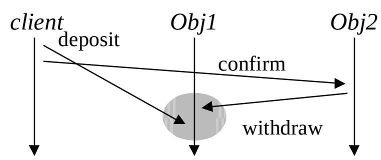
Synchronization

- Problems in synchronization in distributed systems.
- Synchronization *vs.* mutual exclusion
- Centralized synchronization mechanisms in distributed systems
- Distributed synchronization mechanisms

Reading: Coulouris, Chapter 10

Synchronization: Introduction

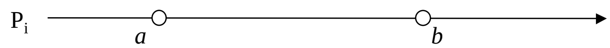
- A scary scenario:



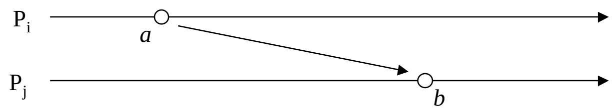
- **Synchronization**: temporal ordering of sets of events produced by concurrent processes in time.
  - Synchronization between senders and receivers of messages.
  - Control of joint activity.
  - Serialization of concurrent access to shared objects/resources.
- Why not Semaphores ?!
  - centralized systems: shared memory, central clock
  - distributed system: message passing, no global clock
- events cannot be totally ordered!

A Partial Event Ordering for Distributed Systems
(Lamport 1978)

- Absence of central time means: no notion of *happened-when* (no total ordering of events)
- But can generate a *happened-before* notion (partial ordering of events)
- *Happened-Before* relation:

1. 

Event *a* happened-before Event *b*. (*a -> b)*

2. 

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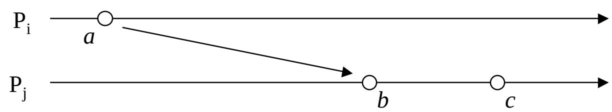
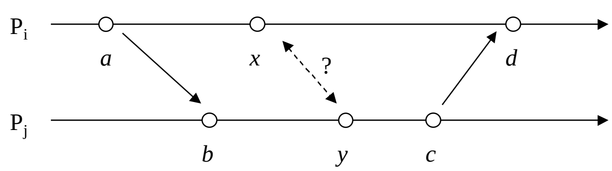
3. 

Event *a* happened-before Event *c*. (*a -> c) (transitivity)*

happened-before Relation

- What when no *happened-before* relation exists between two events?



Events *x* and *y* are concurrent.

- Problem:
  - only approximate knowledge of state of other processes
- Need global time:
  - common clock
  - synchronized clocks

Synchronization Schemes

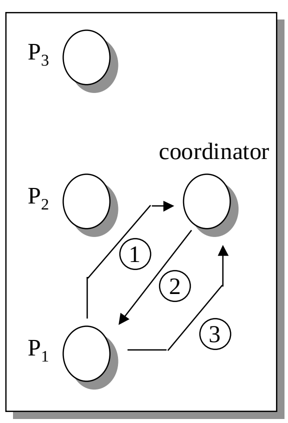
	centralized	distributed
based on mutual exclusion	central process	circulating token
no mutual exclusion	physical clock eventcount	physical clocks logical clocks

Centralized Synchronization Mechanisms

1. Physical Clocks

provide a single clock

2. Central Process



1. Send *request* message to coordinator to enter C.S.
2. If C.S. is free, the coordinator sends a *reply* message. Otherwise it queues request and delays sending *reply* message until C.S. becomes free.
3. When leaving C.S., send a *release* message to inform coordinator.

- Characteristics:
  - ensures mutual exclusion
  - service is fair
  - small number of messages required
  - fully dependent on coordinator

Centralized Synch. Mechanisms: 3. Eventcounts

- Primitives:

advance(E)

- increase value of *E* by one. Indicates that particular event has happened.
- Invoked by *signaler*.

read(E)

- return "current" value of *E*.
- returns lower bound; why?

await(E, v)

- suspend calling process until value of *E* is at least *v*.

Eventcounts *vs.* Semaphores

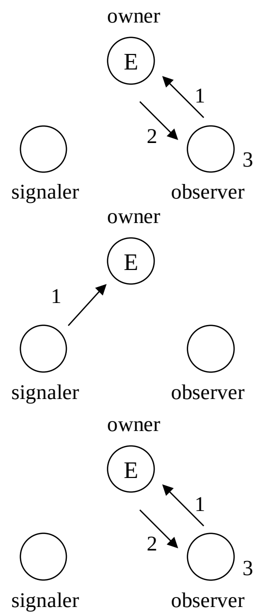
- Example: Producer-Consumer Problem:

```
Eventcount   * FULL;   Eventcount   * EMPTY;
```

```
Producer:
int i = 0;

while (TRUE) {
  i++;
  produce item;

  await(EMPTY, i-N);

  deposit item;

  advance(FULL);

}
```

```
Consumer:
int i = 0;

while (TRUE) {
  i++;
  await(FULL,i);

  remove item;

  advance(EMPTY)

  consume item;

}
```

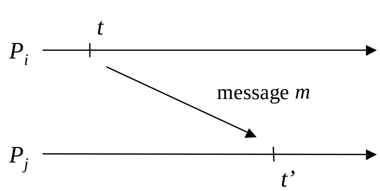
Eventcounts: Implementation



- *read*:
  1. send *read* message with *seq#*.
  2. reply current value with *seq#*.
  3. return from *read* call with value
- *advance*
  1. send *advance* message to owner
- *await*
  1. observer sends *await(v)* message to owner
  2. when value reaches *v*, owner sends "*await confirm*" message to observer.
  3. observer returns from *await*.

Distributed Synchronization: Physical Clocks

- Conditions for a physical clock C_i:
  - runs at approximately correct rate: $\left|\frac{dC_i}{dt} - 1\right| < k$
  - should tell approximately the correct time: $\forall i, j \; \left|C^i(t) - C^j(t)\right| < \varepsilon$
- Synchronizing clocks by exchanging messages:



message delay $\partial^m = t - t'$

minimum delay $\mu^m > 0$

unpredictable delay [illegible]

Clock Synchronization: Basic Algorithm

1.) while no synchronization message arrives, clock C_i increases monotonically

2.) P_i sends synchronization message m at time t with timestamp $T_m = C_i(t)$.

3.) P_j receives synchronization message m at time t'. Updates C_j to be

$$C_j(t') := \max(C_j(t'), T_m + \mu_m)$$

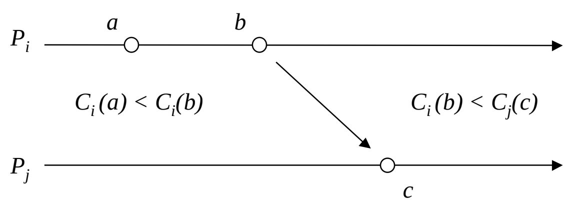
Distributed Synchronization: 2. Logical Clocks

- Absolute time?
- Is chronological ordering necessary?
- Logical clock: assigns a number to each local event.

Clock Condition

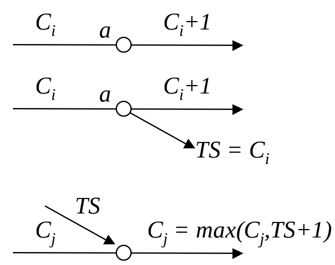
$\forall$ Events a, b : if $a \rightarrow b$ then $C(a) < C(b)$

- In Other Words:



Total Ordering with Logical Clocks

- Rules:
  - Rule 1: increment C_i after every local event.
  - Rule 2: timestamp outgoing messages with current local clock
  - Rule 3: Upon receiving message with timestamp *TS*, P_j updates local clock C_j to be $C_j = max (C_j, TS+1)$



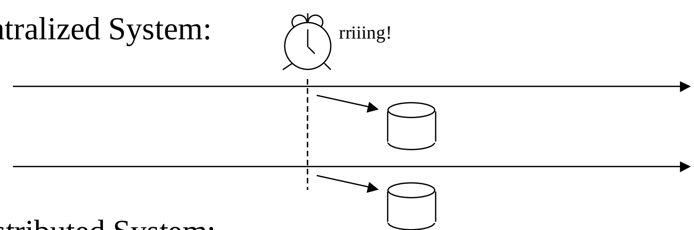
- Total ordering of events: assuming that clocks satisfy Clock Condition, define following relation:

$$a \Rightarrow b \quad \Leftrightarrow \quad \begin{matrix} C_i(a) < C_j(b) \\ \text{or} \\ C_i(a) = C_j(b) \text{ and } i < j \end{matrix}$$

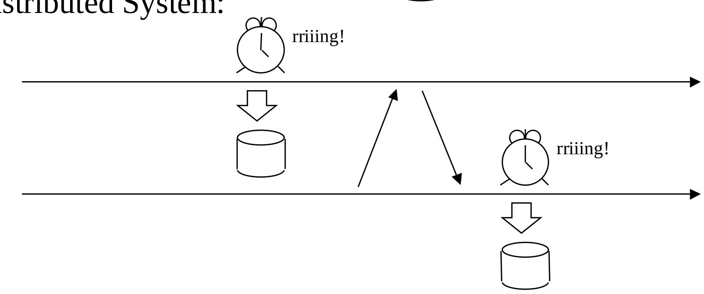
for events *a* on P_i and *b* on P_j.

Example: Distributed Checkpointing

- "At 5pm everybody writes its state to stable storage!"
- Centralized System:

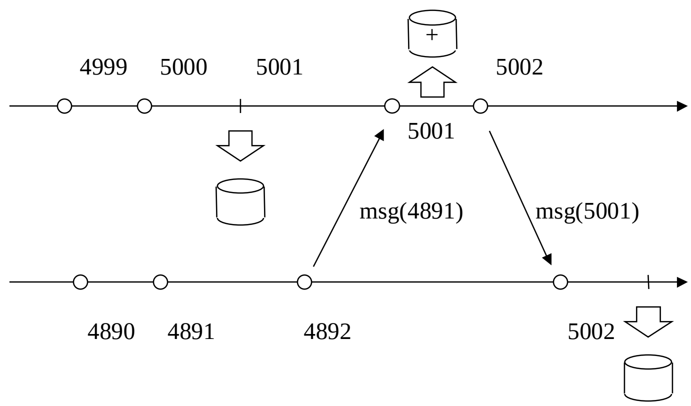


- Distributed System:



Distributed Checkpointing and Logical Clocks

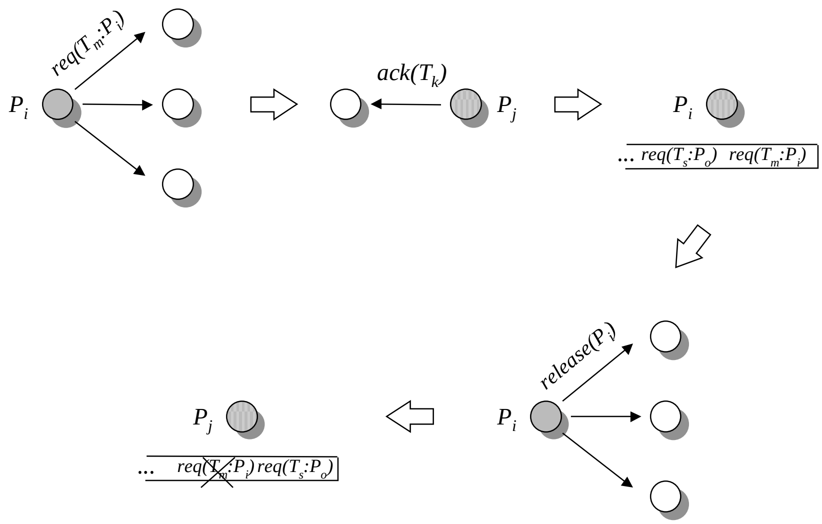
"At logical-clock time 5000 write state to stable storage!"



Logical Clocks and Distributed Mutual Exclusion

- Mutual Exclusion:
  - Process holding resource must release it before another process can acquire it.
  - Grant requests for resources in order in which they were made.
  - Requests are eventually granted, as long as holding processes return resources.

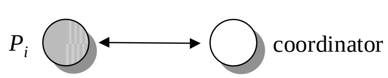
Lamport's Algorithm



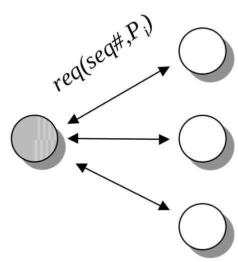
Ricart and Agrawala

Reminder: Central Coordinator

Other participants form Distributed Coordinator



request, *reply*, *release* cycle



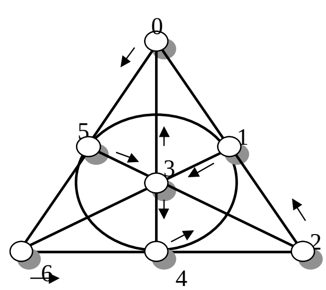
Maekawa (1985)

- Ricart and Agrawala
  - fully symmetric algorithm: all processes run *exactly* the same algorithm.
  - improvements by fiddling with messages.
- Alternative
  - relax symmetry
  - allow arbitration requests to be exchanged be sets of nodes with pairwise non-null intersections.
- Choice of subsets (Coteries)
  - all pairwise intersections are non-null
  - every node *i* contained in its own subset *S(i)*
  - all *S(i)*s should have the same size
  - every node *i* should be contained in same number of subsets

Maekawa (cont)

- Example: <u>Finite Projective Planes</u>

S(0) = {0,5,6}
S(1) = {1,3,6}
S(2) = {2,1,0}
S(3) = {3,0,4}
S(4) = {4,1,5}
S(5) = {5,3,2}
S(6) = {6,4,2}



- Use *request, reply, release* cycle
  - need $\sqrt{\ }$ messages

Distributed Mutual Exclusion: Conclusion