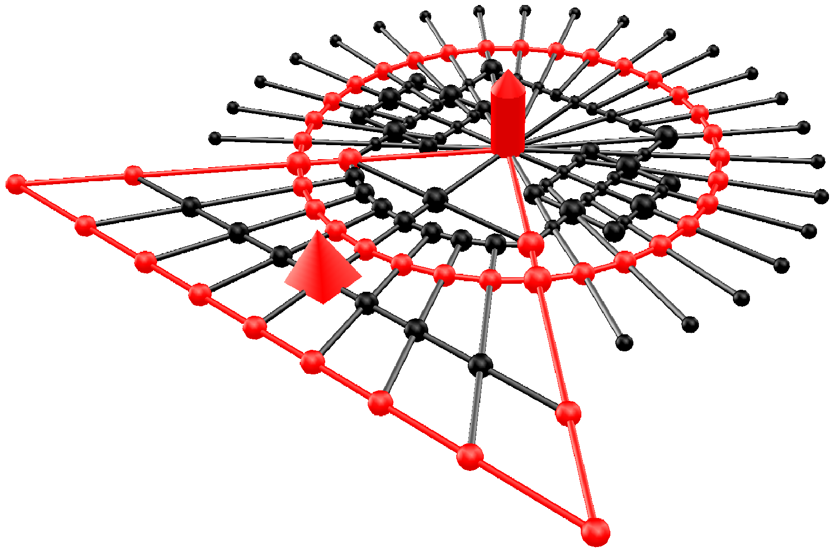
14th International Symposium on

# Graph Drawing

Universität Karlsruhe (TH)
September 18-20, 2006
Karlsruhe, Germany



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14th International Symposium on Graph Drawing

gd06

September 18-20, 2006
Karlsruhe, Germany

# Welcome to Karlsruhe

On behalf of the Organizing Committee it is our pleasure to welcome all participants to the 14th International Symposium on Graph Drawing in Karlsruhe.

In response to the call for papers, the program committee received 90 submissions describing original reasearch and/or system demonstrations. At this year's conference 39 talks and 8 posters will present the very best of graph drawing research. In addition to the usual and stimulating graph drawing contest, developers of graph drawing systems will be given a chance to showcase their software during a special session. Two eagerly anticipated talks will be given be Emo Welzl from ETH Zürich and Oliver Deussen from Universität Konstanz.

We wish you a pleasant and productive sojourn in Karlsruhe.

Michael Kaufmann Dorothea Wagner

14th International Symposium on Graph Drawing

gd06

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# Program with Abstracts

## Monday, September 18, 2006

### 8:30 - 9:00 Opening

### 9:00 - 10:40 Session A

Chair: David Eppstein

Tim Dwyer, Kim Marriott and Michael Wybrow
**Integrating Edge Routing into Force-Directed Layout**

Force-directed layout is typically used to create organic-looking, straight-edge drawings of large graphs while combinatorial techniques are generally preferred for high-quality layout of small to medium sized graphs. In this paper we integrate edge-routing techniques into a force-directed layout method based on constrained stress majorisation. Our basic procedure takes an initial layout for the graph, including poly-line paths for the edges, and improves this layout by moving the nodes to reduce stress and moving edge bend points to straighten the edges and reduce their overall length. Separation constraints between nodes and edge bend points are used to ensure that node labels do not overlap edges or other nodes and that no additional edge crossings are introduced.

Ulrich Lauther
**Multipole-Based Force Approximation Revisited - a Simple but Fast Implementation Using a Dynamized Enclosing-Circle-Enhanced k-d-Tree**

Most force-directed graph drawing algorithms depend for speed crucially on efficient methods for approximating repulsive forces between a large number of particles. A combination of various tree data structures and multi-pole approximations has been successfully used by a number of authors. If a multi-level approach is taken, in the late (and particle number wise challenging) steps, movements of particles are quite limited. We utilize this fact by basing force-calculations on an easy updatable tree data structure. Using explicit distance checks instead of relying on implicit guarantees provided by quadtrees and avoiding local expansions of the multi-pole expansion leads to a very simple implementation that is faster than comparable earlier methods. The latter claim is supported by experimental results.

Ali Civril, Malik-Magdon Ismail and Eli-Bocek Rivele
**SSDE: Fast Graph Drawing Using Sampled Spectral Distance Embedding**

We present a fast spectral graph drawing algorithm for drawing undirected connected graphs. Classical Multi-Dimensional Scaling yields a quadratic-time spectral algorithm, which approximates the real distances of the nodes in the final drawing with their graph theoretical distances. We build from this idea to develop the linear-time spectral graph drawing algorithm SSDE. We reduce the space and time complexity of the spectral decomposition by approximating the distance matrix with the product of three smaller matrices, which are formed by sampling rows and columns of the distance matrix. The main advantages of our algorithm are that it is very fast and it gives aesthetically pleasing results, when compared to other spectral graph drawing algorithms. The runtime for typical 10.000 node graphs is about one second and for 100.000 node graphs about ten seconds.

Ulrik Brandes and Christian Pich

**Eigensolver Methods for Progressive Multidimensional Scaling of Large Data**

Recent proposals for implementing multidimensional scaling (MDS) in the context of information visualization have focused on improving the spring-model approach to make it scale to large data sets. We present an alternative variant of eigensolver approaches. It is progressive in that it quickly gives an initial layout of the entire data which can be refined globally or locally while the data is being explored. Our method is considerably faster and simpler to implement than recent spring-model approaches. Since a full layout is available at any time, it is easily combined with other abstraction and interaction techniques for more effective exploration.

## 11:10 - 12:40 Session B

Chair: Stephen Kobourov

Ulrik Brandes and Barbara Schlieper

**Angle and Distance Constraints on Tree Drawings**

We consider planar drawings of trees that must satisfy constraints on the angles between edges incident to a common vertex and on the distances between adjacent vertices. These requirements arise naturally in many applications such as drawing phylogenetic trees or route maps. For straight-line drawings, either class of constraints is always realizable, whereas their combination is not in general. We show that straight-line realizability can be tested in linear time, and give an algorithm that produces drawing satisfying both groups of constraints together in a model where edges are represented as polylines with at most two bends per edge or as continuously differentiable curves.

Joachim Gudmundsson, Marc van Kreveld and Damian Merrick

**Schematisation of Tree Drawings**

Given a tree T spanning a set of points S in the plane, we study the problem of drawing T using only line segments aligned with a fixed set of directions C. The vertices in the drawing must lie within a given distance r of each original point p in S, and an objective function counting the number of bends must be minimised. We propose five versions of this problem using different objective functions, and algorithms to solve them. This work has potential applications in geographic map schematisation and metro map layout.

Josiah Carlson and David Eppstein

**Trees with Convex Faces and Optimal Angles**

We consider drawings of trees in which all edges incident to leaves can be extended to infinite rays without crossing, partitioning the plane into infinite convex polygons. Among all such drawings we seek the one maximizing the angular resolution of the drawing. We find linear time algorithms for solving this problem, both for plane trees and for trees without a fixed embedding. In any such drawing, the edge lengths may be set independently of the angles, without crossing; we describe multiple strategies for setting these lengths.

Fabrizio Frati and Giuseppe Di Battista

**Three Dimensional Drawings of Bounded Degree Trees**

We show an algorithm for constructing $3D$ straight-line drawings of balanced constant degree trees. The drawings have linear volume and optimal aspect ratio. As a side effect, we also give an algorithm for constructing $2D$ drawings of balanced constant degree trees in linear area, with optimal aspect ratio and with better angular resolution with respect to the one presented in previous work. Further, we present an algorithm for constructing $3D$ poly-line drawings of trees whose degree is bounded by $n^{1/3}$. Such drawings have linear volume and optimal aspect ratio.

## 14:00 Invited Talk

Emo Welzl (ETH Zürich)

**The Number of Crossing-Free Configurations on Planar Point Sets**

## 15:00 - 15:40 Session C

Chair: Michael Kaufmann

Justin Cappos, Alejandro Estrella-Balderrama, Joe Fowler and Stephen Kobourov
**Simultaneous Graph Embedding with Bends and Circular Arcs**

We consider the problem of simultaneous embedding of planar graphs. In particular, we show how to simultaneously embed a path and an n-level planar graph with no crossings. We show how to use radial embeddings for curvilinear simultaneous embeddings of a path and an outerplanar graph without crossings. We also show how to use star-shaped levels to find 2-bends per path edge simultaneous embeddings of a path and outerplanar graph. All embedding algorithms run in O(n) time.

Fabrizio Frati
**Embedding Graphs Simultaneously with Fixed Edges**

We show that a planar graph and any number of trees can always be simultaneously embedded with fixed edges and that there exist two outerplanar graphs that cannot.

## 16:10 - 17:25 Session D

Chair: Yehuda Koren

Balázs Keszegh, János Pach, Dömötör Pálvölgyi and Géza Tóth
**Drawing cubic graphs with at most five slopes**

We show that every graph G with maximum degree threehas a straight-line drawing in the plane using edges of at most five different slopes. Moreover, if G is connected and has at least one vertex of degree less than three, then four directions suffice.

Carsten Gutwenger, Karsten Klein and Petra Mutzel
**Planarity Testing and Optimal Edge Insertion with Embedding Constraints**

There is a variety of algorithms for testing if a graph is planar and for embedding a planar graph in the plane. However, many practical applications demand additional restrictions on an admissible embedding. In particular, constraints on the permitted (clockwise) order of the edges around a vertex, like so-called *side constraints*, abound. In this paper, we introduce a set of hierarchical embedding constraints that also comprises side constraints. We present linear time algorithms for testing if a graph is *ec-planar*, i.e., admits a planar embedding satisfying the given embedding constraints, as well as for computing such an embedding. Moreover, we characterize the set of all possible ec-planar embeddings using BC- and SPQR-trees. We also consider the problem of finding a planar combinatorial embedding of a planar graph $G$ such that an additional edge $e$ can be inserted with the minimum number of crossings under the additional restriction of embedding constraints. We show that the problem can still be solved in linear time.

Kazuyuki Miura, Tetsuya Matsuno and Takao Nishizeki
**Open Rectangle-of-Influence Drawings of Inner Triangulated Plane Graphs**

A straight-line drawing of a plane graph is called an open rectangle-of-influence drawing if there is no vertex in the proper inside of the axis-parallel rectangle defined by the two ends of every edge. In an inner triangulated plane graph, every inner face is a triangle although the outer face is not always a triangle. In this paper, we obtain a necessary and sufficient condition for an inner triangulated plane graph $G$ to have a certain type of an open rectangle-of-influence drawing, and present an algorithm to construct such a drawing on an $(n-1) \times (n-1)$ integer grid in time $O(n^{1.5}/\log n)$ if $G$ satisfies the condition, where $n$ is the number of vertices in $G$.

## 17:30 - 19:00 Software Demos and Posters

## 18:00 – 19:00 Graph Drawing Contest

# Tuesday, September 19, 2006

## 9:00 - 10:40 Session E

Chair: Vida Dujmovic

David Wood and Jan Arne Telle

**Planar Decompositions and the Crossing Number of Graphs with an Excluded Minor**

Tree decompositions of graphs are of fundamental importance in structural and algorithmic graph theory. Planar decompositions generalise tree decompositions by allowing an arbitrary planar graph to index the decomposition. We prove that every graph that excludes a fixed graph as a minor has a planar decomposition with bounded width and a linear number of bags. The crossing number of a graph is the minimum number of crossings in a drawing of the graph in the plane. We prove that planar decompositions are intimately related to the crossing number, in the sense that a graph with bounded degree has linear crossing number if and only if it has a planar decomposition with bounded width and linear order. It follows from the above result about planar decompositions that every graph with bounded degree and an excluded minor has linear crossing number. Analogous results are proved for the convex and rectilinear crossing numbers. In particular, every graph with bounded degree and bounded tree-width has linear convex crossing number, and every $K_{3,3}$-minor-free graph with bounded degree has linear rectilinear crossing number.

Petr Hlineny and Gelasio Salazar

**On the Crossing Number of Almost Planar Graphs**

Crossing minimization is one of the most challenging algorithmic problems in topological graph theory, with strong ties to graph drawing applications. Despite a long history of intensive research, no practical good algorithm for crossing minimization is known (that is hardly surprising, since the problem itself is NP-complete). Even more surprising is how little we know about a seemingly simple particular problem: to minimize the number of crossings in an *almost planar* graph, that is, a graph with an edge whose removal leaves a planar graph. This problem is in turn a building block in an edge insertion heuristic for crossing minimization. We prove that edge insertion provides a good approximation for crossing minimization on almost planar graphs of bounded degrees. On the other hand, we demonstrate non-triviality of the crossing minimization problem on almost planar graphs by exhibiting several examples, among them new families of crossing critical graphs which are almost planar and projective.

Jacob Fox and Csaba Toth

**On the Decay of Crossing Numbers**

The crossing number $\mathrm{cr}(G)$ of a graph $G$ is the minimum number of crossings over all drawings of $G$ in the plane. In 1993, Richter and Thomassen conjectured that there is a constant $c$ such that every graph $G$ with crossing number $k$ has an edge $e$ such that $\mathrm{cr}(G-e) \geq k - c\sqrt{k}$. They showed only that $G$ always has an edge $e$ with $\mathrm{cr}(G-e) \geq \frac{2}{5}\mathrm{cn}(G) - O(1)$. We prove that for every connected graph $G$ with $n$ vertices, $m \geq 1$ edges, and every edge $e$ of $G$, we have $\mathrm{cr}(G-e) \geq \mathrm{cr}(G) - 2m + n/2 + 1$. This confirms the Richter-Thomassen conjecture for dense graphs. We also prove that for every fixed $\epsilon > 0$, there is a constant $n_0$ depending on $\epsilon$ such that if $G$ is a graph with $n > n_0$ vertices and $m > n^{1+\epsilon}$ edges, then $G$ has a subgraph $G'$ with at most $(1 - \frac{1}{24\epsilon})m$ edges such that $\mathrm{cr}(G') \geq (\frac{1}{28} - o(1))\mathrm{cr}(G)$.

Helen C. Purchase, Eve Hoggan and Carsten Goerg

**How Important is the "Mental Map"? – an Empirical Investigation of a Dynamic Graph Layout Algorithm**

While some research has been performed on the human understanding of static graph layout algorithms, dynamic graph layout algorithms have only recently been developed sufficiently to enable similar investigations. This paper presents the first empirical analysis of a dynamic graph layout algorithm, focusing on the assumption that maintaining the "mental map" between time-slices assists with the comprehension of the evolving graph. The results confirm this assumption with respect to some categories of task.

## 11:10 - 12:40 Session F

Chair: Takao Nishizeki

Rolf Klein and Martin Kutz
**Computing Geometric Minimum-Dilation Graphs is NP-Hard**

Consider a geometric graph $G$, drawn with straight lines in the plane. For every pair $a, b$ of vertices of $G$, we compare the shortest-path distance between $a$ and $b$ in $G$ (with Euclidean edge lengths) to their actual Euclidean distance in the plane. The worst-case ratio of these two values, for all pairs of vertices, is called the dilation of $G$. We prove that computing a minimum-dilation graph that connects a given $n$-point set in the plane, using not more than a given number $m < 2n$ of edges, is an NP-hard problem, no matter if edge crossings are allowed or forbidden. In addition, we show that the minimum dilation tree over a given point set may in fact contain edge crossings.

Cornelia Dangelmayr and Stefan Felsner
**Chordal Graphs as Intersection Graphs of Pseudosegments**

We investigate which chordal graphs have a representation as intersection graphs of pseudosegments. The main contribution is a construction which shows that all chordal graphs which have a representation as intersection graph of subpaths on a tree are representable. A family of intersection graphs of substars of a star is used to show that not all chordal graphs are representable by pseudosegments.

Charalampos Papamanthou and Ioannis G. Tollis
**Parameterized st-Orientations of Graphs: Algorithms and Experiments**

*st*-orientations (*st*-numberings) or bipolar orientations of undirected graphs are central to many graph algorithms and applications. Several algorithms have been proposed in the past to compute an *st*-orientation of a biconnected graph. However, as indicated in [1], the computation of more than one *st*-orientation is very important for many applications in multiple research areas, such as this of Graph Drawing. In this paper we show how to compute such orientations with certain (parameterized) characteristics in the final *st*-oriented graph, such as the length of the longest path. Apart from Graph Drawing, this work applies in other areas such as Network Routing and in tackling difficult problems such as Graph Coloring and Longest Path. We present primary approaches to the problem of computing longest path parameterized *st*-orientations of graphs, the analytical presentation (together with proof of correctness) of a new $O(m \log^5 n)$ ($O(m \log n)$ for planar graphs) time algorithm that computes such orientations (and which was used in [1] to compute the orientations used for the drawings) and extensive computational results that reveal the robustness of the algorithm.

Eric Fusy
**Straight-line drawing of quadrangulations**

This article introduces a straight-line drawing algorithm for quadrangulations, in the family of the face-counting algorithms. It outputs a drawing on a regular $W \times H$ grid such that $W + H = n - 1 - \Delta$, where $n$ is the number of vertices and $\Delta$ is an explicit combinatorial parameter of the quadrangulation.

## 14:00 Invited Talk

Oliver Deussen (Universität Konstanz)
**The Algorithmic Beauty of Virtual Nature**

## 15:00 - 15:40 Session G

Chair: Dorothea Wagner

Katharina Anna Lehmann and Stephan Kottler
**Visualizing Large and Clustered Networks**

The need to visualize large and complex networks has strongly increased in the last decade. Although networks with more than 1,000 vertices seem to be prohibitive for a clear layout, real-world networks exhibit a very inhomogenous edge density that can be harnessed to derive an aesthetic and structured layout. Here, we will show a heuristic that finds a spanning tree with a very low average spanner property for most non-tree edges, the so-called *backbone* of a network. This backbone can then be used to either apply a tree-layout algorithm or to assign weights to every edge and apply a spring-embedder layout algorithm. Both methods generate very readable and clear layouts that can additionally be used to cluster the networks, depending on the time spent in an optional optimiziation heuristic.

Martin Siebenhaller
**Partitioned Drawings**

In this paper we consider the problem of creating partitioned drawings of graphs. In a partitioned drawing each vertex is placed inside a prescribed partition cell of a rectangular partitioned drawing area. This problem has several applications in practice, e.g. for UML activity diagrams or wiring schematics. We first formalize the problem and analyze its complexity. Then we give a heuristic approach which has runtime $\mathcal{O}((|V|+c)|E|+(|V|+c)2log(|V|+c))$, where c denotes the number of crossings. Our visualization algorithm follows the topology-shape-metrics approach for orthogonal layouts and produces satisfying results in practice.

## 16:10 - 17:50 Session H

Chair: Walter Didimo

Damian Merrick and Joachim Gudmundsson
**Path Simplification for Metro Map Layout**

We investigate the problem of creating simplified representations of polygonal paths. Specifically, we look at a path simplification problem in which line segments of a simplification are required to conform with a restricted set of directions C. An algorithm is given to compute such simplified paths in $O(|C|^3n^2)$ time, where n is the number of vertices in the original path. This result is extended to produce an algorithm for graphs induced by multiple intersecting paths. The algorithm is applied to construct schematised representations of real world railway networks, in the style of metro maps.

Marc Benkert, Martin Nöllenburg, Takeaki Uno and Alexander Wolff
**Minimizing Intra-Edge Crossings in Wiring Diagrams and Public Transport Maps**

In this paper we consider a new problem that occurs when drawing wiring diagrams or public transportation networks.Given an embedded graph $G = (V, E)$ (e.g. the streets served by a bus network) and a set $L$ of $n$ paths in $G$ (i.e. the bus lines), we want to draw the paths along the edges of $G$ such that they cross each other as few times as possible. For esthetic reasons we insist that the relative order of the lines that traverse a node does not change in that node. Our main contribution is an algorithm that minimizes the number of crossings on a single edge $\{u, v\} \in E$ if we are given the order of the incoming and outgoing paths. The difficulty is deciding the order of the paths that terminate in $u$ or $v$ w.r.t. the fixed order of the paths that do not end there. Our algorithm uses dynamic programming and takes $O(n^2)$ time, where $n$ is the number of terminating paths.

David Eppstein
**Upright-Quad Drawing of st-Planar Learning Spaces**

We consider graph drawing algorithms for learning spaces, a type of st-oriented partial cube graph used to model states of knowledge of students. We show that, whenever such a graph is st-planar, we can draw it so all internal faces are convex quadrilaterals with the bottom side horizontal and the left side vertical, with one minimal and one maximal vertex. Conversely, every such drawing comes from an st-planar learning space in this way. We also describe connections between these graphs and arrangements of translates of a quadrant.

Michael B. Dillencourt, David Eppstein and Michael T. Goodrich
**Choosing Colors for Geometric Graphs via Color Space Embeddings**

Graph drawing research traditionally focuses on producing geometric embeddings of graphs satisfying various aesthetic constraints. However additional work must still be done to draw a graph even after its geometric embedding is specified: assigning display colors to the graph's vertices. We study the additional aesthetic criterion of assigning distinct colors to vertices of a geometric graph so that the colors assigned to adjacent vertices are as different from one another as possible. We formulate this as a problem involving perceptual metrics in color space and we develop algorithms for solving this problem by embedding the graph in color space. We also present an application of this work to a distributed load-balancing visualization problem.

### 19:00 Conference Dinner in Karlsruhe Palace

## Wednesday, September 20, 2006

### 9:00 - 10:40 Session I

Chair: Alexander Wolff

Stephen Kobourov and Matthew Landis

**Morphing Planar Graphs in Spherical Space**

We consider the problem of intersection-free planar graph morphing, and in particular, a generalization from Euclidean space to spherical space. We show that, under certain conditions, there exists a continuous and intersection-free morph between two sphere drawings of a maximally planar graph, where sphere drawings are the spherical equivalent of plane drawings: intersection-free geodesic-arc drawings. In addition, we describe a morphing algorithm along with its implementation. Movies of sample morphs can be found at `http://www.cs.arizona.edu/~mlandis/smorph`.

Stephen Wismath, Emilio Di Giacomo, Walter Didimo, Giuseppe Liotta, Henk Meijer and Francesco Trotta

**k-chromatic point-set embeddability of outerplanar graphs**

This paper addresses the problem of designing drawing algorithms that receive as input a planar graph $G$, a partitioning of the vertices of $G$ into $k$ different semantic categories $V_0, \cdots, V_{k-1}$, and $k$ disjoint sets $S_0, \cdots, S_{k-1}$ of points in the plane with $|V_i| = |S_i|$ ($i \in \{0, \cdots, k-1\}$). The desired output is a planar drawing such that the vertices of $V_i$ are mapped onto the points of $S_i$ and such that the curve complexity of the edges (i.e. the number of bends along each edge) is kept small. Particular attention is devoted to outerplanar graphs, for which lower and upper bounds on the number of bends in the drawings are established.

Mareike Massow and Stefan Felsner

**Thickness of Bar 1-Visibility Graphs**

Bar k-visibility graphs are graphs admitting a representation in which the vertices correspond to horizontal line segments, called bars, and the edges correspond to vertical lines of sight which can traverse up to k bars. These graphs were introduced by Dean et al. who conjectured that bar 1-visibility graphs have thickness at most 2. We construct a bar 1-visibility graph having thickness 3, disproving their conjecture. For a special case of bar 1-visibility graphs we present an algorithm partitioning the edges into two plane graphs, showing that for this class the thickness is indeed bounded by 2.

Canan Yildiz, Petra Mutzel and Wilhelm Barth

**A New Approximation Algorithm for Bend Minimization in the Kandinsky Model**

The Kandinsky model has been introduced by Foessmeier and Kaufmann in order to deal with planar orthogonal drawings of planar graphs with maximal vertex degree higher than four. No polynomial-time algorithm is known for computing a (region preserving) bend minimal Kandinsky drawing. In this paper we suggest a new 2-approximation algorithm for this problem. Our extensive computational experiments show that the quality of the computed solutions is better than those of its predecessors. E.g., for all instances in the Rome graph benchmark library it computed the optimal solution, and for randomly generated triangulated graphs with up to 800 vertices, the absolute error was less than 2 on average.

## 11:10 - 12:40 Session J

Chair: Bettina Speckmann

Emilio Di Giacomo, Walter Didimo and Giuseppe Liotta
**Radial Drawings of Graphs: Geometric Constraints and Trade-offs**

This paper studies how to compute radial drawings of graphs by taking into account additional geometric constraints which correspond to typical aesthetic and semantic requirements for the visualization. The following requirements are considered: vertex centrality, edge crossings, curve complexity, and radial distribution of the vertices. Trade-offs among these requirements are discussed and different linear-time drawing algorithms are presented. The results in this paper also contribute to answer a question about radial level planarity testing left open by Bachmaier, Brandenburg, and Forster ("Radial level planarity testing and embedding in linear time". JGAA, 9(1):53-97, 2005.)

Alejandro Estrella-Balderrama, Joe Fowler and Stephen Kobourov
**Characterization of Unlabeled Level Planar (ULP) Trees**

Consider a graph $G$ drawn in the xy-plane so that each vertex lies on its own distinct horizontal line $L_j = \{(x, j) : x \text{is Reals}\}$ or j-level. The bijection $\phi$ that maps the set of vertices $V$ to a set of distinct horizontal lines $L_j$ (where $j \in \{1, 2, ..., n\}$) forms a labeling of the vertices. Such a graph $G$ with the labeling $\phi$ is called an n-level graph and is said to be level planar if it can be drawn with straight-line edges and no crossings while keeping each vertex on its own level. In this paper, we consider the class of trees that are level planar regardless of their labeling. We call such trees unlabeled level planar (ULP).Our contributions are three-fold. First, we provide a complete characterization of ULP trees in terms of a pair of forbidden subtrees. Second, we show how to embed ULP trees in linear time. Third, we provide a linear time recognition algorithm for ULP trees.

Emilio Di Giacomo, Luca Grilli and Giuseppe Liotta
**Drawing Bipartite Graphs on Two Curves**

Let G be a bipartite graph, and let $\lambda_e$, $\lambda_i$ be two parallel convex curves; we study the question about whether G admits a planar straight line drawing such that the vertices of one partite set of G lie on $\lambda_e$ and the vertices of the other partite set lie on $\lambda_i$. A characterization is presented that gives rise to linear time testing and drawing algorithms.

Emden R. Gansner and Yehuda Koren
**Improved circular layouts**

Circular graph layout is a drawing scheme where all nodes are placed on the perimeter of a circle. An inherent issue with circular layouts is that the rigid restriction on node placement often gives rise to long edges and an overall dense drawing. We suggest here three independent, complementary techniques for lowering the density and improving the readability of circular layouts. First, a new algorithm is given for placing the nodes on the circle such that edge lengths are minimized. Second, we enhance the circular drawing style by allowing some of the edges to be routed around the exterior of the circle. This is accomplished with an algorithm for optimally selecting such a set of externally routed edges. The third technique reduces density by coupling groups of edges as bundled splines that share part of their route. Together, these techniques are able to reduce clutter, density and crossings compared with existing methods.

## 14:00 - 15:30 Session K

Chair: David Wood

Huamin Qu, Hong Zhou and Yingcai Wu
**Controllable and Progressive Edge Clustering for Large Networks**

Node-link diagrams or networks are widely used in information visualization to show relationships among data. However, with the size of data becomes increasingly large, node-link diagrams are easily overwhelmed and become cluttered and visually confusing for users. In this paper, we propose a novel edge clustering method based on Delaunay triangulation to reduce visual clutter for node-link diagrams. Our method uses curves instead of straight lines to represent links and these curves can be grouped together according to their relative spatial positions and directions. We further introduce progressive edge clustering to achieve continuous level-of-details for large network visualization. We demonstrate how our techniques can be used to generate various visualization effects such as embedded flow maps and embedded train tracks.

Michael Hirsch, Henk Meijer and David Rappaport
**Biclique Edge Cover Graphs and Confluent Drawings**

Confluent drawing is a technique that allows some non-planar graphs to be visualized in a planar way. This approach merges edges together, drawing groups of them as single tracks, similar to train tracks. In the general case, producing confluent drawings automatically has proven quite difficult. We introduce the biclique edge cover graph, that represents a graph G as an interconnected set of cliques and bicliques. We do this in such a way as to permit a straightforward transformation to a confluent drawing of G. Our result is a new sufficient condition for confluent planarity and an additional algorithmic approach for generating confluent drawings. We give some experimental results gauging the performance of existing confluent drawing heuristics.

Stefan Felsner and Florian Zickfeld
**Schnyder Woods and Orthogonal Surfaces**

In this paper we study connections between Schnyder woods and orthogonal surfaces. Schnyder woods and the face counting approach have important applications in graph drawing and dimension theory. Orthogonal surfaces explain the connections between these seemingly unrelated notions. We use these connections for an intuitive proof of the Brightwell-Trotter Theorem: The face lattice of a 3-polytopeminus one face has dimension three. Our proof yields a companion linear time algorithm for the construction of the three linear orders that realize the face lattice. Coplanar orthogonal surfaces are in correspondance with a large class of convex straight line drawings of 3-connected planar graphs. We show that Schnyder's face counting approach with weighted faces can be used to construct all coplanar orthogonal surfaces and hence the corresponding drawings. Appropriate weights are computable in linear time.

Therese Biedl and Franz J. Brandenburg
**Partitions of Graphs into Trees**

In this paper, we study the *k-tree partition problem* which is a partition of the set of edges of a graph into $k$ edge-disjoint trees. This problem occurs at several places with applications e.g. in network reliability and graph theory. In graph drawing, there is the still unbeaten $(n-2)\times(n-2)$ area planar straight line drawing of maximal planar graphs using Schnyder's realizers, which are a 3-tree partition of the inner edges. Maximal planar bipartite graphs have a 2-tree partition, as shown by Ringel. Here we give a different proof of this result with a linear time algorithm. The algorithm makes use of a new ordering which is of interest of its own. Then we establish the NP-hardness of the $k$-tree partition problem for general graphs and $k \geq 2$. This parallels partition problems for the vertices, but it sharply contrasts the efficient computation of partitions into forests (also known as arboricity) by matroid techniques.

## 16:30 - 18:00 Visit to the ZKM

# Posters

Bruno Pinaud, Pascale Kuntz and Fabien Picarougne
**The Website for Graph Visualization Software References (GVSR)**

Graph drawing software are now commonly used. However, the choice of a well-adapted program may be hard for an inexperienced user. This poster presents a website – available at `http://hulk.knowesia.fr` – built to help users choose a program adapted to their problems. So far, this site uniformely presents fifty programs and aims at helping users both in their choices and in comparing the programs.

Christopher Homan, Andrew Pavlo and Jonathan Schull
**Smoother transitions between breadth-first-spanning-tree-based drawings**

We demonstrate a collection of techniques that seek to make the transition between drawings based on two topologically distinct spanning trees of the same graph as clear as possible.

Tim Dwyer, Kim Marriott and Peter J. Stuckey
**Fast Node Overlap Removal - Correction**

We detail an oversight in our recent paper on a method for node overlap removal. The error is in the algorithm satisfy VPSC and leads to a rarely occurring case where not all non-overlap constraints are satisfied. We give the required additions to the algorithm to obtain correct behaviour and revise the worst case complexity.

Dennis Goehlsdorf and Martin Siebenhaller
**Placing connected components of disconnected graphs**

A problem arising when drawing disconnected graphs, is the placement of the connected components. The problem corresponds to finding an appropriate two-dimensional, non-overlapping placement of given objects. Most layout algorithms do not care about this problem and layout each component separately. Thus, an additional step is needed to arrange these components. There are only few approaches in literature which perform this task. We review some of them and present new methods that improve existing results. Our approach is based on a classical greedy approach described by Freivalds et al. which uses a polyomino representation of the objects. We introduce new quality measures to evaluate a two-dimensional placement which yield more compact layouts. Our approach particularly eliminates most cases in which previous approaches returned poor results.

Martin Harrigan and Patrick Healy
**Drawing a Significant Spanning Tree of a Directed Graph**

A directed graph can model any ordered relationship between objects. However, many relationships found in practice, for example, the dependency relationship between packages in a large software system, tend to have a specific structure. Packages depend on base packages with common functionality and, more significantly, on certain application-specific packages. It is reasonable to assume that this graph has a significant spanning tree – the presence of certain dependencies between packages are more significant than others. We present a variation of the well-known Sugiyama framework for drawing a directed graph that emphasizes this spanning tree. We combine two steps of the framework (leveling and crossing minimisation) by finding, in linear time, a leveling of the graph that is level planar with respect to some significant spanning tree and restricting the permutations of the vertices on each level to those that constitute a level planar embedding of this subgraph. Using a Fiedler vector we choose permutations of the vertices on each level that reduce the number of crossings between the remaining edges

Anil Ada, Melanie Coggan, Paul Di Marco, Alain Doyon, Liam Flookes, Samuli Heilala, Ethan Kim, Jonathan Li On Wing, Louis-Francois Preville-Ratelle, Sue Whitesides and Nuo Yu
**On Bus Graph Realizability**

We consider the following graph embedding problem: Given a bipartite graph $G = (V1, V2; E)$, where the maximum degree of vertices in V2 is 4, can G be embedded on a two dimensional grid such that each vertex in V1 is drawn as a line segment along a grid line, each vertex in V2 is drawn as a point at a grid point, and each edge $e = (u, v)$ for some u in V1 and v in V2 is drawn as a line segment connecting u and v, perpendicular to the line segment for u? We show that this problem is NP-complete, and sketch how our proof techniques can be used to show the hardness of several other related problems.

Emden R. Gansner, Adam L. Buchsbaum and Suresh Venkatasubramanian
**Directed Graphs and Rectangular Layouts**

This paper deals with the problem, arising in practice, of drawing a directed graph as a collection of disjoint, isothetic rectangles, where the rectangles of the nodes of each edge must touch and where the placement of the rectangles respects the ordering of the edges. It provides characterizations for those graphs having the special type of rectangular layout known as a rectangular dual. It then characterizes the st-graphs having rectangular layouts in terms of the existence of certain planar embeddings and the non-existence of a particular subgraph.

Sergey Bereg, Markus Völker, Alexander Wolff and Yuanyi Zhang
**Straightening Drawings of Clustered Hierarchical Graphs**

We deal with making drawings of clustered layered graphs nicer. Given a planar graph $G = (V, E)$ with an assignment of the vertices to horizontal layers, a plane drawing of G (with polygonal or y-monotone edges) can be specified by stating for each layer the order of the vertices lying on and the edges intersecting that layer. Given these orders and a recursive partition of the vertices into clusters, our aim is to draw G such that (i) edges are straight-line segments, (ii) clusters lie in disjoint convex regions, and (iii) no edge intersects a cluster boundary twice. First we show that a drawing of the above type can be computed using a linear-time recursive algorithm if an additional constraint is imposed on the clustering of the input graph. The constraint is not very restrictive. Second we give a linear programming (LP) formulation that always yields a drawing that fulfills the above three requirements - if such a drawing exists. The number of variables and constraints in our LP formulation is linear in the size of the graph. We discuss two different objective functions and compare them visually. We also develop an algorithm for drawing a clustered graph based on a monotone separating path. The algorithm guarantees the drawing of two clusters if such a path exists.

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