AFRL-AFOSR-VA-TR-2016-0367

(DARPA) Efficient Algorithmic Frameworks via Structural Graph Theory

Erik Demaine
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

12/08/2016
Final Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTA2
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
09-12-2016

2. REPORT TYPE
Final Performance

3. DATES COVERED *(From - To)*
01 Aug 2012 to 30 Sep 2016

4. TITLE AND SUBTITLE
Efficient Algorithmic Frameworks via Structural Graph Theory

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-12-1-0423

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
Erik Demaine

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 MASSACHUSETTS AVE
CAMBRIDGE, MA 02139-4301 US

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AF Office of Scientific Research
875 N. Randolph St. Room 3112
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/AFOSR RTA2

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-AFOSR-VA-TR-2016-0367

12. DISTRIBUTION/AVAILABILITY STATEMENT
A DISTRIBUTION UNLIMITED: PB Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In this project, we developed many new efficient algorithms for analysis of networks. We have published over 100 papers during the course of this project, and we launched a new website BigDND [http://projects.csail.mit.edu/dnd/] for distributing large network data and tools for analyzing them. Within network science, our research develops algorithms to enable efficient and guaranteed-quality analysis of a broad range of types of networks, from social networks to computer networks and transportation networks. Real-world social networks of interest include online services (Facebook, Google+, Twitter), coauthorship/collaboration among people (arXiv, DBLP, patents), phone calls (AT\&T, NSA), in-person interactions (FBI, Pentagon), geographic hierarchical neighborhoods (living or working together, on the same block, in the same district or city), and shared interests (Netflix, Amazon, Match.com).

15. SUBJECT TERMS
graph theory, network

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			LAWTON, JAMES
Unclassified	Unclassified	Unclassified	UU		**19b. TELEPHONE NUMBER** *(Include area code)* 703-696-5999

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

DISTRIBUTION A: Distribution approved for public release.

DARPA GRAPHS Final Report

Erik D. Demaine
MIT

MohammadTaghi Hajiaghayi
UMD

October 28, 2016

In this project, we developed many new efficient algorithms for analysis of networks. We have published over 100 papers during the course of this project, and we launched a new website *BigDND*[1] for distributing large network data and tools for analyzing them, as detailed below. Below we detail a few of the research highlights, focusing in particular on recent results.

1 Foundational Research in Graph Algorithms

Within network science, our research develops algorithms to enable efficient and guaranteed-quality analysis of a broad range of types of networks, from social networks to computer networks and transportation networks. Real-world social networks of interest include online services (Facebook, Google+, Twitter), coauthorship/collaboration among people (arXiv, DBLP, patents), phone calls (AT&T, NSA), in-person interactions (FBI, Pentagon), geographic hierarchical neighborhoods (living or working together, on the same block, in the same district or city), and shared interests (Netflix, Amazon, Match.com). Real-world computer networks of interest include the Internet backbone, ISP networks, ad-hoc wireless networks, sensor networks, and robot swarms. Real-world transportation networks of interest include highways, inner-city roads, supply trains, naval supply routes, flight tracks, and off-road geographic terrains.

One important problem we have studied during the course of this project is *belief propagation control*. In a social network, people's opinions are strongly influenced by their friends' opinions, causing behaviors to cascade through the network given a strong enough start. How can we best exploit such behavioral cascades to infiltrate a known network with a desired idea or belief? For example, to promote a new political view or regime change during a domestic or international campaign, on which demographic groups or influential people should we spend time and money in advertising, lobbying, etc.? Our algorithm efficiently computes the precise budget allocation for each target in order to maximize overall influence after propagation, with a guaranteed bound on solution quality. We have experimentally evaluated our algorithm on real-world social networks mentioned above, and found it to outperform all previous approaches. This problem has applications to real-world politics and advertising, in both military and civilian settings.

Belief propagation control is just one prominent example of the many network problems we are studying, which have applications both within network science and more broadly to the real world and DoD.

Network coverage: Given a network and a notion of "distance" (travel times, affinity between people, etc.), choose the fewest nodes to guarantee that every node is within distance d of a chosen node. For example, in a road network, we might aim to place the fewest emergency response centers

[1] http://projects.csail.mit.edu/dnd/

to guarantee a specified maximum response time to an emergency (terrorism, building collapse, fire, etc.). In a social or computer network, we might want to place infiltration points (spies, wire taps, etc.) while guaranteeing all communication is within a few hops from infiltration.

Opinion formation: In a social network, people's opinions tend to be expressed (e.g., in voting) based on not just personal belief but also the expressed opinion of friends. What are the dynamics of this system in terms of convergence to a particular idea, and how can a few changes early on in the system be used to control the final outcome? We have answered these questions through algorithms and network analysis, and experimentally evaluated our algorithms on real-world social networks mentioned above.

Collaboration via social networks: How can we incentivize people in a social network to work together to achieve a common goal? For example, in the DARPA Network Challenge, the goal was to locate ten balloons around the United States; but more generally, we can imagine goals such as terrorist detection and tracking (e.g., Boston Marathon bombers) and disaster management and tracking (e.g., earthquake or biochemical attack). *Risk aversion* is the reluctance of a person to accept a bargain with an uncertain payoff rather than another bargain with a more certain, but possibly lower, expected payoff. We show how to use this principle to define an incentive structure that guarantees huge groups to form, within a constant fraction of the entire network (where the constant depends on how risk-averse the agents are). We have evaluated our approach on real-world data from the DARPA Network Challenge.

Network creation and formation: When many parties pay to build a shared network (such as the Internet), where improving the network quality serves as incentive to build more, what type of network topologies will form? We are characterizing key properties of these equilibria topologies, in particular, the diameter and the overhead compared to a centrally planned solution.

Policy recommendation: Given a socioeconomic game among multiple parties (countries, armies, political parties, terrorist groups, etc.) in a network, can we find equilibrium strategies that achieve desired effects (such as minimizing casualties)? We have developed a system called PREVE to search for these equilibria which suggest life-saving policies. We have applied this system to a real-world application, using open source data and area experts to develop precise parameters, involving five parties: the US, India, Pakistani military, Pakistani civilian government, and the terrorist group Lashkar-e-Taiba1 (a prominent south Asian terrorist organization responsible for attacks in India, Kashmir, Pakistan, and Afghanistan). Our results suggest new policies for quantifiably reducing this real-world conflict.

Coordinated movement: How can we plan the coordinated motion of a collection of agents (representing robots, soldiers, civilians, vehicles, network messages, etc.) to achieve a global property in the network, such as forming a connected or fault-tolerant communication network (given a model of connectivity), dispersing throughout an environment to ensure coverage or avoid interference, collecting agents together into a small number of collocated groups, or arrange into a desired topological formation such as a grid. The goal is to minimize the required maximum movement (waiting time) or average movement (expended energy). We characterize the boundary between tractable and intractable movement problems in a very general set up. Using our general tools, we determine the complexity of several concrete problems and show that many movement problems of interest can be solved or approximated efficiently.

Technical approach. Our unique expertise is in the development of mathematically grounded algorithms, with precise guarantees on the trade-off between computational resources and the quality/precision of computed solutions. These provably guarantees make for quantifiable improvements on the state-of-the-art in the many application domains described above.

The study of algorithms has a tendency to focus on searching for individual solutions to a specific problem, then moving on to the next problem. Our unique approach is to develop very general frameworks that apply to an entire category of problems all at once. In this way we may approach a general theory of algorithms, wherein a given problem of interest can simply be adapted into the general approach.

Our toolset comes from both algorithms and a branch of mathematics known as *graph structure theory*. Planarity, topological structure, and excluded minors offer powerful footholds for building general algorithmic theories for graph and network problems. We are among the few computer scientists to know this theory in detail — indeed, we have made major contributions to this theory in order to develop better algorithms — giving us a unique edge.

Our research develops two main types of algorithms for solving NP-hard network optimization problems. *Approximation algorithms* allow the solution to be a small factor $1 + \varepsilon$ away from optimal, but requires polynomial time. *Fixed-parameter algorithms* allow the running time to be exponential, but only with respect to a parameter other than problem size, while the solution must be optimal. In general, our goal is to characterize which parts of a problem cause exponential-time behavior, and how the desired approximation factor $1 + \varepsilon$ influences the algorithm's running time.

Research results and future work. Among our results, together we developed the powerful *bidimensionality theory* for network algorithms and better understanding of graph structure theory. Bidimensionality is now the subject of yearly workshops around the world; for example, in just the past nine months, we have co-organized a 5-day Dagstuhl workshop in Germany (2013) and a workshop at the premiere theoretical computer science conference (FOCS 2013).

One offshoot of bidimensionality theory that we developed during this grant is a new technique called *simplifying graph decomposition*. Our result shows how to decompose any given network into a small, desired number of pieces, each of which has low algorithmic complexity. This approach is a strong generalization of typical graph decomposition, which cuts a graph into many small pieces. Our more efficient graph decomposition gives us another unique edge in developing efficient approximation algorithms.

One important direction is to consider *weighted* networks, where some nodes are more important than others and some links represent smaller or larger distances, an aspect often ignored in social network data. Weights also present significant algorithmic challenges, and we aim to extend bidimensionality theory in particular to handle such situations. For example, in the *network coverage* problem above, we have solved the problem in very general graphs, but it remains to fully support weights on the edges to describe general distance functions.

We have made substantial progress on the social network problems mentioned above, but future work remains to be done. In *belief propagation control* and *opinion formation*, we have solved the problem of maximizing propagation for a given budget, but it remains to consider the dual problem of minimizing the budget required to reach a desired level of propagation (e.g., the whole network), as well as other metrics such as maximizing "bang for the buck" (ratio of propagated effect to directly influenced parties), or having parties of different levels of importance (both in terms of desire to convince and their effects on their neighbors). In *collaboration via social networks* and *network creation and formation*, we have solved the problem for many networks of interest, but it remains to characterize exactly which networks have equilibria with the desired properties and to determine their structure. In *policy recommendation*, we have already demonstrated the system in an important real-world scenario; what remains is to make the system easier to use by policy makers, and to apply the system to additional scenarios. In *coordinated movement*, we have developed algorithms for many interesting scenarios, and are currently working on a more general scenario of "moving repairman" where moving supplies (ammo depot vehicles, water or gas supply, etc.) need to visit moving demands (patrol vehicles, pedestrian soldiers, etc.).

2 Graph Structure of Network Creation Games

We completed the final versions of two of our papers about the graph structure inherent in "network creation games", which appeared in the following venues:

> Erik D. Demaine, MohammadTaghi Hajiaghayi, Hamid Mahini, and Morteza Zadimoghaddam, "The Price of Anarchy in Network Creation Games", *ACM Transactions on Algorithms*, volume 8, number 2, 2012, Paper 13.
>
> Erik D. Demaine and Morteza Zadimoghaddam, "Constant Price of Anarchy in Network-Creation Games via Public-Service Advertising", *Internet Mathematics*, volume 8, number 1–2, 2012, pages 29–45.
>
> Noga Alon, Erik D. Demaine, MohammadTaghi Hajiaghayi, and Tom Leighton, "Basic Network Creation Games", *SIAM Journal on Discrete Mathematics*, volume 27, number 2, 2013, pages 656–668.

3 External Memory

In our Algorithmica paper "Worst-Case Optimal Tree Layout in External Memory", we give optimal algorithms to lay out a fixed-topology binary tree of N nodes into external memory with block size B so as to minimize the worst-case number of block memory transfers required to traverse a path from the root to a node of depth D. For this fundamental problem, we prove that the optimal number of memory transfers is

$$\begin{cases} \Theta\left(\frac{D}{\lg(1+B)}\right) & \text{when } D = O(\lg N), \\ \Theta\left(\frac{\lg N}{\lg\left(1+\frac{B\lg N}{D}\right)}\right) & \text{when } D = \Omega(\lg N) \text{ and } D = O(B\lg N), \\ \Theta\left(\frac{D}{B}\right) & \text{when } D = \Omega(B\lg N). \end{cases}$$

4 Streaming Algorithms for Massive Network Analysis

In massive streaming networks, the node and connection data is too large and coming in too fast to even store in the computer's memory, requiring algorithms to manipulate the data immediately as it streams by using relatively little memory. Nonetheless, we would like to compute and update a clustering of the network as the connections streams by.

Streaming algorithms have been developed for polynomial-time problems (the PIs wrote one of the first papers on this topic), but so far have not been developed for NP-hard graph/network problems. We successfully tackled this challenging new family of problems using our expertise in Fixed-Parameter Tractability, Structural Graph Theory, and Approximation Algorithms.

4.1 Streaming Algorithms via Fixed-Parameter Tractability

We newly introduce the approach of *parameterized* streaming algorithms, based on our expertise with fixed-parameter algorithms. In this approach, the goal is to solve the problem much better when the optimal solution (output) is much smaller than the network size (input). Specifically, we aim to characterize the trade-off between overall running time $T(n, \mathrm{OPT}) = O(f(\mathrm{OPT}) \cdot n \text{ polylog } n)$, memory space $M(n, \mathrm{OPT}) = O(g(\mathrm{OPT}) \text{ polylog } n)$, and guaranteed approximation factor $\varepsilon(n, \mathrm{OPT}) = O(1)$ or even exact (guaranteed optimal solution).

More precisely, we use the model of streaming graph processing, in which each edge insertion/deletion triggers an update to a compact summary of the graph structure. Few results are known for optimization problems over such dynamic graph streams. We introduce a new approach to handling graph streams, by instead seeking solutions for the parameterized versions of these problems. Here, we are given a parameter k and the objective is to decide whether there is a solution bounded by k. By combining kernelization techniques with randomized sketch structures, we obtain the first streaming algorithms for the parameterized versions of Maximal Matching and Vertex Cover. We consider various models for a graph stream on n nodes: the insertion-only model where the edges can only be added, and the dynamic model where edges can be both inserted and deleted. We prove the following results:

- In the insertion-only model, there is a one-pass deterministic algorithm for the parameterized Vertex Cover problem which computes a sketch using $O(k^2 \operatorname{polylog} m)$ space, where m is the number of edges, such that at each timestamp in time $O(2^k \operatorname{polylog} m)$ it can either extract a solution of size at most k for the current instance, or report that no such solution exists. We also show a tight lower bound of $\Omega(k^2)$ for the space complexity of any (randomized) streaming algorithms for the parameterized Vertex Cover, even in the insertion-only model.

- In the dynamic model, and under the promise that at each timestamp there is a maximal matching of size at most k, there is a one-pass $O(k^2 \operatorname{polylog} m)$-space (sketch-based) dynamic algorithm that maintains a maximal matching with worst-case update time $O(k^2 \operatorname{polylog} m)$. This algorithm partially solves Open Problem 64 from sublinear.info. An application of this dynamic matching algorithm is a one-pass $O(k^2 \operatorname{polylog} m)$-space streaming algorithm for the parameterized Vertex Cover problem that in time $O(2^k \operatorname{polylog} m)$ extracts a solution for the final instance with probability $1 - \delta/n^{O}(1)$, where $\delta < 1$. To the best of our knowledge, this is the first graph streaming algorithm that combines linear sketching with sequential operations that depend on the graph at the current time.

- In the dynamic model without any promise, there is a one-pass randomized algorithm for the parameterized Vertex Cover problem which computes a sketch using $O(nk \operatorname{polylog} m)$ space such that in time $O((nk + 2^k) \operatorname{polylog} m)$ it can either extract a solution of size at most k for the final instance, or report that no such solution exists.

Some of these results were presented at the top algorithms conference, SODA 2015, and additional results were presented at SODA 2016.

4.2 Streaming Algorithms via Structural Graph Theory

Motivated by real-world applications, we consider instances of graph streams whose underlying graphs have a particular structure. In particular, we are interested in graph streams whose underlying graph is a tree, an H-minor-free graph, or most generally, a graph with constant average degree. We call this streaming model the *promised streaming model.* Motivating examples of the these graph streams include the real-world graphs crawled by the scientists at University of Koblenz-Landau[2] who observed that the average degree of social networks are mostly constant. For example, they measured that, on large samples of the entire network, the Amazon graph has average degree 17.7, the Facebook graph has average degree 37.3, the Flickr graph has average degree 32.7, and the Twitter graph has average out-degree 35.3 (among many others).

Specifically, we consider the problem of estimating the size of a maximum matching when the edges are revealed in a streaming fashion. When the input graph is planar, we present a simple and elegant streaming algorithm that with high probability estimates the size of a maximum matching within a constant factor using $\tilde{O}(n^{2/3})$ space, where n is the number of vertices. The approach generalizes to the family of graphs that have bounded arboricity, which include graphs with an excluded constant-size minor. To the best of our knowledge, this is the first result for estimating the size of a maximum matching in the adversarial-order streaming model (as opposed to the random-order streaming model) in $o(n)$ space. We circumvent the barriers inherent in the adversarial-order model by exploiting several structural properties of planar graphs, and more generally, graphs with bounded arboricity. We further reduce the required memory size to $\tilde{O}(\sqrt{n})$ for three restricted settings: (i) when the input graph is a forest; (ii) when we have 2-passes and the input graph has bounded arboricity; and (iii) when the edges arrive in random order and the input graph has bounded arboricity.

Finally, we design a reduction from the Boolean Hidden Matching Problem to show that there is no randomized streaming algorithm that estimates the size of the maximum matching to within a factor better than 3/2 and uses only $o(n^{1/2})$ bits of space. Using the same reduction, we show that there is no deterministic algorithm that computes this kind of estimate in $o(n)$ bits of space. The lower bounds hold even for graphs that are collections of paths of constant length.

These results were just presented in a second paper at the top algorithms conference, SODA 2015.

4.3 Streaming Algorithms via Approximation Algorithms

Our third approach is to use our expertise in approximation algorithms to relax the requirement of an exact solution and thereby enable the solution to NP-hard problems with provable solution quality guarantees.

We develop the first streaming algorithm and the first two-party communication protocol that uses a constant number of passes and sublinear space for logarithmic approximation to the classic Set Cover problem. Specifically, for n elements and m sets, our algorithm achieves a space bound of $O(m \cdot n^{\delta} \log^2 n \log m)$ (for any $\delta > 0$) using $O(4^{1/\delta})$ passes while achieving an approximation factor of $O(4^{1/\delta} \log n)$ in polynomial time. If we allow the algorithm to spend exponential time per pass/round, we achieve an approximation factor of $O(4^{1/\delta})$. Our approach uses randomization, which we show is necessary: no deterministic constant approximation is possible (even given exponential time) using $o(mn)$ space. These results are some of the first on streaming algorithms for approximation algorithms. Moreover, we show that our algorithm can be applied to multi-party communication model.

Table 1 summarized our results and how they improve upon past work. These results were just presented at a top distributed computing conference, DISC 2014.

[2]http://konect.uni-koblenz.de/about

Result	Approximation	Passes/rounds	Space/communication	Type
Greedy algorithm	$\ln n$	1	$O(m \cdot n)$	deterministic algorithm
	$\ln n$	n	$O(n)$	deterministic algorithm
SDM 2009	$O(\log n)$	$O(\log n)$	$O(n \log n)$	deterministic algorithm
ICALP 2014	$O(\sqrt{n})$	1	$\tilde{O}(n)$	deterministic algorithm
ICALP 2002	$\frac{1}{2} \log n$	any	$\Omega(m)$	randomized lower bound
This paper	$O(4^{1/\delta}\rho)$	$O(4^{1/\delta})$	$O(m \cdot n^{\delta} \log^2 n \log m)$	randomized algorithm[3]
This paper	$\frac{1}{2} \log n$	any	$\Omega(m \cdot n)$	deterministic lower bound

Figure 1: Summary of past work and our results. The algorithmic bounds are stated for the streaming model, while the lower bounds are stated for the two-party communication complexity model. We use ρ to denote the approximation factor of an off-line algorithm solving Set Cover, which is $\ln n$ for the greedy algorithm and 1 for the exponential time algorithm. Furthermore, we allow any $\delta > 0$.

5 Social Behavior and Game Theory

An important challenge in real-world networks is understanding the behavior of independent decision-making agents in the network, each trying to optimize their own benefit. When many agents play such a game, and continually modify their own strategies to optimize against the other players' strategies, what types of equilibria does the system reach? Can we characterize these equilibria as having useful structural properties which can expect of real systems?

In our recent AAAI 2016 paper, we study the problem of computing Nash equilibria of zero-sum games. Many natural zero-sum games have exponentially many strategies, but highly structured payoffs. For example, in the well-studied Colonel Blotto game (introduced by Borel in 1921), players must divide a pool of troops among a set of battlefields with the goal of winning (i.e., having more troops in) a majority. Because of the size of the strategy space, standard LP-based methods for computing equilibria of zero-sum games fail to be computationally feasible. We present a general technique for computing equilibria of zero-sum games like Colonel Blotto. Our approach takes the form of a reduction: to find a Nash equilibrium of a zero-sum game, we prove that it suffices to design a separation oracle for the strategy polytope of any bilinear game that is payoff-equivalent. In particular, we do not require that the strategy polytope have only polynomially many constraints.

We apply our technique to obtain the first polynomial-time algorithms for a variety of games. In addition to Colonel Blotto, we show how to compute equilibria in an infinite-strategy variant called the General Lotto game; this involves showing how to prune the strategy space to a finite subset before applying our reduction. We also consider the class of dueling games, first introduced at STOC 2011. We show that our approach provably extends the class of dueling games for which equilibria can be computed by introducing a new dueling game, the matching duel, on which prior methods fail to be computationally feasible but upon which our reduction can be applied.

This result received significant media attention, e.g., in *Science Daily*, in particular for being the first to solve the Colonel Blotto game after almost 100 years.

6 Influencing Behavior and Game Theory

In a social network, people's opinions are strongly influenced by their friends' opinions, causing behaviors to cascade through the network given a strong enough start. How can we best leverage such behavioral cascades to infiltrate a known network with a desired idea or belief? For example, to promote a health-related idea such as "drink clean water", "don't smoke", "exercise", "get vaccinated", "take a flu shot", etc., on which demographic groups or influential people should we spend effort in advertising, lobbying, etc. to maximize the final impact after propagation? In the simplest model, each individual i has a *threshold* τ_i, each connection $i \to j$ has an *influence* $w(i,j)$, an individual i becomes enabled (infected, convinced to exercise, etc.) whenever $\sum_{j \text{ enabled}} w(j,i) \geq \tau_i$, and this propagation continues until convergence. The algorithmic problem we studied is, given a budget for seeding this process, which individuals should we enable to be most effective. As promised for Phase 2, we developed $n^{O(1)}$-time $O(1)$-approximation algorithms to compute the precise budget allocation for each target in order to maximize overall influence after propagation, with a guaranteed bound on solution quality. These results appeared at the World Wide Web conference.

7 BigDND: Big Dynamic Network Data

Networks are everywhere, and there is an increasing amount of data about networks viewed as graphs: nodes and edges/connections. We have launched a preliminary version of a new website called *BigDND: Big Dynamic Network Data*, http://projects.csail.mit.edu/dnd/. The goal of this website is to collect together large network datasets and network analysis tools, both our own and developed by others.

So far, BigDND links to several existing big data sets:

1. Facebook, Flickr, YouTube, LiveJournal, Orkut social network data
2. Google+ social network data with node attributes
3. Twitter data
4. Paper citation data
5. Web graph data
6. Brain connectome data from Open Connectome (from the GRAPHS program)

In addition, we have developed software to analyze the DBLP dataset, which is a comprehensive database of computer science papers, consisting of a big network of over 4 billion papers and 1.5 billion authors (nodes) and over 9 billion authorship relations (edges). Beyond basic parsing tools, we combined this dataset with lists of faculty in computer science departments in the United States to compute a data-based ranking of theoretical computer science groups.[4] This type of ranking is in important contrast to existing approaches. On the one hand, U.S. News and similar rankings are based on surveys of department heads' opinions of departments, and generally lack transparency and well-defined measures. On the other hand, the National Research Council (the working arm of the United States National Academies, funded by taxpayer money) uses a data-based approach; unfortunately, it has taken several years to even collect the relevant data, the data has been shown to have many errors, and they no longer compute a ranking based on their data. By contrast, our approach is purely data-driven, verifiable, and the data was collected and analyzed efficiently using our algorithmic big-data tools. Our ranking produced much interest and news, with over 10,000 visits on the day of its release.

[4] http://projects.csail.mit.edu/dnd/ranking/

8 Uniform Sampling

In our recent SPAA 2016 paper, we developed the first non-trivial algorithm for the densest subgraph problem in the streaming model with additions and deletions to its edges, i.e., for dynamic graph streams. They present a (0.5-epsilon)-approximation algorithm using $\tilde{O}(n)$ space, where factors of ε and $\log n$ are suppressed in the $\tilde{O}$ notation. However, the update time of this algorithm is large. To remedy this, they also provide a $(0.25 - \varepsilon)$-approximation algorithm using $\tilde{O}(n)$ space with update time $\tilde{O}(1)$.

In this paper we improve the algorithms by Bhattacharya et al. by providing a $(1-\varepsilon)$-approximation algorithm using $\tilde{O}(n)$ space. Our algorithm is conceptually simple — it samples $\tilde{O}(n)$ edges uniformly at random, and finds the densest subgraph on the sampled graph. We also show how to perform this sampling with update time $\tilde{O}(1)$. In addition to this, we show that given oracle access to the edge set, we can implement our algorithm in time $\tilde{O}(n)$ on a graph in the standard RAM model. To the best of our knowledge this is the fastest $(0.5 - \varepsilon)$-approximation algorithm for the densest subgraph problem in the RAM model given such oracle access. Further, we extend our results to a general class of graph optimization problems that we call heavy subgraph problems. This class contains many interesting problems such as densest subgraph, directed densest subgraph, densest bipartite subgraph, d-cut and d-heavy connected component. Our result, by characterizing heavy subgraph problems, partially addresses open problem 13 at the IITK Workshop on Algorithms for Data Streams in 2006 regarding the effects of subsampling in this context.

In collaboration with the Sotera Defense team, we have implemented this algorithm and it works great in practice as well.

9 Spanner Bootstrapping

Very recently, we made substantial and major progress by introducing the "spanner bootstrapping" techniques, which appeared at the premiere theoretical computer science conference, STOC 2016.

More precisely we present the first polynomial-time approximation scheme (PTAS), i.e., $(1+\varepsilon)$-approximation algorithm for any constant $\varepsilon > 0$, for the planar group Steiner tree problem (in which each group lies on a boundary of a face). This result improves on the best previous approximation factor of $(\log n(\log \log n)^{O(1)})$. We achieve this result via a novel and powerful technique called spanner bootstrapping, which allows one to bootstrap from a superconstant approximation factor (even superpolynomial in the input size) all the way down to a PTAS. This is in contrast with the popular existing approach for planar PTASs of constructing light-weight spanners in one iteration, which notably requires a constant-factor approximate solution to start from. Spanner bootstrapping removes one of the main barriers for designing PTASs for problems which have no known constant-factor approximation (even on planar graphs), and thus can be used to obtain PTASs for several difficult-to-approximate problems.

Our second major contribution required for the planar group Steiner tree PTAS is a spanner construction, which reduces the graph to have total weight within a factor of the optimal solution while approximately preserving the optimal solution. This is particularly challenging because group Steiner tree requires deciding which terminal in each group to connect by the tree, making it much harder than recent previous approaches to construct spanners for planar TSP by Klein [SIAM J. Computing 2008], subset TSP by Klein [STOC 2006], Steiner tree by Borradaile, Klein, and Mathieu [ACM Trans. Algorithms 2009], and Steiner forest by Bateni, Hajiaghayi, and Marx [J. ACM 2011] (and its improvement to an efficient PTAS by Eisenstat, Klein, and Mathieu [SODA 2012]. The main conceptual contribution here is realizing that selecting which terminals may be relevant is essentially a complicated prize-collecting process: we have to carefully weigh the cost and benefits of reaching or avoiding certain terminals in the spanner. Via a sequence of involved prize-collecting procedures, we can construct a spanner that reaches a set of terminals that is sufficient for an almost-optimal solution.

Our PTAS for planar group Steiner tree implies the first PTAS for geometric Euclidean group Steiner tree with obstacles, as well as a $(2 + \varepsilon)$-approximation algorithm for group TSP with obstacles, improving over the best previous constant-factor approximation algorithms. By contrast, we show that planar group Steiner forest, a slight generalization of planar group Steiner tree, is APX-hard on planar graphs of treewidth 3, even if the groups are pairwise disjoint and every group is a vertex or an edge.

10 Publications

— 2016 —

1. MohammadTaghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Zeev Nutov: On Fixed Cost k-Flow Problems. Theory Comput. Syst. 58(1): 4-18 (2016)

2. Rajesh Chitnis, Marek Cygan, MohammadTaghi Hajiaghayi, Marcin Pilipczuk, Michal Pilipczuk: Designing FPT Algorithms for Cut Problems Using Randomized Contractions. SIAM J. Comput. 45(4): 1171-1229 (2016)

3. Mohammad Taghi Hajiaghayi, Wei Hu, Jian Li, Shi Li, Barna Saha: A Constant Factor Approximation Algorithm for Fault-Tolerant k-Median. ACM Trans. Algorithms 12(3): 36 (2016)

4. Mohammad Taghi Hajiaghayi, Rohit Khandekar, Mohammad Reza Khani, Guy Kortsarz: Approximation Algorithms for Movement Repairmen. ACM Trans. Algorithms 12(4): 54 (2016)

5. AmirMahdi Ahmadinejad, Sina Dehghani, MohammadTaghi Hajiaghayi, Brendan Lucier, Hamid Mahini, Saeed Seddighin: From Duels to Battlefields: Computing Equilibria of Blotto and Other Games. AAAI 2016: 376-382

6. Melika Abolhassani, T.-H. Hubert Chan, Fei Chen, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Hamid Mahini, Xiaowei Wu: Beating Ratio 0.5 for Weighted Oblivious Matching Problems. ESA 2016: 3:1-3:18

7. Amey Bhangale, Rajiv Gandhi, Mohammad Taghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz: Bicovering: Covering Edges With Two Small Subsets of Vertices. ICALP 2016: 6:1-6:12

8. Sina Dehghani, Mohammad Taghi Hajiaghayi, Hamid Mahini, Saeed Seddighin: Price of Competition and Dueling Games. ICALP 2016: 21:1-21:14

9. Sina Dehghani, Soheil Ehsani, Mohammad Taghi Hajiaghayi, Vahid Liaghat, Harald Rcke, Saeed Seddighin: Online Weighted Degree-Bounded Steiner Networks via Novel Online Mixed Packing/Covering. ICALP 2016: 42:1-42:14

10. Sina Dehghani, Soheil Ehsani, MohammadTaghi Hajiaghayi, Vahid Liaghat: Online Degree-Bounded Steiner Network Design. SODA 2016: 164-175

11. Rajesh Chitnis, Graham Cormode, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Andrew McGregor, Morteza Monemizadeh, Sofya Vorotnikova: Kernelization via Sampling with Applications to Finding Matchings and Related Problems in Dynamic Graph Streams. SODA 2016: 1326-1344

12. Hossein Esfandiari, MohammadTaghi Hajiaghayi, David P. Woodruff: Brief Announcement: Applications of Uniform Sampling: Densest Subgraph and Beyond. SPAA 2016: 397-399

13. MohammadHossein Bateni, Erik D. Demaine, MohammadTaghi Hajiaghayi, Dniel Marx: A PTAS for planar group Steiner tree via spanner bootstrapping and prize collecting. STOC 2016: 570-583

14. Mohammad Taghi Hajiaghayi, Mohammad Reza Mousavi: Topics in Theoretical Computer Science - The First IFIP WG 1.8 International Conference, TTCS 2015, Tehran, Iran, August 26-28, 2015, Revised Selected Papers. Lecture Notes in Computer Science 9541, Springer 2016, ISBN 978-3-319-28677-8 [contents]

15. Mohammad Taghi Hajiaghayi, Erik D. Demaine: Approximation Schemes for Planar Graph Problems. Encyclopedia of Algorithms 2016: 133-137

16. Mohammad Taghi Hajiaghayi, Hamid Mahini: Bargaining Networks. Encyclopedia of Algorithms 2016: 174-177

17. Fedor V. Fomin, Erik D. Demaine, Mohammad Taghi Hajiaghayi, Dimitrios M. Thilikos: Bidimensionality. Encyclopedia of Algorithms 2016: 203-207

18. Erik D. Demaine, Mohammad Taghi Hajiaghayi, Hamid Mahini, Morteza Zadimoghaddam: Network Creation Games. Encyclopedia of Algorithms 2016: 1408-1412

19. Mohammad Taghi Hajiaghayi, Vahid Liaghat: Prophet Inequality and Online Auctions. Encyclopedia of Algorithms 2016: 1634-1636

20. Rajesh Chitnis, Mohammad Taghi Hajiaghayi: Shadowless Solutions for Fixed-Parameter Tractability of Directed Graphs. Encyclopedia of Algorithms 2016: 1963-1966

21. Mahdi Ahmadinejad, Sina Dehghani, MohammadTaghi Hajiaghayi, Brendan Lucier, Hamid Mahini, Saeed Seddighin: From Duels to Battefields: Computing Equilibria of Blotto and Other Games. CoRR abs/1603.00119 (2016)

22. Sina Dehghani, MohammadTaghi Hajiaghayi, Hamid Mahini, Saeed Seddighin: Price of Competition and Dueling Games. CoRR abs/1605.04004 (2016)

23. Mohammad Taghi Hajiaghayi, Amey Bhangale, Rajiv Gandhi, Rohit Khandekar, Guy Kortsarz: Bicovering: Covering edges with two small subsets of vertices. Electronic Colloquium on Computational Complexity (ECCC) 23: 112 (2016)

— 2015 —

22. Hans L. Bodlaender, MohammadTaghi Hajiaghayi, Giuseppe F. Italiano: Editorial. Algorithmica 73(4): 748-749 (2015)

23. Hans L. Bodlaender, Mohammad Taghi Hajiaghayi, Giuseppe F. Italiano: Erratum to: Editorial. Algorithmica 73(4): 750 (2015)

24. Rajesh Hemant Chitnis, Marek Cygan, Mohammad Taghi Hajiaghayi, Dniel Marx: Directed Subset Feedback Vertex Set Is Fixed-Parameter Tractable. ACM Trans. Algorithms 11(4): 28 (2015)

25. Anshul Sawant, John P. Dickerson, Mohammad Taghi Hajiaghayi, V. S. Subrahmanian: Automated Generation of Counterterrorism Policies Using Multiexpert Input. ACM TIST 6(4): 44 (2015)

26. Hui Miao, Peixin Gao, MohammadTaghi Hajiaghayi, John S. Baras: HyperCubeMap: Optimal Social Network Ad Allocation Using Hyperbolic Embedding. ASONAM 2015: 357-362

27. Melika Abolhassani, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Hamid Mahini, David L. Malec, Aravind Srinivasan: Selling Tomorrow's Bargains Today. AAMAS 2015: 337-345

28. MohammadHossein Bateni, Sina Dehghani, MohammadTaghi Hajiaghayi, Saeed Seddighin: Revenue Maximization for Selling Multiple Correlated Items. ESA 2015: 95-105

29. Hossein Efsandiari, Mohammad Taghi Hajiaghayi, Jochen Knemann, Hamid Mahini, David L. Malec, Laura Sanit: Approximate Deadline-Scheduling with Precedence Constraints. ESA 2015: 483-495

30. Hossein Esfandiari, MohammadTaghi Hajiaghayi, Vahid Liaghat, Morteza Monemizadeh: Prophet Secretary. ESA 2015: 496-508

31. Mohammad Taghi Hajiaghayi, Guy Kortsarz, Robert MacDavid, Manish Purohit, Kanthi K. Sarpatwar: Approximation Algorithms for Connected Maximum Cut and Related Problems. ESA 2015: 693-704

32. AmirMahdi Ahmadinejad, Sina Dehghani, MohammadTaghi Hajiaghayi, Hamid Mahini, Saeed Seddighin, Sadra Yazdanbod: Forming external behaviors by leveraging internal opinions. INFOCOM 2015: 1849-1857

33. Hossein Esfandiari, Mohammad Taghi Hajiaghayi, Vahid Liaghat, Morteza Monemizadeh, Krzysztof Onak: Streaming Algorithms for Estimating the Matching Size in Planar Graphs and Beyond. SODA 2015: 1217-1233

34. Rajesh Hemant Chitnis, Graham Cormode, Mohammad Taghi Hajiaghayi, Morteza Monemizadeh: Parameterized Streaming: Maximal Matching and Vertex Cover. SODA 2015: 1234-1251

35. Rajesh Hemant Chitnis, Graham Cormode, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Morteza Monemizadeh: Brief Announcement: New Streaming Algorithms for Parameterized Maximal Matching & Beyond. SPAA 2015: 56-58

36. Kotaro Hara, Mohammad Taghi Hajiaghayi, Benjamin B. Bederson: FluTCHA: Using Fluency to Distinguish Humans from Computers. WWW (Companion Volume) 2015: 43-44

37. Rajesh Hemant Chitnis, Graham Cormode, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Andrew McGregor, Morteza Monemizadeh, Sofya Vorotnikova: Kernelization via Sampling with Applications to Dynamic Graph Streams. CoRR abs/1505.01731 (2015)

38. Rajesh Hemant Chitnis, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Saeed Seddighin: A Tight Algorithm for Strongly Connected Steiner Subgraph On Two Terminals With Demands. CoRR abs/1506.03760 (2015)

39. Hossein Esfandiari, MohammadTaghi Hajiaghayi, David P. Woodruff: Applications of Uniform Sampling: Densest Subgraph and Beyond. CoRR abs/1506.04505 (2015)

40. Gagan Goel, MohammadTaghi Hajiaghayi, Mohammad Reza Khani: Randomized Revenue Monotone Mechanisms for Online Advertising. CoRR abs/1507.00130 (2015)

41. MohammadTaghi Hajiaghayi, Guy Kortsarz, Robert MacDavid, Manish Purohit, Kanthi K. Sarpatwar: Approximation Algorithms for Connected Maximum Cut and Related Problems. CoRR abs/1507.00648 (2015)

42. Hossein Esfandiari, Mohammad Taghi Hajiaghayi, Jochen Knemann, Hamid Mahini, David L. Malec, Laura Sanit: Approximate Deadline-Scheduling with Precedence Constraints. CoRR abs/1507.00748 (2015)

43. Hossein Esfandiari, MohammadTaghi Hajiaghayi, Vahid Liaghat, Morteza Monemizadeh: Prophet Secretary. CoRR abs/1507.01155 (2015)

44. Erik D. Demaine, Martin L. Demaine, Eli Fox-Epstein, Duc A. Hoang, Takehiro Ito, Hirotaka Ono, Yota Otachi, Ryuhei Uehara, Takeshi Yamada: Linear-time algorithm for sliding tokens on trees. Theor. Comput. Sci. 600: 132-142 (2015)

— 2014 —

45. Mohammad Taghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Vahid Liaghat: On a Local Protocol for Concurrent File Transfers. Theory Comput. Syst. 55(3): 613-636 (2014)

46. Noga Alon, Erik D. Demaine, MohammadTaghi Hajiaghayi, Panagiotis Kanellopoulos, Tom Leighton: Correction: Basic Network Creation Games. SIAM J. Discrete Math. 28(3): 1638-1640 (2014)

47. Erik D. Demaine, Mohammad Taghi Hajiaghayi, Philip N. Klein: Node-Weighted Steiner Tree and Group Steiner Tree in Planar Graphs. ACM Trans. Algorithms 10(3): 13:1-13:20 (2014)

48. Erik D. Demaine, Mohammad Taghi Hajiaghayi, Dniel Marx: Minimizing Movement: Fixed-Parameter Tractability. ACM Trans. Algorithms 11(2): 14:1-14:29 (2014)

49. Mahdi Hajiaghayi, Carl Wijting, Cssio B. Ribeiro, Mohammad Taghi Hajiaghayi: Efficient and practical resource block allocation for LTE-based D2D network via graph coloring. Wireless Networks 20(4): 611-624 (2014)

50. Hossein Esfandiari, MohammadTaghi Hajiaghayi, Mohammad Reza Khani, Vahid Liaghat, Hamid Mahini, Harald Rcke: Online Stochastic Reordering Buffer Scheduling. ICALP (1) 2014: 465-476

51. MohammadTaghi Hajiaghayi, Vahid Liaghat, Debmalya Panigrahi: Near-Optimal Online Algorithms for Prize-Collecting Steiner Problems. ICALP (1) 2014: 576-587

52. Rajesh Hemant Chitnis, Hossein Esfandiari, MohammadTaghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Saeed Seddighin: A Tight Algorithm for Strongly Connected Steiner Subgraph on Two Terminals with Demands (Extended Abstract). IPEC 2014: 159-171

53. MohammadTaghi Hajiaghayi, Hamid Mahini, David L. Malec: The polarizing effect of network influences. EC 2014: 131-148

54. MohammadTaghi Hajiaghayi, Wei Hu, Jian Li, Shi Li, Barna Saha: A Constant Factor Approximation Algorithm for Fault-Tolerant k-Median. SODA 2014: 1-12

55. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Dniel Marx: Tight Bounds for Planar Strongly Connected Steiner Subgraph with Fixed Number of Terminals (and Extensions). SODA 2014: 1782-1801

56. Mohammad Taghi Hajiaghayi, Theodore Johnson, Mohammad Reza Khani, Barna Saha: Hierarchical graph partitioning. SPAA 2014: 51-60

57. Melika Abolhassani, MohammadHossein Bateni, MohammadTaghi Hajiaghayi, Hamid Mahini, Anshul Sawant: Network Cournot Competition. WINE 2014: 15-29

58. Gagan Goel, MohammadTaghi Hajiaghayi, Mohammad Reza Khani: Randomized Revenue Monotone Mechanisms for Online Advertising. WINE 2014: 324-337

59. AmirMahdi Ahmadinejad, Sina Dehghani, MohammadTaghi Hajiaghayi, Hamid Mahini, Saeed Seddighin, Sadra Yazdanbod: How effectively can we form opinions? WWW (Companion Volume) 2014: 213-214

60. Erik D. Demaine, MohammadTaghi Hajiaghayi, Hamid Mahini, David L. Malec, S. Raghavan, Anshul Sawant, Morteza Zadimoghaddam: How to influence people with partial incentives. WWW 2014: 937-948

61. Erik D. Demaine, MohammadTaghi Hajiaghayi, Hamid Mahini, David L. Malec, S. Raghavan, Anshul Sawant, Morteza Zadimoghaddam: How to Influence People with Partial Incentives. CoRR abs/1401.7970 (2014)

62. Rajesh Hemant Chitnis, Graham Cormode, Mohammad Taghi Hajiaghayi, Morteza Monemizadeh: Parameterized Streaming Algorithms for Vertex Cover. CoRR abs/1405.0093 (2014)

63. Melika Abolhassani, MohammadHossein Bateni, MohammadTaghi Hajiaghayi, Hamid Mahini, Anshul Sawant: Network Cournot Competition. CoRR abs/1405.1794 (2014)

64. MohammadHossein Bateni, Sina Dehghani, MohammadTaghi Hajiaghayi, Saeed Seddighin: Revenue Maximization for Selling Multiple Correlated Items. CoRR abs/1412.3187 (2014)

65. Glencora Borradaile, Erik D. Demaine, Siamak Tazari: Polynomial-Time Approximation Schemes for Subset-Connectivity Problems in Bounded-Genus Graphs. Algorithmica 68(2): 287-311 (2014)

66. Erik D. Demaine, Piotr Indyk, Sepideh Mahabadi, Ali Vakilian: On Streaming and Communication Complexity of the Set Cover Problem. DISC 2014: 484-498

67. Erik D. Demaine, Felix Reidl, Peter Rossmanith, Fernando Snchez Villaamil, Somnath Sikdar, Blair D. Sullivan: Structural Sparsity of Complex Networks: Random Graph Models and Linear Algorithms. CoRR abs/1406.2587 (2014)

— 2013 —

68. Erik D. Demaine, Mohammad Ghodsi, MohammadTaghi Hajiaghayi, Amin S. Sayedi-Roshkhar, Morteza Zadimoghaddam: Scheduling to minimize gaps and power consumption. J. Scheduling 16(2): 151-160 (2013)

69. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Dniel Marx: Fixed-Parameter Tractability of Directed Multiway Cut Parameterized by the Size of the Cutset. SIAM J. Comput. 42(4): 1674-1696 (2013)

70. Noga Alon, Erik D. Demaine, Mohammad Taghi Hajiaghayi, Tom Leighton: Basic Network Creation Games. SIAM J. Discrete Math. 27(2): 656-668 (2013)

71. MohammadHossein Bateni, Mohammad Taghi Hajiaghayi, Morteza Zadimoghaddam: Submodular secretary problem and extensions. ACM Trans. Algorithms 9(4): 32 (2013)

72. Saeed Alaei, MohammadTaghi Hajiaghayi, Vahid Liaghat: The Online Stochastic Generalized Assignment Problem. APPROX-RANDOM 2013: 11-25

73. MohammadTaghi Hajiaghayi, Rohit Khandekar, M. Reza Khani, Guy Kortsarz: Approximation Algorithms for Movement Repairmen. APPROX-RANDOM 2013: 218-232

74. John P. Dickerson, Anshul Sawant, Mohammad Taghi Hajiaghayi, V. S. Subrahmanian: PREVE: a policy recommendation engine based on vector equilibria applied to reducing LeT's attacks. ASONAM 2013: 1084-1091

75. Marek Chrobak, Uriel Feige, Mohammad Taghi Hajiaghayi, Sanjeev Khanna, Fei Li, Seffi Naor: A Greedy Approximation Algorithm for Minimum-Gap Scheduling. CIAC 2013: 97-109

76. Mohammad Taghi Hajiaghayi, Vahid Liaghat, Debmalya Panigrahi: Online Node-Weighted Steiner Forest and Extensions via Disk Paintings. FOCS 2013: 558-567

77. MohammadHossein Bateni, MohammadTaghi Hajiaghayi, Vahid Liaghat: Improved Approximation Algorithms for (Budgeted) Node-Weighted Steiner Problems. ICALP (1) 2013: 81-92

78. Li Erran Li, Vahid Liaghat, Hongze Zhao, MohammadTaghi Hajiaghayi, Dan Li, Gordon T. Wilfong, Yang Richard Yang, Chuanxiong Guo: PACE: Policy-Aware Application Cloud Embedding. INFOCOM 2013: 638-646

79. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Guy Kortsarz: Fixed-Parameter and Approximation Algorithms: A New Look. IPEC 2013: 110-122

80. MohammadTaghi Hajiaghayi, Hamid Mahini, Anshul Sawant: Scheduling a Cascade with Opposing Influences. SAGT 2013: 195-206

81. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Jonathan Katz, Koyel Mukherjee: Brief announcement: a game-theoretic model motivated by the darpa network challenge. SPAA 2013: 115-118

82. MohammadTaghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Zeev Nutov: On Fixed Cost k-Flow Problems. WAOA 2013: 49-60

83. MohammadHossein Bateni, MohammadTaghi Hajiaghayi, Vahid Liaghat: Improved Approximation Algorithms for (Budgeted) Node-weighted Steiner Problems. CoRR abs/1304.7530 (2013)

84. MohammadTaghi Hajiaghayi, Rohit Khandekar, M. Reza Khani, Guy Kortsarz: Approximation Algorithms for Movement Repairmen. CoRR abs/1306.3739 (2013)

85. Mohammad Taghi Hajiaghayi, Wei Hu, Jian Li, Shi Li, Barna Saha: A Constant Factor Approximation Algorithm for Fault-Tolerant k-Median. CoRR abs/1307.2808 (2013)

86. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Guy Kortsarz: Fixed-Parameter and Approximation Algorithms: A New Look. CoRR abs/1308.3520 (2013)

87. Mohammad Taghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz: The Foundations of Fixed Parameter Inapproximability. CoRR abs/1310.2711 (2013)

88. MohammadTaghi Hajiaghayi, Hamid Mahini, Anshul Sawant: Scheduling a Cascade with Opposing Influences. CoRR abs/1311.5925 (2013)

89. Erik D. Demaine, Fedor V. Fomin, MohammadTaghi Hajiaghayi, Dimitrios M. Thilikos: Bidimensional Structures: Algorithms, Combinatorics and Logic (Dagstuhl Seminar 13121). Dagstuhl Reports 3(3): 51-74 (2013)

— 2012 —

90. MohammadHossein Bateni, MohammadTaghi Hajiaghayi: Euclidean Prize-Collecting Steiner Forest. Algorithmica 62(3-4): 906-929 (2012)

91. MohammadTaghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz: Local Search Algorithms for the Red-Blue Median Problem. Algorithmica 63(4): 795-814 (2012)

92. Erik D. Demaine, Mohammad Taghi Hajiaghayi, Hamid Mahini, Morteza Zadimoghaddam: The price of anarchy in network creation games. ACM Trans. Algorithms 8(2): 13 (2012)

93. MohammadHossein Bateni, MohammadTaghi Hajiaghayi: Assignment problem in content distribution networks: Unsplittable hard-capacitated facility location. ACM Trans. Algorithms 8(3): 20 (2012)

94. Mohammad Taghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Zeev Nutov: Prize-collecting steiner network problems. ACM Trans. Algorithms 9(1): 2 (2012)

95. MohammadTaghi Hajiaghayi, Rohit Khandekar, Guy Kortsarz, Julin Mestre: The checkpoint problem. Theor. Comput. Sci. 452: 88-99 (2012)

96. Marek Cygan, MohammadTaghi Hajiaghayi, Samir Khuller: LP Rounding for k-Centers with Non-uniform Hard Capacities. FOCS 2012: 273-282

97. Rajesh Hemant Chitnis, Marek Cygan, MohammadTaghi Hajiaghayi, Marcin Pilipczuk, Michal Pilipczuk: Designing FPT Algorithms for Cut Problems Using Randomized Contractions. FOCS 2012: 460-469

98. Rajesh Hemant Chitnis, Marek Cygan, Mohammad Taghi Hajiaghayi, Dniel Marx: Directed Subset Feedback Vertex Set Is Fixed-Parameter Tractable. ICALP (1) 2012: 230-241

99. Suk-Bok Lee, Dan Pei, MohammadTaghi Hajiaghayi, Ioannis Pefkianakis, Songwu Lu, He Yan, Zihui Ge, Jennifer Yates, Mario Kosseifi: Threshold compression for 3G scalable monitoring. INFOCOM 2012: 1350-1358

100. Saeed Alaei, MohammadTaghi Hajiaghayi, Vahid Liaghat: Online prophet-inequality matching with applications to ad allocation. EC 2012: 18-35

101. MohammadHossein Bateni, MohammadTaghi Hajiaghayi, Philip N. Klein, Claire Mathieu: A polynomial-time approximation scheme for planar multiway cut. SODA 2012: 639-655

102. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Dniel Marx: Fixed-parameter tractability of directed multiway cut parameterized by the size of the cutset. SODA 2012: 1713-1725

103. Rajesh Hemant Chitnis, MohammadTaghi Hajiaghayi, Jonathan Katz, Koyel Mukherjee: A Game-Theoretic Model Motivated by the DARPA Network Challenge. CoRR abs/1204.6552 (2012)

104. Rajesh Hemant Chitnis, Marek Cygan, MohammadTaghi Hajiaghayi, Dniel Marx: Directed Subset Feedback Vertex Set is Fixed-Parameter Tractable. CoRR abs/1205.1271 (2012)

105. Erik D. Demaine, MohammadTaghi Hajiaghayi, Dniel Marx: Minimizing Movement: Fixed-Parameter Tractability. CoRR abs/1205.6960 (2012)

106. Rajesh Hemant Chitnis, Marek Cygan, MohammadTaghi Hajiaghayi, Marcin Pilipczuk, Michal Pilipczuk: Designing FPT algorithms for cut problems using randomized contractions. CoRR abs/1207.4079 (2012)

107. Marek Cygan, MohammadTaghi Hajiaghayi, Samir Khuller: LP Rounding for k-Centers with Non-uniform Hard Capacities. CoRR abs/1208.3054 (2012)

108. Erik D. Demaine, Morteza Zadimoghaddam: Constant Price of Anarchy in Network-Creation Games via Public-Service Advertising. Internet Mathematics 8(1-2): 29-45 (2012)

AFOSR Deliverables Submission Survey

Response ID:7260 Data

1.

Report Type

Final Report

Primary Contact Email
Contact email if there is a problem with the report.

edemaine@MIT.EDU

Primary Contact Phone Number
Contact phone number if there is a problem with the report

617-253-6871

Organization / Institution name

Massachusetts Institute of Technology

Grant/Contract Title
The full title of the funded effort.

Efficient Algorithmic Frameworks via Structural Graph Theory

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0423

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Erik D Demaine

Program Officer
The AFOSR Program Officer currently assigned to the award

Reza Ghanadan

Reporting Period Start Date

08/01/2012

Reporting Period End Date

09/30/2016

Abstract

In this project, we developed many new efficient algorithms for analysis of networks. We have published over 100 papers during the course of this project, and we launched a new website BigDND [http://projects.csail.mit.edu/dnd/] for distributing large network data and tools for analyzing them. Within network science, our research develops algorithms to enable efficient and guaranteed-quality analysis of a broad range of types of networks, from social networks to computer networks and transportation networks. Real-world social networks of interest include online services (Facebook, Google+, Twitter), coauthorship/collaboration among people (arXiv, DBLP, patents), phone calls (AT\&T, NSA), in-person interactions (FBI, Pentagon), geographic hierarchical neighborhoods (living or working together, on the same block, in the same district or city), and shared interests (Netflix, Amazon, Match.com).

Real-world computer networks of interest include the Internet backbone, ISP networks, ad-hoc wireless networks, sensor networks, and robot swarms. Real-world transportation networks of interest include highways, inner-city roads, supply trains, naval supply routes, flight tracks, and off-road geographic terrains.

An example of an important problem we have studied during the course of this project is belief propagation control. In a social network, people's opinions are strongly influenced by their friends' opinions, causing behaviors to cascade through the network given a strong enough start. How can we best exploit such behavioral cascades to infiltrate a known network with a desired idea or belief? For example, to promote a new political view or regime change during a domestic or international campaign, on which demographic groups or influential people should we spend time and money in advertising, lobbying, etc.? Our algorithm efficiently computes the precise budget allocation for each target in order to maximize overall influence after propagation, with a guaranteed bound on solution quality. We have experimentally evaluated our algorithm on real-world social networks mentioned above, and found it to outperform all previous approaches. This problem has applications to real-world politics and advertising, in both military and civilian settings.

Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form

Please attach your SF298 form. A blank SF298 can be found here. Please do not password protect or secure the PDF The maximum file size for an SF298 is 50MB.

sf0298.pdf

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.

Final-report.pdf

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

Archival Publications (published) during reporting period:

See attached Report

New discoveries, inventions, or patent disclosures:
Do you have any discoveries, inventions, or patent disclosures to report for this period?

No

Please describe and include any notable dates

Do you plan to pursue a claim for personal or organizational intellectual property?

Changes in research objectives (if any):

N/a

Change in AFOSR Program Officer, if any:

N/a

Extensions granted or milestones slipped, if any:

N/a

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Nov 16, 2016 16:36:05 Success: Email Sent to: edemaine@MIT.EDU