MicroQoSCORBA: A Configurable Middleware Framework for Small Embedded Systems that Supports Multiple Quality of Service Properties

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MicroQoSCORBA Research Team

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Outline

• Introduction
  – Middleware
  – Embedded systems
  – Quality of Service
• Related Work
• MicroQoSCORBA
  – Middleware Architectural Design Taxonomy
  – Fine-grained Configurable Middleware Framework
  – Embedded System Security
  – Security Subsystem Design & Implementation
  – Experimental Evaluation
• Conclusions

Middleware

“A layer of software above the operating system but below the application program that provides a common programming abstraction across a distributed system”

Middleware: Heterogeneity & Transparency

• Middleware’s programming building blocks mask heterogeneity
  – Makes programmer’s life much easier!!
• Kinds of heterogeneity masked by middleware
  – Heterogeneity in network technology always masked
  – Heterogeneity in host CPU always masked
  – Heterogeneity in operating system (or family thereof) usually masked
  – Heterogeneity in programming language usually masked
  – Heterogeneity in vendor implementations sometimes masked
• Middleware can provide transparency with respect to distribution:
  – Location transparency
  – Replication transparency
  – Mobility transparency
  – Concurrency transparency
  – Failure transparency
• Masking heterogeneity and providing transparency makes programming distributed systems much easier to do!
Existing Middleware Frameworks

- Support is lacking for
  - Small memory footprint
  - Generality to a wide range of hardware devices
  - Power awareness
  - Multi-property QoS (esp. non-RT properties)
  - Fine-grained configurability
  - Software Engineering & Analysis tools

Embedded Systems Market

- 11 Billion CPUs per year
- System size varies
  - Aircraft, PDAs, Home appliances
- Application volume varies
  - Radios, TVs, Satellites
- Application constraints vary
  - Business applications
  - Sensor Networks
    - Single-purpose sensors → High-end signal processing
    - Environmental monitoring, battlefield networks, …

Quality of Service

- Real-World applications have real-world tradeoffs!
- QoS Properties
  - Security
    - Multiple strengths/Algorithms
  - Fault Tolerance
    - Quantity and types of faults tolerated
  - Real-time Behavior
    - Scheduling algorithms, Network performance
- Resource Issues
  - Memory footprint
  - Power awareness

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Related Work—CORBA

- **MinimumCORBA**
  - Removes support for dynamic interfaces, etc
  - Reduces the memory footprint of an ORB (~in half)

- **Real-time CORBA**
  - Provides tools to better predict time delays
  - Enables hard real-time CORBA applications

- **Fault Tolerant CORBA**
- **CORBA Security Service**
- **Smart Transducers Interface**
- **Stand-alone specifications—they do not compose**

Related Work, cont.

- **Java Remote Method Invocation (RMI)**
  - Lacks cross-language support, configurability, QoS mechanisms

- **Small Footprint**
  - legORB — UIUC, ~ 6 Kb Client IIOP engine
  - e*ORB — Vertel, ~ 35 Kb Client ORB
  - ORBlite — HP Labs: evolvability flexibility, subsetting
  - Stripped-down, Point solutions

- **VEST**
  - Application specific operating systems
  - Lightweight components
  - Strong analysis toolkit
  - Aspects for RT performance & dependability

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- **Conclusions**
MicroQoSCORBA Objectives

- Support wide ranges of (deeply) embedded H/W
  - Resources vary widely (memory, power, etc.)
  - Home appliances, Sensor networks
- Tailor middleware to both application and hardware constraints, with fine granularity
- Develop a multi-property QoS enabled MW framework
- Maintain CORBA interoperability
  - Develop an IDL based framework that interoperates with other ORBs, rather than just another IIOP engine

Lifecycle Time Epochs

<table>
<thead>
<tr>
<th>Lifecycle Epoch</th>
<th>Constraint Bound</th>
<th>Representative Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>HW Heterogeneity</td>
<td>Symmetric, asymmetric</td>
</tr>
<tr>
<td></td>
<td>HW Choice</td>
<td>X86, TINI, ColdFire</td>
</tr>
<tr>
<td></td>
<td>Communications HW</td>
<td>Ethernet, Serial, Infrared</td>
</tr>
<tr>
<td></td>
<td>Processing Capability</td>
<td>50 Mhz, 1 Ghz, 8bit, 32bit</td>
</tr>
<tr>
<td></td>
<td>System size</td>
<td>small, medium, large (e.g., transducers to jets)</td>
</tr>
<tr>
<td></td>
<td>Power Usage</td>
<td>line, battery, and/or parasitic power</td>
</tr>
<tr>
<td>IDL Compilation</td>
<td>Communication Style</td>
<td>Passive, Pro-active, Push, Pull</td>
</tr>
<tr>
<td></td>
<td>Stub/Proxy Generation</td>
<td>Inline vs. library usage</td>
</tr>
<tr>
<td></td>
<td>Message Lengths</td>
<td>Fixed, variable length messages</td>
</tr>
<tr>
<td></td>
<td>Parameter Marshalling</td>
<td>Fixed Formats</td>
</tr>
<tr>
<td>Application</td>
<td>Space/Time Optimizations</td>
<td>Loop unrolling, code migration, function and proxy inlining</td>
</tr>
<tr>
<td>Compilation</td>
<td>Library Usage</td>
<td>Static vs. dynamic library linkage</td>
</tr>
<tr>
<td>System / App.</td>
<td>Device Initialization</td>
<td>Serial port baud rate, handshaking</td>
</tr>
<tr>
<td>Startup</td>
<td>Network Startup</td>
<td>Booip, dhcp</td>
</tr>
<tr>
<td></td>
<td>Major QoS adaptation</td>
<td>Select between QoS modules</td>
</tr>
<tr>
<td>Run Time</td>
<td>Minor QoS adaptation</td>
<td>Adjust QoS parameters</td>
</tr>
</tbody>
</table>

Middleware Architectural Taxonomy

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Architectural Considerations

- Fine-grained composability
- Baseline Functionality
  - CORBA IDL support
  - Autogenerated Code (e.g., stubs & skeletons)
- QoS Functionality
  - Security (to be presented later)
  - Fault Tolerance
  - Timeliness
- Development Tools

Fault Tolerance Mechanisms

<table>
<thead>
<tr>
<th>Redundancy</th>
<th>Reliability</th>
<th>Ordering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal</td>
<td>Group Communication</td>
<td>Sender FIFO</td>
</tr>
<tr>
<td>Multiple</td>
<td>Best Effort</td>
<td>Causal</td>
</tr>
<tr>
<td>transmits</td>
<td>Reliable</td>
<td>– Logical Timestamping</td>
</tr>
<tr>
<td>Spatial</td>
<td>Atomic</td>
<td>Total</td>
</tr>
<tr>
<td>Multiple</td>
<td>Uniform</td>
<td>– Sequencer / Token based</td>
</tr>
<tr>
<td>Channels</td>
<td>Failure</td>
<td></td>
</tr>
<tr>
<td>Replicated</td>
<td>Detection</td>
<td></td>
</tr>
<tr>
<td>Servers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checksums, CRC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Development Tools

- Not all developers are created equal
- **Goal:** Make it easy for the casual programmer
  - Domain expert, but QoS novice
  - Lifecycle support personnel
  - Temporary/contract employees
- Tools choose compatible components based upon
  - QoS requirements
  - Resource configuration
- Application and Hardware specific configuration file for the IDL Compiler
  - IDL compiler custom-generates stub/skeleton code

Architecture Overview
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Embedded System Security

• Security must be designed in
• Deep coupling with a physical environment
  – Exposure to the elements, tampering, etc.
• Significant tradeoffs between
  – Security
  – Cost & Resource Usage
  – Generality / Adaptability
• Relatively limited computation power
• Denial of Service attacks are more acute

Security Design Space

<table>
<thead>
<tr>
<th>Confidentiality</th>
<th>Integrity</th>
<th>Availability</th>
<th>Accountability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>Message Digests*</td>
<td>Service Continuity</td>
<td>Authentication</td>
</tr>
<tr>
<td></td>
<td>—MD5/5</td>
<td>—See Fault Tolerance</td>
<td>—Physical Tokens</td>
</tr>
<tr>
<td></td>
<td>—SHA</td>
<td>Disaster Recovery</td>
<td>—Shared Secrets*</td>
</tr>
<tr>
<td>Encryption</td>
<td>Message Authentication Codes*</td>
<td></td>
<td>—Passwords</td>
</tr>
<tr>
<td></td>
<td>—HMAC</td>
<td>See Fault Tolerance</td>
<td>—Challenge/Resp.</td>
</tr>
<tr>
<td></td>
<td>Error Control/Correction Codes</td>
<td></td>
<td>Authorization</td>
</tr>
<tr>
<td></td>
<td>—CRC32*</td>
<td>—Physical Tokens</td>
<td>—Access Controls</td>
</tr>
<tr>
<td></td>
<td>Digital Signatures</td>
<td></td>
<td>—Data Protection</td>
</tr>
<tr>
<td></td>
<td>—DSA</td>
<td>—Physical Tokens</td>
<td>Audit</td>
</tr>
<tr>
<td></td>
<td>—RSA</td>
<td>—Physical Tokens</td>
<td>Non-Repudiation</td>
</tr>
</tbody>
</table>

* Currently Implenented

Some aspects of this design space are beyond the scope of MicroQoSCORBA (e.g., Dedicated networks, authentication tokens, PKI infrastructure)

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Configurable Security Subsystem

- Initial Prototype
  - Caesar & AES Ciphers
- Implementing additional mechanisms
  - Reused existing cryptographic mechanisms
    - Cryptix Java Cryptography Extensions (JCE) mechanisms
    - Substantially rewrote the Cryptix JCE class hierarchy
  - Implemented “low-cost” mechanisms
    - XOR cipher
    - Parity & CRC message digests
- Security mechanisms are enabled/disabled via MicroQoSCORBA’s macro mechanisms

MicroQoSCORBA Security Mechanisms

- Supported Ciphers
  - XOR, Caesar, CAST5, DES, 3DES, IDEA, MARS, RC2, RC4, AES, Serpent, SKIPJACK, Square, Twofish
- Support Message Digests
  - Parity, CRC32, MD2, MD4, MD5, RIPEMD, RIPEMD128, RIPEMD160, SHA0, SHA1, SHA256, SHA384, SHA512, Tiger
- Supported Message Authentication Codes
  - HMAC is supported with the above MDs

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Supported Platforms

- Linux Workstation
  - Pentium 4, 1.5 GHz, 256 MB RAM
- Systronix SaJe
  - 100 MHz aJile aJ-100 CPU, 1 MB RAM
  - Native Java execution
- TINI
  - 40 MHz DS80C390 CPU, 512 KB RAM
  - (~equiv. 100 MHz 8051)
  - Emulated JVM (slow)
- PDAs (soon)
Automated Tools

- Necessitated by MicroQoSCORBA’s fine-grained configurability of both functional and QoS properties
  - (i.e., literally hundreds of configurations were evaluated)
- Complex Makefile targets
  - Update configurations, Execute IDL compiler, Build configurations, Archive builds for later execution
- Expect scripts
  - Automate the performance testing of multiple configurations
  - Scripts developed for the Linux, SaJe, and TINI platforms
- Analysis Routines
  - Common file formats, Expect logs

Example Application

- Timing Example
  - Very simple
  - Note: MicroQoSCORBA has not been completely optimized for memory usage or run time performance

- CORBA IDL

```plaintext
module timing {
    interface foo {
        long bar(in long arg1);
    }
};
```

Memory & File Size Comparisons

- MicroQoSCORBA and JacORB are Java based
- TAO is a C++ ORB

<table>
<thead>
<tr>
<th>Sizes (on Linux)</th>
<th>MicroQoSCORBA</th>
<th>JacORB</th>
<th>TAO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client Server</td>
<td>4,222 B</td>
<td>2,476 B</td>
<td>6,591 B</td>
</tr>
<tr>
<td>Client Server</td>
<td>6,363 B</td>
<td>243,120 B</td>
<td>33,422 B</td>
</tr>
<tr>
<td>Server Server</td>
<td>6,363 B</td>
<td>243,120 B</td>
<td>66,635 B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Java Mem.</th>
<th>Linux RSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MicroQoSCORBA</td>
<td>153,560 B</td>
</tr>
<tr>
<td>JacORB</td>
<td>160,648 B</td>
</tr>
<tr>
<td>TAO</td>
<td>11.46 MB</td>
</tr>
</tbody>
</table>

Baseline Application Size & Memory Usage

<table>
<thead>
<tr>
<th>QoS Property</th>
<th>Linux (Filtered/Raw)</th>
<th>SaJe (Filtered/Raw)</th>
<th>TINI (Filtered/Raw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-Property QoS Latencies (ms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency</td>
<td>Linux Client Server</td>
<td>SaJe Client Server</td>
<td>TINI Client Server</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Baseline</td>
<td>0.170 / 0.182</td>
<td>4.162 / 4.425</td>
<td>248.6 / 256.8</td>
</tr>
<tr>
<td>Value Red.</td>
<td>0.178 / 0.195</td>
<td>5.184 / 5.309</td>
<td>415.2 / 465.8</td>
</tr>
<tr>
<td>AES-128</td>
<td>0.207 / 0.222</td>
<td>5.945 / 7.137</td>
<td>858.2 / 1,050.2</td>
</tr>
<tr>
<td>AES-192</td>
<td>0.207 / 0.222</td>
<td>6.173 / 8.246</td>
<td>951.1 / 1,180.9</td>
</tr>
<tr>
<td>AES-256</td>
<td>0.219 / 0.229</td>
<td>6.399 / 8.547</td>
<td>1,047.2 / 1,311.7</td>
</tr>
</tbody>
</table>

Results from best of three runs; TR=Temporal Redundancy
Security Performance

<table>
<thead>
<tr>
<th>Security Mechanism</th>
<th>Linux</th>
<th>SaJe</th>
<th>TINI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.161</td>
<td>0.247</td>
<td>0.351</td>
</tr>
<tr>
<td>X86-128</td>
<td>0.194</td>
<td>0.406</td>
<td>0.647</td>
</tr>
<tr>
<td>AES-256</td>
<td>0.199</td>
<td>0.449</td>
<td>0.717</td>
</tr>
<tr>
<td>DES-56</td>
<td>0.190</td>
<td>0.538</td>
<td>0.914</td>
</tr>
<tr>
<td>3DES-168</td>
<td>0.229</td>
<td>0.997</td>
<td>1.796</td>
</tr>
<tr>
<td>Parity</td>
<td>0.165</td>
<td>0.307</td>
<td>0.467</td>
</tr>
<tr>
<td>MD5</td>
<td>0.184</td>
<td>0.318</td>
<td>0.471</td>
</tr>
<tr>
<td>SHA1</td>
<td>0.202</td>
<td>0.360</td>
<td>0.558</td>
</tr>
<tr>
<td>SHA2-512</td>
<td>0.315</td>
<td>0.878</td>
<td>1.466</td>
</tr>
<tr>
<td>XOR &amp; Parity</td>
<td>0.170</td>
<td>0.247</td>
<td>0.351</td>
</tr>
<tr>
<td>AES-128 &amp; SHA1</td>
<td>0.235</td>
<td>0.538</td>
<td>0.867</td>
</tr>
<tr>
<td>AES-256 &amp; SHA2</td>
<td>0.375</td>
<td>1.095</td>
<td>1.859</td>
</tr>
</tbody>
</table>

Security Mechanism Latencies for 56/12/1024 byte messages (ms)

Performance Impacts

- Java garbage collection and system/network performance impacts best-case performance

Performance Impacts (cont.)

- On Linux and SaJe the experiments were repeated with µs timer.
- The ms and µs results motivate the need for “event filtering”.

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Overview of Ongoing/Future Work
• C++ version in progress, late October-ish
• Temporal profiling toolkit
• Additional protocol support (SMTP, IPv6)
• Wireless compensation layer
• IDS mechanisms for embedded middleware
• CASE tools for (in collab. with Prof. Andrews)
  – Generation of instrumentation & validation code
  – Aspect oriented QoS+resource constraint management

Dual Use:
MicroQoSCORBA as embedded middleware and
MicroQoSCORBA for multi-property QoS investigations

Conclusions
• MicroQoSCORBA the only framework that
  – Is a “bottom-up” rethinking from the device level of
    what should be configurable, and in what ways
  – Is tailorable for a given application to the wide range of
    • Device constraints, and
    • Application-dictated constraints
    • with a fine granularity of configuration constraints
  – Supports both “functional” and QoS properties
    • Security and fault tolerance as well as real-time performance
      are all key QoS properties

• … one more important conclusion …

External Use
• MicroQoSCORBA is being used at:
  – CMU: Fault tolerance & Real-time mechanism research
  – U. Maryland: Power-aware middleware
• MQC is being considered at
  – TU Berlin: Interested in MQC for their QoS
    specification research
  – U. Oslo: MQC’s use has been written into Norwegian
    Research Council proposal
  – Cisco: Interested in MQC for used in low-end and mid-
    range routers (control plane; uses TAO now)
  – Boeing: MQC for avionics helping with validation
  – WSU: Beginning joint work with Dr. Andrews
  – Lockheed Martin: military

One More Important Conclusion …
Hunt the Ducks!
Drown them Webfeet!
Smack the Quackers!
Eat Beijing Duck!
The real SI cover FYI (outside Oregon):

QB, Meet Will Derting!

(Fark courtesy of DobasD03 on www.cougfan.com)