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.

<table>
<thead>
<tr>
<th>Set: 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>164</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>76</td>
</tr>
<tr>
<td>144</td>
</tr>
<tr>
<td>105</td>
</tr>
</tbody>
</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?

For verily, computers are lowly beasts and must be instructed tediously.
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?

*Everybody's talking at me, I don't hear a word their say'ng...*

*Fred Neil*
Comment on Scaling

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

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

• How efficient is it (two types)?

\[ E_p = \frac{T_1}{nT_n} \quad E_{\text{serial}} = \frac{T_{\text{serial}}}{nT_n} \]

“Lies, damn lies, and statistics . . .”
Hypothetical Speedup Chart

Solution Speedup

Number of Workers

1 Worker 2 Workers 3 Workers 4 Workers 5 Workers 6 Workers

1 2 3 4 5 6

S_4 = 3.2  E_4 = 0.8

Parallel Programming Workshop – LSU
2-4 June 2014
13 of 44
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 machines have access to shared file systems?
Concept Summary

When you approach programming a problem, ask yourself:

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

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

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

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

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Sums</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>78</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>60</td>
<td>138</td>
<td>34</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>108</td>
<td>108</td>
<td>188</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>137</td>
<td>50</td>
<td>4</td>
<td>167</td>
<td>189</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>83</td>
<td>136</td>
<td>215</td>
<td>26</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>187</td>
<td>77</td>
<td>216</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>

Total
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 use 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 program?

  • Algorithm – numerical stability? programmability?
  • Data size – memory needs?
  • Machine architecture – shared/distributed/both(?)
  • Code lifetime – save FTE's or machine hours?
  • Choice of language
  • Choice of tools
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

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

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

70 iterations to reach 0.001% convergence bound.

|   | 16.6661 | 33.3324 | 49.9988 | 66.6658 | 83.3327 | 100   |
Ex. 6

Now the question is, how would we do this in parallel?

Note one small modification so we can begin by using 2 workers.
Process Start

Initialize:

```
0 0 0 0 0 0 0 0 100
```

Decompose:

```
0 0 0 0 0 0 100
```

Worker 1

```
0 0 0 0 0 0 100
```

Worker 2

“Ghost” or overlapped cells.
Process Iteration

Compute:

Worker 1

[Diagram]

Worker 2

Communicate:

Worker 1

[Diagram]

Worker 2

Rinse, repeat.
What Would 3 Workers Involve?

Communicate:

Worker 1

Worker 2

Worker 3

Workers in the middle have to communicate intermediate results to neighbors on both sides!
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 0.01

Solution has converged.

Iterations: 2241
Max error: 0.01
Total time: 0.079s

What if the problem gets bigger, and error condition was changed to 0.001?
Higher Accuracy Run

$ ./laplace 1000 1000 30000 1000 0.001

Solution has converged.

Iterations: 29812
Max error: 0.001
Total time: 60.546s
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 over all 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 *compute bound*.
- When the number of processes approach the number of mesh points, it becomes *communication bound*.
- All parallel programs exhibit one form or the other depending on the problem specifics.
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