NSF/TCPP Curriculum Standards Initiative in Parallel and Distributed Computing – Core Topics for Undergraduates

Sushil K. Prasad, Georgia State University
Alan Sussman, University of Maryland
Viktor Prasanna, USC
Manish Parashar, Rutgers
Jie Wu, Temple University

Curriculum Initiative Website: 
Session Outline

• Introduction & Overview – S. Prasad (5 mins)
  – Why this initiative?
  – Curriculum Released: Preliminary: Dec-10, Version I: May 2012
  – Process and Bloom’s Classification

• Rationale for various topics
  – Architectures – V. Prasanna (5 mins)
  – Programming – A. Sussman (5 mins)
  – Algorithms - S. Prasad (5 mins)
  – Cross-Cutting Topics – J. Wu (4 mins)

• Call for Early Adopters – Fall 2012 (1 min)
  – Seed funds from NSF

• Q&A - 20 minutes
Who are we?

- Chtchelkanova, Almadena - NSF
- Dehne, Frank - University of Carleton, Canada
- Gouda, Mohamed - University of Texas, Austin, NSF
- Gupta, Anshul - IBM T.J. Watson Research Center
- JaJa, Joseph - University of Maryland
- Kant, Krishna - NSF, Intel
- La Salle, Anita - NSF
- LeBlanc, Richard, University of Seattle
- Lumsdaine, Andrew - Indiana University
- Padua, David - University of Illinois at Urbana-Champaign
- Parashar, Manish - Rutgers
- Prasad, Sushil - Georgia State University
- Prasanna, Viktor - University of Southern California
- Robert, Yves - INRIA, France
- Rosenberg, Arnold - Northeastern and Colorado State University
- Sahni, Sartaj - University of Florida
- Shirazi, Behrooz - Washington State University
- Sussman, Alan - University of Maryland
- Weems, Chip, University of Massachusetts
- Wu, Jie - Temple University
Why now?

• Computing Landscape has changed
  – Mass marketing of multi-cores
  – General purpose GPUs even in laptops (and handhelds)
• A student with even a Bachelors in Computer Science (CS) or Computer Engineering (CE) must acquire skill sets to develop parallel software
  – No longer instruction in parallel and distributed computing primarily for research or high-end specialized computing
  – Industry is filling the curriculum gap with their preferred hardware/software platforms and “training” curriculums as alternatives with an eye toward mass market.
Stakeholders

- CS/CE Students
- Educators – teaching core courses as well as PDC electives
- Universities and Colleges
- Employers
- Developers
- Vendors
- Authors
- Researchers
- NSF and other funding agencies
- IEEE Technical Committees/Societies, ACM SIGs,
- ACM/IEEE Curriculum Task Force
Current State of Practice

• Students and Educators
  – CS/CE students have no well-defined expectation of what skill set in parallel/distributed computing (PDC) they must graduate with.
  – Educators teaching PDC courses struggle to choose topics, language, software/hardware platform, and balance of theory, algorithm, architecture, programming techniques…
  – Textbooks selection has increasingly become problematic each year, as authors cannot keep up; no single book seems sufficient
  – Industry promotes whatever best suits their latest hardware/software platforms.
  – The big picture is getting extremely difficult to capture.
Expected Benefits to other Stakeholders

• University and Colleges
  • New programs at colleges (nationally and internationally)
  • Existing undergraduate (and graduate) programs/courses need some periodic guidance
  • 2013 ACM/IEEE curriculum task force is now focussed on PDC as a thrust area

• Employers
  – Need to know the basic skill sets of CS/CE graduates
    – No well-defined expectations from students, but will increasingly require PDC skills
  – Retraining and certifications of existing professionals
Expected Benefits to Stakeholders

• Authors
  – Will directly benefit when revising textbooks
  – Are participating in the curriculum process

• NSF and Funding Agencies
  – Educational agenda setting
  – Help fund shared resources

• Sisters Organizations (IEEE TCs: TCPP, TCDP, TCSC, ACM SIGs, etc.)
  – Need help in setting their Educational Agenda
  – Can Employ this template elsewhere
Curriculum Planning Workshops at DC (Feb-10) and at Atlanta (April-10)

• Goals
  – setup mechanism and processes which would provide periodic curricular guidelines
  – employ the mechanism to develop sample curriculums

• Agenda:
  – Review and Scope
  – Formulate Mechanism and Processes
  – Preliminary Curriculum Planning
    • Core Curriculum
    • Introductory and advanced courses
  – Impact Assessment and Evaluation Plan

Main Outcomes

- Priority: Core curriculum revision at undergraduate level
- Preliminary Core Curriculum Topics
- Sample Intro and Advanced Course Curriculums
Weekly Meetings on Core Curriculum (May-Dec’10; Aug’11-Feb’12)

**Goal:** Propose core curriculum for CS/CS graduates

- **Every individual** CS/CE undergraduate must be at the proposed level of knowledge as a result of their *required* coursework

**Process:** For each topic and subtopic

1. Assign **Bloom’s classification**
   - K = Know the term (basic literacy)
   - C = Comprehend so as to paraphrase/illustrate
   - A = Apply it in some way (requires operational command)

2. Write **learning outcomes**

3. Identify core CS/CE courses impacted

4. Assign number of hours

5. Write suggestions for “how to teach”
How to Read the Proposal

• Oh no! Not another class to squeeze into our curriculum!
How to Read the Proposal

• Oh yes! **Not** another class to squeeze into your curriculum!
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• Teaching parallel thinking requires a pervasive but subtle shift in approach
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• We identified topics that contribute to the shift
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• Teaching parallel thinking requires a pervasive but subtle shift in approach
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  – Descriptions are brief to give you flexibility
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  – ...but they’re not meant to invoke thoughts of “you can’t teach that at the sophomore level”
How to Read the Proposal

• Oh yes! **Not** another class to squeeze into your curriculum!

• Teaching parallel thinking requires a pervasive but subtle shift in approach

• We identified topics that contribute to the shift
  – Descriptions are brief to give you flexibility
  – ...but they’re not meant to invoke thoughts of “you can’t teach that at the sophomore level”
  – If that’s what you see, you’re missing the point
How to Read the Proposal

• Oh yes! **Not** another class to squeeze into your curriculum!
• Teaching parallel thinking requires a pervasive but subtle shift in approach
• We identified topics that contribute to the shift
• You choose the places they fit in your courses
How to Read the Proposal

• Oh yes! Not another class to squeeze into your curriculum!
• Teaching parallel thinking requires a pervasive but subtle shift in approach
• We identified topics that contribute to the shift
• You choose the places they fit in your courses
  – We offer some suggestions
  – Early adopters are developing examples
### Algorithms Topics

<table>
<thead>
<tr>
<th>Algorithms Topics</th>
<th>Bloom#Course</th>
<th>Learning Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithmic problems</td>
<td></td>
<td><em>The important thing here is to emphasize the parallel/distributed aspects of the topic</em></td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>broadcast</td>
<td>C/A</td>
<td><em>Data Struc/Algo represents method of exchanging information</em>- one-to-all broadcast (by recursive doubling)</td>
</tr>
<tr>
<td>multicast</td>
<td>K/C</td>
<td><em>Data Struc/Algo Illustrate macro-communications on rings, 2D-grids and trees</em></td>
</tr>
<tr>
<td>scatter/gather</td>
<td>C/A</td>
<td><em>Data Structures/Algorithms</em></td>
</tr>
<tr>
<td>gossip</td>
<td>N</td>
<td><em>Not in core</em></td>
</tr>
<tr>
<td>Asynchrony</td>
<td>K</td>
<td><em>CS2 asynchrony as exhibited on a distributed platform, existence of race conditions</em></td>
</tr>
<tr>
<td>Synchronization</td>
<td>K</td>
<td><em>CS2, Data Struc/Algo aware of methods of controlling race condition,</em></td>
</tr>
<tr>
<td>Sorting</td>
<td>C</td>
<td><em>CS2, Data Struc/Algo parallel merge sort,</em></td>
</tr>
<tr>
<td>Selection</td>
<td>K</td>
<td><em>CS2, Data Struc/Algo min/max, know that selection can be accomplished by sorting</em></td>
</tr>
</tbody>
</table>
Rationale for Architecture Topics

Viktor Prasanna
University of Southern California
Rationale for Architecture Topics

- Multicore parallelism is everywhere
- Internet, Facebook exemplify distributed computing
- Students are familiar users of PDC
- They will encounter PDC architecture concepts earlier in core

**Architecture/Organization Classes**

- Parallelism of control vs. data
  - Pipeline (K,N), stream e.g., GPU (N/K), vector (N/K), heterogeneous (K)
  - Multithreading (K), multicore (C), cluster and cloud (K)
- Memory partitioning – shared vs. distributed memory
  - SMP bus (C), topologies (C), latency (K), bandwidth (K), routing (N), ...
Architecture Topics

• **Memory Hierarchy**
  – issues of atomicity, consistency, and coherence become more significant in PDC context (but easier to address in programming, rather than architecture context)
    • Cache (C), Atomicity (N), Consistency (N), ...

• **Performance Metrics**
  – unique challenges because of asynchrony
  – much harder to approach peak performance of PDC systems than for serial architectures
    • Cycles per instruction (C), Benchmarks (K), Peak performance (C), LinPack (N), ...

• **Floating-point representation**
  – Range (K), Precision (K), Rounding issues (N)
Architecture Topics Philosophy

• There are some PDC topics that are easily explained by appealing to hardware causes
  – Those belong in the context of architecture
• Many topics that could be explained through architectural examples are easier to grasp in other contexts
  – Programming, algorithms, crosscutting ideas
Architecture Topics Philosophy

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• Just because you can, doesn’t mean you should
Parallel Programming Topics

Alan Sussman
University of Maryland
Overall Rationale

• Assume some conventional (sequential) programming experience

• Key is to introduce parallel programming *early* to students

• Four overall areas
  – Paradigms – By target machine model and by control statements
  – Notations – language/library constructs
  – Correctness – concurrency control
  – Performance – for different machine classes
Parallel Programming Paradigms

• By target machine model
  – Shared memory (Bloom classification A)
  – Distributed memory (C)
  – Client/server (C)
  – SIMD (K) – Single Instruction, Multiple Data
  – Hybrid (K) – e.g., CUDA for CPU/GPU

• Program does not have to execute on a target machine with same model
Paradigms (cont.)

• By control statements
  – Task/thread spawning (A)
  – Data parallel (A)
  – SPMD (C) – Single Program Multiple Data
  – Parallel Loop (C)

• All of these can run on shared or distributed memory machines
Parallel Programming Notations

• Overall goal is to know several (at least one per group), have expertise in at least one

• Array languages
  – Vector extensions (K) – SSE
  – Fortran 95, C++ array classes (N)

• Shared memory
  – Compiler directives/pragmas (C)
  – Libraries (C)
  – Language extensions (K)
Notations (cont.)

• SPMD (C)
  – CUDA and OpenCL – for GPUs
  – MPI, Global Arrays, BSP

• Functional/Logic Languages (N)
  – Parallel Haskell
  – Erlang
  – Parlog
Correctness and semantics

• Creating parallel tasks (K)
  – Implicit vs. explicit (K)

• Synchronization (A)
  – Critical regions (A), producer/consumer (A), monitors (K)

• Concurrency defects (C)
  – Deadlocks (C), Race conditions (K)
  – Detection tools (K)

• Memory models (N)
  – Sequential, relaxed consistency (N)
Performance

• Computation
  – Decomposition strategies (C) – owner computes (C), atomic tasks (C), work stealing (N)
  – Scheduling, mapping, load balancing (C) – static, dynamic
  – Elementary program transformations (N) – loop fusion/fission/skewing

• Performance monitoring (K)
  – Tools – gprof, etc.
Performance (cont.)

• Data organization (\textbf{K})
  – Data distribution (\textbf{K}) – block, cyclic
  – Data locality (\textbf{K})
  – False sharing (\textbf{K})

• Metrics (\textbf{C})
  – Speedup (\textbf{C}), Efficiency (\textbf{C}), Amdahl’s Law (\textbf{K})
Algorithms in the Parallel/Distributed Computing Curriculum

Sushil Prasad

Georgia State University
Algorithms in the Parallel/Distributed Computing Curriculum

Overview (Decreasing order of abstractness)

– Parallel and Distributed Models and Complexity
– Algorithmic Paradigms
– Algorithmic Problems
Overall Rationale

- The algorithmics of Parallel and Distributed computing is much more than just parallelizing sequential algorithms.
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To this end, we must offer the students
- conceptual frameworks adequate to thinking “parallel-ly”

=> the topic, Parallel and Distributed Models and Complexity
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• conceptual tools for crafting parallel algorithms
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To this end, we must offer the students

• conceptual frameworks adequate to thinking “parallel-ly”
  => the topic, Parallel and Distributed Models and Complexity

• conceptual tools for crafting parallel algorithms
  => the topic, Algorithmic Paradigms

• a range of examples to concretize the abstractions
  => the topic, Algorithmic Problems
The Bloom Classification
(A reminder)

K  Know the term
C  Comprehend the term: paraphrase or illustrate
A  Apply the notion (in some appropriate way)
N  Not in the core curriculum
The Bloom Classification
(A reminder)

K  *Know* the term
   (useful for following technology and for further enrichment)

C  *Comprehend* the term: paraphrase or illustrate
   (understanding necessary for thinking parallel-ly)

A  *Apply* the notion (in some appropriate way)
   (mastery necessary for thinking parallel-ly)

N  *Not* in the core curriculum
   (deferred to advanced courses)
Parallel and Distributed Models and Complexity

K Know the term
C Comprehend the term: paraphrase or illustrate
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Sample Topics

Costs of Computation (C): Time, Space, Power, . . .
Cost reduction (K): Speedup, Space compression, . . .
Scalability (C): (in algorithms and architectures)
Model-Based Notions (K): the PRAM (P-completeness), BSP, CILK
Scheduling Notions (C): Task graphs (dependencies), Makespan
Asymptotic Analysis (C): (Possibly via an Intro to Algorithms class)
Advanced Topics (N): Cellular automata (firing squad synch),
Cost tradeoffs (time vs. space, power vs. time)
Parallel and Distributed Models and Complexity

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Sample Topics

Theme: Benefits and Limits of parallel computing

Costs of Computation (C): Time, Space, Power, . . .
Cost reduction (K): Speedup, Space compression, . . .
Scalability (C): (in algorithms and architectures)
Model-Based Notions (K): the PRAM (P-completeness), BSP, CILK
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Advanced Topics (N): Cellular automata (firing squad synch),
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Sample Topics

*Divide & Conquer* (A) (parallel aspects)
*Recursion* (C) (parallel aspects)
*Scan* (K) a/k/a parallel-prefix
from “low-level” (carry-lookahead adders) to “high-level”
*Reduction* (K) a/k/a map-reduce
*Advanced Topics* (N) Series-parallel composition, Stencil-based iteration,
Dependency-based partitioning,
“Out-of-core” algorithms, Blocking, Striping
Algorithmic Paradigms

K Know the term
C Comprehend the term: paraphrase or illustrate
A Apply the notion (in some appropriate way)
N Not in the core curriculum

Sample Topics

Theme: Multi-purpose “tools” — you’ve seen some of these before

*Divide & Conquer* (A) (parallel aspects)
*Recursion* (C) (parallel aspects)
*Scan* (K) a/k/a parallel-prefix
from “low-level” (carry-lookahead adders) to “high-level”
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**Sample Topics**

*Collective communication:* Broadcast (A), Multicast (K), Scatter/Gather (C), Gossip (N)

*Managing ordered data:* Sorting (A), Selection (K)

*Clocking issues:* Asynchrony (K), Synchronization (K)

*Graph algorithms:* Searching (C), Path selection (N)

*Specialized computations:* Convolutions (A), Matrix computations (A)
  (matrix product, linear systems, matrix arithmetic)

*Advanced topics (N):* Termination detection, Leader election/Symmetry breaking
Algorithmic Problems

K  Know the term
C  Comprehend the term: paraphrase or illustrate
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Sample Topics

Theme: Important specific computations, (some specialized, some familiar)

Collective communication:  Broadcast (A), Multicast (K),
(Scatter/Gather (C), Gossip (N)

Managing ordered data:  Sorting (A), Selection (K)

Clocking issues:  Asynchrony (K), Synchronization (K)

Graph algorithms:  Searching (C), Path selection (N)

Specialized computations:  Convolutions (A), Matrix computations (A)
(matrix product, linear systems, matrix arithmetic)

Advanced topics (N):  Termination detection,
Leader election/Symmetry breaking
Cross-Cutting Topics

Jie Wu
Temple University
Overall Rationale

• For entering students, concurrency isn’t a paradigm shift (there is no existing paradigm)
• It is a shift for educators / educated
• Concurrency early and broadly establishes it as a natural part of computer science
Rationale for Cross-Cutting Topics

• High level themes:
  – Why and what is parallel/distributed computing (K)?

• Concurrency topics
  – Concurrency, Non-determinism, Power (K),
  – Locality (C)
Hot Topics

• Concurrency has become visible as well as important and pervasive

• Current/Hot/Advanced Topics
  • Cluster, cloud/grid, p2p, fault tolerance (K)
  • Security in Distributed System, Distributed transactions, Web search (K)
  • Social Networking/Context, performance modeling, (N)
Early Adopter Program

Sushil Prasad
How to obtain Early Adopter Status?

- **Spring-11**: 16 institutions; **Fall’11**: 18; **Spring-12**: 21
- **Fall-12 round of competition**: Deadline **June 30, 2012**
  - NSF funded Cash Award/Stipend up to $2500/proposal
  - *Which course(s), topics, evaluation plan?*

- **Instructors** for
  - **core CS/CS courses** such as CS1/2, Systems, Data Structures and Algorithms
    - department-wide multi-course multi-semester adoption preferred
  - **elective courses** such as Algorithms, Architecture, Programming Languages, Software Engg., etc.
  - introductory/advanced **PDC course**
  - dept chairs, dept curriculum committee members responsible
Conclusion

• Time is right for PDC curriculum standards
• Core Curriculum Revision is a community effort
  – Curriculum Initiative Website:
    – Linked through TCPP site: tcpp.computer.org

• Feedback: Email sprasad@gsu.edu
• Need to inculcate “parallel thinking” to all
Acknowledgements

- US NSF: Primary Sponsor (CNS/CISE/OCI)
  - Intel: Early Adopters
  - IBM: EduPar Workshop
  - NVIDIA: Early Adopters
Q&A

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