Execution Environments for Building Dependable Systems

Ben Zorn
Software Design and Implementation
Microsoft Research

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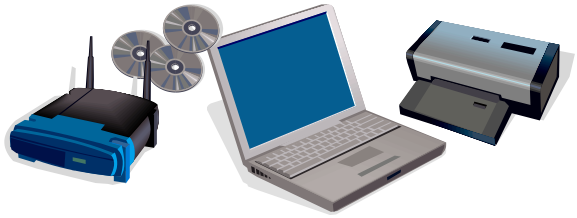
What is a Computer?

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/)
  - 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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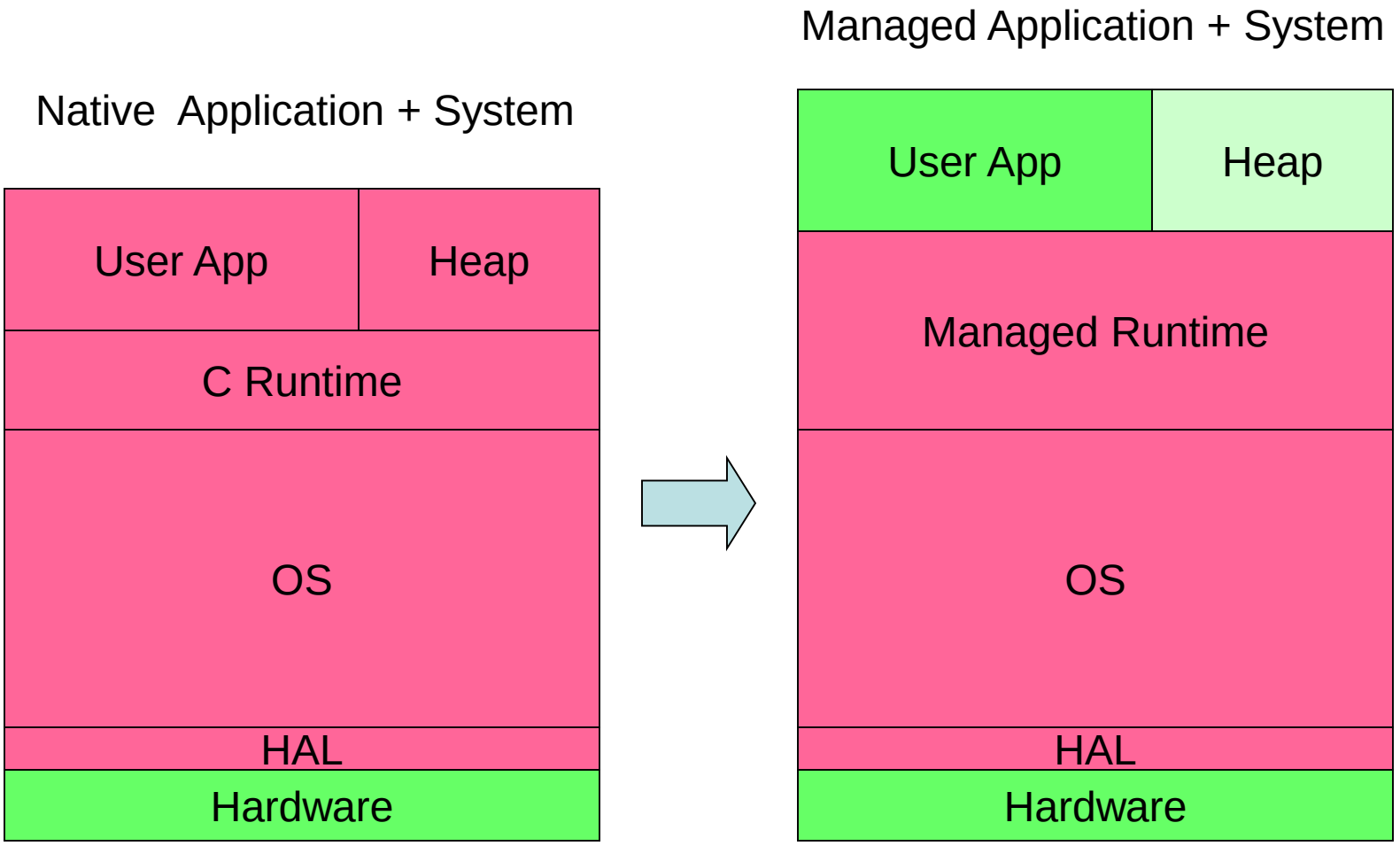
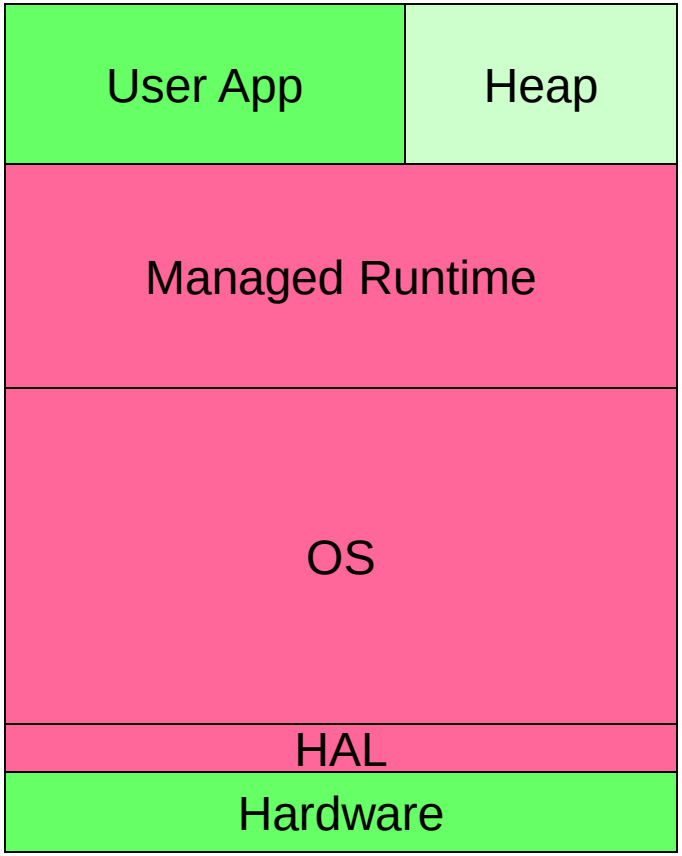
The Evolution of Agile, Dependable Systems

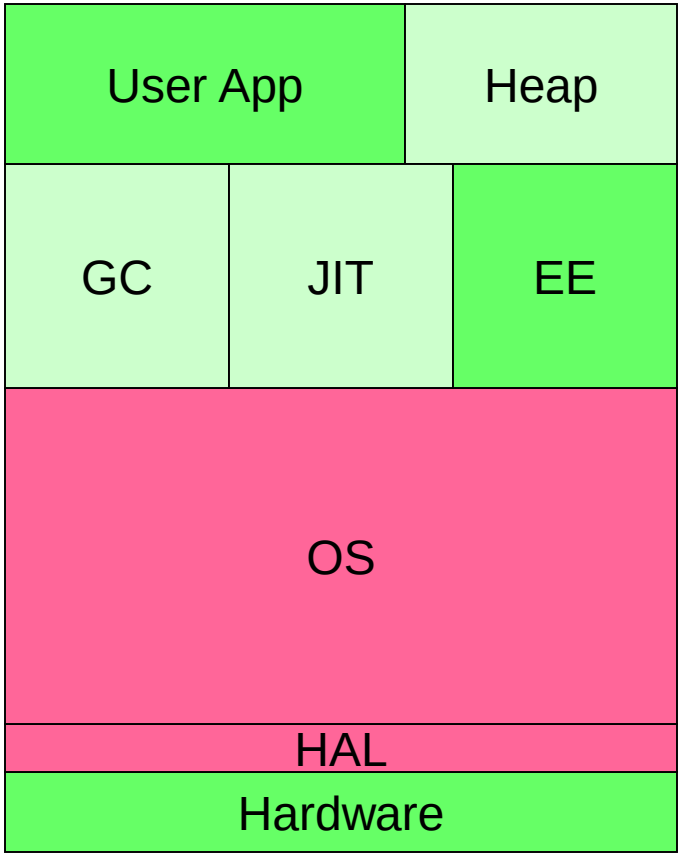


Modular, Type-safe MREs

Managed Application + System



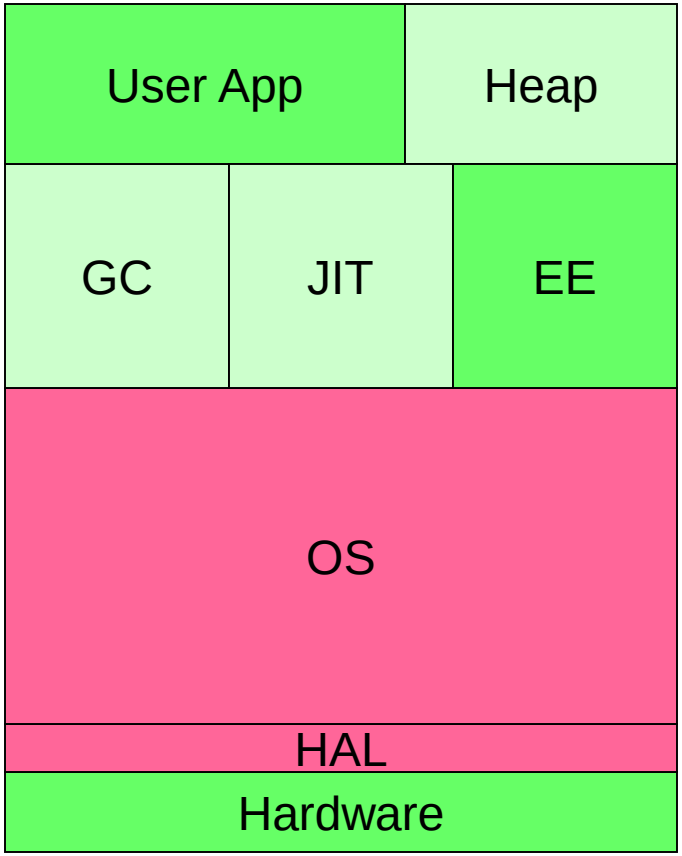
Managed Application + Research MRE



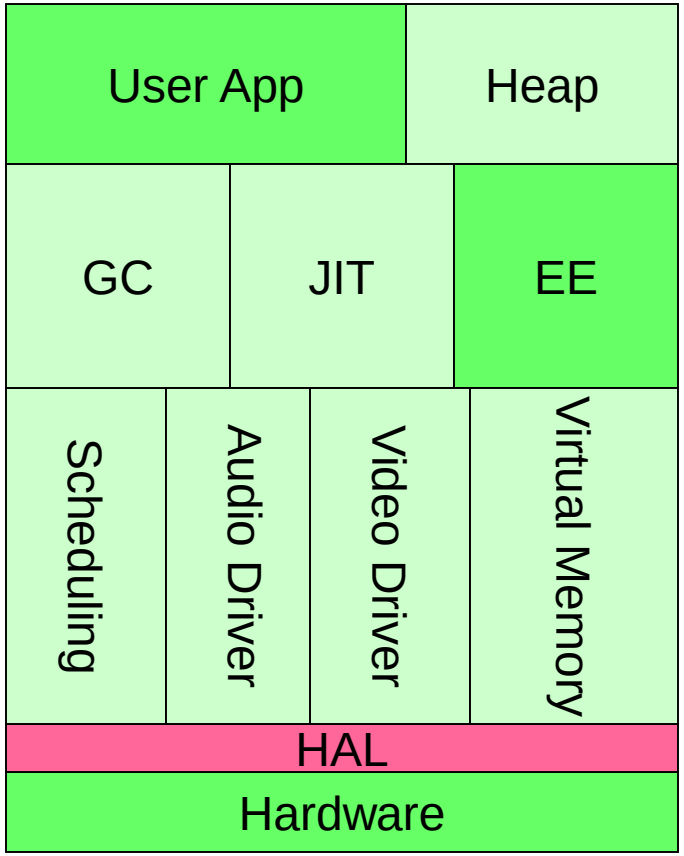
Examples: JMTk, Jikes RVM, ORP

Managed App + MRE + OS

Managed Application +
Research MRE

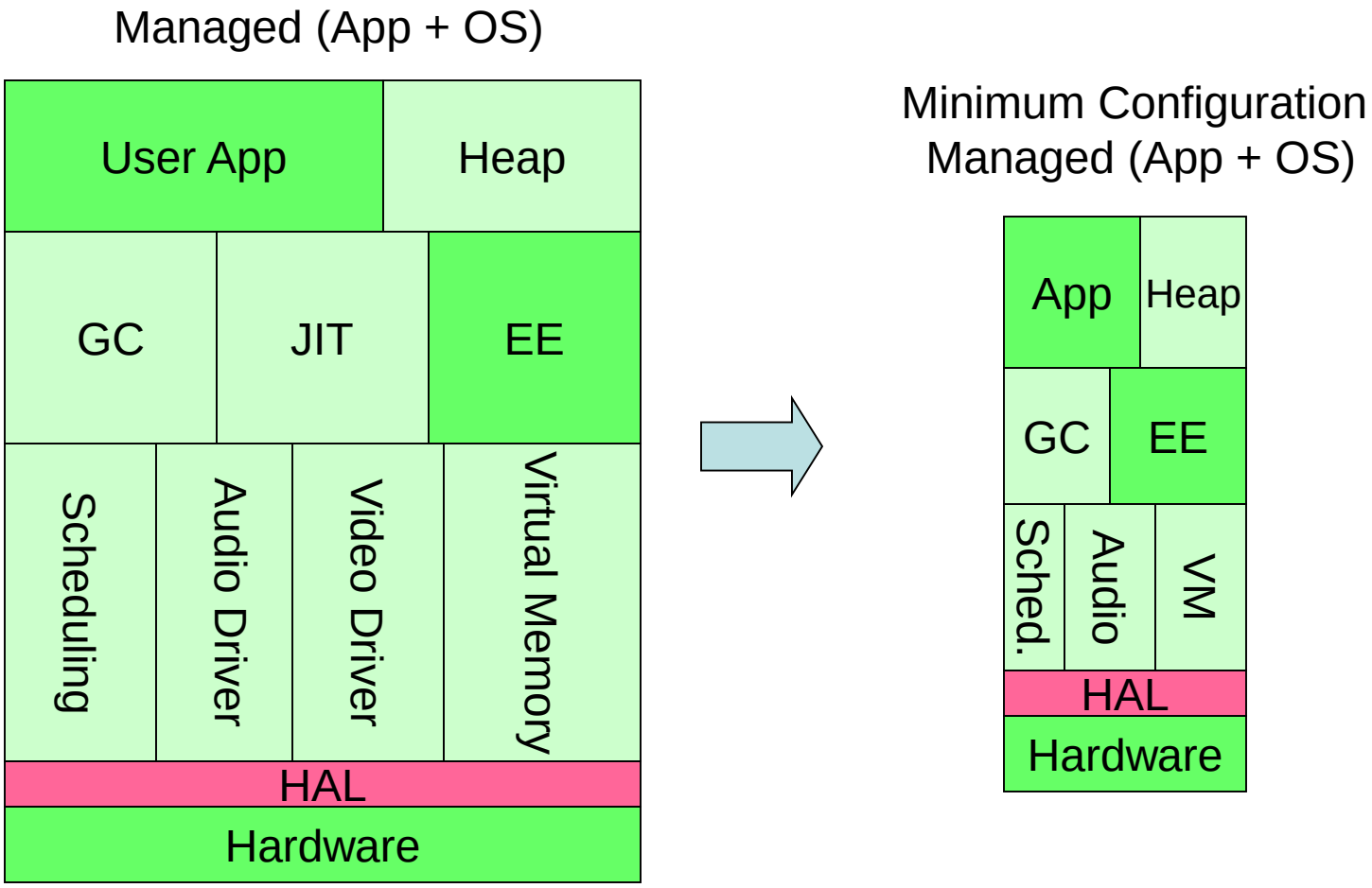


Managed (App + OS)



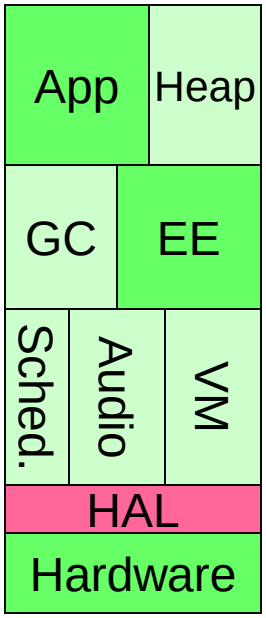
Examples: Singularity, SPIN

Focus on Configurability

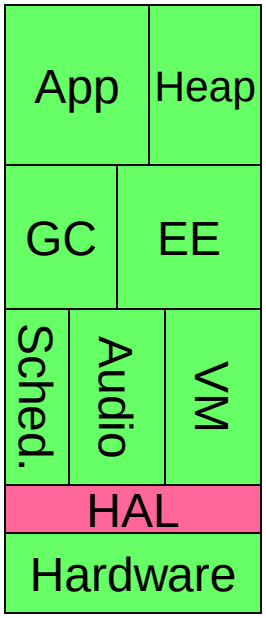


Building Better Abstractions

Minimum Configuration
Managed (App + OS)



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



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

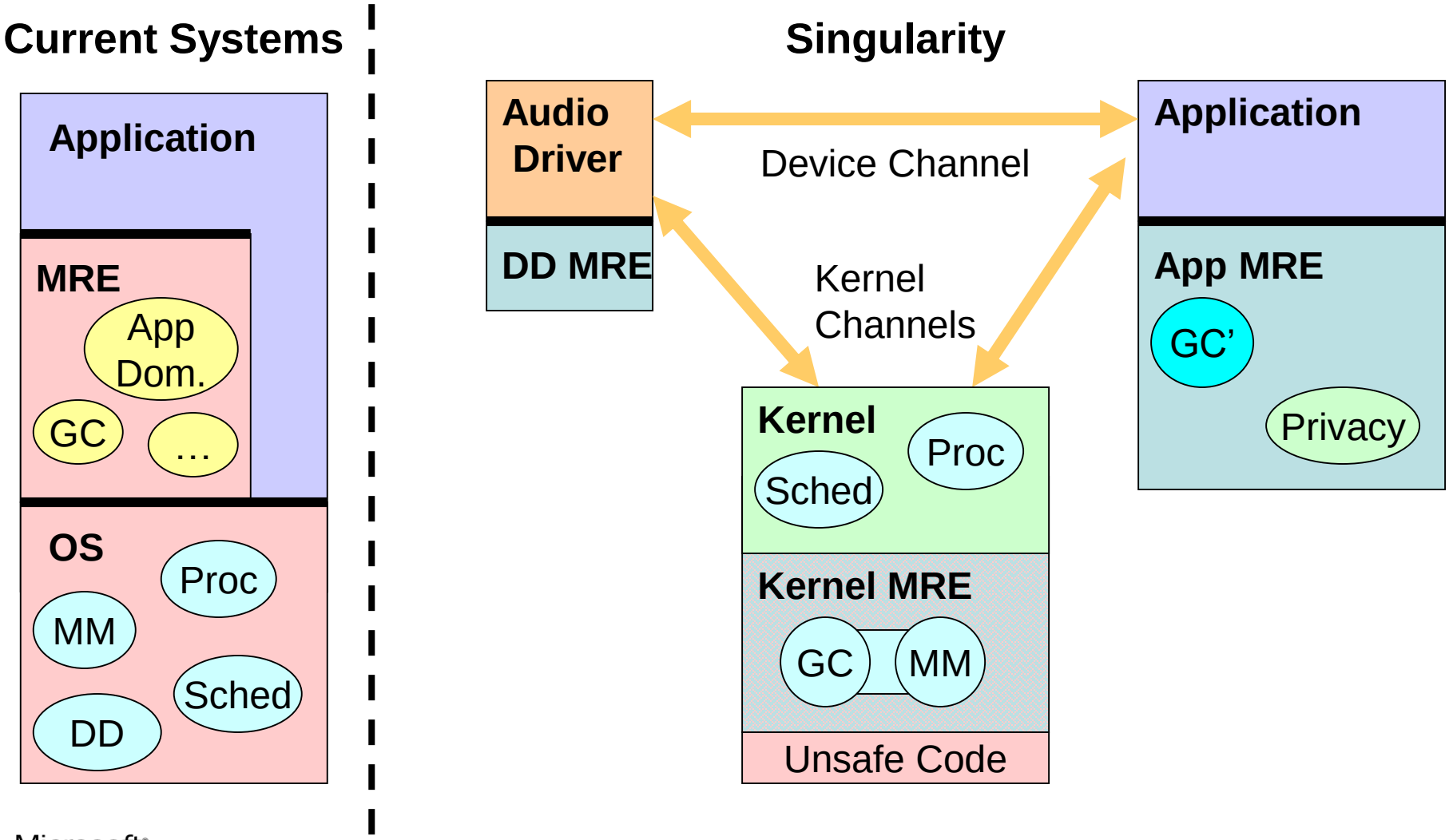
Singularity

- 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



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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/