CSCI-UA.0480-003

Parallel Computing

Lecture 4: Parallel Software: Basics

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The burden is on software

- From now on…
  - In shared memory programs:
    - Start a single process and fork threads.
    - Threads carry out tasks.
  - In distributed memory programs:
    - Start multiple processes.
    - Processes carry out tasks.

SPMD – single program multiple data

- A SPMD programs consists of a single executable that can behave as if it were multiple different programs through the use of conditional branches.

```
if (I'm thread process i)
    do this;
else
    do that;
```

Writing Parallel Programs

1. Divide the work among the processes/threads
   (a) so each process/thread gets roughly the same amount of work
   (b) and communication is minimized.
2. Arrange for the processes/threads to synchronize.
3. Arrange for communication among processes/threads.

```
double x[n], y[n];
…
for (i = 0; i < n; i++)
    x[i] += y[i];
```

Shared Memory Systems

Shared Memory

- **Dynamic threads**
  - Master thread waits for work, forks new threads, and when threads are done, they terminate
  - \+ Efficient use of resources
  - \- thread creation and termination is time consuming
- **Static threads**
  - Pool of threads created and are allocated work, but do not terminate until cleanup.
  - \+ Better performance
  - \- potential waste of system resources

Nondeterminism

```
. . .
printf ( "Thread %d > my_val = %d\n" ,
         my_rank , my_x ) ;
. . .
```

Thread 1 > my_val = 19

Thread 0 > my_val = 7

Thread 0 > my_val = 7

Thread 1 > my_val = 19

Nondeterminism

- Race condition
- Critical section
- Mutually exclusive
- Mutual exclusion lock (mutex, semaphore, …)

```
my_val = Compute_val ( my_rank ) ;
Lock(&add_my_val_lock ) ;
x += my_val ;
Unlock(&add_my_val_lock ) ;
```

Important!!

What is the relationship between cache coherence and nondeterminism?
Isn't cache coherence enough to ensure determinism?

Busy-waiting

```
my_val = Compute_val ( my_rank ) ;
if ( my_rank == 1)
    while ( ! ok_for_1 ) ;  /* Busy−wait loop */
x += my_val ;  /* Critical section */
if ( my_rank == 0)
    ok_for_1 = true ;  /* Let thread 1 update x */
```

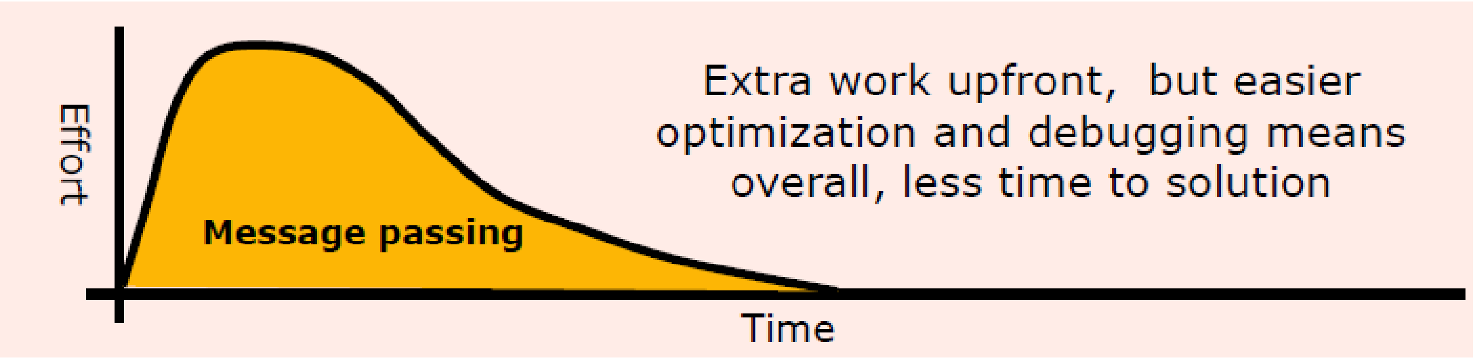
What is wrong with that?

Distributed Memory Systems

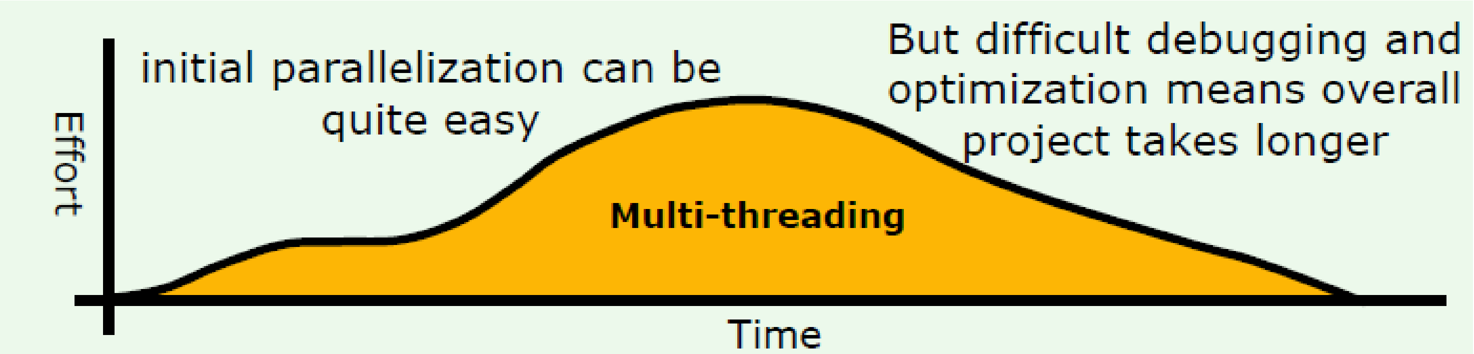
Distributed Memory: message-passing

```
char message [100] ;
. . .
my_rank = Get_rank();
i f ( my_rank == 1) {
    sprintf ( message , "Greetings from process 1" ) ;
    Send ( message , MSG_CHAR , 100 , 0 ) ;
} else if ( my_rank == 0) {
    Receive ( message , MSG_CHAR , 100 , 1 ) ;
    printf ( "Process 0 > Received: %s\n" , message ) ;
}
```

How do shared-memory and distributed-memory compare in terms of programmer's effort?



Distributed Memory



Shared Memory

Source: "Many Core Processors … Opportunities and Challenges" by Tim Mattson

We want to write a parallel program … Now what?

- We have a serial program.
- How to parallelize it?
- We know that we need to divide work, ensure load balancing, manage synchronization, and reduce communication! → Nice! How to do that?
- Unfortunately: there is no mechanical process.
- **Ian Foster** has some nice framework.

Foster's methodology
(The PCAM Methodology)

1. Partitioning: divide the computation to be performed and the data operated on by the computation into small tasks.

   The focus here should be on identifying tasks that can be executed in parallel.

   This step brings out the parallelism in the algorithm

Foster's methodology (The PCAM Methodology)

2. Communication: determine what communication needs to be carried out among the tasks identified in the previous step.

Foster's methodology (The PCAM Methodology)

3. Agglomeration or aggregation: combine tasks and communications identified in the first step into larger tasks.

   For example, if task A must be executed before task B can be executed, it may make sense to aggregate them into a single composite task.

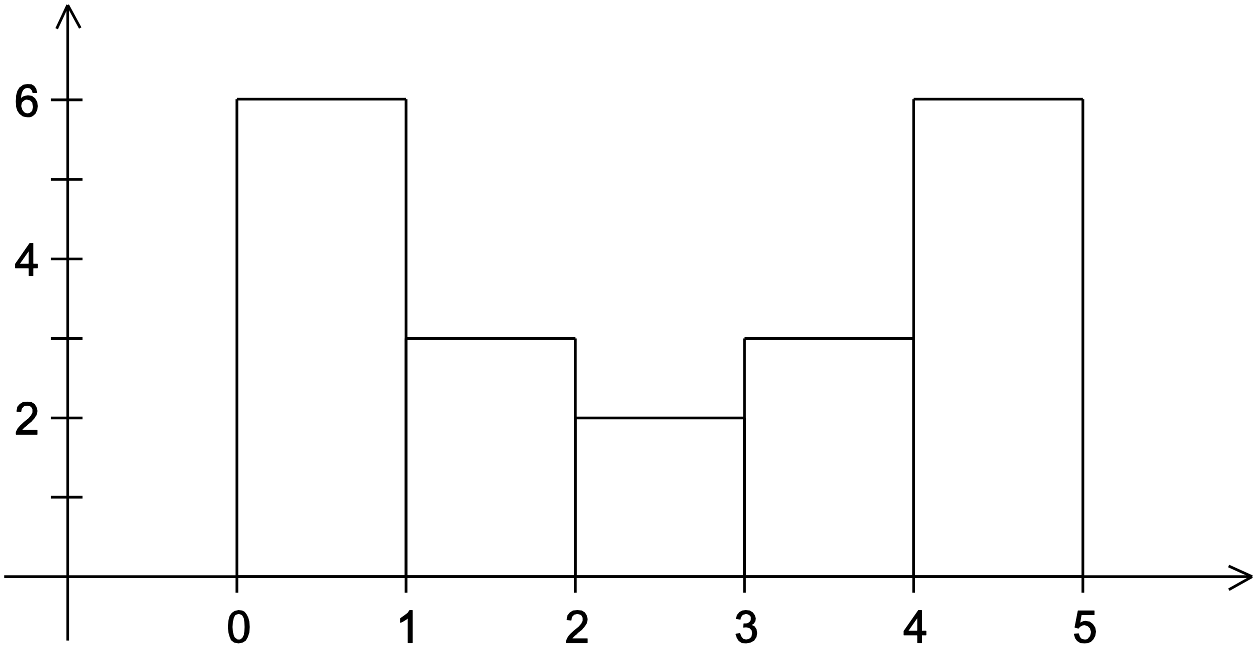
Foster's methodology (The PCAM Methodology)

4. Mapping: assign the composite tasks identified in the previous step to processes/threads.

   This should be done so that communication is minimized, and each process/thread gets roughly the same amount of work.

Example - histogram

- 1.3,2.9,0.4,0.3,1.3,4.4,1.7,0.4,3.2,0.3,4.9,
2.4,3.1,4.4,3.9,0.4,4.2,4.5,4.9,0.9



Serial program - input

1. The number of measurements: data_count
2. An array of data_count floats: data
3. The minimum value for the bin containing the smallest values: min_meas
4. The maximum value for the bin containing the largest values: max_meas
5. The number of bins: bin_count

- Data[0] = 1.3
- Data[1] = 2.9
- Data[2] = 0.4
- Data[3] = 0.3
- Data[4] = 1.3
- Data[5] = 4.4
- Data[6] = 1.7
- Data[7] = 0.4
- Data[8] = 3.2
- Data[9] = 0.3
- Data[10] = 4.9
- Data[11] = 2.4
- Data[12] = 3.1
- Data[13] = 4.4
- Data[14] = 3.9,
- Data[15] = 0.4
- Data[16] = 4.2
- Data[17] = 4.5
- Data[18] = 4.9
- Data[19] = 0.9

data_count = 20

- Data[0] = 1.3
- Data[1] = 2.9
- Data[2] = 0.4
- Data[3] = 0.3
- Data[4] = 1.3
- Data[5] = 4.4
- Data[6] = 1.7
- Data[7] = 0.4
- Data[8] = 3.2
- Data[9] = 0.3
- Data[10] = 4.9
- Data[11] = 2.4
- Data[12] = 3.1
- Data[13] = 4.4
- Data[14] = 3.9,
- Data[15] = 0.4
- Data[16] = 4.2
- Data[17] = 4.5
- Data[18] = 4.9
- Data[19] = 0.9

data_count = 20

min_meas = 0.3

max_meas = 4.9

bin_count = 5

Serial program - output

1. bin_maxes : an array of bin_count floats → store the upper bound of each bin

2. bin_counts : an array of bin_count ints → stores the number of elements in each bin

- Data[0] = 1.3
- Data[1] = 2.9
- Data[2] = 0.4
- Data[3] = 0.3
- Data[4] = 1.3
- Data[5] = 4.4
- Data[6] = 1.7
- Data[7] = 0.4
- Data[8] = 3.2
- Data[9] = 0.3
- Data[10] = 4.9
- Data[11] = 2.4
- Data[12] = 3.1
- Data[13] = 4.4
- Data[14] = 3.9,
- Data[15] = 0.4
- Data[16] = 4.2
- Data[17] = 4.5
- Data[18] = 4.9
- Data[19] = 0.9

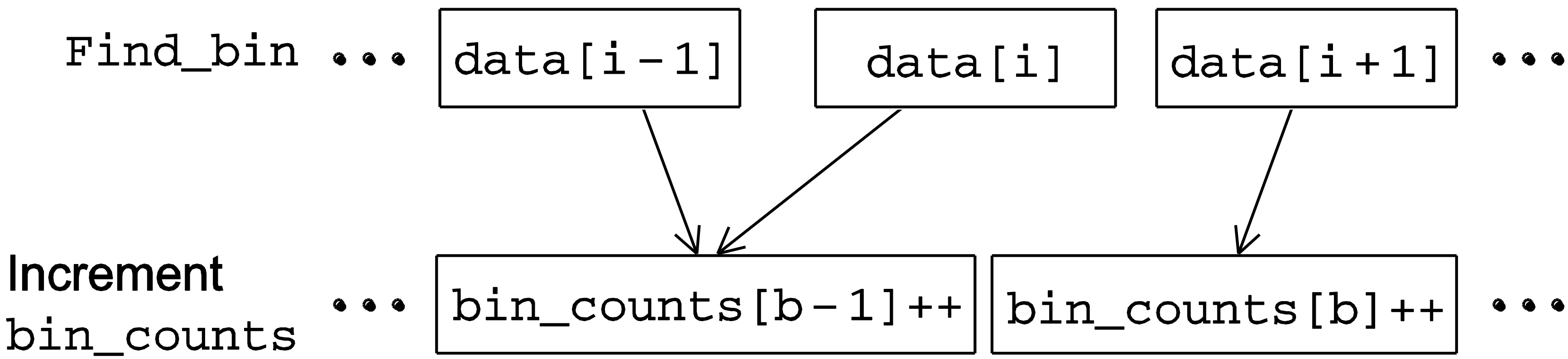
bin_maxes[0] = 0.9
bin_maxes[1] = 1.7
bin_maxes[2] = 2.9
bin_maxes[3] = 3.9
bin_maxes[4] = 4.9

bin_counts[0] = 6
bin_counts[1] = 3
bin_counts[2] = 2
bin_counts[3] = 3
bin_counts[4] = 6

Serial Program

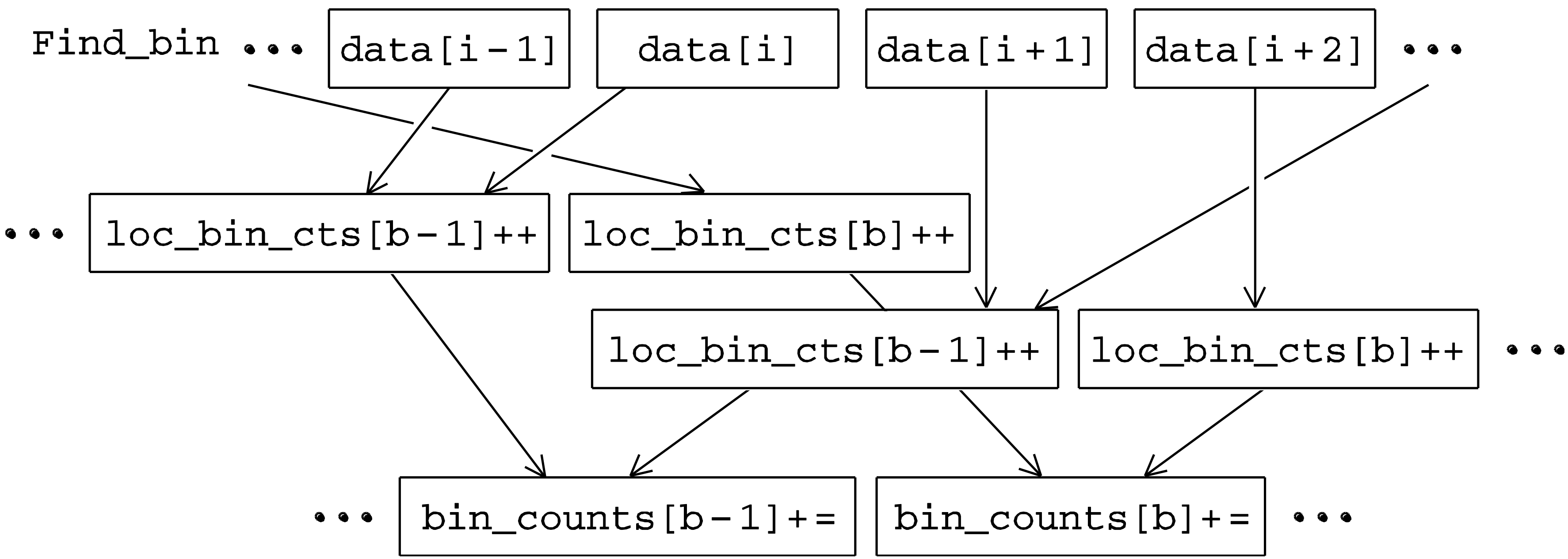
```
int bin = 0;
for( i = 0; i < data_count; i++){
  bin = find_bin(data[i], ...);
  bin_counts[bin]++;
}
```

First two stages of Foster's Methodology

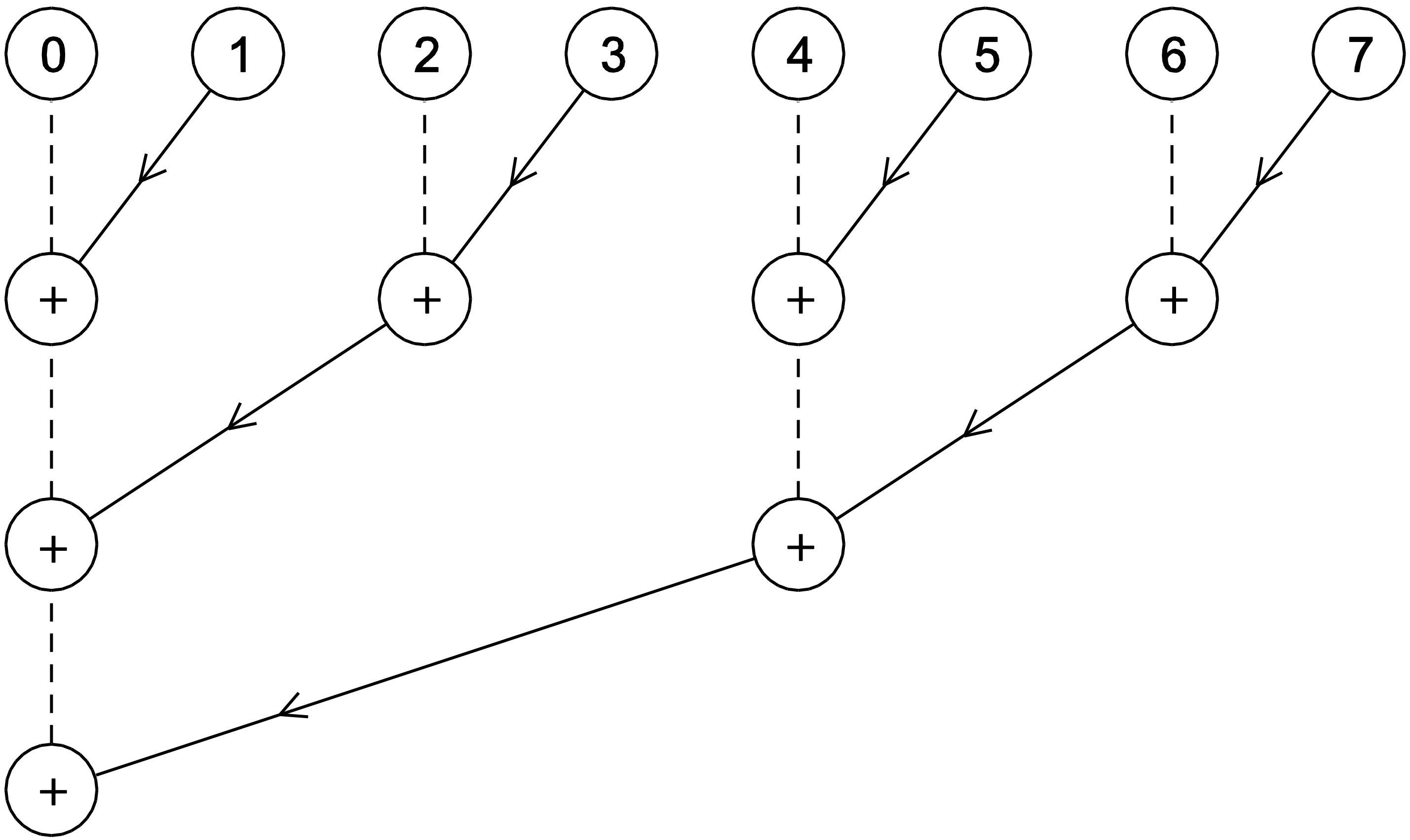


Find_bin returns the bin that data[i] belongs to.

Alternative definition of tasks and communication



Adding the local arrays



Conclusions

- Parallel software
  - We focus on software for homogeneous MIMD systems, consisting of a single program that obtains parallelism by branching.
  - Later we will look at GPUs
- Parallel Program Design
  - Partition
  - Determine communication
  - Aggregate (if needed)
  - Map