Performance in the Age of Trustworthy Computing

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PPRC

Microsoft Research

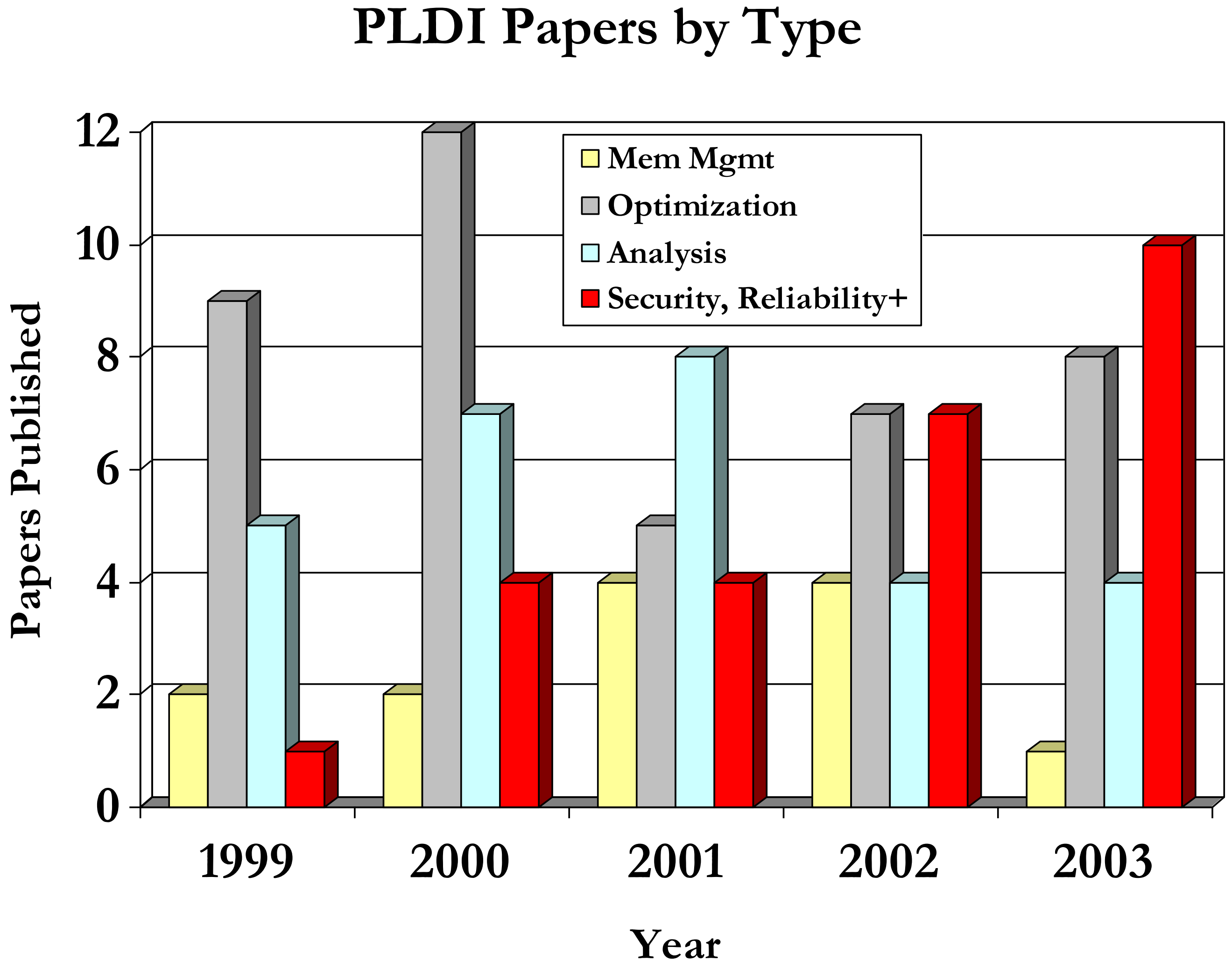
Trustworthy Computing (TwC)

- “Six months ago, I sent a call-to-action to Microsoft's 50,000 employees, outlining what I believe is the highest priority for the company and for our industry over the next decade: building a Trustworthy Computing environment for customers that is as reliable as the electricity that powers our homes and businesses today.”

  Bill Gates
  Executive Memo, 7/18/02

  (emphasis mine)
- Trustworthy = secure, reliable, available, private, etc.

TwC Research on the Rise

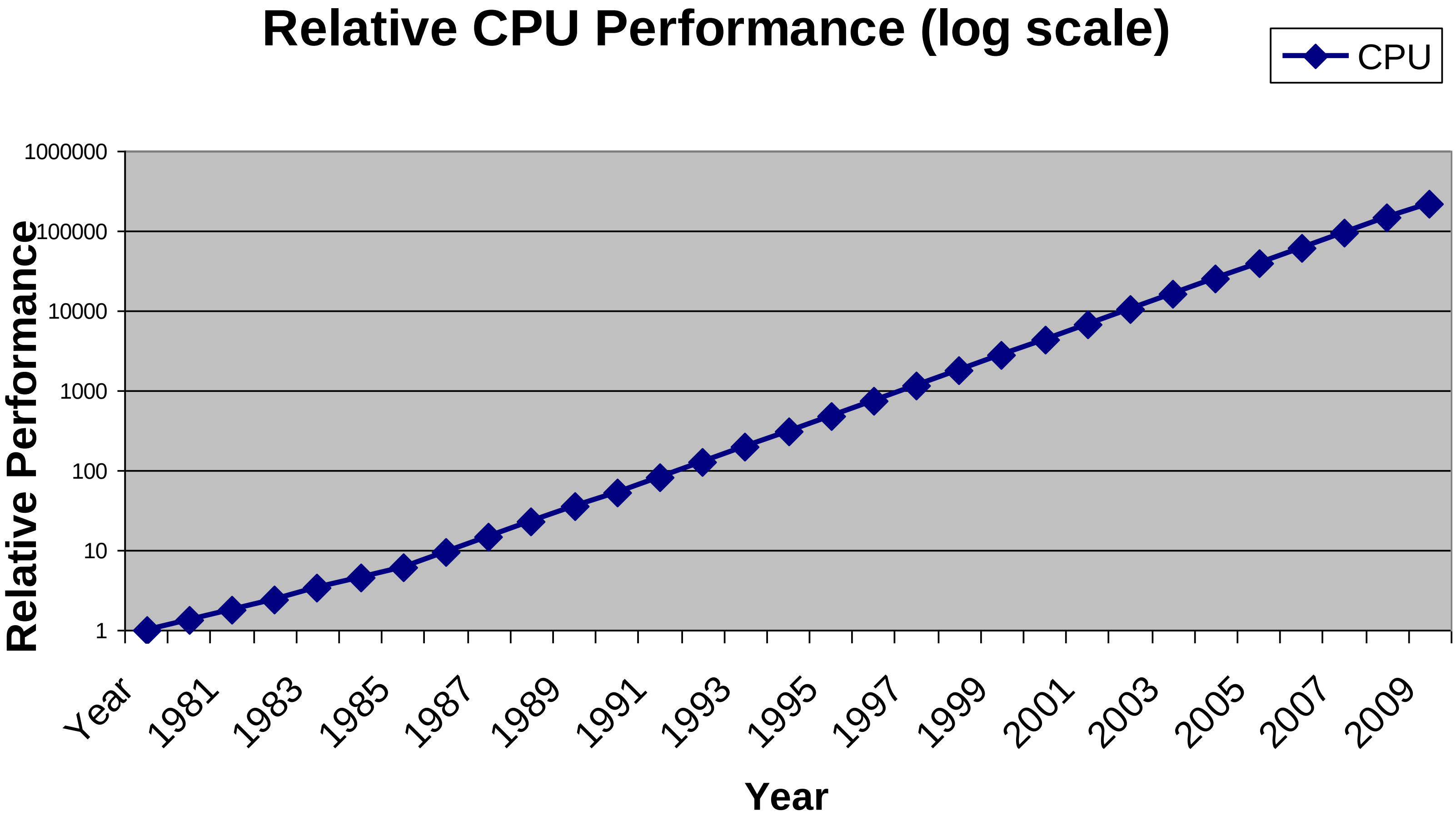


Proebsting's Law and other Doubts

- Moore's Law states roughly that advances in hardware double computing power every 18 months
- **"Compiler Advances Double Computing Power Every 18 *Years*"**
  - Todd Proebsting, Microsoft Research
  - ***"Perhaps this means Programming Language Research should be concentrating on something other than optimizations. Perhaps programmer productivity is a more fruitful arena."*** http://research.microsoft.com/~toddpro/papers/law.htm

- Other doubts about performance and optimization research
  - "Is Code Optimization Research Relevant?" Bill Pugh, U. Maryland
  - "Systems Software Research is Irrelevant" Rob Pike, Bell Labs

Exponential Growth is Hard to Beat…



Data from *Computer Architecture: A Quantitative Analysis (3rd ed.)* by Hennessy and Patterson

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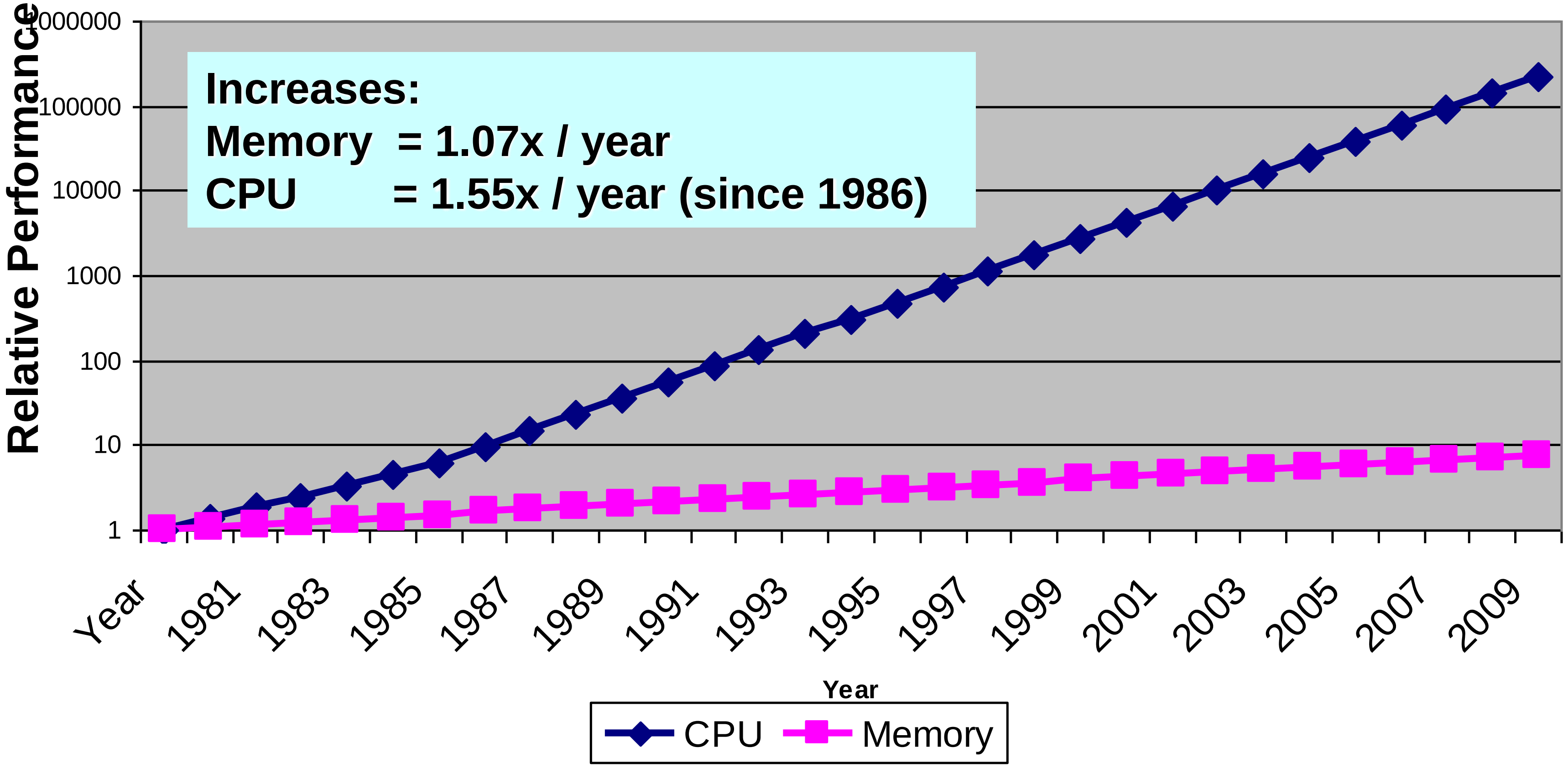
Performance is Dead, Long Live Performance!

- A revolution is happening, but…
- Performance is not a solved problem
- Outline for rest of talk
  - The Memory Wall and Efforts to Climb It
    - Memory latency
    - Optimizing layout to reduce disk I/O
  - Challenges and Opportunities of Managed Code
  - Concurrency (I wish I had time…)

Revisiting Moore's Law…

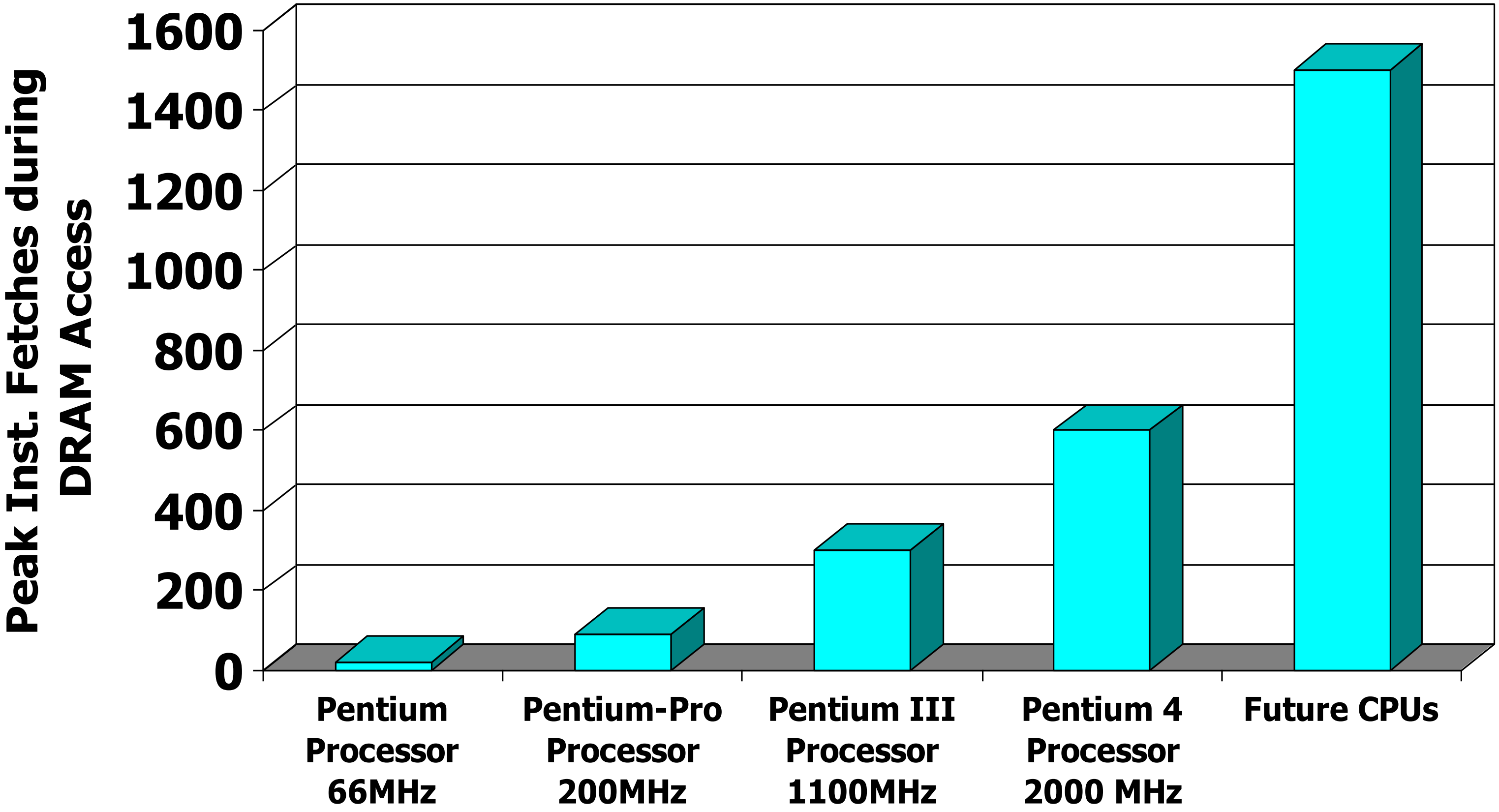
CPU / Memory Performance Gap (log scale)



Increases:
Memory = 1.07x / year
CPU = 1.55x / year (since 1986)

Data from *Computer Architecture: A Quantitative Analysis (3rd ed.)* by Hennessy and Patterson

Caches Hide Many Cycles of Latency



Data from Dileep Bhandarkar, Intel Architect, PACT 2002 Keynote Address
“Parallelism in Mainstream Enterprise Platforms of the Future”

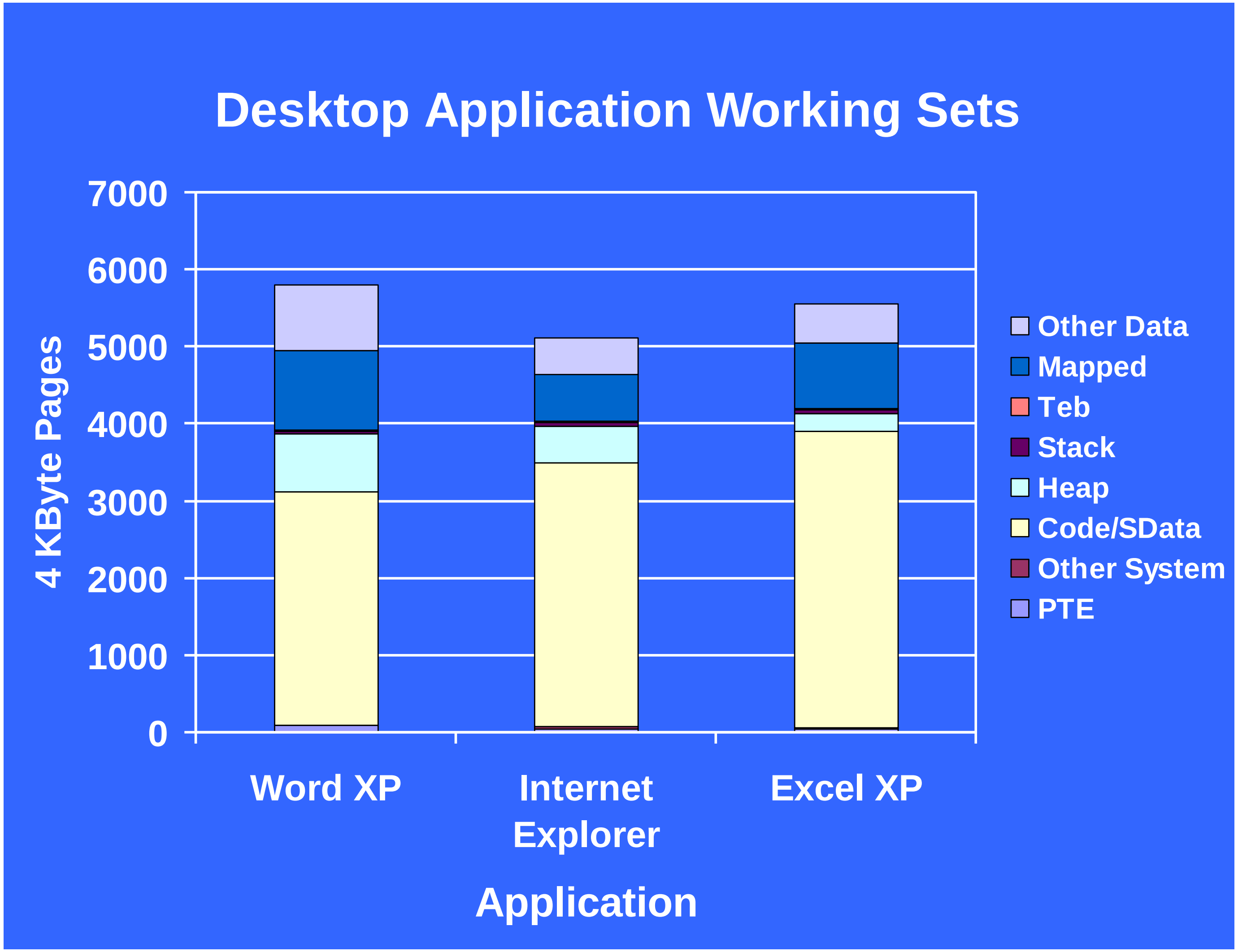
A Case Study – Optimizing Working Set

- Relative cost of I/O is enormous
  - 40,000,000+ cycles per page fault
  - Much user-perceived latency is disk-related
- Overview
  - PPRC and our approach
  - Improving code locality via reordering with profiles
  - Results
  - Process considerations
- Work of Hoi Vo’s Binary Technologies (BiT) group

What is PPRC?

- PPRC – Programmer Productivity Research Center
  - Amitabh Srivastava, Director
  - Focus on improving software development process
  - Areas: performance, correctness, compilation, tools
  - Approach
    - Build flexible infrastructure on which to layer tools, research
    - Build strong interactions with product teams by focused solutions
    - Used knowledge of important problems to drive infrastructure and further research
  - Successes
    - Vulcan – binary instrumentation
    - PREfix – static analysis for error detection

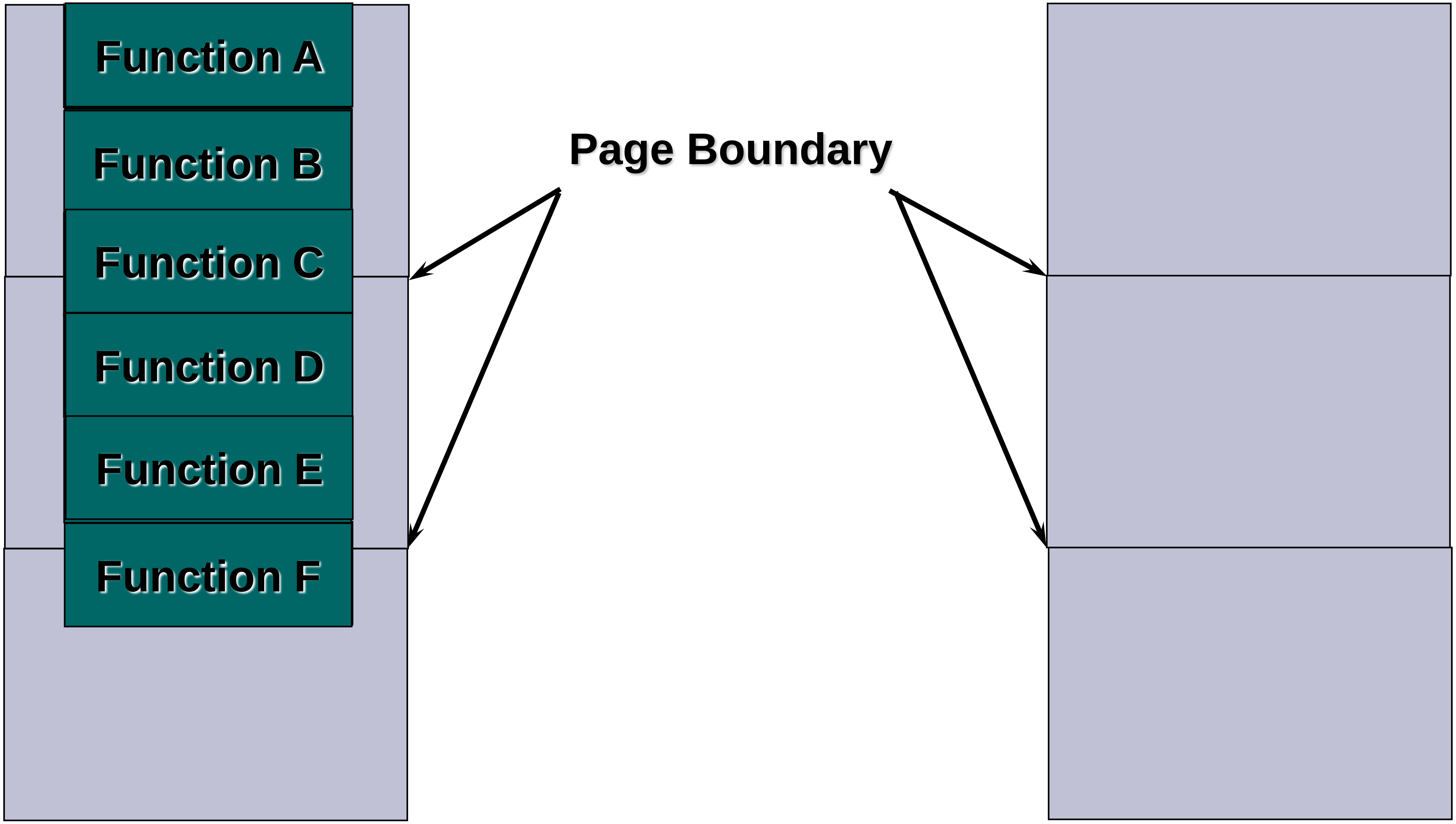
Code Does Matter



Improving Code Locality

- Basic idea – use profiles to direct code placement
    - Separate hot/cold functions, basic-blocks
    - Impact at page level, cache level
    - Static data can be placed with code where used
- Profile methodology
    - Separate instrumented build to gather profiles
    - Requires mechanisms to integrate profiles from different scenarios, weight them
    - Impact on build process cannot be ignored

Function Reordering



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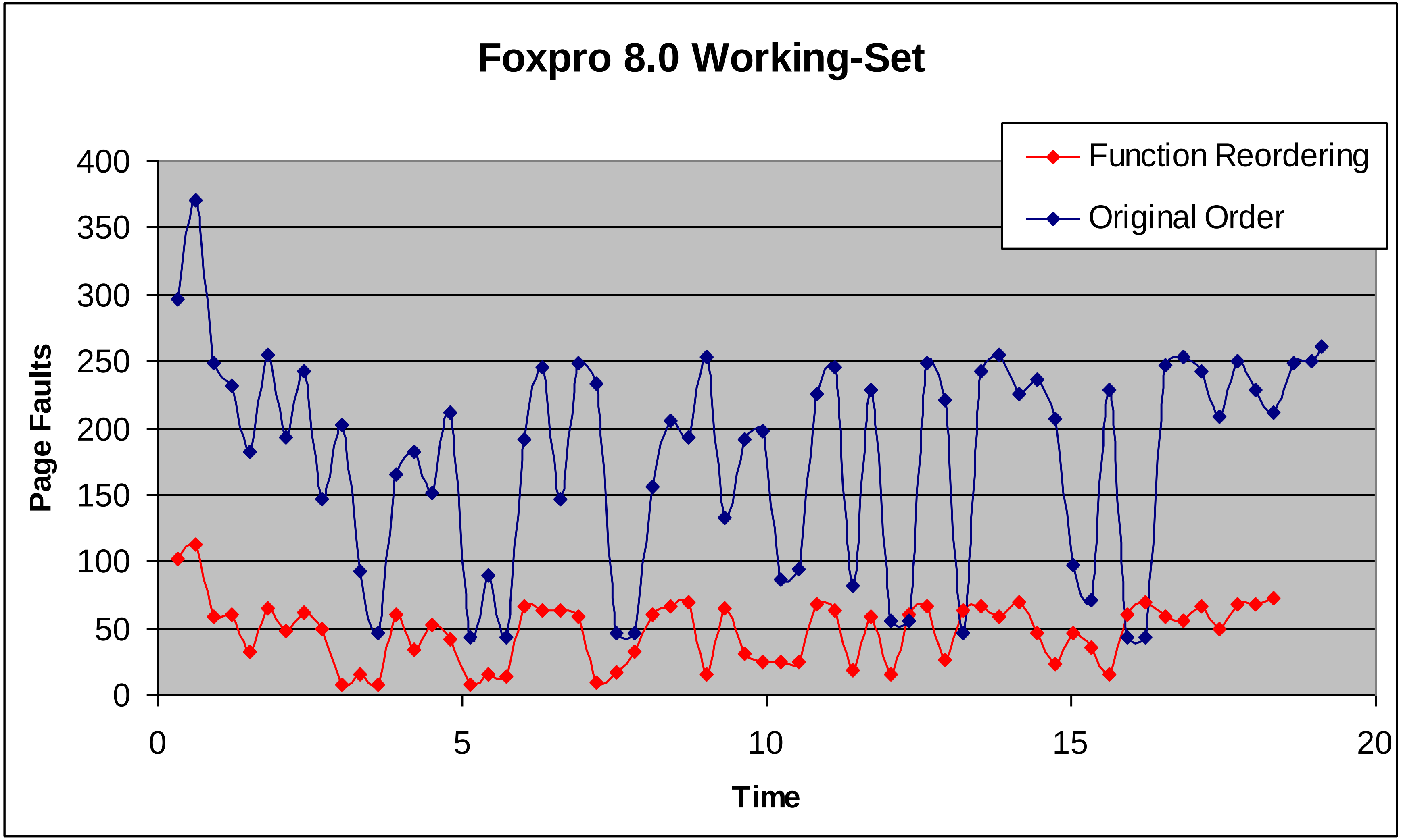
Results



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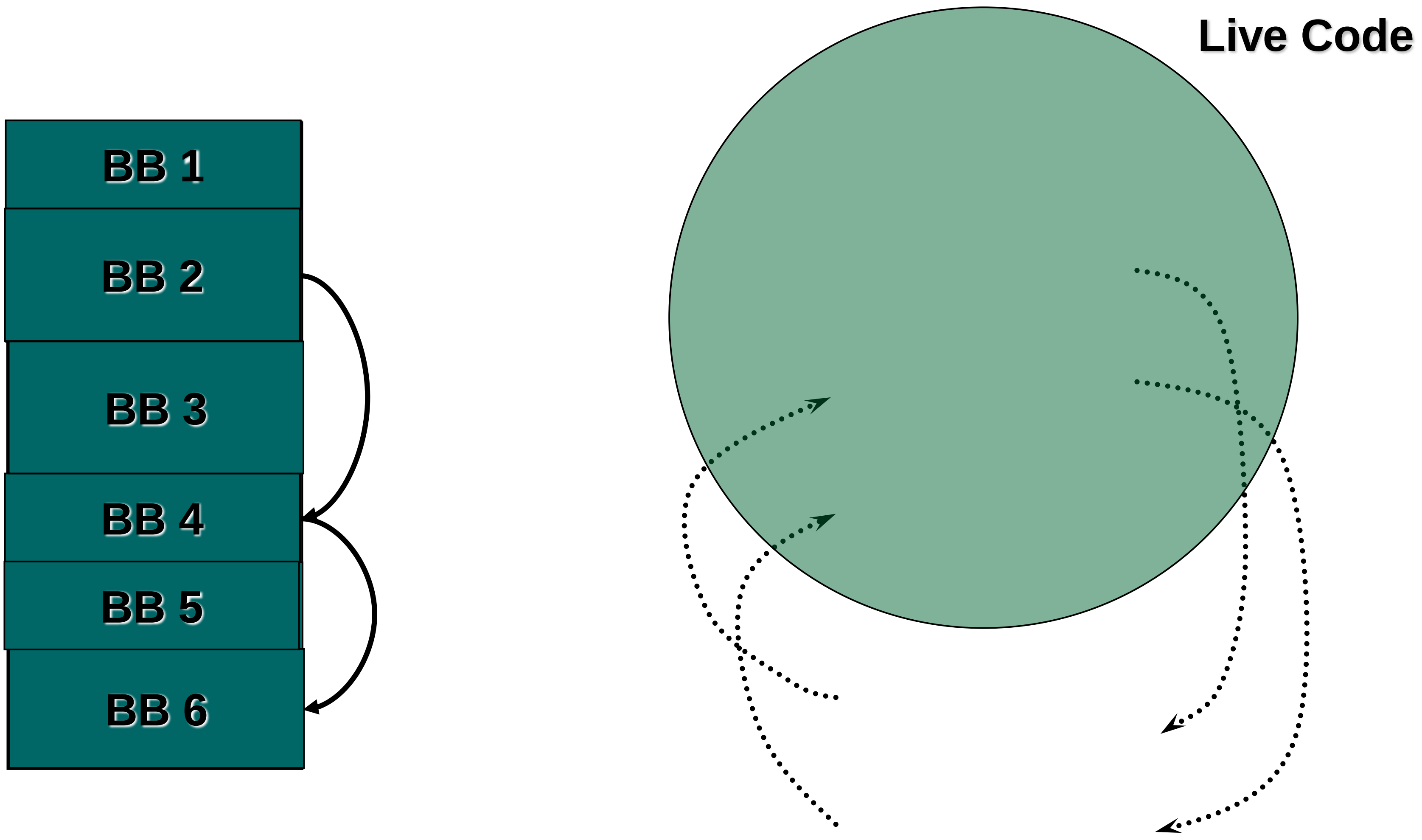
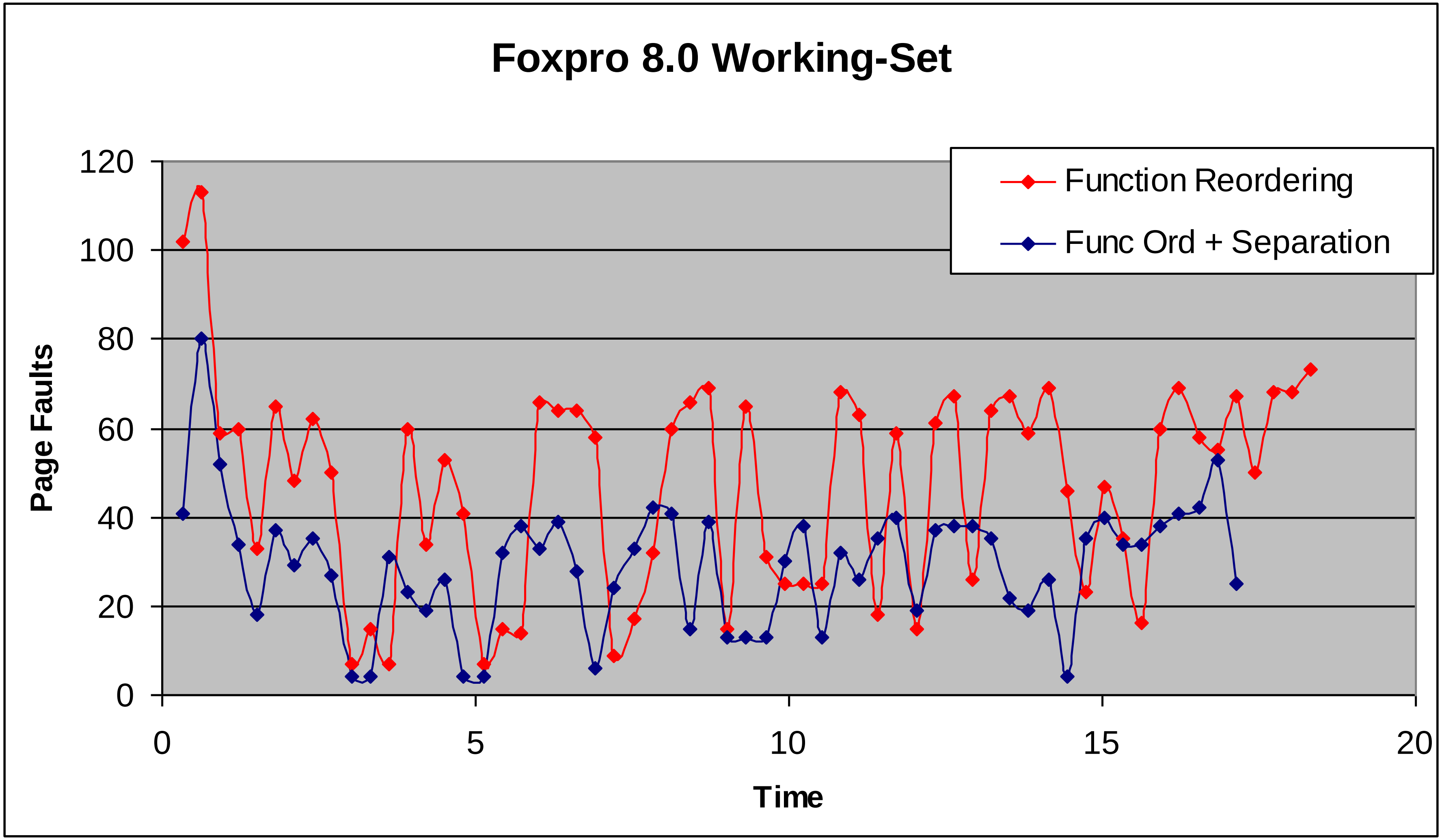
Function Separation



Results


Foxpro 8.0 Working-Set
Function Reordering
Func Ord + Separation
Page Faults
120
100
80
60
40
20
0
Time
0
5
10
15
20

Making It Work for Real

- Must be well integrated into build process
  - Different for every major group
  - Vulcan technology key to widespread adoption
- Time budget
  - “Compile -> Profile -> Opt” process rarely fits within time constraint
  - Profile rarely matches the same build
- Multiple platform support
- Serviceability
  - Debuggers work after code reordering
  - Patching

Managing Profile Data

- Organizing scenarios
  - Startup important in reducing delay
  - Phases associated with typical uses (print, spell check, etc.)
- Stale profile data
  - Collecting new profiles takes lots of time
  - Delaying the build cycle is unacceptable
  - Solution: profile propagation via binary matching
    - Most profile data remains similar between builds

Data Locality Research

- Data presents additional challenges
- Trishul Chilimbi – Daedalus Project
- Goal – identify opportunities to improve data locality and exploit
- Contributions
  - Hot data streams data abstraction (PLDI’01)
  - Bursty-tracing measurement approach (FDDO’01)
  - Prefetching hot data streams (PLDI’02)
- Runtime Analysis and Design (RAD) group
  - http://research.microsoft.com/rad
  - http://research.microsoft.com/~trishulc/Daedalus.htm

So What about TwC?

- Question: What software technology is likely to have the most impact on computing in the next 5-10 years?
- My answer: Managed code

What is Managed Code?

- **Managed code* =**
  - Code executed by the Common Language Runtime (CLR)
  - Provides metadata to allow the CLR to
    - Locate methods encoded in assembly modules
      - Dynamic loading with interface type checking
    - Store and retrieve security information
      - Implement a security model
    - Handle exceptions
    - Walk the program stack
    - Garbage collect the heap

back

* As defined by .Net Glossary

Impact of Managed Code

- Performance implications
  - Pointers = abstraction (less direct control)
  - GC has global properties
  - Runtime metadata continually present, referenced
  - Large, feature-filled class frameworks

Shift in Platform

- Should most software be managed?
  - Historically, transitions from asm to C, C to C++, and now C++ to Java / C#
  - Transition to Java / C# in progress but stalled
    - Where does most Java code run? Why?
    - Just a matter of time or technology?
- Should most interfaces be managed?
  - Class libraries a start – what about OS APIs?
- These are not hypothetical questions

Managed Code on the Client

- Managed code research is mature…
  - Many Java implementation papers since 1995
  - SPECJVM benchmarks in widely used, cited
  - New GC research after 40+ years!
- However
  - Increasing client-side managed code
  - Client-side performance issues less understood
  - Opportunities for research + product impact

CLR Platform Research Opportunities

- C# / CLR / .Net available, used on clients
  - Caveat: in transition 1.0 -> 1.1 -> Whidbey (1.2)
- Sizeable applications written
  - HeadTrax (see next slides)
  - FxCop, clrprofiler (download from gotdotnet.com)
- Rich profiling API exists in CLR, Windows
  - Hook calls, returns, allocations
  - Easy integration with Windows perfmon APIs, tools
  - clrprofiler written in C#, sources available

The HeadTrax Experience Report

- HeadTrax study (Ovidiu Platon, July 2003)
  - Multi-tier internal MS app manages HR information
  - Client / server - focus on client experience
  - Client configuration: 128 Mb, 1 GHz CPU
- Implementation
  - Client written in C# with .Net Framework 1.1
  - Network interaction via web services and database APIs
  - Security important – strongly signed binaries, encryption
- Preliminary numbers (startup)
  - Cold start 23 seconds
  - Warm start 10 seconds
- Report available at: http://gotdotnet.com/

How they Improved Performance

- Changes performed
  - Made web service calls asynchronous
  - Cache data locally
  - Lazy instantiation of proxies
  - Show UI before populating
  - Results: cold **23 -> 10** secs, warm **10 -> 8** secs
- Changes proposed
  - Merge assemblies, DLLs
  - Merge threads
  - Use thread pool

What We can Learn from This

- 10 seconds is still a long time to wait
  - 1500 16+ Kb chunks read from disk at 6 ms / seek
- Logical and physical organization are at odds
  - E.g., 21 assemblies, 50 DLLs for 1 app
  - Databases figured this out long ago
  - Determining “correct” granularity is tough
    - What choices do systems provide? How easy to use?
  - Performance at odds with logical and physical isolation
- XML serialization uses reflection, C# compiler
- Eclipse faces many similar issues
- Pre-JIT is important (what is it?)

What is Pre-JIT (aka Ngen)?

- Pre-JIT is ahead-of-time compilation
  - Generates high-quality native code
  - Reduces runtime checking required across interfaces
  - Opportunities for placement of code and static data
- Ngen represents one choice in design space
  - Full runtime solutions not proven (esp. on client)
  - Best solution employs thoughtful integration of
    - Compiler, load time, runtime organization and optimization
  - Any solution requires care in widespread deployment

Longhorn on the Horizon

- MS Longhorn (OS after XP)
  - Details given in Oct 2003 (PDC conference)
  - Large components written in managed code
    - WinFS – transactional file system
    - Avalon – managed UI + shell
    - Web Services
  - Managed APIs
- Longhorn emphasis…
  - Increases availability of interesting managed apps
  - Increases potential impact of performance solutions

Managed Code Challenges

- New overheads
  - I/O, Memory, CPU beyond SPECJVM issues
- Complex mental model
  - Biggest performance improvements involve human intervention
  - Managed code abstraction creates new developer challenges

I/O Overhead

- Substantial overhead at startup and ongoing
  - Code, metadata, static data all important
    - Static nature enhances optimization opportunities
- Disk and OS interaction cannot be ignored
  - HeadTrax warm start times highly variable
  - How useful is I/O data without a disk model?
  - OS / PL communities should get together on this
    - Who is considering placement on the disk?
- Should startup be a 1st class research focus?
  - Why isn't it now?

Memory Overhead

- Memory footprint has broad implications
  - GC is only one aspect
  - Who is looking at / solving other problems?
- What’s the memory cost of runtime ops?
  - How much space does JIT compiler, metadata, GC tables, etc. take up?
  - What’s overall performance impact of footprint on client?
- How to balance small program units versus memory fragmentation?
  - Current pressure to merge units
- Tools needed to expose issues and optimize

CPU Overhead

- Significant sources of CPU overhead
  - GC – thankfully, lots of research here
    - CPU overhead not currently on critical path for client
  - Exceptions – not as exceptional as one might expect
  - Managed / unmanaged interface
  - Security model
  - Runtime checking

What a Developer has to Think About

- GC gotcha’s from Rico Mariani (April 2003)
  - Too many allocations
  - Too large allocations
  - Too many pointers (high connectivity)
    - Too many roots
  - Too many writes (esp. to older objects)
  - Too many almost long-lived objects
    - Reasoning about lifespans and promotions
  - Finalization
- What tool support does a dev need or have?

Thoughts about the Future…

- Performance space is getting trickier
  - Memory latency is bad, getting worse
    - Prediction, placement, compression only go so far
  - Chip design favors chip multiprocessors
    - Pentium 4 – 2 HW threads, Prescott 4? HW threads
    - Power 4 – 2 processor, Power 5 – 2 processors w/ 2 threads each
    - Intel “core hopping” to balance temperature hot spots!
- Design is and should be a research option

Where Could Managed Code Go?

- How suitable for defining large-grain abstractions?
  - CLR has assemblies, Java has MJ, what else?
- How suitable for defining OS?
  - Several Java attempts, any serious contenders?
  - Valuable exercise or waste of time?
- Existing support for concurrency
  - Threads just too hard to get right? Alternative?
- Better models for isolation and robustness?

How do we get there?

Summary

- TwC (reliability, security) an important focus
  - Systems can and will get better
- Performance challenges remain
  - Can always trade performance for other qualities
- Memory latency threatens Moore’s Law
  - I/O performance a major challenge, underinvestigated
- Increasing investment in managed code
  - Developer experience is still immature
  - Current research misses important challenges

Things to be aware of…

- Phoenix research compiler infrastructure
  - Intended to be the basis of commercial compiler + research vehicle
  - Infrastructure for analysis, optimization at multiple compilation stages
- Rotor (SSCLI) continues to be developed
  - Tracking Whidbey design changes
  - Increased awareness of performance requirements for research use
  - Second RFP funded

Additional Resources

- CLR Performance Info
  - http://gotdotnet.com/team/clr/about_clr_performance.aspx
  - Includes white papers, clrprofiler tool
- FxCop
  - http://gotdotnet.com/team/fxcop/
- PPRC
  - http://research.microsoft.com/pprc
  - Application info: http://research.microsoft.com/pprc/pprc-recruiting-2004.htm
- Phoenix
  - http://research.microsoft.com/phoenix
- Rotor
  - http://research.microsoft.com/collaboration/university/europe/rfp/rotor/
  - http://sscli.net

More things to be aware of…

- PPRC now has link to Windows Org.
  - Amitabh now Windows VP of Development
- PPRC Groups
  - Advanced Compiler Technology (ACT) – David Tarditi
  - Binary Technologies (BiT) – Hoi Vo
  - Runtime Analysis and Design (RAD) – Trishul Chilimbi
  - Reliability – G.S. Rana
  - Static Program Analysis (SPA) – Manuvir Das
  - Software Productivity Tools (SPT) – Sriram Rajamani
  - Testing, Measurement, and Verification (TMV) – Tom Ball
- Applications for interns, fulltime hires requested by **Feb 15, 2004**

Something to think about…

back

Chip Multiprocessors are real

Today:
IBM dual processor Power4
HP dual processor PA-8800

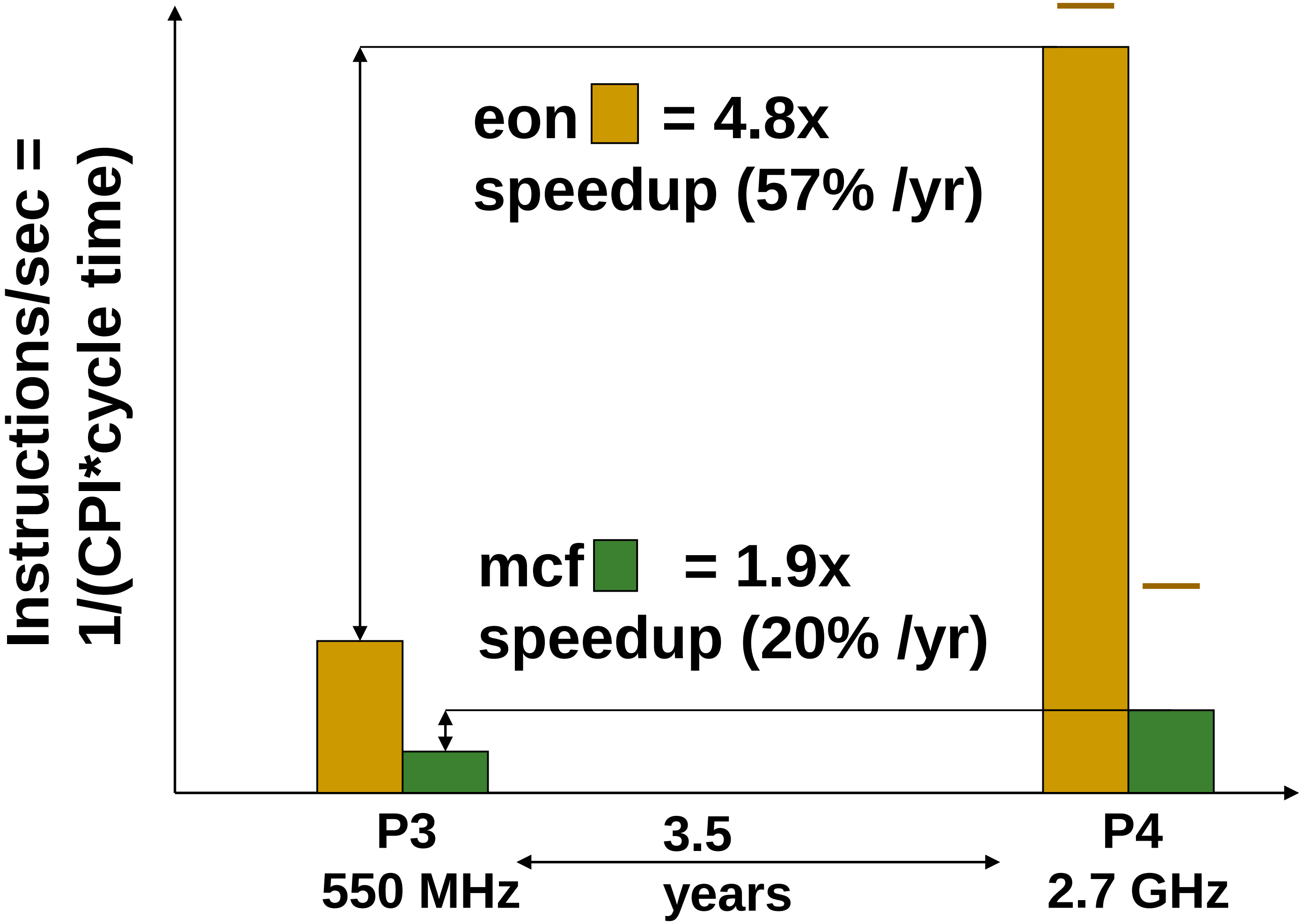
2004:
IBM / Sony "Cell" processor (speculated to have 4-16 processors on a chip)

2010 ?
The potential for these chips is enormous!

1 CPU	2 CPU	4 CPU	8 CPU	16 CPU	. . .		

Time is running out! Thank you…

SPEC2000: eon vs mcf

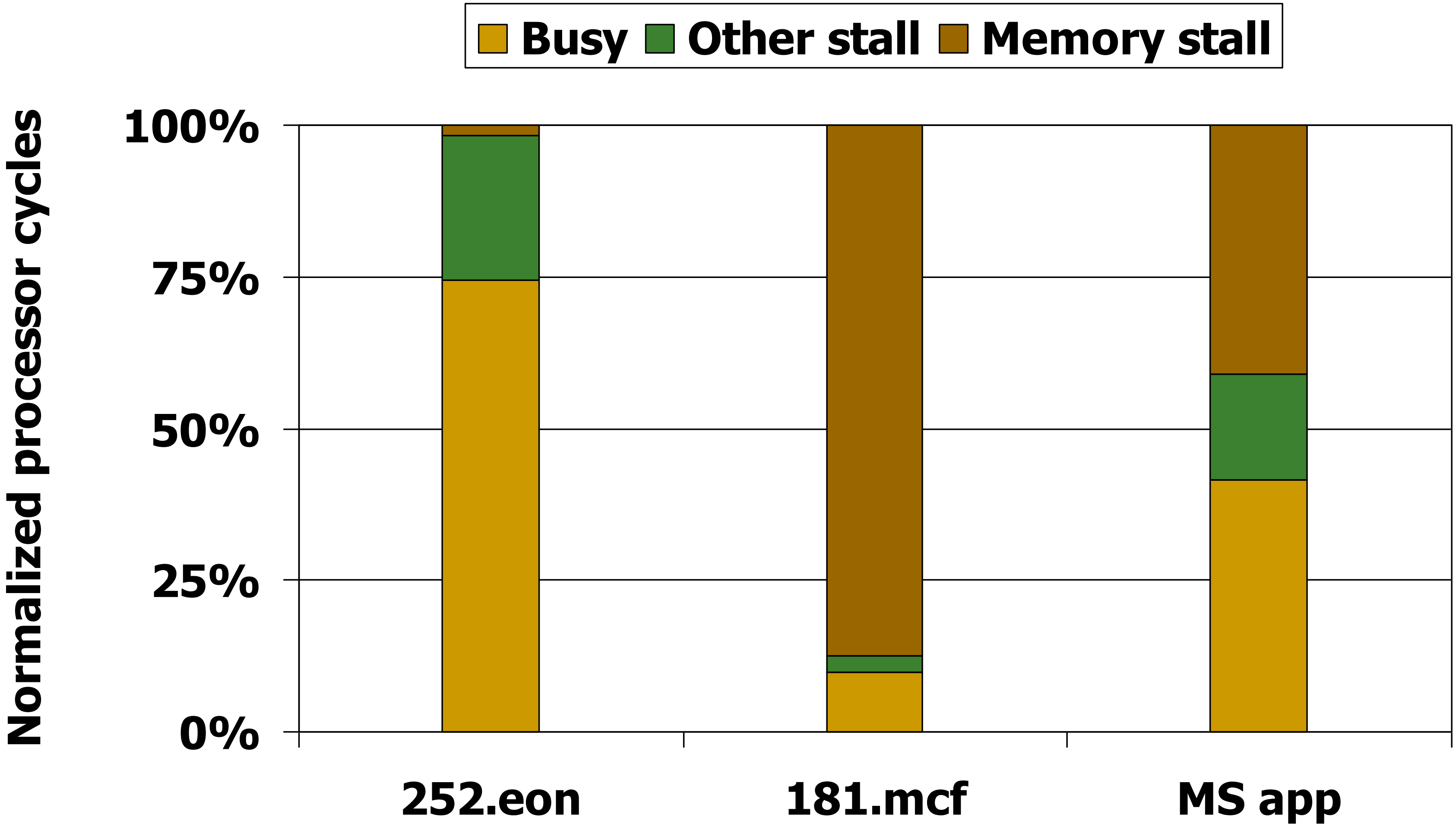


eon 🟨 = 4.8x speedup (57% /yr)

mcf 🟩 = 1.9x speedup (20% /yr)

Data gathered and reported by Trishul Chilimbi

eon / mcf Differences



Data gathered and reported by Trishul Chilimbi

FxCop – a Short Introduction

- Managed app available on the Web
  - Checks conformance rules for .Net assemblies (think “lint” for CLR)
  - Easy to make it do a lot of work
- Presents performance challenges
  - Startup, memory footprint, CPU overhead
- Keeps GC busy as well!
  - Lots of strings
- Easy to get, I’m happy to demo + tools