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17th International Symposium on

Graph Drawing

September 22–25, 2009 - Chicago

Tuesday, September 22nd

18:00 – 20:30	Reception at Park Grill, Millenium Park

Wednesday, September 23rd

All talks in room 8005, DePaul Center, 1 East Jackson Street.

9:00 – 9:10	Opening Remarks
	Session 1 Chair: Christian Duncan
9:10 – 9:35	*Drawing Hamiltonian Cycles with No Large Angles*, Adrian Dumitrescu, János Pach, and Geza Toth
9:35 – 9:55	*Area, Curve Complexity, and Crossing Resolution of Non-Planar Graph Drawings*, Emilio Di Giacomo, Walter Didimo, Giuseppe Liotta, and Henk Meijer
9:55 – 10:20	*On the Perspectives Opened by Right Angle Crossing Drawings*, Patrizio Angelini, Luca Cittadini, Giuseppe Di Battista, Walter Didimo, Fabrizio Frati, Michael Kaufmann, and Antonios Symvonis
10:20 – 10:45	Break
	Session 2 Chair: Beppe Liotta
10:45 – 11:10	*Drawing 3-Polytopes with Good Vertex Resolution*, André Schulz
11:10 – 11:35	*Planar Drawings of Higher-Genus Graphs*, Christian Duncan, Michael Goodrich, and Stephen Kobourov
11:35 – 12:00	*Splitting Clusters to Get C-Planarity*, Patrizio Angelini, Fabrizio Frati, and Maurizio Patrignani
12:00 – 13:30	Lunch at DePaul Club (DePaul Center, 11th floor)
	Invited Talk sponsored by: **DePaul University**
13:30 – 14:30	*Why are String Graphs so Beautiful?*, János Pach (EPFL Lausanne and Rény Inst. Budapest)
14:30 – 14:55	Break
	Session 3 Chair: Franz Brandenburg
14:55 – 15:20	*On the Characterization of Level Planar Trees by Minimal Patterns*, Alejandro Estrella-Balderrama, J. Joseph Fowler, and Stephen Kobourov
15:20 – 15:45	*Characterization of Unlabeled Radial Level Planar Graphs*, J. Joseph Fowler
15:45 – 16:10	*Upward Planarization Layout*, Markus Chimani, Carsten Gutwenger, Petra Mutzel, and Hoi-Ming Wong
16:10 – 16:35	*More Flexible Radial Layout*, Ulrik Brandes and Christian Pich
16:35 – 17:00	Poster Review
17:00 – 20:00	Graph Drawing Contest

Thursday, September 24th

	Session 4 Chair: Yifan Hu
9:00 – 9:25	*WiGis: a Framework for Web-based Interactive Graph Visualizations*, Brynjar Gretarsson, Svetlin Bostandjiev, John O'Donovan, and Tobias Hollerer
9:25 – 9:50	*Port Constraints in Hierarchical Layout of Data Flow Diagrams*, Miro Spönemann, Hauke Fuhrmann, Reinhard von Hanxleden, and Petra Mutzel
9:50 – 10:15	*Fast Edge-Routing for Large Graphs*, Tim Dwyer and Lev Nachmanson
10:15 – 10:40	*Leftist Canonical Ordering*, Melanie Badent, Michael Baur, Ulrik Brandes, and Sabine Cornelsen
10:40 – 11:05	Break
	Session 5 Chair: Erin Chambers
11:05 – 11:30	*Succinct Greedy Drawings Do Not Always Exist*, Patrizio Angelini, Giuseppe Di Battista, and Fabrizio Frati
11:30 – 11:55	*Geometric Simultaneous Embeddings of a Graph and a Matching*, Sergio Cabello, Marc van Kreveld, Giuseppe Liotta, Henk Meijer, Bettina Speckmann, and Kevin Verbeek
11:55 – 12:15	*Algebraic Methods for Counting Euclidean Embeddings of Rigid Graphs*, Ioannis Emiris, Elias Tsigaridas, and Antonios Varvitsiotis
12:15 – 12:35	*Removing Independently Even Crossings*, Michael Pelsmajer, Marcus Schaefer, and Daniel Stefankovic
12:35 – 14:00	Lunch at DePaul Club (DePaul Center, 11th floor)
	Session 6 Chair: Therese Biedl
14:00 – 14:25	*Geodesic Embedding of Planar Graphs*, Bastian Katz, Marcus Krug, Ignaz Rutter, and Alexander Wolff
14:25 – 14:50	*Orthogonal Connector Routing*, Michael Wybrow, Kim Marriott, and Peter J. Stuckey
14:50 – 15:15	*On Rectilinear Drawing of Graphs*, Peter Eades, Seok-Hee Hong, and Sheung-Hung Poon
15:15 – 15:45	Break
	Session 7 Chair: Ioannis Tollis sponsored by: **Tom Sawyer Software**
15:45 – 16:10	*Semi-Bipartite Graph Visualization for Gene Ontology Networks*, Kai Xu, Seok-Hee Hong, Rohan Williams, Qing Liu, and Ji Zhang
16:10 – 16:35	*On Open Problems in Biological Network Visualization*, Mario Albrecht, Andreas Kerren, Karsten Klein, Oliver Kohlbacher, Petra Mutzel, Wolfgang Paul, Falk Schreiber, and Michael Wybrow
16:35 – 17:00	*A Novel Grid-based Visualization Approach for Metabolic Networks with Advanced Focus & Context View*, Markus Rohrschneider, Christian Heine, Andre Reichenbach, Andreas Kerren, and Gerik Scheuermann
18:00 – 21:00	Conference Dinner at Berghoff

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Friday, September 25th

	Session 8 Chair: Roberto Tamassia
9:00 – 9:25	*On Small Drawings of Series-Parallel Graphs and Other Subclasses of Planar Graphs*, Therese Biedl
9:25 – 9:50	*Drawing Trees in a Streaming Model*, Carla Binucci, Ulrik Brandes, Giuseppe Di Battista, Walter Didimo, Marco Gaertler, Pietro Palladino, Maurizio Patrignani, Antonios Symvonis, and Katharina Zweig
9:50 – 10:15	*The Planar Slope Number of Planar Partial 3-Trees of Bounded Degree*, Vít Jelínek, Eva Jelinkova, Jan Kratochvil, Bernard Lidicky, Marek Tesar, and Tomáš Vyskocil
10:15 – 10:35	*Drawing Planar 3-trees with Given Face-Areas*, Therese Biedl and Lesvia Elena Ruiz Velasquez
10:35 – 11:00	Break
	Invited Talk II sponsored by: **AT&T**
11:00 – 12:00	*The Art of Cheating when Drawing a Graph*, Martin Wattenberg (IBM Watson Research)
12:00 – 13:30	Lunch at DePaul Club (DePaul Center, 11th floor)
	Session 9 Chair: Sue Whitesides
13:30 – 13:55	*3D Visibility Representations by Regular Polygons*, Jan Stola
13:55 – 14:20	*Complexity of Some Geometric and Topological Problems*, Marcus Schaefer
14:20 – 14:45	*On Planar Supports for Hypergraphs*, Kevin Buchin, Marc van Kreveld, Henk Meijer, Bettina Speckmann, and Kevin Verbeek
14:45 – 15:10	*DAGmaps and ε-Visibility Representation of DAGs*, Vassilis Tsiaras and Ioannis Tollis
15:10 – 15:35	Break
	Session 10 Chair: Graham Wills
15:35 – 16:00	*Drawing Directed Graphs Clockwise*, Christian Pich
16:00 – 16:25	*An Improved Algorithm for the Metro-Line Crossing Minimization Problem*, Martin Nöllenburg
16:25 – 16:60	*Layout with Circular and Other Non-Linear Constraints Using Procrustes Projection*, Tim Dwyer and George Robertson
16:50 – 17:00	Closing Remarks

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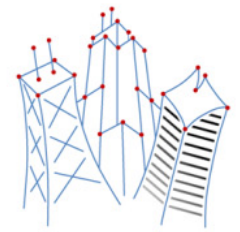

Abstracts

Invited Talks

Why are String Graphs so Beautiful?

János Pach, EPFL Lausanne, Rényi Inst. Budapest

Abstract: String graphs are intersection graphs of continuous simple arcs ("strings") in the plane. They may have a complicated structure, they have no good characterization, the recognition of string graphs is an NP-complete problem. Yet these graphs show remarkably beautiful properties from the point of view of extremal graph theory. What is the explanation for this phenomenon? We do not really know, so we offer three answers. (1) Being a string graph is a hereditary property. (2) String graphs are nicely separable into smaller pieces. (3) As in any geometric picture, one can discover several natural partial orders on a collection of strings.

The Art of Cheating when Drawing a Graph

Martin Wattenberg, IBM Watson Research

Abstract: The prime directive of graph drawing is to depict a network faithfully and accurately. But sometimes it's better to cheat. I will discuss a series of examples—both my own work and that of others—that involve discarding information, distorting the data, encouraging visual clutter, or even adding random noise. The benefits of breaking the rules can range from the scientific to the artistic.

Talks

Drawing Hamiltonian Cycles with No Large Angles

Adrian Dumitrescu, Janos Pach, and Geza Toth

Abstract: Let $n \geq 4$ be even. It is shown that every set S of n points in the plane can be connected by a (possibly self-intersecting) spanning tour (Hamiltonian cycle) consisting of n straight line edges such that the angle between any two consecutive edges is at most $2\pi/3$. For $n = 4$ and 6, this statement is tight. It is also shown that every even-element point set S can be partitioned into at most two subsets, S_1 and S_2, each admitting a spanning tour with no angle larger than $\pi/2$. Fekete and Woeginger conjectured that for sufficiently large even n, every n-element set admits such a spanning tour. We confirm this conjecture for point sets in convex position. A much stronger result holds for large point sets *randomly* and uniformly selected from an open region bounded by finitely many rectifiable curves: for any $\varepsilon > 0$, these sets almost surely admit a spanning tour with no angle larger than ε.

On the Characterization of Level Planar Trees by Minimal Patterns

Alejandro Estrella-Balderrama, J. Joseph Fowler, and Stephen Kobourov

Abstract: We consider characterizations of level planar trees. Healy et al. characterized the set of trees that are level planar in terms of two minimal level non-planar (MLNP) patterns. Fowler et al. later proved that the set of patterns was incomplete and added two additional patterns. In this paper, we show that the characterization is still incomplete by providing new MLNP patterns not included in the previous characterizations. Moreover, we introduce an iterative method that can be used to create an arbitrary number of MLNP patterns, thus proving that the set of minimal patterns that characterizes level planar trees is infinite.

Drawing 3-Polytopes with Good Vertex Resolution

André Schulz

Abstract: We study the problem how to obtain a small drawing of a 3-polytope with euclidean distance between any two points at least 1. The problem can be reduced to a one-dimensional problem, since it is sufficient to guarantee distinct integer x-coordinates. We develop an algorithm that yields an embedding with the desired property such that the polytope is contained in a $2(n-2) \times 1 \times 1$ box. The constructed embedding can be scaled to a grid embedding whose x-coordinates are contained in $[0, 2(n-2)]$. Furthermore, the point set of the embedding has a small spread, which differs from the best possible spread only by a multiplicative constant. Our algorithm is based on the combination of Tutte's spring embedding with liftings induced by equilibrium stresses. As novelty we show how to handle stresses that are more complicated than "always 1".

Geodesic Embedding of Planar Graphs

Bastian Katz, Marcus Krug, Ignaz Rutter, and Alexander Wolff

Abstract: In this paper, we explore a new convention for drawing graphs, the geodesic drawing convention. It requires that edges are drawn as interior disjoint monotone chains of axis-parallel line segments, that is, as geodesics with respect to the Manhattan metric. First, we show that geodesic embeddability on the grid is equivalent to 1-bend embeddability on the grid. It is known that the latter question can be decided efficiently. Second, we consider geodesic point-set embeddability where the task is to decide whether a given graph can be embedded on a given point set. We show that this problem is NP-hard. In contrast, we efficiently solve geodesic polygonization—the special case where the graph is a cycle. Third, we consider geodesic point-set embeddability where the vertex-point correspondence is given. We show that on the grid, this problem is NP-hard even for perfect matchings, but without the grid restriction, we solve the matching problem efficiently.

WiGis: a Framework for Web-based Interactive Graph Visualizations

Brynjar Gretarsson, Svetlin Bostandjiev, John O'Donovan, and Tobias Hollerer

Abstract: Traditional network visualization tools inherently suffer from scalability problems, particularly when such tools are interactive and web-based. In this paper we introduce WiGis—Web-based Interactive Graph Visualizations. WiGis exemplify a fully web-based framework for visualizing large-scale graphs natively in a user's browser at interactive frame rates with no discernible associated startup costs. We demonstrate fast, interactive graph animations for up to hundreds of thousands of nodes in a browser through the use of asynchronous data and image transfer. Empirical evaluations show that our system outperforms traditional web-based graph visualization tools by at least an order of magnitude in terms of scalability, while maintaining fast, high-quality interaction.

Drawing Trees in a Streaming Model

Carla Binucci, Ulrik Brandes, Giuseppe Di Battista, Walter Didimo, Marco Gaertler, Pietro Palladino, Maurizio Patrignani, Antonios Symvonis, and Katharina Zweig

Abstract: We introduce a data stream model of computation for Graph Drawing, where a source produces a graph one edge at a time. When an edge is produced, it is immediately drawn and its drawing can not be altered. The drawing has an image persistence, that controls the lifetime of edges. If the persistence is k, an edge remains in the drawing for the time spent by the source to generate k edges, then it fades away. In this model we study the area requirement of planar straight-line grid drawings of trees, with different streaming orders, layout models, and quality criteria. We assess the output quality of the presented algorithms by computing the competitive ratio with respect to the best known offline algorithms.

Planar Drawings of Higher-Genus Graphs

Christian Duncan, Michael Goodrich, and Stephen Kobourov

Abstract: In this paper, we give polynomial-time algorithms that can take a graph G with a given combinatorial embedding on a surface S of genus g and produce a planar drawing of G in $\mathbb{R}^2$, with a bounding face defined by a polygonal schema P for S. Our drawings are planar, but they allow for multiple copies of vertices and edges on P's boundary, which is a common way of visualizing higher-genus graphs in the plane. As a side note, we show that it is NP-complete to determine whether a given graph embedded in a genus-g surface has a set of 2g fundamental cycles with vertex-disjoint interiors, which would be desirable from a graph-drawing perspective.

Drawing Directed Graphs Clockwise

Christian Pich

Abstract: We present a method for clockwise drawings of directed cyclic graphs. It is based on the eigenvalue decomposition of a skew-symmetric matrix associated with the graph and draws edges clockwise around the center instead of downwards, as in the traditional hierarchical drawing style. The method does not require preprocessing for cycle removal or layering, which often involves computationally hard problems. We describe a linear-time algorithm which produces optimal solutions, and we present some application examples.

Area, Curve Complexity, and Crossing Resolution of Non-Planar Graph Drawings

Emilio Di Giacomo, Walter Didimo, Giuseppe Liotta, and Henk Meijer

Abstract: In this paper we study non-planar drawings of graphs, and study tradeoffs between the crossing resolution (i.e., the minimum angle formed by two crossing segments), the curve complexity (i.e., maximum number of bends per edge), the total number of bends, and the area.

Algebraic methods for counting Euclidean embeddings of rigid graphs

Ioannis Emiris, Elias Tsigaridas, and Antonios Varvitsiotis

Abstract: The study of (minimally) rigid graphs is motivated by numerous applications, mostly in mechanism theory and structural bioinformatics. A major open problem concerns the number of embeddings of such graphs, up to rigid motions, in Euclidean space. We focus on lower bounds and on tight bounds for small cases, in $\mathbb{R}^2$ and $\mathbb{R}^3$, where Laman graphs and 1-skeleta of convex simplicial polyhedra, respectively, admit inductive constructions. We establish, in $\mathbb{R}^2$, a bound of about 2.37^n improving the best existing bound of about 2.29^n by Borcea and Streinu, whereas in $\mathbb{R}^3$ we establish the first bound of about 2.52^n, where n denotes the number of vertices. We capture embeddability by polynomial systems with suitable structure, so that their mixed volume, which bounds the number of common roots, to yield interesting bounds on the number of embeddings. Our implementation yields the first tight bounds for $n = 7, 8$ in $\mathbb{R}^2$, and for $n = 6, 7$ in $\mathbb{R}^3$ by enumerating all rigid graphs up to isomorphism.

Characterization of Unlabeled Radial Level Planar Graphs

J. Joseph Fowler

Abstract: Suppose that an n-vertex graph has a distinct labeling with the integers 1, ..., n. Such a graph is radial level planar if it admits a crossings-free drawing under two constraints. First, each vertex lies on a concentric circle such that the radius of the circle equals the label of the vertex. Second, each edge is drawn with a radially monotone curve. We characterize the set of unlabeled radial level planar (URLP) graphs that are radial level planar in terms of 7 and 15 forbidden subdivisions depending on whether the graph is disconnected or connected, respectively. We also provide linear-time drawing algorithms for any URLP graph.

3D Visibility Representations by Regular Polygons

Jan Stola

Abstract: We study 3D visibility representations of complete graphs where vertices are represented by equal regular polygons lying in planes parallel to the xy-plane. Edges correspond to the z-parallel visibility among these polygons. We improve the upper bound on the maximum size of a complete graph with a 3D visibility representation by regular n-gons from $2^{O(n)}$ to $O(n^4)$.

Semi-Bipartite Graph Visualization for Gene Ontology Networks

Kai Xu, Seok-Hee Hong, Rohan Williams, Qing Liu, and Ji Zhang

Abstract: In this paper we proposed three layout algorithms for semi-bipartite graphs-bipartite graphs with edges within one partition-that emerges from the gene function analysis in bioinformatics. The algorithms reduce edge crossings or total edge length to facilitate visual analysis of microarray experiment results. Their drawing quality and running time are evaluated with five real-world datasets. The results show significant improvement in crossing number and total edge length and have been well received by the biologists. Additionally, we present a method that can effectively reduce visual complexity by removing less informative terms, and the test results show reduction in graph size by more than half. All the proposed methods are implemented as a plug-in for the GEOMI visualization package, in which they can be used together with other visualization and analysis methods designed for biological networks.

On Planar Supports for Hypergraphs

Kevin Buchin, Marc van Kreveld, Henk Meijer, Bettina Speckmann, and Kevin Verbeek

Abstract: A graph G is a support for a hypergraph $H = (V, \mathcal{S})$ if the vertices of G correspond to the vertices of H such that for each hyperedge $S_i \in \mathcal{S}$ the subgraph of G induced by S_i is connected. G is a planar support if it is a support and planar. Johnson and Pollak proved that it is NP-complete to decide if a given hypergraph has a planar support. In this paper we present algorithms which test in polynomial time if a given hypergraph H has a planar support that is (i) a path, (ii) a cycle, (iii) a tree, or (iv) a tree where the maximal degree of each vertex is bounded. Our algorithms are constructive, they compute a support if it exists. Furthermore, we prove that it is already NP-hard to decide if a hypergraph has a 3-outerplanar support.

Complexity of Some Geometric and Topological Problems

Marcus Schaefer

Abstract: We show that recognizing intersection graphs of convex sets has the same complexity as deciding truth in the existential theory of the reals. Comparing this to similar results on the rectilinear crossing number and intersection graphs of line segments, we argue that there is a need to recognize this level of complexity as its own class.

On Open Problems in Biological Network Visualization

Mario Albrecht, Andreas Kerren, Karsten Klein, Oliver Kohlbacher, Petra Mutzel, Wolfgang Paul, Falk Schreiber, and Michael Wybrow

Abstract: Much of the data generated and analyzed in the life sciences can be interpreted and represented by networks or graphs. Network analysis and visualization methods help in investigating these networks, and many universal as well as special-purpose tools and libraries are available for this purpose. However, the two fields of graph drawing and network biology are still largely disconnected. Hence, visualization of biological networks typically does not apply state-of-the-art graph drawing techniques and graph drawing tools do not respect the drawing conventions of the life science community. In this paper we analyze some of the major problems arising in biological network visualization. We characterize these problems and formulate a series of open graph drawing problems. These use cases illustrate the need for efficient algorithms to present, explore, evaluate, and compare biological network data. For each use case problems are discussed and a possible solution is suggested.

Upward Planarization Layout

Markus Chimani, Carsten Gutwenger, Petra Mutzel, and Hoi-Ming Wong

Abstract: Recently, we have presented a new practical method for upward crossing minimization, which clearly outperformed existing approaches for drawing hierarchical graphs in that respect. The outcome of this method is an upward planar representation (UPR), a planarly embedded graph in which crossings are represented by dummy vertices. However, straight-forward approaches for drawing such UPRs lead to quite unsatisfactory results. In this paper, we present a new algorithm for drawing UPRs that greatly improves the layout quality, leading to good hierarchal drawings with few crossings. We analyze its performance on well-known benchmark graphs and compare it with alternative approaches.

A Novel Grid-based Visualization Approach for Metabolic Networks with Advanced Focus & Context View

Markus Rohrschneider, Christian Heine, Andre Reichenbach, Andreas Kerren, and Gerik Scheuermann

Abstract: The universe of biochemical reactions in metabolic pathways can be modeled as a complex network structure augmented with domain specific annotations. Based on the functional properties of the involved reactions, metabolic networks are often clustered into so-called pathways inferred from expert knowledge. To support the domain expert in the exploration and analysis process, we follow the well-known Table Lens metaphor with the possibility to select multiple foci. In this paper, we introduce a novel approach to generate an interactive layout of such a metabolic network taking its hierarchical structure into account and present methods for navigation and exploration that preserve the mental map. The layout places the network nodes on a fixed rectilinear grid and routes the edges orthogonally between the node positions. Our approach supports bundled edge routes heuristically minimizing a given cost function based on the number of bends, the number of edge crossings and the density of edges within a bundle.

An Improved Algorithm for the Metro-Line Crossing Minimization Problem

Martin Nöllenburg

Abstract: In the metro-line crossing minimization problem, we are given a plane graph $G = (V, E)$ and a set L of simple paths (or lines) that cover G, that is, every edge e in E belongs to at least one path in L. The problem is to draw all paths in L along the edges of G such that the number of crossings between paths is minimized. This crossing minimization problem arises, for example, when drawing metro maps, in which multiple transport lines share parts of their routes. We present a new line-layout algorithm with $O(|L|^2|V|)$ running time that improves the best previous algorithms for two variants of the metro-line crossing minimization problem in unrestricted plane graphs. For the first variant, in which the so-called periphery condition holds and terminus side assignments are given in the input, Asquith et al. gave an $O(|L|^3|E|^{2.5})$-time algorithm. For the second variant, in which all lines are paths between degree-1 vertices of G, Argyriou et al. gave an $O((|E| + |L|^2)|E|)$-time algorithm.

Leftist Canonical Ordering

Melanie Badent, Michael Baur, Ulrik Brandes, and Sabine Cornelsen

Abstract: Canonical ordering is an important tool in planar graph drawing and other applications. Although a linear-time algorithm to determine canonical orderings is known for a while, it is rather complicated to understand and implement, and the output is not uniquely determined. We present a new approach that is simpler and more intuitive, and that computes a newly defined leftist canonical ordering of a triconnected graph which is a uniquely determined leftmost canonical ordering.

Removing Independently Even Crossings

Michael Pelsmajer, Marcus Schaefer, and Daniel Stefankovic

Abstract: We show that $\mathrm{cr}(G) \leq \binom{2\,\mathrm{iocr}(G)}{2}$ settling an open problem of Pach and Tóth. Moreover, $\mathrm{iocr}(G) = \mathrm{cr}(G)$ if $\mathrm{iocr}(G) \leq 2$.

Orthogonal Connector Routing

Michael Wybrow, Kim Marriott, and Peter J. Stuckey

Abstract: Orthogonal connectors are used in a variety of common network diagrams. Most interactive diagram editors provide orthogonal connectors with some form of automatic connector routing. However, these tools use ad-hoc heuristics that can lead to strange routes and even routes that pass through other objects. We present an algorithm for computing optimal object-avoiding orthogonal connector routings where the route minimizes a monotonic function of the connector length and number of bends. The algorithm is efficient and can calculate connector routings fast enough to reroute connectors during interaction.

Port Constraints in Hierarchical Layout of Data Flow Diagrams

Miro Spönemann, Hauke Fuhrmann, Reinhard von Hanxleden, and Petra Mutzel

Abstract: We present a new application for graph drawing in the context of graphical model-based system design, where manual placing of graphical items is still state-of-the-practice. The KIELER framework aims at improving this by offering novel user interaction techniques, enabled by automatic layout of the diagrams. In this paper we present extensions of the well-known hierarchical layout approach, originally suggested by Sugiyama et al., to support port constraints, hyperedges, and compound graphs in order to layout diagrams of data flow languages. A case study and experimental results show that our algorithm is well suited for application in interactive user interfaces.

Splitting Clusters to Get C-Planarity

Patrizio Angelini, Fabrizio Frati, and Maurizio Patrignani

Abstract: In this paper we introduce a generalization of the c-planarity testing problem for clustered graphs. Namely, given a clustered graph, the goal is to split as few clusters as possible in order to make it c-planar. Determining whether zero splits are enough coincides with testing c-planarity. We show that this problem is NP-complete for non-c-connected clustered paths and cycles and for c-connected clustered triangulations. On the other hand, we present a polynomial-time algorithm for flat c-connected clustered graphs whose underlying graph is a biconnected series-parallel graph, both in the fixed and in the variable embedding setting, when the splits are assumed to maintain the c-connectivity of the clusters.

Succinct Greedy Drawings Do Not Always Exist

Patrizio Angelini, Giuseppe Di Battista, and Fabrizio Frati

Abstract: A greedy drawing is a graph drawing containing a distance-decreasing path for every pair of nodes. A path $(v_0, v_1, \ldots, v_m)$ is distance-decreasing if $d(v_i, v_m) < d(v_{i-1}, v_m)$, for $i = 1, \ldots, m$. Greedy drawings easily support geographic greedy routing. Hence, a natural and practical problem is the one of constructing greedy drawings in the plane, using few bits for representing vertex Cartesian coordinates and using the Euclidean distance as a metric. We show that this may be unfeasible.

On the Perspectives Opened by Right Angle Crossing Drawings

Patrizio Angelini, Luca Cittadini, Giuseppe Di Battista, Walter Didimo, Fabrizio Frati, Michael Kaufmann, and Antonios Symvonis

Abstract: Right Angle Crossing (RAC) drawings are poly-line drawings where each crossing forms four right angles. RAC drawings have been introduced because cognitive experiments provided evidence that the number of crossings does not decrease drawing readability if the edges cross at right angles. We investigate to which extent RAC drawings can help in overcoming the limitations of widely adopted planar graph drawing conventions, providing both positive and negative results. First, we prove that there exist acyclic planar digraphs not admitting any straight-line upward RAC drawing and that the corresponding decision problem is NP-hard. Also, we show digraphs whose straight-line upward RAC drawings require exponential area. Second, we study if RAC drawings allow to draw bounded-degree graphs with lower curve complexity than the one required by more constrained drawing conventions. Namely, we prove that every graph with vertex-degree at most six (three) admits a RAC drawing with curve complexity two (resp. one) and with quadratic area. Third, we consider a natural non-planar generalization of planar embedded graphs. Here we give bounds for curve-complexity and area different from the ones known for planar embeddings.

On Rectilinear Drawing of Graphs

Peter Eades, Seok-Hee Hong, and Sheung-Hung Poon

Abstract: A *rectilinear drawing* is an orthogonal grid drawing without bends, possibly with edge crossings, without any overlapping between edges, between vertices, or between edges and vertices. Rectilinear drawings without edge crossings (*planar* rectilinear drawings) have been extensively investigated in Graph Drawing. Testing rectilinear planarity of a graph is NP-complete. Restricted cases of the planar rectilinear drawing problem, sometimes called the "no-bend orthogonal drawing problem", have been well studied. In this paper, we study the problem of general *non-planar* rectilinear drawing; this problem has not received as much attention as the planar case. We consider a number of restricted classes of graphs and obtain a polynomial time algorithm, NP-hardness results, an FPT algorithm, and some bounds. We define a structure called a "4-cycle block". We give a linear time algorithm to test whether a graph that consists of a single 4-cycle block has a rectilinear drawing, and draw it if such a drawing exists. We show that the problem is NP-hard for the graphs that consist of 4-cycle blocks connected by single edges, as well as the case where each vertex has degree 2 or 4. We present a linear time fixed-parameter tractable algorithm to test whether a degree-4 graph has a rectilinear drawing, where the parameter is the number of degree-3 and degree-4 vertices of the graph. We also present a lower bound on the area of rectilinear drawings, and a upper bound on the number of edges.

Geometric Simultaneous Embeddings of a Graph and a Matching

Sergio Cabello, Marc van Kreveld, Giuseppe Liotta, Henk Meijer, Bettina Speckmann, and Kevin Verbeek

Abstract: The geometric simultaneous embedding problem asks whether two planar graphs on the same set of vertices in the plane can be drawn using straight lines, such that each graph is plane. Geometric simultaneous embedding is a current topic in graph drawing and positive and negative results are known for various classes of graphs. So far only connected graphs have been considered. In this paper we present the first results for the setting where one of the graphs is a matching. In particular, we show that there exists a planar graph and a matching which do not admit a geometric simultaneous embedding. This generalizes the same result for a planar graph and a path. On the positive side, we describe algorithms that compute a geometric simultaneous embedding of a matching and a wheel, outerpath, or tree. Our proof for a matching and a tree sheds new light on a major open question: do a tree and a path always admit a geometric simultaneous embedding? Our drawing algorithms minimize the number of orientations used to draw the edges of the matching. Specifically, when embedding a matching and a tree, we can draw all matching edges horizontally. When embedding a matching and a wheel or an outerpath, we use only two orientations.

Drawing Planar 3-Trees with Given Face-Areas
Therese Biedl and Lesvia Elena Ruiz Velasquez
Abstract: We study straight-line drawings of planar graphs such that each interior face has a prescribed area. It was known that such drawings exist for all planar graphs with maximum degree 3. We show here that such drawings exist for all planar partial 3-trees. Moreover, vertices have rational coordinates if the face-areas are rational, and we can bound the resolution. We also give some negative results for other graph classes.

On Small Drawings of Series-Parallel Graphs and Other Subclasses of Planar Graphs
Therese Biedl
Abstract: In this paper, we study small planar drawings of planar graphs. For arbitrary planar graphs, $\Theta(n^2)$ is the established upper and lower bound on the area. It is a long-standing open problem for what graphs smaller area can be achieved, with results known only for trees and outer-planar graphs. We show here that series-parallel can be drawn in $O(n^{3/2})$ area, but 2-outer-planar graphs and planar graphs of proper pathwidth 3 require $\Omega(n^2)$ area. Our drawings are visibility representations, which can be converted to poly-line drawings of asymptotically the same area.

Layout with Circular and Other Non-Linear Constraints Using Procrustes Projection
Tim Dwyer and George Robertson
Abstract: Recent work on constrained graph layout has involved projection of simple two-variable linear equality and inequality constraints in the context of majorization or gradient-projection based optimization. While useful classes of containment, alignment and rectangular non-overlap constraints could be built using this framework, a severe limitation was that the layout used an axis-separation approach such that all constraints had to be axis aligned. In this paper we use techniques from Procrustes Analysis to extend the gradient-projection approach to useful types of non-linear constraints. The constraints require subgraphs to be locally fixed into various geometries—such as circular cycles or local layout obtained by a combinatorial algorithm (e.g. orthogonal or layered-directed)—but then allow these sub-graph geometries to be integrated into a larger layout through translation, rotation and scaling.

Fast Edge-Routing for Large Graphs
Tim Dwyer and Lev Nachmanson
Abstract: To produce high quality drawings of graphs with nodes drawn as shapes it is important to find routes for the edges which do not intersect node boundaries. Recent work in this area involves finding shortest paths in a tangent-visibility graph. However, construction of the full tangent-visibility graph is expensive, at least quadratic time in the number of nodes. In this paper we explore two ideas for achieving faster edge routing using approximate shortest-path techniques.

More Flexible Radial Layout
Ulrik Brandes and Christian Pich
Abstract: We describe an algorithm for radial layout of undirected graphs, in which nodes are constrained to the circumferences of a set of concentric circles around the origin. Such constraints frequently occur in the layouts of social or policy networks, when structural centrality is mapped to geometric centrality, or when the primary intention of the layout is the display of the vicinity of a distinguished node. We describe an extension of stress majorization, in which a weighting scheme is used to impose the radial constraints on the layout, but also preserves as much of the information about the graph structure as possible.

DAGmaps and ε-Visibility Representation of DAGs

Vassilis Tsiaras and Ioannis Tollis

Abstract: DAGmaps are space filling visualization of DAGs that generalize treemaps. Deciding whether or not a DAG admits a DAGmap is NP-complete. Recently we defined a special case called one-dimensional DAGmap where the admissibility is decided in linear time. However there is no complete characterization of the class of DAGs that admit a one-dimensional DAGmap. In this paper we prove that a DAG admits a one-dimensional DAGmap if and only if it admits a directed ε-visibility representation. Then we give a characterization of the DAGs that admit directed ε-visibility representations. Finally we show that a DAGmap defines a directed three-dimensional ε-visibility representation of a DAG.

The Planar Slope Number of Planar Partial 3-Trees of Bounded Degree

Vít Jelínek, Eva Jelinkova, Jan Kratochvil, Bernard Lidicky, Marek Tesar, and Tomáš Vyskocil

Abstract: It is known that every planar graph has a planar embedding where edges are represented by non-crossing straight-line segments. We study the planar slope number, i.e., the minimum number of distinct edge-slopes in such a drawing of a planar graph with maximum degree Δ. We show that the planar slope number of every series-parallel graph is at most 2Δ. We also show that the planar slope number of every planar partial 3-tree and also every plane partial 3-tree is at most $2^{O(\Delta)}$. In particular, we answer the question of Dujmović et al. [Computational Geometry 38 (3), pp. 194–212 (2007)] whether there is a function f such that plane maximal outerplanar graphs can be drawn using at most $f(\Delta)$ slopes.