Legion Overview: What's New in 2015?

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Bootcamp Logistics

- Monday
  - Parking
  - Lunch
  - Dinner
- Tuesday
  - Programming exercise
  - Bring your laptops!

Bootcamp Focus

- Writing Legion programs
  - Different from the academic papers
  - Cover many pragmatic, usability aspects
- Today
  - Brief overview of the programming model
  - Deeper dives on major changes in 2015
  - Overview of a familiar application (MiniAero)
  - Debugging & profiling
- Tomorrow: Programming exercise

Programming System Goals

High Performance

We must be fast

Performance Portability

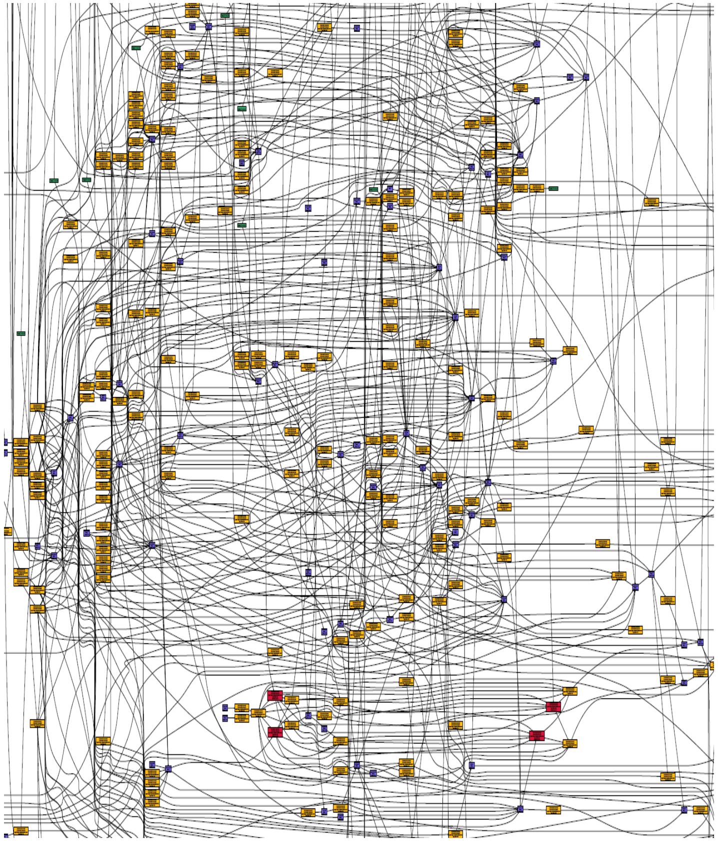
Across many kinds of machines and over many generations

Programmability

Sequential semantics, parallel execution

Can We Fulfill These Goals Today?

Yes … at great cost:



Task graph for one time step on one node…

… of a mini-app

Who will schedule the graph?
(High Performance)

Who will re-schedule the graph
for every new machine?
(Performance Portability)

Who is responsible
for generating the graph?
(Programmability)

Today: programmer's responsibility

Tomorrow: programming system's responsibility

Legion Overview

- A programming model for heterogeneous, distributed machines

- Heterogeneous
  - Mixed CPUs and GPUs

- Distributed
  - Large spread, and variability, of communication latencies
  - Caches, RAM, NUMA, network, …

Philosophy

- Designed to be a real programming system
- Good abstractions, clear semantics
- But can also “open the hood”
  - Ways to drop down to lower levels of abstraction
  - Within the programming model

Legion: Tasks & Regions

- A *task* is the unit of parallel execution
- Task arguments are *regions*
  - Collections
  - Rows are an *index space*
  - Columns are *fields*
- Tasks declare how they use their regions

0	2.72
1	3.14
2	42.0
3	12.7
4	0.0

```
task saxpy(is : ispace(int1d), x,y: region(is, float), a: float )
where reads(x, y), writes(y)
```

Example Task

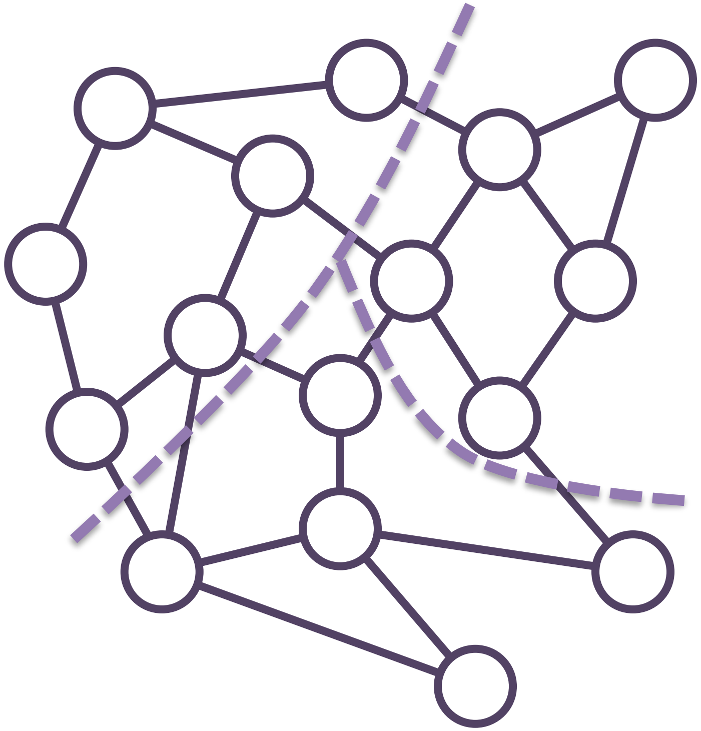
```
task saxpy(is : ispace(int1d), x: region(is, float),
               y: region(is, float), a: float)
where
  reads(x, y), writes(y)
do
  for i in is do
    y[i] += a*x[i]
  end
end
```

Regions

- Regions can be *partitioned* into *subregions*

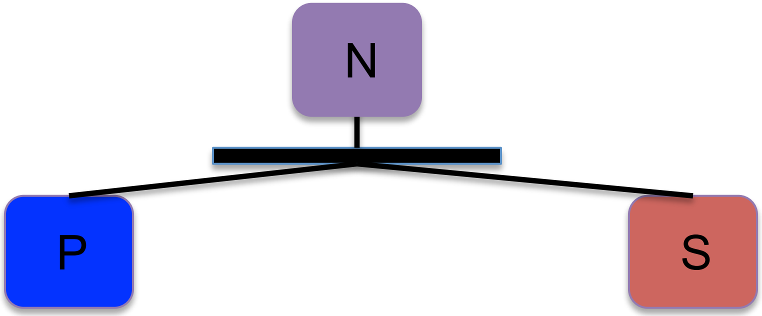
- Partitioning is a primitive operation
  - Supports describing arbitrary subsets of a region

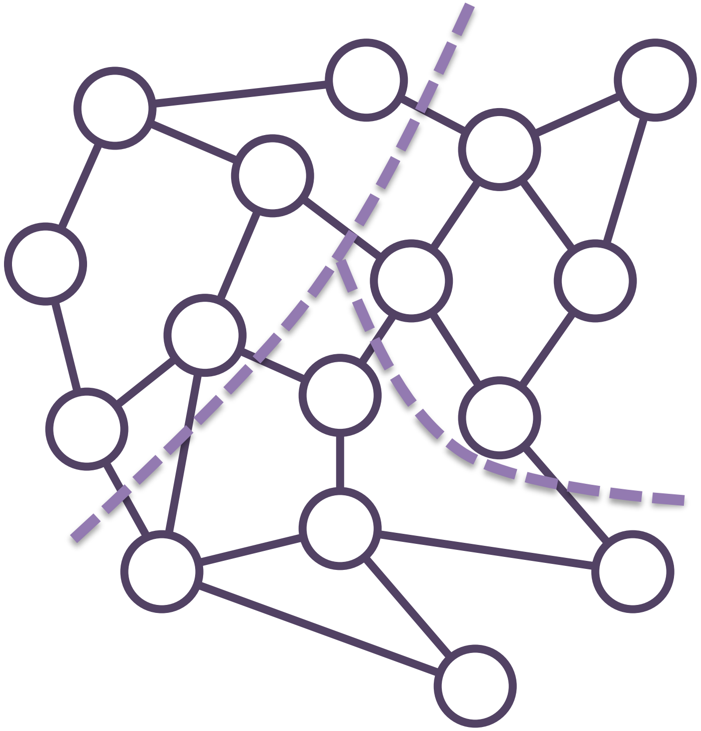
Partitioning



Partitioning

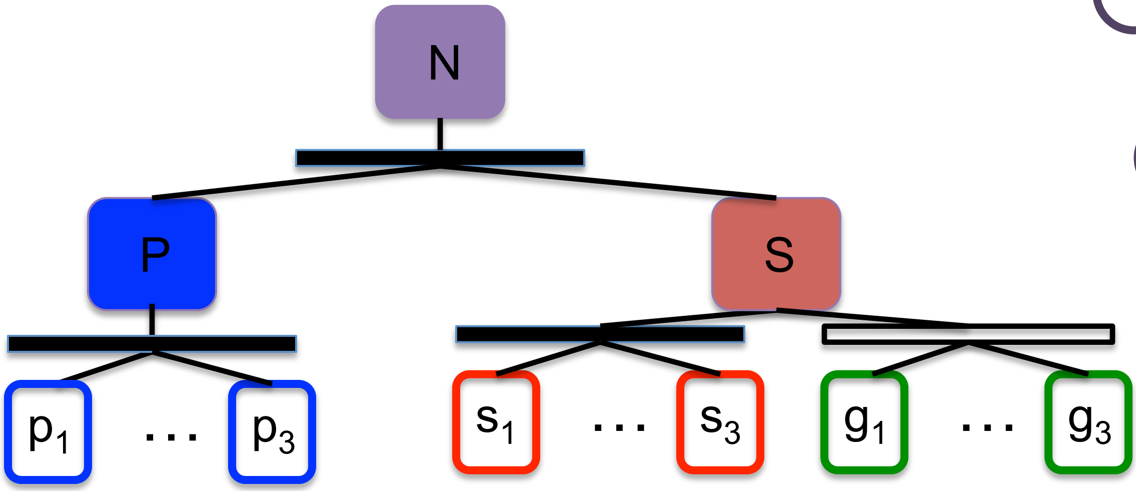
[P, S] = partition(ps_map, N)

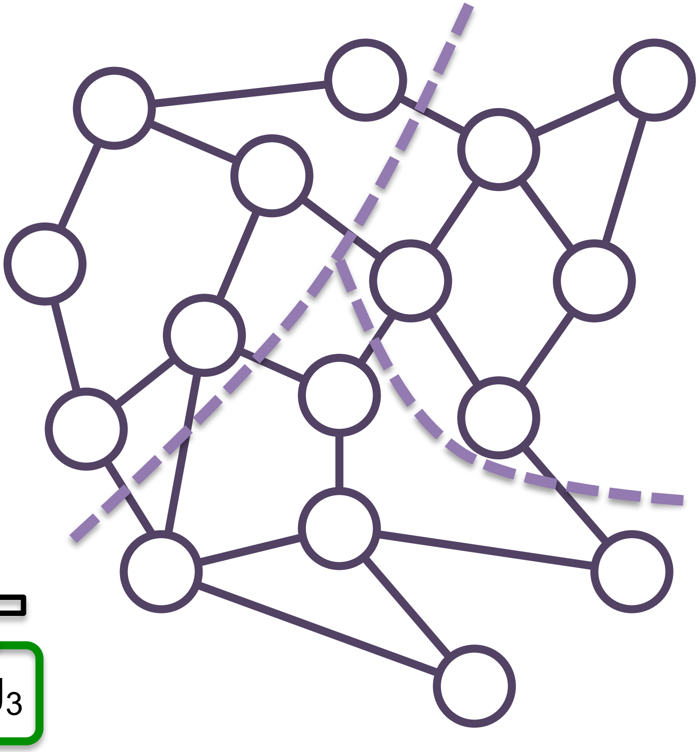




Partitioning

```
[ P, S ] = partition(ps_map, N)
private = partition(private_map, P)
shared = partition(shared_map, S)
ghost = partition(ghost_map, S)
```

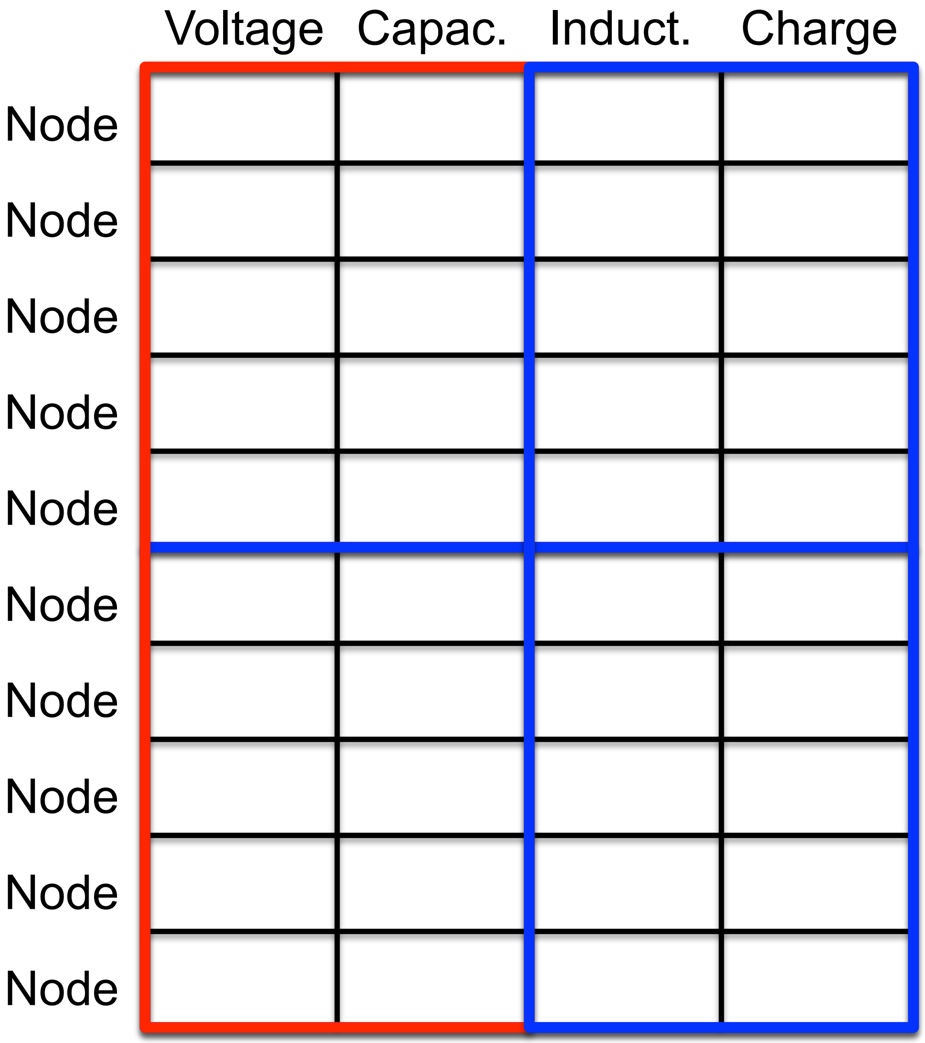




Summary: Regions

- Regions have
  - Entries (rows)
  - Fields (columns)

- Regions can be
  - Partitioned by rows
  - Sliced by fields



	Voltage	Capac.	Induct.	Charge
Node				
Node				
Node				
Node				
Node				
Node				
Node				
Node				
Node				
Node				

Tasks

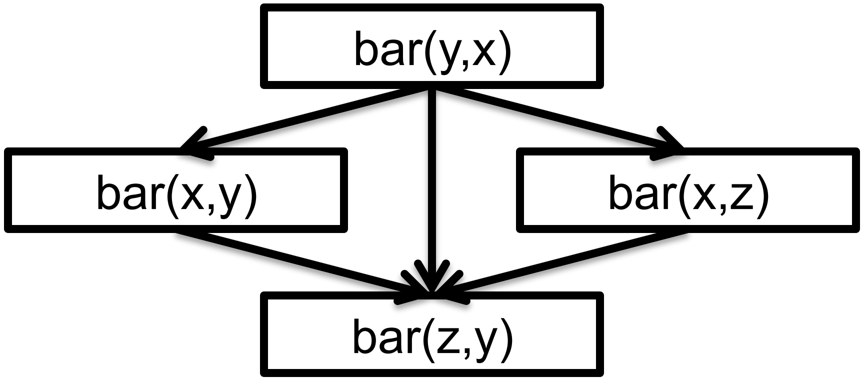
- Tasks can call *subtasks*
  - Sequential semantics, implicit parallelism
  - If tasks do not *interfere,* can be executed in parallel

```
task foo(x,y,z: region(…))
where reads(x,y,z),writes(x,y,z) do
        bar(y,x)
        bar(x,y)
        bar(x,z)
        bar(z,y)
end
task bar(r,s: region(…)) where reads(r), writes(s)
```

Deferred Execution

```
task foo(x,y,z: region(…))
where reads(x,y,z),writes(x,y,z) do
      bar(y,x)
      bar(x,y)
      bar(x,z)
      bar(z,y)
end
task bar(r,s: region(…)) where reads(r), writes(s)
```

Legion Runtime



bar(y,x)

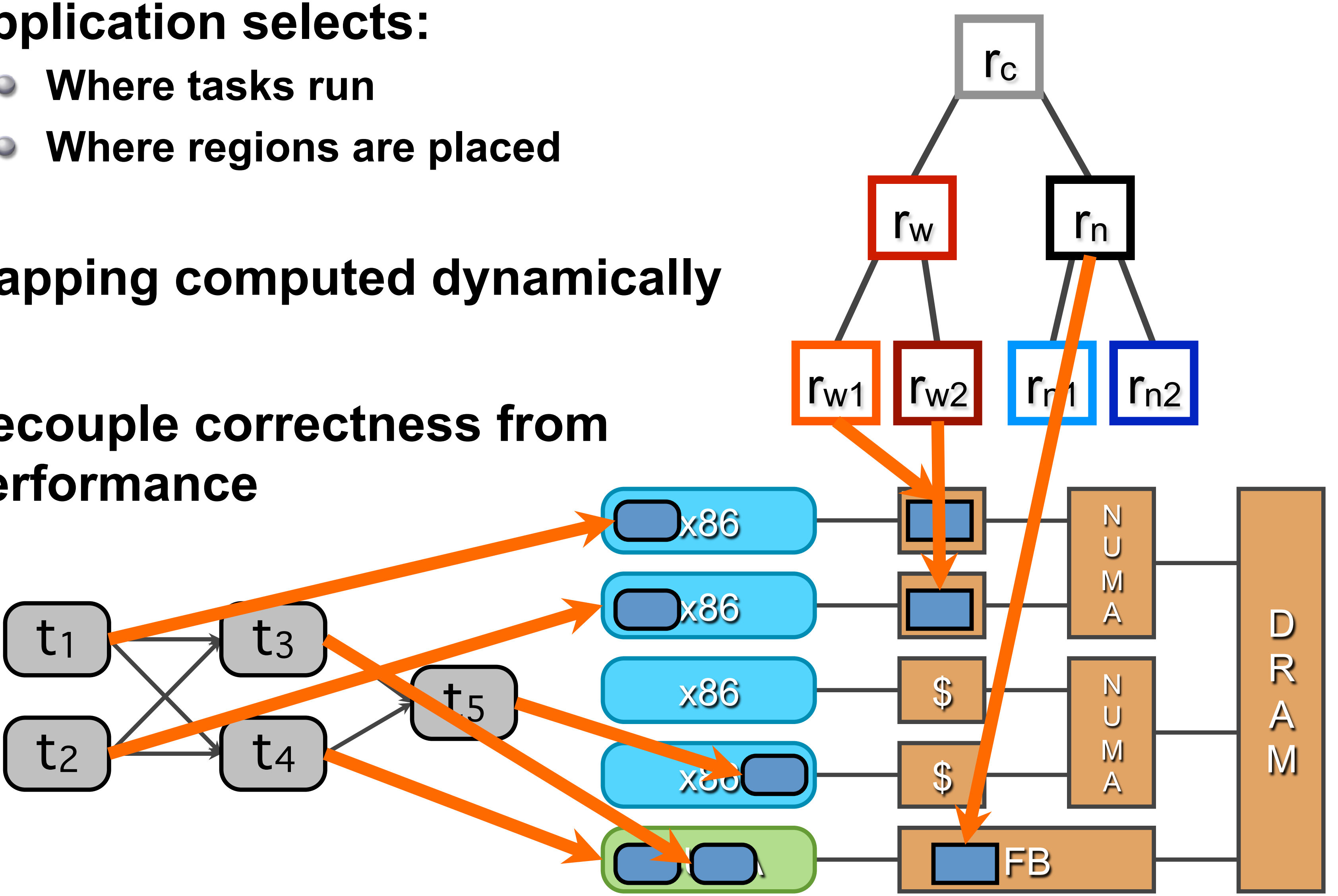
bar(x,y)

bar(x,z)

bar(z,y)

Mapping Interface

- Application selects:
  - Where tasks run
  - Where regions are placed
- Mapping computed dynamically
- Decouple correctness from performance



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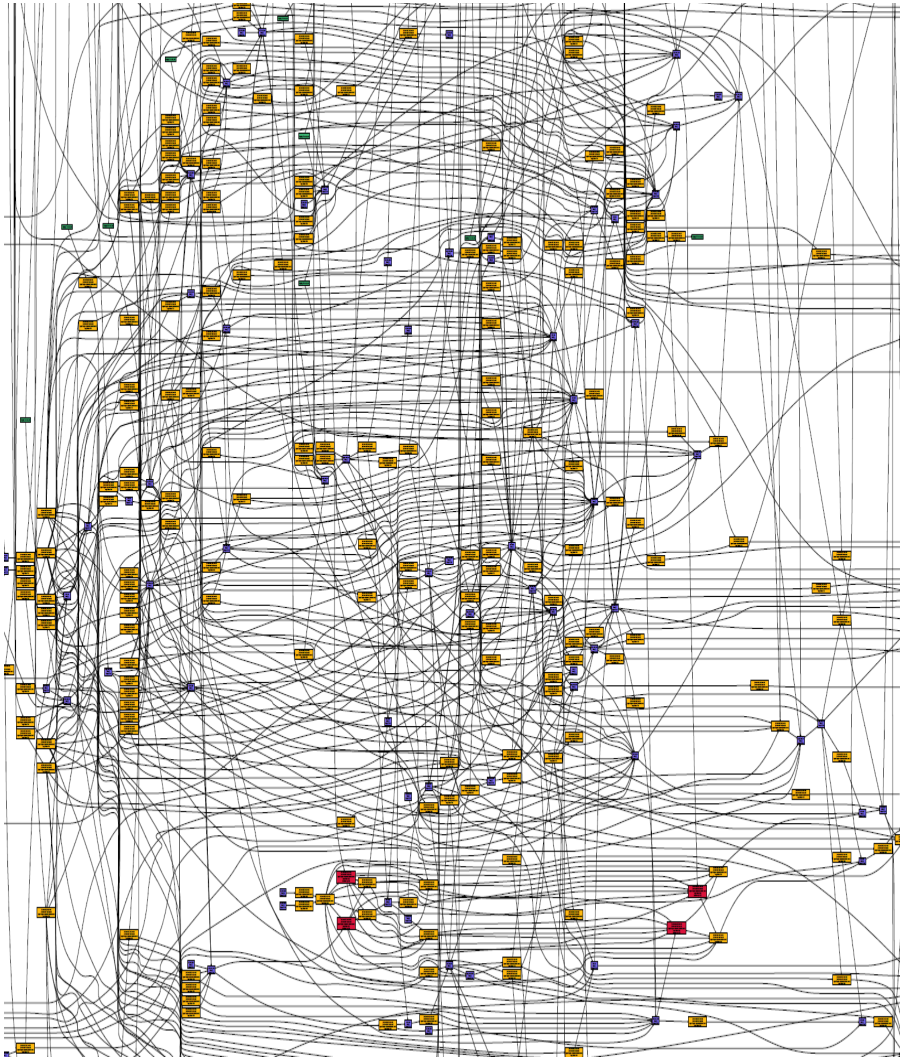


Who will schedule the graph?
(High Performance)

Who will re-schedule the graph
for every new machine?
(Performance Portability)

Who is responsible
for generating the graph?
(Programmability)

More on Permissions

- Tasks declare *permissions* on regions

```
task bar(r: region(…)) where reads(r)

task bar(r: region(…)) where writes(r)

task bar(r: region(…)) where reduces +(r)
```

And Coherence

- Tasks declare *coherence* of regions
  - With respect to sibling tasks

```
task bar(r: region(…)) where exclusive(r)

task bar(r: region(…)) where atomic(r)

task bar(r: region(…)) where simultaneous(r)
```

Atomic Coherence

```
task foo(x: region(…)) where reads(x), writes(x),
                                        exclusive(x)
do
        bar(x)
        bazz(x)
end

task bar(r: region(…)) where reads(r), writes(r), atomic(r)

task bazz(r: region(…)) where reads(r), writes(r), atomic(r)
```

Simultaneous Coherence

```
task foo(x: region(…)) where reads(x), writes(x)
do
        bar(x)
        bazz(x)
end

task bar(r: region(…)) where reads(r), writes(r),
                                      simultaneous(r)

task bazz(r: region(…)) where reads(r), writes(r),
                                      simultaneous(r)
```

Simultaneous Coherence

- Progressive relaxation of coherence

  Exclusive > Atomic > Simultaneous

- Simultaneous coherence
  - Implies programmer involvement in managing concurrency
  - Additional primitives
    - acquire(r), release(r), phase barriers

- An example of “opening the hood”
  - Programmer takes responsibility for coordination between tasks using simultaneous coherence

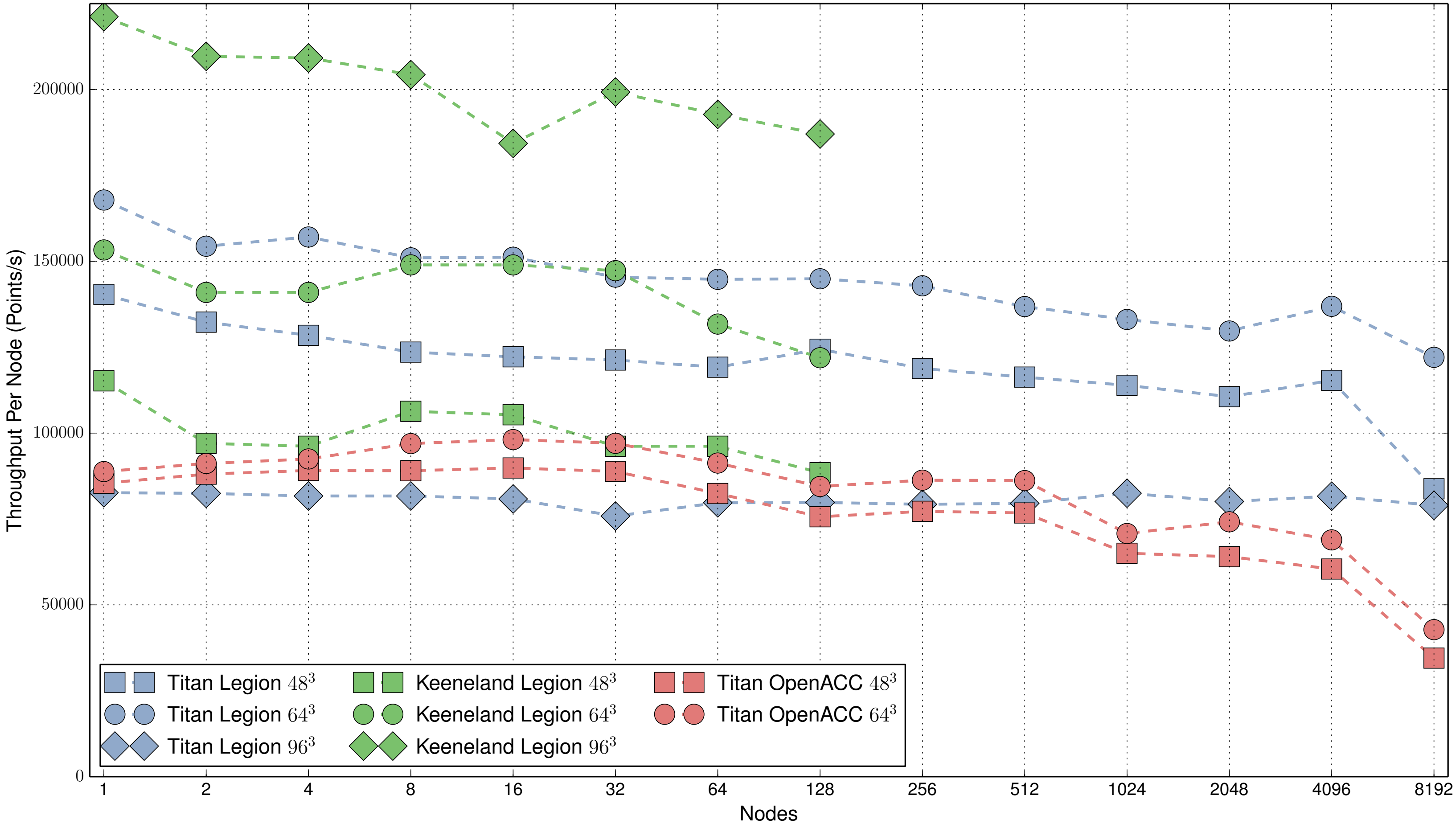
S3D

- Combustion simulation, explicit method
  - Physics and complex chemistry
  - Collaboration with Jackie Chen's group (Sandia)
  - Part of the ExaCT Center

- Structure of S3D
  - Partition volume across nodes
  - Launch one long-running task per node
    - Some private data (exclusive)
    - Some shared data (simultaneous)
    - Use acquire/release to mediate access
  - Within a node
    - Tasks launch subtasks with exclusive or atomic coherence
    - Some tasks mapped to GPU, some to CPU

Legion Heptane Performance

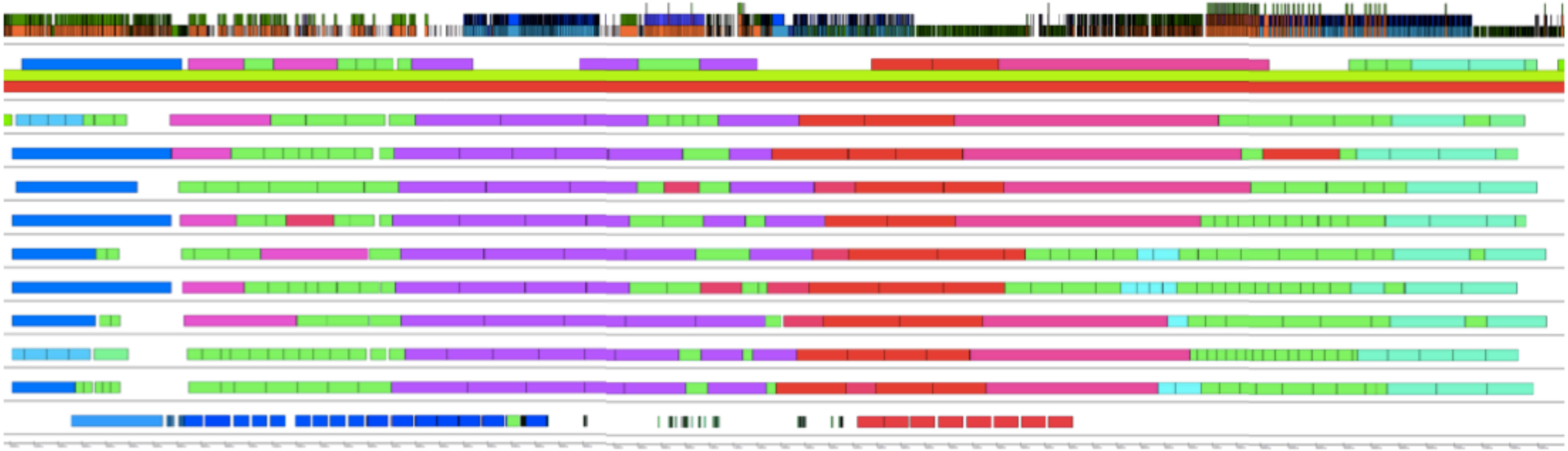
- **1.73X - 2.85X faster between 1024 and 8192 nodes**



http://legion.stanford.edu

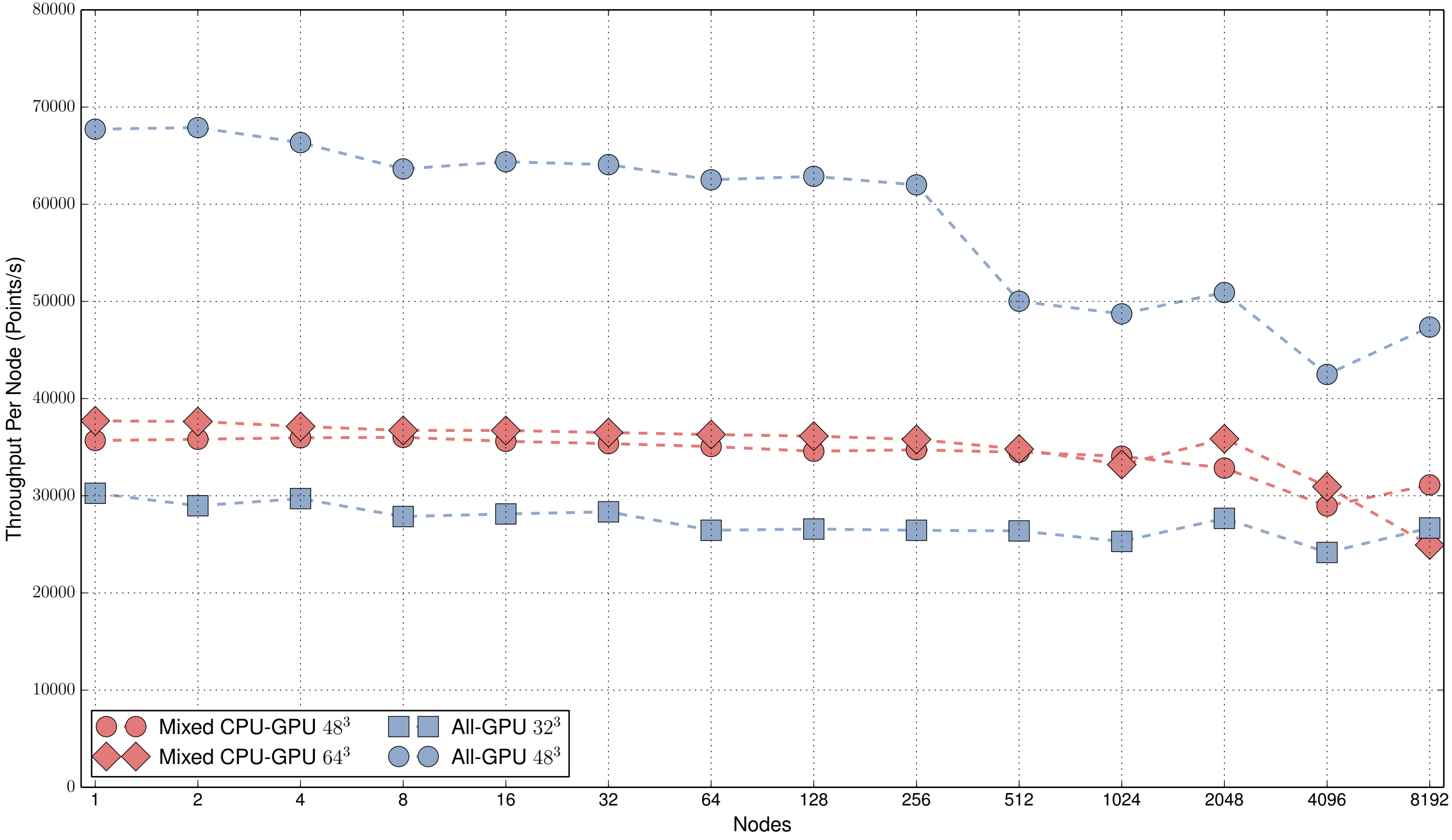
Heptane Mapping for 96^3

- Different mapping than smaller problem sizes
  - Not enough room in 6 GB GPU framebuffer
  - OpenACC requires code changes
- Note “ragged phases”
  - Deferred execution tolerant of latency/execution variance
- Not shown: Overlap of data movement



Legion PRF Performance

- 116 species mechanism, >2X as large as heptane
  - New science, never before done



The Crux

- Crucial design decisions in a Legion program are:
- What are the regions?
- How are the regions partitioned?
- The answers drive the program’s design

Legion Overview Summary

- The programmer
  - Describes the structure of the program’s data
    - Regions
  - The tasks that operate on that data

- The Legion implementation
  - Guarantees tasks appear to execute in sequential order
    - Unless the programmer relaxes coherence
  - Ensures tasks have the correct versions of their regions

The Past Year

- The project has changed
  - Legion group has grown substantially
  - Lots of interaction with users
  - Learned a lot about Legion, including flaws!

- Mid-2015 strategic plan
  - Focus on fixing core issues
  - Even if it involves major changes
  - Will not get any easier in the future!

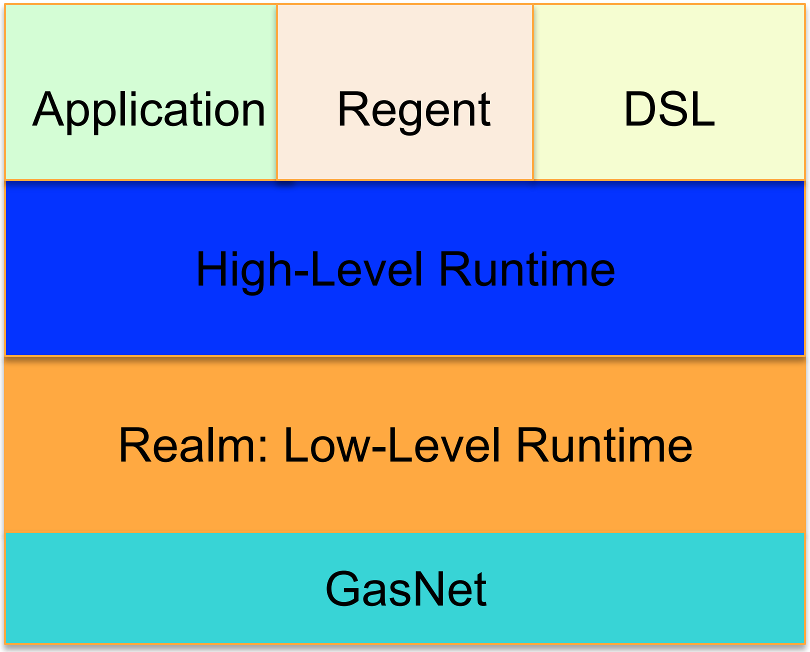
- Results are starting to roll out now.

Problem #1

- C++ API is verbose, a lot to learn
- Many semantic requirements are unchecked
- No help with kernel code
  - Legion is about managing data and black-box tasks
  - Doesn't address generating efficient task code

Decision: These issues can't and shouldn't be addressed in the C++ API

Legion Architecture



Regent: A Legion Language

```
task saxpy(is : ispace(int1d), x: region(is, float),
                       y: region(is, float), a: float)
where reads(x, y), writes(y)
do
  for i in is do
    y[i] += a*x[i]
  end
end
```

Problem #2: Partitioning

- Creation of partitions is hard to fully distribute
  - Inherent in the original design
  - Deal-breaker for some applications

- Solution
  - Design a new partitioning system
  - More concise and much higher performance

Problem #3: Mapping

- Mapping interface is at the wrong level of abstraction
  - User has to say "do exactly this"
  - Much better would be "do at least this"
  - Or "do at most this"

- Solution
  - A new constraint-based mapper interface

Problem #4: I/O

- Must be able to
  - Read/write files
  - Produced by other applications
  - In parallel

- Solution
  - A new I/O subsystem
  - Understands how to interpret distributed file formats as partitioned regions

Problem #5: Breaking Changes

- More developers + more users
  - Users getting blocked by research-level software practices

- Introduce more disciplined development
  - Clean-up, rationalization of the repository
  - Investing in testing infrastructure
  - Including the mundane and the high-end

Today's Talks

- Regent (Elliott)
- Partitioning (Sean)
- Mapping (Mike)
- I/O (Zhihao)
- Debugging & Profiling (Wonchan)

- Application walkthrough (Wonchan)
- User experiences (Galen, Steve, Hemanth, Philippe)

More To Come

- These are not the only changes/features coming
- More at the end of the day

Questions?