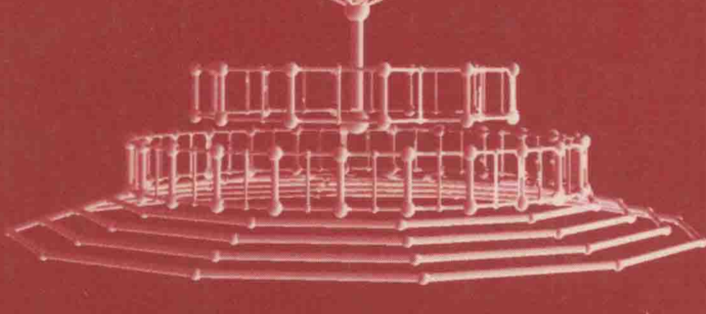
Giuseppe Liotta (Ed.)

LNCS 2912

Graph Drawing

11th International Symposium, GD 2003
Perugia, Italy, September 2003
Revised Papers



Springer

Giuseppe Liotta (Ed.)

Graph Drawing

11th International Symposium, GD 2003
Perugia, Italy, September 21-24, 2003
Revised Papers

Springer

Series Editors

Gerhard Goos, Karlsruhe University, Germany
Juris Hartmanis, Cornell University, NY, USA
Jan van Leeuwen, Utrecht University, The Netherlands

Volume Editor

Giuseppe Liotta
Università di Perugia
Dipartimento di Ingegneria Elettronica e dell'Informazione
Via G. Duranti, 93, 06125 Perugia, Italy
E-mail: liotta@diei.unipg.it

Cataloging-in-Publication Data applied for

A catalog record for this book is available from the Library of Congress.

Bibliographic information published by Die Deutsche Bibliothek
Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at <http://dnb.ddb.de>.

CR Subject Classification (1998): G.2, F.2, I.3

ISSN 0302-9743
ISBN 3-540-20831-3 Springer-Verlag Berlin Heidelberg New York

Springer-Verlag is a part of Springer Science+Business Media

springeronline.com

Printed in Germany

Typesetting: Camera-ready by author, data conversion by PTP-Berlin, Protago-TeX-Production GmbH
Printed on acid-free paper SPIN: 10977415 06/3142 5 4 3 2 1 0

Preface

The 11th International Symposium on Graph Drawing (GD 2003) was held on September 21–24, 2003, at the Università degli Studi di Perugia, Perugia, Italy. GD 2003 attracted 93 participants from academic and industrial institutions in 17 countries.

In response to the call for papers, the program committee received 88 regular submissions describing original research and/or system demonstrations. Each submission was reviewed by at least 4 program committee members and comments were returned to the authors. Following extensive e-mail discussions, the program committee accepted 34 long papers (12 pages each in the proceedings) and 11 short papers (6 pages each in the proceedings). Also, 6 posters (2 pages each in the proceedings) were displayed in the conference poster gallery.

In addition to the 88 submissions, the program committee also received a submission of special type, one that was not competing with the others for a time slot in the conference program and that collects selected open problems in graph drawing. The aim of this paper, which was refereed with particular care and went under two rounds of revisions, is to stimulate future research in the graph drawing community. The paper presents 42 challenging open problems in different areas of graph drawing and contains more than 120 references. Although the length of the paper makes it closer to a journal version than to a conference extended abstract, we decided to include it in the conference proceedings so that it could easily reach in a short time the vast majority of the graph drawing community.

GD 2003 invited two distinguished lecturers. Pat Hanrahan, from Stanford University, gave a talk about the connection between semantic constraints and aesthetics in graph drawing and information visualization. Giuseppe Italiano, from the Università di Roma Tor Vergata, gave a talk on algorithm engineering and experimental analysis of graph algorithms.

As usual, the annual graph drawing contest was held during the conference. A report about the contest is included in the proceedings.

Many people in the graph drawing community contributed to the success of GD 2003. In particular, the authors of submitted papers, demos, and posters are due special thanks, as are the members of the program committee and the external reviewers. Many thanks to the organizing committee members Carla Binucci, Emilio Di Giacomo, Luca Grilli, Maurizio Patrignani, and Maurizio Pizzonia for their support. My very special thanks go to the local arrangements chair Walter Didimo, for his invaluable help. Without his support of the organization and his many comments and suggestions, the conference would have been impossible to organize.

Thanks are due to the industrial sponsors of the conference: the "gold" sponsors, Tom Sawyer Software; the "silver" sponsors, Mitsubishi Electrics, Oreas, Digilab 2000, and Integra Sistemi s.r.l.; and the "contributor," Kelyan SMC.

Finally, many thanks go to the Dipartimento di Informatica e Automazione of the Università degli Studi di Roma Tre and to the Dipartimento di Ingegneria Elettronica e dell'Informazione of the Università degli Studi di Perugia for their help and financial support. The conference was also supported in part by "Progetto ALINWEB: Algoritmica per Internet e per il Web," MIUR Programmi di Ricerca Scientifica di Rilevante Interesse Nazionale.

The 12th International Symposium on Graph Drawing GD 2004 will be held in New York City, September 29–October 2, 2004, with Janos Pach as the conference chair.

October 2003 Giuseppe Liotta

Organization

Program Committee

Ashim Garg	SUNY Buffalo, USA
Michael T. Goodrich	University of California, Irvine, USA
Ferran Hurtado	Universitat Politécnica de Catalunya, Spain
Giuseppe Liotta	University of Perugia, Italy (Conference Chair)
Joe Marks	MERL, USA
Henk Meijer	Queen's University, Canada
Stephen C. North	AT&T Research Labs, USA
Patrice Ossona de Mendez	EHESS, CNRS, France
Md. Saidur Rahman	Tohoku University, Japan
Farhad Shahrokhi	University of North Texas, USA
Roberto Tamassia	Brown University, USA
Ioannis G. Tollis	University of Crete and ICS-FORTH, Greece
Dorothea Wagner	University of Karlsruhe, Germany
Sue H. Whitesides	McGill University, Canada
Stephen K. Wismath	University of Lethbridge, Canada
David R. Wood	Carleton University, Canada

Contest Committee

Franz J. Brandenburg	University of Passau (Contest Committee Chair)
Ulrik Brandes	University of Passau, Germany
Peter Eades	University of Sydney, Australia
Joe Marks	MERL, USA

Organizing Committee

Carla Binucci	University of Perugia, Italy
Emilio Di Giacomo	University of Perugia, Italy
Walter Didimo	University of Perugia, Italy (Local Arrangements Co-chair)
Giuseppe Liotta	University of Perugia, Italy (Conference Chair)
Maurizio Patrignani	University of Roma Tre, Italy
Maurizio Pizzonia	University of Roma Tre, Italy

Steering Committee

Franz J. Brandenburg	University of Passau, Germany
Giuseppe Di Battista	University of Roma Tre, Italy
Peter Eades	University of Sydney, Australia
Micheal T. Goodrich	University of California, Irvine, USA
Stephen G. Kobourov	University of Arizona, USA
Giuseppe Liotta	University of Perugia, Italy
Takao Nishizeki	Tohoku University, Japan
Janos Pach	New York University, USA
Pierre Rosenstiehl	EHESS, France
Roberto Tamassia	Brown University, USA
Ioannis G. Tollis	University of Crete and ICS-FORTH, Greece
Sue H. Whitesides	McGill University, Canada

External Referees

Manuel Abellanas
Bernardo Abrego
Oswin Aichholzer
Marc Benkert
Therese Biedl
Carla Binucci
Prosenjit Bose
Matt Brand
Ulrik Brandes
Juergen Branke
Sergio Cabello
Timothy Chan
Fco. Javier Cobos Gavala
Pier Francesco Cortese
Ovidiu Daescu
Erik Demaine
Emilio Di Giacomo
Walter Didimo
Vida Dujmović
Tim Dwyer
Thomas Erlebach
Guy Even
Hazel Everett
Wendy Feng
Julia Floetotto
Marco Gaertler
Alfredo Garcia
Maria Angeles Garrido
Daya Gaur
George F. Georgakopoulos
Patrick Healy
Petr Hlineny
Seokhee Hong
Wen-Lian Hsu
Kostas Kakoulis
Michael Kaufmann
Stephen Kobourov
Jan Kratochvil
Sebastian Leipert
Anna Lubiw
Karol Lynch
Csaba Megyeri
Martin Middendorf
Kazuyuki Miura
Pat Morin
Shin-ichi Nakano
Naomi Nishimura
Rom Pinchasi
Maurizio Pizzonia
Eduardo Rivera-Campo
Gelasio Salazar
Thomas Schank
Frank Schulz
Janet Six
Steven Skiena
Jerry Spinrad

Daniel Stefankovic
Ileana Streinu
Matthew Suderman
Kozo Sugiyama
Ondrej Sýkora
László A. Szekely
Javier Tejel
Gabriel Valiente
Marc van Kreveld
Suresh Venkatasubramanian
Imrich Vrt'o
Leland Wilkinson
Thomas Willhalm
Alexander Wolff

Sponsoring Institutions

We gratefully acknowledge the contributions of the following sponsors of the Graph Drawing Conference 2003.

Table of Contents

Straight-Line, Circular, and Circular-Arc Drawings

Symmetries

3D-Drawings

Embeddings and Triangulations

Applications and Systems – Part II

Fixed Parameter Tractability

Clusters, Cuts, and Orthogonal Drawings

k-Level Drawings

Force Directed and Energy-Based Techniques

Surfaces and Diagrams

Posters

Graph Drawing Contest

Invited Talks

Open Problems

Confluent Drawings: Visualizing Non-planar Diagrams in a Planar Way*

Matthew Dickerson[1], David Eppstein[2], Michael T. Goodrich[2], and Jeremy Yu Meng[2]

[1] Middlebury College, Middlebury, VT 05753, USA dickerso@middlebury.edu
[2] University of California, Irvine, Irvine, CA 92697, USA
{eppstein, goodrich, ymeng}@ics.uci.edu

Abstract. We introduce a new approach for drawing diagrams. Our approach is to use a technique we call *confluent drawing* for visualizing non-planar graphs in a planar way. This approach allows us to draw, in a crossing-free manner, graphs—such as software interaction diagrams—that would normally have many crossings. The main idea of this approach is quite simple: we allow groups of edges to be merged together and drawn as "tracks" (similar to train tracks). Producing such confluent diagrams automatically from a graph with many crossings is quite challenging, however, so we offer two heuristic algorithms to test if a non-planar graph can be drawn efficiently in a confluent way. In addition, we identify several large classes of graphs that can be completely categorized as being either confluently drawable or confluently non-drawable.

1 Introduction

In most graph visualization applications, graphs are often drawn in a standard way: the vertices of a graph are drawn as simple shapes, such as circles or boxes, and the edges are drawn as individual curves connecting pairs of these shapes (e.g., see [12,13,22]).

Related Prior Work. There are several aesthetic criteria that have been explored algorithmically in the area of graph drawing (e.g., see [12,13,22]). Examples of aesthetic goals designed to facilitate readability include minimizing edge crossings, minimizing a drawing's area, minimizing bends, and achieving good separation of vertices, edges, and angles. Of all of these criteria, however, the arguably most important is to minimize edge crossings, since crossing edges tend to confuse the eye when one is viewing adjacency relationships. Indeed, an experimental analysis by Purchase [31] suggests that edge-crossing minimization [19, 20,25] is the most important aesthetic criteria for visualizing graphs. Ideally, we would like drawings that have no edge crossings at all.

* This is an extended abstract. The full version of this paper can be found at http://arxiv.org/abs/cs.CG/0212046. Work by the second author is supported by NSF grant CCR-9912338. Work by the third and the forth author is supported by NSF Grants CCR-0098068, CCR-0225642, and DUE-0231467.

G. Liotta (Ed.): GD 2003, LNCS 2912, pp. 1–12, 2004.

Graphs that can be drawn in the standard way in the plane without edge crossings are called *planar graphs* [28], and there are a number of existing efficient algorithms for producing crossing-free drawings of planar graphs (e.g., see [8,9,11,34,6,21,36]). Unfortunately, most graphs are not planar; hence, most graphs cannot be drawn in the standard way without edge crossings, and such non-planar graphs seem to be common in many applications. There are some heuristic algorithms for minimizing edge crossings of non-planar graphs (e.g., see [19,26,20,25]), but the general problem of drawing a non-planar graph in a standard way that minimizes edge-crossings is NP-hard [16]. Thus, we cannot expect an efficient algorithm for drawing non-planar graphs so as to minimize edge crossings.

The technique of replacing complete bipartite subgraphs (bicliques) with star-like structures is used as *Edge Concentration* in [27] and *Factoring* in [5], both to reduced the number of edges in the original graphs. This technique has the desired side effect of reducing the number of crossings, however, its primary goal is to minimize the total number of edges, not to minimize the number of crossings. Furthermore, the time complexity of approximation algorithm given in [27] is not desirable. Recently Lin [24] proves that the optimization problem of edge concentration is NP-hard. A similar idea is used in [15] for weighted graph compressions, where cliques and bicliques are replaced with stars. It is shown that the general unit weight problem is essentially as hard to approximate as graph coloring and maximum clique. Again, [15] doesn't directly address the minimization of the number of crossings.

Our Results. Given the difficulty of edge-crossing minimization and the ubiquity of non-planar graphs, we explore in this paper a diagram visualization approach, called *confluent drawing*, that attempts to achieve the best of both worlds—it draws non-planar graphs in a planar way. Moreover, we provide two heuristic algorithms for producing confluent drawings for directed and undirected graphs, respectively, focusing on graphs with bounded arboricity.

The main idea of the confluent drawing approach for visualizing non-planar graphs in a planar way is quite simple—we merge edges into "tracks" so as to turn edge crossings into overlapping paths. (See Fig. 1.)

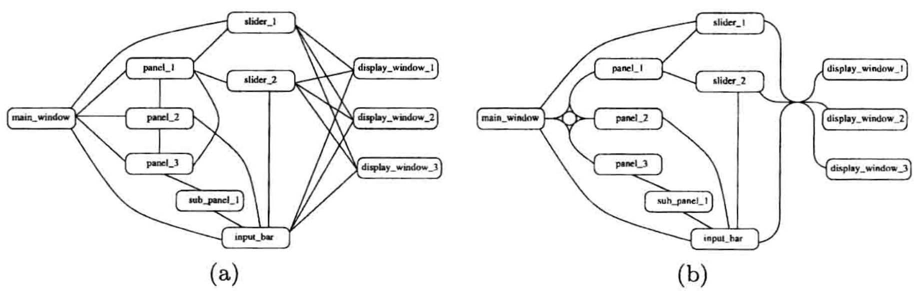


Fig. 1. An example of confluent drawing of an object-interaction diagram. We show a standard drawing in (a) and a confluent drawing in (b).

The resulting graphs are easy to read and comprehend, while also encapsulating a high degree of connectivity information. Although we are not familiar with any prior work on the automatic display of graphs using this confluent diagram approach, we have observed that some airlines use hand-crafted confluent diagrams to display their route maps. Diagrams similar to our confluent drawings have also been used by Penner and Harer [29] to study the topology of surfaces.

In addition to providing heuristic algorithms for recognizing and drawing confluent diagrams, we also show that there are large classes of non-planar graphs that can be drawn in a planar way using our confluent diagram approach.

2 Confluent Drawings

It is well-known that every non-planar graph contains a subgraph homeomorphic to the complete graph on five vertices, K_5, or the complete bipartite graph between two sets of three vertices, $K_{3,3}$ (e.g., see [3]). On the other hand, confluent drawings, with their ability to merge crossing edges into single tracks, can easily draw any $K_{n,m}$ or K_n in a planar way. Fig. 2 shows confluent drawings of $K_{3,3}$ and K_5.

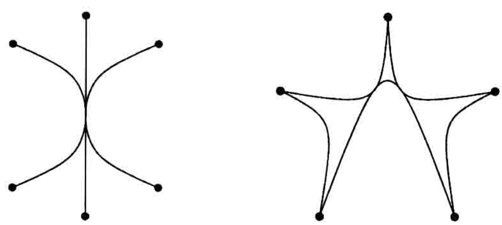


Fig. 2. Confluent drawings of $K_{3,3}$ and K_5.

A curve is *locally-monotone* if it contains no self intersections and no sharp turns, that is, it contains no point with left and right tangents that form an angle less than or equal to 90 degrees. Intuitively, a locally-monotone curve is like a single train track, which can make no sharp turns. Confluent drawings are a way to draw graphs in a planar manner by merging edges together into *tracks*, which are the unions of locally-monotone curves.

An undirected graph G is *confluent* if and only if there exists a drawing A such that:

- There is a one-to-one mapping between the vertices in G and A, so that, for each vertex $v \in V(G)$, there is a corresponding vertex $v' \in A$, which has a unique point placement in the plane.
- There is an edge (v_i, v_j) in $E(G)$ if and only if there is a locally-monotone curve e' connecting v'_i and v'_j in A.
- A is planar. That is, while locally-monotone curves in A can share overlapping portions, no two can cross.

Our definition does not allow for confluent graphs to contain self loops or parallel edges, although we do allow for tracks to contain cycles and even multiple ways of realizing the same edge. Moreover, our definition implies that tracks in a confluent drawing have a "diode" property that does not allow one to double-back or make sharp turns after one has started going along a track in a certain direction.

Directed confluent drawings are defined similarly, except that in such drawings the locally-monotone curves are directed and the tracks formed by unions of curves must be oriented consistently.

3 Heuristic Algorithms

Though the planarity of a graph can be tested in linear time, it appears difficult to quickly determine whether or not a graph can be drawn confluently. If a graph G contains a non-planar subgraph, then G itself is non-planar too. But similar closure properties are not true for confluent graphs. Adding vertices and edges to a non-confluent graph increases the chances of edges crossing each other, but it also increases the chances of edges merging. Currently, the best method we know of for determining conclusively in the worst case whether a graph is confluent or not is a brute force one of exhaustively listing all possible ways of edge merging and checking the merged graphs for planarity. Therefore, it is of interest to develop heuristics that can find confluent drawings in many cases.

Fig. 3 shows confluent drawings using a "traffic circle" structure for complete subgraphs (cliques) and complete bipartite subgraphs (bicliques). At a high level, our heuristic drawing algorithm iteratively finds clique subgraphs and biclique subgraphs and replaces them with traffic-circle subdrawings.

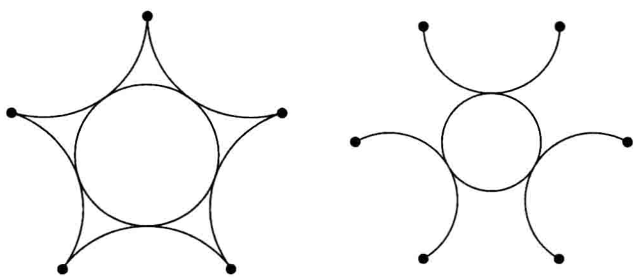


Fig. 3. Confluent drawings of K_5 and $K_{3,3}$ using "traffic circle" structures.

Chiba and Nishizeki [7] discuss the problem of listing complete subgraphs for graphs of bounded arboricity. The *arboricity* $a(G)$ is the minimum number of forests into which the edges of G can be partitioned. The listing algorithm is applicable for such graphs. Chiba and Nishizeki show that there can be at most $O(n)$ cliques of a given size in such graphs and give a linear time algorithm for listing these clique subgraphs. Eppstein [14] gives a linear time algorithm for listing maximal complete bipartite subgraphs in graphs of bounded arboricity.