Jon Dis 8 Notes

CS 61C Fall 2018

Parallelism, SDS

Discussion 9: October 22, 2018

1 Thread-Level Parallelism

As powerful as data level parallelization is, it can be quite inflexible, as not all applications have data that can be vectorized. Multithreading, or running a single piece of software on multiple hardware threads, is much more powerful and versatile. OpenMP provides an easy interface for using multithreading within C programs. Some examples of OpenMP directives:

The `parallel` directive indicates that each thread should run a copy of the code within the block. If a for loop is put within the block, **every** thread will run every iteration of the for loop.

```
#pragma omp parallel {
    ...
}
```

The `parallel for` directive will split up iterations of a for loop over various threads. Every thread will run **different** iterations of the for loop. The following two code snippets are equivalent.

```
#pragma omp parallel for
for (int i = 0; i < n; i++) {
    ...
}
```

```
#pragma omp parallel {
#pragma omp for
    for (int i =0; i < n; i++) { ... }
}
```

There are two functions you can call that may be useful to you:

- `int omp_get_thread_num()` will return the number of the thread executing the code
- `int omp_get_num_threads()` will return the number of total hardware threads executing the code

1.1 For each question below, state and justify whether the program is **sometimes incorrect**, **always incorrect**, **slower than serial**, **faster than serial**, or **none of the above**. Assume the default number of threads is greater than 1. Assume no thread will complete before another thread starts executing. Assume `arr` is an `int[]` of length `n`.

(a)
```
// Set element i of arr to i
#pragma omp parallel
{
    for (int i = 0; i < n; i++)
        arr[i] = i;
}
```

slower
all threads run parallel section

← fair assumption

(for $n \geq 4$)

Why 4?

0, 1 already done → 2 will be correct but 3 won't be

(b)

```
// Set arr to be an array of Fibonacci numbers.
arr[0] = 0;
arr[1] = 1;
#pragma omp parallel for
for (int i = 2; i < n; i++)
    arr[i] = arr[i-1] + arr[i - 2];
```

Always incorrect

Assumption 2: no thread finishes before another starts ⇒ other threads read wrong value.

(c)

```
// Set all elements in arr to 0;
int i;
#pragma omp parallel for
for (i = 0; i < n; i++)
    arr[i] = 0;
```

Faster than serial

- for directive, work can be split up. Yay!

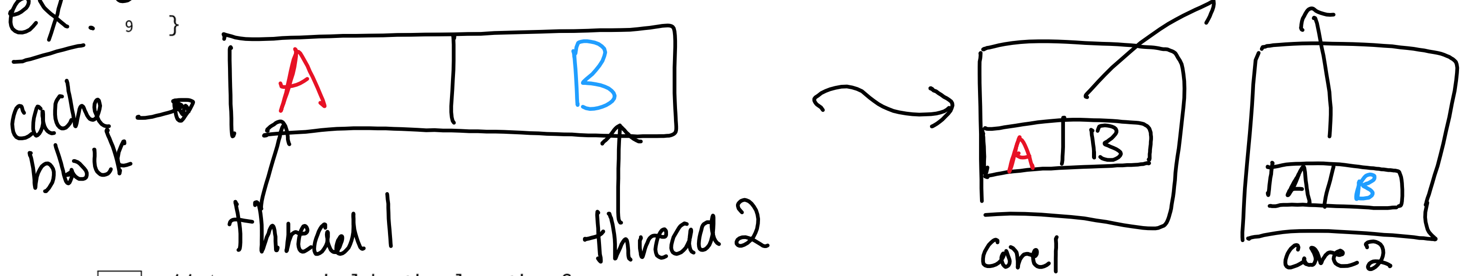
1.2 What potential issue can arise from this code?

```
// Decrements element i of arr. n is a multiple of omp_get_num_threads()
#pragma omp parallel
{
int threadCount = omp_get_num_threads();
int myThread = omp_get_thread_num();
for (int i = 0; i < n; i++) {
    if (i % threadCount == myThread) arr[i] *= arr[i];
    }
}
```

False Sharing

- think we share data → ping pong invalidation (bad performance)

false sharing ex.



1.3

```
// Assume n holds the length of arr
double fast_product(double *arr, int n) {
    double product = 1;
    #pragma omp parallel for
    for (i = 0; i < n; i++) {
        product *= arr[n];
    }
    return product;
}
```

#pragma omp parallel for reduction(*:product)

#pragma omp critical

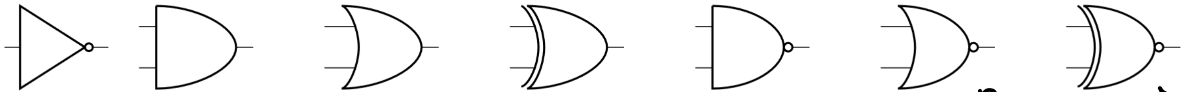
(a) What is wrong with this code? product is shared & not in critical section.

(b) Fix the code using **#pragma** omp critical

(c) Fix the code using **#pragma** omp reduction(operation: var).

2 Logic Gates

2.1 Label the following logic gates:



NOT AND OR XOR NAND NOR XNOR

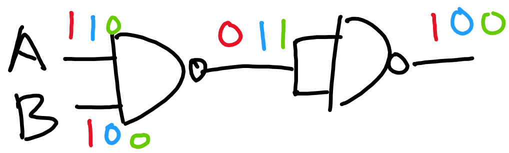
2.2 Convert the following to boolean expressions:

(a) NAND $\bar{A}\bar{B} + \bar{A}B + A\bar{B}$ (AND is AB, NAND is opposite)

(b) XOR $\bar{A}B + A\bar{B}$

(c) XNOR $\bar{A}\bar{B} + AA$ (XOR is $\bar{A}B + A\bar{B}$, XNOR is opposite)

2.3 Create an AND gate using only NAND gates.



A	B	Out
1	1	1
1	0	0
0	1	0
0	0	0

Consistent w/ AND!

2.4 How many different two-input logic gates can there be? How many n-input logic gates?

2^n rows for n inputs.

each input has a 0 or 1

$\underbrace{\text{function as a } 2^n \text{ bit number}}_{\text{maps the } 2^n \text{ rows to things}} \Rightarrow 2^{2^n}$ funcs

if $n=2 \Rightarrow 2^{2^2} = 16$