

Distributed Computation on Graphs: Shortest Path Algorithms

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We use the paradigm of diffusing computation, introduced by Dijkstra and Scholten, to solve a class of graph problems. We present a detailed solution to the problem of computing shortest paths from a single vertex to all other vertices, in the presence of negative cycles.

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General Terms: Algorithm, Theory

Additional Key Words and Phrases: distributed computation, shortest path, negative cycle, depth first search, diffusing computation

1. Introduction

This paper presents distributed algorithms based on the work of Dijkstra and Scholten [1], for solving graph problems using networks of communicating processes. The solution to one particular graph problem, that of finding shortest paths from a single vertex to all other vertices in a weighted, directed graph, in the presence of negative cycles, is discussed in detail. We then show how this solution may be applied to other graph problems including depth-first search in an undirected graph.

* Former editor of Programming Techniques and Data Structures, of which Ellis Horowitz is the current editor.

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Our model of computation is a network of processes in which processes communicate only by sending and receiving messages; the model is presented in detail in Sec. 2. We describe the classical shortest path problem [2] and the necessary terminology from graph theory in Sec. 3. The distributed algorithm is given in Sec. 4 and its proof in Sec. 5. Applications to other graph problems are discussed in Sec. 6.

2. Model of a Network of Communicating Processes

A process is a sequential program which can communicate with other processes by sending/receiving messages. Two processes P and Q are said to be neighbors if they can communicate directly with one another without having messages go through intermediate processes. We assume that communication channels are bidirectional: if P can send messages to Q then Q can send messages to P . A process knows the identities of its neighbors; otherwise it is ignorant of the identities of all other processes and of the general structure of the network.

We assume a very simple protocol for message communication; this protocol is equivalent to the one used by Dijkstra and Scholten [1]. Every process has an input buffer of unbounded length. If process P sends a message to a neighbor process Q , then the message gets appended at the end of the input buffer of Q after a finite, arbitrary delay. We assume that (1) messages are not lost or altered during transmission, (2) messages sent from P to Q arrive at Q 's input buffer in the order sent, and (3) two messages arriving simultaneously at an input buffer are ordered arbitrarily and appended to the buffer. A process receives a message by removing one from its input buffer.

The assumption of unbounded length buffers is for ease of exposition. We show, in Sec. 6, that for our problem the input buffer length of process Q can be bounded by the number of neighbors of Q .

3. The Shortest Path Problem

$G = (V, E)$ is a directed graph in which V is the set of vertices and E is the set of edges. Edge (v_i, v_j) has an associated length w_{ij} . If edge (v_i, v_j) exists then v_j is said to be a successor of v_i and v_i is said to be a predecessor of v_j . It is required to determine lengths of the shortest paths from a special vertex v_1 in V to all other vertices in V .¹ Since some w_{ij} may be negative, a cycle of negative total length (called a negative cycle) may exist in the graph. If a negative cycle is reachable from v_1 then all vertices reachable from that negative cycle will have a shortest path length of $-\infty$. The distance of a vertex v_i is the length of the shortest path from v_1 to v_i and is denoted by L_i .

¹ We assume familiarity with graph theoretic terms such as path, shortest path, etc.

Distributed Computation On Graphs Shortest Path Algorithms

Limin Jia, Li Wang, Yong Qin



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Table of Contents Distributed Computation On Graphs Shortest Path Algorithms

1. Understanding the eBook Distributed Computation On Graphs Shortest Path Algorithms
 - The Rise of Digital Reading Distributed Computation On Graphs Shortest Path Algorithms
 - Advantages of eBooks Over Traditional Books
2. Identifying Distributed Computation On Graphs Shortest Path Algorithms
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Distributed Computation On Graphs Shortest Path Algorithms
 - User-Friendly Interface
4. Exploring eBook Recommendations from Distributed Computation On Graphs Shortest Path Algorithms
 - Personalized Recommendations
 - Distributed Computation On Graphs Shortest Path Algorithms User Reviews and Ratings
 - Distributed Computation On Graphs Shortest Path Algorithms and Bestseller Lists
5. Accessing Distributed Computation On Graphs Shortest Path Algorithms Free and Paid eBooks
 - Distributed Computation On Graphs Shortest Path Algorithms Public Domain eBooks
 - Distributed Computation On Graphs Shortest Path Algorithms eBook Subscription Services

- Distributed Computation On Graphs Shortest Path Algorithms Budget-Friendly Options
- 6. Navigating Distributed Computation On Graphs Shortest Path Algorithms eBook Formats
 - ePub, PDF, MOBI, and More
 - Distributed Computation On Graphs Shortest Path Algorithms Compatibility with Devices
 - Distributed Computation On Graphs Shortest Path Algorithms Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Distributed Computation On Graphs Shortest Path Algorithms
 - Highlighting and Note-Taking Distributed Computation On Graphs Shortest Path Algorithms
 - Interactive Elements Distributed Computation On Graphs Shortest Path Algorithms
- 8. Staying Engaged with Distributed Computation On Graphs Shortest Path Algorithms
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Distributed Computation On Graphs Shortest Path Algorithms
- 9. Balancing eBooks and Physical Books Distributed Computation On Graphs Shortest Path Algorithms
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Distributed Computation On Graphs Shortest Path Algorithms
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Distributed Computation On Graphs Shortest Path Algorithms
 - Setting Reading Goals Distributed Computation On Graphs Shortest Path Algorithms
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Distributed Computation On Graphs Shortest Path Algorithms
 - Fact-Checking eBook Content of Distributed Computation On Graphs Shortest Path Algorithms
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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