OpenMP

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CMPT370
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Review last time

- Memory models:
  - Shared (SMP)
  - Distributed (cluster)
  - Hybrid
- Programming models:
  - Threads (PThreads, OpenMP)
  - Message passing (MPI)
  - Data-parallel (HPF)
  - Hybrids

Writing a parallel program

- Designing a program to work and make full use of multiple processors is tough
- Fully automatic parallelizing compilers exist:
  - Analyzes your code for parallel opportunities
  - For loops, iteration over arrays, etc.
- Directives can make the compiler's job easier:
  - #pragma delimits portions of code that have minimal dependencies (coarse granularity)
- The most control and speedup is from manually programming it: explicit parallelism

OpenMP

- An industry standard API for shared-memory parallelism for high-performance computing
- Programmers interface to OpenMP via:
  - Compiler directives (#pragma omp parallel)
  - Library subroutines (omp_get_num_threads())
  - Environment variables (OMP_NUM_THREADS)
- Fork/join threading model:
  - Fork at start of a parallel construct
  - Join (implied barrier) at end of construct

OpenMP parallel constructs

- #pragma omp parallel
  - Code duplicated to all threads (SIMD)
- #pragma omp for
  - Distribute iterations of a for loop
- #pragma omp sections
  - #pragma omp section
  - #pragma omp section
  - Each section has different code, one thread per section (MIMD)

Compiling with OpenMP

- OpenMP is implemented in gcc/g++:
  - 4.1.2 (OpenMP 2.0) (on carmel)
  - 4.2 (OpenMP 2.5) (current)
  - 4.4 (OpenMP 3.0) (devel)
- Also in MSVC 2005, 2008 (but not .NET)
- See OpenMP website for more details
- Include: #include <omp.h>
- Compile with flag: -fopenmp
- Link with: -lgomp (GNU OpenMP)
- See sample Makefiles on carmel under /home/seanho/cmpt370/

Shared vs. private variables

- By default, most variables in OpenMP are shared by all threads
  - Except variables declared within a block inside a parallel region
  - Or can declare a variable to be private to each thread
  - Also a reduce operation to combine partial results from each thread (more later)

- helloworld.c example on carmel:
  - /home/seanho/cmpt370/helloworld/

OpenMP synchronization pragmas

- #pragma omp parallel
  - Next block (use {}) is a parallel section
- #pragma omp critical
  - Next block should be one-thread-at-a-time
- #pragma omp single
  - next block run by only one of the threads
- #pragma omp barrier
  - Wait for all threads: synchronization point
- Others: master, ordered, atomic, flush
- Handy reference card: OpenMP homepage (v3.0)

How many threads?

- Can be fewer threads than physical processors
  - Wasting the other processors
- Or more threads than processors
  - Threads will queue, waiting for a free CPU
- By default, OpenMP will use as many threads as there are processors (8 on carmel)
- Change at runtime with environment variable:
  - OMP_NUM_THREADS=1 ./helloworld
- Can also change inside program with a library subroutine

OpenMP library routines

- int omp_get_num_threads()
- int omp_set_num_threads()
  - How many threads are currently in use
- int omp_get_thread_num()
  - Which thread id I am
- double omp_get_wtime()
  - Get wall-clock time in number of seconds
- double omp_get_wtick()
  - Get precision of omp_get_wtime() in seconds
- A few others (not many) for locking

Scheduling a for loop

- How is work distributed amongst threads?
  - schedule(static) *(optional chunk-size)*
    - Divide iterations into chunks, distribute evenly amongst threads
  - schedule(dynamic) *(optional chunk-size)*
    - Queue of chunks: threads take next avail. chunk
  - schedule(guided) *(optional chunk-size)*
    - Like dynamic, but chunk size is exponentially reduced
  - schedule(runtime)
    - Follow OMP_SCHEDULE environment variable

Reduce

- Option to for loops: reduction(op:var)
  - Each thread contributes toward var
  - Results are combined using the op
  - e.g.: finding sum of a vector

```
#pragma omp for reduction(+:sum)
for (i = 0; i < num_iters; i++)
    sum += vector[i];
```

  - Ops: sum(+), product(*), and(&&), or(||).

- See pi-leibniz.c example

Lab2: Your OpenMP program

- Ideas:
  - Numerical integration (like pi-leibniz.c)
  - Generating fractals:
    - See mandelbrot/ example
  - Dictionary/brute force encryption cracking?
  - Prime number generation?