



# Load Balancing

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# Announcements

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- Assignment 4 and 5 (extra credit) have been posted
  - Due dates: Nov 13 and 20 respectively

# Performance issues

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

# Load balancing

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- 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?

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- 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?

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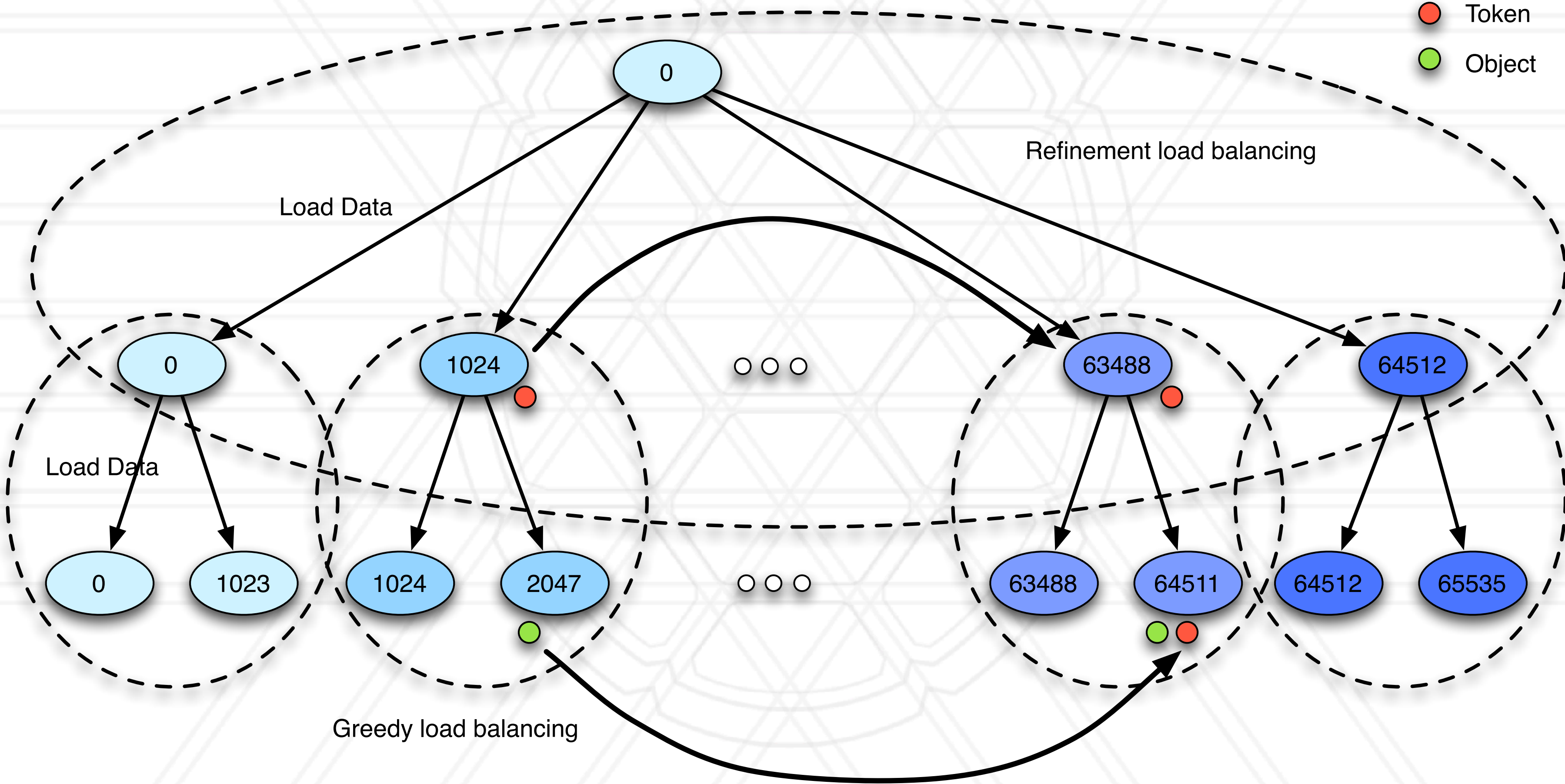
- Initial work distribution or partitioning or static load balancing
  - At program startup
  - Or sometimes in a separate run to determine new load distribution
- Dynamic load balancing: does load distribution evolve over time?
  - During program execution
  - How often? It depends ...

# Information gathering for load balancing

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- **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

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

# Load balancing algorithms

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- 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

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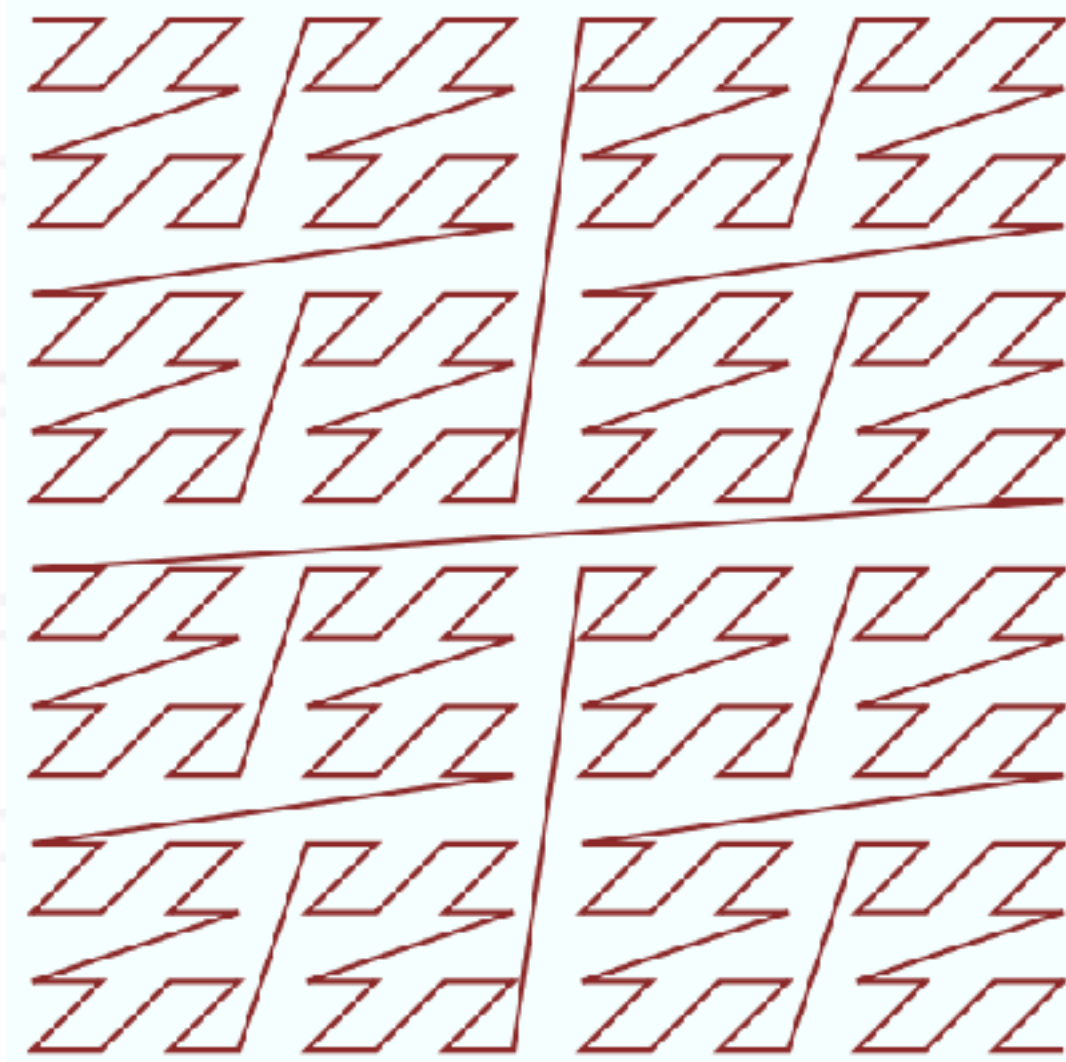
- Decomposition of  $n$ -D Stencil
- Using orthogonal recursive bisection (ORB), space-filling curves, etc.

<http://datagenetics.com/blog/march22013/>  
[https://en.wikipedia.org/wiki/Z-order\\_curve](https://en.wikipedia.org/wiki/Z-order_curve)

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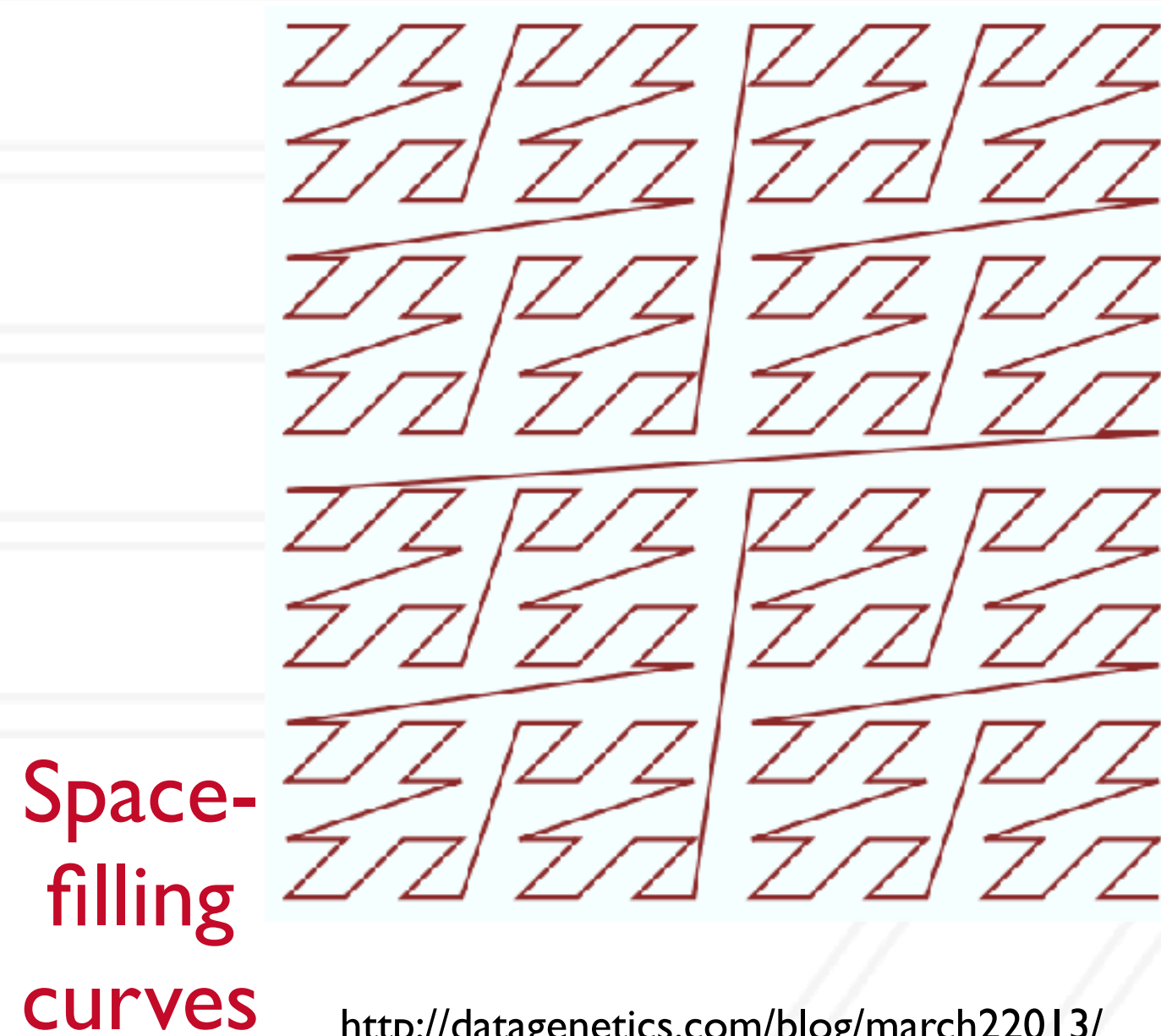


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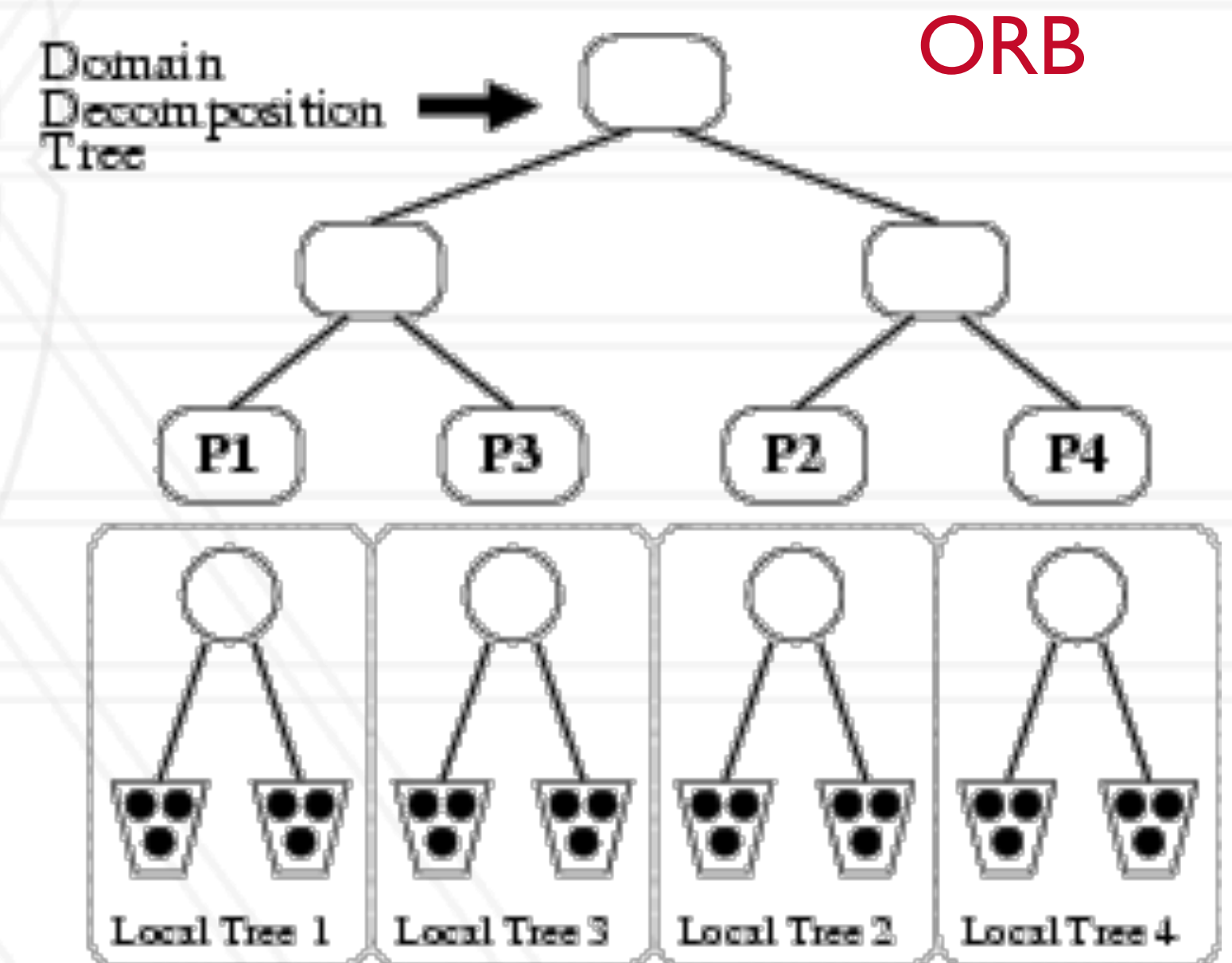
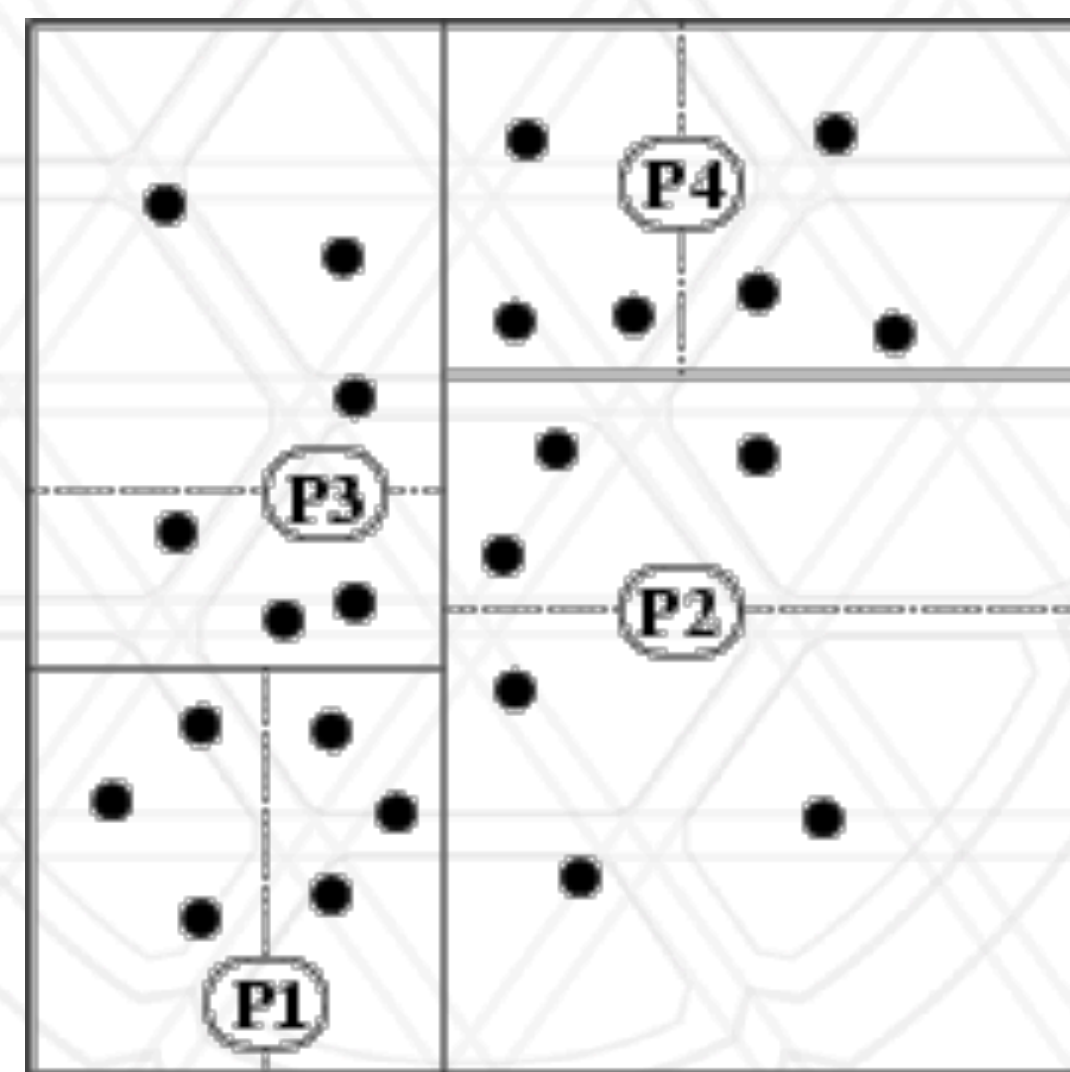


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# Simple greedy strategy

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- 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

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- 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

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- **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.)



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