



## *16th International Symposium on Graph Drawing*

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## Conference Abstracts

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## Succinct Greedy Graph Drawing in the Hyperbolic Plane

David Eppstein and Michael Goodrich

**Abstract:** We describe an efficient method for drawing any  $n$ -vertex simple graph  $G$  in the hyperbolic plane. Our algorithm produces *greedy* drawings, which support *greedy geometric routing*, so that a message  $M$  between any pair of vertices may be routed geometrically, simply by having each vertex that receives  $M$  pass it along to any neighbor that is closer in the hyperbolic metric to the message's eventual destination. More importantly, for networking applications, our algorithm produces *succinct* drawings, in that each of the vertex positions in one of our embeddings can be represented using  $O(\log n)$  bits and the calculation of which neighbor to send a message to may be performed efficiently using these representations. These properties are useful, for example, for routing in sensor networks, where storage and bandwidth are limited.

## An Algorithm to Construct Greedy Drawings of Triangulations

Patrizio Angelini, Fabrizio Frati, and Luca Grilli

**Abstract:** We show an algorithm to construct greedy drawings of every given triangulation.

## Crossing and Weighted Crossing Number of Near-planar Graphs

Sergio Cabello and Bojan Mohar

**Abstract:** A nonplanar graph  $G$  is near-planar if it contains an edge  $e$  such that  $G - e$  is planar. The problem of determining the crossing number of a near-planar graph is exhibited from different combinatorial viewpoints. On the one hand, we develop min-max formulas involving efficiently computable lower and upper bounds. These min-max results are the first of their kind in the study of crossing numbers and improve the approximation factor for the approximation algorithm given by Hliněný and Salazar (Graph Drawing GD 2006). On the other hand, we show that it is NP-hard to compute a weighted version of the crossing number for near-planar graphs.

## Cubic Graphs Have Bounded Slope Parameter

Balázs Keszegh, János Pach, Dömötör Pálvölgyi, and Géza Tóth

**Abstract:** We show that every finite connected graph  $G$  with maximum degree three and with at least one vertex of degree smaller than three has a straight-line drawing in the plane satisfying the following conditions. No three vertices are collinear, and a pair of vertices form an edge in  $G$  if and only if the segment connecting them is parallel to one of the sides of a previously fixed regular pentagon. It is also proved that every finite graph with maximum degree three permits a straight-line drawing with the above properties using only at most seven different edge slopes.

## Unimaximal sequences of pairs in rectangle visibility drawing

(short paper)

Jan Stola

**Abstract:** We study the existence of unimaximal subsequences in sequences of pairs of integers e.g. the subsequences that have exactly one local maximum in each component of the subsequence. We show that every sequence of  $\frac{1}{12}n^2(n^2-1)+1$  pairs has a unimaximal subsequence of length  $n$ . We prove that this bound is tight. We apply this result to the problem of the largest complete graph with a 3D rectangle visibility representation and improve the upper bound from 55 to 50.

## Visibility Representations of Four-Connected Plane Graphs with Near Optimal Heights

Chie-Yu Chen, Ya-Fei Hung, and Hsueh-I Lu

**Abstract:** A *visibility representation* of a graph  $G$  is to draw the nodes of  $G$  with non-overlapping horizontal line segments such that the line segments representing any two distinct adjacent nodes are vertically visible to each other. If  $G$  is a plane graph, i.e., a planar graph equipped with a planar embedding, a visibility representation of  $G$  has the additional requirement of reflecting the given planar embedding of  $G$ . For the case that  $G$  is an  $n$ -node four-connected plane graph, we give an  $O(n)$ -time algorithm to produce a visibility representation of  $G$  with height at most  $\frac{n}{2} + 2\sqrt{\frac{n}{2}} - 1$ . For infinite number of  $n$ , we also show  $n$ -node four-connected plane graphs  $G$  whose visibility representations require heights at least  $\frac{n}{2}$ .

## The Topology of Bendless Three-Dimensional Orthogonal Graph Drawing

David Eppstein

**Abstract:** We consider embeddings of 3-regular graphs into 3-dimensional Cartesian coordinates, in such a way that two vertices are adjacent if and only if two of their three coordinates are equal (that is, if they lie on an axis-parallel line) and such that no three points lie on the same axis-parallel line; we call a graph with such an embedding an *xyz graph*. We describe a correspondence between xyz graphs and face-colored embeddings of the graph onto two-dimensional manifolds, and we relate bipartiteness of the *xyz graph* to orientability of the underlying topological surface. Using this correspondence, we show that planar graphs are *xyz graphs* if and only if they are bipartite, cubic, and three-connected, and that it is NP-complete to determine whether an arbitrary graph is an *xyz graph*. We also describe an algorithm with running time  $O(n2^{n/2})$  for testing whether a given graph is an *xyz graph*.

## Rapid Multipole Graph Drawing on the GPU

Apeksha Godiyal, Jared Hoberock, Michael Garland, and John Hart

**Abstract:** As the general purpose GPUs are becoming powerful, ubiquitous and easier to program, they have become more amenable to improve the computationally expensive task of drawing large graphs. This paper describes a new parallel analysis of the multipole method of graph drawing to support its efficient GPU implementation. We use a variation of the Fast Multipole Method to estimate the long distance repulsive forces,

between graph vertices, in the force directed layout. We support these multipole computations efficiently with a k-d tree constructed and traversed on the GPU. The algorithm achieves impressive speedup over previous CPU and GPU methods, drawing graphs with millions of vertices within a few seconds via CUDA on an nVidia GeForce 8800.

## Networks in Biology - from Identification, Analysis to Interpretation

(invited talk)

Jesper Tegnér

**Abstract:** Over the last decade networks has become a unifying language in biology. Yet we are only in the beginning of understanding their significance for biology and their medical applications. I will talk about the diversity of biological networks composed either of genes, proteins, metabolites, or cells and the associated methods for finding these graphs in the data. Next I will provide an overview of different methods of analysis and what kind of insights that have been obtained. During the talk I will highlight current challenging problems requiring computational skills w.r.t. identification, analysis, algorithms, visualization and software.

## Clustered Planarity: Clusters with Few Outgoing Edges

Ondřej Suchý, Vít Jelínek, Marek Tesař, and Tomáš Vyskočil

**Abstract:** We present a linear algorithm for c-planarity testing of clustered graphs, in which every cluster has at most four outgoing edges.

## Computing Maximum C-Planar Subgraphs

(short paper)

Markus Chimani, Carsten Gutwenger, Mathias Jansen, Karsten Klein, and Petra Mutzel

**Abstract:** Deciding c-planarity for a given clustered graph  $C = (G, T)$  is one of the most challenging problems in current graph drawing research. Though it is yet unknown if this problem is solvable in polynomial time, latest research focused on algorithmic approaches for special classes of clustered graphs. In this paper, we introduce an approach to solve the *general* problem using integer linear programming (ILP) techniques. We give an ILP formulation that also includes the natural generalization of c-planarity testing—the *maximum c-planar subgraph problem* (MCSP)—and solve this ILP with a branch-and-cut algorithm. Our computational results show that this new approach is already successful for many clustered graphs of small to medium sizes and thus can be the foundation of a practically efficient algorithm that integrates further sophisticated ILP techniques.

## Clustered Planarity: Embedded Clustered Graphs with Two-Component Clusters

Vít Jelínek, Eva Jelinkova, Jan Kratochvíl, and Bernard Lidický

**Abstract:** We present a polynomial-time algorithm for c-planarity testing of clustered graphs with fixed plane embedding and such that every cluster induces a subgraph with at most two connected components.

## Visual Analysis of One-To-Many Matched Graphs

(long demo)

Emilio Di Giacomo, Walter Didimo, Giuseppe Liotta, and Pietro Palladino

**Abstract:** Motivated by applications of social network analysis and of Web search clustering engines, we describe an algorithm and a system for the display and the visual analysis of two graphs  $G_1$  and  $G_2$  such that: (i) Each  $G_i$  is defined on a different data set with its own primary relationships; (ii) there are secondary relationships between the vertices of  $G_1$  and those of  $G_2$ . Our main goal is to compute a drawing of  $G_1$  and  $G_2$  that makes clearly visible the relations between the two graphs by minimizing their crossings, and that also takes into account some other important aesthetic requirements like number of bends, area, and aspect ratio. Application examples and experiments on the system performances are also presented. We observe that other systems have been recently described in the literature for the visual analysis of graphs with secondary relationships between their vertices, but these systems follow the common approach of drawing each graph independently of the other, which may give rise to many unwanted crossings for the secondary relationships.

## Topological Morphing of Planar Graphs

Patrizio Angelini, Pier Francesco Cortese, Giuseppe Di Battista, and Maurizio Patrignani

**Abstract:** In this paper we study how two planar embeddings of the same biconnected graph can be morphed one into the other while minimizing the number of elementary changes.

## An SPQR-Tree Approach to Decide Special Cases of Simultaneous Embedding with Fixed Edges

J. Joseph Fowler, Carsten Gutwenger, Michael Juenger, Petra Mutzel, and Michael Schulz

**Abstract:** We present an almost linear time algorithm for solving the simultaneous embedding problem with fixed edges (SEFE) for a planar graph and a pseudoforest (a graph with at most one cycle) by reducing it to the following embedding problem: Given a planar graph  $G$ , a cycle  $C$  of  $G$ , and a partitioning of the remaining vertices of  $G$ , does there exist a planar embedding in which the induced subgraph on each vertex partite of  $G - C$  is contained entirely inside or outside  $C$ ? For the latter problem, we present an algorithm that is based on SPQR-trees and has running time  $O(|V|\alpha(|V|))$  where  $\alpha$  is the inverse Ackermann function. We also show how we can employ SPQR-trees to decide SEFE for two planar graphs where one graph has at most two cycles and the intersection is a pseudoforest in  $O(|V|\alpha(|V|))$  time. These results give rise to our hope that our SPQR-tree approach might eventually lead to a polynomial time algorithm for deciding the general SEFE problem for two planar graphs.

## Graph Simultaneous Embedding Tool

(long demo)

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

**Abstract:** Problems in simultaneous graph drawing involve the layout of several graphs on a shared vertex set. This paper describes a Graph Simultaneous Embedding Tool, GraphSET, designed to allow the investigation of a wide range of embedding problems. GraphSET can be used in the study of several variants of simultaneous



embedding including simultaneous geometric embedding, simultaneous embedding with fixed edges with and without edge bends, and colored simultaneous embedding with the vertex set partitioned into color classes. The tool has two primary uses: (i) studying theoretical problems in simultaneous graph drawings through the production of examples and counterexamples and (ii) producing layouts of given classes of graphs using built-in implementations of known algorithms. GraphSET along with movies illustrating its utility are available at <http://graphset.cs.arizona.edu>.

## Hamiltonian Alternating Paths on Bicolored Double-chains

Josef Cibulka, Jan Kyncl, Viola Meszaros, Rudolf Stolar, and Pavel Valtr

**Abstract:** We find arbitrarily large finite sets  $S$  of points in general position in the plane with the following property. If the points of  $S$  are equitably 2-colored (i.e., the sizes of the two color classes differ by at most one), then there is a polygonal line consisting of straight-line segments with endpoints in  $S$ , which is Hamiltonian, non-crossing, and alternating (i.e., each point of  $S$  is visited exactly once, every two non-consecutive segments are disjoint, and every segment connects points of different colors). We show that the above property holds for so-called double-chains with each of the two chains containing at least one fifth of all the points. Our proof is constructive and can be turned into a linear-time algorithm. On the other hand, we show that the above property does not hold for double-chains in which one of the chains contains at most roughly  $1/29$  of all the points.

## The Binary Stress Model for Graph Drawing

Yehuda Koren and Ali Civril

**Abstract:** We introduce a new force-directed model for computing graph layout. The model bridges the two more popular force directed approaches – the stress and the electrical-spring models – through the *binary stress* cost function, which is a carefully defined energy function with low descriptive complexity allowing fast computation via a Barnes-Hut scheme. This allows us to overcome optimization pitfalls from which previous methods suffer. In addition, the binary stress model often offers a unique viewpoint to the graph, which can occasionally add useful insight to its topology. The model uniformly spreads the nodes within a circle. This helps in achieving an efficient utilization of the drawing area. Moreover, the ability to uniformly spread nodes regardless of topology, becomes particularly helpful for graphs with low connectivity, or even with multiple connected components, where there is not enough structure for defining a readable layout.

## Efficient Node Overlap Removal Using a Proximity Stress Model

Emden Gansner and Yifan Hu

**Abstract:** When drawing graphs whose nodes contain text or graphics, the non-trivial node sizes must be taken into account, either as part of the initial layout or as a post-processing step. The core problem in avoiding or removing overlaps is to retain the structural information inherent in a layout while minimizing the additional area required. This paper describes two methods for measuring the similarity of two layouts. It also presents a new node overlap removal algorithm that, by the measures mentioned, does well at retaining a graph's shape while using little additional area and time.

## An Experimental Study on Distance-Based Graph Drawing

Ulrik Brandes and Christian Pich

**Abstract:** In numerous application areas, general undirected graphs need to be drawn, and force-directed layout appears to be the most frequent choice. We present an extensive experimental study showing that, if the goal is to represent the distances in a graph well, a combination of two simple algorithms based on variants of multi-dimensional scaling is to be preferred because of their efficiency, reliability, and even simplicity. We also hope that details in the design of our study help advance experimental methodology in algorithm engineering and graph drawing, independent of the case at hand.

## Topology Preserving Constrained Graph Layout

Tim Dwyer, Kim Marriott, and Michael Wybrow

**Abstract:** Constrained graph layout is a recent generalization of force-directed graph layout which allows constraints on node placement. We give a constrained graph layout algorithm that takes an initial feasible layout and improves it while preserving the topology of the initial layout. The algorithm supports poly-line connectors and clusters. During layout the connectors and cluster boundaries act like impervious rubber-bands which try to shrink in length. The intended application for our algorithm is dynamic graph layout, but it can also be used to improve layouts generated by other graph layout techniques.

## Graph Drawing for Security Visualization

(invited talk)

Roberto Tamassia

**Abstract:** As the number of devices connected to the internet continues to grow rapidly and software systems are being increasingly deployed on the web, security and privacy have become crucial properties for networks and applications. Due the complexity and subtlety of cryptographic methods and protocols, software architects and developers often fail to incorporate security principles in their designs and implementations. Also, most users have minimal understanding of security threats. While several tools for developers, system administrators and security analysts are available, these tools typically provide information in the form of textual logs or tables, which are cumbersome to analyze. Thus, in recent years, the field of security visualization has emerged to provide novel ways to display security-related information so that it is easier to understand. In this talk, we give a survey of approaches to the visualization of computer security concepts that use graph drawing techniques. We consider a variety of fundamental security and privacy issues, including network traffic monitoring, intrusion detection, vulnerability analysis, forensic analysis, authentication, access control, privacy compliance, and trust negotiation. We show how graphs can be used as an effective modeling tool in computer security and we give examples of how several classic graph drawing techniques have been used in current security visualization prototypes. Finally, we mention some promising research directions for the graph drawing community that can contribute to the development of the next generation of visual security tools. This presentation is based on joint work with Bernardo Palazzi and Charalampos Papamanthou.

This talk is dedicated to the memory of Paris C. Kanellakis, a prominent computer scientist and Brown faculty member who died with his family in an airplane crash in December 1995. His unbounded energy and outstanding scholarship greatly inspired all those who interacted with him.

## Embeddability Problems for Upward Planar Digraphs

Francesco Giordano, Giuseppe Liotta, and Sue Whitesides

**Abstract:** We study two embedding problems for upward planar digraphs. Both problems arise in the context of drawing sequences of upward planar digraphs having the same set of vertices, where the location of each vertex is to remain the same for all the drawings of the graphs. We develop a method, based on the notion of book embedding, that gives characterization results for embeddability as well as testing and drawing algorithms.

## A Fully Dynamic Algorithm to Test The Upward Planarity of Single Source Embedded Digraphs

Aimal Rextin and Patrick Healy

**Abstract:** We present a dynamic algorithm that checks if a single-source embedded digraph is upward planar in the presence of edge insertions and edge deletions. Let  $G_\phi$  be an upward planar single-source embedded digraph and let  $G'_{\phi'}$  be a single-source embedded digraph obtained by updating  $G_\phi$ . We show that the upward planarity of  $G'_{\phi'}$  can be checked in  $O(\log n)$  amortized time when the external face is fixed. Moreover, we show that  $O(n)$  time is needed when the external face is allowed to change.

## On the Hardness of Orthogonal-Order Preserving Graph Drawing

Barbara Pampel and Ulrik Brandes

**Abstract:** There are several scenarios in which a given drawing of a graph is to be modified subject to preservation constraints. Examples include shape simplification, sketch-based, and dynamic graph layout. While the orthogonal ordering of vertices is a natural and frequently called for preservation constraint, we show that, unfortunately, it results in severe algorithmic difficulties even for the simplest graphs. More precisely, we show that orthogonal-order preserving rectilinear and uniform edge length drawing is NP-hard even for (unions of) paths.

## Generalizing the Shift Method for Rectangular Shaped Vertices with Visibility Constraints

(short paper)

Martin Mader and Seok-Hee Hong

**Abstract:** In this paper we present a generalization of the shift method algorithm to obtain a straight-line grid drawing of a triconnected graph, where vertex representations have a certain area. In contrast to earlier work, we propose vertex representations having a rectangular shape. Additionally, one may demand maintainance of the criterion of strong visibility, that is, any possible line segment connecting two adjacent vertices cannot cross another vertex' representation. We prove that the proposed method produces a straight-line grid drawing of a graph in linear time with an area bound, that, compared to the bound of the original algorithm, is only extended by the size of the rectangles.

## Placing Text Boxes on Graphs: A Fast Approximation Algorithm for Maximizing Overlap of a Square and a Simple Polygon

Sjoerd van Hagen and Marc van Kreveld

**Abstract:** In this paper we consider the problem of placing a unit square on a face of a drawn graph bounded by  $n$  vertices such that the area of overlap is maximized. Exact algorithms are known that solve this problem in  $O(n^2)$  time. We present an approximation algorithm that—for any given  $\epsilon > 0$ —places a  $(1 + \epsilon)$ -square on the face such that the area of overlap is at least the area of overlap of a unit square in an optimal placement. The algorithm runs in  $O(\frac{1}{\epsilon} n \log^2 n)$  time.

Extensions of the algorithm solve the problem for unit discs, using  $O(\frac{\log(1/\epsilon)}{\epsilon\sqrt{\epsilon}} n \log^2 n)$  time, and for bounded aspect ratio rectangles of unit area, using  $O(\frac{1}{\epsilon^2} n \log^2 n)$  time.

## Removing Node Overlaps Using Multi-sphere Scheme

(short paper)

Takashi Imamichi, Yohei Arahori, Jaeseong Gim, Seok-Hee Hong, and Hiroshi Nagamochi

**Abstract:** In this paper, we consider the problem of removing overlaps of labels in a given layout by changing locations of some of the overlapping labels, and present a new method for the problem based on a packing approach, called multi-sphere scheme. Based on this scheme, each label in a given layout is approximated by a set of circles, and a cost function that penalizes the overlap between two objects is introduced. By minimizing the penalty function using a quasi-Newton method, we compute a layout of the set of circles as an approximate solution to the original problem.

We consider two new variations of the label overlap problem, inspired by real world applications, and provide a solution to each problem. Our new approach is very flexible to support various operations such as translation, translation with direction constraints, and rotation. Further, our method can support labels with arbitrary shapes in both 2D and 3D layout settings. Our extensive experimental results show that our new approach is very effective for removing label overlaps.

## Minimal Obstructions for 1-immersions and Hardness of 1-planarity Testing

Vladimir Korzhik and Bojan Mohar

**Abstract:** A graph is 1-planar if it can be drawn on the plane so that each edge is crossed by no more than one other edge. A non-1-planar graph  $G$  is minimal if the graph  $G - e$  is 1-planar for every edge  $e$  of  $G$ . We construct two infinite families of minimal non-1-planar graphs and show that for every integer  $n \geq 63$ , there are at least  $2^{\frac{n}{4} - \frac{54}{n}}$  nonisomorphic minimal non-1-planar graphs of order  $n$ . It is also proved that testing 1-planarity is NP-complete. As an interesting consequence we obtain a new, geometric proof of NP-completeness of the crossing number problem, even when restricted to cubic graphs. This resolves a question of Hliněný.

## Connected Rectilinear Graphs on Point Sets

(short paper)

Maarten Löffler and Elena Mumford

**Abstract:** Let  $V$  be a set of  $n$  points in  $R^d$ . We study the question whether there exists an orientation such that  $V$  is the vertex set of a connected rectilinear graph in that orientation. A graph is rectilinear if its edges are straight line segments in  $d$  pairwise perpendicular directions. We prove that at most one such orientation can be possible, up to trivial rotations of 90 degrees around some axis. In addition, we present an algorithm for computing this orientation (if it exists) in  $O(n^2)$  time when  $d = 2$ .

## 3-Regular non 3-Edge-Colorable Graphs with Polyhedral Embeddings in Orientable Surfaces

(short paper)

Martin Kochol

**Abstract:** The Four Color Theorem is equivalent with its dual form stating that each 2-edge-connected 3-regular planar graph is 3-edge-colorable. In 1968, Grunbaum conjectured that similar property holds true for any orientable surface, namely that each 3-regular graph with a polyhedral embedding in an orientable surface has a 3-edge-coloring. Note that an embedding of a graph in a surface is called polyhedral if its geometric dual has no multiple edges and loops. We present a negative solution of this conjecture, showing that for each orientable surface of genus at least 5, there exists a 3-regular non 3-edge-colorable graph with a polyhedral embedding in the surface.

## Drawing (Complete) Binary Tanglegrams: Hardness, Approximation, Fixed-Parameter Tractability

Kevin Buchin, Maike Buchin, Jaroslaw Byrka, Martin Nöllenburg, Yoshio Okamoto, Rodrigo Silveira, and Alexander Wolff

**Abstract:** A binary tanglegram is a pair  $\langle S, T \rangle$  of binary trees whose leaf sets are in one-to-one correspondence; matching leaves are connected by inter-tree edges. For applications, for example in phylogenetics, it is essential that both trees are drawn without edge crossing and that the inter-tree edges have as few crossings as possible. It is known that finding a drawing with the minimum number of crossings is NP-hard and that the problem is fixed-parameter tractable with respect to that number.

We prove that under the Unique Games Conjecture there is no constant-factor approximation for general binary trees. We show that the problem is hard even if both trees are complete binary trees. For this case we give an  $O(n^3)$ -time 2-approximation and a new and simple fixed-parameter algorithm. We show that the maximization version of the dual problem for general binary trees can be reduced to a version of MaxCut for which the algorithm of Goemans and Williamson yields a 0.878-approximation.

## Two Polynomial Time Algorithms for the Metro-Line Crossing Minimization Problem

Evmorfia Argyriou, Michael Bekos, Michael Kaufmann, and Antonios Symvonis

**Abstract:** The *metro-line crossing minimization (MLCM)* problem was recently introduced as a response to the problem of drawing metro maps or public transportation networks, in general. According to this problem, we are given a planar, embedded graph  $G = (V, E)$  and a set  $L$  of simple paths on  $G$ , called *lines*. The main task is to place the lines on the embedding of  $G$ , so that the number of crossings among pairs of lines is minimized.

Our main contribution is two polynomial time algorithms. The first solves the general case of the MLCM problem, where the lines that traverse a particular vertex of  $G$  are allowed to use any side of it to either “enter” or “exit”, assuming that the endpoints of the lines are located at vertices of degree one. The second one –which is more efficient in terms of time complexity– solves the restricted case, where only the left and the right side of each vertex can be used.

To the best of our knowledge, this is the first time where the general case of the MLCM problem is solved. Previous work in the graph drawing literature was devoted to the restricted case of the MLCM problem under the additional assumption that the endpoints of the lines are either the topmost or the bottommost in their corresponding vertices, i.e., they are either on top or below the lines that pass through the vertex. Even for this case, we improve a known result of Asquith et al. from  $O(|E|^{5/2}|L|^3)$  to  $O(|V|(|E| + |L|))$ .

## Cyclic Leveling of Directed Graphs

Christian Bachmaier, Franz Josef Brandenburg, Wolfgang Brunner, and Gergő Lovász

**Abstract:** The Sugiyama framework is the most commonly used concept for visualizing directed graphs. It draws them in a hierarchical way and operates in four phases: cycle removal, leveling, crossing reduction, and coordinate assignment.

However, there are situations where cycles must be displayed as such, e. g., distinguished cycles in the biosciences and processes that repeat in a daily or weekly turn. This forbids the removal of cycles. In their seminal paper Sugiyama et al. also introduced recurrent hierarchies as a concept to draw graphs with cycles. However, this concept has not received much attention since then.

In this paper we investigate the leveling problem for cyclic graphs. We show that minimizing the sum of the length of all edges is NP-hard for a given number of levels and present three different heuristics for the leveling problem. This sharply contrasts the situation in the hierarchical style of drawing directed graphs, where this problem is solvable in polynomial time.

## Constrained Point-Set Embeddability of Planar Graphs

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

**Abstract:** This paper starts the investigation of a constrained version of the point-set embeddability problem. Let  $G = (V, E)$  be a planar graph with  $n$  vertices,  $G' = (V', E')$  a subgraph of  $G$ , and  $S$  a set of  $n$  distinct points in the plane. We study the problem of computing a point-set embedding of  $G$  on  $S$  subject to the constraint that  $G'$  is drawn with straight-line edges. Different drawing algorithms are presented that guarantee small curve complexity of the resulting drawing, i.e. a small number of bends per edge. It is proved that:

- If  $G'$  is an outerplanar graph and  $S$  is any set of points in convex position, a point-set embedding of  $G$  on  $S$  can be computed such that the edges of  $E - E'$  have at most 4 bends each.
- If  $S$  is any set of points in general position and  $G'$  is a face of  $G$  or if it is a simple path, the curve complexity of the edges of  $E - E'$  is at most 8.

- If  $S$  is in general position and  $G'$  is a set of  $k$  disjoint paths, the curve complexity of the edges of  $E - E'$  is  $O(2^k)$ .

## Tree Drawings on the Hexagonal Grid

Christian Bachmaier, Franz Josef Brandenburg, Wolfgang Brunner, Andreas Hofmeier, Marco Matzeder, and Thomas Unfried

**Abstract:** We consider straight-line drawings of trees on a hexagonal grid. The hexagonal grid is an extension of the common grid, with inner nodes of degree six. We restrict the number of directions used for the children from one to five, and so obtain five patterns: straight,  $Y$ ,  $\psi$ ,  $X$ , and full. The  $\psi$ -drawings generalize hv- or strictly upward drawings to ternary trees. We show that complete ternary trees have a  $\psi$ -drawing on a square of size  $O(n^{1.262})$  and general ternary trees can be drawn within  $O(n^{1.631})$  area. Both bounds are optimal. Sub-quadratic bounds are also obtained for  $X$ -drawings of complete tetra trees, and for full layouts of penta trees. These results parallel and complement the ones of Frati for straightline orthogonal drawings of ternary trees. Moreover, we provide an algorithm for straight-line drawings of penta trees on the hexagonal grid, such that the direction of the edges from a node to its children is given by our patterns and these edges have the same length. However, drawing trees on a hexagonal grid within a prescribed area or with unit length edges is NP-hard.

## Isometric Diamond Subgraphs

(short paper)

David Eppstein

**Abstract:** We describe polynomial time algorithms for determining whether an undirected graph may be embedded in a distance-preserving way into the hexagonal tiling of the plane, the diamond structure in three dimensions, or analogous structures in higher dimensions. The graphs that may be embedded in this way form an interesting subclass of the partial cubes.

## Non-Convex Representations of Graphs

(short paper)

Giuseppe Di Battista, Fabrizio Frati, and Maurizio Patrignani

**Abstract:** We show that every plane graph admits a planar straight-line drawing in which all faces with more than three vertices are non-convex polygons.

## Subdivision Drawings of Hypergraphs

Michael Kaufmann, Marc van Kreveld, and Bettina Speckmann

**Abstract:** We introduce the concept of subdivision drawings of hypergraphs. In a subdivision drawing each vertex corresponds uniquely to a face of a planar subdivision and, for each hyperedge, the union of the faces corresponding to the vertices incident to that hyperedge is connected. Vertex-based Venn diagrams and concrete Euler diagrams are both subdivision drawings. In this paper we study two new types of subdivision drawings



which are more general than concrete Euler diagrams and more restricted than vertex-based Venn diagrams. They allow us to draw more hypergraphs than the former while having better aesthetic properties than the latter.

## Minimum Segment Drawings of Series-Parallel Graphs with the Maximum Degree Three

Md. Abul Hassan Samee, Jawaherul Alam, Muhammad Abdullah Adnan, and Md. Saidur Rahman

**Abstract:** A minimum segment drawing  $T$  of a planar graph  $G$  is a planar straight line drawing of  $G$  that has the minimum number of line segments among all possible planar straight line drawings of  $G$ . In this paper, we give a linear-time algorithm for computing a minimum segment drawing of a biconnected series-parallel graph with the maximum degree three. To the best of our knowledge, this is the first such algorithm for computing minimum segment drawings of an important subclass of biconnected planar graphs.

## Dunnart: A Constraint-Based Network Diagram Authoring Tool

(long demo)

Tim Dwyer, Kim Marriott, and Michael Wybrow

**Abstract:** We present a new network diagram authoring tool, Dunnart, that provides continuous network layout. It continuously adjusts the layout in response to user interaction, while still maintaining the layout style and, as far as possible, the current layout topology. The diagram author uses placement constraints, such as alignment and distribution, to tailor the layout style and can guide the layout by repositioning diagram components or rerouting connectors. The key to the exibility of our system is the use of topology-preserving constrained graph layout.



## POSTERS

### **Approximating the Crossing Number of Apex Graphs**

Markus Chimani, Petr Hlineny and Petra Mutzel

### **Policy-aware Visualization of Internet Dynamics**

Luca Cittadini, Tiziana Refice, Alessio Campisano, Giuseppe Di Battista and Claudio Sasso

### **On Enhancing the Visualization of Business Processes**

Philip Effinger, Michael Kaufmann and Martin Siebenhaller

### **A Robust Biclustering Method Based on Crossing Minimization in Bipartite Graphs**

Cesim Erten and Melih Sözdinler

### **Visualizing the Results of Metabolic Pathway Queries**

Allison Heath and Lydia Kavrakı

### **Visual Specification of Layout**

Sonja Maier, Steffen Mazanek and Mark Minas

### **Spine Crossing Minimization in Upward Topological Book Embeddings**

Tamara Mchedlidze and Antonios Symvonis

### **ILOG Elixir**

Georg Sander

### **DAGmap View**

Vassilis Tsiaras and Ioannis Tollis

### **Brain Network Analyzer**

Vassilis Tsiaras, Ioannis Tollis and Vangelis Sakkalis