Cilk for High Productivity Computing

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A C language for dynamic multithreading with a provably good runtime system.

Platforms
- AMD Opteron
- Sun UltraSparc
- SGI Altix
- Intel Pentium

Applications
- virus shell assembly
- graphics rendering
- \( n \)-body simulation
- ★ Socrates and Cilkchess

Cilk automatically manages low-level aspects of parallel execution, including protocols, load balancing, and scheduling.
Example: Vector Addition

```c
void vadd (real *A, real *B, int L, int H){
    int i; for (i=L; i<H; i++) A[i]+=B[i];
}
```
Example: Vector Addition

To expose parallelism, convert loops to recursion.

**Side benefit:** Divide-and-conquer is good for caches!
Example: Vector Addition

\begin{verbatim}
void vadd (real *A, real *B, int L, int H) {
    int i; for (i=L; i<H; i++) A[i] += B[i];
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\end{verbatim}

\begin{verbatim}
cilk void vadd (real *A, real *B, int L, int H) {
    if (L+BASE>H) {
        int i; for (i=L; i<H; i++) A[i] += B[i];
    } else {
        spawn vadd (A, B, L, (L+H)/2);
        spawn vadd (A, B, (L+H)/2, H);
        sync;
    }
}
\end{verbatim}

Cilk is a \textit{faithful} extension of C. A Cilk program’s \textit{serial elision} is always a legal implementation of Cilk semantics. Cilk provides \textit{no} new data types.
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Cilk Productivity

I implemented all 6 HPC Challenge benchmarks. Distance to Desktop: # of Cilk keywords added to the serial program.

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>SLOC* (Cilk)</th>
<th>SLOC* (MPI)</th>
<th>Distance to Desktop</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAM</td>
<td>58</td>
<td>658</td>
<td>11</td>
</tr>
<tr>
<td>PTRANS</td>
<td>81</td>
<td>2261</td>
<td>13</td>
</tr>
<tr>
<td>RandomAccess</td>
<td>123</td>
<td>1883</td>
<td>18</td>
</tr>
<tr>
<td>HPL</td>
<td>348</td>
<td>15608</td>
<td>41</td>
</tr>
<tr>
<td>DGEMM</td>
<td>97</td>
<td>??†</td>
<td>19</td>
</tr>
<tr>
<td>FFTTE</td>
<td>230</td>
<td>1747</td>
<td>35</td>
</tr>
</tbody>
</table>

* “Source lines of code” omits comments and blank lines, but includes .h files (official count does not).

† MPI DGEMM uses the HPL parallel matrix multiplication. The framework is 184 SLOC.
## Performance

<table>
<thead>
<tr>
<th>$P$</th>
<th>HPL Gflop/s</th>
<th>DGEMM Gflop/s</th>
<th>STREAM Gflop/s</th>
<th>STREAM GB/s</th>
<th>PTRANS GB/s</th>
<th>PTRANS η</th>
<th>FFTE Gflop/s</th>
<th>FFTE η</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.2</td>
<td>5.1</td>
<td>0.8</td>
<td>0.7</td>
<td></td>
<td></td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9.4</td>
<td>9.7</td>
<td>0.9</td>
<td>0.5</td>
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<td>0.9</td>
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<tr>
<td>4</td>
<td>17.3</td>
<td>19.7</td>
<td>1.8</td>
<td>0.9</td>
<td>0.9</td>
<td>1.8</td>
<td>1.8</td>
<td>68</td>
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<tr>
<td>8</td>
<td>30.8</td>
<td>35.7</td>
<td>2.9</td>
<td>1.7</td>
<td>1.7</td>
<td>2.9</td>
<td>2.9</td>
<td>55</td>
</tr>
<tr>
<td>16</td>
<td>52.5</td>
<td>64.9</td>
<td>4.0</td>
<td>3.3</td>
<td>3.3</td>
<td>4.0</td>
<td>4.0</td>
<td>38</td>
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<tr>
<td>32</td>
<td>88.6</td>
<td>118.9</td>
<td>6.8</td>
<td>6.1</td>
<td>6.1</td>
<td>6.8</td>
<td>6.8</td>
<td>32</td>
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<td>11.6</td>
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<td>25.0</td>
<td>18.3</td>
<td>25.9</td>
<td>25.9</td>
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<td>25.9</td>
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<td>27.2</td>
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<tr>
<td>384</td>
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<td>54.1</td>
<td>11</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

What is limiting the speedup? The language or the hardware?
## Performance vs. MPI

Cilk beats the best reported Altix numbers for PTRANS and FFTE.

<table>
<thead>
<tr>
<th></th>
<th>HPL</th>
<th>PTRANS</th>
<th>RandomAccess</th>
<th>FFTE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gflop/s</td>
<td>GB/s</td>
<td>GUPS</td>
<td>GB/s</td>
</tr>
<tr>
<td>$P$</td>
<td>$\eta$</td>
<td>$\eta$</td>
<td>$\eta$</td>
<td>$\eta$</td>
</tr>
<tr>
<td>Cilk32</td>
<td>88.6 52%</td>
<td>6.1 27%</td>
<td>0.15</td>
<td>6.8 32%</td>
</tr>
<tr>
<td>MPI32</td>
<td>129.2 77%</td>
<td>2.6 11%</td>
<td>0.004</td>
<td>4.1 19%</td>
</tr>
<tr>
<td>Cilk/MPI</td>
<td>0.68</td>
<td>2.35</td>
<td>37.5</td>
<td>1.65</td>
</tr>
<tr>
<td>Cilk128</td>
<td>18.3 20%</td>
<td>0.11</td>
<td>25.9 31%</td>
<td></td>
</tr>
<tr>
<td>MPI128</td>
<td>638.9 95%</td>
<td>7.5 8%</td>
<td>0.11</td>
<td>14.1 17%</td>
</tr>
<tr>
<td>Cilk/MPI</td>
<td>?</td>
<td>2.43</td>
<td>0.96</td>
<td>1.84</td>
</tr>
</tbody>
</table>

MPI performance taken from HPC web site for Altix 3700.
Conclusion

• Cilk is *simple*, faithfully extending the legacy C language with only a handful of new keywords.
  ◦ *Cilk contains no new data types.*

• Cilk encourages *recursive* programming.
  ◦ *Divide-and-conquer exploits data locality for caches.*

• Cilk *scales down* to run on one processor with nearly the efficiency of C.
  ◦ *Fast C code ⇔ fast Cilk code.*

• Cilk *scales up* provably well, guaranteeing near-perfect linear speedup, assuming that
  ◦ *sufficient parallelism exists in the application, and*
  ◦ *the platform has adequate communication bandwidth.*
Cost of Programming

• Commodity codes are amortized over $10^4$ to $10^6$ more users than custom codes.

• Today’s custom scalable codes employ arcane programming models usable only by experts.

• Our research is focused on reinventing scalable computing as a seamless extension of commodity serial computing.
Current Research

• **JCilk**, a Java-based multithreaded language, fuses dynamic and persistent multithreading.

• **Adaptive thread and job scheduling** guarantees fair and efficient resource sharing.

• **Transactional memory** simplifies thread synchronization and improves performance compared with locking, especially for multicore processors.

• **Cilk-DXM** integrates Cilk with distributed transactional memory for clusters.

• **Parallel data-race detectors** can guarantee to find synchronization bugs efficiently.

• **Cache-oblivious algorithms** offer high performance for streaming file I/O through passive self-tuning.
World Wide Web

Cilk source code, programming examples, documentation, technical papers, tutorials, and up-to-date information can be found at:

http://supertech.csail.mit.edu/cilk
**HPC Challenge (Class 2)**

*Most productivity:* Most “elegant” implementation of two or more of seven parallel benchmarks:

- **STREAM:** vector addition & scaling
- **PTRANS:** matrix transpose
- **RandomAccess:** eponymous
- **HPL:** PLU decomposition
- **DGEMM:** matrix multiplication
- **FFTE:** fast Fourier transform
- **b_eff:** bandwidth and efficiency
Acknowledgments

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Keith Randall helped implement HPL in Cilk.