EE382N (20): Computer Architecture - Parallelism and Locality
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# Lecture 10 – Parallelism in Software I

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# Outline

- Parallel programming
  - Start from scratch
  - Reengineering for parallelism
- Parallelizing a program
  - Decomposition (finding concurrency)
  - Assignment (algorithm structure)
  - Orchestration (supporting structures)
  - Mapping (implementation mechanisms)
- Patterns for Parallel Programming

# Credits

- Most of the slides courtesy Dr. Rodric Rabbah (IBM)
  - Taken from 6.189 IAP taught at MIT in 2007.

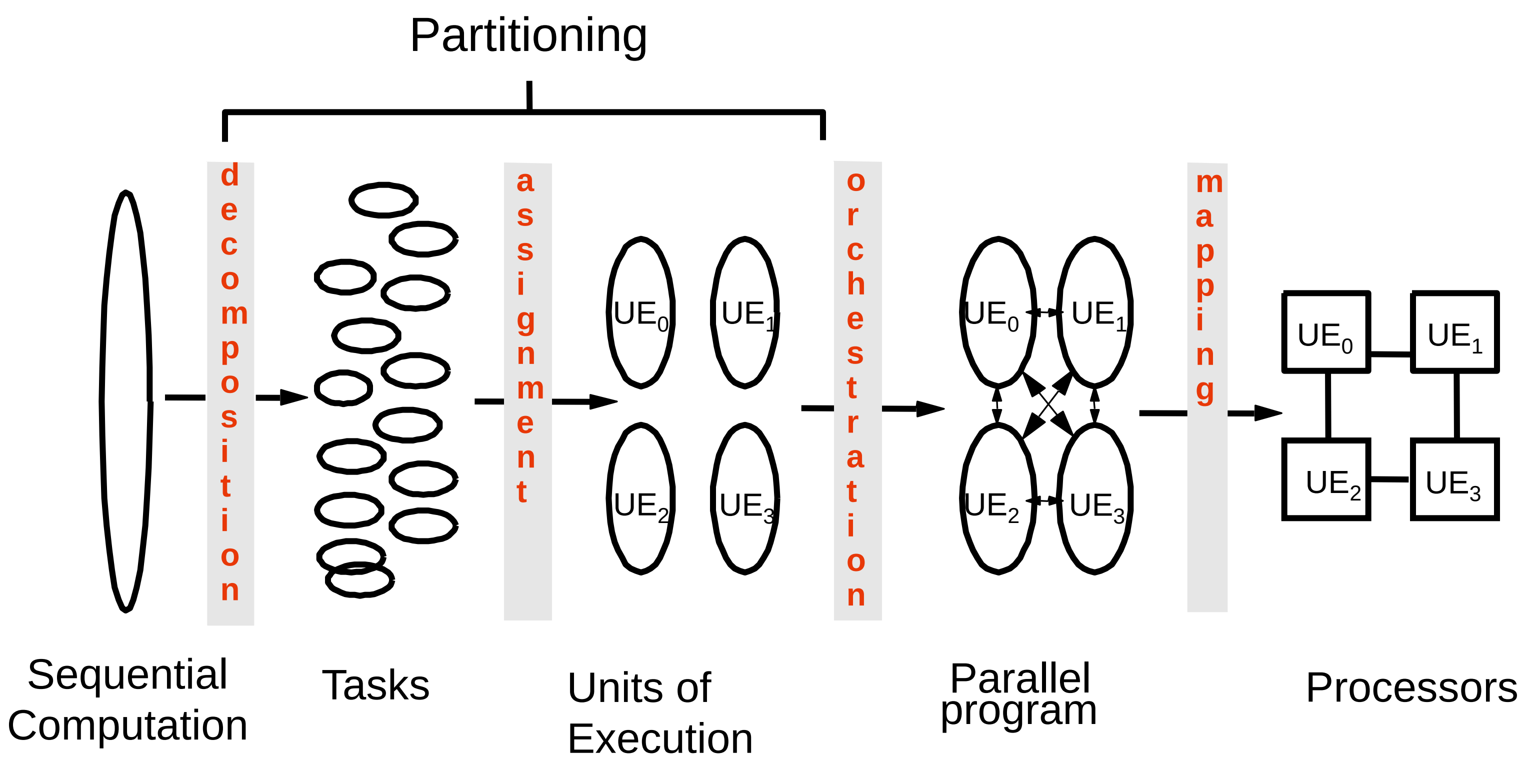
# Parallel programming from scratch

- Start with an algorithm
  - Formal representation of problem solution
  - ***Sequence*** of steps
- Make sure there is parallelism
  - In each algorithm step
  - Minimize synchronization points
- Don't forget locality
  - Communication is costly
    - Performance, Energy, System cost
- More often start with existing sequential code

# Reengineering for Parallelism

- Define a testing protocol
- Identify program hot spots: where is most of the time spent?
  - Look at code
  - Use profiling tools
- Parallelization
  - Start with hot spots first
  - Make sequences of small changes, each followed by testing
  - Patterns provide guidance

# 4 Common Steps to Creating a Parallel Program



# Decomposition



- Identify concurrency and decide at what level to exploit it
- Break up computation into tasks to be divided among processes
  - Tasks may become available dynamically
  - Number of tasks may vary with time
- Enough tasks to keep processors busy
  - Number of tasks available at a time is upper bound on achievable speedup

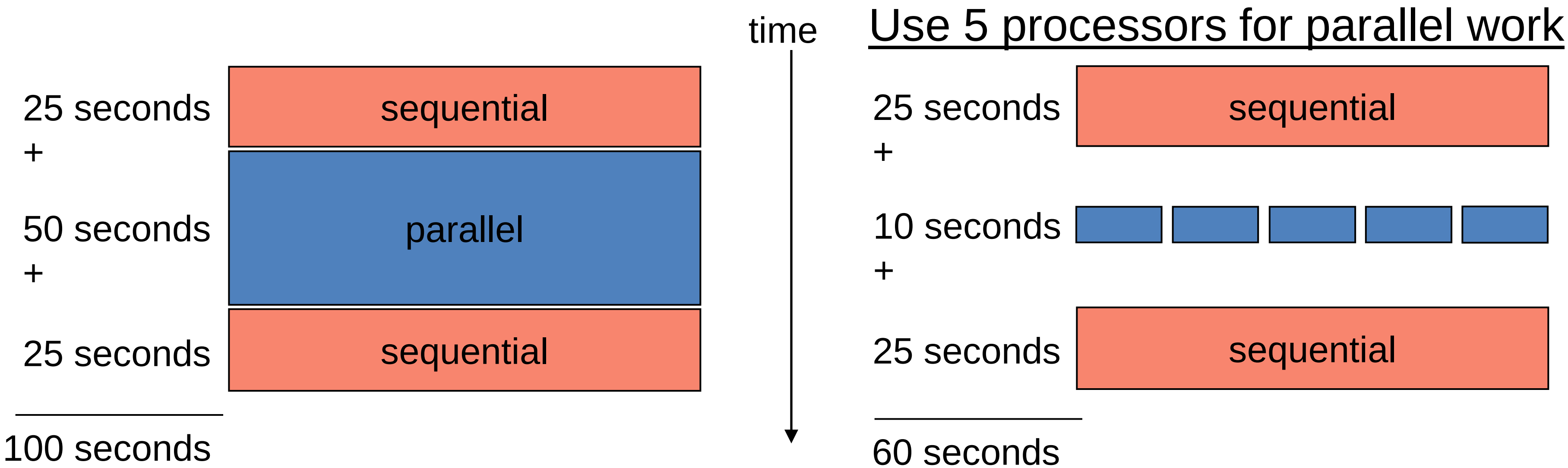
**Main consideration: coverage and Amdahl's Law**

# Coverage

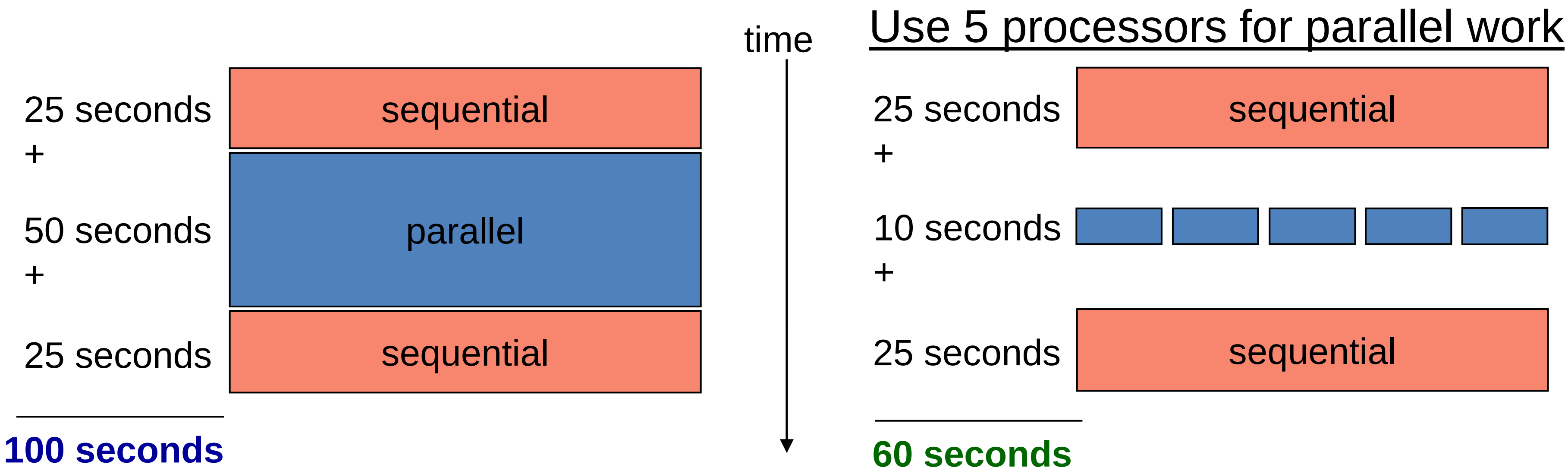
- **Amdahl's Law**: *The performance improvement to be gained from using some faster mode of execution is limited by the fraction of the time the faster mode can be used.*
  - Demonstration of the law of diminishing returns

# Amdahl's Law

- Potential program speedup is defined by the fraction of code that can be parallelized



# Amdahl's Law




- Speedup= old running time / new running time

  = 100 seconds / 60 seconds

  = 1.67

  (parallel version is 1.67 times faster)

# Amdahl's Law

- $p$ = fraction of work that can be parallelized
- $n$ = the number of processor

$$speedup = \frac{\text{old running time}}{\text{new running time}}$$

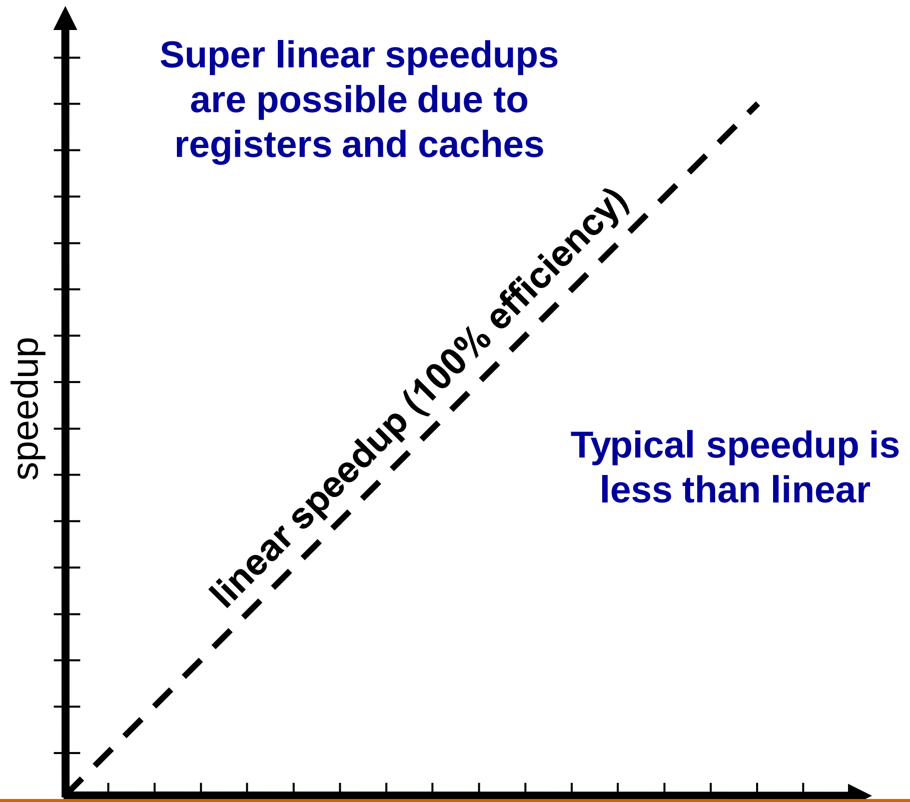
$$= \frac{1}{(1-p) + \frac{p}{n}}$$

fraction of time to complete sequential work

fraction of time to complete parallel work

# Implications of Amdahl's Law

- Speedup tends to $\frac{1}{1-p}$ as number of processors tends to infinity




**Parallelism only worthwhile when it dominates execution**

# Assignment

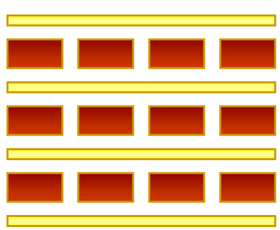
- Specify mechanism to divide work among PEs
  - Balance work and reduce communication
- Structured approaches usually work well
  - Code inspection or understanding of application
  - Well-known design patterns
- As programmers, we worry about partitioning first
  - Independent of architecture or programming model?
  - Complexity often affects decisions
  - Architectural model affects decisions

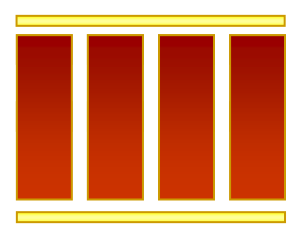
**Main considerations: granularity and locality**

# Fine vs. Coarse Granularity

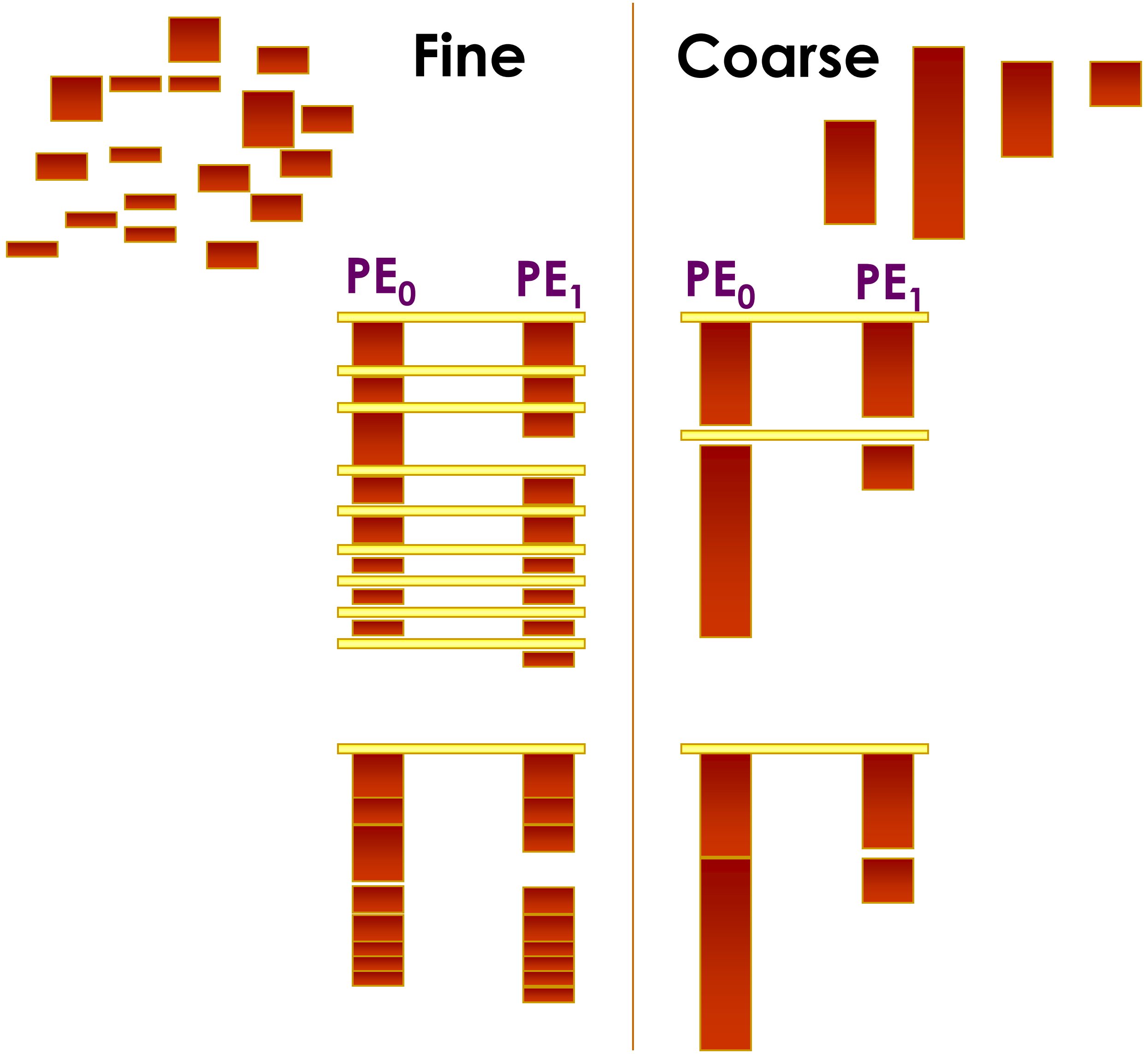
- Fine-grain Parallelism
  - Low computation to communication ratio
  - Small amounts of computational work between communication stages
  - High communication overhead
    - Potential HW assist

- Coarse-grain Parallelism
  - High computation to communication ratio
  - Large amounts of computational work between communication events
  - Harder to load balance efficiently

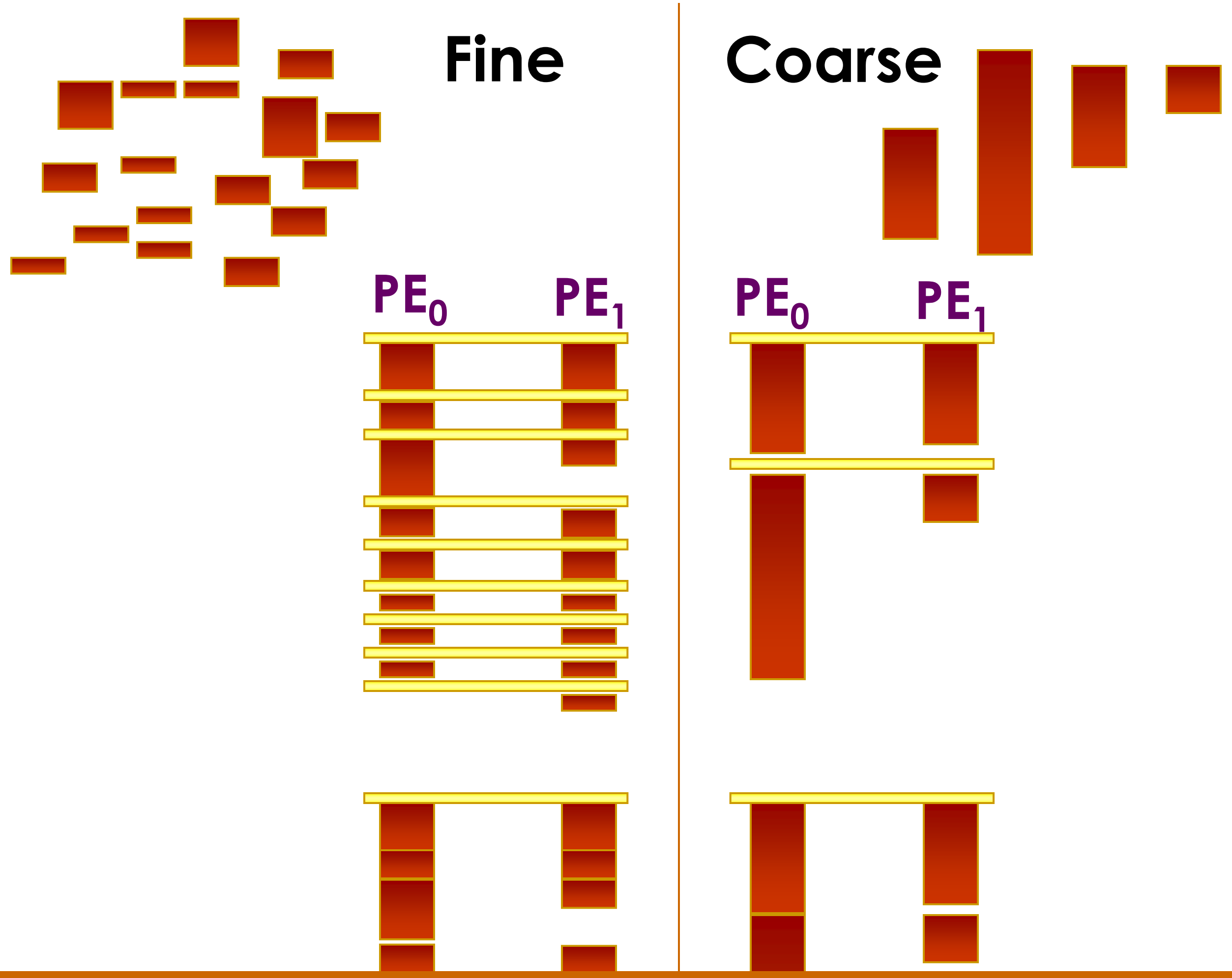




# Load Balancing vs. Synchronization



# Load Balancing vs. Synchronization




**Expensive sync → coarse granularity**

**Few units of exec + time disparity → fine granularity**

# Orchestration and Mapping

- Computation and communication concurrency
- Preserve locality of data
- Schedule tasks to satisfy dependences early
- Survey available mechanisms on target system

**Main considerations: locality, parallelism, mechanisms (efficiency and dangers)**

# Parallel Programming by Pattern

- Provides a cookbook to systematically guide programmers
  - Decompose, Assign, Orchestrate, Map
  - Can lead to high quality solutions in some domains
- Provide common vocabulary to the programming community
  - Each pattern has a name, providing a vocabulary for discussing solutions
- Helps with software reusability, malleability, and modularity
  - Written in prescribed format to allow the reader to quickly understand the solution and its context
- Otherwise, too difficult for programmers, and software will not fully exploit parallel hardware