Scheduling Strategies for Optimistic Parallel Execution of Irregular Programs

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Amorphous Data Parallelism

- Many irregular programs implement iterative algorithms over worklists
  - Mesh refinement, agglomerative clustering, maxflow algorithms, compiler analyses, ...
- Complex dependences between iterations
- But many iterations can be executed in parallel
- New elements can be added to worklist

Delaunay Mesh Refinement (DMR)

```
Worklist wl;
wl.add(mesh.badTriangles());

while (wl.size() != 0) {
    Triangle t = wl.get();
    if (t no longer in mesh)
        continue;
    Cavity c = new Cavity(t);
    c.expand();
    c.retriangulate();
    mesh.update(c);
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}
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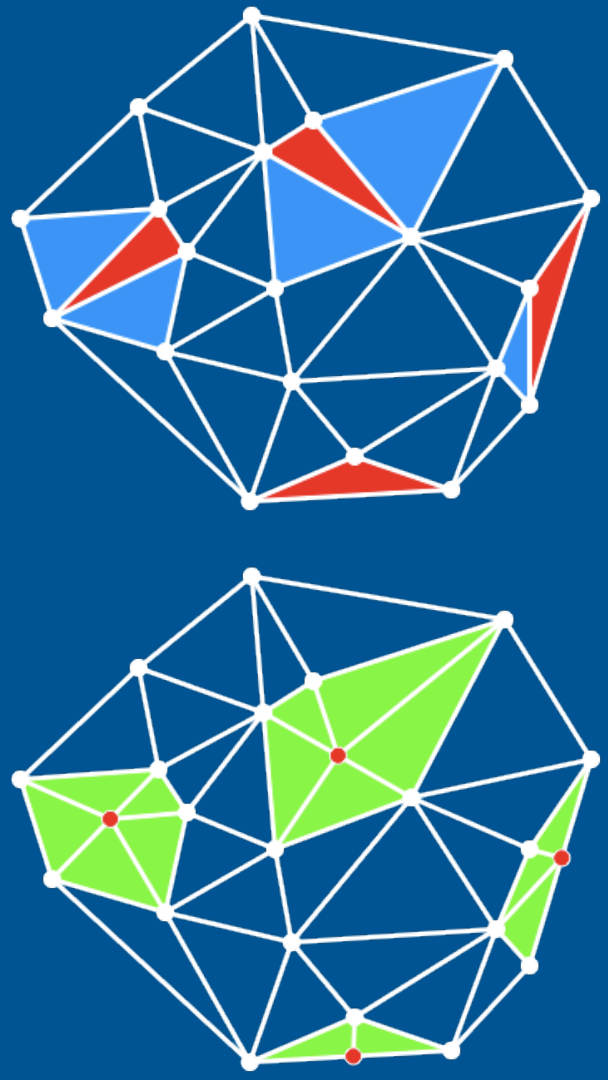

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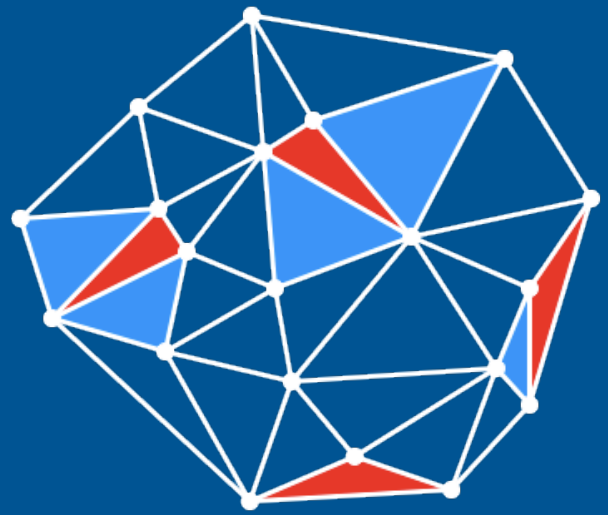
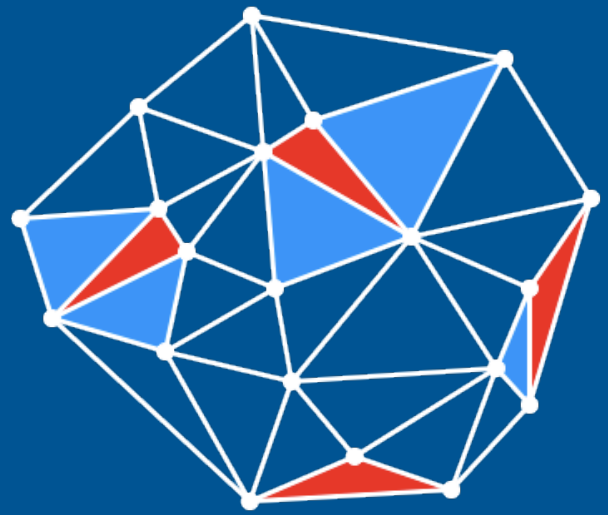


No ordering constraints on processing of worklist items

Parallelism in DMR

- Can process bad triangles concurrently
  - As long as cavities do not overlap
  - Cannot determine this until run time
- Example of amorphous data parallelism
- Our approach: Galois system for optimistic parallelization [PLDI'07, ASPLOS'08]

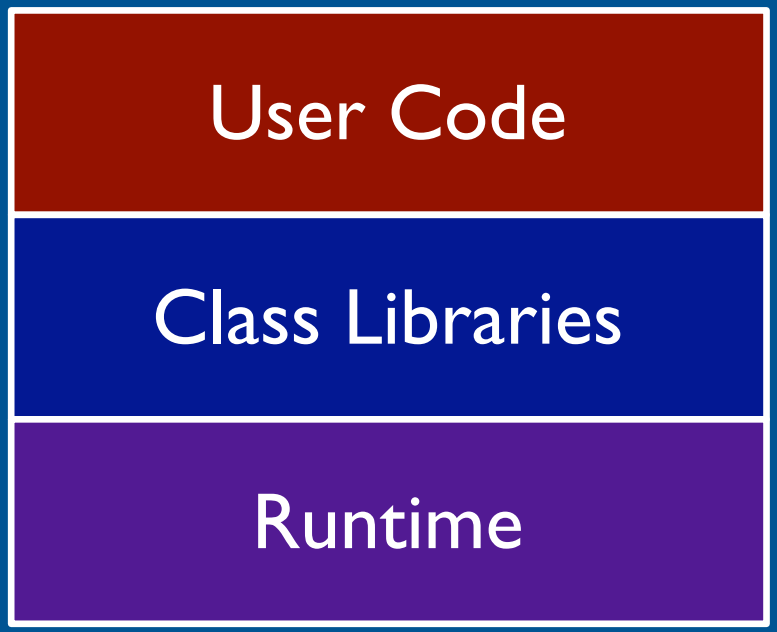


Galois System

- User code
  - Optimistic iterators

    ```
    foreach e in Set s do B(e)
    ```

  - Sequential Semantics
- Class libraries
  - Data structures
  - Conflict conditions
- Runtime system
  - Optimistic parallelization
  - Conflict detection & handling



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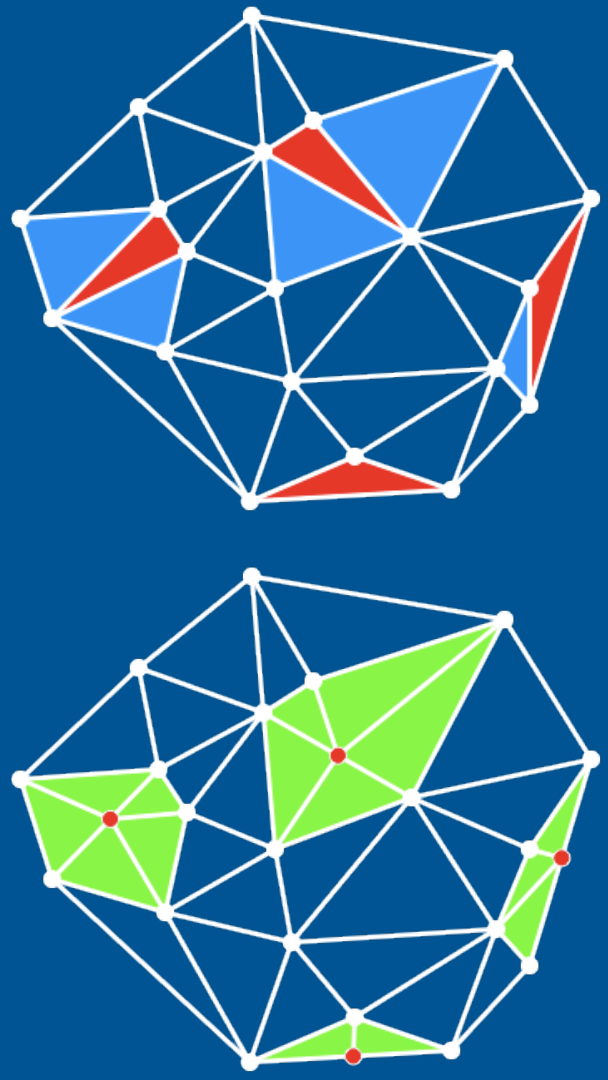

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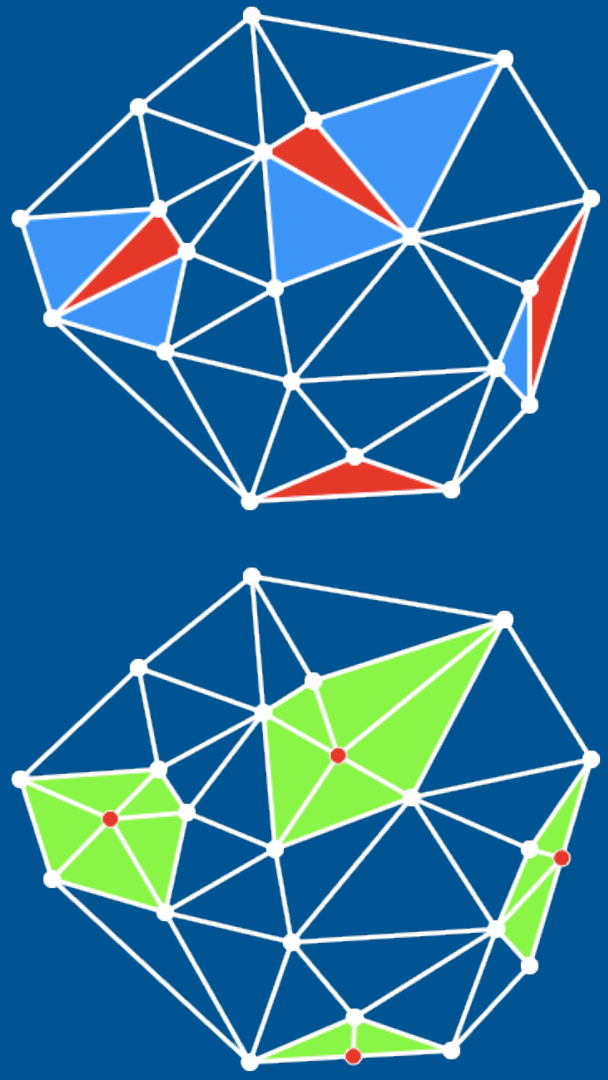
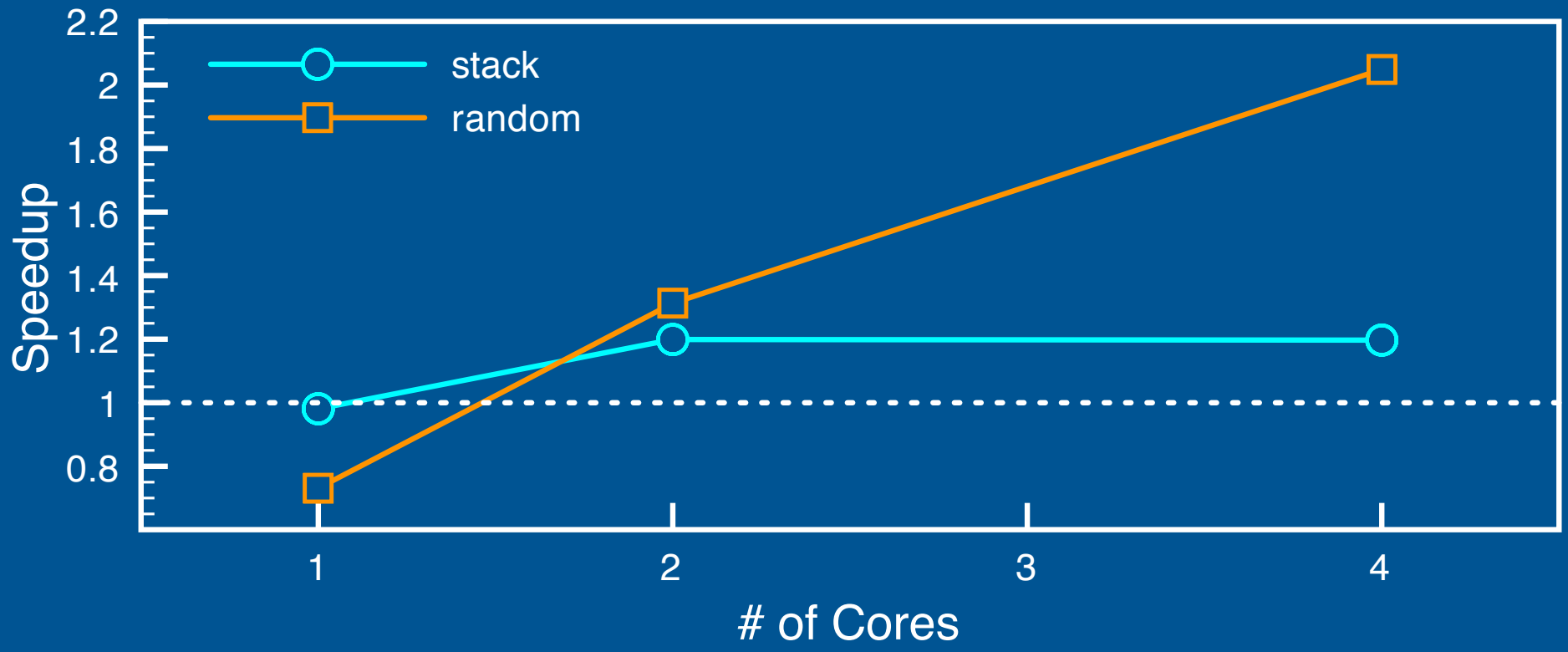


Scheduling Impact: DMR



Evaluation platform: 4-core Xeon system, running Java 1.6 HotSpot JVM

Input mesh: 100K triangles, ~40K bad triangles

Scheduling in OpenMP

- OpenMP provides parallel DO-ALL loops for regular programs
- Major scheduling concerns are load-balancing and overhead
- OpenMP scheduling policies address these issues
  - static, dynamic, guided

Amorphous Data Parallelism Issues

- Algorithmic – The efficiency of the algorithm or data structures
- Conflicts – The likelihood that two iterations executed in parallel will conflict
- Locality – The temporal or spatial locality exhibited in the data structures
- Dynamically created work
- Load-balancing and contention still an issue

Scheduling Basics

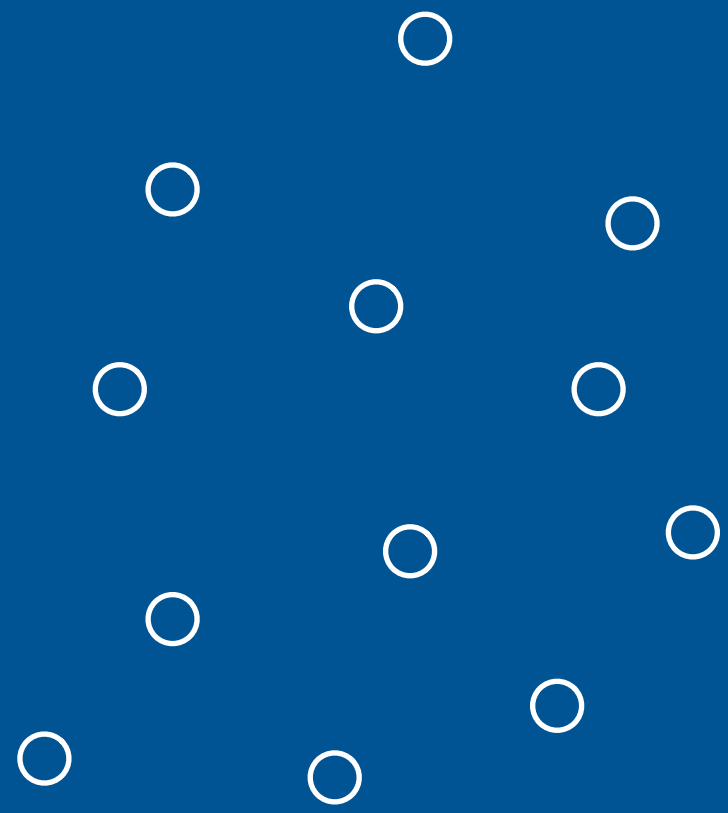
- Each iteration is executed by a single core
- Each core executes a set of iterations in a linear order
- Scheduling maps work from an "iteration space" to positions in an "execution schedule"
  - Each iteration is mapped to a core, and a position in that core's execution schedule

Scheduling Functions

Clustering – Groups iterations into clusters; Each cluster executed on a single core

Labeling – Maps clusters to cores; Each core can have multiple clusters

Ordering – Specifies a serial execution order for each core



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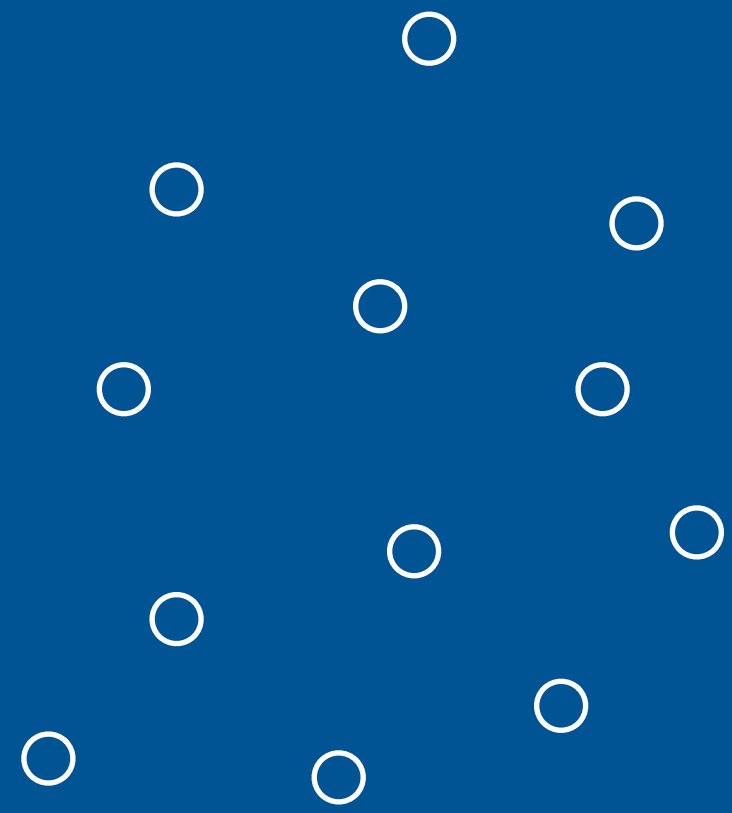

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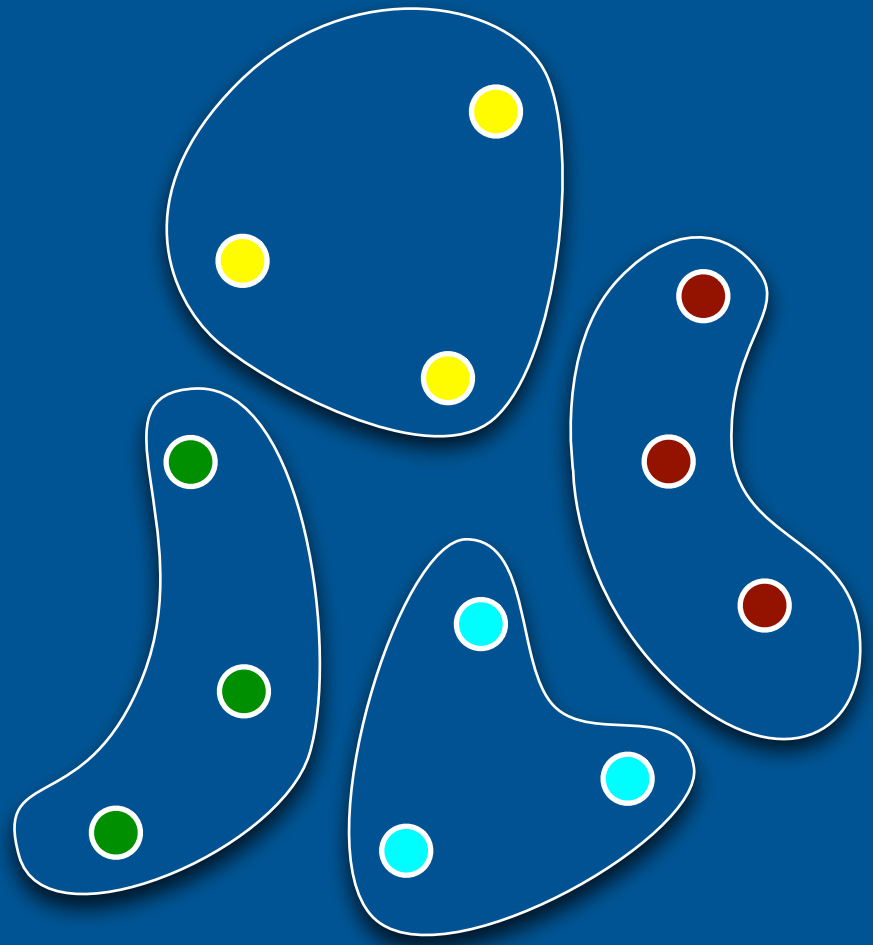

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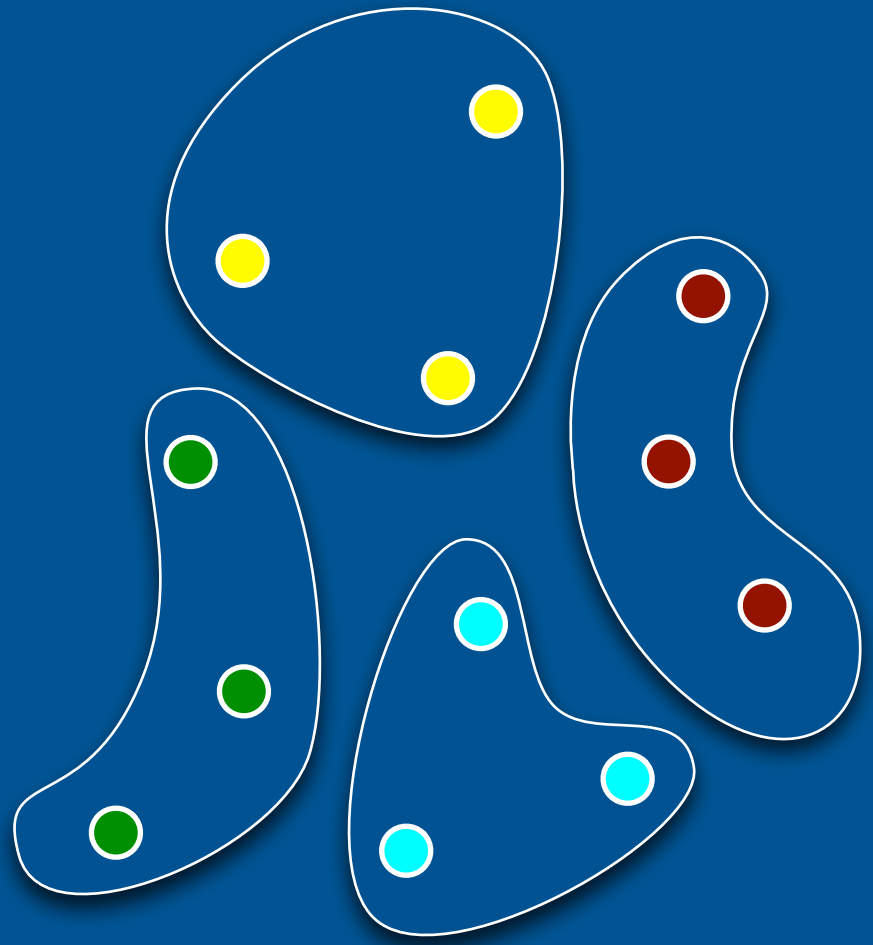

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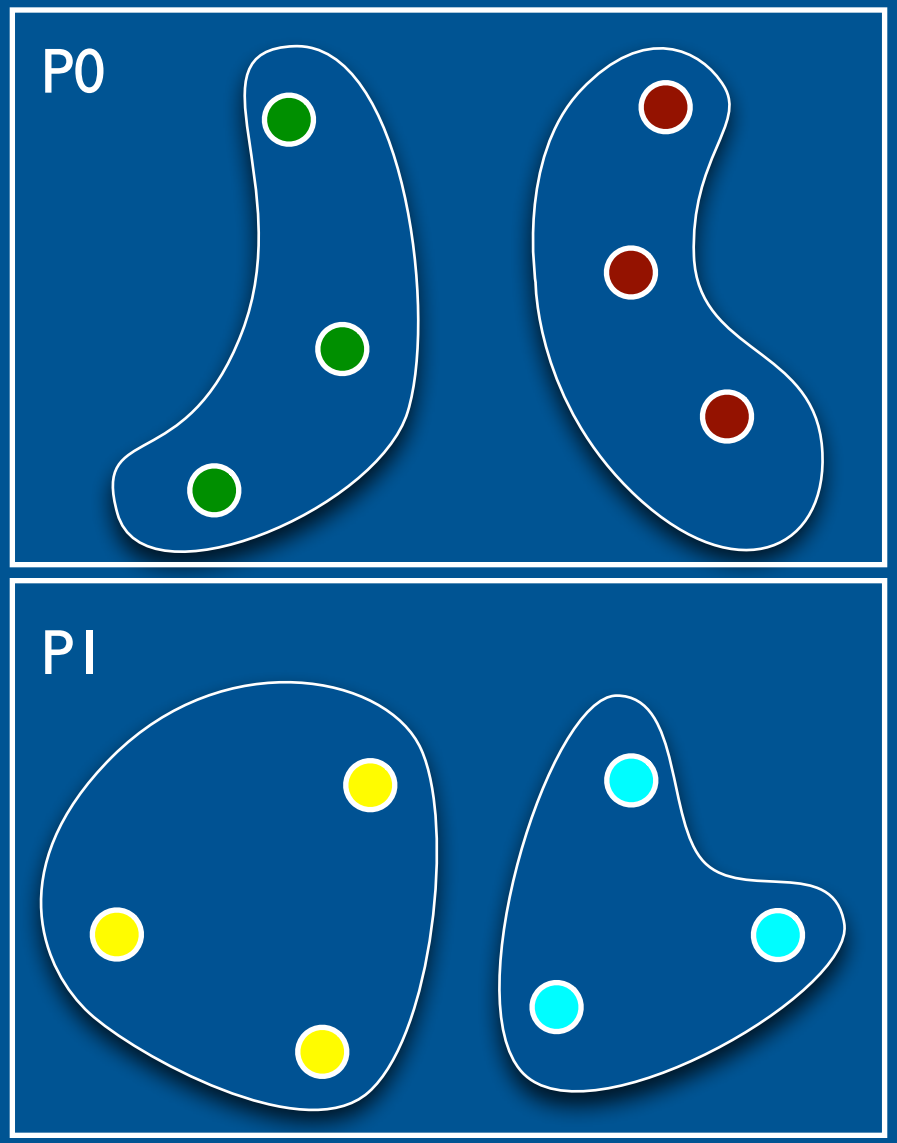

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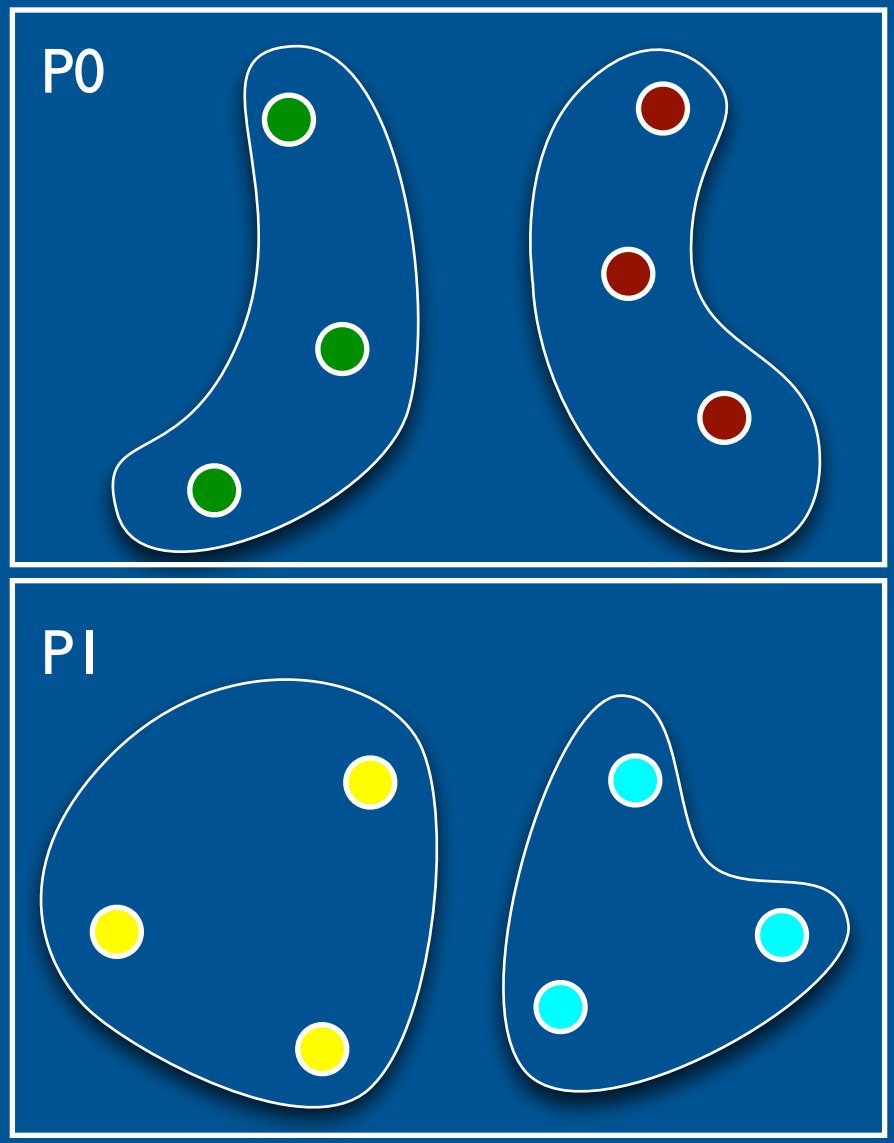

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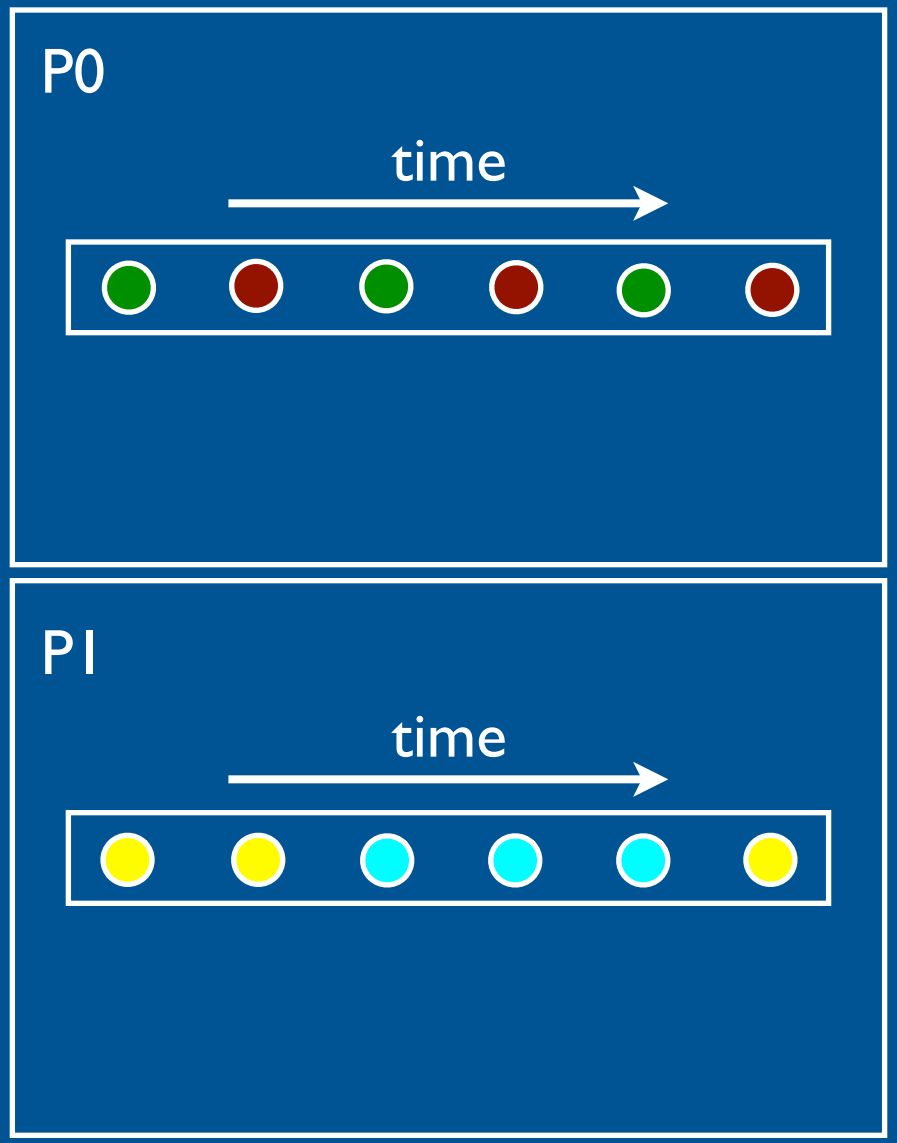

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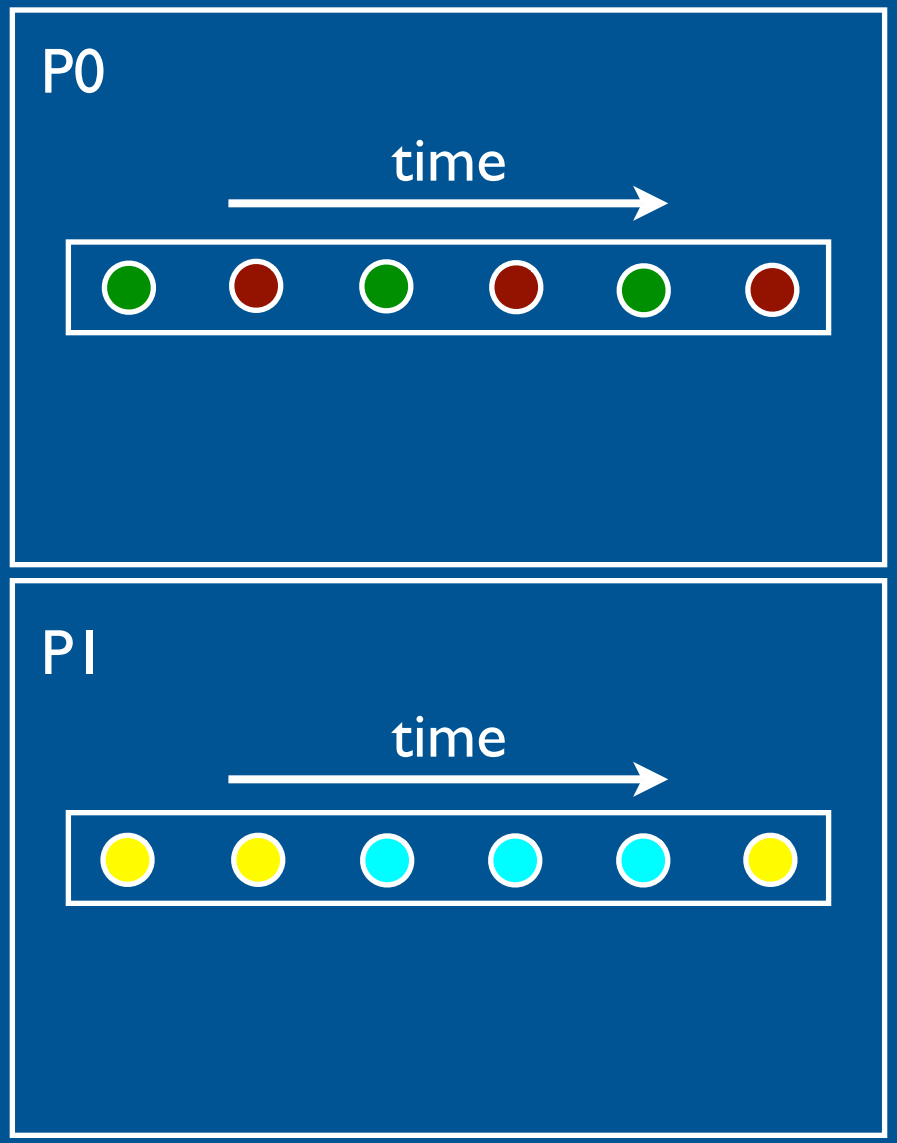
Functions can be defined "online"



Example Instantiations

- OpenMP's chunked self-scheduling
  - Clustering: chunked
  - Labeling: dynamic
  - Ordering: cluster-major
- DMR's "generator-computes"
  - Clustering: chunked + generator-computes
  - Labeling: dynamic
  - Ordering: LIFO

The Galois system provides a number of built-in scheduling policies

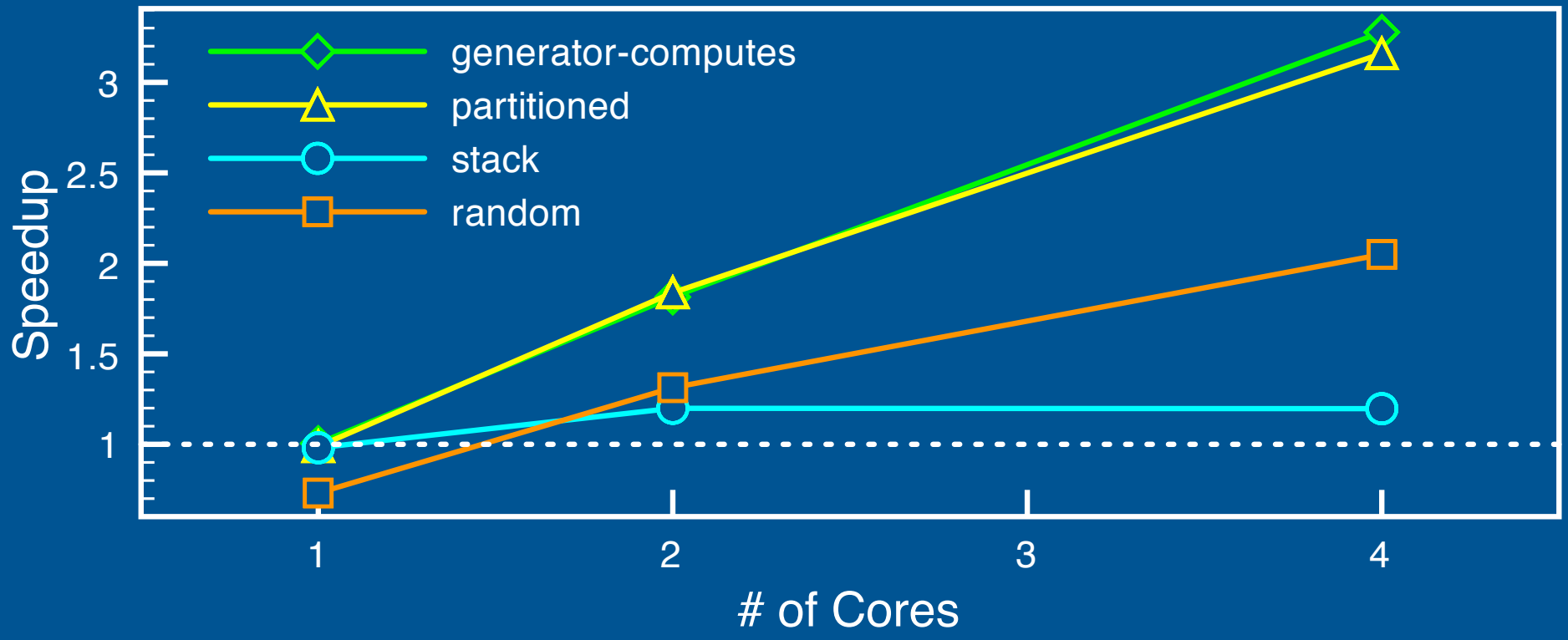
Evaluated Applications

- Delaunay mesh refinement
- Delaunay triangulation
- Augmenting-paths maxflow
- Preflow-push maxflow
- Agglomerative clustering

Sample Schedules for DMR

- random – default Galois schedule
- stack – LIFO schedule
- partitioned – data-centric schedule, based on partitioning of mesh
- generator-computes – random schedule, new work immediately processed by core that created it

DMR Results


generator-computes
partitioned
stack
random
Speedup
3
2.5
2
1.5
1
1
2
3
4
# of Cores

Summary of Results

- Best combination of policies for each application

	Clustering	Labeling	Ordering
Delaunay Mesh Refinement	random/ inherited	dynamic/ random	—/ LIFO
Delaunay Triangulation	data-centric/ —	static/ data-centric	cluster-major/ random
Augmenting Paths Maxflow	data-centric/ inherited	static/ data-centric	cluster-major/ LIFO
Preflow Push Maxflow	data-centric/ inherited	static/ data-centric	cluster-major/ LIFO
Agglomerative Clustering	unit/ custom	dynamic/ custom	—/ —

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Conclusions

- Developed a general framework for scheduling programs with amorphous data parallelism
  - Subsumes OpenMP scheduling policies
- Implemented framework in Galois system
  - Provides several default scheduling policies
  - Allows programmers to specify their own scheduling policies when needed