Lecture 1

Introduction to Data Centric Computation
Welcome to CSE 262!

- Your instructor is Scott B. Baden
  baden@ucsd.edu

- Office: room 3244 in EBU3B

- Office hours
  - Mon 2-4, or by appointment

- The class home page is
  http://www.cse.ucsd.edu/classes/sp09/cse262
Course Requirements

• Class participation and preparation: 20%
  – Be prepared to discuss the assigned readings
  – Write-ups due at start of class (12)
• In class presentation of readings: 10%
• Project: 70%
  – Includes proposal, progress report and in class presentation, final report
Policies

• Academic Integrity
  – Do you own work
  – Plagiarism and cheating will not be tolerated

• By taking this course, you implicitly agree to abide by the following the course polices:

  http://www.cse.ucsd.edu/classes/sp09/cse262/Admin.html
Background

• Common Background
  – Programming and Data structures

• Differing backgrounds
  – Prior experience in parallel computation?
  – GPUs/Cell?
  – Numerical analysis?
  – C/C++ Java Fortran? Python? Matlab?
Background Markers

• Navier Stokes Equations
  \[ \nabla \cdot u = 0 \]
  \[ \frac{D\rho}{Dt} + \rho(\nabla \cdot v) = 0 \]
  \[ \nabla \times u \]

• Sparse factorization

• TLB misses

• Multithreading

• RPC

• Abstract base class

• Amdahl’s law
  \[ f(a) + \frac{f'(a)}{1!} (x - a) + \frac{f''(a)}{2!} (x - a)^2 + \ldots \]

• Relational or Spatial Join
Motivation

- Technical obstacles are limiting our ability to derive knowledge from numerical simulations to understand technologically important phenomena.
- Exponential growth in datasets
  - Produced by numerical simulations
  - Data generated by instruments
  - Media
- Exponential increase in hardware capability
  - Multicore processors
  - Clusters
  - Networking
Observation

- The more we know about the how the data was generated …
- … the context in which the data will be used
- … the more we can employ that knowledge to improve productivity
Syllabus

• Techniques, tools and algorithms to improve our ability to derive knowledge from data or media
• Spatial query techniques and access methods
• Feature extraction and tracking
• Data compression
• Wavelets, image processing
• Hardware acceleration (i.e. Cell BE and GPUs)
• Applications
  – Simulation data sets
  – Media/observational
Scheduling

• Project Symposium
  – June 4th-5th
  – No class on 6/2

• Some lectures to be rescheduled
  – Monday 5/19 → Friday 5/8
    (In class presentations of progress reports)
  – Tuesday 5/21: Friday 5/15
  – Tuesday 5/26 → 6/5
Hardware platforms

• Abe
  – Dell cluster at NCSA
  – Lincoln: attached NVIDIA Tesla

• Cell Broadband Engine (Georgia Tech)

• If you want to use Cell BE, fill out an account request form
  https://cell-web.cc.gatech.edu/signup/index.pl
Motivating Applications
Computational fluid dynamics

- Direct Numerical Simulation of horizontal shear
- Sutanu Sarkar, UCSD MAE Department
- **80 Terabytes** of data per simulation
  - 1024 Cray XT-4 processors for 48 hours
  - $2 \times 10^9$ unknowns, 10K time steps [$4096 \times 1024 \times 512$]
  - 1000 snapshots @ $80 \times 10^9$ bytes

Horizontal spanwise vorticity (mag) using DNS, [Basak & Sarkar, JFM 2006]
The Input Data

- Time dependent simulation
- Each snapshot
  - 5 components: velocity (vector), density, pressure
The end-to-end application

- Identify vortex cores using the “$\Delta$ criterion”
  \[ \Delta > 1.75 \times 10^{-4} \]
- Compute $\Delta$ directly on a compressed version of the dataset
- Compute quantities conditioned on $\Delta$
  $F(x; \text{condition})$
Working with sparse representations

- Controlled operations on irregular multiblock structures
- Geometric abstractions, e.g. KeLP, Chombo, Titanium
- TeraLab, Faisal Mir, KTH Sweden

With William Kerney, Peter Diamessis, and Keiko Nomura (UCSD) [2002]
Dynamics

- Continuation: the overlap between a feature and a descendent or an ancestor
- Creations and dissipations are not continuations
How large can a dataset get?

• “TeraShake” Ground Fault Simulator
• Seismic waves generated by large earthquakes that occur on the southern San Andreas Fault
• 43 Terabytes of data
  – 240 IBM Power4 processors for 5 days
  – 2000 snapshots @ 21.1 × 10^9 bytes
  – Stored on tape in SDSC’s Storage Research Broker (SRB) http://www.sdsc.edu/SCEC/
• Southern California Earthquake Center’s Community Modeling Environment Project (SCEC/CME), NSF http://www.scec.org/cme
  – USC, Scripps Inst. for Oceanography, San Diego Supercomputer Center(SDSC), SDSU ...
Simulates a 7.7 earthquake along the southern San Andreas fault close to LA using seismic, geophysical, and other data from the Southern California Earthquake Center

**How it works:**

1. Divide up Southern California into “blocks”

2. For each block, get all the data on ground surface composition, geological structures, fault information, etc.
Animation

3. Map the blocks on the processors

4. Run the simulation using current information on fault activity and the physics of earthquakes

SDSC's DataStar Slide Courtesy of DataCentral@SDSC
240 procs on SDSC Datastar, 5 days, 1 TB of main memory

Continuous I/O 2GB/sec

47 TB output data for 1.8 billion grid points

Data parking of 100s of TBs for many months

Large memory Nodes with 256 GB of DS for pre-processing and post visualization

10-20 TB data archived a day

The next generation simulation will require even more resources: Researchers plan to double the temporal/spatial resolution of TeraShake
The Role of Compression

- If the information content of a dataset is low, compression can help us …
  - increase resolution for a given storage budget
  - discover knowledge hidden within the data

Diamessis, Kerney, Nomura, Baden [Para ‘02]
Data Compression

• Lossless
  – Perfect reconstruction, not more than 2:1 compression
  – RLE, Huffman coding, LZ77, DEFLATE (gzip)

• In practice: lossy
  – Wavelet Compression (WC)
  – Feature Extraction
  – Introduces artifacts into the data
  – Adaptive Compression (with Hromadka, Unat, Shafaat)
Technology

• Multicore processors may enable us to continue the trend of exponential growth in processing speeds

• Workstations or clusters with accelerators
  – Roadrunner: with STI Cell BE (IBM and Los Alamos)
  – Lincoln: with Nvidia Tesla (NCSA and Nvidia)

• Distributed computation
  – “Cloud” and “Grid” computing

http://computing.llnl.gov/tutorials/ibm_sp (IBM)
Today’s laptop would have been yesterday’s’s supercomputer

- Cray-1 Supercomputer
- 80 MHz processor
- 8 Megabytes memory
- Water cooled
- 6 feet H x 7 feet W
- 4 tons
- Over $10M in 1976

- MacBook
- 2.4GHz Intel Core 2 Duo
- 2 GBytes DDR2 SDRAM
- 4 Megabyte shared cache
- Air cooled
- 1.1 × 12.8 × 8.9 inches
- 5.0 pounds (2.3 kg)
- $1299 in 2008
The processor-memory gap
An important universal: the locality principle

• Programs generally exhibit two forms of locality when accessing memory, often involving loops
  – Temporal locality (time)
  – Spatial locality (space)

• Often involves loops

\[
\text{for } t = 0 \text{ to } T-1 \\
\text{for } i = 1 \text{ to } N-2 \\
\quad u[i] = (u[i-1] + u[i+1] - 8*h*h) / 2
\]
Re-use

- Memory hierarchies rely on locality to improve memory access times through re-use.

- Underlying principles for improving cache use apply to stored data, parallel memory hierarchies and hardware accelerators.
STI Cell Broadband Engine

64-bit Power Architecture with VMX

IBM
NVIDIA GeForce GTX 280

- 240 cores @ 1.296 GHz
- Parallel computing or graphic mode
- 1 GB memory
- 512 bit memory interface @ 141.7 GB/s