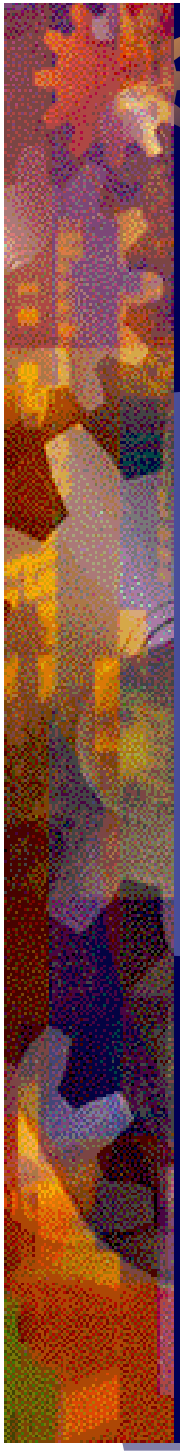
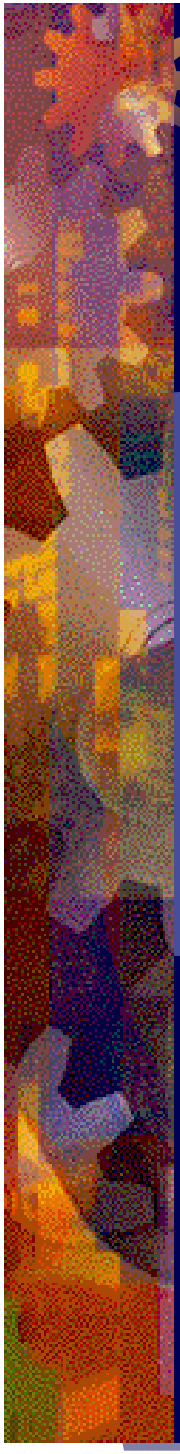


CS 286
Two Lecture Introduction

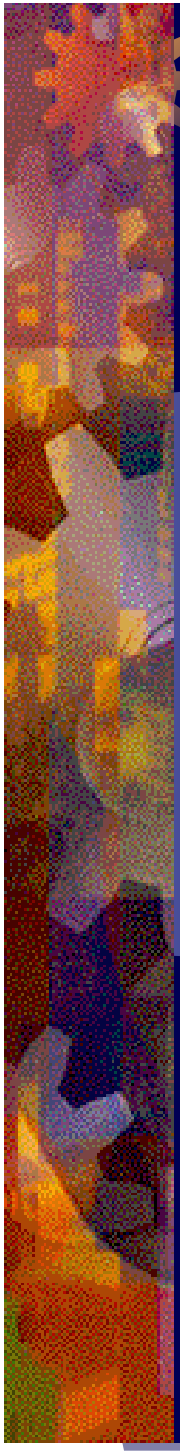
Parallel Processing:

A Hardware Solution
&
A Software Challenge



Outline

- Hardware Solution (Day 1)
- Software Challenge (Day 2)
- Opportunities



Key Points from Day 1

Hardware Solution

- Parallel Processing is Essentially an Evolution in
  - Micro- and Macro-Architecture Hardware
    - That provides a Solution to:
      - The Heat and Power Wall
      - The Limitations of ILP
      - Cost-Effective Higher Performance

- **HW Paradigm Shift Occurring (esp. Micro-level)**
  - **More Cores; Not a Faster Clock or more ILP**

Outline

- Hardware Solution
- Software Challenge
  - Technical
  - Business
- Opportunities

Software Challenge - Technical

Change in Hardware Requires Change in Software

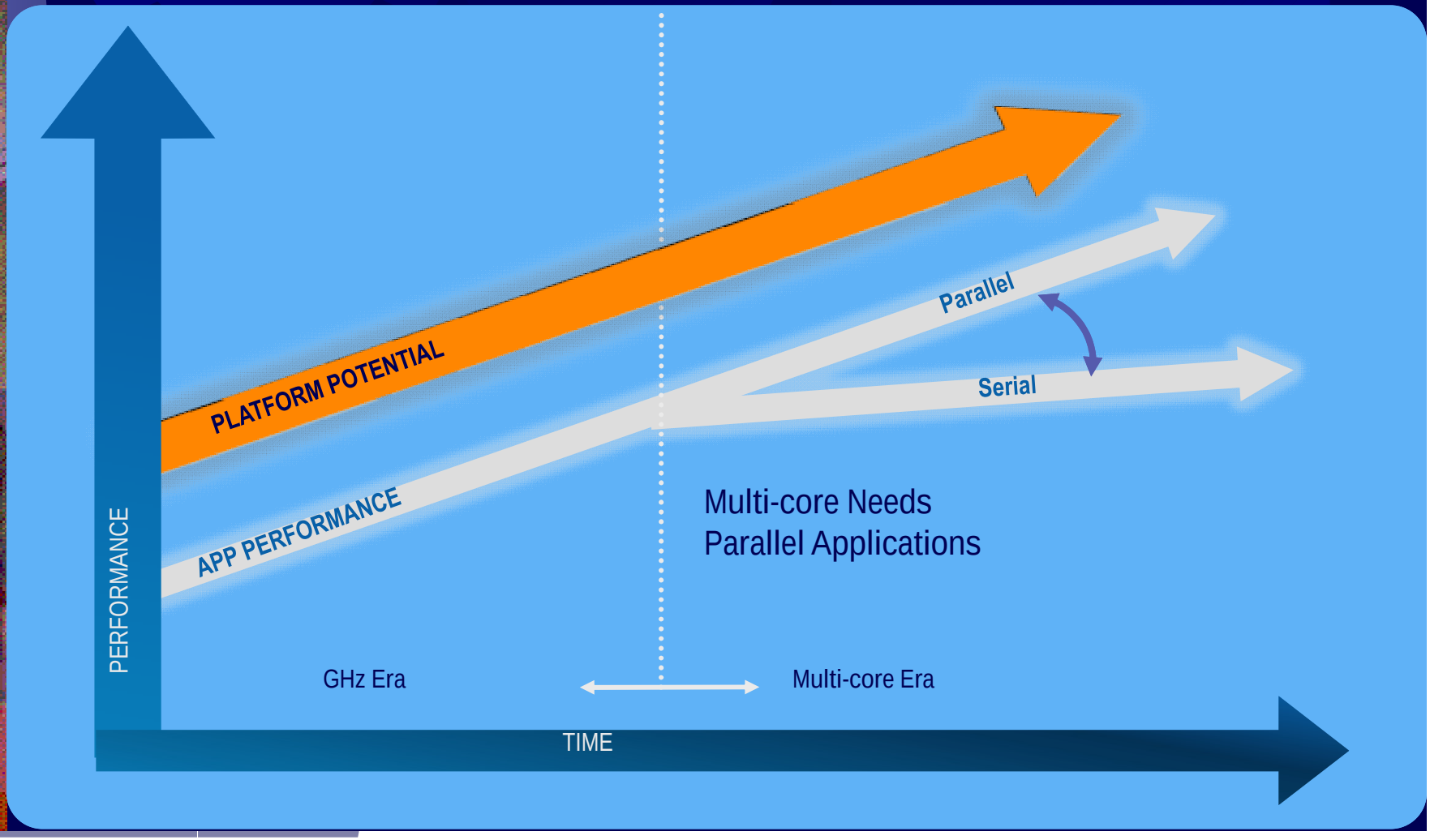
- The Car (Hardware) has Changed
  - From a Sequential Engine To a Parallel Engine
- The Driver (Software) Must Change Driving Techniques
  - Otherwise, Sub-Optimal Performance will Result

Car & Driver

Hardware & Software

Software Challenge - Technical

- Because HW is going Parallel, so must the SW in order to get performance gains from HW platform



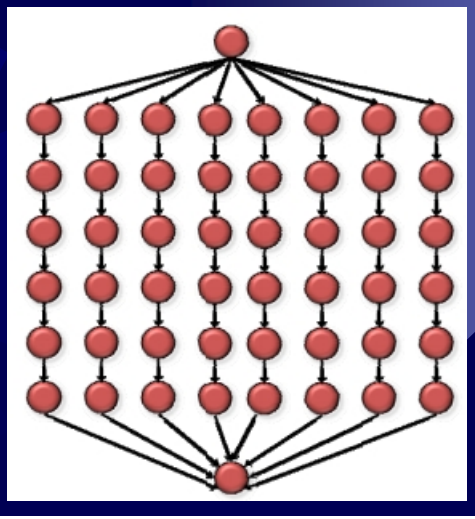
Software Challenge - Technical Overview

- The Challenge:

  Cannot Extract Parallelism Without User Support

- The Goal: Make Parallel Programming the Mainstream Method for Improving SW Performance

- But Parallel Programming is Harder in all Aspects:
  - Design & Re-engineering
  - Debugging
  - Testing
  - Profiling
  - Scaling

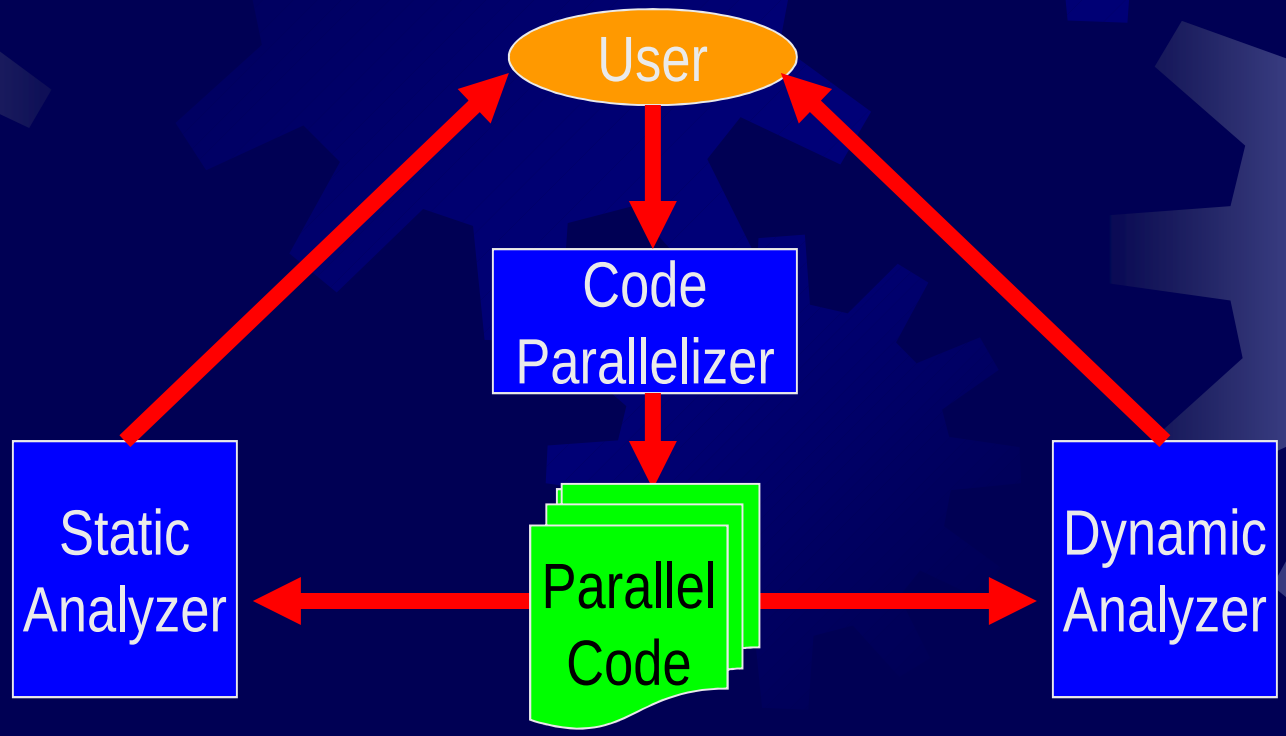


Software Challenge - Technical Design & Re-engineering

- Increased Complexity will Require More Careful Analysis
  - Parallelism Adds Temporal Dimension to Problem
  - Hard for Humans to Think about Parallel Events
  - Large Permutation of Operation Interleavings Possible
- Increased Programmer Expertise Needed in:
  - The Application Domain and Algorithms
  - Source Code Parallelization Techniques
  - Communication & Synchronization
  - Performance Optimization

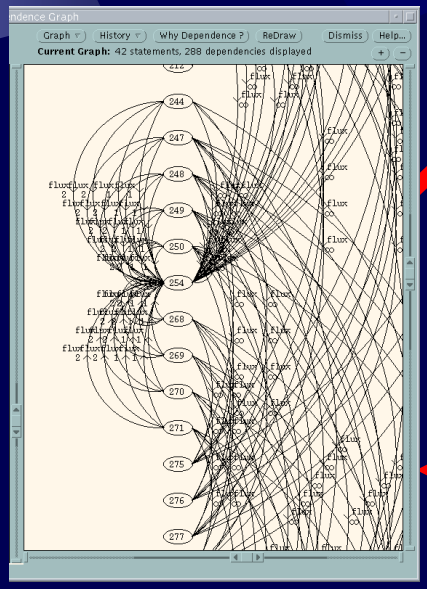
Code Parallelization Tools

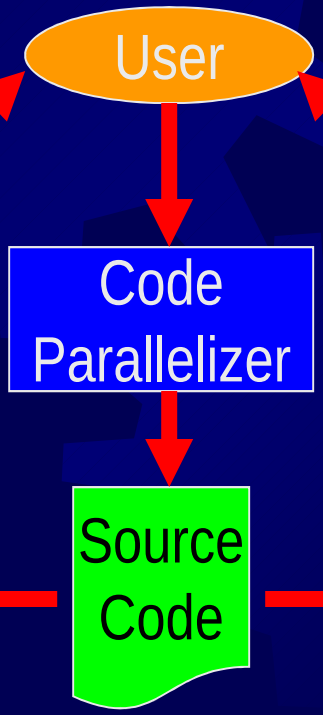
- Static Dependency Analyzer: Draws Call-Graph Structure
- Dynamic Profile Analyzer: Plots Thread Activity vs. Time
- Code Parallelizer: Parallel Language, Paradigm, Compiler

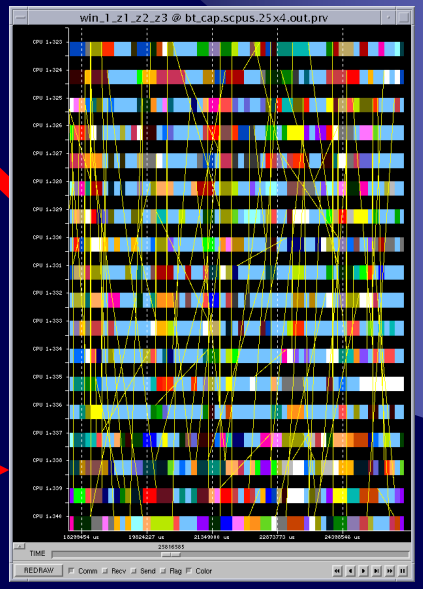


User Role in Code Parallelization

- Run & Interpret Static Data Dependency Analysis
- Run & Interpret Dynamic Profile Analysis
- Drive Code Parallelizer Transformations

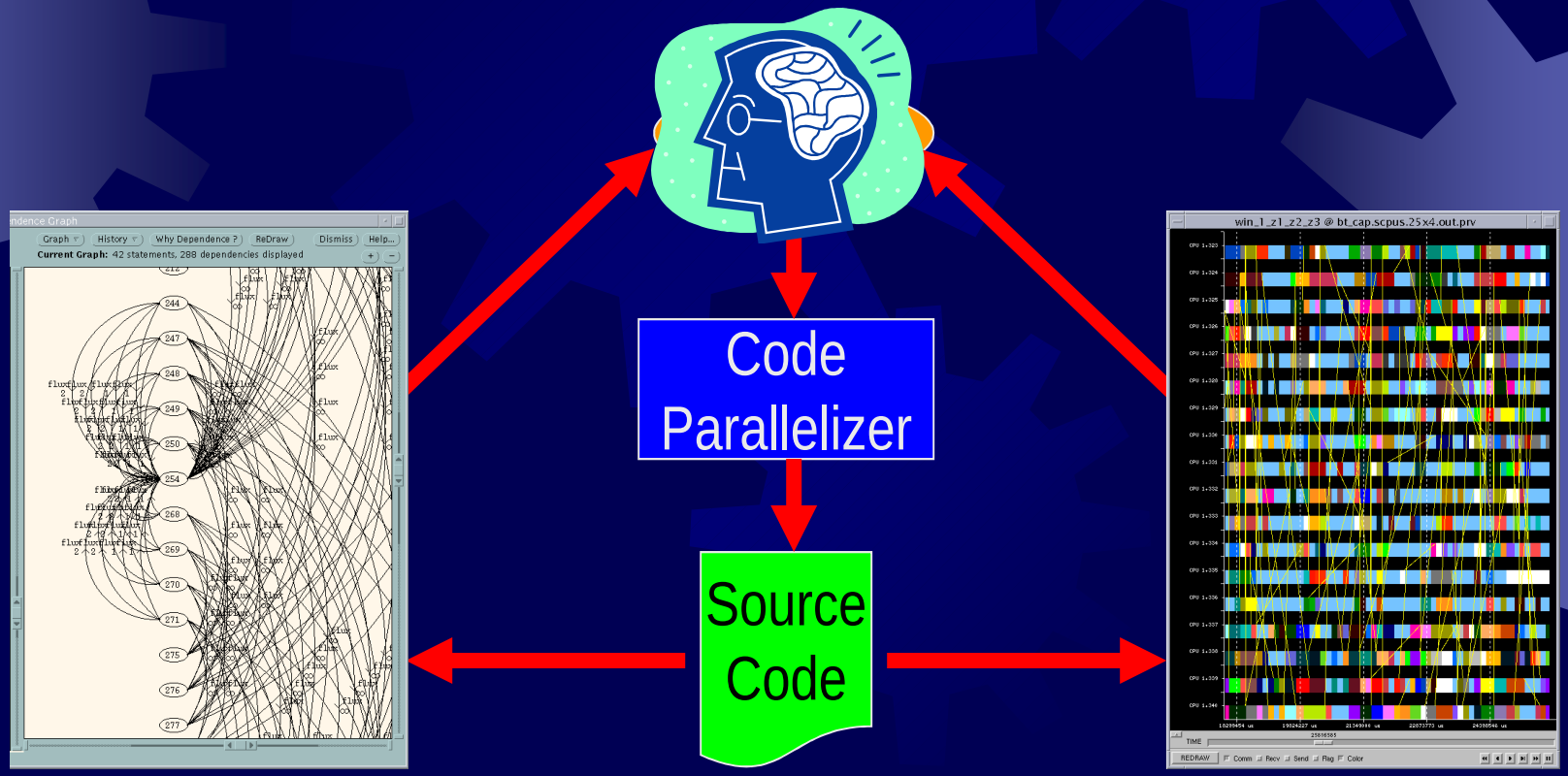






User Knowledge in Code Parallelization

- High-Level Application Code and Algorithms
- Low-Level Thread and Communication Profile
- Source Code Parallelization & Optimization Techniques



User Knowledge in Code Parallelization

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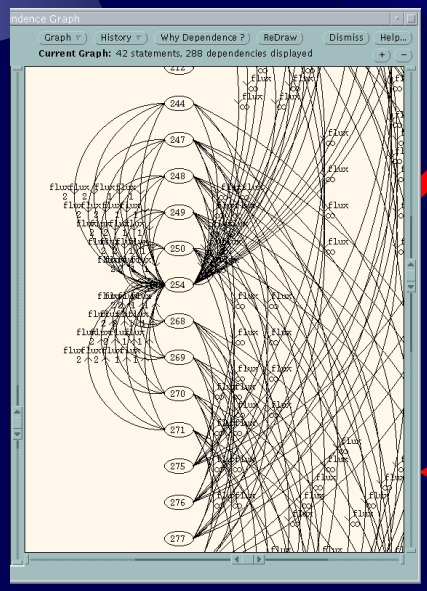
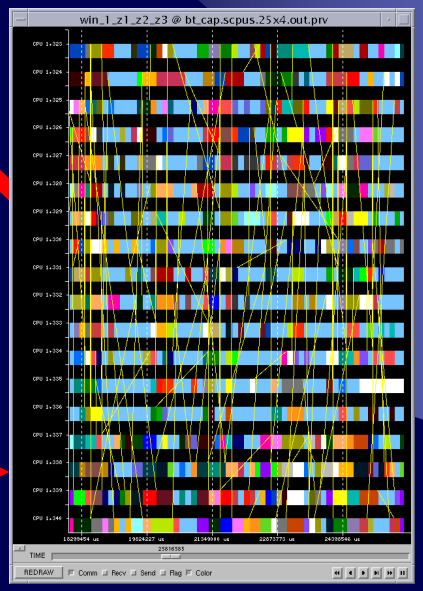


Code Parallelizer

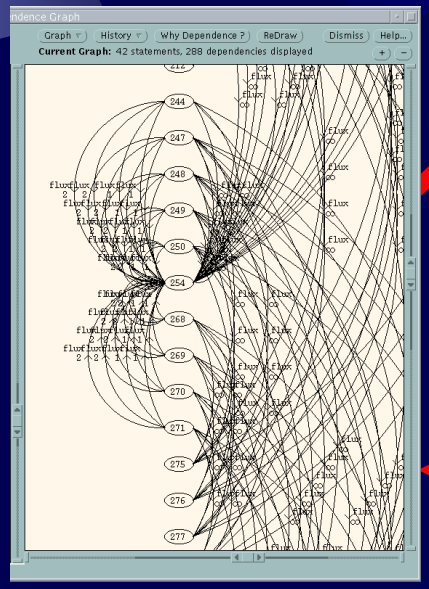
Source Code



Goal:
Assist The User

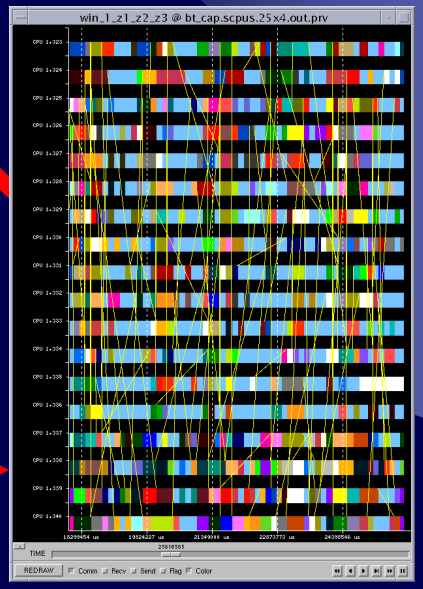
Help User Focus on
Relevant Information
from Analyses

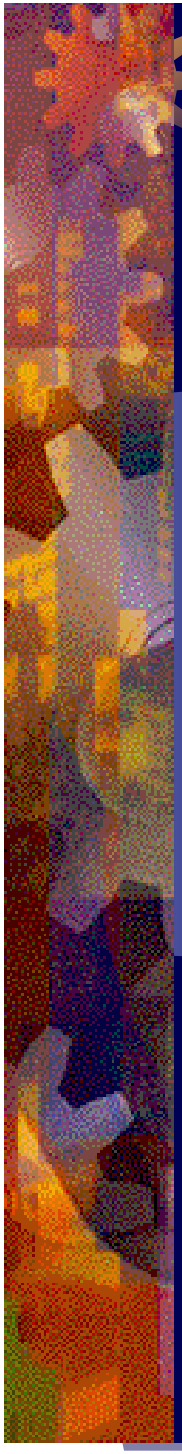
Help User Focus on
the Code with Best
Potential Speedup



Code
Parallelizer

Source
Code





Ultimate Goals

An Ideal Set of Parallelization Tools Would:

- Off-Load User as Much as Possible
- Make Parallelization Easier and More Efficient
  - Maximize Code Performance Gain
  - Minimize Analysis and Transformation Time
- Perform Data Fusion on Static and Dynamic Analysis
  - Filter, Correlate, and Interpret the Results
- Produce Correct, Bug-Free Parallel Code
- Increase Degree of Automation

But, Current SW Tools Still Need Further Development

Software Challenge - Technical Tools

- Lack of Tools Compounds Problem
  - Existing Tool Chain only for Sequential Programming
- Need New Parallel Programming Tools & Infrastructure
  - Effective Models for Parallel Systems
  - Constructs to make Parallel Architecture more Visible
  - Languages to More Clearly Express Parallelism
  - Reverse Engineering Analysis Tools
    - To Assist with Conversion of Sequential to Parallel
      - Especially for Optimized Sequential Code

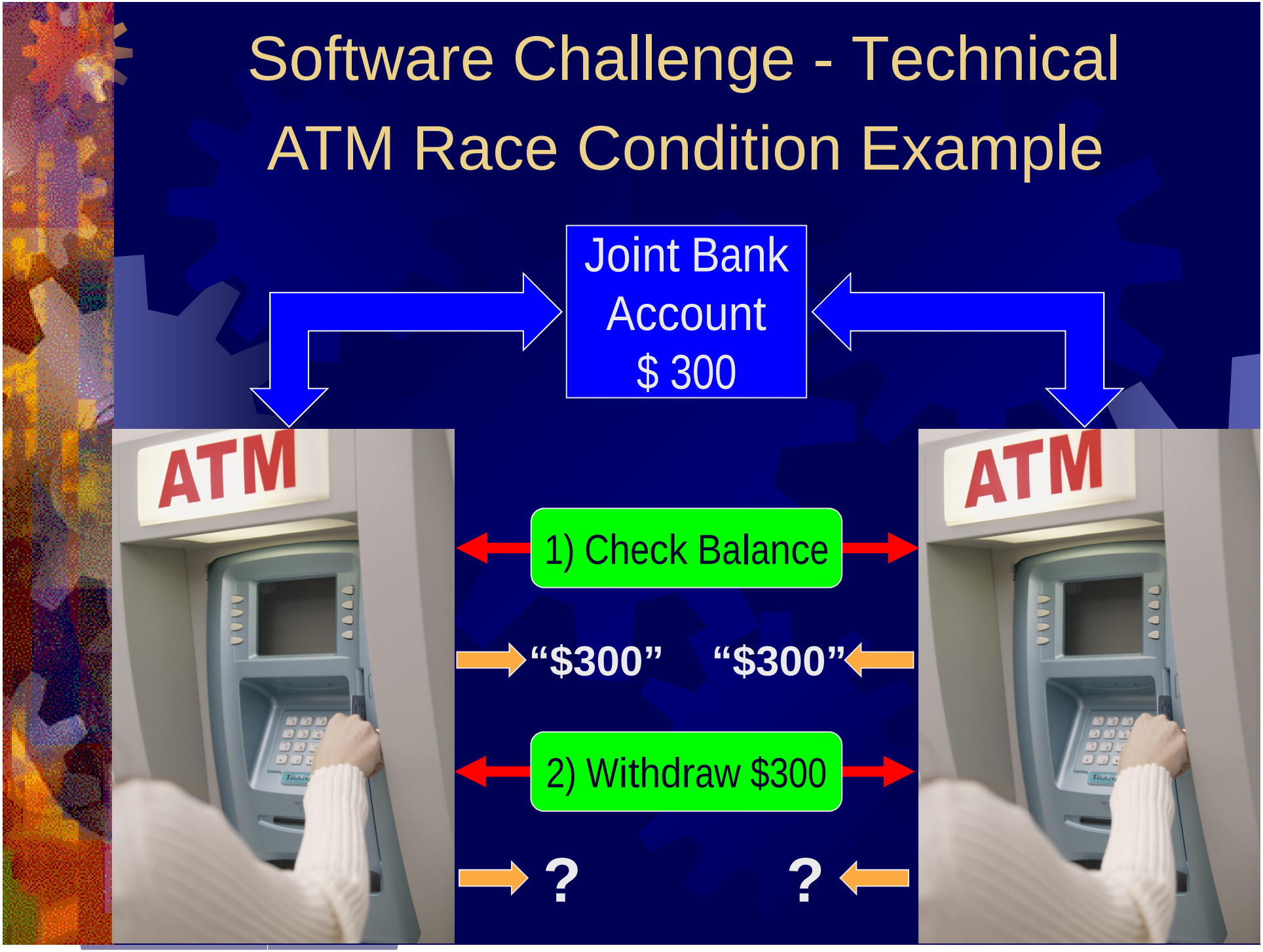
Software Challenge - Technical
Race Conditions

- Parallelism can Give Rise to a New Class of Problems
  - Caused by the Interactions Between Parallel Threads
- Race Condition:

  Multiple Threads Perform Concurrent Access

  to the Same Shared Memory Location
- Threads “Race” Against Each Other
  - Execution order is assumed but cannot be guaranteed
  - Outcome depends on which one wins (by chance)
  - Results in Non-Deterministic Behavior

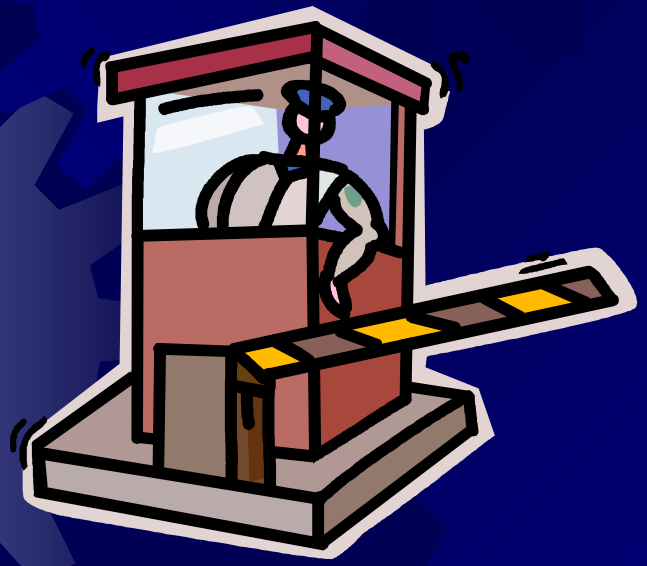
Software Challenge - Technical
ATM Race Condition Example

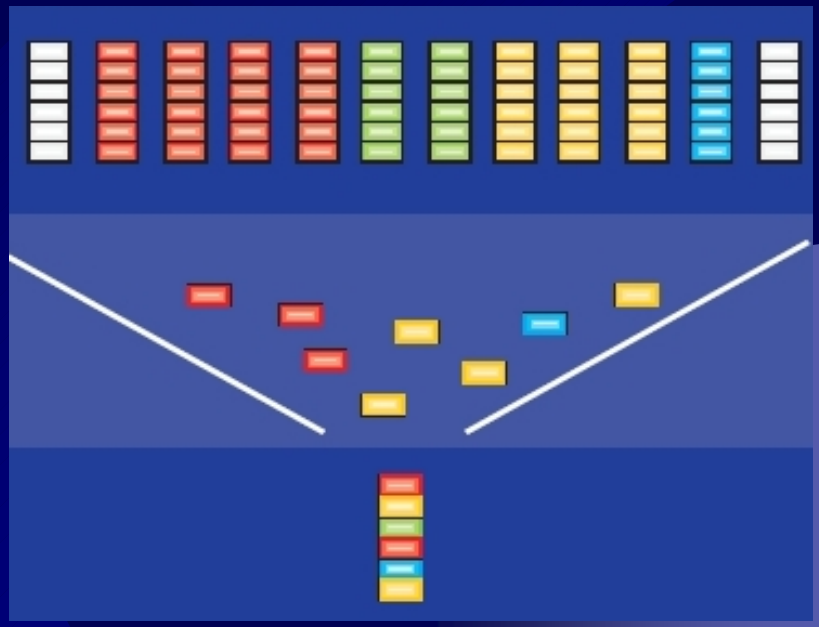


Software Challenge - Technical Race Conditions

- Race Conditions are Especially Hard to Detect & Debug
  - Errors are Very Subtle
    - No Apparent “Failure” Occurs
    - Program Continues to Run “Normally”
    - Program Completes “Normally”
  - Errors are Intermittent
    - Hard to Reproduce and Diagnose
  - Errors Can Slip Through SQA Testing Process
    - Potential Lurking Bug
- Most Common Error in Parallel Programs

Software Challenge - Technical Semaphores





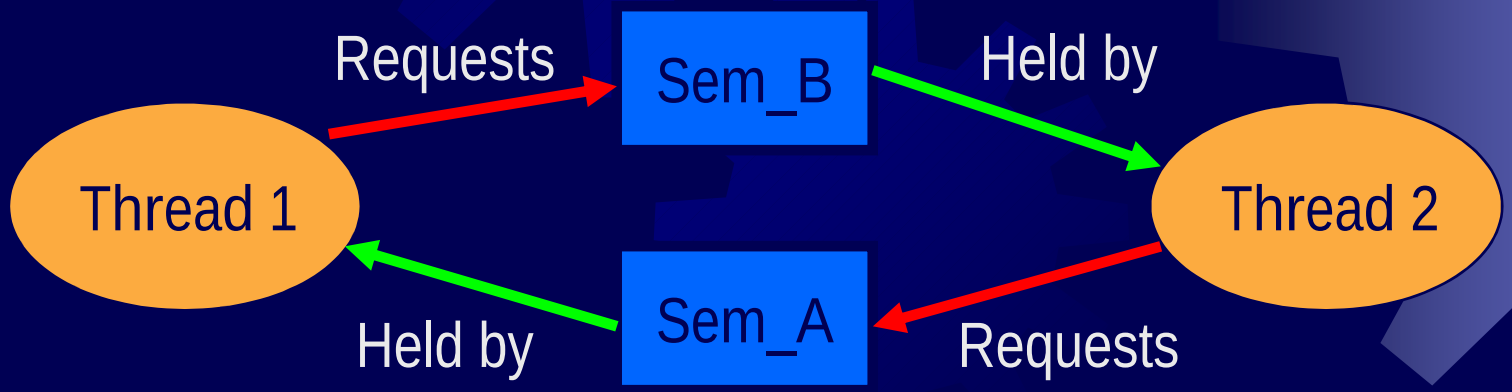
- Semaphores Offer a Solution to Race Conditions
  - However Semaphores themselves can cause Problems:
    - Introduce Overhead
    - Can Create Bottlenecks
      - Mutually Exclusive (one-at-a-time) Access

Software Challenge - Technical Deadlock

- Another Potential Problem Arising From Parallelism
- Deadlock:

Two or More Threads are Blocked because

Each is Waiting for a Resource Held by the Other



Software Challenge - Technical Deadlock

- Not as Hard as Race Conditions
  - Errors are More Obvious
    - System Usually Freezes
- But Similar to Race Conditions
  - Errors are Intermittent
    - Hard to Detect, Reproduce, Diagnose, Debug
  - Errors Can Slip Through SQA Testing Process
    - Potential Lurking Bug

➢ Another Common Error in Parallel Programs

Software Challenge - Technical
Concurrent vs. Parallel

- Time-Sharing = Multi-Tasking = Multiplexing = Concurrent
  - One Processor is being shared (switched quickly) between tasks making them appear to be “Concurrent”
  - But it’s essentially just an illusion, because at any instant in time, only one task is really executing
- Concurrency is not the same as true Parallelism

Concurrent: Two Threads are *In Progress* at Same Time

vs.

Parallelism: Two Threads are *Executing* at Same Time

Software Challenge - Technical
Concurrent vs. Parallel

- SW Problem is Harder than that from “Time-Sharing” Era
  - Multi-Cores (Micro) & Multi-Nodes (Macro) HW enable:
    - Not Just “Multi-Tasking” or Concurrency, but
    - True Parallelism
- Potential Problem when migrating “Multi-Tasking” Code
- Consider a SW Application Programmed with Two Tasks:
  - One task is assigned a low priority; other a high priority
  - In Multi-Tasking: LP task cannot run until HP is done
    - Programmer could have assumed Mutual Exclusion
  - In Parallel System: LP and HP can run at Same Time

Software Challenge - Technical Debugging

- Harder Because of Intermittent, Non-Deterministic Bugs
- Time Sensitive (Temporally Aware) SW Tools Needed
- New Parallel Debugging Tools Required
  - Need to Exert Temporal Control over Multiple Threads
  - Ideal Debugger would have:

    Reverse Execution Capability (cycle-accurate undo)

    Instant Replay Capability (w/ accurate time counter)
- Cannot Use Ad-hoc Debugging via PRINT Statements
  - Adds Extra Instructions which could Change Timing

Software Challenge - Technical Testing

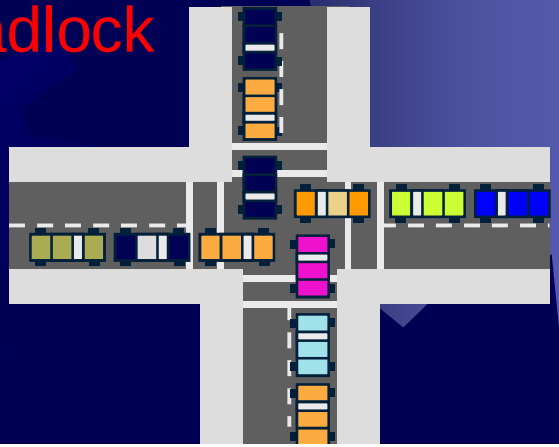
- Simple Code Coverage Metrics Insufficient

  e.g.) Just Tracking Statement or Branch Executions

- Need to Consider Other Code Executing in Parallel
  - Want to Test All Possible Instruction Interleavings
  - Otherwise, Code Would Not Be Fully Exercised
    - Especially Important to Check Interactions In Time

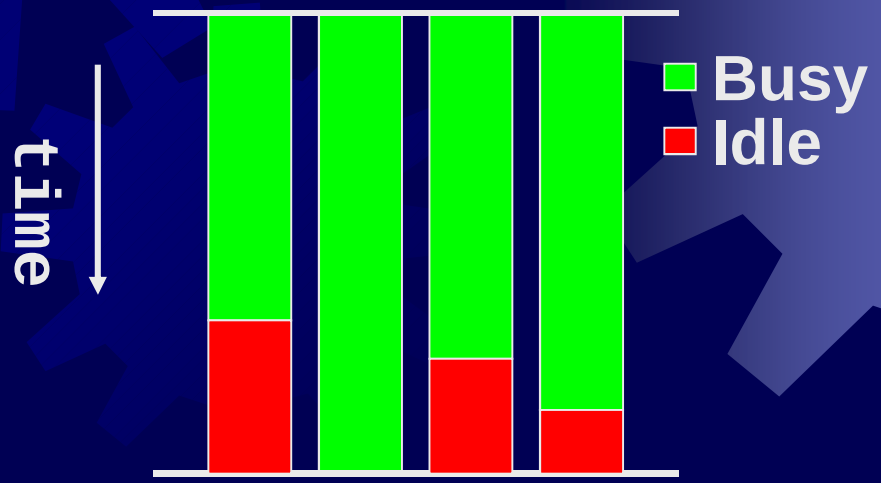
Race Condition

Deadlock



Software Challenge - Technical Performance Profiling and Tuning

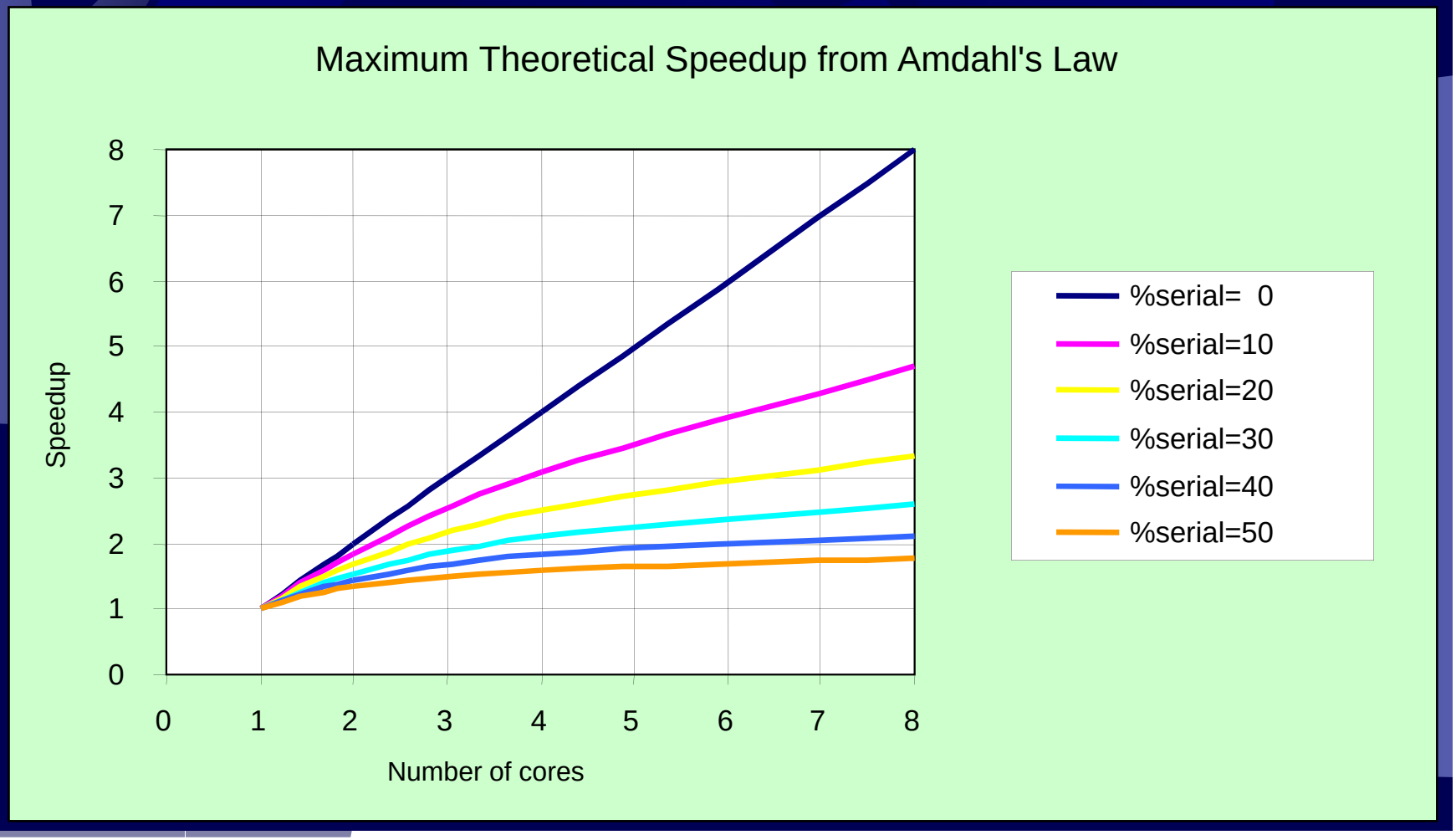
- Important to Know Which Code (sections) to Optimize
  - Concentrate on “Hot” Spots
- Harder in Parallel Because Must Consider:
  - Thread Creation & Synchronization Overhead
  - Communication to Computation Ratio
  - Thread Balancing



Software Challenge - Technical

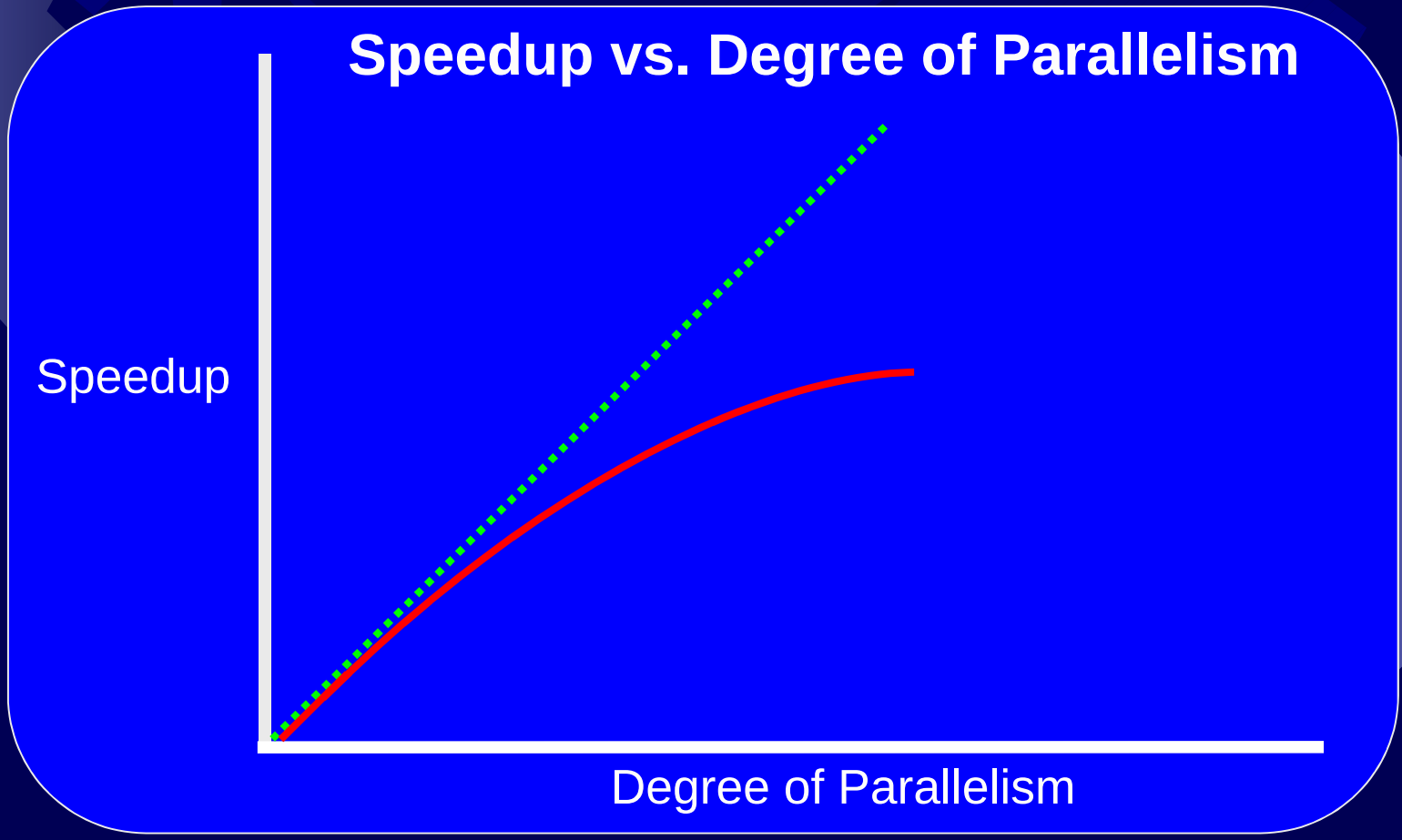
Amdahl's Law

- Parallel Speedup is Limited by the Amount of Serial Code



Software Challenge - Technical Parallel Scaling

- Potentially Negative ROI due to Parallel Overhead



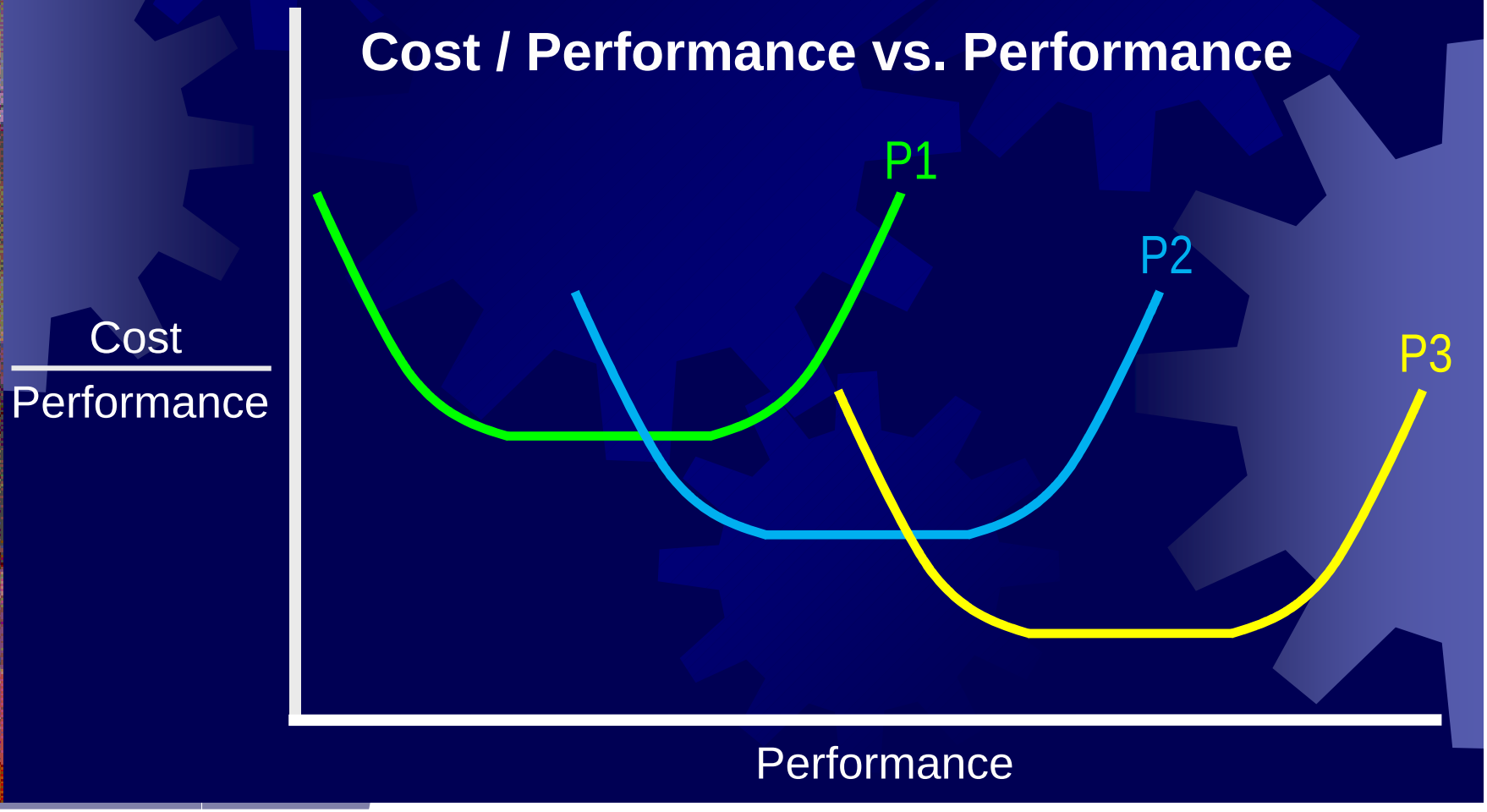
Software Challenge - Technical Parallel Scaling

- Implications of Amdahl's Law:
  - Diminishing Marginal Rates of Return from Parallelism
    - It will be Hard to get good Parallel Scaling from SW
  - Eliminating Sequential Code is Important
    - Even Small Amounts of Serial Execution can Render a Parallel Machine Ineffective

- Applications That Lack Sufficient Parallelism Will Be Performance Dead Ends

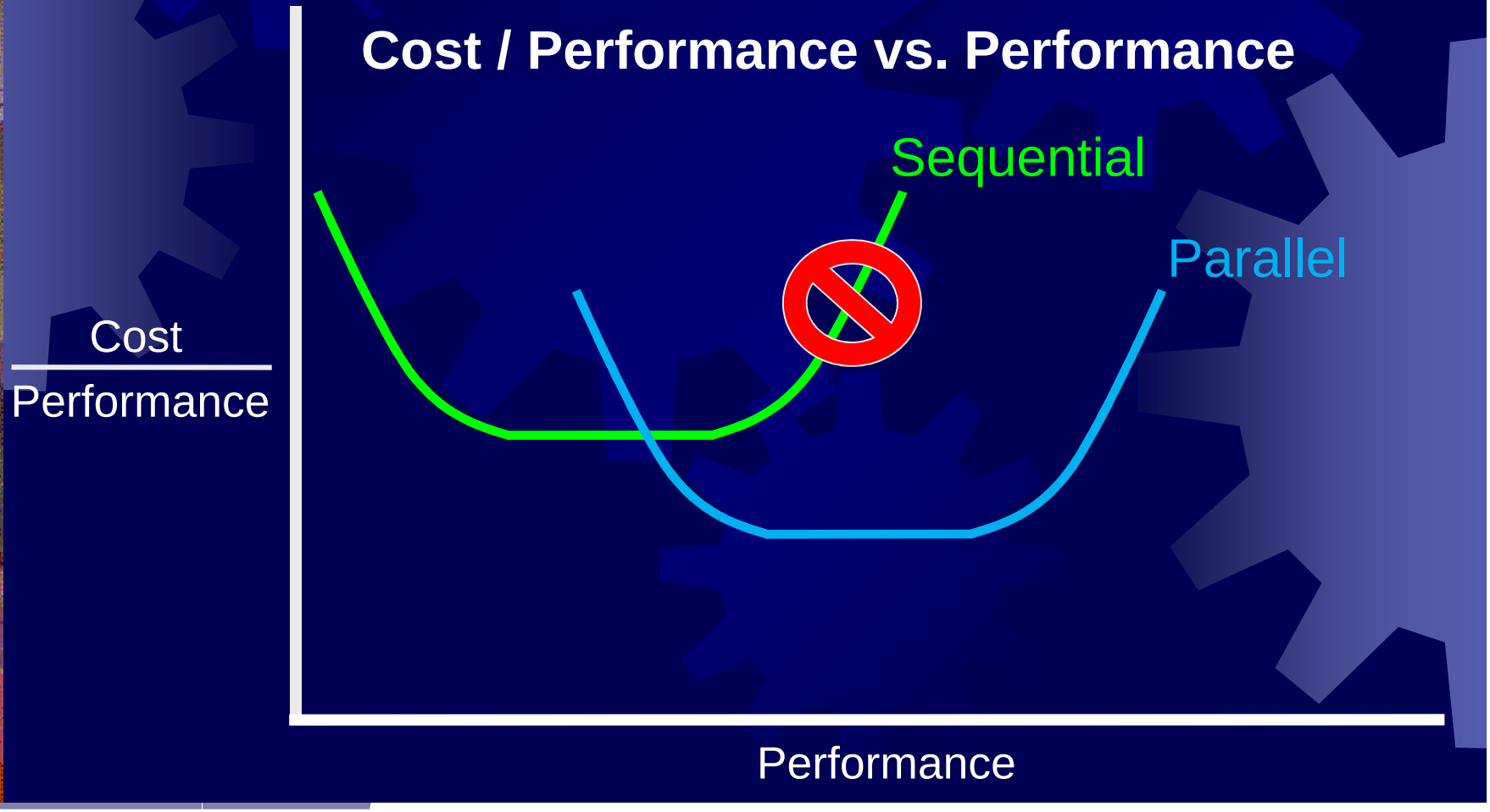
Software Challenge - Business Changing Technology Curves is Hard

- New Technology Curves Generally Appear “Down Right”



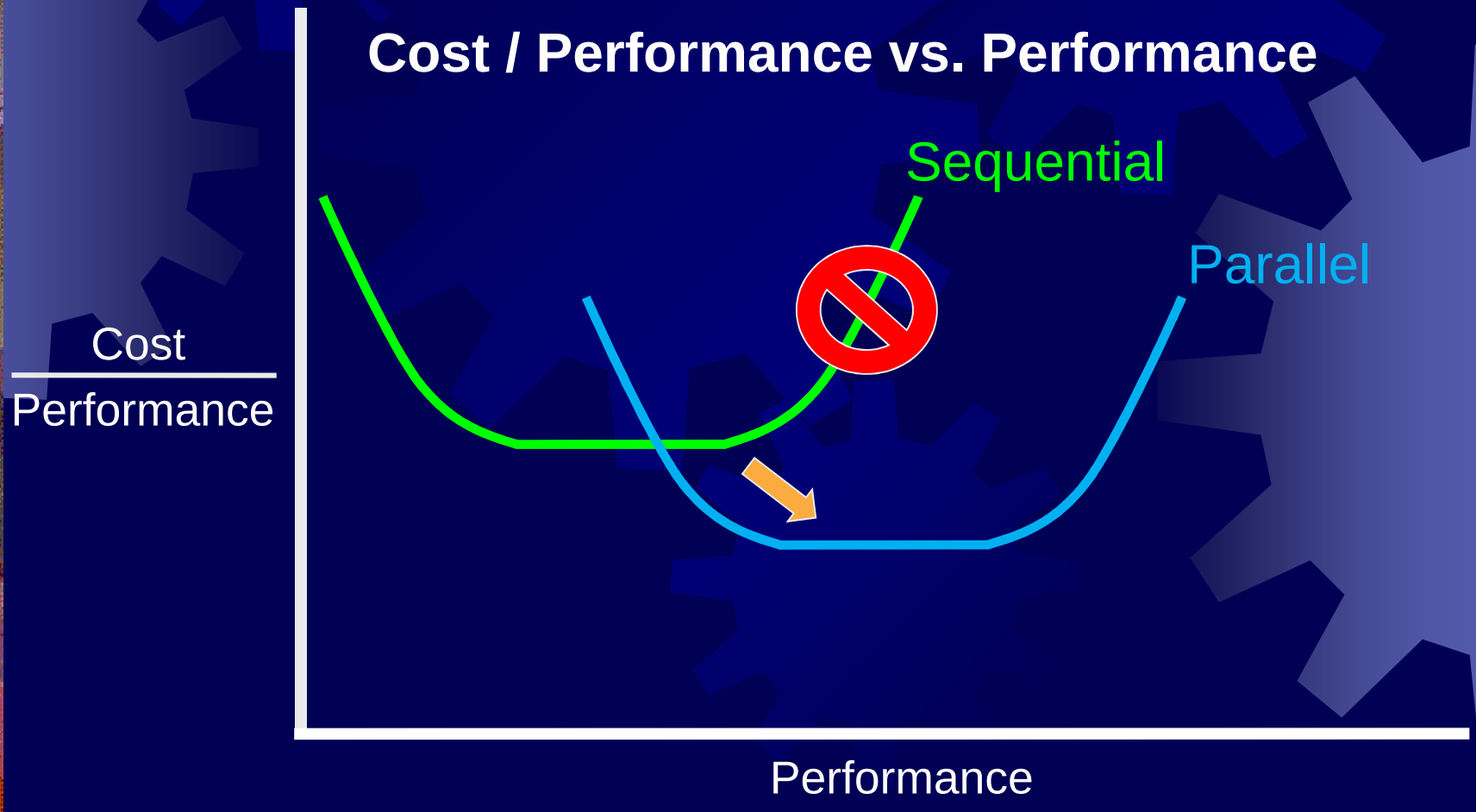
Software Challenge - Business Changing Technology Curves is Hard

- Never Ride Technology Curve “Up” into Over-Utilization



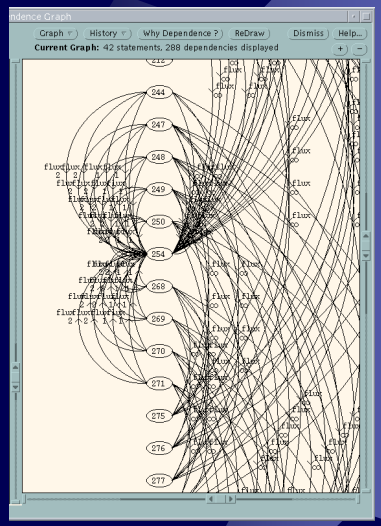
Software Challenge - Business Changing Technology Curves is Hard

- Change ("Hop Down Right") to New Tech Curve Instead

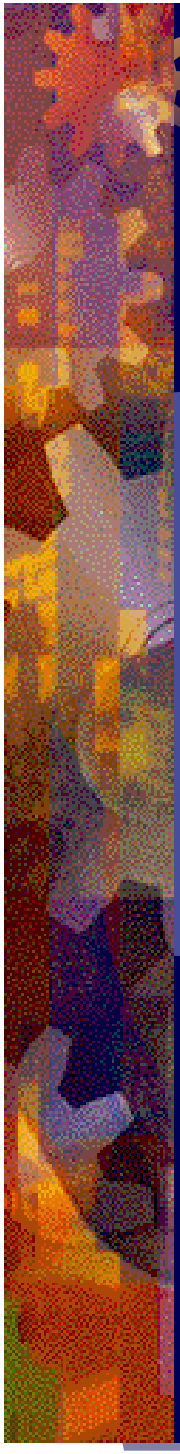


Software Challenge - Business Changing Technology Curves is Hard

- Investment in Training and New Tools Required
  - Learning Curve for Employees
  - Entirely New SW Engineering Infrastructure
    - Design / Re-engineering
    - Debugging
    - Testing
    - Profiling
    - Scaling



- Legacy Code Needs to be Re-engineered for Parallelism



Key Points

Software Challenge

- Parallel Programming is Hard
  - More Complex
  - Lack of Tools
  - New Type of Bugs
    - Race Conditions
    - Deadlocks
  - Harder to Debug, Test, Profile, Tune, Scale

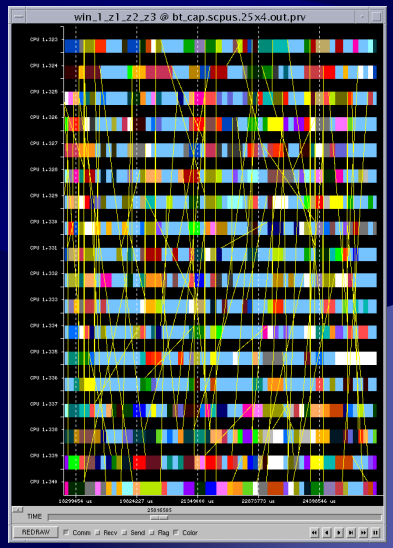
- Parallel Programming is a Software Challenge

Outline

- Hardware Solution
- Software Challenge
- Opportunities
  - Technical
  - Business

Opportunities - Technical

- Opportunity to Create New SW Engineering Infrastructure
  - Better, Smarter Tools for
    - Design / Re-engineering
    - Debugging
    - Testing
    - Profiling



- Opportunity to Re-Invent Entire SW Engineering Field
  - Algorithms, Languages, Compilers, Processes……
  - Dawn of a New Era
    - Second Chance (to get it right)

Opportunities - Technical

- The Universe is Inherently Parallel
  - Natural Physical and Social / Work Processes
    - Weather, Galaxy Formation, Epidemics, Traffic Jam
- Can Leverage Unique Capabilities offered by Parallelism
- Add New Features via Separate Parallel Modules
  - Avoids Re-engineering of Old Module
  - More Functionality
  - No Increase in Wall Processing Times
- Speculative Computation

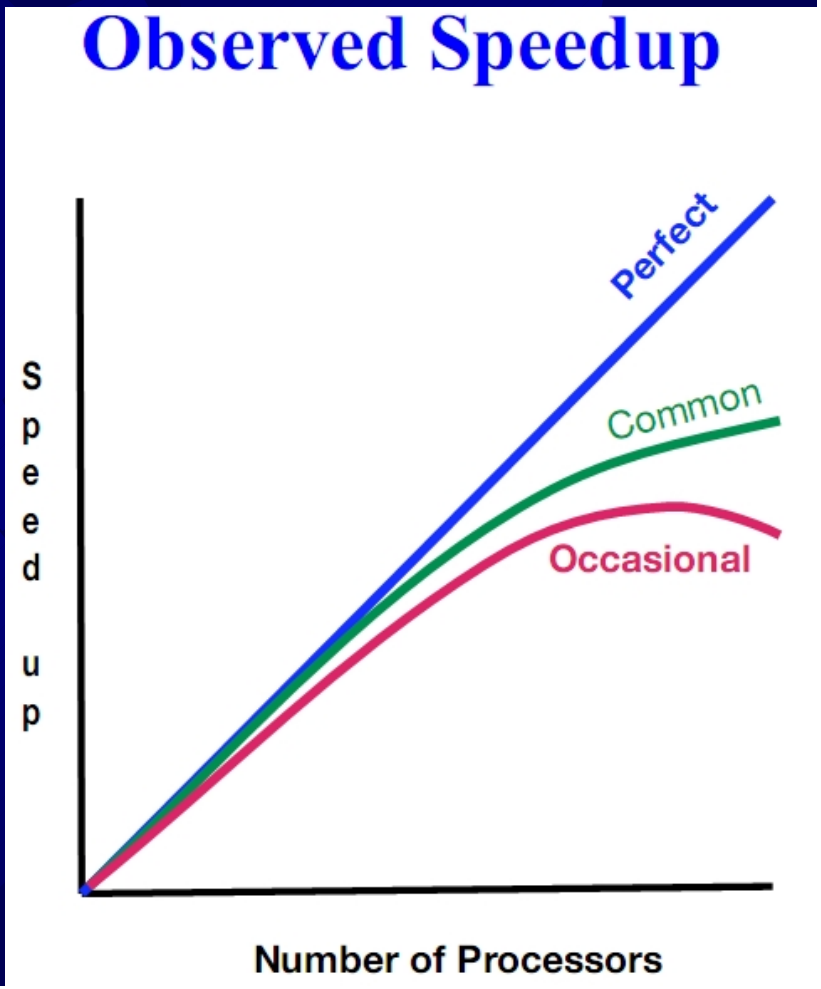
  Precompute alternatives to Minimize Response Time

  e.g.) Video Game Up / Down / Left / Right

  More Responsive User Interfaces

Opportunities - Technical

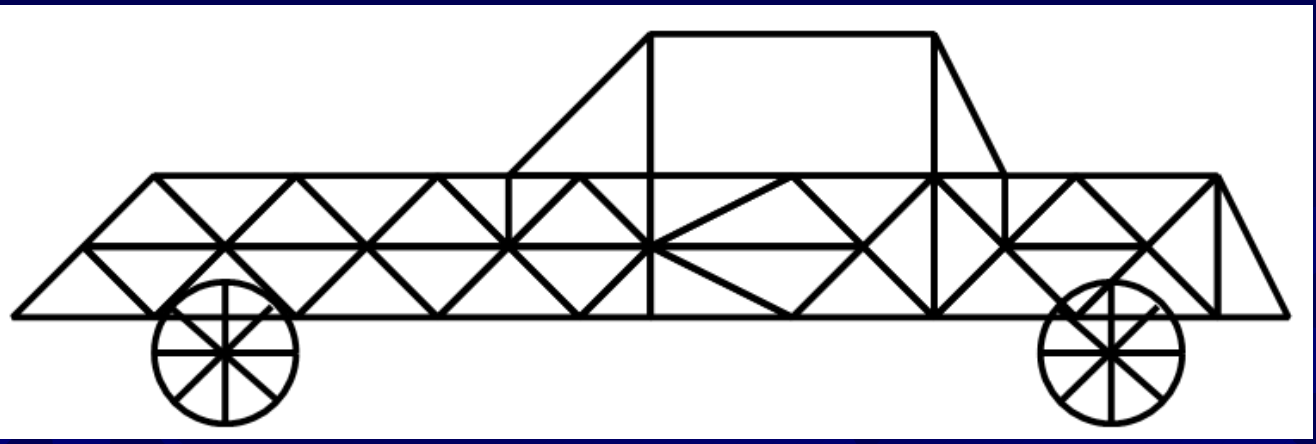
- (Yet) Undiscovered Technical Opportunities
- New Parallel Algorithms
- Super-Linear Speedups
  - Parallel Computer has N times more Memory
  - Larger % of SW can fit in upper Levels of Memory Hierarchy
  - "Divide and Conquer" leverages faster Mems
  - An Important Reason for using Parallel Computers



Opportunities - Business High Performance Computing (HPC)

- Cloud and Parallel Processing Makes HPC Ubiquitous
- New Applications Become Possible
  - Personalized Drugs (Genetic & Molecular Profiling)
  - Stream Computing (Real-Time Analytics)
- Smarter Applications Become Possible
  - Virtual Assistants
- Efficiency Becomes Possible
  - High-Fidelity Simulations

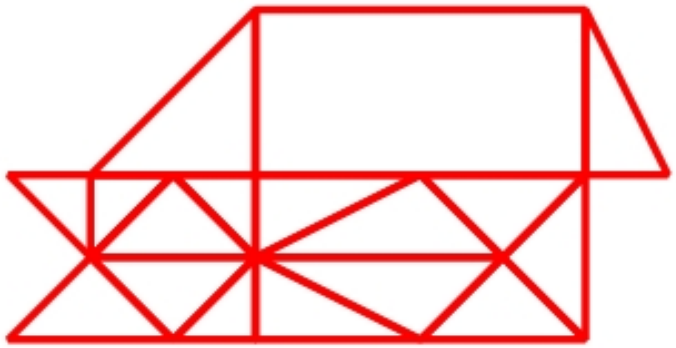
    e.g.) Car Safety Tests

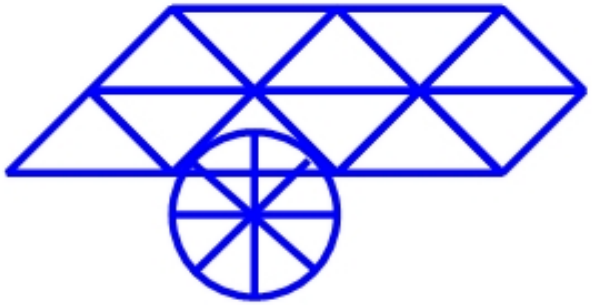


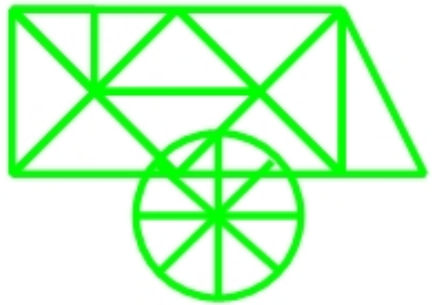
Basic Serial Crash Simulation

```
1  For all elements
2      Read State(element), Properties(element),
           Neighbor_list(element)
3  For time=1 to end_of_simulation
4      For element = 1 to num_elements
5          Compute State(element) for next time step,
               based on previous state of element and its
               neighbors, and on properties of element
```

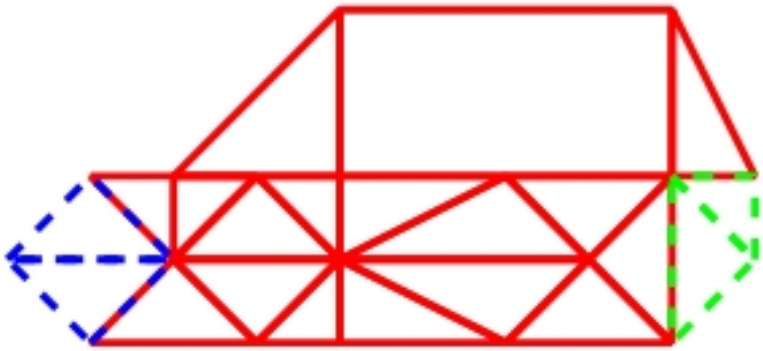
A Distributed Car

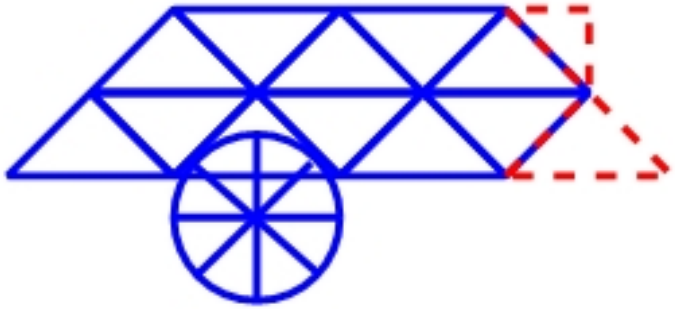


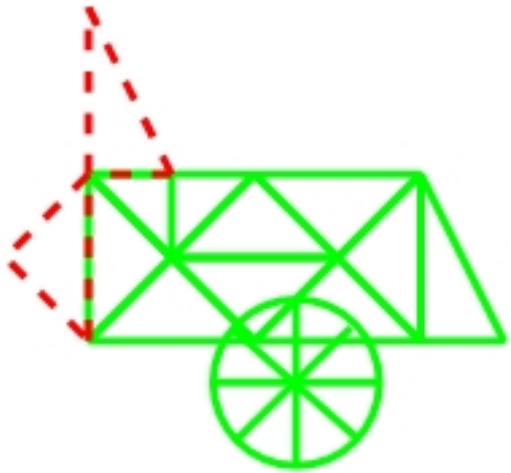




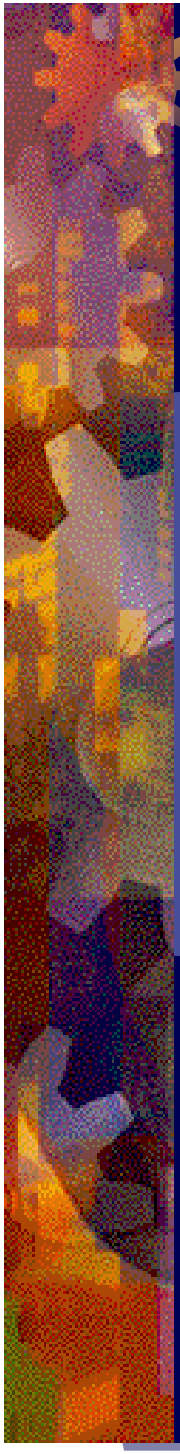
Ghost Cells







Opportunities - Business



Opportunities - Business High Performance Computing (HPC)

- Grand Challenges Become Possible
- Grand Challenge was Defined by Wilson in 1987:
  - Fundamental Problem in Science or Engineering
  - Has Potentially Broad Economic and Scientific Impact
  - Could be Advanced with HPC Resources
- Grand Challenge 3T Goal:
  - 1 TeraFlop/second of Processor Power
  - 1 TeraByte of Main Memory
  - 1 TeraByte/second of I/O Bandwidth

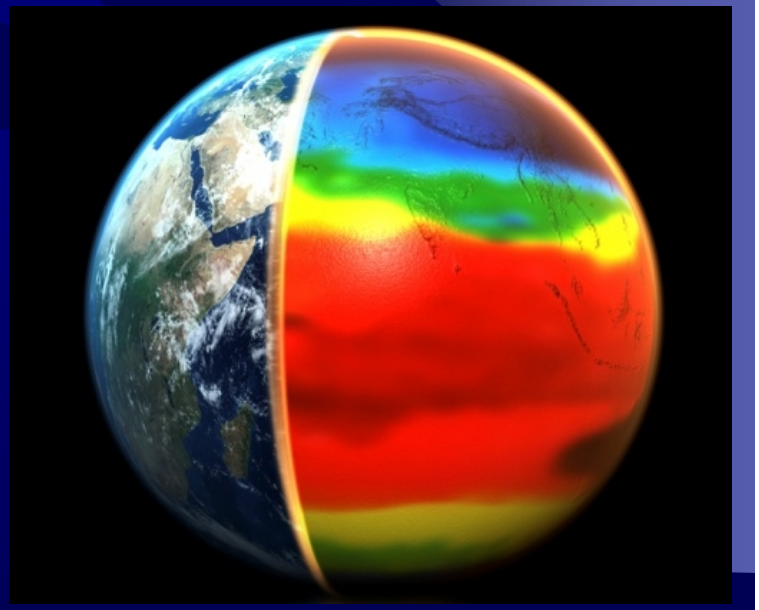
Opportunities - Business High Performance Computing (HPC)

- Examples of Grand Challenges
  - Data Mining and Fusion
  - Hurricane Prediction
  - Global Warming
  - World Hunger
  - Cure for Serious Diseases

REVIEW & OUTLOOK | JANUARY 8, 2010

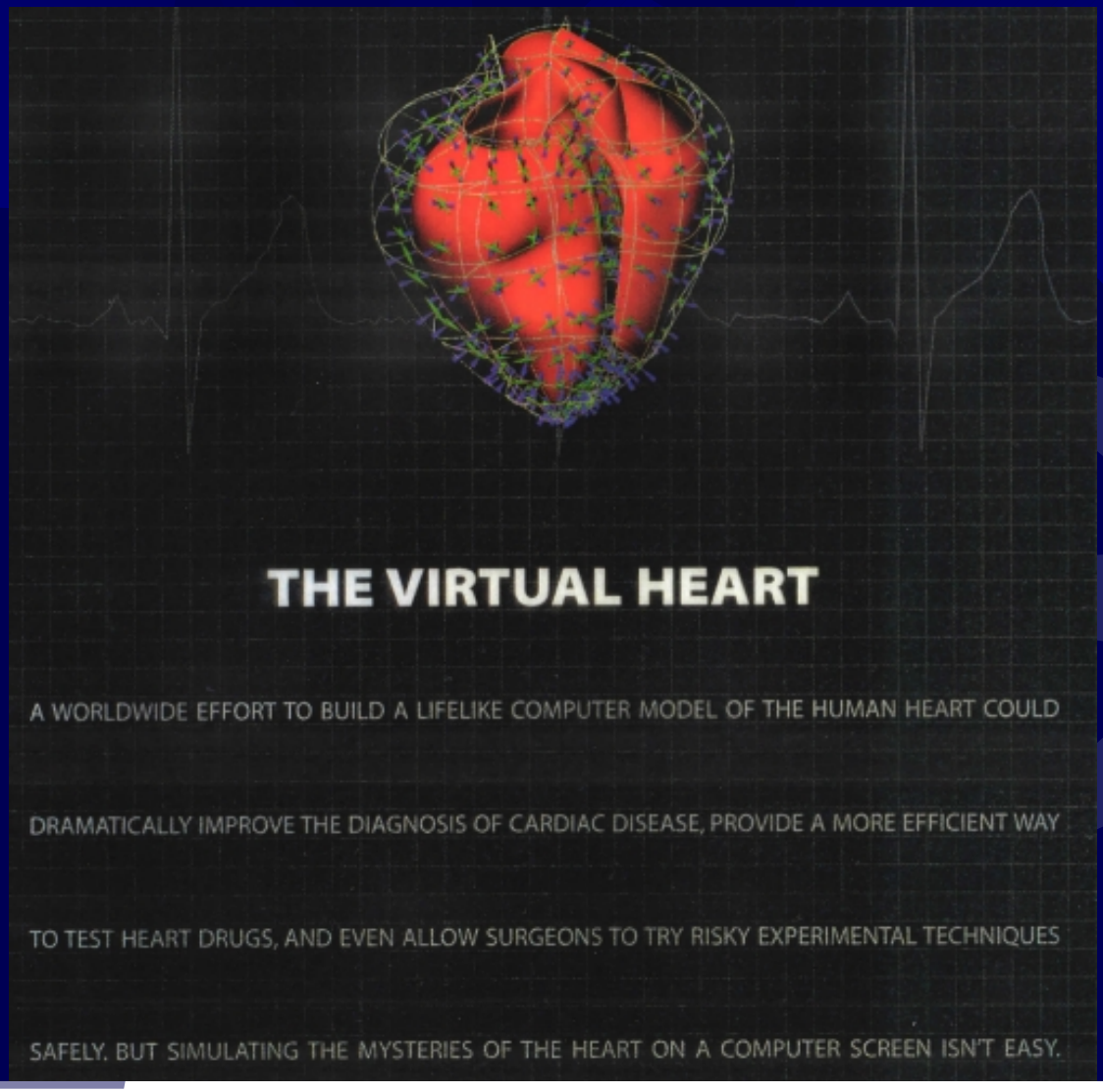
'A Failure to Connect the Dots'

A lesson in the lack of bureaucratic intelligence.



Opportunities - Business

New Capabilities to Benefit Mankind



Opportunities - Business

New Capabilities to “Entertain” Mankind

…. Maybe even “OutSmart” Mankind

NETWORKWORLD

This story appeared on Network World at
http://www.networkworld.com/news/2010/021010-ibm-jeopardy-game.html

IBM's Jeopardy-playing machine can now beat human contestants

'Watson' may face Jeopardy public challenge within a year
By Jon Brodkin, Network World
February 10, 2010 04:58 PM ET

IBM's Jeopardy-playing supercomputer is now capable of beating human Jeopardy contestants on a regular basis, but has a ways to go before it takes on the likes of 74-time champion Ken Jennings.

IBM announced plans to build a computer that can win on Jeopardy last April, and expects to stage a public tournament involving human players and the machine within the next year or so.

IBM Supercomputer to Compete on Jeopardy

The question-answering system, nicknamed "Watson", is already doing trial runs against people who have actually appeared on the Alex Trebek-hosted Jeopardy. Watson's competition includes people who qualified for the show but lost, people who appeared and won once, and people who appeared and won twice.

Opportunities - Business

Corporate & National Competiveness

IBM Reclaims Supercomputer Lead

But stay tuned—supercomputers are getting faster, at an even faster rate

NASA Ames machine sets new speed record

SILICON GRAPHICS PROVIDED 'COLUMBIA' SYSTEM

IBM Takes On Petaflop Barrier

NEVER SAY THAT NOTHING good comes out of computer games. By harnessing a processor originally built for the upcoming Sony PlayStation 3, IBM is building a supercomputer that's expected to smash the petaflop barrier with a speed of 1,000 trillion calculations per second.

gress laid out $35 million, is a base cluster that runs on the Linux operating system and uses IBM System x 3755 servers based on AMD Opteron technology. That system is slated to ship to the national lab next month.

But the computer's real

The real challenge ahead lies in building software sophisticated enough to examine a calculation and decide which processor to assign to it, Addison Snell of IDC says.

1,000 TRILLION The number of calculations per second Roadrunner will run

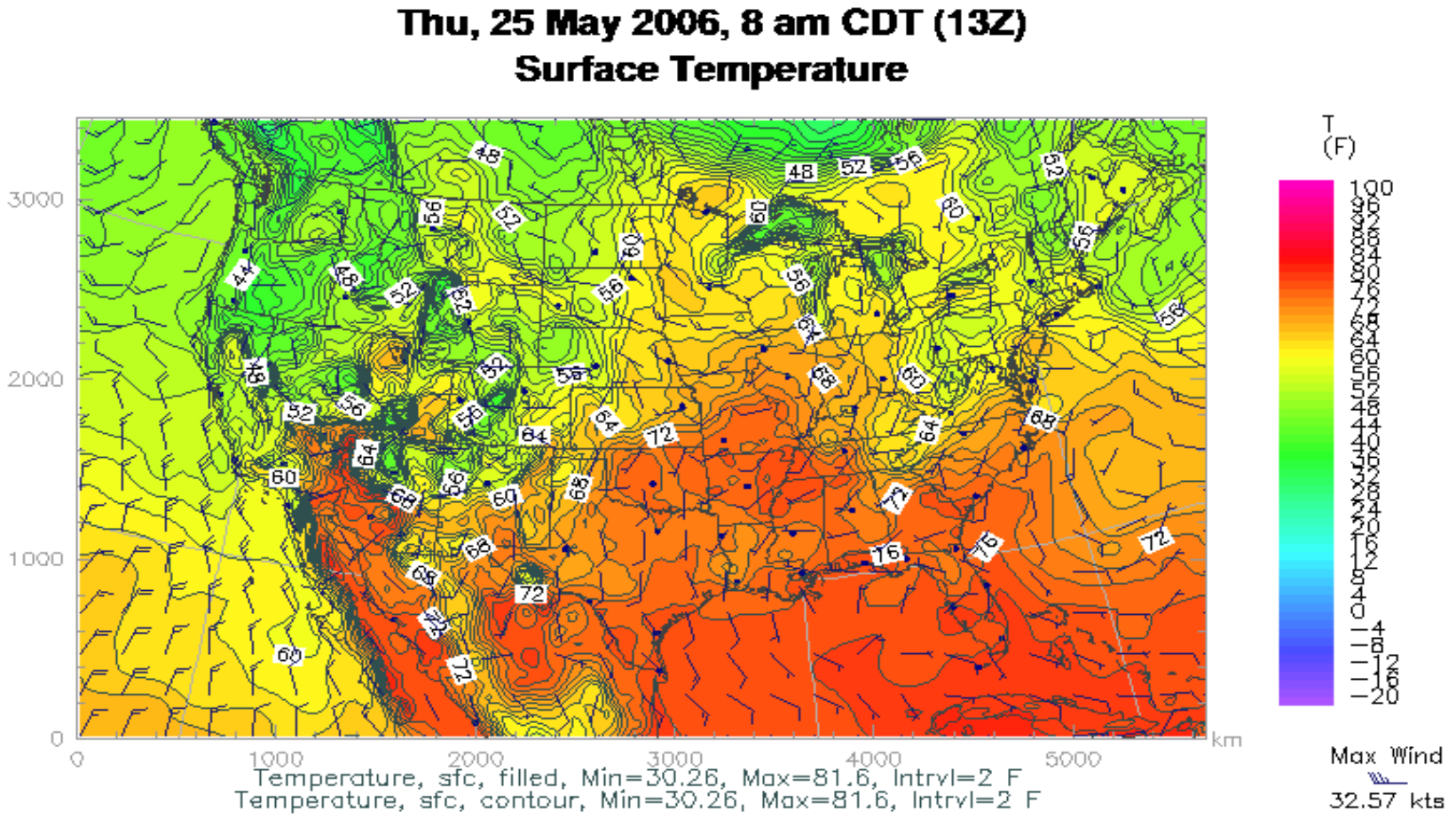
IBM's Blue Gene/L is currently the fastest supercomputer in the

Opportunities - Business Visualization

- Assist in the Interpretation of Massive Data Sets.
- For example, a 5 day weather forecast of the continental U.S. would produce **10 terabytes**
- No one can look at that many numbers,
  But a Picture is worth a Thousand Words.
  And a Movie or Animation is worth a Million Words.
  - Time-lapse simulation of Global Warming
- Humans can detect and interpret high-level visual Patterns even better than a computer can today.

"If a picture is worth a thousand words, don't ever show Margaret any pictures!"

Example Visualization: Weather Forecast

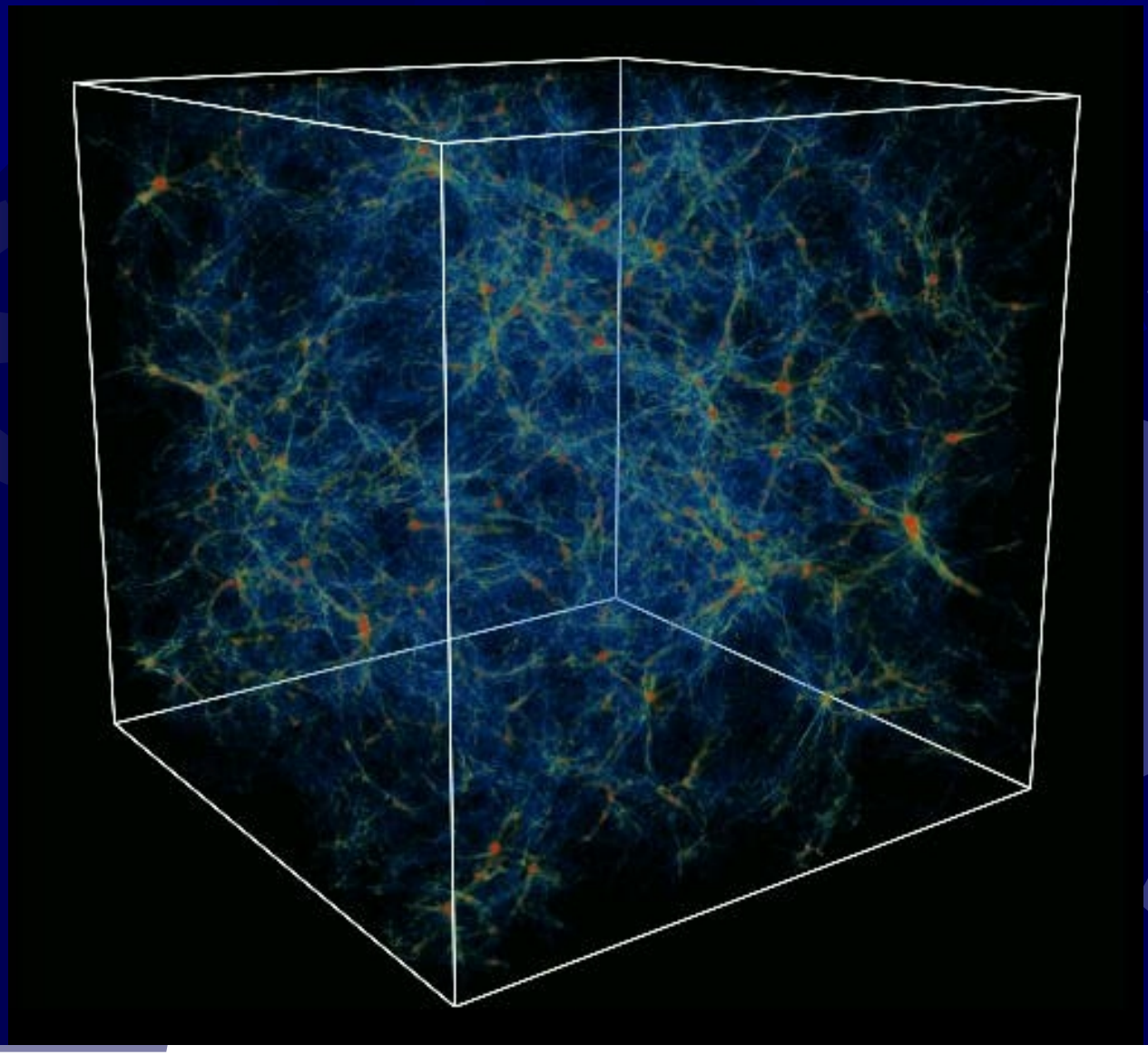


CAPS/OU Experimental ADAS Anlys

CONUS, 210x128x50, dx=27 km

05/25/06 08:45 CDT

Example Visualization: Structure of the Universe



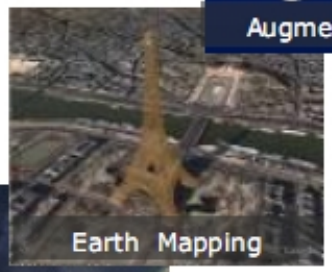
Opportunities - Business

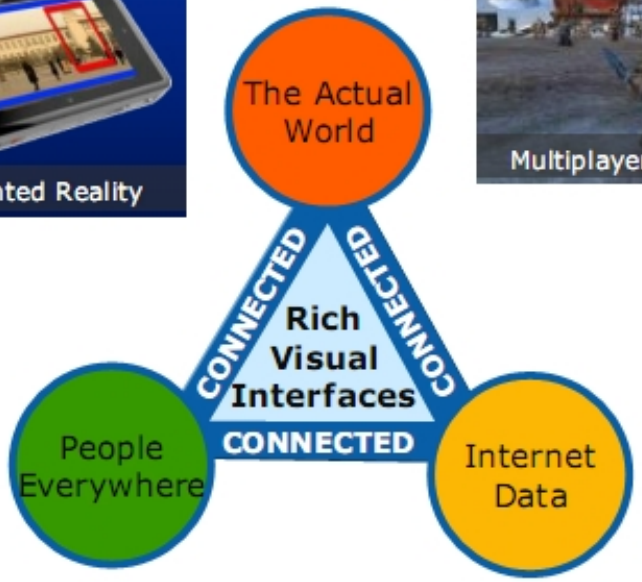
Next: Immersive Connected Experiences

Bringing the richness of VC to connected usage models such as social networking, collaboration, online gaming, & online retail.

Enhancing the actual world

Creating new digital worlds





Better content quality, social interaction

Opportunities – Business Meeting People's Expectations About Multitasking Capabilities

Apple
iPad
Jan 2010

There's no multitasking. "Are you saying I can't listen to Pandora while writing a document? I can't have my Twitter app open at the same time as my browser? I can't have AIM open at the same time as my email? Are you kidding me? This alone guarantees that I will not buy this product," Gizmodo's Adam Frucci writes.

The World is Moving Towards Parallel Processing On The Cloud

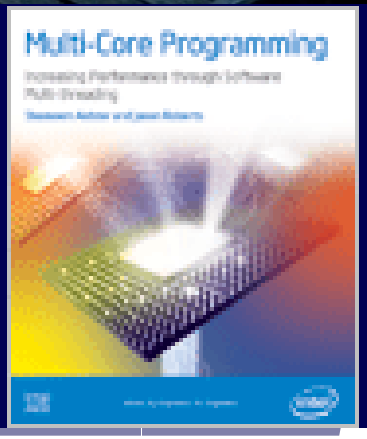
The Cloud Offers Even More Opportunities

Opportunities - Business
Ubiquitous HPC via Cloud

- HPC on Mobile Devices Possible
- "CloneCloud" (Berkeley Research Labs)
  - Clone Smartphone in Cloud
    - Off-load Compute-Intensive tasks
    - Conserve Mobile Device Battery Life
- "Fusion Render Cloud" for Mobile Gaming (AMD)
  - Cloud Computes Game Graphics and Compresses it
  - Mobile's Computation Simplified to Decompression


Using Parallel Programming,
You Can Reach The Clouds
And The Sky is The Limit !

Wondering about Parallel Programming?



Plan to Read Entire MCP Book, *Except* for:

- Skip Ch. 5
- Read only the first part of Ch. 8 (up to 219)
- Read only the first part of Ch. 10 (up to 265)
- Only Skim Ch. 11