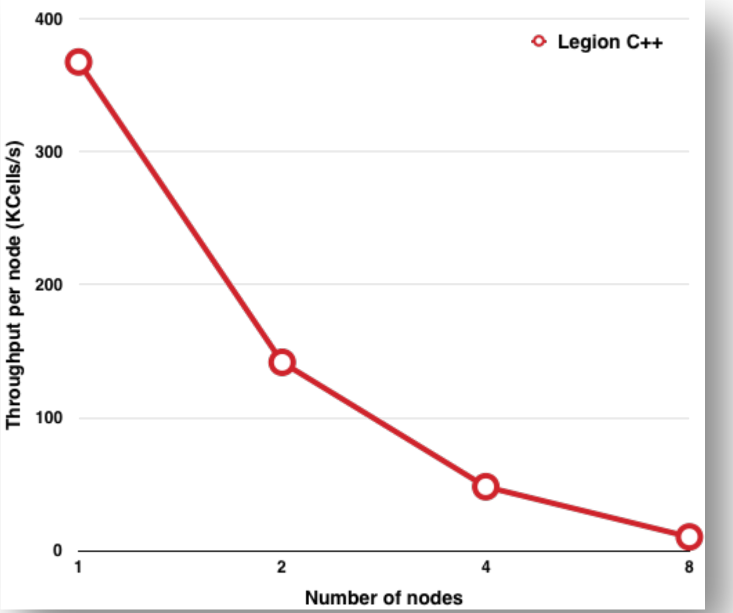
MiniAero

Wonchan Lee

MiniAero

- Fluid dynamics mini-app that uses the Runge-Kutta forth-order time marching scheme
- Ported to both Legion C++ API (Sandia) and Regent (Stanford)
- Initial versions do not scale up well:

Each node is becoming less efficient as the node count is growing

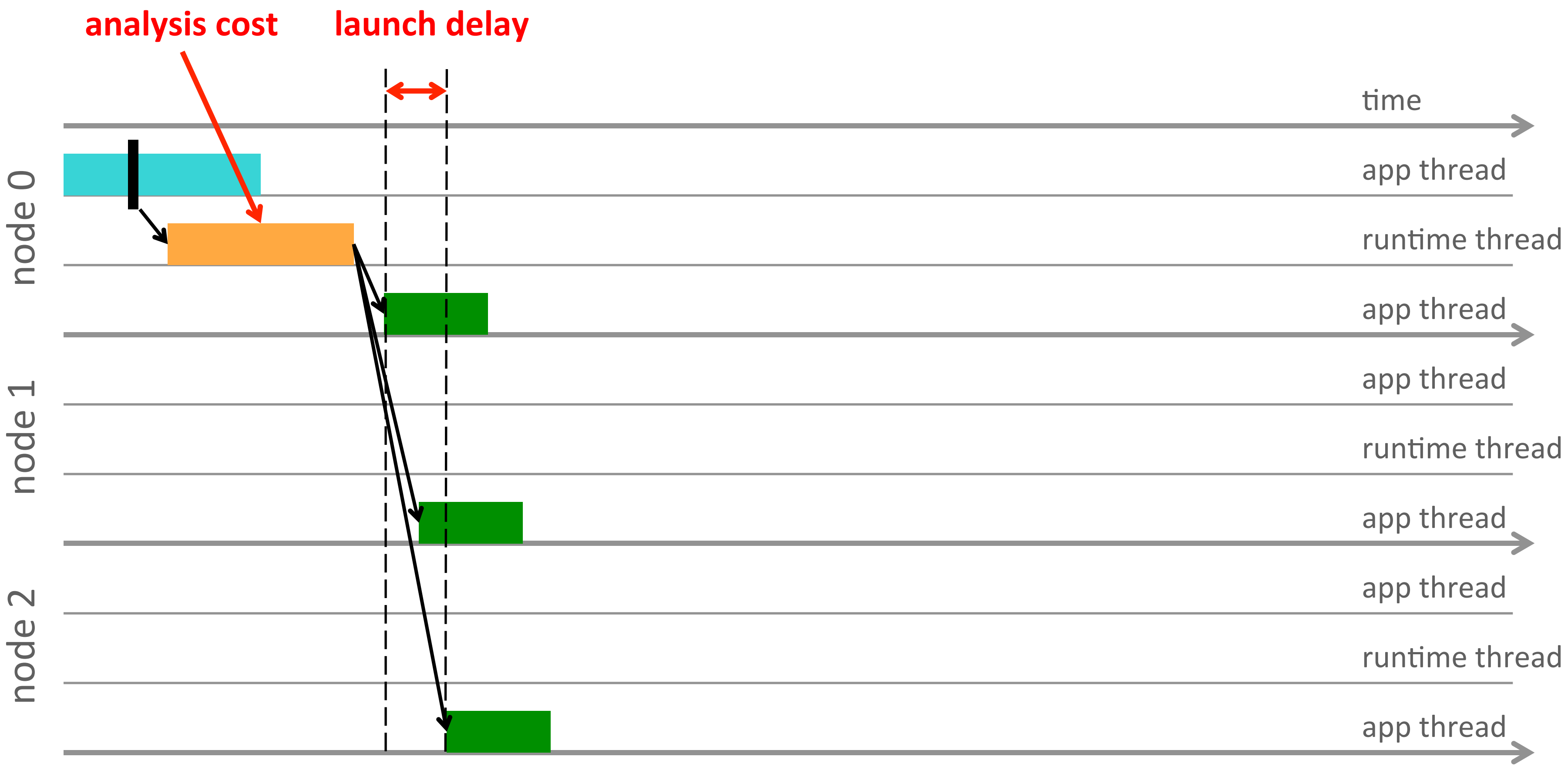


Weak-scaling graph with 256K cells per node

http://legion.stanford.edu

Sources of Inefficiency

- Having a **single control task** launch tasks on all nodes
  - Adds delay between tasks being launched



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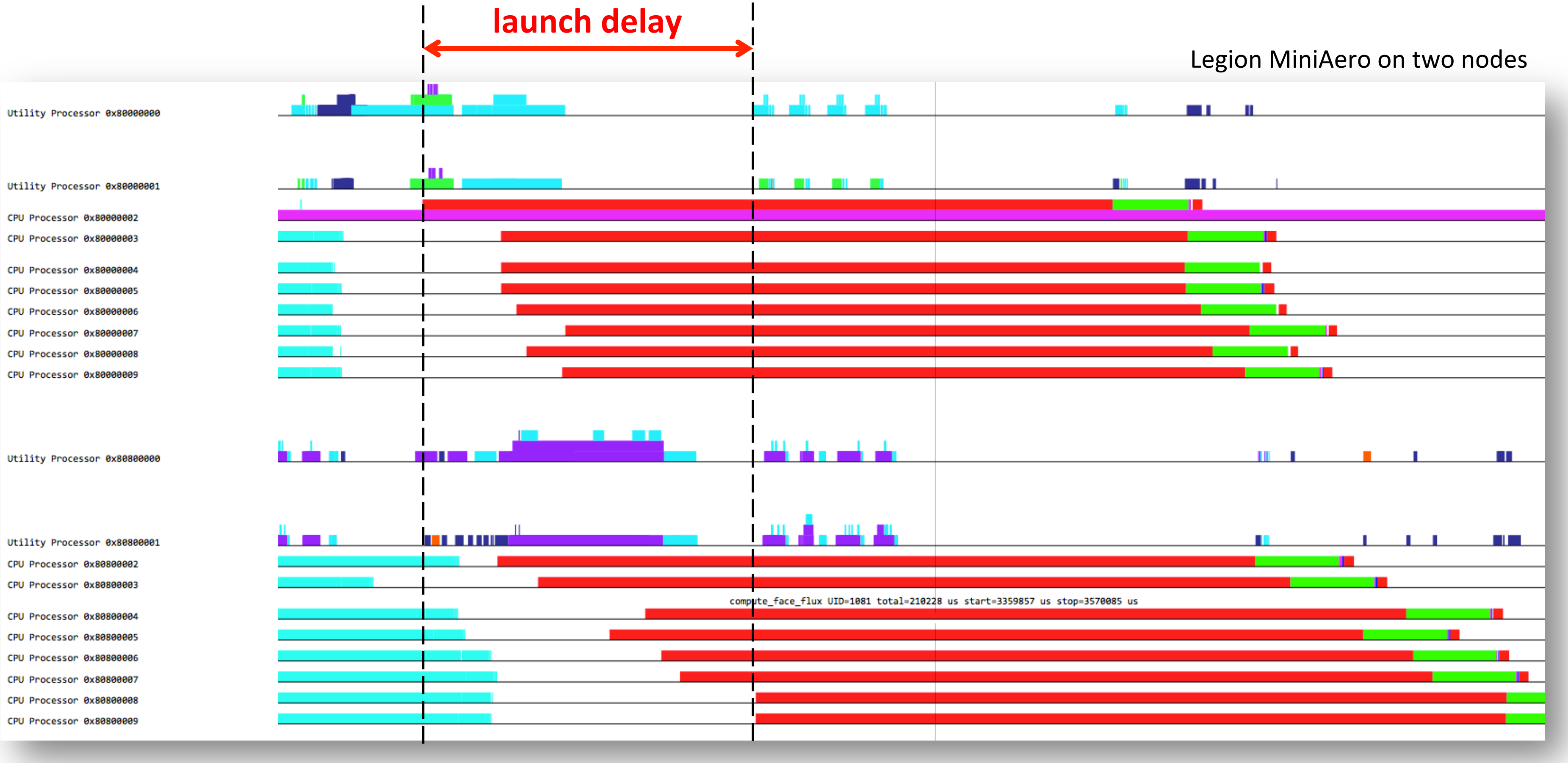


```
compute_face_flux UID=1081 total=210228 us start=3359857 us stop=3570085 us
```

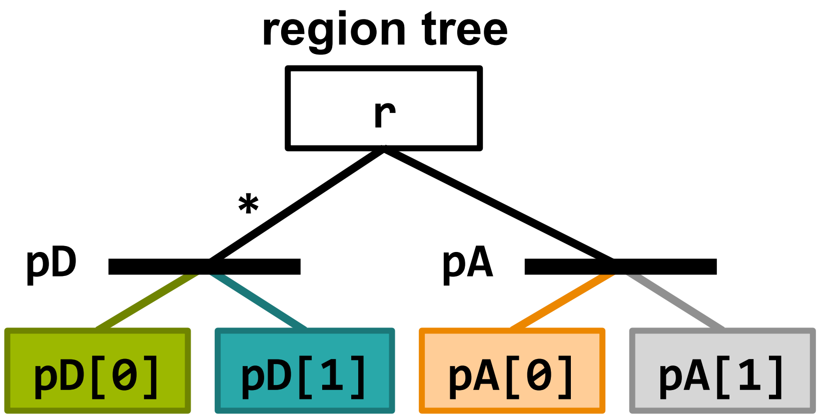
Legion MiniAero on two nodes

Sources of Inefficiency

- Using different partitions of the same region can effectively serialize tasks

```
var r = region(...)
var pD = partition(disjoint,r,...)
var pA = partition(aliased,r,...)

for i = 0,2: F(pD[i]) -- writes pD
for i = 0,2: G(pA[i]) -- reads  pA
```



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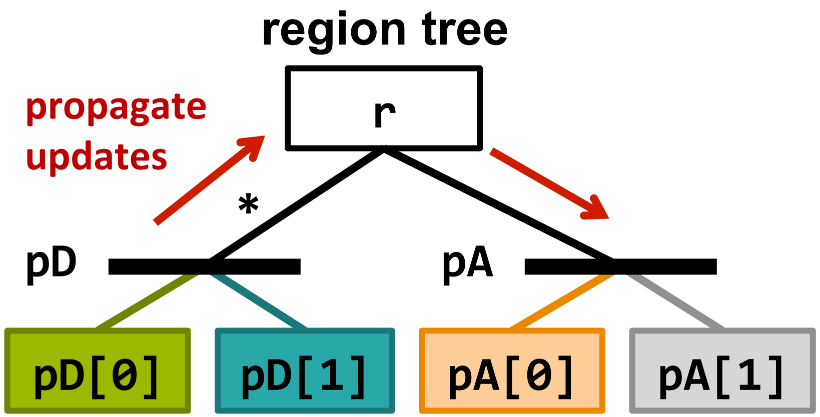
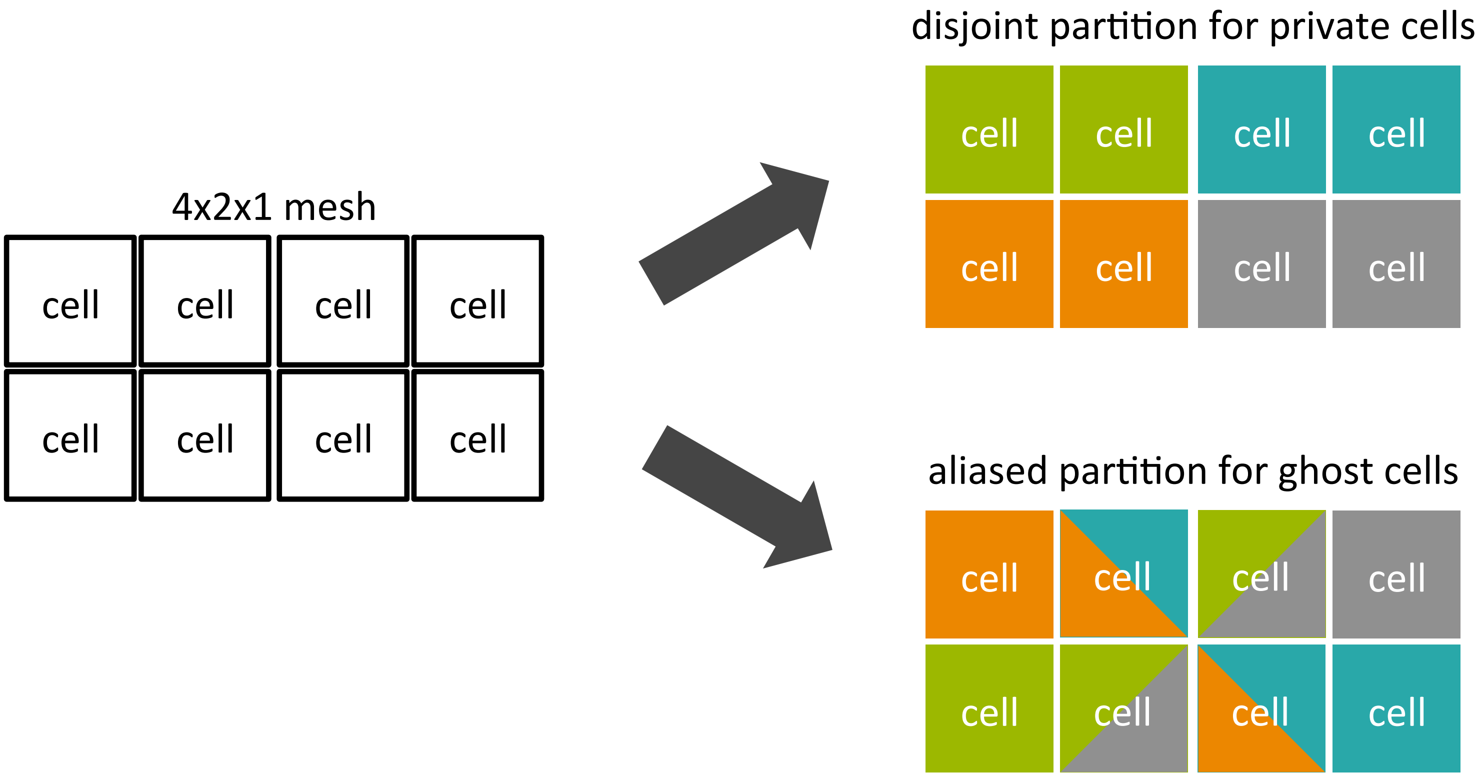


  - To start G, runtime waits for all updates of F on r to be visible to pA[i]
  - The runtime can minimize the underlying data movement between instances but cannot avoid the serialization

Sources of Inefficiency

- Using different partitions of the same region can effectively serialize tasks
  - Tasks in MiniAero read cells from other blocks on the border



4x2x1 mesh

cell	cell	cell	cell
cell	cell	cell	cell

disjoint partition for private cells

cell	cell	cell	cell
cell	cell	cell	cell

aliased partition for ghost cells

cell	cell	cell	cell
cell	cell	cell	cell

Sources of Inefficiency

- Using different partitions of the same region can effectively serialize tasks
  - Tasks in MiniAero read cells from other blocks on the border
  - Updating private cells makes the next task accessing ghost cells wait

```
...
var cells = region(...)
var pcells = partition(disjoint, cells, ...)
var pghost = partition(aliased, cells, ...)
...
for i = 0,4:
  compute_limiter(pcells[i],  pghost[i], pfaces[i])  -- writes pcells[i]
for i = 0,4:
  compute_face_flux(pcells[i], pghost[i], pfaces[i]) -- reads pghosts[i]
...
```

Sources of Inefficiency

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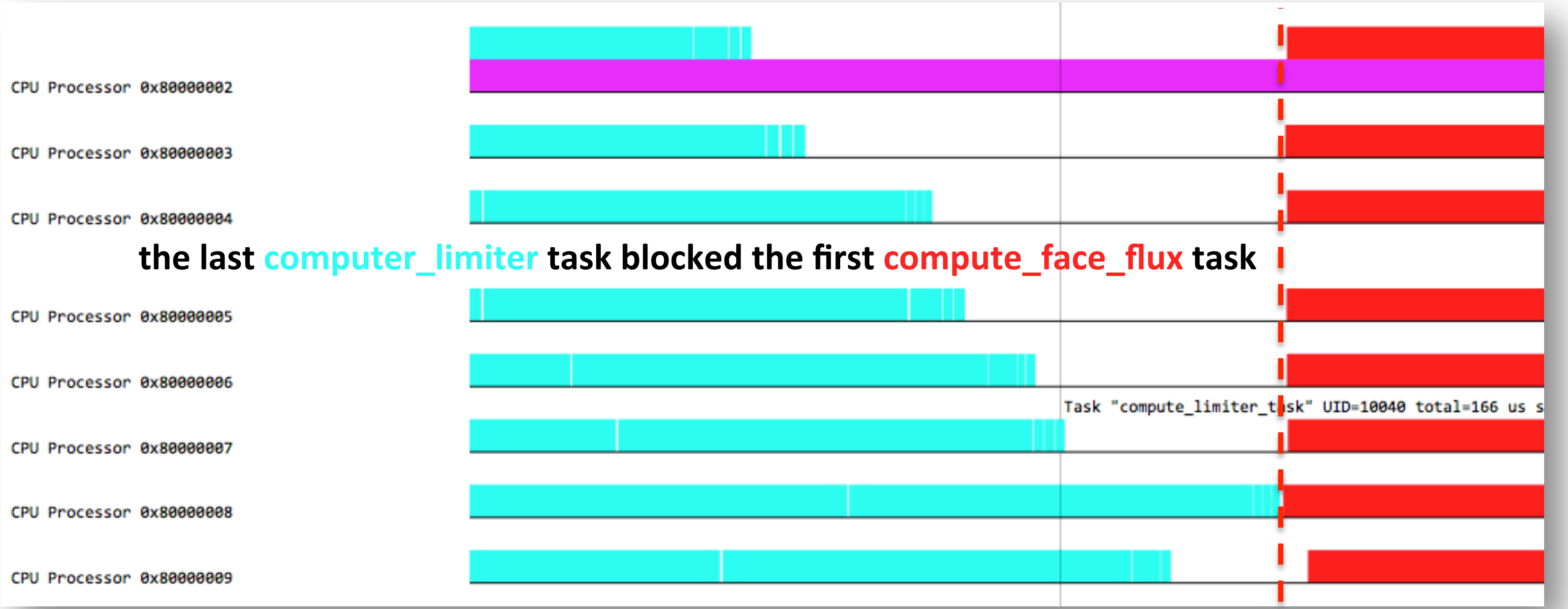
Legion MiniAero on one node

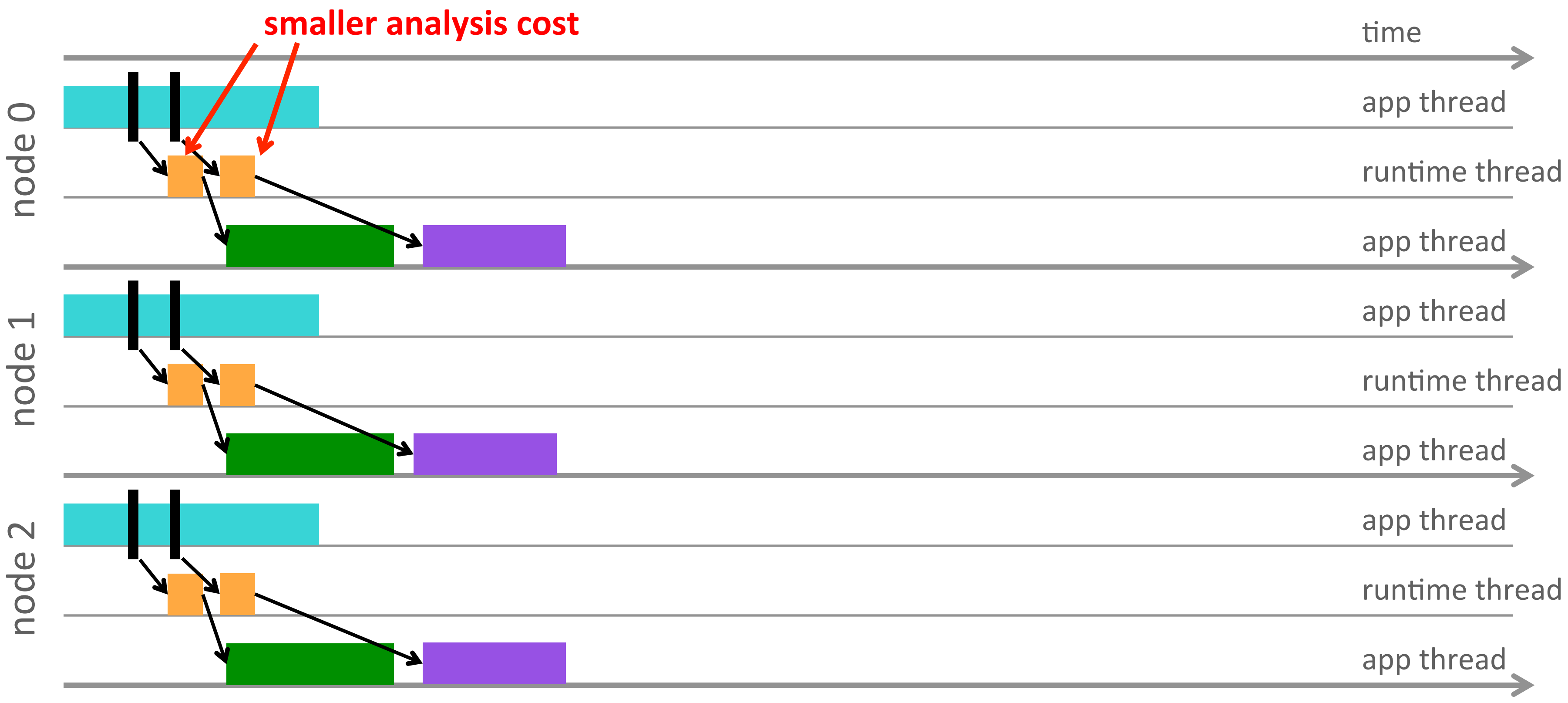


the last computer_limiter task blocked the first compute_face_flux task

```
Task "compute_limiter_task" UID=10040 total=166 us s
```

Solution: SPMD, Legion Style

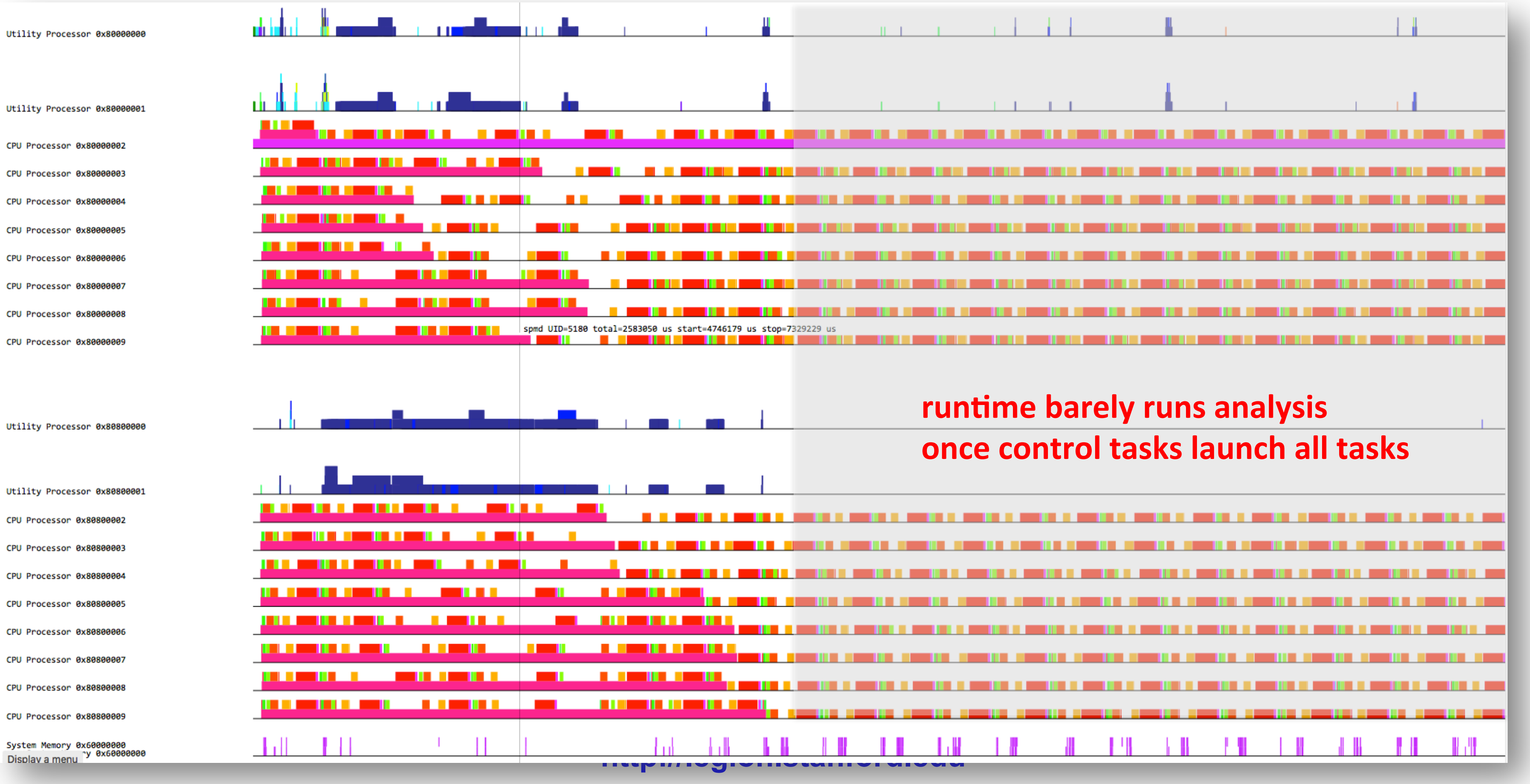
- Have multiple control tasks launch tasks on their own node
  - Lower latency from analysis cost



Solution: SPMD, Legion Style

- Have **multiple control tasks** launch tasks on their own node
  - Lower latency from analysis cost

SPMD-ified Legion MiniAero on two nodes



```
spmd UID=5180 total=2583050 us start=4746179 us stop=7329229 us
```

runtime barely runs analysis
once control tasks launch all tasks

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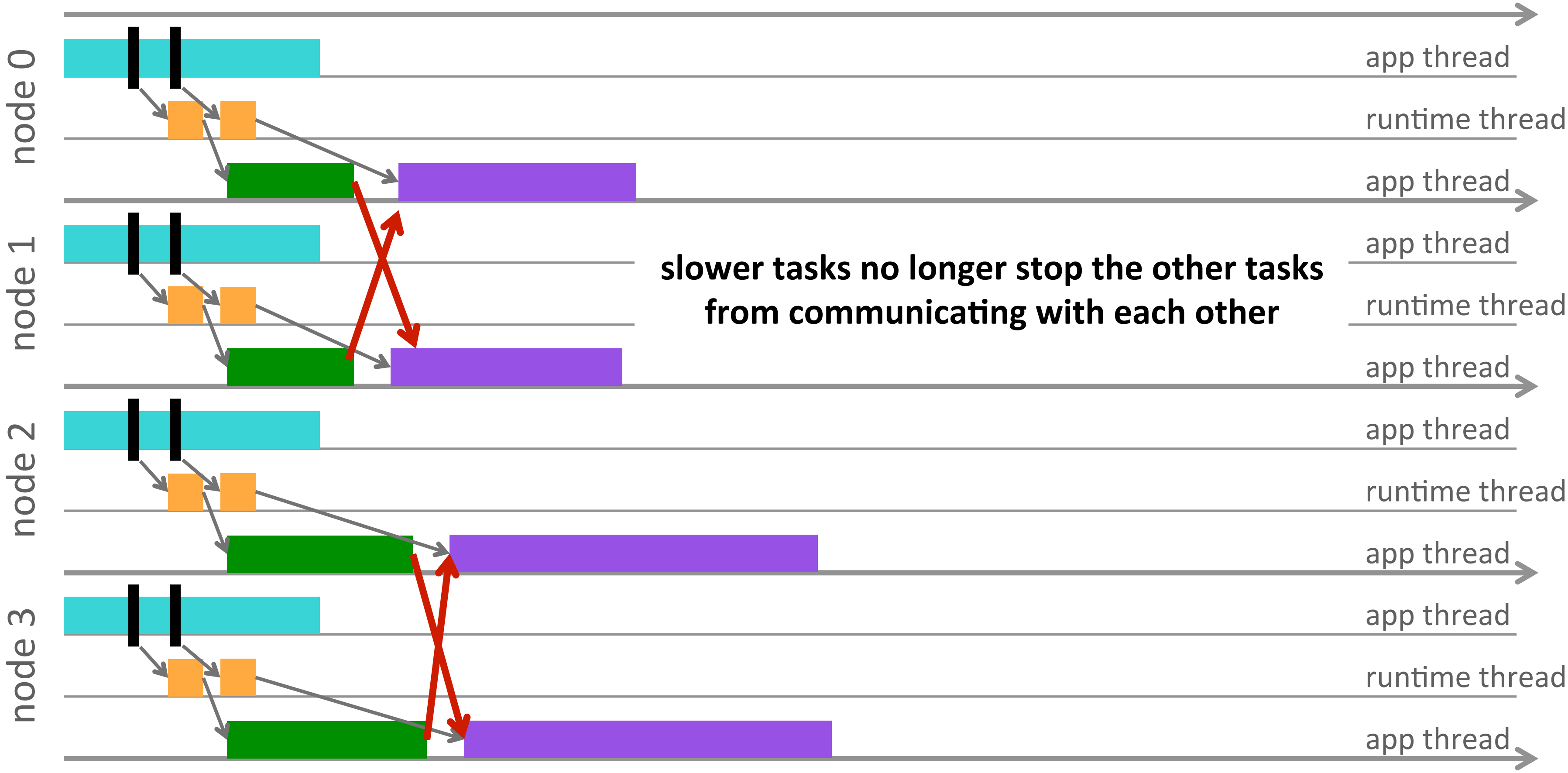
Solution: SPMD, Legion Style

- Have multiple control tasks launch tasks on their own node
- Have tasks locally **share their updates** with each other



slower tasks no longer stop the other tasks from communicating with each other

Solution: SPMD, Legion Style

- Have multiple control tasks launch tasks on their own node
- Have tasks locally share their updates with each other
- **Not necessarily manual**
  - Planned automatic SPMD transformation in the Regent compiler
  - Planned automatic SPMD optimization in the Legion runtime

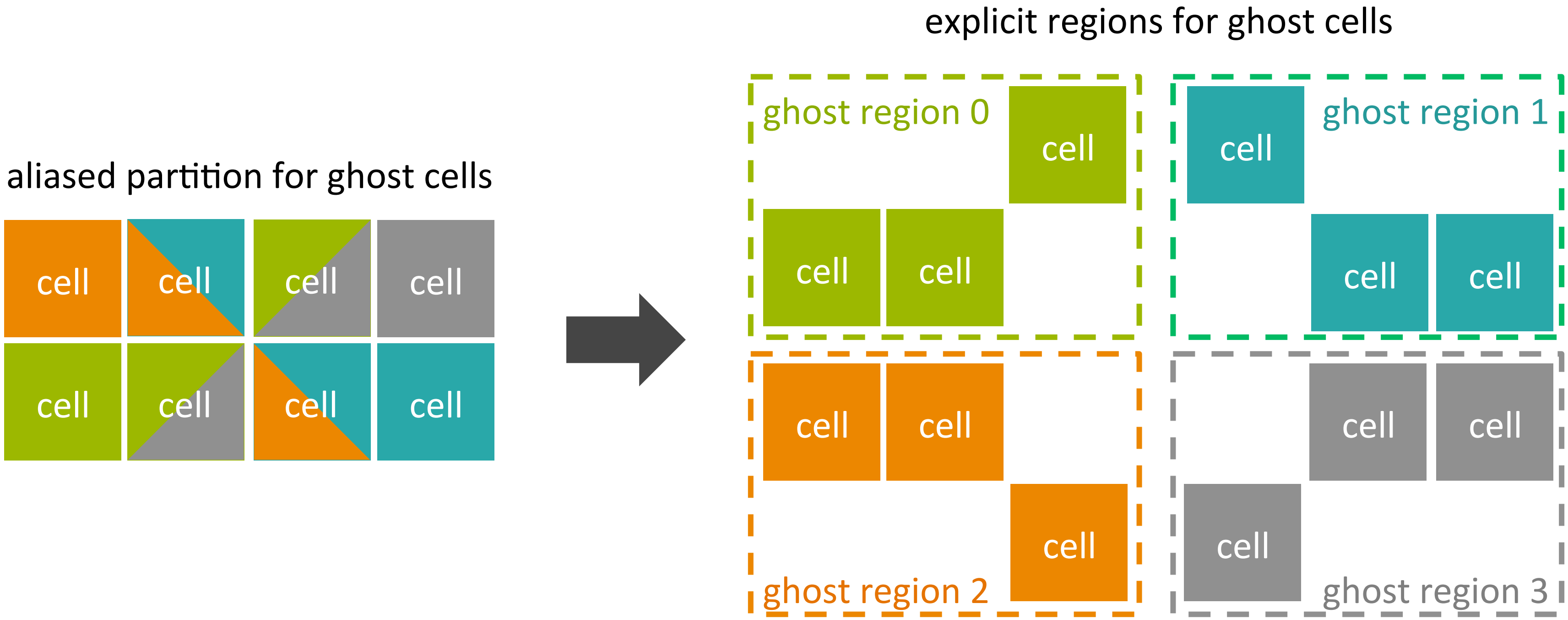
Solution: SPMD, Legion Style

- Have multiple control tasks launch tasks on their own node
- Have tasks locally share their updates with each other
- **Not necessarily manual**
  - Planned automatic SPMD transformation in the Regent compiler
  - Planned automatic SPMD optimization in the Legion runtime
- Manual SPMD-ification is always an option
  - Can be done relatively easily for simple cases
  - Regent provides a cleaner syntax for hand-written SPMD-style code
  - Good exercise to understand transformations that the future compiler and runtime will provide

    ➔ **Let's talk about how I've transformed MiniAero**

MiniAero in Legion's SPMD Style

- Makes **ghost regions** be their own **root regions**



MiniAero in Legion’s SPMD Style

- Makes ghost regions be separate regions explicitly
- Tell runtime to run **simultaneously** a list of control tasks

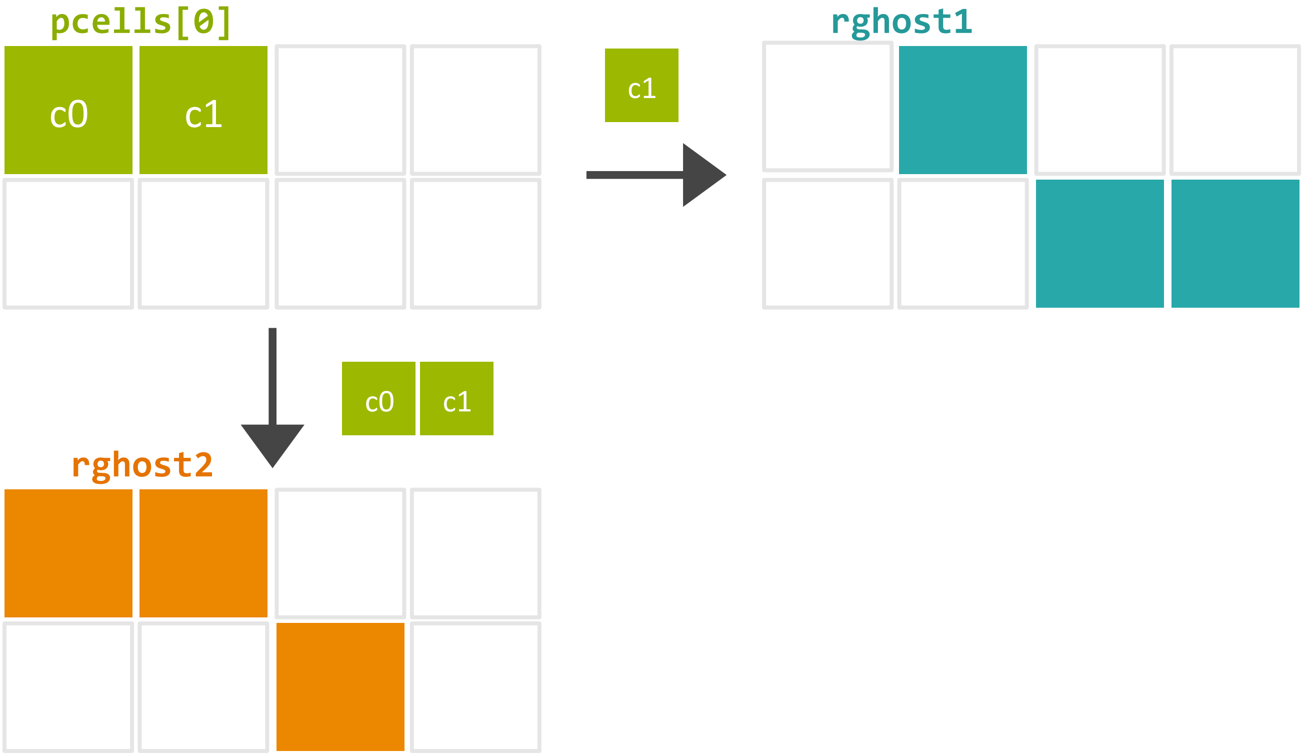
```
must_epoch
  spmd_control(pcells[0], rghost0, ...)
  spmd_control(pcells[1], rghost1, ...)
  spmd_control(pcells[2], rghost2, ...)
  spmd_control(pcells[3], rghost3, ...)
end
```

owned cells

ghost cells

MiniAero in Legion's SPMD Style

- Makes ghost regions be separate regions explicitly
- Tell runtime to run simultaneously a list of control tasks
- Control tasks should copy changes from their owned cells to ghost regions



MiniAero in Legion's SPMD Style

- Makes ghost regions be separate regions explicitly
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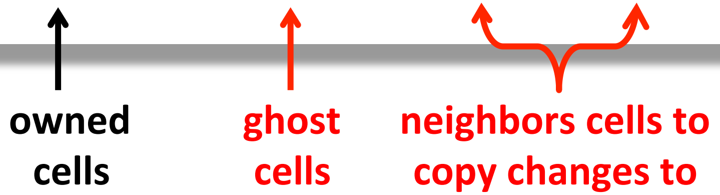
```
must_epoch
  spmd_control(pcells[0], rghost0, rghost1, rghost2, ...)
  spmd_control(pcells[1], rghost1, rghost0, rghost3, ...)
  spmd_control(pcells[2], rghost2, rghost0, rghost3, ...)
  spmd_control(pcells[3], rghost3, rghost1, rghost2, ...)
end
```



owned cells

ghost cells

neighbors cells to copy changes to

should see one instance of the same region
➔ simultaneous coherence!

MiniAero in Legion’s SPMD Style

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```
task spmd_control(rcells     : region(...), rghost     : region(...),
                  rneighbor1 : region(...), rneighbor2 : region(...),
                  ...)
where reads exclusive(cells), reads simultaneous(rghost)
      reads writes simultaneous(rneighbor1, rneighbor2)
  ...
end
```

MiniAero in Legion's SPMD Style

- Makes ghost regions be separate regions explicitly
- Tell runtime to run simultaneously a list of control tasks
- Control tasks should copy changes from their owned cells to ghost regions

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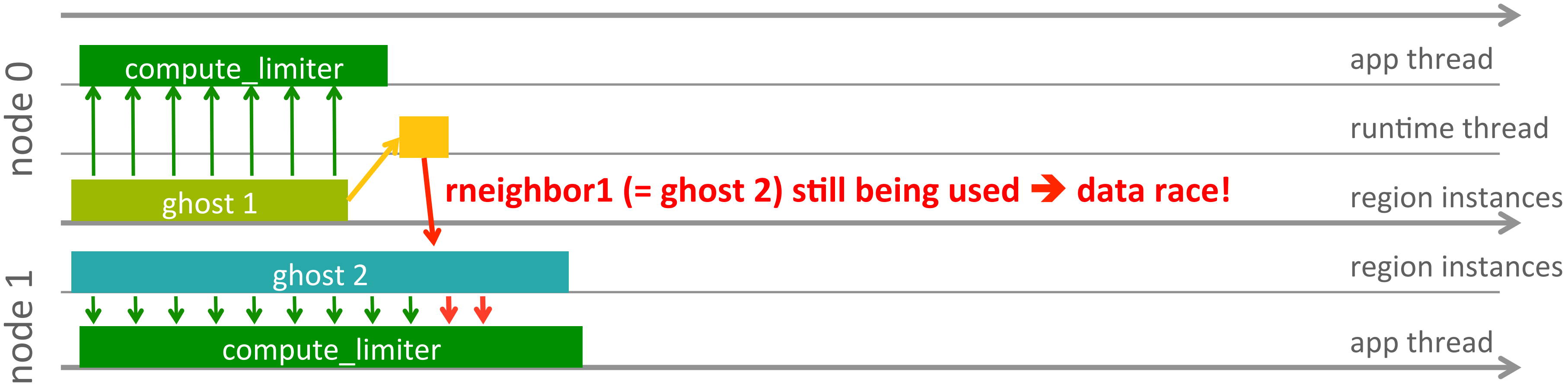
                  rneighbor1 : region(...), rneighbor2 : region(...),
                  ...)
where reads exclusive(cells), reads simultaneous(rghost)
      reads writes simultaneous(rneighbor1, rneighbor2)
  ...
end
```

tell runtime to map these regions simultaneously

Pushing Updates to Ghost Regions

- Tasks and copies must be **synchronized** to avoid races

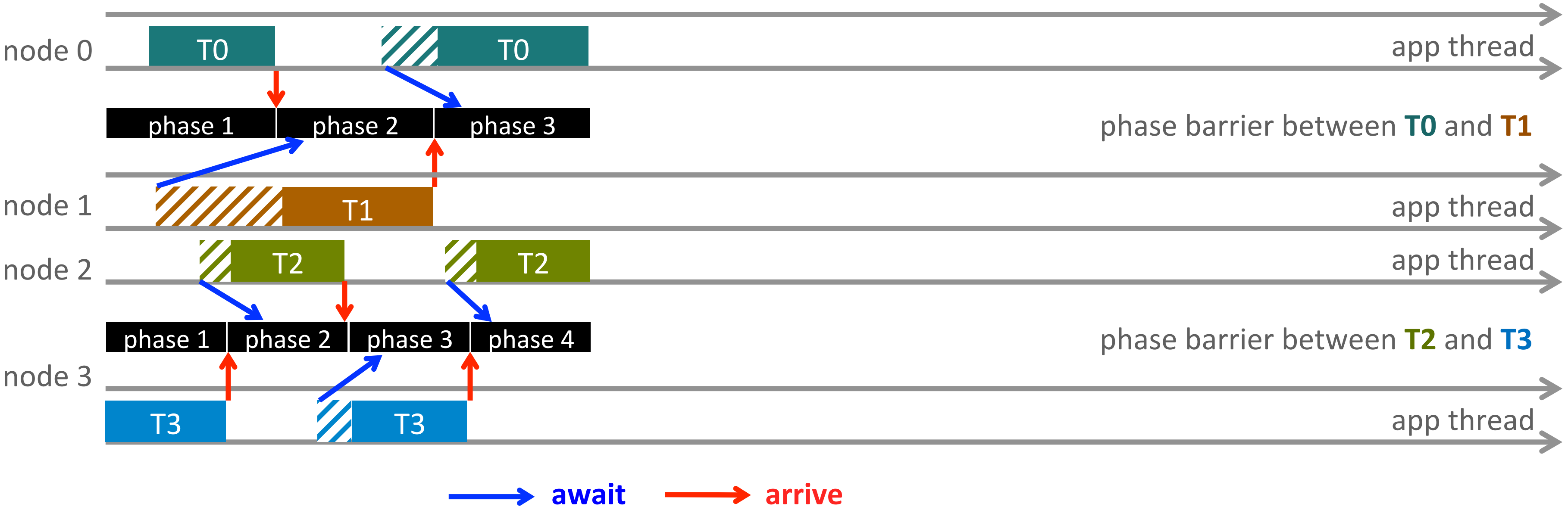
```
task spmd_control(...) where ...
do
  ...
  compute_limiter(rcells, rghost, rfaces)
  copy(rcells, rneighbor1) -- data race!
...
end
```



rneighbor1 (= ghost 2) still being used → data race!

Phase Barriers for Synchronization

- Legion provides phase barriers, a light-weight mechanism to synchronize between operations
  - Phase barriers are not a global barrier, unlike MPI barriers
  - Each barrier can make progress at a different rate



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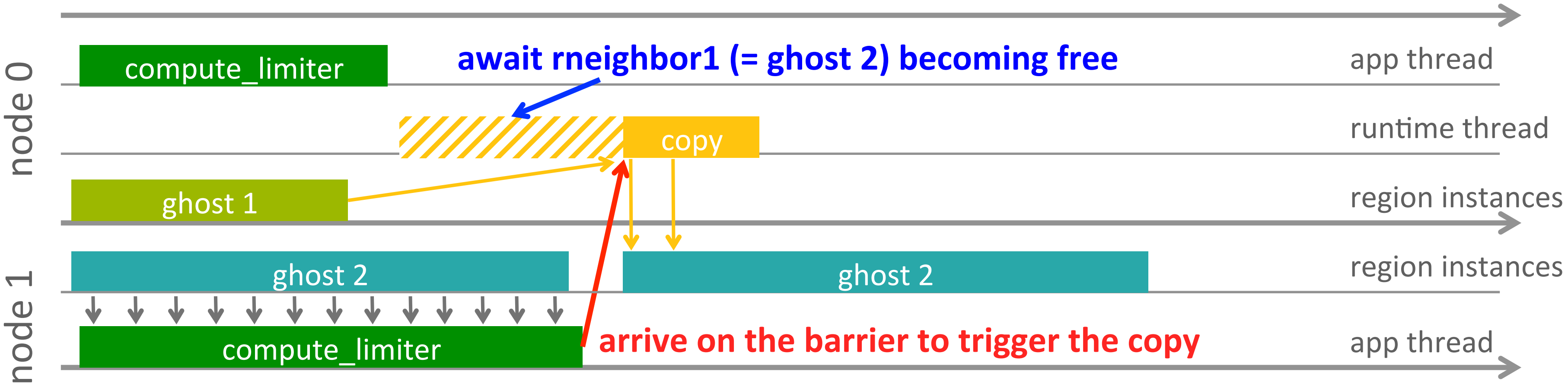
Synchronizing Tasks and Copies

- Each control task is responsible for synchronizing its subtasks

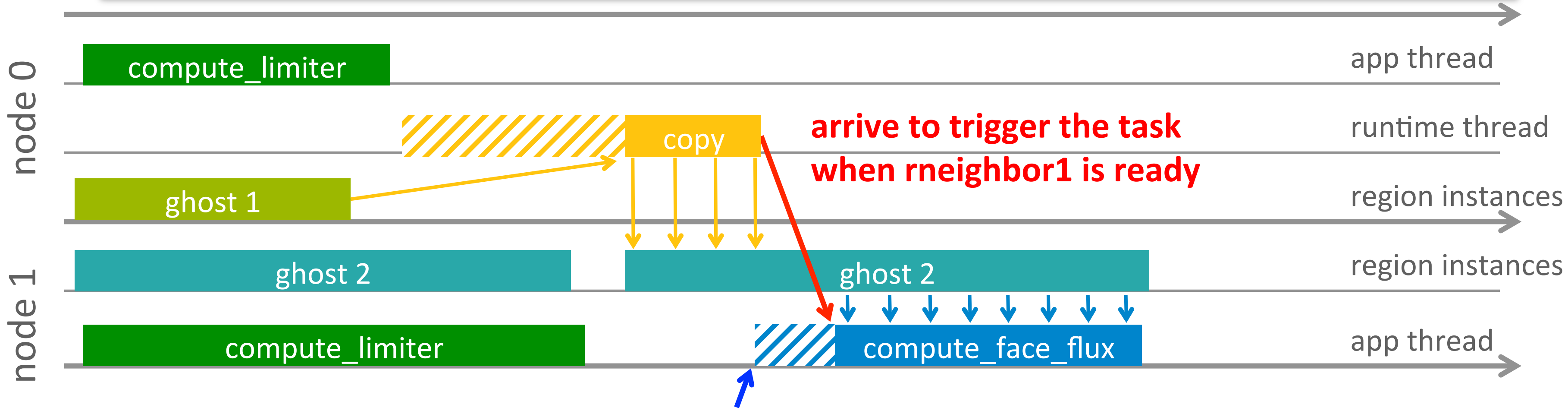
```
task spmd_control(...) where ...
do
  ...
  compute_limiter(rcells, rghost, rfaces) arrives(pb_g_free)
  copy(rcells, rneighbor1) awaits(pb_n1_free)
...
end
```



Synchronizing Tasks and Copies

- Each control task is responsible for synchronizing its subtasks

```
task spmd_control(...) where ...
do
  ...
  compute_limiter(rcells, rghost, rfaces) arrives(pb_g_free)
  copy(rcells, rneighbor1) awaits(pb_n1_free) arrives(pb_n1_ready)
  compute_face_flux(rcells, rghost, rfaces) awaits(pb_g_ready)
...
end
```

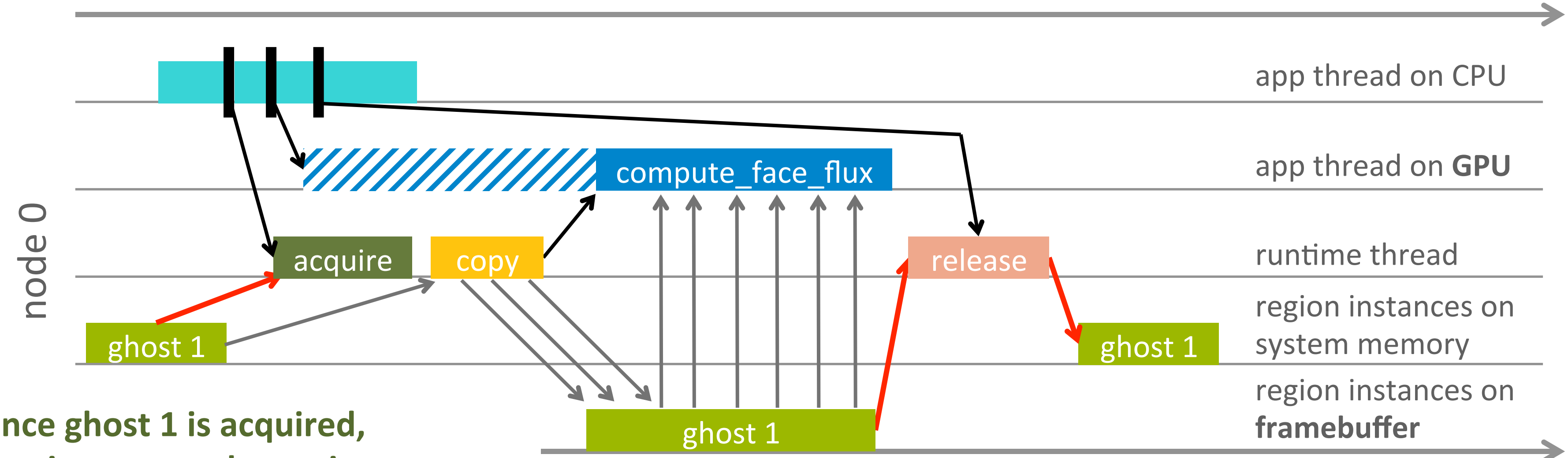


arrive to trigger the task
when rneighbor1 is ready

await ghost 2 becoming ready

Relaxing Simultaneous Constraints

- Simultaneous coherence enforces that all tasks use the same region instance
- Acquire and release operations relax that constraint
    - Useful when the task needs to copy the instance somewhere else (e.g. GPU framebuffer memory)



once ghost 1 is acquired, runtime can make copies

back to the simultaneous instance once ghost 1 is released

Programming Experience

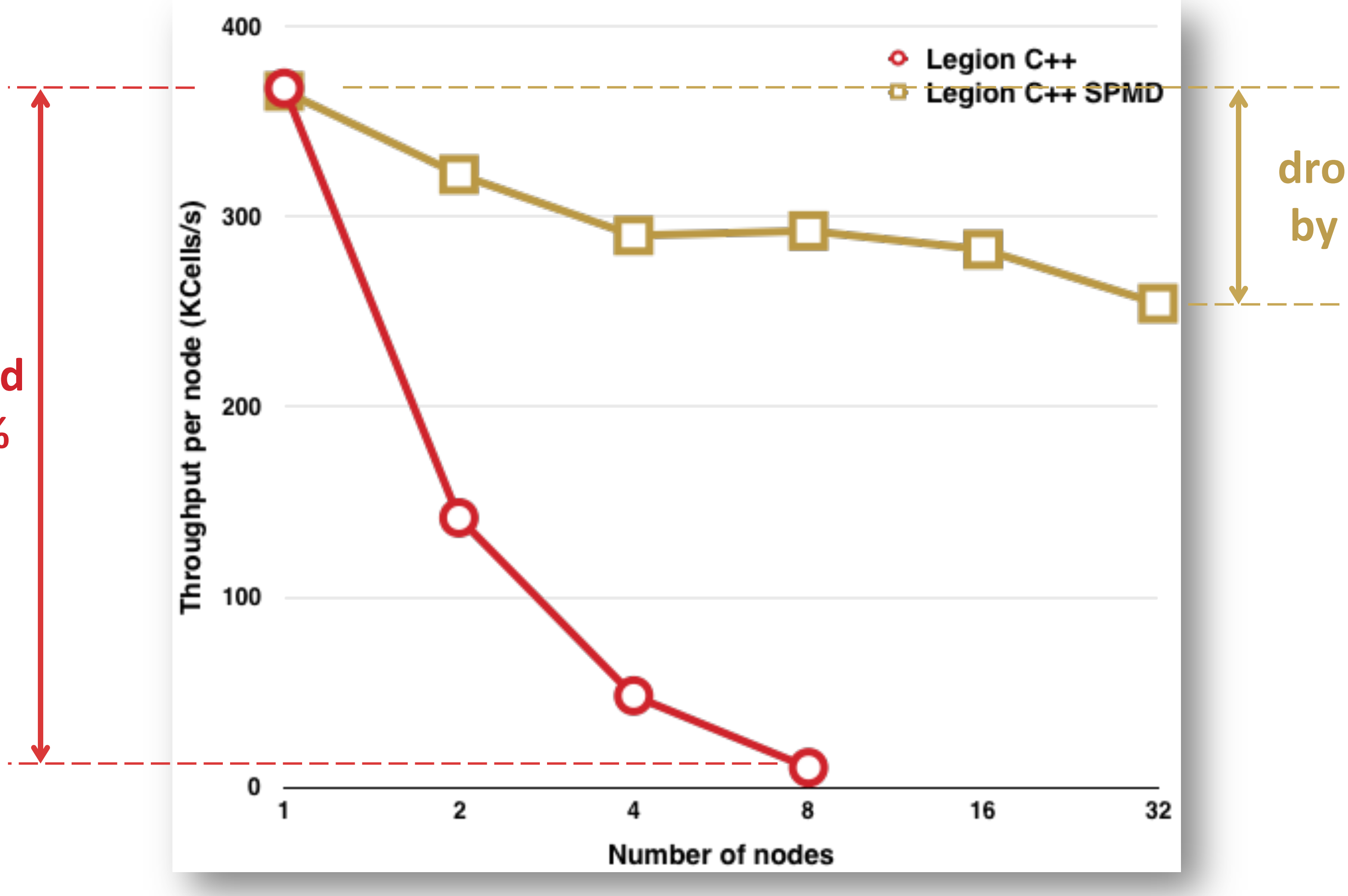
- Started with the initial C++ port
  - Regent support for SPMD-style programs wasn't ready yet
  - First correct version in 2 weeks
  - A few more weeks to optimize and tune
  - Would have been quicker with Regent
- Legion Spy was helpful in tracking down synchronization bugs
  - Currently, this is the price of managing tasks manually
  - Event graphs show which tasks are depending on which phases of barriers
  - Physical dependence analysis shows some missing dependencies if tasks are synchronized incorrectly

Preliminary Performance Study

- Weak scaling experiments
  - 256K cells per node
  - Certainty Cluster
- Two target versions
  - Initial version without SPMD
  - Manually SPMD-ified version (one control task per processor)

Weak Scaling Graph

- SPMD version scales much better than the original

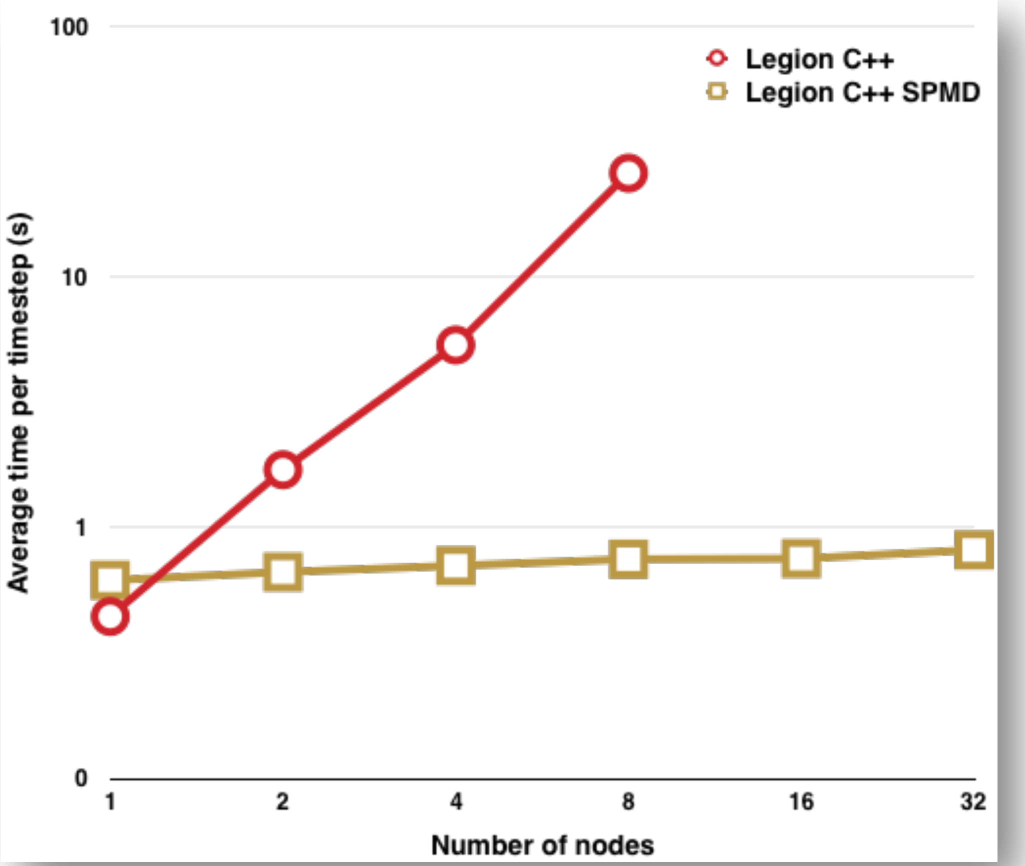


dropped by 97%

dropped by 30%

Measuring Runtime Overhead

- Commenting out task bodies
  - Runtime still issues all tasks with necessary copies
  - SPMD-style version has stable overhead (0.6s – 0.8s per timestep)



Plans

- SPMD-ification in Regent
  - Will be faster due to better leaf tasks in Regent
  - Manual SPMD-ification support is now available
  - Automatic SPMD-ification will become available soon

- Comparing between various SPMD configurations
  - We can have M control tasks each of which manages N processors
    - More control tasks better amortizes analysis cost but has more overhead due to partitioning
    - Fewer control tasks can reduce communication overhead but be less adaptable to load imbalance
  - We'll explore with Regent's automatic SPMD-ification

Concluding Remarks

- Legion’s SPMD-style is a practical way to achieve high scalability
  - MiniAero shows steady weak-scaling performance up to 32 nodes
- SPMD style is not too difficult
  - Requires only the control task to be rewritten
  - Does require explicit programmer-managed synchronization between control tasks
- SPMD-style programming will become easier
  - Cleaner syntax for in Regent
  - Planned automatic SPMD transformation in the Regent compiler
  - Planned automatic SPMD optimization in the Legion runtime