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Introduction to OpenMP

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Open Multi-Processing

- OpenMP is almost as storied as MPI
  - Version 1.0 was published in 1997
- It occupies a similar position as a *de facto* standard tool for scientific number crunching
- It targets shared-memory systems
  - MPI's unit of parallelism is the process
  - OpenMP's unit of parallelism is the thread
- You can think of it as a more convenient way to handle pthreads
  - It's not *obliged* to be implemented using pthreads, but it very often is
  - It doesn't *only* encompass threads, but that is by far its most common use

What's in a name?

- Many moons ago, a major MPI implementation called LAM/MPI merged with two less prominent ones
- A new name was required after the merger, so they settled on…
  "OpenMPI"
  - ****sigh****
  - I think they should have chosen a different name, but here we are
- OpenMPI is one out of many MPI implementations
- **<u>OpenMP</u>** is an entirely different programming model, with its own specifications document
  - Various implementations of this interface emerge and disappear...
  - So it goes.

Parts of the puzzle

- As we've seen
  - MPI is a separate 3rd party library of functions that you install in addition to your compiler
  - Pthreads are provided by the operating system, the function declarations come with the compiler
- OpenMP is a little bit of both
  - Its core is a set of language extensions that must be supported by the compiler
  - It also has a runtime library of functions that you can call to inspect the state of what the compiler has generated

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Language extensions?

- Yes; C has a standardized way to do nonstandard things, so to speak
- The `#pragma` directive can be followed by some text that the compiler will discover during its initial scan of the program code
  - If it understands the text, it can insert appropriate code to replace the directive with
  - If it doesn't understand the text, the compiler is free to discard it
- This way, compilers can support optional features in the code that
  - Work when you use a compiler that supports them
  - Don't break the program even if you use a compiler that doesn't support them

A hypotetical example

- #pragma can ask for literally anything:

```
#include <stdio.h>
int main() {
    printf ( “Hello, world!\n” );
    #pragma play me a song
    return 0;
}
```

- You can compile this code without issue (try it at home)
  - My compiler only makes the usual hello-world binary without any special effects
  - It still reads the command
  - It just doesn’t know what to do with it, and throws it away
- Given a compiler that supported it, this directive could produce a musical executable

A more practical use

- Pthreads code is tediously repetitive
- We have to do the same things over and over:
  - Declare, initialize, use, and destroy a mutex for every thing that needs protection
  - Declare, initialize, use, and destroy a cond for every signal
  - Declare, initialize, use, and destroy an object for every barrier
  - Simple sets of operations make for lots of repetitive typing
- Since the code is practically the same over and over, we might as well make the compiler generate it
- It can figure out what to generate from a tiny language embedded in well-placed #pragma directives
- That’s OpenMPs mechanism of choice

Stack contexts

- We've covered how a function call encapsulates a local set of values on the call stack
  - That's the connection between function calls and pthread creation
- Other local scopes also contain stack contexts
- Consider this program fragment:

```
int main ()
{
    int a = 42, b = 32, c = 0;
    {
        int a = 64;
        c = a – b;
    }
    printf ( “a = %d, b = %d, c = %d\n”, a, b, c );
    return 0;
}
```

The output is “a = 42, b = 32, c = 32”

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What’s going on?

- An open `{ /* basic block */ }` establishes a local stack context
  - Just like a function call, except that it doesn’t have arguments and return value
- A basic block can appear wherever a statement can
  - That’s how we make if-branches and loop bodies
    (and function bodies, for that matter)

```
int main ()
{
    int a = 42, b = 32, c = 0;
    {
        int a = 64;
        c = a – b;
    }
    printf ( “a = %d, b = %d, c = %d\n”, a, b, c );
    return 0;
}
```

Basic block acting as a statement

Block local scope

- Even when they don't have names and arguments, basic blocks let you declare variables that live only inside the block
- That is a stack context at work:

Execution is here →

```
int main ()
{
    int a = 42, b = 32, c = 0;
    {
        int a = 64;
        c = a – b;
    }
    printf ( "a = %d, b = %d, c = %d\n", a, b, c );
    return 0;
}
```

Stack state

c=0
b=32
a=42

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Block local scope

- After a few more steps, another stack context has been started
- We now have two variables called ‘a’
  - The most recent one is near the top of the stack in the scope of the most recently opened block
  - The other one sits in the stack space of the enclosing block

Execution is here →

```
int main ()
{
    int a = 42, b = 32, c = 0;
    {
        int a = 64;
        c = a – b;
    }
    printf ( “a = %d, b = %d, c = %d\n”, a, b, c );
    return 0;
}
```

Stack state

a=64
c=0
b=32
a=42

Block local scope

- When the time comes to evaluate this expression
  - The nearest declaration of a is used
  - The current block's context doesn't contain b and c, so they are tracked down in the enclosing scope
  - (If they hadn't been there, the next thing would be to check if they were declared globally)

Execution is here

```
int main ()
{
    int a = 42, b = 32, c = 0;
    {
        int a = 64;
        c = a – b;
    }
    printf ( “a = %d, b = %d, c = %d\n”, a, b, c );
    return 0;
}
```

Stack state

a=64
c=32
b=32
a=42

Block local scope

- When the block ends, its local context is deleted from the stack
  - the “old” value of a becomes the topmost one in our stack context again
  - Hence, c is 32 even though a-b is 10 now
  - We temporarily created a stack context with a different local variable in

```
int main ()
{
    int a = 42, b = 32, c = 0;
    {
        int a = 64;
        c = a – b;
    }
    printf ( “a = %d, b = %d, c = %d\n”, a, b, c );
    return 0;
}
```

Execution is here

Stack state

c=32
b=32
a=42

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Stack contexts can be threads

- We might as well leave it to the compiler to write the thread spawning and joining logic
- There's a program called 'hello_openmp' in today's example archive
- Notice that the Makefile has added the flag

  -fopenmp

  to the C compiler's command line
  - This enables OpenMP using gcc and clang
  - Using icc, the flag is -qopenmp
  - Using MSVC I don't know what it is, but it's something (read the manual)

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We have the magic ingredients again

- Armed with a thread count and a thread id#, we can solve all the embarrasingly parallel problems again
  - Pick a task based on the id#
  - Handle it
- OpenMP has a far richer set of concepts and tools than this
  - So far, it's definitely the least amount of typing to make a hello world example parallel, though

How many threads do we get?

- By default, OpenMP assumes that you want one thread per core that your O/S recognizes
- You can adjust it without recompiling the program
  - if you set the environment variable

    OMP_NUM_THREADS

    in your shell, OpenMP will look it up there
- You can also hard-code it into the program

    #pragma omp parallel num_threads(4)

    will always spawn 4 threads, overriding both your system information and the environment variable
  - There's rarely a good reason to do this, though

We can do locking
(just like pthreads)

- The example program ‘pi_mutex_openmp.c’ is (functionally) identical to last lecture’s ‘pi_mutex_fast’ example
  - Computes local estimates per thread
  - Uses a mutex data structure to avoid race conditions for a global value
- There are smoother ways to do this in OpenMP
  - Don’t take it as a wonderful implementation strategy
  - I just wanted to demonstrate that OpenMP code can act precisely like pthread code

We can do barriers

(just like pthreads)

- The example program 'pi_barrier_openmp.c' is (functionally) identical to last lecture's 'pi_barrier' example
  - Repeats computation 10 times
  - Synchronizes between repetitions, to avoid race conditions when resetting the global value
- There are smoother ways to do this in OpenMP as well
  - Don't take it as a wonderful implementation strategy
  - I just wanted to demonstrate… oh, you get the point

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We can’t do pthread_cond_t

- Inter-thread signals aren’t a thing in OpenMP
- OpenMP threads aren’t supposed to be sleeping, they’re supposed to be computing something
  - The constructs contain lots of busy-waiting, critical sections are expected to be as short as possible
  - Oversubscribe thread counts at your own peril
- If you want to yield CPU cores, just shut down the threads instead
  - They’re very easy to bring back again

(There <u>is</u> actually a different technique as well, but we’ll get back to it later)

How safe is this stuff?

- It is a little easier to write correct OpenMP code than it is to write correct pthreads code
  - That's mostly because it requires you to consider fewer details at a time, though
- The *"gentleman's agreement"* philosophy still applies
  - OpenMP makes threads when you tell it to
  - If you treat a shared variable as if it were private, OpenMP will take you at your word
  - If you say that something should be parallelized when it should not, you will get programs that compute wrong answers

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Our reason to do this

- Today’s examples are really written in a pretty clunky style
  - It is actually quite rare to need the thread id# and count for anything in OpenMP
  - I just wanted to show you that they are there, so as to demonstrate that the correspondence to pthreads lurks just below the surface
- That’s kind of why we covered pthread programming in the first place
  - Like assembly code, it’s not very common to need explicit pthread code
  - Like assembly code, it’s good to know what’s going on even if you don’t type it out by hand

Going forward

- Next time, we'll start on the rich library of OpenMP abstractions