Parallel Programming Workshop

Brought to you by

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Registration

- Please make sure you're signed in.
- Won't need a computer this morning
  - unless you need a calculator to add integers
Important Concepts

- Decomposition
- Scaling
- Speedup

We will jointly “discover” the meaning of these terms through experiment and group exercises – ease into programming only when necessary.
Distributed Memory Programming

- Two main models for doing parallel programming:
  - Distributed Memory – workers must talk with one another to get data.
  - Shared Memory – Workers view the same memory space.

Each has different issues.

Take on Distributed Memory first.
The Data Set

- Any confusion over the terms “integer” and “real” numbers?
- The data at hand consists of:
  - 50 data cards.
  - 5 integer numbers per card.
  - An integer card identifier.

Set: 14

<p>| | | | | |</p>
<table>
<thead>
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<td>164</td>
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<td>105</td>
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</table>
Exercise 1

- Desired analysis: summation over 4 cards
- Divide into groups.
- Each group needs a time keeper.

Pay attention to the process.
Ex 1 Outcomes

- What was the basic “unit of work” or task?
- What discreet steps were involved?
Adding Workers

- What happens if we add more “workers”?
- Do the steps involved change?
Ex 2 – Two Workers

- Repeat Ex 1, only with 2 people adding numbers.
- What changes?
Exercise 3

- What happens with 3 workers?
- What happens with 4 workers?
- Could we use more than 4 workers?
Ex. 3 Outcomes

- More workers => More communication
- Balanced work assignments?
- Task starvation?
- How do the input and output compare with Ex 1?
Comment on Scaling

- How does this type of work scale?
- How does it speed up (two types)?

\[ S_p = \frac{T_1}{T_n} \]
\[ S_{\text{serial}} = \frac{T_{\text{serial}}}{T_n} \]

- How efficient is it (two types)?

\[ E_p = \frac{T_1}{n T_n} \]
\[ E_{\text{serial}} = \frac{T_{\text{serial}}}{n T_n} \]
Hypothetical Speedup Chart

Solution Speedup

Number of Workers

S_4 = 3.2  E_4 = 0.8

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Distributing Data

- **Shared data?**
  - Each worker has a copy
  - Each worker has an ID
  - Use ID to compute what to work on.

- **Distributed data?**
  - Head worker has all the data.
  - Head worker knows # of workers.
  - Head worker computes decomposition.
  - Head worker sends pieces to workers.
Sharing Data

- Parallel file system – all workers see same data files.
- Broadcast – head worker broadcasts all data to all workers.
Trade-offs

- How much time is required to communicate?
- Does program have to work on machines with and without shared file systems?
Concept Summary

When you approach programming a problem, ask yourself:

- What algorithm?
- How do I decompose the work?
- How is it suppose to scale?
- Minimize comm to get speedup.
Shared Memory Programming

- **Distributed Memory Programming:**
  - Each worker was isolated.
  - Sent or computed work decomposition info.
  - Sent data or shared via file system.

- **Shared Memory Programming:**
  - Workers part of same system (i.e. cores).
  - Workers can see same data in memory.
  - Problem will be coordinating access.
Exercise 4

Example of *sharing memory*: all workers can see all the data.

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<th></th>
<th>A</th>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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</table>
Ex 4 Outcomes

• Benefits?
• Difficulties?
Concept Summary

- Shared memory lets all processors see all data, it is just there – no work to distribute it.
- Shared Memory Model is growing in popularity as more cores per node become available, and new devices such as GPUs become common place – multi-core PCs are shared memory.
- Hybrid or Heterogeneous models are becoming important as the needed to combine Shared and Distributed models increase.
Parallel Thinking

• What kind of questions do you need to consider when approaching a new problems?
Break
The Laplace Heat Equation

- For a real problem, consider how to go about solving the Laplace Heat Equation in 2-D. Idea is to determine the temperature at any point on a surface, given the temperature at the boundaries:
Formal Solution

The solution must satisfy:

$$\nabla^2 \phi = 0$$

with the application of Dirichlet boundary conditions (constant values around edge of region.)
The Serial Solution

Subdivide the surface into a mesh of points.

Apply the following 5-point stencil iteratively until the temperature stops changing (new temp approximates old temp):

\[ T_{i,j}^{n+1} = 0.25 \left( T_{i-1,j}^n + T_{i+1,j}^n + T_{i,j-1}^n + T_{i,j+1}^n \right) \]
Ex 5: 1-D Problem

\[ T_{i}^{n+1} = 0.5 \times (T_{i-1}^{n} + T_{i+1}^{n}) \]

Think about working this problem in your group.
Ex 5: Solution

70 iterations to reach 0.001% convergence bound.

<table>
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<th>16.6661</th>
<th>33.3324</th>
<th>49.9988</th>
<th>66.6658</th>
<th>83.3327</th>
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</tr>
</thead>
</table>
Serial Program

- Grab a copy of the program named: /work/jalupo/laplace_solver_serial.f90
- Open with “less” or “vi” so you can follow along.
- Anyone have trouble reading Fortran?
- Anyone not know how to compile and run a Fortran program?
Main Components

- program laplace_main – program main line.
- subroutine laplace – the actual solver. It also allocates memory to hold the 2-D mesh based on the requested rows and columns.
- subroutine initialize – sets the internal temperatures to 0.
- subroutine set_bcs – sets up the boundary conditions.
Compiling Fortran

• Here is a quick summary of how to compile and run this particular program (assumes default environment):
  
  $ ifort -o laplace laplace_solver_serial.f90
  $ ./laplace

• You should see the following line of text on your screen:
  Usage: laplace nrows ncols niter iprint relerr

Now try executing the program with some real numbers:
  $ ./laplace 100 200 3000 300 0.001
Results of Run

$ ./laplace 100 200 10000 3000 0.001

Solution has converged.

Iterations: 8437
Max error: 0.001
Total time: 0.461

What if the error condition was changed to 0.0001?
Higher Accuracy Run

$ ./laplace 100 200 25000 1000 0.0001

Solution has converged.

Iterations: 15909
Max error: 0.000
Total time: 0.887
Why go to parallel?

What if this was only part of a simulation and the temperatures changed 25,000 times?

Even though 1 solution taking 1 second seems fast, 25,000 solutions would take 7 hours!

Can it be done in parallel to speed up the overall simulation time?

How do we approach the solution in parallel?
Decomposition

Assuming 2 processors, let's divide the surface in half.

What overhead do we have to consider adding to make this give the same answer?
Ghost Cells

Process 1

Process 2
Overhead

• Breaking up the problem so multiple processes can work on it introduces *overhead*:
  • Logic must be added so each process knows which part of the mesh it is expected to work on. This directly impacts how the code will start up.
  • Communication must be added so data from adjoining regions can be properly updated.
  • Code must be added so the final results can be communicated. This directly impacts how the code will report results and terminate.

• A serial program is not the same as a parallel program running on 1 processor!
Compute/Communication Bound

- Clearly, if you increase the number of processes working on this problem, the amount of communication required increases.
- With a few processes, this problem exhibits the property of being \textit{compute bound}.
- When the number of processes approach the number of mesh points, it becomes \textit{communication bound}.
- All parallel programs exhibit one form or the other depending on the problem specifics.
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