Jin-Yi Cai
S. Barry Cooper
Hong Zhu (Eds.)

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Theory and Applications of Models of Computation

4th International Conference, TAMC 2007
Shanghai, China, May 2007
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Preface

Theory and Applications of Models of Computation (TAMC) is an international conference series with an interdisciplinary character, bringing together researchers working in computer science, mathematics (especially logic) and the physical sciences. This cross-disciplinary character, together with its focus on algorithms, complexity and computability theory, gives the conference a special flavor and distinction.

TAMC 2007 was the fourth conference in the series. The previous three meetings were held May 17 – 19, 2004 in Beijing, May 17 – 20, 2005 in Kunming, and May 15 – 20, 2006 in Beijing, P. R. China. TAMC 2007 was held in Shanghai, May 22 – 25, 2007. Future annual meetings are planned.

At TAMC 2007 we were very pleased to have two plenary speakers, Miklós Ajtai and Fan Chung Graham, each gave a one hour invited talk. Miklós Ajtai spoke on "Generalizations of the Compactness Theorem and Godel's Completeness Theorem for Nonstandard Finite Structures," and Fan Chung Graham spoke on "Detecting Sharp Drops in PageRank and a Simplified Local Partitioning Algorithm." Their respective papers accompanying the talks are included in these proceedings.

In addition, there were two special sessions organized by Barry Cooper and Andrew Lewis on "Computability and Randomness" and by Manindra Agrawal and Angsheng Li on "Algorithms and Complexity." The invited speakers included George Barmpalias, Cristian Calude, Bjorn Kjos-Hanssen, Andre Nies, and Jan Reimann in the "Computability and Randomness" special session, and Manindra Agrawal, Alberto Apostolico, Jin-Yi Cai, Andreas Dress, Naveen Garg and Jaikumar Radhakrishnan in the "Algorithms and Complexity" special session.

The TAMC conference series arose naturally in response to important scientific developments affecting how we compute in the twenty-first century. At the same time, TAMC is already playing an important regional and international role, and promises to become a key contributor to the scientific resurgence seen throughout China and other parts of Asia.

The enthusiasm with which TAMC 2007 was received by the scientific community is evident in the large number of quality articles submitted to the conference. There were over 500 submissions, originating from all over the world. This presented the Program Committee with a major assessment task. The Program Committee finally selected 67 papers for presentation at the conference and inclusion in this LNCS volume. This results in an acceptance rate of just over 13%, making TAMC an extremely selective conference, compared to other leading international conferences.

We are very grateful to the Program Committee, and the many outside referees they called on, for the hard work and expertise which they brought to the difficult selection process. We also wish to thank all those authors who submitted their work for our consideration. The Program Committee could have accepted many more submissions without compromising standards, and were only restrained by the practicalities of scheduling so many talks, and by the inevitable limitations on the size of this proceedings volume.

Finally, we would like to thank the members of the Editorial Board of *Lecture Notes in Computer Science* and the Editors at Springer for their encouragement and cooperation throughout the preparation of this conference.

Of course TAMC 2007 would not have been possible without the support of our sponsors, and we therefore gratefully acknowledge their help in the realization of this conference.

May 2007

Jin-Yi Cai
S. Barry Cooper
Hong Zhu

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The conference was organized by: the Software School of Fudan University; University of Leeds, UK; and the University of Wisconsin–Madison, USA.

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Detecting Sharp Drops in PageRank and a Simplified Local Partitioning Algorithm

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Abstract. We show that whenever there is a sharp drop in the numerical rank defined by a personalized PageRank vector, the location of the drop reveals a cut with small conductance. We then show that for any cut in the graph, and for many starting vertices within that cut, an approximate personalized PageRank vector will have a sharp drop sufficient to produce a cut with conductance nearly as small as the original cut. Using this technique, we produce a nearly linear time local partitioning algorithm whose analysis is simpler than previous algorithms.

1 Introduction

When we are dealing with computational problems arising in complex networks with prohibitively large sizes, it is often desirable to perform computations whose cost can be bounded by a function of the size of their output, which may be quite small in comparison with the size of the whole graph. Such algorithms we call *local algorithms* (see [1]). For example, a local graph partitioning algorithm finds a cut near a specified starting vertex, with a running time that depends on the size of the small side of the cut, rather than the size of the input graph.

The first local graph partitioning algorithm was developed by Spielman and Teng [8], and produces a cut by computing a sequence of truncated random walk vectors. A more recent local partitioning algorithm achieves a better running time and approximation ratio by computing a single personalized PageRank vector [1]. Because a PageRank vector is defined recursively (as we will describe in the next section), a sweep over a single approximate PageRank vector can produce cuts with provably small conductance. Although this use of PageRank simplified the process of finding cuts, the analysis required to extend the basic cut-finding method into an efficient local partitioning algorithm remained complicated.

In this paper, we consider the following consequence of the personalized PageRank equation,

$$p = \alpha v + (1 - \alpha)pW,$$

where p is taken to be a row vector, v is the indicator vector for a single vertex v, and W is the probability transition matrix of a random walk on the graph (this

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will be defined in more detail later). When a random walk step is applied to the personalized PageRank vector p, every vertex in the graph has more probability from pW than it has from p, except for the seed vertex v. This implies something strong about the ordering of the vertices produced by the PageRank vector p: there cannot be many links between any set of vertices with high probability in p and any set of vertices with low probability in p. More precisely, whenever there is a *sharp drop* in probability, where the kth highest ranked vertex has much more probability than the $k(1+\delta)$th vertex, there must be few links between the k highest ranked vertices and the vertices not ranked in the top $k(1+\delta)$.

We will make this observation rigorous in Lemma 1, which provides an intuitive proof that personalized PageRank identifies a set with small conductance. In the section that follows, we will prove a series of lemmas that describe necessary conditions for a sharp drop to exist. In the final section, we will use these techniques to produce an efficient local partitioning algorithm, which finds cuts in nearly linear time by detecting sharp drops in approximate PageRank vectors.

2 Preliminaries

PageRank was introduced by Brin and Page [3,7]. The PageRank vector $\mathrm{pr}(\alpha, s)$ is defined to be the unique solution of the equation

$$\mathrm{pr}(\alpha, s) = \alpha s + (1-\alpha)\mathrm{pr}(\alpha, s)W, \tag{1}$$

where α is a constant in $(0,1)$ called the *teleportation constant* , s is a vector called the *starting vector*, and W is the random walk transition matrix $W = D^{-1}A$. Here D denotes the diagonal matrix whose diagonal entries are the degrees of the vertices, and A denotes the adjacency matrix of the graph.

The PageRank vector that is usually associated with search ranking has a starting vector equal to the uniform distribution $\frac{1}{n}\mathbf{1}$. PageRank vectors whose starting vectors are concentrated on a smaller set of vertices are often called *personalized PageRank vectors*. These were introduced by Haveliwala [5], and have been used to provide personalized search ranking and context-sensitive search [2,4,6]. We will consider PageRank vectors whose starting vectors are equal to the indicator function 1_v for a single vertex v. The vertex v will be called the *starting vertex*, and we will use the notation $\mathrm{pr}(\alpha, v) = \mathrm{pr}(\alpha, 1_v)$.

The *volume* of a subset $S \subseteq V$ of vertices is $\mathrm{Vol}(S) = \sum_{x \in S} d(x)$. We remark that $\mathrm{Vol}(V) = 2m$, and we will sometimes write $\mathrm{Vol}(G)$ in place of $\mathrm{Vol}(V)$. We write $e(S,T)$ to denote the number of edges between two disjoint sets of vertices S and T. The *conductance* of a set is

$$\Phi(S) = \frac{e(S,T)}{\min\left(\mathrm{Vol}(S), 2m - \mathrm{Vol}(S)\right)}.$$