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科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Approximation algorithms in environments with uncertainty

研究課題名（英文）Approximation algorithms in environments with uncertainty

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研究成果の概要（和文）：本研究の目的は、不確実性を伴う環境、すなわち分散環境に対する基本的なアルゴリズムの理解を深めることである。そのために、グラフの基本的な問題（例えば、組み合わせ最適化、グラフ検出）に対する新しいアルゴリズムを提示することで、これを達成する。

さらに、実世界のシステムをよりよく捉えることができる動的分散環境に対する新しいアルゴリズムを示す。最後に、worst-case analysisにとどまらず、動的分散環境における基本的な問題のSmoothed complexityについて考察する。

研究成果の学術的意義や社会的意義
We present new distributed algorithms for fundamental problems in the distributed setting. As many modern real world systems have a distributed aspect to them, our algorithm can be used to improve their performance of this systems in the future, and provide theoretical understanding in the present.

研究成果の概要（英文）：The goal of this research is to advance the understanding of fundamental algorithms for environments with uncertainty, namely, the distributed environment. We achieve this by presenting novel algorithms for fundamental graph problems (e.g,. combinatorial optimization, graph detection).

Furthermore, we show novel algorithms for the dynamic distributed setting which better captures real world systems. Finally, we go beyond worst-case analysis and consider the smoothed-complexity of fundamental problems in the dynamic distributed setting.

研究分野：Distributed algorithms

キーワード：Graph algorithms　Distributed algorithms

１．研究開始当初の背景

Background: *New models of computation and algorithms are required for the emerging fields of big-data and distributed computing*

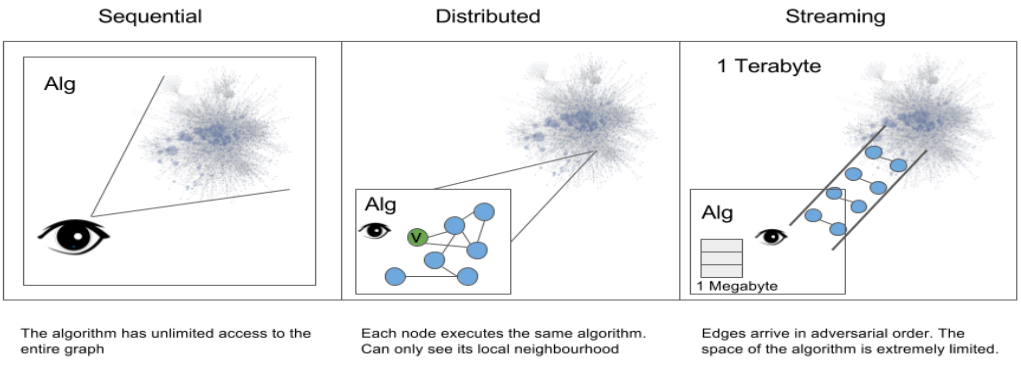
In this research we wish to address **fundamental** graph problems in *environments with uncertainty*. The problems we consider have been extensively researched in the classical setting, are used as building blocks in many algorithms, and the techniques used to solve them have been generalized to a myriad of other problems. By uncertainty, we mean that the algorithm does not have complete knowledge about its input. Specifically, we are interested in approximation algorithms; while finding an exact solution is a global problem, which might require knowing the entire input, finding an approximate solution is a local problem, which admits to very fast algorithms in these environments.

The two main models of computations we focus on are the *distributed and streaming environments*. Both contain uncertainty, but each of a different flavor. In the distributed setting, each node in a network can only see its local environment which is only a tiny part of communication graph. While in the streaming environments, the input arrives in an adversarial fashion and the algorithm can only use a very limited amount of space. Next, we give more detailed descriptions of these two models.

Distributed Algorithms: In the distributed setting we have a network of computers communicating with each other in synchronous rounds. We aim to design algorithms that solve some task while minimizing the number of communication rounds. This models modern day networks where the main bottleneck of an algorithm is the overhead of sending messages over the network. Algorithms designed for this environment are directly applicable to a wide range of real-world distributed systems. The problems we address were extensively researched in this environment and are used as primitives in other distributed algorithms.

Streaming Algorithms: In the streaming environment the input arrives in small chunks, but we only have a limited amount of memory space and cannot keep all of the data. We must solve some task under the space constraints. Streaming algorithms are widely used in networking, some applications include: flow monitoring, load balancing and denial of service attack identification. We focus on streaming algorithms for graphs, here we are interested in solving some graph problem while using space which is at most $O(n \cdot \text{polylog}(n))$, where n is the number of nodes in the graph (this is called the semi-streaming model). This model is very natural in the emerging world of big-data; for example, Facebook's social graph, which has billions of nodes, can be easily processed by a semi-streaming algorithm on a PC, but can require extensive resources if we must use $O(n^2)$ space.

The above models of computation are summarized in the following figure:



２．研究の目的

Purpose of the research: *develop new techniques for designing efficient approximation algorithms in the distributed and streaming environments*

We achieve the above by focusing on fundamental problems in distributed computing, e.g., maximum independent set, set cover. We show how to achieve state of the art algorithms for these problems. Specifically, our goal is to consider fundamental graph problems which have shown their usefulness in the sequential setting and present fast distributed and streaming algorithms for these problems with the hope that they will be useful in the future of distributed computing \ big data algorithms.

３．研究の方法

Our research employed various methods to achieve our objectives. We used the Prima-Dual method to achieve time optimal algorithms for distributed covering problems. For the maximum independent set problem we introduced a novel sampling technique which essentially results in a sparsifier for the problem. We introduced parameterized algorithms to the distributed setting, in doing so, we showed extremely fast algorithms for many combinatorial optimization problems when the solution is small.

Our research went far beyond the scope of the original proposal. Not only did we consider static networks, but also dynamic networks. And we went beyond worst-case analysis and considered the smoothed complexity of many fundamental problems.

４．研究成果

Despite the fact that the original research aimed to focus on both distributed and streaming environments, during the process of conducting the research we realized that we are able to achieve many important results for the the distributed setting. Therefor we chose to focus on the distributed setting, with the insight that our techniques are general enough such that they can be transferred to the streaming setting in the future.

Our main contributions can be divided as follows:

- We considered fundamental problems for distributed **static networks**. We presented time optimal covering algorithms, and settled the complexity of the weighted set cover problem in the distributed setting. We showed an exponentially faster algorithm for weighted maximum independent set in the distributed setting. Finally, we were the first to consider parameterized algorithms in the distributed setting.

- We the considered algorithms for fundamental problems in **dynamic networks**. Unlike static networks, they better represent real-world networks. We showed that many fundamental problems such as subgraph detection (for specific subgraphs) and maintaining solutions for combinatorial optimization problems can be achieved in amortized constant time in dynamic networks. Then we turn our attention beyond worst-case analysis and consider the smoothed complexity of dynamic distributed algorithms. We introduce new models of distributed smoothing and consider fundamental problems such as flooding and load balancing. Finally we even show that smoothed analysis is very natural for the population protocol model.

５．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　0件／うち国際共著　0件／うちオープンアクセス　0件）

１．著者名 Censor-Hillel Keren、Parter Merav、Schwartzman Gregory	４．巻 33
２．論文標題 Derandomizing local distributed algorithms under bandwidth restrictions	５．発行年 2020年
３．雑誌名 Distributed Computing	６．最初と最後の頁 349～366
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/s00446-020-00376-1	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

〔学会発表〕　計11件（うち招待講演　1件／うち国際学会　11件）

１．発表者名 Victor Kolobov
２．発表標題 Finding Subgraphs in Highly Dynamic Networks
３．学会等名 SPAA 2021（国際学会）
４．発表年 2021年

１．発表者名 Gregory Schwartzman
２．発表標題 On the Complexity of Load Balancing in Dynamic Networks
３．学会等名 SPAA 2021（国際学会）
４．発表年 2021年

１．発表者名 Gregory Schwartzman
２．発表標題 Smoothed Analysis of Population Protocols
３．学会等名 DISC 2021（国際学会）
４．発表年 2021年

１．発表者名
Victor Kolobov

２．発表標題
Fast and Simple Deterministic Algorithms for Highly-Dynamic Networks

３．学会等名
OPODIS 2020（国際学会）

４．発表年
2020年

１．発表者名
Seri Khoury

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Brief Announcement: Improved Distributed Approximations for Maximum-Weight Independent Set

３．学会等名
PODC 2020（国際学会）

４．発表年
2020年

１．発表者名
Seri Khoury

２．発表標題
Improved Distributed Approximations for Maximum Independent Set

３．学会等名
DISC 2020（国際学会）

４．発表年
2020年

１．発表者名
Ami Paz

２．発表標題
Models of Smoothing in Dynamic Networks

３．学会等名
DISC 2020（国際学会）

４．発表年
2020年

１．発表者名
Victor Kolobov

２．発表標題
Fast Deterministic Algorithms for Highly-Dynamic Networks

３．学会等名
OPODIS 2020（国際学会）

４．発表年
2020年

１．発表者名
Gregory Schwartzman

２．発表標題
Optimal Distributed Covering Algorithms

３．学会等名
DISC 2019（国際学会）

４．発表年
2019年

１．発表者名
Gregory Schwartzman

２．発表標題
Parameterized Distributed Algorithms.

３．学会等名
DISC 2019（国際学会）

４．発表年
2019年

１．発表者名
Gregory Schwartzman

２．発表標題
Fast and Simple Deterministic Algorithms for Highly-Dynamic Networks

３．学会等名
Diadn @ DISC 2019（招待講演）（国際学会）

４．発表年
2019年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関