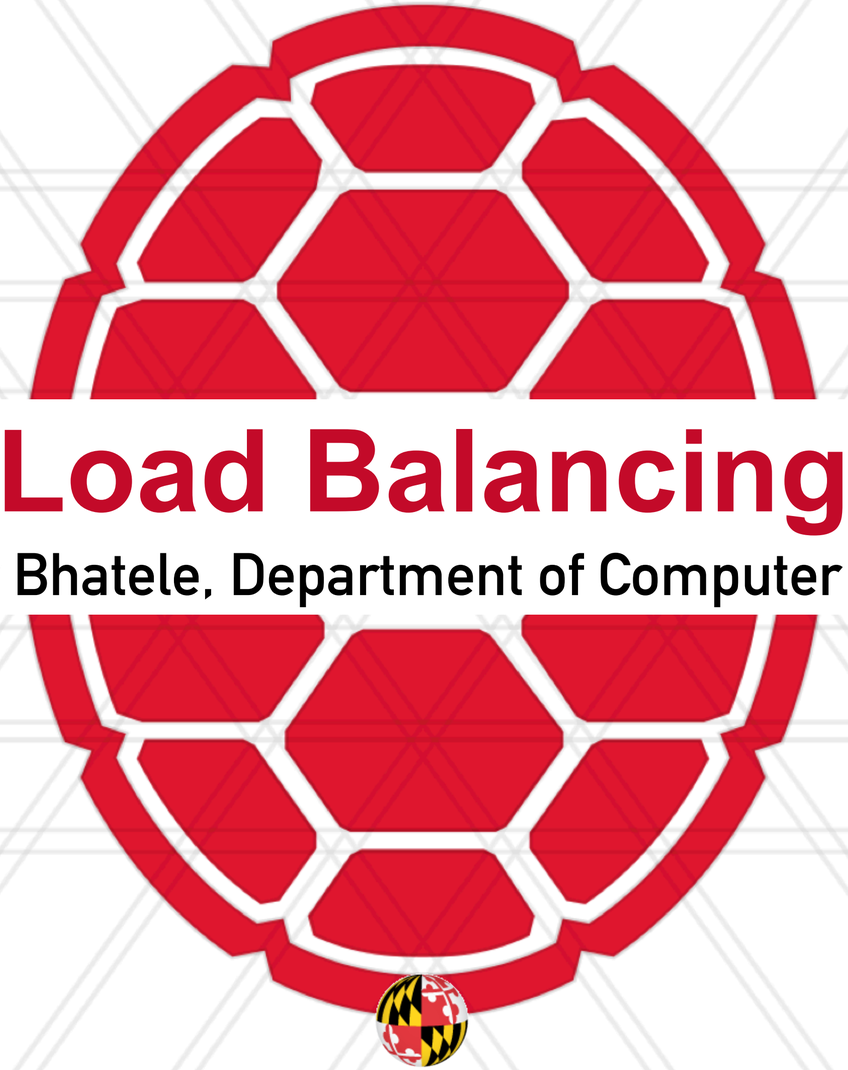
Parallel Computing (CMSC416 / CMSC616)



Load Balancing

Abhinav Bhatele, Department of Computer Science

UNIVERSITY OF MARYLAND

Announcements

- We are using MOSS to detect plagiarism in programming assignments
- Also catches ChatGPT / AI usage

Performance issues

- Sequential performance issues
- Load imbalance
- Communication performance issues / parallel overhead
- Algorithmic overhead / replicated work
- Speculative loss
- Critical paths
- Insufficient parallelism
- Bottlenecks

Load imbalance

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$$\text{Load imbalance} = \frac{max\_load}{mean\_load}$$

Load balancing

- The process of balancing load across threads, processes etc.
- Goal: to bring the maximum load close to average as much as possible
- Steps for balancing load include:
  - Determine if load balancing is needed
  - Determine when and how often to load balance
  - Determine what information to gather/use for load balancing
  - Choose/design a load balancing algorithm

Is load balancing needed?

- Need the distribution of load ("work") across processes
- Collect empirical information using performance tools
- Developer knowledge
- Analytical models of load distribution

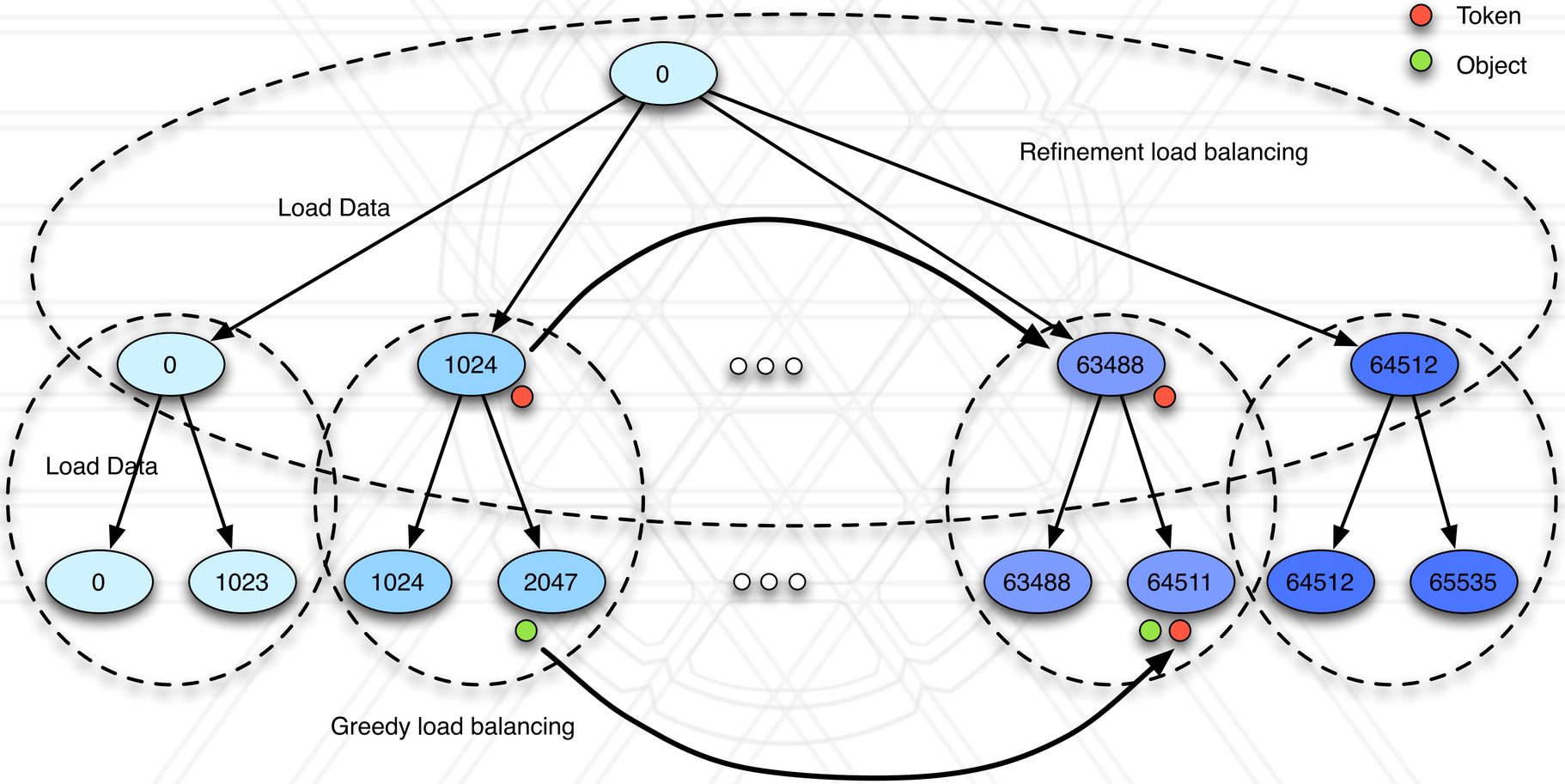
When/how often to load balance?

- Initial work distribution or partitioning or static load balancing
  - At program startup
  - Or sometimes in a separate run to determine new load distribution
- Dynamic load balancing: does load distribution evolve over time?
  - During program execution
  - How often? It depends …

Information gathering for load balancing

- Centralized load balancing
  - Gather all load information at one process — global view of data
- Distributed load balancing
  - Every process only knows the load of a constant number of "neighbors"
- Hybrid or hierarchical load balancing

Hierarchical load balancing



What information is used for load balancing

- Computational load
- Possibly, communication load (number/sizes of messages)
- Communication graph

Load balancing algorithms

- Input: Amount of work (n_i) assigned to each process p_i
- Output: New assignments of work units to different processes
- Goals:
  - Bring maximum load close to average
  - Minimize the amount of data migration
- Secondary goals:
  - Balance (possibly reduce) communication load (volume)
  - Keep the time for doing load balancing to a minimum

Examples of static load balancing

- Decomposition of *n*-D Stencil
- Using orthogonal recursive bisection (ORB), space-filling curves, etc.

http://datagenetics.com/blog/march22013/

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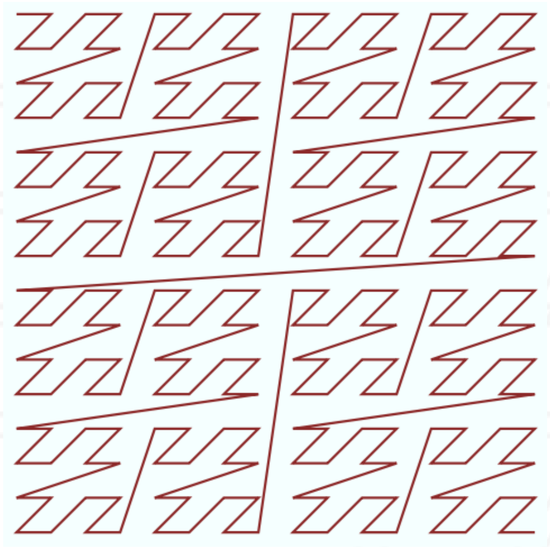

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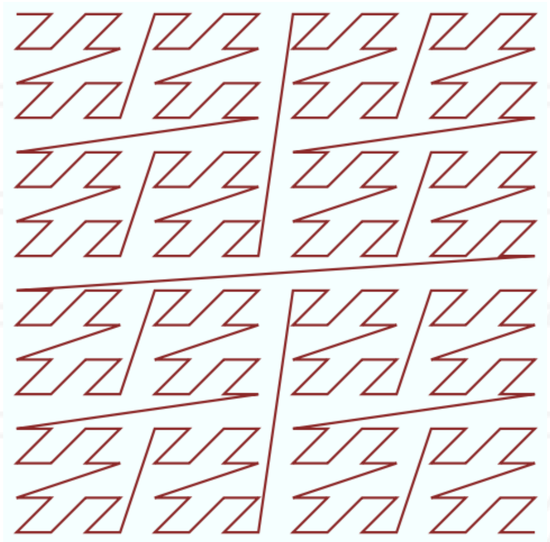
Space-filling curves



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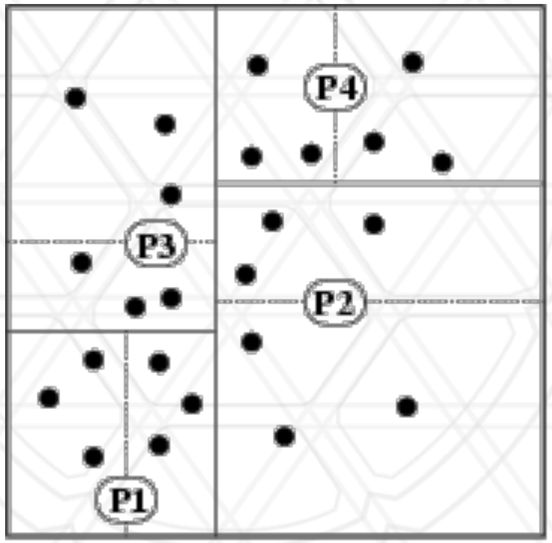
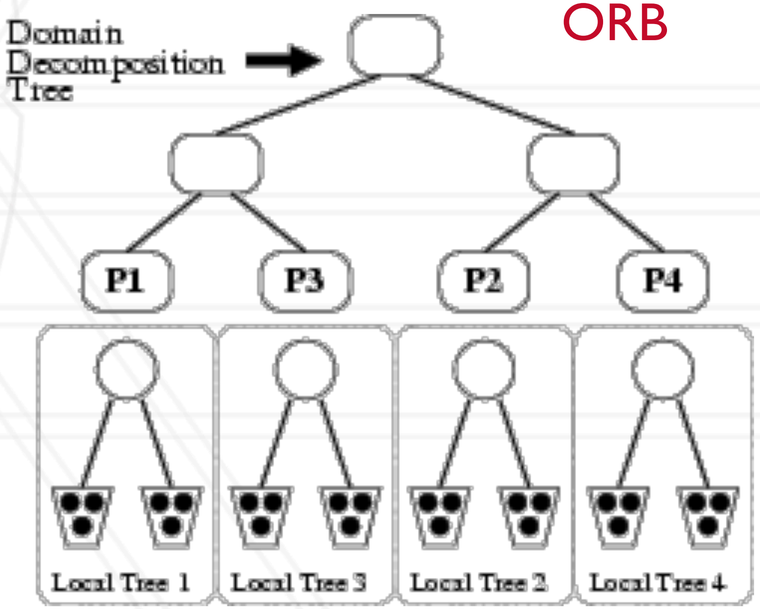


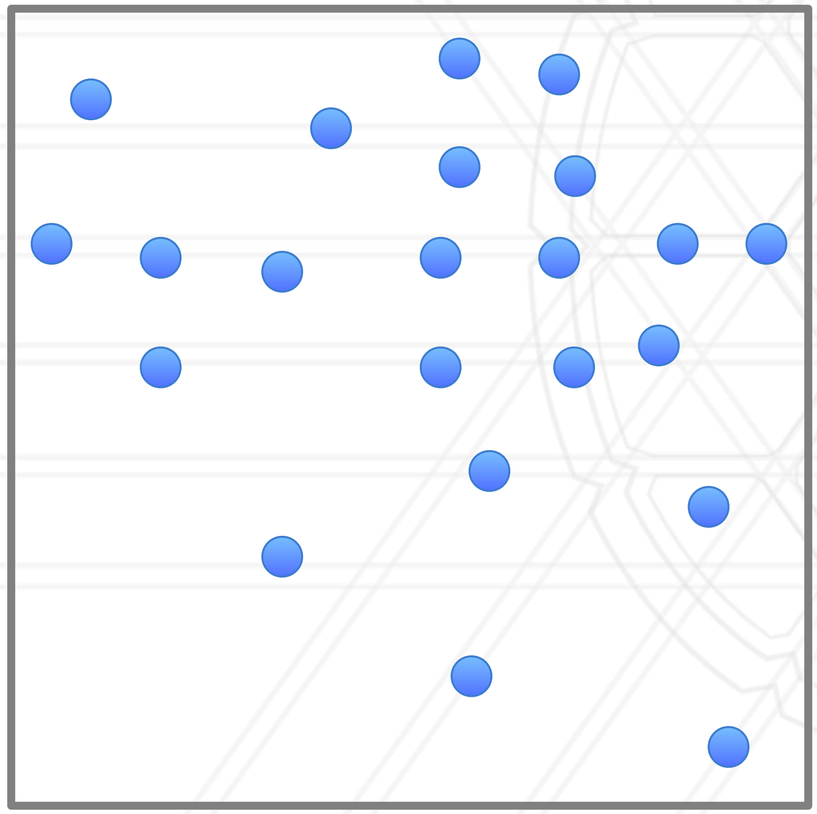
ORB



http://charm.cs.uiuc.edu/workshops/charmWorkshop2011/slides/CharmWorkshop2011_apps_ChaNGa.pdf

Examples of static load balancing

- Quad-tree for particles in 2D



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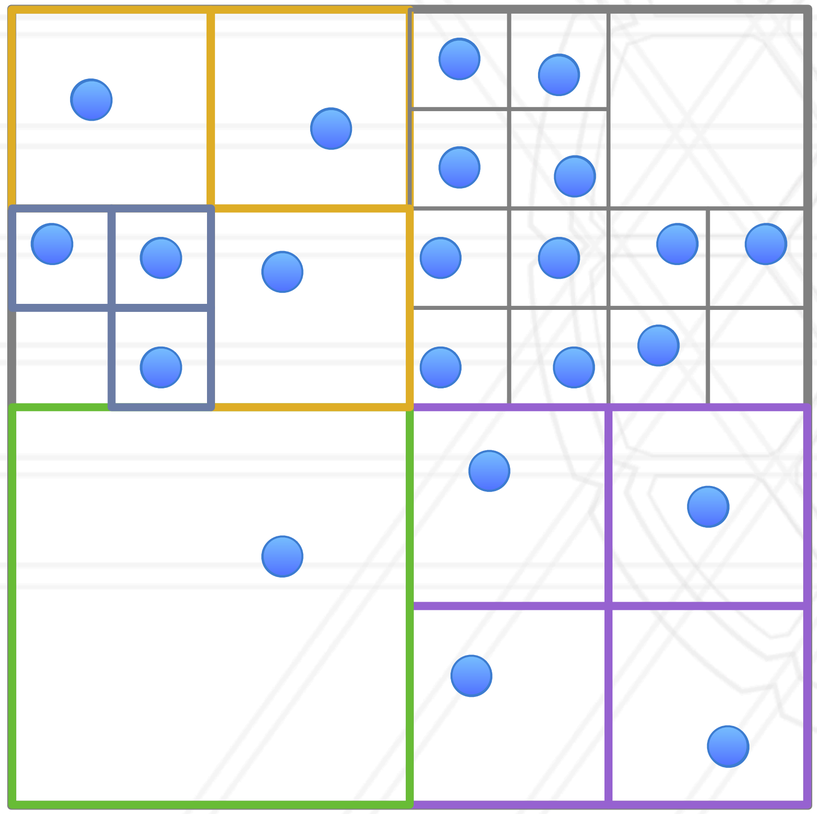

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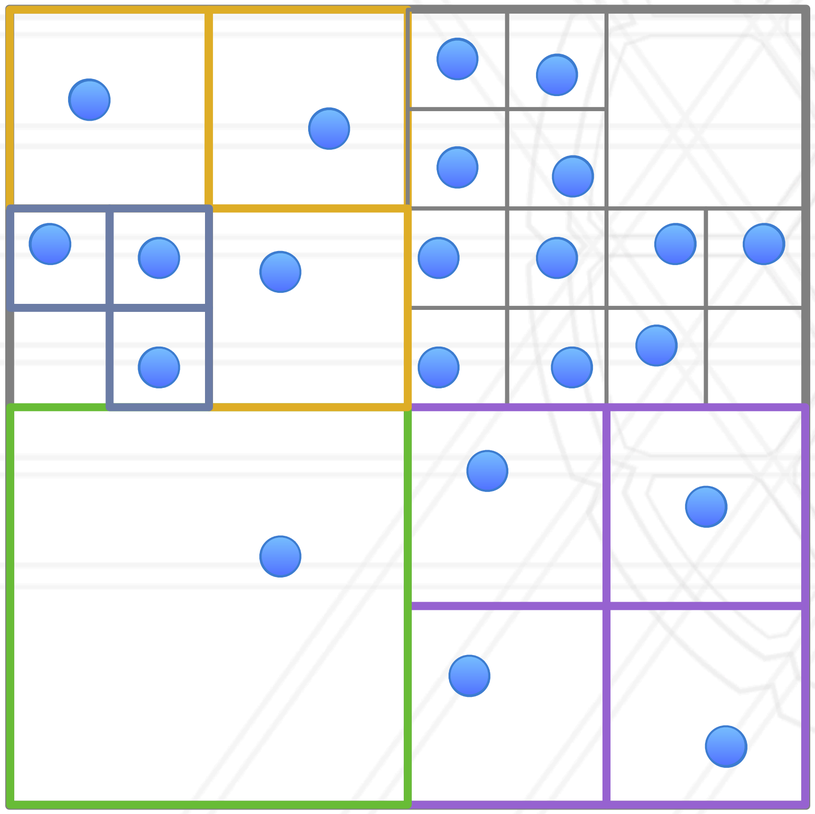

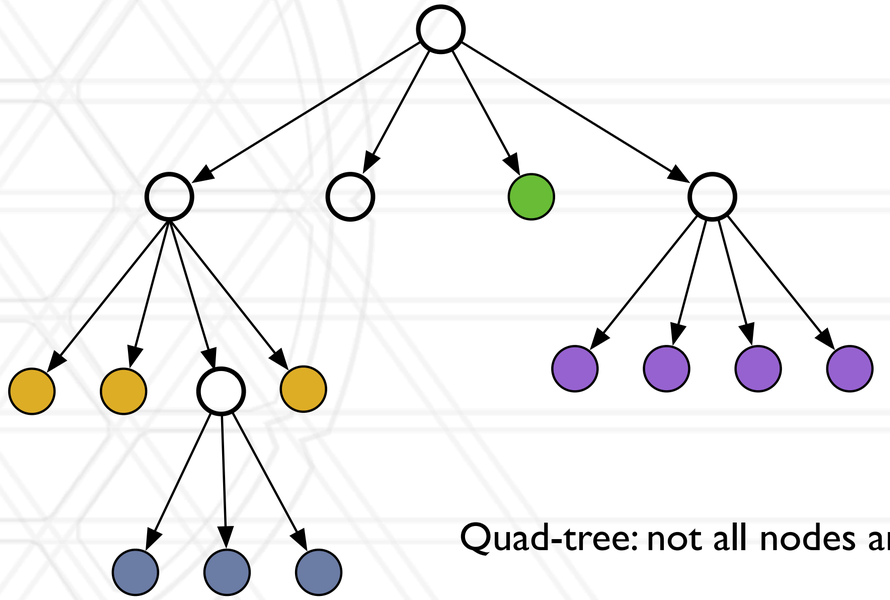

Quad-tree: not all nodes are shown

Simple greedy strategy

- Sort all the processes by their load
- Take some load (work) from the heaviest loaded process and assign that work to the most lightly loaded process

Work stealing

- Decentralized strategy where processes steal work from nearby processes when they have nothing to do
- Each process has a queue of work items
  - Looks at the other processes' queues when there are no items remaining
- Implemented in Cilk, among other languages

Other considerations

- Communication-aware load balancing
  - Try to move (units of) work to processes that this work communicates with frequently
- Network topology-aware load balancing
  - Take into account how the nodes are connected to one another to minimize some metrics (number of hops, average link load etc.)

UNIVERSITY OF
MARYLAND

Abhinav Bhatele

5218 Brendan Iribe Center (IRB) / College Park, MD 20742

phone: 301.405.4507 / e-mail: bhatele@cs.umd.edu