PDES

(Don’t worry, this isn’t calculus)

Parallel

Discrete

Event

Simulation

Classification of Computer Simulations

Computer Simulation

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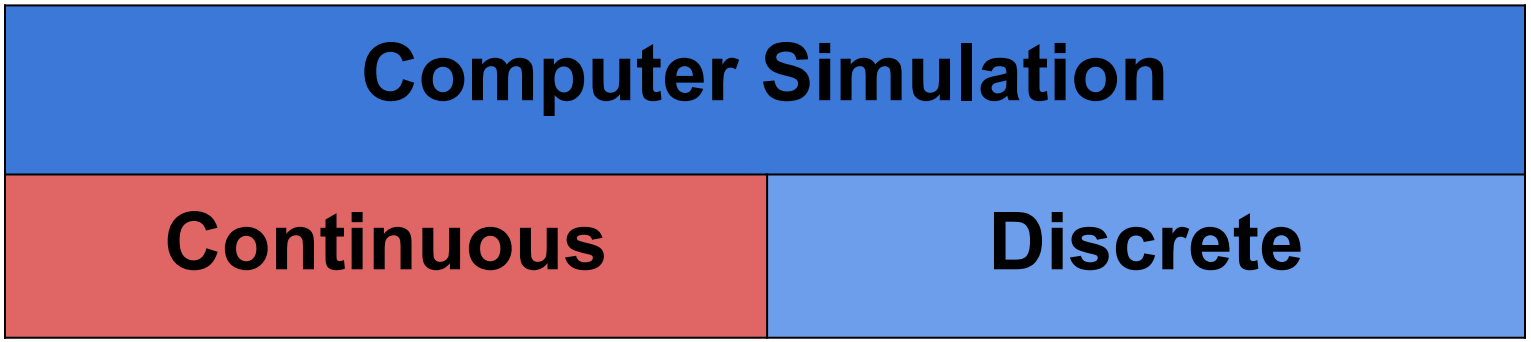

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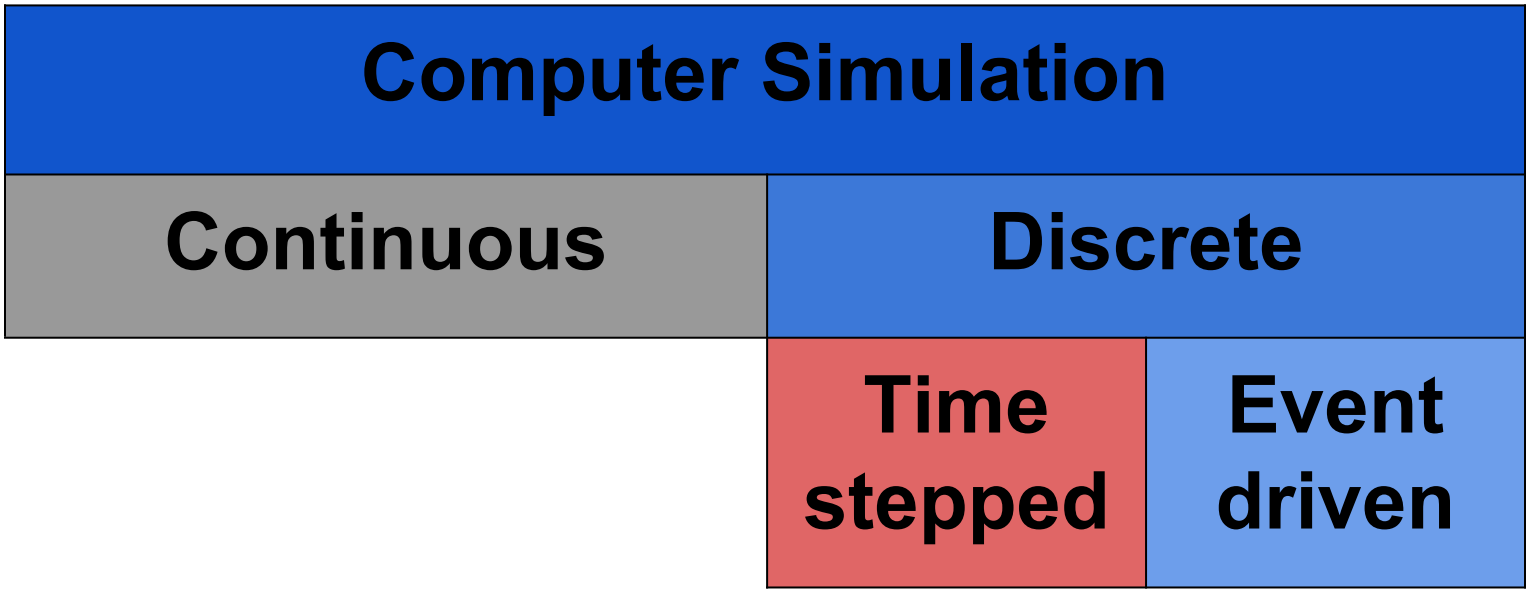

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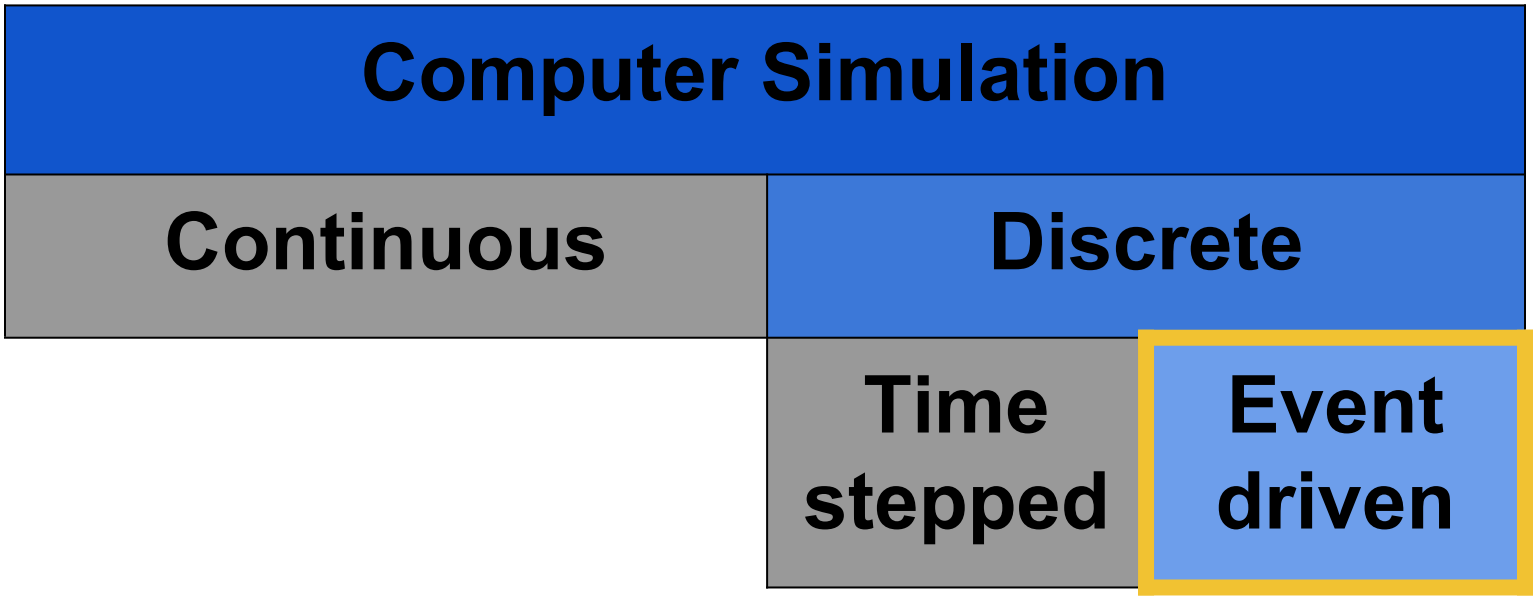


Discrete Event Simulations

- Logical Processes (LPs) execute events
- Executing an event updates the LP’s state
- Events have a virtual timestamp
- Events must be executed in order

Applications

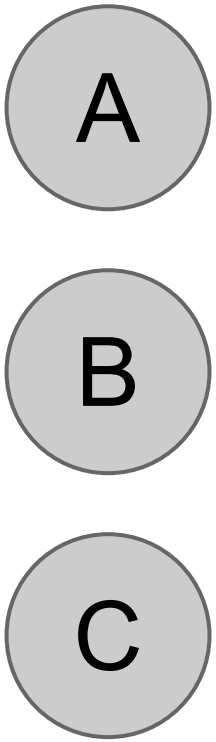
- Traffic analysis
- Military battles
- Networks
- Circuits
- Economic models
- and many more...

Implementation

- Single event queue
- Sorted by timestamp
- Loop over queue and execute events
- Efficiency depends on queue used
- Very simple

Discrete Event Simulations

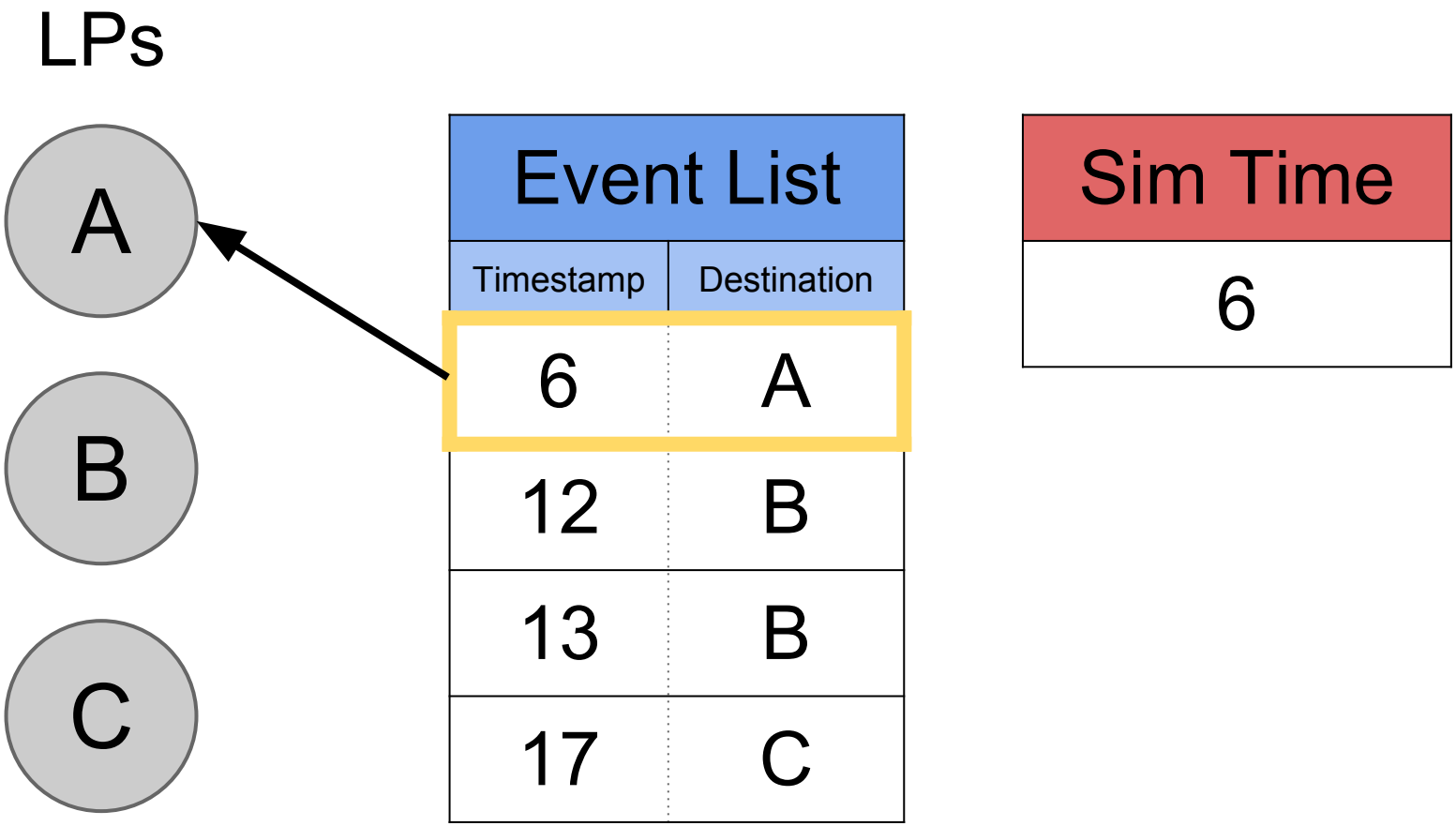
LPs



Event List	
Timestamp	Destination
6	A
12	B
13	B
17	C

Sim Time
6

Discrete Event Simulations



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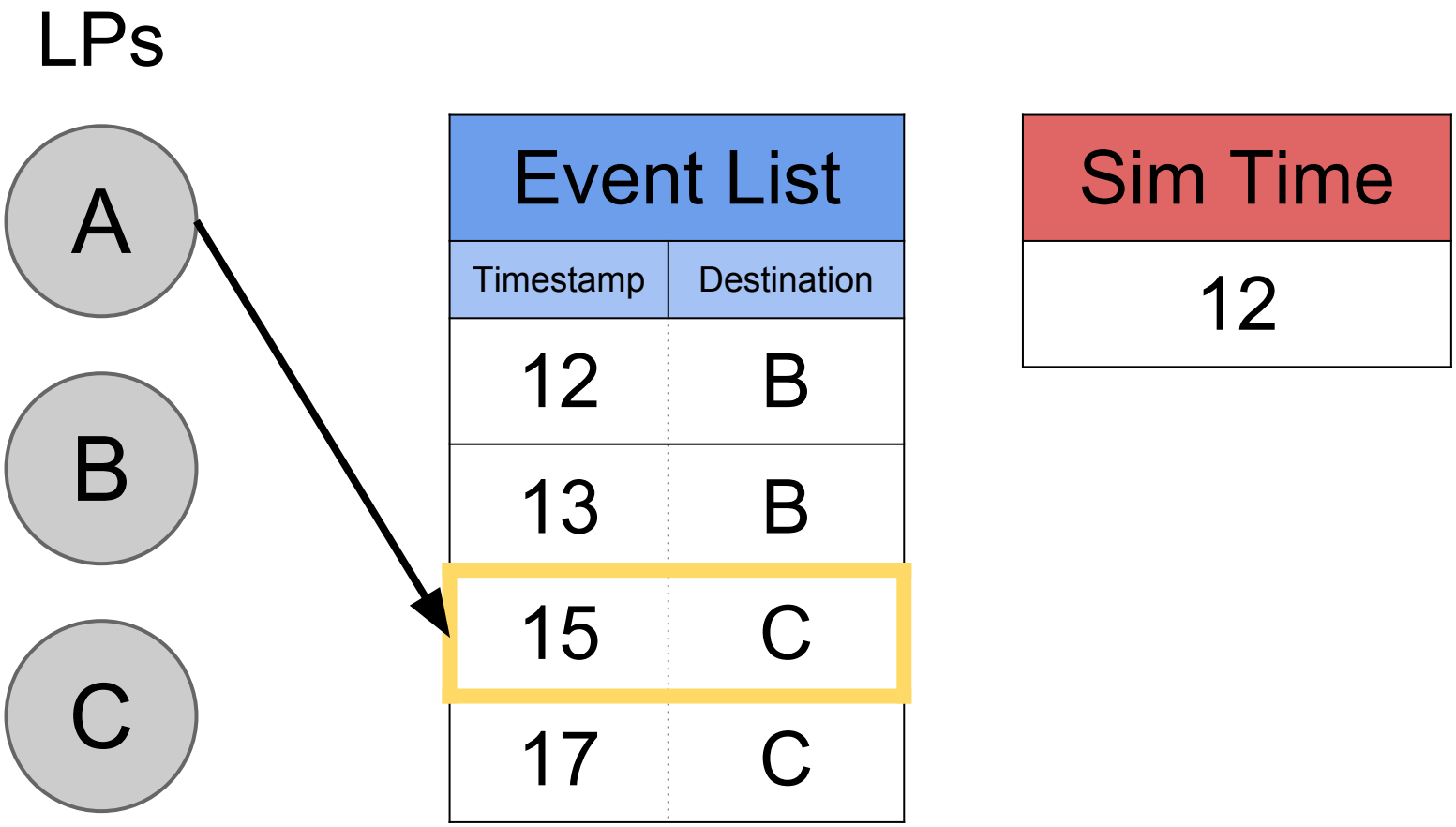


Pseudocode

```
while (running) {
   Event* e = eventList.pop();
   LP* lp = e->destination();
   lp->execute(e);
}
```

Pretty simple right?

Limitations of Sequential DES

- Millions of LPs
- Billions of events to simulate
- Sequential simulations will take too long

How will parallelization help?

- Events are generally very small
- Simulations can have of billions of events

Benefits of parallelism come from executing many events at once

How do we parallelize DES?

- Distribute LPs across processors
- Each processor has its own event list and virtual clock
- How to synchronize event lists and clocks?

(Super) Naive Implementation

```
while (running) {
   AllReduce(simTime);
   if (events.top()->ts==simTime) {
      Event* e = events.pop();
      LP* lp = e->destination();
      lp->execute(e);
   }
}
```

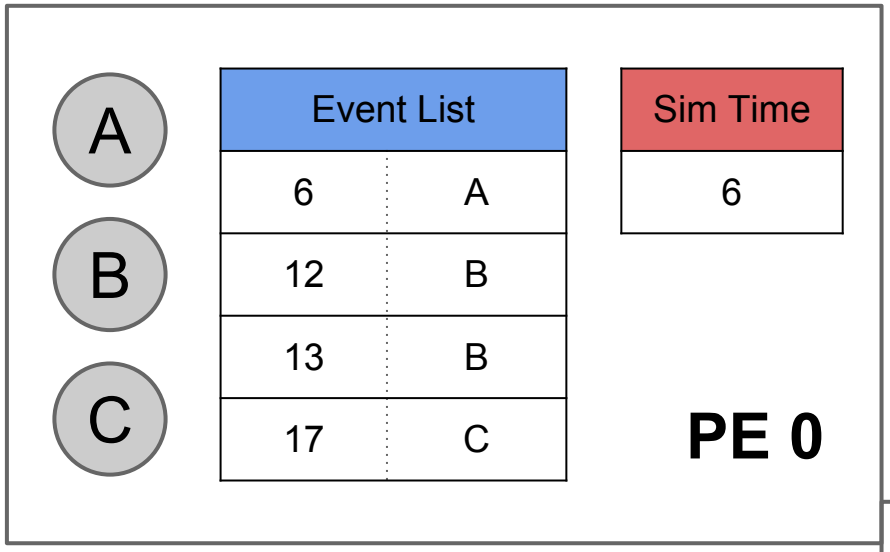
(Super) Naive Implementation

- Exactly matches sequential semantics
- NO PARALLELISM
- Way too much synchronization

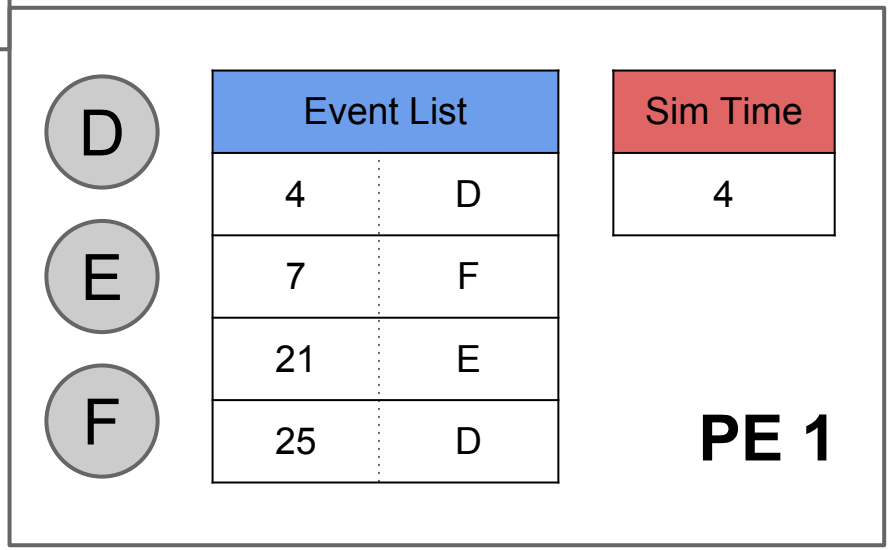
Moral of the Story:

We need to relax our ordering restrictions!

What is the fundamental problem?



Can PE 0 safely execute any events?



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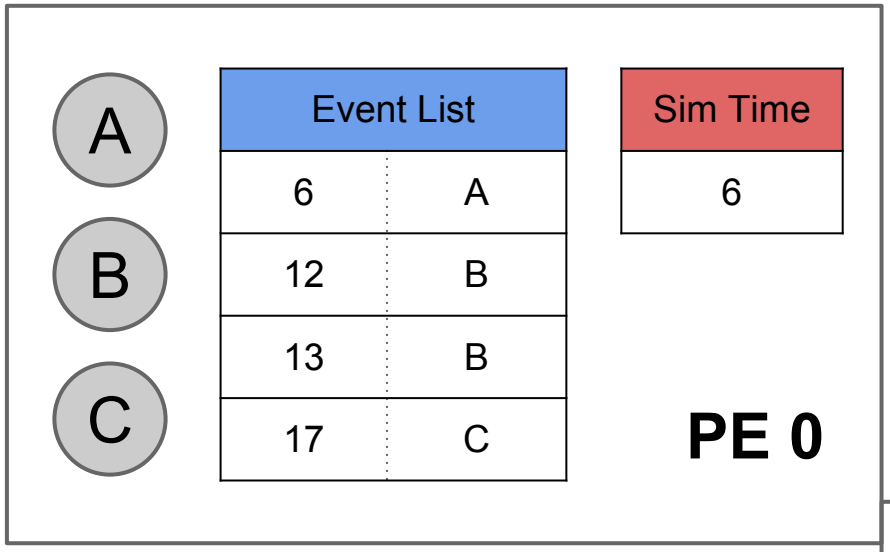

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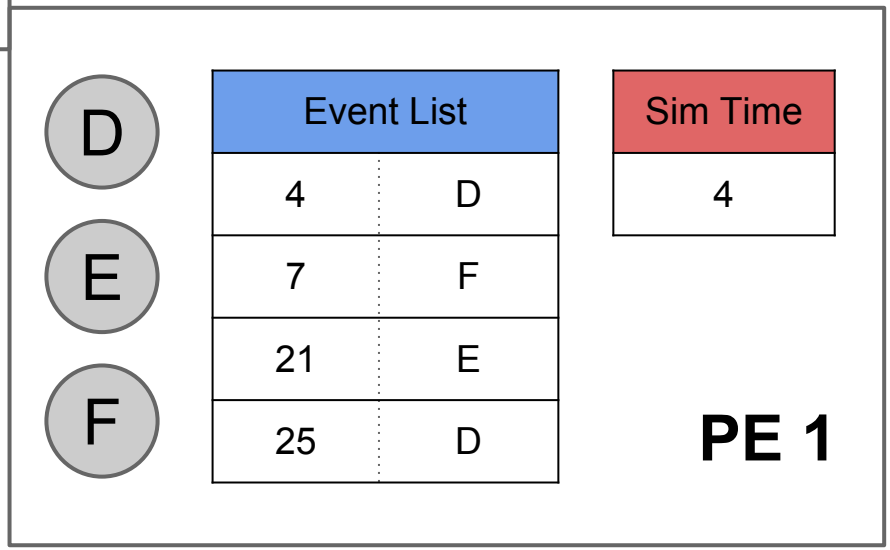

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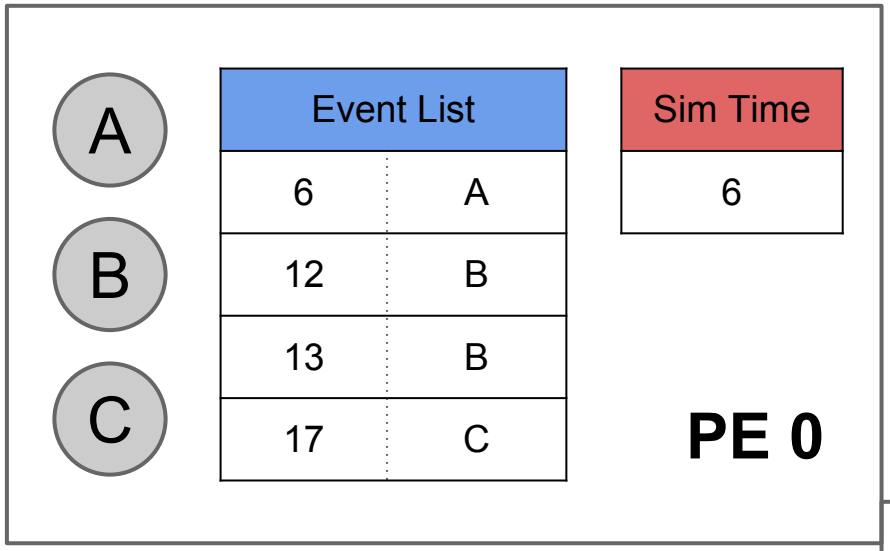

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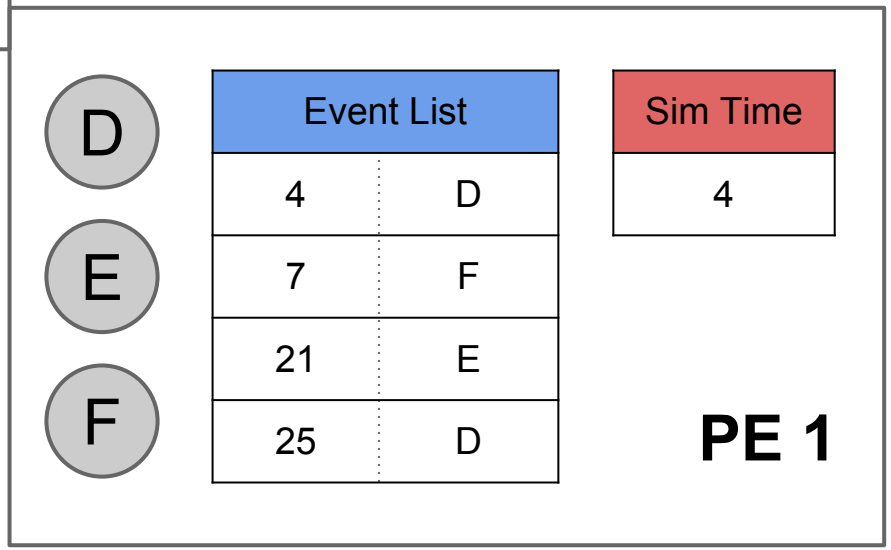
What if the first event on PE 1 generates event (5,A)?

Causality Error!



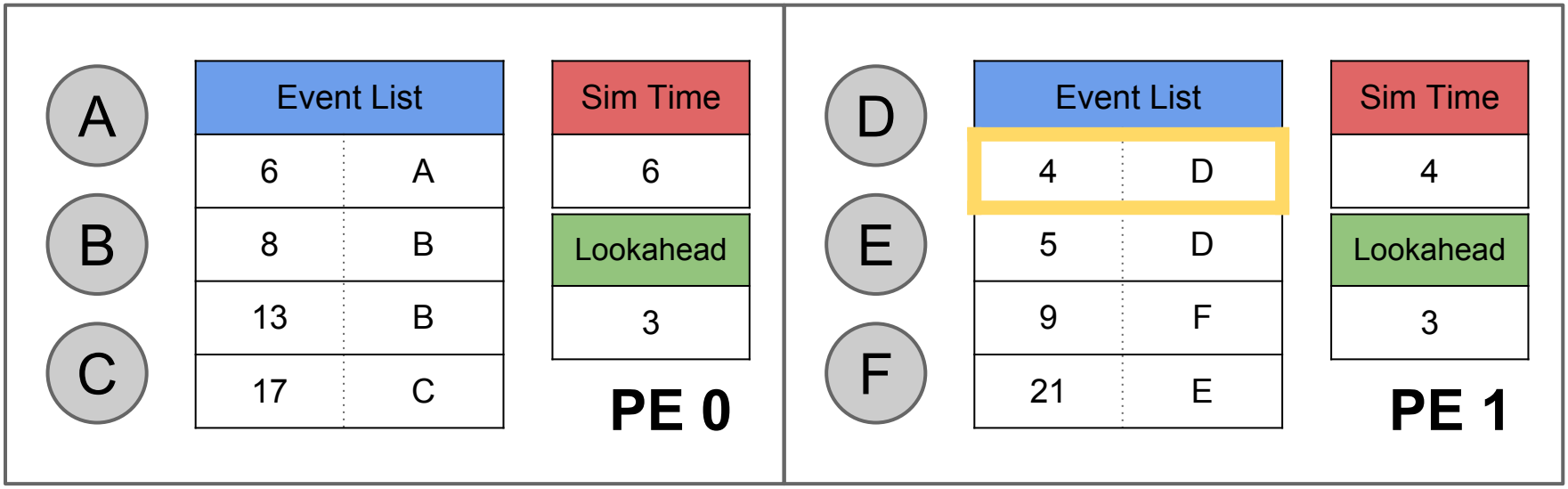
How can we ever execute events!?

Two Approaches

- Conservative (don’t screw up)
  - Only execute events we know won’t be preempted
  - High amount of synchronization
  - Low amount of parallelism
  - Inflexible
  - Simple
- Optimistic (if we screw up, we’ll fix it)
  - Execute events freely
  - If a causality error occurs, rollback the processor
  - High amount of parallelism
  - Flexible
  - Complex

Conservative (Windowed)

- Requires a model-specific lookahead
- Determine the min timestamp in the system
- Execute events in (min + lookahead) window



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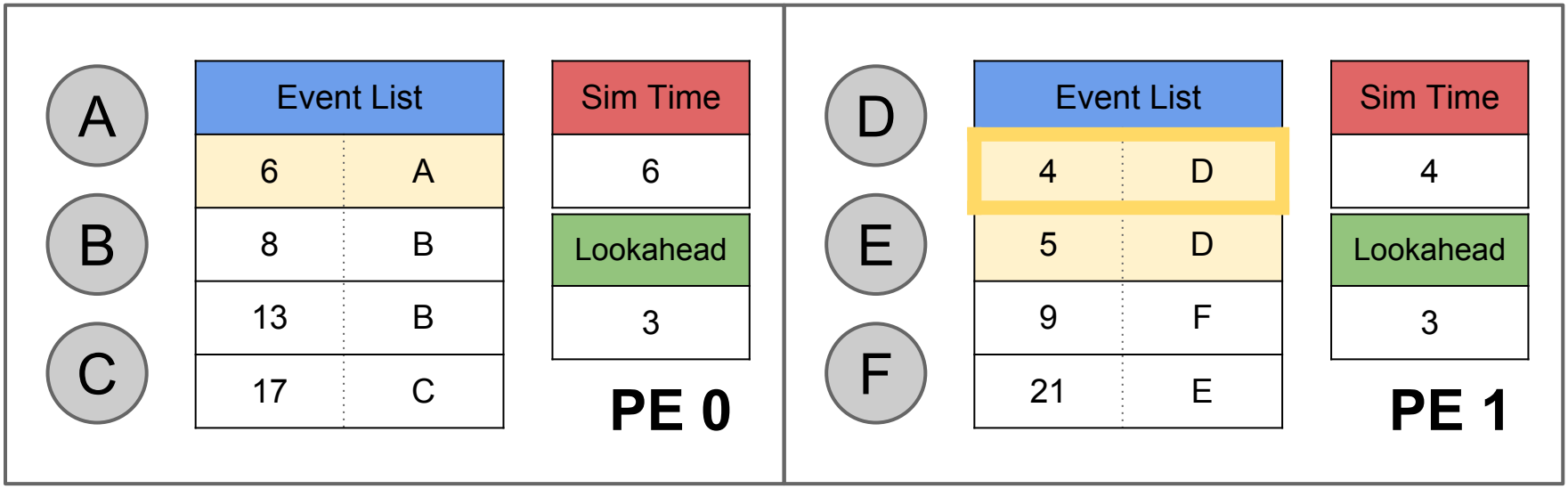

(Super) Naive Implementation

```
while (running) {
   AllReduce(simTime);
   if (events.top()->ts==simTime) {
      Event* e = events.pop();
      LP* lp = e->destination();
      lp->execute(e);
   }
}
```

Windowed Implementation

```
while (running) {
   AllReduce(simTime);
   while (events.top()->ts <
             simTime + lookahead) {
      Event* e = events.pop();
      LP* lp = e->destination();
      lp->execute(e);
   }
}
```

Windowed Analysis

- Very similar to naive solution
- Performance depends on lookahead
- Low lookahead = low parallelism and high synchronization
- Workload can be unbalanced

Optimistic

- Execute events freely
- When an event is received with a smaller timestamp then your clock, rollback
- How do we rollback efficiently?
- How do rollbacks affect performance?
- How many PEs will a rollback affect?

Rollbacks

- Save previous events (How many?)
- Revert your own state (How?)
- Cancel sent events (How?)

Saving Previous Events

- Events take up memory
  - Limits how many events we can save
  - Need to reclaim memory periodically
- What can we safely reclaim?
- Find the Global Virtual Time (GVT)
  - Minimum clock time of the system
  - Everything prior to this can be reclaimed
  - Events with observable effects can be committed

GVT

- Global synchronization required
- All events must be accounted for
- Can be synchronous or asynchronous

Reverting Your State

- State saving
  - Save the states of LPs after each event
  - Rolling back is equivalent to reverting states
  - High memory consumption
  - Need to reclaim memory more often
- Reverse computation
  - During rollback execute events in reverse
  - Better for memory
  - Overhead of executing in reverse
  - Reverse computation is complex
  - Can compilers help?

Cancelling Events

- Events sent erroneously must be cancelled
- First we must find the event
  - If it’s local, that’s easy
  - If it’s remote we need to send an anti-event
- Then we must cancel it
  - If they weren’t executed, just delete them
  - If they have been executed, do a rollback
- Rollbacks can snowball out of control

Pseudocode

```
while (running) {
   while (executing_events) {
      check_for_rollbacks();
      Event* e = events.pop();
      LP* lp = e->destination();
      lp->execute(e);
   }
   compute_gvt();
}
```

Summary

Two Main Classes of PDES:

- Conservative
  - Low parallelism/High synchronization cost
  - Model dependent
  - Low memory footprint
- Optimistic
  - High parallelism/Low synchronization cost
  - Model independent
  - Memory Hungry
  - Rollbacks can snowball