Today

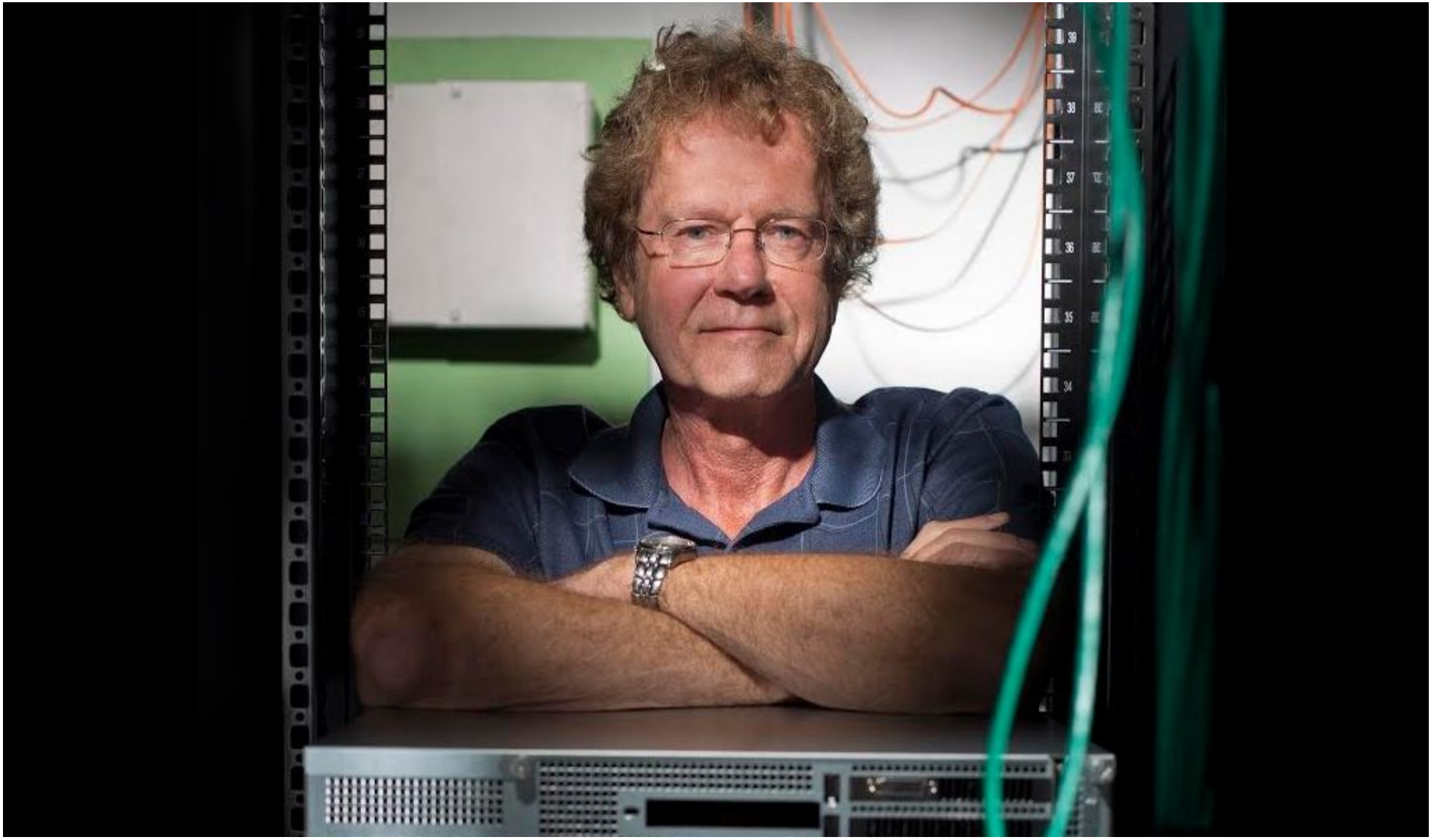
Mon: Midterm in class

Distributed systems

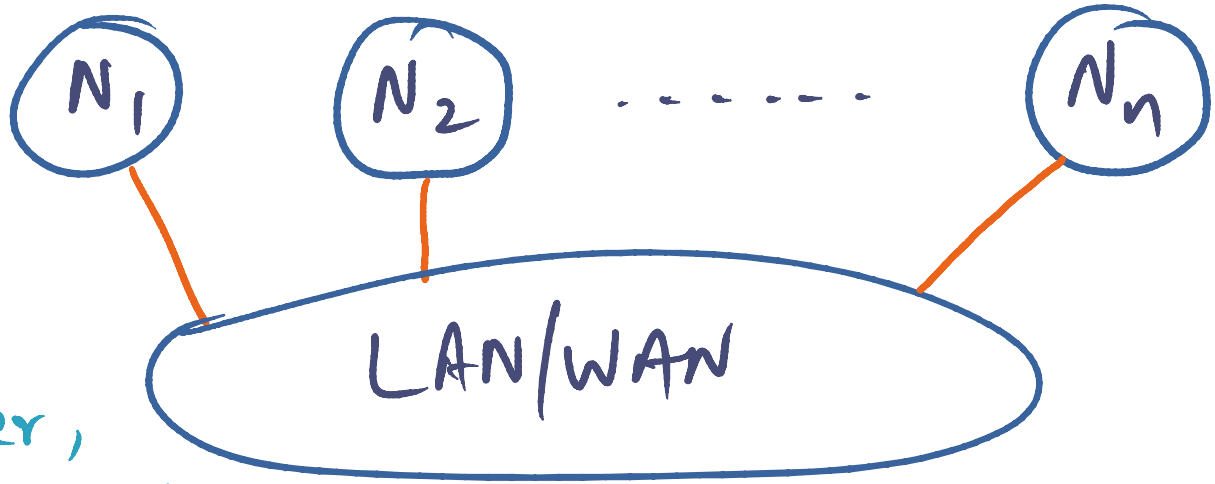
* Basics
* Lamport clock
  - Logical
* Example of using Logical clock
  - Distr. M.E.
* physical clock

Friday

* Townhall

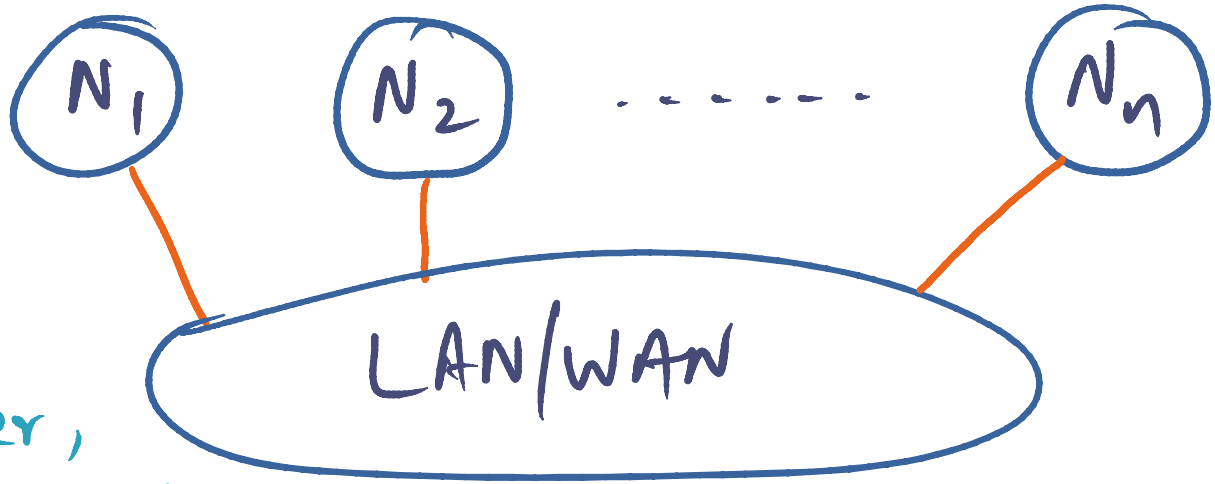


Distributed Systems Definition



Fiber, coaxle, Satellite

Distributed Systems Definition



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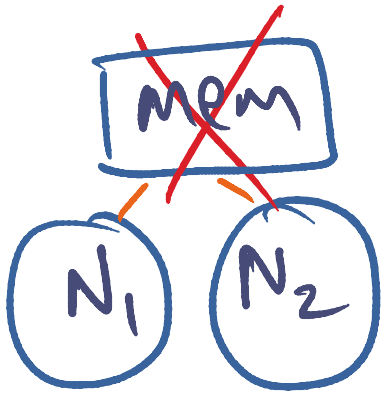
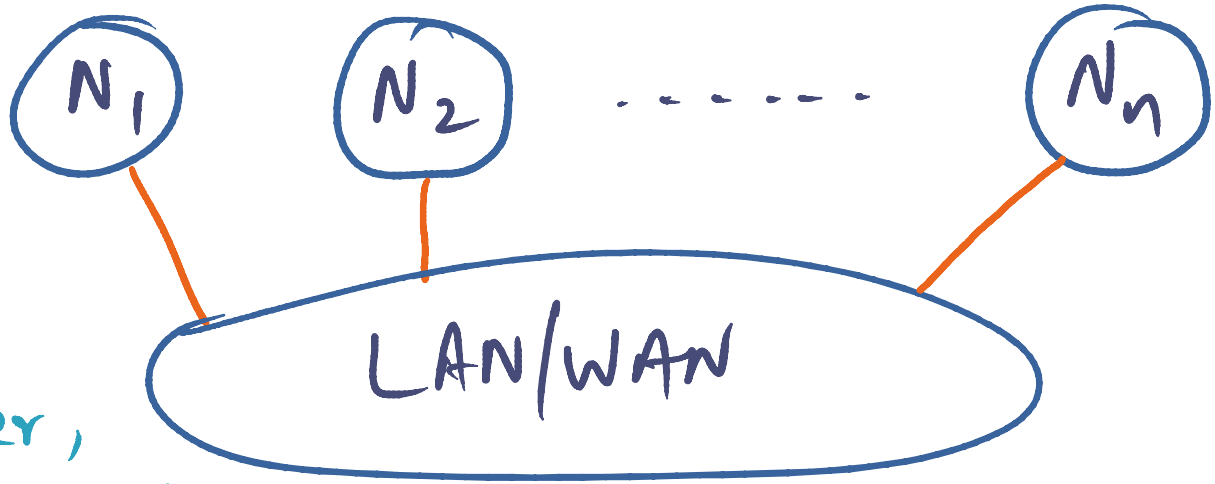


No physical shared memory between nodes

Distributed Systems Definition



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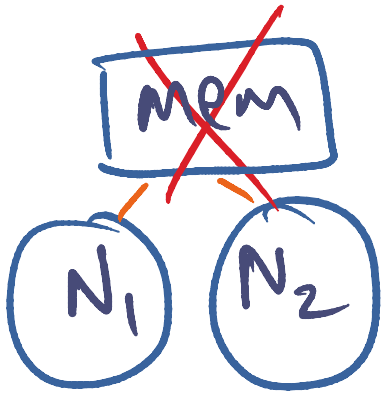

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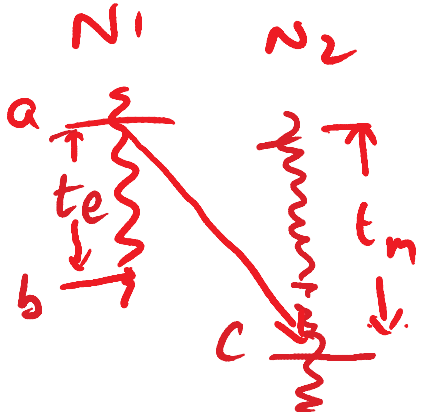
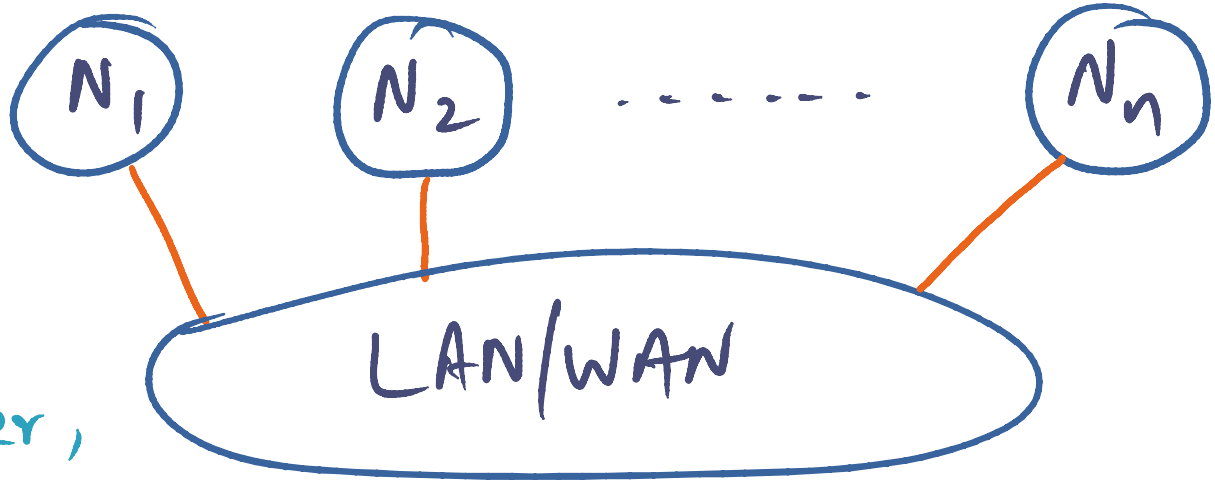
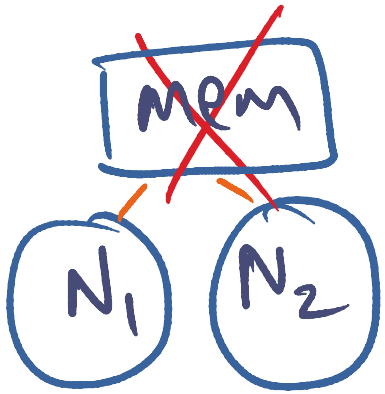


$t_m^{a-c} >> t_e^{a-b}$

Distributed Systems Definition



Fiber, coaxle, Satellite



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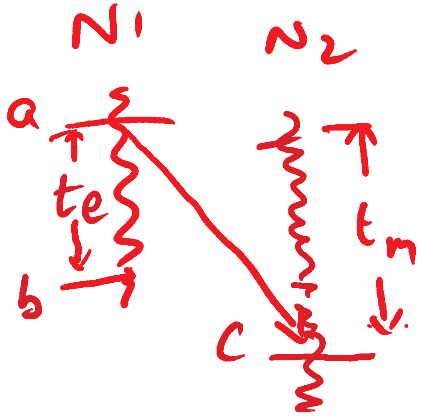
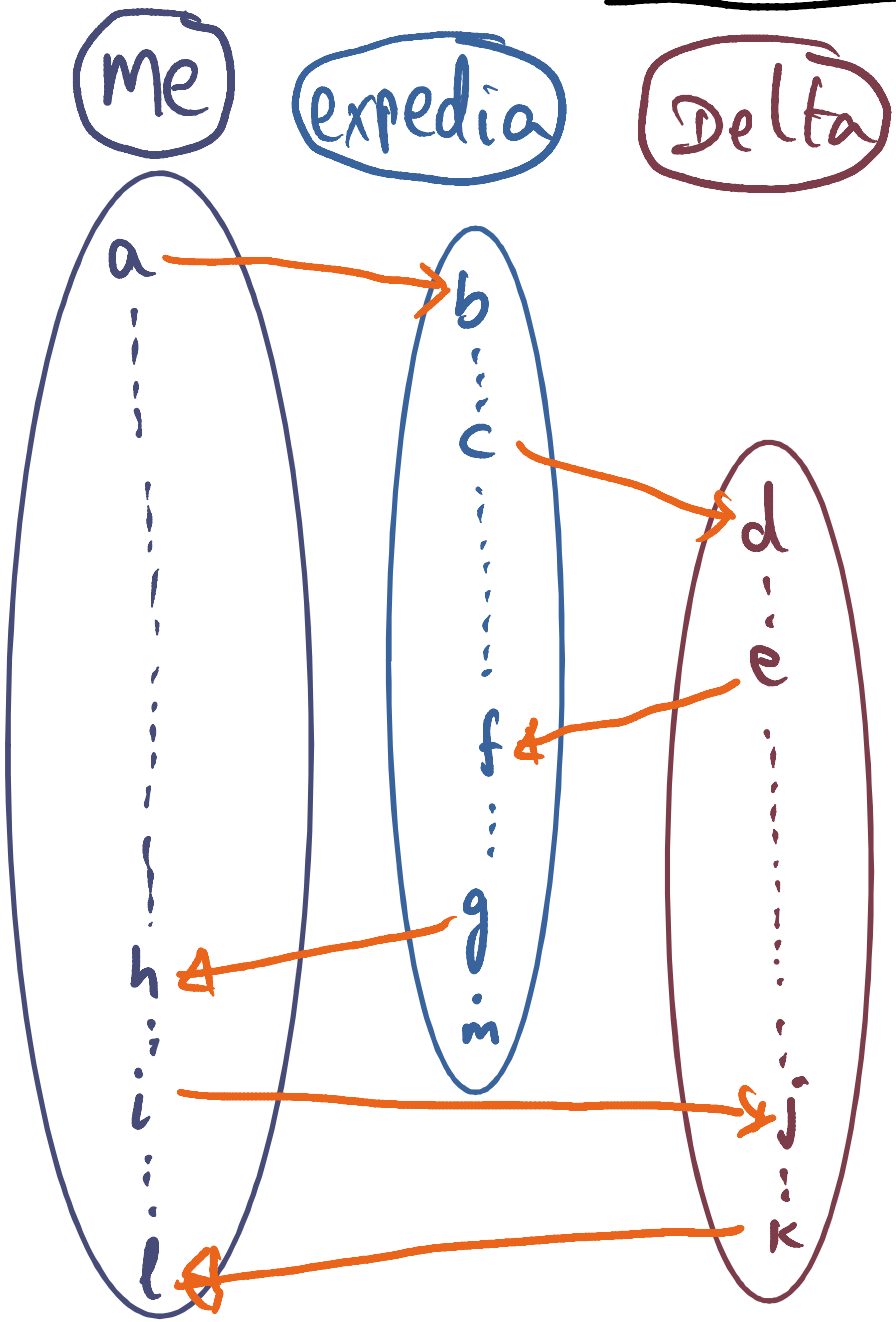


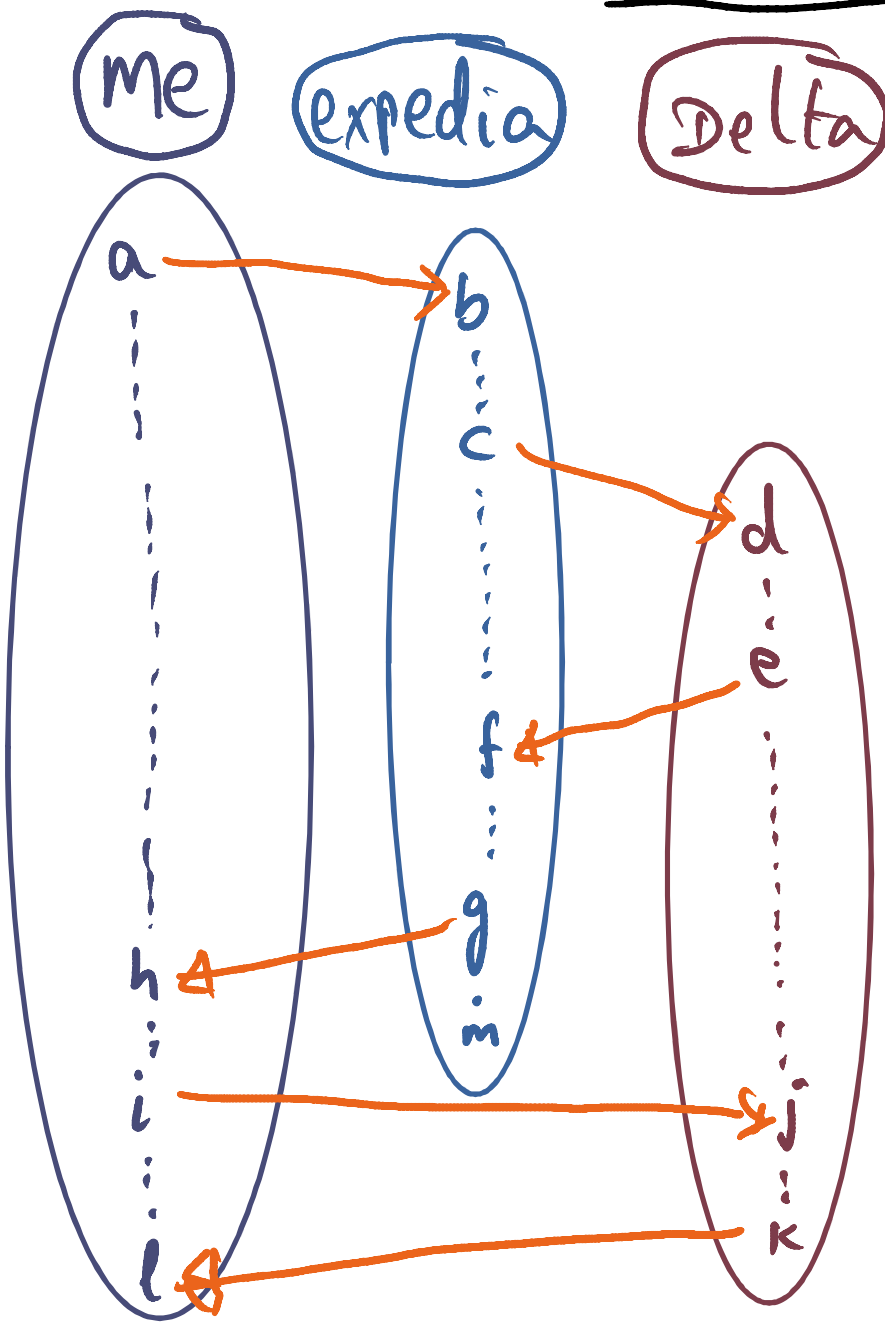
$t_m^{a-c} >> t_e^{a-b}$

Even a cluster is a distributed system!

A fun Example



A fun Example



Beliefs!

- Processes Sequential

  ⇒

  events totally ordered

  h→i , f→g , d→e...

- send before receive

  ⇒

  a→b, e→f, ...

"Happened Before" Relation

$a \rightarrow b \Rightarrow$ either 

Same process

or 

Communication

"Happened Before" Relation

$a \rightarrow b \Rightarrow$ either 

Same process

or 

Communication

Transitivity of "happened before"

$a \rightarrow b$

$b \rightarrow c$

$\Rightarrow a \rightarrow c$

"Happened Before" Relation

$a \rightarrow b \Rightarrow$ either 

or 

Same process

Communication

Transitivity of "happened before"

$a \rightarrow b$

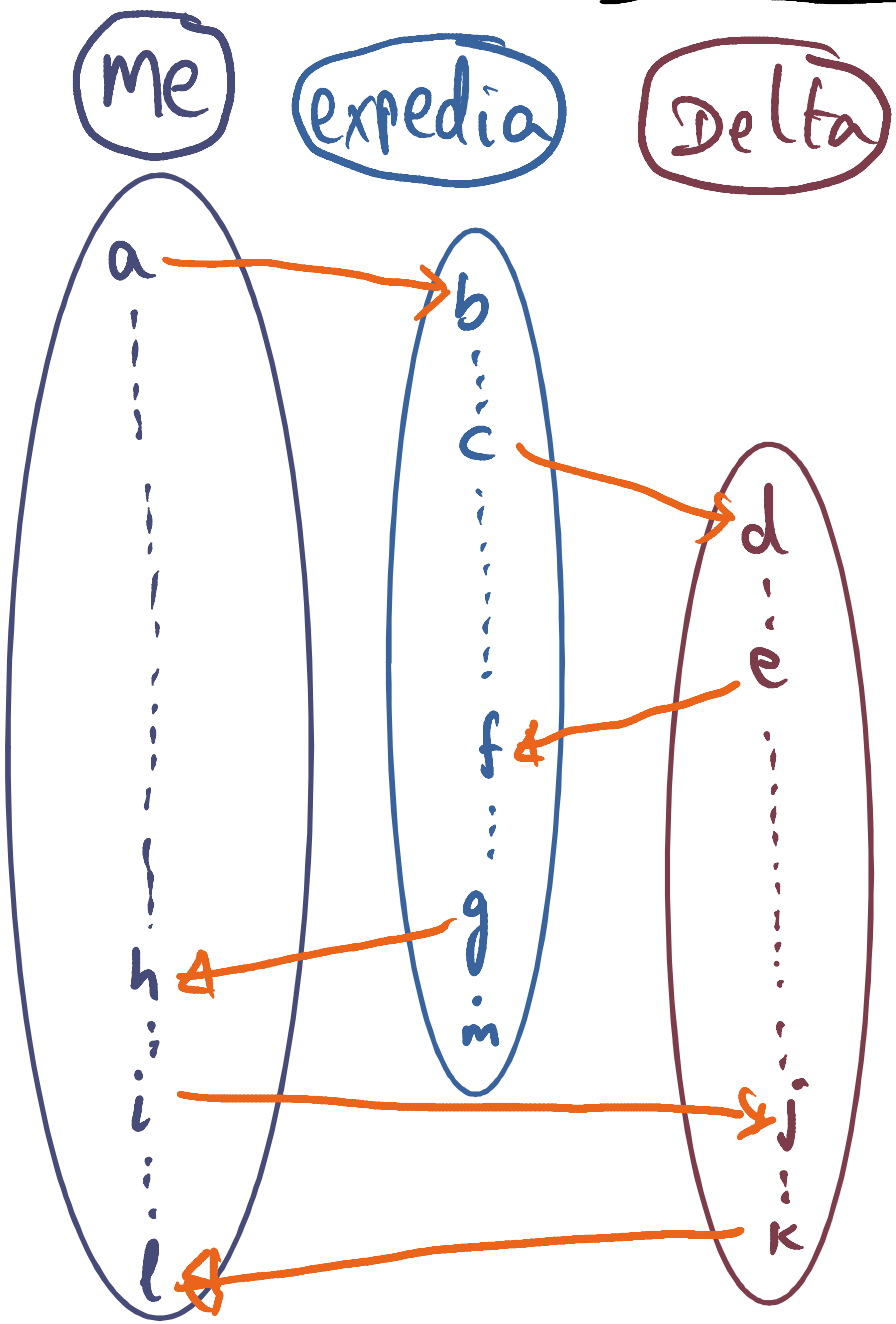
$b \rightarrow c$

$\Rightarrow a \rightarrow c$

Concurrent events 

$a \parallel b$

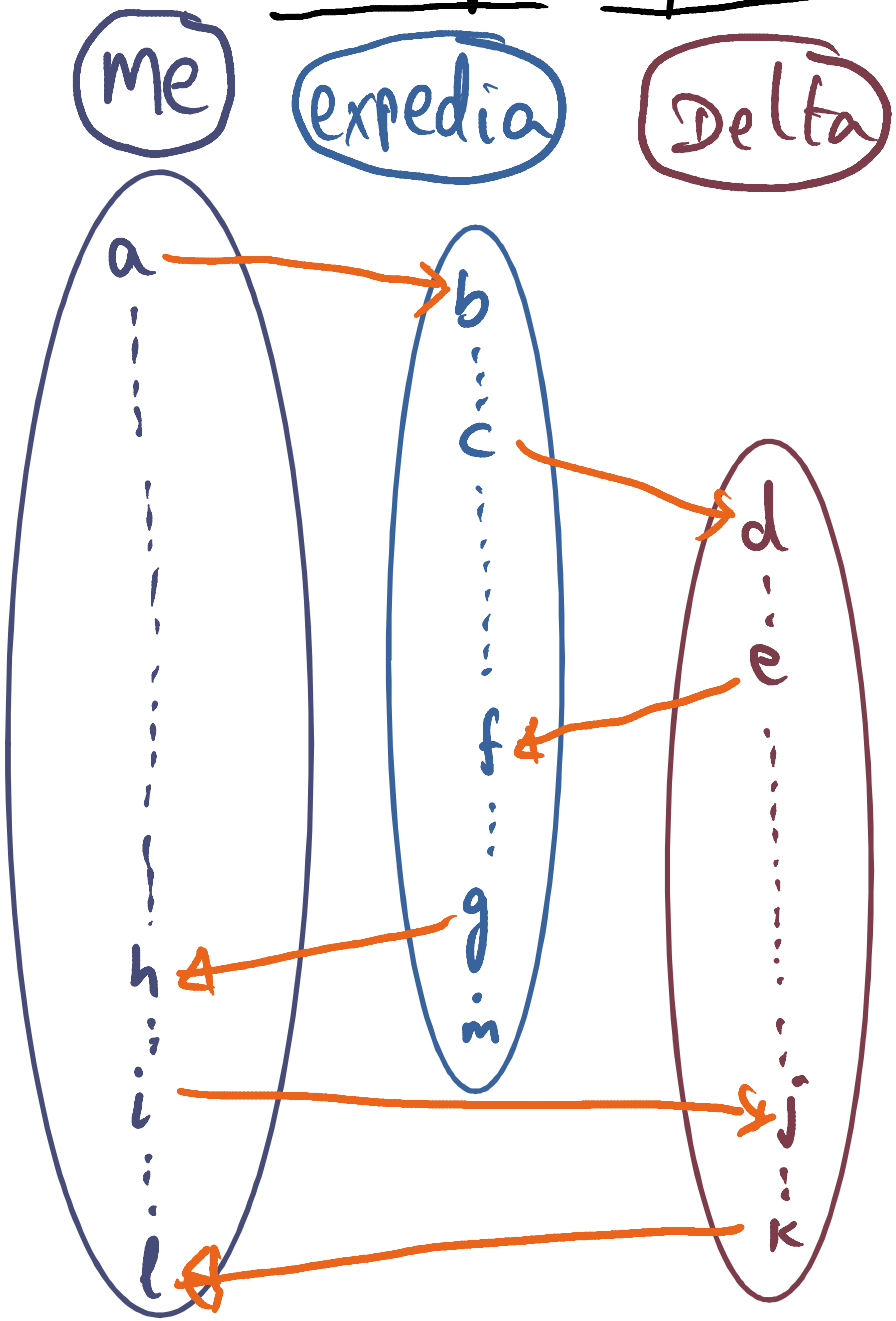
Question



1) Identify all the events connected by →

2) Identify all || events

Example of Event Ordering with →



Events connected by →

$a \to h \to i \to l$

$b \to c \to f \to g \to m$

$d \to e \to j \to K$

$a \to b$ $i \to j$

$c \to d$ $K \to l$

$e \to f$

$g \to h$

Transitive →

$a \to e$, $d \to m$, ...

concurrent events ||

$h \| m$ $m \| j$

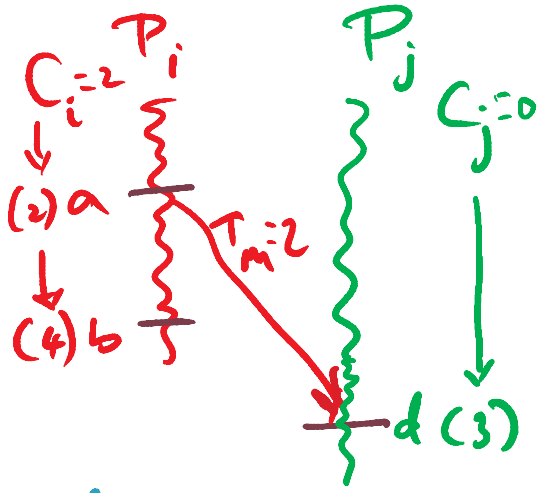
$i \| m$ $m \| K$

$l \| m$

Lamport's Logical Clock

Each node

* its Own events
* its Communication events



Lamport's Logical clock

* Monotonic increase of own event times

  Condition 1: $C_i(a) < C_i(b)$

* Message receipt time greater than send time

  Condition 2: $C_i(a) < C_j(d)$

  $\Rightarrow$ Choose $C_j(d) = \text{Max}(C_i(a)++, C_j)$

* Timestamp of Concurrent events?

Logical Clock Conditions

Clock Conditions

* Monotonic increase of own event-times

  Condition 1: $C_i(a) < C_i(b)$

* Message receipt time greater than send time

  Condition 2: $C_i(a) < C_j(d)$

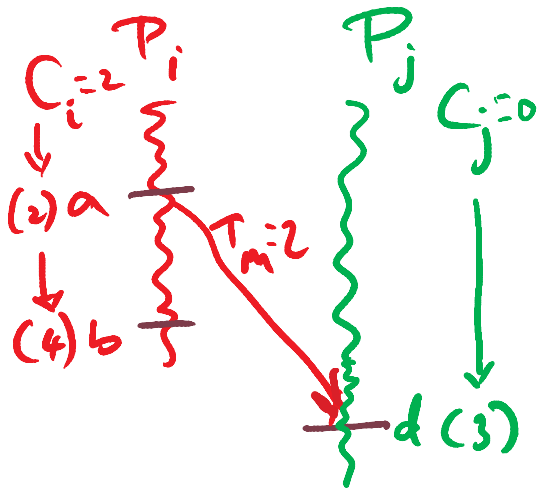
  $\Rightarrow$ Choose $C_j(d) = \text{Max}(C_i(a)++, C_j)$

* Concurrent events (b and d)

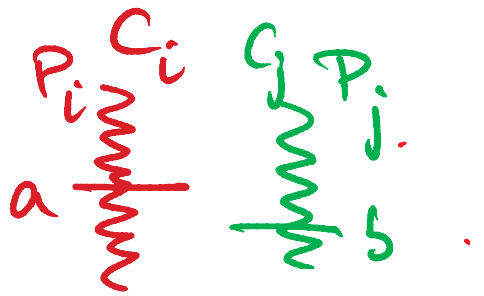
  arbitrary timestamps

* $C(x) < C(y)$

  $\not\Rightarrow x \rightarrow y$



Lamport's total order



Condition for $\Rightarrow$

$a \Rightarrow b$ iff

$C_i(a) < C_j(b)$

or

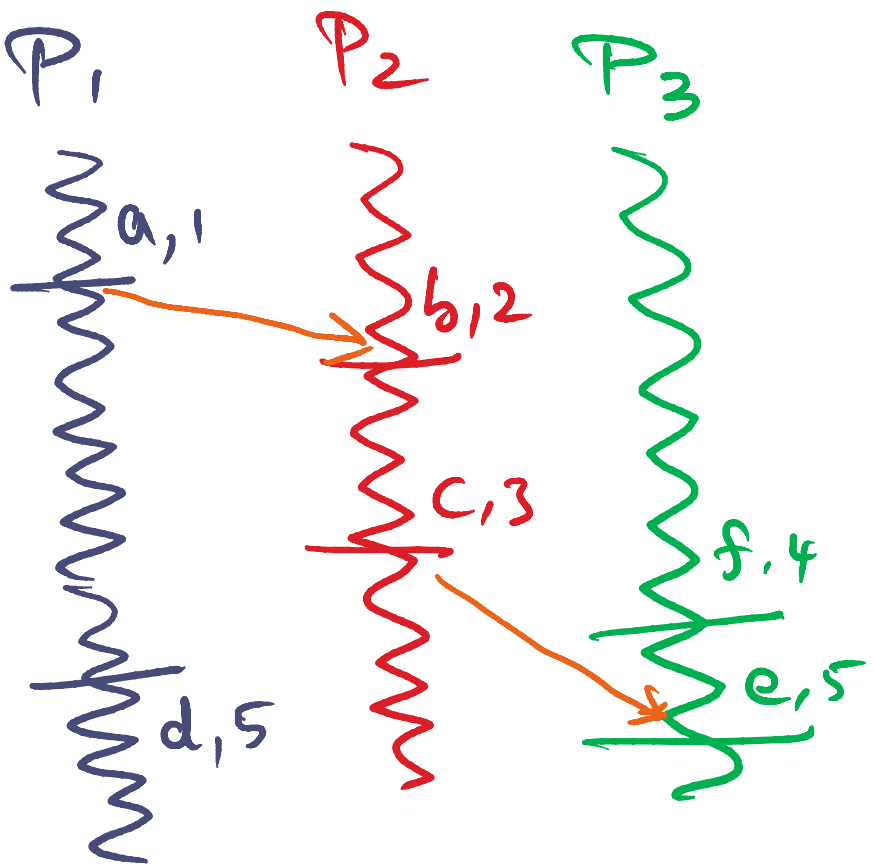
$C_i(a) = C_j(b)$ and $P_i << P_j$

($<<$ arbitrary "well known" condition

to break a tie)

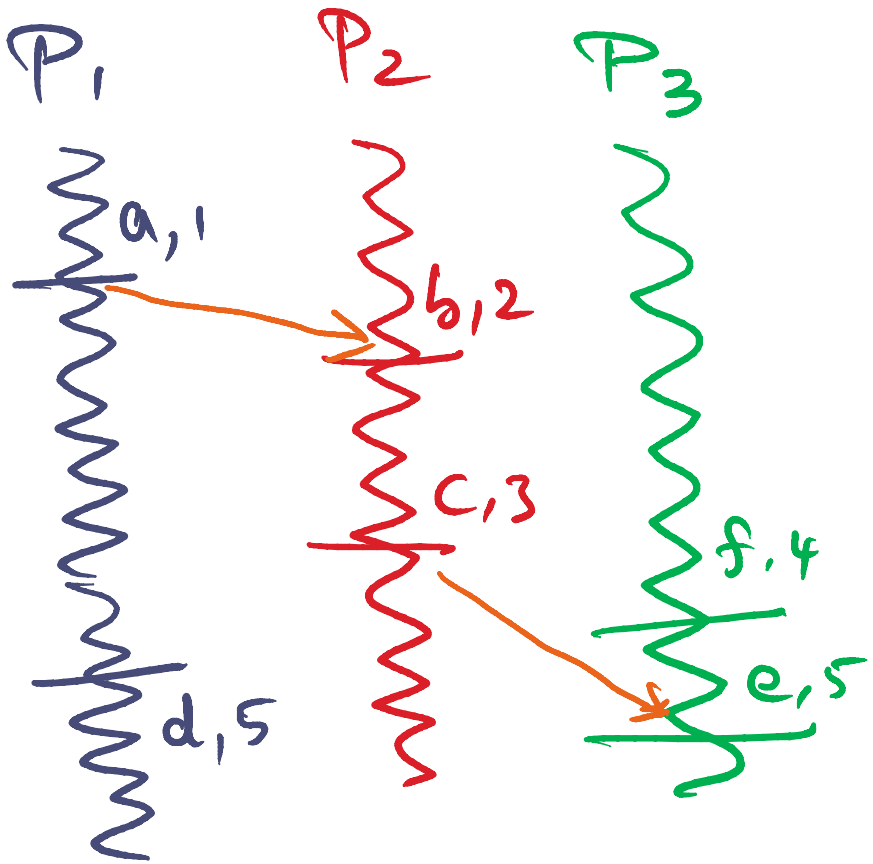
No single total order

Question



What is the total order using Process ID to break the tie?

Question/Solution



What is the total order using Process ID to break the tie?

Partial orders by $\rightarrow$

$a \rightarrow b \rightarrow c \rightarrow e$; $f \rightarrow e$

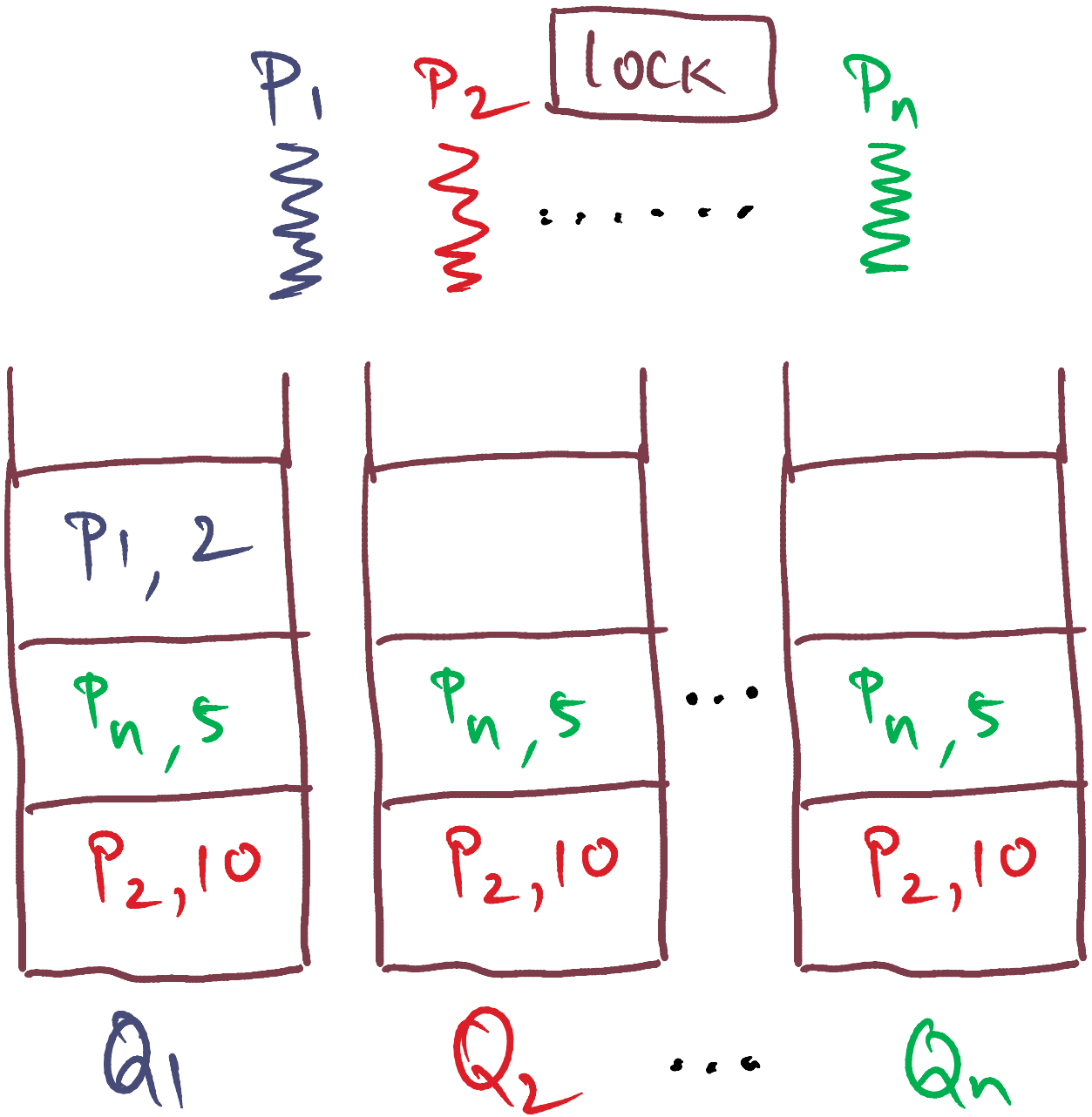
concurrent events $\|$

$d \| \{b, c, f, e\}$; $f \| \{a, d, b, c\}$

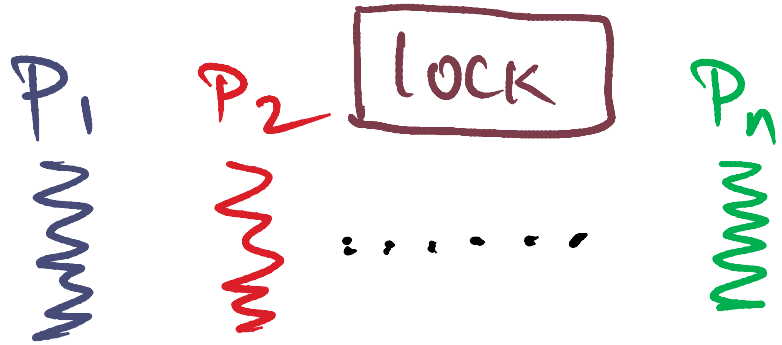
Total order respecting timestamps + PID $\Rightarrow$

a b c f d e

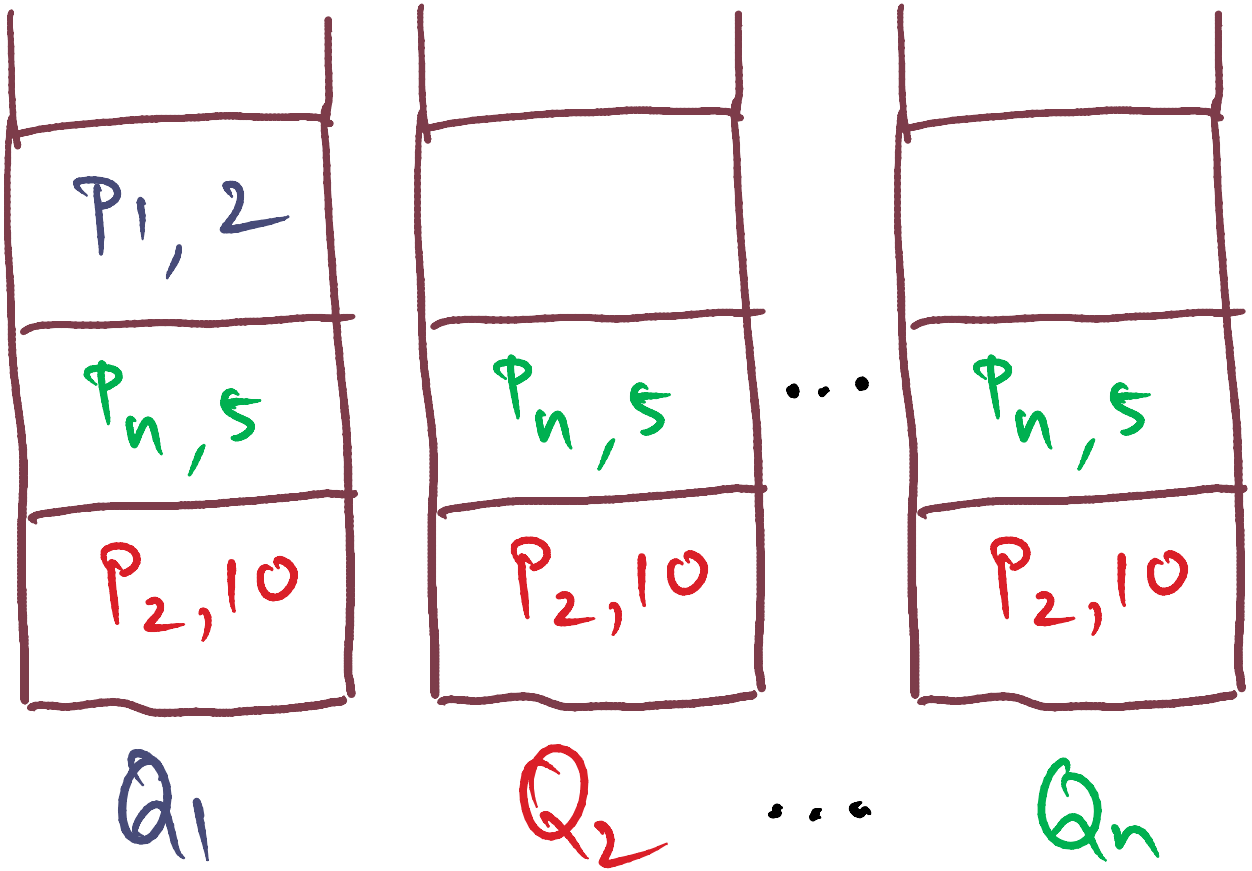
Distributed M.E. lock algorithm



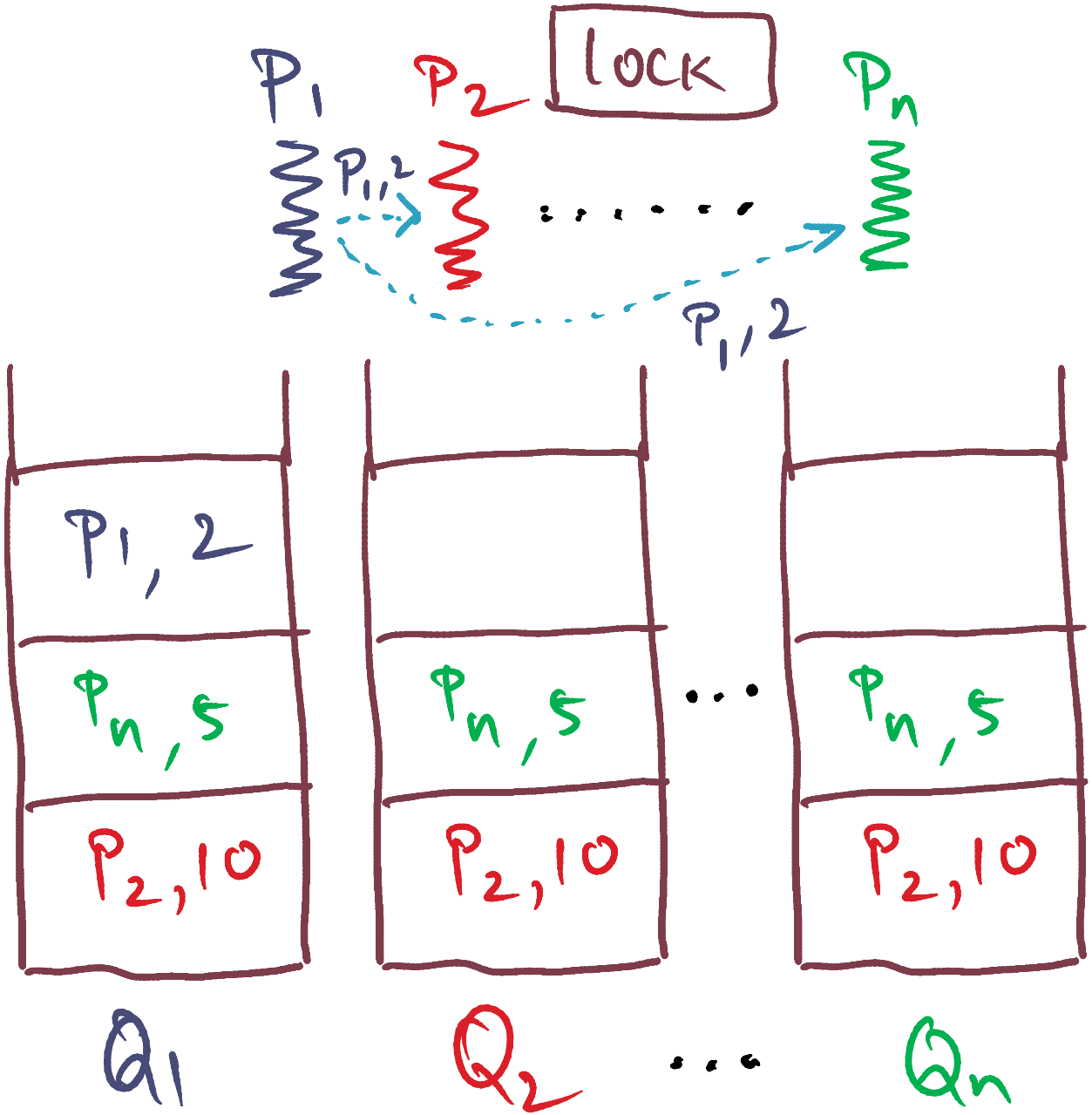
Distributed M.E. lock algorithm



Possible ?



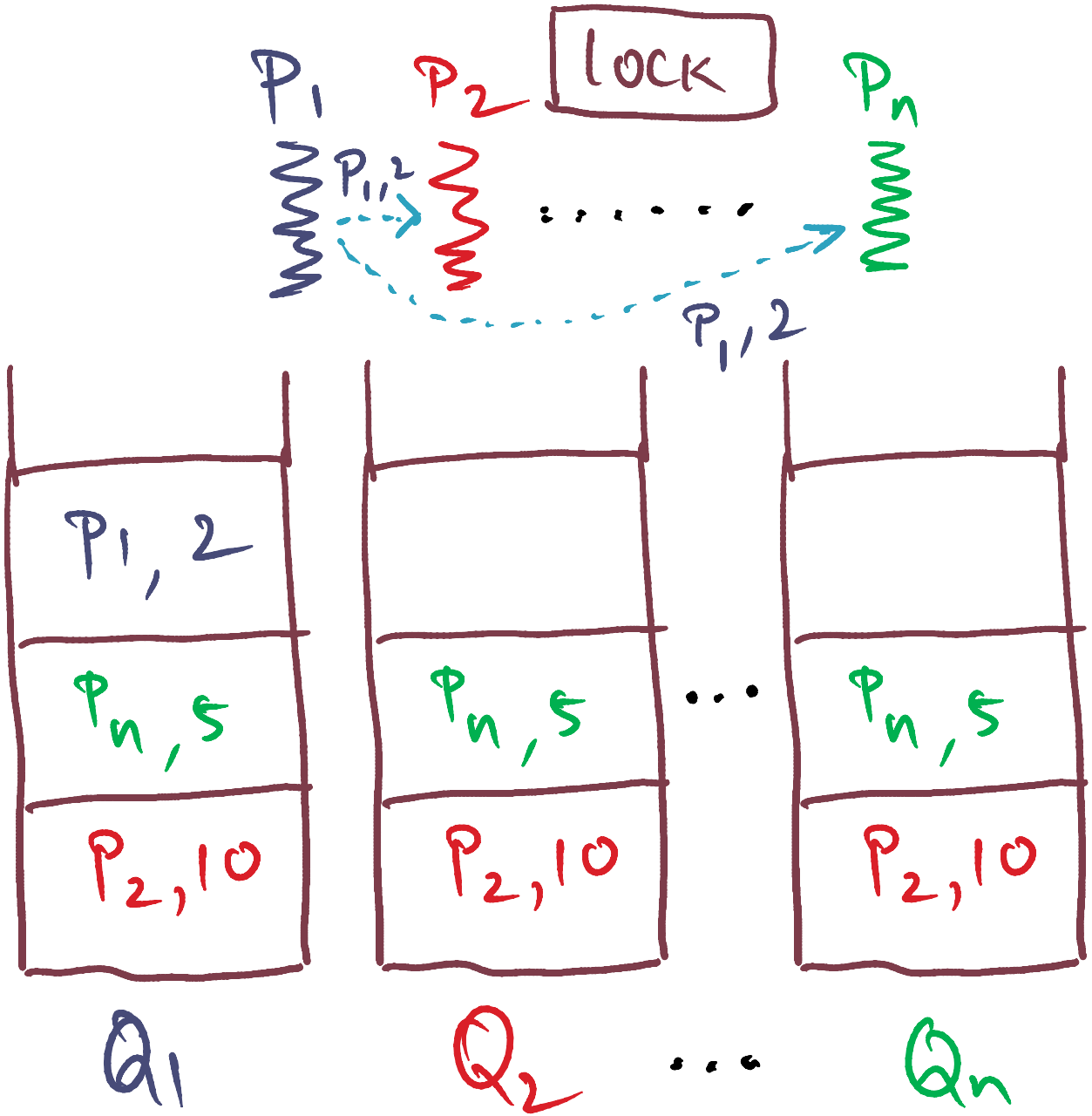
Distributed M.E. lock algorithm



Possible ?

* P_1's msg in transit
* P_1 received P_2's & P_n's subsequently

Distributed M.E. lock algorithm



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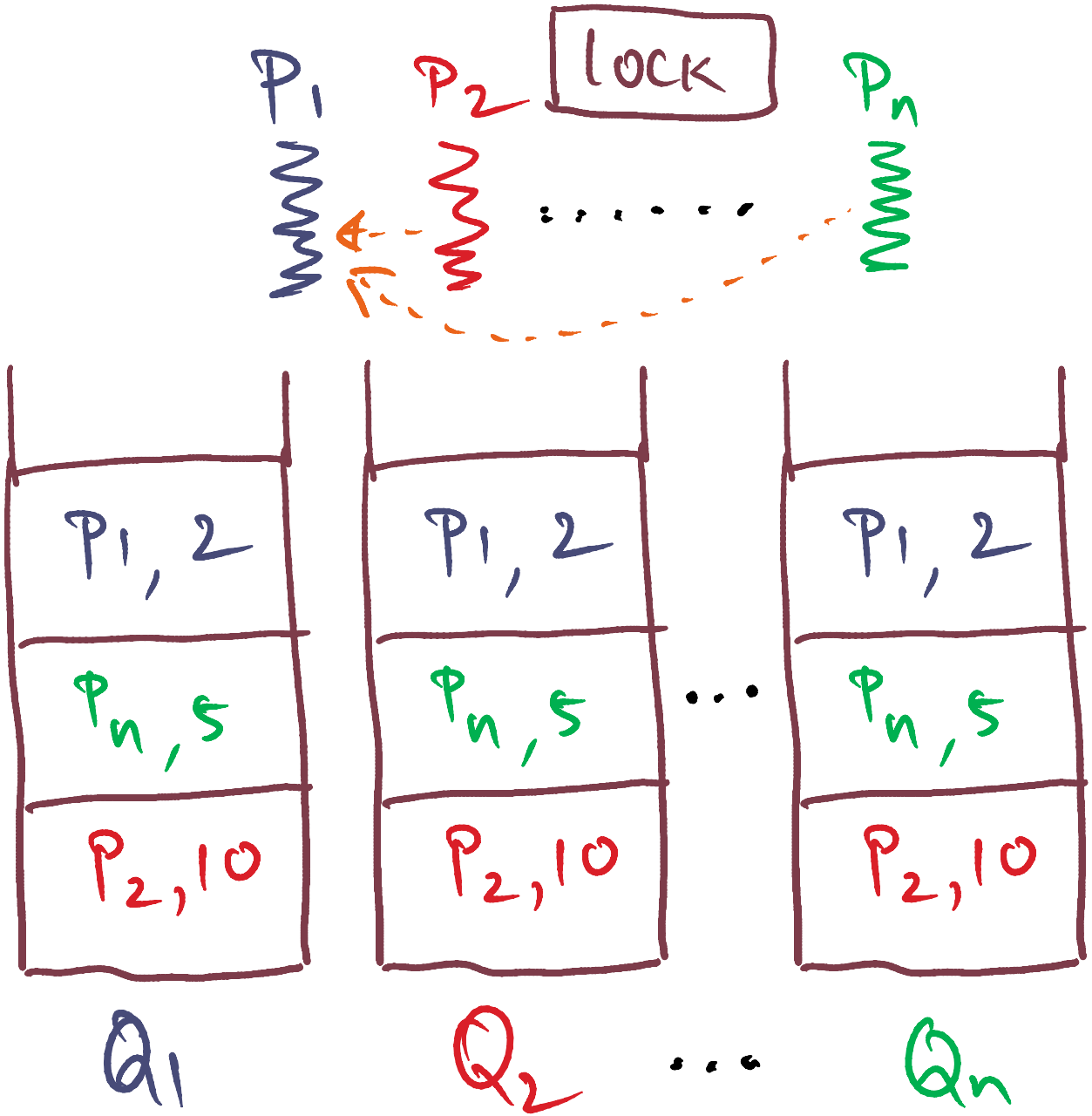
Do I have it?

Distributed M.E. lock algorithm



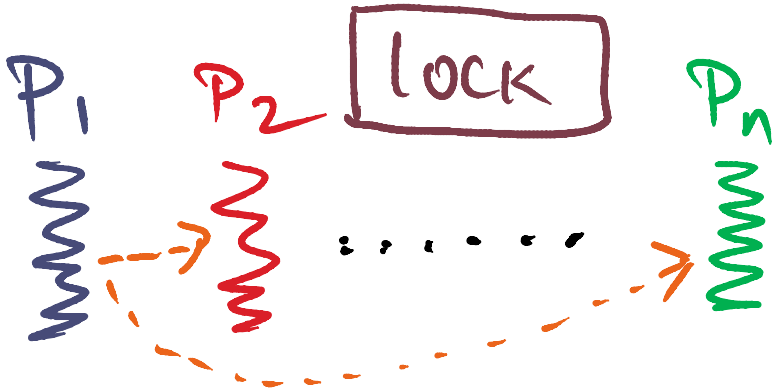
Possible?

* P_1's msg in transit
* P_1 received P_2's & P_n's subsequently

Do I have it?

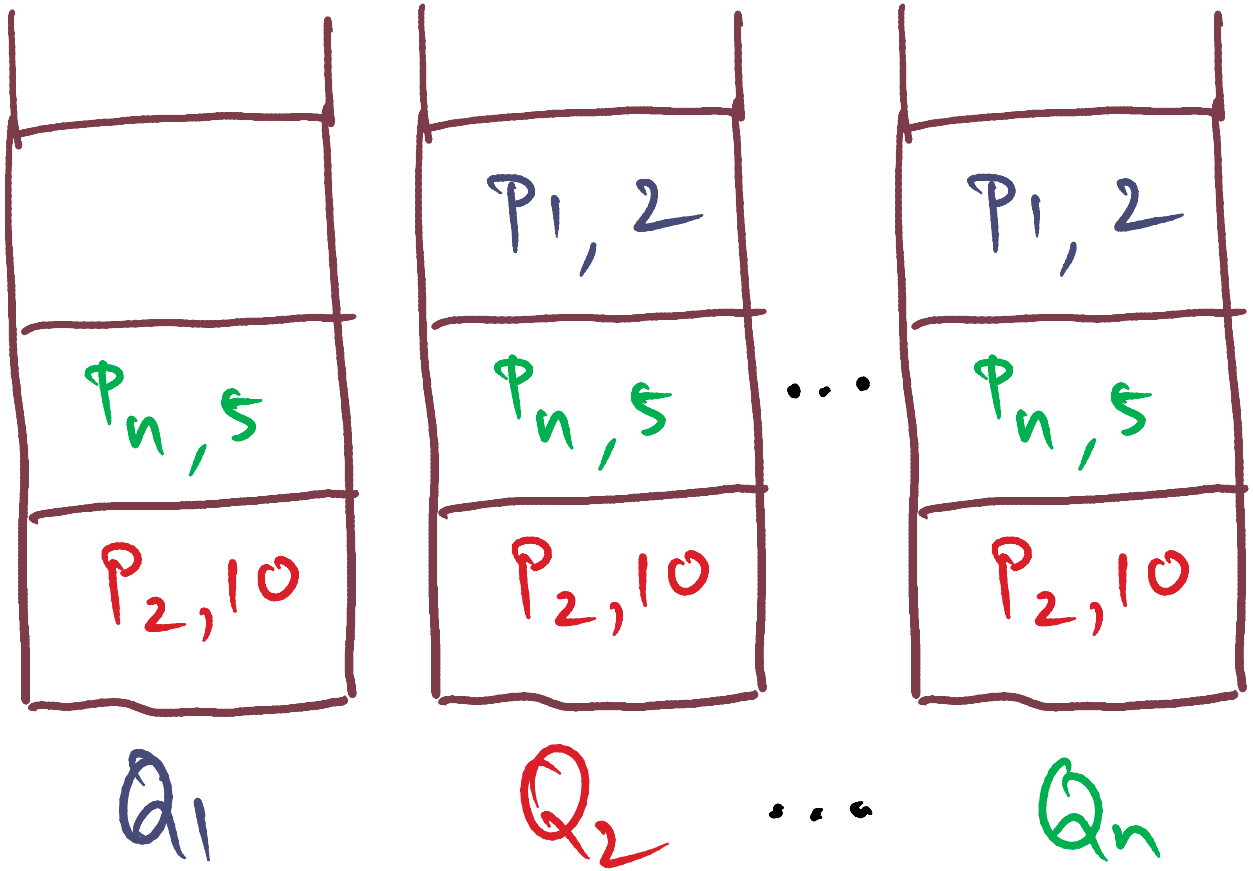
* Top of my Q
* Ack from others or later lock reqs

Distributed M.E. lock algorithm

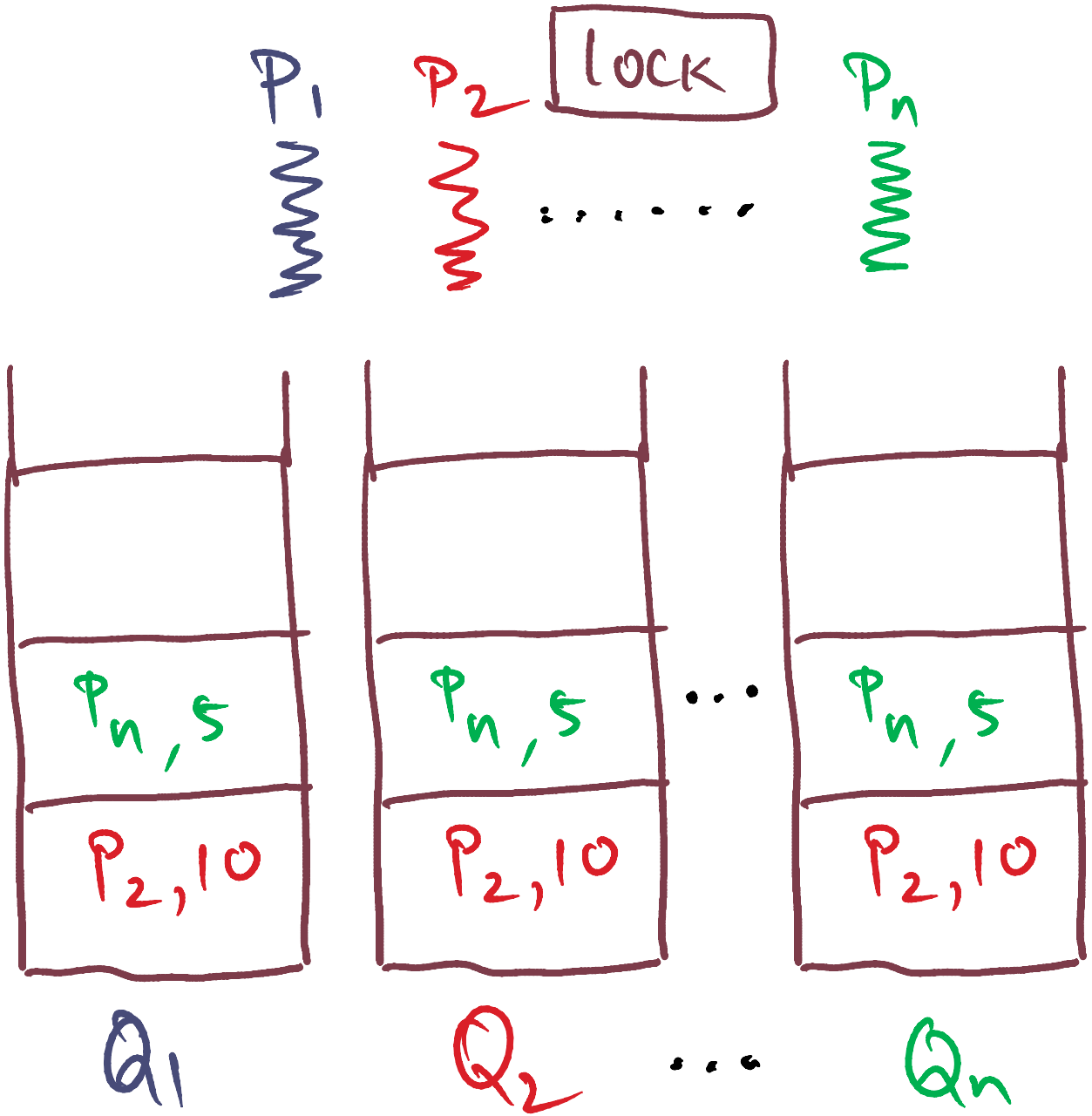


Lock release

* P_1 sends unlock msg



Distributed M.E. lock algorithm



Lock release

* P_i sends unlock msg
* peers remove P_i's completed request from their respective queues

Distributed M.E. lock algorithm

Correctness?

* msgs arrive in order
* no message loss
* Q's totally ordered ⇒ by Lamport's Logical clocks plus PID to break ties

Distributed M.E. lock algorithm

Correctness?

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message complexity?

Message Complexity

Lock(L) ⇒ N-1 req msgs

N-1 Ack msgs

Unlock(L) ⇒ N-1 unlock msgs

Total 3(N-1)

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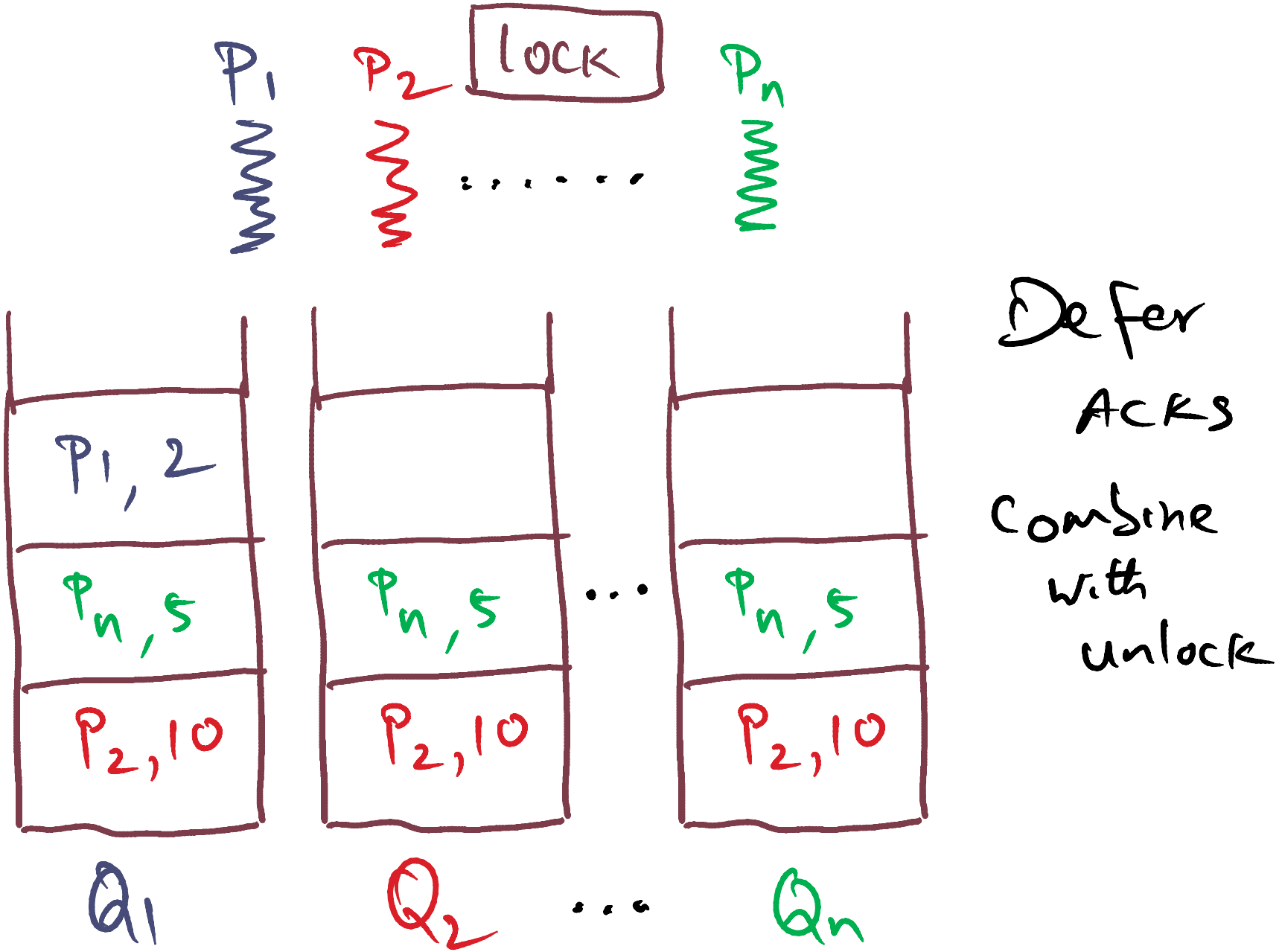
N-1 Ack msgs

Unlock(L) ⇒ N-1 unlock msgs

Total 3(N-1)

Can we do better?

Distributed M.E. lock algorithm



Message Complexity

Lock(L) ⇒ N-1 req msgs

N-1 ACK msgs

⋮

Unlock(L) ⇒ N-1 unlock msgs

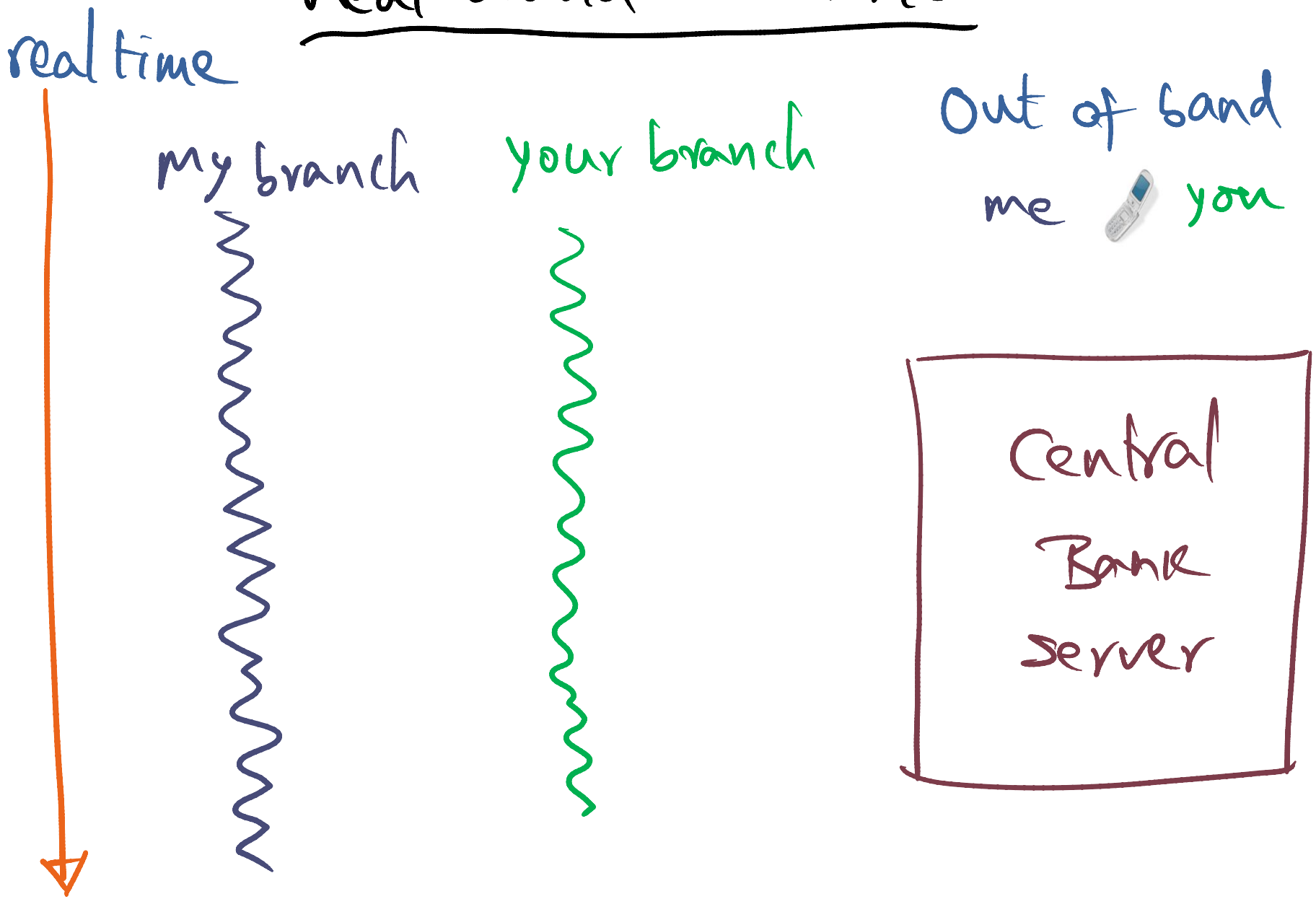
Total 3(N-1)

Can we do better?

* Defer ACKs if my req precedes yours

⇒ combine with unlock ⇒ 2(N-1)

Real world scenario



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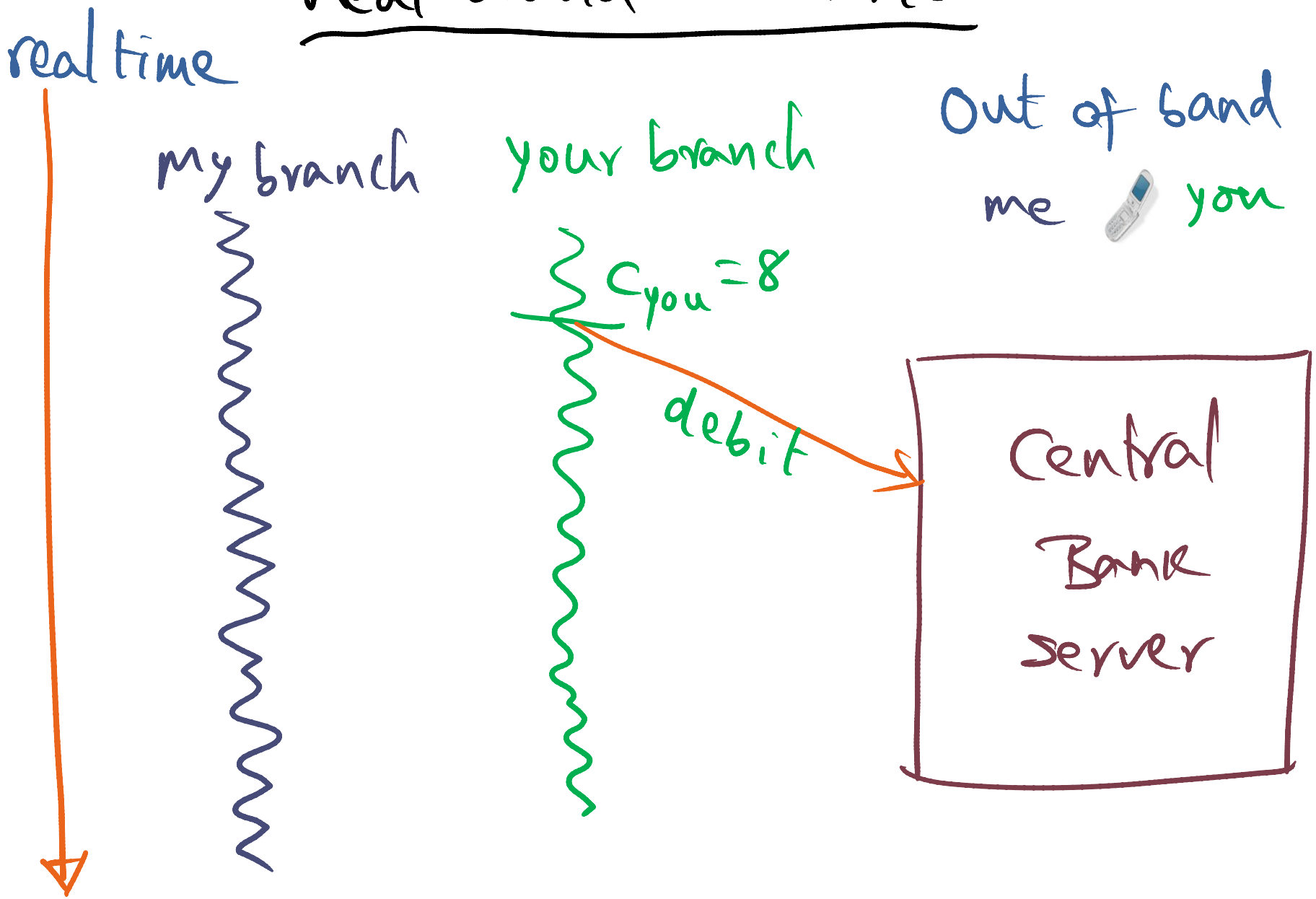

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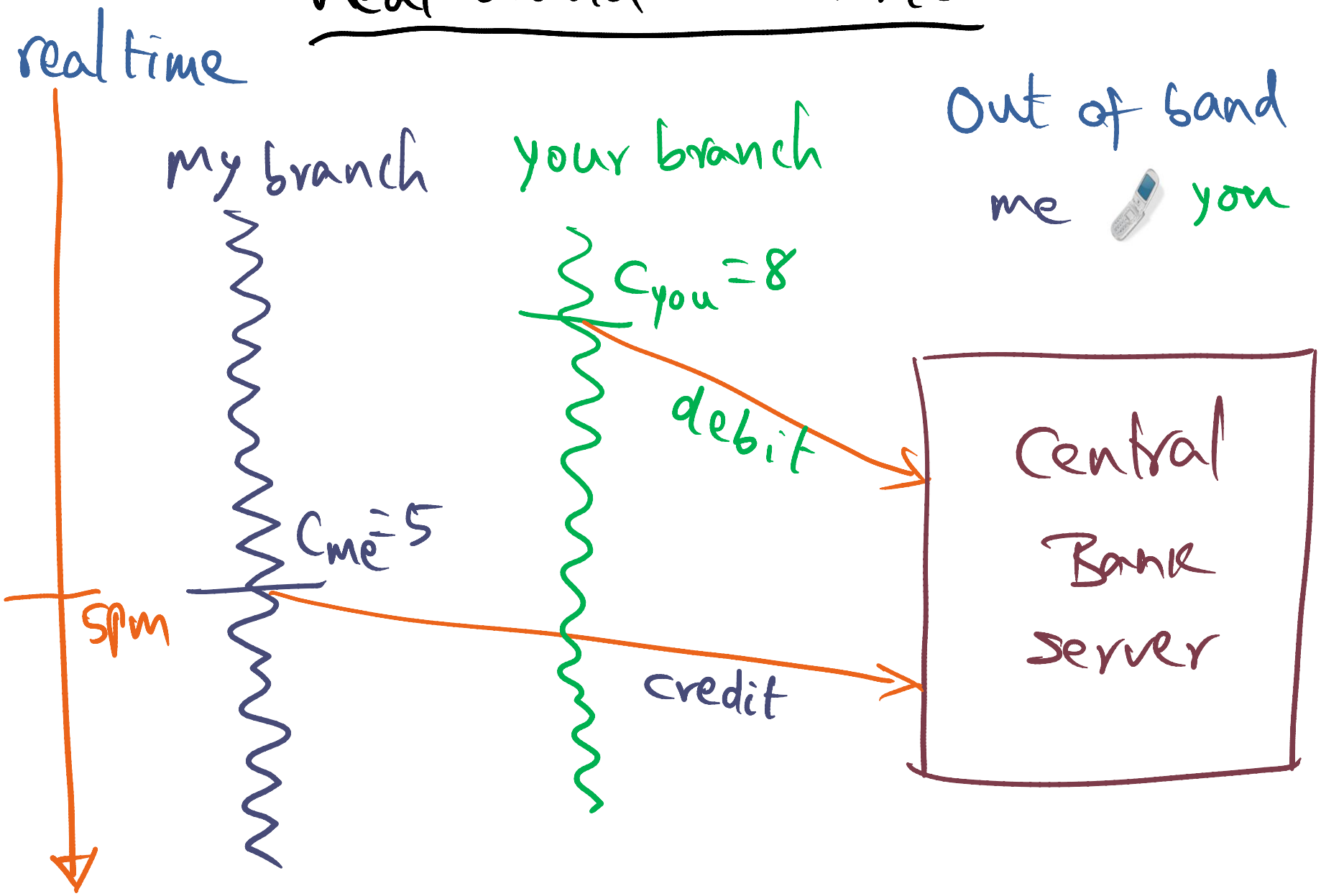

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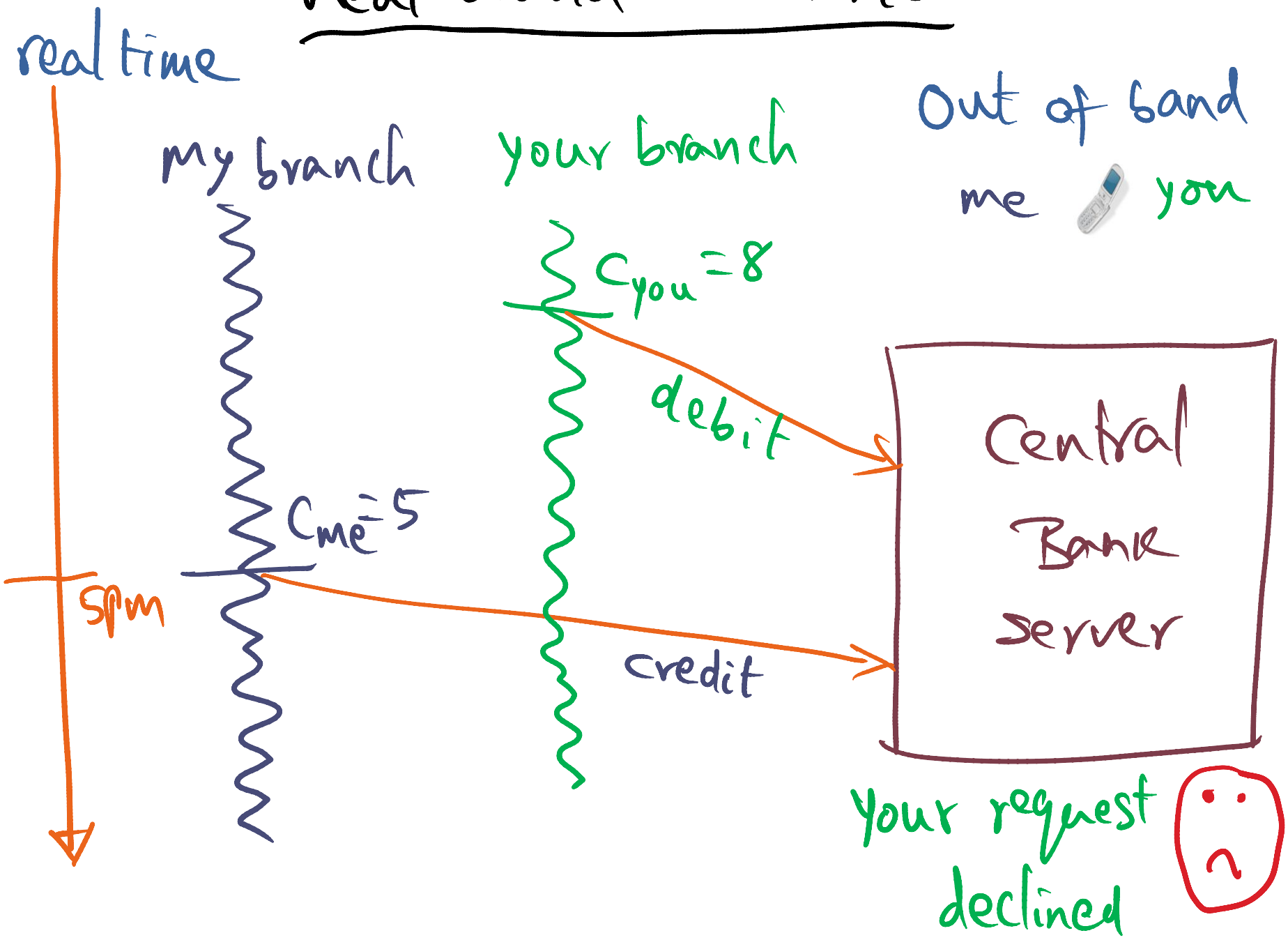
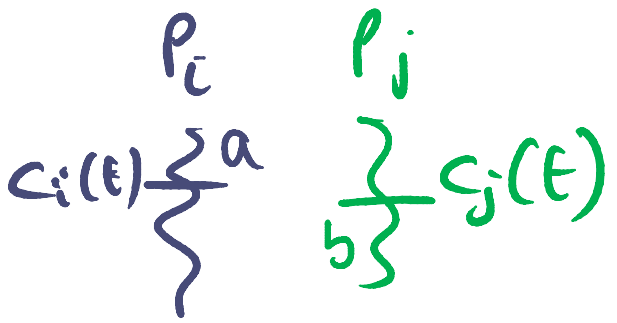


Lamport's Physical clock

$a \mapsto b$

$\Rightarrow C_i(a) < C_j(b)$



Physical clock conditions:

1) PC1 (bound on individual clock drift)

$$\left(\frac{dc_i(t)}{dt} - 1\right) < \kappa \quad \forall i ; (\kappa << 1)$$

2) PC2 (bound on mutual drift)

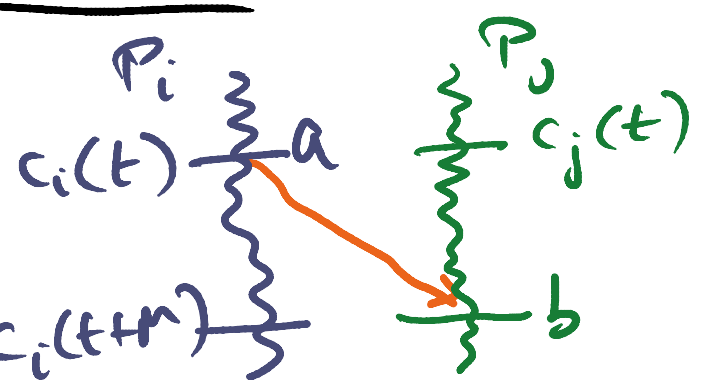
$$\forall i,j : |C_i(t) - C_j(t)| < \epsilon$$

IPC time and clock drift

Let μ be lower bound on IPC

To avoid anomalies if

a on $P_i \mapsto$ b on P_j



1) $c_i(t+\mu) - c_j(t) > 0$

2) $c_i(t+\mu) - c_i(t) > \mu(1-\kappa)$

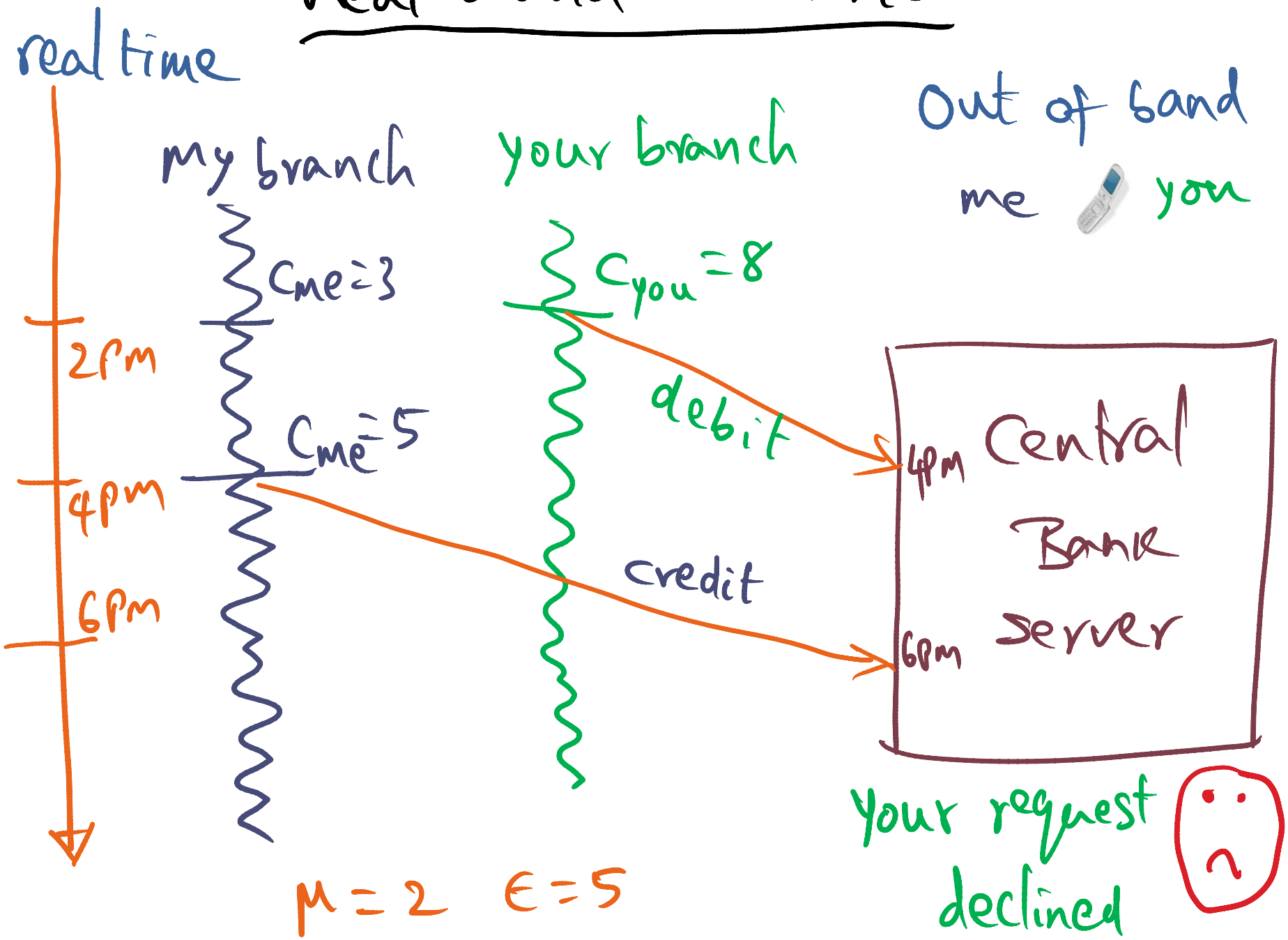
(difference equation formulation of PC1) PC2

using ① + ② and bound ϵ on mutual drift

$$\mu >= \epsilon/(1-\kappa)$$

to avoid anomalies

Real world scenario



Real world scenario