Designing Parallel Programs
Abhinav Bhavele, Department of Computer Science
Announcements

- Deepthought2 (dt2) accounts have been mailed to everyone
- Please cc the TAs also when emailing me
- Prefix [CMSC416] or [CMSC818X] in your email subject
Writing parallel programs

- Decide the serial algorithm first
- Data: how to distribute data among threads/processes?
  - Data locality: assignment of data to specific processes to minimize data movement
- Computation: how to divide work among threads/processes?
- Figure out how often communication will be needed
Two-dimensional stencil computation

- Commonly found kernel in computational codes
- Heat diffusion, Jacobi method, Gauss-Seidel method

2D stencil computation in parallel
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- 1D decomposition
  - Divide rows (or columns) among processes
2D stencil computation in parallel

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2D stencil computation in parallel

- **1D decomposition**
  - Divide rows (or columns) among processes

- **2D decomposition**
  - Divide both rows and columns (2d blocks) among processes
2D stencil computation in parallel

• 1D decomposition
  • Divide rows (or columns) among processes

• 2D decomposition
  • Divide both rows and columns (2d blocks) among processes
Prefix sum

- Calculate partial sums of elements in array
- Also called a “scan” sometimes

\[ pSum[0] = A[0] \]

\[
\text{for}(i=1; \ i<N; \ i++) \ { \\
\quad \ pSum[i] = pSum[i-1] + A[i] \\
}\]

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>pSum</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>15</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>
Parallel prefix sum

| 2 | 8 | 3 | 5 | 7 | 4 | 1 | 6 |
Parallel prefix sum

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
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<tbody>
<tr>
<td></td>
<td>2</td>
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<td>7</td>
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Parallel prefix sum

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<tr>
<td>2</td>
<td>8</td>
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<td>5</td>
<td>7</td>
<td>4</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

2 → 10 → 11 → 8 → 12 → 11 → 5 → 7
Parallel prefix sum

\[
\begin{array}{cccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
2 & 8 & 3 & 5 & 7 & 4 & 1 & 6 \\
 & & 2 & 10 & 11 & 8 & 12 & 11 & 5 & 7 \\
 & & & & 2 & 10 & 13 & 18 & 23 & 19 & 17 & 18 \\
\end{array}
\]
Parallel prefix sum

<table>
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<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
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<td>2</td>
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<td>8</td>
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<td>7</td>
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<td>6</td>
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<td>2</td>
<td>10</td>
<td>11</td>
<td>8</td>
<td>12</td>
<td>11</td>
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<td>18</td>
<td>23</td>
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<td>17</td>
<td>18</td>
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<td>2</td>
<td>2</td>
<td>10</td>
<td>13</td>
<td>18</td>
<td>25</td>
<td>29</td>
<td>30</td>
<td>36</td>
</tr>
</tbody>
</table>
In practice
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- You have $N$ numbers and $P$ processes, $N >> P$
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- You have $N$ numbers and $P$ processes, $N >> P$
- Assign a $N/P$ block to each process
  - Do calculation for the blocks on each process locally
In practice

- You have $N$ numbers and $P$ processes, $N \gg P$
- Assign a $N/P$ block to each process
  - Do calculation for the blocks on each process locally
- Then do parallel algorithm with partial prefix sums
The $n$-body problem

- Simulate the motion of celestial objects interacting with one another due to gravitational forces

- Naive algorithm: $O(n^2)$
  - Every body calculates forces pair-wise with every other body (particle)

Data distribution in $n$-body problems

- Naive approach: Assign $n/p$ particles to each process
- Other approaches?
Data distribution in $n$-body problems

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- Other approaches?

http://datagenetics.com/blog/march2013/
https://en.wikipedia.org/wiki/Z-order_curve

Space-filling curves
Data distribution in \( n \)-body problems

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- Other approaches?

Space-filling curves

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Data distribution in \( n \)-body problems

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- Other approaches?

Space-filling curves

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Data distribution in \( n \)-body problems

- Let us consider a two-dimensional space with bodies/particles in it
Data distribution in $n$-body problems

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Data distribution in $n$-body problems

- Let us consider a two-dimensional space with bodies/particles in it
Load balance and grain size

• Load balance: try to balance the amount of work (computation) assigned to different threads/processes
  - Bring ratio of maximum to average load as close to 1 as possible
  - Secondary consideration: also load balance amount of communication

• Grain size: ratio of computation-to-communication
  - Coarse-grained (more computation) vs. fine-grained (more communication)