Sisteme Tolerante la Defecte

Consens în Sisteme Distribuite

Lect. Dr. Ing. Cristian Chilipirea – cristian.chilipirea@mta.ro

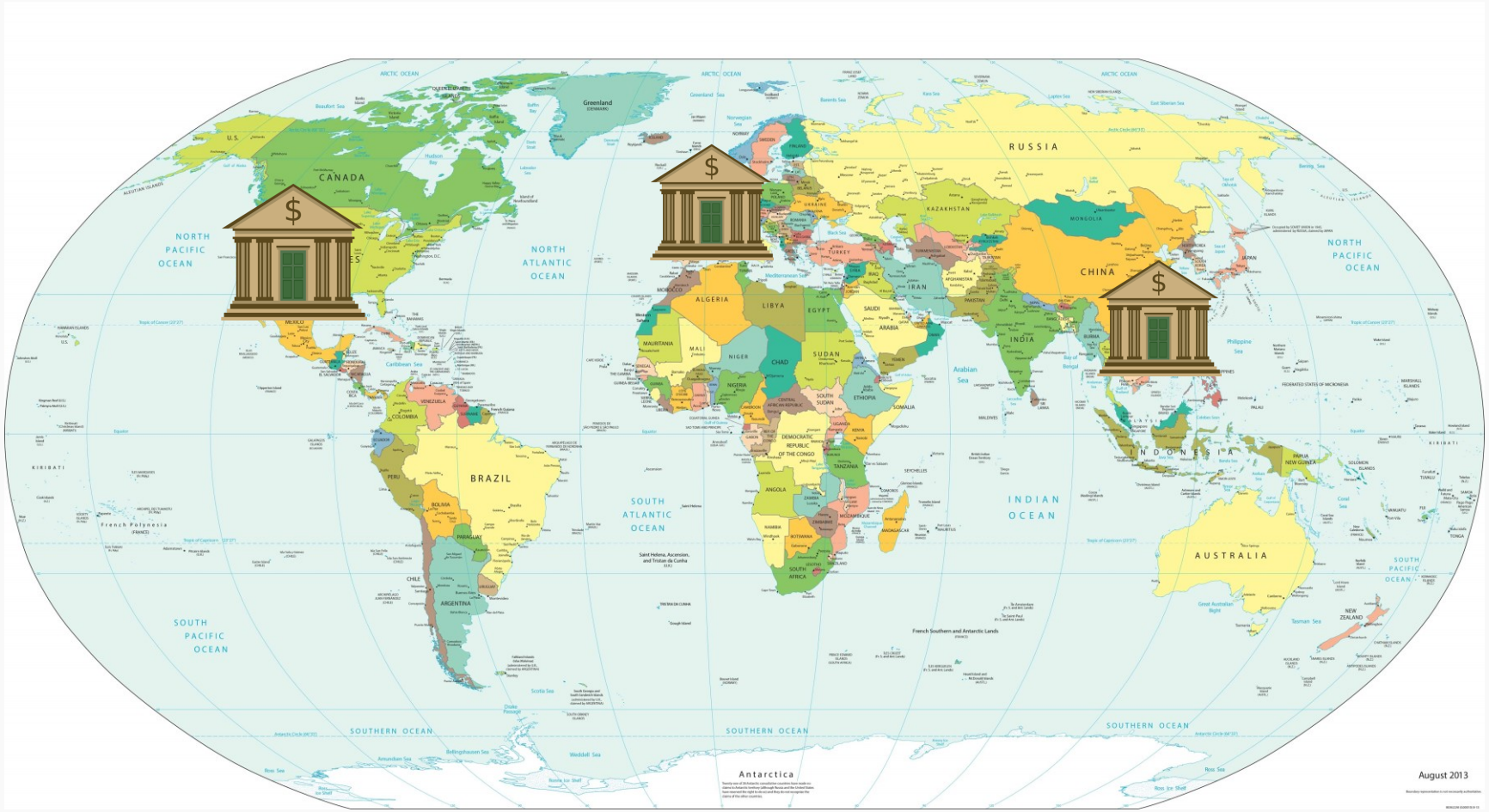
Dorim sisteme distribuite care să

- dea mereu un rezultat corect.
- dea mereu același rezultat având aceleași intrări.
- funcționeze chiar dacă părți din sistem se opresc.
- funcționeze chiar dacă și părți din sistem se comportă defectuos (au bug-uri).
- funcționeze chiar dacă părți din sistem sunt compromise și devin malițioase.

Presupunem un sistem bancar

Presupunem un sistem bancar scalabil

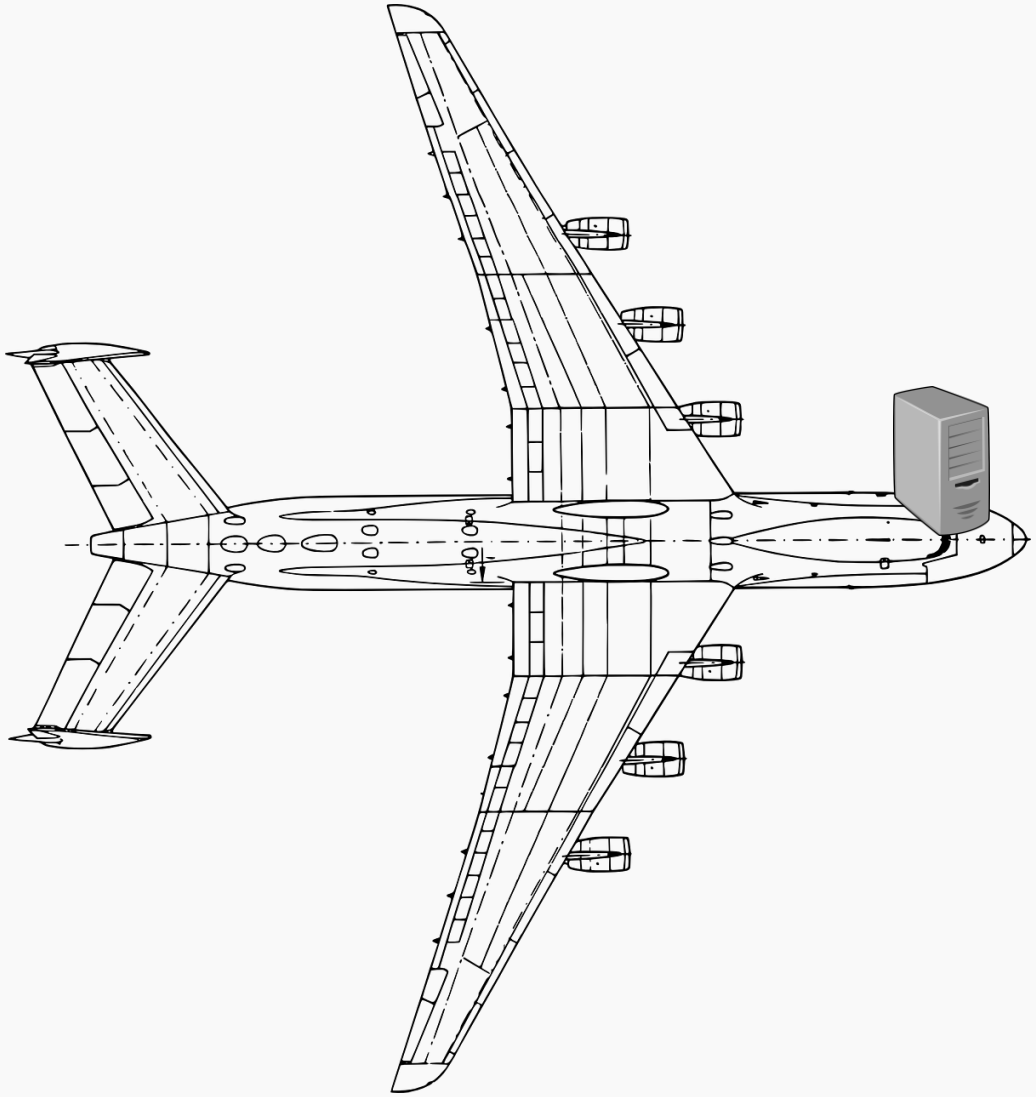
Presupunem un sistem bancar scalabil distribuit global



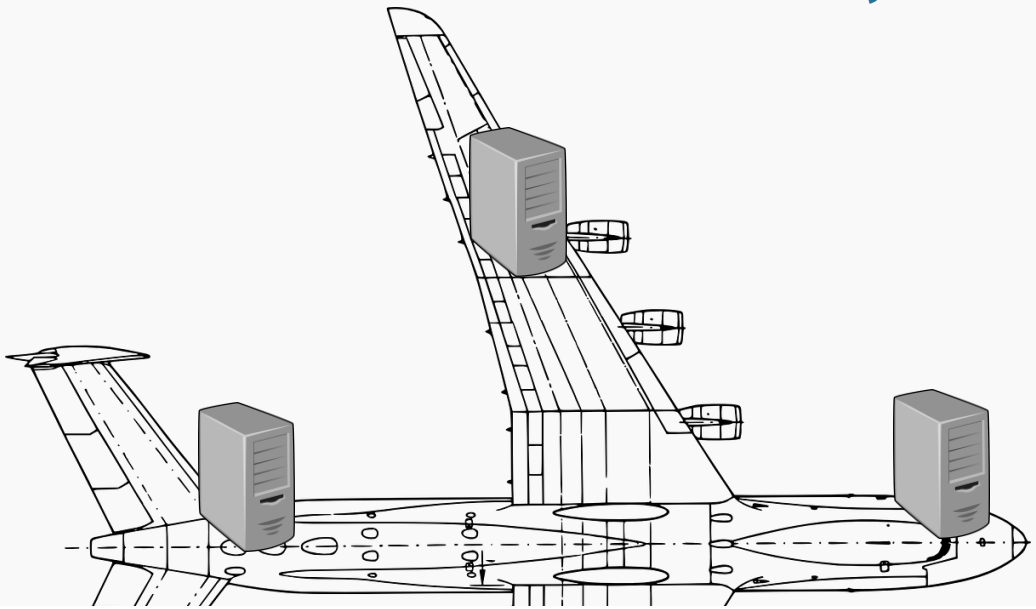
Presupunem un sistem bancar scalabil distribuit global

Dacă pun bani într-o bancă vreau să îi pot scoate din alta.
Dacă scot bani dintr-o bancă când alta calculează o taxă ca procent din banii mei vreau să fie calculat corect.

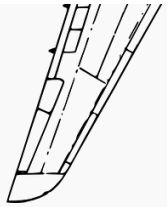
Presupun un sistem ce controlează un avion



Presupun un sistem ce controlează un avion cu redundanță



Dacă un calculator se defectează vreau ca avionul să poată funcționa.
Dacă un calculator dă comenzi greșite vreau ca celelalte să ia decizia corectă.



Generalizare

- Am mai multe sisteme rulând un program distribuit.
- Oricărui sistem îi dau comenzi (sau le generează singur) vreau ca totalitatea lor să vadă comanda ca și executată.
- Ordinea comenzilor (chiar dacă sunt date pe sisteme diferite) este importantă. (A + B) / 2 != A / 2 + B
- Dacă unele sisteme pică, programul distribuit trebuie să funcționeze corect în continuare.
- Dacă unele sisteme se comportă malițios, doresc ca programul distribuit să funcționeze corect în continuare.

- Toate aceste exemple sunt inexistente în programele secvențiale

Generalizare

- Automat avem comunicare asincronă.
- Dacă comunicarea ar fi sincronă și un sistem s-ar opri, un altul ar putea și el rămâne blocat așteptând după acesta.

Dar timpul în sine e o problemă dificilă în sisteme distribuite

Dacă avem două sisteme avem două “păreri” despre timpul current.

Cu ce protocol se sincronizează ceasul calculatoarelor?

Sincronizarea timpilor între 2 sisteme

Probabilistic clock synchronization

Flaviu Cristian
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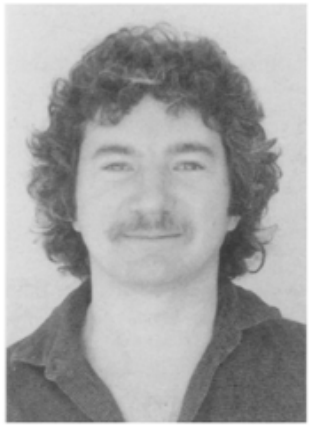


Flaviu Cristian is a computer scientist at the IBM Almaden Research Center in San Jose, California. He received his PhD from the University of Grenoble, France, in 1979. After carrying out research in operating systems and programming methodology in France, and working on the specification, design, and verification of fault-tolerant programs in England, he joined IBM in 1982. Since then he has worked in the area of fault-tolerant distributed protocols and systems. He has participated in the design and implementation of a highly available system prototype at the Almaden Research Center and has reviewed and consulted for several fault-tolerant distributed system designs, both in Europe and in the American divisions of IBM. He is now a technical leader in the design of a new U.S. Air Traffic Control System which must satisfy very stringent availability requirements.

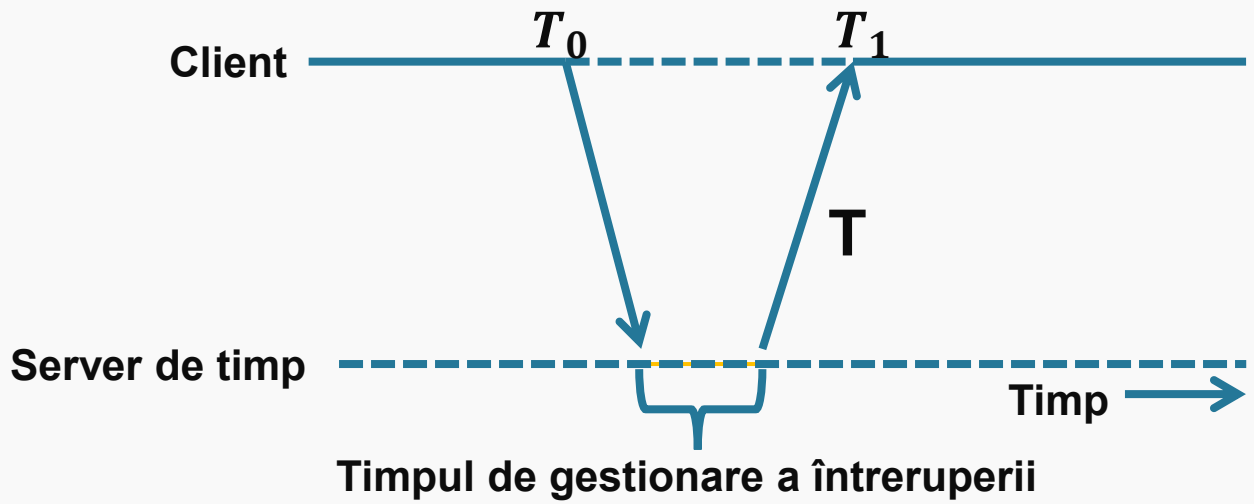
Abstract. A probabilistic method is proposed for reading remote clocks in distributed systems subject to unbounded random communication delays.

in some given maximum derivation from a time reference external to the system. *Internal* clock synchronization keeps processor clocks within some maximum relative deviation of each other. Externally synchronized clocks are also internally synchronized. The converse is not true: as time passes internally synchronized clocks can drift arbitrarily far from external time.

Clock synchronization is needed in many distributed systems. Internal clock synchronization enables one to measure the duration of distributed activities that start on one processor and terminate on another processor and to totally order distributed events in a manner that closely approximates their real time precedence. To allow exchange of information about the timing of events with other systems and users, many systems require external clock synchronization. For example external time can be used to record the occurrence of events for later analysis by humans, to instruct a system to take certain actions when certain specified (external) time deadlines occur, and to order the occurrence of related events observed by distinct sys-

Sincronizarea timpilor între 2 sisteme

T + RTT/2



Cu ce protocol se sincronizează ceasul calculatoarelor?

Internet Engineering Task Force (IETF)
Request for Comments: 5905
Obsoletes: 1305, 4330
Category: Standards Track
ISSN: 2070-1721

D. Mills
U. Delaware
J. Martin, Ed.
ISC
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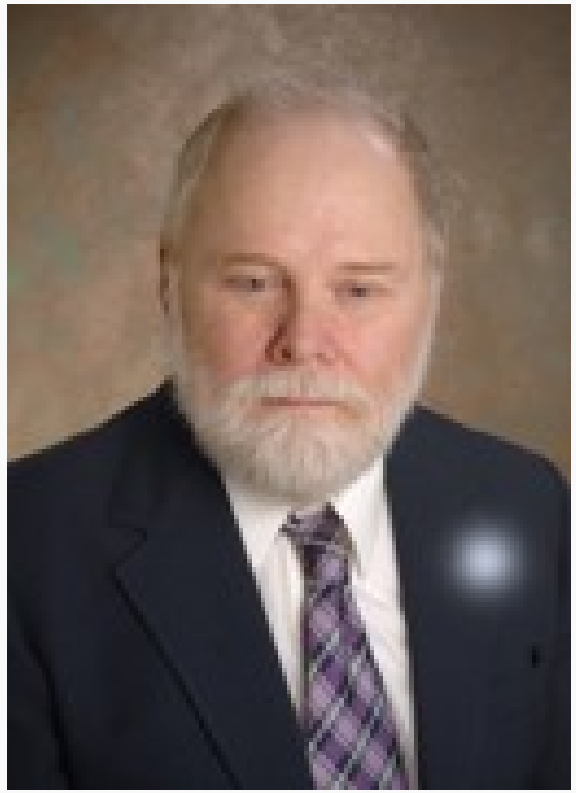
JHU/APL
June 2010

Network Time Protocol Version 4: Protocol and Algorithms Specification

Abstract

The Network Time Protocol (NTP) is widely used to synchronize computer clocks in the Internet. This document describes NTP version 4 (NTPv4), which is backwards compatible with NTP version 3 (NTPv3), described in RFC 1305, as well as previous versions of the protocol. NTPv4 includes a modified protocol header to accommodate the Internet Protocol version 6 address family. NTPv4 includes fundamental improvements in the mitigation and discipline algorithms that extend the potential accuracy to the tens of microseconds with modern workstations and fast LANs. It includes a dynamic server discovery scheme, so that in many cases, specific server configuration is not required. It corrects certain errors in the NTPv3 design and implementation and includes an optional extension mechanism.



Ce “viteză” au calculatorele?

- Reminder: viteză e un cuvânt extrem de nepotrivit

În cât timp va executa următorul program?

```
int main() {
    int i;

    for(i=0; i < 1000 * 1000 * 1000; i++);

    return 0;
}
```

În cât timp va executa următorul program?

```
int main() {
    int i;

    for(i=0; i < 1000 * 1000 * 1000; i++);

    return 0;
}
```

```
real    0m1.783s
user    0m1.766s
sys     0m0.000s
```

Timp transmitere pachet?

Timp transmitere pachet?

```
root@Nyx:/mnt/d/Dropbox/backupServer/apd-homework/rezults# ping 8.8.8.8
PING 8.8.8.8 (8.8.8.8) 56(84) bytes of data.
64 bytes from 8.8.8.8: icmp_seq=1 ttl=120 time=15.4 ms
64 bytes from 8.8.8.8: icmp_seq=2 ttl=120 time=13.0 ms
64 bytes from 8.8.8.8: icmp_seq=3 ttl=120 time=15.3 ms
64 bytes from 8.8.8.8: icmp_seq=4 ttl=120 time=14.5 ms
64 bytes from 8.8.8.8: icmp_seq=5 ttl=120 time=32.5 ms
```

Scala

Tera	T	1 000 000 000 000	12	
Giga	G	1 000 000 000	9	
Mega	M	1 000 000	6	
kilo	k	1 000	3	
UNITATE		1	0	
mili	m	0. 001	-3	Trimitere pachet
micro	μ	0. 000 001	-6	
nano	n	0. 000 000 001	-9	Executare operație
pico	p	0. 000 000 000 001	-12	

Pentru a avea încrede în obținerea proprietăților dorite trebuie să validăm matematic sistemele noastre

Pentru a valida un program matematic acesta trebuie modelat

Modelarea unui sistem simplu/secvențial?

Modelarea unui sistem simplu/secvențial?

First Draft of a Report
on the EDVAC

by

John von Neumann

Modelarea unui sistem simplu/secvențial?

Un set de stări.

Operațiile sau acțiunile modifică starea.

Modelarea unui sistem distribuit?

Obligatoriu trebuie să ia în calcul comunicarea

Se pot executa milioane de operații până la primirea unui mesaj de la un alt sistem

Modelarea unui sistem distribuit: CSP

Programming Techniques — S. L. Graham, R. L. Rivest Editors

Communicating Sequential Processes

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This paper suggests that input and output are basic primitives of programming and that parallel composition of communicating sequential processes is a fundamental program structuring method. When combined with a development of Dijkstra's guarded command, these concepts are surprisingly versatile. Their use is illustrated by sample solutions of a variety of familiar programming exercises.

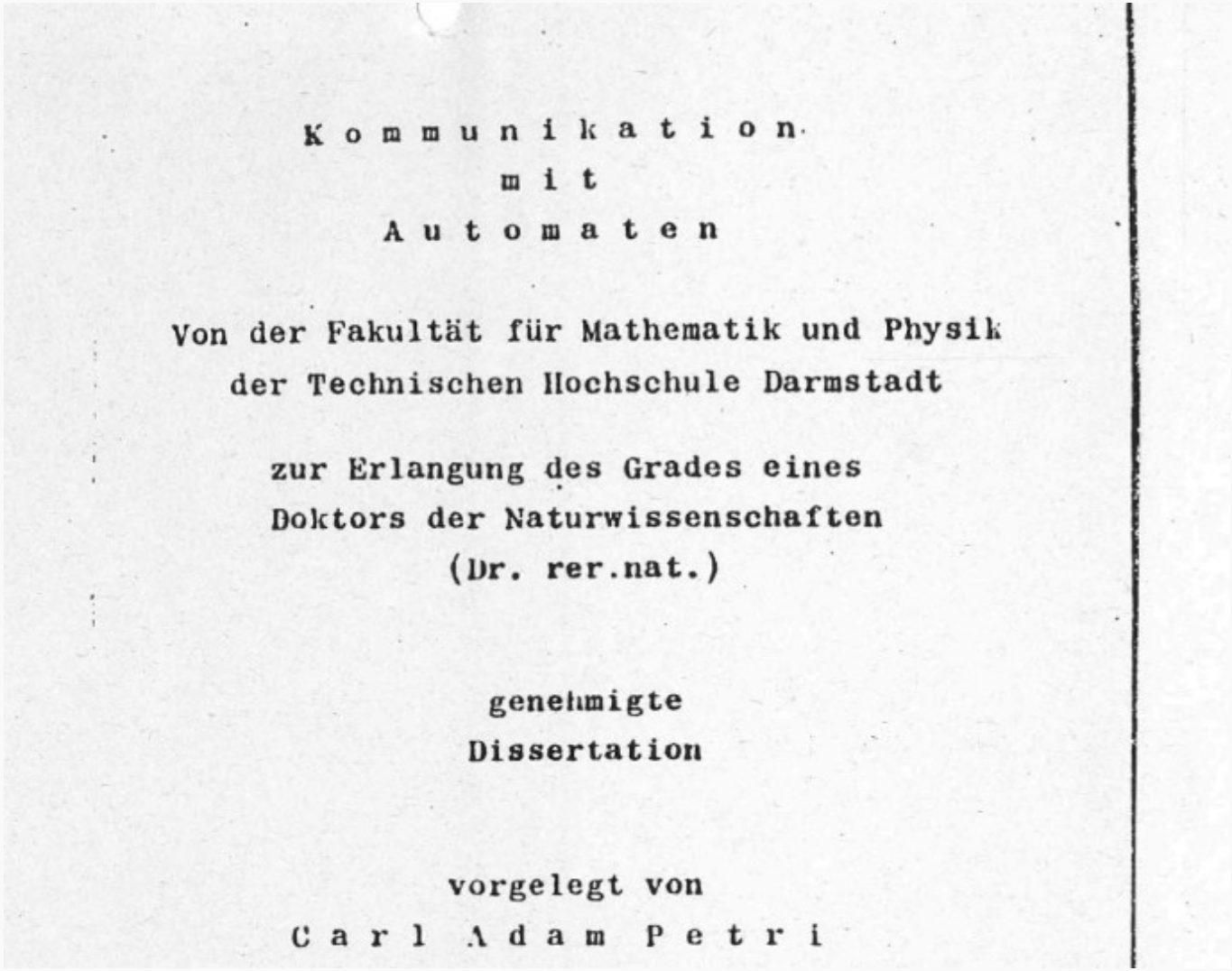
Key Words and Phrases: programming, programming languages, programming primitives, program structures, parallel programming, concurrency, input, output, guarded commands, nondeterminacy, coroutines, procedures, multiple entries, multiple exits, classes, data representations, recursion, conditional critical regions, monitors, iterative arrays
CR Categories: 4.20, 4.22, 4.32

grams, three basic constructs have received widespread recognition and use: A repetitive construct (e.g. the **while** loop), an alternative construct (e.g. the conditional **if..then..else**), and normal sequential program composition (often denoted by a semicolon). Less agreement has been reached about the design of other important program structures, and many suggestions have been made: Subroutines (Fortran), procedures (Algol 60 [15]), entries (PL/I), coroutines (UNIX [17]), classes (SIMULA 67 [5]), processes and monitors (Concurrent Pascal [2]), clusters (CLU [13]), forms (ALPHARD [19]), actors (Hewitt [1]).

The traditional stored program digital computer has been designed primarily for deterministic execution of a single sequential program. Where the desire for greater speed has led to the introduction of parallelism, every attempt has been made to disguise this fact from the programmer, either by hardware itself (as in the multiple function units of the CDC 6600) or by the software (as in an I/O control package, or a multiprogrammed operating system). However, developments of processor technology suggest that a multiprocessor machine, constructed from a number of similar self-contained processors (each with its own store), may become more powerful, capacious, reliable, and economical than a machine which is disguised as a monoprocessor.

In order to use such a machine effectively on a single task, the component processors must be able to communicate and to synchronize with each other. Many methods of achieving this have been proposed. A widely adopted method of communication is by inspection and updating of a common store (as in Algol 68 [18], PL/I, and many machine codes). However, this can create severe problems in the construction of correct programs

Modelarea unui sistem distribuit: Rețele Petri



K o m m u n i k a t i o n
m i t
A u t o m a t e n

Von der Fakultät für Mathematik und Physik
der Technischen Hochschule Darmstadt

zur Erlangung des Grades eines
Doktors der Naturwissenschaften
(Dr. rer.nat.)

genehmigte
Dissertation

vorgelegt von
C a r l A d a m P e t r i

Modelarea unui sistem distribuit: Mașini de stări

Operating Systems — R. Stockton Gaines Editor

Time, Clocks, and the Ordering of Events in a Distributed System

Leslie Lamport
Massachusetts Computer Associates, Inc.

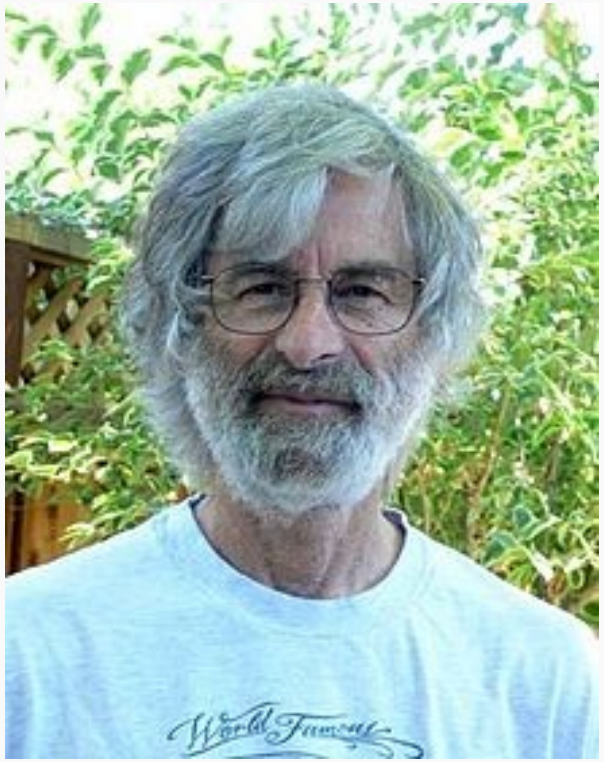
The concept of one event happening before another in a distributed system is examined, and is shown to define a partial ordering of the events. A distributed algorithm is given for synchronizing a system of logical clocks which can be used to totally order the events. The use of the total ordering is illustrated with a method for solving synchronization problems. The algorithm is then specialized for synchronizing physical clocks, and a bound is derived on how far out of synchrony the clocks can become.

A distributed system consists of a collection of distinct processes which are spatially separated, and which communicate with one another by exchanging messages. A network of interconnected computers, such as the ARPA net, is a distributed system. A single computer can also be viewed as a distributed system in which the central control unit, the memory units, and the input-output channels are separate processes. A system is distributed if the message transmission delay is not negligible compared to the time between events in a single process.

We will concern ourselves primarily with systems of spatially separated computers. However, many of our remarks will apply more generally. In particular, a multiprocessing system on a single computer involves problems similar to those of a distributed system because of the unpredictable order in which certain events can occur.

In a distributed system, it is sometimes impossible to say that one of two events occurred first. The relation "happened before" is therefore only a partial ordering of the events in the system. We have found that problems often arise because people are not fully aware of this fact and its implications.

In this paper, we discuss the partial ordering defined by the "happened before" relation, and give a distributed algorithm for extending it to a consistent total ordering of all the events. This algorithm can provide a useful mechanism for implementing a distributed system. We



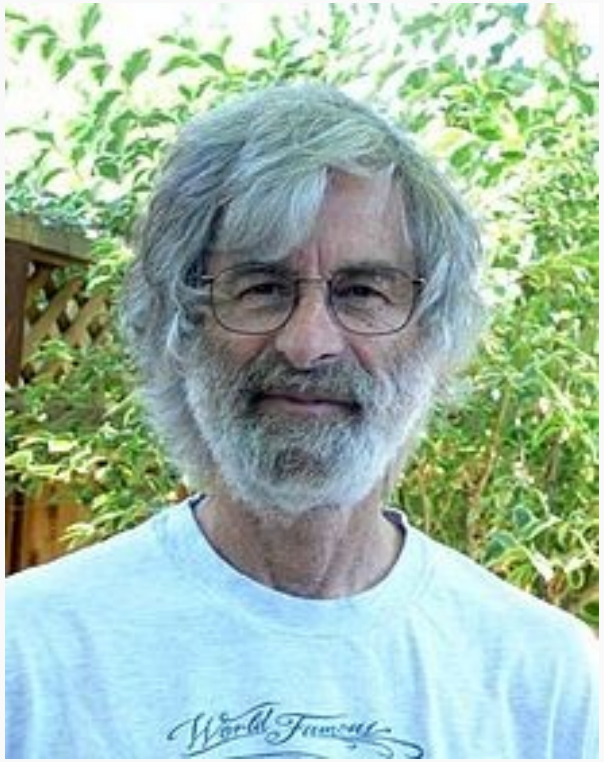
Leslie Lamport

- Majoritatea problemelor/soluțiilor prezentate în acest curs sunt construite de Leslie Lamport.
- Câștigător premiul **Turing 2013**
- Are una din cele mai citate lucrări
- Ne este contemporan și are

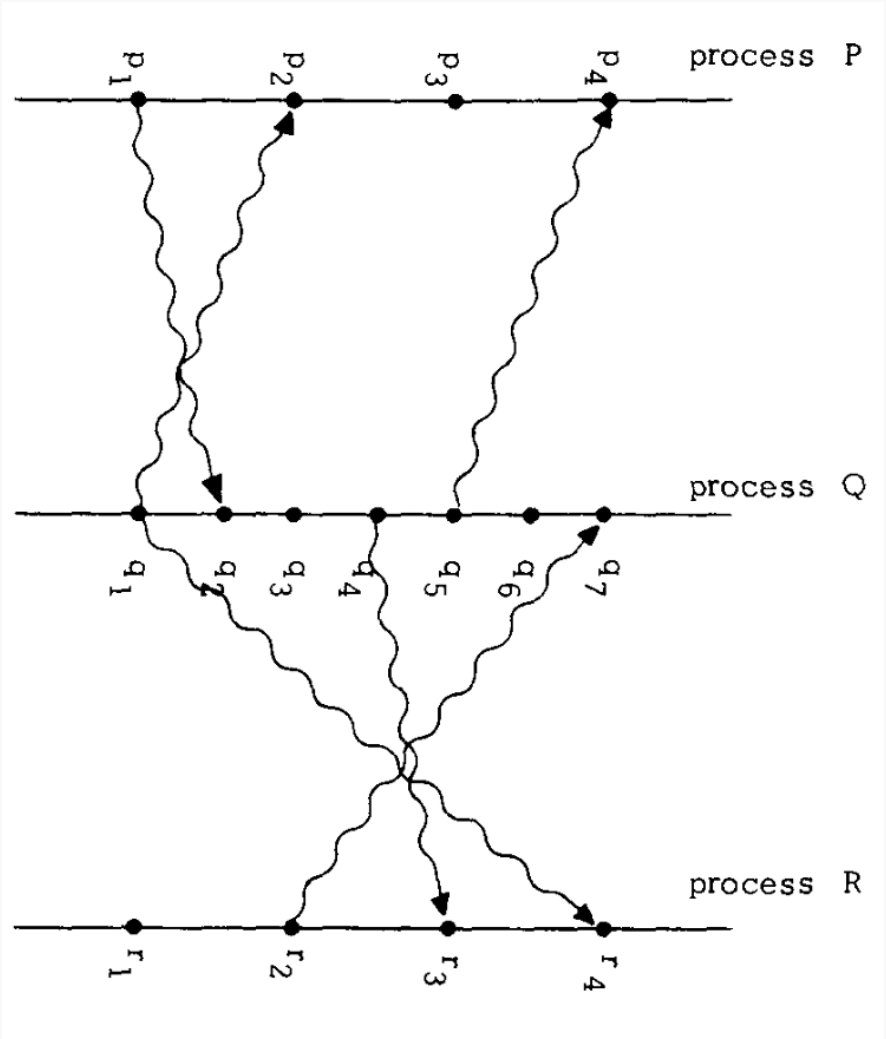
multiple înregistrări pe Youtube scurte:

1 2 3 4 5

- Și un interviu lung în două părți



Lamport – ceasuri logice, ordonare parțială



Lamport – ceasuri logice, ordonare parțială

IR1. Each process P_i increments C_i between any two successive events.

IR2. (a) If event a is the sending of a message m by process P_i, then the message m contains a timestamp $T_m = C_i\langle a\rangle$. (b) Upon receiving a message m, process P_j sets C_j greater than or equal to its present value and greater than T_m.

Clock Condition. For any events a, b:

$$\text{if } a \rightarrow b \text{ then } C\langle a\rangle < C\langle b\rangle.$$

Invers NU este adevărat

Lamport – ordonare totală ⇒

- Putem să definim o relație de ordine totală folosindu-ne de id-ul proceslui.
- Dacă două evenimente au același C atunci le comparăm și după id-ul procesului.

Lamport – mutex distribuit

1. To request the resource, process P_i sends the message T_m:P_i *requests resource* to every other process, and puts that message on its request queue, where T_m is the timestamp of the message.

2. When process P_j receives the message T_m:P_i *requests resource*, it places it on its request queue and sends a (timestamped) acknowledgment message to P_i.[5]

3. To release the resource, process P_i removes any T_m:P_i *requests resource* message from its request queue and sends a (timestamped) P_i *releases resource* message to every other process.

Lamport – mutex distribuit

4. When process P_j receives a P_i *releases resource* message, it removes any T_m:P_i *requests resource* message from its request queue.

5. Process P_i is granted the resource when the following two conditions are satisfied: (i) There is a T_m:P_i *requests resource* message in its request queue which is ordered before any other request in its queue by the relation $\Rightarrow$. (To define the relation "$\Rightarrow$" for messages, we identify a message with the event of sending it.) (ii) P_i has received a message from every other process time-stamped later than T_m.[6]

Vector Clocks

Timestamps in Message-Passing Systems That Preserve the Partial Ordering

Colin J. Fidge
Department of Computer Science, Australian National University, Canberra, ACT.

ABSTRACT

Timestamping is a common method of totally ordering events in concurrent programs. However, for applications requiring access to the global state, a total ordering is inappropriate. This paper presents algorithms for timestamping events in both synchronous and asynchronous message-passing programs that allow for access to the partial ordering inherent in a parallel system. The algorithms do not change the communications graph or require a central timestamp issuing authority.

Keywords and phrases: concurrent programming, message-passing, timestamps, logical clocks
CR categories: D.1.3

INTRODUCTION

A fundamental problem in concurrent programming is determining the order in which events in different processes occurred. An obvious solution is to attach a number representing the current time to a permanent record of the execution of each event. This assumes that each process can access an accurate clock, but practical parallel systems, by their very nature, make it difficult to ensure consistency among

Vector Clocks

Virtual Time and Global States of Distributed Systems *

Friedemann Mattern †

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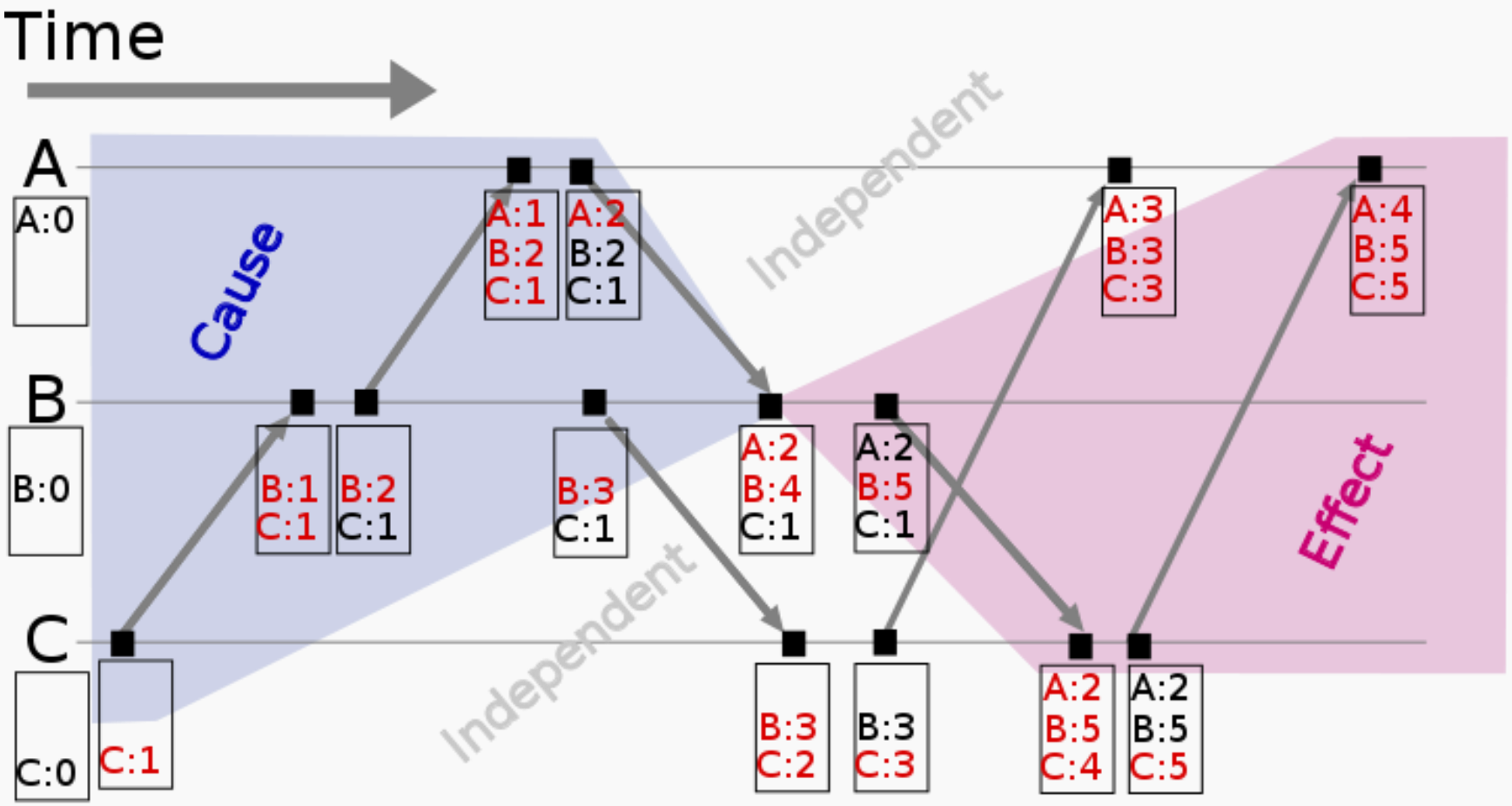
Abstract

A distributed system can be characterized by the fact that the global state is distributed and that a common time base does not exist. However, the notion of time is an important concept in every day life of our decentralized "real world" and helps to solve problems like getting a consistent population census or determining the potential causality between events. We argue that a linearly ordered structure of time is not (always) adequate for distributed systems and propose a generalized non-standard model of time which consists of vectors

view of an idealized external observer having immediate access to all processes.

The fact that *a priori* no process has a consistent view of the global state and a common time base does not exist is the cause for most typical problems of distributed systems. Control tasks of operating systems and database systems like *mutual exclusion, deadlock detection, and concurrency control* are much more difficult to solve in a distributed environment than in a classical centralized environment, and a rather large number of distributed control algorithms for those problems has found to be wrong. *New problems* which do not exist in centralized systems or in parallel systems with common

Vector Clocks



Problema Generalilor Bizantini

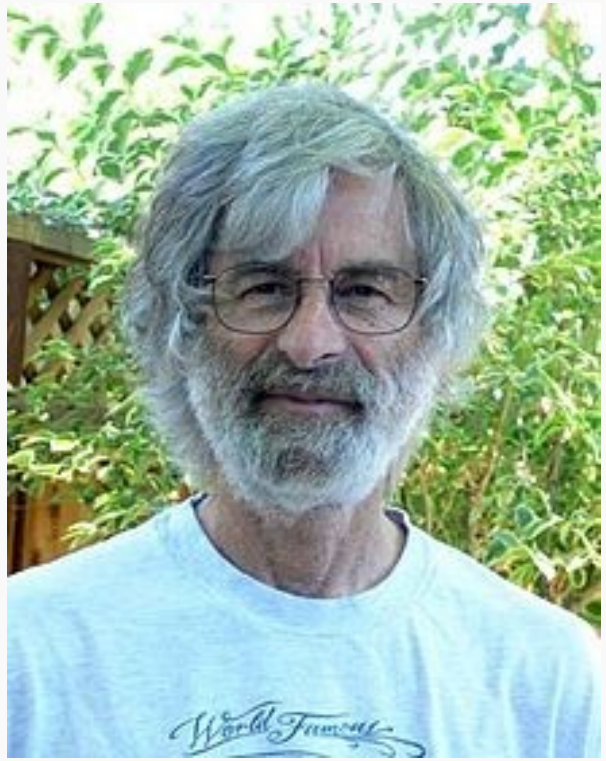
The Byzantine Generals Problem

LESLIE LAMPORT, ROBERT SHOSTAK, and MARSHALL PEASE
SRI International

Reliable computer systems must handle malfunctioning components that give conflicting information to different parts of the system. This situation can be expressed abstractly in terms of a group of generals of the Byzantine army camped with their troops around an enemy city. Communicating only by messenger, the generals must agree upon a common battle plan. However, one or more of them may be traitors who will try to confuse the others. The problem is to find an algorithm to ensure that the loyal generals will reach agreement. It is shown that, using only oral messages, this problem is solvable if and only if more than two-thirds of the generals are loyal; so a single traitor can confound two loyal generals. With unforgeable written messages, the problem is solvable for any number of generals and possible traitors. Applications of the solutions to reliable computer systems are then discussed.

Categories and Subject Descriptors: C.2.4. [**Computer-Communication Networks**]: Distributed Systems—*network operating systems*; D.4.4 [**Operating Systems**]: Communications Management—*network communication*; D.4.5 [**Operating Systems**]: Reliability—*fault tolerance*

General Terms: Algorithms, Reliability



Soluție Generali Bizantini – fără semnături

- Există doar dacă mai mult de două treimi din generali sunt onești.
  - **NU există soluție pentru 3 sau mai puțini generali.**
- Necesită multă comunicație, mesajele de la un general sunt transmise la toți ceilalți într-o formă recursivă.

Soluție Generali Bizantini – cu semnătură

(a) A loyal general's signature cannot be forged, and any alteration of the contents of his signed messages can be detected.
(b) Anyone can verify the authenticity of a general's signature.

Funcționează dacă sunt minim doi generali corecți.
Înseamnă că există soluție pentru 3 generali.

Our algorithm assumes a function *choice* which is applied to a set of orders to obtain a single one. The only requirements we make for this function are

1. If the set V consists of the single element v, then $choice(V) = v$.
2. $choice(\emptyset)$ = RETREAT, where $\emptyset$ is the empty set.

Soluție Generali Bizantini – cu semnătură

Algorithm SM(m).

Initially $V_i = \emptyset$.

(1) The commander signs and sends his value to every lieutenant.
(2) For each i:

(A) If Lieutenant i receives a message of the form $v:0$ from the commander and he has not yet received any order, then

(i) he lets V_i equal $\{v\}$;
(ii) he sends the message $v:0:i$ to every other lieutenant.

(B) If Lieutenant i receives a message of the form $v:0:j_1:\cdots:j_k$ and v is not in the set V_i, then

(i) he adds v to V_i;
(ii) if $k < m$, then he sends the message $v:0:j_1:\cdots:j_k:i$ to every lieutenant other than $j_1, \ldots, j_k$.

(3) For each i: When Lieutenant i will receive no more messages, he obeys the order *choice*(V_i).

Soluție Generali Bizantini – cu semnătură