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Dedicated to Professor Subir Kumar Ghosh on the Occasion of His 65th Birthday

Prof. Subir Kumar Ghosh is an internationally renowned expert on geometric graphs, visibility algorithms, and other areas of computational geometry. He was a Professor of Computer Science at the Tata Institute of Fundamental Research (TIFR), Mumbai, untill July 2015. Since then, he has been Professor in the Department of Computer Science at the Ramakrishna Mission Vivekananda Educational and Research Institute (RKMVERI), Belur, West Bengal (formerly known as RKM Vivekananda University). He is a Fellow of the Indian Academy of Sciences.

After his doctorate from TIFR in computational geometry during the mid-1980s, Prof. Ghosh contributed around 65 papers in the fields of computational geometry, discrete applied mathematics, geometric graph theory, algorithms (sequential, parallel, on-line and approximation), and robot motion planning. Some of his discoveries are considered landmarks in the respective areas. In fact, Prof. Ghosh has solved some outstanding open problems with his doctoral students and collaborators. Moreover, his famous conjectures on visibility graphs and art gallery problems have generated many research activities.

His widely acclaimed book *Visibility Algorithms in the Plane*, published by Cambridge University Press in 2007, is used as a textbook in universities of Europe, North America, and India. Prof. Ghosh has visited several reputed universities and research institutes around the world and has delivered invited lectures in national and international conferences, workshops, and in research institutes and universities.

An excellent teacher, Prof. Ghosh is also passionate about improving algorithms and discrete mathematics education in India. In a span of eight years (2008–2015), Prof. Ghosh conducted 22 introductory workshops on graph and geometric algorithms for teachers and students of engineering colleges and universities in different states and union territories of India, at the undergraduate, postgraduate, and doctoral levels. The workshops have been successful in motivating students toward algorithmic research. He has also organized seven international schools in India for doctoral students of algorithms and discrete mathematics. In 2015, he initiated the new international conference on algorithms and discrete applied mathematics (CALDAM).

Preface

This volume contains the papers presented at CALDAM 2019: the 5th International Conference on Algorithms and Discrete Applied Mathematics held during February 14–16, 2019, in Kharagpur. CALDAM 2019 was organized by the Department of Computer Science and Engineering, Indian Institute of Technology, Kharagpur, and the Association for Computer Science and Discrete Mathematics (ACSDM). The conference had papers in the areas of algorithms, graph theory, combinatorics, computational geometry, discrete geometry, and computational complexity. The 86 submissions had authors from 13 different countries. Each submission received at least one detailed review and nearly all were reviewed by three Program Committee members. The committee decided to accept 22 papers. The program also included three invited talks by Janos Pach, Matthew Katz, and David Mount.

The first CALDAM was held in February 2015 at the Indian Institute of Technology, Kanpur, and had 26 papers selected from 58 submissions from 10 countries. The second edition was held in February 2016 at the University of Kerala, Thiruvananthapuram (Trivandrum), and had 30 papers selected from 91 submissions from 13 countries. The third edition was held in February 2017 at Birla Institute of Technology and Science, Pilani (BITS Pilani), K. K. Birla Goa Campus, Goa, and had selected 32 papers from 103 submissions from 18 countries. The fourth edition was held in February 2018 at the Department of Computer Science Engineering, Indian Institute of Technology, Guwahati (IIT Guwahati), and had 23 papers from 68 submissions from 12 countries.

CALDAM 2019 included a special session on February 14, 2019, at the end of the first day of the conference, in honor of Prof. Subir Ghosh on the occasion of his 65th birthday, and for completing 40 years of active research and teaching activities to date.

We would like to thank all the authors for contributing high-quality research papers to the conference. We express our sincere thanks to the Program Committee members and the external reviewers for reviewing the papers within a very short period of time. We thank Springer for publishing the proceedings in the *Lecture Notes in Computer Science* series. We thank the invited speakers Janos Pach, Matthew Katz, and David Mount for accepting our invitation. We thank the Organizing Committee chaired by Rogers Mathew from Indian Institute of Technology, Kharagpur, for the smooth functioning of the conference. We thank the chair of the Steering Committee, Subir Ghosh, for his active help, support, and guidance throughout. We thank our sponsors Google Inc., the National Board of Higher Mathematics (NBHM), the Department of Atomic Energy, and Microsoft Research India, for their financial support. We also thank Springer for its support for the Best Paper Presentation Awards. We thank the EasyChair conference management system, which was very effective in handling the entire reviewing process.

February 2019

Sudebkumar Prasant Pal
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Short Papers

Guarding a Polygon from Its Boundary

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Abstract. In this talk, we survey some recent and not-so-recent results dealing with guarding a polygon from its boundary. In particular, we discuss problems in which the goal is to place as few guards as possible on the boundary of a polygon, either at vertices or at arbitrary points, in order to guard the polygon's vertex set or its entire boundary. The v2v version is especially interesting, since it is equivalent to finding a minimum dominating set in the visibility graph of the polygon. Among other results, we present a local-search-based PTAS for guarding the vertices of a weakly-visible polygon from its vertices. Previously, only a constant-factor approximation algorithm (by Bhattacharya, Ghosh and Roy, 2017) was known for this problem.

Strings and Order

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Given a family of sets, $\mathcal{C}$, the *intersection graph* of $\mathcal{C}$ is the graph, whose vertices correspond to the elements of $\mathcal{C}$, and two vertices are joined by an edge if and only if the corresponding sets have a nonempty intersection. The complement of the intersection graph of $\mathcal{C}$ is called the *disjointness graph* of $\mathcal{C}$. A *string* (or *curve*) is the image of a continuous function $\phi : [0,1] \to \mathbb{R}^2$.

A *string graph* is an intersection graph of strings. The study of string graphs was initiated by Benzer [1], who investigated certain genetic structures in cells, and shortly after by Sinden [15], for the design of integrated circuits (chips). The recognition of string graphs is an NP-complete problem [13]. There exist string graphs on n vertices such that no matter how we represent them by strings, two of them will intersect exponentially many times [5]. Every planar graph is the intersection graphs of segments (straight-line strings) [2]. The number of string graphs on n vertices is $2^{\left(\frac{3}{4}+o(1)\right)\binom{n}{2}}$ [11]. Almost all string graphs on n vertices are intersection graphs of convex sets in the plane. The vertex sets of almost all string graphs can be partitioned into 5 cliques so that there are two of them not connected by any edge [8]. The vertex set of every string graph G with m edges can be partitioned into three parts $V(G) = A \cup S \cup B$ such that $|A|, |B| \leq 2|V(G)/3$, $|S| = O(\sqrt{m})$, and no vertex of A is connected to any vertex of B by an edge [6].

Partially ordered sets seem to play an important role in the study of string graphs. An *incomparability graph* is a graph whose vertices correspond to the elements of a partially ordered set, with two vertices being joined by an edge if and only if they are incomparable. It is known that every incomparability graph is a string graphs [7, 12, 14]. A partial converse of this theorem is also true: Given a collection of n strings such that their intersection graph has at least cn^2 edges, we can shorten each string in such a way that their intersection graph becomes an incomparability graph and still has at least $c'n^2$ edges [4].

A string is said to be *x-monotone* if every vertical line intersects it in at most one point. A string is called a *grounded* if one of its endpoints lies on the y-axis and the rest of the curve lies in the nonnegative half-plane $\{x \geq 0\}$. A graph G is called *magical* if there are two total orderings, $<_1$ and $<_2$, on its vertex set such that any three distinct

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vertices $a, b, c \in V(G)$ with $a <_1 b <_1 c$ satisfy the following condition: if $ab, bc \in E(G)$ and $ac \notin E(G)$, then $b <_2 a$ and $b <_2 c$.

Theorem 1. [10] *A graph is the disjointness graph of a finite collection of grounded x-monotone curves if and only if it is magical.*

A graph G is said to be *double-magical* if there exist three total orderings $<_1, <_2, <_3$ on $V(G)$ such that G is the union of two graphs, G^1 and G^2, with $V(G^1) = V(G^2) = V(G)$, where G^1 is magical with respect to the orders $<_1, <_2$ and G^2 is magical with respect to the orders $<_1, <_3$.

Theorem 2. [10] *A graph is the disjointness graph of a finite collection of x-monotone curves, each of which intersects the y-axis, if and only if it is double-magical.*

These characterizations can be used to deduce some coloring properties of disjointness graphs of curves (that is, complements of string graphs).

Theorem 3. [9, 10] *There exist disjointness graphs G_k of collections x-monotone curves containing no clique of size k, such that their chromatic numbers satisfy $\chi(G_k) = \Omega(k^4)$. The order of magnitude of this bound, as $k \to \infty$, cannot be improved.*

It is a major unsolved problem to decide whether there exists a constant $\varepsilon > 0$ such that every string graph (and, therefore, every disjointness graph of strings) has a clique of size at least n^ε or an independent set of size at least $\varepsilon > 0$. For intersection graphs of x-monotone curves, this follows from Theorem 3. This problem is closely related to the celebrated Erdős-Hajnal conjecture [3].

Theorems 1–3 are joint work with István Tomon.

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Contents