Design Principles and Optimizations for High-performance, Real-time CORBA

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Presentation Outline

1. Motivation
   - Need for CORBA
   - Lack of Real-time support in CORBA
   - Research Contributions

2. Research Contributions – Optimizations in TAO ORB
   - Optimized IIOP Protocol engine
   - TAO IDL Compiler optimizations
   - Efficient Demultiplexing

3. Concluding Remarks

4. Future Work
CORBA: Solution to the Distributed Software Crisis?

- **Goals of CORBA**
  - Simplify distribution by automating
    - Object location and activation
    - Parameter marshaling
    - Demultiplexing
    - Error handling
  - Provide foundation for higher-level services

www.cs.wustl.edu/~schmidt/corba.html

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http://www.cs.wustl.edu/~gokhale/Talks/defense.ps.gz
Need for Real-time Features in CORBA

- Many applications require QoS guarantees
  - e.g., telecom, avionics, WWW
- Building these applications manually is hard
- Existing middleware doesn’t support QoS effectively
  - e.g., CORBA, DCOM, DCE
- Solutions must be integrated

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Rapid Growth in Hand-held Devices

- **Devices**: WebPhones, WebTVs, PIMs, Palm PCs
- **RTOS**: Inferno, Windows CE2.0, PalmOS, VXWorks
- **Constraints**: Low power consumption => less storage => small footprint, but good and predictable performance
Caveat: Limitations of CORBA for Real-time Systems

- Limitations
  - Lack of QoS specifications
  - Lack of QoS enforcement
  - Lack of real-time programming features
  - Lack of performance optimizations

Related Work: Gokhale, Schmidt, Levine, Mungee, Flores,
Parulkar, Harrison – SIGCOMM’96, GLOBECOM’96, ICDCS’97,
IEEE Communications Feb’97, IEEE RTAS’98, IEEE RTSS’97

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Problem: Meeting End-to-End QoS Requirements

- **Design Challenges**
  - Reducing presentation layer overhead
  - Reducing demultiplexing latency
  - Maintaining small footprint
  - Specifying QoS requirements
  - Meeting operation scheduling deadlines

Related OMG Documents: – ORBOS/97-09-31 (RT CORBA), ORBOS/97-11-08 (Minimum CORBA)
The ACE ORB (TAO)

- **TAO Overview**
  - A high-performance, real-time ORB
    - Telecom and avionics focus
  - Leverages the ACE framework
    - Runs on VxWorks, POSIX, and Win32

- **Related Work**
  - U. RI, MITRE
  - ARMADA (U. Mich.)
  - QuO (BBN)
Research Contributions: TAO Optimizations

Efficient Stub and Skeleton Generation
Presentation Layer Optimizations
Data Copying Optimizations
Request Demuxing and Dispatching Optimizations
Communication Protocol Optimizations
I/O Subsystem Optimizations
Network Adapter Optimizations
Problem (1): Reducing IIOP Protocol Engine Overhead

- Design Challenges
  - Small memory footprint
  - Predictable, efficient performance
  - Minimize the typecode interpreter overhead
  - IIOP compliant
Throughput of the SunSoft IIOP Implementation

- Experimental design
  - Transfer 64 Mbytes of “oneway” data
  - Various types of data
- Note very poor initial performance

- Baseline TCP
- shorts
- longs
- chars/octetes
- doubles
- structs
Receiver-side Analysis of SunSoft IIOP Implementation

Percent Execution Time for doubles and structs

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Solution: TypeCode Interpreter Optimizations

- **Problem**
  - Optimizing complex software is hard
  - Small “mistakes” are costly over high-speed networks

- **Solution Approach (Iterative)**
  - Pinpoint sources of overhead via *white-box* metrics
    * e.g., Quantify, TNF, etc.
  - Apply optimization principles
  - Validate via white-box and black-box metrics

- **Related work**
  - Hoschka ’97
  - O’Malley, Proebsting, and Montz ’94 - USC Stub Compiler
  - Eide, Lepreau - Flick IDL compiler
## Optimization Principles

<table>
<thead>
<tr>
<th>Number</th>
<th>Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Optimize for the common case</td>
</tr>
<tr>
<td>2</td>
<td>Eliminate gratuitous waste</td>
</tr>
<tr>
<td>3</td>
<td>Replace inefficient general-purpose methods with efficient special-purpose ones</td>
</tr>
<tr>
<td>4</td>
<td>Precompute values, when possible</td>
</tr>
<tr>
<td>5</td>
<td>Store redundant state to speed up expensive operations</td>
</tr>
<tr>
<td>6</td>
<td>Pass information between layers</td>
</tr>
<tr>
<td>7</td>
<td>Optimizations for cache</td>
</tr>
</tbody>
</table>

### Related Work

- G. Varghese, SIGCOMM'96
- Clark:90, Abott:93 – ILP
- Peterson:96 – Outlining
- Clark:89 – Header prediction
- Peterson:94 (PathFinder), Engler:96 (DPF), Mahesh:95 (packet filters)

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Sequences Mapping

- Key overheads
  - Redundant computation of nested size and alignment
  - Wasteful deallocation for primitives
  - Excessive overhead of function calls

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Throughput After Optimizations

Throughput for doubles and structs

double

struct
Throughput Comparisons

Original SunSoft

Optimized TAO

www.cs.wustl.edu/~schmidt/HICSS-97.ps.gz (Best Paper Award)
Problem (2): Inefficient stubs/skeletons

- **Key sources of overhead**
  - Excess heap allocation
  - Repetitive code in every skeleton $\Rightarrow$ large footprint
  - Interpretive deallocation

- **Solution: Principle-based Optimizations**
  1. Eliminate gratuitous waste
  2. Factor out common tasks
  3. Optimize for the expected case
  4. Use compile-time knowledge as much as possible
Optimized, Small footprint Skeletons
TAO IDL Compiler Design
Results: Compiled versus Interpretive Marshaling

Performance

Footprint

Related work – Hoschka ’97, O'Malley’94 (USC Stub Compiler), Lepreau (Flick IDL compiler)

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Problem (3): Reducing Demultiplexing Latency

- **Design Challenges**
  - Minimize demuxing layers
  - Provide $O(1)$ operation demuxing
  - Avoid priority inversions
  - Remain CORBA-compliant
**Solution: De-layered Active Demultiplexing**

- **Solution Approach**
  - Pre-negotiate demuxing keys
  - Tunnel demuxing key with Object key

- **Related Work**
  - Yau and Lam ’97
  - Dittia and Parulkar ’97
  - Engler and Kaashoek ’96
Demultiplexing Performance Experiments

- Linear search based on Orbix demuxing strategy
- Perfect hashing based on GNU gperf
  - http://www.cs.wustl.edu/~schmidt/gperf.ps.gz
Demultiplexing Performance Results

Random

Worst case

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Applicability of Demultiplexing Strategies

- Linear Search approach is 100% compatible, but very poor performance
- Dynamic Hashing approach is 100% compatible, much better than linear search, but not predictable
- gperf solution is 100% compatible, but static
- Optimal active demuxing isn’t 100% compatible, but is dynamic
Publications

• Journal Papers
  1. IEEE Transactions on Computers (April'98) – with D. Schmidt
  2. IEEE Communications Magazine, Feb’97 – with D. Schmidt, G. Parulkar, T. Harrison

• Conference Papers
  1. IEEE RTAS’98 – with D. Schmidt, S. Mungee, S. Flores
  2. HICSS-31, Jan’98 (Received the Best paper Award) – with D. Schmidt
  3. IEEE Globecom ’97 – with D. Schmidt
  4. ISS’97 – with D. Schmidt, S. Moyer
  5. IEEE ICDCS’97 – with D. Schmidt
  6. IEEE Globecom’96 – with D. Schmidt
  7. ACM SIGCOMM’96 – with D. Schmidt

• Workshops and Poster
  1. ACM OOPSLA'97 Poster Session
  2. ACM OOPSLA’96 Poster Session
  3. IWOOOS’96 Workshop – with D. Schmidt, G. Parulkar, T. Harrison

• Currently under Review
  1. IEEE JSAC’99 – with D. Schmidt

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Concluding Remarks

• Distributed Software Crisis
  – CORBA - potential solution
  – Lack of real-time features in CORBA
  – The TAO RT-ORB project

• Research Contributions in TAO
  – Reducing latency via *de-layered active demuxing* and *perfect hashing*
  – Applying optimization principles to TypeCode interpreter and presentation layer
  – IDL compiler and optimized stub/skeleton generation

• Results – widely used ORB

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Research Contributions Revisited: TAO Optimizations
Future Work

• Generate compiled stubs/skeletons

• Backend emitter framework for OMG IDL compiler

• Integrate IDL compiler with University of Utah’s Flick compiler

• ORBs for PDAs and other embedded systems. Issues involved –
  – Small footprint
  – Real-time performance
  – Efficient tradeoff between compiled and interpreted forms of marshaling

• Reliability and Fault-tolerance (at Lucent Bell Labs)
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9. And finally - Dr. Douglas Schmidt without whom these achievements would have been just a dream
Does TAO mean anything?

Main Entry: Tao
Pronunciation: ’dau, ’tau
Function: noun
Etymology: Chinese (Beijing) dao, literally, way
Date: 1736

1.(a) : the unconditional and unknowable source and guiding principle of all reality as conceived by Taoists
   (b) the process of nature by which all things change and which is to be followed for a life of harmony

2. often not capitalized : the path of virtuous conduct as conceived by Confucians

3. often not capitalized : the art or skill of doing something in harmony with the essential nature of the thing <the Tao of archery>