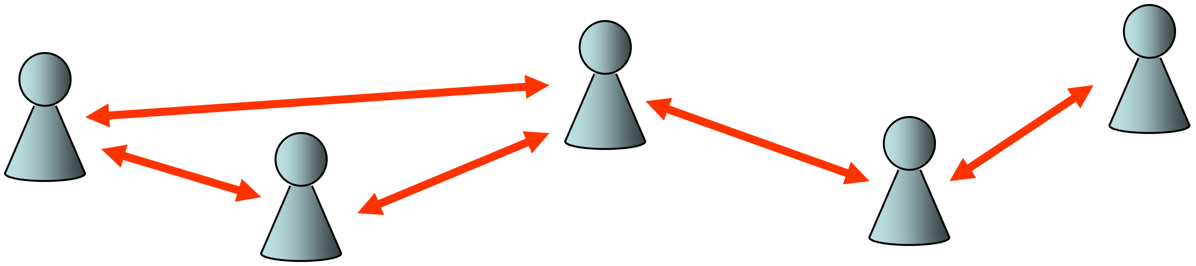
Advanced Distributed Algorithms and Data Structures



Christian Scheideler
Institut für Informatik
Universität Paderborn

Advanced Distributed Algorithms and Data Structures

Lecture: Thu 2-4 pm, F2.211
Tutorial: Thu 10-11 am, F2.211 (starts 3rd week)

Website:
http://cs.uni-paderborn.de/ti/lehre/veranstaltungen/ws-20162017/advanced-distributed-algorithms-and-data-structures/

Modules and Grading:
- MuA Modules III.2.1, III.2.2 and III.2.4
- 50%: oral exam, 50%: software project
  both parts must be passed to pass the course

Prerequisites:
- basic knowledge in algorithms and data structures
- recommended: distributed algorithms and data structures course

Advanced Distributed Algorithms and Data Structures

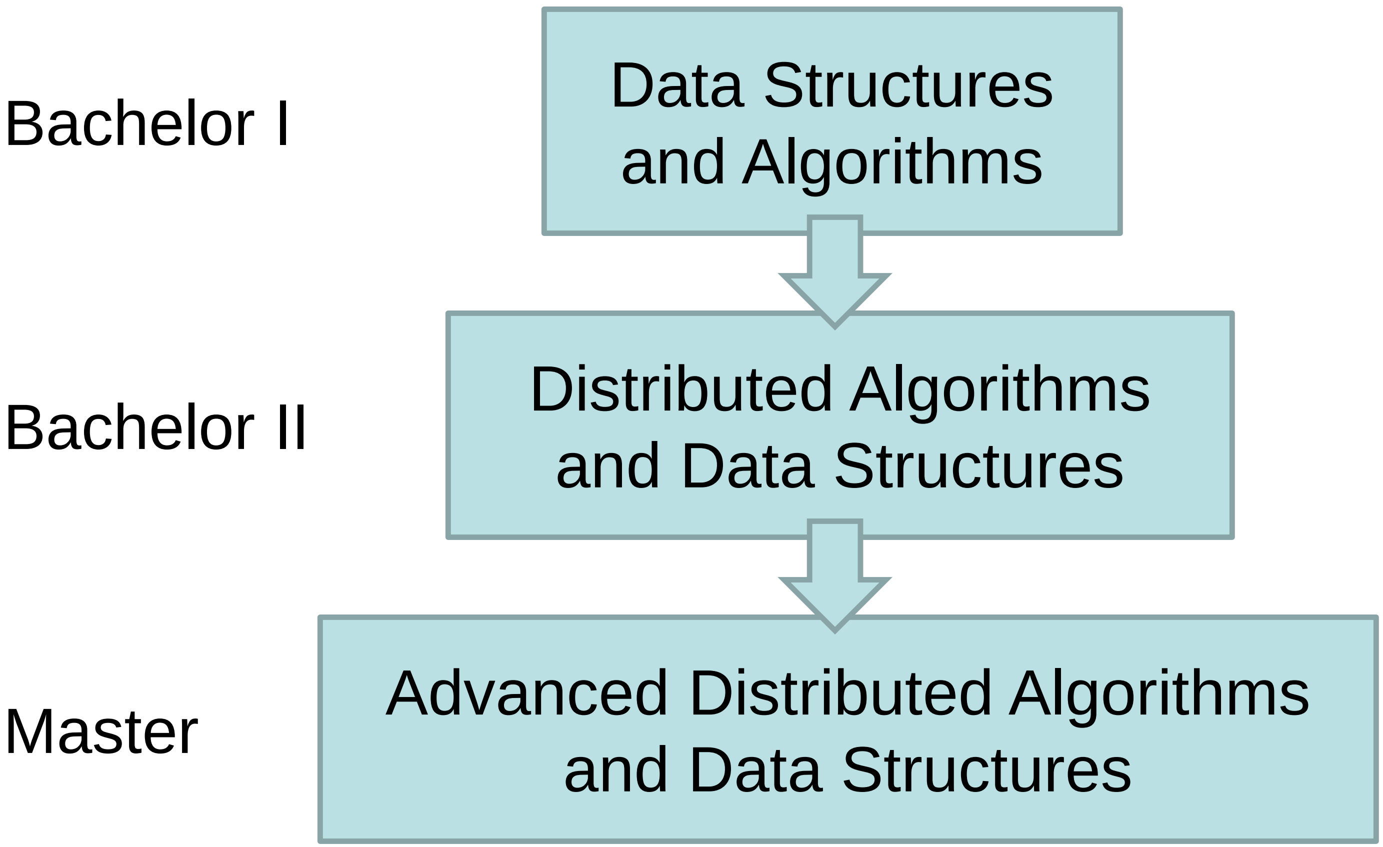
Homework assignments:

- Weekly assignments each Thursday on the website (starting with next week)
- Theoretical and implementations

Slides and assignments: course website

Book recommendations: no book available (lecture is based on newest results)

Embedding into CS Curriculum



Embedding into CS Curriculum

Advanced Distributed Algorithms and Data Structures

Master

Project Group: Design of a Trusted Communication Module

Advanced Distributed Algorithms and Data Structures

Goals:

1. Introduction to advanced concepts in distributed algorithms and data structures.
2. Introduction to important design methods.
3. Introduction to important analytical methods.

Introduction

Sequential Algorithms and Data Structures

Distributed Algorithms and Data Structures

Introduction

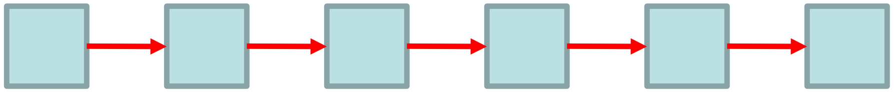
What are the basic problems for distributed algorithms and data structures?

Introduction

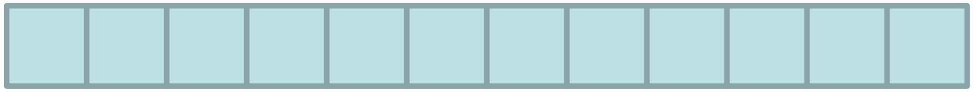
Definition 1.1: A *data structure* is a certain way to organize data in a computer so that operations like, for example, *search, insert,* and *delete* are simple and effective to realize.

Simple examples:

- Lists

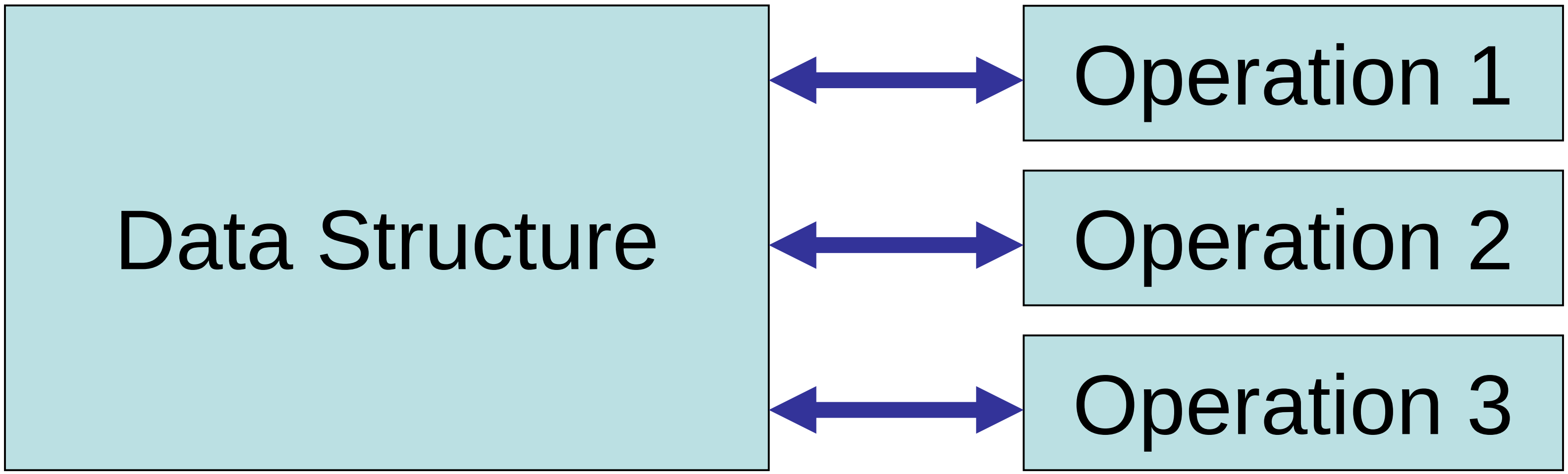


- Arrays



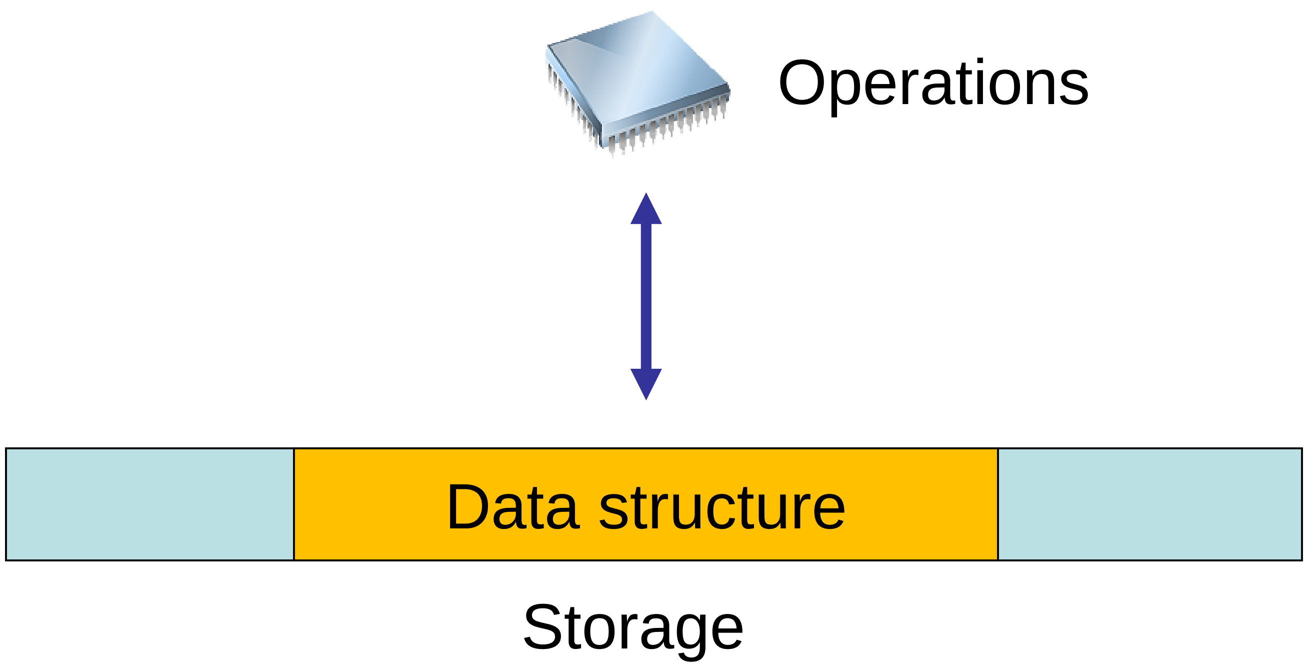
Introduction

Basic view:



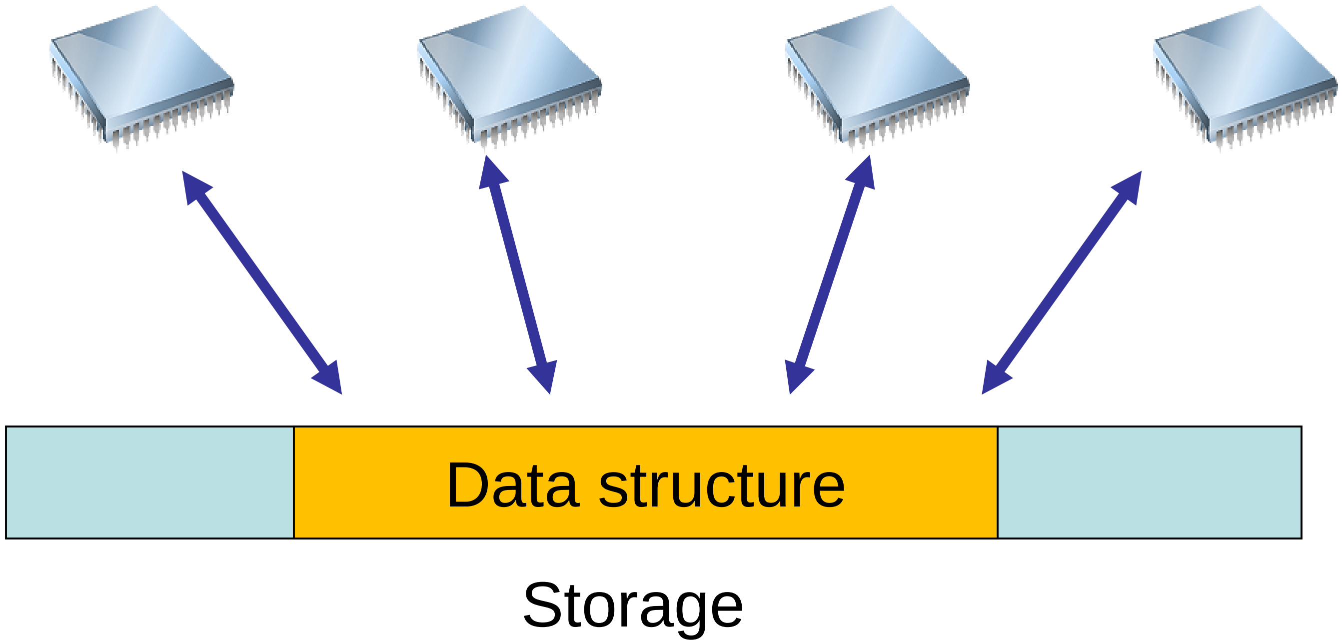
Introduction

Classical case: computer with one processor



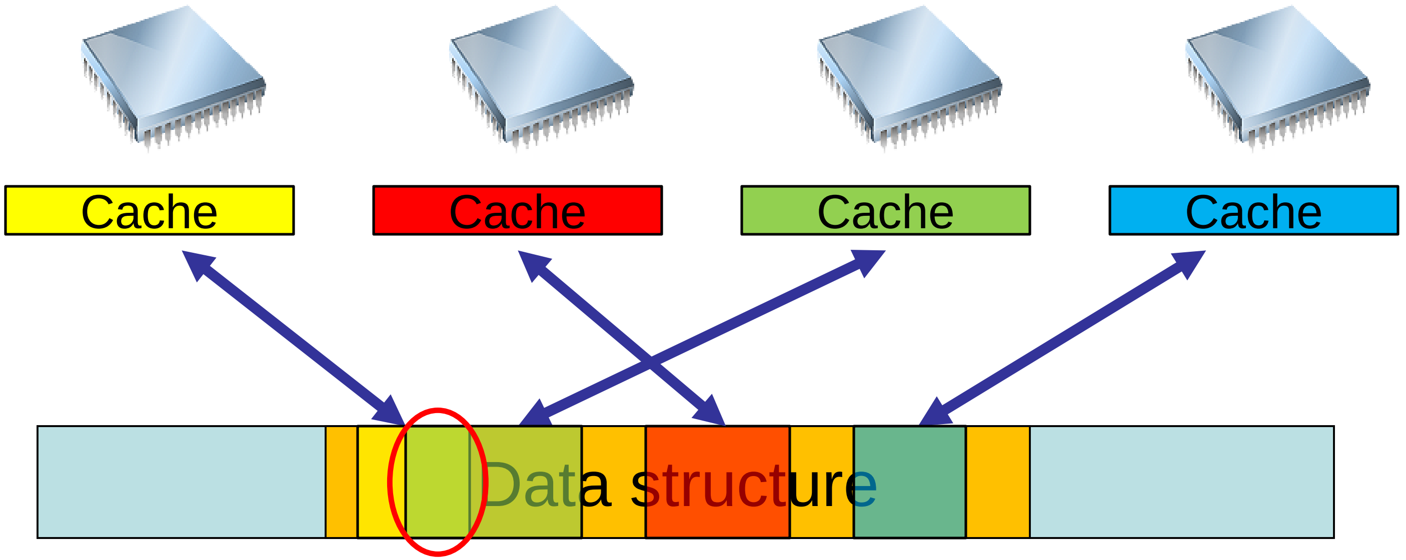
Introduction

Computer with several processors/cores:



Introduction

Computer with several processors/cores:

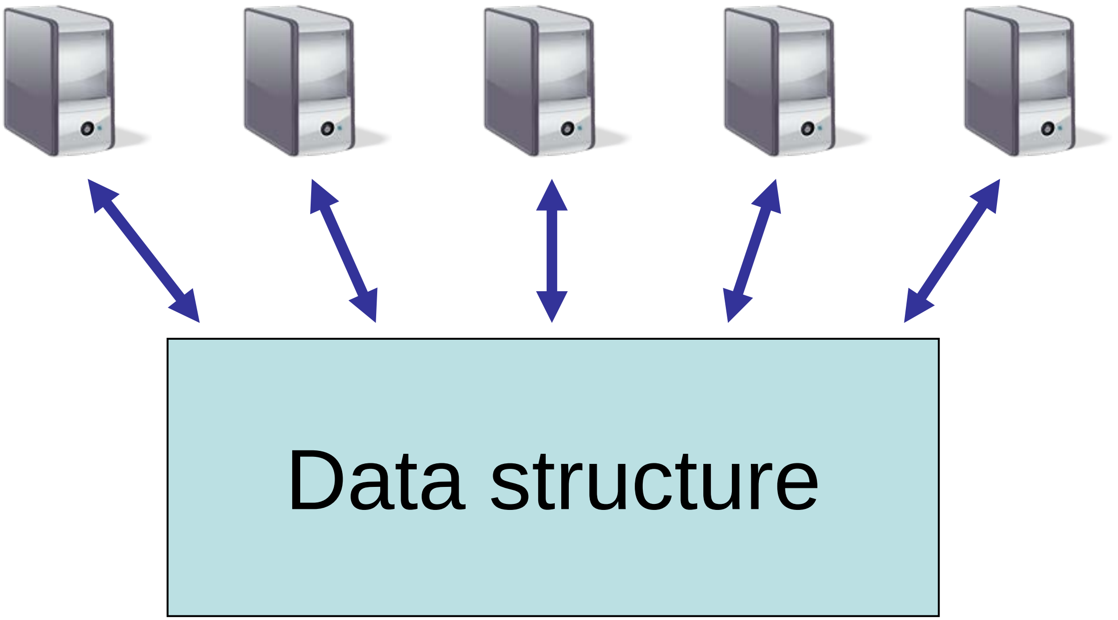


Overlaps:

- access conflicts (correctness)
- performance problems (efficiency)

Introduction

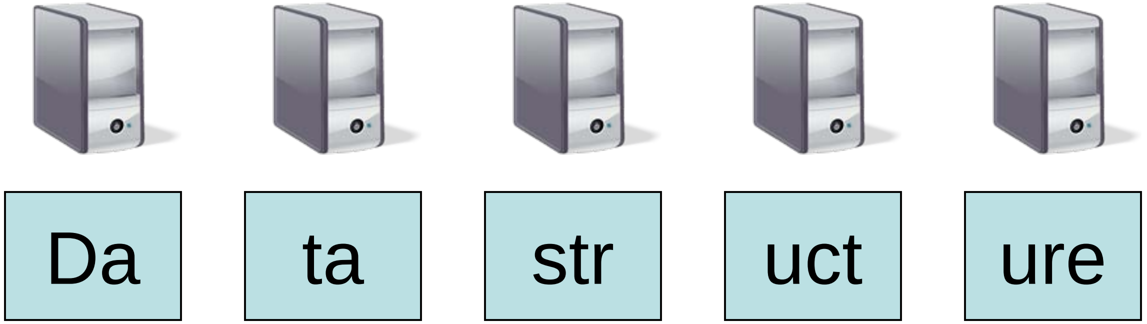
Multiple computers:



Problem: distribution of DS among computers

Introduction

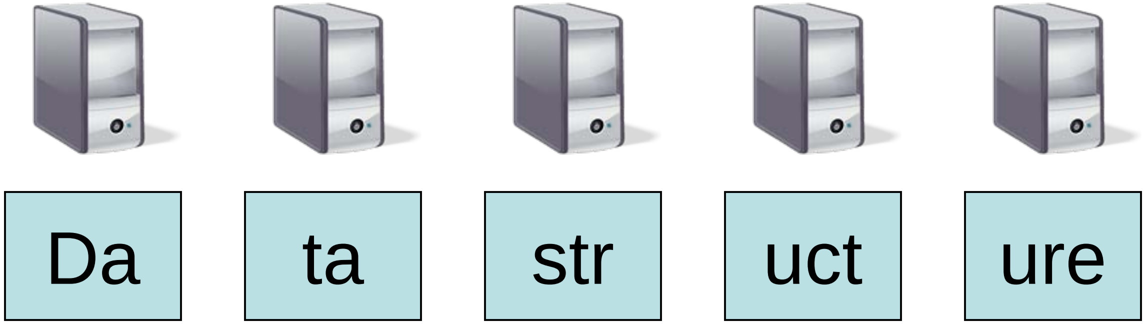
Multiple computers:



Problem: distribution of DS among computers

Introduction

Multiple computers:

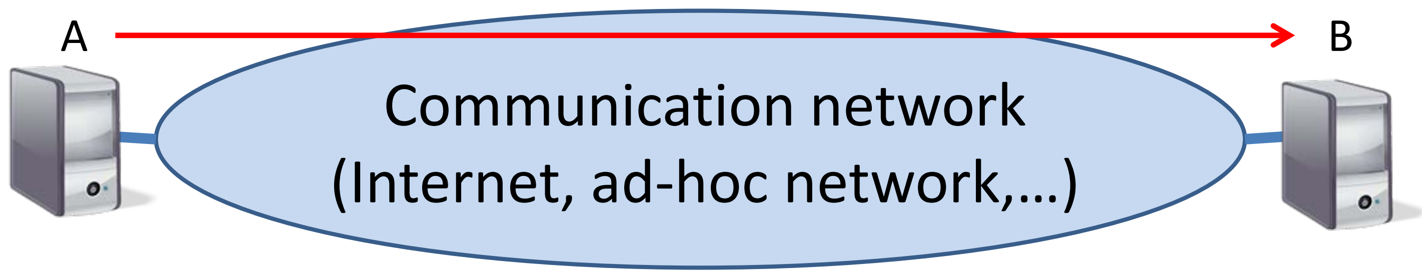


Basic problems:

- How to interconnect the computers?
- How to coordinate the management of the DS among the computers?

Introduction

How to represent the connections between the computers?



A knows (IP address, MAC address,… of) resp. has access autorization for B : network can send message from A to B

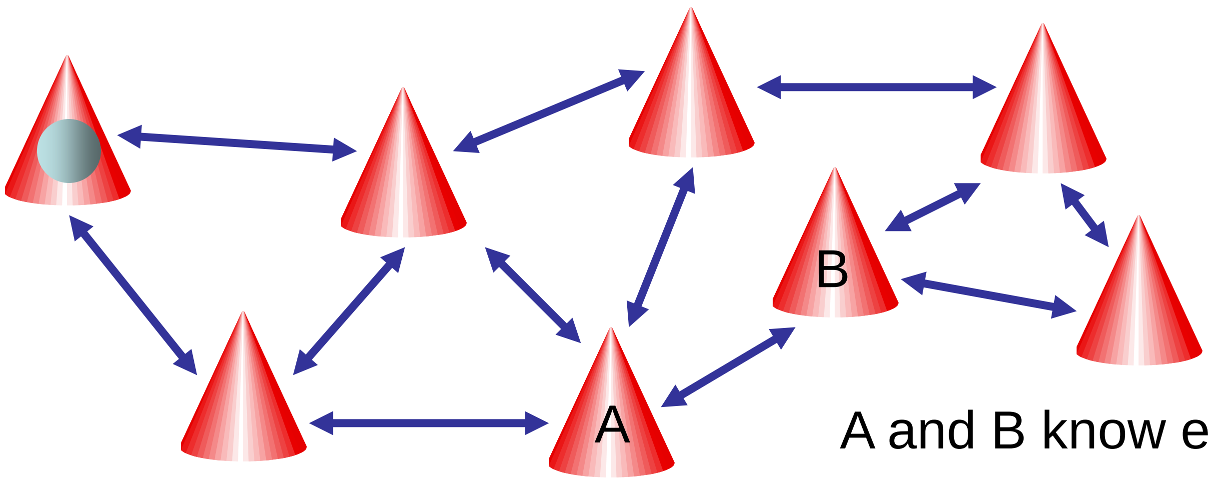
High-level view:

A knows B $\Rightarrow$ overlay edge (A,B) from A to B (A → B)

Set of all overlay edges forms directed graph known as overlay network.

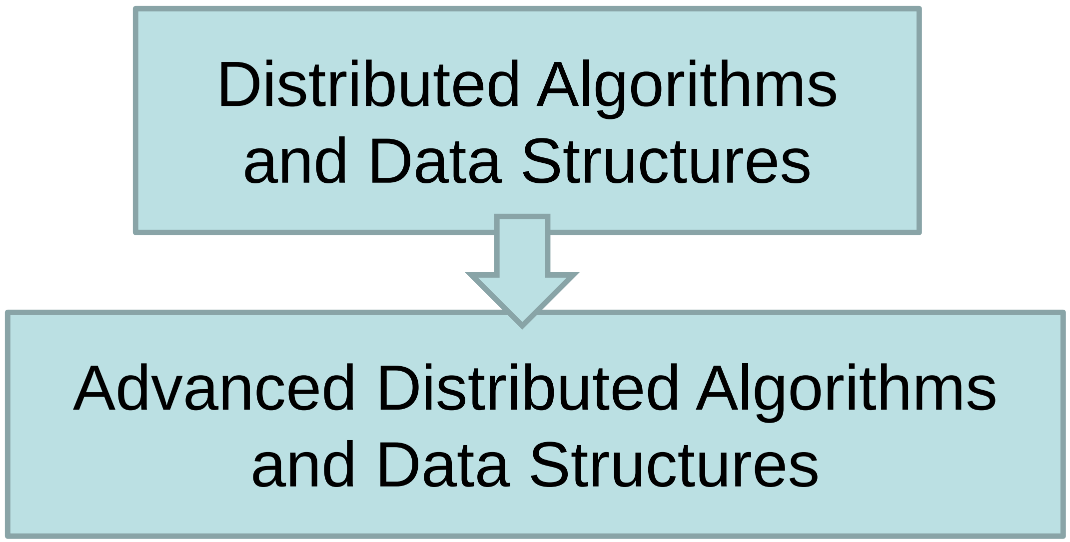
Introduction

Problem: find suitable overlay network for the computers / processes



Best topology depends on problem and context.

Introduction

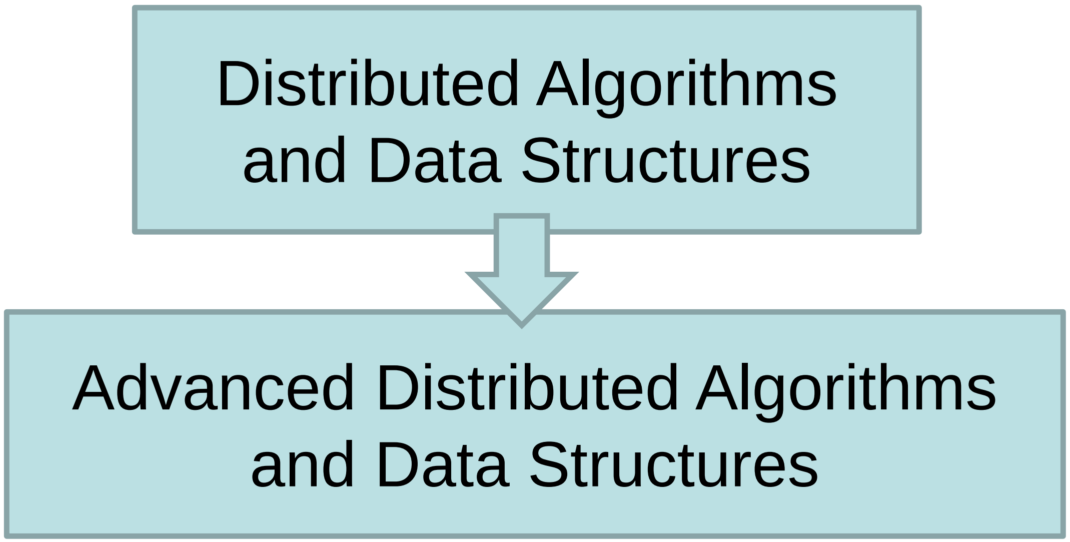


Extensive study of overlay networks

Assumption: processes form a clique

Still many problems left: link management, access control, synchronization, communication primitives, transactions, and various applications.

Introduction

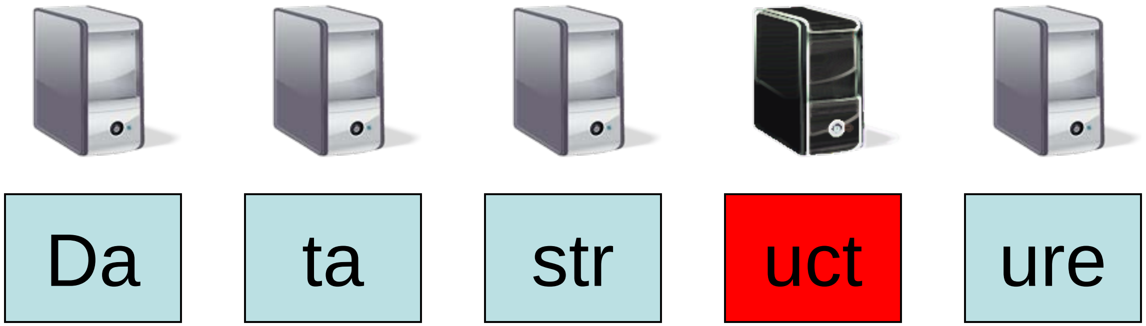


Extensive study of overlay networks

Assumption: processes form a clique

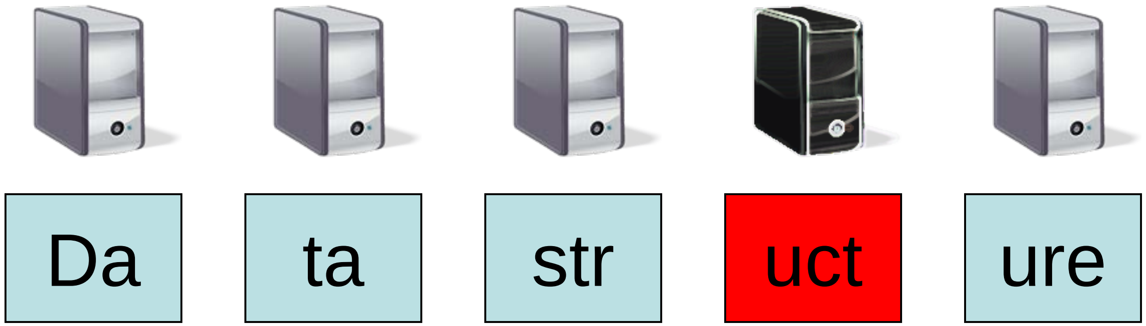
Focus: strategies that are scalable, robust and secure.

Introduction



Focus: strategies that are scalable, robust and secure (because participants might be faulty or adversarial, or might get attacked from outside!)

Introduction



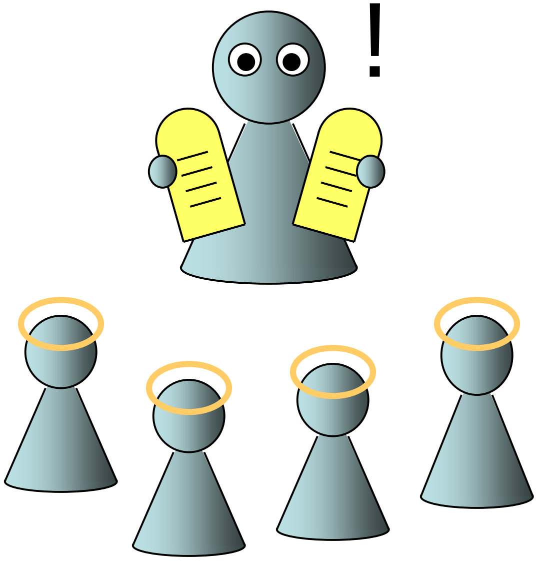
Central properties a system should satisfy:

- Robustness: availability
- Security: integrity and confidentiality

Introduction

Four Commandments:

1. You shall not sleep
2. You shall not fail
3. You shall not lie
4. You shall not leak



Introduction

Four Commandments:

1. You shall not sleep
2. You shall not fail
3. You shall not lie
4. You shall not leak

(1–2: availability; 3: integrity; 4: confidentiality)

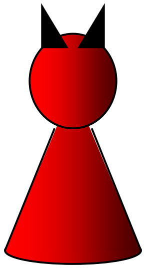
Measures against violations:

Quite challenging…

Introduction

Examples of violations:

1. You shall not sleep
   → asynchronicity
2. You shall not fail
   → message loss, process/link failures,
   Denial-of-Service attacks
3. You shall not lie
   → corrupted information/messages/protocols
4. You shall not leak
   → outsider (e.g., man-in-the-middle) or insider (e.g., through viruses) attacks



Introduction

Measures to be robust to asynchronicity:

Decoupling of time and flow

- Time decoupling: interacting processes do not need to be available at the same time (usually needs mediator)
- Flow decoupling: the execution of an action within a process should not depend on the availability of another process (no remote calls asking for immediate return values)

Introduction

Measures against message loss and failures:

- Reactive approaches: recovery from any illegal state (such systems known as self-healing / self-stabilizing)
- Proactive approaches: maintain availability even in faulty states (requires redundancy)

Measures against Denial-of-Service attacks:

- Standard approach: enforce confidentiality to make targeted DoS attacks hard

Introduction

Measures against corrupted messages and information:

- Algorithmic approach: use redundancy
- Cryptographic approach: integrity measures (encode messages and information so that correctness can be checked)

Measures against corrupted protocols:

- Hard and expensive ($\rightarrow$ Byzantine general models)

Introduction

Measures against leaking:

- Algorithmic approach: secret sharing
- Cryptographic approach: use encryption

In the real world, leaking is hard to avoid.

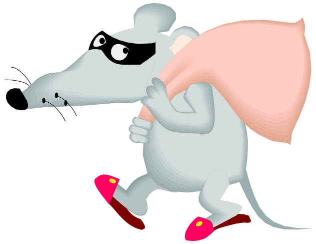
Main problem: exposure!

Introduction

- SPAM:
  Anyone can send you an email and disseminate your email address.

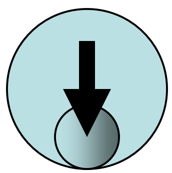
- DoS attacks:
  Anyone who has your IP address can send you a message and freely disseminate your IP address.

- Viruses:
  Once a virus is in your system, it has access to all information in it.



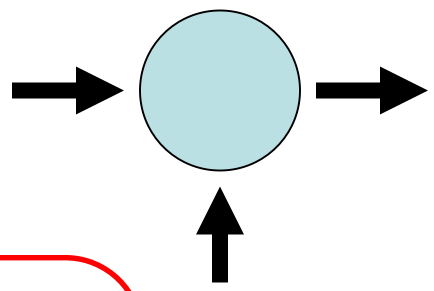
Introduction

Owner consent and control:



- Clearly defined responsibilities
- Complete control over own info & resources

Least exposure:



- Not more knowledge than necessary
- Complete control over information flow

Self-recovery:

- Recovery from every possible state (as long as underlying layer is still in a legal state)

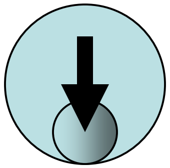
Decoupling:

- No synchronization necessary for primitives

Bachelor course: overlays

Introduction

Owner consent and control:



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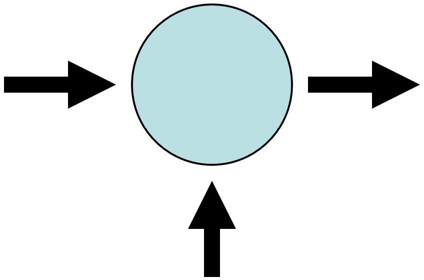
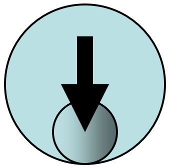


- Not more knowledge than necessary
- Complete control over information flow

Problem: current systems cannot enforce these rules (because they are too open, too complex)

Introduction

Owner consent and control:



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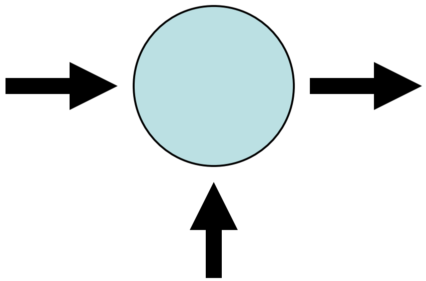
Least exposure:



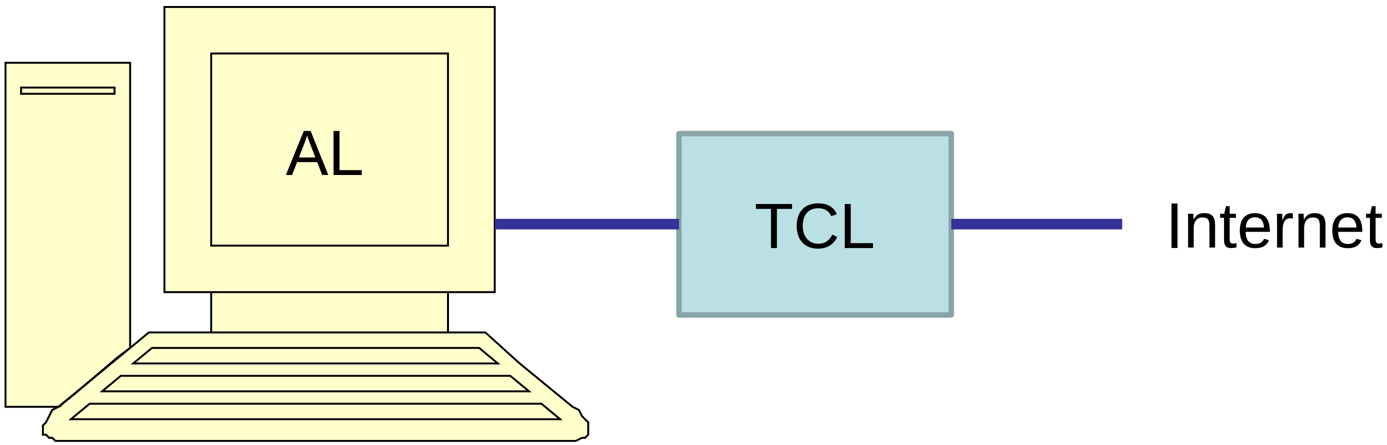
- Not more knowledge than necessary
- Complete control over information flow

Not even suitable models and primitives available to rigorously study guidelines in the algorithms community. So viruses, trojans, and DoS attacks are usually ignored.

In this lecture: new approach

Introduction

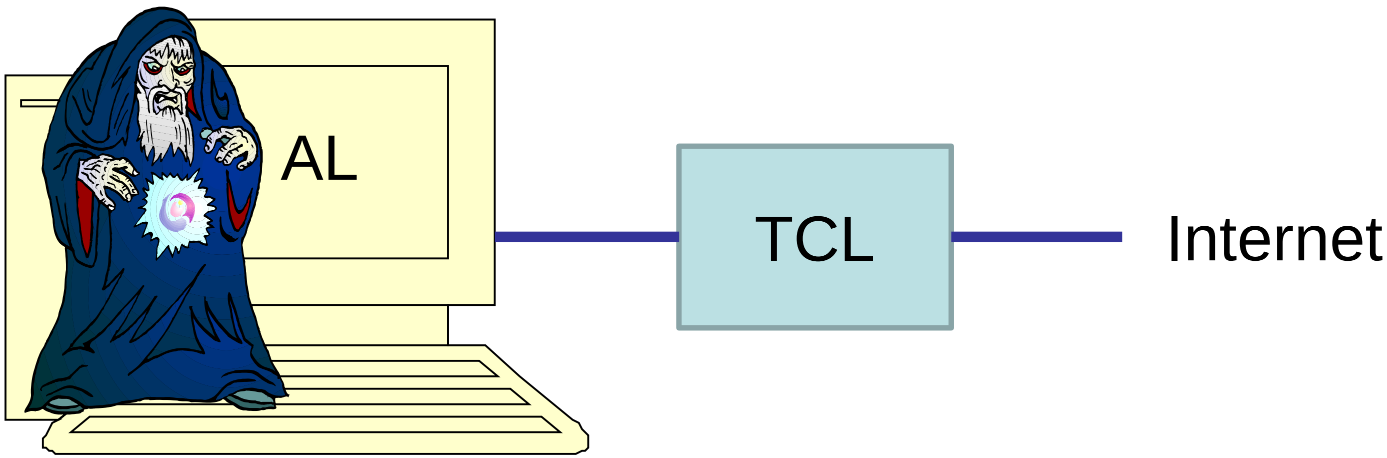
New approach: Trusted Communication Model (TCM)



- AL (Application Layer): large storage capacity and computational power, but potentially insecure
- TCL (Trusted Communication Layer): low storage capacity and computational power but can securely manage ports and keys and can securely execute basic primitives

Introduction

New approach: Trusted Communication Model (TCM)

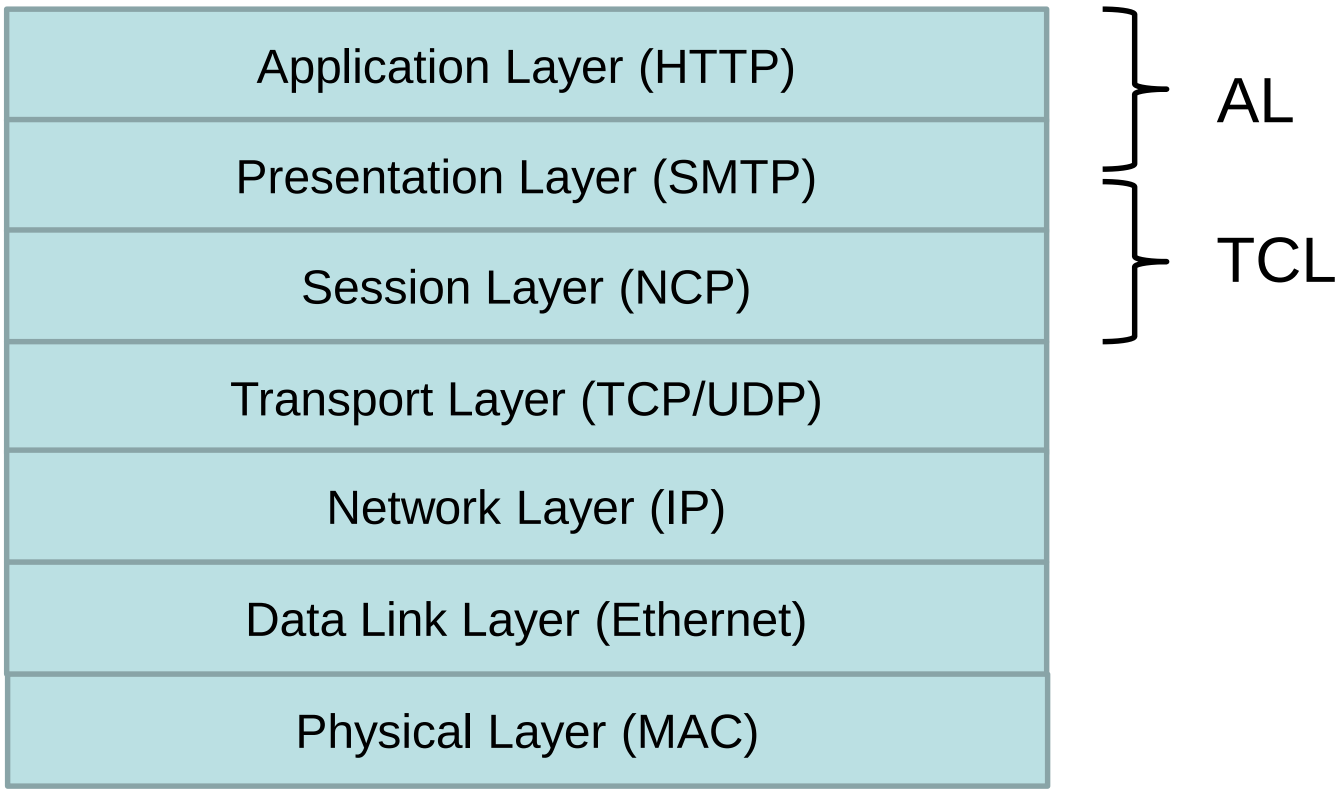


- AL: can be invaded
- TCL: cannot be invaded or inspected

Goal of TCL: support AL in ensuring availability, integrity, and confidentiality

Introduction

ISO OSI-Model:



Advanced distributed algorithms and data structures

Contents:

1. Introduction
2. Graph theory
3. Probability theory
4. Link primitives
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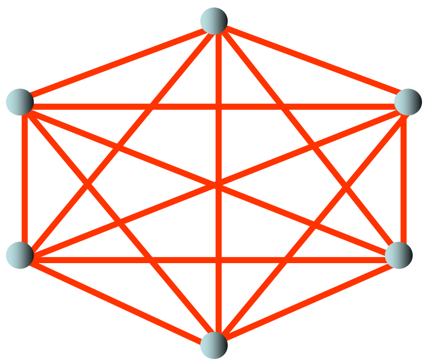
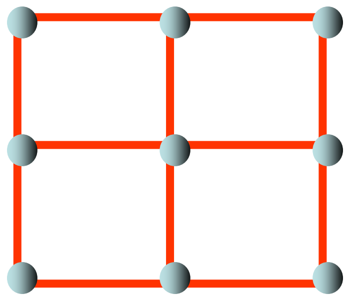
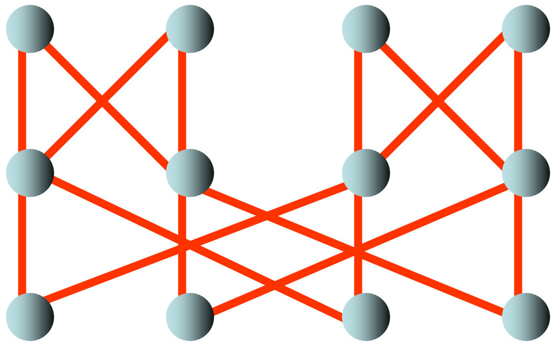
12. Applications

Graph Theory

- Introduction to fundamental topologies

- Basic graph parameters
(degree, diameter, expansion,…)

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Probability Theory

- Random variable
- Expectation
- Variance
- Markov inequality
- Chernoff bounds

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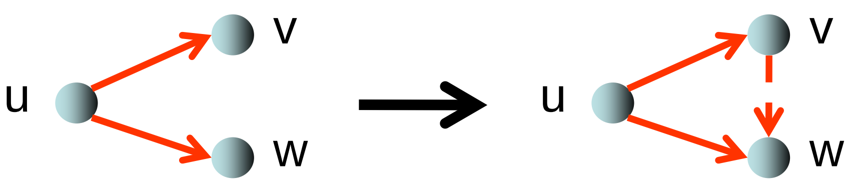
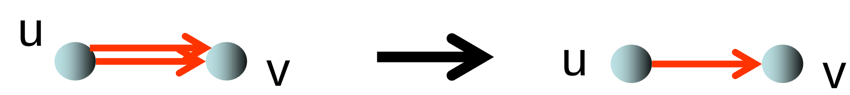
Link Primitives

Safe forms of

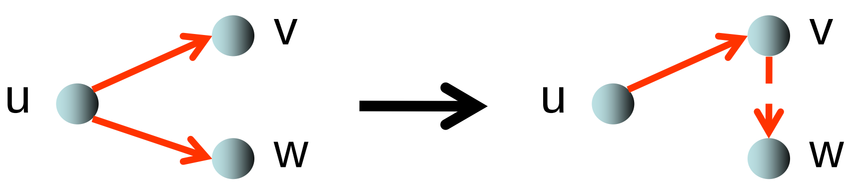
Introduction



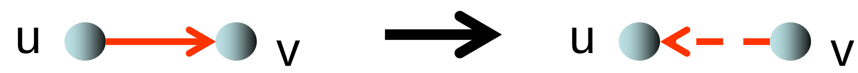
Fusion



Delegation



Reversal



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TCM Model and Programming Environment

Processes can interconnect (using link primitives) and execute actions.

Types of actions:

- Triggered by a local/remote call:
  ⟨name⟩(⟨parameters⟩) → ⟨commands⟩
- Triggered by a local state:
  ⟨name⟩: ⟨predicate⟩ → ⟨commands⟩

All messages are remote action calls.

Example:

```
minimum(x,y) →
        if x<y then m:=x else m:=y
        print(m)                          no return command!
```

Action „minimum“ is executed whenever a request to call minimum(x,y) is processed.

TCM Model and Programming Environment

Processes can interconnect (using link primitives) and execute actions.

Types of actions:

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  ⟨name⟩(⟨parameters⟩) → ⟨commands⟩
- Triggered by a local state:
  ⟨name⟩: ⟨predicate⟩ → ⟨commands⟩

All messages are remote action calls.

Example:

timeout: true →
    print(„I am still alive!“)

„true“ ensures that action timeout is periodically executed by the given peer (length of period handled by access control).

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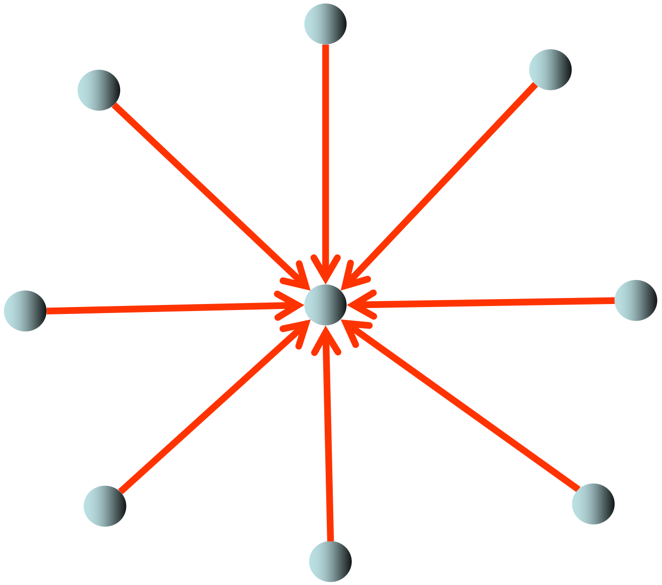
Congestion Control

Problem: nodes need to periodically contact their neighbors (synchronization, failure detection,…) without overwhelming them



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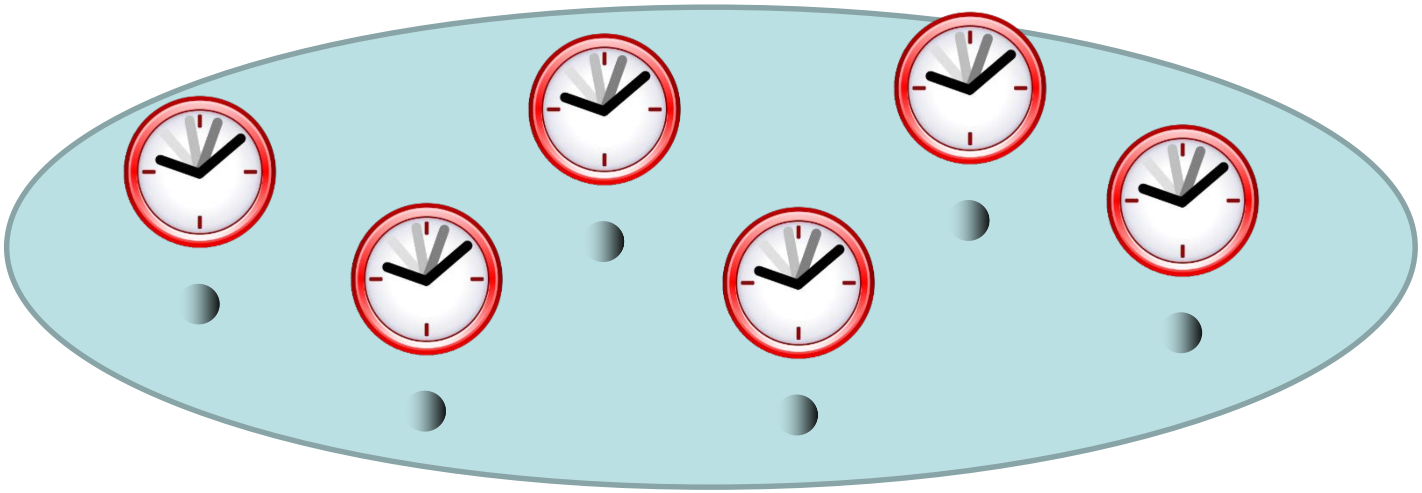
Clock Synchronization

The physical clocks of the processes should show the same time.



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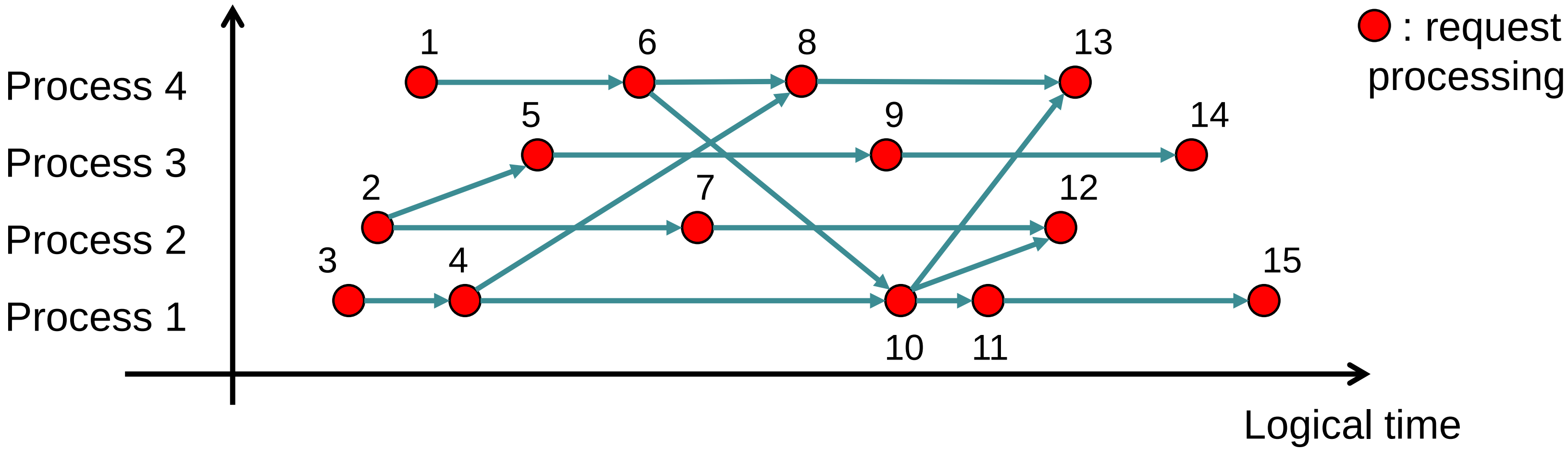
Logical Clocks

Each request obtains a logical time stamp when processed so that requests can be topologically sorted.



→ Important for transactions, snapshots, …

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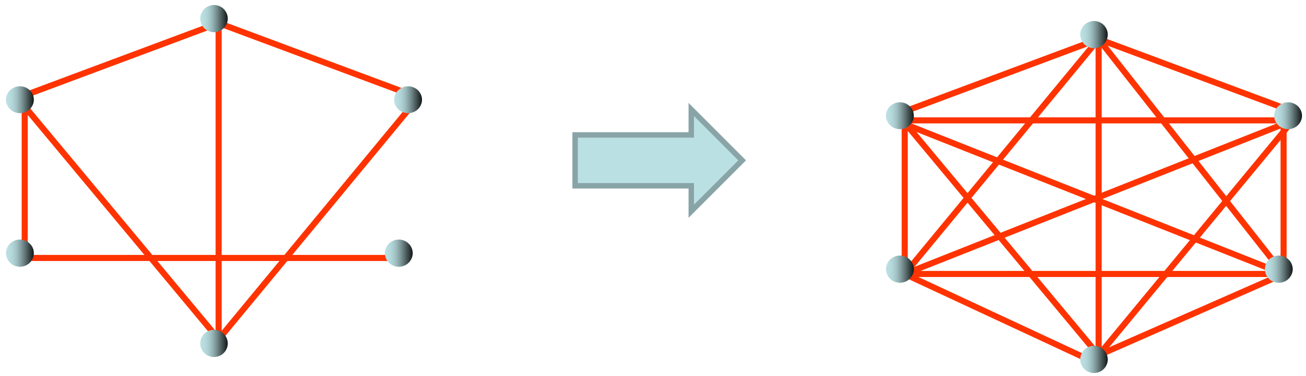
Dynamic Overlay Networks

- Self-stabilizing clique and 2-clique (diameter 2)



- Other topologies: see Bachelor lecture

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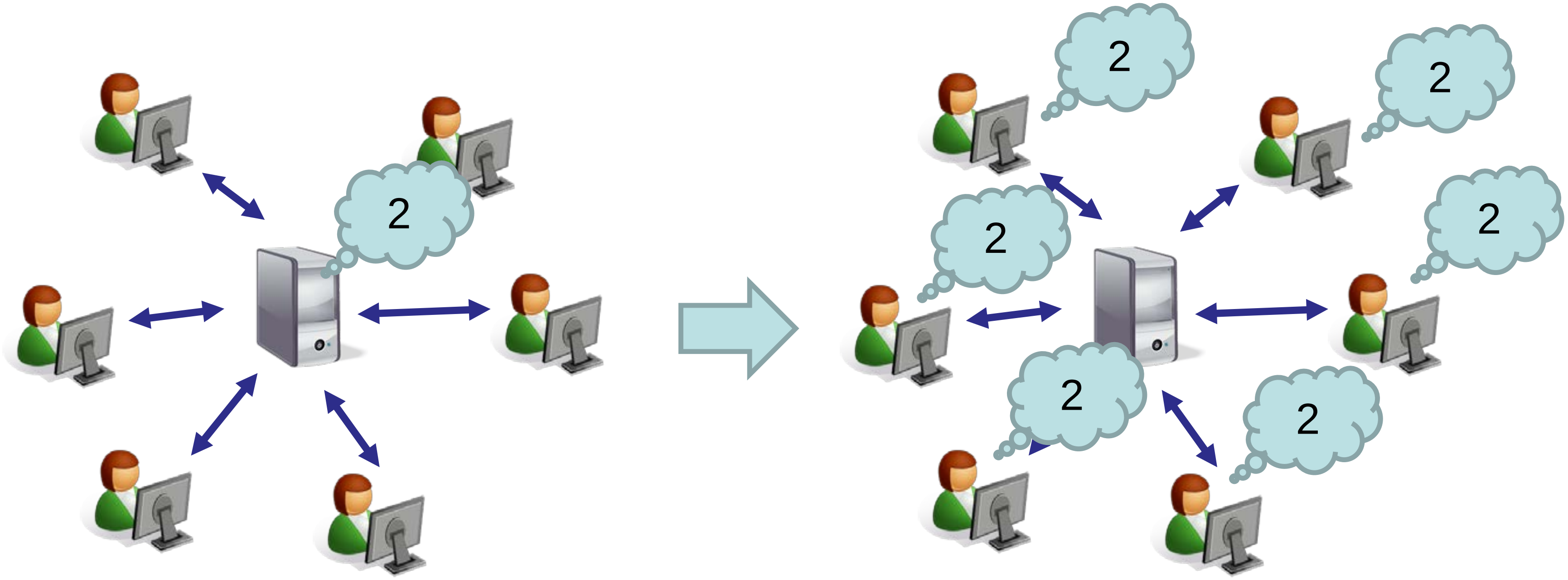
Broadcasting and Anycasting

Broadcasting: send a message to all nodes



Anycasting: send a message to a random node

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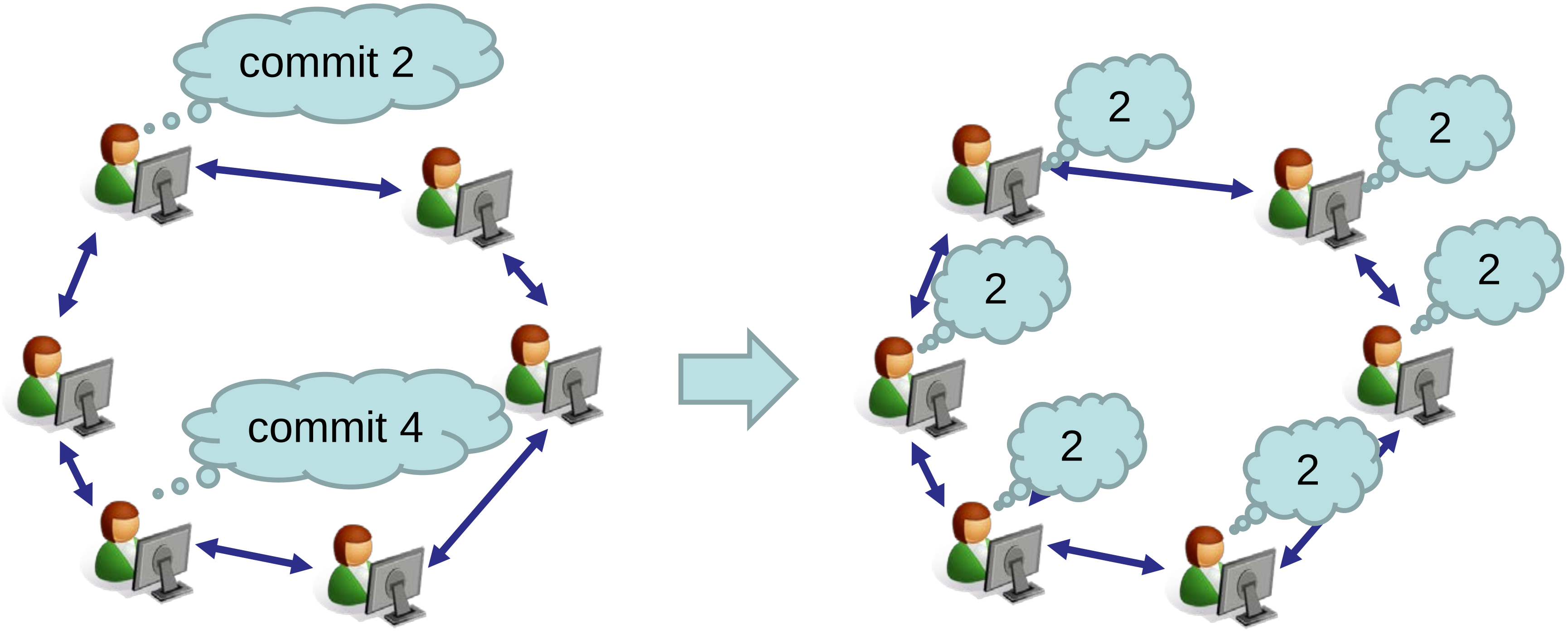
Distributed Commit



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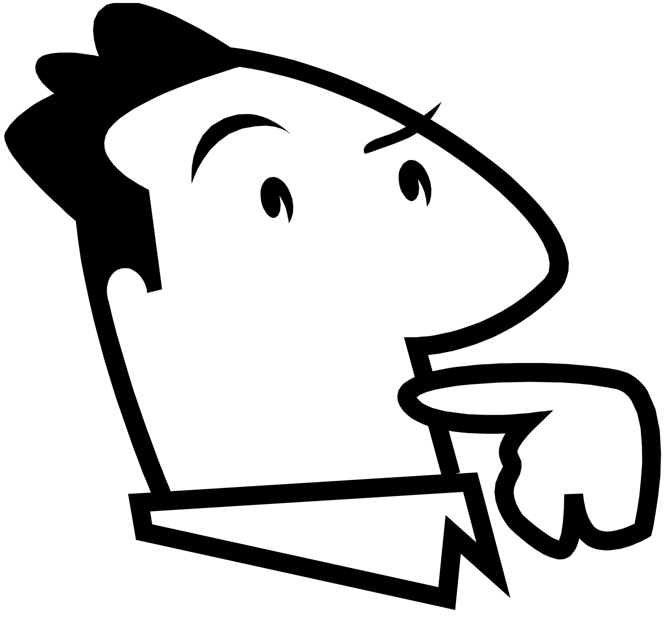
Applications

- Authenticated information system
- Crypto currencies
- Publish / subscribe systems

(may still change)



Questions?