L23: Future Parallel Programming Languages

November 30, 2010

Administrative

- Grades to date
  - Sriram will mail out this afternoon
- CHPC accounts
- Schedule for the rest of the semester
  - "Final Exam" = long homework
    - Handed out Thursday (plus review)
    - Open notes, open text but do not discuss (ask for help)
    - Return electronically or physically by Dec. 14
  - Projects
    - 1 page status report due Friday, Dec. 3 at 11:59PM
      - handin cs4961 pstatus <file, ascii or PDF ok>
      - Where are you and what do you have left
      - How have you addressed questions in the feedback
    - Poster session dry run (to see material) Dec. 7
    - Poster details (next slide)
    - Final Report (2-4 pages) also due Dec. 14

Final Project

- Purpose:
  - A chance to dig in deeper into a parallel programming model and explore concepts.
  - Present results to work on communication of technical ideas
- Write a non-trivial parallel program that combines two parallel programming languages/models. In some cases, just do two separate implementations.
  - OpenMP + SSE-3
  - OpenMP + CUDA (but need to do this in separate parts of the code)
  - TBB + SSE-3
  - MPI + OpenMP
  - MPI + SSE-3
  - MPI + CUDA
- Present results in a poster session on the last day of class

Poster Details

- I am providing:
- Foam core, tape, push pins, easels
- Plan on 2ft by 3ft or so of material (9-12 slides)
- Content:
  - Problem description and why it is important
  - Parallelization challenges
  - Parallel Algorithm
  - How are two programming models combined?
  - Performance results (speedup over sequential)

Outline

- Parallel Programming Language Concepts
- Chapel, an example Global View Language
- Transactional Memory
- Sources for today's lecture
  - Book, chapters 9-10
  - The Landscape of Parallel Computing Research: A View from Berkeley by Krste Asanovic, Ras Bodik, Bryan Christopher Catanzaro, Joseph James Gebis, Parry Husbands, Kurt Keutzer, David A. Patterson, William Lester Plishker, John Shalf, Samuel Webb Williams and Katherine A. Yelick, Berkeley TR UCB/EECS-2006-183, December 18, 2006.
  - Brad Chamberlain, Cray
  - Transactional Coherence and Consistency, ASPLOS 2004, Stanford University

Some Philosophical Grounding

- Most programs of the future will be parallel programs
- Not every university even teaches parallel programming, and most offer it as an elective to undergraduates
- Where will companies find parallel programmers?
  - Hide parallelism by making it implicit, only a few experts need to understand details
    - Libraries ala STL
    - High-level programming models, domain-specific tools
    - Examples?
- General conventional wisdom (propagated by Berkeley)
  - 90% of parallel programmers are only slightly more sophisticated than sequential programmers
  - 10% of experts understand how to obtain performance (this class!)

A Broader Look at Parallel Programming Languages

- What are some important features of parallel programming languages (Ch. 9)?
  - Correctness
  - Performance
  - Scalability
  - Portability

And what about ease of programming?
Related to correctness but sometimes at odds with performance and scalability

Correctness concepts

- P-Independence
  - If and only if a program always produces the same output on the same input regardless of number or arrangement of processors
- Global view
  - A language construct that preserves P-independence
  - Example (Chapel in today's lecture)
- Local view
  - Does not preserve P-independent program behavior
  - Example from previous lecture?
- Transactional memory (later in lecture)
  - Eliminate need for fine-grain synchronization through a higher level abstraction

Performance

- Role of programming language in achieving performance
  - Relationship between language, architecture and application
  - ?
- How well does language achieve performance across a range of architectures?
- How much work do you the programmer have to do to achieve performance? Is it possible?

Scalability

- Weak scaling
  - Program continues to achieve speedup on more processors on a larger problem size
  - Example: A program for problem size M that runs with a speedup of Ts/Tp on N processors will achieve a similar speedup on a problem size of 2M on 2N processors
  - Limitations to weak scaling?
- Strong scaling
  - Program achieves speedup on more processors with the same problem size
  - Speedup of program on problem size M on 2N processors higher than speedup of same problem and N processors
  - This is very, very hard, but part of how we will achieve exascale performance.
- Importance of scaling on multi-core?

Portability

- Will a program written in parallel programming language "L" run on all the platforms on which I want to run my program, now and in the future?
  - May require a compiler implementation effort
  - Often this is the #1 barrier to acceptance of a new language
  - Contemporary positive and negative examples?
- Will it achieve "performance portability", meaning it runs not only correctly but efficiently?

What is a PGAS Language?

- PGAS = Partitioned Global Address Space
  - Present a global address space to the application developer
  - May still run on a distributed memory architecture
  - Examples: Co-Array Fortran, Unified Parallel C
- Modern parallel programming languages present a global address space abstraction
  - Performance? Portability?
- A closer look at a NEW global view language, Chapel
  - From DARPA High Productivity Computing Systems program
  - Language design initiated around 2003
  - Also X10 (IBM) and Fortress (Sun)

Chapel Domain Example: Sparse Matrices

Recall sparse matrix-vector multiply computation

```
for (j=0; j<nr; j++) {
   for (k = rowstr[j]; k<rowstr[j+1]-1; k++)
     t[j] = t[j] + a[k] * x[colind[k]];
 }
```


Chapel Formulation

Declare a dense domain for sparse matrix

```
const dnsDom = [1..n, 1..n];
```

Declare a sparse domain

```
var spsDom: sparse subdomain(dnsDom);
Var spsArr: [spsDom] real;
```

Now you need to initialize the spsDom. As an example,

```
spsDom = [(1,2),(2,3),(2,7),(3,6),(4,8),(5,9),(6,4),(9,8)];
```

Iterate over sparse domain:

```
forall (i,j) in spsDom
  result[i] = result[i] + spsArr(i,j) * input[j];
```


Transactional Memory: Motivation

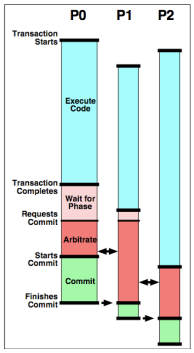
- Multithreaded programming requires:
  - Synchronization through barriers, condition variables, etc.
  - Shared variable access control through locks . . .
- Locks are inherently difficult to use
  - Locking design must balance performance *and correctness*
    Coarse-grain locking: Lock contention
  - *Fine-grain locking: Extra overhead, more error-prone*
  - *Must be careful to avoid deadlocks or races in locking*
  - *Must not leave anything shared unprotected, or program may fail*
- *Parallel performance tuning is unintuitive*
  - *Performance bottlenecks appear through low level events*
    Such as: false sharing, coherence misses, …
- *Is there a simpler model with good performance?*

Using Transactions (Specifically TCC)

- Concept: Execute *transactions all of the time*
- Programmer-defined groups of instructions within a program
  End/Begin Transaction Start Buffering Results
  Instruction #1
  Instruction #2 . . .
  End/Begin Transaction Commit Results Now (+ Start New Transaction)
- Can only "commit" machine state at the end of each transaction
  - To Hardware: Processors update state atomically only at a coarse granularity
  - To Programmer: Transactions encapsulate and replace locked "critical regions"
- Transactions run in a continuous cycle . . .

Transaction (TCC) Cycle

- Speculatively execute code and buffer
- Wait for commit permission
  - "Phase" provides commit ordering, if necessary
  - Imposes programmer-requested order on commits
  - Arbitrate with other CPUs
- Commit stores together, as a block
  - Provides a well-defined write ordering
  - To other processors, *all instructions within a transaction "appear" to execute atomically at transaction commit time*
  - *Provides "sequential" illusion to programmers Often eases parallelization of code*
  - *Latency-tolerant, but requires high bandwidth*
- *And repeat!*



A Parallelization Example

- Simple histogram example
  - Counts frequency of 0–100% scores in a data array
  - Unmodified, runs as a single large transaction (1 sequential code region)

```
int* data = load_data();
int i, buckets[101];
for (i = 0; i < 1000; i++) {
   buckets[data[i]]++;
}
print_buckets(buckets);
```


A Parallelization Example

- t_for transactional loop
  - Runs as 1002 transactions (1 sequential + 1000 parallel, ordered + 1 sequential)
  - Maintains sequential semantics of the original loop

```
int* data = load_data();
int i, buckets[101];
t_for (i = 0; i < 1000; i++) {
   buckets[data[i]]++;
}
print_buckets(buckets);
```


Conventional Parallelization of example

- Conventional parallelization requires explicit locking
  - Programmer must manually define the required locks
  - Programmer must manually mark critical regions Even more complex if multiple locks must be acquired at once
  - Completely *eliminated with TCC!*

```
int* data = load_data();  int i, buckets[101];
LOCK_TYPE bucketLock[101];
for (i = 0; i < 101; i++)    LOCK_INIT(bucketLock[i]);
for (i = 0; i < 1000; i++) {
  LOCK(bucketLock[data[i]]);
   buckets[data[i]]++;
 UNLOCK(bucketLock[data[i]]);
 }
print_buckets(buckets);
```

Other Concepts: Coherence and Fault Tolerance

- Main idea:
  - Convenience of coarse-grain reasoning about parallelism and data sharing
  - Hardware/software takes care of synchronization details
  - Well-suited to code with heavy use of locking
- If two transactions try to commit the same data?
- If a transaction fails to complete?