Execution Environments for Building Dependable Systems

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What is a Computer?

pre 1970s (it’s hard to find a mainframe picture now)

1970s – minis to micros

1980s – PC revolution

1990s – laptops, networks, CDs

2000s - what’s the iconic computer image?
Computing Technology is Changing

• “Intel to ship dual-core Xeon MP in Q1 06” — The Register 3/1/2005
• “Intel is shifting most of its focus in the processor market to dual core CPUs, suggesting that by the end of 2006, better than 75% of the CPUs Intel ships will be multicore processors.” ExtremeTech 3/2/2005
• “AMD Details Dual-Core Plans” PCWorld 2/23/2005
• “The Cell processor consists of a general-purpose POWERPC processor core connected to eight special-purpose DSP cores.” Ars Technica
• “The first rumor on the actual [Xbox 2] CPU specifications appeared in a February 2004 Mercury News story, which reported that the system will have three "IBM-designed 64-bit microprocessors".” Gamespot.com (Hardware) 2/25/2005
Expectations are Changing

- “New worm poses as tsunami relief plea”
  Reuters 3/8/2005
- “First mobile phone virus found in messaging”
  Reuters 3/8/2005
- “New Google tool poses privacy risks”
  AP 10/18/2004
- “LAPD studies facial recognition software”
  AP 12/27/2004
- “Credit card leaks continue at furious pace”
  MSNBC 9/24/2004
- “LexisNexis says 32,000 consumer profiles stolen”
  Reuters 3/9/2005
Really Dependable Systems

• AED – automated external defibrillator
  – Cheap (< $2000), effective at restarting hearts
  – “Should be as readily available as fire extinguishers”

• Pacemakers
  – “Hackers may target pacemaker technology”
    Portsmouth Herald, 3/16/2005

• Respirocyte* – “post-biological” era
  – 1 micron nanomedical device intended to replace red blood cells
  – 236 times more oxygen / unit volume vs cell
  – 18 billion atoms, onboard nanocomputer

*See ”Respirocytes” by Robert A. Freitas, Jr. (www.KurzweilAI.net)
Insights

• Device form factor and function exploding
  – Special functions with general capabilities
  – Diverse requirements, many need to be dependable

• Applications will drive the system requirements
  – What OS? Execution environment?

• Complexity is the enemy
  – For correctness, security, reliability
  – For performance
  – For agility
Foundations for Future Systems

• What’s the equivalent of TCP/IP for software systems?
  – TCP/IP survived 40 years of exponential technology growth (still going strong)
  – Foundation on which great innovation and diversity is based

• Systems need stronger software foundations
  – Tight, well-engineered core
  – Strong, consistent abstraction layers
  – Specifications
  – Multiple independent interoperating implementations (take a page from the IETF handbook)
What’s this got to do with MREs?

• Questions
  – How do we build strong software foundations for future applications?
  – What language / MRE / OS is appropriate?
  – What are the relative roles of the MRE and OS?

• Position
  – Pace of technological innovation is gated by the quality of software infrastructure
  – MREs an important part of a future that is racing toward us
Outline

• Motivation
• MREs today
• Challenges for future MRE designs
• Bartok and Singularity
• Thoughts and conclusions
MREs Increasing in Role, Function

- Increasingly dynamic software ecosystem
  - Dynamic libraries
  - Components, plug-ins, applets
- Enhanced programmer productivity
  - High-level (e.g., Visual Basic controls)
  - Less bookkeeping (e.g., GC vs malloc)
- Increasing focus on security, privacy
- Language-level feature integration
  - Threads, security model, isolation model, etc.
Implications of MRE Evolution

• Increasing overlap with OS
  – Example: isolation mechanisms
    • Use OS processes or CLR AppDomains?
  – Projects: KaffeOS – adding OS functions to MRE
  – What is the right boundary?

• Increasing leveraging of metadata
  – Types, reflection, security – expect more in future
  – More data at runtime sustainable?

• Increasing use in new domains
  – Systems, real-time, embedded, etc.
Commercial MREs a Huge Success

• Productivity benefits real, measurable
  – Higher-level abstractions available
  – Code reuse via libraries
  – More errors detected statically, dynamically
  – Reduced bookkeeping, programmer effort

• Many performance challenges overcome
  – Increased engineering, tools, programmer understanding
  – Sophisticated optimization, runtime systems
  – Successful integration of managed / unmanaged code

• Challenges remain…
HeadTrax Experience with .Net

• **HeadTrax study** (Ovidiu Platon, July 2003, see [http://gotdotnet.com/](http://gotdotnet.com/))
  – 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

• **Measured startup times**
  • Cold start 23 seconds, warm start 10 seconds
Improving HeadTrax Performance

- Implemented
  - Made web service calls asynchronous
  - Cache data locally
  - Lazy instantiation of proxies
  - Show UI before populating
- Cold 23 -> 10 secs, warm 10 -> 8 secs
- Proposed
  - Merge assemblies, DLLs
  - Merge threads, use thread pool
SAP Experience with Java

• “Using VEEs for Standard Business Applications”
  – Hans-Christoph Rohland, VP Java Server Technology, SAP AG
  – Presented at IBM Future of VEEs Workshop, Sept. 2004 (see http://www.research.ibm.com/vee04/)

• Evaluated move from ABAP (in-house MRE) to Java for:
  – Portability – but…runtime behavior is platform specific
  – Security – but…resources not protected by security model
  – Performance – but…performance hard to predict, GC doesn’t eliminate memory management problems
  – Productivity – but…tool support insufficient, concurrency is hard

• Conclusions
  – Isolation and layering important (OS also addresses)
  – Non-functional aspects should be better specified
Observations

• Some things require time, engineering
  – 10 seconds is still a long time to wait
    • 1500 16+ Kb chunks read from disk at 6 ms / seek
  – Better tools will be built

• Logical and physical organization are at odds
  – E.g., 21 assemblies, 50 DLLs for 1 app

• Some things are more architectural
  – How do we specify non-functional aspects and build systems to those specifications?
  – How do we make concurrency easier?
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Future Directions for MREs

• Call to action: more innovation, experiments, experience needed

• Many important challenges
  – Performance
  – Correct concurrency
  – “Metadata scale” and data locality
  – Error detection and recovery
  – Core architectural issues
    • Modularity, componentization, versioning
  – “Managed code at the bottom” – building an entire system (App + MRE + OS managed)
Modules, Components, Versions

• Modularity – language support still inadequate
  – How to define large-grain decomposition units?
  – Proposals exist (e.g., IBM MJ, partial classes)
  – How to build systems out of such units?

• MREs are currently one-size fits all
  – Are domain-specific MREs valuable, feasible?
    • Beyond J2EE, J2SE, J2ME
  – What mechanisms are necessary to enable?

• Versioning is a critical part of solution
  – How many components in an MRE?
  – Can they be individually up-leveled?
  – How does this look to an application?
“Managed Code at the Bottom”

• All-managed OS / MRE will be necessary

• Keys to building successful systems
  – GC in the kernel
    • Performance, accounting, integration
    • Encouraging research results
  – Type safety in system code (e.g., GC)
    • Typed-assembly language for runtimes
  – Meeting hard resource constraints
    • Space, real-time, hardened to failure
  – Design with compiler / runtime optimization in mind
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The Evolution of Agile, Dependable Systems

Native Application + System

- User App
- C Runtime
- OS
- HAL
- Hardware

Managed Application + System

- User App
- Managed Runtime
- OS
- HAL
- Hardware

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Modular, Type-safe MREs

Managed Application + System

User App

Heap

Managed Runtime

OS

HAL

Hardware

Managed Application + Research MRE

User App

Heap

GC

JIT

EE

OS

HAL

Hardware

Examples: JMTk, Jikes RVM, ORP

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Managed App + MRE + OS

Managed Application + Research MRE

Managed (App + OS)

Examples: Singularity, SPIN

Managed Application +
Research MRE

Hardware

HAL

GC

JIT

EE

User App

Heap

OS

Scheduling

Audio Driver

Video Driver

Virtual Memory

HAL

Hardware
Focus on Configurability

Managed (App + OS)

Minimum Configuration
Managed (App + OS)

User App
GC
Video Driver
Scheduling
Hardware
HAL

Heap
JIT
EE
Virtual Memory

App
GC
Audio
VM

Heap
EE

Hardware
HAL

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Building Better Abstractions

Minimum Configuration
Managed (App + OS)

- App
- Heap
- GC
- EE
- Sched.
- Audio
- VM
- HAL
- Hardware

Minimum Configuration
Managed (App + OS) with enhanced abstractions, tools, checking

- App
- Heap
- GC
- EE
- Sched.
- Audio
- VM
- HAL
- Hardware
Bartok

• What
  – Compiler / runtime system for reduced CLI
  – Support managed-code at the bottom, written in C#
  – Exploring impact of dynamism (reflection, loading, etc.)
  – Developed by ACT group at MSR (Tarditi)

• Research focus areas
  – Optimizations for OO, systems
  – Real-time garbage collection
  – Type-safe abstractions (TAL, well-typed runtimes)
  – Compiler / runtime / OS coupling
Typed Intermediate Languages

• Big picture
  – How much of an MRE implementation can be type-safe?
    • Even the grungy stuff, type-tests, vtables, GC, etc.
  – How about type-safety of MRE implementation combined with application code?
    • Check that generated code and meta-data satisfy MRE invariants
    • Optimizations that combine MRE + application code
      – Examples: Inlining type tests, optimizing virtual dispatch
  – How to do this?
Typed intermediate languages

TIL for OO languages: POPL ’05 (Chen and Tarditi)

• Type system:
  – Preserve class names in low-level code
    • Class names are precise
    • Represent objects of a class, not its subclasses
  – Add record types for object layout
  – Allow coercions between objects and records
  – Use class names as bounds in existential types

• Can typecheck low-level code for standard implementation techniques for:
  – Type test, virtual dispatch, interface calls, array covariance checks
  – Including some optimized versions

• Formal semantics, proof of correctness
• Type system ideas could be applied to the source level
Heap Analysis

- Heap analysis not amenable to pure static techniques
- Empirical data indicates program heap is simple
  - Small fraction of heap is actively modified
  - Heap structure is simple
  - Many invariants that are never explicitly stated
- Leverage this to build sound heap abstractions
- Canonical heap representation to combine information from multiple program runs
- Hybrid static-dynamic analyses for soundness & scalability
Singularity

• What
  – Multi-group MSR project led by Galen Hunt and Jim Larus
  – New OS design and implementation from ground up
  – Central focus on high dependability
  – Leverages / extends Bartok compiler and runtime

• Design Principles
  – Type-safe (managed) code everywhere
  – Isolate components as much as possible
  – Design for analysis as early as possible
    • Design informed by availability of software analysis tools
  – Willing to trade performance for correctness
Singularity Architectural Elements

- **Strong isolation between processes**
  - No shared data, communicate via channels

- **No dynamic loading, extend via new process**
  - Closed world model facilitates checking, customization

- **MREs customized on a per-process basis**
  - Device drivers, apps, kernel have different MREs

- **Checking tools go beyond type-safety**
  - Specify, check process interactions
  - Add pre/post conditions (Spec#)

- **Reason about the system as a whole**
  - Configuration as first-class abstraction
  - Entire system is a self-describing artifact, enabling static inspection and analysis
Vision for OS / MRE Integration

Current Systems

Application

MRE
- App Dom.
- GC
- ...

OS
- Proc
- MM
- DD

Sched

DD MRE

Audio Driver

Singularity

Device Channel

Kernel Channels

Application

App MRE
- GC'
- Privacy

Kernel
- Sched
- Proc

Kernel MRE
- GC
- MM

Unsafe Code

MRE’05
March 2005

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Summary

• Applications, expectations rapidly changing
  – Software has to keep pace
• MREs are a central part of long-term solution
• Big challenges remain for future designs
  – Core architectural questions need answers
• Related MSR efforts
  – Defining stronger abstractions
    • For language, IL, runtime, heap
  – Bartok - compiler and runtime system
  – Singularity - OS / MRE co-design
Future Investments

• Troubling CISE statistics
  – NSF proposal success rates falling
    • 36% in 1994 to 16% in 2004, some programs much lower
  – Underinvestment in infrastructure

• Software infrastructure research requires increasingly large investment
  – How big before an OS, MRE is “real”
  – Universities, companies need to collaborate
  – MS Phoenix compiler and tools infrastructure is one example
  – Failure to invest, experiment has significant long-term impact
More Information

• Advanced Compiler Technology / Bartok
  – http://research.microsoft.com/act/
• Runtime Analysis and Design
  – http://research.microsoft.com/rad/
• Singularity
  – http://research.microsoft.com/os/singularity/
• Spec#
  – http://research.microsoft.com/projects/specsharp/