NOTES TO STUDENTS

- Exams: July 18 and September 4 (5)
- watch out for
  “Systems Programming Lab” in Fall !!!

TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Computer Science Institute of Systems Architecture, Operating Systems Group

MODELING DISTRIBUTED SYSTEMS

HERMANN HÄRTIG, DISTRIBUTED OPERATING SYSTEMS, SS2017

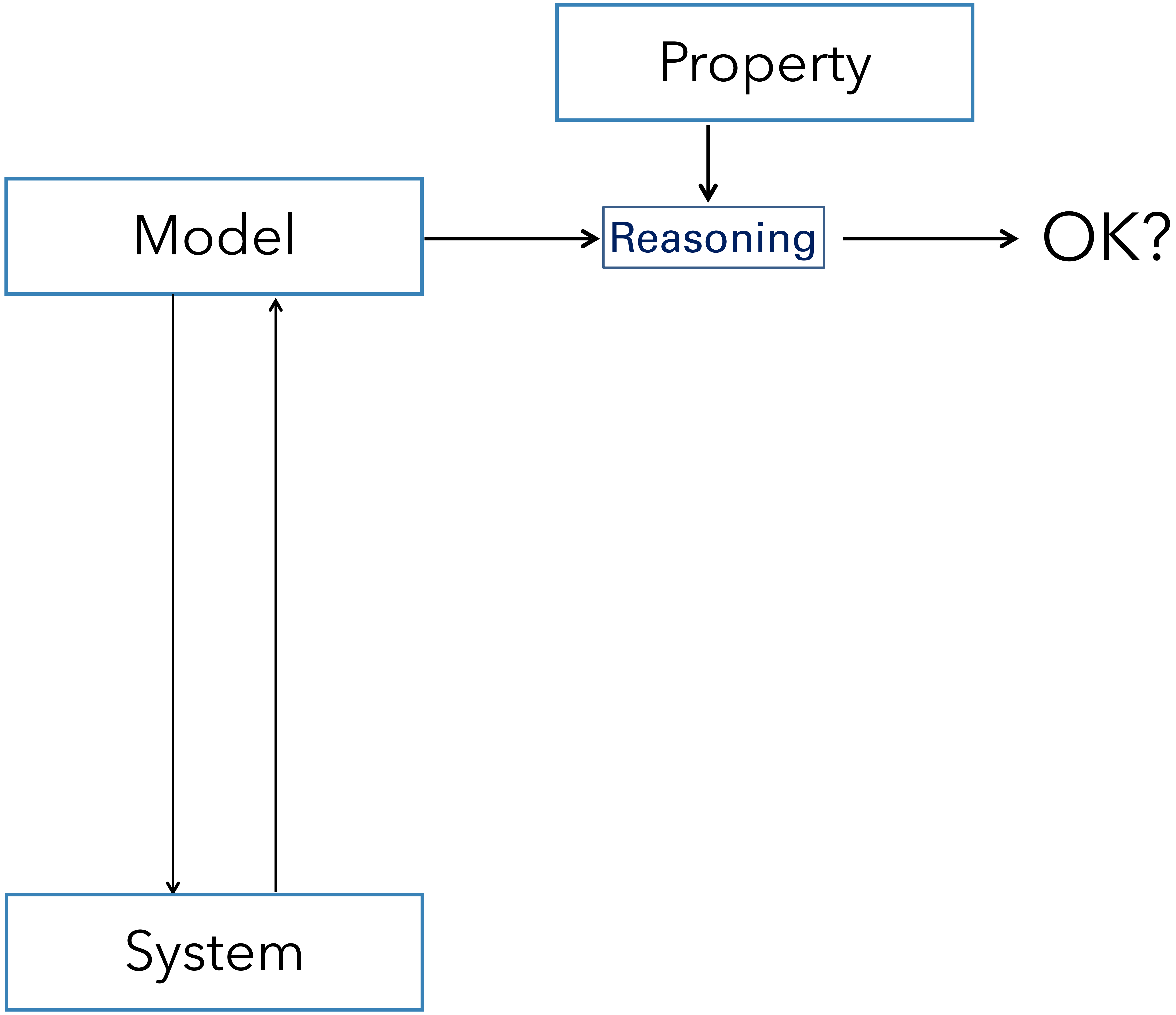
MODELS IN GENERAL

- abstract from details
- concentrate on functionality, properties, ... that are considered important for a specific system/application
- use model to analyze, prove, predict, ... system properties and to establish fundamental insights
- models in engineering disciplines very common, not (yet) so in CS
- we'll see many models in "Real-Time Systems" class

THE GENERAL APPROACH

Reasoning:

- Common sense
- Formal Verification
- Careful Inspection
- Mathematics ...



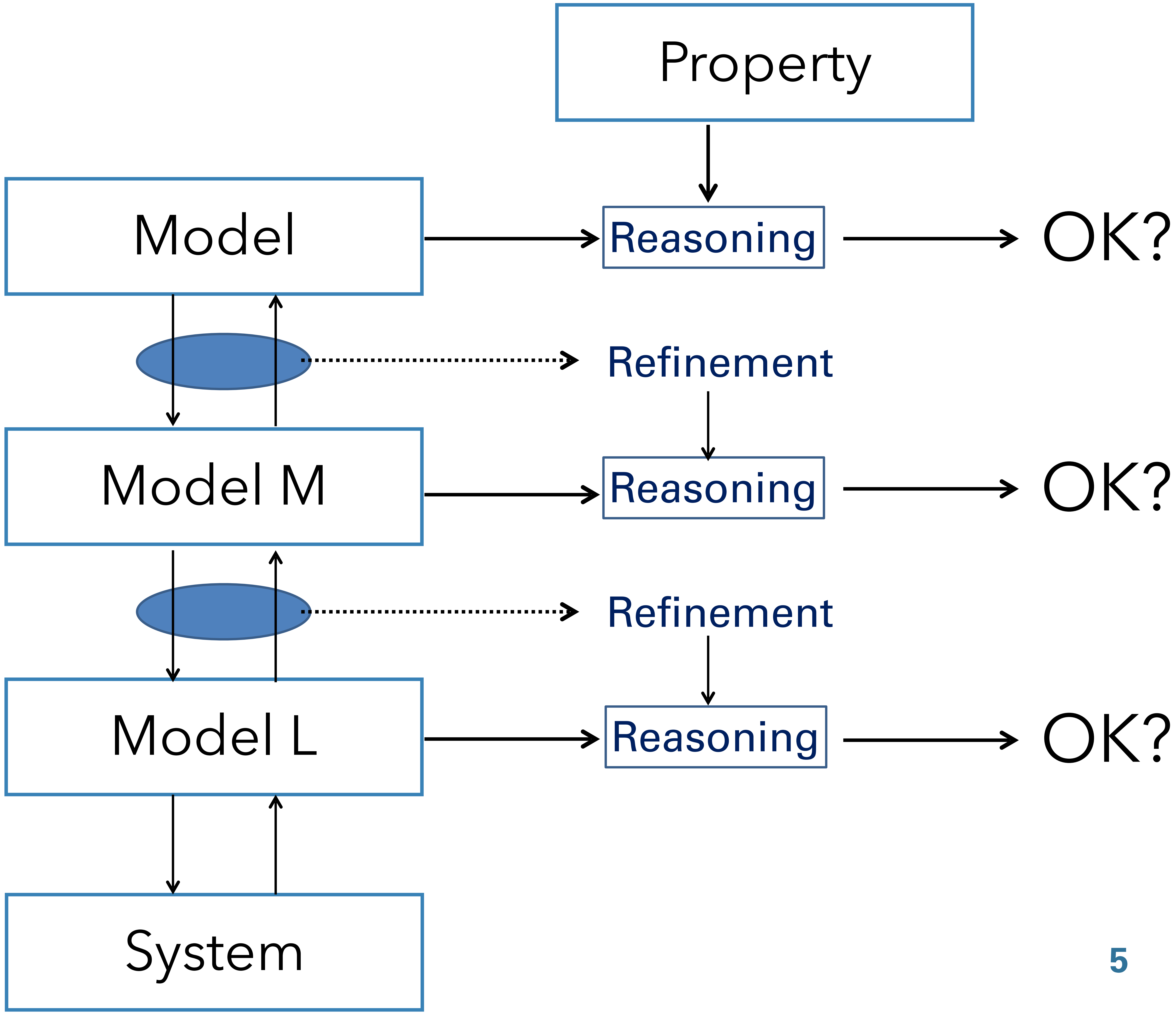
THE GENERAL APPROACH

Reasoning:

- Common sense
- Formal Verification
- Careful Inspection
- Mathematics …

"Refinement":

- Abstraction
- Implementation
- Formal Refinement



MODEL EXAMPLES IN GENERAL

Model	Objective/Question
■ Failure Trees	are all failure combinations taken into account
■ static models	does a house eventually fall down what kind of vehicles on a bridge
■ control laws	stability of controllers
■ Ohm's Law	behavior of circuits

WELL KNOWN EXAMPLES FOR MODELS

I=V/R

MODEL EXAMPLES COMPUTER SCIENCE

Model	Objective/Question
▪ Turing Machine	Decidability
▪ Amdahl's Law	Scalability
▪ Logic	Correctness, Precision, …
▪ Real-Time "tasks"	can all timing requirements be met
▪ Byzantine Agreement	Consensus
Two Army	Consensus

WELL KNOWN EXAMPLES FOR MODELS

UML ???

MODELS IN DOS

- Objective of lecture:
  understand the power of models and the need for their careful understanding
- Intuition, No (real) proofs

THIS LECTURE'S QUESTIONS

- Q1: Is possible to build arbitrarily reliable Systems out of unreliable components?
- Q2: Can we achieve consensus in the presence of faults (consensus: all non-faulty components agree on action)?
- Q3: Is there an algorithm to determine for a system with a given setting of access control permissions, whether or not a Subject A can obtain a right on Object B?

2 Models per Question !

All questions/answers/models -> published 1956 - 1982 !!!

LIMITS OF RELIABILITY

Q1: Can we build arbitrarily reliable Systems out of unreliable components ?

- How to build reliable systems from less reliable components
- Fault(Error, Failure, Fault, ...)
  terminology in this lecture synonymously used for "something goes wrong"
  (more precise definitions and types of faults in SE)

DEFINITIONS

Reliability:

- R(t): probability for a system to survive time t

Availability:

- A: fraction of time a system works

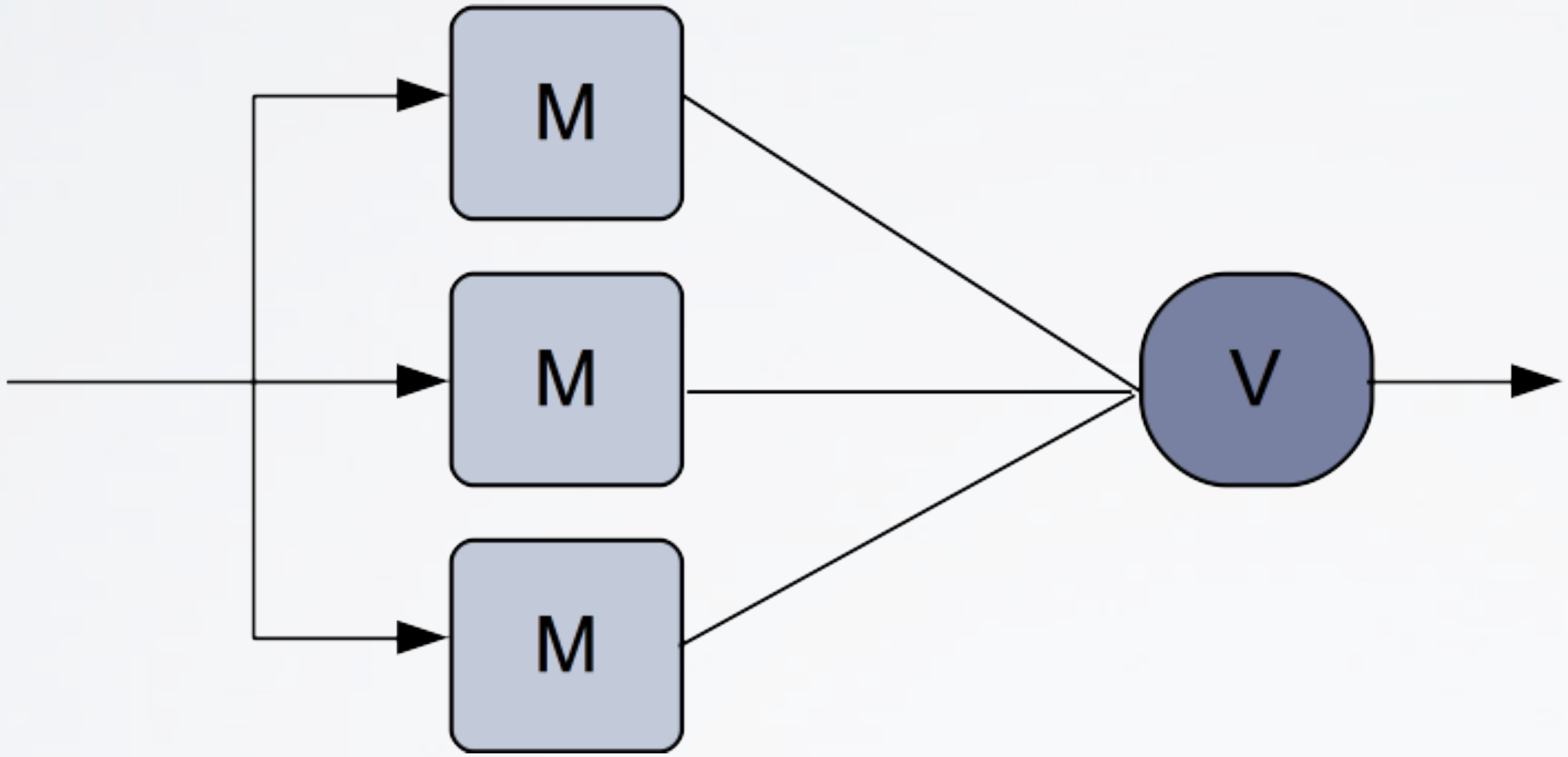
INGREDIENTS

- Fault detection and confinement
- Recovery
- Repair

- Redundancy
  - Information
  - time
  - structural
  - functional

WELL KNOWN EXAMPLE

John v. Neumann
Voter: *single point of failure*

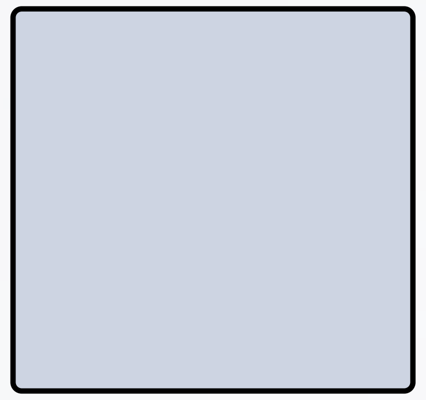


Can we do better
→ distributed solutions?

Q1/MODEL1: LIMITS OF RELIABILITY

Parallel-Serial-Systems

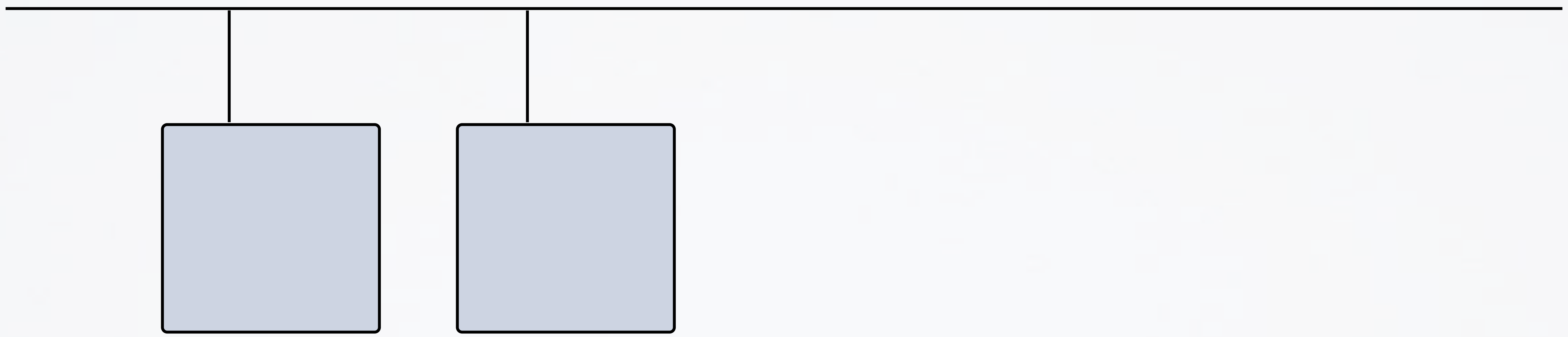
(Pfitzmann/Härtig 1982)



Q1/MODEL1: LIMITS OF RELIABILITY

Parallel-Serial-Systems

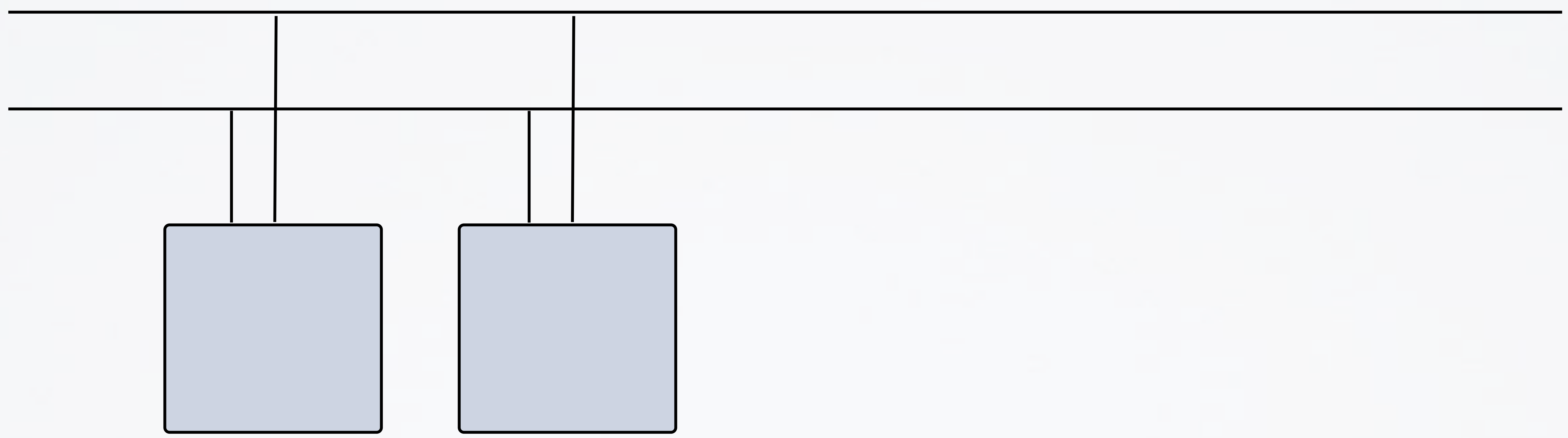
(Pfitzmann/Härtig 1982)



Q1/MODEL1: LIMITS OF RELIABILITY

Parallel-Serial-Systems

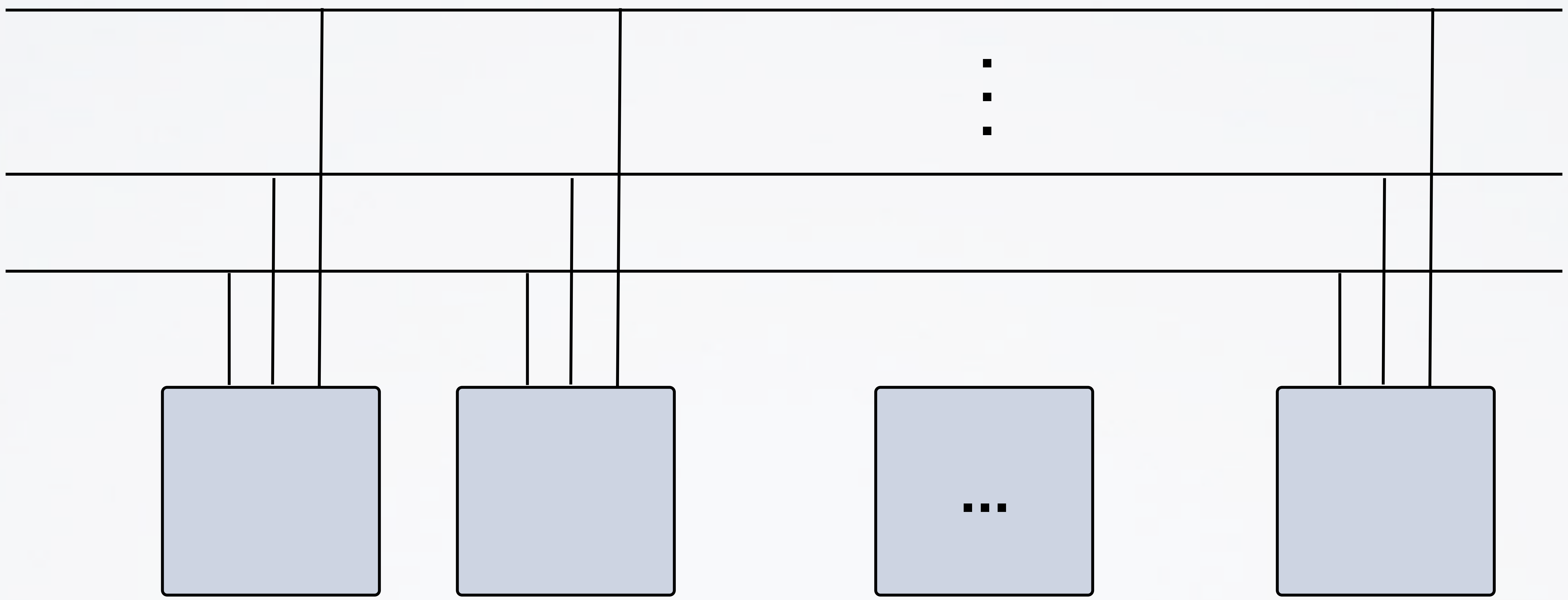
(Pfitzmann/Härtig 1982)



Q1/MODEL1: LIMITS OF RELIABILITY

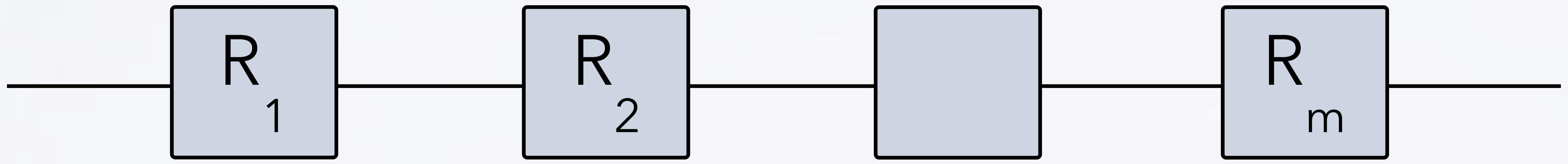
Parallel-Serial-Systems

(Pfitzmann/Härtig 1982)



Q1/MODEL1: ABSTRACT RELIABILITY MODEL

Serial-Systems

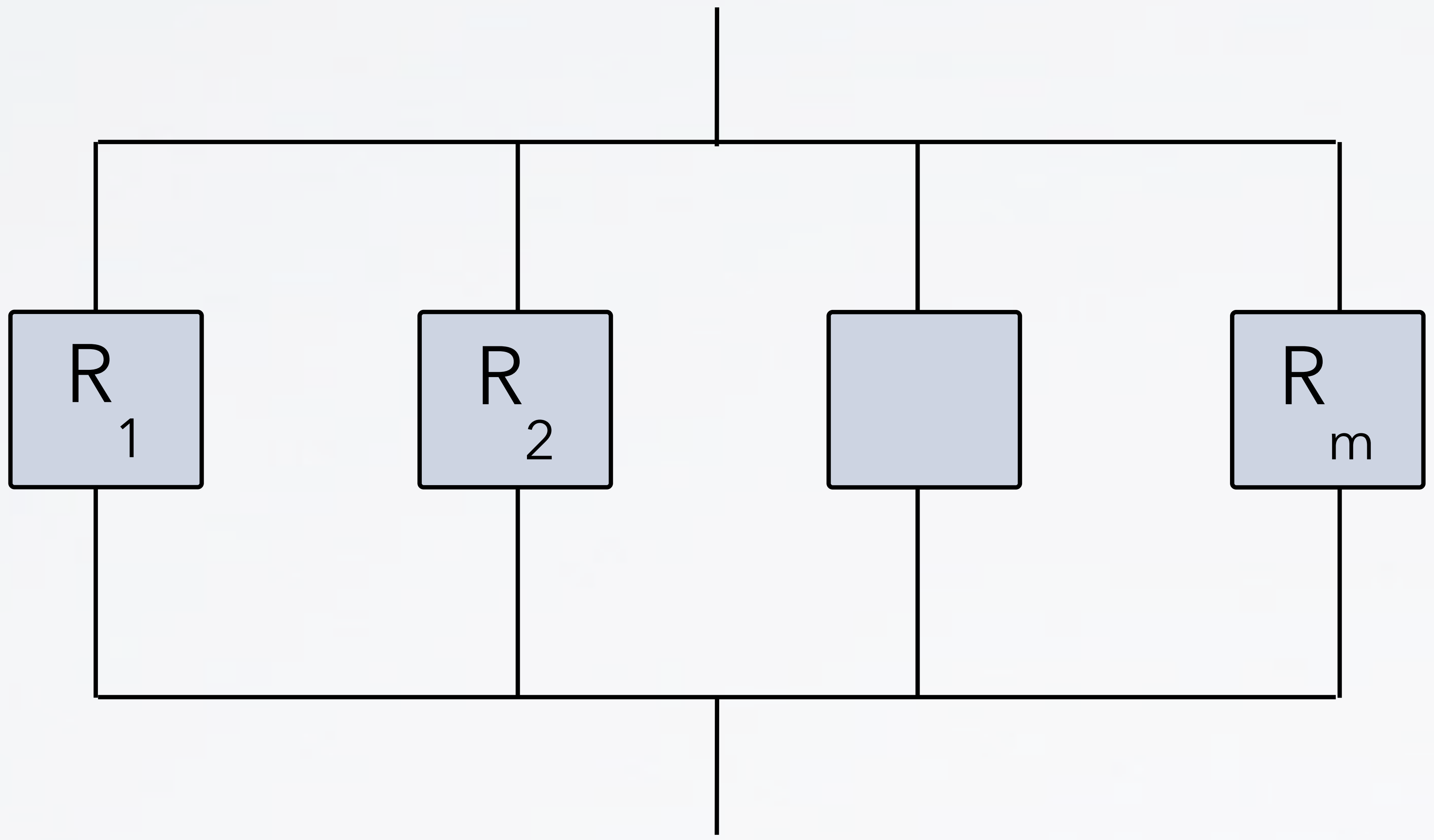


$$R_{whole} = \prod_{j=1}^{m} R_j$$

Each component must work for the whole system to work.

Q1/MODEL1: ABSTRACT MODEL

Parallel-Systems



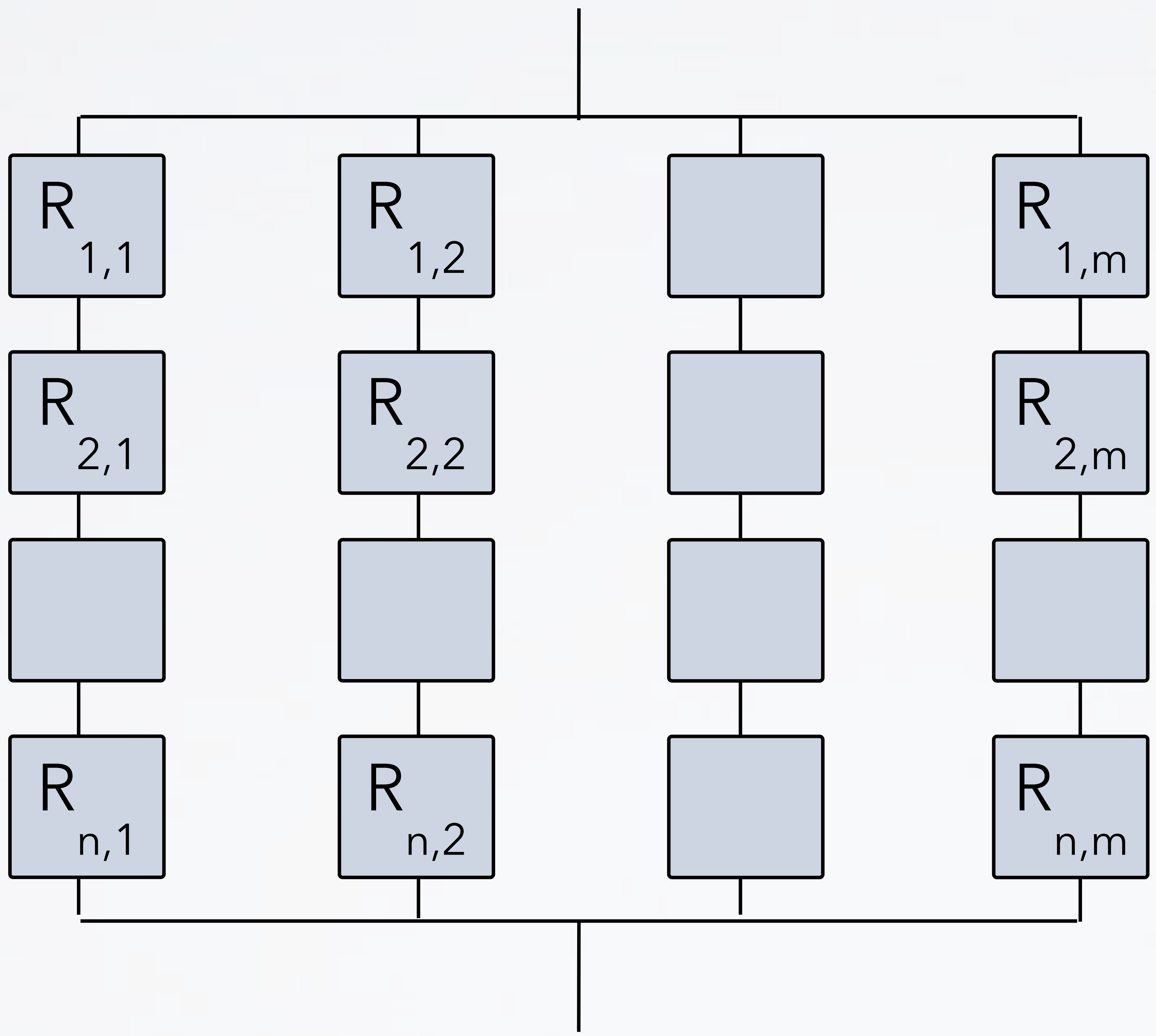
$$R_{whole} = 1 - \prod_{i=1}^{m} \left(1 - R_i\right)$$

One component must work for the whole system to work.

Each component must fail for the whole system to fail.

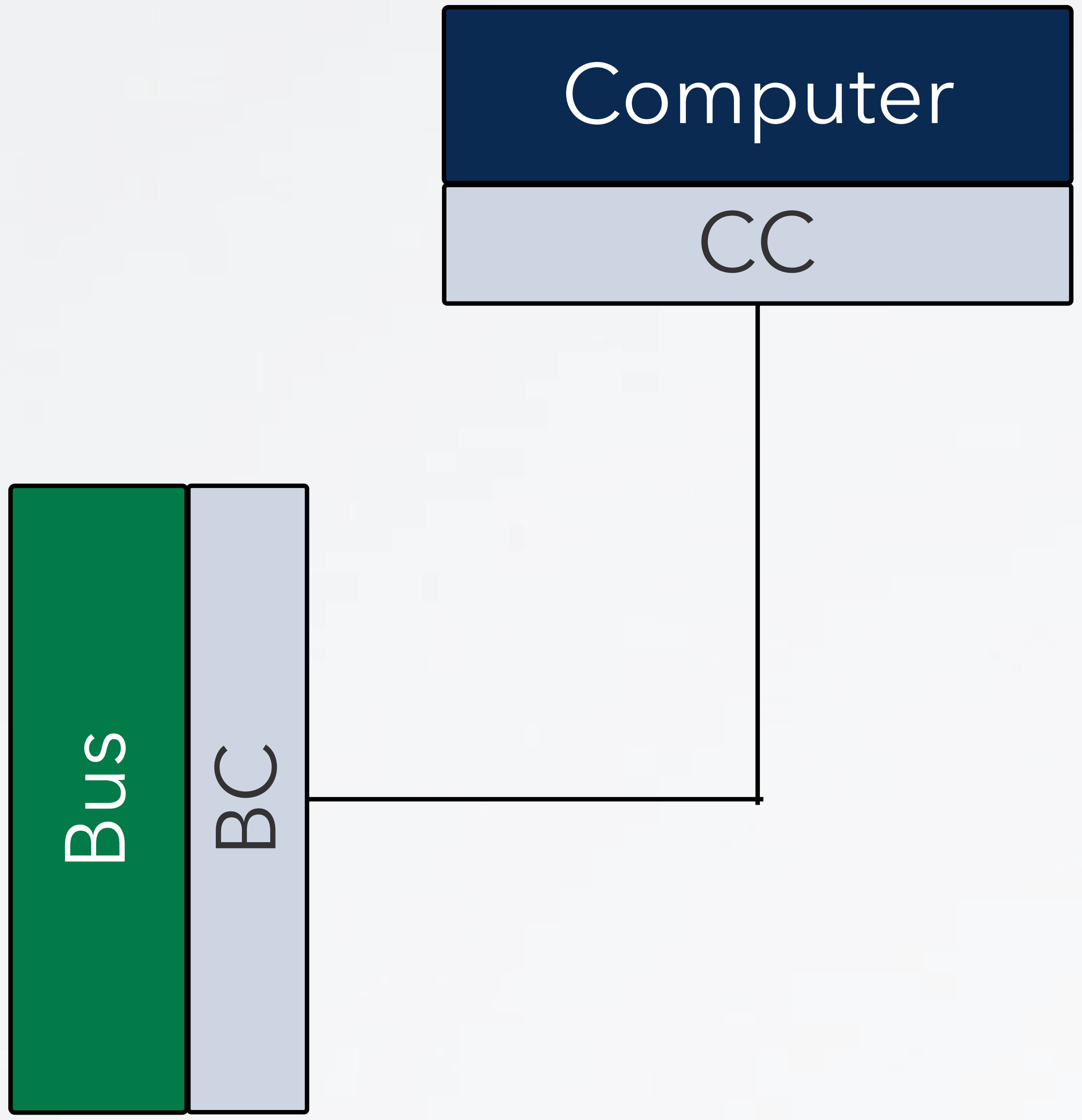
Q1/MODEL1: ABSTRACT MODEL

Serial-Parallel-Systems



$$R_{whole} = 1 - \prod_{j=1}^{m} \left(1 - \prod_{i=1}^{n} R_{i,j} \right)$$

Q1/MODEL1: CONCRETE MODEL



Fault Model

„Computer-Bus-Connector"
can fail such that Computer and/or Bus also fail

=>

conceptual separation of components into

Computer, Bus: can fail per se

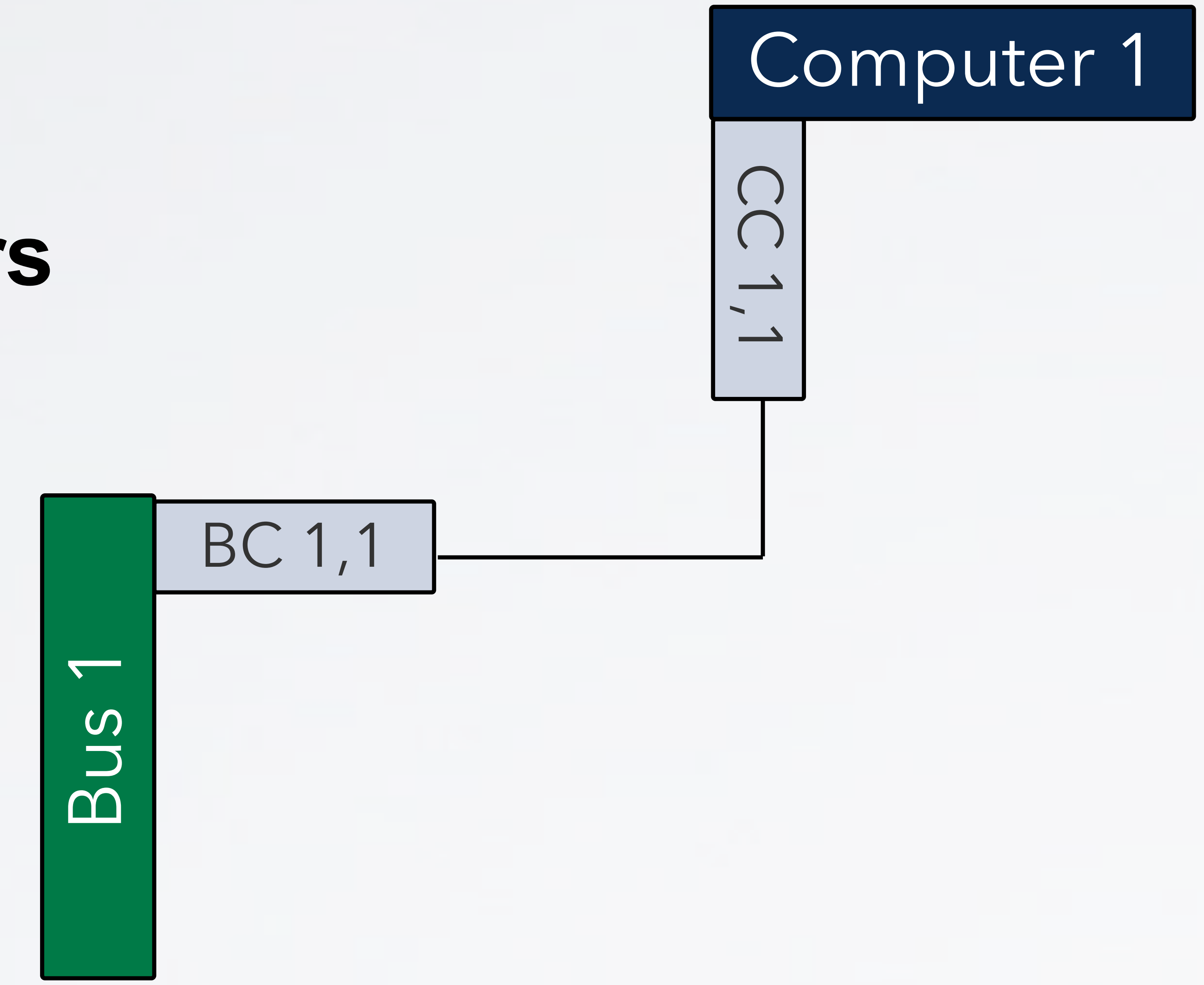
CC: Computer-Connector
fault also breaks the Computer

BC: Bus-Connector
fault also breaks Bus

Q1/MODEL1: CONCRETE MODEL

1 Buses

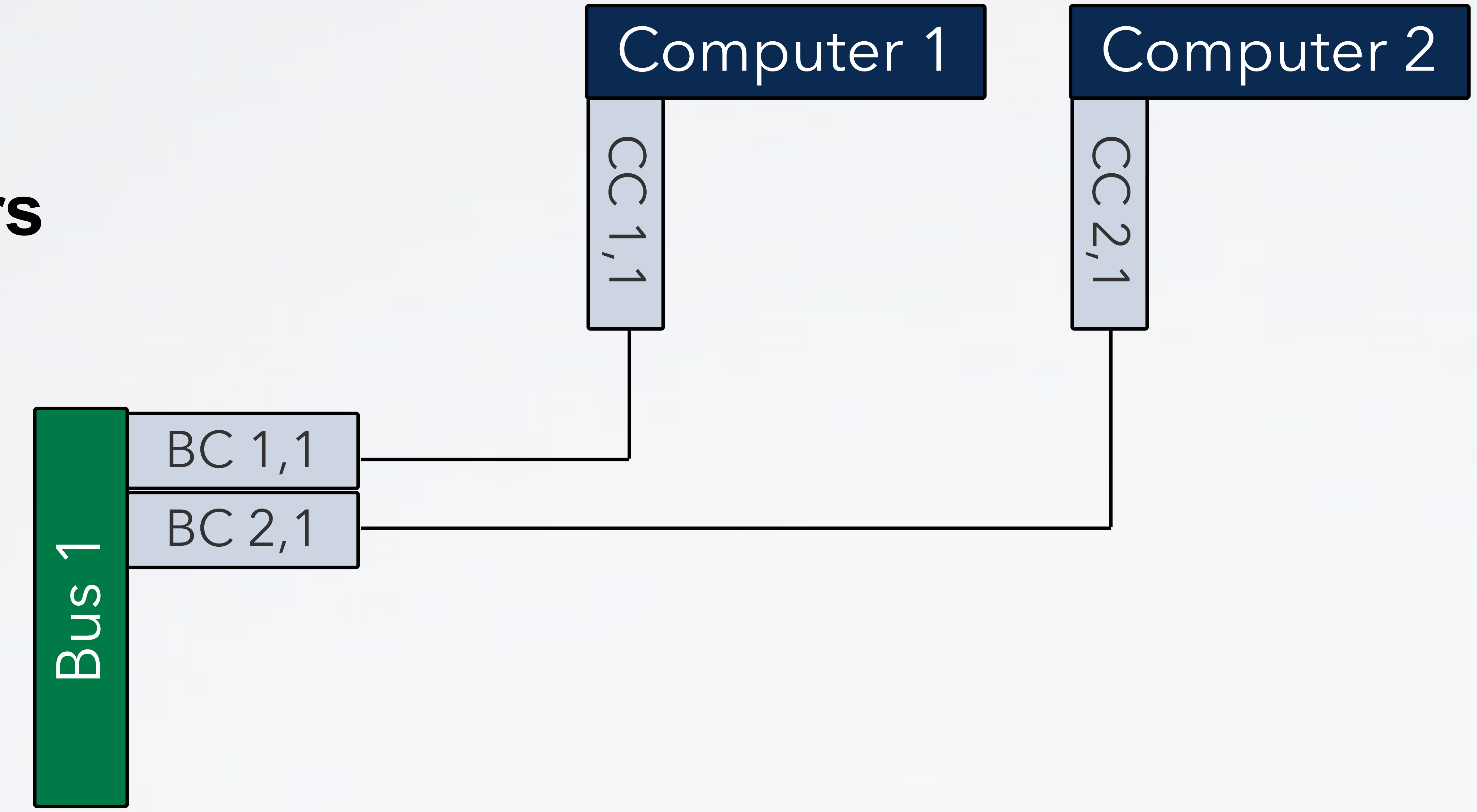
1 Computers



Q1/MODEL1: CONCRETE MODEL

1 Buses

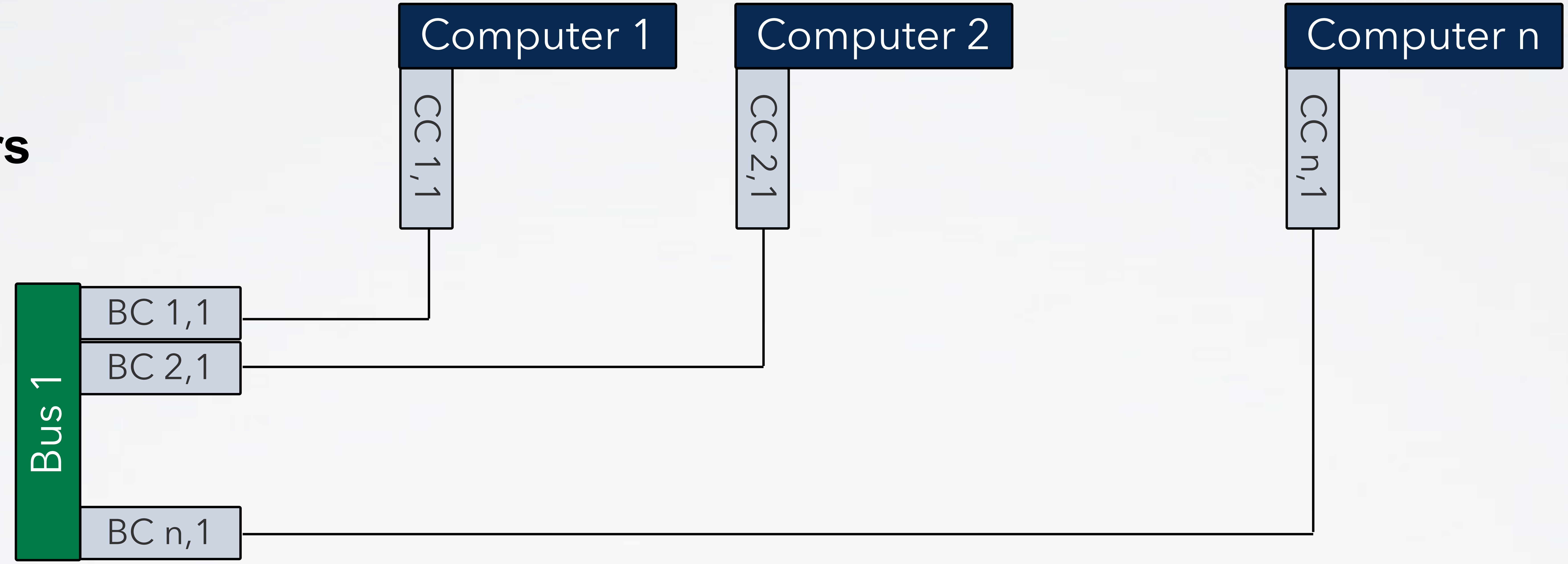
2 Computers



Q1/MODEL1: CONCRETE MODEL

1 Buses

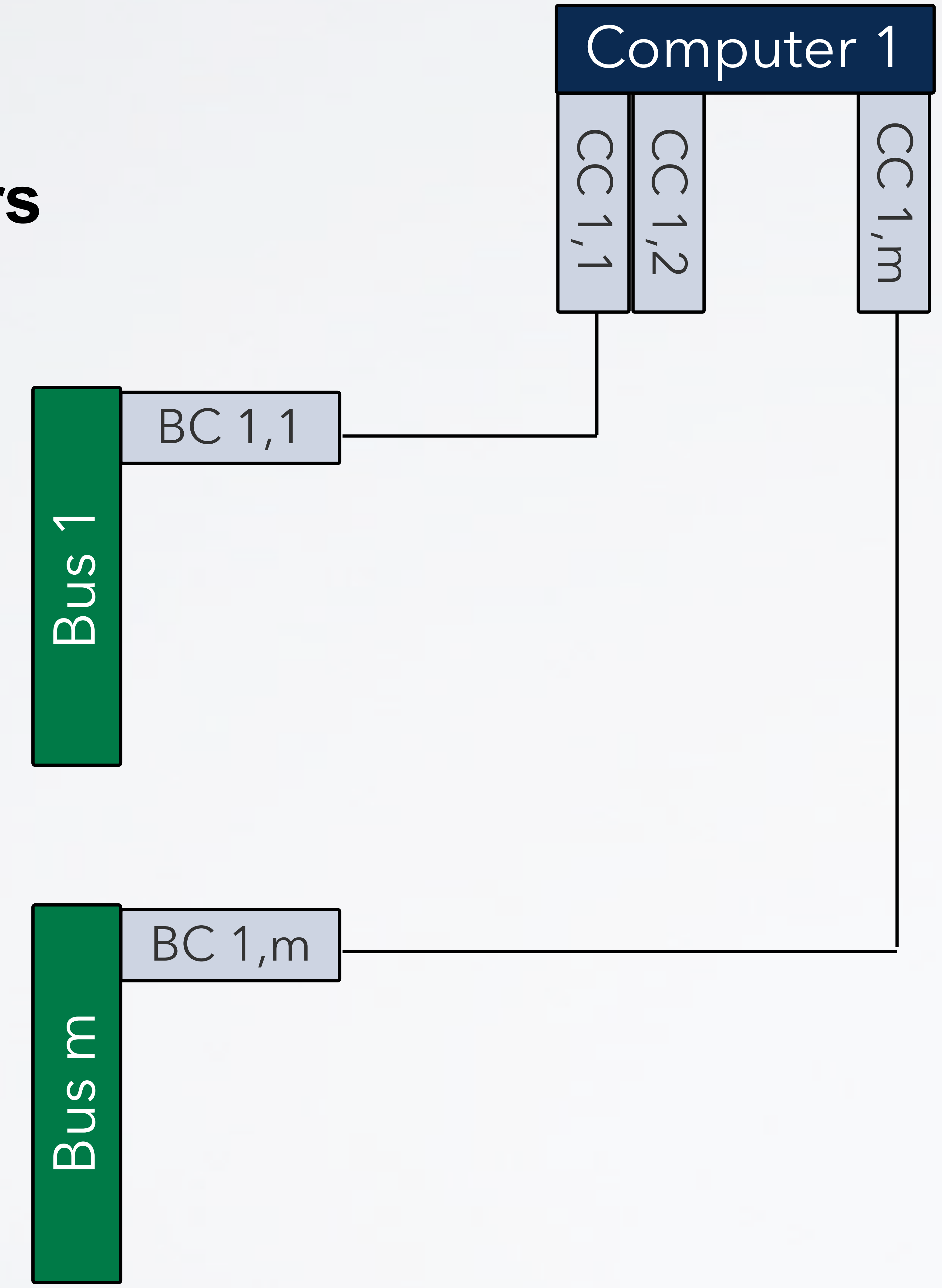
N Computers



Q1/MODEL1: CONCRETE MODEL

M Buses

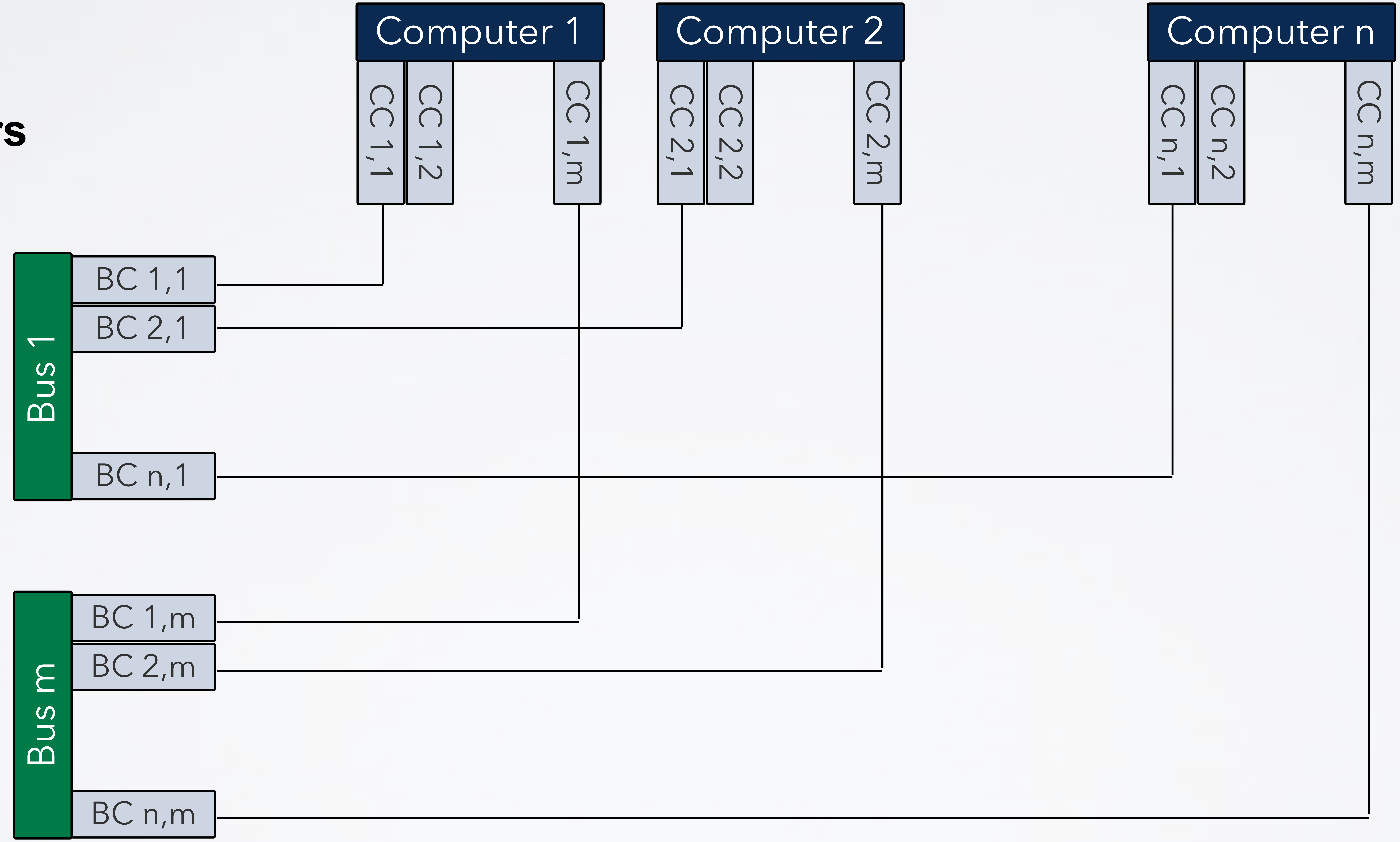
1 Computers



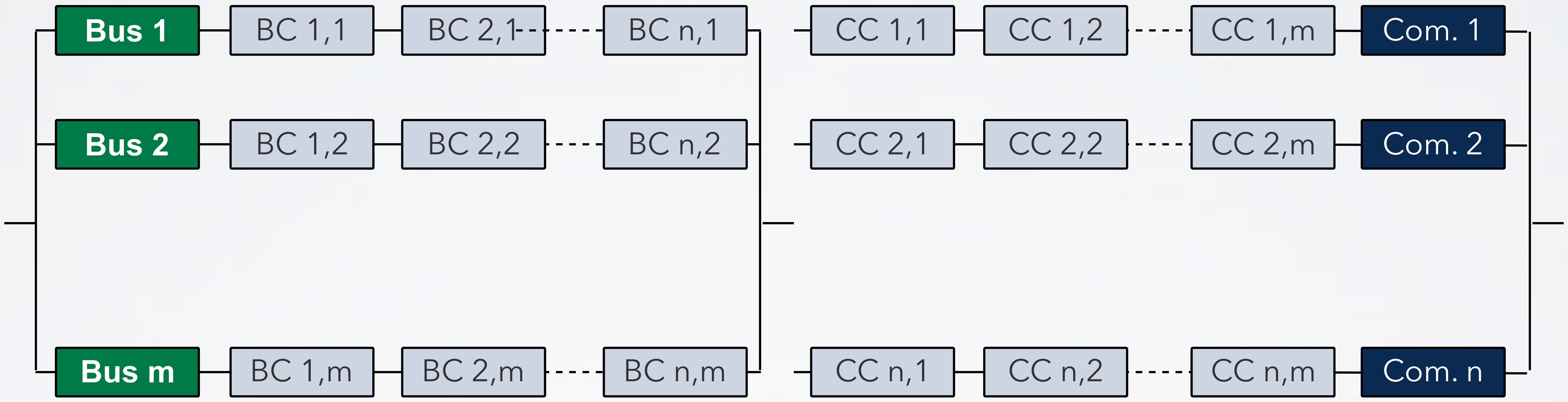
Q1/MODEL1: CONCRETE MODEL

M Buses

N Computers



Q1/MODEL1: CONCRETE MODEL FOR N,M



$$R_{whole}(n,m) = \left(1-\left(1-R_{Bus}\cdot R_{BC}^{n}\right)^{m}\right)\cdot\left(1-\left(1-R_{Computer}\cdot R_{CC}^{m}\right)^{n}\right)$$

$$\text{then: } R_{CC}, R_{BC} < 1 : \lim_{n,m\to\infty} R(n,m) =$$

Q1/MODEL2: LIMITS OF RELIABILITY

- System built of Synapses (John von Neumann, 1956)
- Computation and Fault Model :
  - Synapses deliver „0“ or „1“
  - Synapses deliver with R > 0,5:
    - with probability R correct result
    - with (1-R) wrong result
- Then we can build systems that deliver correct result for any (arbitrarily high) probability R

Q2: CONSENSUS

Q2: Can we achieve consensus in the presence of faults
all non-faulty components agree on action?

- all correctly working units agree on result/action
- agreement non trivial (based on exchange of messages)

Q2/MODEL 1: "2 ARMY PROBLEM"

- p,q processes
  - communicate using messages
  - messages can get lost
  - no upper time for message delivery known
  - do not crash, do not cheat
- p,q to agree on action (e.g. attack, retreat, ...)
- how many messages needed ?

- first mentioned: Jim Gray 1978

Q2/MODEL 1: “2 ARMY PROBLEM”

Result: there is no protocol with finite messages

Prove by contradiction:

- assume there are finite protocols (mp--> q, mq --> p)*
- choose the shortest protocol MP,
- last message MX: mp --> q or mq --> p
- MX can get lost
- => must not be relied upon => can be omitted
- => MP not the shortest protocol.
- => no finite protocol

Q2/MODEL 2: "BYZANTINE AGREEMENT"

n processes, f traitors, n-f loyals

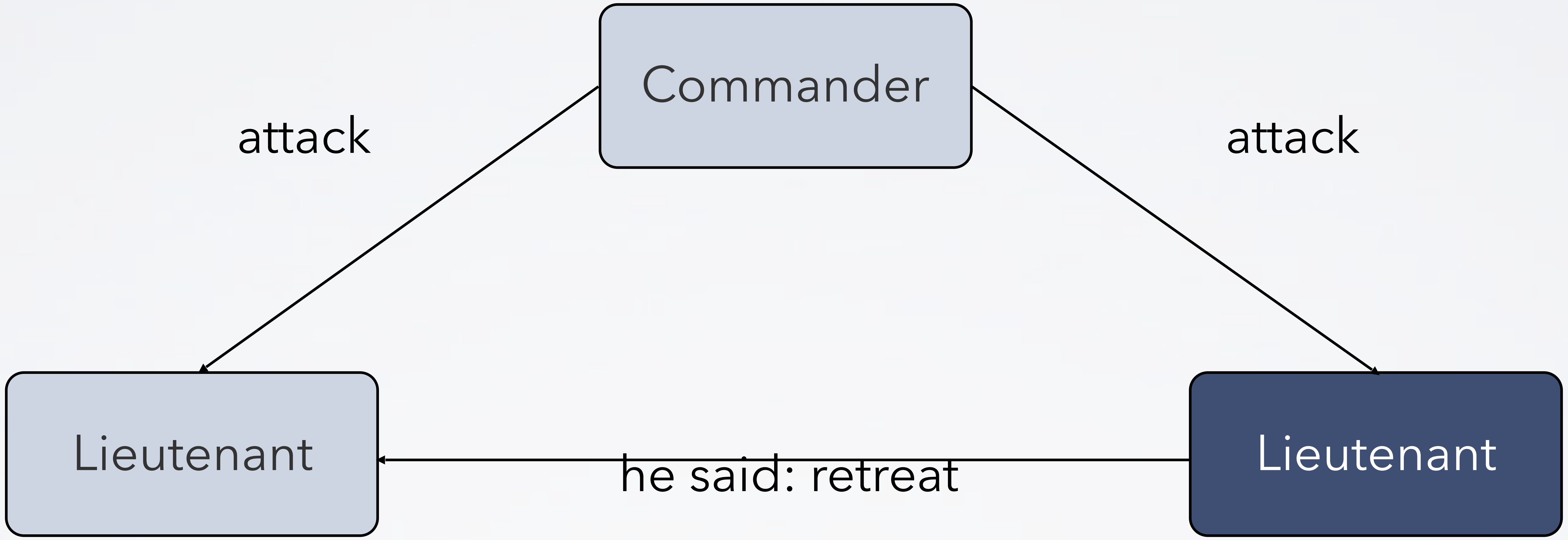
- communicate by reliable and timely messages (synchronous messages)
- traitors lye, also cheat on forwarding messages
- try to confuse loyals

Q2/MODEL 2: "BYZANTINE AGREEMENT"

Goal:

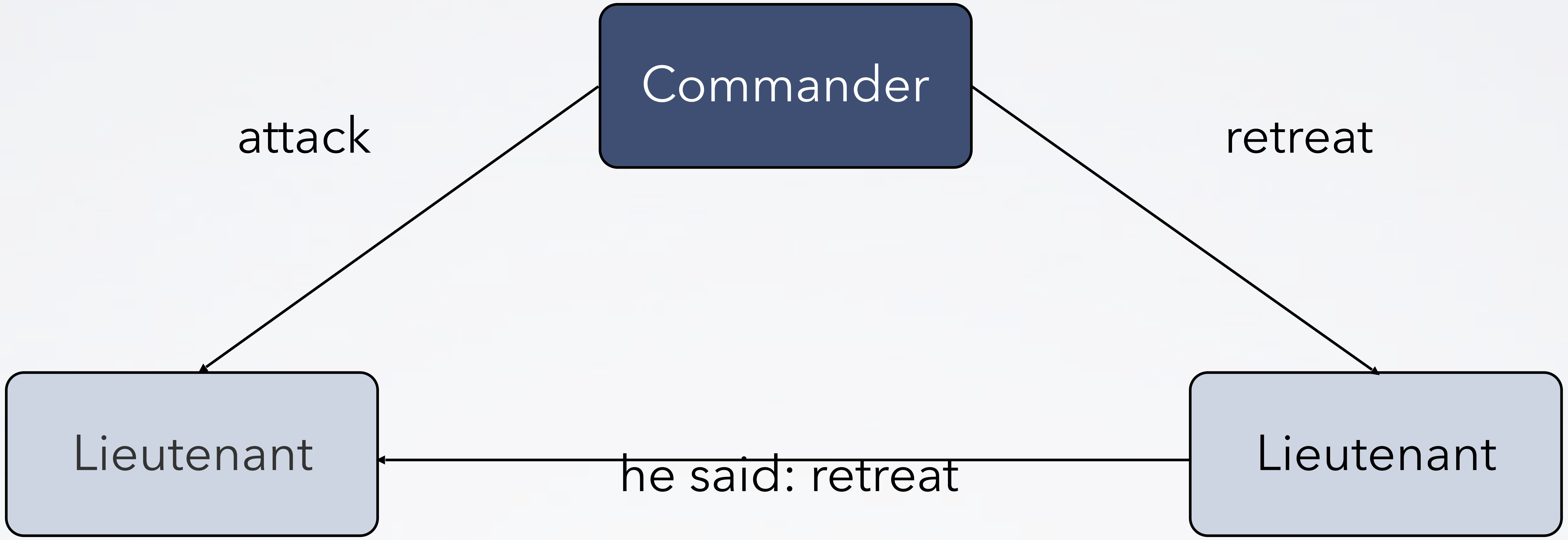
- loyals try to agree on non-trivial action (attack, retreat)
- non-trivial more specific:
  - one process is commander
  - if commander is loyal and gives an order, loyals follow the order otherwise loyals agree on arbitrary action

Q2/MODEL 2: "BYZANTINE AGREEMENT"



3 Processes: 1 traitor, 2 loyals

Q2/MODEL 2: "BYZANTINE AGREEMENT"

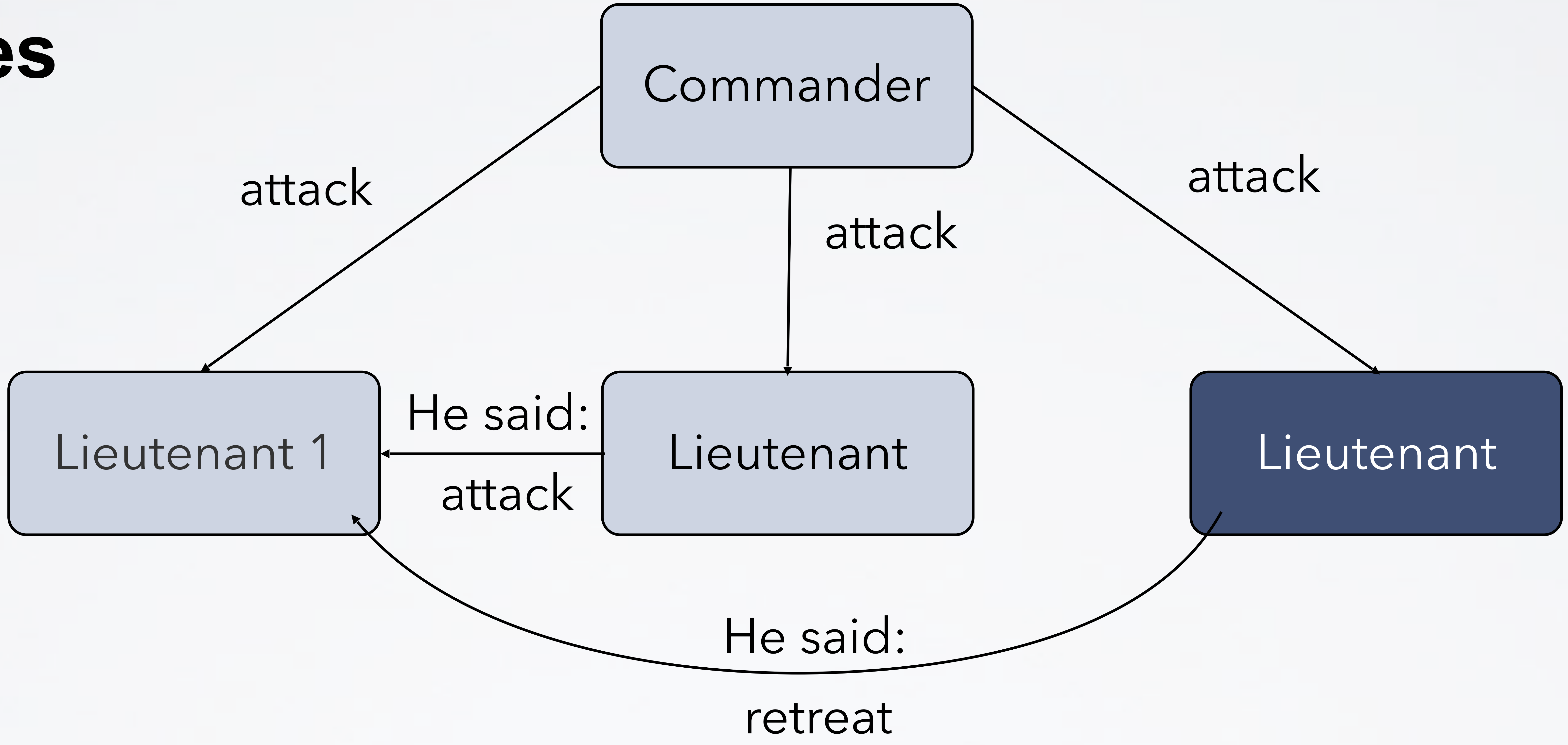


3 Processes: 1 traitor, 2 loyals

=> 3 processes not sufficient to tolerate 1 traitor

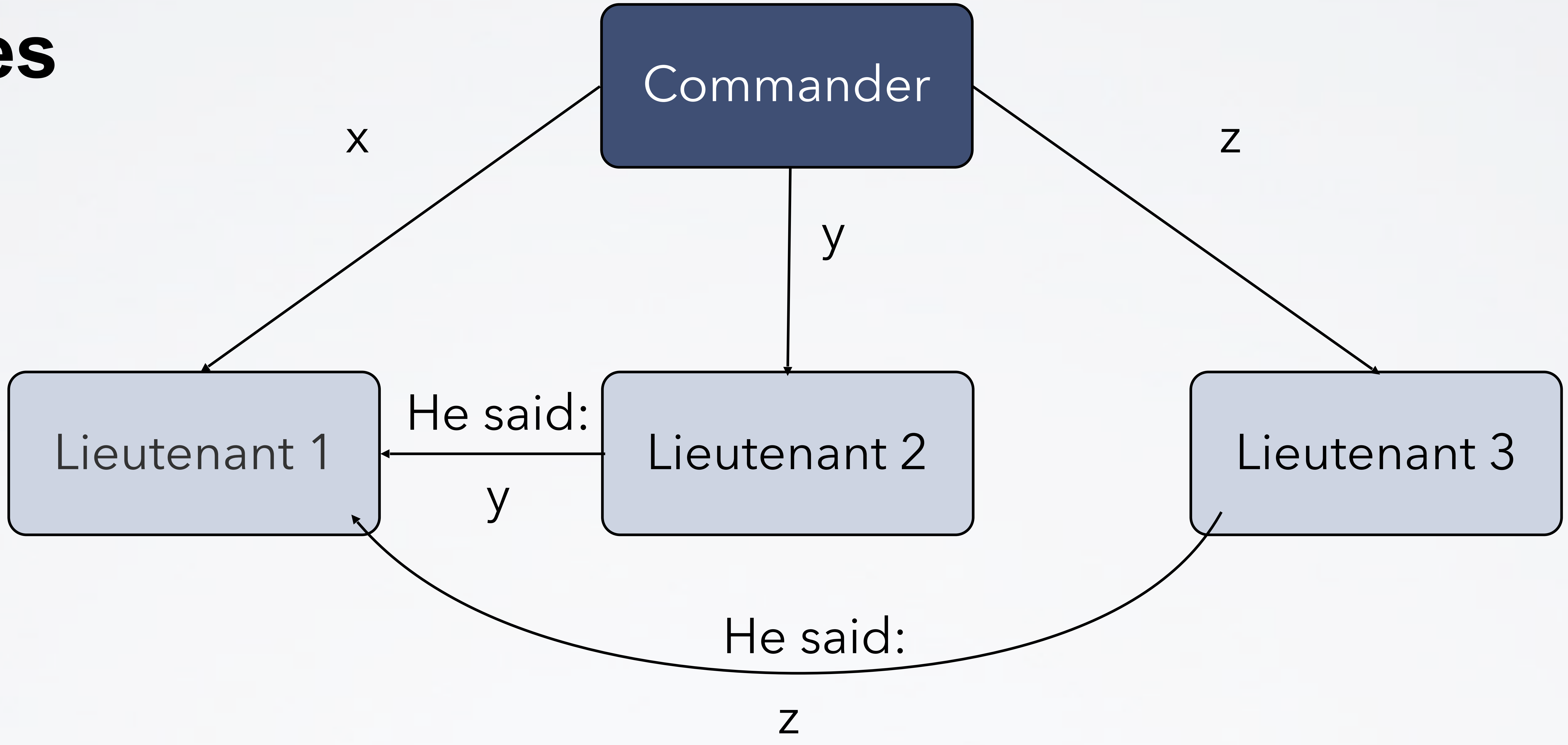
Q2/MODEL 2: "BYZANTINE AGREEMENT"

4 Processes



Q2/MODEL 2: "BYZANTINE AGREEMENT"

4 Processes



all lieutenant receive x,y,z => can decide

General result: 3 f + 1 processes needed to tolerate f traitors

NEXT WEEK

- Q3: Is there an algorithm to determine for a system with a given setting of access control permissions, whether or not a Subject A can obtain a right on Object B?