Vector Clocks

Can we have a Clock Model better than Lamport's Logical Clock?

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Definition

- A vector clock of a system of N processes is an array or vector of N logical clocks with one clock per process.
- A local *smallest possible value* copy of the global clock-array is kept in each process

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Rules for Vector Clock Synch.

- Initially all the clocks are set to zero.
- Each time an event occurs locally, the local logical clock in the vector is increased by one.
- Each time a process prepares to send a message, it sends its entire vector clock along with the message.

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Rules for Vector Clock Synch.

- Each time a process receives a message, it increments its own logical clock in the vector by one
- The recipient updates each element in its vector by the maximum of the value in its own vector clock and the value in the vector in the received message for every component.

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Notations

- VC(E) denotes the vector clock of event E.
- $VC(E)_X$ denotes the component of that clock for node X.
- VC(A) < VC (B) if and only if
  - $\forall$ x, $VC(A)_X \leq VC(B)_X$ and
  - $\exists x[VC(A)_x < VC(B)_x]$

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Story

- Amit, Biman, Chetri, and Dithi are planning to meet next week for dinner.
- The planning starts with Amit suggesting they meet on Wednesday.
- Later, Dithi discuss alternatives with Biman, and they decide on Tuesday.
- Dithi also exchanges email with Chetri, and they decide on Thursday.

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Story

- When Amit pings everyone to find whether they still agree with his on Wednesday, he gets mixed messages:
  - Chetri claims to have settled on Thursday and Biman claims on Tuesday, both with Dithi.
  - Dithi can't be reached, and so no one is able to determine the order in which these communications happened, and so none of Amit, Biman, and Chetri know whether Tuesday or Thursday is the correct choice.

Solution

- Tag the date choice with a vector clock
- Each member update the clock whenever they alter the choice.
- Start with Amit's initial message:
  - date is Wednesday
  - tag with Amit is [A:1] [B:0] [C:0] [D:0]
  - tag with Biman, Chetri and Dithi are still on
    - [A:0] [B:0] [C:0] [D:0]

Solution

- Amit's message reach others:
  - tag with Amit is [A:1] [B:0] [C:0] [D:0]
  - tag with Biman is [A:1] [B:1] [C:0] [D:0]
  - tag with Chetri is [A:1] [B:0] [C:1] [D:0]
  - tag with Dithi is [A:1] [B:0] [C:0] [D:1]

Solution

- Now, Dithi and Biman start talking.
- Biman suggests Tuesday:
  - date is Tuesday
  - tag with Biman is [A:1] [B:2] [C:0] [D:0]
- Dithi accepts it and sends a confirmation
  - tag with Dithi is [A:1] [B:2] [C:0] [D:3]
- Biman gets the message:
  - tag with Biman is now [A:1] [B:3] [C:0] [D:3]

Solution

- Now, Chetri and Dithi start talking.
- Chetri suggests Thursday:
  - date is Thursday
  - tag with Chetri is [A:1] [B:0] [C:2] [D:0]
- Dithi accepts it and sends confirmation
  - tag with Dithi is [A:1] [B:2] [C:2] [D:5]
- Chetri gets the message:
  - tag with Chetri is [A:1] [B:2] [C:3] [D:5]

Solution

- When Amit asks for the response,
- Biman responds as
  - date is Tuesday
  - tag is [A:1] [B:3] [C:0] [D:3]
- Chetri responds as
  - date is Thursday
  - tag is [A:1] [B:2] [C:3] [D:5]

Solution

- From this, Amit understands that Dithi had talks with Chetri to override the decision he made with Biman earlier.
- All Amit has to do is to show Biman the tags from Chetri's message.
- Everybody now knows that which decision is the latest one.

Properties

- If VC(A) < VC(B) then A → B
- If VC(A) < VC(B) and If VC(B) < VC(C) then If VC(A) < VC(C) [transitive]
- If VC(A) < VC(B) then ⌐VC(B) < VC(A) [anti-symmetric]
- Vector Clock generates a partial ordering

How is it different from logical clock?

- In Vector Clock, instead of each node storing only its own timestamp, it stores a vector of timestamps equal to the number of nodes in the system.
- Each node knows its own position in the vector, and the clocks of other nodes when it last synchronized.
- It's a record of that node's knowledge about the rest of the system.

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How is it different from logical clock?

- The synchronization events include the sender's vector clock.
- By comparing these clocks, the algorithm can better determine the causal order of events.

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Event Order and Vector Clock

- If all of the timestamps for event A are less than or equal to all of event B's timestamps, then A occurred before B

A B

[1, 0, 1, 2] [2, 1, 1, 2]

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Event Order and Vector Clock

- If all of the timestamps for event A are less than or equal to all of event B's timestamps, then A occurred before B

A B

[1, 0, 1, 2] [2, 1, 1, 2]

[TC(A) < TC(B)]

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Event Order and Vector Clock

- If all of the timestamps for event A are less than or equal to all of event B's timestamps, then A occurred before B

A → B

[1, 0, 1, 2]   [2, 1, 1, 2]

[TC(A) < TC(B)]

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Event Order and Vector Clock

- If all of the timestamps for event A are greater than or equal to all of event B's, then B came before A

A   B

[3, 1, 2, 2]   [2, 1, 1, 2]

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Event Order and Vector Clock

- If all of the timestamps for event A are greater than or equal to all of event B's, then B came before A

[3, 1, 2, 2]   [2, 1, 1, 2]

[TC(A) > TC(B)]

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Event Order and Vector Clock

- If some A's timestamps are greater than that for event B and some are less, then no ordering can be inferred

[3, 0, 1, 1]   [2, 1, 1, 2]

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Event Order and Vector Clock

- If some A's timestamps are greater than that for event B and some are less, then no ordering can be inferred

A ≋ B

[3, 0, 1, 1] [2, 1, 1, 2]

???

So is it all so good?

- It provides a partial order only – so vector clocks are not enough for a complete ordering of events
- The components of the vectors will grow proportionally with the number of clients.
- In many applications, e.g., in a distributed storage system the number of clients over time can be large.

So, is it all so good?

- Once the vector clocks get that large, they not only take up more space in disk and RAM but also take longer to compute comparisons over.

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Thanks for your kind attention

Questions??

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