Making Programming the Fourth ‘R of Literacy

Arun Chauhan, Indiana University

I399
School of Informatics and Computing
Indiana University
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“What our community should really aim for is the development of a curriculum that turns our subject into the fourth R—as in ’rogramming—of our education systems.

…

A form of mathematics can be used as a full-fledged programming language, just like Turing Machines.”

Matthias Felleisen and Shriram Krishnamurthy
Communications of the ACM, Jul 2009
Programming
“Why can’t you be like the Math Department, which only needs a blackboard and wastepaper basket? Better still, like the Department of Philosophy. That doesn’t even need a wastepaper basket …”

Arthur C. Clarke
3001: The Final Odyssey
Computers are for Computing and ...

- Computers as general-purpose tools
  - communication, navigation, data collection, entertainment, etc.

- Computers as computing tools
  - problem solving
  - data processing and analysis
**TIOBE: Top 20**

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<td>↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑</td>
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<td>+0.37%</td>
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<td>15</td>
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<td>Pascal</td>
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<td>18</td>
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<td>ActionScript</td>
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<td>+0.17%</td>
<td>B</td>
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<tr>
<td>19</td>
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Teaching Programming

Table 1.

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</table>
| 1 | 2 | 3 | 4 | 5 | ... | x  
| 1 | 4 | 9 | 16 | ? | ... | ?  

Teaching Programming

Figure 1.

\[ \text{placeImage} (\text{rocket}, 25, 0, \text{box}) \]

Figure 2.

\[ \text{placeImage} (\text{rocket}, 25, 0, \text{box}) = \text{image} \]
Teaching Programming

Table 2.

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<th></th>
<th></th>
<th>t</th>
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<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>...</td>
<td>t</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>...</td>
<td>height(t) = ?</td>
</tr>
</tbody>
</table>

Table 3.

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<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>...</td>
<td>t</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>rocket(t) = ?</td>
</tr>
</tbody>
</table>
Teaching Programming

Figure 3.

\[
\text{rocket}(t) = \text{placeImage} ( \text{rocket}, 25, 10 \cdot t, \quad )
\]

Figure 4.

\[
\text{rocket}(t) = \text{placeImage} ( \text{rocket}, 25, \text{height}(t), \quad )
\]
Scratch
http://scratch.mit.edu/
Problem

- Nice programming languages
  - domain-specific
  - often dynamically typed and interpreted
- Poor performance
  - inefficient use of computing resources
  - inefficient use of energy
Challenge #1: There is no mathematical model for data locality
One Slide Primer on Locality

Memory

Cache

x = 10;
...
y = x + 2;

Temporal locality
Spatial locality
An Empirical Study

Implementing A Big Expression

Vector size (thousands of double elements)

0 2 4 6 8 10 12 14

0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4

time(parenthesized) / time(distributed)

AMD Opteron
PowerPC 970 (Apple G5)
Intel Xeon
Intel Itanium 2

Programming as the Fourth ‘R of Literacy, Arun Chauhan, I399, 2010-03-29
Reuse Distances

\[ x = a + b; \]
\[ c = a + d[i]*100; \]
\[ y = x * 10; \]

Reuse Distance = 6 (a, b, c, d, i, 100)
Concurrency Trends
(ExaScale Computing Study, Peter Kogge et al.)

Figure 4.16: Total hardware concurrency in the Top 10 supercomputers.

Figure 4.17: Memory capacity in the Top 10 supercomputers.
Challenge #2: There is no easy way to write parallel programs
Parallelism is Useful!
Types of (Parallel) Programmers

- Mainstream Parallelism-Oblivious Developers
  - Joe needs high level Programming Models designed for Domain Experts

- Parallelism-Aware Developers
  - Stephanie needs simple Parallel Programming Models with safety nets

- Concurrency Experts
  - Focus of today’s Parallel Programming Models

Courtesy: Vivek Sarkar, Rice University
One Slide Primer on Parallelism

Shared Memory

x

Distributed Memory

Synchronize

\[
x = 10;
\]
\[
\ldots
\]
\[
y = x + 2;
\]

Pass messages

\[
x = 20;
\]
\[
\ldots
\]
\[
y = x + 2;
\]
Parallelism Oblivious Users

- Programming languages-driven
  - implicit parallelism, compiler support
- Operating System-driven
  - innovative solutions to leverage extra cores
- Architecture-driven
  - Instruction-level parallelism, hyper-threading
Observations for Parallelism-Aware and Expert Users

- Completely automatic parallelization has had limited success
- Writing parallel programs is hard; optimizing and maintaining them is harder!
- Compilation technology has worked well in communication optimization
Concluding Remarks

- Educating the next generation for the fourth ‘R
  - Computing is a core technique in an increasing number of fields
  - programming is no longer restricted to scientists and engineers

- Taking care of non-expert programmers
  - an exponentially growing class
  - locality and parallelism problems

- Solving problems for expert programmers
  - tools to address computational bottlenecks
Toward Exascale ($10^{18}$)
What Should You Do?

- Educate yourself in the basics
  - computer architecture
  - programming languages
  - compilers
- Learn parallel programming!
Research Interests

- High-level Languages
  - Ruby, MATLAB, R, etc.
- Heterogeneous parallel computing
- Large memory-footprint applications
- Automatic parallelization
http://www.cs.indiana.edu/~achauhan

http://phi.cs.indiana.edu/