What is Parallel Programming about?

• The simple notion that 2 heads are better than one.
• In computing terms, 2 CPUs are better than one
• That's really the basic idea
- Find out how to share the work
- Offload parts of the work to different CPUs/GPUs. Nothing more complex than that.

An intelligent solution

• Instead of designing and building faster microprocessors, put multiple processors on a single integrated circuit.
- Microprocessor: is a type of CPU, that is compact and the integrated version designed to perform the functions of a CPU on a SINGLE chip or silicon (IC).
    - Modern day CPU's that we know of
- IC: single integrated circuit

What is serial programming? (diff from parallel prog.)

- Serial programs: execute instructions sequentially, one after the other. This means that at any given moment, the program is executing a single operation before moving on to the next.
    - Serial programs don't benefit from parallel programming (for the most part)

Things that parallel programming can help in:

- Climate modeling, protein folding, drug discovery, energy research, data analysis, etc..
    - These are all things that require ever-increasing performance which can be done possible by techniques such as parallel programing.

Parallelism:

- Move away from single core systems to multicore processors
    - Core = central processing unit (CPU)

Approaches to the serial problem:

- Rewrite serial programs so that they are parallel
- Write translation programs that automatically convert serial programs into parallel programs.
    - Very difficult to do
    - Success has been little

Example of Serial vs Parallel solutions: compute n values and add them together

- Serial:

```
sum = 0;
for (i = 0; i < n; i++) {
    x = Compute_next_value(. . .);
    sum += x;
}
```

Notes:
- This will simply add to the sum after computing the value in steps starting from i all the way to n
    - STEPS

- Parallel:

— all cores perform this

```
my_sum = 0;
my_first_i = . . . ;
my_last_i = . . . ;
for (my_i = my_first_i; my_i < my_last_i; my_i++) {
    my_x = Compute_next_value( . . .);
    my_sum += my_x;
}
```

Each core uses it's own private variables and executes this block of code independently of the other cores.

Example (cont.)

• After each core completes execution of the code, is a private variable my_sum contains the sum of the values computed by its

Notes:
- We have p cores
    - P is much smaller than n
        - Because of this, each core performs a partial sum of approximately n/p values
            - Partial sum meaning:

$$\sum_{i=0}^{4} i + \sum_{i=5}^{10} + \sum_{i=11}^{17} + \dots$$

- Each summation represents a core
- Explaining the example:
    - Each core starts with a sum of 0 and it handles a certain range from my_first_i to my_last_i and it computes the sum of that

Example (cont.)

- After each core completes execution of the code, is a private variable my_sum contains the sum of the values computed by its calls to Compute_next_value.
- Ex., 8 cores, n = 24, then the calls to Compute_next_value return:

1,4,3, 9,2,8, 5,1,1, 5,2,7, 2,5,0, 4,1,8, 6,5,1, 2,3,9

- Explaining the example:
  - Each core starts with a sum of 0 and it handles a certain range from my_first_i to my_last_i and it computes the sum of that range
    - All the cores together will handle up to n

- Once all the cores are done computing their private my_sum, they form a global sum by sending results to a designated "master" core which adds the final result.

```
if (I'm the master core) {
   sum = my_x;
   for each core other than myself {
      receive value from core;
      sum += value;
   }
} else {
   send my_x to the master;
}
```

Notes:
- The master core will handle adding up all of the sums found from the cores

Example (cont.)

first example

Core	0	1	2	3	4	5	6	7
my_sum	8	19	7	15	7	13	12	14

- Global sum
  8 + 19 + 7 + 15 + 7 + 13 + 12 + 14 = 95

Core	0	1	2	3	4	5	6	7
my_sum	95	19	7	15	7	13	12	14

But wait!

There's a much better way to compute the global sum.

Second example

Better parallel algorithm

- Don't make the master core do all the work.
- Share it among the other cores.
- Pair the cores so that core 0 adds its result with core 1's result.
- Core 2 adds its result with core 3's result, etc.
- Work with odd and even numbered pairs of cores.

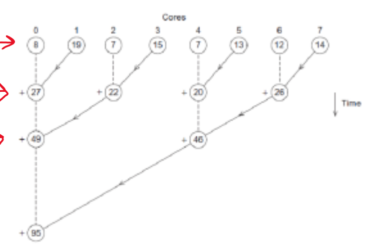
Better parallel algorithm (cont.)

- Repeat the process now with only the evenly ranked cores.
- Core 0 adds result from core 2.
- Core 4 adds the result from core 6, etc.

- Now cores divisible by 4 repeat the process, and so forth, until core 0 has the final result.

Notes:

Multiple cores forming a global sum



Analysis

- In the first example, the master core performs 7 receives and 7 additions.
- In the second example, the master core performs 3 receives and 3 additions.
- The improvement is more than a factor of 2!

Notes:

Analysis (cont.)

- The difference is more dramatic with a larger number of cores.
- If we have 1000 cores:
  - The first example would require the master to perform 999 receives and 999 additions.
  - The second example would only require 10 receives and 10 additions.
- That's an improvement of almost a factor of 100!