Two Topics: IO & Control Replication

CS315B

Lecture 10

I/O in Parallel Programming

- I/O tends to be an afterthought in parallel programming systems
- Many papers ignore I/O time in reported results!
- But in real life, I/O time is … time

Regent I/O

- The situation is better with Regent

- Already have the notion
  - There are distinct collections of data
    - regions
  - That can be in different places, have different layouts, etc.
  - And the details are kept abstract
    - Programmer doesn’t need to know how data is accessed

Regent I/O Outline

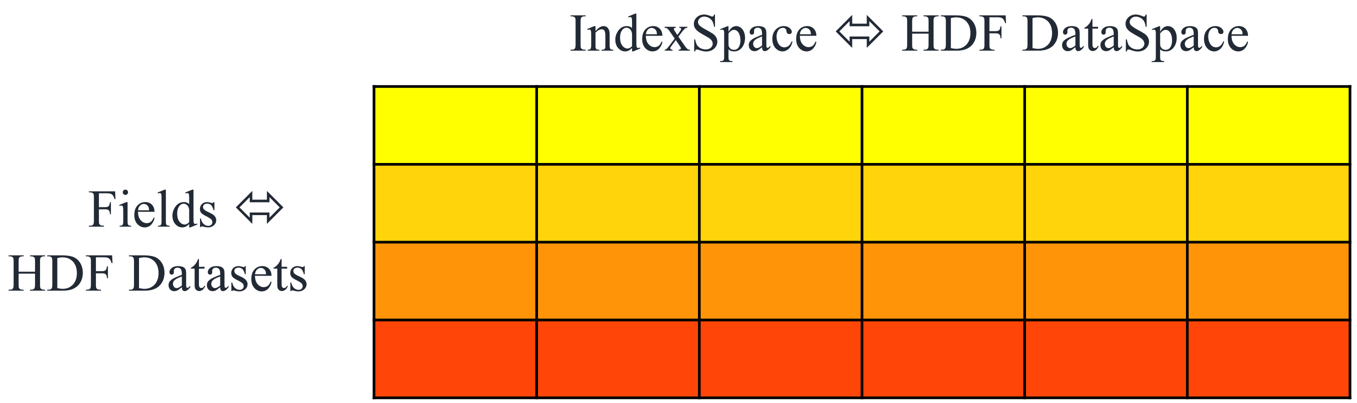
- Interpret files as regions
  - Integrate I/O into the programming model

- Why?
  - Want to overlap I/O with computation
  - Need to define consistency semantics

- Bottom line
  - I/O is (almost) like any other data movement

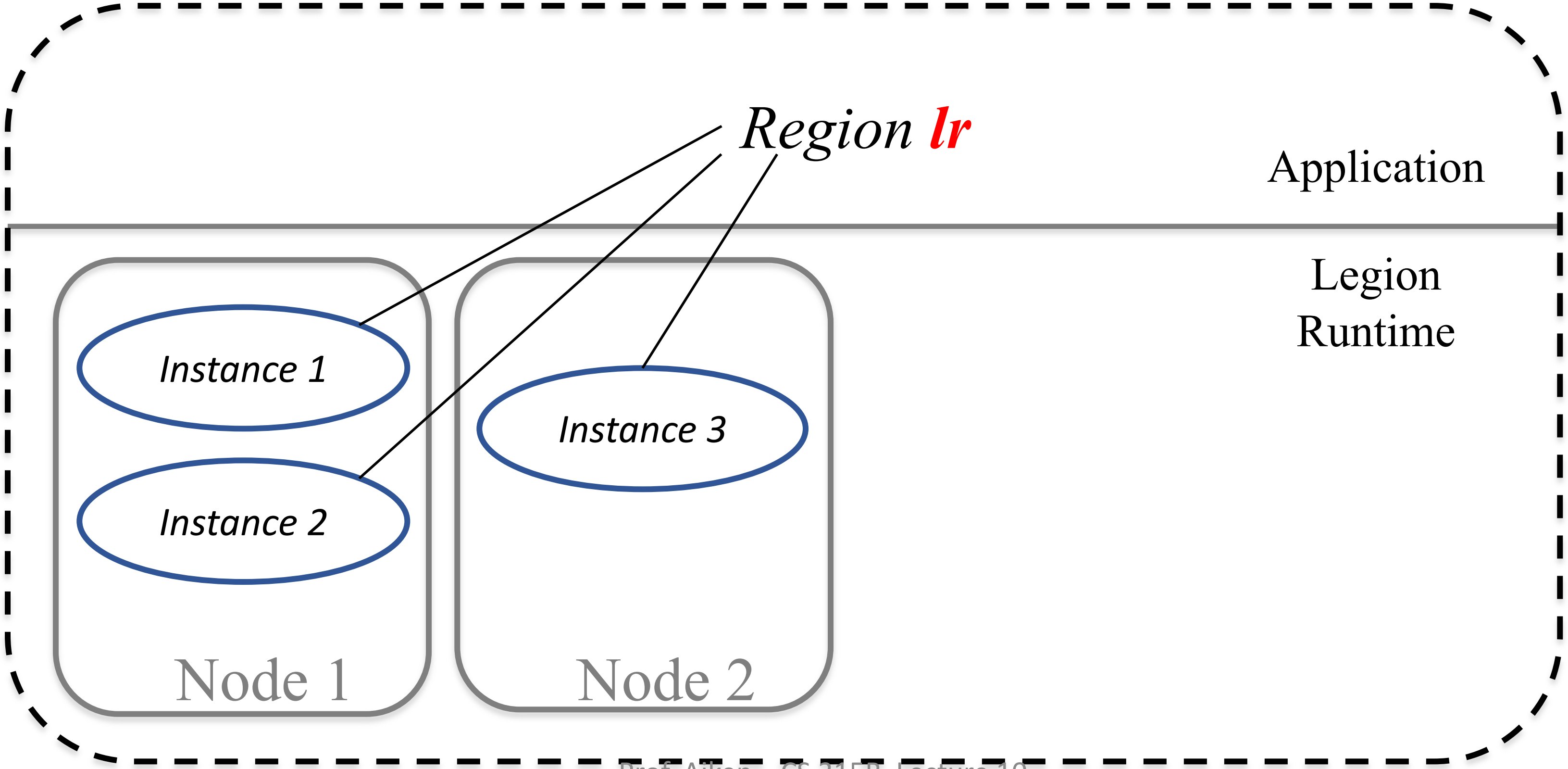
Attach Operation

- Attach external resource to a region
  - Normal files, formatted files (HDF5), …



Attach Operation

- Semantics
  - Invalidate existing physical instance of *lr*
  - Maps *lr* to a new physical instance that represents external data (no external I/O)



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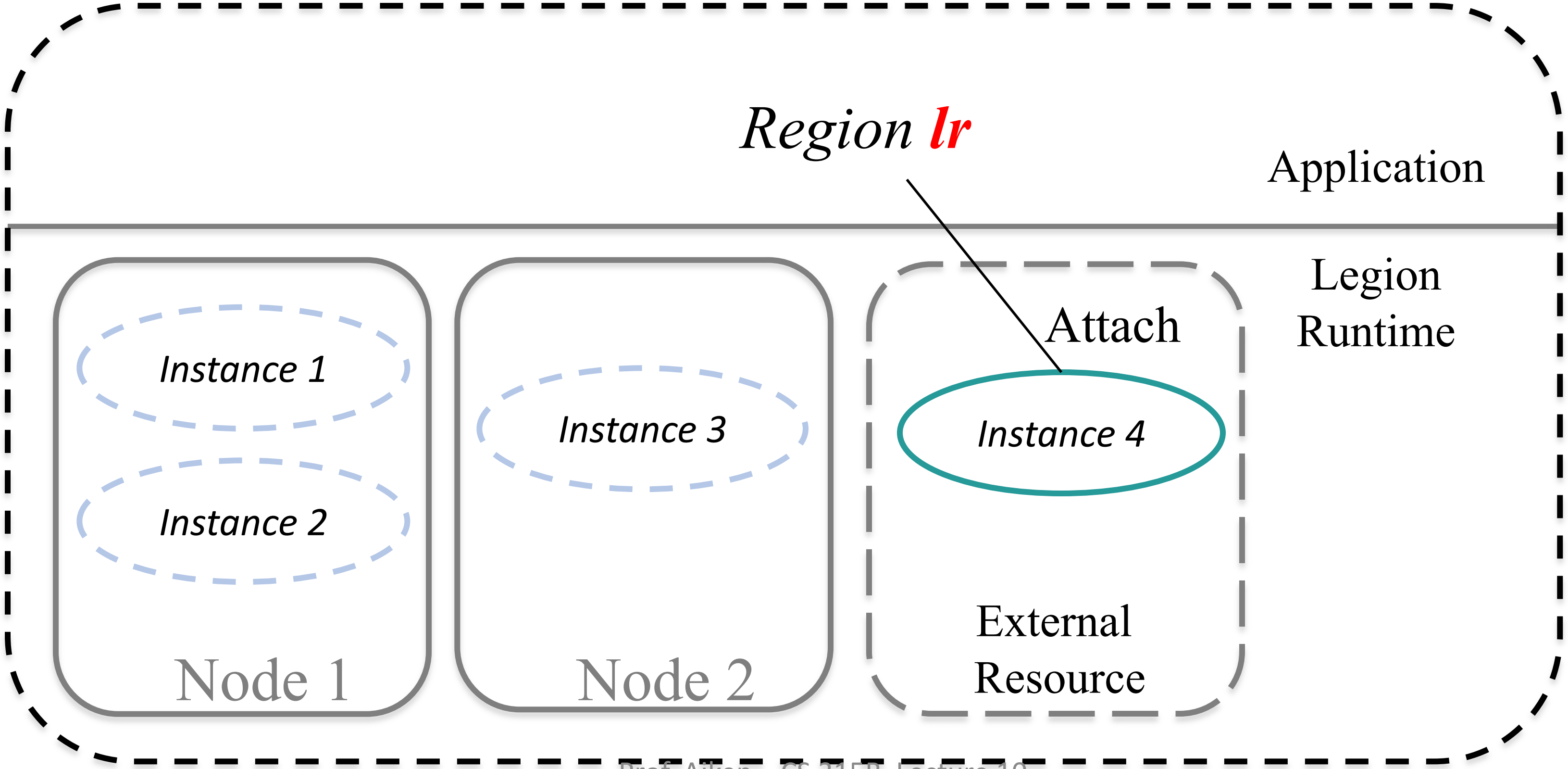


Digression: Task Coherence

Privileges

- Reads
- Reads/Writes
- Reduces (with operator)

Coherence

- Exclusive
- Atomic
- Simultaneous
- Relaxed

- Coherence declarations are wrt *sibling* tasks

Attach Operation

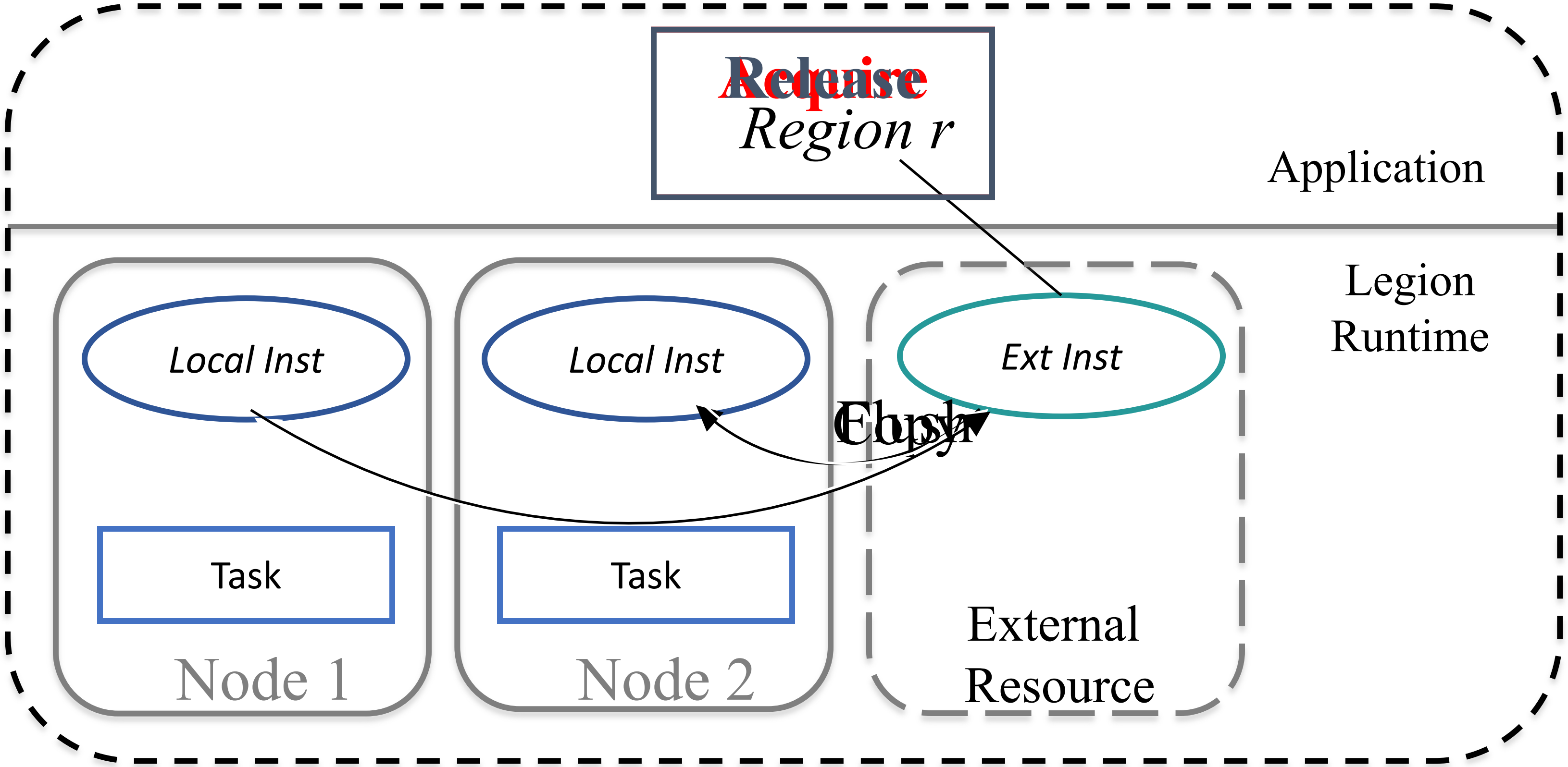
- Attached region accessed using *simultaneous coherence*
  - Different tasks access the region simultaneously
  - Requires that all tasks must use the *only valid* physical instance

- *Copy restriction*
  - Simultaneous coherence implies tasks cannot create local copies
  - May result in inefficient memory accesses

Acquire/Release

- For regions with simultaneous coherence
- Acquire removes the copy restriction
  - Can create copies in any memory
  - Up to application to know this is OK!
- Release restores the copy restriction
  - Invalidates all existing local copies
  - Flushes dirty data back to the file

Acquire/Release Example

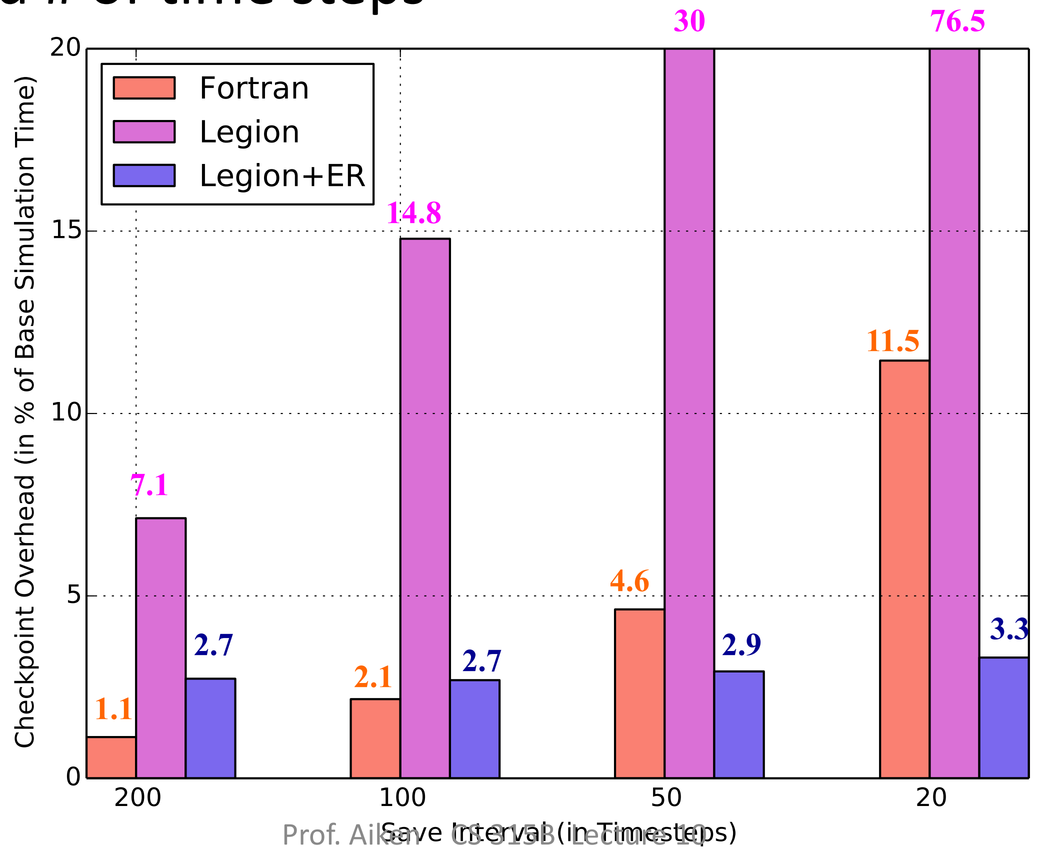


Opaque Data Sources

- Can also attach to sources that are other programs
  - E.g., read/write in-memory data structures from another process
- Done through a serialization/deserialization interface
  - Attach specifies the ser/des routines

S3D I/O Example

- A production combustion simulation
- Checkpoint after fixed # of time steps



I/O Summary

- Definitely a useful feature!
- And less mature than other features
  - But simple cases will work fine
- Let us know if you need/want to use I/O

Control Replication

Implicit Parallel Programming Template

```
while (…) do
  for R in Parts do
        task1(R)
  end
  for R in Parts do
        task2(R)
  end
end
```

How Do We Scale This Program?

```
while (…) do
  for R in Parts do
        task1(R)
  end
  for R in Parts do
        task2(R)
  end
end
```

- Make more Parts
- Make each subregion R smaller

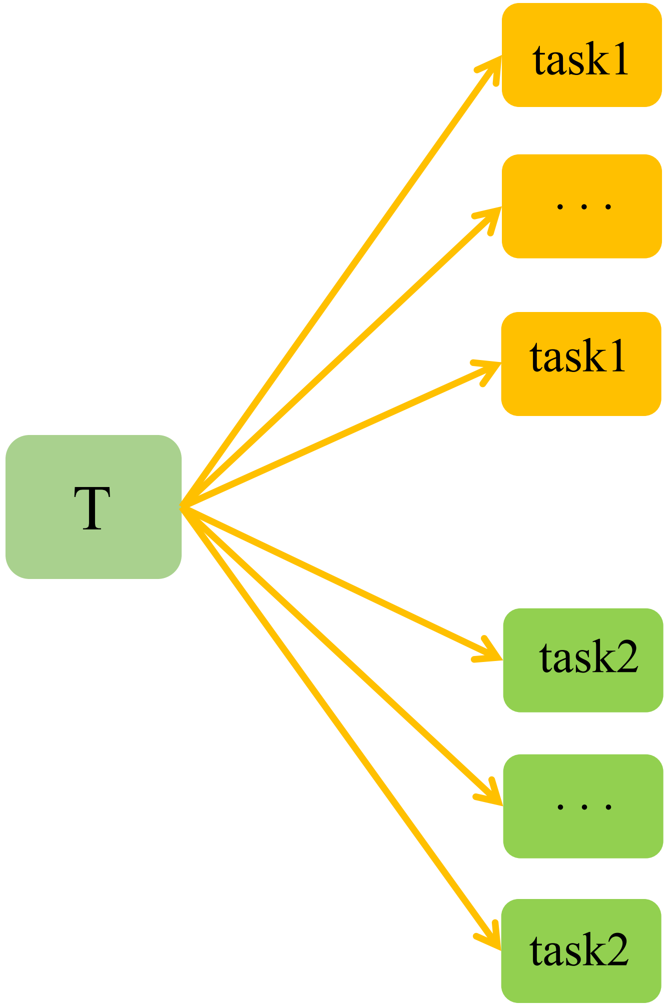
Amdahl Strikes Back

- Recall Amdahl’s law
  - Parallel speedup is limited by the sequential portion left un-parallelized
  - There is some sequential overhead to launching tasks on a single processor

- If we double the # of subregions
  - Each subregion is ½ the size, so <= ½ of the work
  - Launch overhead doubles
  - Useful compute/overhead ratio decreases by >= 4X

Picture

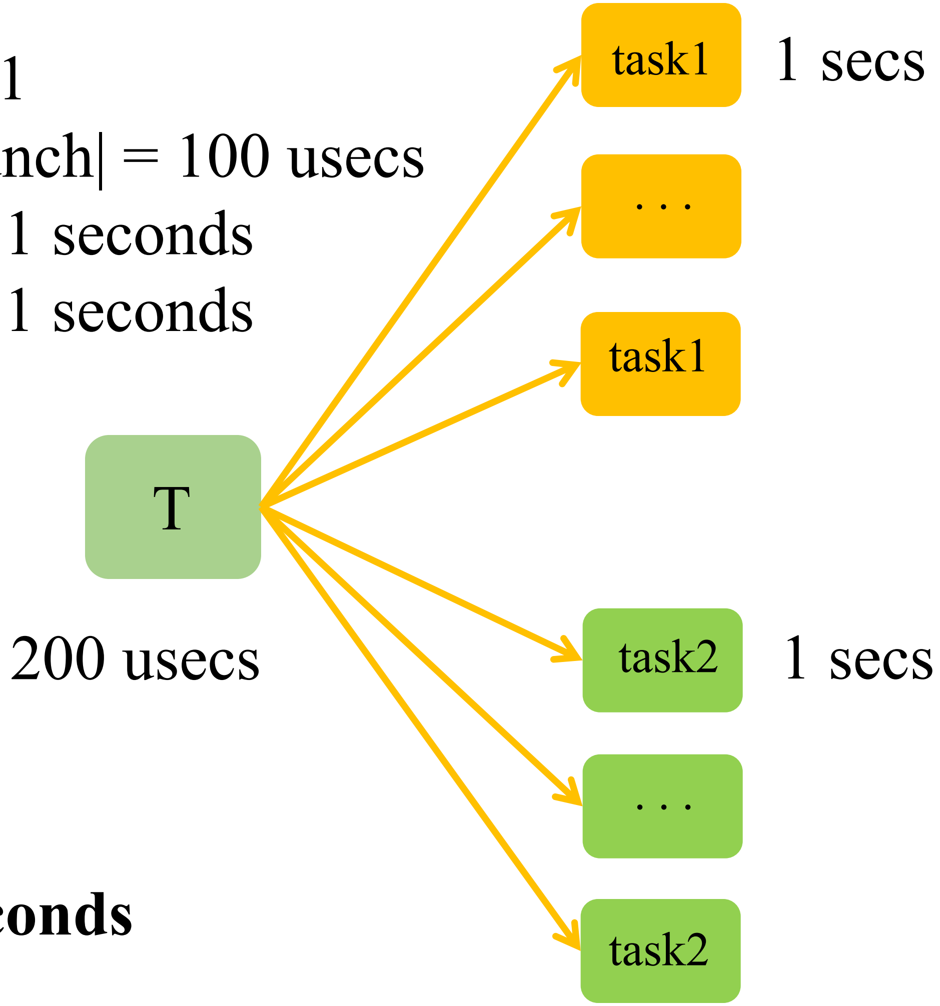
```
task T(){
 while (…) do
  for R in Parts do
       task1(R)
  end
  for R in Parts do
       task2(R)
  end
 end
}
```



Analysis

```
task T(){
 while (…) do
   for R in Parts do
        task1(R)
   end
   for R in Parts do
        task2(R)
   end
 end
}
```

|Parts| = 1
|Task launch| = 100 usecs
|task1| = 1 seconds
|task2| = 1 seconds

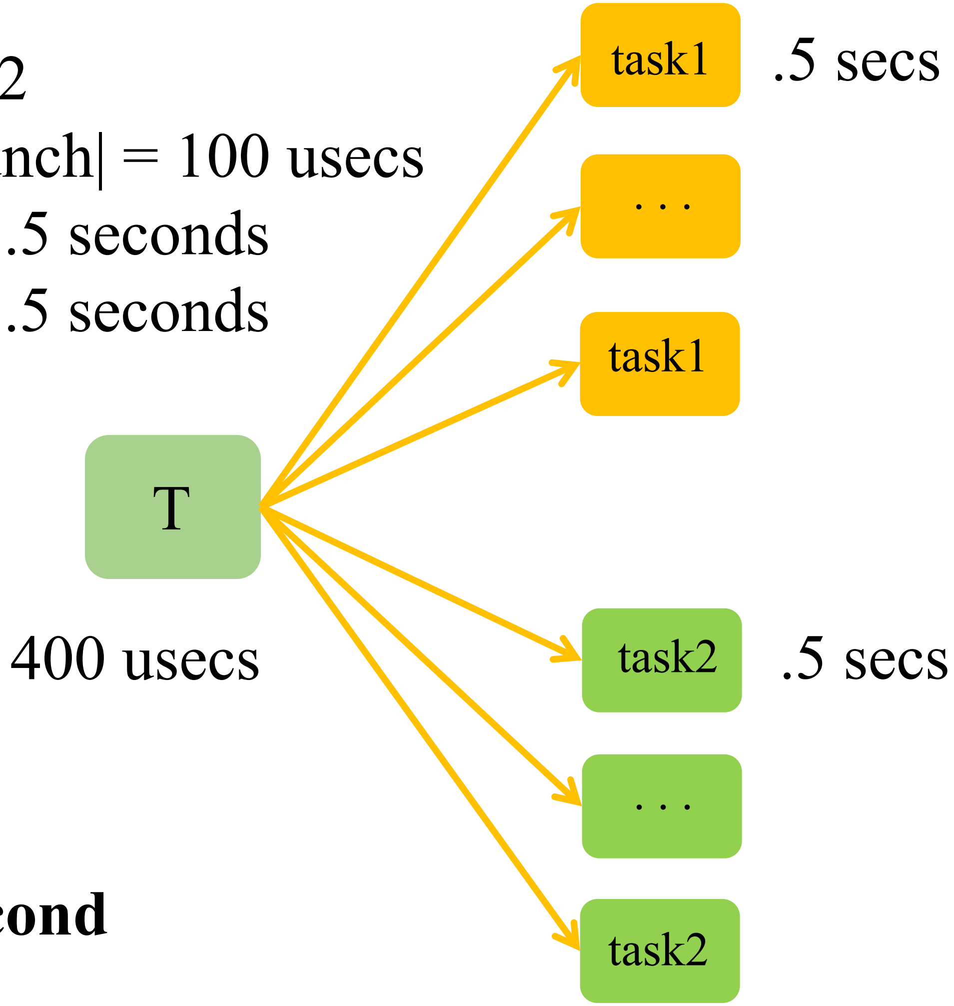


Total: 2 seconds

Analysis

```
task T(){
 while (…) do
  for R in Parts do
        task1(R)
  end
  for R in Parts do
        task2(R)
  end
 end
}
```

|Parts| = 2
|Task launch| = 100 usecs
|task1| = .5 seconds
|task2| = .5 seconds

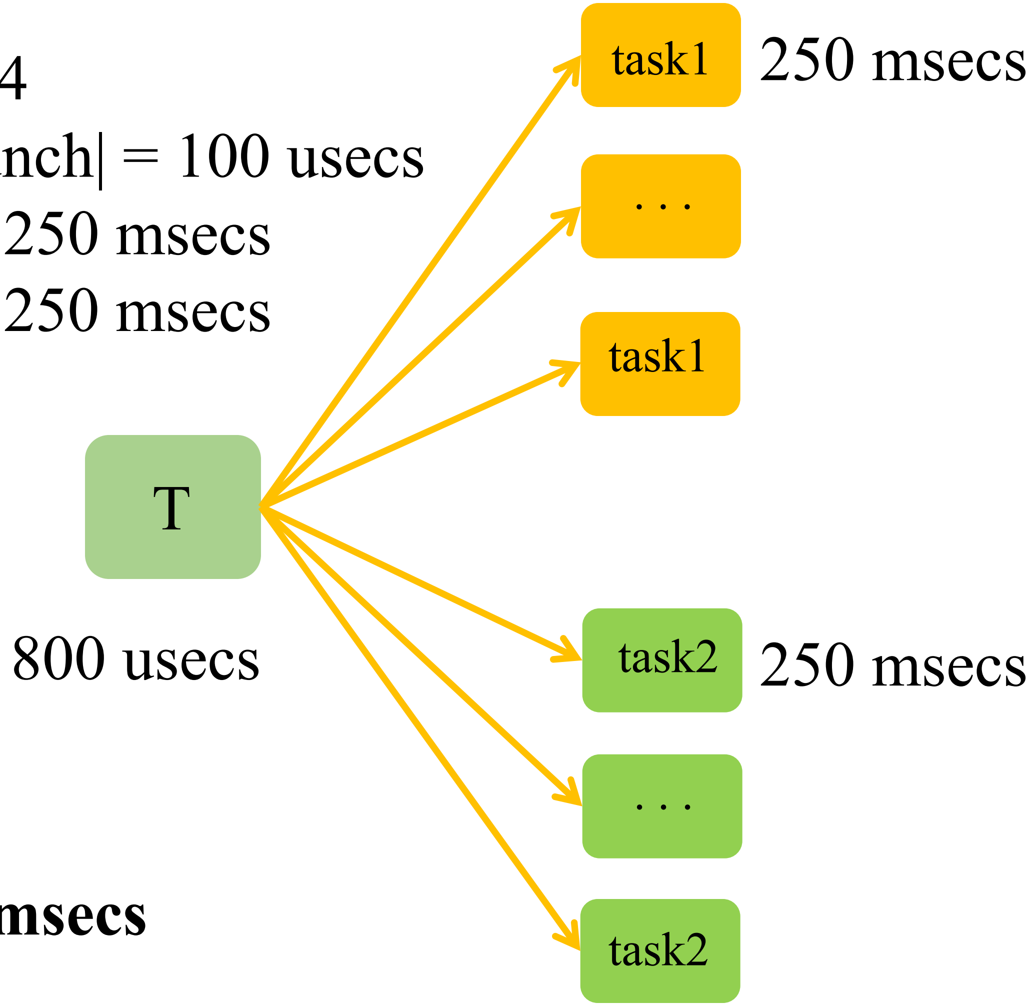


Total: 1 second

Analysis

```
task T(){
 while (…) do
  for R in Parts do
        task1(R)
  end
  for R in Parts do
        task2(R)
  end
 end
}
```

|Parts| = 4
|Task launch| = 100 usecs
|task1| = 250 msecs
|task2| = 250 msecs

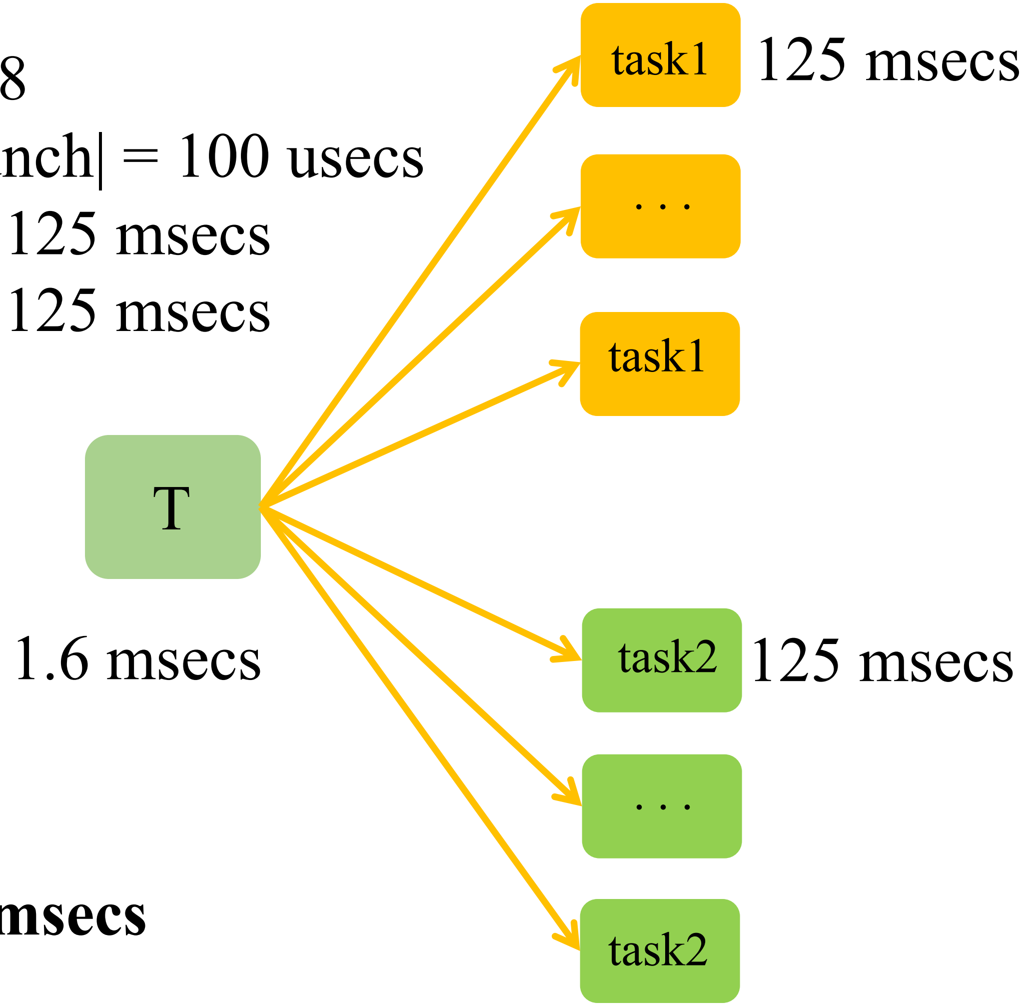


Total: 500 msecs

Analysis

```
task T(){
 while (…) do
   for R in Parts do
          task1(R)
   end
   for R in Parts do
          task2(R)
   end
 end
}
```

|Parts| = 8
|Task launch| = 100 usecs
|task1| = 125 msecs
|task2| = 125 msecs

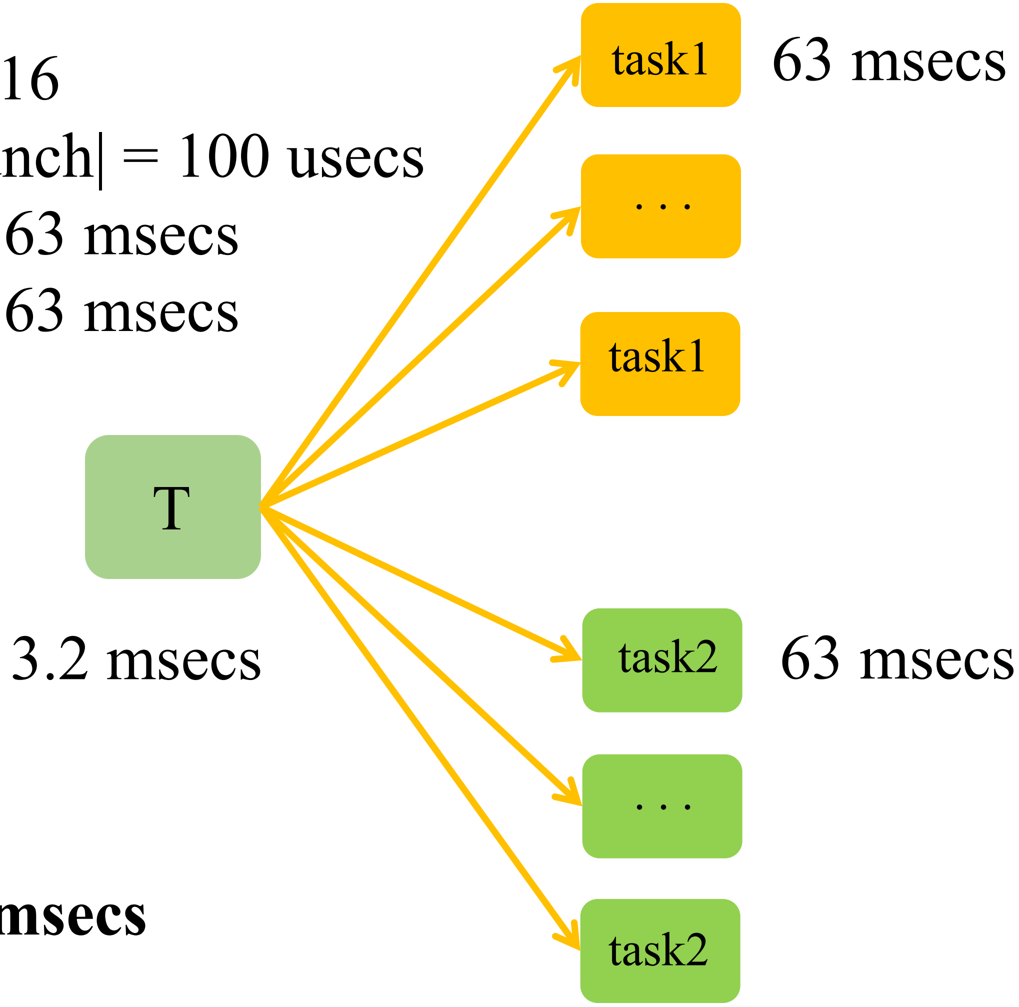


Total: 250 msecs

Analysis

```
task T(){
 while (...) do
   for R in Parts do
          task1(R)
   end
   for R in Parts do
          task2(R)
   end
 end
}
```

|Parts| = 16
|Task launch| = 100 usecs
|task1| = 63 msecs
|task2| = 63 msecs

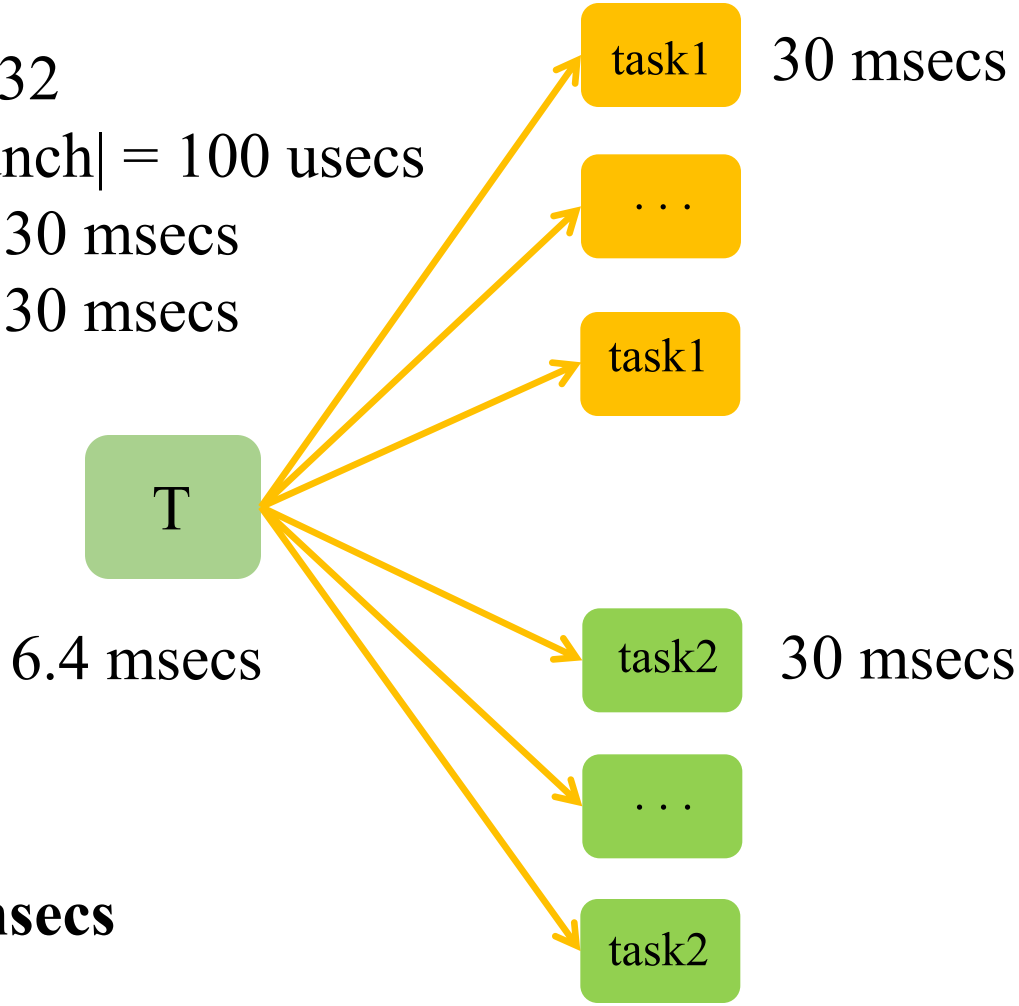


Total: 125 msecs

Analysis

```
task T(){
 while (...) do
  for R in Parts do
      task1(R)
  end
  for R in Parts do
      task2(R)
  end
 end
}
```

|Parts| = 32
|Task launch| = 100 usecs
|task1| = 30 msecs
|task2| = 30 msecs

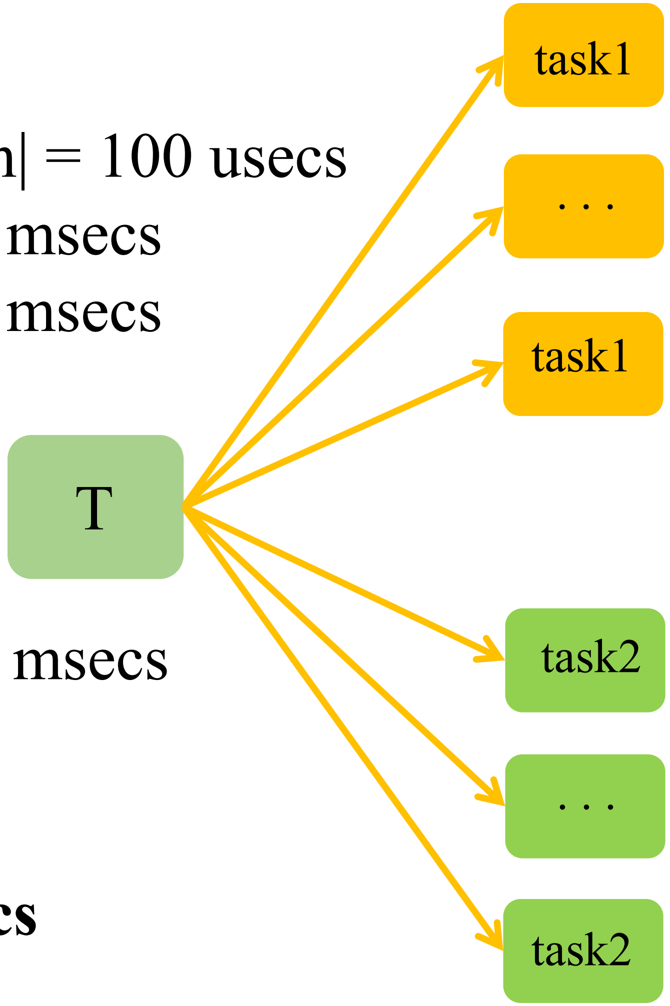


Total: 60 msecs

Analysis

```
task T(){
 while (…) do
   for R in Parts do
          task1(R)
   end
   for R in Parts do
          task2(R)
   end
 end
}
```

|Parts| = 64
|Task launch| = 100 usecs
|task1| = 15 msecs
|task2| = 15 msecs



15 msecs

13 msecs

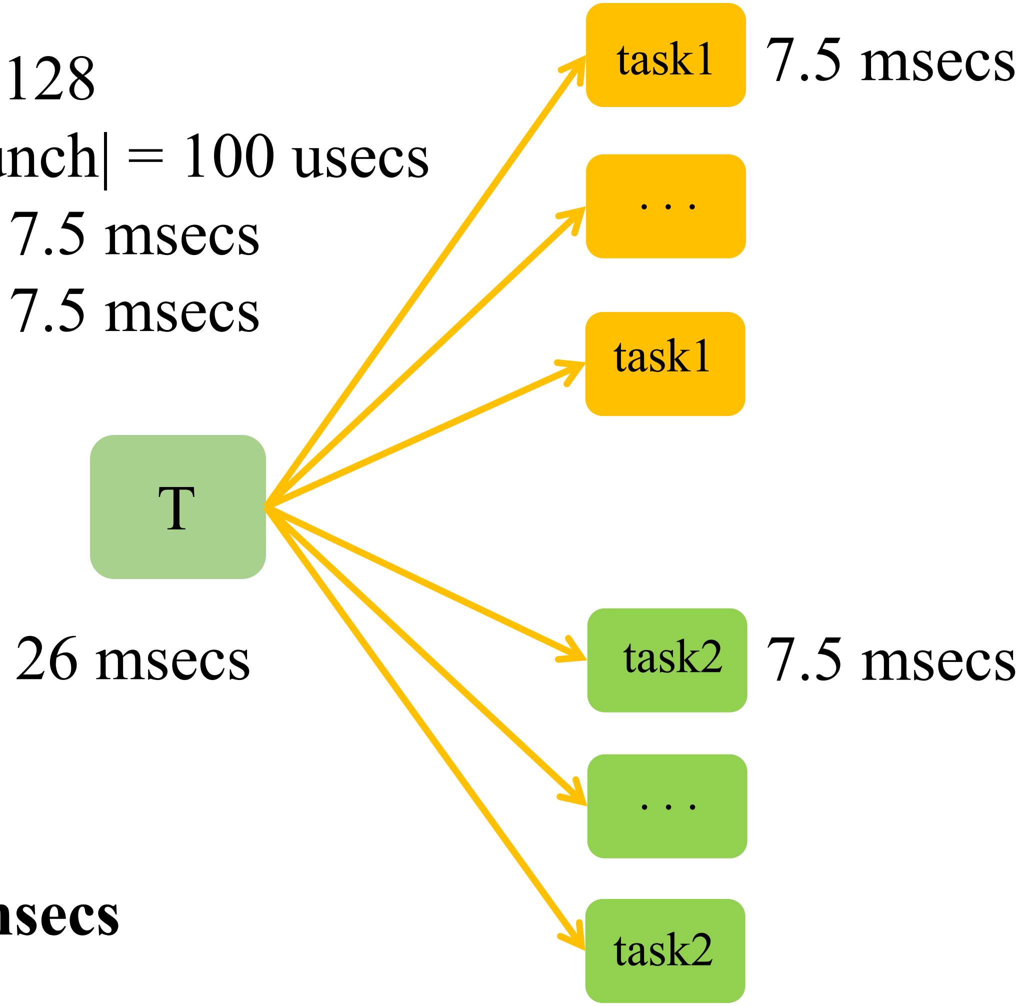
15 msecs

Total: 30 msecs

Analysis

```
task T(){
 while (...) do
   for R in Parts do
          task1(R)
   end
   for R in Parts do
          task2(R)
   end
 end
}
```

|Parts| = 128
|Task launch| = 100 usecs
|task1| = 7.5 msecs
|task2| = 7.5 msecs



Total: 26 msecs

What Does That Mean?

```
while (…) do
  for R in Parts do
        task1(R)
  end
  for R in Parts do
        task2(R)
  end
end
```

- Can scale this program to 8 or 16 nodes
  - Should be more, but…
- We want to run on 100’s or 1,000’s of nodes

SPMD Programming Revisited

- Recall that SPMD programs
  - Launch 1 task per processor at program start-up
  - These tasks run for the duration of the program
  - Tasks explicitly communicate to exchange data

- Notice
  - SPMD programs launch the minimum # of tasks to keep the machine busy
  - These tasks run for the maximum amount of time
  - Best possible launch overhead/work ratio!

How Do We Scale This Program?

```
while (…) do
  for R in Parts do
        task1(R)
  end
  for R in Parts do
        task2(R)
  end
end
```

```
must_epoch
  for i = 1,num_tasks do
    task(part[i],phaseb[i])
end
```

where

tasks know which other tasks they have to communicate with

The Price

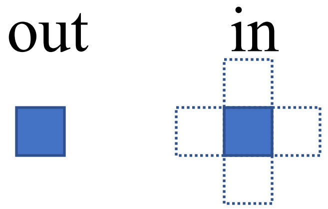
- SPMD programs minimize distributed overheads related to control

- The price is explicit parallel programming
    - Tasks must communicate with each other while they execute
    - Introduces synchronization, message passing …

Implicit Parallelism

Traditional auto-parallelization
[Irigoin 91; Blume 95; Hall 96; …]

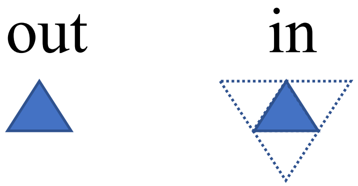
```
for step = 0, nsteps:
 for i, j in grid:
   out[i,j] = F(in[i,j], in[i+1, j], …)
  …
```



- **Requires static analysis of individual memory accesses**
- **Limited applicability**

Inspector/executor method
[Crowley 89; Ravishankar 12; …]

```
for step = 0, nsteps:
  for c in mesh:
    out[c] = G(in[c],in[neighbor[c]])
  …
```



- **Requires dynamic analysis of individual memory accesses**
- **Expensive runtime analysis**

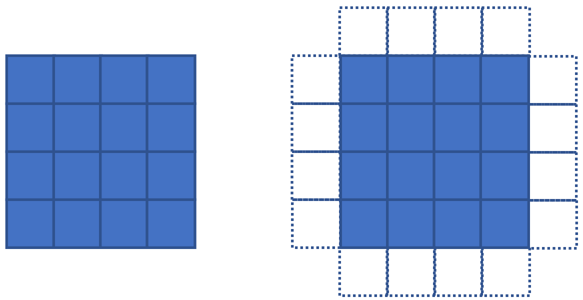
Task-Based Implicit Parallelism

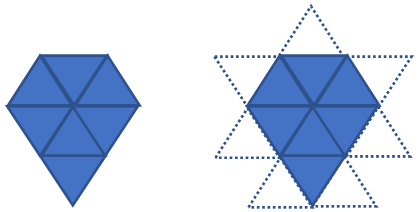
```
task tF(out, in):
  for i, j in out:
     out[i,j] = F(in[i,j], in[i+1, j], …)

for step = 0, nsteps:
  for sg in grid:
    tF(out[sg], in[sg])
  …
```

```
task tG(out, in):
  for c in out:
    out[c] = G(in[c], in[neighbor[c]])

for step = 0, nsteps:
  for sm in mesh:
    tG(out[sm], in[sm])
  …
```

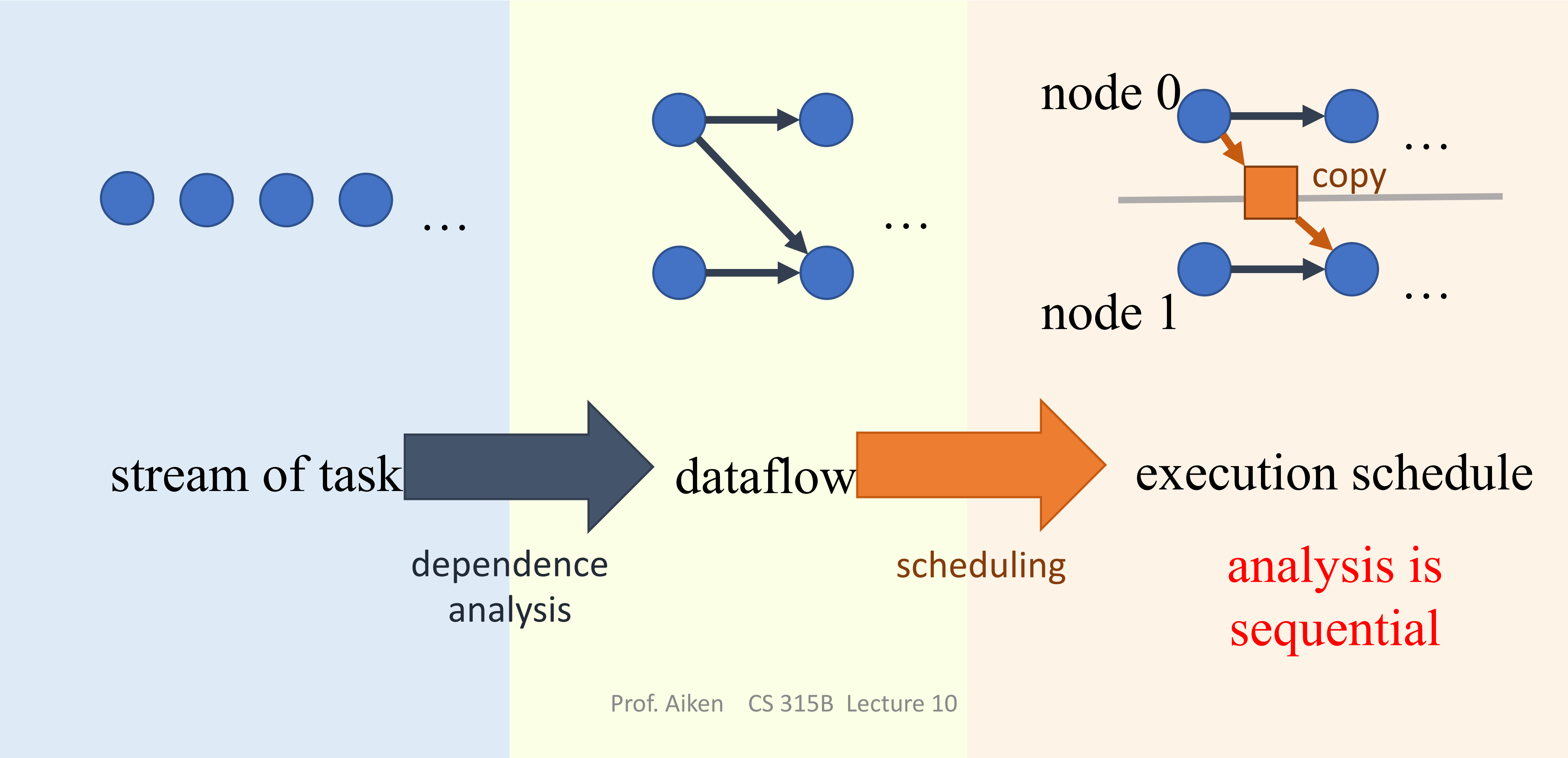




- **User specifies coarse-grain tasks (and data)**
  - **Analysis performed at level of tasks (instead of iterations)**
- **Dynamic analysis is better but still expensive**

Task Execution (Not Replicated)

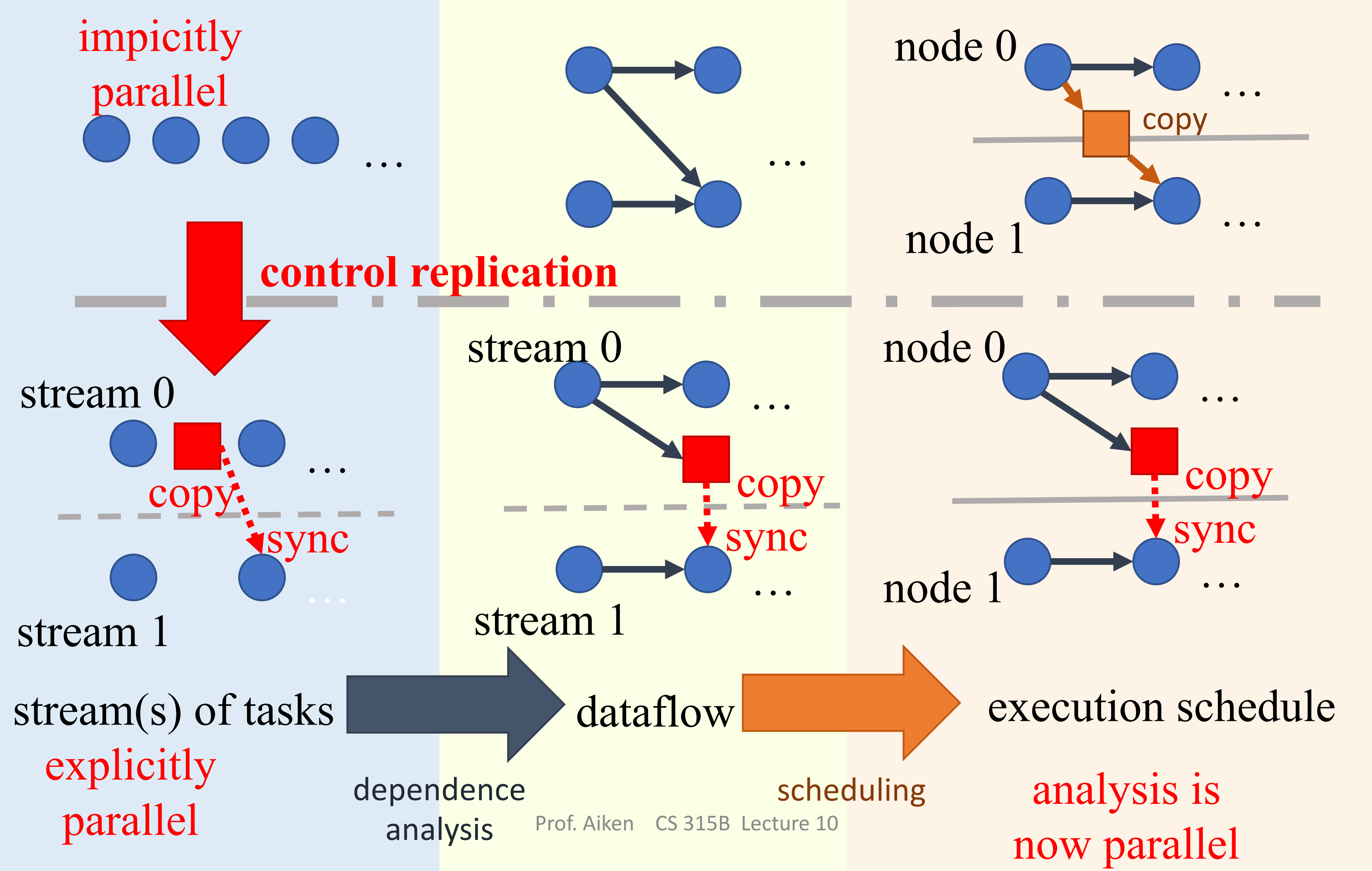
- Sequential execution: tasks form a stream in program order
- System discovers parallelism by analyzing dependencies
- Dataflow is scheduled and copies are inserted as needed



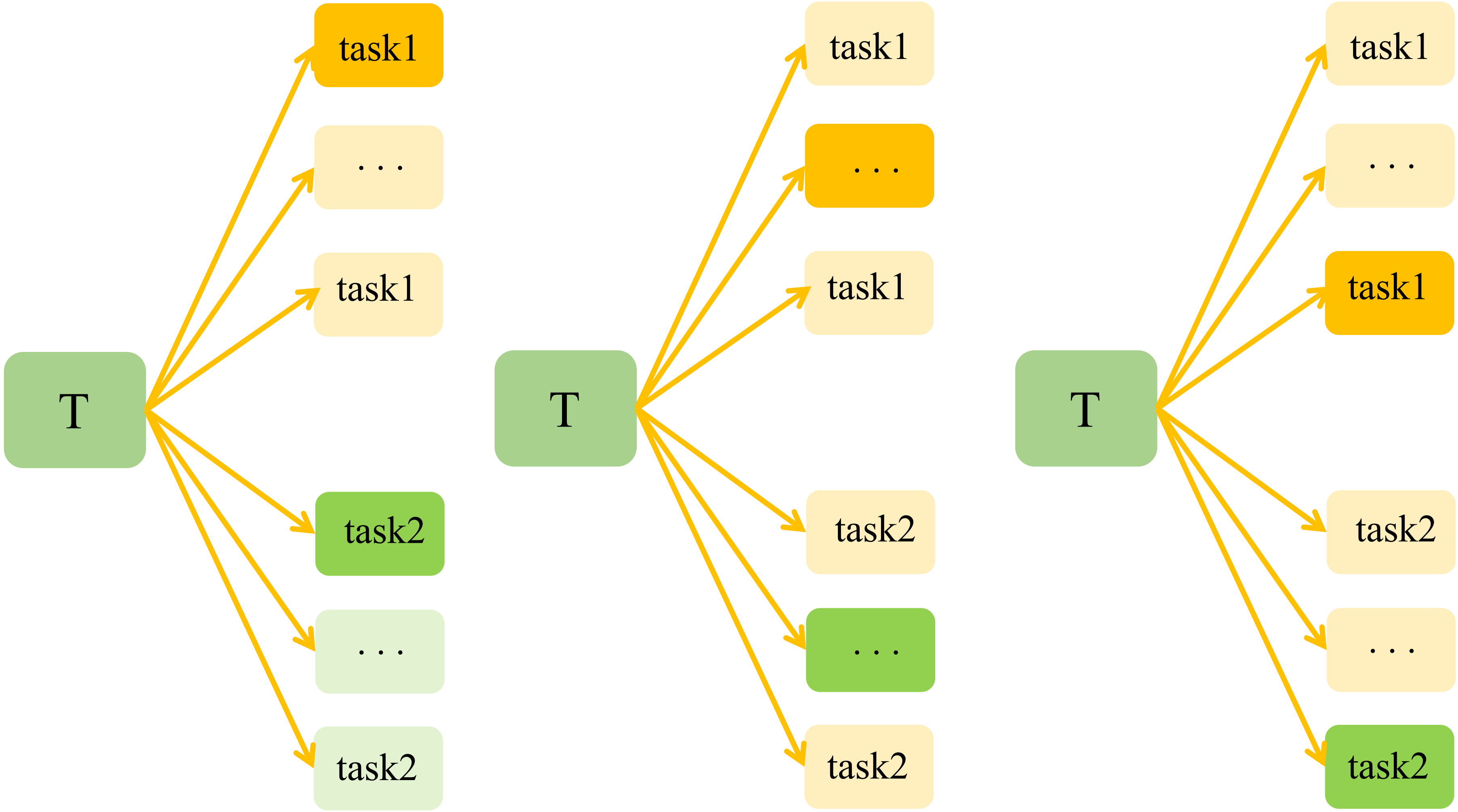
Control Replication

- Technique to generate scalable SPMD code from implicitly parallel (task-based) programs
- Asymptotic reduction in steady state analysis
  - O(1) instead of O(N) in number of nodes

Task Execution (Replicated)



Control Replication



Control Replication

- Regent can do this for you!

- __demand(__replicable)

- Takes a program in implicit parallel style, converts it to SPMD style

- Restrictions
  - Each “rank” must execute the same sequence of Legion API calls
    - i.e., the control code is replicated in each rank

Control Replication

- We recommend using control replication for your project
  - Write in implicit style
- Should scale to 256-512 nodes
  - At least