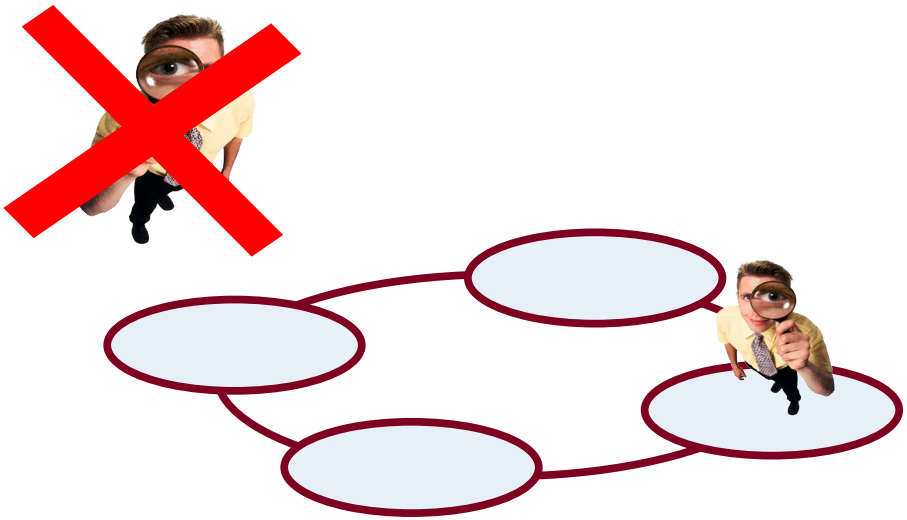
Goals

- No global omniscient observer
- How to observe/reason about the system from the inside?

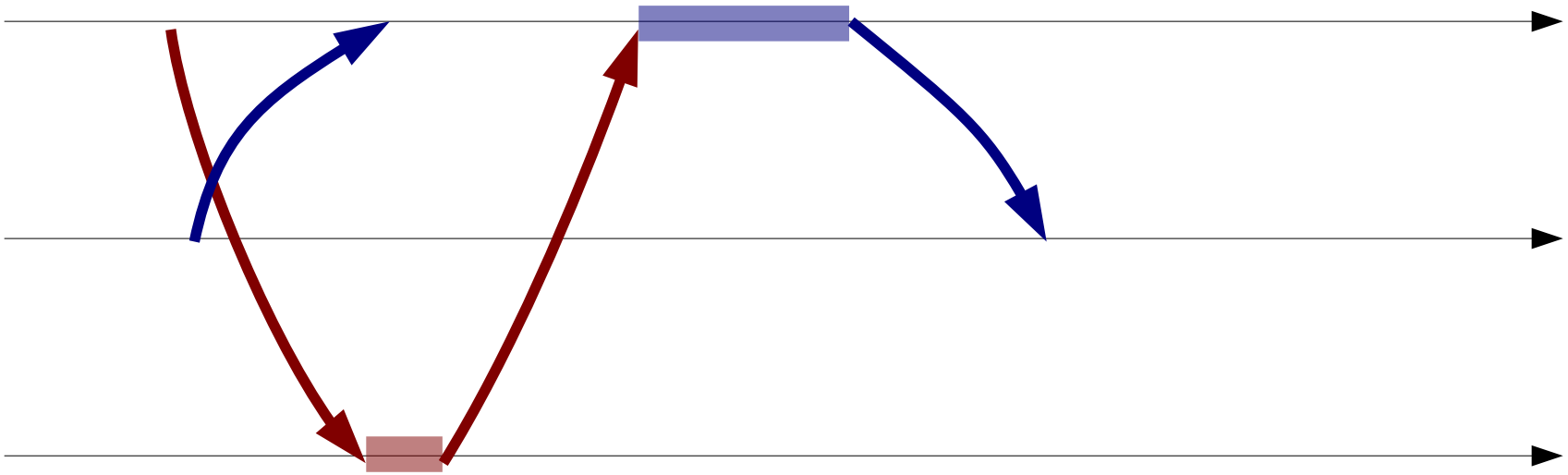


Example: Distributed deadlock

- Remote invocation
- All processes request and reply to invocations
- A mutex is held while invoking remotely or handling remote invocations
- Distributed deadlock possible when multiple processes invoke each other

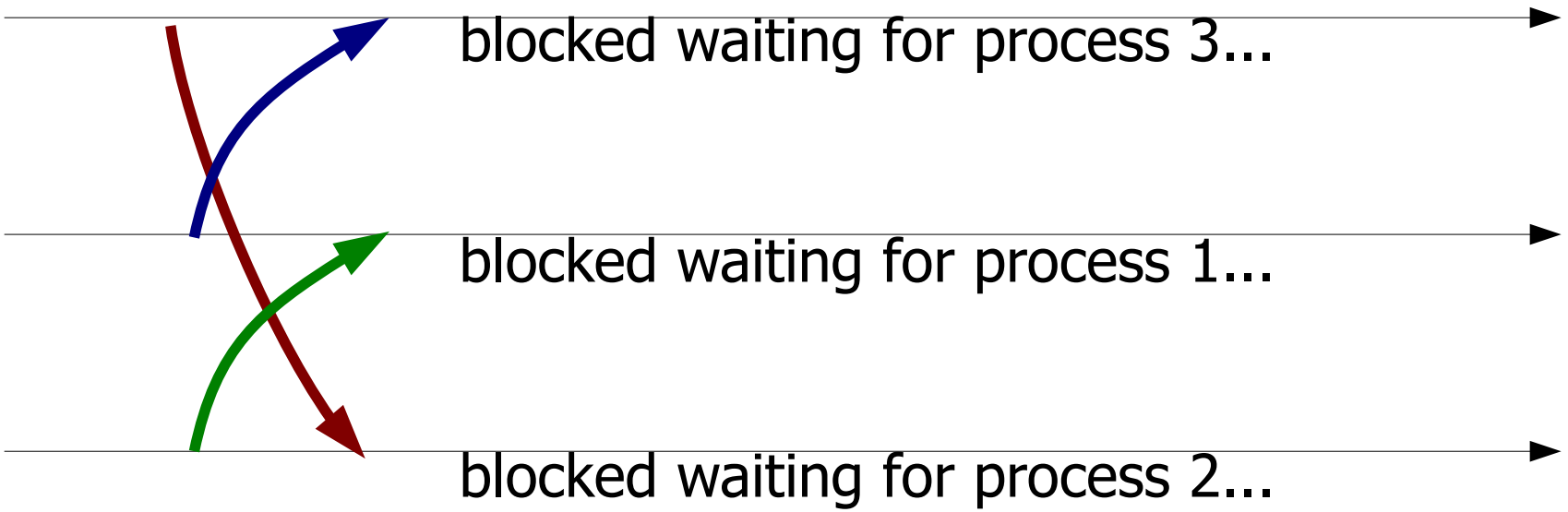
Example: Distributed deadlock

- Deadlock-free run:



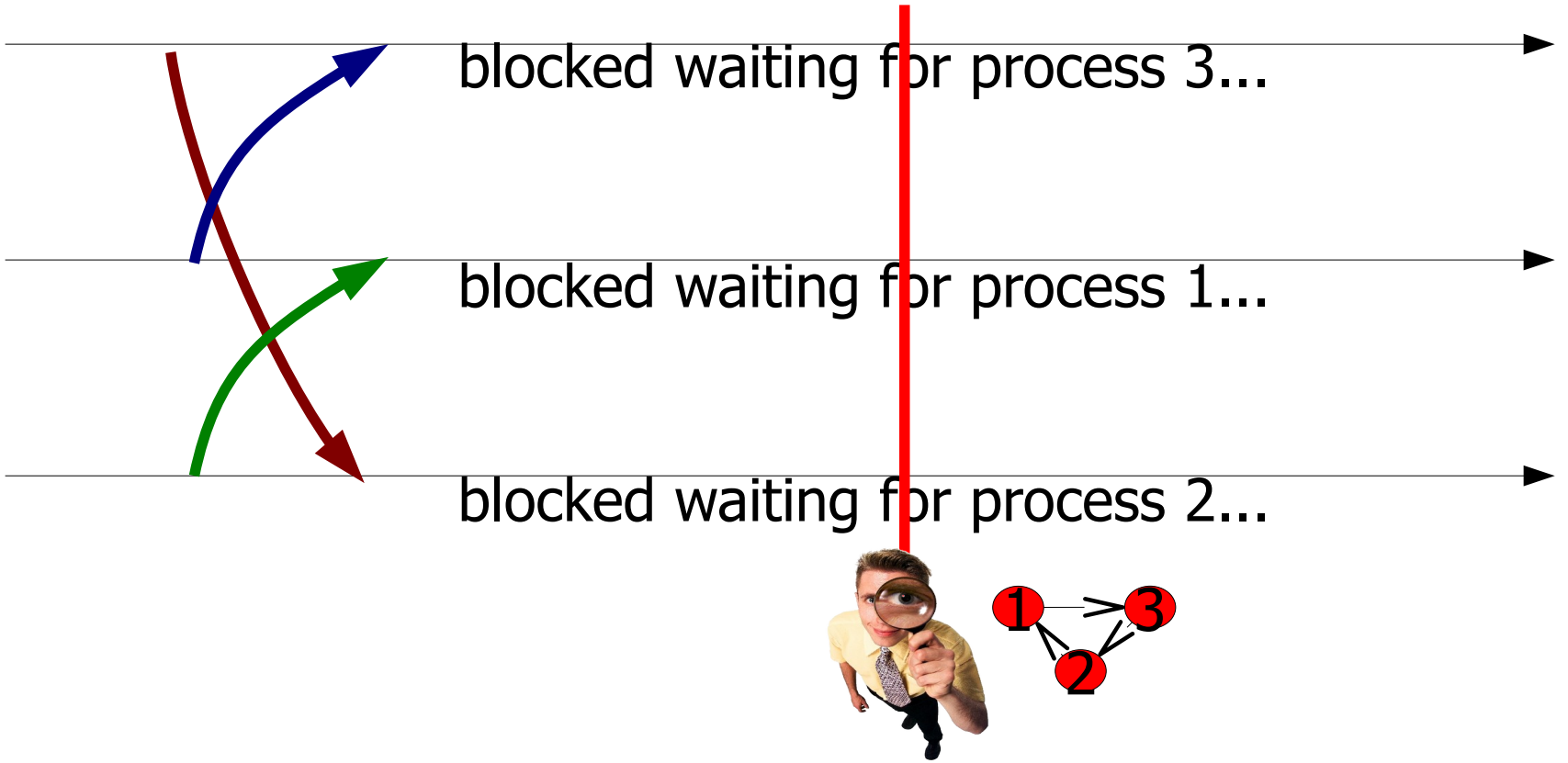
Example: Distributed deadlock

- Distributed deadlock:



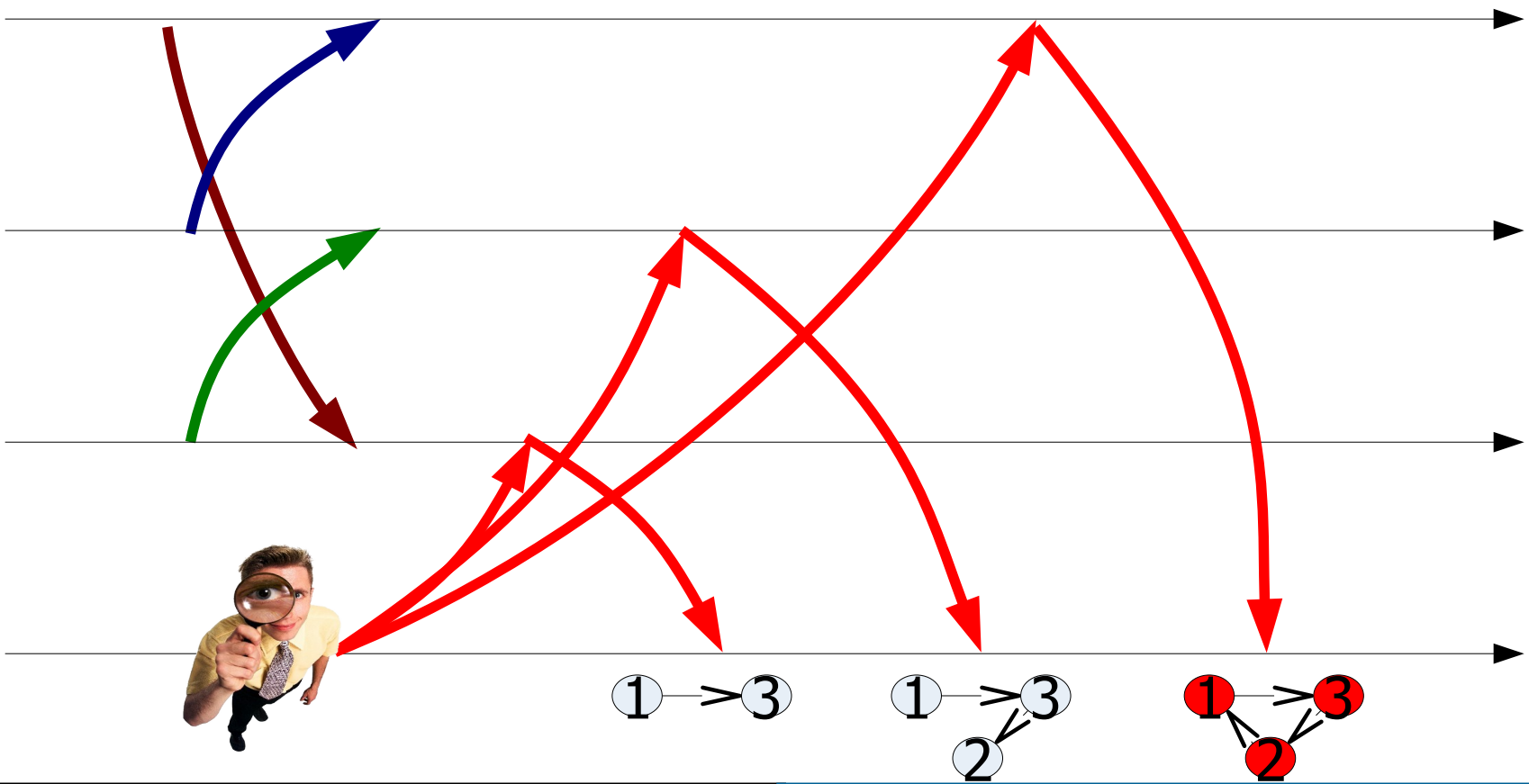
Example: Distributed deadlock

- Instant observation is impossible:



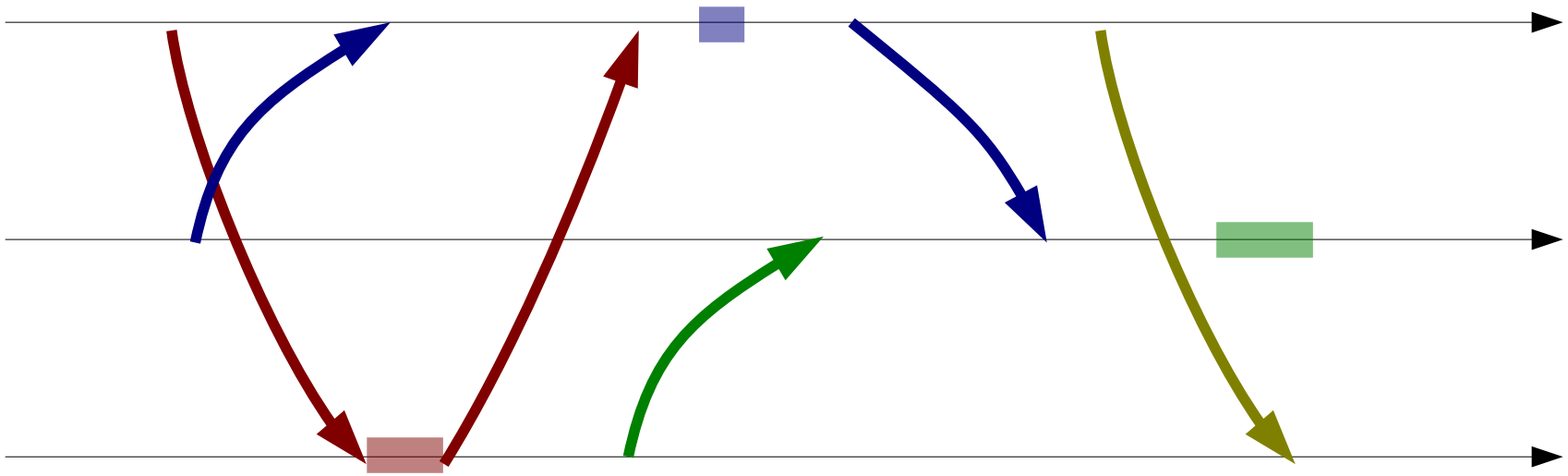
Example: Distributed deadlock

- Deadlock detection with a “wait for” graph:



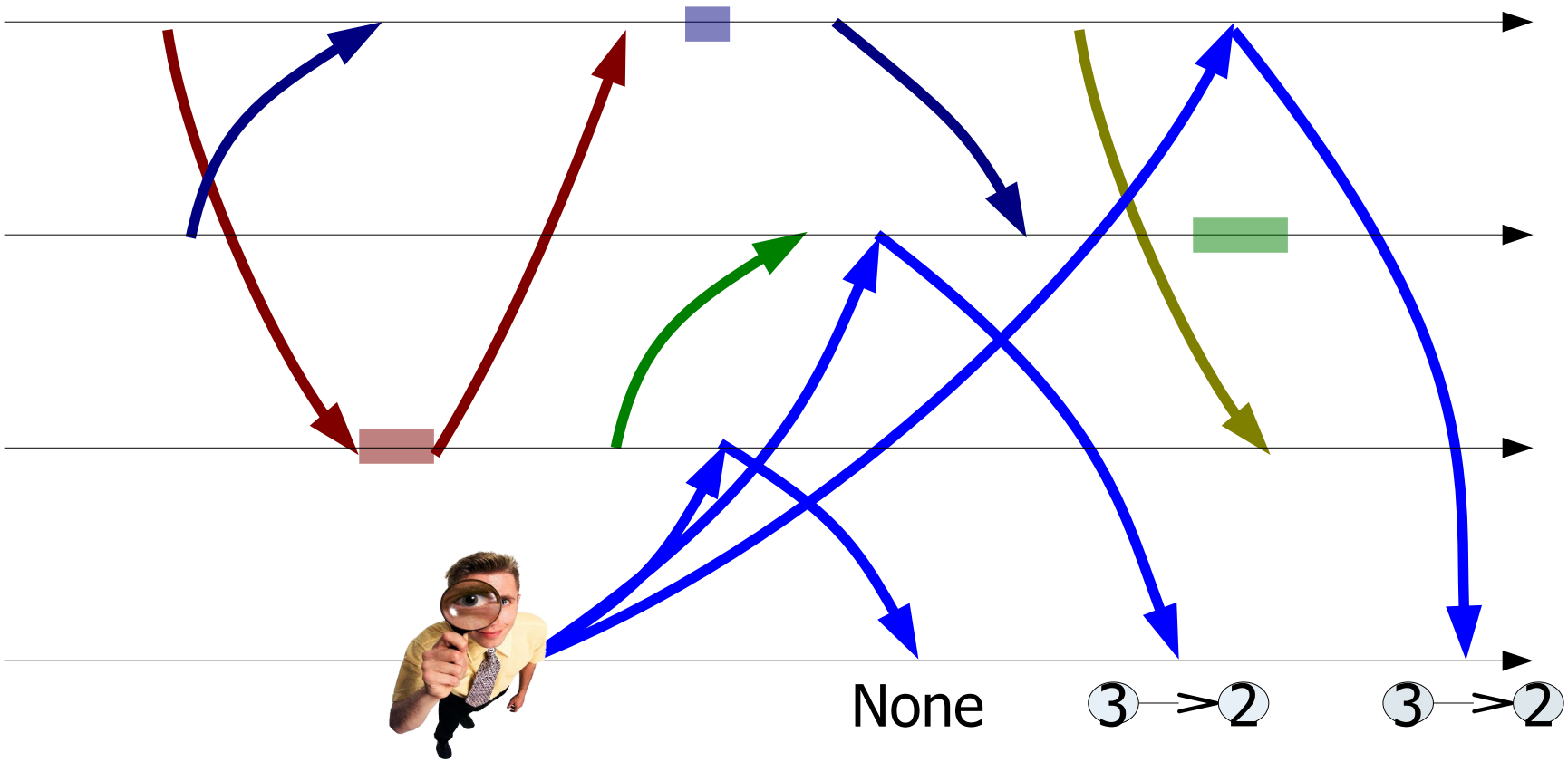
Example: Distributed deadlock

- A more complex deadlock-free run:



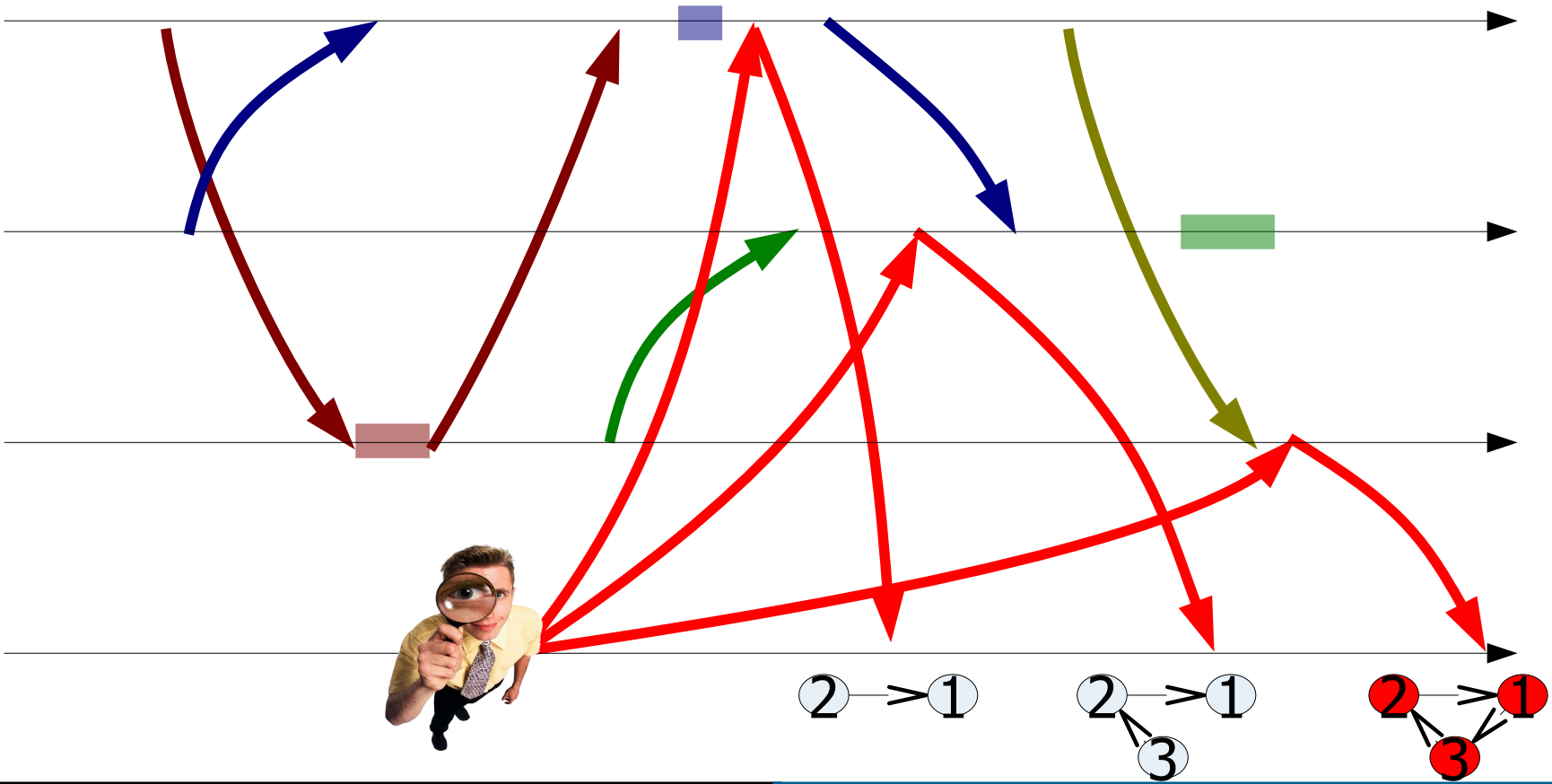
Example: Distributed deadlock

- A deadlock-free WFG:



Example: Distributed deadlock

- A WFG with a ghost deadlock:

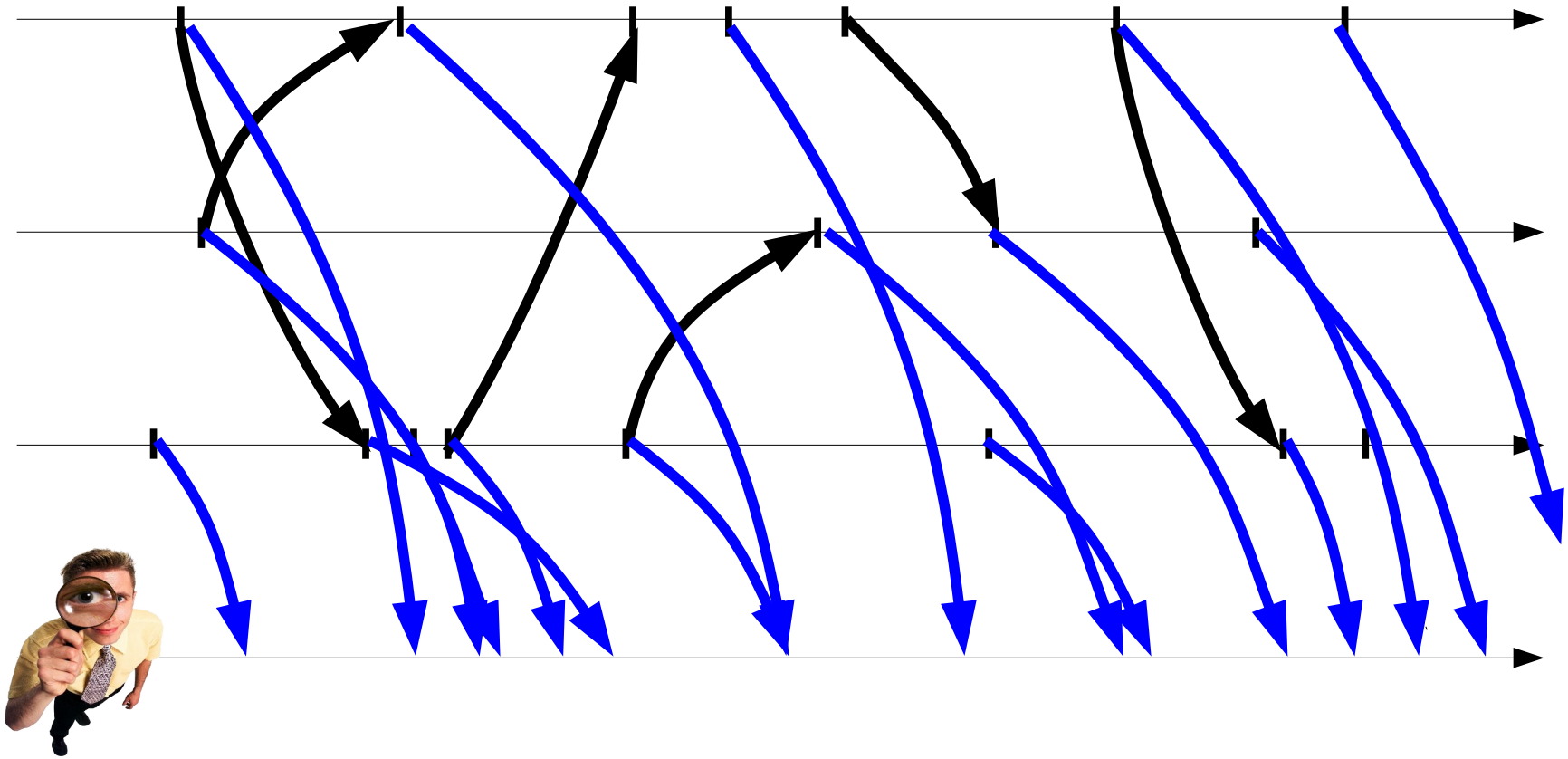


Global Property Evaluation

- Similar problems:
  - Distributed garbage collection
  - Distributed conversation threads
  - …
- Can it be solved in an asynchronous system?
- Methods that can be used? Relative cost?

Passive monitor process

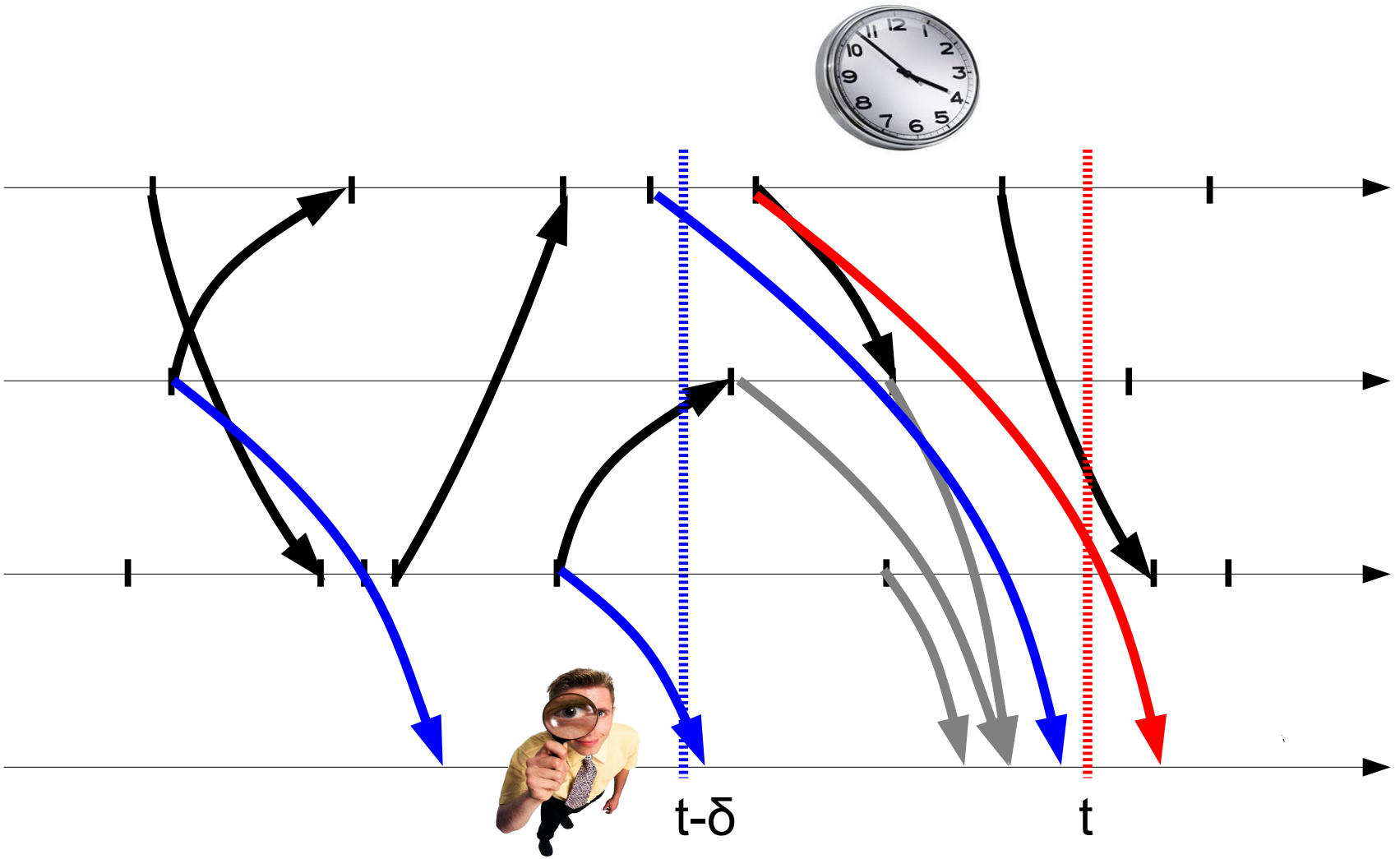
- Report all events to monitor:



First try: Synchronous system

- Global clock, δ upper bound on message delay
- Tag events with real time
- Consider events only up to t-δ
  - With synchronous rounds, this means using messages from the previous round!

First try: Synchronous system



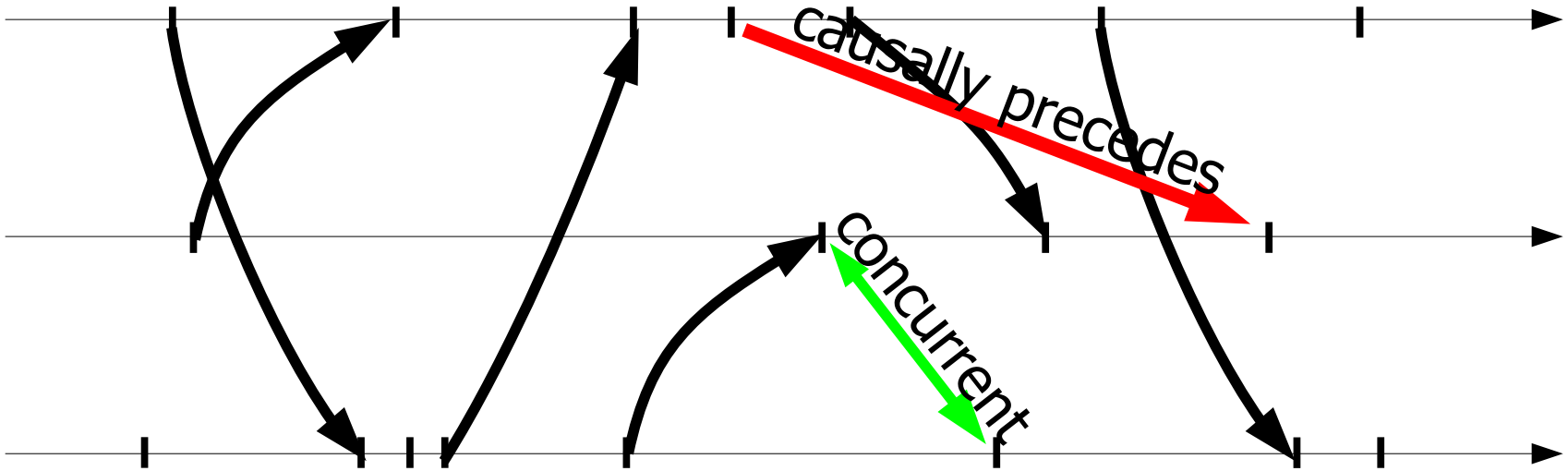
Clock properties

- What properties of a real-time clock make this approach correct?

Definition: Causality

- Events i and j are causally related (i→j) iff:
  - i precedes j in some process p
  - for some m, i=send(m) and j=receive(m)
  - for some k, i→k and k→j (transitivity)
- Events i and j are concurrent (i||j) iff neither i→j or j→i

Causality

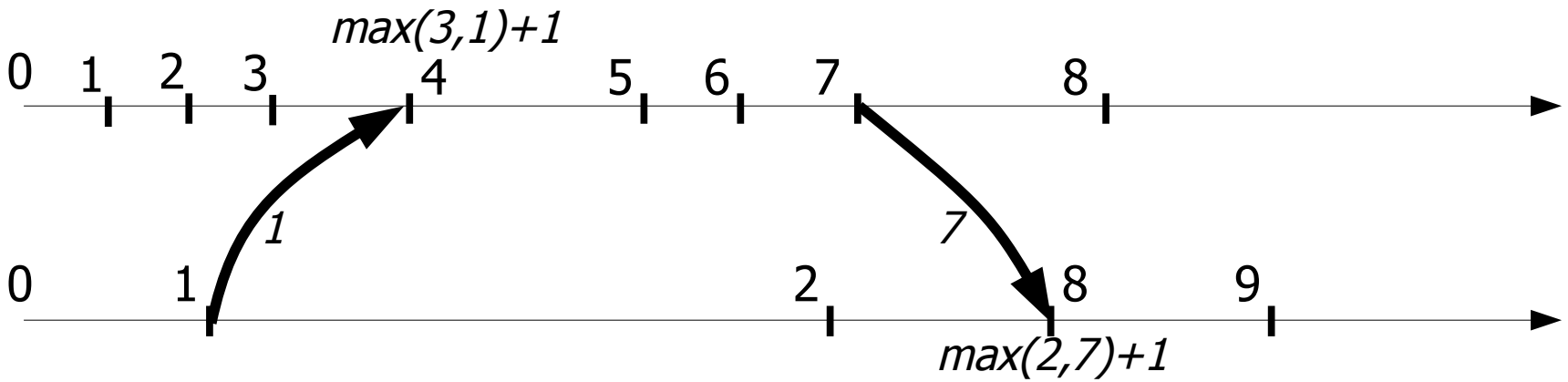


Clock properties

- RC(i) the time at which i happened
- If $i \rightarrow j$ then RC(i)<RC(j)
- For some event j:
  - When we are sure that there is no unknown i such that RC(i)<RC(j)
  - Then there is no i such that $i \rightarrow j$
- Can we build a logical clock with the same property?

Scalar logical clock

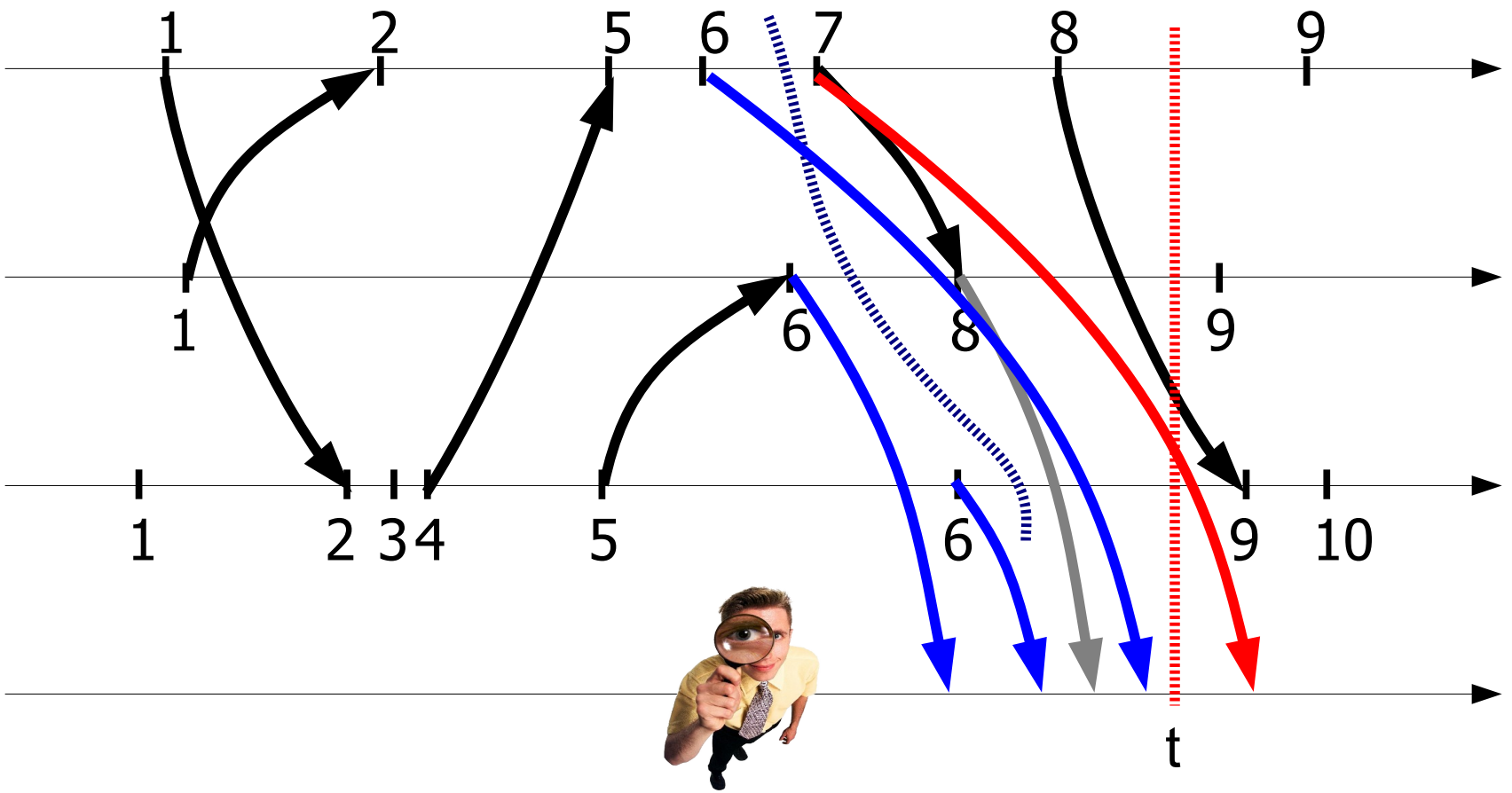
- Local events: increment counter
- Send events: increment and then tag with counter
- Receive events: update local counter to maximum and then increment



Second try: Logical clock

- Use scalar logical clock
- Use FIFO channels
- Consider events only up to the minimum of maximum tags

Second try: Logical clock



Scalar clocks

- Synchronous system (RC):
  - Delay δ to consistency
- Asynchronous system (LC):
  - Possible unbounded delay to consistency
  - Blocks if some process stops sending messages