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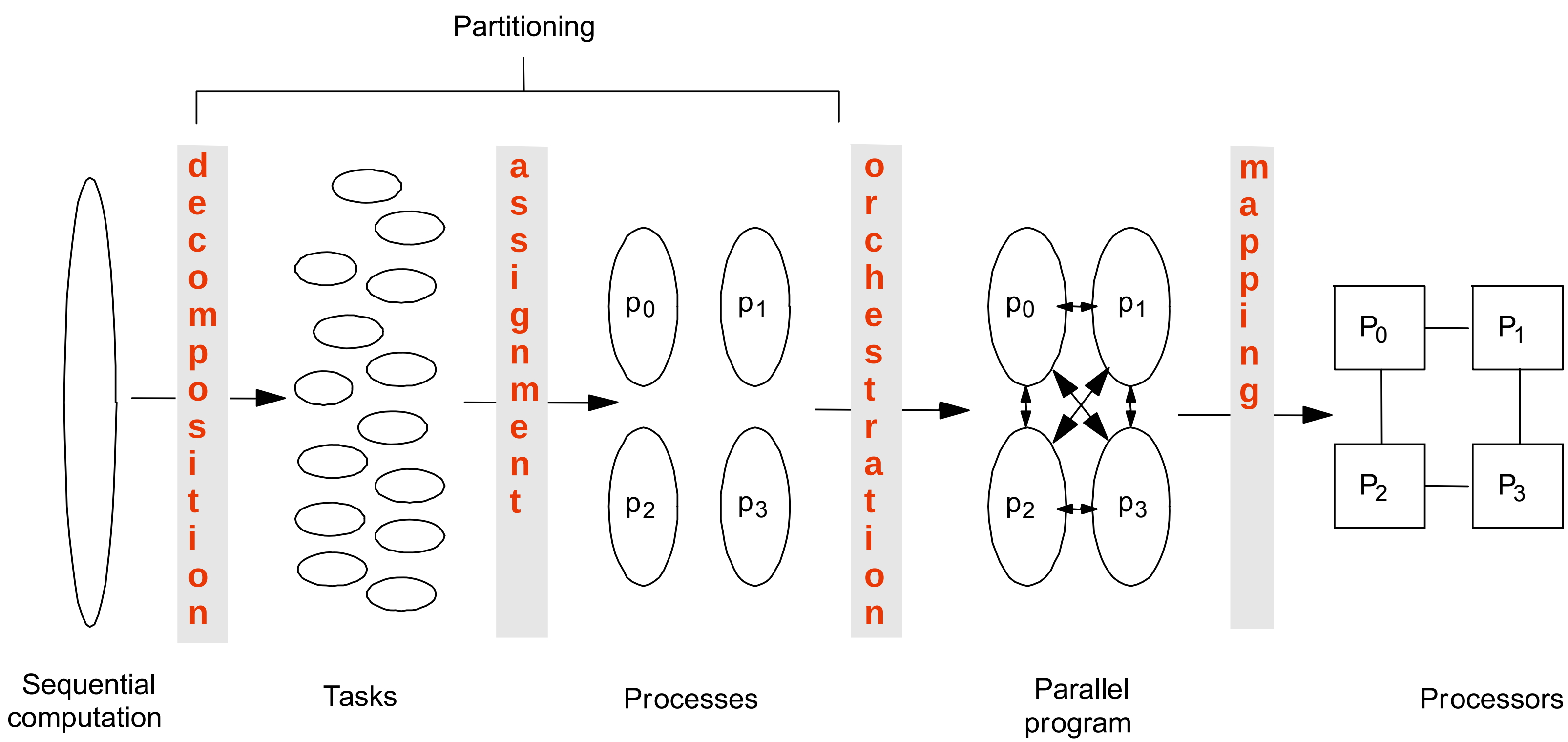
Lecture 6

Design Patterns for Parallel Programming I

4 Common Steps to Creating a Parallel Program



Decomposition (Amdahl’s Law)

- 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

Assignment (Granularity)

- Specify mechanism to divide work among core
  - 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
  - But complexity often affect decisions!

Orchestration and Mapping (Locality)

- Computation and communication concurrency
- Preserve locality of data
- Schedule tasks to satisfy dependences early

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

History

- Berkeley architecture professor Christopher Alexander
- In 1977, patterns for city planning, landscaping, and architecture in an attempt to capture principles for “living” design

Example 167 (p. 783): 6ft Balcony

Therefore:

Whenever you build a balcony, a porch, a gallery, or a terrace always make it at least six feet deep. If possible, recess at least a part of it into the building so that it is not cantilevered out and separated from the building by a simple line, and enclose it partially.

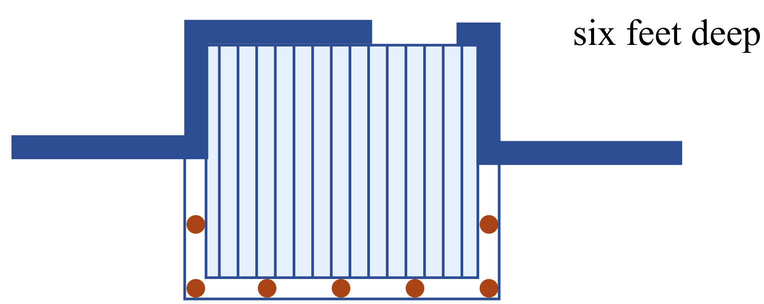


Image by MIT OpenCourseWare.

Patterns in Object-Oriented Programming

- Design Patterns: Elements of Reusable Object-Oriented Software (1995)
  - Gang of Four (GOF): Gamma, Helm, Johnson, Vlissides
  - Catalogue of patterns
  - Creation, structural, behavioral

Patterns for Parallelizing Programs

4 Design Spaces

Algorithm Expression

- Finding Concurrency
  - Expose concurrent tasks
- Algorithm Structure
  - Map tasks to processes to exploit parallel architecture

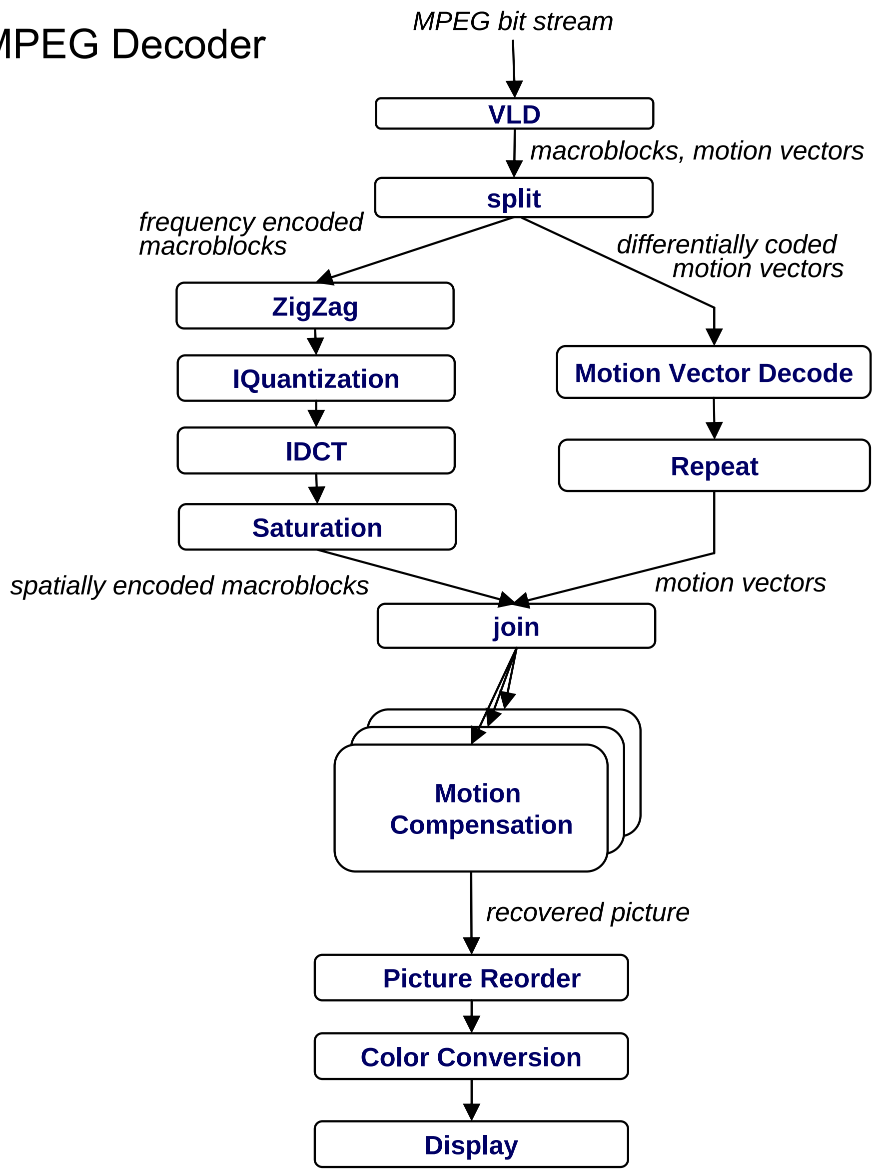
Software Construction

- Supporting Structures
  - Code and data structuring patterns
- Implementation Mechanisms
  - Low level mechanisms used to write parallel programs

Patterns for Parallel Programming. Mattson, Sanders, and Massingill (2005).

Here's my algorithm. Where's the concurrency?

MPEG Decoder



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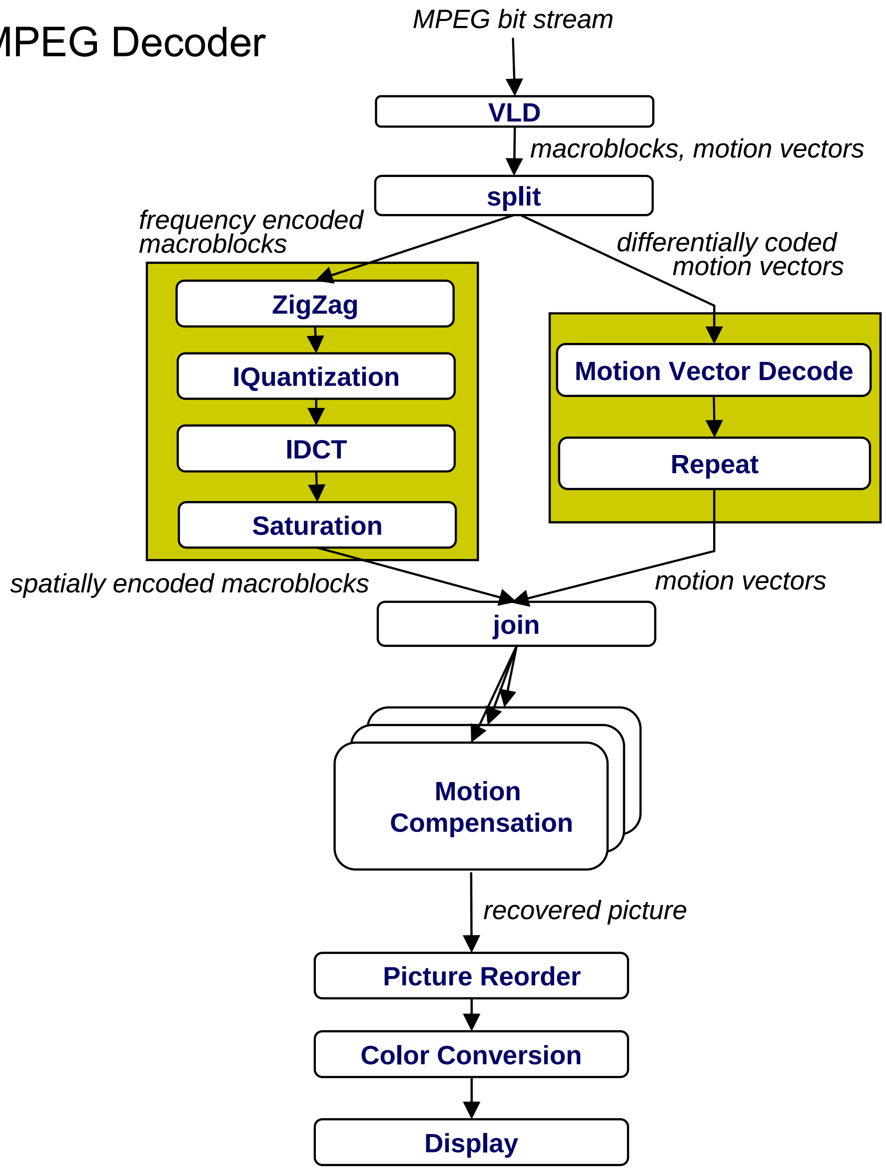
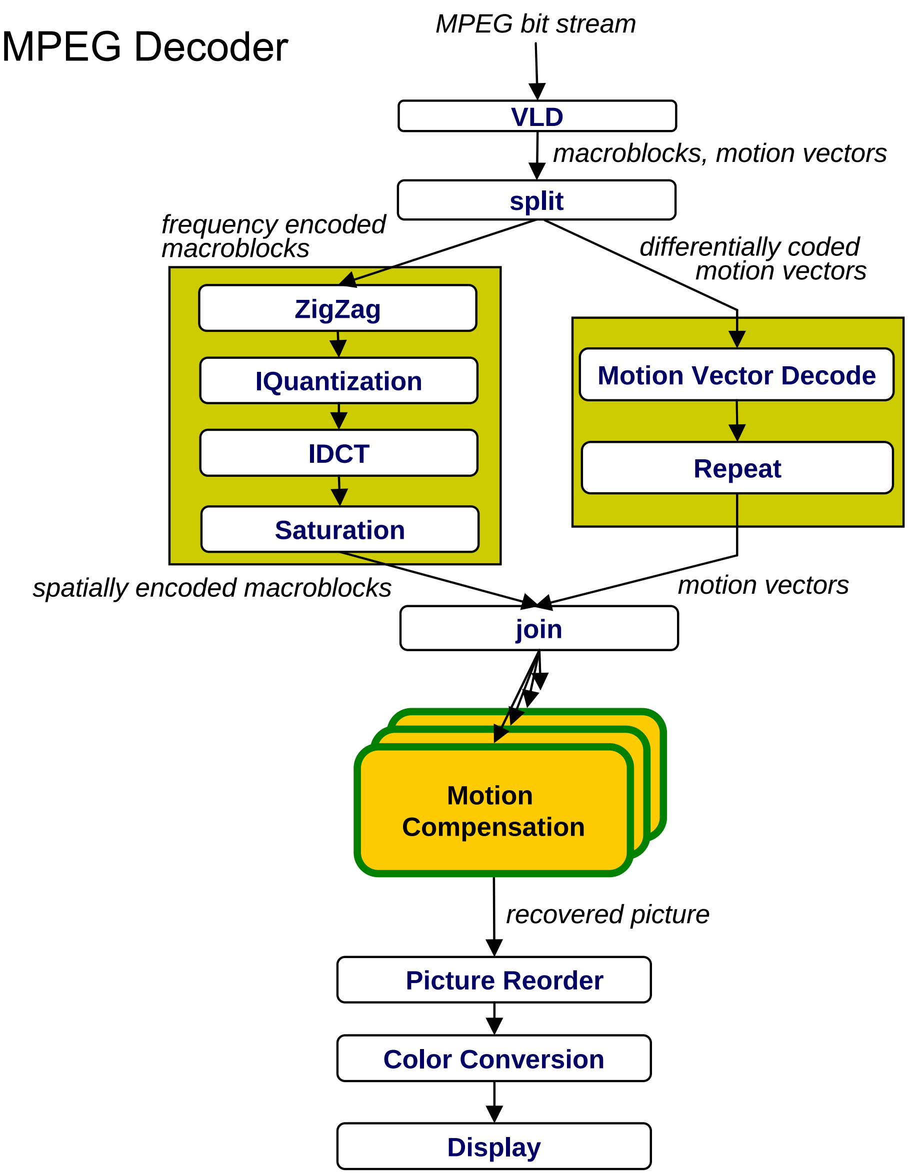
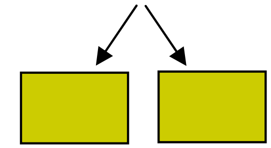


- Task decomposition
  - Independent coarse-grained computation
  - Inherent to algorithm
- Sequence of statements (instructions) that operate together as a group
  - Corresponds to some logical part of program
  - Usually follows from the way programmer thinks about a problem

Here's my algorithm. Where's the concurrency?

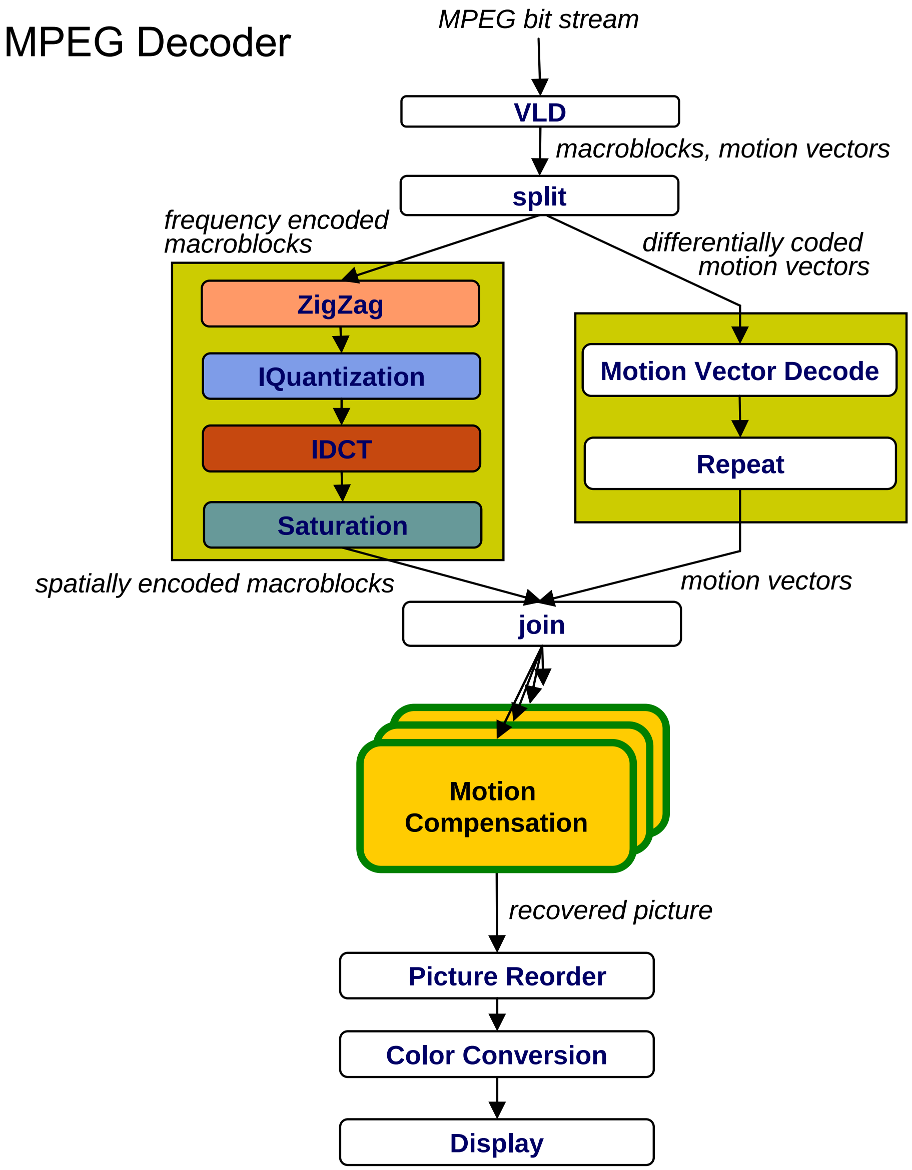
MPEG Decoder

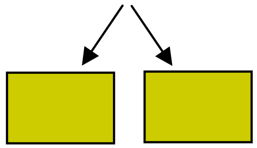
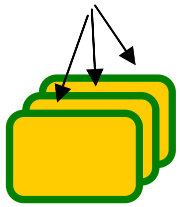


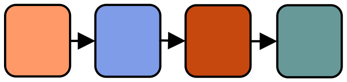


- Task decomposition
  - Parallelism in the application
- Data decomposition
  - Same computation is applied to small data chunks derived from large data set

Here's my algorithm. Where's the concurrency?



- Task decomposition 
  - Parallelism in the application
- Data decomposition 
  - Same computation many data
- Pipeline decomposition
  - Data assembly lines
  - Producer-consumer chains



Guidelines for Task Decomposition

- Algorithms start with a good understanding of the problem being solved
- Programs often naturally decompose into tasks
  - Two common decompositions are
    - Function calls and
    - Distinct loop iterations
- Easier to start with many tasks and later fuse them, rather than too few tasks and later try to split them

Guidelines for Task Decomposition

- Flexibility
  - Program design should afford flexibility in the number and size of tasks generated
    - Tasks should not tied to a specific architecture
    - Fixed tasks vs. Parameterized tasks

- Efficiency
  - Tasks should have enough work to amortize the cost of creating and managing them
  - Tasks should be sufficiently independent so that managing dependencies doesn’t become the bottleneck

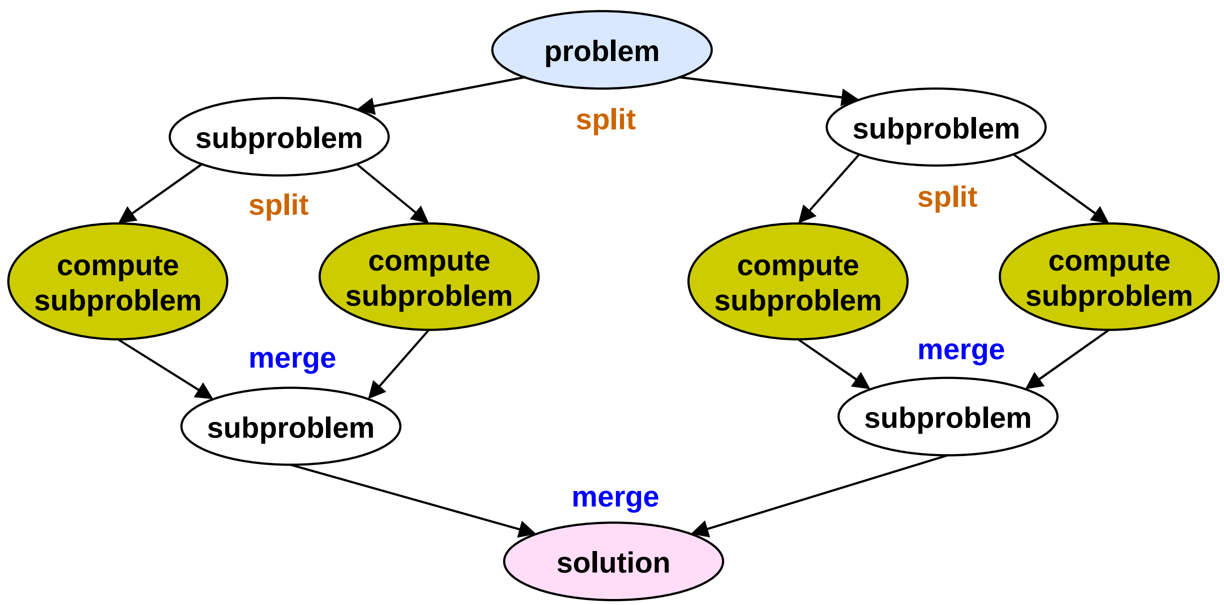
- Simplicity
  - The code has to remain readable and easy to understand, and debug

Guidelines for Data Decomposition

- Data decomposition is often implied by task decomposition
- Programmers need to address task and data decomposition to create a parallel program
  - Which decomposition to start with?
- Data decomposition is a good starting point when
  - Main computation is organized around manipulation of a large data structure
  - Similar operations are applied to different parts of the data structure

Common Data Decompositions

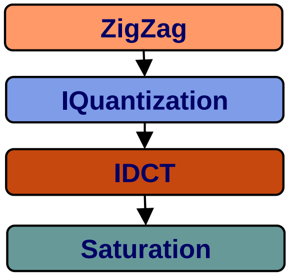
- Array data structures
  - Decomposition of arrays along rows, columns, blocks
- Recursive data structures
  - Example: decomposition of trees into sub-trees



Guidelines for Data Decomposition

- Flexibility
  - Size and number of data chunks should support a wide range of executions
- Efficiency
  - Data chunks should generate comparable amounts of work (for load balancing)
- Simplicity
  - Complex data compositions can get difficult to manage and debug

Case for Pipeline Decomposition



- Data is flowing through a sequence of stages
  - Assembly line is a good analogy
- What's a prime example of pipeline decomposition in computer architecture?
  - Instruction pipeline in modern CPUs
- What's an example pipeline you may use in your UNIX shell?
  - Pipes in UNIX: cat foobar.c | grep bar | wc
- Other examples
  - Signal processing
  - Graphics

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Re-engineering for Parallelism

Reengineering for Parallelism

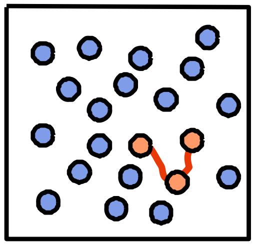
- Parallel programs often start as sequential programs
  - Easier to write and debug
  - Legacy codes
- How to reengineer a sequential program for parallelism:
  - Survey the landscape
  - Pattern provides a list of questions to help assess existing code
  - Many are the same as in any reengineering project
  - Is program numerically well-behaved?
- Define the scope and get users acceptance
  - Required precision of results
  - Input range
  - Performance expectations
  - Feasibility (back of envelope calculations)

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
  - Pattern provides guidance

Example: Molecular dynamics

- Simulate motion in large molecular system
  - Used for example to understand drug-protein interactions
- Forces
  - Bonded forces within a molecule
  - Long-range forces between atoms



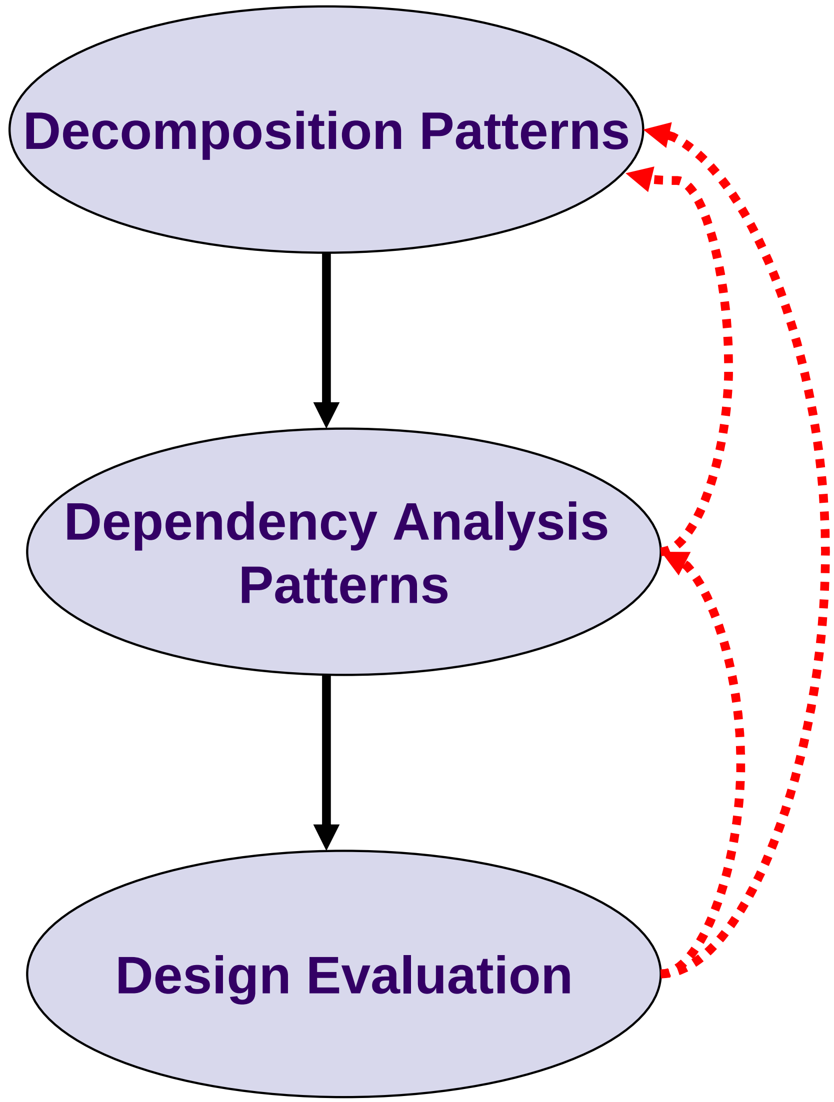
- Naïve algorithm has n^2 interactions: not feasible
- Use cutoff method: only consider forces from neighbors that are "close enough"

Sequential Molecular Dynamics Simulator

```
// pseudo code
real[3,n] atoms
real[3,n] force
int [2,m] neighbors

function simulate(steps)
   for time = 1 to steps and for each atom
      Compute bonded forces
      Compute neighbors
      Compute long-range forces
      Update position
   end loop
end function
```

Finding Concurrency Design Space

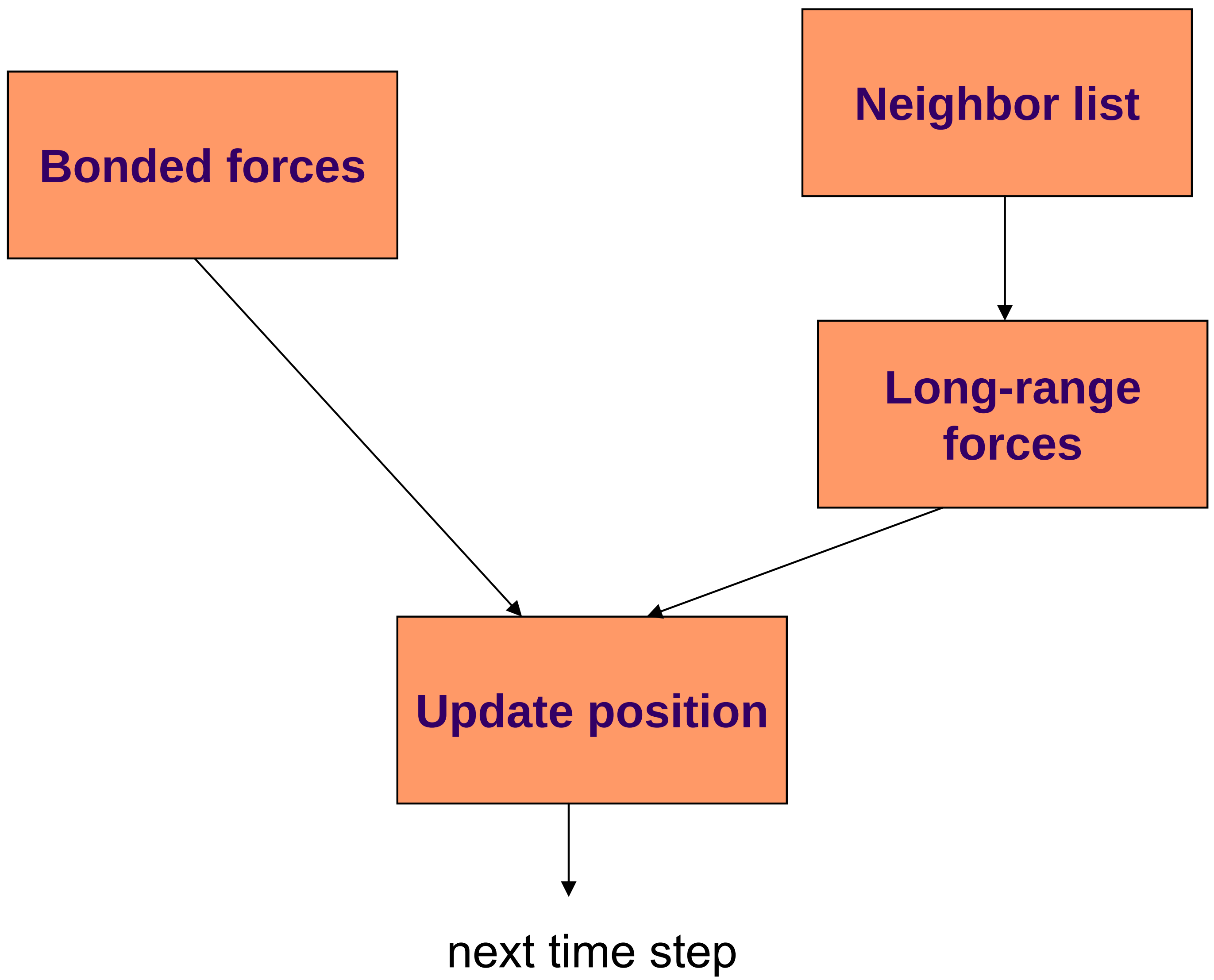


Decomposition Patterns

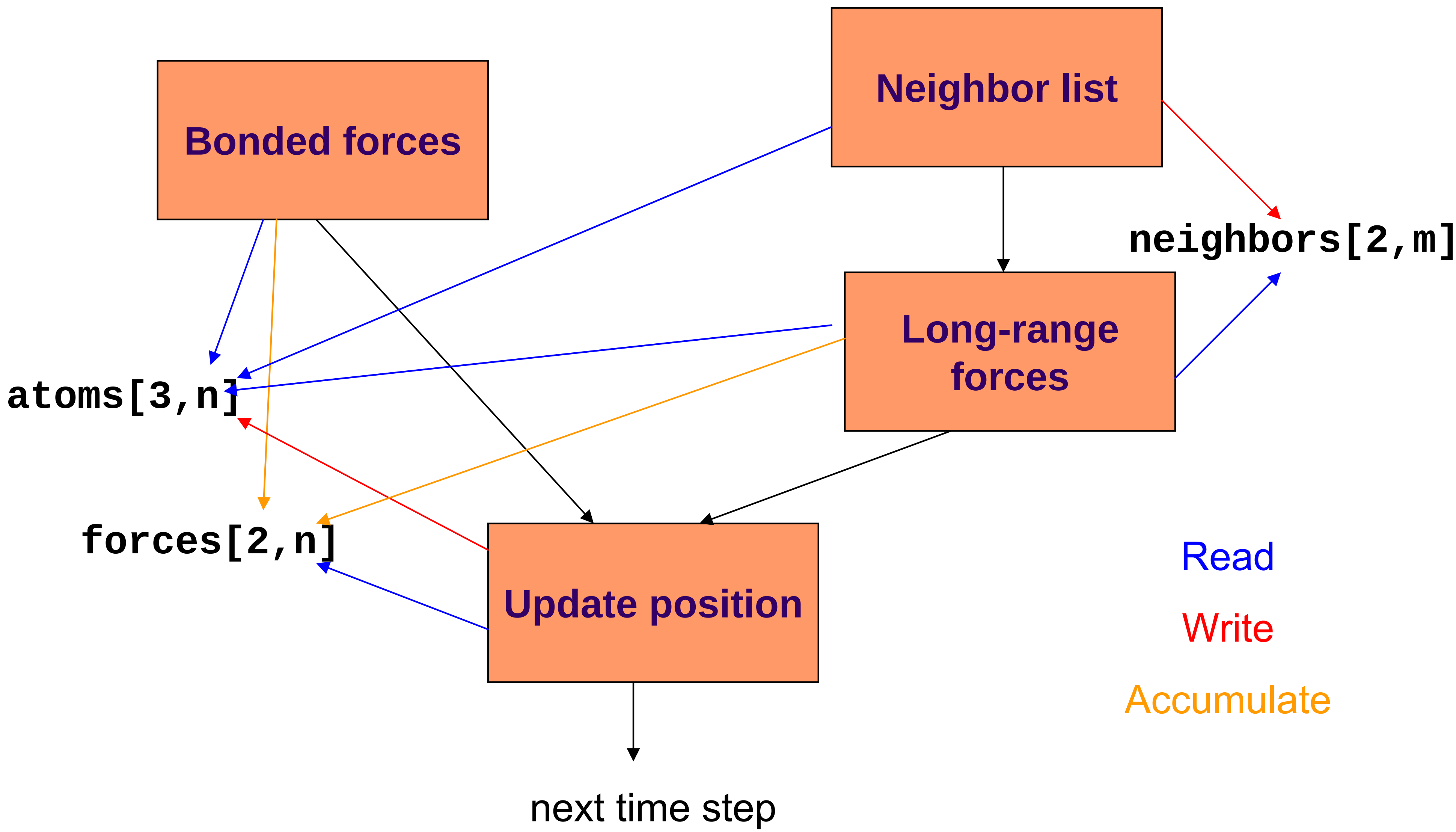
- Main computation is a loop over atoms
- Suggests task decomposition
  - Task corresponds to a loop iteration
    - Update a single atom
  - Additional tasks
    - Calculate bonded forces
    - Calculate long range forces
  - Find neighbors
  - Update position
- There is data shared between the tasks

```
for time = 1 to steps and
  for each atom
      Compute bonded forces
      Compute neighbors
      Compute long-range forces
      Update position
end loop
```

Understand Control Dependences



Understand Data Dependences



Evaluate Design

- What is the target architecture?
  - Shared memory, distributed memory, message passing, …
- Does data sharing have enough special properties (read only, accumulate, temporal constraints) that we can deal with dependences efficiently?
- If design seems OK, move to next design space