Thoughts on the Future of Runtime Systems

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Big Picture

• 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

• Questions
  – What language used to program this device?
  – When will managed languages be used to program every application?
  – What fraction of future applications will be “high dependability”?

• My position
  – Pace of technological innovation is gated by the quality of software infrastructure
  – Most important technology focus of our time
    • MREs important part of a future we can now see
Terminology (Alphabet Soup)

• Managed runtime environment (MRE)
  – Other names: Virtual execution environment (VEE), Virtual Machine (VM), runtime system

• My MRE definition
  – Delivery format that includes
    • Platform neutral intermediate language
    • Metadata for reflection, runtime checking
  – System services (reflection, GC, etc.)
  – Libraries (base class library, frameworks, etc.)
Outline

• MRE evolution over the last 40+ years
• Experience with current commercial MREs
  – Headtrax client in C#
• Future challenges and opportunities
  – Areas of investment
  – Encouraging ideas
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, memory 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

• Important application domains remain
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/
Improving Performance

• Implemented
  – Made web service calls asynchronous
  – Cache data locally
  – Lazy instantiation of proxies
  – Show UI before populating
• Cold $23 \rightarrow 10$ secs, warm $10 \rightarrow 8$ secs
• Proposed
  – Merge assemblies, DLLs
  – Merge threads, use thread pool
Observations

• 10 seconds is still a long time to wait
  – 1500 16+ Kb chunks read from disk at 6 ms / seek
  – Disk is an imposing bottleneck

• Logical and physical organization are at odds
  – E.g., 21 assemblies, 50 DLLs for 1 app
  – Determining “correct” granularity is difficult

• Abstraction can hide high costs
  – XML serialization uses reflection, C# compiler

• Issues not unique to HeadTrax
  – Eclipse, unmanaged apps have similar challenges
Using MREs for Systems

• High performance key to success
  – I/O at startup, during dynamic loading
  – Memory footprint cannot be ignored
  – CPU overheads due to safety, GC, exceptions, security
  – Developer / MRE impedance mismatch
    • What does a developer have to know?

• Next steps are clear, in progress
  – Improved optimization, tools
  – Increase developer experience, education
Future Directions for MREs

• Innovation, experiments, experience needed

• Key challenges
  – Concurrency
  – “Metadata scale” and data locality
  – Error recovery
  – Core architectural issues
    • Modularity, componentization, versioning
  – “Managed code at the bottom” – an all-managed OS

• Singularity Project at MSR
  – Motivation and focus
Concurrency

• Wake up! Chip multiprocessors are here!!!!!!
  – AMD, Intel, IBM all will have dual-core CPUs
  – Technology clearly outpacing research
• Language constructs are brittle, error-prone
  – Threads, shared-memory best approach?
• HW / SW trends toward fine-grain transactions
  – Speculation HW reusable for commit/abort
• Directions:
  – “Atomic” section (e.g., Harris et al.) promising approach to ease programmer effort, reduce errors
  – All alternatives (e.g., *Lisp) need revisiting now
Locality and “Metadata Scale”

• Memory wall growing exponentially
  – Caching, prediction, compression will mitigate
  – GC, MREs (JIT, etc) offer hope here, but…

• Increasing metadata trend exacerbates problem
  – Reflection allows almost arbitrary inspection, creation, execution
  – Metadata required for dynamic checking

• Directions
  – Rethink metadata availability at runtime
  – Increase static checking, improve tools, combine efficiently with dynamic checking
Error Recovery

• Exceptions can be improved
  – Exceptions express control – data consistency left to programmer
• Correct software requires maintaining and reasoning about consistent states
• Increasing the granularity of consistent states
  – Reduces total number of states
    • Easier for human and checking tools to reason about
• Directions
  – Transactions (again) increase granularity of consistent states
  – Expressive annotations, checking tools critical
    • Best error recovery is never encountering one
Modules, Components, Versions

- Modularity – language support still inadequate
  - How to define large-grain decomposition units?
  - Proposals exist (e.g., IBM MJ)
- 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
The Singularity Project

• Revisit OS design from the ground up
• Central focus on high dependability
• Leverage current experience
  – Type-safe (managed) code everywhere
  – Isolate components as much as possible
  – Use software analysis tools in every component at every development stage
  – Be willing to trade performance for correctness
• Result: a research prototype OS / MRE
Summary

• MREs absolutely necessary system component
• Existing commercial MREs
  – Greatly successful, increasing in impact
  – Improvements continue, outcome promising
• Big challenges remain for future designs
  – Accelerating technology trends
  – Core architectural questions
  – Managing complexity key to future success
• Future – MREs everywhere!!!  If not, then what?
  – MREs are only the start – checking tools critical too