

PLANAR GRAPHS (Extended Abstract)

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1. INTRODUCTION

A *book embedding* of a graph consists of an embedding of its nodes along the spine of a book (i.e., a linear ordering of the nodes), and an embedding of its edges on the pages so that edges embedded on the same page do not intersect. The objective is to minimize the number of pages used. The minimum number of pages in which a graph can be embedded is called the *pagenumber* of the graph.

Recent activity in the VLSI community on this problem is motivated largely by an approach to fault-tolerant VLSI design [R, CLR1, CLR2]. Briefly, processing elements have to be interconnected to form a desired pattern. The processing elements are arranged (logically or physically) on a line. There are "bundles" of wires running over the line. The faulty elements are bypassed, and the healthy ones are interconnected through the bundles. If the bundles function as stacks, then the minimum number of bundles required to realise an interconnection graph is equal to its pagenumber.

Computationally, the book embedding problem is hard: it is NP-complete to tell if a planar graph can be embedded in two pages [W, CLR2]. Note that in this case the crux of the problem is in the node-embedding part, as once this is fixed, it is easy to tell whether the edges can be embedded in two pages. The subproblem of embedding optimally the edges for a fixed node-embedding has been studied earlier in connection with other problems such as sorting permutations with stacks [EI, T]; it is also NP-complete, at least for general graphs [GJMP].

Graphs with pagenumber one are exactly the outerplanar graphs. Graphs with pagenumber two are the subhamiltonian planar graphs: these are the subgraphs of planar Hamiltonian graphs. As there are triangulated (maximal) planar graphs which are not Hamiltonian, this implies that there are planar graphs which require at least three pages [BK]. Berhart and Kainen conjectured that planar graphs have unbounded pagenumber, but this was disproved in [BS] and [H]. Buss and Shore gave an algorithm, based on Whitney's theorem, which embeds all planar graphs in nine pages [BS]. Heath used a method of "peeling" the graph to reduce the number to seven [H].

In this paper we show that the right number is four. That is, we give an algorithm which embeds all planar graphs in four pages; the algorithm runs in linear time.

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And conversely, we show that there are planar graphs which cannot be embedded in three pages. In Section 2 we present the four page algorithm. We include all the details of the algorithm; the timing analysis and proofs are omitted. The proof of the lower bound is quite long and tedious. In Section 3 we give a flavour of the arguments.

2. THE FOUR PAGE ALGORITHM

Clearly, if a graph can be embedded in a given number of pages, the same is true of its subgraphs. Therefore, we can assume without loss of generality that our planar graph is triangulated (all faces are triangles). We will assume from now on a fixed embedding of the graph on the plane; the embedding is inherited by its subgraphs. To avoid confusion, we will reserve the term "embedding" for the embedding of the graph on the plane, and use the term "layout" for the book embedding. We will also refer to the embedding of the edges into the pages as coloring of the edges.

Our algorithm builds on Heath's approach. In fact we can show that the node-layout part of Heath's algorithm can be combined with a different edge coloring method (very similar to the one we will describe later), to reduce the number of pages to five. Bringing the number down to four requires a different algorithm for laying out the nodes as well; that is, it is possible to construct graphs such that, if the nodes are laid out with Heath's method, then 5 pages will be needed no matter how the edges are colored.

Outline of the algorithm

The heart of the algorithm is a recursive procedure $\text{EXPAND}(C)$, where C is a cycle of the graph. The cycle C has no external chords, i.e., no edges which lie in the exterior of C and connect two nonconsecutive nodes of C . The purpose of the procedure is to add to an already constructed partial layout the nodes and edges that lie in the interior of C . More specifically, when $\text{EXPAND}(C)$ is called, we have already constructed a layout L of a subgraph. This subgraph includes all nodes of C but no nodes in the interior of C . The nodes of C appear in circular (clockwise or counterclockwise) order in L . To avoid repeated subscripts, we denote the nodes of C by $1, 2, \dots, p$. We call the edge $(1, p)$ that connects the first and last nodes of the cycle, the *long edge* of C , and the rest are the *short edges* of C . In the layout L , we have already colored the long edge of C ; no other edge connecting two nodes of C has been colored. Thus, in the following, by laying out the "interior" of C we mean not only the nodes inside C and their incident edges but also the short edges and chords of C . First, let us explain how chords are handled.

Let G_C be the graph formed by C and its chords (see Fig. 1a). The chords partition the interior of C into a number of inner faces of G_C , each bounded by a cycle. These cycles are also laid out in circular order in L (the same order as C), and furthermore are "nested" (see Fig. 1b). This nesting is modelled by a rooted tree S as shown in Fig. 1a. The tree S is actually the dual graph of G_C (without a node for the outer face), rooted at the face which contains the long edge of C . If F and F' are two inner faces of G_C

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Zurita,Nelson Baloian,2022-10-22 This volume constitutes the proceedings of the 28th International Conference on Collaboration Technologies and Social Computing CollabTech 2022 held in Santiago Chile during November 8 11 2022 The 18 full and 4 work in process papers presented in this volume were selected from 37 submissions and underwent careful double blind peer review The papers focus on innovative technical human and organizational approaches to expand collaboration support including computer science management science design science cognitive and social science CSCW '15 ,2015 CSCW '14 ,2014 *Proceedings of the Second Conference on Computers, Freedom, and Privacy* Lance J. Hoffman,1992 CKBS '90 S.M. Deen,2012-12-06 This is the first international conference aimed at bringing the distributed database and distributed AI DAD experts together from both academia and industry in order to discuss the issues of the next generation of knowledge based systems namely Cooperating Knowledge Based Systems or CKBS for short As the area of CKBS is new we intended it to be an ideas conference a conference where interesting new ideas rather than results from completed projects are explored discussed and debated The conference was organised by the DAKE Centre This is an interdisciplinary centre at the University of Keele for research and development in Data and Knowledge Engineering DAKE The Centre draws most of its strength from the Department of Computer Science which also provides administrative support for the activities of the Centre although its membership is spread over several departments The Centre has three main streams of research activities namely Large Knowledge Bases Software Engineering Neural Networks The Large Knowledge Base group which provided the focus for this conference is active in a number of research areas relating to data and knowledge bases spanning from distributed databases to cooperations among data and knowledge bases The current research topics include integration of data and knowledge bases and cooperating knowledge based systems with several major projects in the latter see the entries under the Poster Session given below **Nineteen hundred and eighty-six 1986 ACM fourteenth annual computer science conference** Computer Science Conference,1986 **ACM ... Annual Computer Science Conference. 21. February 16 - 18, 1993, Indiana Convention Center Indianapolis, Indiana ,1993**

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