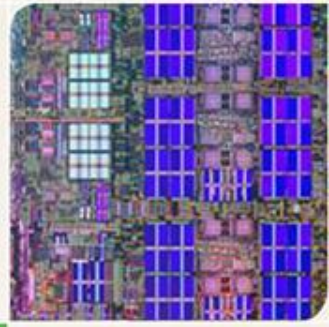
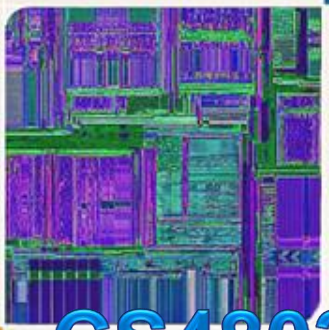





CS4803DGC Design and Programming of Game Console

Spring 2011

Prof. Hyesoon Kim

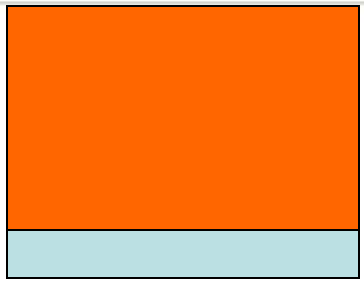
Georgia Tech College of Computing



Today's Goal

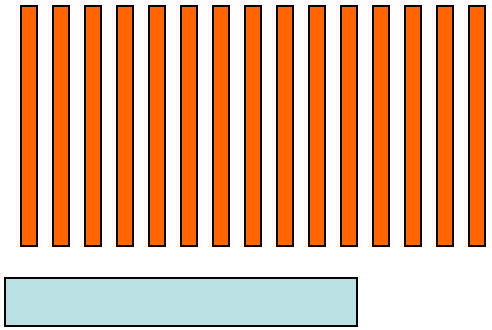
- Today, we will study typical patterns of parallel programming
- This is just one of the ways.
- Materials are based on a book by Timothy.

How to Create a Parallel Application:



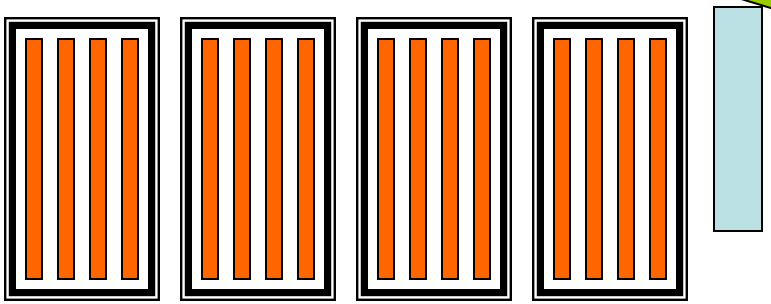
Original Problem

Decompose Into tasks



Tasks, shared and local data

Group into execution units.



Units of execution + new shared data for extracted dependencies

Code with a parallel program Env.

```
Program Thread n
Program Thread 1
{
….
  for (;;;) {
                    ….
}
}
```

Corresponding source code

Learning to “Think Parallel”: Design Patterns

- High quality solution to frequently recurring problem in some domain

- Learning design patterns makes the programmer to quickly understand the solution and its context.



Before Writing Parallel Programs

- Parallel programs often start as sequential programs
  - Easy to write and debug
  - Already developed/tested
- Identify program hot spots
- Parallelization
  - Start with hot spots first
  - Make sequences of small changes, each followed by testing
  - Patterns provide guidance



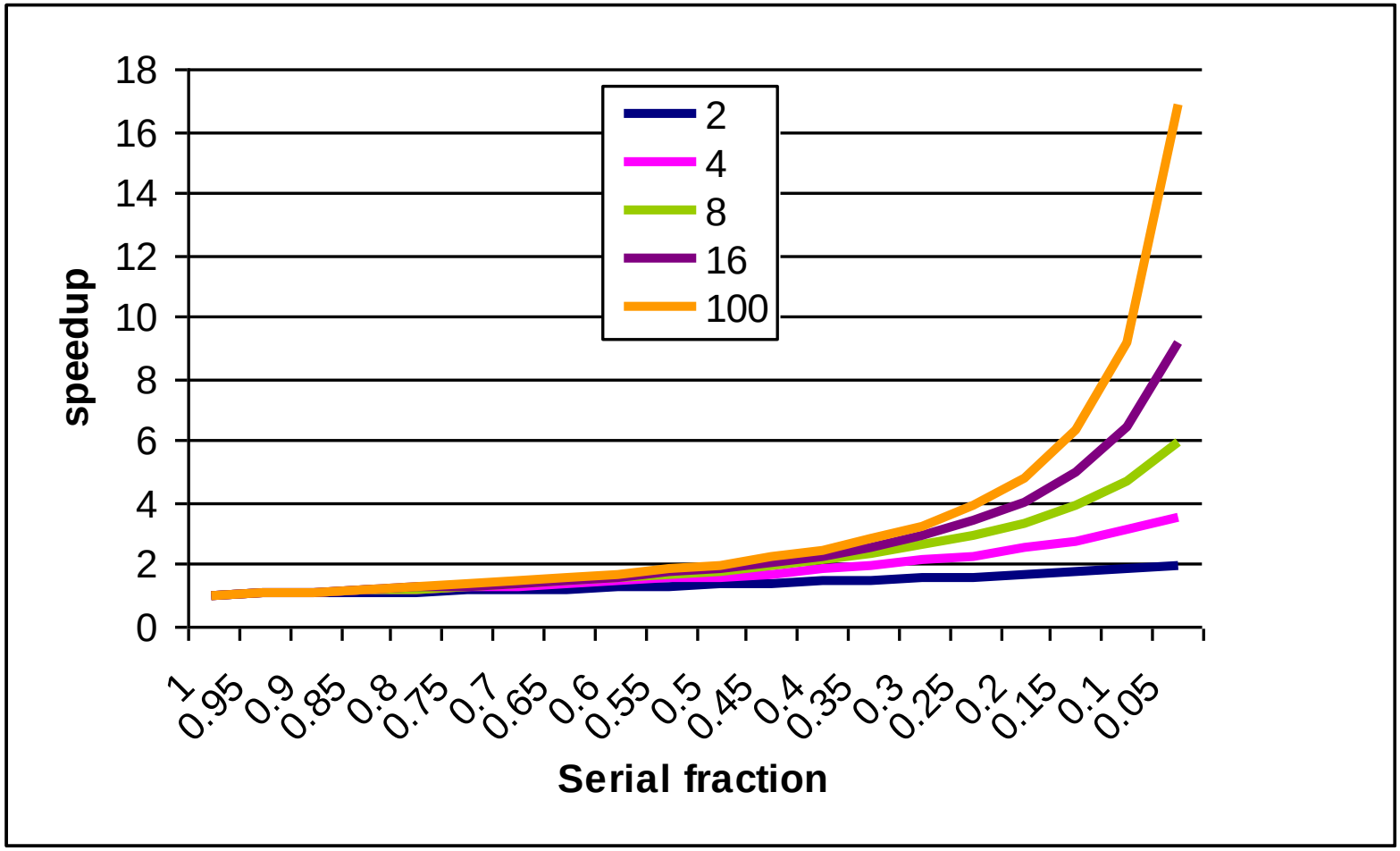
Amdahl's Law

- Speedup =

$$\frac{\text{Performance for entire task using the enhancement when possible}}{\text{Performance for entire task without using the enhancement}}$$

- Speedup = 1 / (P/N+S)
- P = parallel fraction (1-S)
- N = number of processors
- S = serial fraction

Amdahl's Law


18
16
14
12
10
8
6
4
2
0
speedup
2
4
8
16
100
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Serial fraction



Steps to Parallel Programming

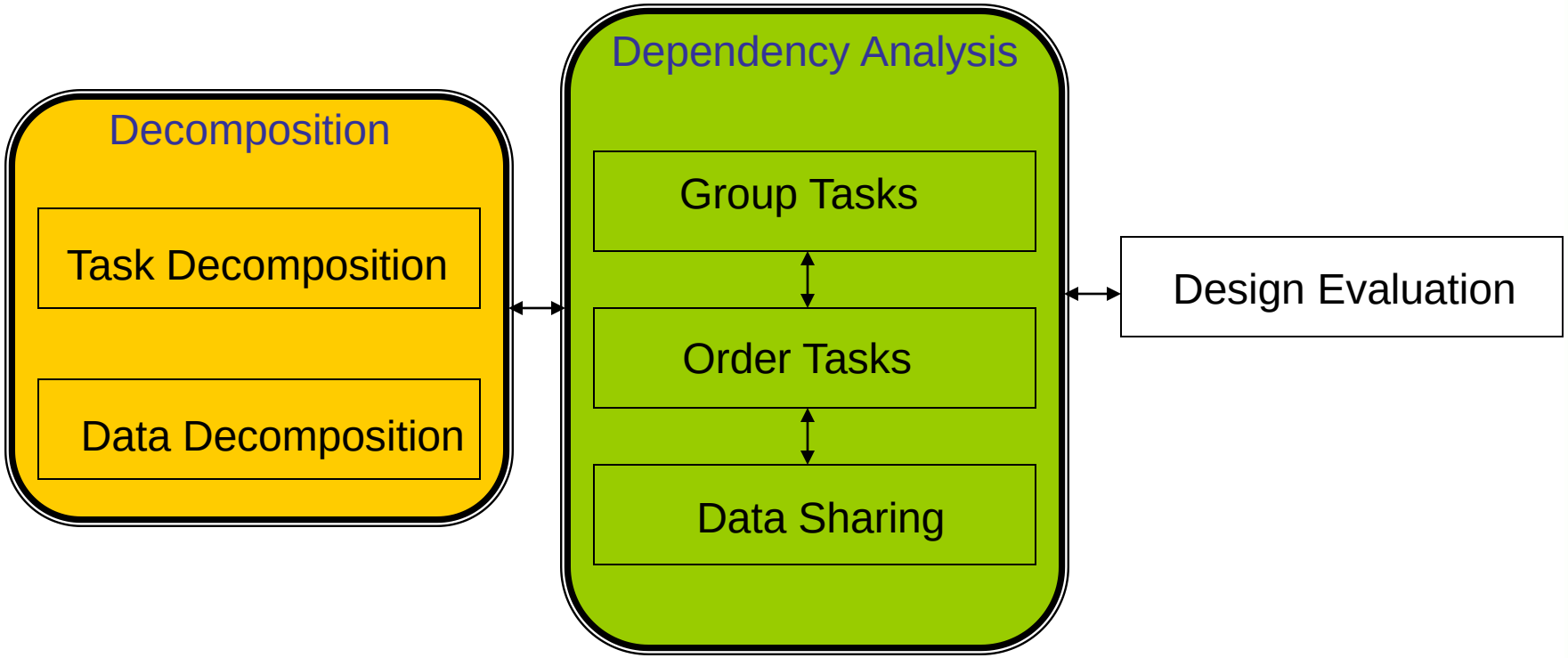
Step 1: Find concurrency

Step 2: Structure the algorithm so that concurrency can be exploited

Step 3 : Implement the algorithm in a suitable programming environment

Step 4: Execute and tune the performance of the code on a parallel system

Step 1: Finding Concurrency



Things to consider: Flexibility, Efficiency, Simplicity

Guidelines for Task Decomposition

- Flexibility
  - Program design should afford flexibility in the number and size of tasks generated
    - Tasks should not tie 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



Guidelines for Data Decomposition

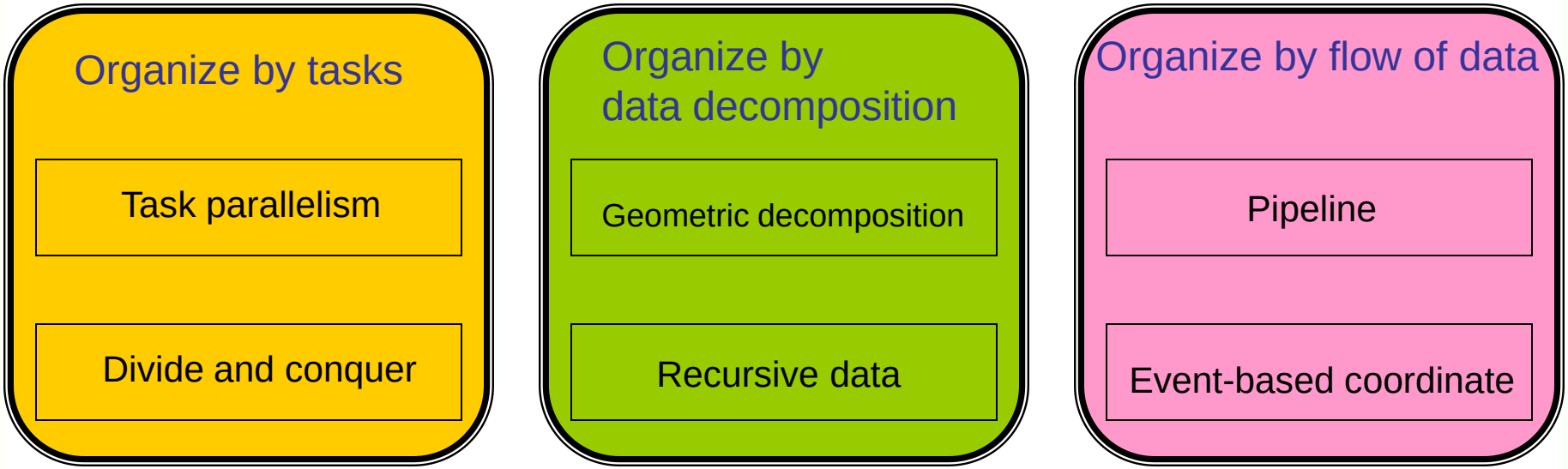
- Flexibility
  - Size and number of data chunks should support a wide range of executions
- Efficiency
  - Data chunks should generate comparable amounts of work (for load balancing)
- Simplicity
  - Complex data compositions can get difficult to manage and debug



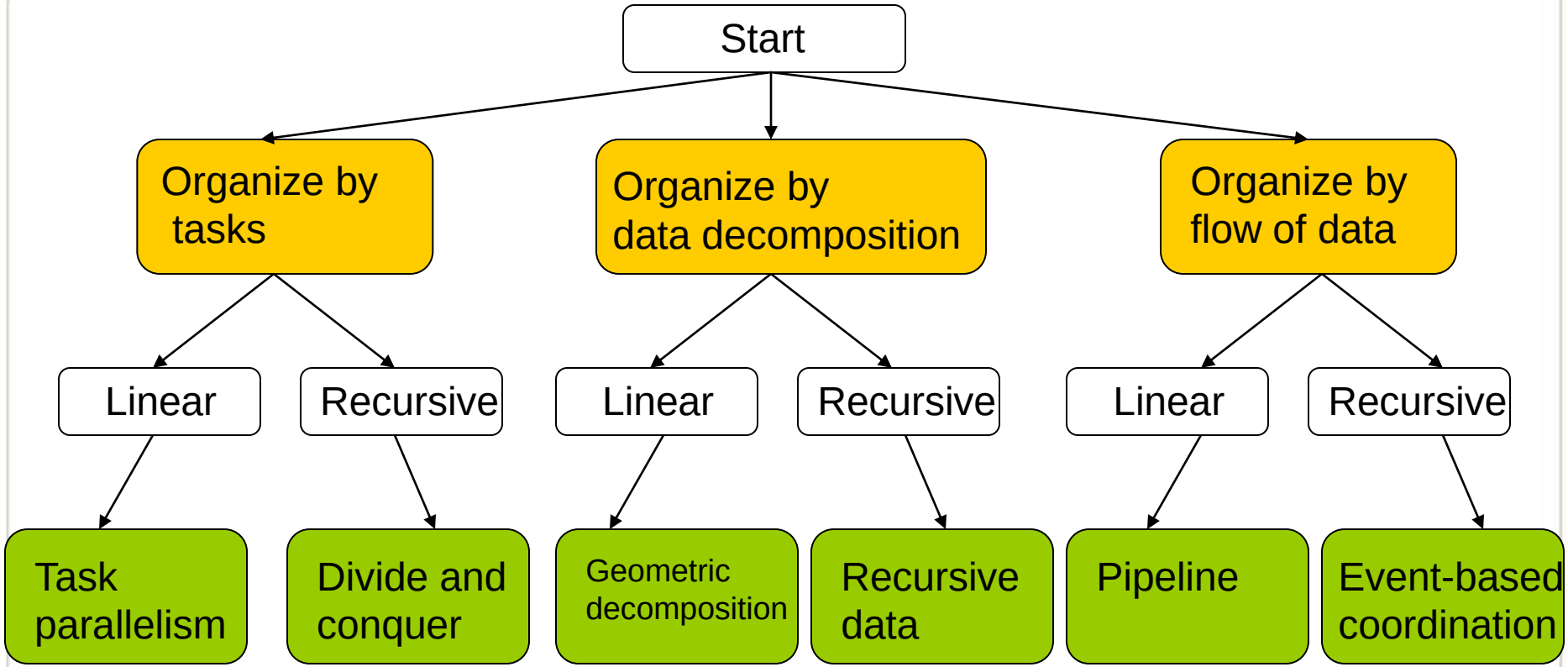
Common Data Decomposition

- Geometric data structures
  - Decomposition of arrays along rows, column, blocks
- Recursive data structures
  - Example: list, tree, graph

Step 2: Algorithm Structure



Algorithm Structure Design Space





Dependencies

- Removable dependencies

  Temporary variable

```
int ii = 0, jj = 0;
for (int i = 0; i < N; i++) {
      ii = ii + 1;
      d[ii] = big_time_consuming_work (ii);
      jj = jj + i;
      a[jj] = other_big_calc(jj);
}
```

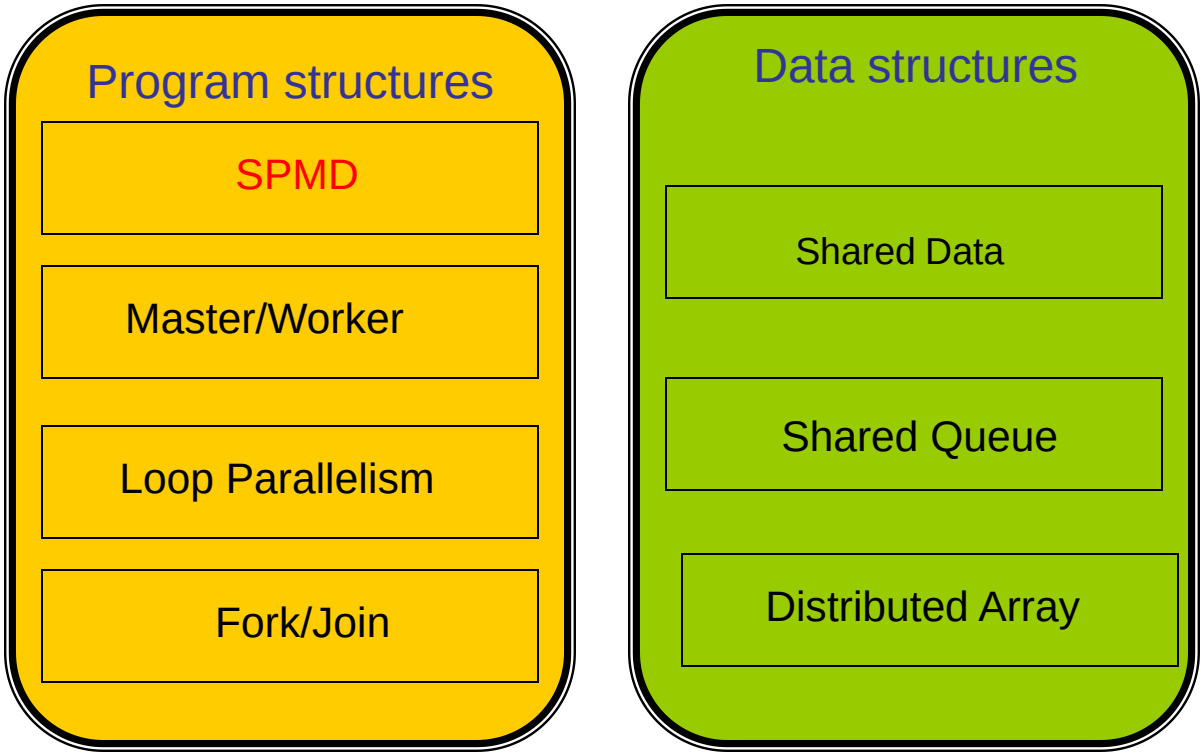
  -→ transformed code

```
For (int i =0; i < N; i++) {
d[i+1] = big_time_consuming_work(i+1);
a[(i*i+i)/2] = other_big_calc((i*i+i)/2));
```

- **Separable dependencies**

```
for (int i = 0; i < N; i++) {
sum = sum + f(i);
}
```

Supporting Structures



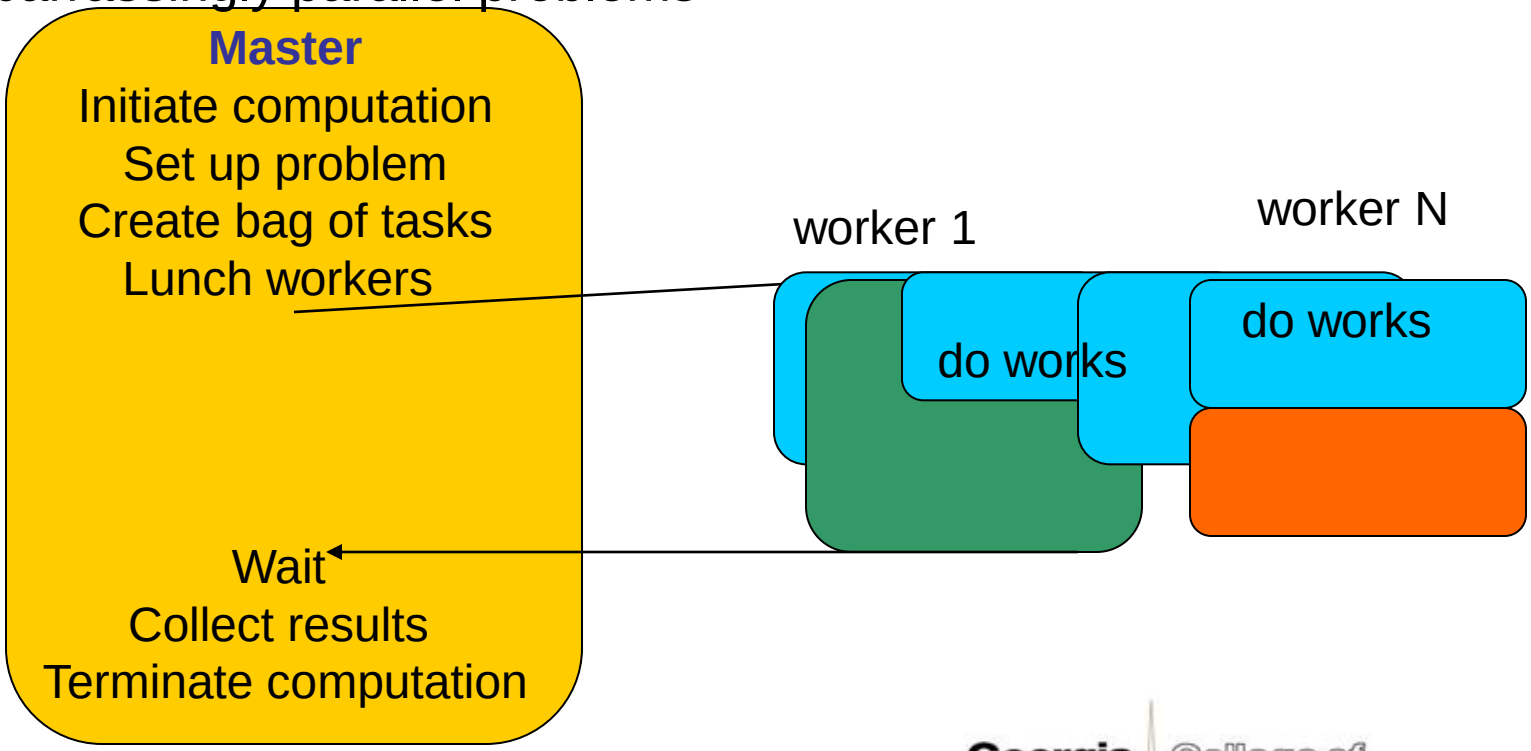


SPMD Pattern

- Single program, multiple data
- All UEs execute the same program in parallel, but each has its own set of data.
  - Initialize
  - Obtain a unique identifier
  - Run the same program each processor
  - Distributed data
  - Finalize
- CUDA

Master/Worker Pattern

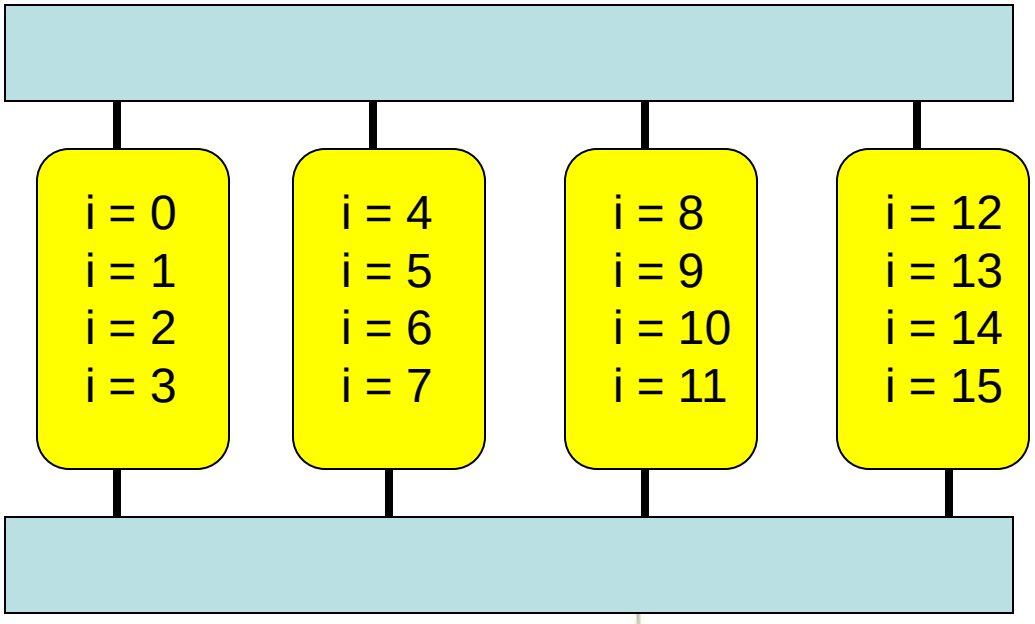
- A master process or thread set up a pool of worker processes of threads and a bag of tasks.
- The workers execute concurrently, with each worker repeatedly removing a tasks from the bag of the tasks.
- Embarrassingly parallel problems



Loop Parallelism Pattern

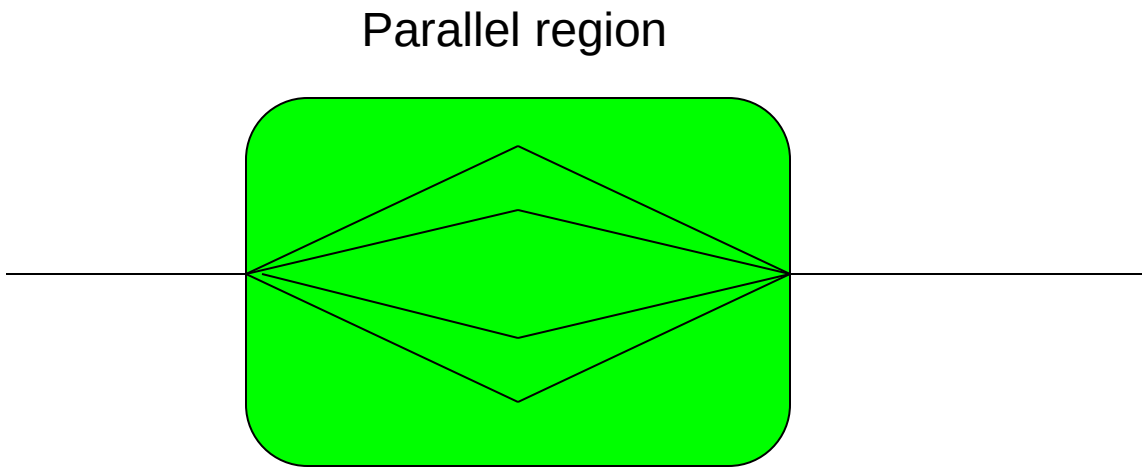
- Many programs are expressed using iterative constructs
  - Programming models like OpenMP provide directives to automatically assign loop iteration to execution units
  - Especially good when code cannot be massively restructured

```
#pragma omp parallel for
For (i = 0; i < 16; i++)
        c[i] = A[i]+B[I];
```



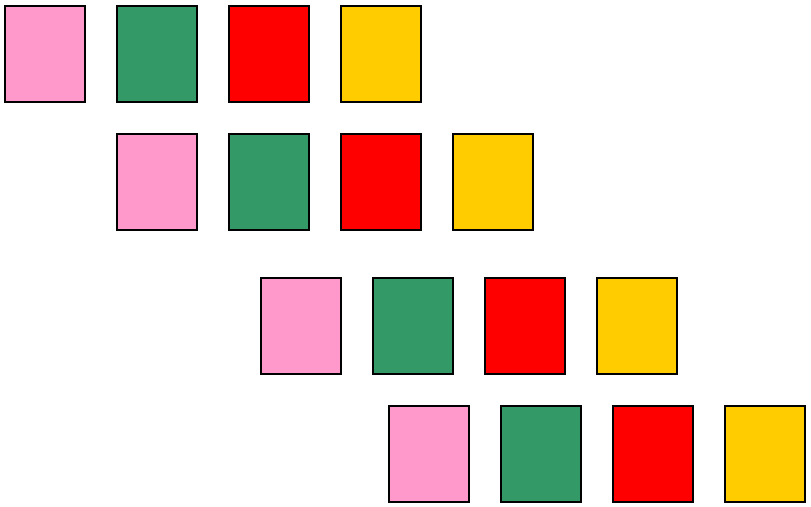
Fork/Join Pattern

- A main UE forks off some number of other UEs that then continue in parallel to accomplish some portion of the overall work.
- Parent tasks creates new task (fork) then waits until all they complete (join) before continuing on with the computation





Pipeline Pattern



- Examples:
  - Instruction pipeline in modern CPUs
  - Algorithm level pipelining
  - Signal processing
  - Graphics
  - Shell programs
  - Cat sampleFile | grep “word” | wc



Choosing the Patterns

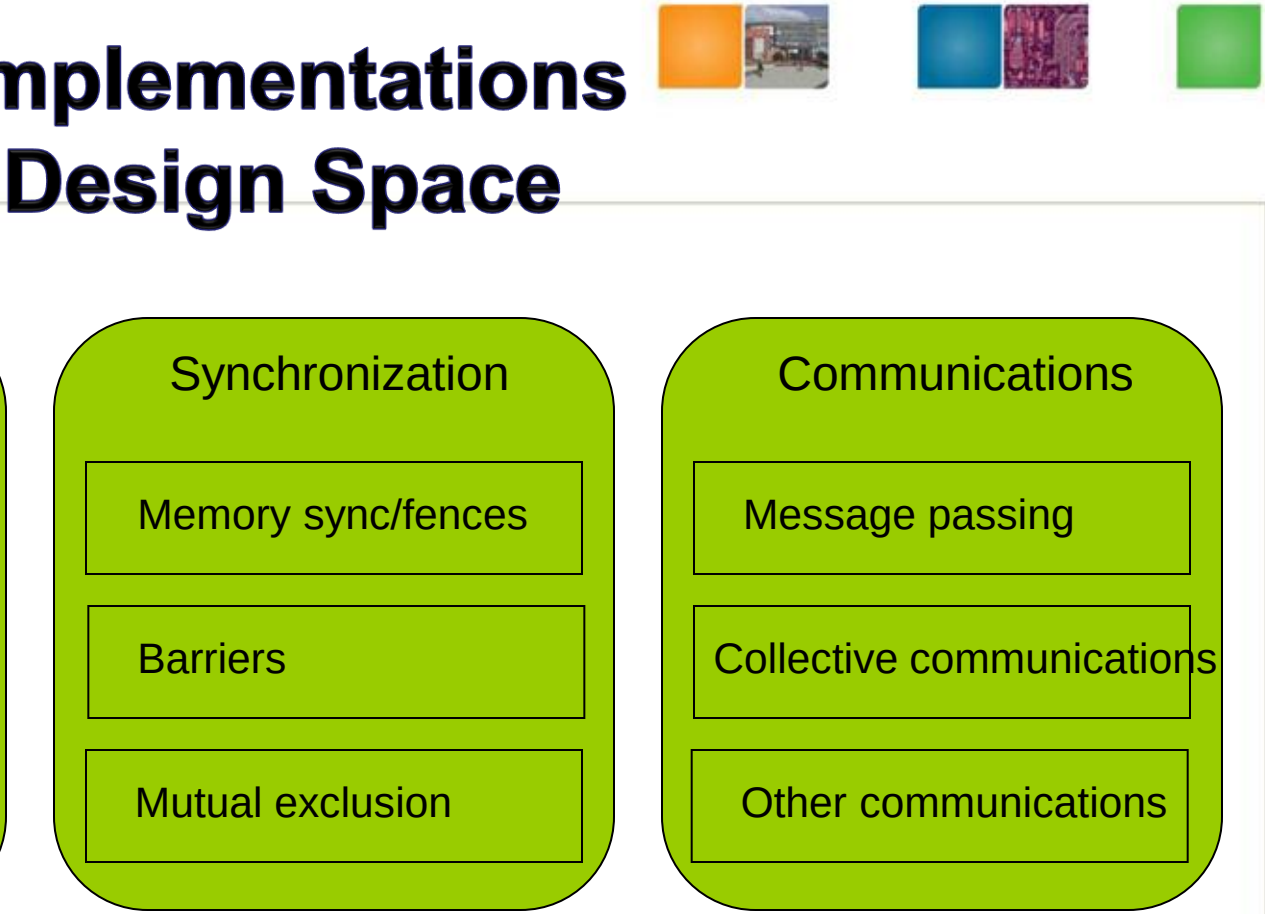
	Task Parallel.	Divide/ Conquer	Geometric Decomp.	Recursive Data	Pipeline	Event-based
SPMD	☺ ☺ ☺ ☺	☺ ☺ ☺	☺ ☺ ☺ ☺	☺ ☺	☺ ☺ ☺	☺ ☺
Loop Parallel	☺ ☺ ☺ ☺	☺ ☺	☺ ☺ ☺			
Master/Worker	☺ ☺ ☺ ☺	☺ ☺	☺	☺	☺	☺
Fork/ Join	☺ ☺	☺ ☺ ☺ ☺	☺ ☺		☺ ☺ ☺ ☺	☺ ☺ ☺ ☺

Supporting Structures Pattern vs. Programming Environment



	OpenMP	MPI	CUDA
SPMD	☺ ☺ ☺	☺ ☺ ☺ ☺	☺ ☺ ☺ ☺ ☺
Loop Parallel	☺ ☺ ☺ ☺	☺	
Master/ Slave	☺ ☺	☺ ☺ ☺	
Fork/Join	☺ ☺ ☺		

Step 3: The Implementations Mechanisms Design Space



- Program language
- Hardware



Jargon of Parallel Computing

- Task
- Unit of Execution (UE): process, thread
- Processing Element (PE)
- Load balance
- Synchronization
- Race conditions
- Dead locks
- Concurrency



Now Parallel programming!

- The lecture is just one guidelines.
- Most parallel programming is finding ways of avoiding data dependences, finding efficient data structures.
- Can compiler do it?
  - Automatic parallelization
  - Speculative parallelization?

Summer and Fall UROP/GRA (summer) Positions

- Paid/non-paid positions.
- Game developers for cloud game
  - Or any companies if you know, let me know
- Other research positions
  - Good programming skills.
  - Not related to games
- If you know other students, let me know.