Reflections on Programming Environments and Productivity
(based on experiences with HPCS and Chapel)

Brad Chamberlain, Chapel Team, Cray Inc.
ASCR Exascale Computing Systems Productivity Workshop
June 3rd, 2014
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Programming Environments

- Programming Notations / Programming Models
  - languages, language extensions, DSLs, pragmas, libraries, ...

- Tools
  - debuggers, profilers, autotuners, IDEs, ...

- Runtime Support
  - communication, tasking, memory, I/O

Coupled closely with applications

Coupled closely with OS

My bias
Chapel (part of the reason for my bias)

- An emerging parallel programming language
  - Design and development led by Cray Inc.
    - in collaboration with academia, labs, industry

- **Goal:** Improve productivity of parallel programming

- A work-in-progress
Productivity: Traditional, pre-Exascale Concerns
What does “Productivity” mean to you?

**Recent Graduates:**
“something similar to what I used in school: Python, Matlab, Java, …”

**Seasoned HPC Programmers:**
“that sugary stuff that I don’t need because I was born to suffer”
want full control to ensure performance

**Computational Scientists:**
“something that lets me express my parallel computations without having to wrestle with architecture-specific details”

**Chapel Team:**
“something that lets computational scientists express what they want, without taking away the control that HPC programmers want, implemented in a language as attractive as recent graduates want.”
Productivity: My nightmare scenario

Scenario:
- A mainstream computing buddy wants to do some scalable parallelism
  - Accustomed to using Python, Matlab, or Java, say
  - Also IDEs with auto-completion, refactoring, integrated debugging, …
- Knowing you’re an expert in the field, wants recommendations

The source of my fears:
“As the HPC community, do we have anything we can recommend as a productive solution to such a person with a straight face?”

“Do any of us even recognize what productivity means to most programmers anymore? Would we know it if it bit us on the leg?”
How to attract/retain HPC programmers?
One Answer: “Decent” Parallel Languages

What was the last parallel notation you used that felt:

- productive?
- high-level?
- powerful?
- flexible?
- effective?
- modern?
- fun?
- (...all the things we judge good software by...)?

(Because that’s what we’re competing against when it comes to attracting new talent)
Productivity in the Exascale Era
Prototypical Exascale Processor Technologies

Intel MIC

Nvidia Echelon

AMD APU

Tilera Tile-Gx

Sources:
- http://download.intel.com/pressroom/images/Aubrey_Isle_die.jpg
- http://www.zdnet.com/amds-trinity-processors-take-on-intels-ivy-bridge-3040155225/
Emerging processor designs...

...are increasingly locality-sensitive

...potentially have multiple processor/memory types

⇒ Exascale programmers will have a lot more to think about at the node level than in the past

⇒ What will it take to keep the productivity bar level (to say nothing of improving it?)
Summarizing: Three Productivity Challenges

1. How to improve productivity relative to current practice?
2. How to improve productivity to entice new users?
3. How to maintain productivity in the face of exascale?  
   - let alone improve it?

Happily, #3 gives us a renewed excuse to work on #’s 1 & 2:

If we’re going to have to switch to something new anyway, it’s a great opportunity to change to something truly productive.
Productivity, HPCS, and Cray: A Brief History/Review
Productivity, as defined by HPCS

Productivity (10x improvement goal) =
  performance
  + programmability
    (readability, writeability, maintainability, modifiability, tunability, …)
  + portability
  + robustness

A reasonable starting point…
…yet, how to combine four areas down to a single metric?
  ● particularly given that most of them are hard to measure individually?

Also some unreasonable (IMO) goals/expectations:
  ● Initially, a stated desire to see the establishment of Moore’s Law-style productivity improvements year after year
Productivity: Played Out?

● There’s some sense that productivity isn’t “hot” anymore
  ● “Didn’t we [solve | fail to solve] that in HPCS?”

● Arguably analogous to “peace”
  ● not particularly “new” or “hip” as an concept
  ● reasonable causes for skepticism about our ability to achieve it
  ● but clearly something to desire over the alternatives

● Personally, I prefer not to throw in the towel (in either case)
### My “Zany Metrics” (a brainstorming exercise)

#### “Zany” Metrics

<table>
<thead>
<tr>
<th><strong>Abstractness of Code</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>how much code must change if we...</td>
<td></td>
</tr>
<tr>
<td>change number of processors, shape of processor set?</td>
<td></td>
</tr>
<tr>
<td>change problem size?</td>
<td></td>
</tr>
<tr>
<td>make processors not divide problem size evenly?</td>
<td></td>
</tr>
<tr>
<td>make processor dimensions, problem size non-2^k?</td>
<td></td>
</tr>
<tr>
<td>switch dense arrays to sparse?</td>
<td></td>
</tr>
<tr>
<td>change an array’s rank?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Portability of Code</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>how much code must change...</td>
<td></td>
</tr>
<tr>
<td>to run on another vendor’s machine?</td>
<td></td>
</tr>
<tr>
<td>to get performance satisfactory to that vendor?</td>
<td></td>
</tr>
</tbody>
</table>
## “Language Bingo”

### Language Comparison

<table>
<thead>
<tr>
<th></th>
<th>MPI</th>
<th>SHMEM</th>
<th>Java</th>
<th>UPC</th>
<th>CAF</th>
<th>HPF</th>
<th>OpenMP</th>
<th>Fortran/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Model</td>
<td>O O</td>
<td>O O</td>
<td>O O</td>
<td>O X</td>
<td>X X</td>
<td>X X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global View</td>
<td>X X</td>
<td>X X</td>
<td>X X</td>
<td>X O</td>
<td>O O</td>
<td>O O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-scalar</td>
<td>~ X</td>
<td>~ X</td>
<td>O X</td>
<td>~ ~</td>
<td>~ ~</td>
<td>~ ~</td>
<td>~ X</td>
<td>~ X</td>
</tr>
<tr>
<td>Abstractions</td>
<td>X X</td>
<td>O ~</td>
<td></td>
<td>X X</td>
<td>X X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Succinct</td>
<td>X X</td>
<td>X X</td>
<td>X X</td>
<td>~ ~</td>
<td>~ ~</td>
<td>~</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>O O</td>
<td>O ~</td>
<td></td>
<td>X X</td>
<td>X X</td>
<td>X O</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-- = no comment  
O = good  
~ = so-so  
X = poor  
? = unproven

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(slide from some HPCS productivity meeting)
Sterling’s Model of Productivity

Productivity Factors
(Sterling Model) Version 2.1

Productivity ($\Psi$)

- Performance
  - Efficiency ($E$)
  - Peak Performance ($S_p, C_m$)

- Application Construction ($C_s$)
  - Programmability
  - Portability

- Availability ($A$)
  - Maintainability
  - Reliability
  - Accessibility
Sterling’s Model of Productivity

**General Model of Productivity**

\[ R_i = i^{th} \text{ result product} \]
\[ T_i = \text{time to compute result } R_i \]
\[ T_L = \text{total lifetime of machine} \]
\[ T_V = \text{total overhead time of machine} \]
\[ T_Q = \text{quiescent time of machine} \]
\[ T_R = \text{working time of machine} \]
\[ N_R = \text{total number of result products during } T_L \]
\[ C_L = \text{all costs associated with machine during } T_L \]
\[ C_{LS} = \text{application software costs during } T_L \]
\[ C_{LO} = \text{costs of ownership during } T_L \]
\[ C_M = \text{cost of procurement and initial installation} \]
\[ C_S = \text{cost of application software for result } R_i \]
\[ \Psi = \frac{R_L}{C_L \times T_L} \]

\[ T_R = \sum_{i}^{N_R} T_i \]
\[ T_L = T_R + T_V + T_Q \]
\[ R_L = \sum_{i}^{N_R} R_i \]
\[ C_L = C_{LS} + C_M + C_{LO} \]
\[ C_{LS} = \sum_{i}^{N_R} C_{Si} \]

\[ \Psi = \frac{R_L}{C_L \times T_L} \]

...coincidence?!? I think not...
Various Others’ Models of Productivity
The Application Kernel Matrix

AKM Dimensions

architecture-neutral implementations
The Application Kernel Matrix Website (R.I.P.)

While the AKM did not catch on, other similar comparison sites have, at least in the mainstream.

One of my favorites (content and form):
- The Computer Language Benchmarks Game
  http://benchmarksgame.alioth.debian.org/

The HPC Challenge, Berkeley Dwarfs, and Graph-500 arguably play similar roles).
HPCS Workflows

Level 1 Functional Workflows

1. Writing Large Multi-Module Codes
   - Formulate questions
   - Develop Approach
   - Develop Code
   - V&V

2. Writing Small Codes
   - Chapel
   - <redacted>
   - <redacted>
   - <redacted>

3. Running Codes
   - Production Runs
   - Analyze Results
   - Decide; Hypothesize

4. Porting Code
   - Identify Differences
   - Change Code
   - Optimize

5. Administration
   - Problem Resolution
   - Resource Management
   - Security Management
   - HWSW Upgrade

Workflow Coverage (2)

- Workflows comprise many steps; many overlapping
- Item in red represent areas with highest HPC specific interest
Timed Markov Models

Our Workflow Analysis Approach

Timed Markov Models

Formulate → Program → Test → Run → Compile → Debug → Optimize

- Compile: 1.0, 268s → .002, 5s → .048, 9s → .266, 5s → .035, 3s
- Debug: 1.0, 380s → .237, 5s
- Test: 1.0, 49s → .713, 5s
- Optimize: 1.0, 629s
- Run: .699, 4s

Workflow Coverage (4)
User Studies: Quantitative Evaluation

Workflow 2 – Productivity Improvement Summary

- Debug Parallel Code
  - Programmers created less bugs when programming in Chapel
  - Global view of data simplifies programming
- Program Parallel
  - Fewer changes needed when going from serial to parallel
  - Multi-resolution of parallelism makes it easier to go from serial to parallel
- Designing Parallel Algorithm
  - MPI programs frequently require restructuring of the serial C code, finding right MPI lib routine

Overall Relative Productivity Improvement 2.3 to 2.6 X
User Studies: Qualitative Evaluation

“The biggest feature from a broad perspective for me was domains. Especially for scientific codes, it is invaluable to be able to define the couple problem domains you're working with. It makes it trivial to change the size or layout or distribution if you decide you need to, it helps guarantee that all of your different arrays match up. A 3D rectangular grid is infinitely more clear in Chapel with domains than in C, where you have to figure out how they laid it out (is it one giant array? what is the major dimension? x? z? y?).”

“I loved not having to think as hard about offsets and counts for the parallel version of the code in Chapel, as opposed to the MPI version, where I almost always had to chase down two or three indexing errors.”

“Lastly, I'm a huge huge fan of the type inference used in Chapel. I like that I don't have to specify types everywhere--they can just be inferred from how I'm using them, but if I mess something up, the compiler catches it.”
Summary: Many Useful Concepts/Techniques...

BUT...
The Catch with Productivity Metrics

My suspicion: If I were to tell you that any of these metrics...
...demonstrated that Chapel was 10x better than Fortran+MPI
...showed that X10 was 2x better than Chapel
...indicated that Perl was 5x better than Python
...proved that emacs was 8.5x better than vim
...dared suggest that alpine is 7x better than Outlook

...would you believe me? Enough to change your practices?

Maxim #1: “I can’t define productivity, but I know it when I see it”
  ● “And seeing is believing”

Maxim #2: “Productivity is in the eye of the beholder”
  ● “To each his/her own productivity solutions”
If Not Metrics, Then What?

For many of us, case studies can be compelling...

Here are three examples from Chapel
Case 1: LULESH in Chapel
LULESH in Chapel

1288 lines of source code
plus 266 lines of comments
487 blank lines

(the corresponding C+MPI+OpenMP version is nearly 4x bigger)

This can be found in Chapel v1.9 in examples/benchmarks/lulesh/*.
LULESH in Chapel

This is the only representation-dependent code. It specifies:

• data structure choices
  • structured vs. unstructured mesh
  • local vs. distributed data
  • sparse vs. dense materials arrays

A good poster child for my “zany metrics”
LULESH’s Technical Productivity Lesson

- Put hardware-mapping-specific choices in declarations
  - Makes computation independent of key decisions like:
    - memory layouts
    - distributions
    - sparse vs. dense
    - # of dimensions
  - Supports switching between options easily

- This is a design trend that (happily) seems to be growing
  - Several similar designs reported on at PADAL 2014 workshop

http://padalworkshop.org
LULESH’s Social Productivity Lesson

● Written by intern in final 2 weeks as a “bonus” project
  ● productive!

● Illustrated Chapel use in a familiar setting to scientists
  ● ones who’d heard many Chapel talks previously, and yet…

● Served as a medium for discussion, collaboration

● Demonstrated productivity of features thought not to be
  ● global indexing, sparse domains

● Provided bidirectional feedback/knowledge transfer
  ● co-design!

(a nice win for DOE’s proxy apps effort)
Case 2: Chapel Rank-Independent AMR Framework

UW applied mathematician wrote one code that could be used to produce results in 2D, 3D, 6D, 17D…

(pictures courtesy of Jonathan Claridge, UW Amath)
Case 3: Chapel’s Appeal to Educators/Students

Today’s Lesson
Programming Zero to Parallel Hero …in Six Hours
by Tim Stitt PhD

http://prezi.com/wp13iqmsl1di/summer-scholars/?utm_campaign=share&utm_medium=copy

http://faculty.knox.edu/dbunde/teaching/chapel/SIGCSE14/

CSEP524: Parallel Computation

Software

- Pthreads: (included with the above)
- OpenMP: (included with the above)
- Chapel: chapel-fedora17-1.6.1.1.tar.gz
  (This is a pre-release of the Chapel 1.6.1 sources, pre-compiled for the Fedora 17 VM, and skipping step 2 if you’re using the VM)
- MPI: Setup MPI
  This describes how to install MPI and how to run it locally and on our course VM cluster

http://courses.cs.washington.edu/courses/csep524/13wi/
Chapel Wrap-up

● (Many other productive demonstrations in addition…)

● Chapel’s Productivity Scorecard
  ● Performance
  ● Programmability
  ● Portability
  ● Robustness

● Work is ongoing to improve Chapel’s weak areas
  ● Productivity often requires long-term investment and patience
Summary / Takeaways

- Productivity still matters
  - even if the term is well-worn

- Exascale brings new productivity challenges
  - but also an opportunity to improve upon past approaches

- Not convinced we can measure productivity
  - nor that it matters whether or not we can

- Proxy apps are a useful medium for productivity studies
  - serve as a place to demonstrate productivity features
  - serve as meeting place for distinct communities

- Educators and Students are a good resource
  - can’t stand in for today’s experts, but may be tomorrow’s

- Productivity gains may not happen overnight
Funding Productivity: Personal Opinions

● Invest in software to compensate for hardware challenges

● Pursue a combination of evolution and revolution
  ● can’t afford to just do one

● Evaluate based on user (or prospective user) viewpoints
  ● computer science viewpoints are not necessarily as relevant

● Must budget for evaluation/study of new technologies
  ● can’t expect such studies to be spare time activities
  ● requires time from experts, not simply novices
  ● again, well-designed proxy apps can be useful here
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