Parallel Programming Patterns

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Overview

- Definition
- Algorithm Patterns Example
- Problems / Weakness
- More Examples
- Directions

Defining Patterns

- *Design Patterns* - Quality description of problem and solution to a frequently occurring problem in some domain.
  - (object oriented programming, network apps…)
  - Description usually involves problem definition, driving forces, solution, benefits, difficulties, related patterns.
- *Pattern Language* - a collection of design patterns, guiding the users through the decision process in building a system.

Example Design Space

"Lunch" Pattern

Definition
- we get hungry every lunch hour.
- usually around 11:30am – 1:00pm.
- must resolve hunger.

Driving Forces
- appetite, intensity of hunger, nearby restaurants

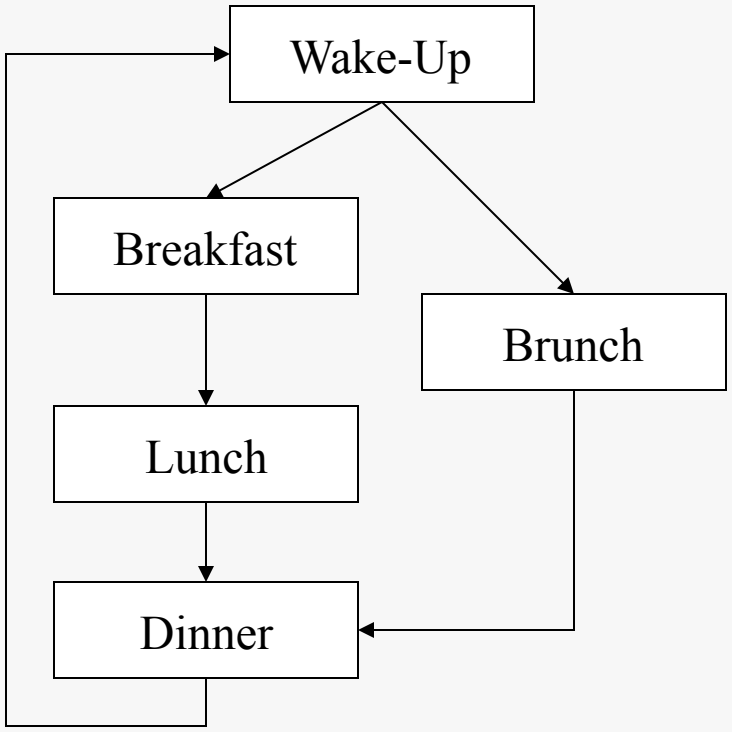
Solution
- eat at nearest restaurant that satisfies minimum appetite requirement.

Benefits
- hunger is resolved

Difficulties
- must not fall asleep afterwards.

Related Patterns
- dinner, breakfast, brunch, and snack

"Eat" Pattern Language



Parallel Programming Pattern : WHY?

- Parallel software does not fully exploit parallel hardw are.
  - Too difficult for programmers
  - Parallel Programming Environments do not focus on design issues.
- Need a "cookbook" that will guide the programmers systematically to achieve peak parallel performance.
  - (decomposition, algorithm, program structure, programmin g environment, optimizations)
- Provide common vocabulary to the programming co mmunity.
- Software reusability & modularity.

Some approaches

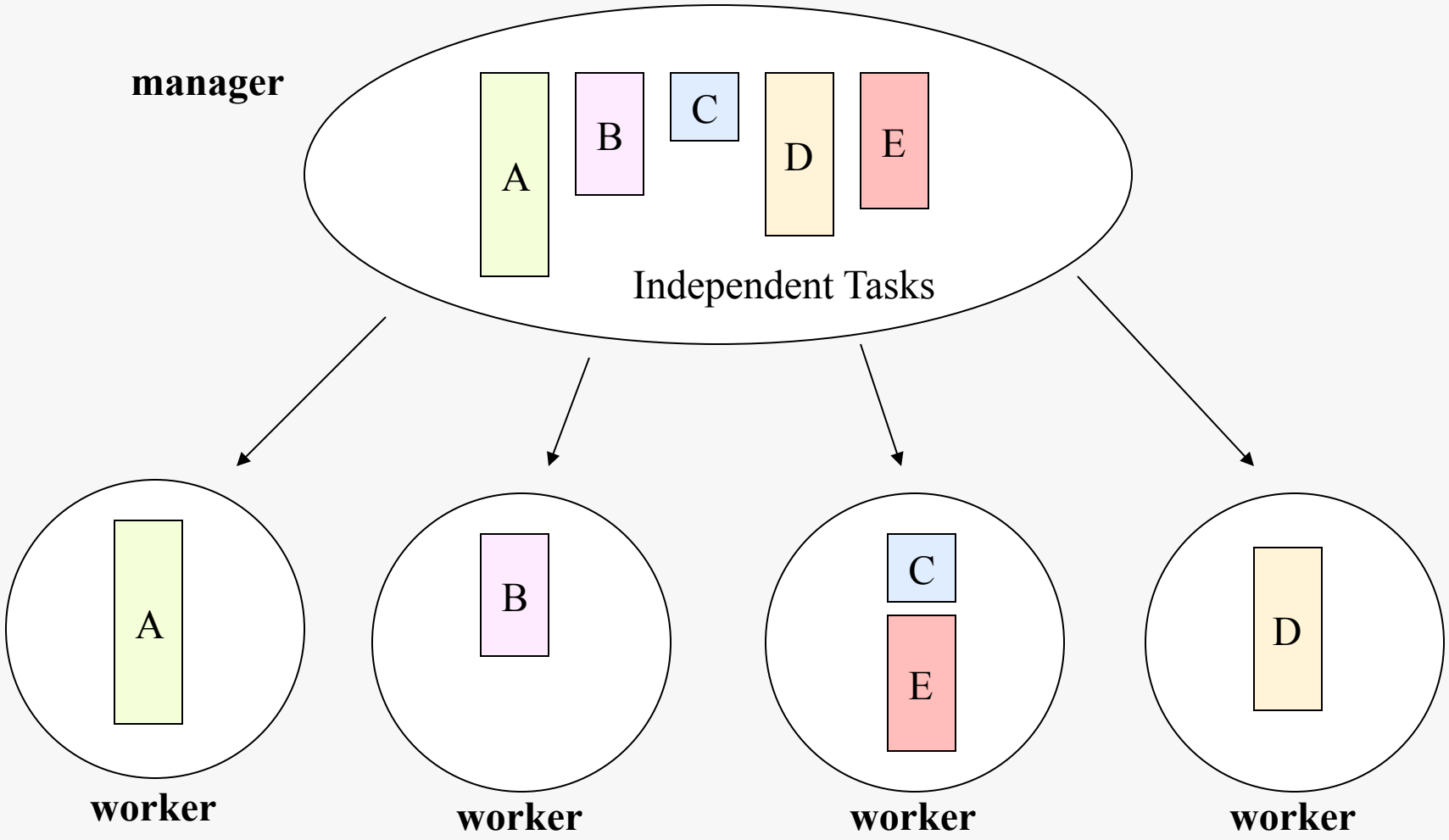
- Foster Methodology
  - Decomposition
  - Communication
  - Agglomeration
  - Mapping
- Massingil
  - FindingConcurrency
    - data vs. control
  - AlgorithmStructure
    - pipeline, replicate…
  - SupportingStructure
    - SPMD, fork/join…
  - Implementation
    - barriers, locks…

Common Parallel Patterns

- Embarassingly Parallel
- Replicable
- Repository
- Divide&Conquer
- Pipeline
- Recursive Data
- Geometric
- IrregularMesh
- Inseparable

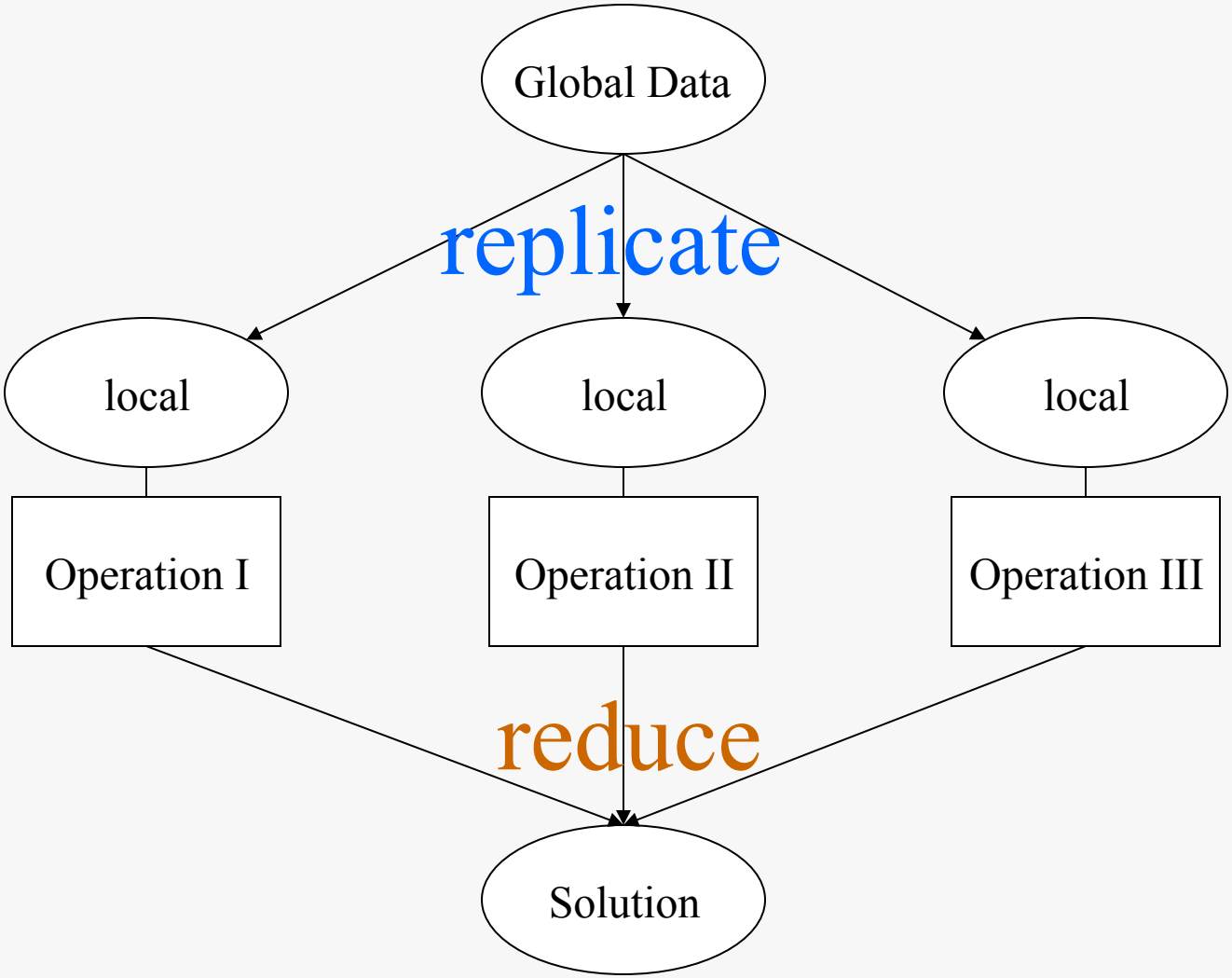
Embarassingly Parallel

Problem: Need to perform same operations to tasks that are independent



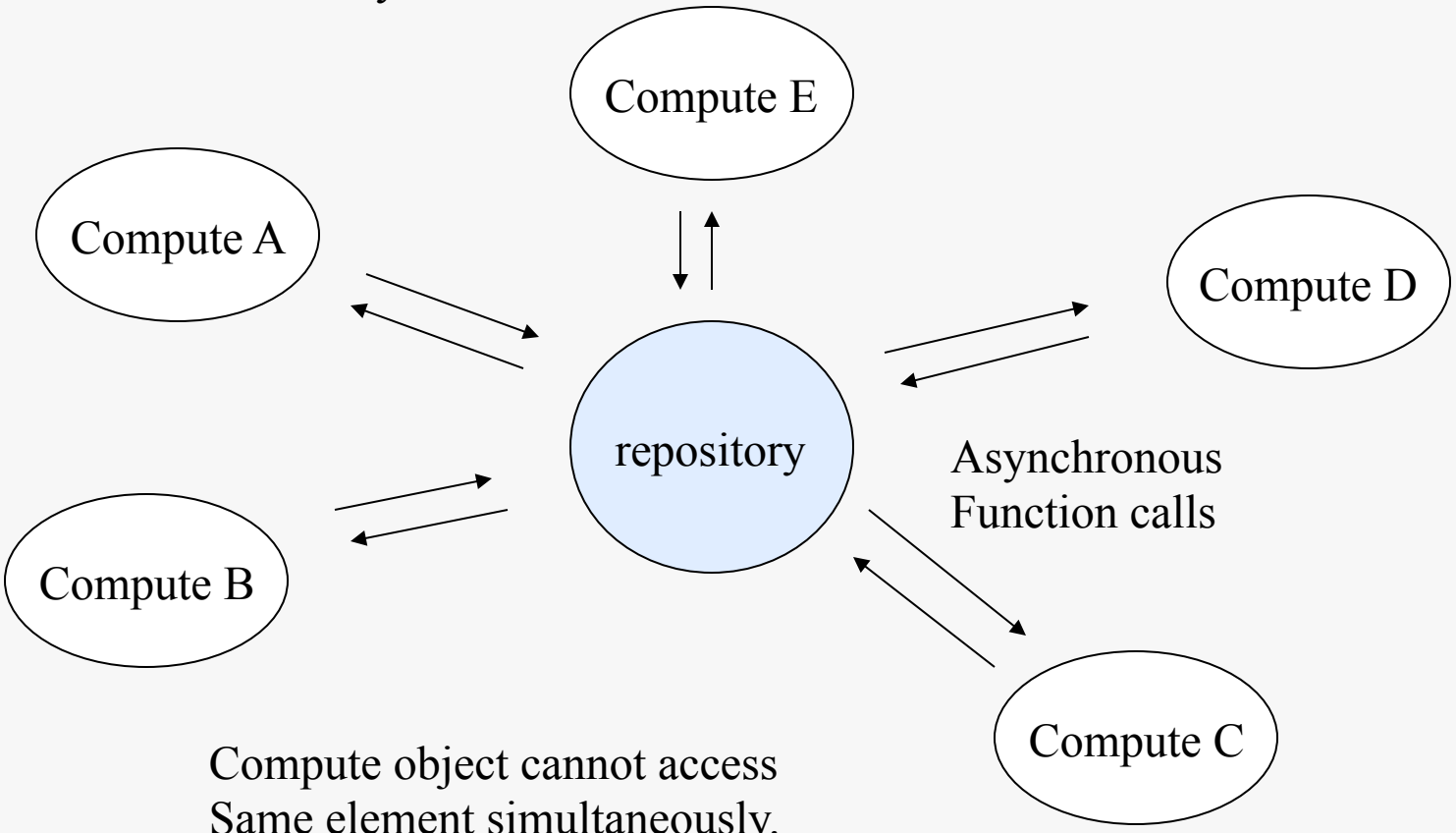
Replicable

Sets of operations need to be performed using global data structure, causing dependency.



Repository

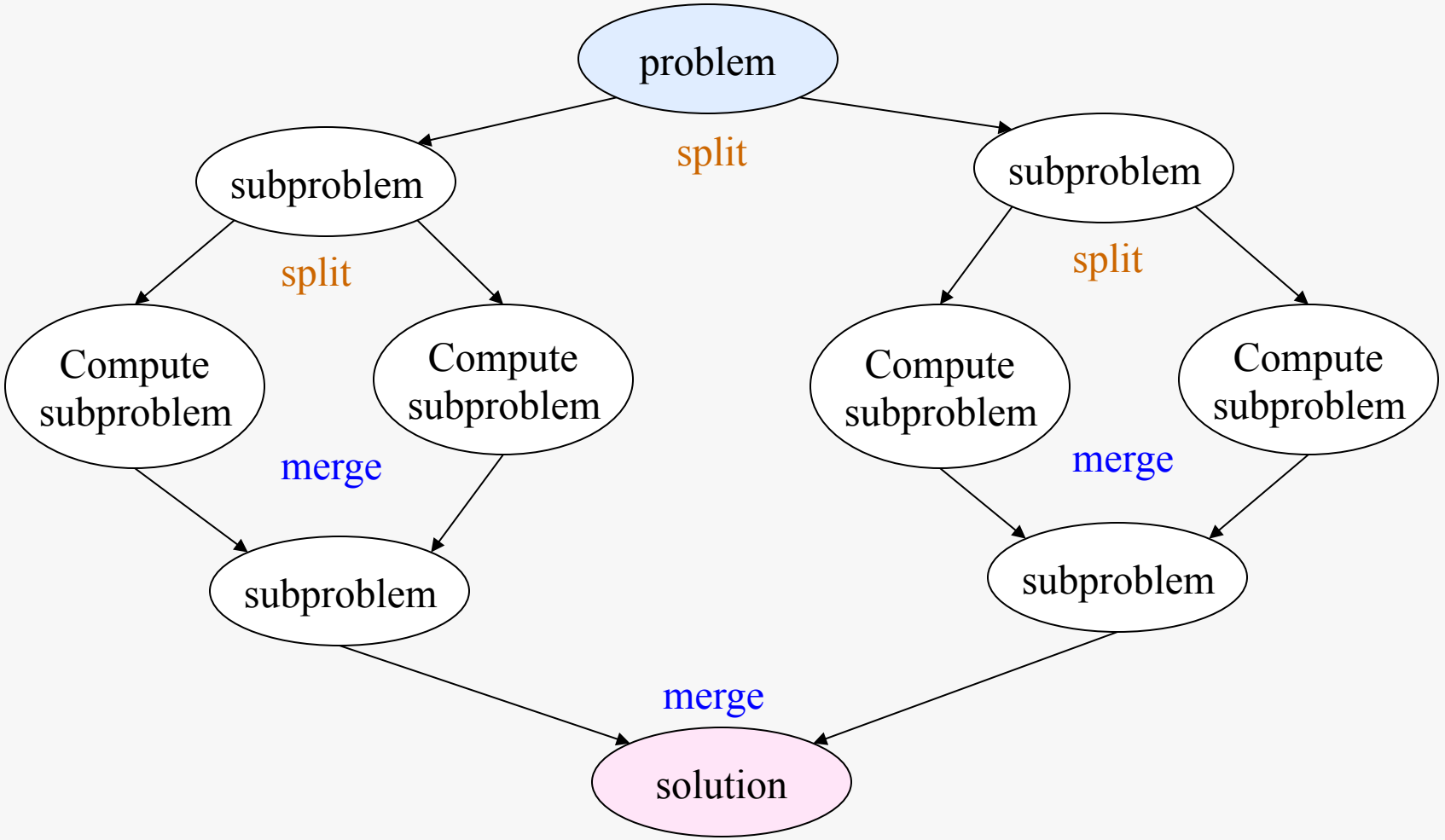
Independent computations needs to applied to centralized data structure in non-deterministic way.



Compute object cannot access
Same element simultaneously.
(Repository controls access)

Divide & Conquer

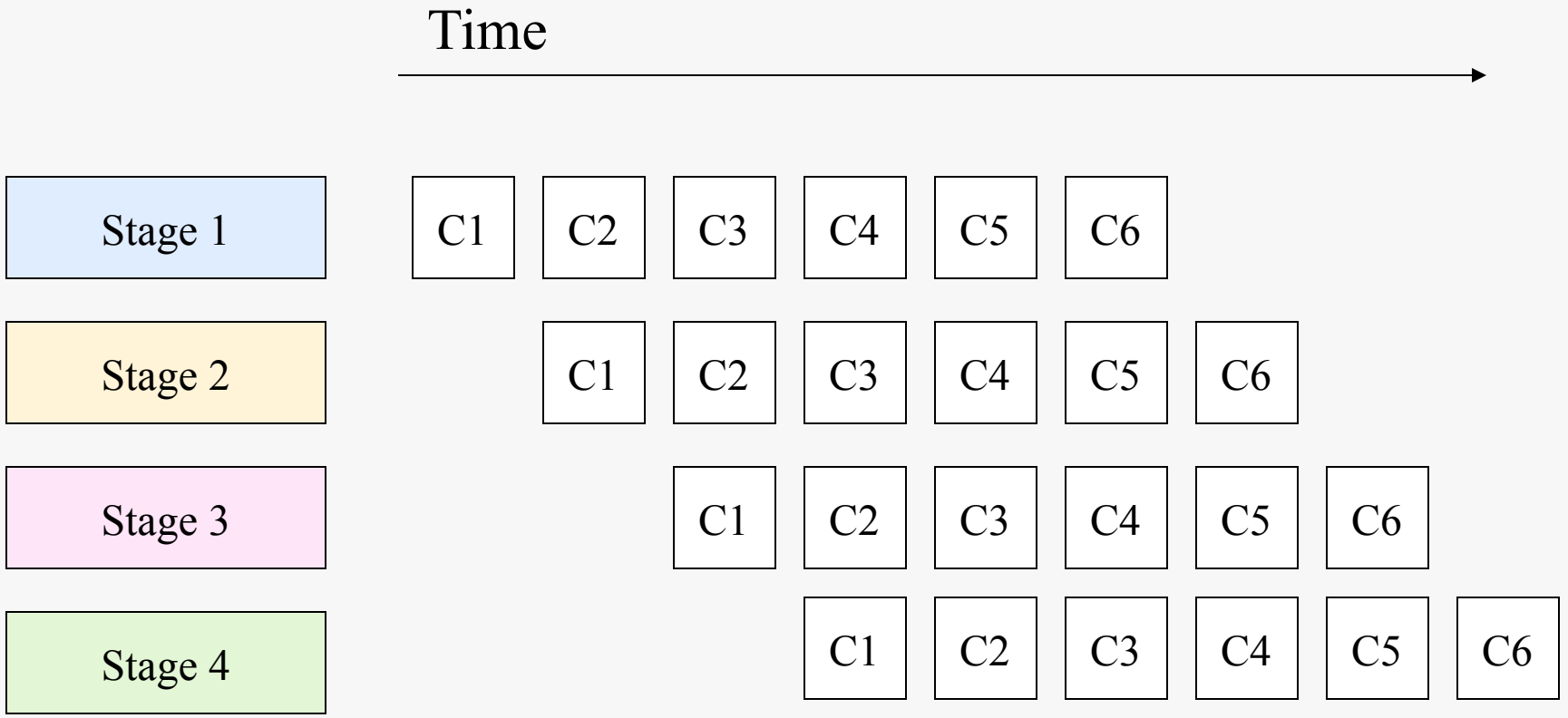
A problem is structured to be solved in sub-problems independently, and merging them later.



* Split level needs to be adjusted appropriately.

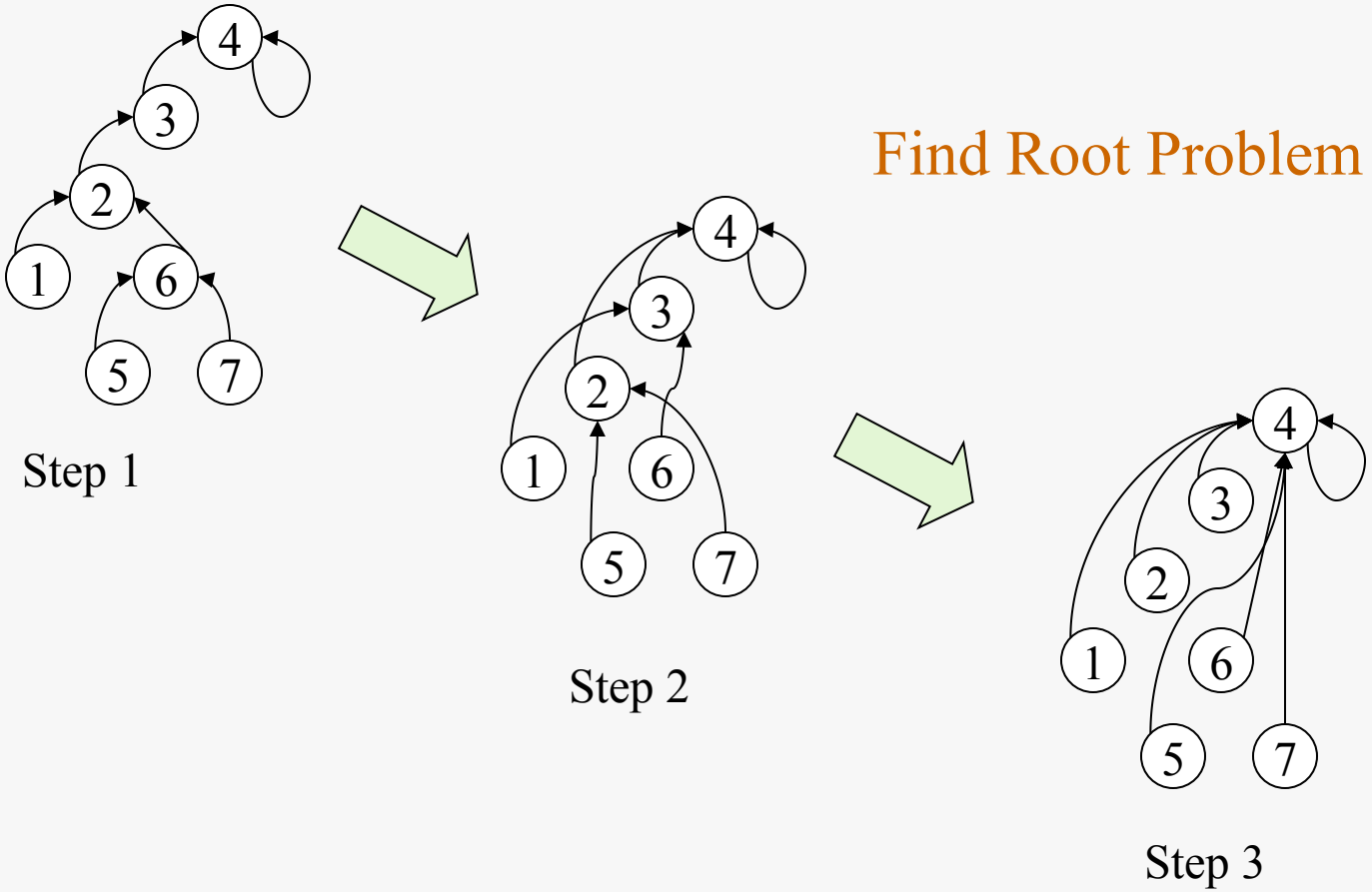
Pipeline

A series of ordered but independent computation stages need to be applied on data, where each output of a computation becomes input of subsequent computation.



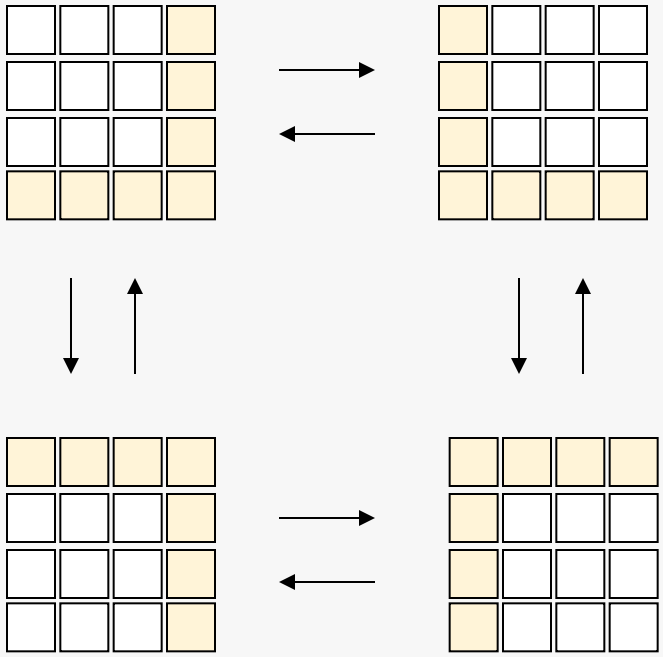
Recursive Data

Recursive data structures seem to have little exploitable concurrency.
But in some cases, the structure can be transformed.



Geometric

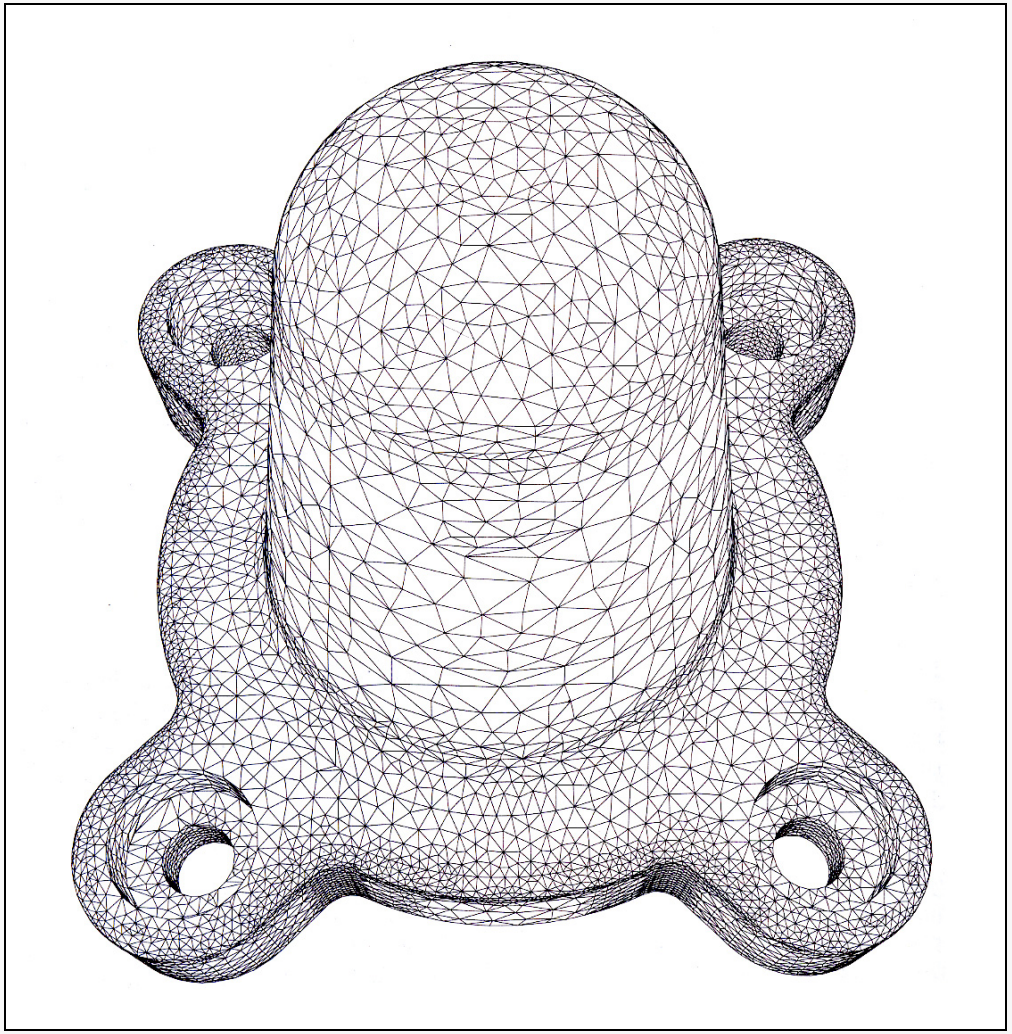
Dependencies exist, but communicate in predictable (geometric) neighbor-to-neighbor paths.



Neighbor-To-Neighbor communication

Irregular Mesh

Communication in non-predictable paths in mesh topology.



Hard to define due to varying communication patterns.

Start point :
Pattern that constructed this mesh.

Inseparable

- All other parallel patterns fails, and need explicit protection when dependent data elements are accessed.
  - i.e. mutual exclusion, producer-consumer.
- Very vague definition.

They all starts from

- Decomposing a sequential problem to expose concurrency.
- Data decomposition
  - Concurrency comes from working on different data elements simultaneously.
- Functional decomposition
  - Concurrency comes from working on independent functional tasks simultaneously.

It's Parallel Programming 101

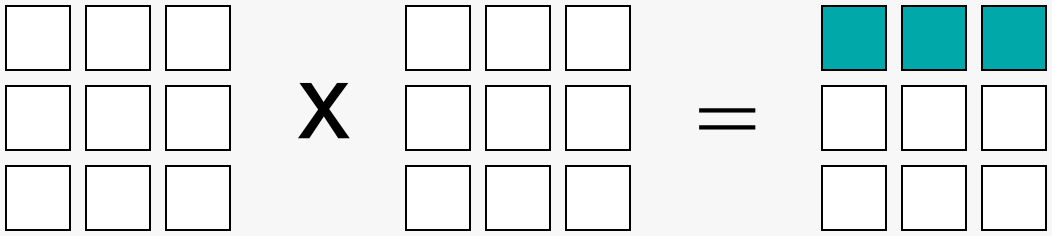
- Why can't we advance from here?
- Almost all of the patterns discussed are either intuitive, or covered in introductory courses.
- Do these patterns capture most of parallel programs today?
- Can these patterns be used to exploit full parallelism?

Why so trivial?

- Only two ways to decompose:
  - Data and Functional.
- Over-simplified just for
  - Intuitiveness & “natural representation”
  - Fitting the problem to “imperative language”
- By defining functional task:
  - We have chosen to reuse a variable.
  - It’s a conscious choice, and brings new constraint.
  - Removing this does not change the problem definition.

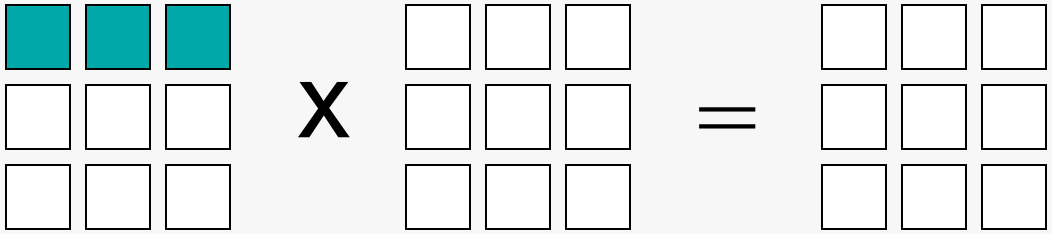
Same Effect

In many cases, different decomposition leads to same computation.



Owner-Compute

Implies / Equivalent to



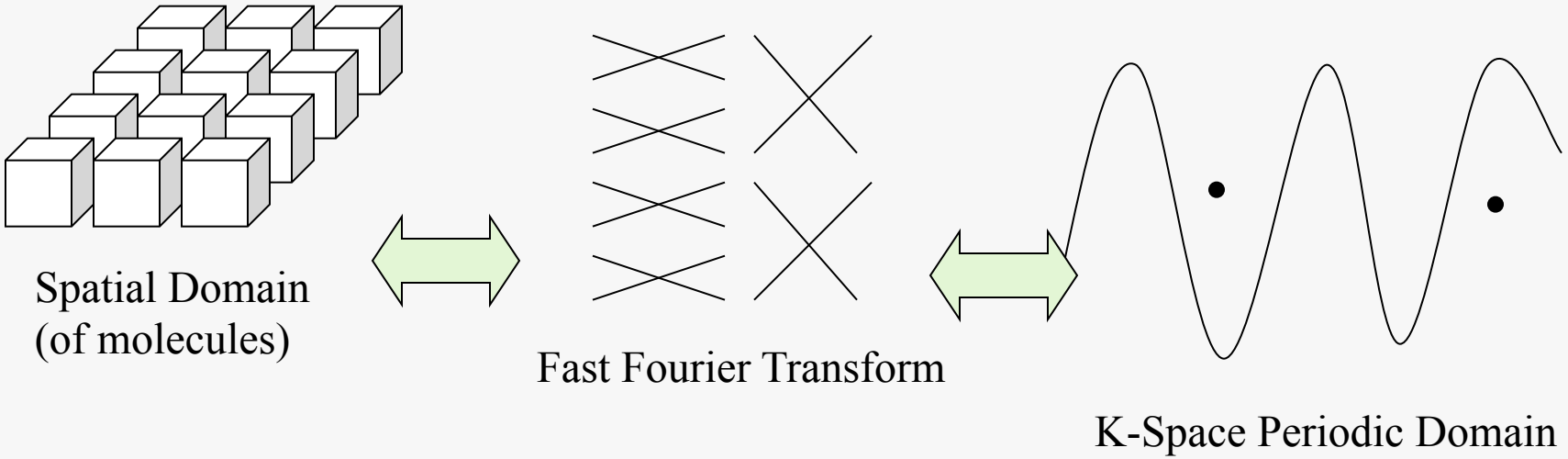
Row-major Decomposition

Exposing Better Parallelism

- Loosen the “natural representation”.
- Free the assumptions
  - Variable reuse
  - Thinking in terms of imperative language

Non-Trivial Parallelism I :Molecular Dynamics

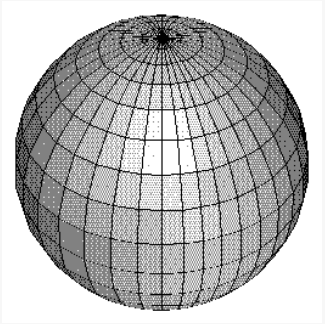
Repeated data of molecules can be processed better in periodic domain.
(but little bit harder to represent)



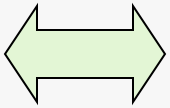
*Decomposition is done in two domains.
Spatial + Periodic

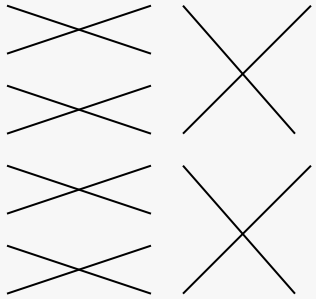
Non-Trivial Parallelism II : Climate Modeling

Physics equation called "Spectral Transform Method" needs spectral domain to work on.

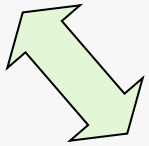


Spatial Domain
(2D/3D representation of sphere)





Fast Fourier Transform



$$\psi(\lambda,\mu) = \sum_{m=-M}^{M} \sum_{n=|m|}^{\mathcal{N}(m)} \psi_n^m P_n^m(\mu) e^{im\lambda},$$

Spectral Domain

Direction

- Capture fundamental decomposition in
  - Systematic
  - Constraint-Free Ways.
- Document more non-trivial patterns
- Map patterns to programming environments
- Structural Patterns

Any Questions?