ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Lecture 4: Synchronizers

CS 539 / ECE 526

Distributed Algorithms

Outline

- Lockstep rounds too strong assumption
- How to enforce lockstep rounds?
  - In synchrony: clock synchronization
  - **Today: In asynchrony: synchronizers**

Synchronizers

- Enforce lockstep rounds in asynchrony
- Message passing
- Generic graph
- No failure

Outline

- A simple local synchronizer
- Awerbuch’s framework
  - An alternative local synchronizer
  - A global synchronizer
  - Hybrid local/global synchronizer
- Fault tolerance of synchronizers
- Correctness of local synchronizers

A Simple Synchronizer

- Idea: a process can send round-(r+1) msgs once it receives all round-r msgs

  (all msgs are marked with round number)

  - Having received round-(r+1) msgs before that?
    - Simply delay processing those
    - Similarly, could be too earlier for other processes, but others can also just buffer round-(r+1) msg

A Simple Synchronizer

- Idea: a process can send round-(r+1) msgs once it receives all round-r msgs

  (all msgs are marked with round number)
- Send "NoMsg, r" if there is nothing to send
  - Do this separately for every link
- Move to round r+1 upon receiving round-r msgs (or NoMsg) from ALL neighbors

A Simple Synchronizer

- This synchronizer is **local**
- Nearby nodes are off by 1 round at most
  - Node i is waiting for round-r msgs
  - Node i has not sent its round-(r+1) msg or NoMsg
  - Node i's neighbors cannot start round r+2
- Far-apart nodes may be off by many rounds

A Simple Synchronizer

- Far-apart nodes may be off by many rounds

A --------- B --------- C --------- D --------- E

Synchronizer Correctness

- Far-apart nodes may be off by many rounds
- Is this really equivalent to lockstep rounds?
- For external observers, no!
  - Also for lockstep using clock synchronization
- For the nodes themselves?
  - Feels like it, but how do we formally prove it? Not trivial, will come back to it

A Simple Synchronizer: Efficiency

- Transforms a lockstep algo into an async one
- Efficiency: measured by blowup
- Round blowup: 1x (i.e., none)
- Message blowup
  - M to R*|E| where R is the lockstep round complexity
- Good for rounds, potentially bad for comm
  - When is communication blowup small?

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Awerbuch's Synchronizers

- A general class of synchronizers
- Do not send NoMsg. ACK every msg.
- A node is "done sending in round r" if all its round-r msgs have been ack'ed
- If ALL neighbors are "done sending in round r", a node has received all round-r msgs
  - Hence, can send round r+1 msgs
  - Question left: how to communicate "done sending"

Awerbuch's Synchronizers

- Only question left: how to communicate "done sending in round r"
- Option 1: simply send to all neighbors
  - Called Alpha Synchronizer by Awerbuch
- This gives an alternative local synchronizer
  - Round and communication blowup?
  - No advantage over the simpler one, but helpful for reasoning about more complex synchronizers

Awerbuch's Synchronizers

- Only question left: how to communicate "done sending in round r"
- Option 1 (alpha): simply send to all neighbors
- Option 2 (beta): via a leader and spanning tree
  - Convergecast "done sending r" to root / leader
  - Leader broadcasts "start round r+1"

Awerbuch's Beta Synchronizer

- A global synchronizer
- No process sends round-(r+1) msg until ALL round-r msgs (from/to all procs) are received
- Correctness straightforward / by definition

Beta Synchronizer Efficiency

- Round blowup
  - R to R*(2+2D) where D is the depth of spanning tree
  - But D could be |V| in async if unlucky

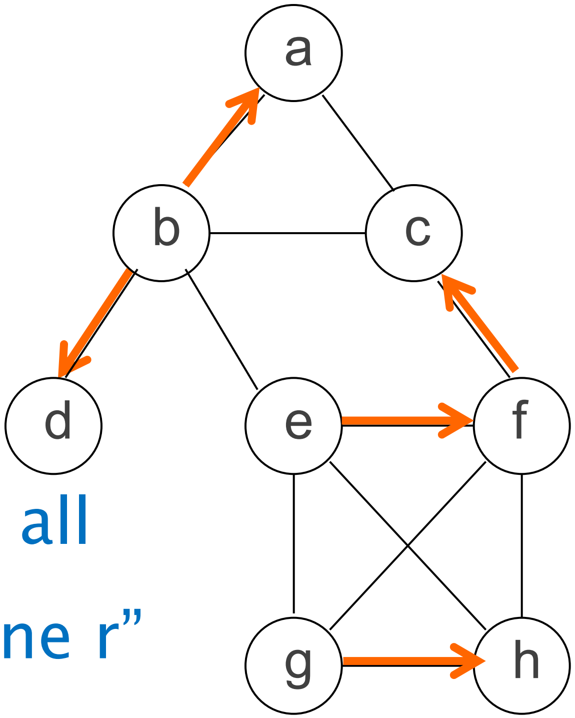
- Message blowup
  - M to 2M + 2*R*|V|
  - 2M from acks, rest are convergecast & broadcast

Awerbuch's Synchronizers

- Only question left: how to communicate "done sending in round r"
- Option 1 (alpha): simply send to all neighbors
- Option 2 (beta): via a leader and spanning tree
- Option 3 (gamma): tradeoff between 1 and 2

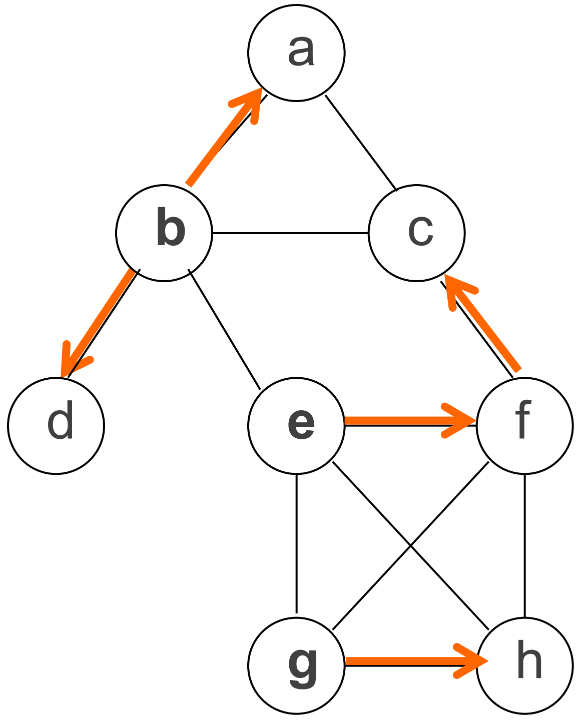
Awerbuch's Gamma Synchronizer

- A spanning forest (multiple spanning trees)
  - E.g., **b** -> a/d, **e** -> f -> c, **g** -> h
- First, beta synchronizer within each tree
- Then, alpha synchronizer among roots
  - Root: "done r" (for my tree)
  - Go to round r+1 if my tree and all **neighboring** trees send "done r"



Awerbuch's Gamma Synchronizer

- Which trees are neighboring trees?
  - If and only if any of their members are in contact
- Is it OK to have no link between b and g?
  - OK in this example
  - Not OK if d --- g (or a --- h)



Awerbuch's Gamma Synchronizer

- Correctness
  - All my neighbors are in same or neighboring trees
  - My root broadcasts "start round r+1" if it receives "done r" from our entire tree (via convergecast) AND all neighboring roots
    - Former takes care of my neighbors in same tree
    - Latter takes care of my neighbors in neighboring trees

Awerbuch's Gamma Synchronizer

- Efficiency depends on forest structure
- Example: k trees of size n/k, roots form clique
  - Round blowup: depth of tree, so O(n/k)
  - Msg blowup: M to 2M + R($2k*n/k + (n/k)^2$)
  - Tune k for a trade-off between round and msg (between alpha and beta), e.g., k = sqrt(n) is typical

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Fault Tolerance

- None of the synchronizers today tolerates even a single crash fault
  - Fault tolerant synchronizer impossible!
- Clock synchronization using a reference also does not tolerate a single crash
  - Fault tolerant clock synchronization is possible (in synchrony)

Fault Tolerance

- Fault tolerant synchronizer impossible!
- Proof sketch:
  - If no one hears from node x, what do we do?
  - Must move on eventually (liveness)
    - Cannot wait forever, x may have crashed
  - But x could be just slow due to asynchrony
    - Moving on violates correctness (safety)

Safety and Liveness

- Desired property: “good” things happen
- Common and helpful to break it down
- Safety: nothing “bad” happens
- Liveness: something happens

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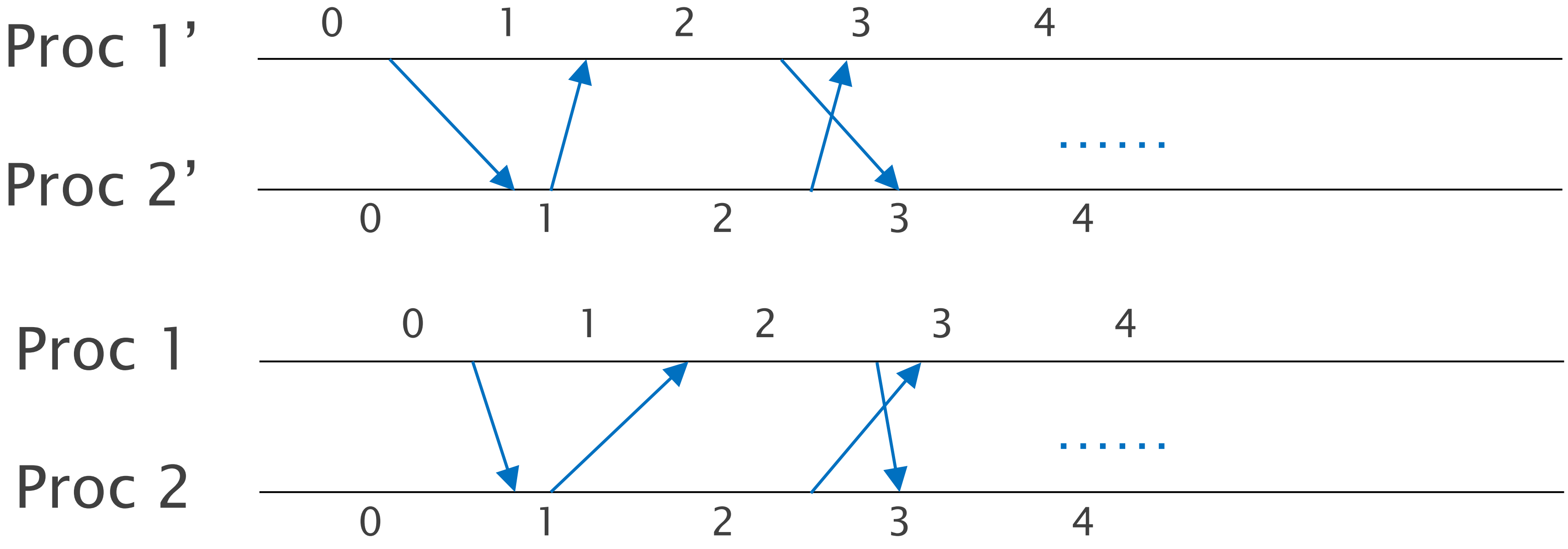
Correctness of Synchronizers

- Desired property: equivalence to lockstep
- Straightforward for global synchronizers
- Want to show other synchronizers are equivalent to global synchronizer
- How do we define equivalence?
  - Intuitively today, rigorously next lecture

Equivalence of Executions

- We have seen one example
- Again, not equivalent for external observers
- In asynchrony, process cannot rely on time
  - Unlike in synchrony



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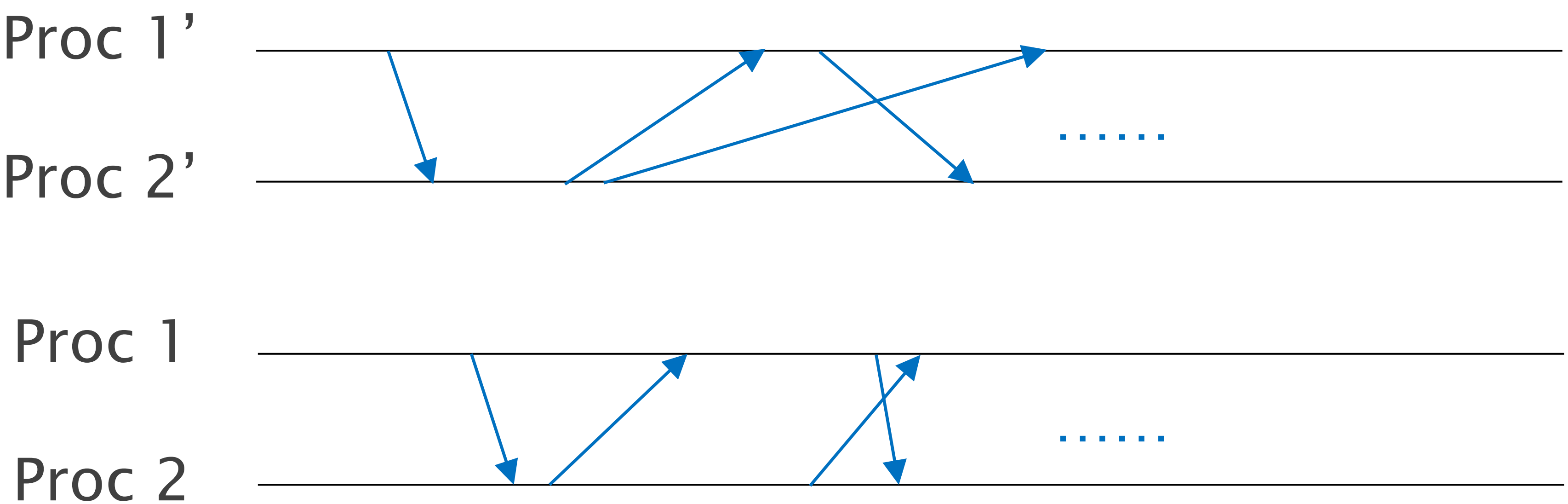
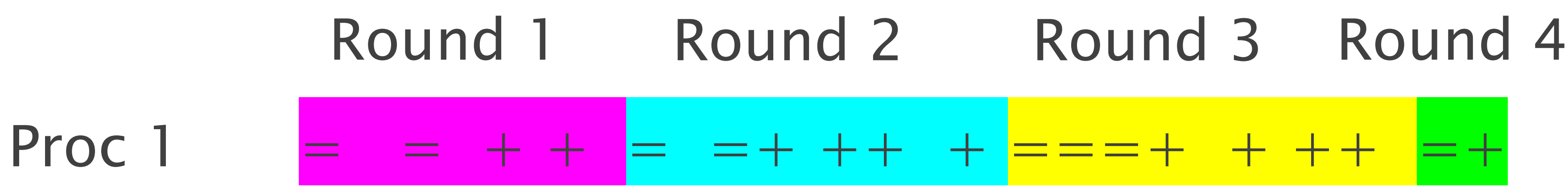


Back to Synchronizers

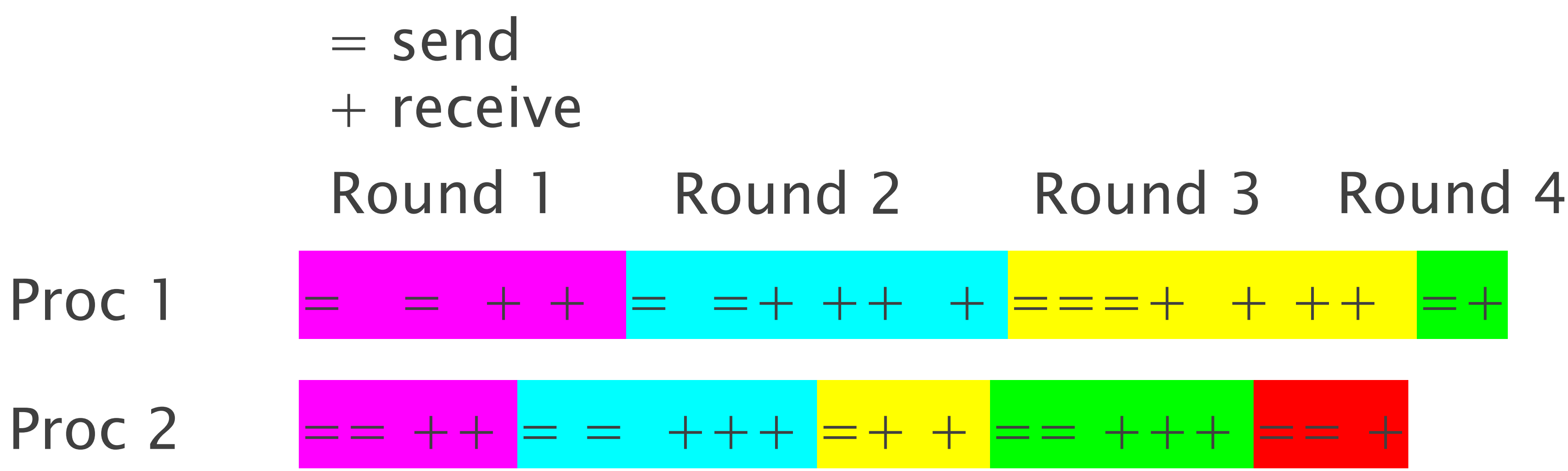
- Recall guarantee: a process sends round-(r+1) msgs once it receives all round-r msgs
  - A process reads round-r msgs (from others) only after it finishes sending round-r msgs
- So the local view at one process looks like



= send
+ receive

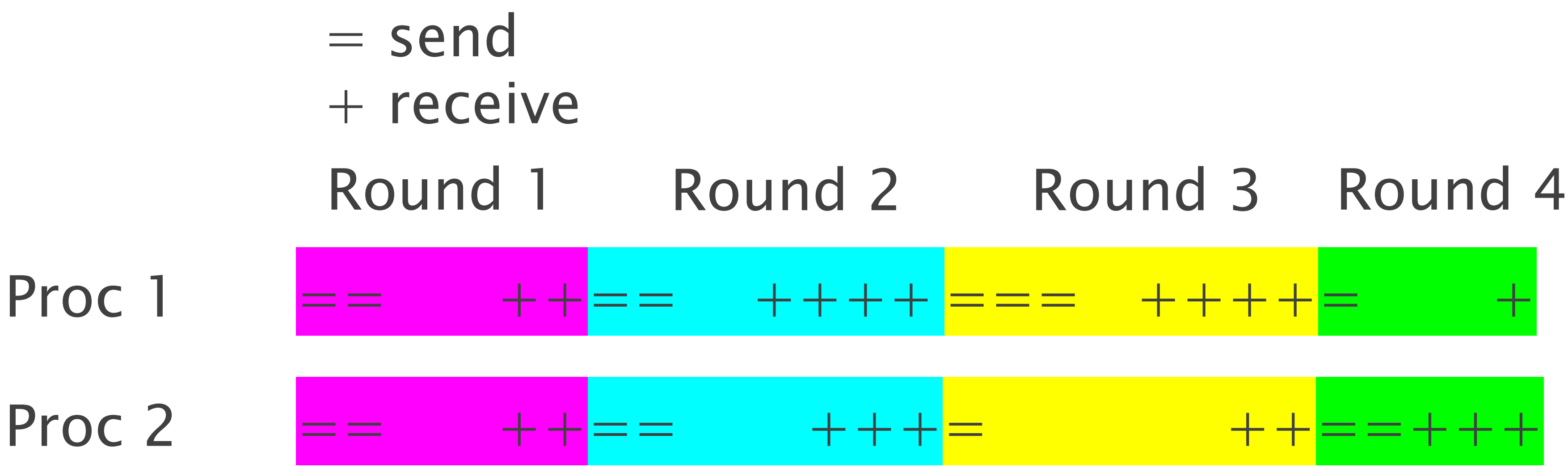
Correctness of Synchronizers

- An execution that results from a local/hybrid synchronizer may look “unsynchronized”
- But it is equivalent to …



Correctness of Synchronizers

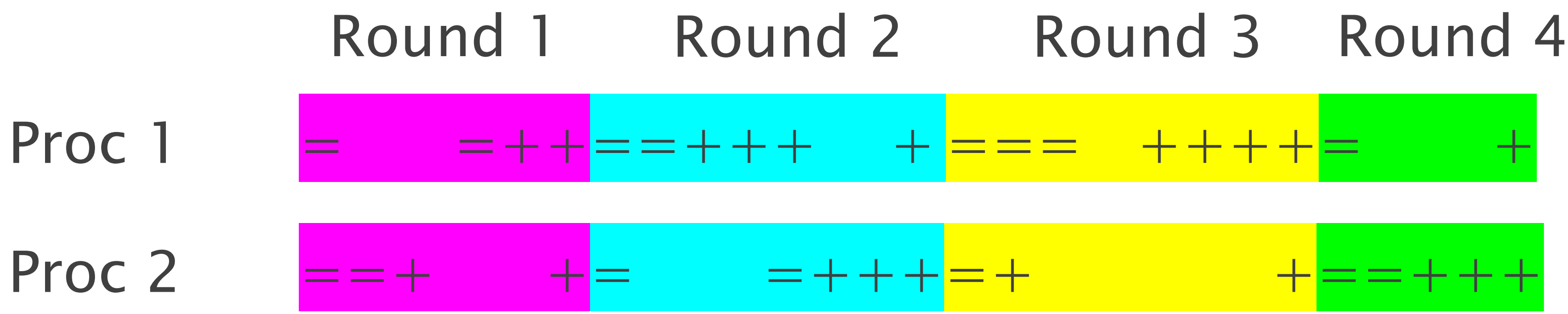
- A globally synchronized execution
  - Events ordered by rounds
  - Within a round, send events before receive events



Correctness of Synchronizers

- Why not the following? Is it also equivalent?
- How do we define equivalence formally?
- Topics for next lecture, exercise for now!

= send
+ receive



Summary

- Synchronizers: ensure lockstep in async
- Local, global, and hybrid
  - Good for rounds, communication, or a trade-off
  - Correctness of global synchronizers is clear
  - Local/hybrid produce equivalent executions
- Fault tolerant synchronizers impossible