Patterns and Performance of Real-time Object Request Brokers

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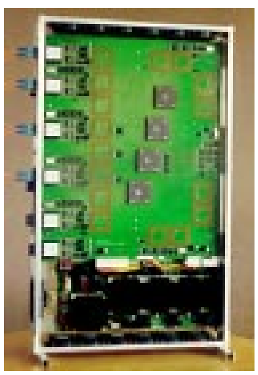
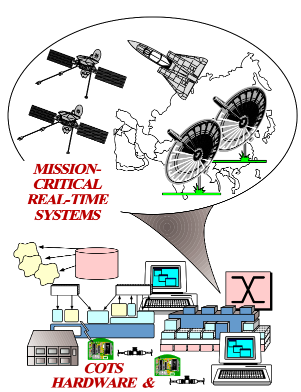
Motivation: the QoS-enabled Software Crisis



www.arl.wustl.edu/arl/

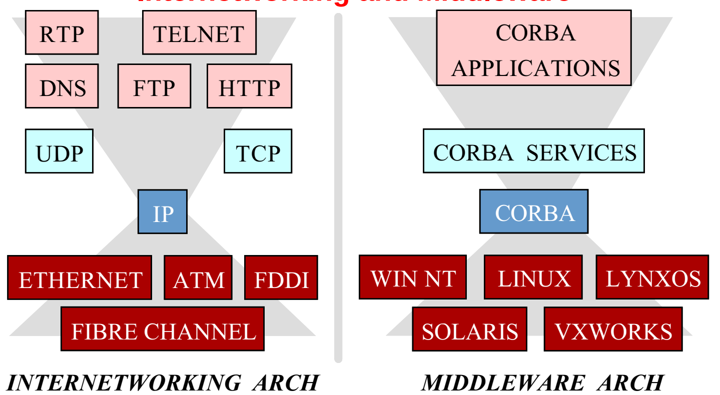
- **Symptoms**
  - Communication ***hardware*** gets smaller, faster, cheaper
  - Communication ***software*** gets larger, slower, more expensive
- **Culprits**
  - ***Inherent*** and ***accidental*** complexity
- **Solution Approach**
  - ***Standards-based COTS Hardware & Software***

Problem: the COTS Hardware & Software Crisis

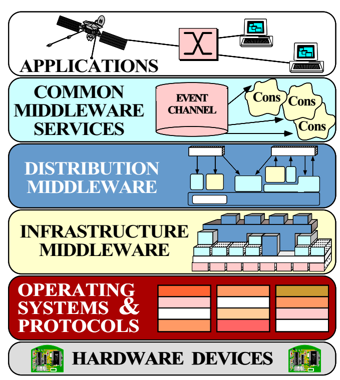


- **Context**
  - Adopting ***COTS hardware & software*** is increasingly essential for real-time mission-critical systems
- **Problems**
  - ***Inherent*** and ***accidental*** complexity
  - ***Integration*** woes
- **Solution Approach**
  - ***Standards-based adaptive COTS middleware***

Context: Levels of Abstraction in Internetworking and Middleware

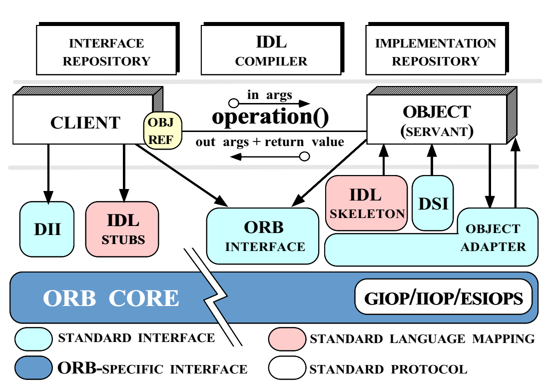


Problem: Lack of QoS-enabled Middleware



- Many applications require QoS guarantees
  - *e.g.*, avionics, telecom, WWW, medical, high-energy physics
- Building these applications manually is hard and inefficient
- Existing middleware doesn't support QoS effectively
  - *e.g.*, CORBA, DCOM, DCE, Java
- Solutions must be integrated horizontally & vertically

Candidate Solution: CORBA

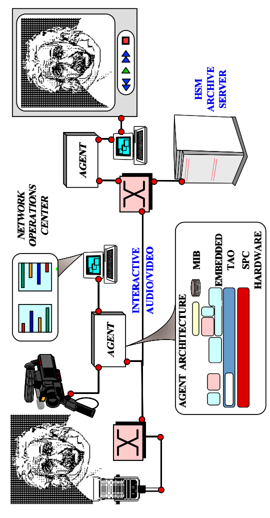


www.cs.wustl.edu/~schmidt/corba.html

Goals of CORBA

- Simplify distribution by automating
  - Object location & activation
  - Parameter marshaling
  - Demultiplexing
  - Error handling
- Provide foundation for higher-level services

Caveat: Requirements/Limitations of CORBA for QoS-enabled Systems



www.cs.wustl.edu/∼schmidt/RT-ORB.ps.gz

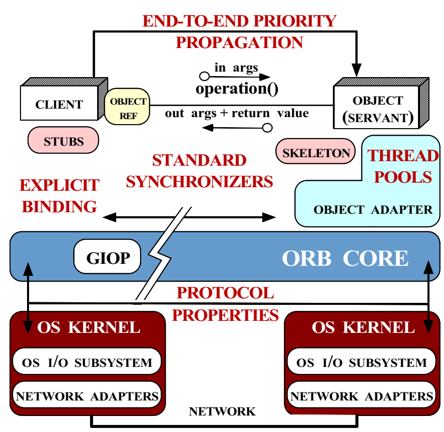
Requirements

- Location transparency
- Performance transparency
- Predictability transparency
- Reliability tranparency

Limitations

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

Overview of the Real-time CORBA Specification



Features

1. Portable priorities
2. End-to-end priority propagation
3. Protocol properties
4. Thread pools
5. Explicit binding
6. Standard synchronizers

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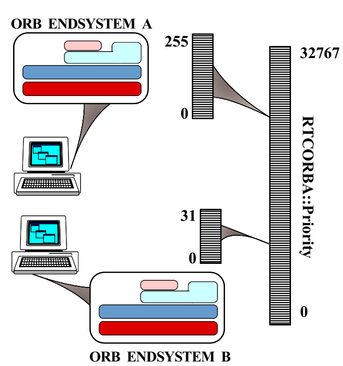
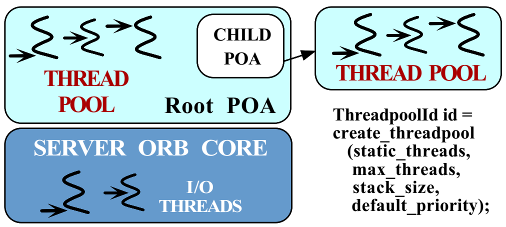
Portable Priorities



Features

- Designed to support heterogeneous real-time platforms
- *CORBA priorities* range from 0 → 32767
- Users can map CORBA priorities to *native OS priorities*
- No silver bullet, but rather an “enabling technique”

Thread Pools



Features

- Pre-allocate threads and thread attributes
  - Stacksize
  - Static threads
  - Maximum threads
  - Default priority
- Applicable at both the ORB and POA level

Configurable Protocol Properties

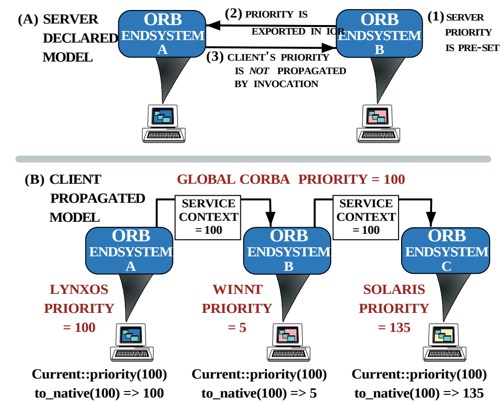
```
interface ProtocolProperties {};
typedef struct {
  IOP::ProfileId protocol_type;
  ProtocolProperties
    orb_protocol_properties;
  ProtocolProperties
    transport_protocol_properties;
} Protocol;
typedef sequence <Protocol> ProtocolList;

interface TCPProtocolProperties
  : ProtocolProperties
{
  attribute long send_buffer_size;
  attribute long recv_buffer_size;
  attribute boolean keep_alive;
  attribute boolean dont_route;
  attribute boolean no_delay;
};
```

Features

- Select and configure communication protocols
  - *e.g.*, TCP socket options
- Supports *ORB protocol* and *transport protocol* configuration
- Ordering in `ProtocolList` indicates preferences

End-to-End Priority Propagation

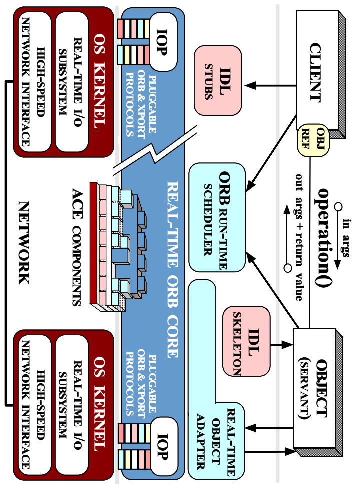


www.cs.wustl.edu/~schmidt/RT-ORB-std-new.pdf.gz

Features

- Client priorities can propagate end-to-end
- Servers can also declare priority

Our Approach: The ACE ORB (TAO)

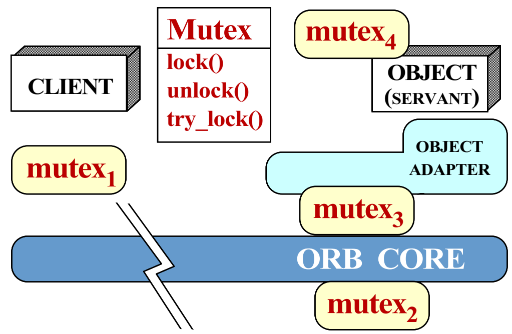


www.cs.wustl.edu/~schmidt/TAO.html

TAO Overview →

- An open-source, standards-based, real-time, high-performance CORBA ORB
- Runs on POSIX/UNIX, Win32, & RTOS platforms
  - *e.g.*, VxWorks, Chorus, LynxOS
- Leverages ACE

Standard Synchronizers

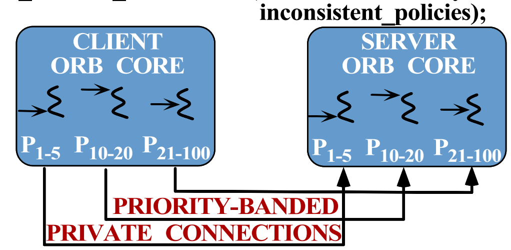


Features

- A portable Mutex API
  - *e.g.*, `lock`, `unlock`, `try_lock`
- Necessary to ensure consistency between ORB and application synchronizers
- Locality constrained

Explicit Binding

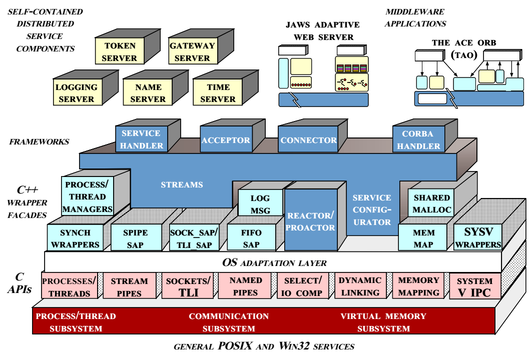
_validate_connection (out CORBA::PolicyList inconsistent_policies);



Features

- Enables pre-establishment of connections
  - Priority-banded connections
  - Private connections
  - Protocol policies

The ADAPTIVE Communication Environment (ACE)



www.cs.wustl.edu/∼schmidt/ACE.html

ACE Overview →

- A concurrent OO networking framework
- Available in C++ and Java
- Ported to POSIX, Win32, and RTOSs

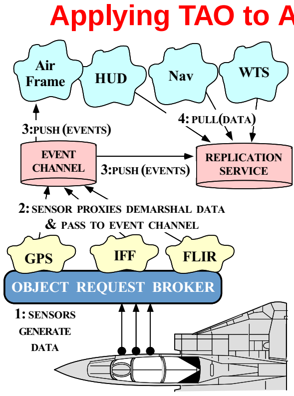
Related work →

- x-Kernel
- SysV STREAMS

ACE and TAO Statistics

- Over 50 person-years of effort
  - ACE > 200,000 LOC
  - TAO > 200,000 LOC
  - TAO IDL compiler > 130,000 LOC
  - TAO CORBA Object Services > 150,000 LOC
- Ported to UNIX, Win32, MVS, and RTOS platforms
- Large user community
  - ∼schmidt/ACE-users.html
- Currently used by dozens of companies
  - Bellcore, BBN, Boeing, Ericsson, Hughes, Kodak, Lockheed, Lucent, Motorola, Nokia, Nortel, Raytheon, SAIC, Siemens, etc.
- Supported commercially
  - ACE → www.riverace.com
  - TAO → www.theaceorb.com

Applying TAO to Avionics Mission Computing



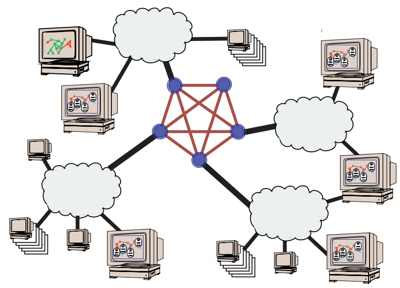
www.cs.wustl.edu/∼schmidt/JSAC-98.ps.gz

Domain Challenges

- Deterministic & statistical real-time deadlines
- Periodic & aperiodic processing
- COTS and open systems
- Reusable components
- Support platform upgrades

www.cs.wustl.edu/∼schmidt/TAO-boeing.html

Applying TAO to Distributed Interactive Simulations



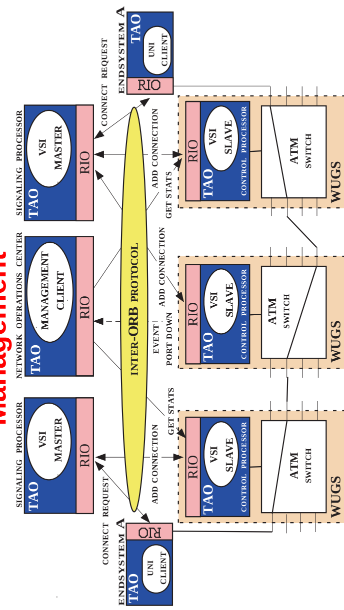
www.cs.wustl.edu/∼schmidt/
Words99.ps.gz

Domain Challenges

- High scalability and group communication
- High throughput and low latency
- “Interactive” real-time
- Multi-platform

hlasdc.dmso.mil/RTISUP/hla_soft/
hla_soft.htm

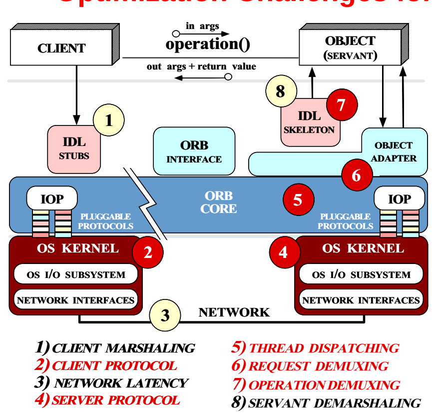
Applying TAO to Real-time Switch Management



Domain Challenges

- High-speed (20 Gbps) ATM switches w/embedded controllers
- Low-latency and statistical real-time deadlines
- COTS infrastructure, open systems, and small footprint

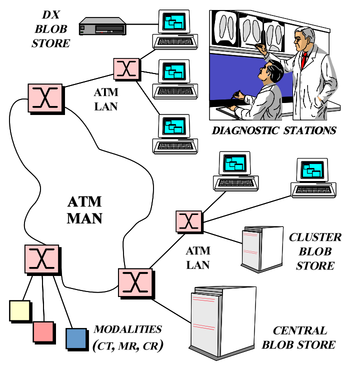
Optimization Challenges for QoS-enabled ORBs



Key Challenges

- Alleviate priority inversion and non-determinism
- Reduce demultiplexing latency/jitter
- Ensure protocol flexibility
- Specify QoS requirements
- Schedule operations
- Eliminate (de)marshaling overhead
- Minimize footprint

Problem: Optimizing Complex Software



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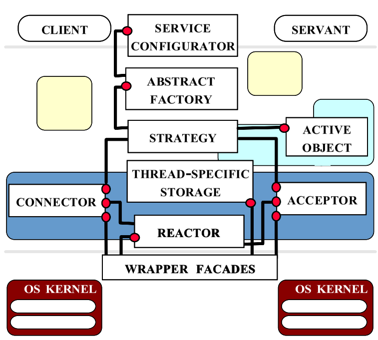
Common Problems →

- Optimizing complex software is hard
- Small "mistakes" can be costly

Solution Approach (Iterative) →

- Pinpoint overhead via *white-box* metrics
  – *e.g.*, `Quantify` and `VMEtro`
- Apply patterns and framework components
- Revalidate via white-box and black-box metrics

Solution 1: Patterns and Framework Components



www.cs.wustl.edu/∼schmidt/ORB-patterns.ps.gz

Definitions

- *Pattern*
  – A solution to a problem in a context
- *Framework*
  – A "semi-complete" application built with components
- *Components*
  – Self-contained, "pluggable" ADTs

Solution 2: ORB Optimization Principle Patterns

Definition

- ***Optimization principle patterns*** document rules for avoiding common design and implementation problems that can degrade the efficiency, scalability, and predictability of complex systems

Optimization Principle Patterns Used in TAO

#	Optimization Principle Pattern
1	Optimize for the common case
2	Remove gratuitous waste
3	Replace inefficient general-purpose functions with efficient special-purpose ones
4	Shift computation in time, *e.g.*, precompute
5	Store redundant state to speed-up expensive operations
6	Pass hints between layers and components
7	Don't be tied to reference implementations/models
8	Use efficient/predictable data structures

Lessons Learned Developing QoS-enabled ORBs

- Avoid dynamic connection management
- Minimize dynamic memory management and data copying
- Avoid multiplexing connections for different priority threads
- Avoid complex concurrency models
- Integrate ORB with OS and I/O subsystem and avoid reimplementing OS mechanisms
- Guide ORB design by empirical benchmarks and patterns

Concluding Remarks

- Researchers and developers of distributed, real-time applications confront many common challenges
  - *e.g.*, service initialization and distribution, error handling, flow control, scheduling, event demultiplexing, concurrency control, persistence, fault tolerance
- Successful researchers and developers apply *patterns*, *frameworks*, and *components* to resolve these challenges
- Careful application of patterns can yield efficient, predictable, scalable, *and* flexible middleware
  - *i.e.*, middleware performance is largely an "implementation detail"
- Next-generation ORBs will be highly QoS-enabled, though many research challenges remain

Web URLs for Additional Information

- These slides: `~schmidt/TAO4.ps.gz`
- More information on CORBA: `~schmidt/corba.html`
- More info on ACE: `~schmidt/ACE.html`
- More info on TAO: `~schmidt/TAO.html`
- TAO Event Channel: `~schmidt/JSAC-98.ps.gz`
- TAO static scheduling: `~schmidt/TAO.ps.gz`
- TAO dynamic scheduling: `~schmidt/dynamic.ps.gz`
- ORB Endsystem Architecture: `~schmidt/RIO.ps.gz`
- Pluggable protocols: `~schmidt/pluggable_protocols.ps.gz`

Web URLs for Additional Information (cont'd)

- Network monitoring, visualization, & control: ~schmidt/NMVC.html
- Performance Measurements:
  - Demuxing latency: ~schmidt/COOTS-99.ps.gz
  - SII throughput: ~schmidt/SIGCOMM-96.ps.gz
  - DII throughput: ~schmidt/GLOBECOM-96.ps.gz
  - ORB latency & scalability: ~schmidt/ieee_tc-97.ps.gz
  - IIOP optimizations: ~schmidt/JSAC-99.ps.gz
  - Concurrency and connection models: ~schmidt/RT-perf.ps.gz
  - RTOS/ORB benchmarks:
    ~schmidt/RT-OS.ps.gz
    ~schmidt/words-99.ps.gz