Clocks Broadcast Replication

Source:

- IB Distributed System
- y2014p5q7
- y2020p5q8
- y2010p5q6 (b)

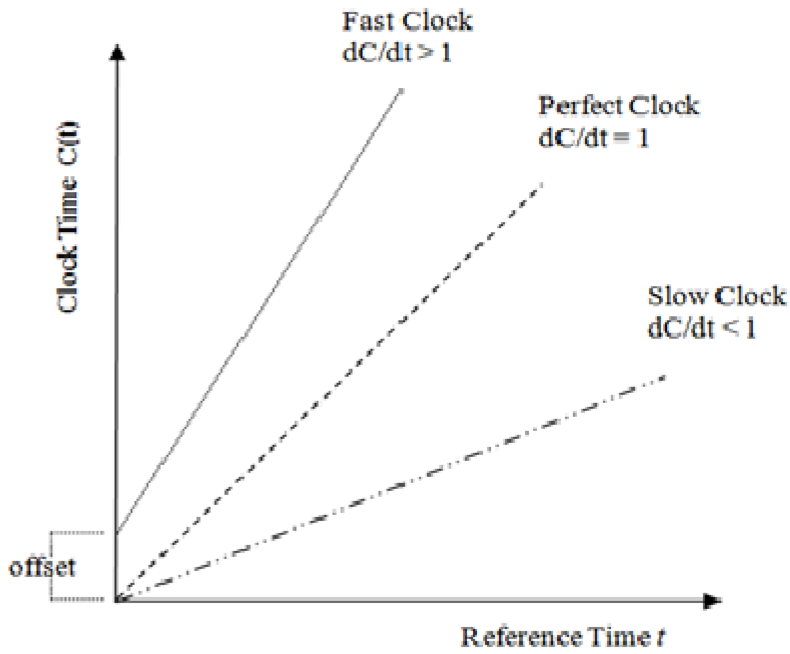
Clock	Physical	Logical
measure	seconds	events with causality
example	analogue/mechanic digital: Quartz (drift) Atomic, GPS	Lamport Vector

Physical Clock

Time-of-day and Monotonic

Physical Clock	Real Time	Monotonic
since	a fixed date time	arbitrary point (start-up)
correction	$slew \implies step$	always slew*forward*
behaviour	human readable; compare ts among nodes if sync	measure elapsed time on a single node
usage	certificate time	measure intervals / timeouts

Synchronization



The time of a clock in a machine p is $C_p(t)$, frequency/rate of a clock is $C_p'(t)$

- perfect clock ⇔ $C_p(t) = t$

Clock skew / offset

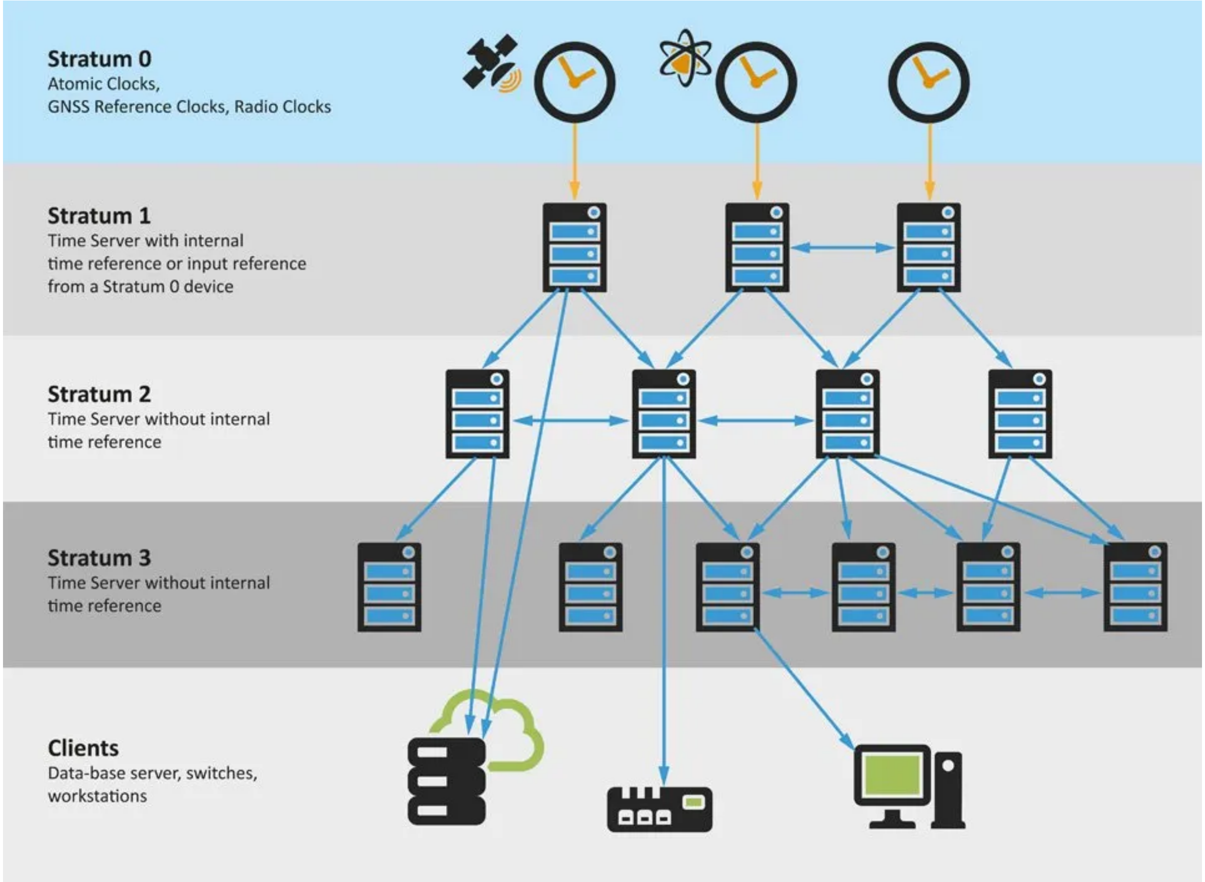
- the difference between the time on two clocks
- skew $\Delta_s = C_a(t) - C_b(t)$ (ms)
- measure: RTT δ, Cristian's Algorithm wiki
  - assumption:
    - symmetric latency
    - not consider the derivative of the clock (i.e. drift) or higher derivatives
- correction
  - as Δ_s increases, $slew \implies step \implies panic$

Clock drift

- the difference of clock rate of oscillations / ticks
- drift $\Delta_d = C_a'(t) - C_b'(t) = \Delta_s(t_1) - \Delta_s(t_2)$ (ms/day, parts per million)
  - affected by temperature, etc.
- measure: Cristian's Algorithm twice
  - assumption
    - symmetric latency
    - not considering the second or higher derivatives of the clock

NTP / PTP (Stratum 0-2)

- Less accurate synchronization
  - Time source (higher stratum)
  - Assumption of Cristian's Algorithm



Logical Clock

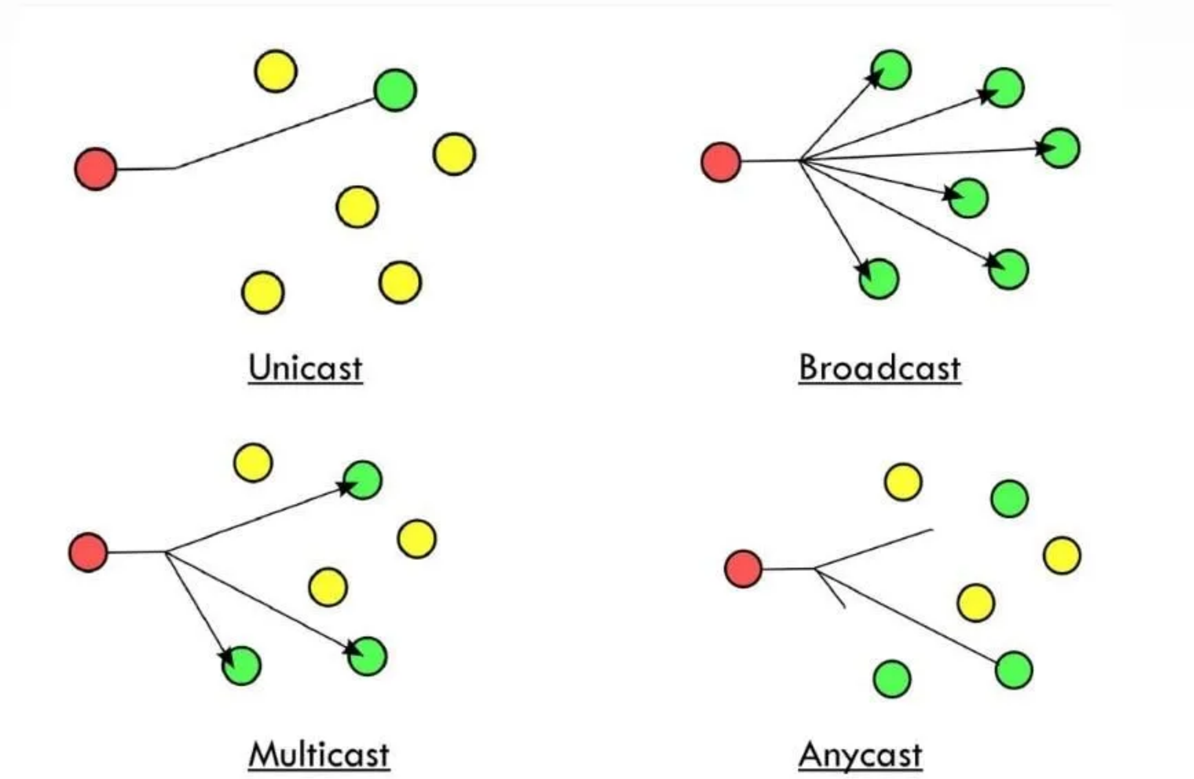
- causal / happen-before dependency $e_1 \to e_2$
  - e_1 and e_2 occurred at the same node, different by execution time
  - e_1 is sending message to e_2
  - transitivity, $\exists e_3.(e_1 \to e_3) \wedge (e_3 \to e_2) \implies e_1 \to e_2$.
  - (strict) partial order, asymmetric, undefined when race condition has occurred $e_1 || e_2$
- logical clock timestamp is consistency with causal dependency
  - But lamport may not get causal dependency of events back from logical timestamps.

$$e_1 \to e_2 \implies T(e_1) < T(e_2)$$

	Lamport	**Vector**
format	$(N(e), L(e))$ (i, Seq)	$\langle N_1, ..., N_n \rangle$ $V(e) = \langle t_1, ..., t_n \rangle$
order	$total \prec$	$partial < \|\|$
timestamp	scalar	vector
	$\implies$	$\iff$
initial	$(i, 0)$	$\langle 0, ..., 0, ..., 0 \rangle$
event occur	$(i, t) \to (i, t+1)$	$T_V[i] := T_V[i] + 1$

	Lamport	Vector
$receive(t'/T', m)$	$t := max(t, t') + 1$	$T_V := max_j(T_V, T')$ $T_V[i] := T_V[i] + 1$
$e = broadcast(m)$	FIFO of each sender	Causal

Broadcast



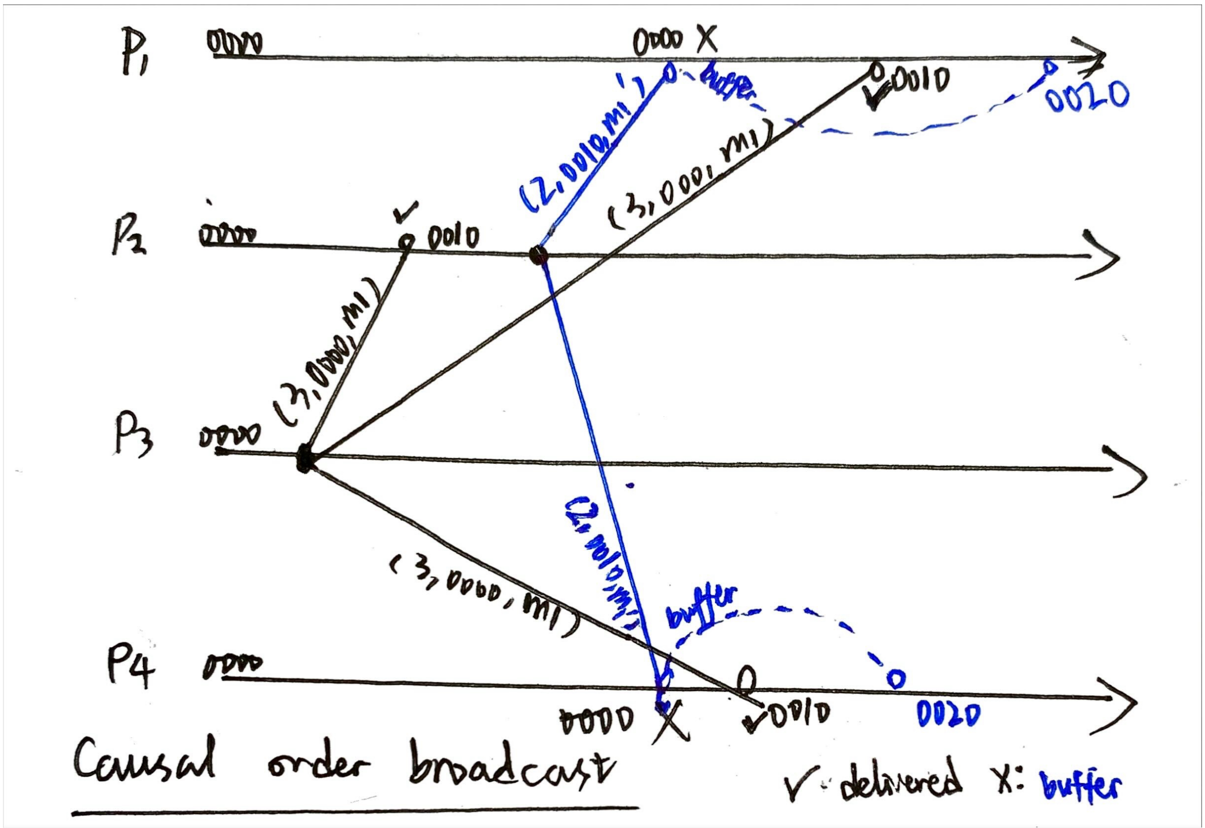
$$sendSeq := 0, delivered = \langle 0, ..., 0 \rangle, buffer := \{\}$$

FIFO order broadcast

- any messages *sent by the same sender* are delivered in the order in which they were sent.
  - $\forall m_1.(broadcast(m_1) \rightarrow broadcast(m_2))$ from the same sender, then every message (m_1) causally preceding ($\rightarrow$) m_2 , *from the same sender*, must be sent before m_2.
- **send**
  - $(i, sendSeq, m)$ via reliable broadcast
- **receive**
  - if $delivered[senderID] = sendSeq$
    - deliver the msg & update the *accumulator* $delivered$
  - otherwise, buffer (delay/hold back) the msg
    - $buffer := buffer \cup \{msg\}, buffer := buffer - \{msg\}$

Causal order broadcast

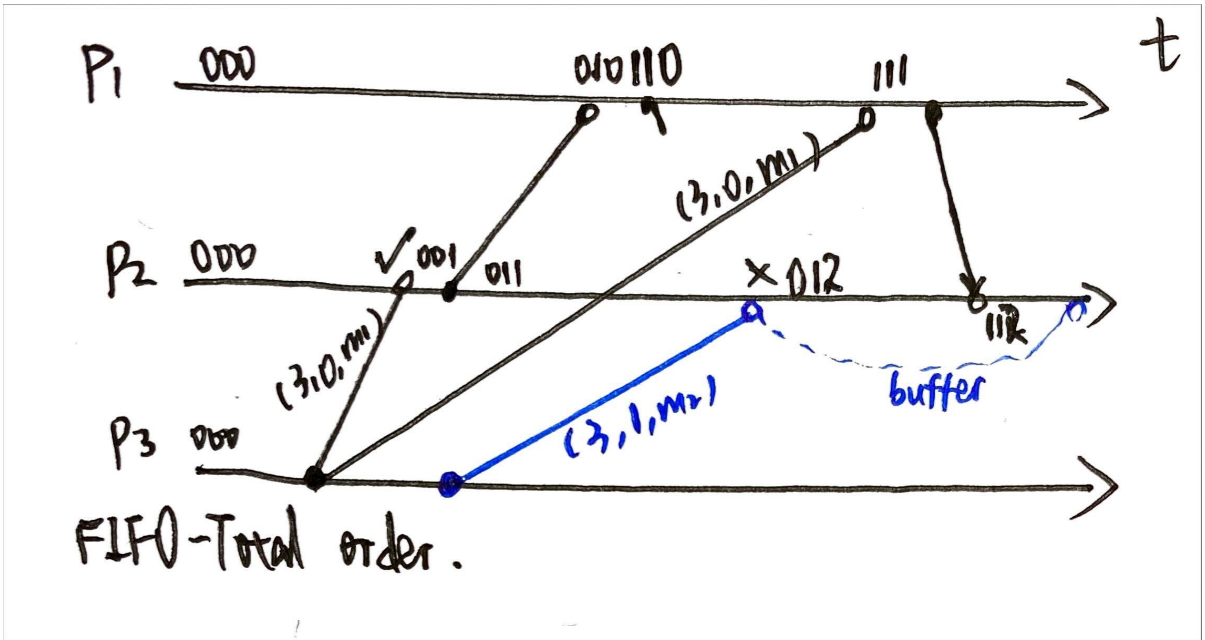
- any messages are delivered in the order of causality of broadcast events.
    - $\forall m_1.(\mathit{broadcast}(m_1) \to \mathit{broadcast}(m_2))$, then every message m_1 causally preceding ($\to$) m_2 must be sent before m_2.
    - **causality** between broadcast events is preserved by the corresponding delivery events.
    - concurrent broadcast events give *multiple* delivery choices, thus require commutative
- **send**
    - $(i, \mathit{delivered}', m)$ via reliable broadcast
- **receive**
    - if $\mathit{delivered}' \leq \mathit{delivered}$
        - deliver the msg & update the *accumulator* $\mathit{delivered}$
    - otherwise, buffer (delay/hold back) the msg



Total order broadcast

- the order of delivery is the same across all nodes.
    - If m_1 is delivered before m_2 on one node, then the same on all other nodes.
    - even need to hold back/delay/buffer message for itself.
- 1: Single Leader
    - upon broadcast, use FIFO link broadcast msg to the leader
    - the leader then broadcast the msg via FIFO link.
    - problem
        - Single Leader $\implies$ Single Point of Failure
        - Solution: fail over (for planned unavailable) or consensus
- 2: FIFO Total order
    - invariant

        - the order of delivery is the same across all nodes (total)
        - every message (m_1) causally preceding ($\rightarrow$) m_2 *from the same sender*, must be sent before m_2. (FIFO)
    - **send**
        - $(i, sendSeq, m)$ via **FIFO** broadcast
    - **receive**
        - update the *accumulator* $delivered$ first
        - total order of $(i, delivered[i])$
            - as future msg will have larger timestamp by FIFO link.
        - if $buffer.getMin() \leq delivered[argmin_j(j, delivered)]$
            - deliver the msg
        - otherwise, buffer (delay/hold back) the msg with priority queue ($getMin$)
            - wait for all the previous message to be broadcasted to all nodes
    - problem
        - not tolerant to node crashes



node crashes nw partition	link / broadcast	fault tolerance	Replication Consistency	Wait	Timing
crash	FIFO-Total order		SMR	all nodes	partially syn
SPOF	single leader Total order	atomic 2PC Consensus fail over	 linearizable CAS linearizable g/s	all nodes quorum quorum	partially syn partially syn asyn
	Causal order	$V(e) = \langle t_1, ..., t_n \rangle$ $\|\|commute$	eventual consistency	local replica	asyn
	FIFO order	(i, Seq)		local	asyn
	Reliable	commute			
crash-recovery fail-arbitrary crash-stop	Fair-loss Best-effort (*node crashes*)	retry+dedup (*idempotent*) n:eager / 3:gossip			
	Arbitrary	TLS			