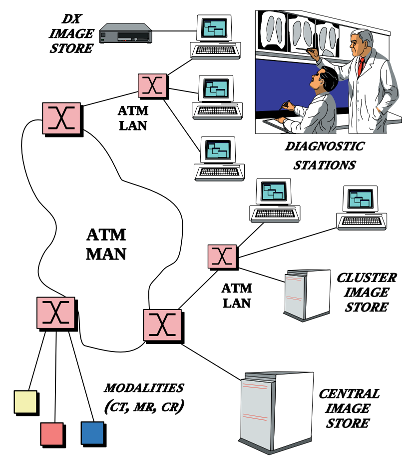
High-performance and Real-time CORBA

Douglas C. Schmidt
schmidt@cs.wustl.edu

Washington University, St. Louis
www.cs.wustl.edu/∼schmidt/

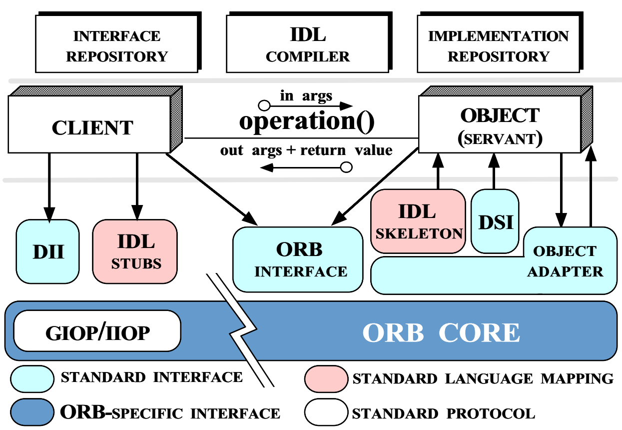
This work was sponsored in part by Boeing and DARPA

Problem: High-Performance, Real-time Middleware



- Many applications require high-performance
  - *e.g.*, telecom, imaging, WWW
- Building these applications manually is hard
- Existing middleware doesn't support performance effectively
  - *e.g.*, CORBA, DCOM, DCE

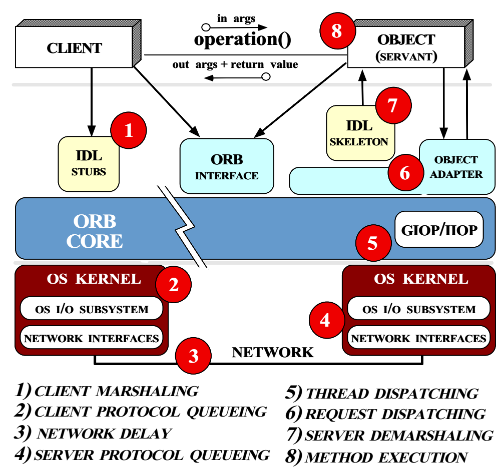
Candidate Solution: CORBA



www.cs.wustl.edu/∼schmidt/corba.html

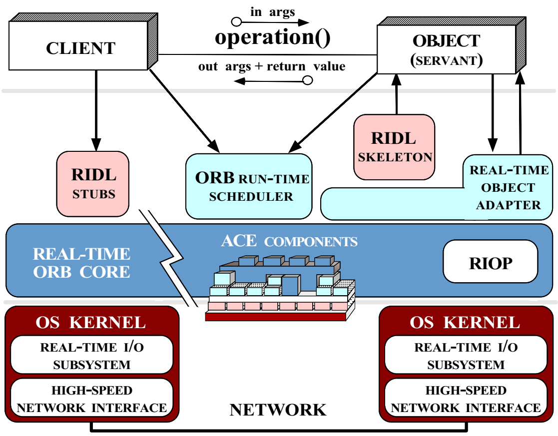
- **Goals of CORBA**
  - Simplify distribution by automating
    - ∗ Object location & activation
    - ∗ Parameter marshaling
    - ∗ Demultiplexing
    - ∗ Error handling
  - Provide foundation for higher-level services

Performance Challenges for ORB Middleware



- **Key Challenges**
  - Specifying QoS requirements
  - Determining operation schedules
  - Alleviating priority inversion and non-determinism
  - Reducing latency/jitter for demultiplexing
  - Reducing presentation layer overhead
  - Maintaining small footprint

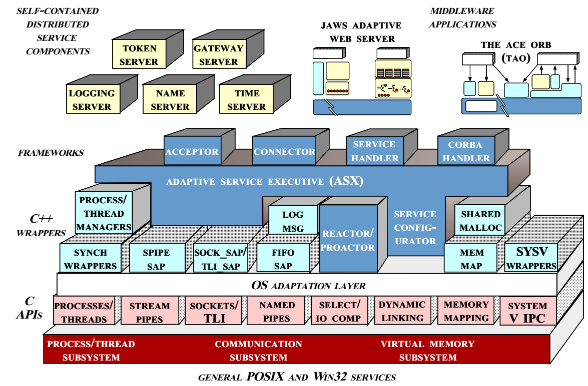
The ACE ORB (TAO)



www.cs.wustl.edu/∼schmidt/TAO.html

- **TAO Overview**
  - A real-time, high-performance ORB
  - Leverages ACE
    - ∗ Runs on POSIX, Win32, RTOSs
- **Related work**
  - U. RI, Mitre
  - QuO at BBN
  - ARMADA at U. Mich.

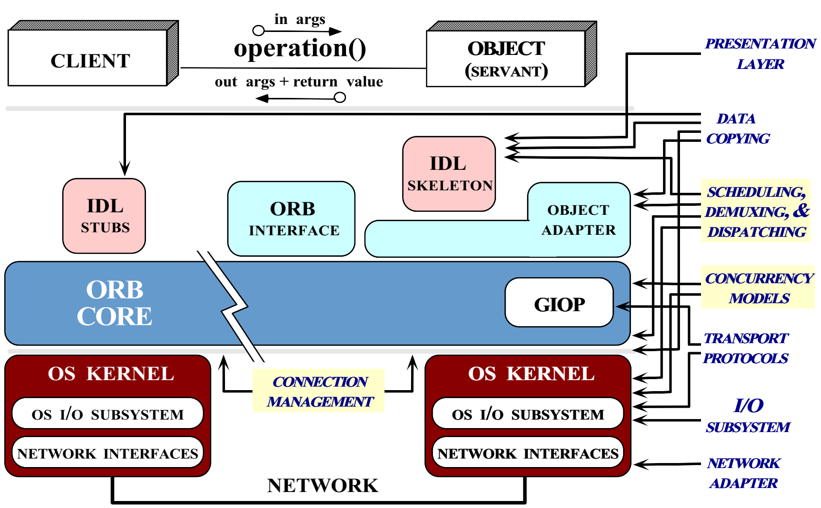
The ADAPTIVE Communication Environment (ACE)



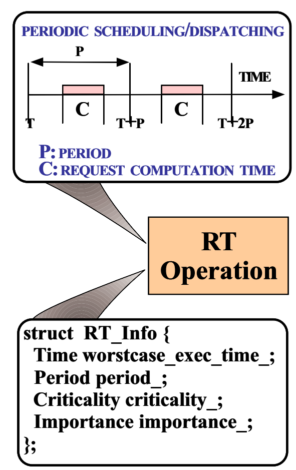
www.cs.wustl.edu/∼schmidt/ACE.html

- **ACE Overview**
  - Concurrent OO networking framework
  - Ported to C++ and Java
  - Runs on RTOSs, POSIX, and Win32
- **Related work**
  - x-Kernel
  - SysV STREAMS

Scope: Performance Optimizations in TAO

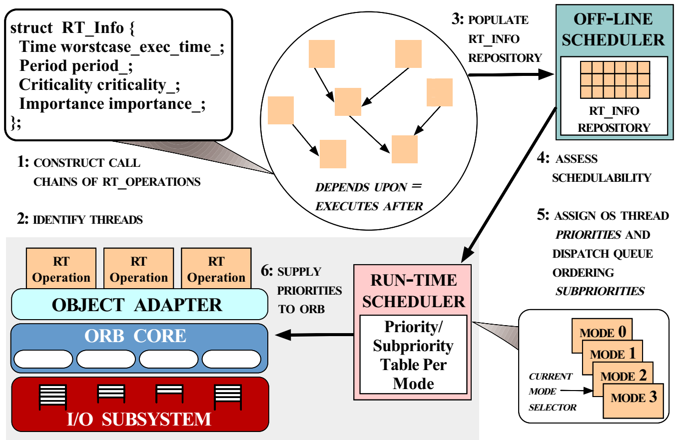


Problem: Providing QoS to CORBA Operations



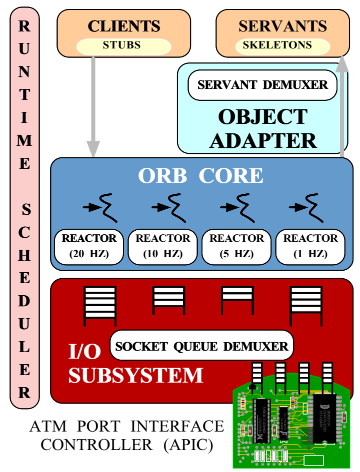
- **Design Challenges**
  - Specifying/enforcing QoS requirements
  - Focus on *Operations* upon *Objects*
    - ∗ Rather than on communication channels or threads/synchronization
  - Support static *and* dynamic scheduling
- **Solution Approach**
  - Servants publish resource (*e.g.*, CPU) requirements and (periodic) deadlines
  - Most clients are also servants

Solution: TAO's Real-time Static Scheduling Service



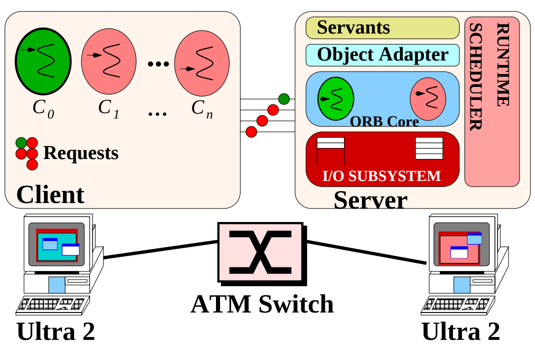
www.cs.wustl.edu/∼schmidt/TAO.ps.gz

TAO's High-Performance, Real-time ORB Endsystem



- **Solution Approach**
  - Integrate RT dispatcher into ORB endsystem
  - Support multiple request scheduling strategies
    - ∗ *e.g.*, RMS, EDF, and MUF
  - Requests ordered *across* thread priorities by OS dispatcher
  - Requests ordered *within* priorities based on *data dependencies* and *importance*

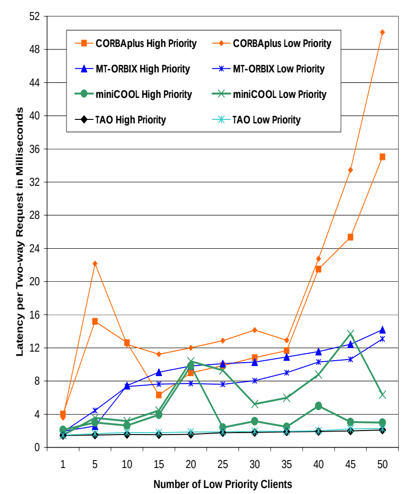
ORB Latency and Priority Inversion Experiments



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

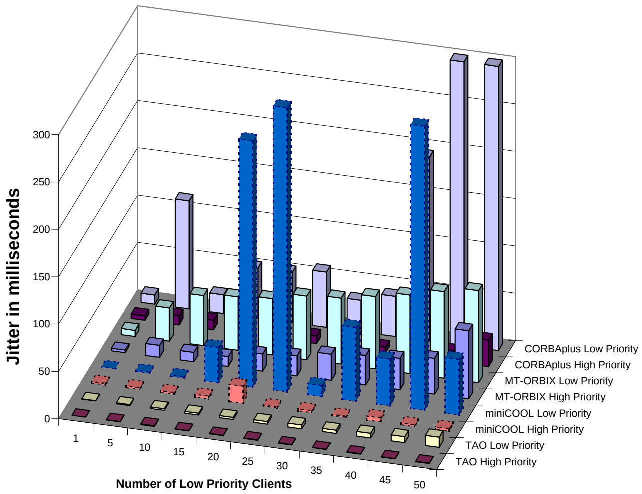
- Vary ORBs, hold OS constant
- Solaris real-time threads
- High priority client C_0 connects to servant S_0 with matching priorities
- Clients $C_1 \ldots C_n$ have same lower priority
- Clients $C_1 \ldots C_n$ connect to servant S_1
- Clients invoke twoway CORBA calls that cube a number on the servant and returns result

ORB Latency and Priority Inversion Results



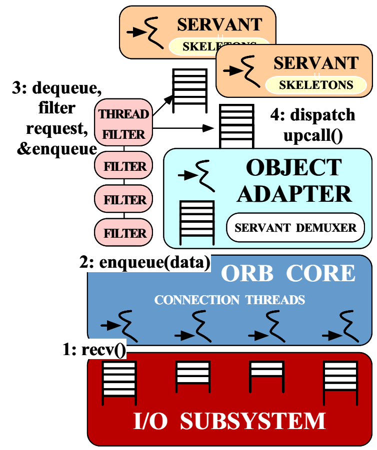
- **Synopsis of results**
  - TAO's latency is lowest for large # of clients
  - TAO avoids priority inversion
    - ∗ *i.e.*, high priority client always has lowest latency
  - Primary overhead stems from *concurrency* and *connection* architecture
    - ∗ *e.g.*, synchronization and context switching

ORB Jitter Results



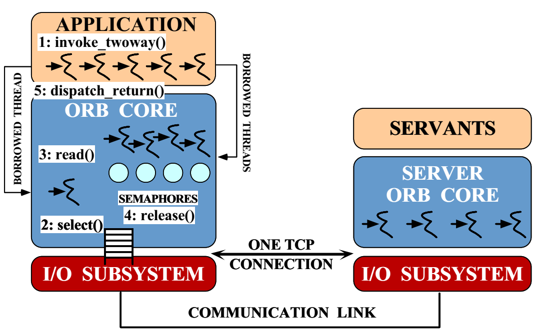
- **Definition**
  - Standard deviation from average latency
- **Synopsis of results**
  - TAO's jitter is lowest and most consistent
  - CORBAplus' jitter is highest and most variable

Problem: Improper ORB Concurrency Model



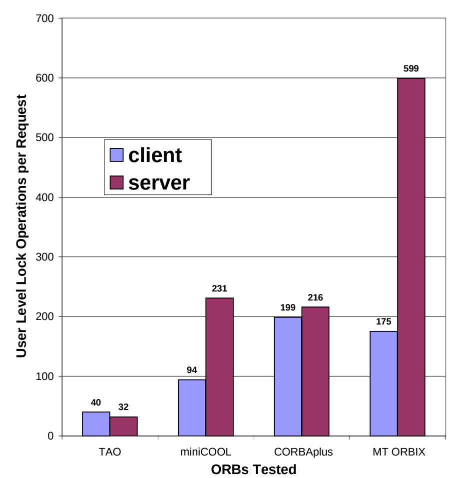
- **Common Problems**
  - High overhead
    - ∗ Context switching
    - ∗ Synchronization
  - Thread-level priority inversions
    - ∗ FIFO request queueing
    - ∗ Improper thread priorities
  - Lack of application control over concurrency model

Problem: ORB Shared Connection Model



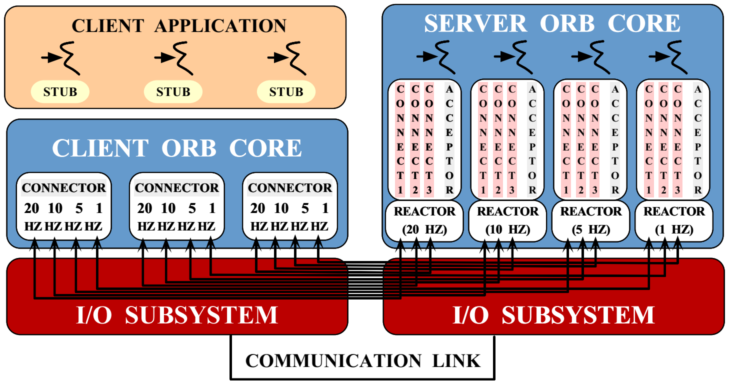
- **Common Problems**
  - Request-level priority inversions
    - ∗ Sharing multiple priorities on a single connection
  - Complex connection multiplexing
  - Synchronization overhead

Problem: High Locking Overhead



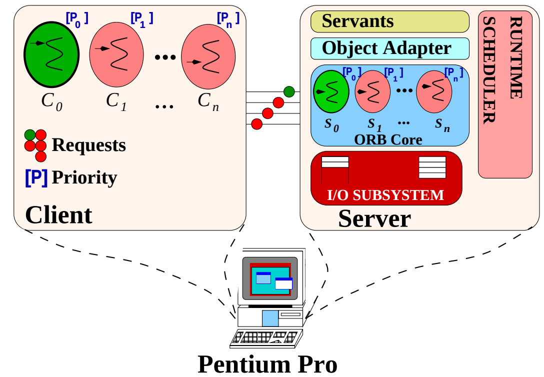
- Locking overhead significantly affects latency and jitter
  - Memory management commonly involves locking
- RT ORBs should minimize or eliminate all locking operations
- TAO is carefully designed to minimize locking and memory allocation

Solution: TAO's Inter-ORB Connection Topology



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

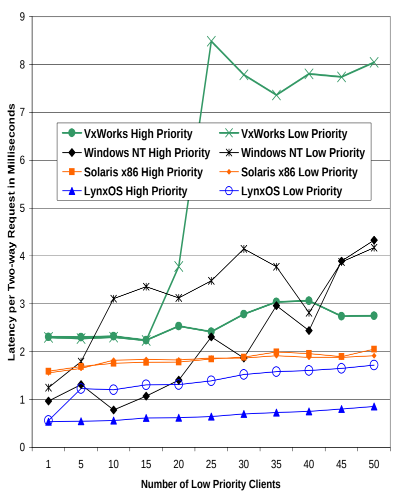
Real-time OS/ORB Performance Experiments



www.cs.wustl.edu/∼schmidt/RT-OS.ps.gz

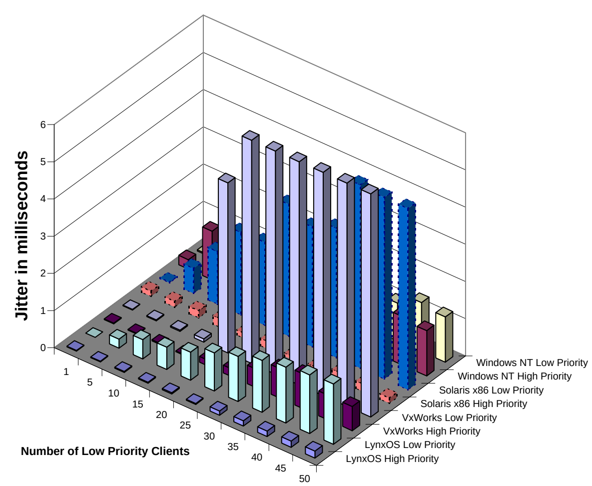
- Vary OS, hold ORBs constant
- Single-processor Intel Pentium Pro 200 Mhz, 128 Mbytes of RAM
- Client and servant run on the same machine
- Client C_i connects to servant S_i with priority P_i
  - i ranges from $1 \ldots 50$
- Clients invoke twoway CORBA calls that cube a number on the servant and returns result

Real-time OS/ORB Performance Results



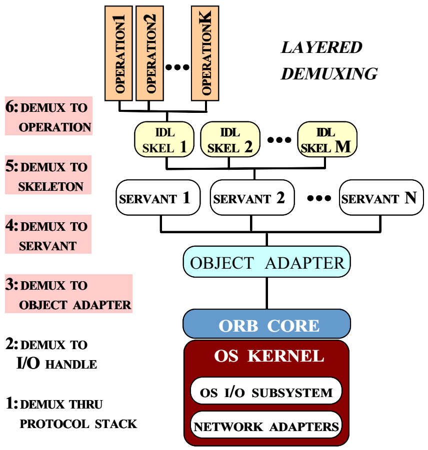
- **Synopsis of results**
  - LynxOS yielded very good latency and deterministic behavior
  - Erratic behavior and high latency are a problem for Windows NT
  - Windows NT also showed priority inversion at 50 low priority clients
  - VxWorks performs surprisingly erratically
  - Solaris' latency is high but predictable

Real-time OS/ORB Jitter Results



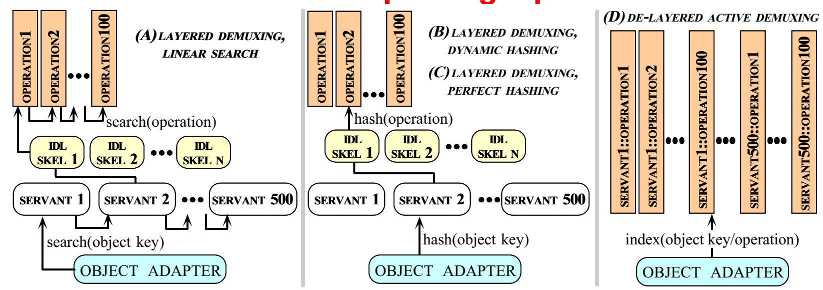
- **Definition**
  - Standard deviation from average latency
- **Synopsis of results**
  - Some RTOS's provide low jitter
  - ORB (TAO) doesn't introduce jitter

Problem: Reducing Demultiplexing Latency



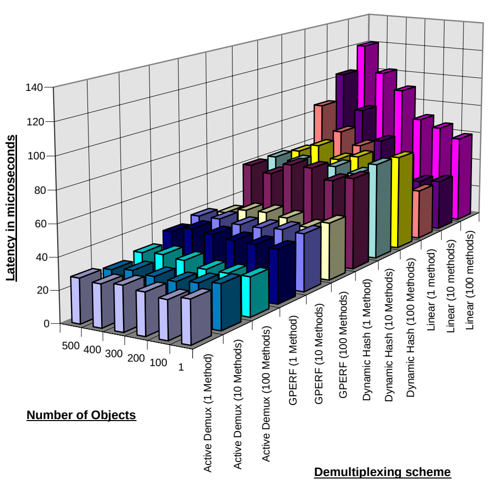
- **Design Challenges**
  - Minimize demuxing layers
  - Provide $O(1)$ operation demuxing
  - Avoid priority inversions
  - Remain CORBA-compliant

Solution: Demultiplexing Optimizations



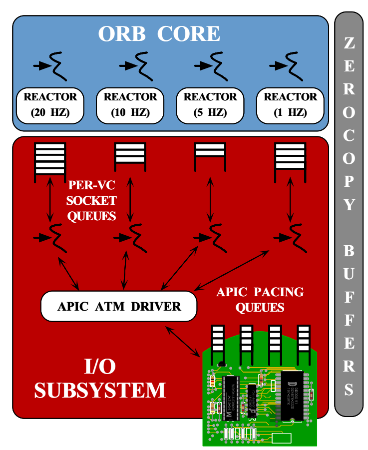
- Results at www.cs.wustl.edu/~schmidt/ieee_tc-97.ps.gz
- Linear search based on `Orbix` demuxing strategy
- Perfect hashing based on GNU `gperf`
  - www.cs.wustl.edu/~schmidt/gperf.ps.gz

Demultiplexing Performance Results



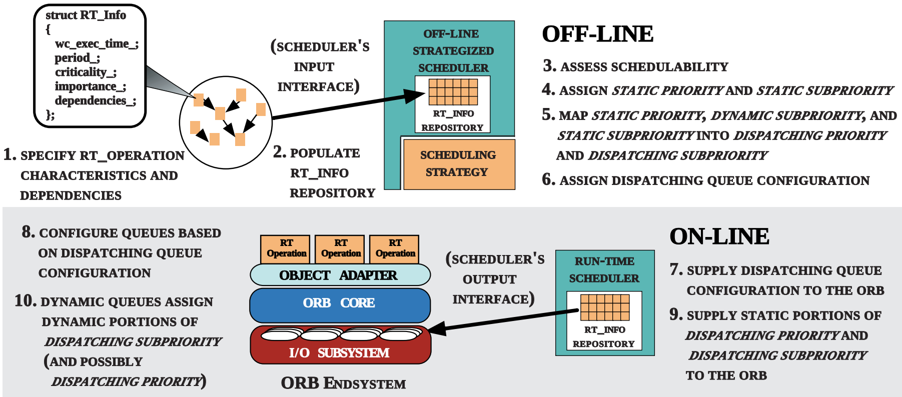
- **Synopsis**
  - Linear search is far too costly
  - Dynamic hashing can be unstable
  - `gperf` solution is 100% compatible, but static
  - Optimal active demuxing may not be 100% compatible, but is dynamic
  - Strategy pattern facilitates flexibility

Next Steps: Integrating TAO with ATM I/O Subsystem



- **Key Features**
  - Vertical integration of QoS through ORB, OS, and ATM network
  - Real-time I/O enhancements to Solaris kernel
  - Provides rate-based QoS end-to-end
  - Leverages APIC features for cell pacing and zero-copy buffering

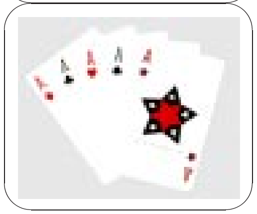
Next Steps: Strategized Scheduling Service Framework



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

Principles for High-Performance, Real-time 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



TAO Project Research Summary

- Current focus: real-time ORBs
  - Developed first deployed real-time CORBA scheduling service and first POA
  - Minimized ORB Core priority inversion and non-determinism
  - Reduced end-to-end latency via demuxing optimizations
  - Applied optimizations to IIOP protocol engine
  - Co-submitters to OMG's real-time CORBA RFP
- Future work
  - Dynamic and hybrid scheduling of CORBA operations
  - Distributed QoS and integration with real-time ATM I/O Subsystem
  - Optimizing IDL compiler
  - Technology transfer with DARPA Quorum program

Web URLs for Additional Information

- These slides: `www.cs.wustl.edu/∼schmidt/PDF/tutorial4.ps.gz`
- More information on TAO: `www.cs.wustl.edu/∼schmidt/RT-ORB.ps.gz`
- TAO Event Channel: `www.cs.wustl.edu/∼schmidt/JSAC-98.ps.gz`
- TAO static scheduling: `www.cs.wustl.edu/∼schmidt/TAO.ps.gz`
- TAO dynamic scheduling: `www.cs.wustl.edu/∼schmidt/dynamic.ps.gz`
- ORB Endsystem Architecture: `www.cs.wustl.edu/∼schmidt/RT-middleware.ps.gz`

Web URLs for Additional Information (cont'd)

- Performance Measurements:
  - Demuxing latency: www.cs.wustl.edu/∼schmidt/GLOBECOM-97.ps.gz
  - SII throughput: www.cs.wustl.edu/∼schmidt/SIGCOMM-96.ps.gz
  - DII throughput: www.cs.wustl.edu/∼schmidt/GLOBECOM-96.ps.gz
  - Latency, scalability: www.cs.wustl.edu/∼schmidt/ICDCS-97.ps.gz
  - IIOP optimizations: www.cs.wustl.edu/∼schmidt/JSAC-99.ps.gz
- More detail on CORBA: www.cs.wustl.edu/∼schmidt/corba.html
- ADAPTIVE Communication Environment (ACE): www.cs.wustl.edu/∼schmidt/ACE.html
- The ACE ORB (TAO): www.cs.wustl.edu/∼schmidt/TAO.html