1

Introduction

By living always with enthusiasm,
being interested in everything
that seems inaccessible,
one becomes greater
by striving constantly upwards.
The sense of life is creativity,
and creativity itself is unlimited.

Maxim Gorky

1.1 Motivation and Aims

If one were required to characterize the recent development of the known human civilization using one word, then one would probably choose the term "communication". The interconnected world became reality. It does not matter whether one considers the Internet, telephone networks, mobile phones, e-mail, TV and radio broadcasting, parallel computer architecture or computer networks, or even something else, the dynamics of our current lives are essentially influenced by the communication facilities provided. Thus, it is not surprising that topics related to communication belong among the research areas of main interest in computer science as well as in electrical engineering. While engineering mainly focuses on the development of hardware technologies, computer science develops algorithms and communication strategies that efficiently use the structure (topology) of communication networks.

This work is devoted to the design of communication strategies (algorithms) in different frameworks and under distinct constraints determined by the communication technologies used. Presenting this topic we follow the following two aims making this book interesting for students and beginners as well as for researchers and practitioners:

1. to provide an introductory textbook on information dissemination in communication networks; and
2. to provide a monograph that surveys the main methods, results and research problems related to the design of communication algorithms (strategies, protocols) under different technological constraints.

To fulfill both these aims we start very slowly, assuming only elementary knowledge on algorithmics, and so have made this material self-contained.

Going to more complex matters we partition the track into a large number of steps that are as small as possible and provide enough exercises supporting learning by doing. We try to avoid any interruptions in thought. We spent a lot of time with the development of informal ideas, concepts and the creation of new terms that extend our formal language and become transparent instruments for solving problems posed. Presenting complex, technical arguments and proofs we will first explain the ideas in a simple and transparent way before providing technical details. In several cases we present hard proofs in two stages. When a transparent argument of a weaker result can bring across the idea succinctly then we first give it, and later provide the interested reader with a strong but technically demanding and probably confusing argument of the best known results. In this way we hope to be able to communicate also complex matters in a well readable way.

Our whole presentation does not only focus on a survey of known results, but on a transparent presentation of methods and techniques that can be useful for discovering new communication strategies or improving the best known results. This feature can make this book of special interest for Ph.D. students and researchers.

1.2 Organization of the Book

Our work consists of two books. This first one is devoted to frameworks when two parties communicate by a direct link between them, while the second one focuses on frameworks when one reserves a path (via several nodes of the network) between the two parties for the communication. Thus, the first book works mainly with the telephone and telegraph communication modes in either synchronous or asynchronous manner. The second book works with technologies such as switching networks, optical networks, ATM networks, and wireless networks such as radio networks and mobile networks.

This first textbook is organized as follows. It is divided into two parts. Part I consists of 5 chapters (Chapters 2 to 6) and Part II consists of 3 chapters (Chapters 7 to 9).

Part I deals with synchronous communication performed by the classical telegraph and telephone communication modes. These modes provide a simple communication framework, which is very suitable as a starting point for introducing communication tasks (problems) and techniques for designing and analyzing communication algorithms.

The aim of Chapter 2 is to provide all necessary preliminaries, to fix the notation, and to introduce the fundamental communication tasks. Here, we first present fundamentals of graph theory and combinatorics in Sections 2.2 and 2.3. Section 2.4 introduces broadcasting, accumulation and gossiping as fundamental communication tasks and explains what is considered to be a solution to these tasks. Here we consider the complexity of communication algorithms as the number of synchronous rounds. Section 2.5 presents some

elementary general relations between the complexity of broadcasting, accumulation and gossiping in a way so that one gets the first touch with the matters studied in the chapters that follow.

Section 2.6 surveys the fundamental interconnection networks that were intensively investigated in the past, especially in relation to the design of parallel architectures with good communication facilities.

Chapter 3 is devoted to different aspects of broadcasting. After presenting some fundamental observations and techniques in Section 3.2, we introduce some design methods for broadcast algorithms in Section 3.3 and apply them for some common network structures. Section 3.4 is devoted to methods for proving lower bounds on the number of rounds necessary for broadcasting in concrete degree-bounded networks. An overview on results in broadcasting in fundamental networks is given in Section 3.5. Section 3.6 considers a completely different scenario. The task is to design an optimization algorithm that, for any given network, derives a good (possibly) optimal broadcast strategy. This problem is an NP-hard optimization task and we survey the current knowledge about this topic there.

Chapter 4 is devoted to gossiping. After presenting some basic facts about the complexity of gossiping and its relation to broadcasting in Section 4.2, the next sections deal with the design of gossip algorithms in concrete networks. In Section 4.3 one considers communication structures with a small bisection width. The main result here is optimal gossiping in cycle in both telegraph and telephone communication modes. The optimal gossip algorithms in cycle are used in Section 4.4 for designing efficient gossip algorithms in the hypercube-like networks. An optimal gossip algorithm in complete graphs is designed in Section 4.5. An important point is that in Sections 4.3 and 4.5 we develop nontrivial techniques for proving lower bounds on the complexity of gossiping and in this way the optimality of the designed algorithms. Finally, Section 4.6 provides an overview on gossiping in concrete networks.

So-called systolic communication as a very regular, distributed form of communication is introduced in Chapter 5. The idea is to allow the processors (nodes) of the network to repeat a short sequence of communication activities only and the main research question is how much communication complexity has to be paid for this regularity of algorithms. Chapter 5 is organized as follows. First the concept of systolic communication is introduced and some relations to the general communication modes are established. Then systolic gossip algorithms in different networks are designed. Surprisingly, for several networks the systolic algorithms can be as efficient as the general ones.

Chapter 6 is devoted to fault-tolerance, which is one of the central topics of current interest. The task is to design robust communication algorithms in the sense that they solve a given communication task even when some connections or nodes do not work correctly (or at all). Section 6.1 introduces the different kinds of faults that may appear in a communication network. Some basic facts about fault-tolerance are presented in Section 6.2. Then, Section 6.3 focuses

on the results related to the bounded-fault model, and Section 6.4 is devoted to the probabilistic fault model.

In contrast to the simple, nice world of synchronous communication rounds in Part I, Part II is devoted to asynchronous networks that are a better model of the current reality. In this general network model there are inherently three sources of nondeterminism. Processes (performing within network nodes) are inherently asynchronous since there is no universal clock available for synchronizing their actions. The uncertainties in communication delays imply nondeterministic behavior in the sending and receiving of messages. And if FIFO requirements on links are not necessary, messages via the same link can overtake each other. These three forms of nondeterminism make the network model not only substantially complex, but the basic terms such as communication tasks and complexity change in meaning.

Part II is divided into three chapters. Chapter 7 is devoted to broadcasting in the asynchronous world. In Section 7.1 the general broadcast strategies in arbitrary networks are considered. Section 7.2 shows lower and upper bounds on broadcasting on tori, and Section 7.3 deals with broadcast tasks in hypercubes.

Chapter 8 is devoted to leader election in asynchronous distributed networks. The first two sections fix the communication model and the leader election problem as a communication task. Sections 8.1 and 8.2 present the algorithms for leader election in rings. The leader election algorithm on complete graphs and a lower bound on the complexity of this problem are given in Section 8.3. Leader election on hypercubes is studied in Section 8.4. Chapter 8 finishes with leader election in synchronous rings in Section 8.5.

Chapter 9 is, analogous to Chapter 6, devoted to fault-tolerance, but here in the general framework of distributed networks. Section 9.1 deals with the consensus problem with unsigned and signed messages. Broadcasting in synchronous networks with dynamic faults on hypercubes, tori and star graphs is studied in Section 9.2.

The exercises in this book are distributed in the text and not presented in separate sections. In this way the reader knows when it is the optimal time for dealing with them. The exercises marked by * are considered to be essentially nontrivial.

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