Mixed Physical and Cyber Clocks for CPS

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SEI – Carnegie Mellon

New Clockwork for CPS Workshop
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Role of clocks in CPS

Order events across distributed processes

Synchronize cyber and physical processes

Synchronize different cyber processes

Synchronize different physical processes

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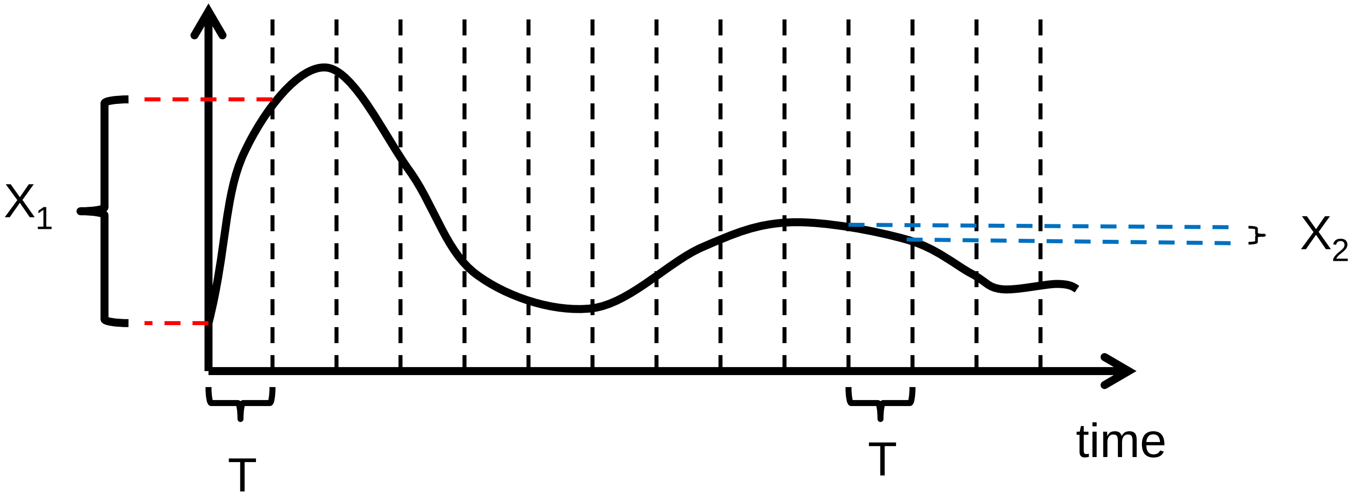
Synchronize cyber processes with physical processes

Traditionally done by fixing a “sampling” period



Drawbacks:

Variation in the evolution of physical process can be large (X_1>>X_2)

Need to force minimum period

Pessimistic resource utilization for guaranteed deadlines

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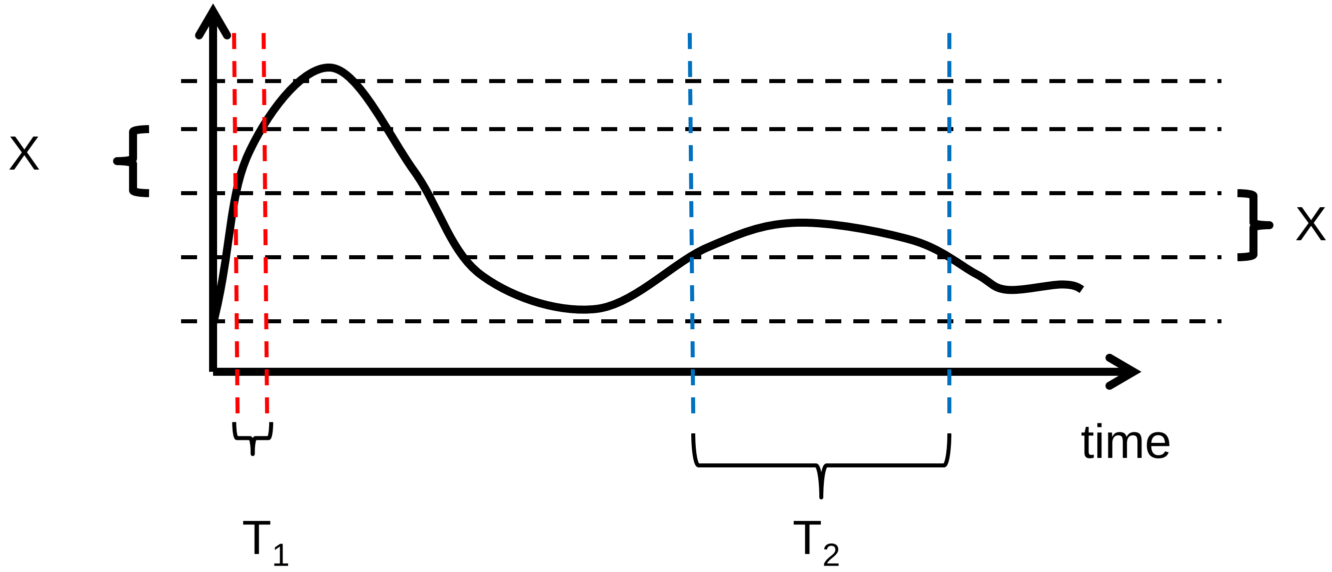
Synchronize cyber processes with physical processes

Approach: Let the physical process drive the computation



Alternative approaches:
Event-based control
Self-triggered control

Improved resource utilization for guaranteed deadlines

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Synchronizing different cyber processes

Using a "common" clock

- Common reference (e.g. GPS)
- Synchronized local clocks (e.g. NTP)
- Logical clocks

Reliability needs to be taken into account

- Loss of satellite signals (GPS)
- Synchronization message loss (NTP)
- Synchronization message delays (logical clocks)

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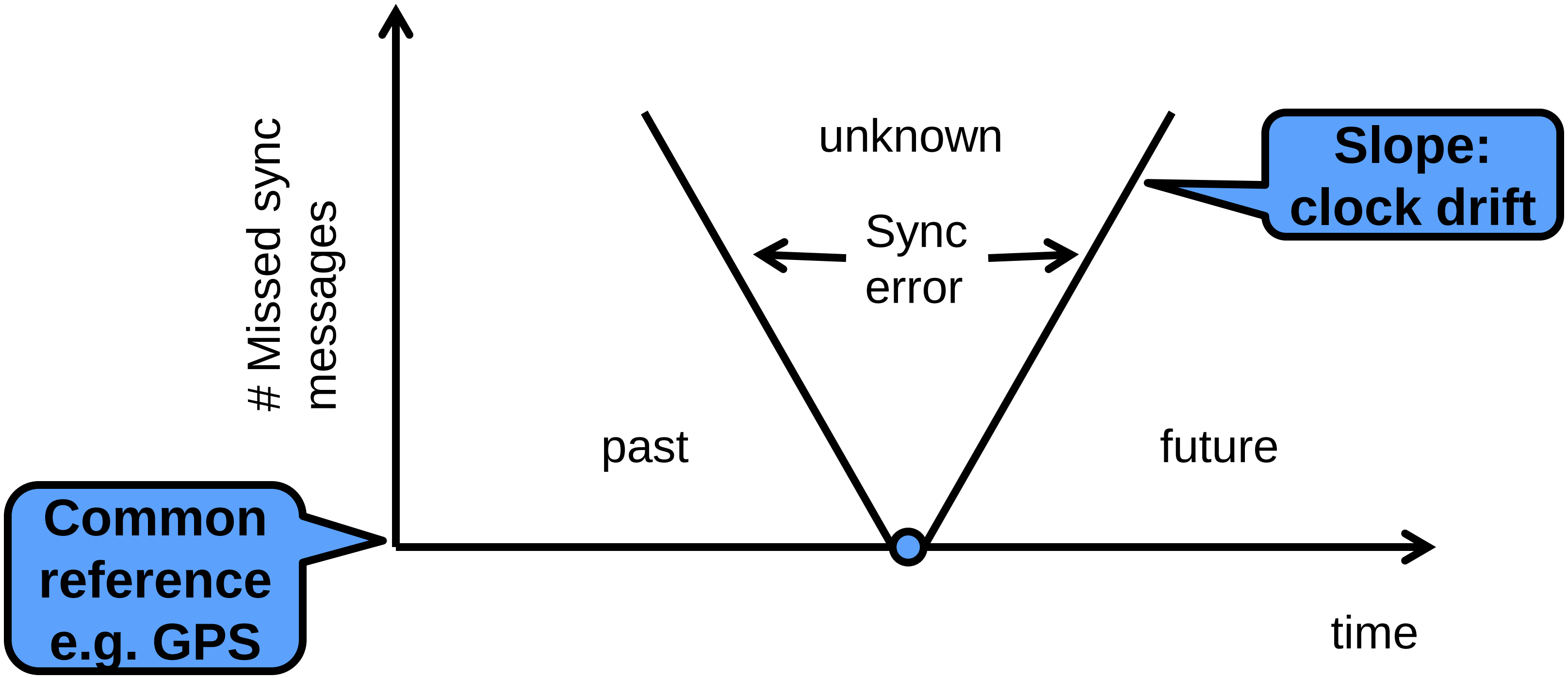
Synchronized cyber-clock accuracy



From the loss of the common reference
every time we miss a sync message the sync error increases

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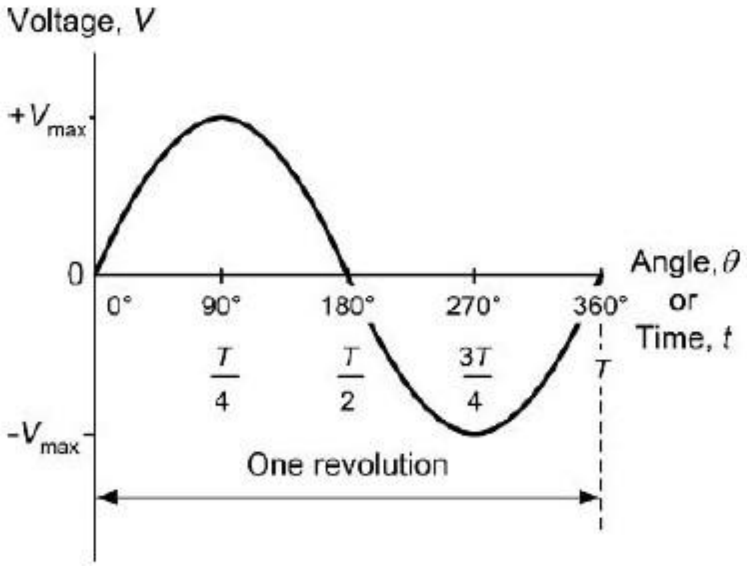
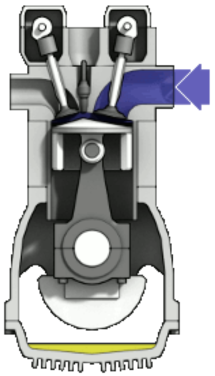
Common physical processes in CPS

In a CPS cyber processes may observe a common physical process (physical variable)

- AC cycle in the smart grid
- Crankshaft angle in an engine





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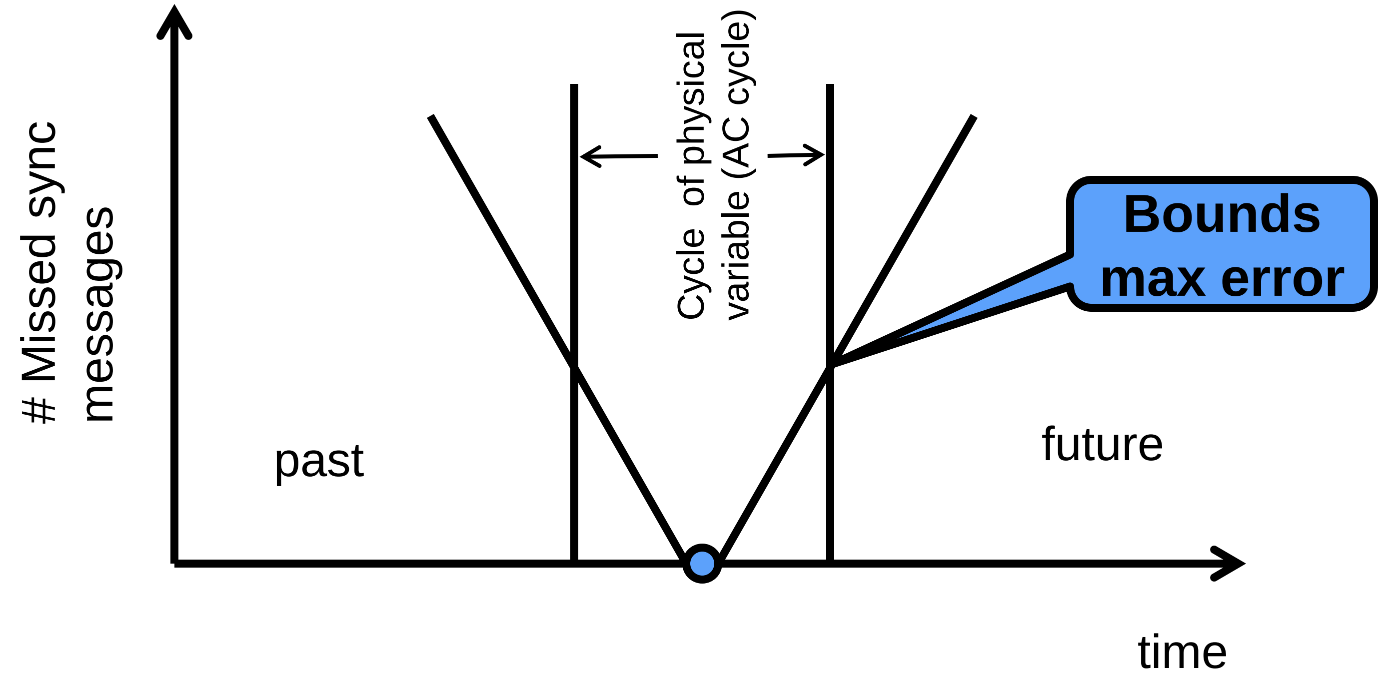
Combining sync clocks with physical variable



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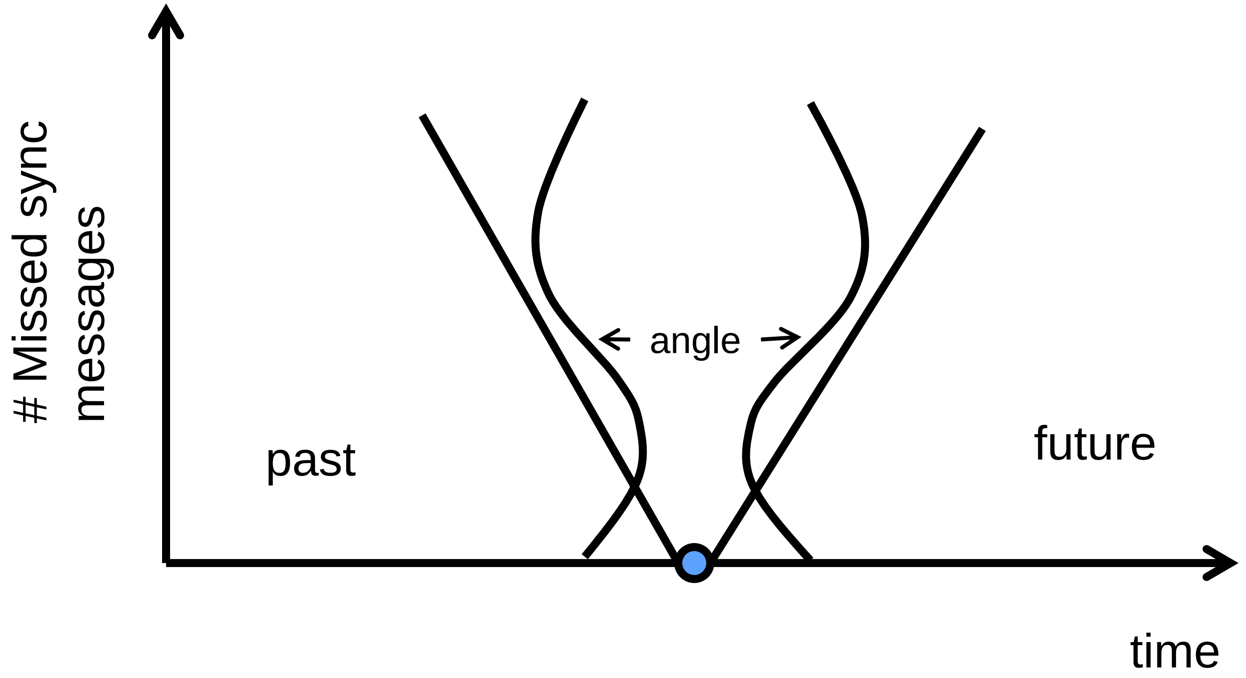
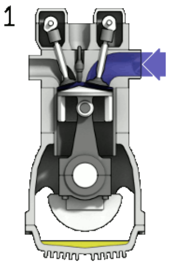
Physical process with variable cycles





In CPS time is frequently a proxy for physical variable
Hence, cyber processes only require sync with physical variable

E.g. open/close valves sync with fuel injection

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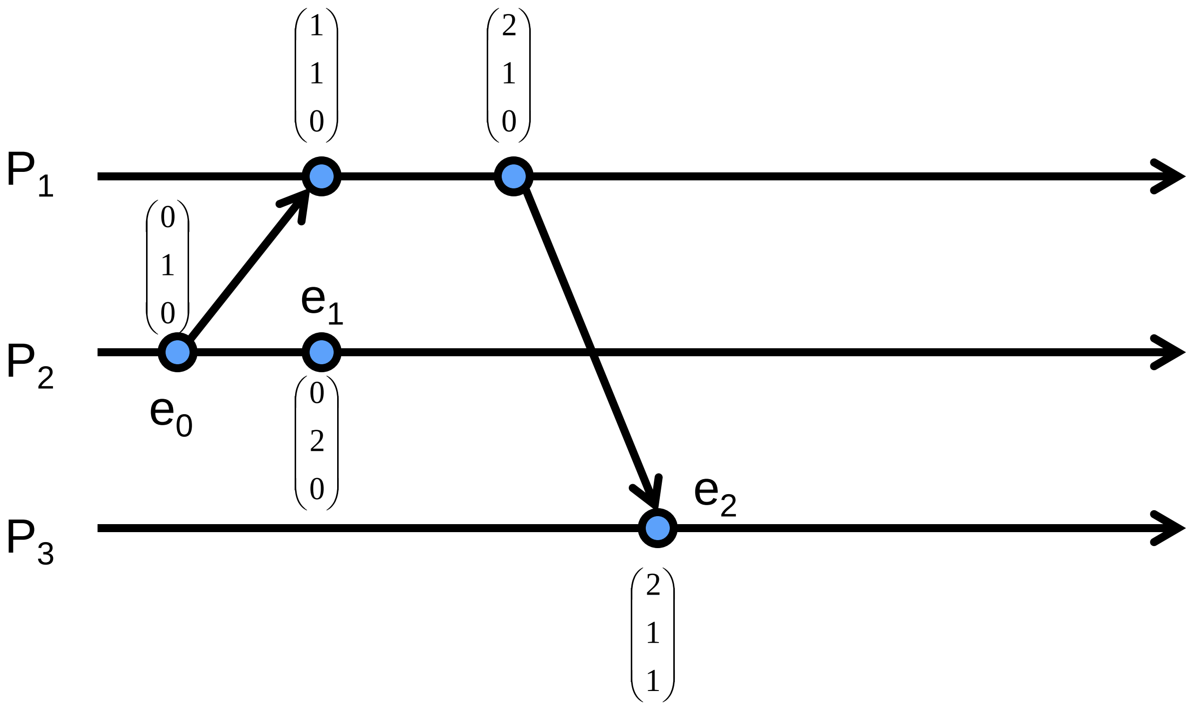
Logical (vector) clocks can also complement sync



But they are also sensitive to “missed” syncs

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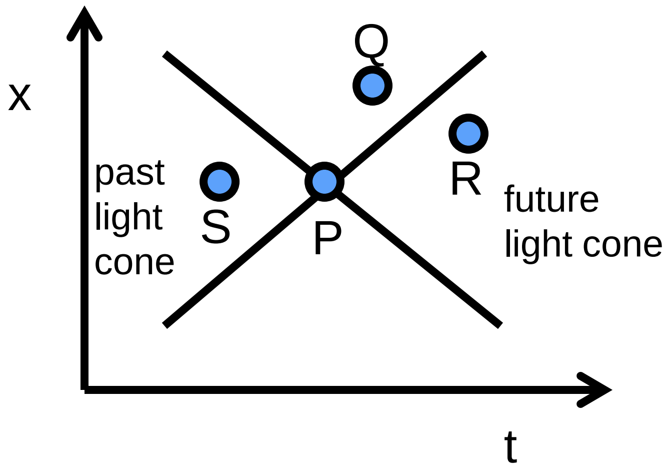
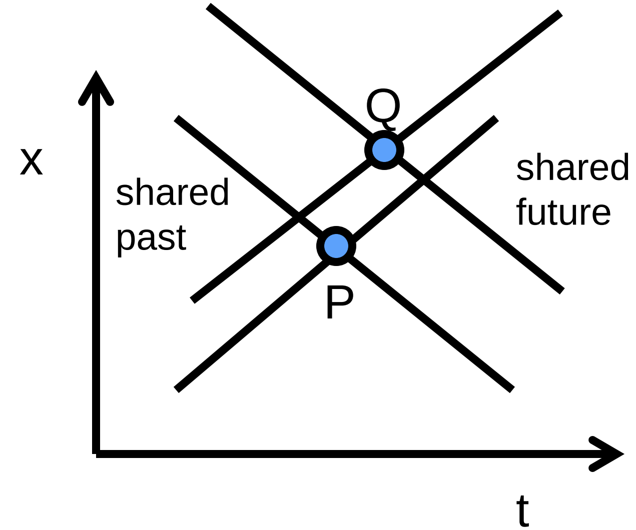
Mattern related vector clocks to Minkowski's spacetime





In CPS "x" can also be related to a physical variable
(and back to time)

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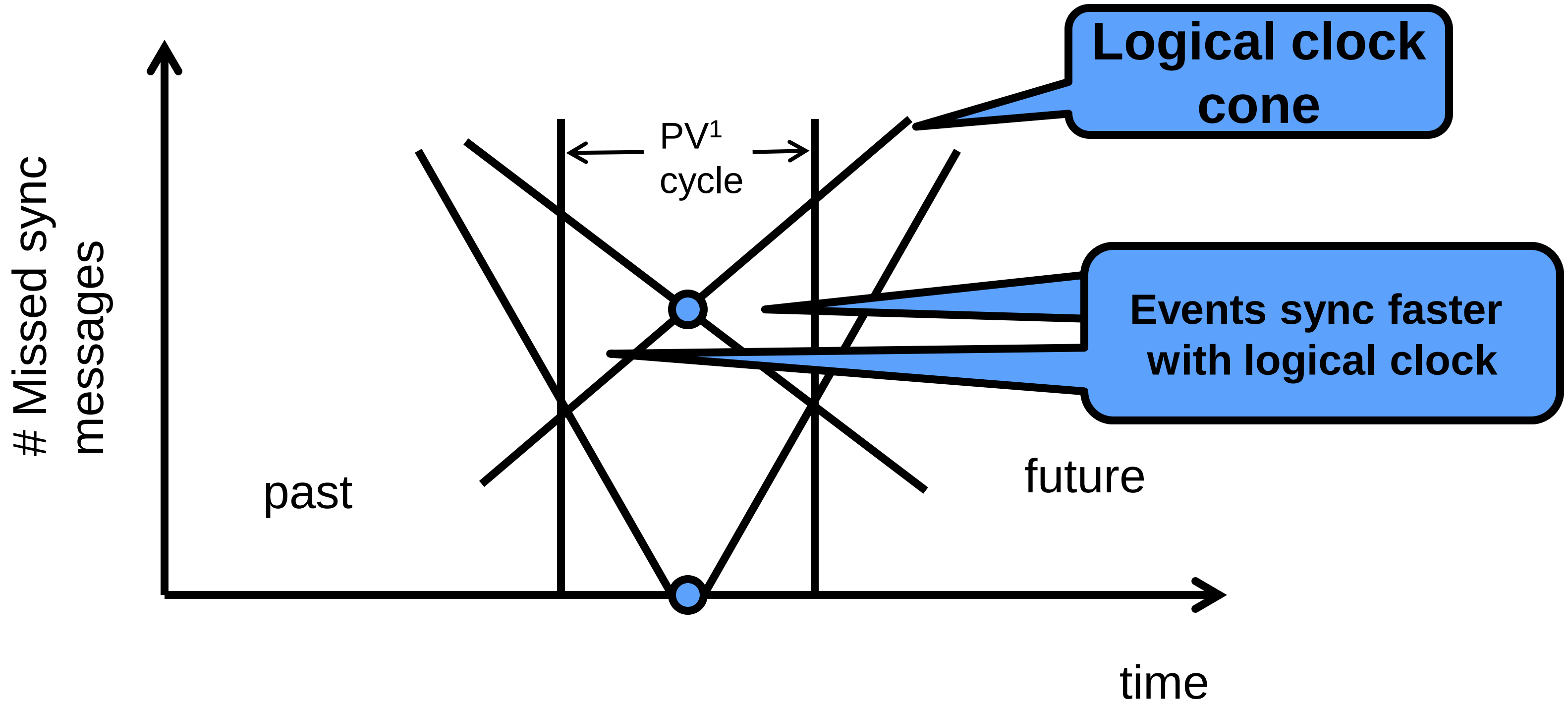
Mixed Physical and Cyber Clocks



[1]PV: physical variable

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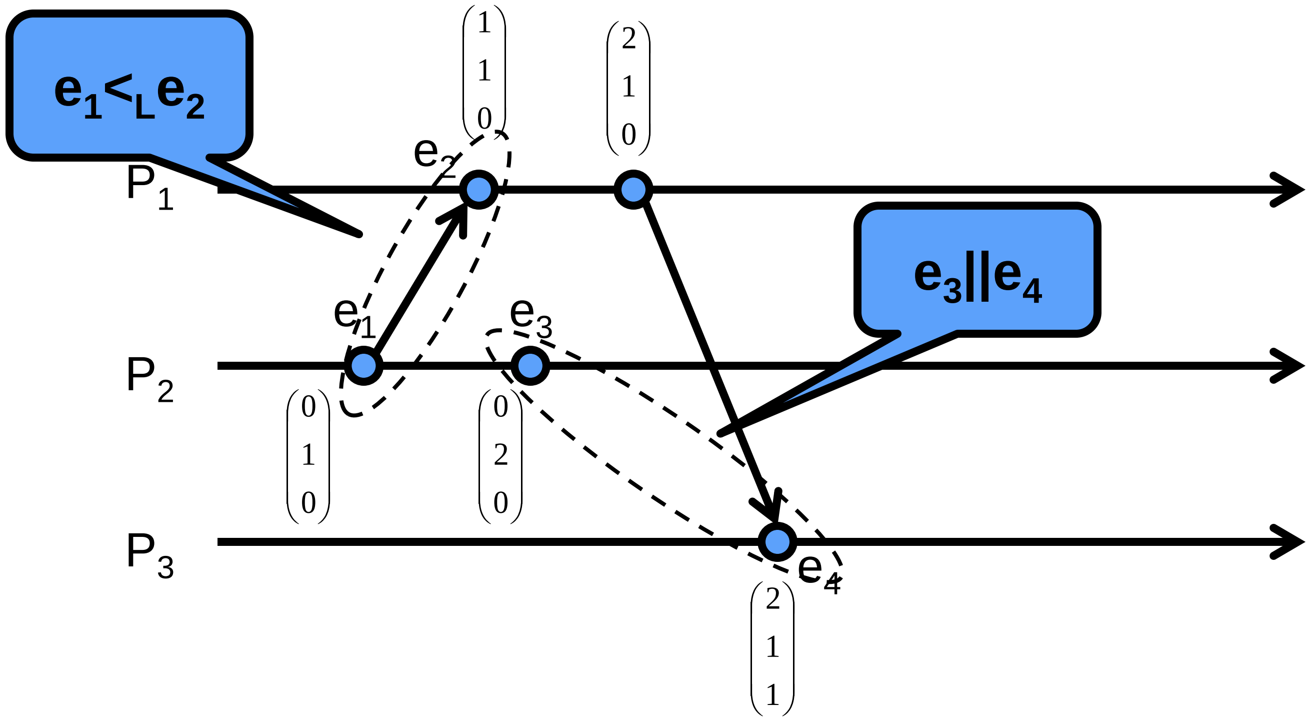
Limitations of Logical Clock



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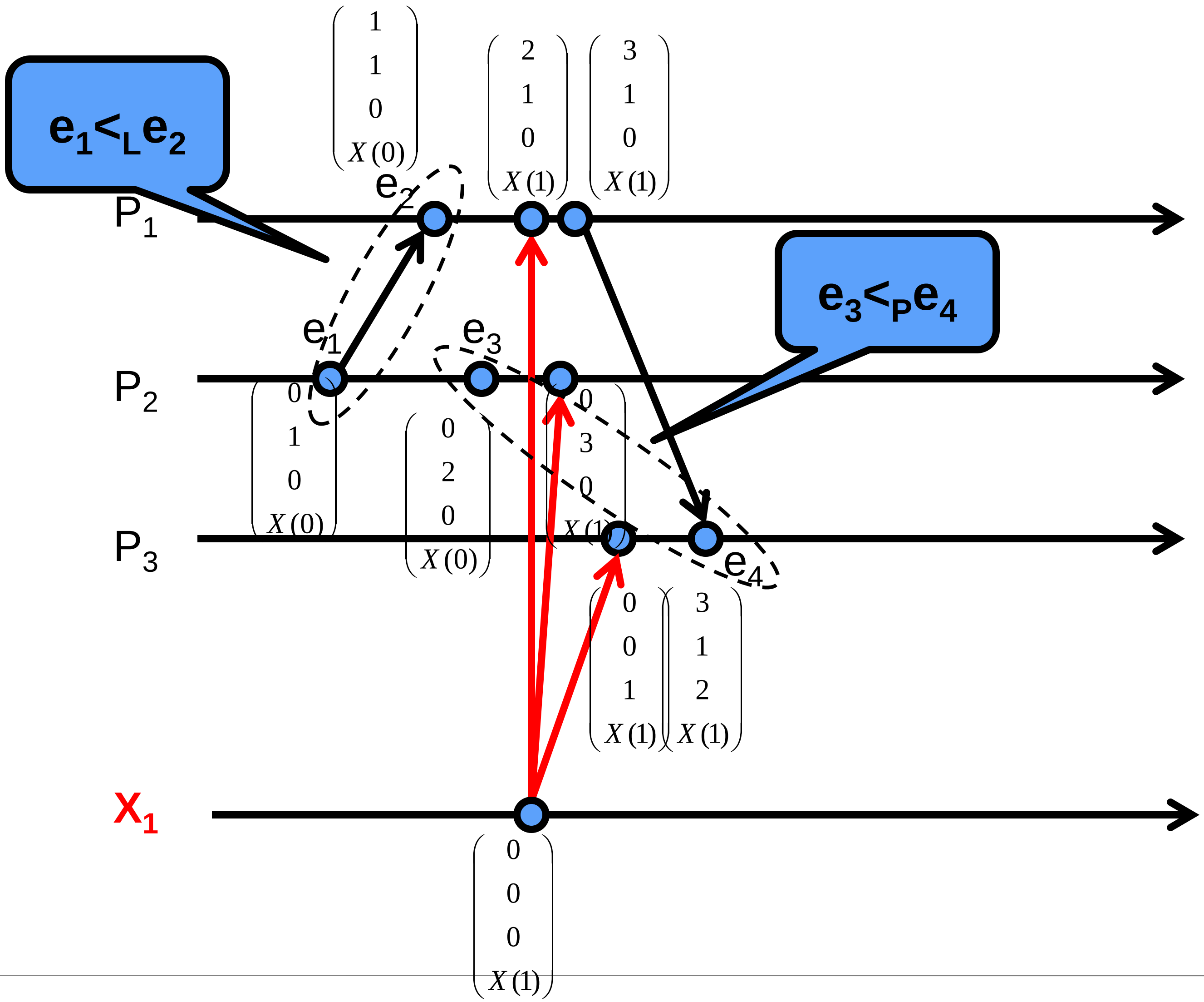
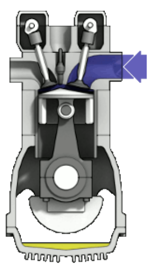
Logical + Physical Clock



1 

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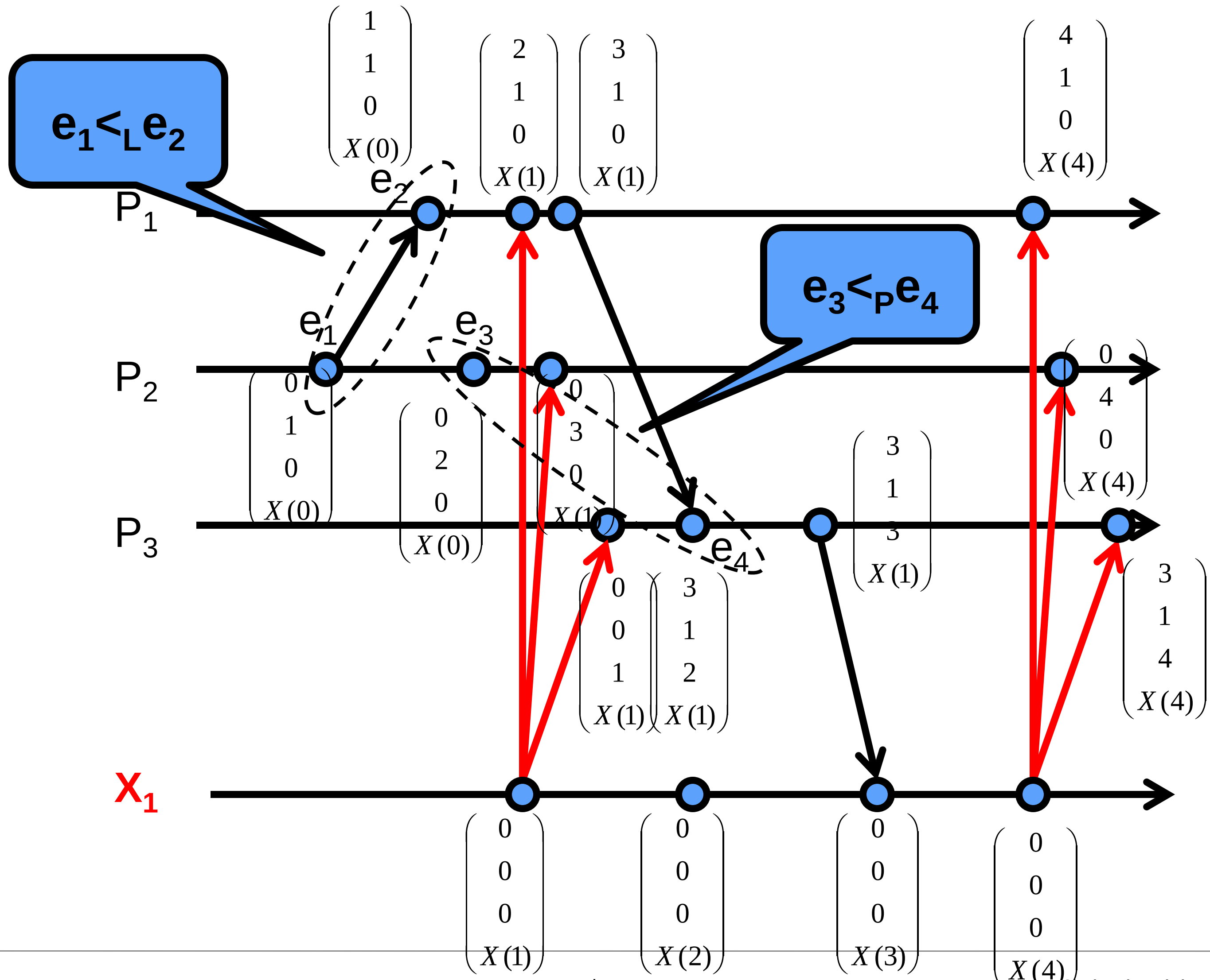
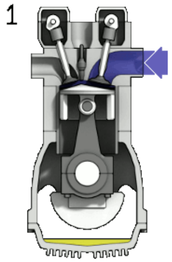
Physical processes also "receive" messages (actuation)





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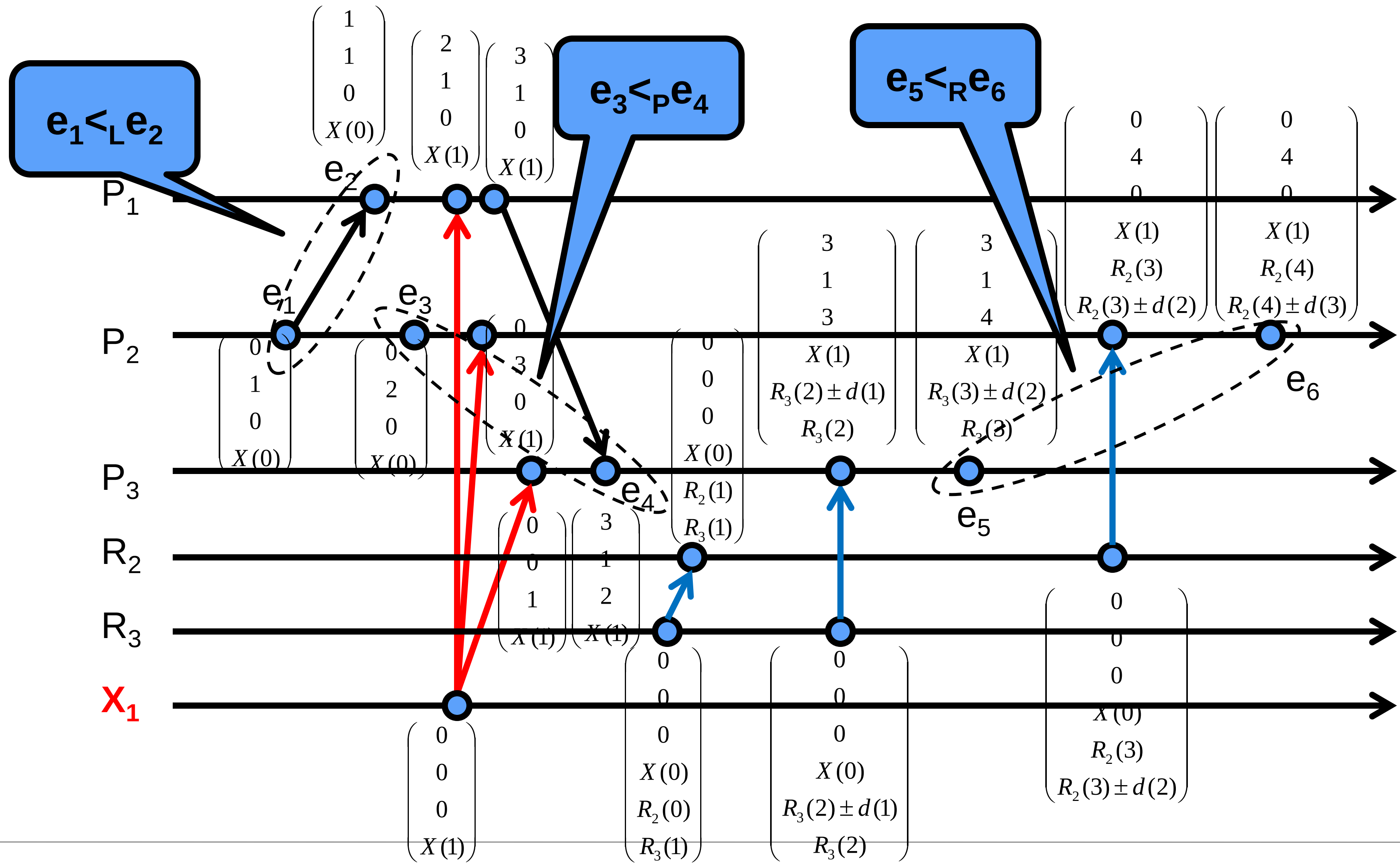
Logical + Physical Clock + Real-time clock



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Preserving time properties[1]

1. Transitivity
   - Mixed vectors allows transitivity across domains (logical, physical, real-time)
   - But can also exhibits non-transitive concurrency
2. Irreflexibility
3. Linearity
4. Eternity
5. Density
   - Improved but variable density

[1]The Logic of Time. van Benthem.

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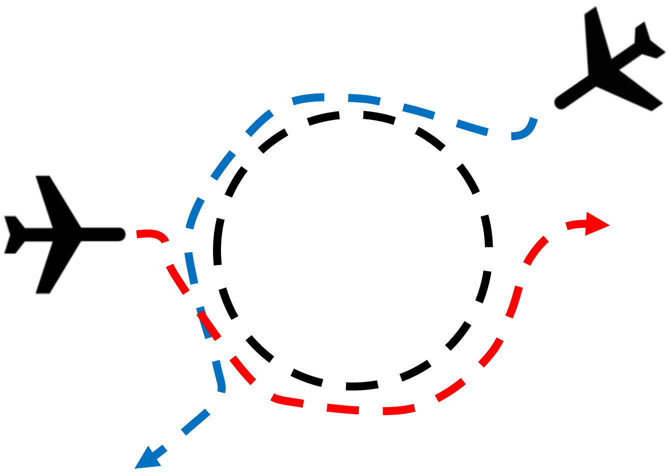
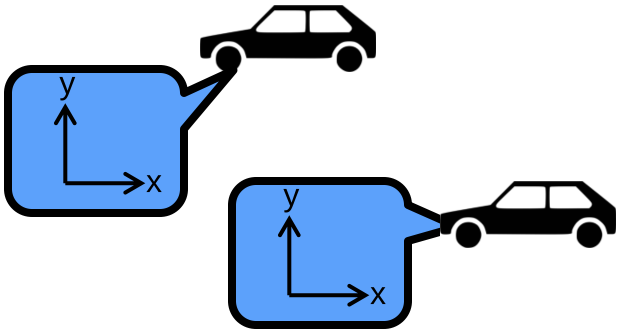
Sync (couple) different physical processes

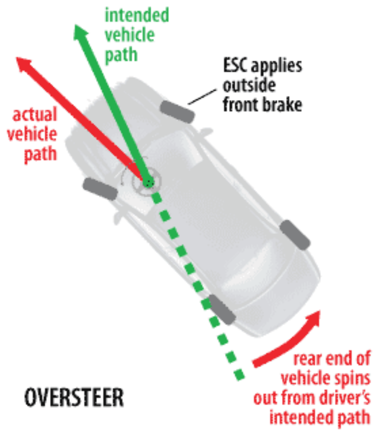
Use cyber-clocks to create a virtual process

Safety

- Airplane collision avoidance maneuvers
- Cooperative collision warning system[1]
- Electronic Stability Control







Clock failures can jeopardize coupling

[1]California PATH Research. Sengupta et al.

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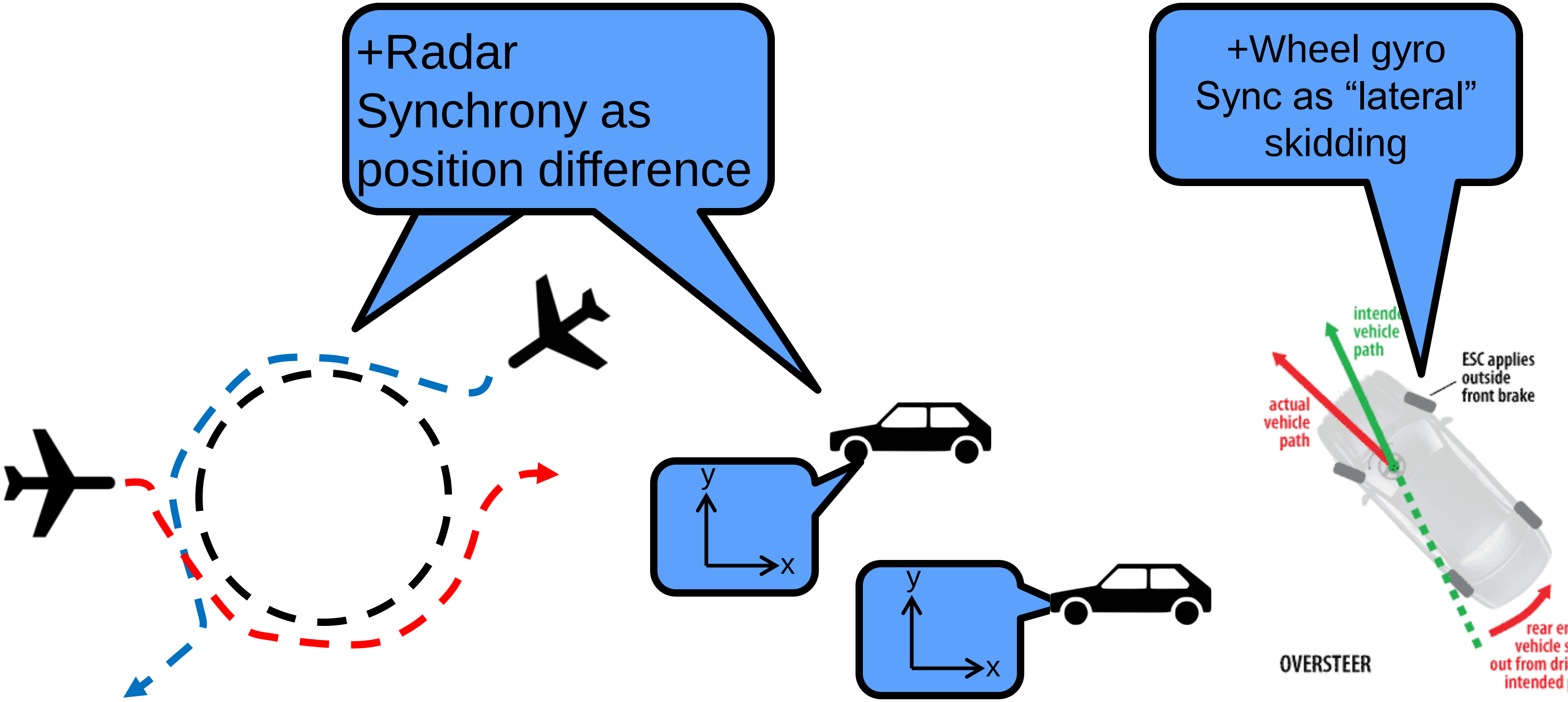
Robustness of Mixed Physical and Cyber Clocks



Nissan steer-by-wire:
maybe in market in 2013

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Using mixed clocks: robust agreement

Co-relate cyber agreement with physical agreement

Prevent false faults

- Acknowledge cyber clock timeout but observed physical change
  - Physical model allows the detection “physical clock” advance

False agreement

- Collision avoidance:
  - Agreed roundabout trajectory
  - But no trajectory correction
    - Physical clock timeout: need physical model of expected change

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Concluding Remarks

CPS allows us to revisit the concept of time

- Implementation mechanisms to improve robustness
- Application requirements

Challenges combining physical, cyber, and logical clocks

- Variable density
- Requires building consistent transitivity across domains

Improves synchronization across different types of processes

- Cyber to physical
- Physical to physical

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