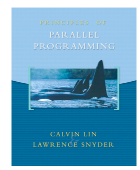
CS4961 Parallel Programming

Lecture 1: Introduction

Mary Hall
August 25, 2009

Course Details

- Time and Location: TuTh, 9:10-10:30 AM, WEB L112
- Course Website
  - http://www.eng.utah.edu/~cs4961/
- Instructor: Mary Hall, mhall@cs.utah.edu, http://www.cs.utah.edu/~mhall/
  - Office Hours: Tu 10:45-11:15 AM; Wed 11:00-11:30 AM
- TA: Sriram Aananthakrishnan, sriram@cs.utah.edu
  - Office Hours: TBD
- Textbook
  - "Principles of Parallel Programming," Calvin Lin and Lawrence Snyder.
  - Also, readings and notes provided for MPI, CUDA, Locality and Parallel Algs.



Today's Lecture

- Overview of course (done)
- Important problems require powerful computers …
  - … and powerful computers must be parallel.
  - Increasing importance of educating ***parallel programmers*** (you!)
- What sorts of architectures in this class
  - Multimedia extensions, multi-cores, GPUs, networked clusters
- Developing ***high-performance*** parallel applications
  - An optimization perspective

Outline

- Logistics
- Introduction
- Technology Drivers for Multi-Core Paradigm Shift
- Origins of Parallel Programming: Large-scale scientific simulations
- The fastest computer in the world today
- Why writing fast parallel programs is hard

Some material for this lecture drawn from:
Kathy Yelick and Jim Demmel, UC Berkeley
Quentin Stout, University of Michigan,
(see http://www.eecs.umich.edu/~qstout/parallel.html)
Top 500 list (http://www.top500.org)

Course Objectives

- Learn how to program parallel processors and systems
  - Learn how to think in parallel and write correct parallel programs
  - Achieve performance and scalability through understanding of architecture and software mapping
- Significant hands-on programming experience
  - Develop real applications on real hardware
- Discuss the current parallel computing context
  - What are the drivers that make this course timely
  - Contemporary programming models and architectures, and where is the field going

Parallel and Distributed Computing

- Parallel computing (processing):
  - the use of two or more processors (computers), ***usually within a single system***, working simultaneously to solve a single problem.
- Distributed computing (processing):
  - any computing that involves ***multiple computers remote from each other*** that each have a role in a computation problem or information processing.
- Parallel programming:
  - the human process of developing programs that express what computations should be executed in parallel.

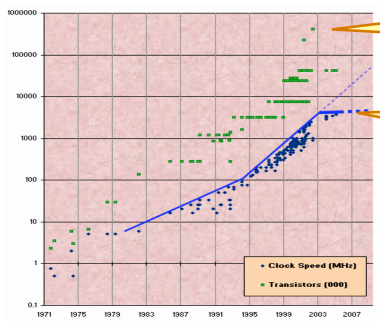
Why is Parallel Programming Important Now?

- **All computers are now parallel computers (embedded, commodity, supercomputer)**
  - On-chip architectures look like parallel computers
  - Languages, software development and compilation strategies originally developed for high end (supercomputers) are now becoming important for many other domains
- **Why?**
  - Technology trends
- **Looking to the future**
  - Parallel computing for the masses demands better parallel programming paradigms
  - And more people who are trained in writing parallel programs (possibly you!)
  - How to put all these vast machine resources to the best use!

Detour: Technology as Driver for "Multi-Core" Paradigm Shift

- Do you know why most computers sold today are parallel computers?
- Let's talk about the technology trends

Technology Trends: Microprocessor Capacity

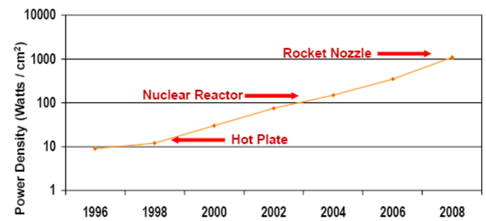


Slide source: Maurice Herlihy

Moore's Law:
Gordon Moore (co-founder of Intel) predicted in 1965 that the transistor density of semiconductor chips would double roughly every 18 months.

Technology Trends: Power Density Limits Serial Performance

Moore's Law Extrapolation:
Power Density for Leading Edge Microprocessors



Power Density Becomes Too High to Cool Chips Inexpensively

Source: Shekhar Borkar, Intel Corp

The Multi-Core Paradigm Shift

What to do with all these transistors?

- Key ideas:
  - Movement away from increasingly complex processor design and faster clocks
  - Replicated functionality (i.e., parallel) is simpler to design
  - Resources more efficiently utilized
  - Huge power management advantages

All Computers are Parallel Computers.

Proof of Significance: Popular Press

- This week's issue of Newsweek!
- Article on 25 things "smart people" should know
- See

http://www.newsweek.com/id/212142

Scientific Simulation: The Third Pillar of Science

- Traditional scientific and engineering paradigm:
  1)Do theory or paper design.
  2)Perform experiments or build system.
- Limitations:
  - **Too difficult -- build large wind tunnels.**
  - **Too expensive -- build a throw-away passenger jet.**
  - **Too slow -- wait for climate or galactic evolution.**
  - **Too dangerous -- weapons, drug design, climate experimentation.**
- Computational science paradigm:
  3)Use high performance computer systems to simulate the phenomenon
  - **Base on known physical laws and efficient numerical methods.**

The quest for increasingly more powerful machines

- Scientific simulation will continue to push on system requirements:
  - To increase the precision of the result
  - To get to an answer sooner (e.g., climate modeling, disaster modeling)
- The U.S. will continue to acquire systems of increasing scale
  - For the above reasons
  - And to maintain competitiveness

A Similar Phenomenon in Commodity Systems

- More capabilities in software
- Integration across software
- Faster response
- More realistic graphics
- …

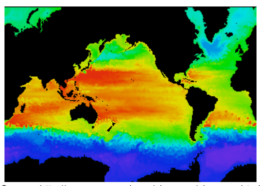
The fastest computer in the world today

- What is its name? RoadRunner
- Where is it located? Los Alamos National Laboratory
- How many processors does it have? ~19,000 processor chips (~129,600 "processors")
- What kind of processors? AMD Opterons and IBM Cell/BE (in Playstations)
- How fast is it? 1.105 Petaflop/second One quadrilion operations/s 1×10^{16}

See http://www.top500.org

Example: Global Climate Modeling Problem

- Problem is to compute:
  f(latitude, longitude, elevation, time) →
  temperature, pressure, humidity, wind velocity
- Approach:
  - *Discretize* the domain, e.g., a measurement point every 10 km
  - Devise an algorithm to predict weather at time t+δt given t
- Uses:
  - Predict major events, e.g., El Nino
  - Use in setting air emissions standards

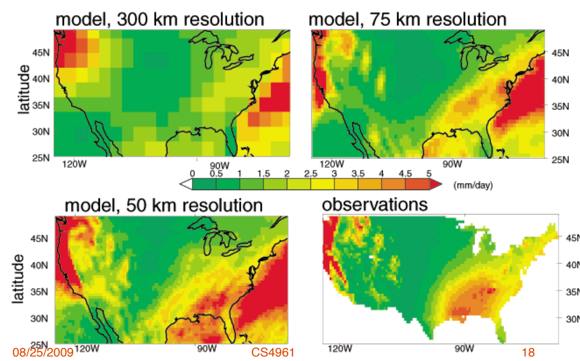


Source: http://www.epm.ornl.gov/chammp/chammp.html

High Resolution Climate Modeling on NERSC-3 – P. Duffy, et al., LLNL

Wintertime Precipitation

As model resolution becomes finer, results converge towards observations

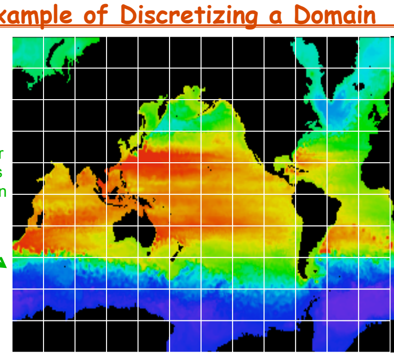


Some Characteristics of Scientific Simulation

- Discretize physical or conceptual space into a grid
  - Simpler if regular, may be more representative if adaptive
- Perform local computations on grid
  - Given yesterday's temperature and weather pattern, what is today's expected temperature?
- Communicate partial results between grids
  - Contribute local weather result to understand global weather pattern.
- Repeat for a set of time steps
- Possibly perform other calculations with results
  - Given weather model, what area should evacuate for a hurricane?

Example of Discretizing a Domain

Another processor computes this part in parallel



One processor computes this part

Processors in adjacent blocks in the grid communicate their result.

Parallel Programming Complexity

An Analogy to Preparing Thanksgiving Dinner

- Enough parallelism? (Amdahl's Law)
  - Suppose you want to just serve turkey
- Granularity
  - How frequently must each assistant report to the chef
    - After each stroke of a knife? Each step of a recipe? Each dish completed?
- *All of these things makes parallel programming even harder than sequential programming.*
- Load Balance
  - Each assistant gets a dish? Preparing stuffing vs. cooking green beans?
- Coordination and Synchronization
  - Person chopping onions for stuffing can also supply green beans
  - Start pie after turkey is out of the oven

Finding Enough Parallelism

- Suppose only part of an application seems parallel
- Amdahl's law
  - let s be the fraction of work done sequentially, so (1-s) is fraction parallelizable
  - P = number of processors

Speedup(P) = Time(1)/Time(P)

<= 1/(s + (1-s)/P)

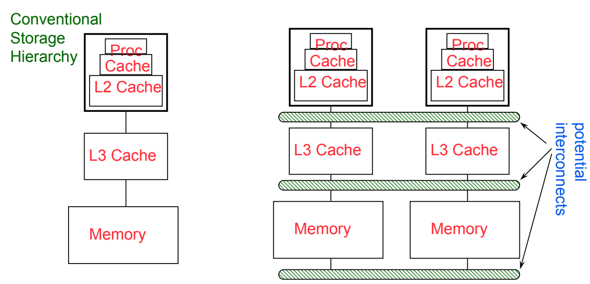
<= 1/s

- Even if the parallel part speeds up perfectly performance is limited by the sequential part

Overhead of Parallelism

- Given enough parallel work, this is the biggest barrier to getting desired speedup
- Parallelism overheads include:
  - cost of starting a thread or process
  - cost of communicating shared data
  - cost of synchronizing
  - extra (redundant) computation
- Each of these can be in the range of milliseconds (=millions of flops) on some systems
- Tradeoff: Algorithm needs sufficiently large units of work to run fast in parallel (I.e. large granularity), but not so large that there is not enough parallel work

Locality and Parallelism



- Large memories are slow, fast memories are small
- Program should do most work on local data

Load Imbalance

- Load imbalance is the time that some processors in the system are idle due to
  - insufficient parallelism (during that phase)
  - unequal size tasks
- Examples of the latter
  - adapting to "interesting parts of a domain"
  - tree-structured computations
  - fundamentally unstructured problems
- Algorithm needs to balance load

Some Popular Parallel Programming Models

- Pthreads (parallel threads)
  - Low level expression of threads, which are independent computations that can execute in parallel
- MPI (Message Passing Interface)
  - Most widely used at the very high-end machines
  - Extension to common sequential languages, express communication between different processes along with parallelism
- Map-Reduce (popularized by Google)
  - Map: apply the same computation to lots of different data (usually in distributed files) and produce local results
  - Reduce: compute global result from set of local results
- CUDA (Compute Unified Device Architecture)
  - Proprietary programming language for NVIDIA graphics processors

Summary of Lecture

- Solving the "Parallel Programming Problem"
  - Key technical challenge facing today's computing industry, government agencies and scientists
- Scientific simulation discretizes some space into a grid
  - Perform local computations on grid
  - Communicate partial results between grids
  - Repeat for a set of time steps
  - Possibly perform other calculations with results
- Commodity parallel programming can draw from this history and move forward in a new direction
- Writing fast parallel programs is difficult
  - Amdahl's Law → Must parallelize most of computation
  - Data Locality
  - Communication and Synchronization
  - Load Imbalance

Next Time

- An exploration of parallel algorithms and their features
- First written homework assignment