their key product is the "All in One" schematic London Transport Map in which the economic centres and transport hubs within the M25 are stretched in a non-linear "rubber sheet" projection and connected with bus, tube, tram and rail routes. The design aims to "overcome the deficiencies of traditional cartography" and consists of two maps showing the centres and connections during daytime and night-time. For a clipping of the latter; see Figure 1.

Fig. 1. Clipping of Quickmap's "All in One" schematic London Transport Map

http://www.quickmap.com/pdfs/complete-london-daytime.pdf

Folded paper versions of the maps were made available for comment and critiquing. These seemed to be popular with the audience! QuickMap also produce

digital animated maps to provide user and task-centred views of local transportation networks. Interestingly, many of these show no network initially, drawing attention to economic centres and enabling those wanting to explore connectivity and route possibilities to select towns that interest them and reveal destinations. Their work in Rotherham is an example:

http://www.quickmap.com/r/commuter/commuter2.htm.

"MapMovies" draw attention to the connectivity of schools and shopping centres. Work with the Highcross Centre in Leicester and Leicester City Council provides an example:

http://www.quickmap.com/bl/highcross1.htm

QuickMap also provide specialist pocket maps of London focusing on the underground network and walking.

Automatised construction of chorematic diagrams

Andreas Reimer (GFZ Potsdam, DE)

Chorematic maps, as introduced by French cartographer R. Brunet in the 1980ies, are a class of diagrams that allow to depict complex situations in a highly synthesized and generalized manner. In essence they are a tool for the structural and iconic representation of complex geospatial situations. They consist of terms and graphics that largely prescind from actual objects and precise cartographic symbols and have enjoyed several documented successes as effective communication tool. Until now, chorematic diagrams have been created manually. Automatizing their construction is the goal of this research. For this, two major research questions need to be answered: How can chorematic diagrams be described formally? Which process steps are needed to derive chorematic diagrams from geodata? Several process steps are interpreted as schematisation similiar to cartographic generalisation tasks. Design rules are being extracted from published evidence qualitatively as well as quantitatively and modelled by rules and generalisation constraints.

Keywords: Generalisation, chorematic diagrams, schematised maps

Using the Metro Map Metaphor for Visualizing Flight Routes

Christophe Hurter (ENAC – Toulouse, FR)

Aircraft must follow strict Air Traffic Control (ATC) rules. One of these rules is that aircraft have to fly over pre-defined Flight Routes (FR). Current ATC visualizations do not display FRs because they are numerous and run into each other, and thus spoil the visualization. Therefore we developed a schematic visualization of flights routes for air traffic controllers. To do so, we transposed mathematical constraints used to produce metro maps into the specific field of ATC. Second, we propose to investigate the generation and placement of colors to be assigned to lines of the network, so that colors must be perceptually as distinct as possible, and available in the vocabulary of colors.

References

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Five Minutes on Rectangular and Rectilinear Cartograms

Bettina Speckmann (TU Eindhoven, NL)

A rectangular (rectilinear) cartogram is a thematic map where every region is depicted as a rectangle (rectilinear polygon). The area of the regions corresponds to a geographic variable, such as population or GDP. I very, very briefly introduce the way in which we create such cartograms. Namely, we explore the lattice of regular edges labelings of the dual graph of the input map and find good solutions with respect to correct areas, correct adjacencies, and suitable relative positions by simulated annealing. The final cartograms are produced by an iterative linear programming approach.

Dynamic Schematic Maps: vizLib / vizTweets

Jason Dykes (City University – London, GB)

The giCentre is involved in a series of projects in which novel abstract dynamic map designs have been developed and deployed.

vizLib. This ESRC project funded a fellowship through which a local authority researcher developed skills in visualization by focusing on the exploration of a database held by the local authority. Abstract views of Leicestershire were developed to address research questions posed by the local authority regarding library usage. These included spider maps, RF plots and spatial treemaps. Figure 2 shows a spatial treemap of RF plots.

Animated transitions between alternative spatial and aspatial views of the data set draw attention to their similarities and differences, and the relatively arbitrary nature of many schematic representations. More information online – including papers, videos and demos:

http://gicentre.org/vizLib/

vizTweets. This JISC funded rapid development project produced HiVE: a high level language for describing hierarchical graphics such as treemaps. We have implemented several applications that produce and interpret the language, and
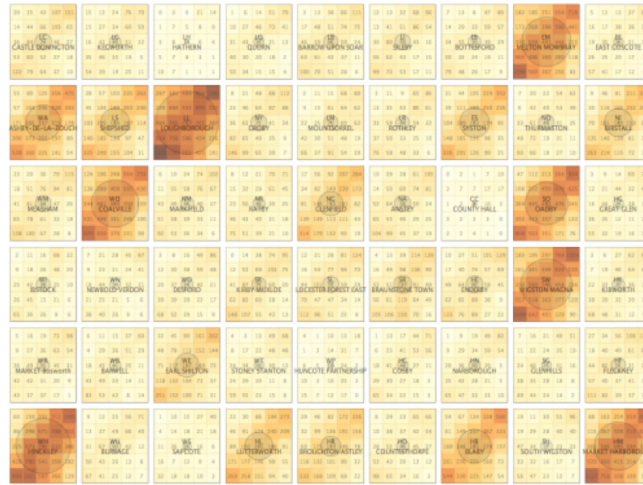
Fig. 2. A spatial treemap of RF plots.

are using the Twitter API to store HiVE statements direct form our applications. These statements can be subsequently retrieved to return interactive exploratory visualization software to the graphical state that they describe. When our HiDE software stores HiVE statements it generates an image showing the current graphic and a QR code encoding the HiVE statement. HiDE can use a local camera to interpret the QR codes and use these to return to the graphical state described by the encoded QR. This means that our software can update its state from QR codes printed on paper – such as posters or printed journal publications. Figure 3 shows a spatial treemap with a HiVE description of the graphic.
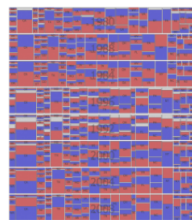
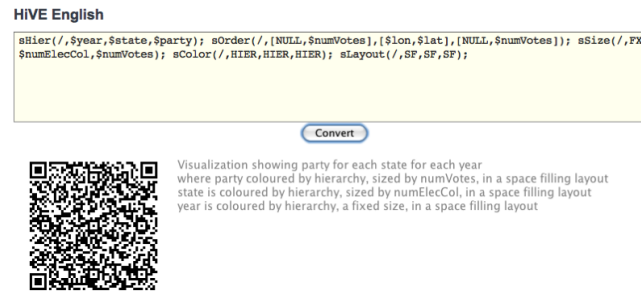**Fig. 3.** A spatial treemap with a HiVE description of the graphic.

Our "HiVE English" application interprets the HiVE statement and produces a caption and QR code; see Figure 4.

More information online – including software, code and demos see:

http://gicentre.org/vizTweets/

HiVE English

```
sHier(/,$year,$state,$party); sOrder(/,[NULL,$numVotes],[$lon,$lat],[NULL,$numVotes]); sSize(/,FX,
$numElecCol,$numVotes); sColor(/,HIER,HIER,HIER); sLayout(/,SF,SF,SF);
```

(Convert)

Visualization showing party for each state for each year
where party coloured by hierarchy, sized by numVotes, in a space filling layout
state is coloured by hierarchy, sized by numElecCol, in a space filling layout
year is coloured by hierarchy, a fixed size, in a space filling layout

Fig. 4. Caption and QR code generated by our "HiVE English" application.

How to Make a Picturesque Maze

Yoshio Okamoto (JAIST, JP)

In the picturesque maze generation problem, we are given a rectangular black-and-white raster image and want to randomly generate a maze in which the solution path fills up the black pixels.

While a simple formulation of the problem faces with NP-hardness, the proposed method generates such a maze in polynomial time by appropriately changing the formulation itself.

Therefore, the algorithm itself is quite simple.

Updates are available at http://www.jaist.ac.jp/~okamotoy/misc/2009/picturesquemaze_update.html.

Joint work of: Okamoto, Yoshio; Ryuhei Uehara

Full Paper:
http://cccg.ca/proceedings/2009/cccg09_36.pdf

4   Introductory Talks

We spent the first morning of the seminar giving very short 3-minute / 2-slide talks to introduce ourselves. A timer announcing the speakers in order proved invaluable for this session format. The introductory talks were also a good first opportunity to advertise interesting open problems to work on in the remainder of the seminar. The speakers are listed in alphabetic order. Not all speakers chose to submit an abstract.

Silvania Avelar (EMPA-Akademie – Zürich, CH)

I have given a short presentation about my main past research on the computational and cartographic challenges of schematic transport maps. The main references are as follows.

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Therese Biedl (University of Waterloo, CA)

The purpose of this talk is to mention some recent results regarding cartograms and pose some open problems. A cartogram is a deformation of a map such that countries have a pre-specified area. This is rarely possibly without giving up either adjacencies among countries, or using complicated shapes for faces. Recent results focused on creating orthogonal cartograms that have few corners per face and respect adjacencies and face areas. What, if anything, is known about hexagonal or octagonal cartograms?

Marcus Brazil (The University of Melbourne, AU)

My main area of research has been in the optimisation of physical interconnection networks, particularly Steiner Trees. In particular, I have focused on developing exact algorithms for Steiner trees under a range of metrics, including: Euclidean; Fixed Orientation metrics (eg, rectilinear); and Gradient-Constrained metrics in higher dimensions.

This work has applications in a range of areas including: VLSI physical design; underground mine access design; and relay deployment in Wireless Sensor Networks.

Open problems and future work in this area include: applications of Steiner networks to network schematisation; exact algorithms for the Beam Detector Problem; and the construction and properties of higher connectivity Steiner networks (eg, 2-connected or 3-connected Steiner networks).

Keywords: Network optimization, Steiner trees, computational geometry

Victor Chepoi (Université de la Méditerrannée – Marseille, FR)

My research interests include structure and algorithmics of metric spaces, metric graph theory, computational geometry, approximation algorithms. My recent research includes the following results:

1. A factor-2.5 approximation algorithm for minimum Manhattan network problem in the normed plane (and some other related work);
2. Constant factor approximation algorithms for multiplicative and additive distortions of embedding graph metrics into simpler metrics (trees, outerplanar metrics, Robinsonian metrics);
3. Simple and efficient algorithms for center, diameter, radius problems in Gromov hyperbolic spaces; shortest path problem in some polygonal complexes.

Walter Didimo (University of Perugia, IT)

One frequent problem in graph schematization is comparing two graphs G_1 and G_2, defined on different vertex sets and such that vertices of G_1 have relationships with vertices of G_2. Such relationships are called matching connections. The goal is to automatically compute drawings of G_1 and G_2 such that each drawing is aesthetically pleasing and the matching connections are clearly conveyed (for example, one can try to avoid or to minimize crossings between them).

In the past, we worked on the case where the vertices of G_1 are locations of a geographic map (and therefore they have fixed or almost fixed positions) and are associated with disjoint subsets of vertices of G_2. For this kind of one-to-many matched graphs we described effective visualization paradigms and polynomial drawing algorithms, which avoid crossings between matching connections.

The case of many-to-many matched graphs, where vertices of G_1 are associated with intersecting subsets of vertices of G_2, appears to be a much more

difficult problem. In this case, both visualization paradigms and drawing algorithms are required. Hence, the study of this problem represent in our opinion an interesting direction for future research.

Jason Dykes (City University – London, GB)

I showed a Tube map of my career and some schematization needs.

Keywords: Geography, Cartography, Cartographic Visualization, GeoVisualization, GISystems, GIScience, Information Visualization

Peter Eades (The University of Sydney, AU)

I gave a talk about the "Metro Map problem" at the VIP conference in Sydney in 1999 (see http://www.it.usyd.edu.au/~peter/downloads). The main issue raised in the talk was the problem of finding a layout algorithm from the Real-World to the ScreenWorld that preserves three properties of the RealWorld ("Orthogonal ordering", "Topology", and "Proximity"), and draws nominated paths as horizontally/vertically as possible. There are many excellent examples of hand-drawn metro maps, and the problem of automatically producing a layout that matches the quality of hand-drawn maps is a grand challenge for network visualization.

Later, people in his group began a study of metro maps. SeokHee Hong and Damien Merrick investigated force-directed algorithms for the grand challenge mentioned above. Hugo do Nascimento studied the problem of labeling a metro map. Keith Nesbitt blended art and Information Visulization with pictures of the concepts in his PhD thesis, using a metro map metaphor.

Since then, Nöllenburg, Rogers, and others have made much progress in automatic methods for metro-map layout; however, the grand challenge remains.

Stefan Felsner (TU Berlin, DE)

My research background is in graph theory, order theory and discrete geometry. I like to investigate combinatorial structures and look for applications in graph drawing or in algorithms. Schematization seems to become a new bridge between theory and applications.

Martin Fink (Universität Würzburg, DE)

My research interests include graph algorithms and especially graph drawing. My diploma thesis was on centrality measures in graphs where I focused on the Group Betweenness Centrality which measures the centrality of a set of nodes. My current problem is the drawing of so-called calculus graphs which help to analyze the problems in solving mathematical exercises which a class of school students might have.

Keywords: Betweenness centrality, calculus graphs

David Forrest (University of Glasgow, GB)

My main research interests focus around cartographic design and map use. My PhD was about knowledge based systems to help non cartographers produce sensible maps with minimal input. I am interested in the usability of maps and geospatial information by the general public, which includes tourist and public transport maps. I recently supervised a PhD on "Stop Specific Bus Maps", a novel way of focusing on essential information for bus travellers.

My open problem for the seminar is about the user understanding of location in schematic maps. Part of this relates to orientation of schematics (Which way is up?), but also the provision of landmarks and other key information to help the user relate the schematic map to the real world.

Emden R. Gansner (AT&T Research – Florham Park, US)

Visualization of graphs can provide an effective tool for the exploratory analysis of relational data, with visual perception identifying patterns that would be lost in raw or analytically processed data. As graphs increase in size, however, patterns can be lost in the sheer amount of ink or pixels used. Schematization techniques, such as angle restrictions, edge bundling, and representing graphs as maps, have the potential to aid the eye, by simplifying such drawings and helping to expose flow trends and cluster relations.

Matthias Müller-Hannemann (Martin-Luther Universität Halle-Wittenberg, DE)

My main fields of research are algorithm engineering, graph algorithms, combinatorial optimization, computational geometry, and network analysis. In my talk, I briefly highlighted two applications in schematization. First, my previous work on octilinear Steiner trees in the plane under obstacle restrictions. Second, current research on usability issues and schematic visualization of tree structures representing passenger delays in public transportation.

Jan-Henrik Haunert (Universität Würzburg, DE)

Both map schematization and map generalization aim at more abstract maps, and therefore they are related problems. The difference, however, is that map schematization allows for more freedom in how to represent geographic space, that is, the position of a map object is not determined with a map projection. Instead, network structures and relationships among objects define the map layout.

In my introductory talk on Monday, I'm presenting an optimization-based approach to map generalization that applies mathematical programming. I'm

showing results of this approach obtained for area aggregation [HW10a] and building simplification [HW10b].

In the open-mic-session on Thursday, I'm discussing how to apply this approach to map schematization, in particular, to the problem of optimally generating a variable-scale map layout. I'm presenting a prototype software that deforms a given network map by applying constraints that ensure an area of interest to be enlarged. The effect on the map is similar to that of a fish-eye lense. An open problem is how to integrate the automatic selection of relevant road sections into this approach.

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Keywords: Map generalization, map schematization, mathematical programming, fish-eye projection

Herman J. Haverkort (TU Eindhoven, NL)

I am a computational geometer, specialised in space-filling curves and their applications, computations on digital elevation models, and external-memory algorithms. I have worked on connecting labels to points in figures by schematized leaders ("boundary labelling") and on geometric network optimization problems, where schematized drawings of network topologies are required.

I propose to work on one or more of the following problems:

– drawing optimal metro maps while including a "theoretical planning error" measure in the cost function: this measure expresses how much a map user's travel time might increase if (s)he always takes the visually shortest route according to the map, instead of the actual fastest route;
– drawing metro maps using differentiable curves for metro lines (possibly composed of circular arcs) while maximizing angular spacing between curves (metro lines) passing through the same vertex (station) and minimizing curve complexity and curvature;
– optimal boundary labelling with circular arcs for leaders.

Seok-Hee Hong (The University of Sydney, AU)

My research interests include Graph Drawing, Information Visualisation and Visual Analytics. In particular, I have been working on research problems, addressing both the theory and practice of graph drawing, i.e. designing efficient algorithms for automatic visualisation of graphs in two and three dimensions.

My recent research projects have mainly focussed on application of Graph Drawing algorithms for good visualisations of large and complex networks such as social networks (collaboration networks and citation networks), biological networks (biochemical pathways and PPI networks) and transportation networks (metro maps).

Some of my recent research is closely related to schematisation. I have written the first paper on "Automatic Visualisation of Metro Maps", presenting a set of criteria and method for achieving those criteria. Recently, I have been working on "edge bundling" and "info map" projects to use schematisation for visualisation of large and complex data sets.

Michael Kaufmann (Universität Tübingen, DE)

In the first part, a review has been given about previous work related to schematization in VLSI routing and Steiner trees. Also, more recent work on Metro Maps routing and Manhattan network has been mentioned. More emphasize has been provided to a certain variant of labeling called boundary labeling. In boundary labeling, which is commonly used e.g. for medical maps the labels are placed on the sides of the map. The labels are connected by schematized lines called leaders to their corresponding sites. The problem of many-to-one boundary labeling has been introduced, and a very simple variant has been proposed as a possible topic for further research. Here complexity issues, efficient algorithms and even the choice for suitable optimization criteria are wide open.

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Stephen Kobourov (University of Arizona – Tucson, US)

Graphs are often used to represent relations between objects with vertices as the objects and edges as the relationships. While pretty graph drawings can be obtained for simple kinds of graphs (e.g., trees) or small graphs (e.g., the social network of the kids in a karate club) graph drawings of complicated and large graph are usually not a pretty. With the help of the geographic map metaphor we might be able to produce more aesthetically appealing graph-based visualizations which can capture more than just the relationships between pairs of objects but relationships between groups of objects.

Marcus Krug (KIT – Karlsruhe Institute of Technology, DE)

I am interested in problems related to graph drawing, computational geometry, network optimization and graph generators. In the area of graph drawing I have been working on compact planar straight-line grid drawings, network visualization and orthogonal graph drawing. I propose working on the problem of computing a schematic sketch of a given drawing of a large graph in order to reduce the visual complexity while simultaneously maintaining the main features of the original drawing.

Giuseppe Liotta (University of Perugia, IT)

Problem: For a given map, the boundary labeling problem asks for an effective placement of labels around the map that are connected to the elements in the map by curves called leaders. We consider leaders that are horizontal segments; also, we assume that the set of labels are vertices of a graph (this may happen if, for example, the labels are the nodes of a social network).

We therefore have the following problem. For a given angle α ($0 < \alpha < 90$ degrees) characterize UL-aAC graphs, i.e., those graphs for which a mapping between the vertices and a set of horizontal lines is given and a straight-line drawing exists such that:

(i) the line-vertex mapping is respected;
(ii) any crossing has an angle of at least α degrees (special case: $\alpha = 90$ degrees, UL-RAC graphs).

For some preliminary results, see
http://www.dagstuhl.de/Materials/Files/10/10461/10461.LiottaGiuseppe1.Slides.pdf.

Keywords: Graph drawing, total angle resolution, crossing angle resolution

Anna Lubiw (University of Waterloo, CA)

I work in the areas of computational geometry, graph drawing, and graph algorithms.

Two recent topics I have worked on are:

1. morphing of graph drawings
2. simultaneous graph representations

Open questions in these areas are:

1. Given two straight-line planar drawings of the same graph, is there a polynomially-bounded piece-wise linear morph between them?
2. Is there an efficient algorithm to test if two planar graphs with some shared vertices and edges have planar drawings where shared vertices (edges) are represented by the same points (curves).

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Wouter Meulemans (TU Eindhoven, NL)

In the area of schematization, I have worked on subdivision schematization; the schematization of multiple shapes that may have shared boundaries, such as a set of countries. In particular, I have worked on an iterative approach to produce a rectilinear schematization that preserves the area of each face ("country") [MvRS10]. The way to schematize must be such that the shape is still recognizable. This raises the question how to quantify shapes. Although a lot of measures have been proposed in the past, these are not satisfactory in this setting.

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Yoshio Okamoto (JAIST, JP)

The following are my papers closely related to the subject of this seminar.

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Peter Rodgers (University of Kent, GB)

When discussing the open question *Dynamic Schematic Layout* we addressed issues surrounding what happens when a schematic layout changes. Initially highlighted aspects included:

- How do we compromise between maintaining the mental map and a good layout?
- Is there a sensible way of measuring the amount of change?
- What happens when 'hard' constraints might best broken (e.g., octilinarity, station spacing) for ideal layout?
- Can current drawing techniques be adapted to dynamic layout?
- Can we prepare initial layouts for the possibility of change?

The group took a view that dynamic schematic visualization has a wide interpretation and looked at various methodologies for describing change in visualizations. Its clear that there are multiple orthogonal characterizations: what changes (topological, spatial, attribute, semantic); time of change (permanency, repetition); trigger for change (forced, user, agent); scale of change (localization, temporal); certainty (real-time systems).

Keywords: Dynamic layout, schematic visualization

Ignaz Rutter (KIT – Karlsruhe Institute of Technology, DE)

These slides give an overview of research interests and recent work. In particular, orthogonal graph drawing with flexibility constraints and partially embedded planar graphs. I proposed to work on schematization in a dynamic context, where the network that is to be schematized changes over time. As a starting point it might be useful to focus on incremental networks as this is probably simpler than the problem of schematizing a network that changes arbitrarily.

Falko Schmid (Universität Bremen)

In my talk I presented approaches to generate schematic wayfinding maps for small mobile devices. Mobile devices pose challenges on the visualization of geographic information. Geographic information is highly constraint data. This makes it hard to visually compress the information by at the same time preserving the semantics in an accessible way. Straightforward techniques like zooming force the user to interact intensively with the represented data which hinders the understanding of it. Zooming, panning, and rotating views of spatial information is connected to heavy cognitive costs and introduces encoding and processing based mental distortions.

However, the maps used for wayfinding assistance did not evolve much during the last decades, they still contain information similar to traditional printed city maps. Although current digital maps offer interactive querying, they are still rather general problem solvers with no clear use case. They show the same level of detail for every part of the map of the visible area independent for what they are used (e.g., car drivers can see small trails in parks). This undefined visualization of information is not only dispensable for nearly all use cases, but makes it hard for the user to focus on the relevant parts.

One possible solution to develop accessible maps for small mobile devices is to consider the specifics of a query: Which task has to be supported? Which environment is addressed? Which user has to be considered? By considering the constituents and their specifics involved in a spatial task we can select and represent the really required information from the underlying geographic data set. We are taking the $TEAR$ approach: by considering the task T, the environment E, the agent (user) A, we can generate the specific schematic representation R (the map).

In my work I developed approaches for prior knowledge based maps [SR06, Sch08, Sch09], for multi-granular maps [SRP10, SKW+10], for sub-task specific maps [SKW+10, RPKS08], methods for analyzing, representing and compressing trajectory data for map generation [SR06, SRL09], as well as analyzing human place conceptualization [SK09].

In my future work I want to focus on the interaction with schematic maps and the combination of different schematic maps for seamless wayfinding support. One particular area of interest is the problem of dealing with incomplete and possibly insufficient information: once we have a computational approach to select information, users will need to express the need for different or additional information. This requires intuitive interaction based query methods, but also strategies to communicate that additional information is available but not yet communicated.

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Takeshi Shirabe (KTH − Stockholm, SE)

My research interests include network flows and paths, regionalization, other op-
timization problems in geographic settings, and their application to urban and
regional planning and geographic information systems. Although I am increas-
ingly interested in schematization, this area of study is still new to me. The
only relevant work I have done so far is integer programming formulation of the
minimum Manhattan network problem.

Andreas Spillner (Universität Greifswald, DE)

In my talk I give a brief overview over some of the topics my research currently
focuses on and to what extend they include aspects of schematization.

Many of the problems I currently work on are related to *phylogenetics* (see,
e.g., [SS03].

In particular, I am interested in combinatorial problems arising in this area
and in visualizing the various types of data involved in phylogenetic analysis,
especially so-called *split systems*. The latter are often represented by a certain
type of labeled network (see, e.g., [DH04]). We recently explored ways to produce

visually appealing drawings without crossing edges of such networks. The latter provides some connection to the theme of the workshop.

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He Sun (MPI für Informatik – Saarbrücken, DE)

I gave a brief overview of my research on minimum Manhattan network problem.

Given a set of points in the plane, the minimum Manhattan network (MMN) problem is to find a shortest rectilinear network such that for any pair of points, there is a shortest path between them of length equal to their distance in the L_1-metric. Our results include two aspects: First of all, we gave two approximation algorithms for constructing 2-approximate MMNs using the combinatorial approach. Secondlly, we proved that the decision version of the MMN is strongly NP-complete and there is no FPTAS unless P=NP.

Alexandru C. Telea (University of Groningen, NL)

Edge bundling layouts (EBLs) have received increased attention in the last years. EBLs aim at creating layouts for trees, compound graphs, or general graphs where edges connecting nodes which are close with respect to a graph metric are routed along visually separate trajectories, or bundles [Hol06, HvW09].

However effective in disentangling large graphs, EBLs may create many bundles that intersect at different angles, which makes reading the final image difficult.

We propose to solve the above problem by combining the strengths of bundles and schematization: Given an EBL, we can extract the so-called skeleton of the layout using image processing techniques (splatting, distance transforms, and medial axes) [TE10]. Next, we can use this skeleton to route the edges, thereby creating bundles where overlaps occur at controlled points.

Finally, we can use different distance metrics to compute the skeletons, such as the Manhattan metric, thereby creating EBLs where bundles are constrained to orientations similar to octilinear diagrams [ST04]. All in all, this line of research should be able to create schematized *and* bundled layouts of very large graphs effectively and efficiently, thereby extending the added value of schematization for application areas such as software engineering, network visualization, and visual analytics.

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Marc van Kreveld (Utrecht University, NL)

I have sketched my main results related to schematization in a very short talk.

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Keywords: Computational geometry, cartography

Mark Ware (University of Glamorgan, GB)

I am a Reader in GIS at the University of Glamorgan. My main area of re-
search is automated map generalization. Among others, I have worked on the
development of map schematization algorithms that make use of probabilistic
optimization techniques ([SAWJ08], [WR10], [WTAT06]) – including simulated
annealing and ant colony optimization. Areas earmarked for research in the near
future include: labelling (currently our methods do not consider this explicitly),
problems relating edge symbolization (e.g., multi-tracks) and on-the-fly applica-
tions (e.g., integrated transport travel maps).

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Alexander Wolff (Universität Würzburg, DE)

I'm giving a quick overview of my recent work related to angular schematization.

First, I have attacked the problem of drawing metro maps using a mixed-integer-programming formulation [NW10]. The formulation guarantees some hard constraints (for example, each edge must be horizontal, vertical, or 45-degree diagonal) and optimizes a set of soft constraints (such as the number of bends or the total length of the network).

Second, I have introduced the problem of boundary labeling, where a set of points on a map (that is, a rectangular section of the plane) must be connected to predefined slots on the map's boundary [BKSW07]. The connections are called leaders; typically they are schematized and one aims at finding a layout with few bends or of minimum total length.

Third, I have introduced the problem of drawing (4-planar) graphs such that edges are laid out as *Manhattan paths*, that is, as geodesics with respect to the Manhattan norm [KKRW10]. Even if the given graph is a matching and all vertex positions are specified, it is hard to decide whether the edges can be routed without intersections on the integer grid. Off the grid, the problem can be solved efficiently.

Last but not least, I have contributed to the minimum Manhattan network problem [BWWS06]. This is a network construction problem where one is given a set of points (called *terminals*) in the plane and the aim is to find a minimum-length rectilinear network (that is, a set of horizontal and vertical line segments) that contains a Manhattan path for each pair of terminals. I have given a factor-3 approximation algorithm for this problem; the algorithm runs in $O(n \log n)$ time.

Currently, I'm trying to find a constant-factor approximation for the three-dimensional minimum Manhattan problem. It is known that this problem cannot be approximated arbitrarily well (unless P=NP).

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Keywords: Metro maps, boundary labeling, minimum Manhattan networks, Manhattan-geodesic layout

Jo Wood (City University – London, GB)

Introduction to my background (20 years of working with geographic information and its visualization; moved from multi-scale terrain and surface modelling to more general information visualization of data with a geographic component). Introduced my approach – embedding visualization approaches in task-driven applications including the requirements elicitation, design, implementation with Java and Processing and evaluation.

Demonstrated two examples of an approach to schematization that involve interactive control over the degree to which geographic patterns are preserved in the visualization. The first example used a force directed approach to visualizing city infrastructure (telecoms and power) where the weighting of forces that attract elements could be continuously varied between geographic location and element dependency. The second example showed an approach to visualizing the London Cycle Hire Scheme where docking stations could be shown in their geographic location or gridded schematization with animation between the two layouts. It was asserted in both examples, that allowing interaction and animation may affect the way in which we choose to design our schematization. The work raises the open question "what are the rules and guidelines that should determine the degree to which geographic relations are preserved in our schematizations?"

Keywords: Schematization, GIS, information visualization, cartography, treemaps

Martin Zachariasen (University of Copenhagen, DK)

Schematization problems can often be cast as geometric network optimization problems, where the objective is to minimize some objective function (such as network length) under various constraints (such as dilation and stretch factor). I would like to investigate links between classical geometric network optimization problems - such as spanner network and Steiner tree/network problems - and schematization problems. In particular, problems that require a fixed set of line segment orientations are of interest.

An overview of the state-of-the-art for the fixed orientation Steiner tree problem can be found in [Zac09].

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Qiuju Zhang (University of Twente, NL)

My research focus is on developing geovisual analytics methods to visually explore massive network and movement data, specially focusing on developing visual approaches. Now I am developing a conceptual framework for the research as shown in the slides. Since nowadays the data are complex and the size is huge, the direct display of these data easily leads to overplotting and visual clutter, and the important spatial and temporal patterns could be hidden. Therefore, we suggest as a solution the following approach: By applying good visualization strategies, selecting suitable visual representations for each strategy step, using appropriate cartographic designs and including interactive functions in a geovisual environment. The visualization strategies suggest to proceed the data in steps. A well known strategy is Shneiderman's visual information seeking mantra, and later was extend by Keim et al. to a "Visual Analysis" mantra to deal with data in Five steps. For different steps, suitable visual representations should be designed. For example, the massive network/movement data can be firstly analyzed and translated in to schematic representations to abstract the important information/pattern. The assumption here is that schematic representations are suitable to show the important in an overview step, and geographically realistic representations are suitable in a details step. A flexible transition between them, both up and down, is needed that allows users to smoothly switch between different representations. These visual representations should be carefully designed. We made a classification of cartographic designs from a locational, attributes and temporal perspective to provide a guide to design these visual representations. The locational perspective distinguishes geographically realistic and schematic visualizations, according to whether the visual representations correctly represent the real geography of the base map, such as network infrastructure. From the attribute perspective, visualization visually encodes the attributes by applying basic cartographic principles such as visual variables or overlaying an attribute surface on top of the base map. Temporal perspective summarizes the methods to represent time.

There are two research problems related to this framework. Firstly, In a visual analytics process, schematic representations are suitable to show the important in an overview phase, while geographically realistic representations are needed in a detail phase with flexible transitions between them. Does it make sense? And is it applicable to massive spatio-temporal network/movement data? Secondly, Based on what criteria to schematize network/movement visualizations? data related? user related? Or design related?

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