one.world — Programming for Pervasive Computing Environments

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The One Slide Summary

**Problem**
Highly dynamic environment

**Solution, part I:**
Principled architecture
- Expose change
- Compose dynamically
- Separate data and functionality

**Solution, part II:**
Developer discipline

**Result**
Adaptable applications

**one.world**
The Vision

• Make computers usable for (computer) illiterate
  – Enabled by ubiquitous smart devices
• Implies a shift in focus
  – Away from devices and technology
  – Towards users and their tasks
The Reality

- Hardware is almost there
  - Handhelds, tablets, cars, fridges, dogs
  - Wireless networking
  - Location sensing

- Applications are missing
  - Too hard to design, build, and deploy in a giant, ad-hoc distributed system
  - Stuck with email and WWW
    - Case in point: AIBO Messenger

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The Challenge

• Average hacker needs to develop applications that
  – Adapt to a changing environment
  – Work even if
    • Devices are roaming
    • Users switch devices
    • Network provides only limited services, or none at all
This Is A Systems Problem!

• Need dedicated systems support to make programmers’ task feasible
• But existing approaches to building distributed systems are not suitable
  – Extend single-node programming models
  – Designed for smaller, less dynamic environments
Talk Outline

• Problem
• Principled Architecture
  – Principles
  – Architecture
• Programming for Change
• Evaluation
• Conclusion
Structure of Systems Support

- Three principles guide the design
  - Expose change
  - Compose dynamically
  - Separate data and functionality
Expose Change

- Let applications handle change, incl. failures
  - Do not hide distribution
    - Distributed file systems break single-node applications
- Provide primitives that simplify this task
  - “Checkpoint” and “restore”
  - “Move to a remote node”
  - “Find matching resource”
Compose Dynamically

• Recompose applications at runtime
  – Simplify interposition on interactions
    • Modify and add behaviors
      – Replication
      – Migration logic
    – Eschew composition through interfaces
      • Hard to interpose on
      • Hard to make extensible
Separate Data and Functionality

- Manage them separately
  - Simplify sharing, searching, translating of data
    - Relational databases do this well
  - Do not hide them behind unifying interface
    - Objects are too general and too complex
- Let them evolve independently
  - Standard bodies define data formats
  - Vendors compete on functionality
- Provide the ability to group the two
  - Preserve independent access

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Architecture

- Each device runs one instance of one.world
  - Independent of other instances
  - Shared by applications
- Each such node provides a uniform platform
  - Same core abstractions and services
  - Same safe instruction set
    - Mobile code
- Written mostly in Java
  - Relies on Berkeley DB for storage management
  - Released as open source
Basic Abstractions

• Tuples
  – Represent data as self-describing records
  – Used for storage, networking, and events
• Components
  – Implement functionality
  – Interact by exchanging asynchronous events
    • Import and export event handlers
• Environments
  – Group stored data and application functionality
  – Contain tuples, components, environments

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An Environment Hierarchy

User

foo
Chat
music

bar

Environment  Tuple  Components

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Core Services

• Checkpointing
  – Captures and restores execution state
• Migration
  – Moves or copies environment tree
• Remote event passing
  – Sends events to remote receivers, including those with an unknown location
• Replication
  – Makes data available on several nodes
Digging Deeper

• Remote event passing
• Migration
• Managing asynchrony
Remote Event Passing

• Three simple operations
  – Export event handler
    • Under identifier or arbitrary tuple
    • Resulting binding is leased
  – Send event
    • <Node, identifier> of specific handler
    • Discovery query
  – Resolve
    • Discovery query $\rightarrow <\text{node}, \text{identifier}>^*$

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Remote Event Passing

- Considerable power
  - Early and late binding
    - Selected by type of resource descriptor
    - Anycast and multicast for late binding
      - Selected by flag
  
- Reasonable implementation
  - Central discovery server
    - Elected from nodes on local network
    - Routes events for late binding

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Migration

- Moves/copies an application and its data
- Affects entire environment tree
  - Tuples
  - Components
  - Environments
  - But nothing outside the tree
    - Breaks bindings to outside
Capturing Execution State

- Quiesce environments
- Serialize state
  - Components
  - <Event handler, event> queues
- Null out references to outside event handlers
  - Need to be restored by application
Composing for Migration

- Root of tree controls
  - When to migrate
  - Where to migrate to
- Compose for migration
  - Isolate migration logic in separate environment
  - Embed application in that environment

\[ \text{migrator} \]

\[ \text{app} \]

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How to Structure Applications?

• Considerable uncertainty
  – Leases expire
  – Event queues fill up
  – Resources are temporarily unavailable

• Established programming styles don’t scale
  – State machines
The Logic/Operation Pattern

- Logic
  - Computations that do not fail
- Operations
  - Interactions that may fail
  - Implementation includes time-out and retry code
- Composition
  - if-then-else’s, loops
  - Combination is an operation as well
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Programming for Change

• “No application is an island!”
  – An application’s runtime environment
    • May change quite frequently
    • May be changed by others

• Examples
  – Emcee
  – Chat

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Emcee

- Manages users and their applications
  - Provides support for
    - Creating and deleting users and applications
    - Migrating users and individual applications
  - Structures environment hierarchy
    - / User / <user-name> / <application>
- Dynamically scans environments
  - Once a second for users
  - On demand for applications
Chat

- Supports text and audio messaging across channels
  - Relies on discovery for message routing
- Verifies user after activation, restoration, or migration
- Runs without audio if hardware is missing
- Silences audio channel if music has been deleted
- Checks for concurrent termination before handling events (including chat messages)
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Evaluation Criteria

• Programmability
  – Design and implementation process
  – Comparative studies

• Performance
  – Microbenchmarks
  – End-to-end

• Reactivity/resilience
  – How do applications react to change?

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Lessons Learned
Things That Worked

• Asynchronous events
  + Synchronous timers
  + Operations
• Nested environments
  + Checkpointing
  + Migration
• Remote event passing
  + Integration with discovery
Data Model Is Contentious

• Conflicting requirements
  – Integration with programming language
    • Java objects restricted to public fields
  – Flexibility
    • Expressive enough for applications
  – Simplicity
    • Easy to exchange between applications and services
Data Model

• Programmatic model
  – Structural definition
    • Public fields
    • Semantic constraints
      • validate()
  – Formatting
    • toString()
  – Versioning
    • serialVersionUID
Data Model

- Programmatic model
  - Structural definition
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- Declarative model
  - Structural definition
    - ???
  - Semantic constraints
    - ???
  - Formatting
    - ???
  - Versioning
    - ???
XML Is Not It!

- XML fails on three accounts
  - Integration with programming language
    - DOM is unwieldy
  - Simplicity
    - XML + XML-Schema + XSL
    - Versioning still not addressed
  - Performance
    - Incredibly verbose encoding

“To a Lisp hacker, XML is s-expressions in drag.”

Bob Bane
Summary

- Pervasive applications require dedicated systems support
  - Expose change
  - Compose dynamically
  - Separate data and functionality
- \textit{one.world} is a viable platform
  - Asynchronous events, leases
  - Nested environments and discovery’s late binding
  - Tuples and components
- We can build adaptive applications on top of it

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