Models of Distributed Computation

Distributed System (DS) – overview

- A distributed system is a collection of computers that are spatially separated and do not share a common memory
- Processes executing on those computers communicate with one another by exchanging messages (msg) over communication channels of arbitrary transmission delays
- DS has **inherent limitations** caused by
  - lack of common memory
  - lack of a system-wide common clock

$\Rightarrow$ Learn how to overcome these inherent limitations

Sequential programs have a simple model of computation

- one global state
- one instruction is executed at a time

Model of computation for **distributed** program is complex due to

- concurrent executing components
- no global time and no global state (inherent limitations)
- possible failure of components

Approaches to modeling a distributed computation
$\Longrightarrow$ **causality** and **consistent state**

Fundamental property of distributed system $\Rightarrow$ $\boxed{\text{lack of a global state}}$

Why??? – from an observer's point of view

- **non-instantaneous communication**

$\Rightarrow$ observer's view of the global state of the system depends on the observation point

- **drift of clock**

$\Rightarrow$ real clocks tend to drift apart in their readings

- **interruptions** – CPU contention, page fault, cache miss, *etc.*

$\Rightarrow$ no guarantee of *simultaneous reactions* from different processors

We cannot count on simultaneous observations (by different observers) of global states in a distributed system
$\Longrightarrow$ So, what properties can we depend on???

Causality

$\boxed{\textbf{Distributed systems are causal}}$

Causality – *the cause preceeds the effect*

e.g. sending of a msg precedes the receipt of a msg

Event

- sending of a msg
- receipt of a msg
- local action

Notations

- ε – the set of all events
- A distributed system is composed of M processors: $p_1, p_2, \cdots, p_M$
- ε_p – all events that occur at processor p

Orders between events — e_1 occurs before e_2 is denoted as $\boxed{e_1 < e_2}$

- Processor Ordering (PO) – events that occur on the same processor are *totally* ordered

  if $e_1 \in \varepsilon_p$ and $e_2 \in \varepsilon_p$
  $\Longrightarrow$ either $\boxed{e_1 <_p e_2}$ or $\boxed{e_2 <_p e_1}$

- Message Passing Ordering (MPO)

  $[e_1$ – sending of msg $m]$ and $[e_2$ – receipt of msg $m]$
  $\Longrightarrow \boxed{e_1 <_m e_2}$

Happened-Before relation ($<_H$) – *transtive closure* of PO and MPO

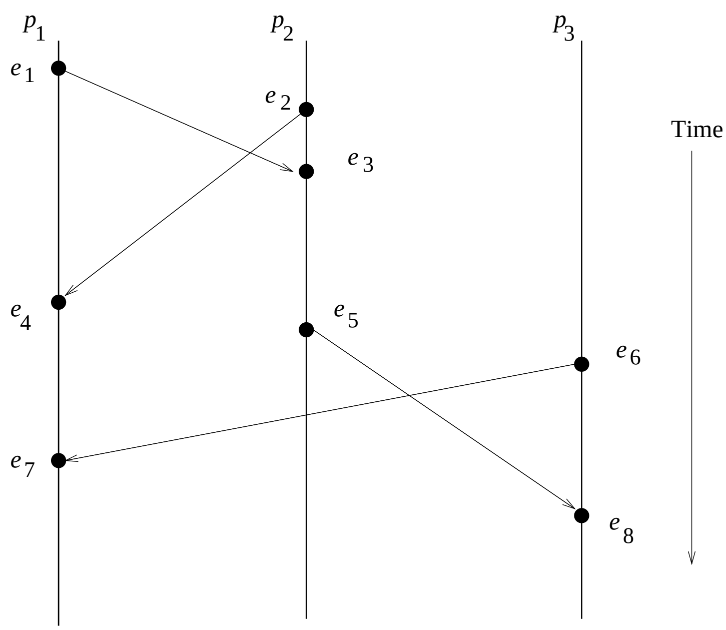
- if $e_1 <_p e_2$ then $e_1 <_H e_2$
- if $e_1 <_m e_2$ then $e_1 <_H e_2$
- if $e_1 <_H e_2$ and $e_2 <_H e_3$ then $e_1 <_H e_3$

$\Rightarrow$ $e_1 <_H e_2$ if $\exists$ a *causally linked chain of events* leading from e_1 to e_2

$\Rightarrow$ a **partial oreder**

$\Rightarrow$ if two events are not ordered by $<_H$, they are **concurrent** ($e_1 \parallel e_2$)

$\Rightarrow$ as a **Directed Acyclic Graph** (DAG)

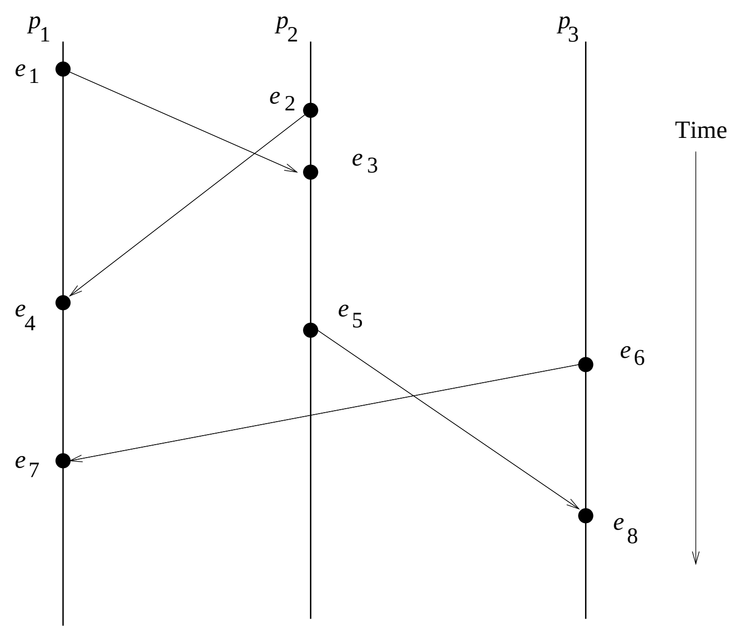


Global **time** does not exist in a DS
$\Longrightarrow$ need to construct a global **clock** (a system of local clocks)
$\Longrightarrow$ the clock assigns a **total order** (TO) to events such that the TO imposed by the global clock is *consistent* with the PO imposed by $<_H$
$\Longrightarrow$ fair request arbitration based on who asked first

Lamport's Logical Clock Algorithm $\Longrightarrow$ create the TO *on-the-fly*

- each e has a **timestamp** (e.TS) and each p maintains a local TS (my_TS)
- **algorithm** $\Longrightarrow$ *completely distributed*

```
my_TS = 0;
On event e,
  if (e == receipt of msg m) my_TS = max(m.TS, my_TS);
  my_TS++;
  e.TS = my_TS;
  if (e == sending of msg m) m.TS = my_TS;
```



- The timestaps are **causal**, *i.e.* $\boxed{\text{if } e_1 <_H e_2 \text{ then } e_1.\text{TS} < e_2.\text{TS}}$
- However, timestamps alone do not assign a total order

$\Rightarrow$ break ties via processor ID (p) $\Longrightarrow$ TO with **timestamp (e.TS, p)**