THIS LECTURE'S QUESTIONS

- Q1: Is it 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 !

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

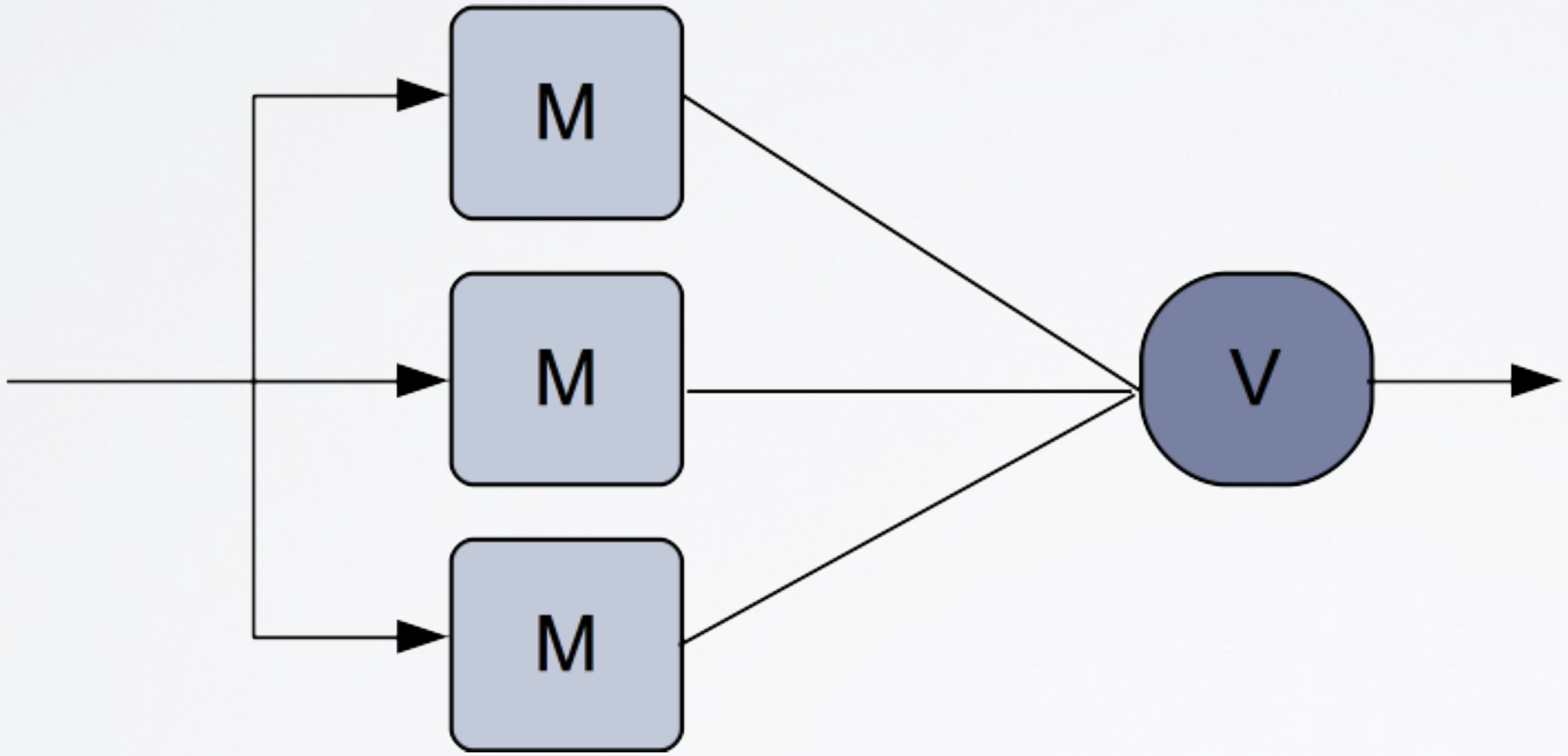
INGREDIENTS OF FT

- Fault detection and confinement
- Recovery
- Repair

- Redundancy
  - Information
  - time
  - structural
  - functional

WELL KNOWN EXAMPLE

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

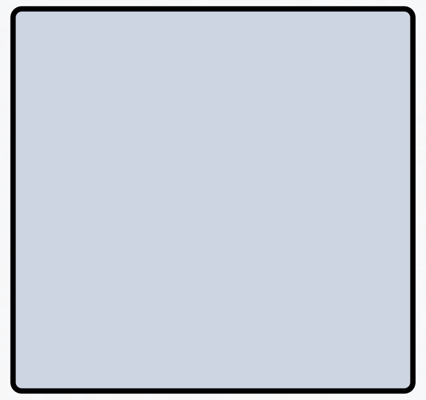


Can we do better
→ distributed solutions?

Q1/MODEL1: LIMITS OF RELIABILITY

Parallel-Serial-Systems

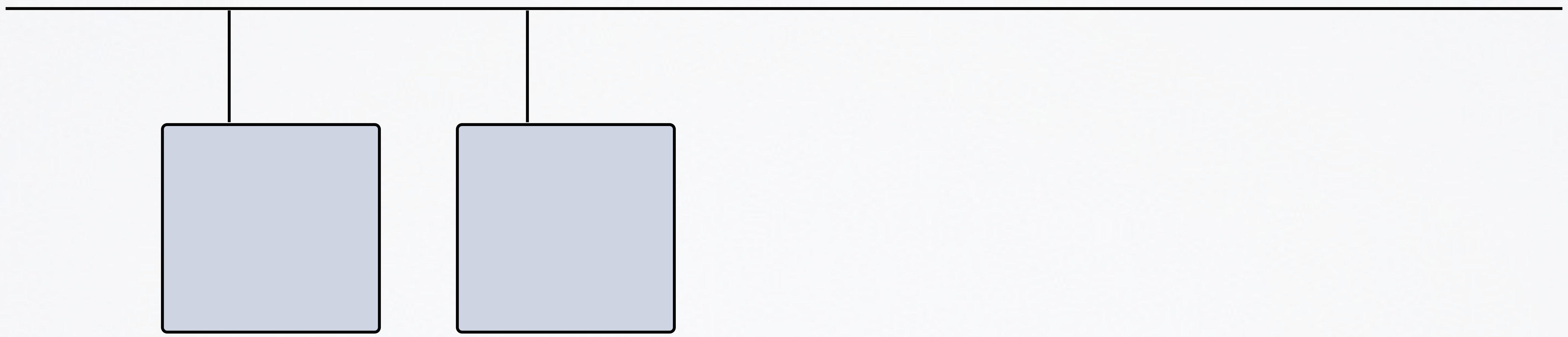
(Pfitzmann/Härtig 1982)



Q1/MODEL1: LIMITS OF RELIABILITY

Parallel-Serial-Systems

(Pfitzmann/Härtig 1982)



Q1/MODEL1: LIMITS OF RELIABILITY

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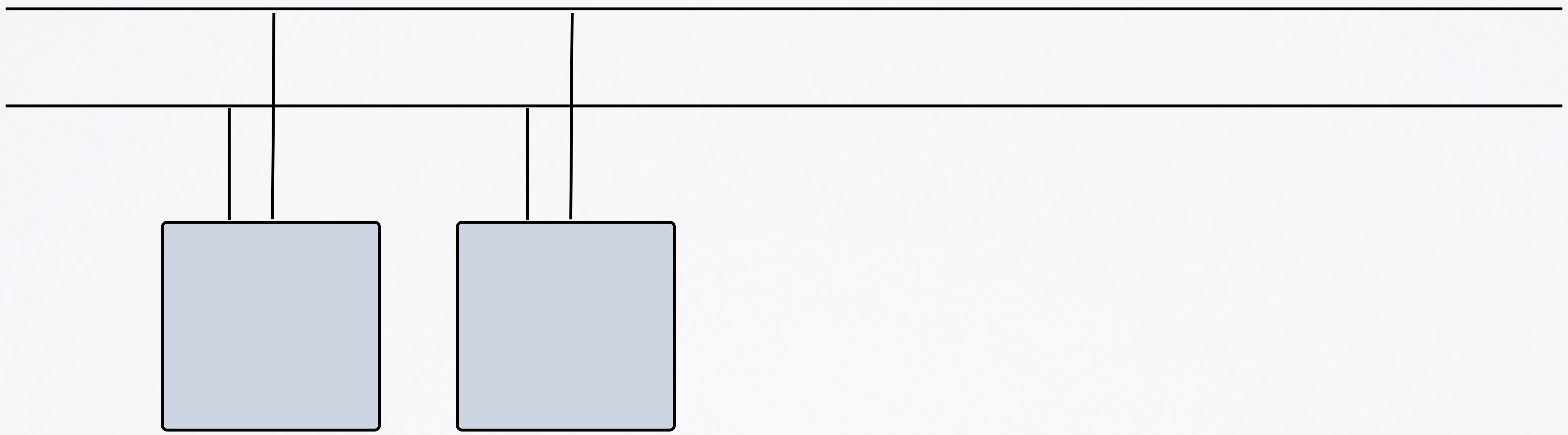

Q1/MODEL1: LIMITS OF RELIABILITY

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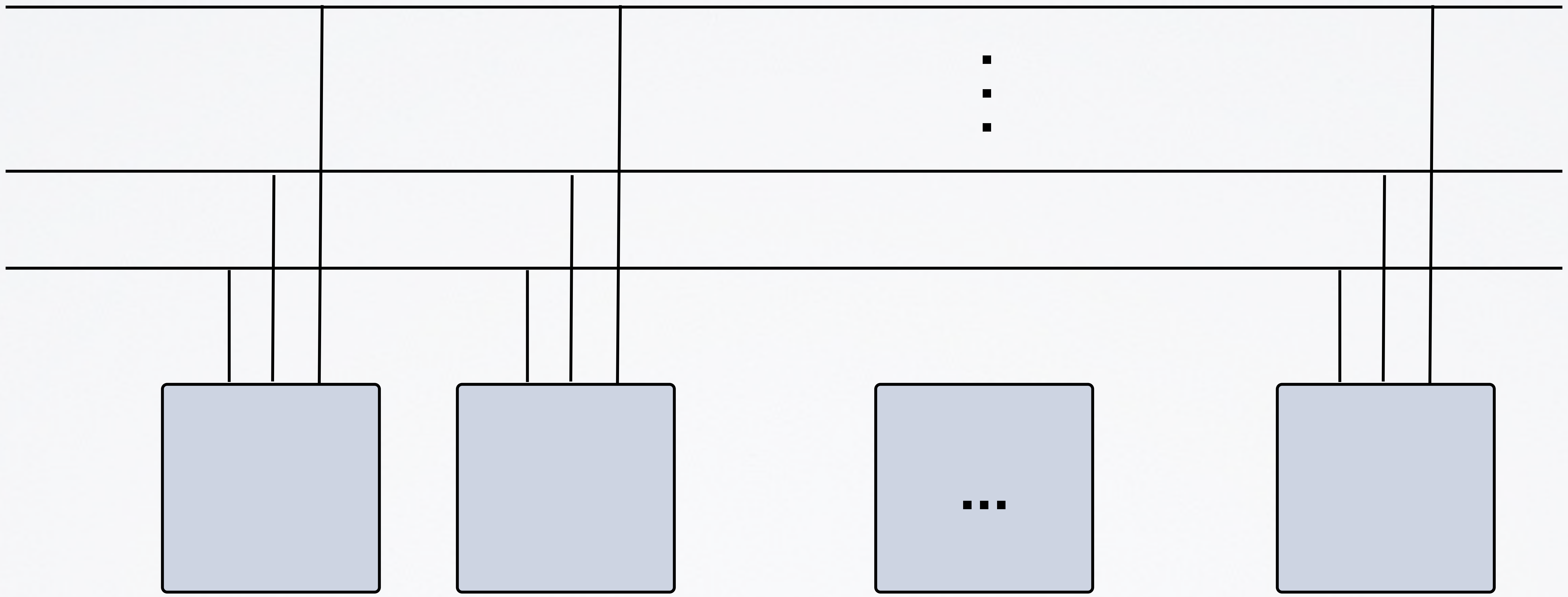
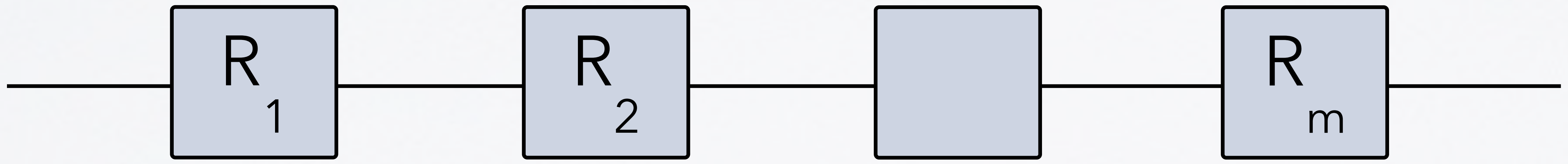
(Pfitzmann/Härtig 1982)



Q1/MODEL1: ABSTRACT RELIABILITY MODEL

Serial-Systems

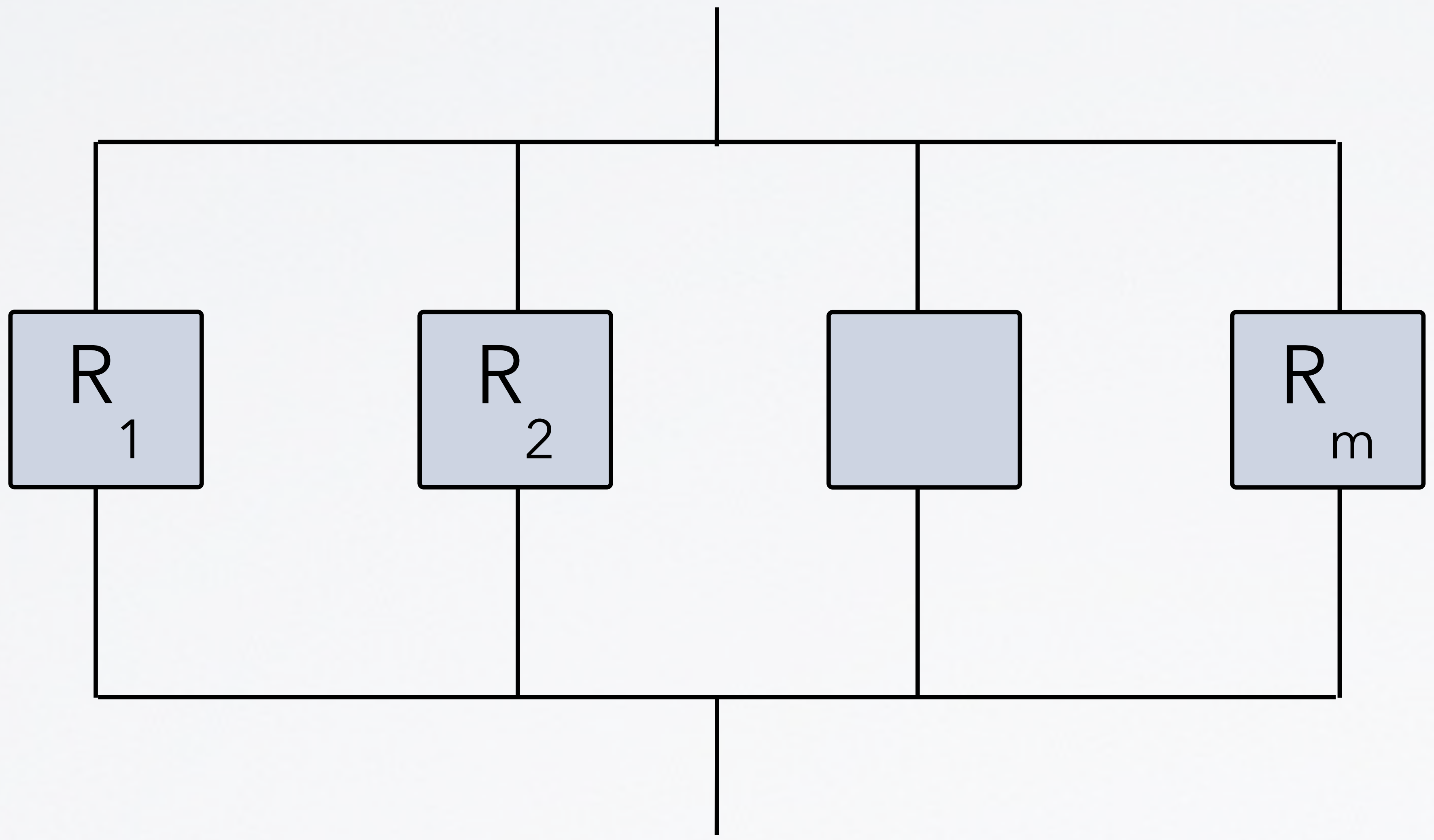


$$R_{whole} = \prod_{j=1}^{m} R_j$$

Each component must work for the whole system to work.

Q1/MODEL1: ABSTRACT MODEL

Parallel-Systems



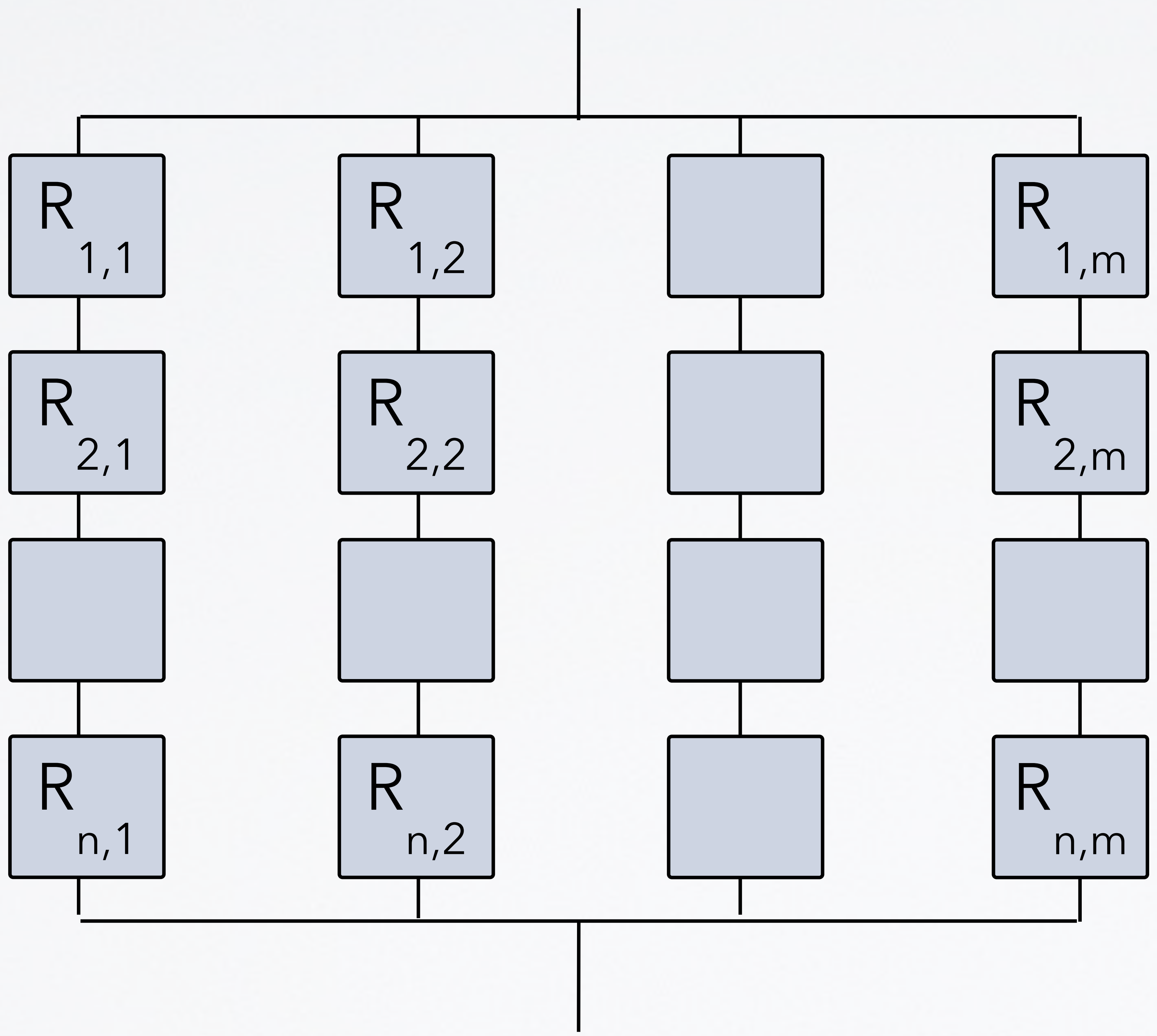
$$R_{whole} = 1 - \prod_{i=1}^{m} \left(1 - R_i\right)$$

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

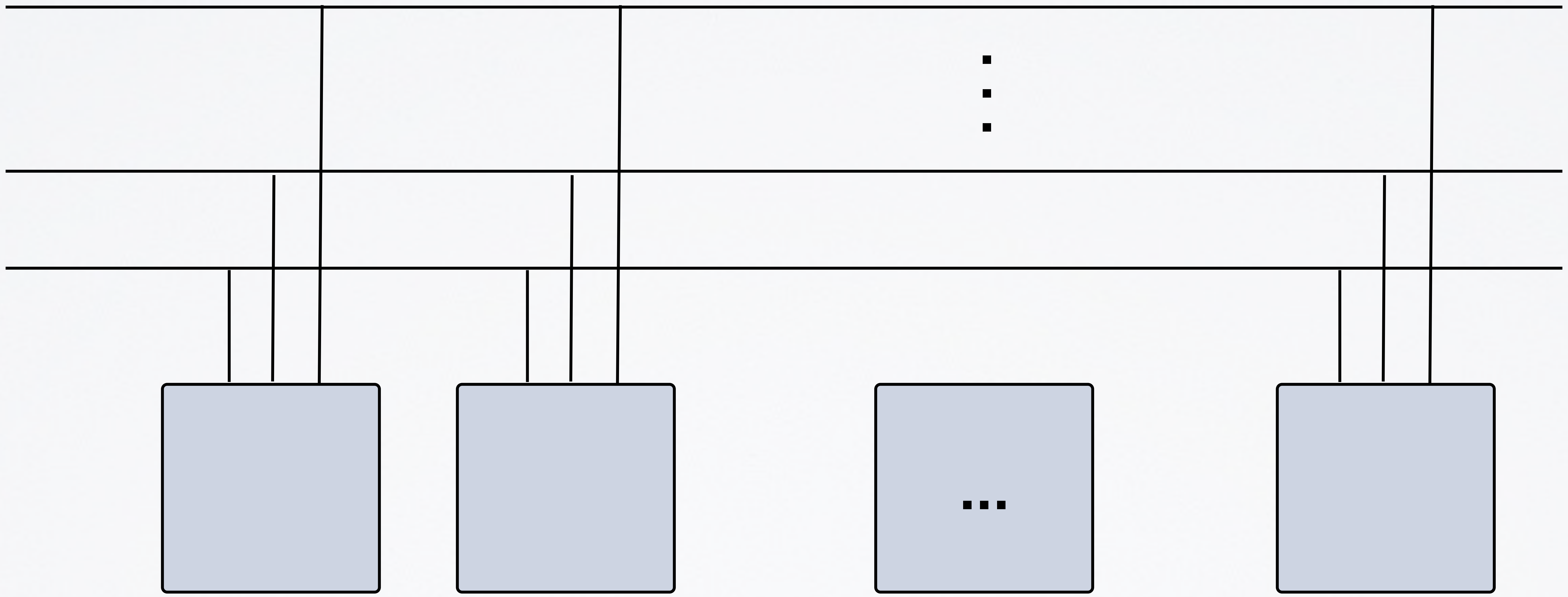


$$R_{whole} = 1 - \prod_{j=1}^{m} \left(1 - \prod_{i=1}^{n} R_{i,j} \right)$$

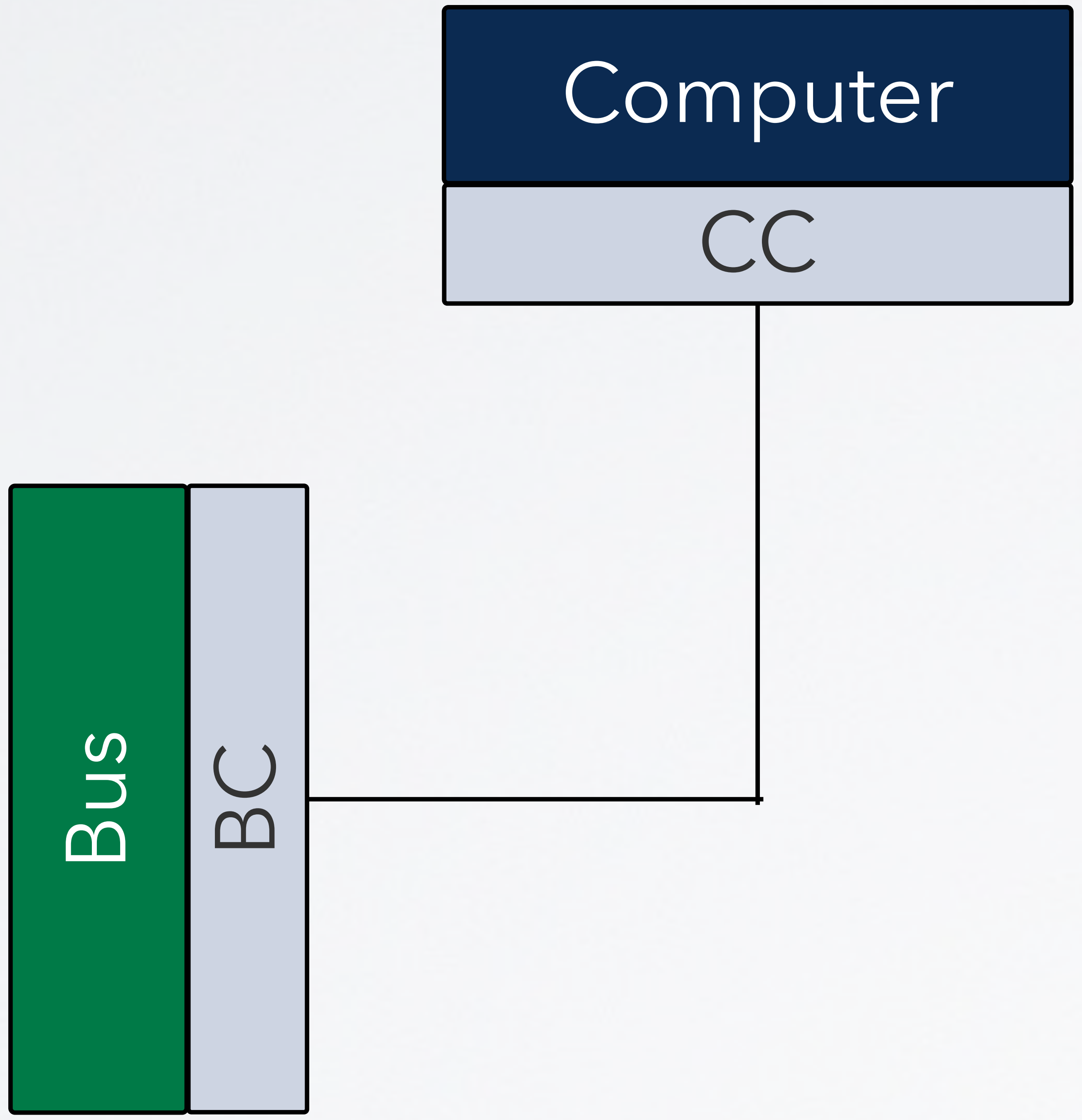
Q1/MODEL1: LIMITS OF RELIABILITY

Parallel-Serial-Systems

(Pfitzmann/Härtig 1982)



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

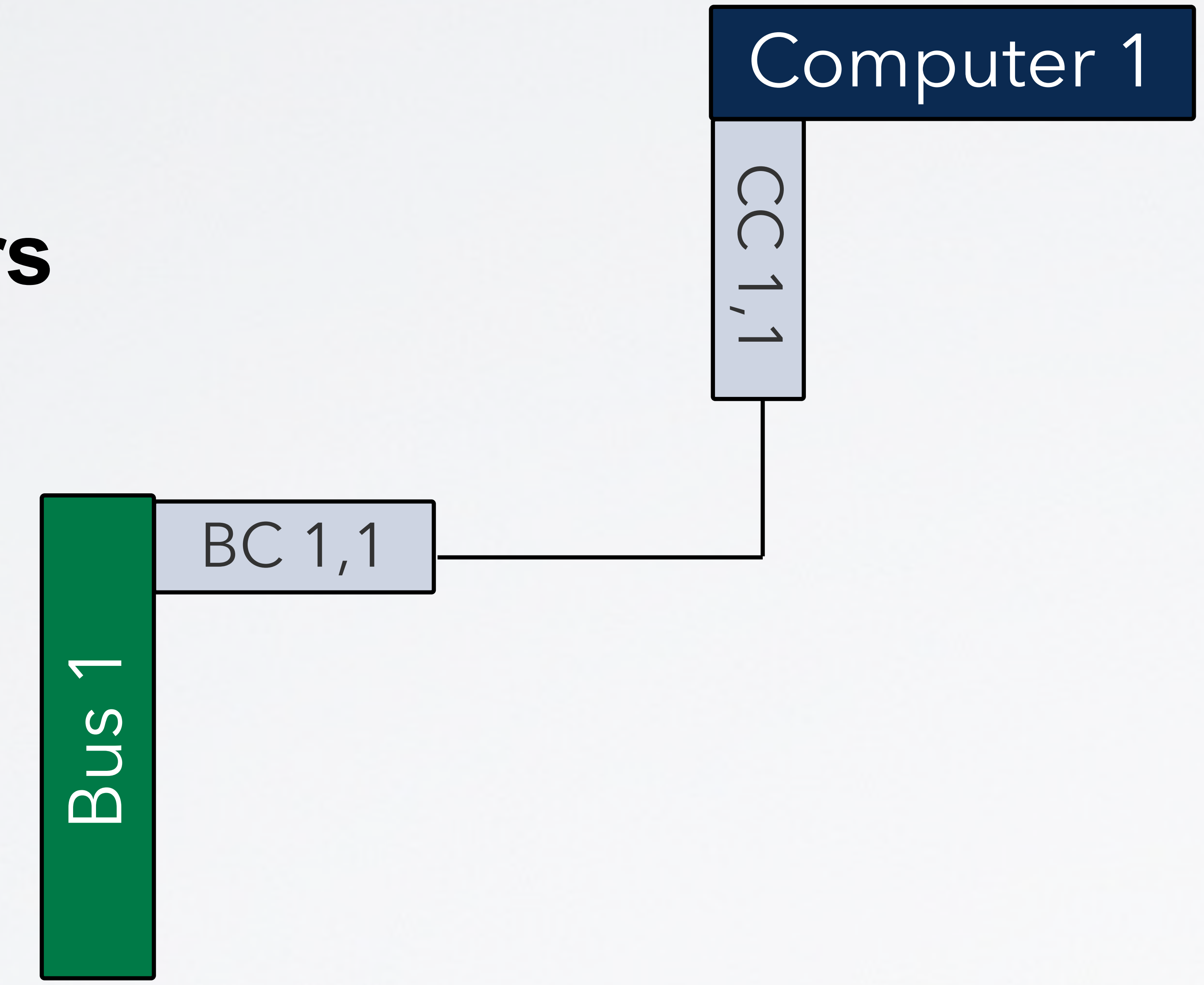
CC: Computer-Connector
fault also breaks the Computer

BC: Bus-Connector
fault also breaks Bus

Q1/MODEL1: CONCRETE MODEL

1 Buses

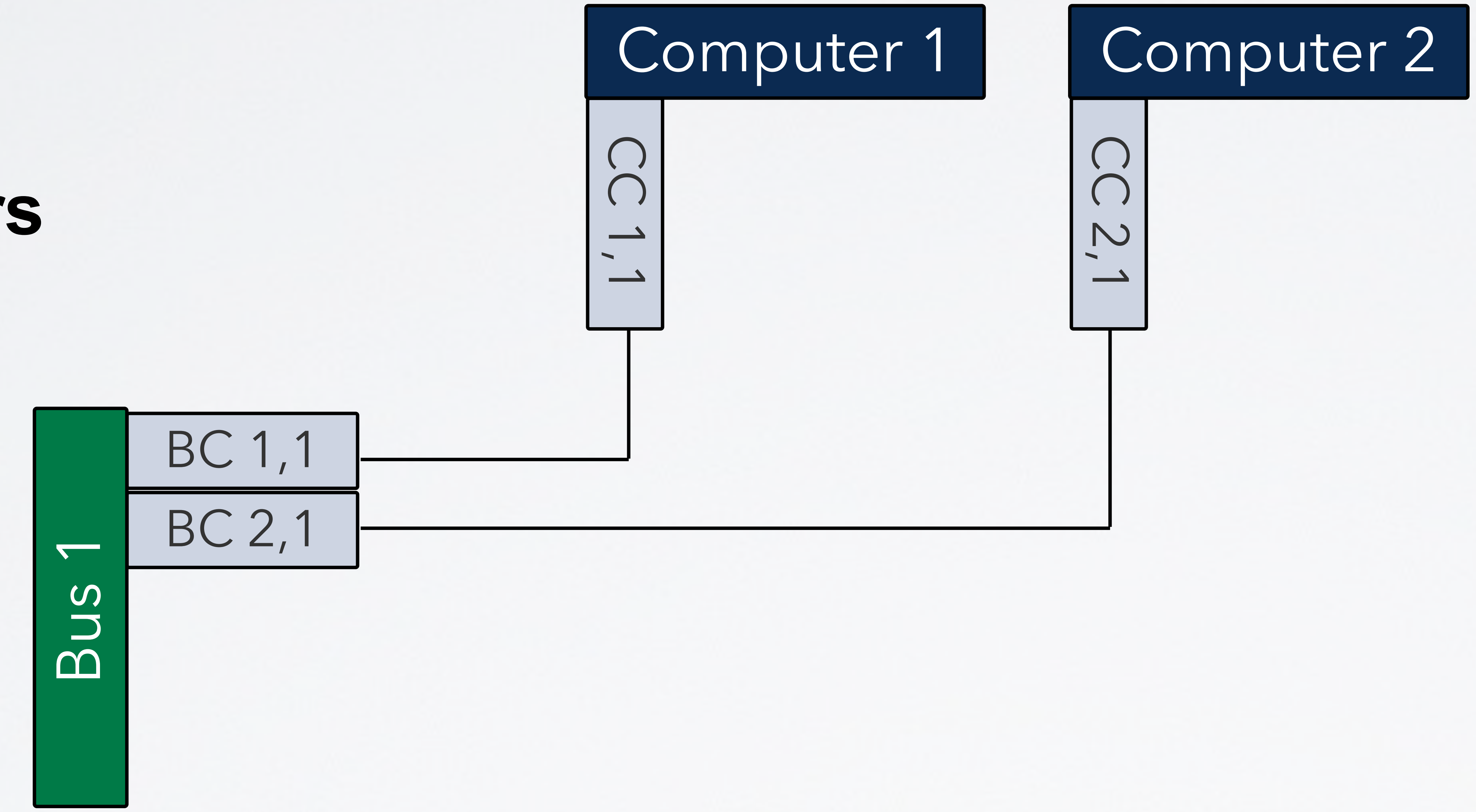
1 Computers



Q1/MODEL1: CONCRETE MODEL

1 Buses

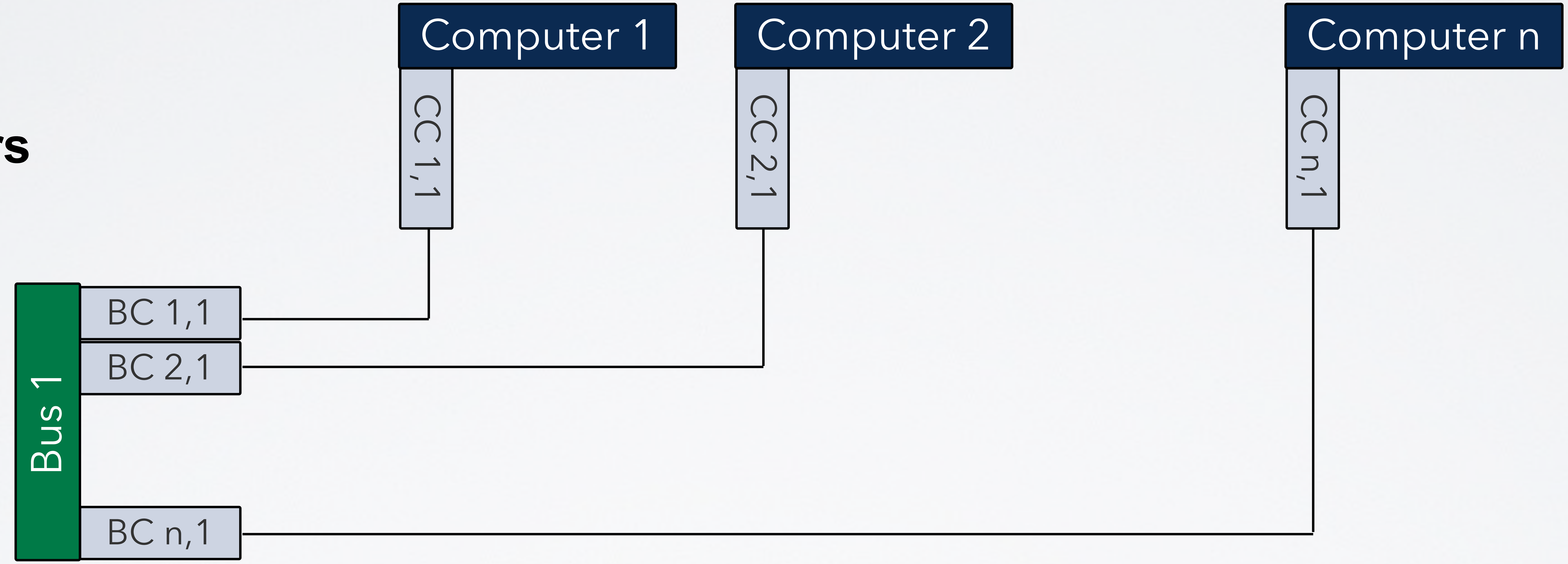
2 Computers



Q1/MODEL1: CONCRETE MODEL

1 Buses

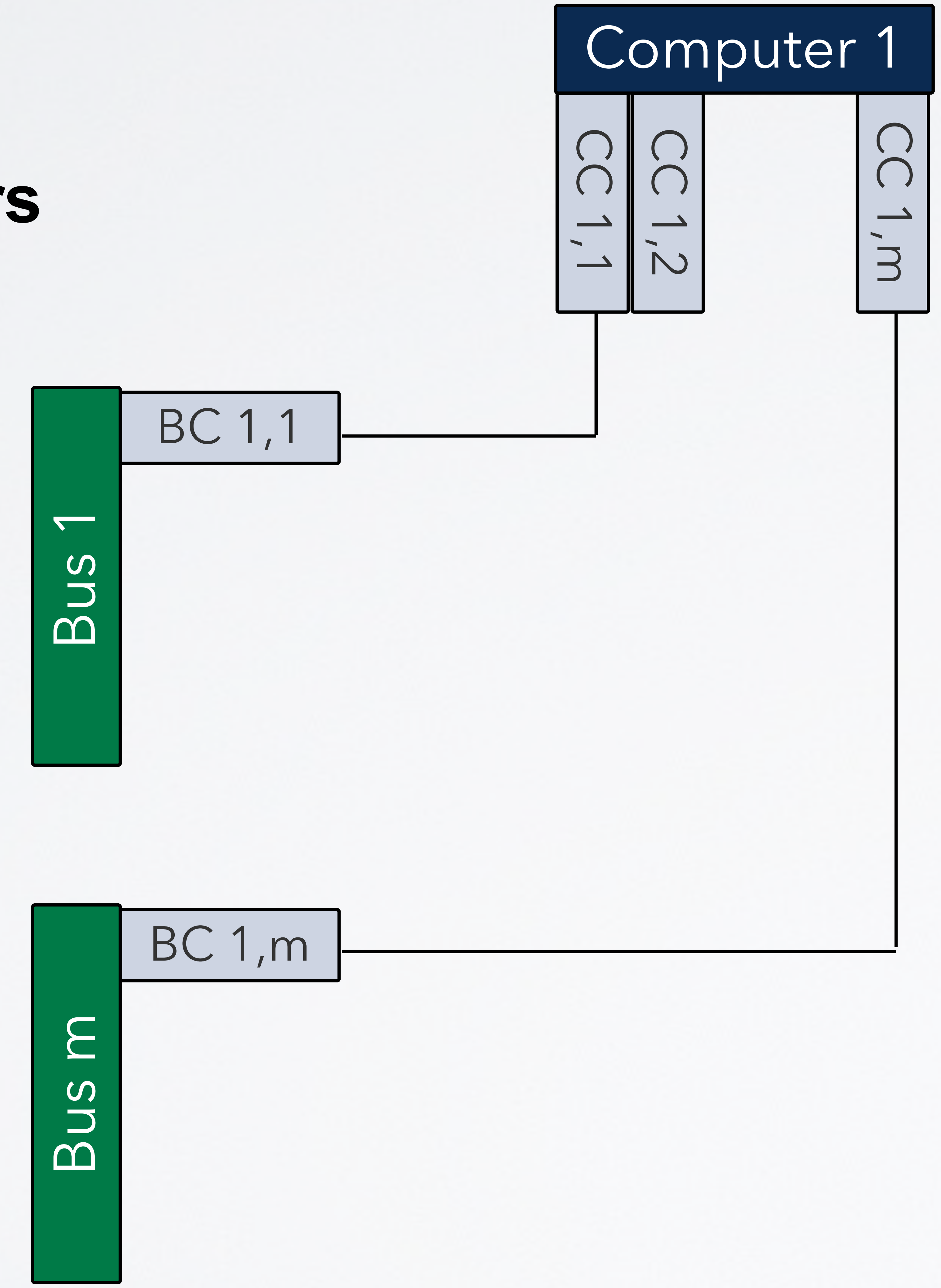
N Computers



Q1/MODEL1: CONCRETE MODEL

M Buses

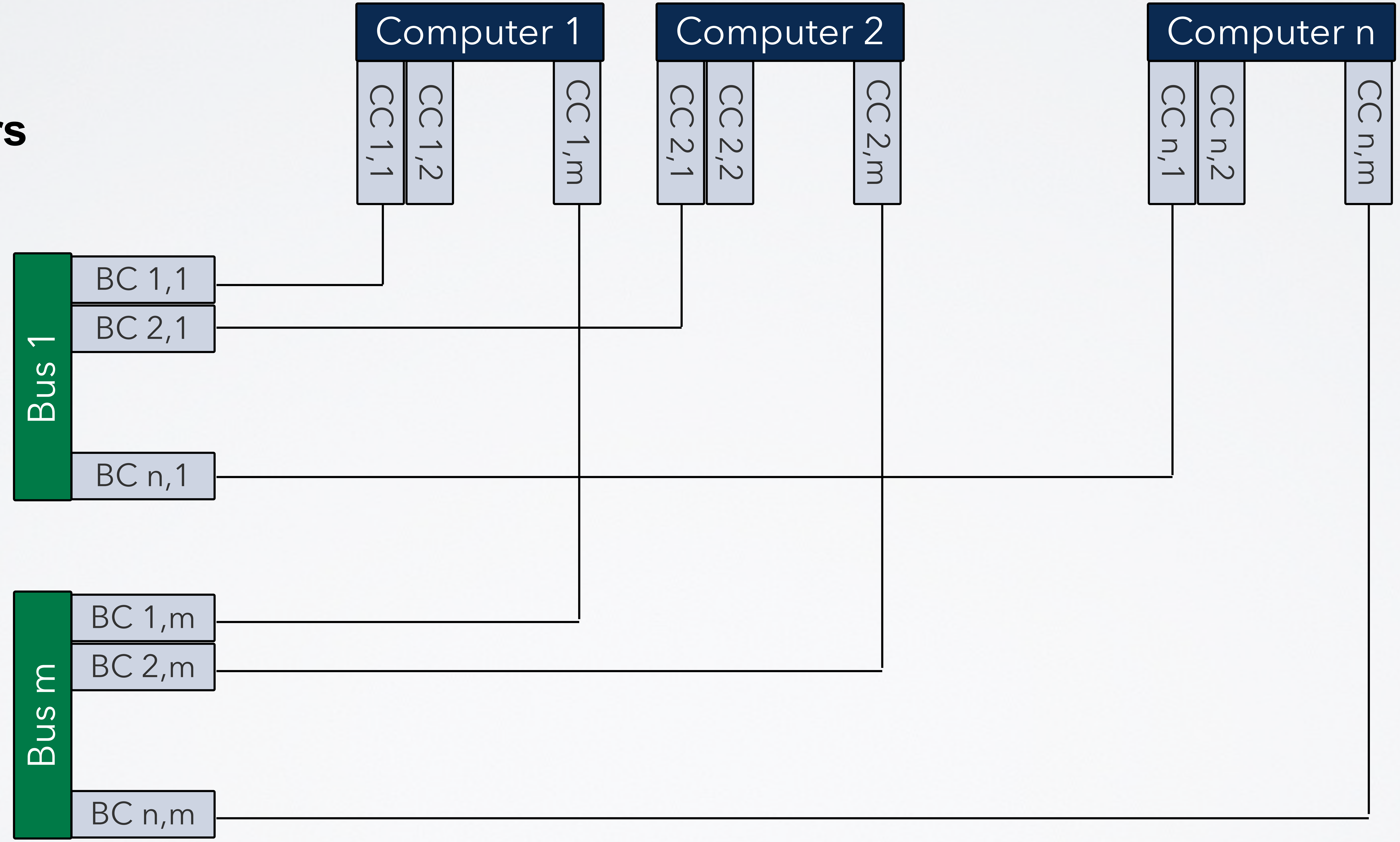
1 Computers



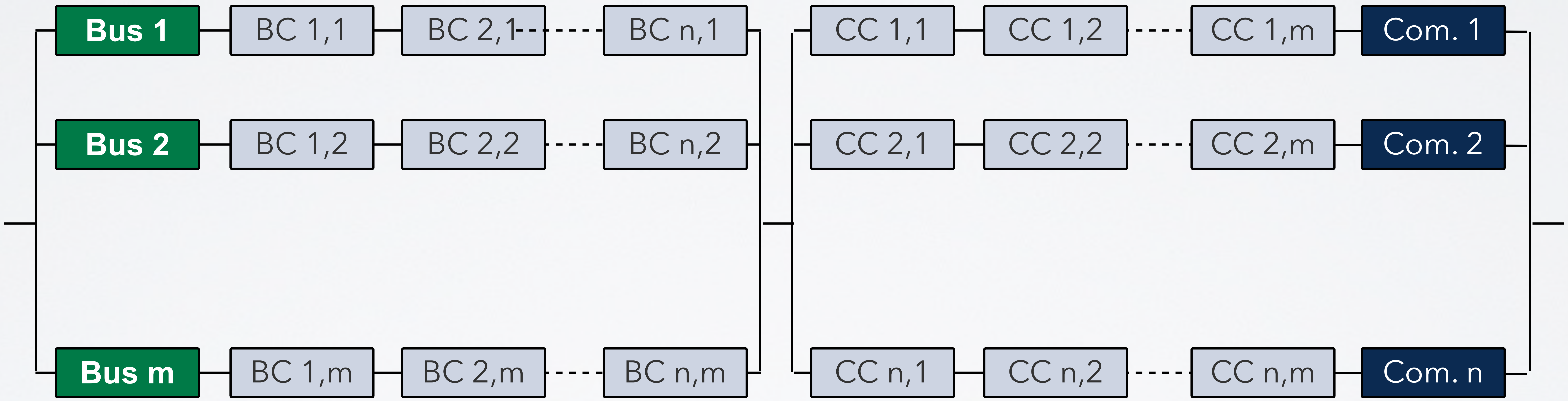
Q1/MODEL1: CONCRETE MODEL

M Buses

N Computers



Q1/MODEL1: CONCRETE MODEL FOR N,M



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

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

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

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2 Models per Question !

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

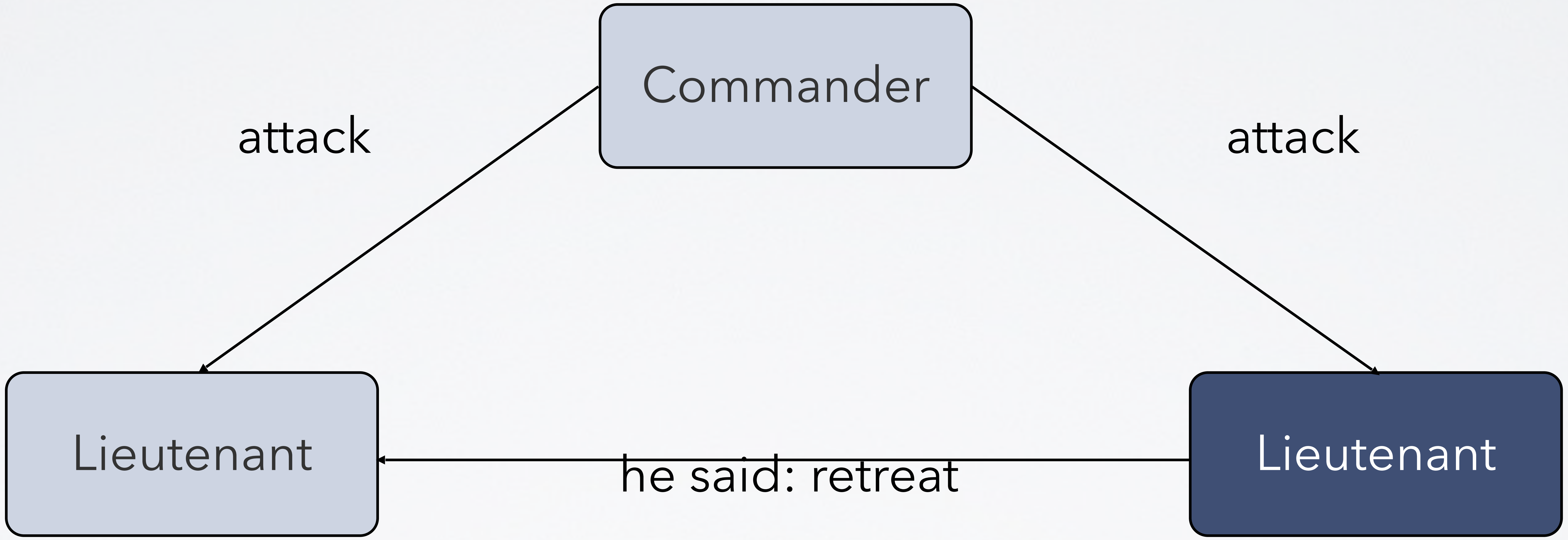
- communicate by reliable and timely messages (synchronous messages)
- traitors lye, also cheat on forwarding messages
- try to confuse loyals

Q2/MODEL 2: "BYZANTINE AGREEMENT"

Goal:

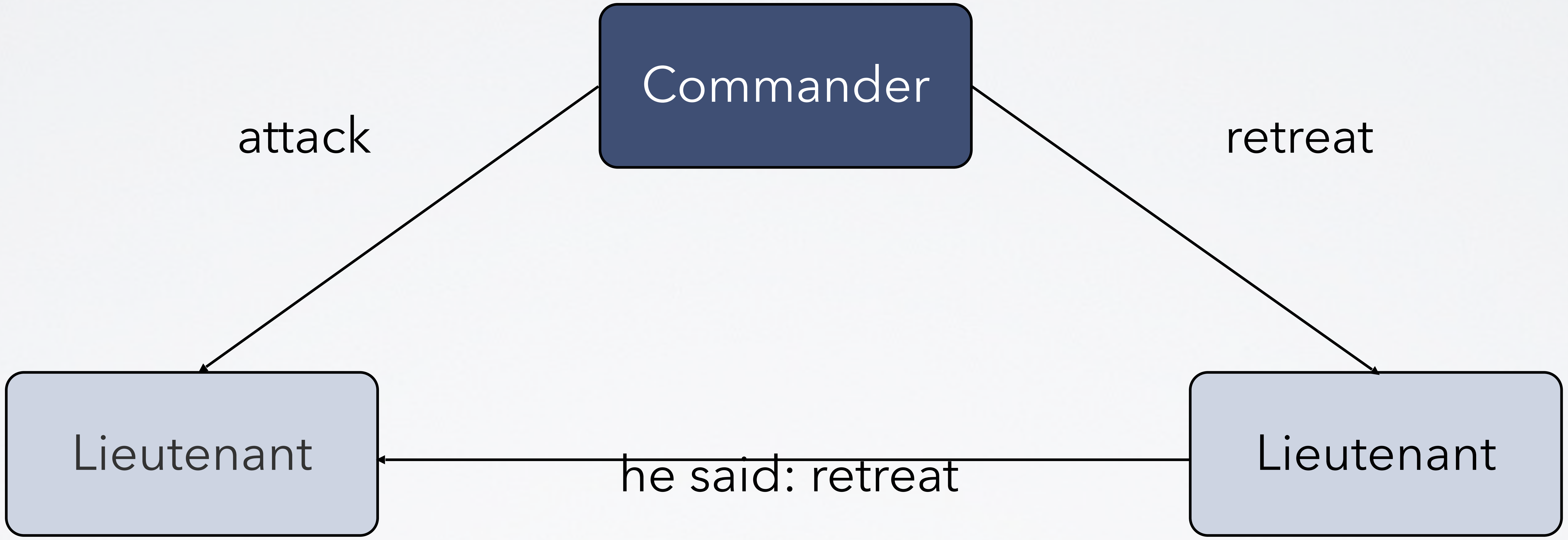
- loyals try to agree on non-trivial action (attack, retreat)
- non-trivial more specific:
  - one process is commander
  - if commander is loyal and gives an order, loyals follow the order otherwise loyals agree on arbitrary action

Q2/MODEL 2: "BYZANTINE AGREEMENT"



3 Processes: 1 traitor, 2 loyals

Q2/MODEL 2: "BYZANTINE AGREEMENT"

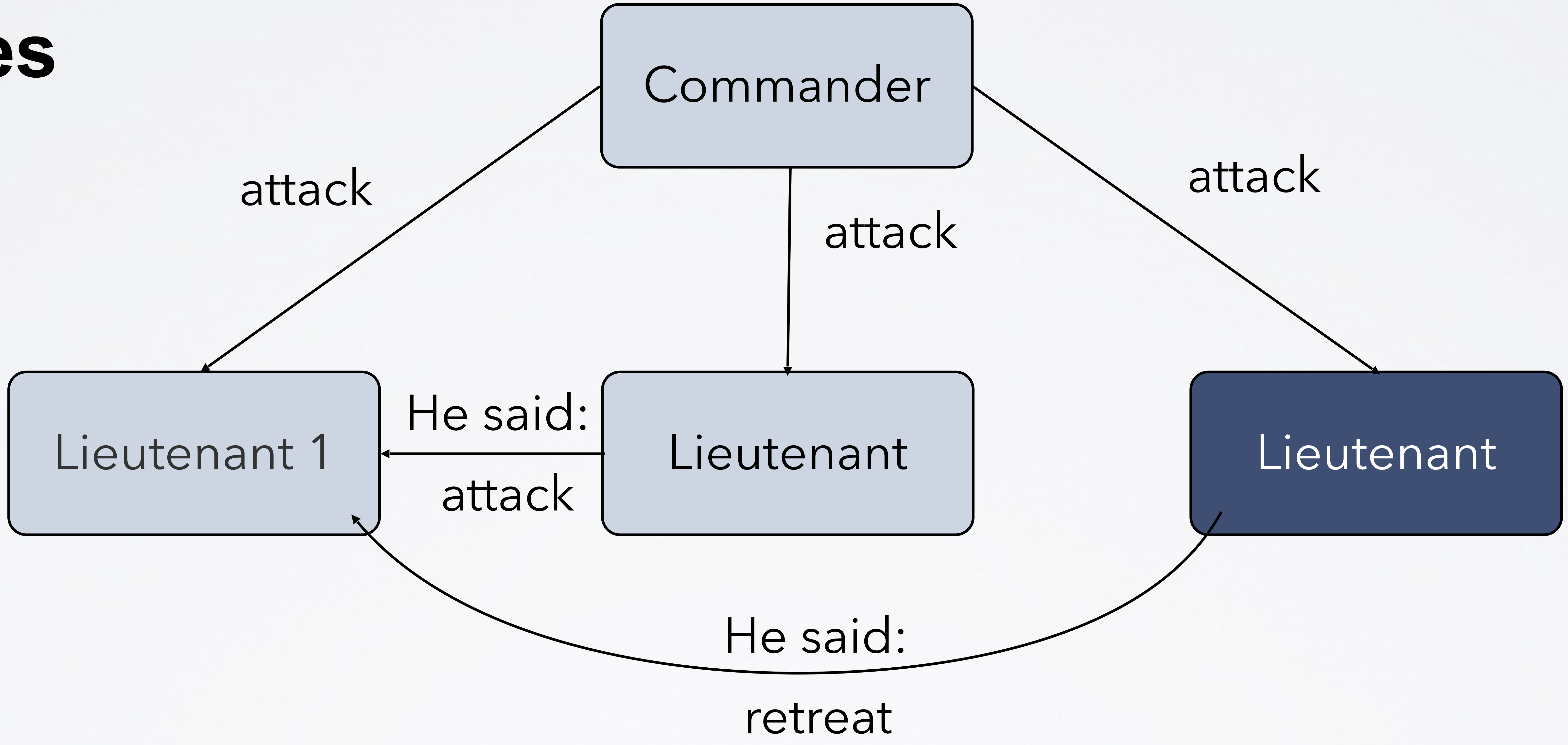


3 Processes: 1 traitor, 2 loyals

=> 3 processes not sufficient to tolerate 1 traitor

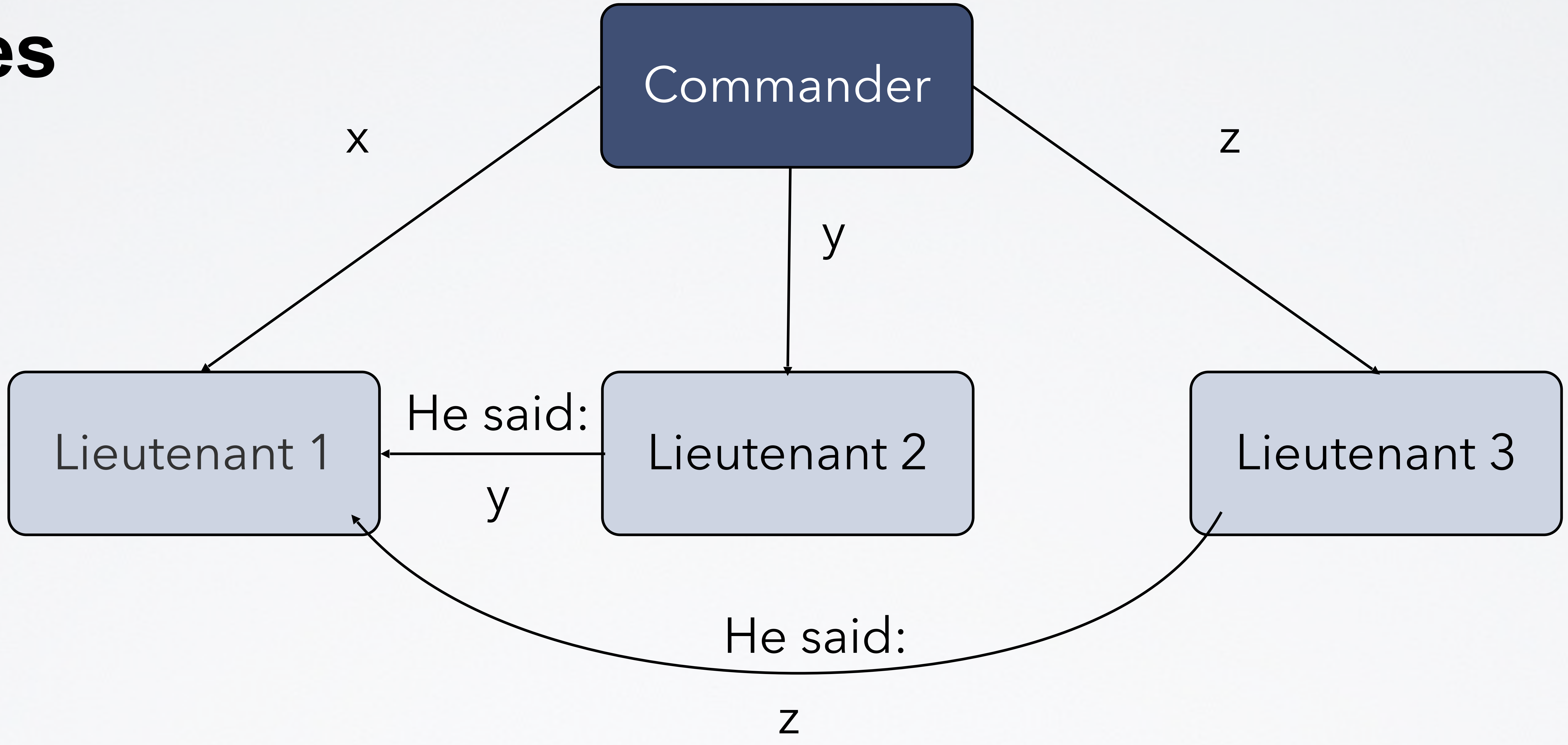
Q2/MODEL 2: "BYZANTINE AGREEMENT"

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

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2 Models per Question !

Q3: ACCESS CONTROL

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?

- given a system of entities, acting as subjects and objects subjects performs operations on objects
- dynamic: subjects and objects are created and deleted
- access control permissions between entities can be changed according to some rules

THE GENERAL IDEA

higher level models:

- Bell La Padula,

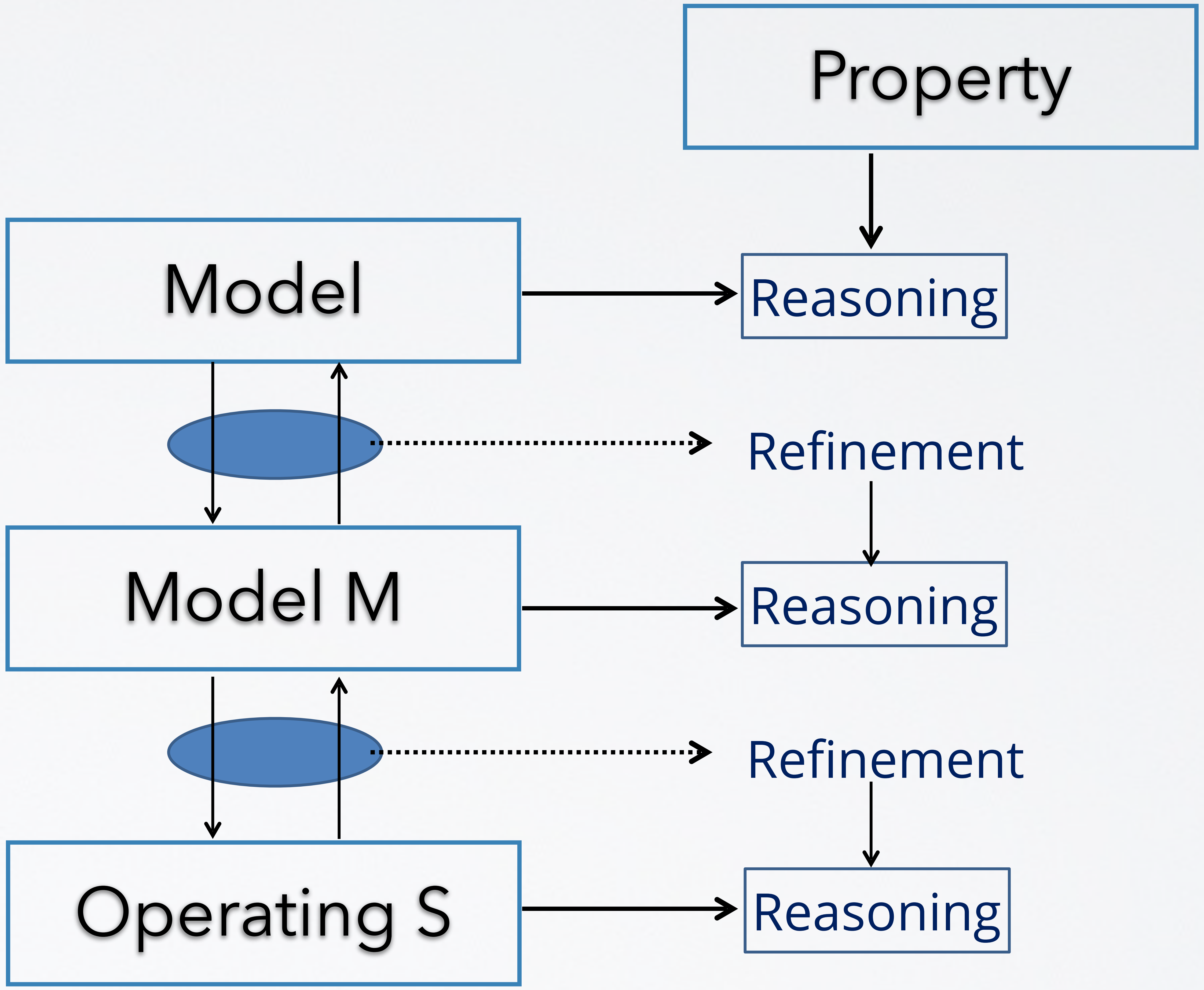
- Chinese wall

...

access control:

1) ACM-based operations

2) take grant



MECHANISMS: ACCESS CONTROL MATRIX

Subjects: S

Objects: O

Entities: E = S ∪ O

Rights: {read, write, own,…}

Matrix: S x E x R

	O1	O2	S1	S2	S3
S1	r,w,own	r,w	r,w,own	–-	r,w
S2	r,w	r,w,own	–	r,w,own	r
S3	r,w	r	w	–-	r,w,own

Simple ACM Operations:

enter / delete R into cell (s,o)

create subject / object

destroy subject / object

ref MB: chapter 2.2

OS MECHANISMS: ACL & CAPS

ACM

- Access Control List (ACL)

	O1	O2	S1	S2	S3
S1	r,w,own	r,w	r,w,own	–-	r,w
S2	r,w	r,w,own	–	r,w,own	r
S3	r,w	r	w	–-	r,w,own

- Capabilities

	O1	O2	S1	S2	S3
S1	r,w,own	r,w	r,w,own	–-	r,w
S2	r,w	r,w,own	–	r,w,own	r
S3	r,w	r	w	–-	r,w,own

ref MB: chapter 2.2

Q3/MODEL 1: ACL & "LEAKAGE"

- Define Protection Mechanisms of an Operating System in terms of sequences of simple ACM operations
- only such defined mechanism provided by the OS can used to manipulate ACM

ref MB: chapter 2.2

Q3/MODEL 1: ACL & "LEAKAGE"

- "Leakage":
  an access right is placed into S/O that has not been there before
  it does not matter whether or not that is allowed
- Is leakage decidable ?

ref MB: chapter 3

Q3/MODEL 1: ACL & "LEAKAGE"

Define OS-Mechanisms by simple ACM-Operations:

example:

UNIX create file (S1,F)

- create object
- enter own into A(S1,F)
- enter read into A(S1,F)
- enter write into A(S1,F)

	O1	O2	S1	S2	F
S1	r,w,own	r,w	r,w,own	–-	r,w, own
S2	r,w	r,w,own	–	r,w,own	–
S3	r,w	r	w	–-	–

ref MB: chapter 2.2

Q3/MODEL 1: ACL & "LEAKAGE"

Example:

UNIX chmod -w (S2,F)

if own ∊ A(caller,F)

then delete w in A(S2,F)

	O1	O2	S1	S2	F
S1	r,w,own	r,w	r,w,own	–-	r,w, own
S2	r,w	r,w,own	–	r,w,own	r,-
S3	r,w	r	w	–-	–

Q3:

Given an OS with a ACM-based description of protection mechanisms is "Leakage" decidable for any R in A(x,y) ?

ref MB: chapter 2.2

Q3/MODEL 1: DECIDABILITY OF LEAKAGE

Decidable

- no subjects/objects can be created

or
- only **one** primitive ACM operation per OS-Mechanism

by exhaustive search !

Q3 in general:

- undecidable (proof: reduction to Turing machine)

ref MB: chapter 3

OS MECHANISMS: ACL & CAPS

ACM

- Access Control List (ACL)

	O1	O2	S1	S2	S3
S1	r,w,own	r,w	r,w,own	--	r,w
S2	r,w	r,w,own	–	r,w,own	r
S3	r,w	r	w	--	r,w,own

- Capabilities

	O1	O2	S1	S2	S3
S1	r,w,own	r,w	r,w,own	--	r,w
S2	r,w	r,w,own	–	r,w,own	r
S3	r,w	r	w	--	r,w,own

ref MB: chapter 2.2

Q3/MODEL 2: "TAKE GRANT"

<u>Directed Graph:</u>

Subjects: ●

Objects: ○

Either S or O: ⊗

x has capability on Y
with set of rights **α** on y:

$x \xrightarrow{\alpha} y$

t <u>take right</u>

x has cap with set of rights
τ that includes t

$x \xrightarrow{\mathbf{t}} y$

g <u>grant right</u>

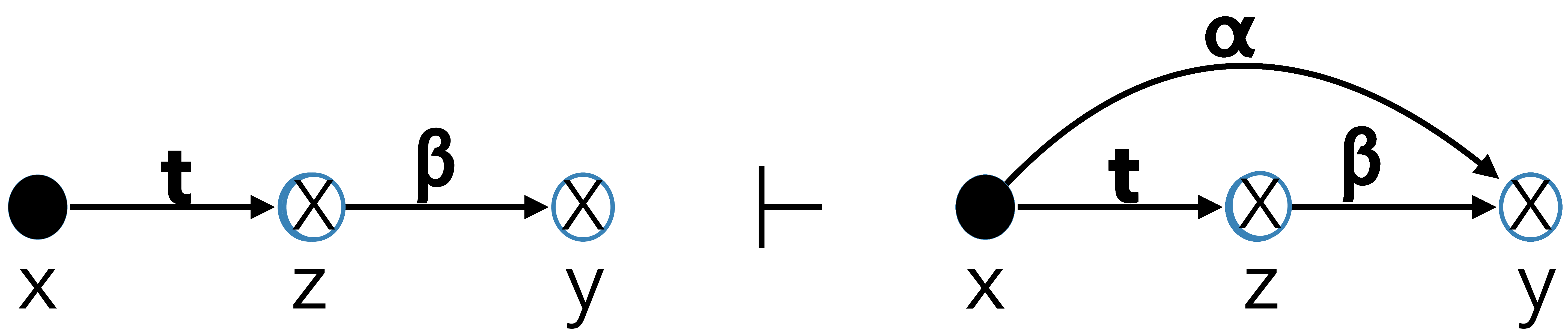
x has cap with set of rights
γ that includes **g**

$x \xrightarrow{\mathbf{g}} y$

Q3/ 2: TAKE GRANT RULES

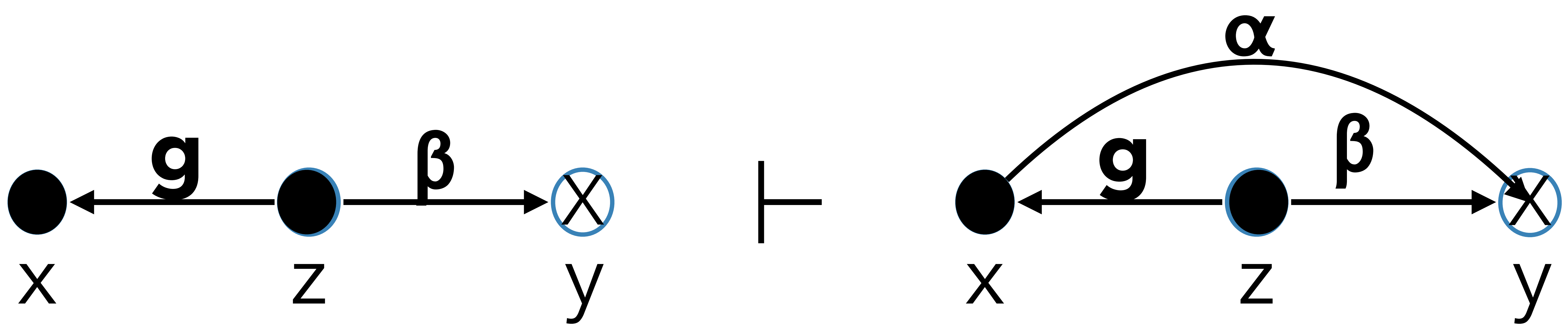
Rules:

take rule ($\alpha \subseteq \beta$)



a takes (α to y) from z

grant rule ($\alpha \subseteq \beta$)

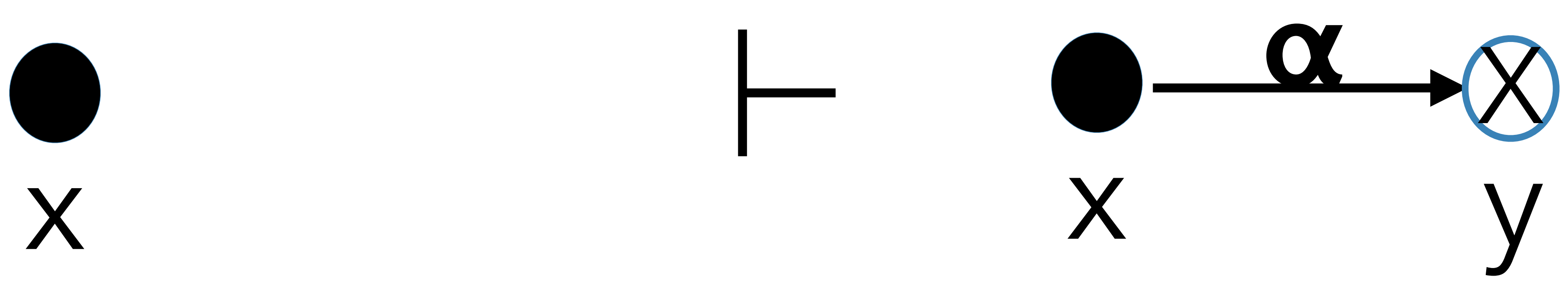


ref MB: chapter 3.3

Q3/ 2: TAKE GRANT RULES

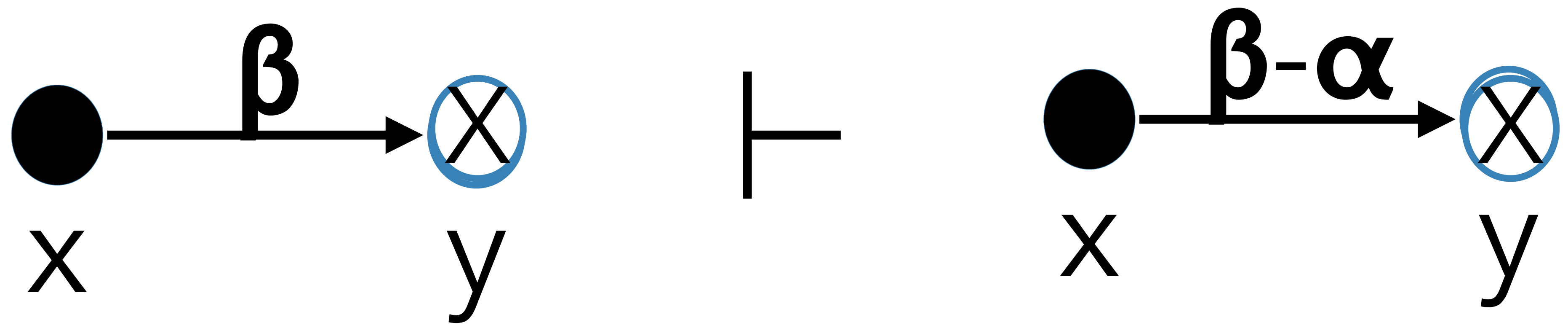
Rules:

create rule



x create (α to new vertex) y

remove rule



x removes (α to) y

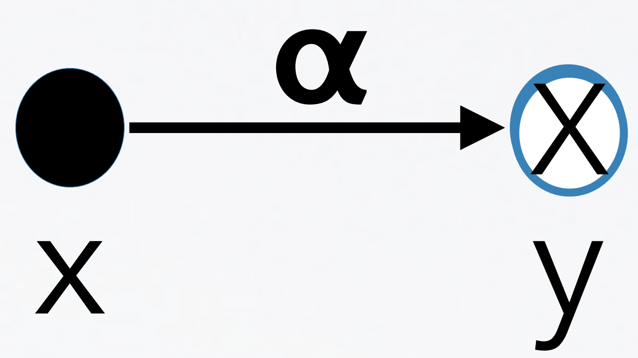
ref MB: chapter 3.3

Q3/M2: FORMALIZED

<u>CanShare(α, x, y, G_0):</u>

there exists a sequence of G_0 ... G_n with $G_0 \vdash^* G_n$

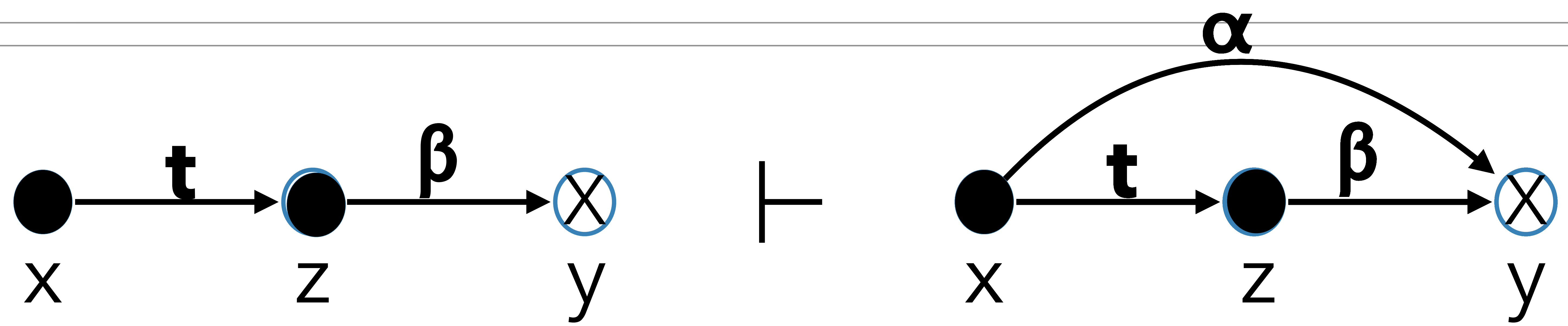
and there is an edge in G_n:



ref MB: chapter 3.3

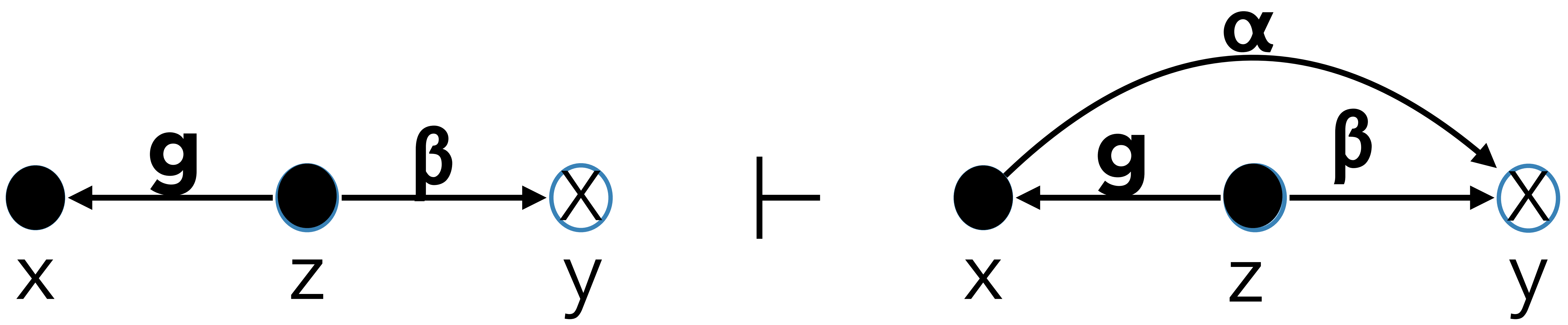
Q3/ 2: CAREFUL: LEMMA

take rule (α⊆β)



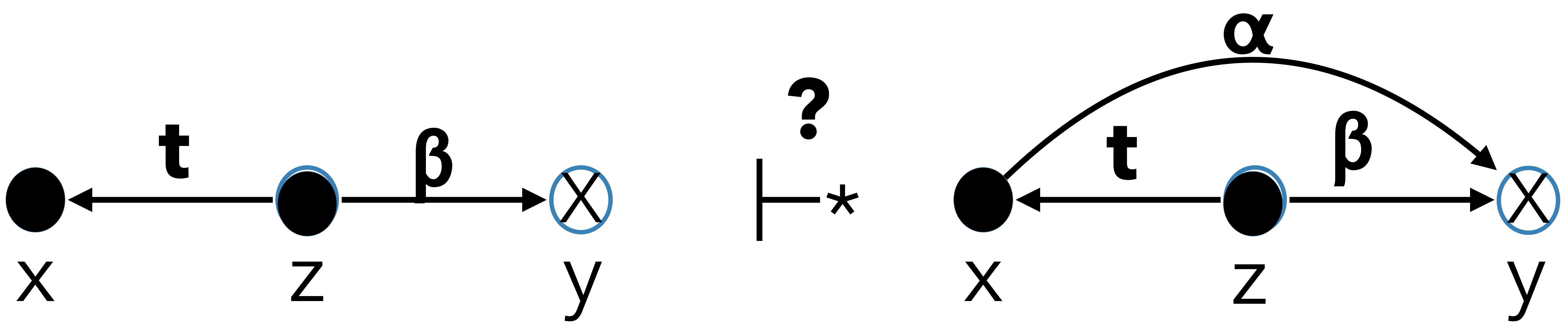
a takes (α to y) from z

grant rule (α⊆β)



z grants (α to y) to

Question:

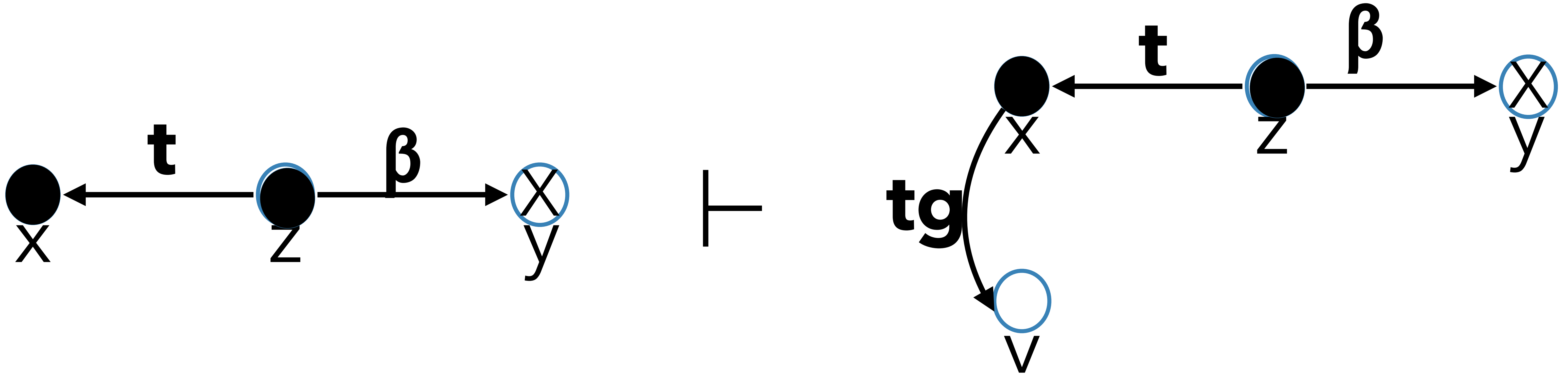


ref MB: chapter 3.3

Q3/ 2: CAREFUL: LEMMA

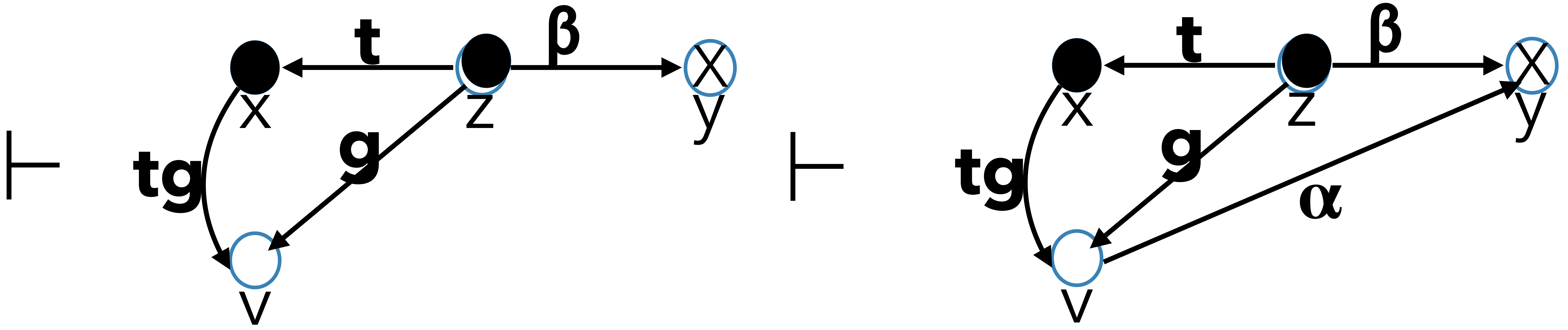
($\alpha \subseteq \beta$)

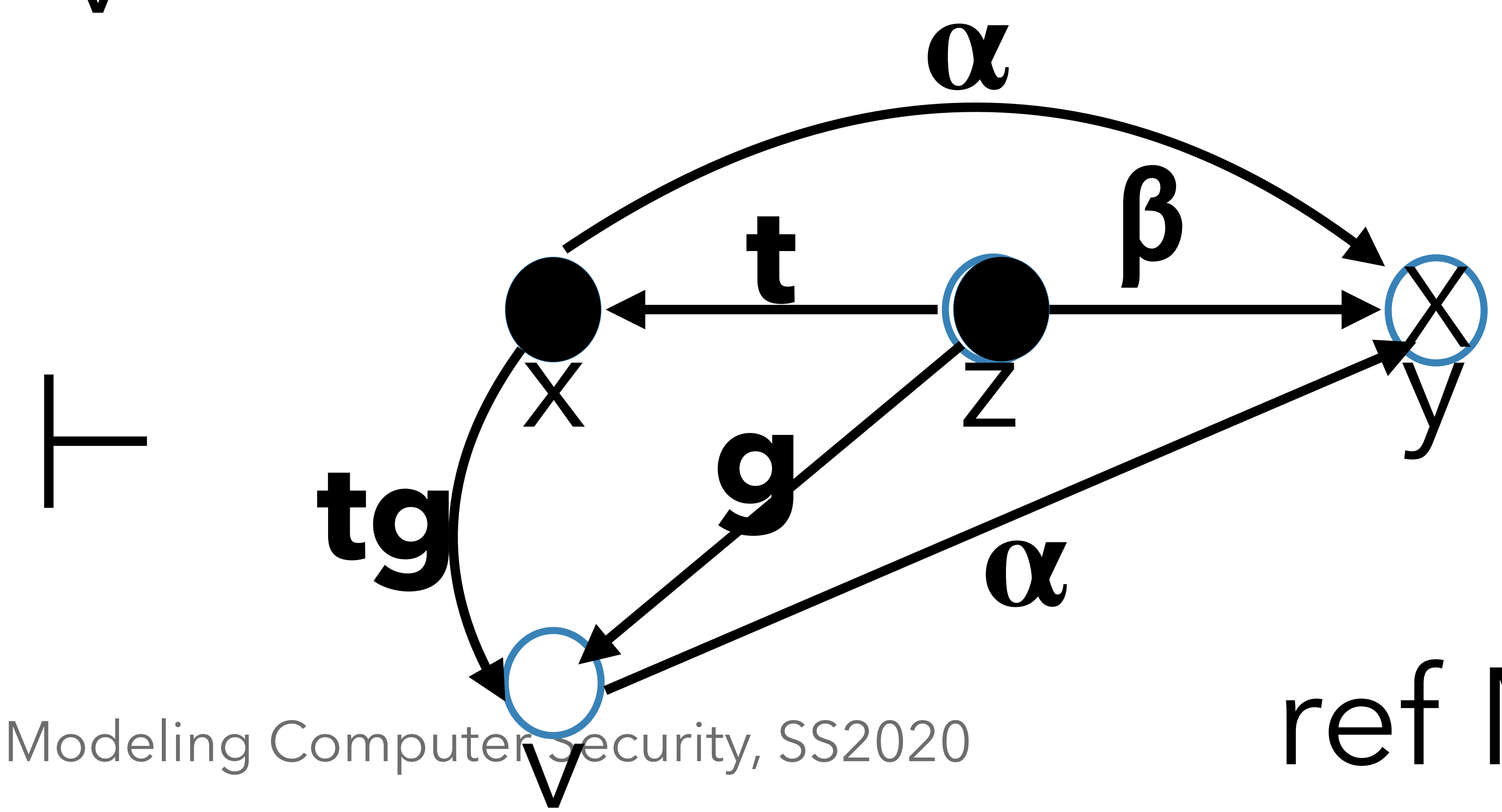
create rule



z takes (g to v) from x

z grants (α to y) to v





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there exists a sequence of G_0 … G_n with $G_0 \vdash^* G_n$

and there is an edge: $x \xrightarrow{\alpha} y$

CanShare decidable in linear time !

ref MB: chapter 3.3

TAKE AWAY

- three questions, 2 models per question, different answers !!!
- modeling is powerful
- need to look extremely carefully into understanding models !!!

TECHNISCHE UNIVERSITÄT DRESDEN

REFERENCES

- Q1/M1:

  Pfitzmann A., Härtig H. (1982) Grenzwerte der Zuverlässigkeit von Parallel-Serien-Systemen. In: Nett E., Schwärtzel H. (eds) Fehlertolerierende Rechnersysteme. Informatik-

  Fachberichte, vol 54. Springer, Berlin, Heidelberg (in German only)

  Q1/M2:

  John v. Neuman, PROBABILISTIC LOGICS AND THE SYNTHESIS OF RELIABLE. ORGANISMS FROM UNRELIABLE COMPONENTS.

- Q2: most textbooks on distributed systems
- Q3: textbook: Matt Bishop, Computer Security, Art and Science, Addison Wesley 2002