Real-time CORBA Tutorial

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DC Real-time and Embedded Workshop

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Agenda

- Motivation
- Introduction to Real-time Principles
- Challenges in Distributing Real-time Systems
- Overview of Real-time CORBA
- Applying Real-time CORBA to problem domains
- Real-time CORBA Architecture
- Example Application
- Dynamic Scheduling
- Future Directions
- Summary

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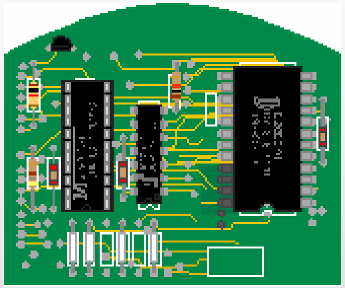
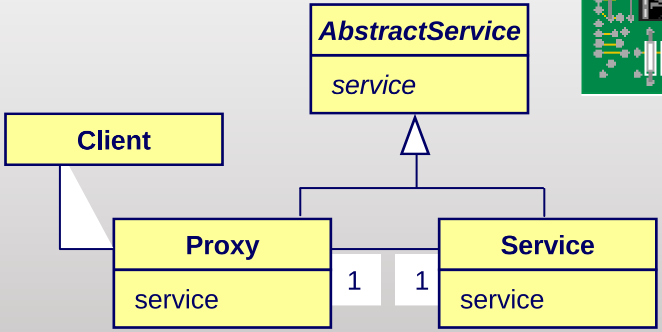
Motivation for Real-time Middleware

Trends

- Hardware keeps getting smaller, faster, & cheaper
- Software keeps getting larger, slower, & more expensive



- Building distributed systems is hard
- Building them on-time & under budget is even harder



AbstractService

service

Client

Proxy

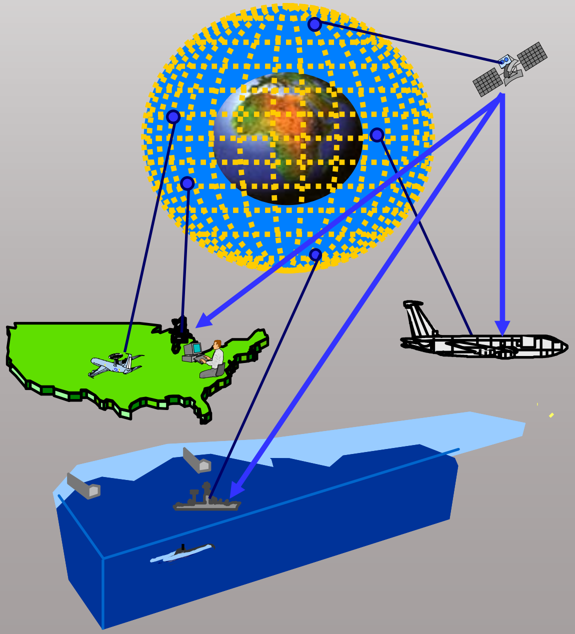
service

1

1

Service

service

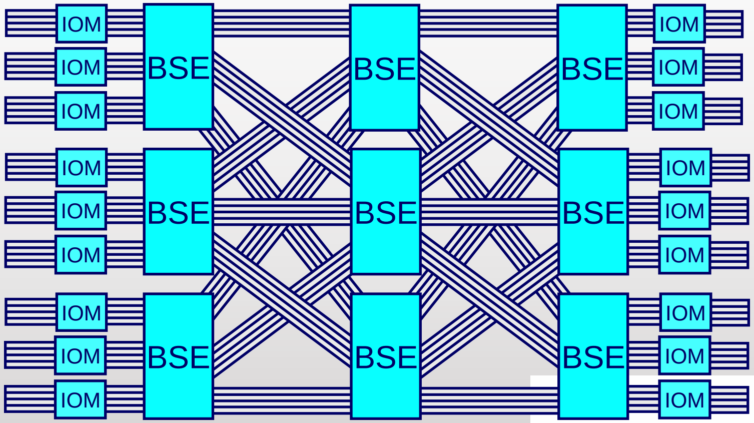


New Challenges

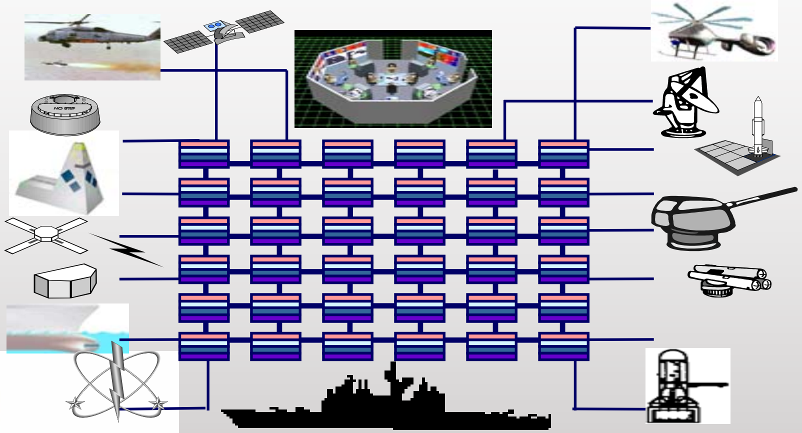
- Many mission-critical distributed applications require real-time guarantees
  - e.g., combat systems, online trading, telecom
- Building real-time applications manually is tedious, error-prone, & expensive
- Conventional middleware does not support real-time requirements effectively

Motivating Mission-Critical Applications

Large-scale Switching Systems

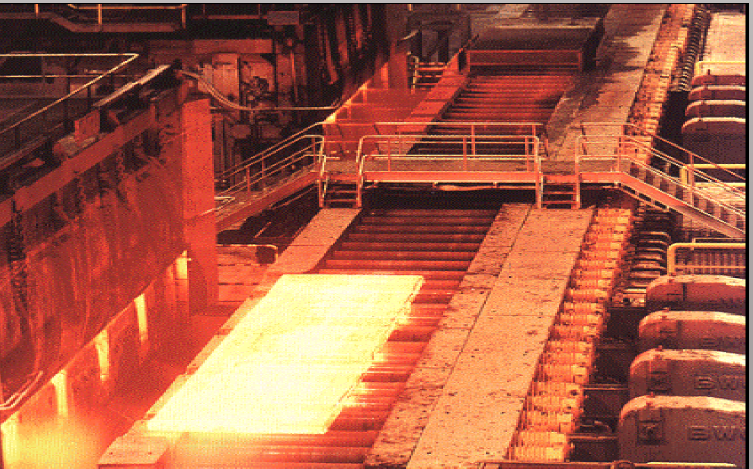


Total Ship Computing Environments

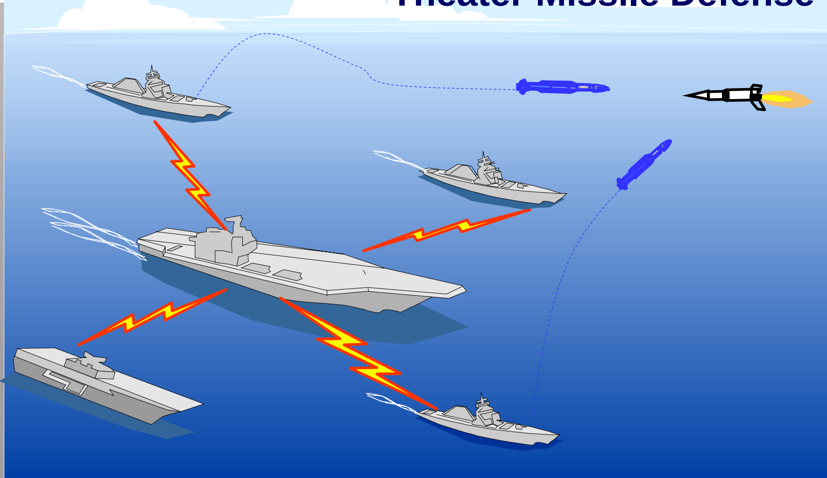


Avionics

Industrial Process Control



Theater Missile Defense

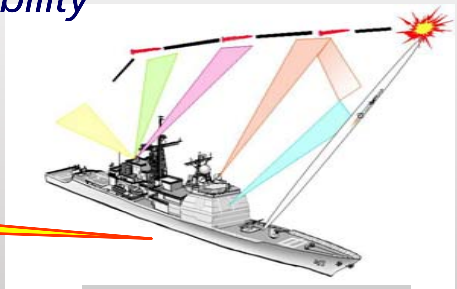


Problems with Current Approaches

- Mission-critical system QoS requirements historically not supported by COTS
  - *i.e.*, COTS is too big, slow, buggy, incapable, & inflexible

- Likewise, the proprietary ***multiple technology bases*** in systems today limit effectiveness by impeding
  - *Assurability* (of QoS),
  - *Adaptability*, &
  - *Affordability*

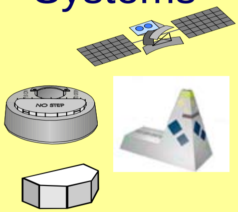
Today, each combat system brings its own:
•networks
•computers
•displays
•software
•people



Applications

Applications

Sensor Systems



Technology base:
Proprietary MW
Mercury
Link16/11/4

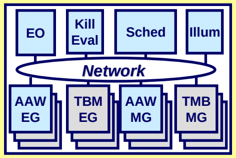
Command & Control System

Technology base:
DII-COE
POSIX
ATM/Ethernet

Engagement System

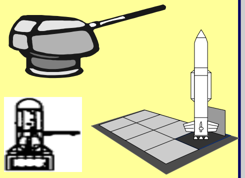
Technology base:
Proprietary MW
POSIX
NTDS

Weapon Control Systems



Technology base:
Proprietary MW
VxWorks
FDDI/LANS

Weapon Systems

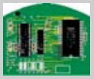


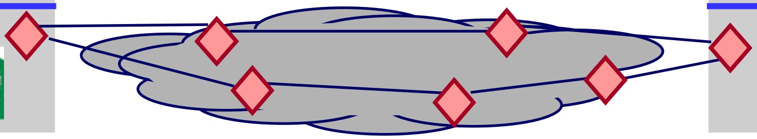
Technology base:
Proprietary MW
POSIX
VME/1553

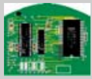
Problems

- ***Non-scalable*** tactical performance
- ***Inadequate real-time*** control for joint operations
  - *e.g.*, distributed weapons control
- ***High*** software lifecycle ***costs***
  - *e.g.*, many "accidental complexities" & low-level platform dependencies

Operating System







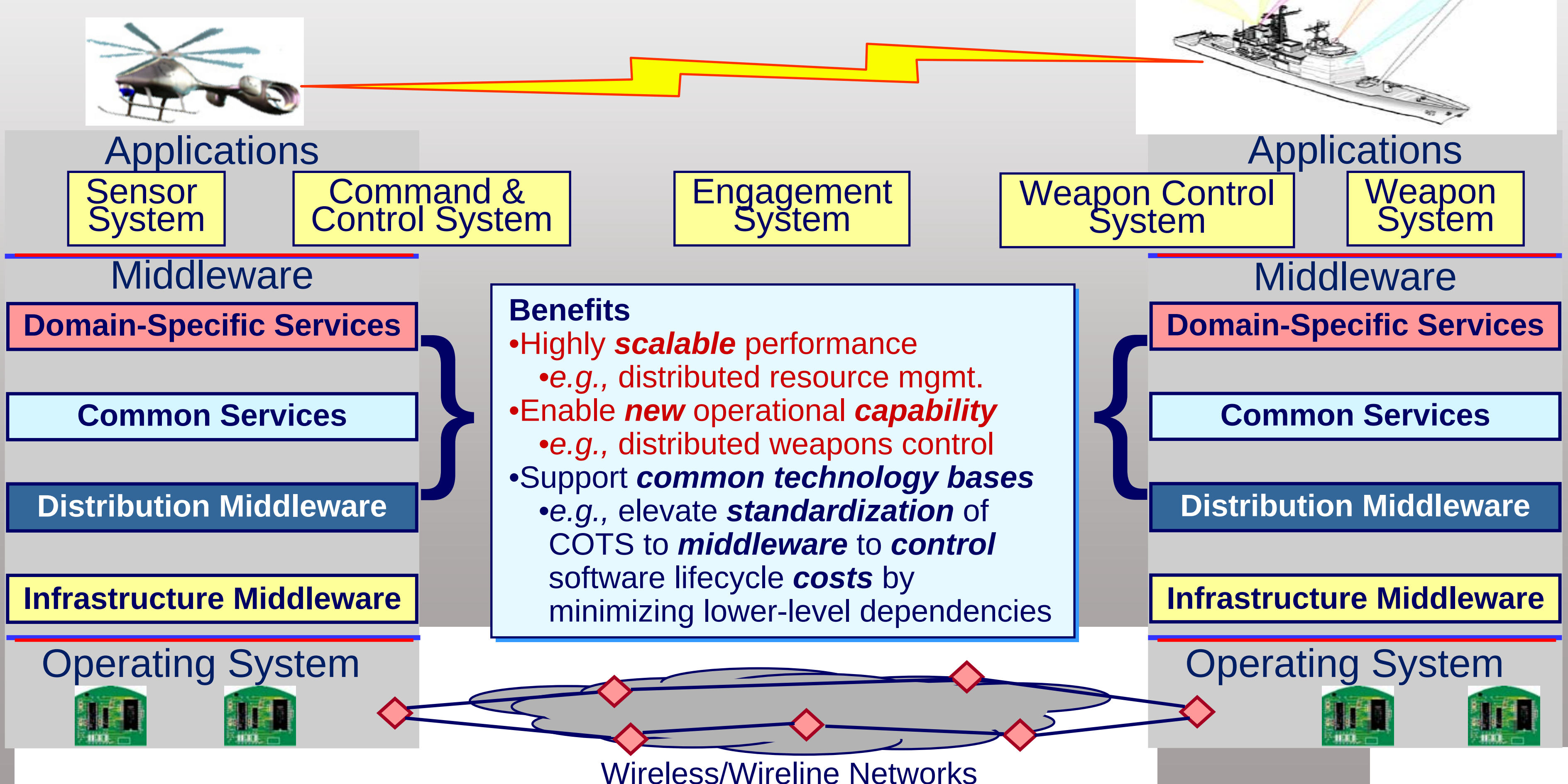
Operating System

Wireless/Wireline Networks

A More Effective Approach

Create the new generation of ***middleware*** technologies for distributed real-time & embedded systems that enable

1. Simultaneous control of ***multiple QoS properties*** &
2. Composable & customizable ***common technology bases***



Benefits

- •Highly ***scalable*** performance
  - •*e.g.,* distributed resource mgmt.
- •Enable ***new*** operational ***capability***
  - •*e.g.,* distributed weapons control
- •Support ***common technology bases***
  - •*e.g.,* elevate ***standardization*** of COTS to ***middleware*** to ***control*** software lifecycle ***costs*** by minimizing lower-level dependencies

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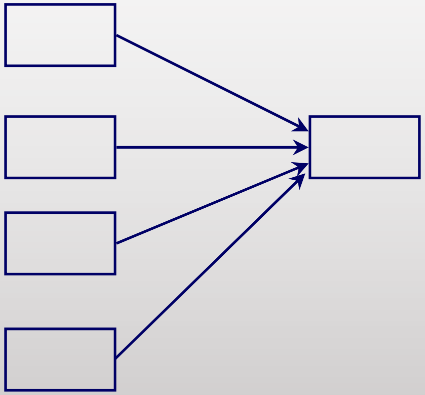
What is Real-Time All About?

- Real-Time is Not About
  - Speed
  - Efficiency

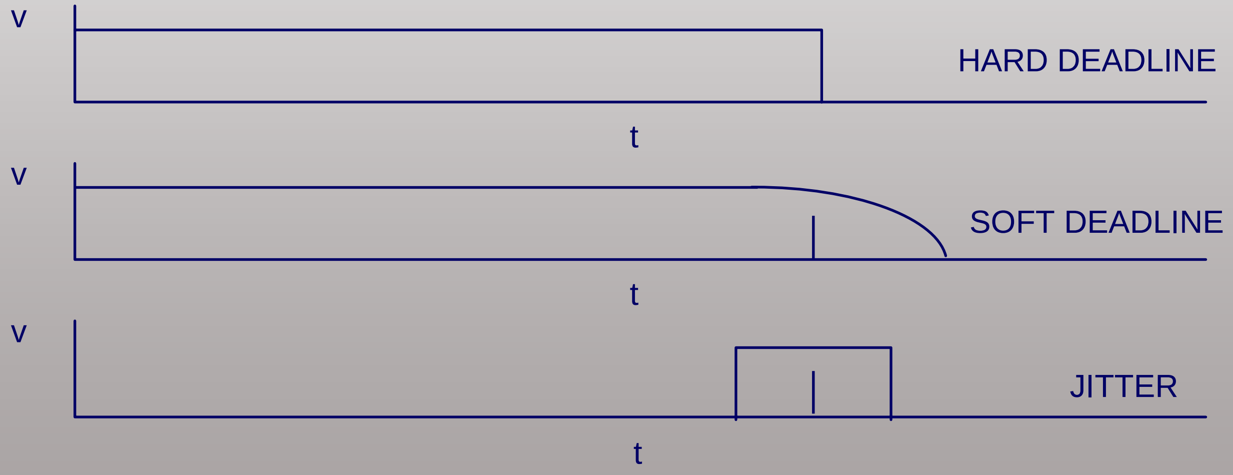


- Real-Time is About Time Constraints
  - Objects contend for system resources (e.g., CPU, LAN,I/O)
  - Rules for contention resolution follow different strategies
    - These strategies are **NOT** equivalent in terms of resource utilization or engineering viability
    - There is a wide range of approaches (e.g., frames, round-robin, priority)

Introduction to Real-Time

- Definition of a Real-Time System
- A real-time system is one in which correctness depends on meeting time constraints.
  - Correctness arguments must reason about response time requirements as well as functional requirements
- A real-time system produces a value to the user which is a function of time

Sample real-time program values



Hard Real-Time, Soft Real-Time

- Hard Real-Time
  - Resources must be managed to guarantee all hard real-time constraints are met, all the time
  - No unbounded priority inversions are permitted
  - Missing a time constraint is considered a failure to meet requirements
- Soft Real-Time
  - At least three kinds, possibly in combination:
    - Time constraints may be missed by only small amounts (usually expressed as a percentage of the time constraint)
    - Time constraints may be missed infrequently (usually expressed as a percentage of instances)
    - Occasional events or periodic instances may be skipped (usually expressed as a probability)
  - Resources must be managed to meet the stated requirements
    - Same mechanisms as for hard real-time, but guarantees harder to define
    - Soft real-time is not the same as non-real-time, or meeting an average response time
- Hard Real-Time is hard, but Soft Real-Time is harder!

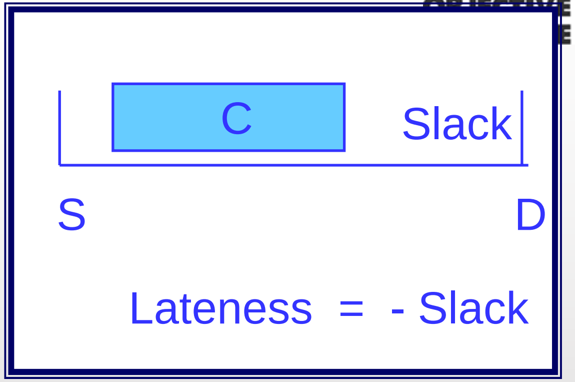
Timing Requirement Sources

- Time Constraint Requirements Have Only Two Sources:
  - Explicit Top Level Requirements, e.g.,
    - Display a video frame within 33 milliseconds.
    - This is not the most common source of Timing Requirements.
  - Derived Requirements, e.g.,
    - Accuracy – "Maintain aircraft position to within 1 meter => Periodicity"
    - Fault Tolerance – "Recover from message loss within 500 ms."
    - Human Computer Interface Requirements –
      - Process switch depressions within 250 ms.
      - Refresh display within 68 ms.

Real-Time Scheduling

- System Resource Scheduling: The Principal Difference Between a Real-Time and Non-Real-Time System.
  - Definition of Real-Time Scheduling:
    - Real-Time scheduling is the process of sequencing shared resource allocations to meet user's time constraints.
  - The Principal Three Goals:
    - Meet all application time constraints, if feasible.
    - Meet all important time constraints if meeting all time constraints is not feasible.
    - Be able to accurately predict how well goals 1 and 2 are met for any given process load.
  - Real-Time ≢ Real-Fast

Known Real-Time Scheduling Algorithms


C

Slack

S

D

Lateness = - Slack

- Shortest Processing Time First (SPT)
  - Minimizes mean lateness
  - Optimal for Goals 1 and 3, stochastically
- Earliest Deadline First (EDD or Deadline)
  - Minimizes maximum lateness
  - Optimal for Goals 1 and 3 (fails disastrously on overload)
- Smallest Slack Time First (Minimum Slack or Minimum Laxity)
  - Maximizes minimum lateness
  - Optimal for Goals 1 and 3 (fails disastrously on overload)
- Rate Monotonic Scheduling (RMS)
  - Approximates EDD with reduced utilization bound
  - Non-optimal, but fulfills all real-time goals for mostly periodic processing domains
  - Optimal for fixed priority scheduling

Scheduling Example

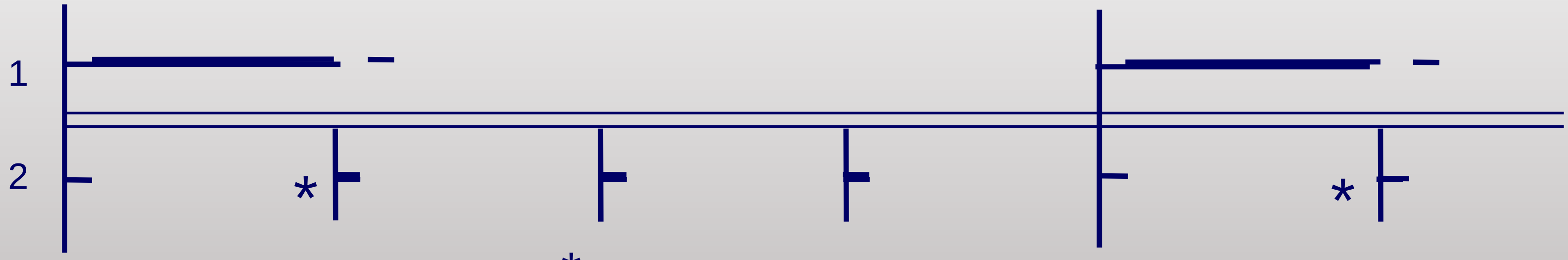
Two Preemptible Processes:

Process 1 needs 1 second every 4 seconds
Process 2 needs 0.01 second every second

Total Utilization
26 %

Process 2 has priority

Process 1 has priority



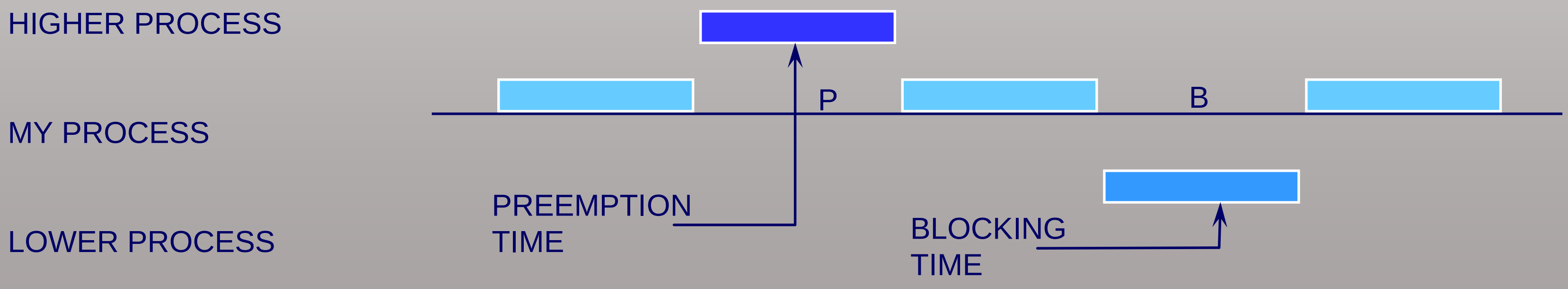
* Missed deadline

World’s Lowest Budget Nuclear Power Plant

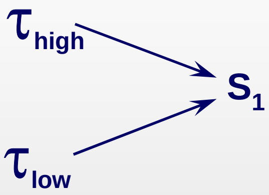
- **Process 1 => Reactor Control Rods**
- **Process 2 => Dishwasher Water Valve**

Shared Resource Concepts

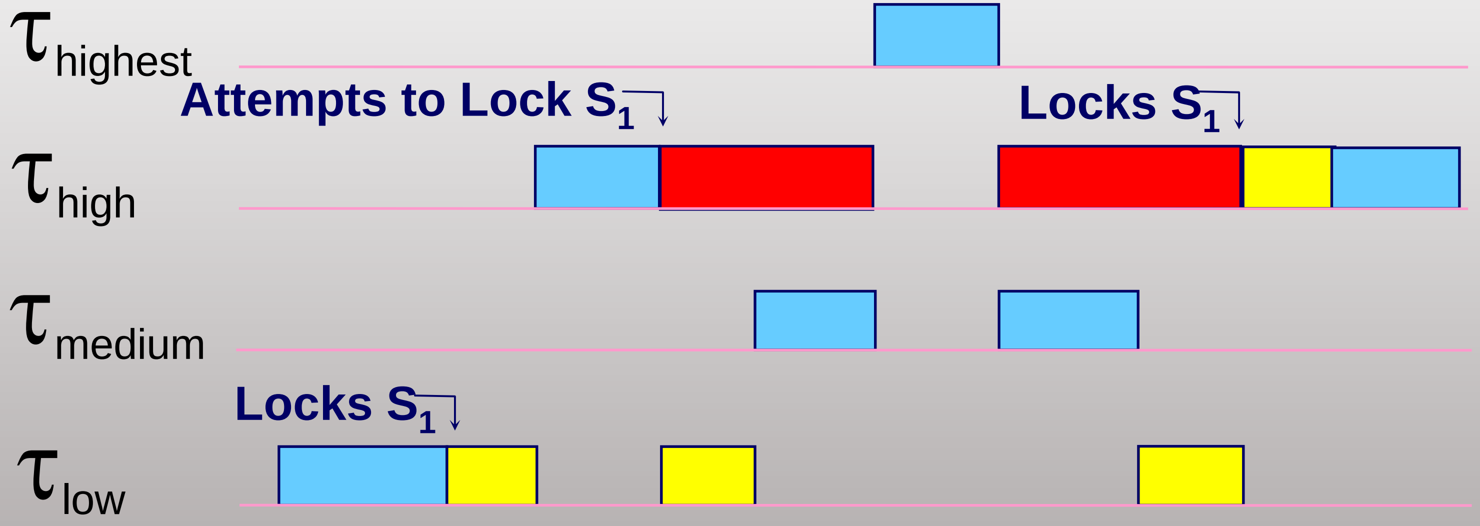
- Preemption.
  - Execution delayed by higher priority tasks
- Blocking (Priority inversion)
  - Execution delayed by lower priority tasks
- Mutual Exclusion (Mutex)
  - Sequenced access to a shared resource, typically implemented by locking and waiting for locks.
- Critical Section
  - Execution while holding a lock.



Shared Resources and Priority Inversion



High and low priority tasks share a critical section—Can lead to UNBOUNDED Blocking



🟦 **Normal execution** 🟨 **Execution in Critical Section**

🟥 **Priority Inversion**

Static Real-Time Systems

- Static
  - Processing load within known bounds
  - A-priori analysis can be performed
  - Set of applications known in advance
  - Workload imposed can be predicted within a known bound
  - Typically limited number of application configurations/modes
  - Schedule can be worked out in advance for each mode within bounded variation
  - O/S and middleware only support executing that schedule
  - Common Approaches
    - use O/S priorities to manage deadlines
    - offline analysis to map different temporal requirements (such as frequency of execution) onto O/S priorities
    - sufficient if O/S, middleware, & application always respects these priorities

Dynamic Real-Time Systems

- Dynamic
  - Super-set of static systems
  - May not have sufficiently predictable workload to allow static approach
  - Set of applications is may be too large or not known in advance
  - Variable application processing requirements may impair pre-planning
  - The arrival time of the inputs may be too variable
    - other sources of variability
    - the underlying infrastructure must be still able satisfy real-time requirements in a changing environment

Real-Time Principles Summary

- Real-Time ≠ Real-Fast
- Scheduling concepts are frequently counter-intuitive
- Resource management is the fundamental requirement to deal with response time issues, whether hard real-time or soft real-time

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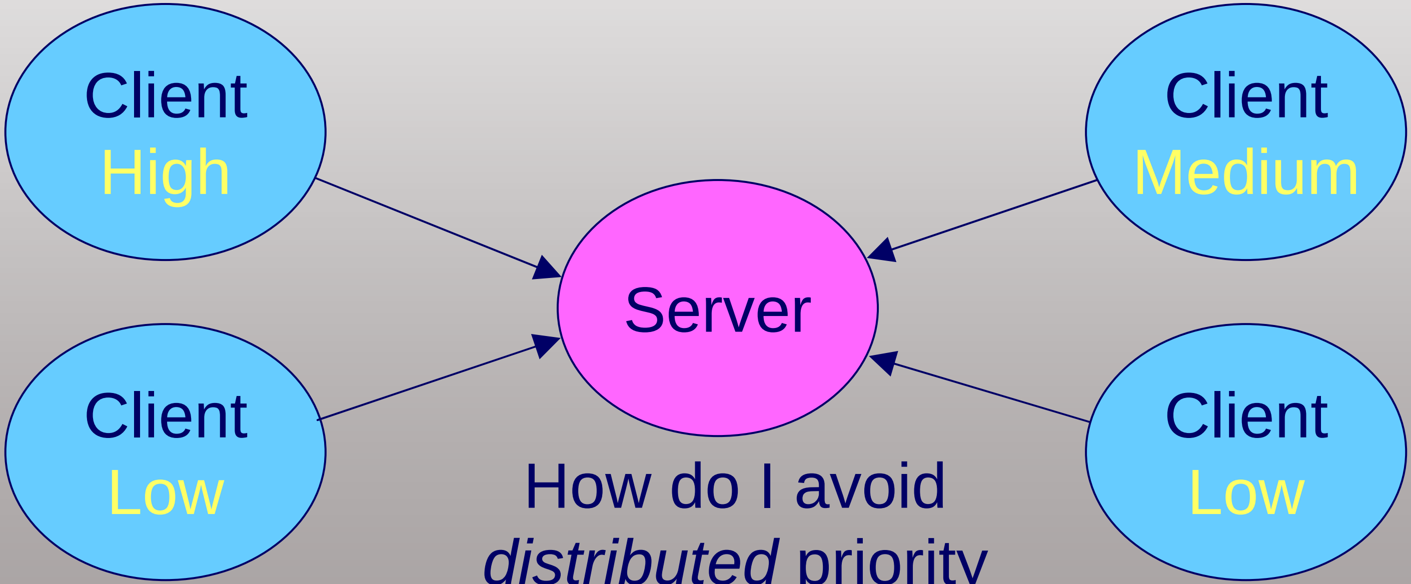
Real-time Distribution Challenges – 1

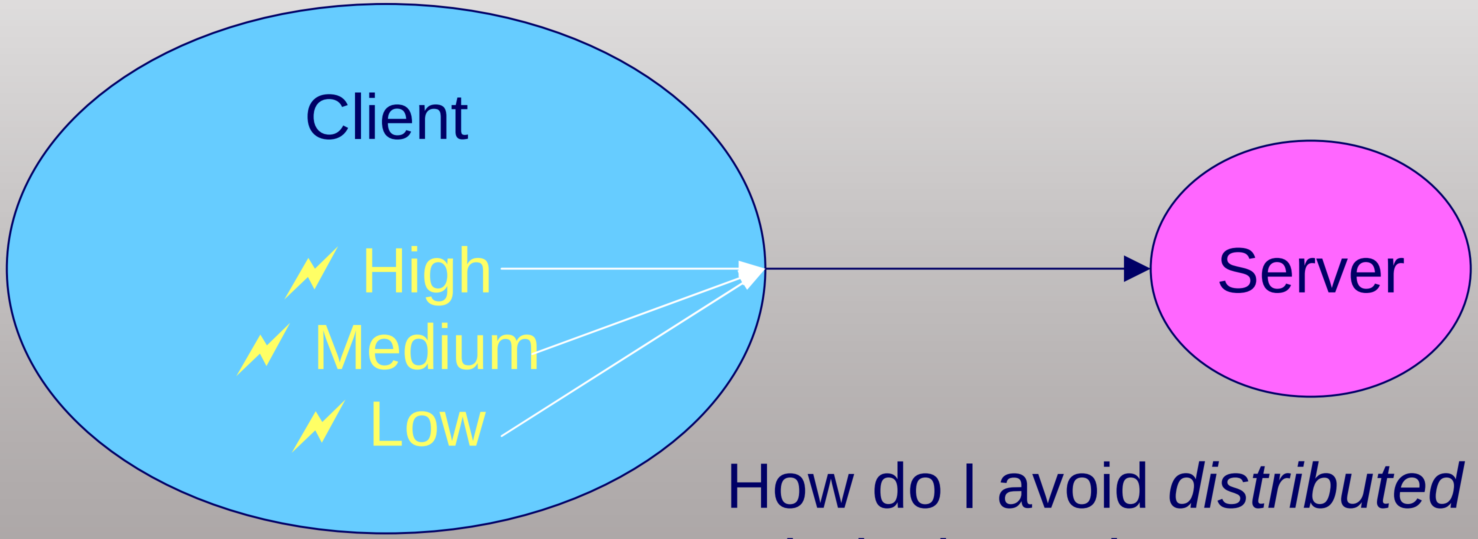
- How does a server resolve contention by multiple clients?



How do I avoid *distributed* priority inversions?

Real-time Distribution Challenges – 2

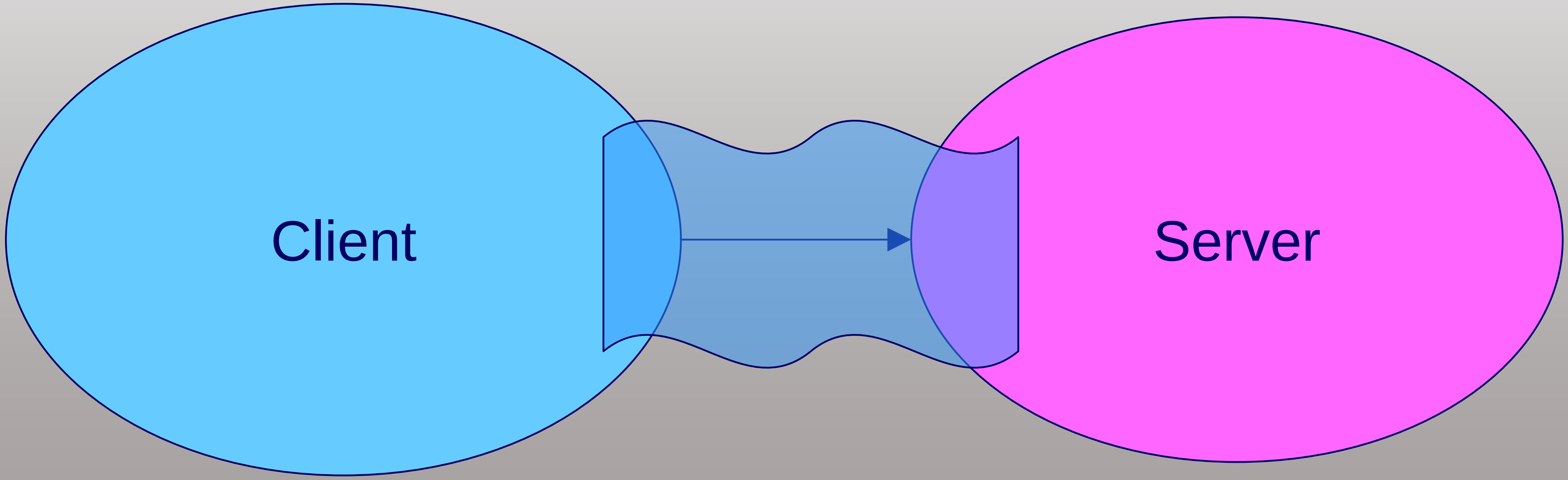
- How does a server resolve contention by multiple *threads* within each clients?



How do I avoid *distributed* priority inversions?

Real-time Distribution Challenges – 3

- How do I use a real-time transport
  but remain *independent of the transport API?*



Real-time Distribution is Hard

- Most engineers don’t understand complexities of real-time distribution *with software*
- Real-time communication theory is hard
- Implementing correct semantics in a software application is *harder*

Simple, but Expensive Solutions Commonplace

- Result:
  - – Engineers are not confident that their communications software will meet deadlines
  - – No trust of real-time communication software
  - – Time constraints solved with dedicated hardware
  - – Software architecture designed around hardware
  - – Software oversimplified at the expense of functionality
  - ➢ Expensive to build and maintain
  - ➢ Software investment is thrown away in future re-designs

Real-time Communication Solutions

- What if there was a real-time communication software infrastructure that:
  - Makes communication easy
  - Can meet application time constraints
  - Can save software investment over product generations
  - Can reduce product time-to-market
  - Is based on an open standard
  - Has alternative, competing products available
  - Is proven reliable in many existing systems

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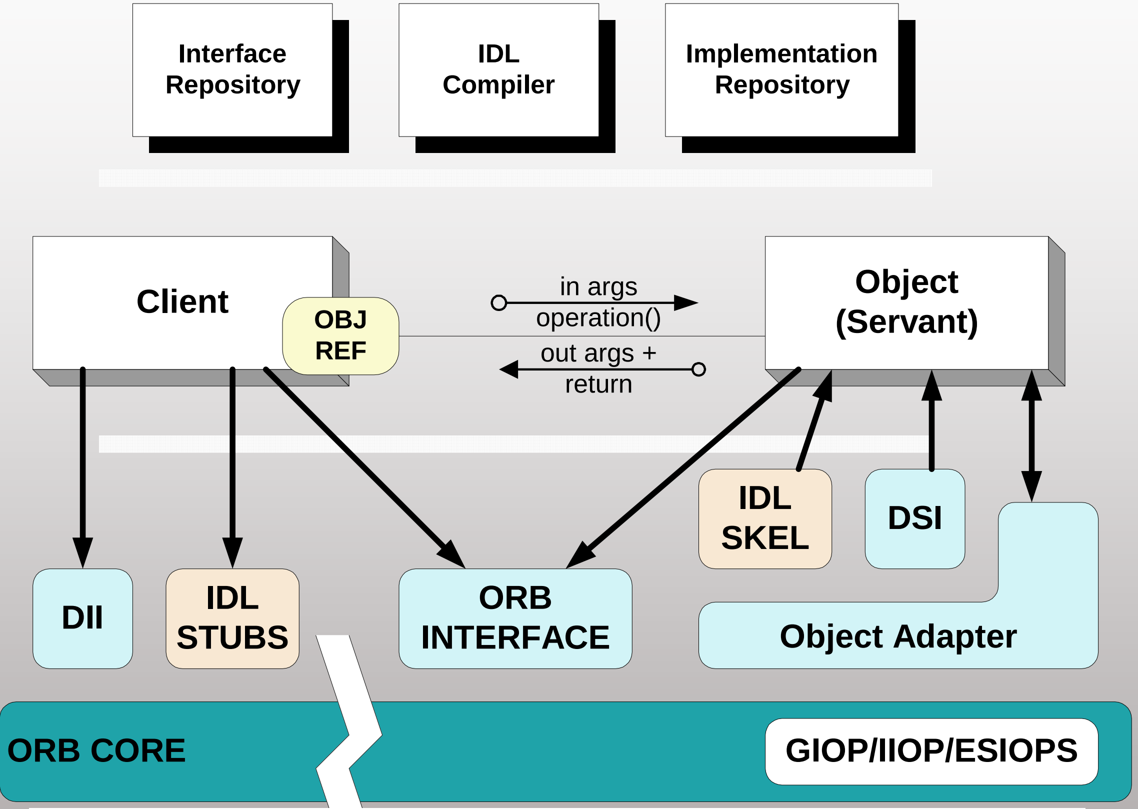
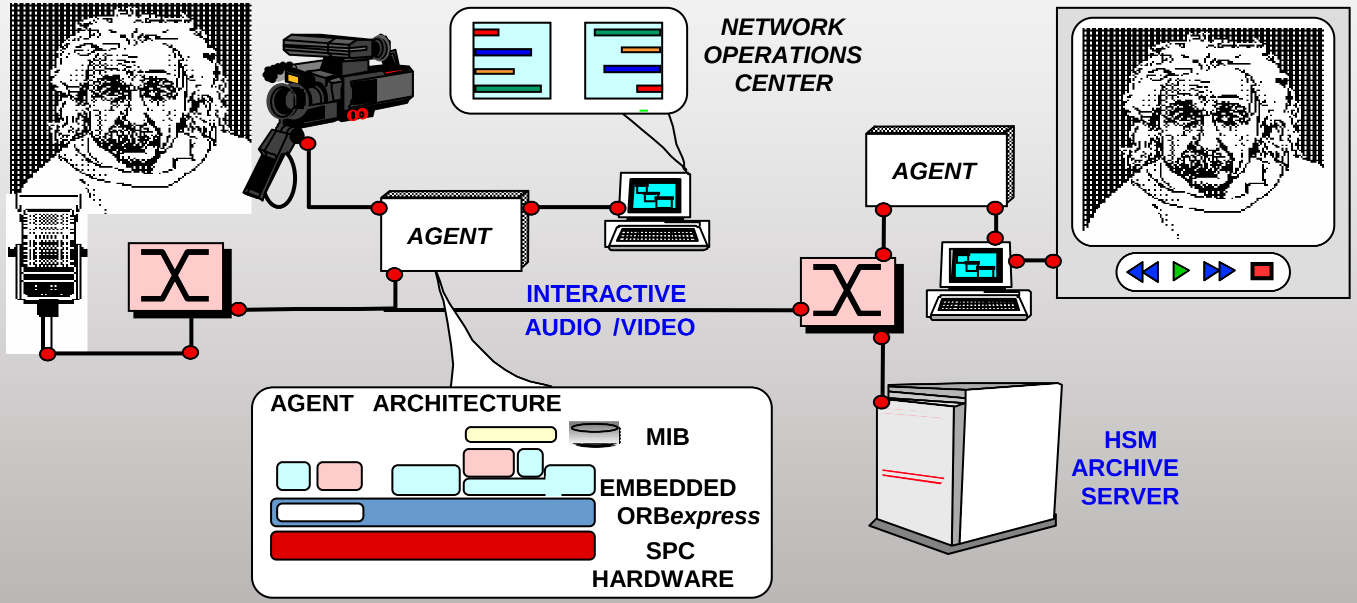
Overview of CORBA



- CORBA shields applications from heterogeneous platform *dependencies*
  - *e.g.*, languages, operating systems, networking protocols, hardware

- Common Object Request Broker Architecture (CORBA)
  - A family of specifications
  - OMG is the standards body
  - Over 800 companies
- CORBA defines *interfaces*, not *implementations*
- It simplifies development of distributed applications by automating/encapsulating
  - Object location
  - Connection & memory mgmt.
  - Parameter (de)marshaling
  - Event & request demultiplexing
  - Error handling & fault tolerance
  - Object/server activation
  - Concurrency
  - Security

Caveat: Historical Limitations of CORBA for Real-time Systems



Requirements

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

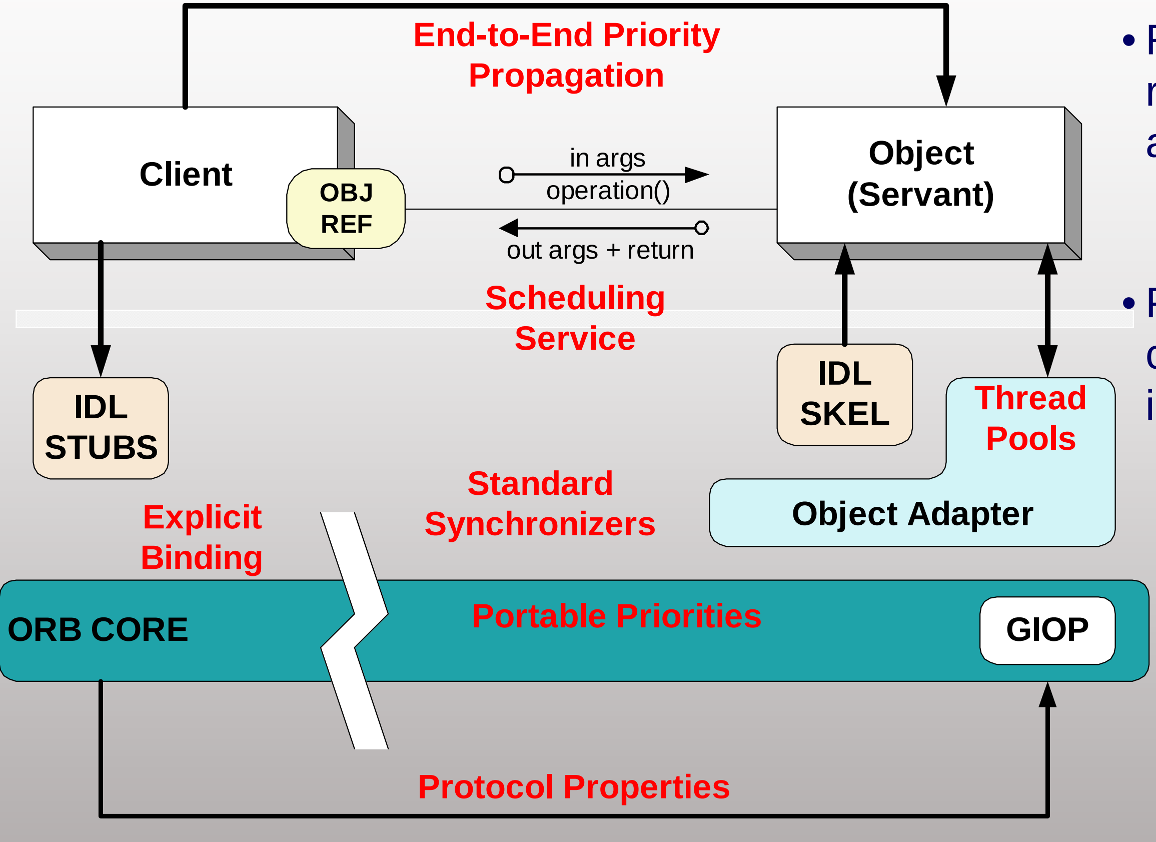
Historical Limitations

- Lack of timeliness specifications
- Lack of timeliness enforcement
- Lack of real-time programming feature
- Lack of performance optimizations

Do I Need Real-Time CORBA?

- You need Real-Time CORBA if:
  - You use priorities in your distributed system
  - You want application-level control of the resources used by the ORB, including connections and connection-related resources
  - You need a foundation for building predictable systems

Real-Time CORBA Overview



Real-time CORBA leverages the CORBA Messaging Policy framework

- RT CORBA adds QoS control to regular CORBA improve the application *predictability*, *e.g.*,
  - Bounding priority inversions &
  - Managing resources end-to-end
- Policies & mechanisms for resource configuration/control in RT-CORBA include:
  1. **Processor Resources**
     - Thread pools
     - Priority models
     - Portable priorities
     - Priority banding
  2. **Communication Resources**
     - Protocol policies
     - Explicit binding
     - Priority banding
  3. **Memory Resources**
     - Request buffering
- These capabilities address some important real-time application development challenges

History

- Real-Time CORBA 1.1
  - RFP issued 9/1997
  - Final submissions 7/1999
  - OMG document formal/2002-08-02
- Dynamic Scheduling
  - RFP issued 3/1999
  - Final submissions 6/2001
  - Draft Adopted Specification: 8/2001
  - OMG Document ptc/01-08-34
    - http://cgi.omg.org/cgi-bin/doc?ptc/01-08-34.pdf
- Real-Time CORBA 1.2
  - result of finalizing and combining Dynamic Scheduling
  - formal/2005-01-04

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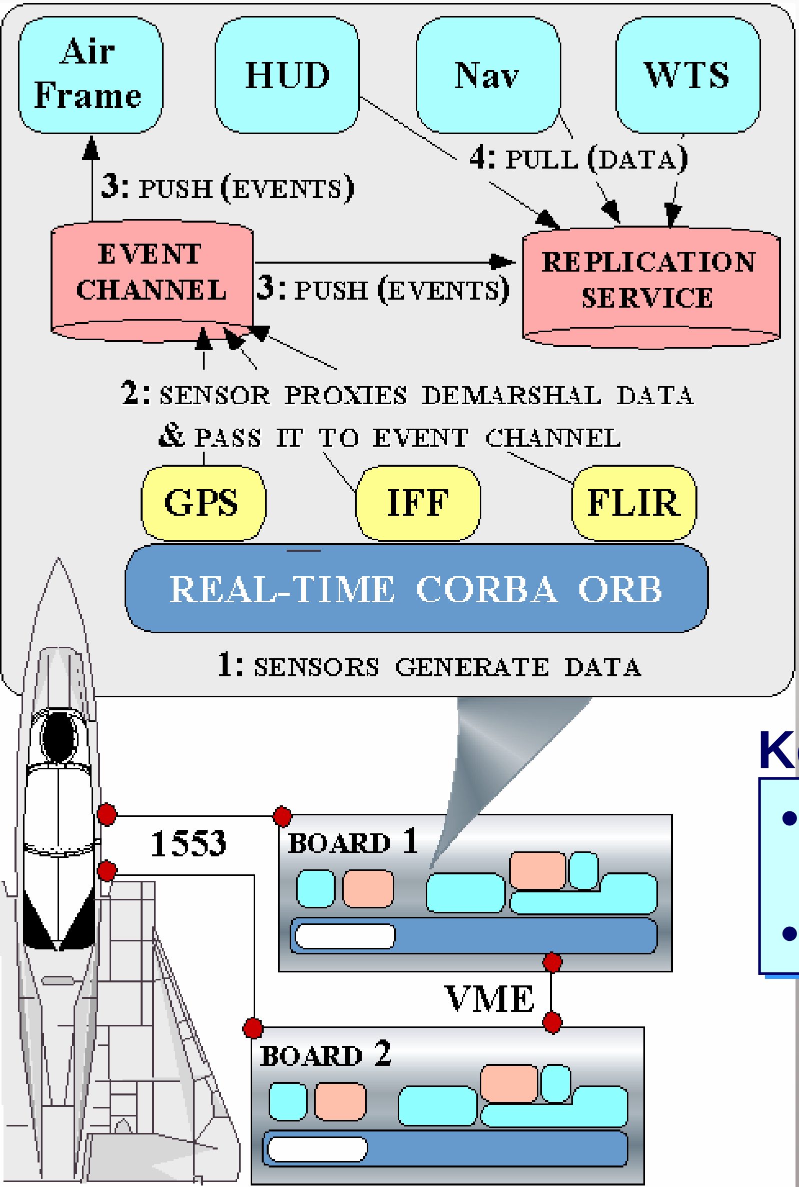
Applying RT CORBA to Real-time Avionics



Goals

- Apply COTS & open systems to mission-critical real-time avionics

Key System Characteristics

- Deterministic & statistical deadlines
  - ~20 Hz
- Low latency & jitter
  - ~250 *u*secs
- Periodic & aperiodic processing
- Complex dependencies
- Continuous platform upgrades

Key Results

- Test flown at China Lake NAWS by Boeing OSAT II ‘98, funded by OS-JTF
- Also used on SOFIA project by Raytheon

Applying RT CORBA to Time-Critical Targets

Time-critical targets require immediate response because:

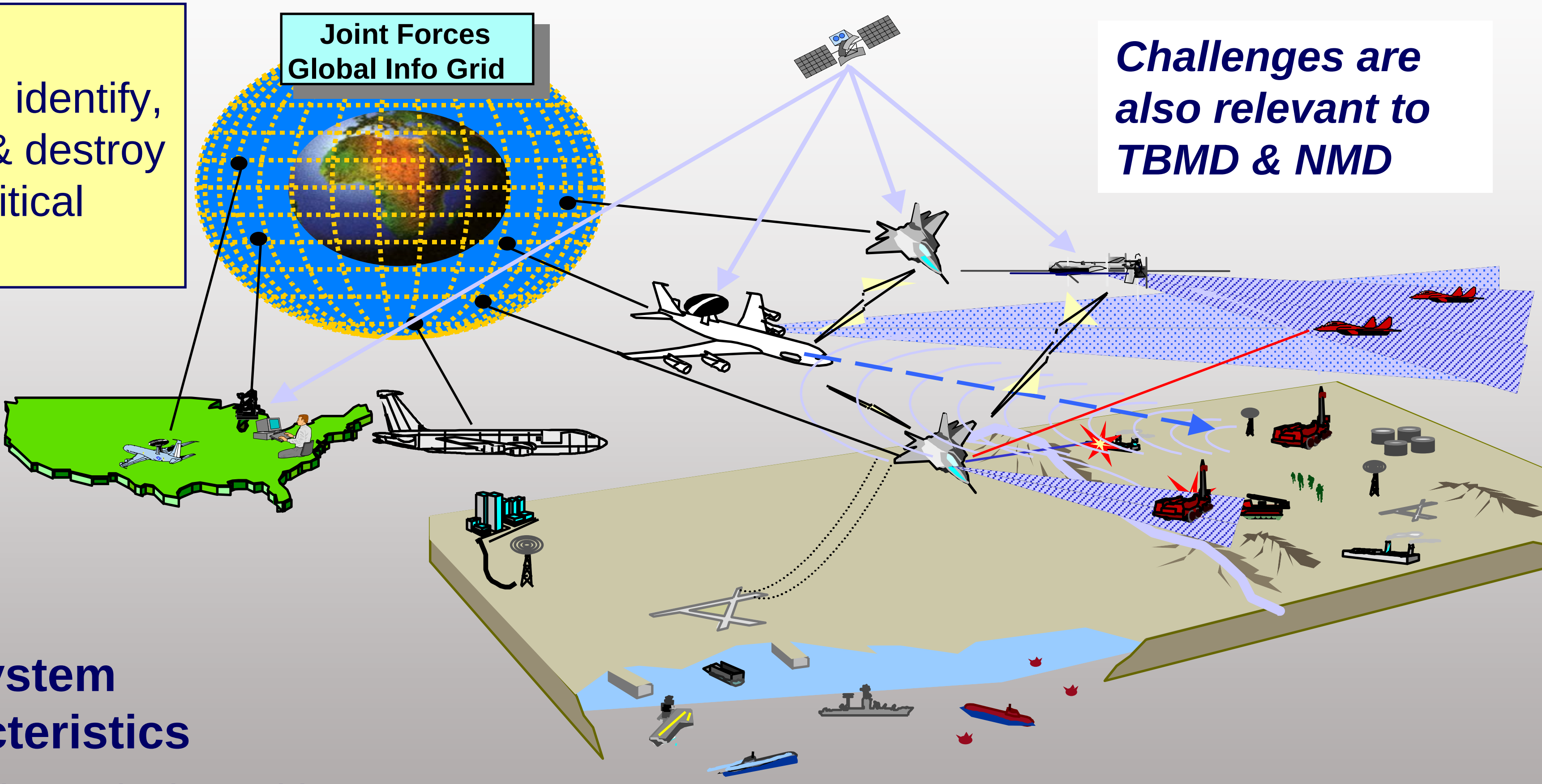
•They pose a clear and present danger to friendly forces &

•Are highly lucrative, fleeting targets of opportunity

Applying RT CORBA to Time-Critical Targets

Goals

- Detect, identify, track, & destroy time-critical targets



Challenges are also relevant to TBMD & NMD

Key System Characteristics

- Real-time mission-critical sensor-to-shooter needs
- Highly dynamic QoS requirements & environmental conditions
- Multi-service & asset coordination

Key Solution Characteristics

- Adaptive & reflective
- High confidence
- Safety critical

- Efficient & scalable
- Affordable & flexible
- COTS-based

Applying RT CORBA to Hot Rolling Mills

OBJECTIVE INTERFACE

Goals

- Control the processing of molten steel moving through a hot rolling mill in real-time

System Characteristics

- Hard real-time process automation requirements
  - *i.e.*, 250 ms real-time cycles
- System acquires values representing plant's current state, tracks material flow, calculates new settings for the rolls & devices, & submits new settings back to plant

Key Software Solution Characteristics

- Affordable, flexible, & COTS
  - Product-line architecture
  - Design guided by patterns & frameworks
  - Windows NT/2000
  - Real-time CORBA

Applying RT CORBA to Image Processing

Goals

- Examine glass bottles for defects in real-time

System Characteristics

- Process 20 bottles per sec
  - *i.e.*, ~50 msec per bottle
- Networked configuration
- ~10 cameras

Key Software Solution Characteristics

- Affordable, flexible, & COTS
  - Embedded Linux (Lem)
  - Compact PCI bus + Celeron processors
  - Remote booted by DHCP/TFTP
  - Real-time CORBA

Real-time CORBA in Action: JTRS—Joint Tactical Radio System

OBJECTIVE INTERFACE

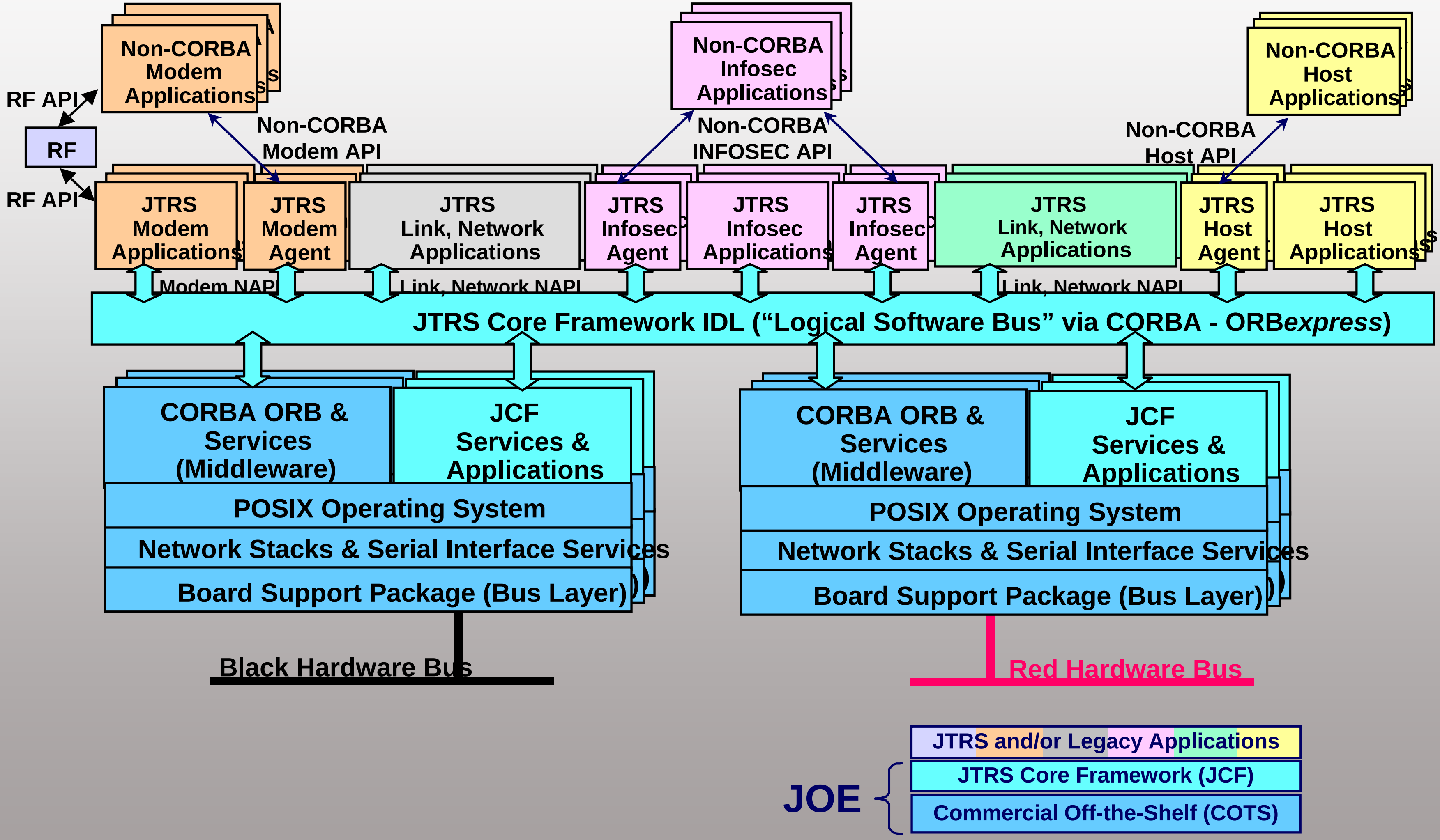
- JTRS Business Case
  - Today's operating environment requires diverse, interoperable communications
  - Single purpose radios sets are a way of the past
  - Legacy systems required redundant development of capabilities

Open-systems architectures allow for:

- more efficient use of R&D and Procurement dollars
- faster rate of technology insertion
- interoperability through the use of common implementations
- End result:

  more capable customer
  with current capabilities

JTRS Software Structure


Non-CORBA Modem Applications
RF API
RF
RF API
Non-CORBA Modem API
Non-CORBA Infosec Applications
Non-CORBA INFOSEC API
Non-CORBA Host Applications
Non-CORBA Host API
JTRS Modem Applications
JTRS Modem Agent
JTRS Link, Network Applications
JTRS Infosec Agent
JTRS Infosec Applications
JTRS Infosec Agent
JTRS Link, Network Applications
JTRS Host Agent
JTRS Host Applications
Modem NAPI
Link, Network NAPI
Link, Network NAPI
JTRS Core Framework IDL ("Logical Software Bus" via CORBA - ORBexpress)
CORBA ORB & Services (Middleware)
JCF Services & Applications
POSIX Operating System
Network Stacks & Serial Interface Services
Board Support Package (Bus Layer)
Black Hardware Bus
CORBA ORB & Services (Middleware)
JCF Services & Applications
POSIX Operating System
Network Stacks & Serial Interface Services
Board Support Package (Bus Layer)
Red Hardware Bus
JTRS and/or Legacy Applications
JOE
JTRS Core Framework (JCF)
Commercial Off-the-Shelf (COTS)

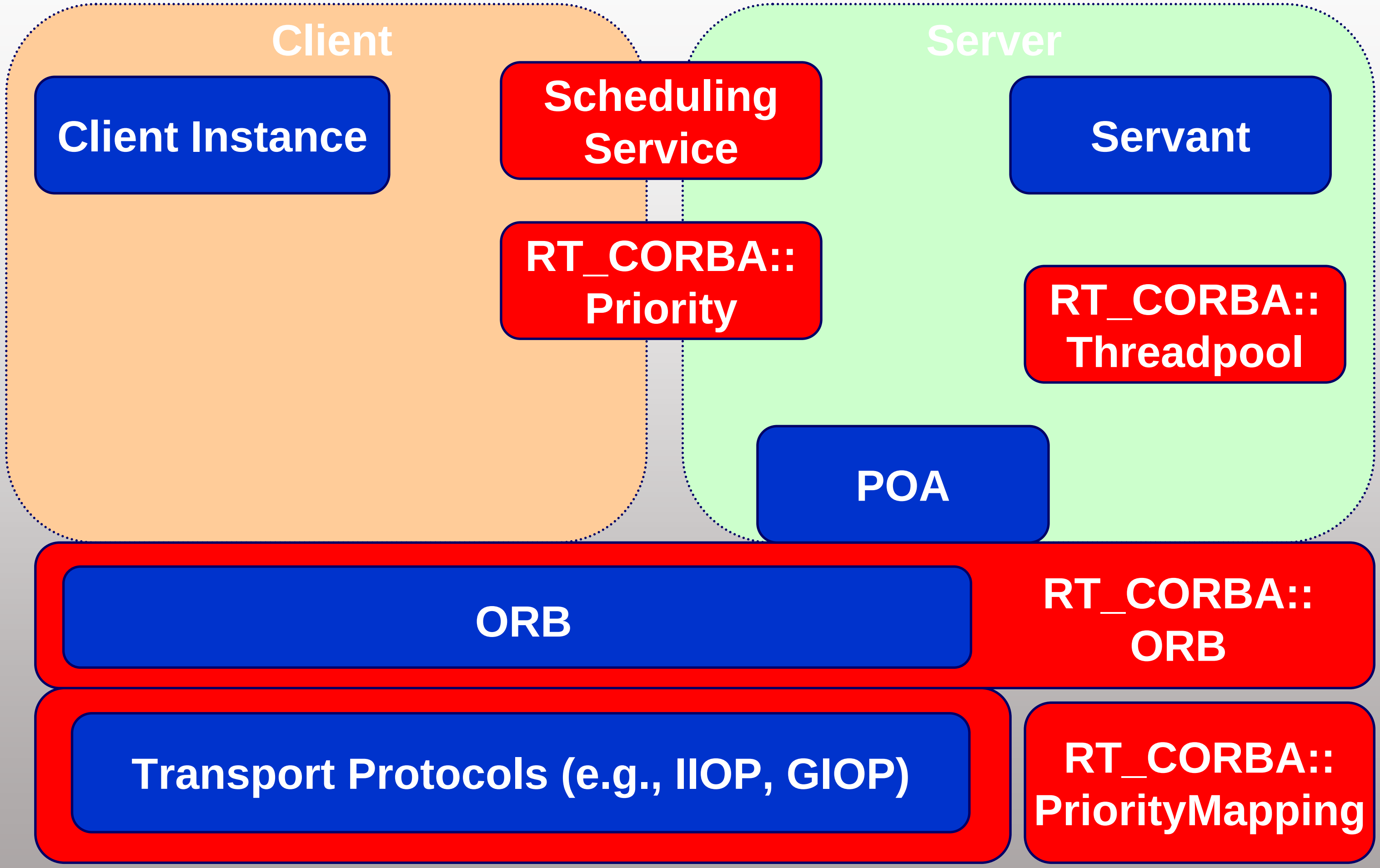
Agenda

- Motivation
- Introduction to Real-time Principles
- Challenges in Distributing Real-time Systems
- Overview of Real-time CORBA
- Applying Real-time CORBA to problem domains
- Real-time CORBA Architecture
- Example Application
- Dynamic Scheduling
- Future Directions
- Summary

Real-time CORBA

- Robust, theoretically-sound specifications
  - Avoids distributed priority inversions
  - Propagates scheduling information
- Based on flexible, maintainable CORBA software architecture
- Rich set of competing implementations
- Allows development of software-based time-bounded systems
  - Can utilize predictable transport hardware
  - Without requiring that system design is centered around transport hardware

Real-time CORBA Components



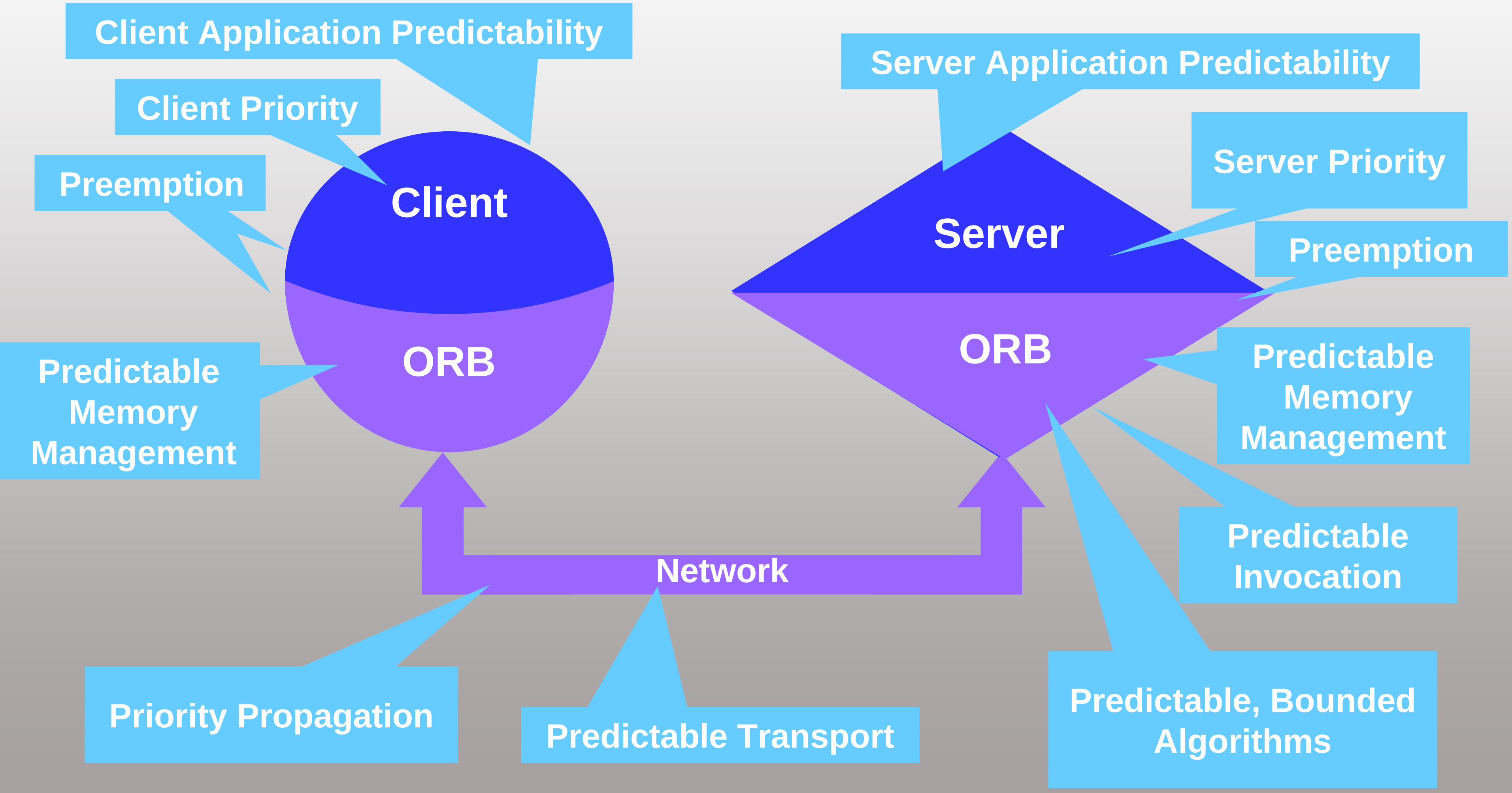
Scheduling in
Real-time CORBA

- Fixed Priority (Static) Scheduling
  - Provides a basis for resource allocation
  - Threads have priority based on time constraints
  - Underlying Theoretical Basis
    - Rate Monotonic Scheduling
    - Deadline Monotonic Scheduling
  - Fixed Priority means priorities change only
    - To prevent priority inversion
    - When required by application
- Dynamic Scheduling
  - Details later…

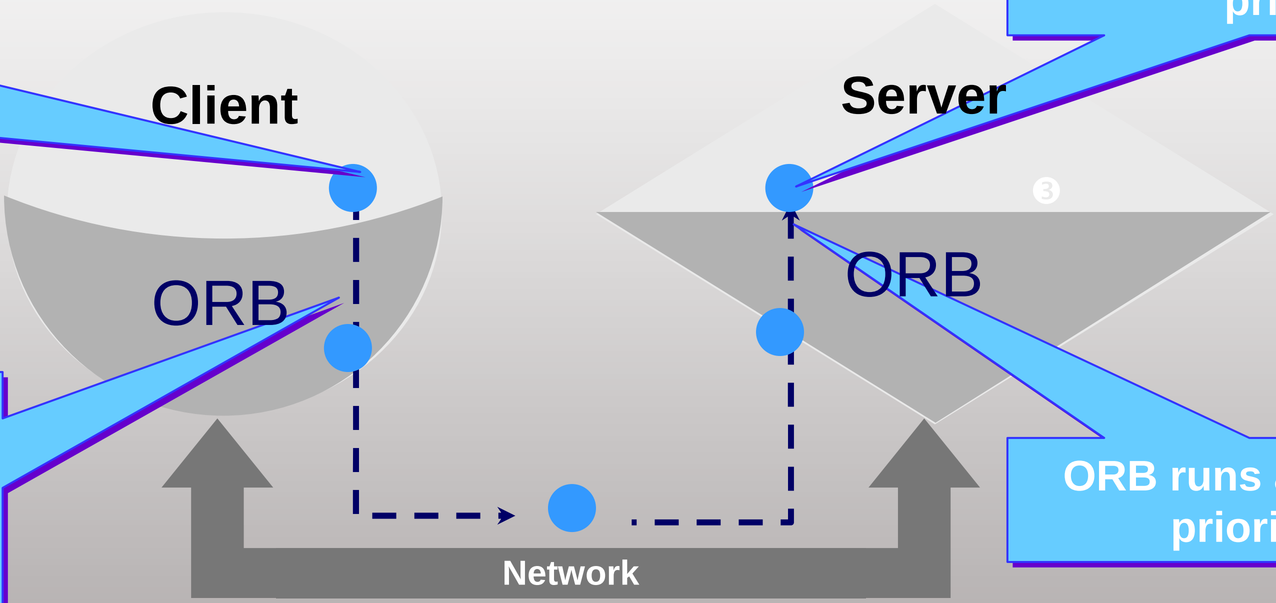
Real-Time CORBA Goals

- Support developers in meeting real-time requirements by:
  - ***Facilitating*** end-to-end predictability
  - Providing application-level management of ORB resources
- Provide interoperability with traditional ORB’s
- Three *magic* bullets
  - “For the purposes of this specification, ‘end-to-end predictability’ of timeliness in a fixed priority CORBA system is defined to mean:
    - respecting thread priorities between client and server for resolving resource contention during the processing of CORBA invocations;
    - bounding the duration of thread priority inversions during end-to-end processing;
    - bounding the latencies of operation invocations.”

Real-Time System Predictability


Client Application Predictability
Client Priority
Preemption
Client
ORB
Predictable Memory Management
Server Application Predictability
Server Priority
Preemption
Server
ORB
Predictable Memory Management
Predictable Invocation
Network
Priority Propagation
Predictable Transport
Predictable, Bounded Algorithms

Traditional CORBA



Desktop: Client Thread priority 7

RTOS: Server Thread executes at server-set priority

ORB runs at Client Thread Priority 7 - MAYBE

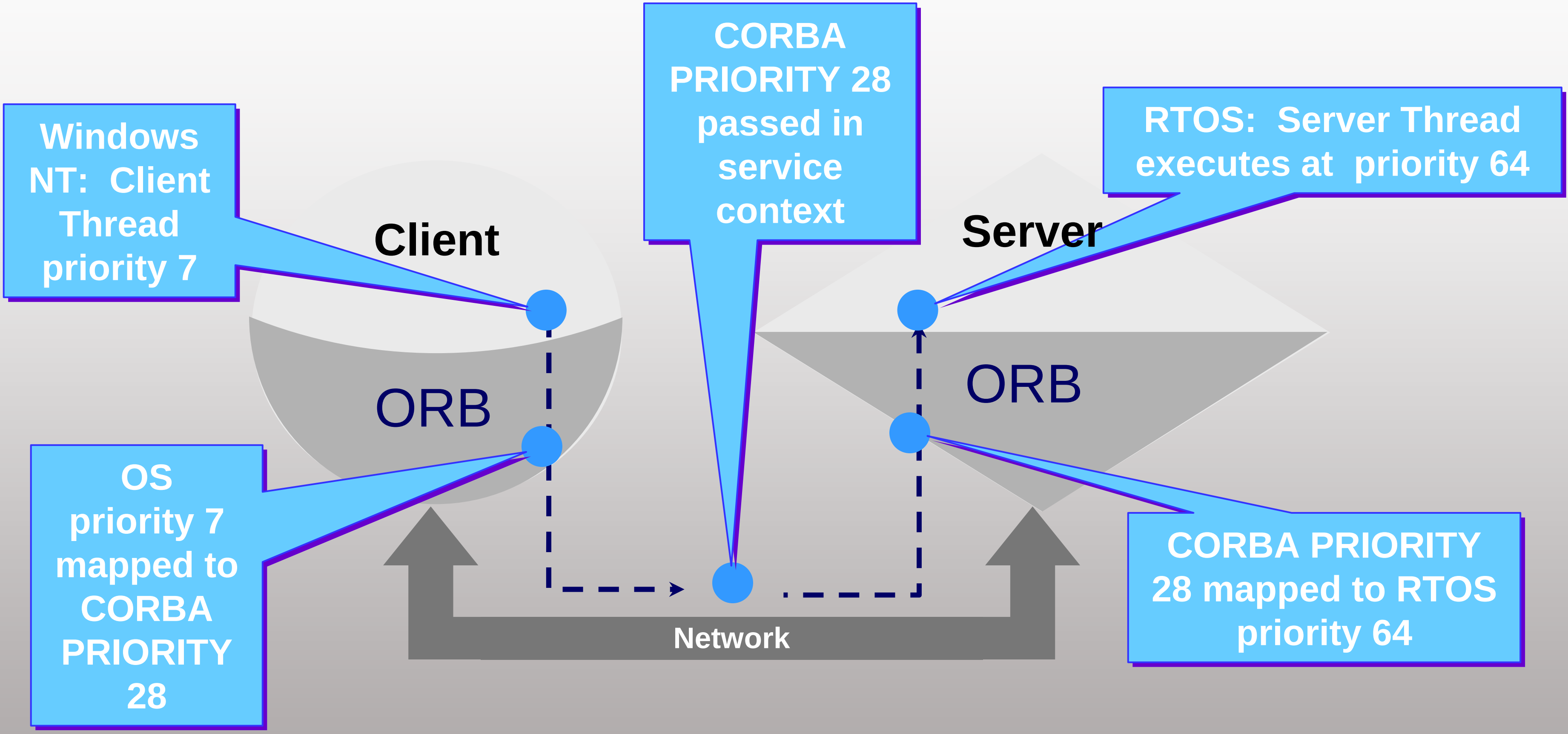
ORB runs at Server-set priority level

Results are a Possible Priority Inversion

End-to-End Predictability

- Respect thread priorities between client and server
- Bound duration of thread priority inversions
- Bound latencies of operation invocations
- Provide explicit control over ORB-managed resources

CORBA Priority Propagation

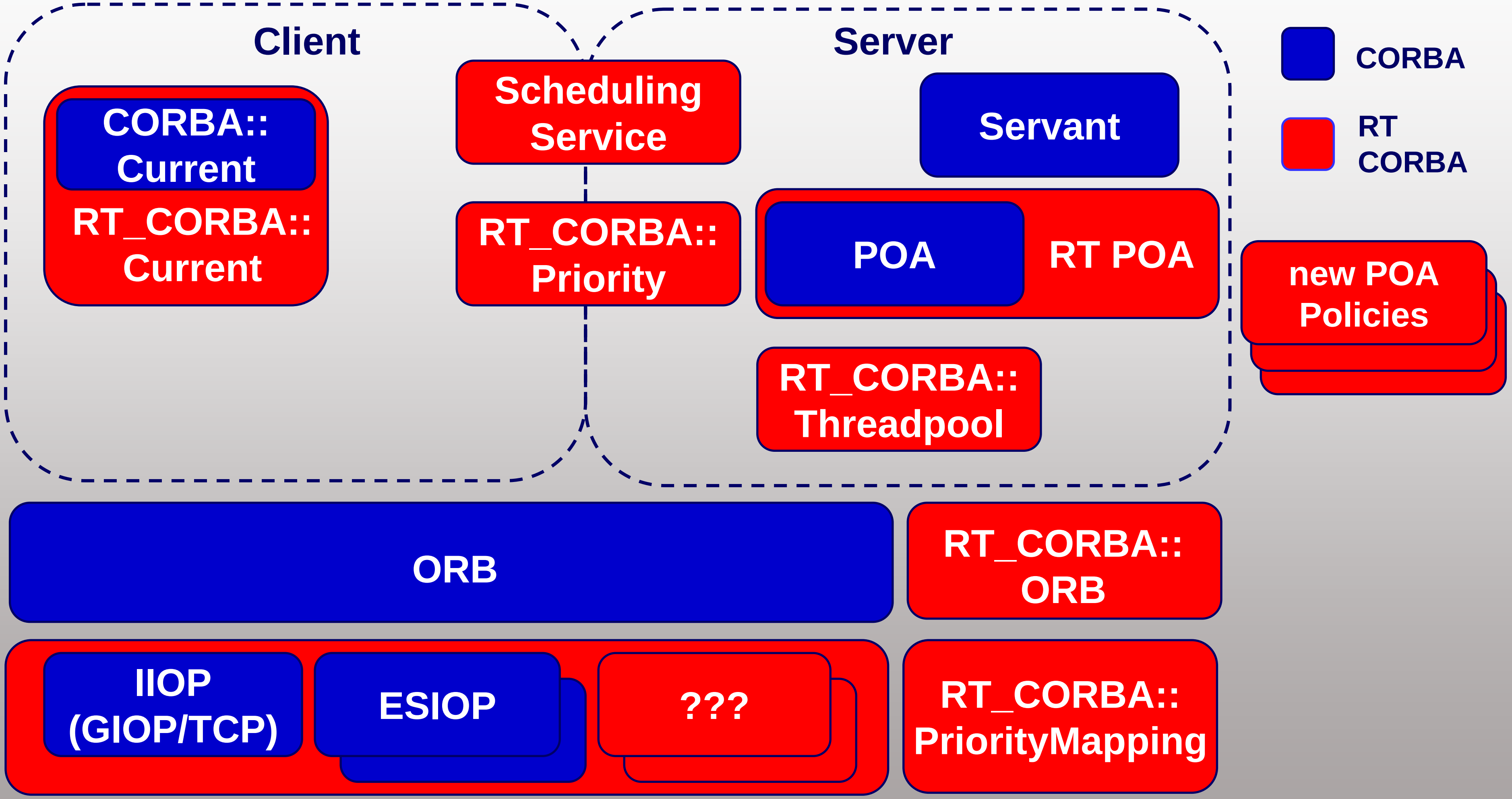

Windows NT: Client Thread priority 7
Client
ORB
OS priority 7 mapped to CORBA PRIORITY 28
CORBA PRIORITY 28 passed in service context
Network
Server
RTOS: Server Thread executes at priority 64
ORB
CORBA PRIORITY 28 mapped to RTOS priority 64

End-to-End Predictability

Operating System Assumptions

- Not a portability layer for heterogeneous Operating Systems
- POSIX is sufficient … but not necessary
  - POSIX 1003. 1b- 1996 Real- time Extensions
- Extent to which the ORB is deterministic may be limited by RTOS characteristics

Real-Time CORBA Extensions



RTORB & RT POA

- RTCORBA::RTORB
  - Consider as an extension of the CORBA::ORB interface
  - Specified just to provide operations to create and destroy other Real-Time CORBA entities
    - Mutex, Threadpool, Real-Time Policies
  - One RTORB per ORB instance
  - Obtain using: ORB::resolve_initial_references(“RTORB”);
- RTPortableServer::POA
  - Adds operations to POA to allow setting of priority on a per-Object basis
  - Implements policies for the RT POA
  - Inherits from PortableServer::POA (so not PIDL)

New RT POA Policies

- Priority Model Policy
- Threadpool Policy
- Priority Banded Connection Policy
- Private Connection Policy
- Server Protocol Policy
- Client Protocol Policy

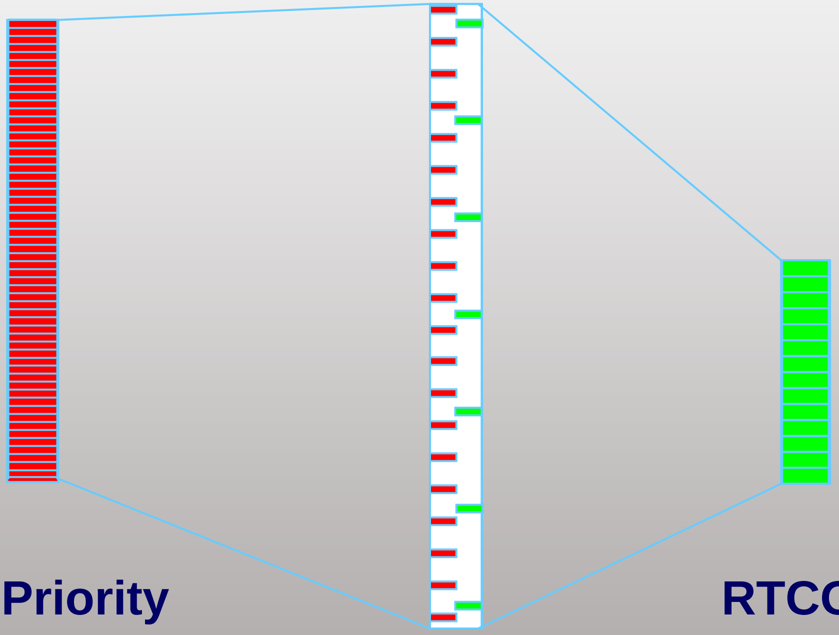
Universal Real-time Priorities

- RTCORBA::Priority
  - Universal, platform independent priority scheme
  - Allows prioritized CORBA invocations to be made in a consistent fashion between nodes with different native priority schemes
- Priority Mapping
  - Default Priority Mapping
    - Not standardized
    - Real-time ORB must supply a default mapping for each platform (RTOS) that the ORB supports
  - User-defined Priority Mapping
    - Real-time ORB must provide method for user to override default mapping
  - One Priority Mapping installed at any one time per ORB instance
    - installation mechanisms are not standardized

Real-Time CORBA
Priority Mapping

RTCORBA::Priority

MaxPriority = 32767



0

255

OS #1
RTCORBA:NativePriority

31

0

OS #2
RTCORBA:NativePriority

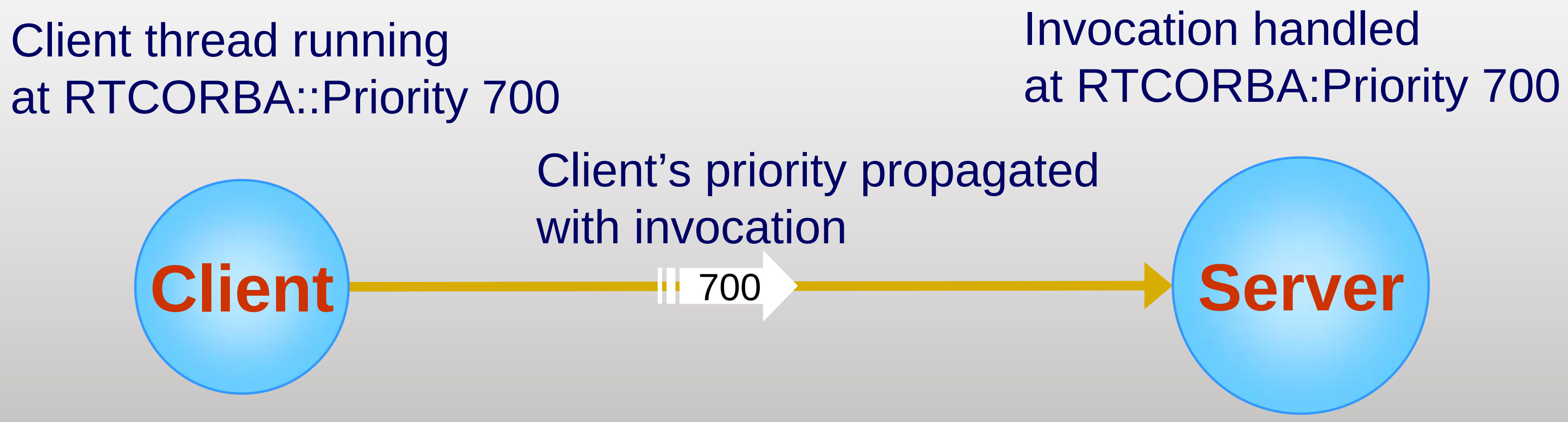
MinPriority = 0

to_corba → *to_native* →

Priority Model Policy

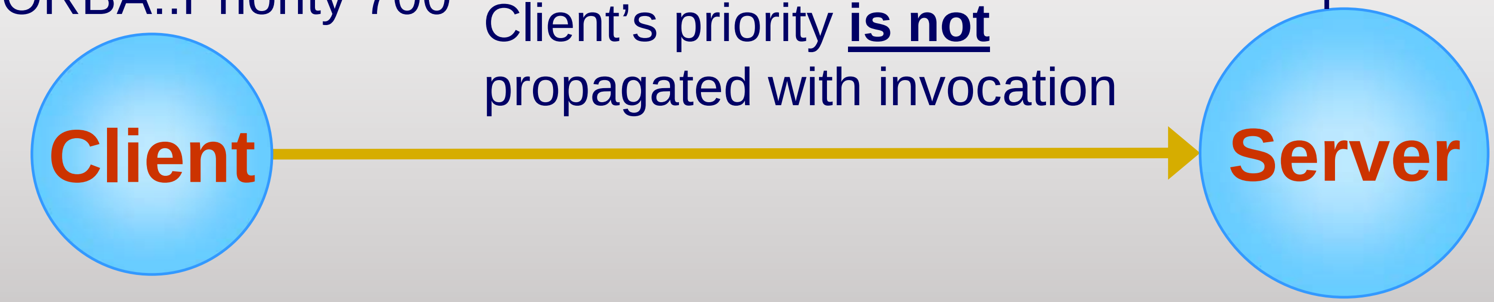
- Two Priority Models Specified
  - Client Propagated
    - Via client-side Policy override
    - Via server-side POA Policy
  - Server Declared
    - Only server-side POA Policy
- A Server-side (POA) Policy
  - configure by adding a PriorityModelPolicy to policy list in POA_create
  - all objects from a given POA support the same model

Client Propagated Priority Model



Scheduling based on end-to-end activities across node boundaries

Server Declared Priority Model



Client running at
RTCORBA::Priority 700

Client's priority **is not** propagated with invocation

Server Priority
is pre-set

Client

Server

Invocation handled
at pre-set Server
priority

Scheduling based on relative priorities of different objects on the same node.

Priority of ORB threads writing to and reading from transport is not defined for Server Declared Priority Model.

Real-Time CORBA Mutex

- API that gives the application access to the same Mutex implementation that the ORB is using
  - important for consistency in using a Priority Inheritance Protocol
    e.g. Priority Ceiling Protocol
- The implementation must offer (at least one) Priority Inheritance Protocol
  - No particular protocol is mandated though
  - application domain and RTOS specific

Threadpools

Threadpool Benefits

Control invocation concurrency

Thread pre-creation and reuse

Partition threads according to Priority

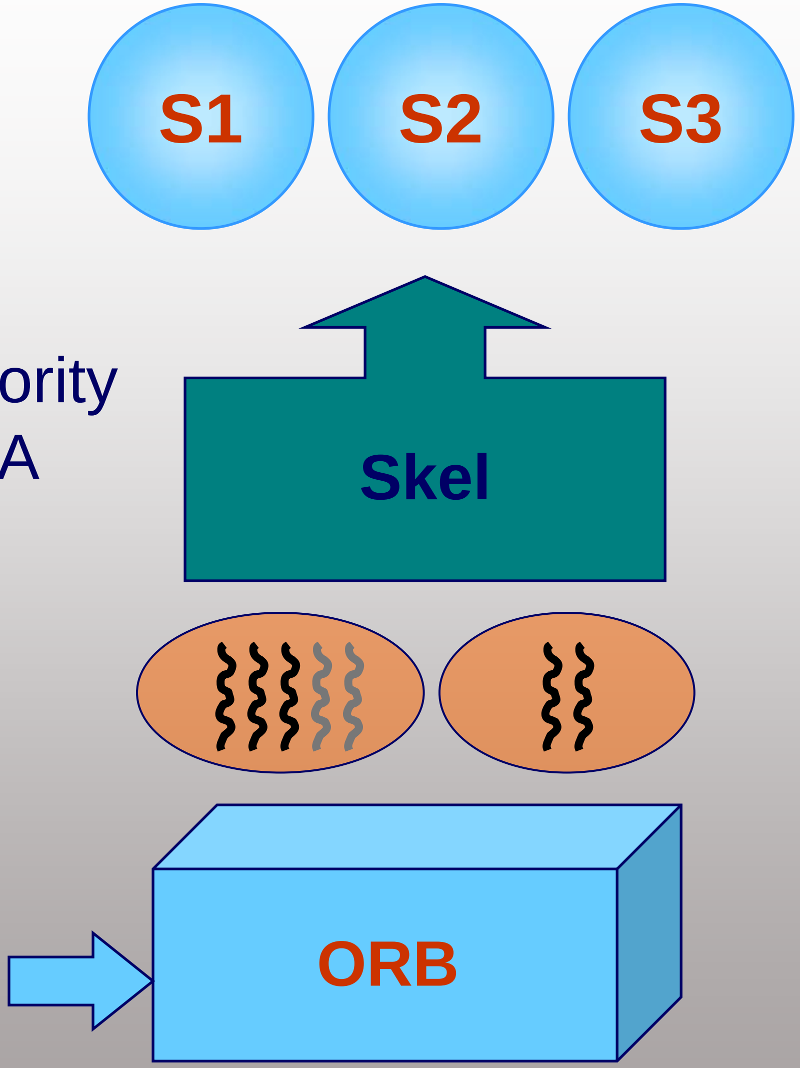
Bound thread usage by each POA

Multiple Threadpools

System partitioning

Protect resources

Integrate different systems more predictably

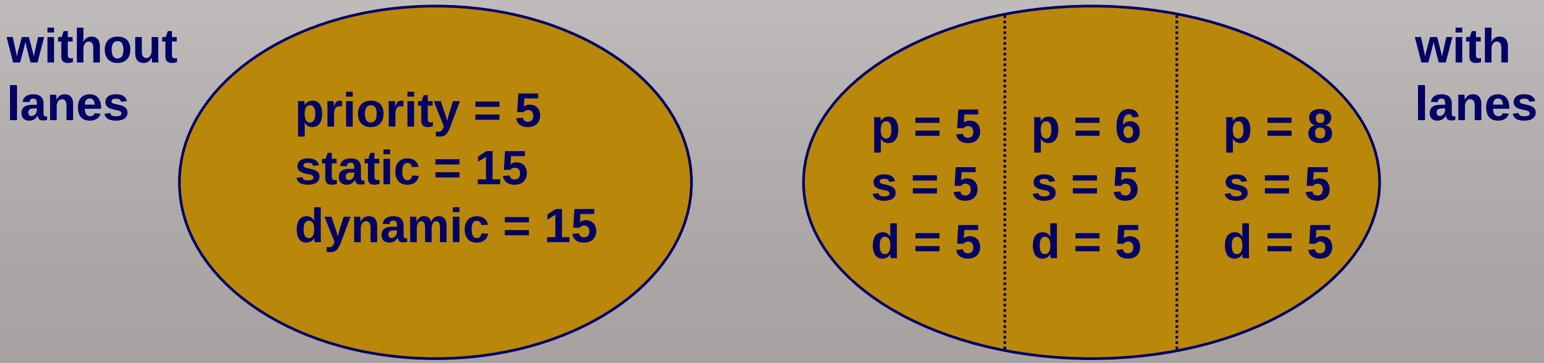


Threadpool Policy

- A POA may only be associated with one Threadpool
- Threadpools may be shared between POA’s
- Threadpool parameters
  - number of static threads
  - dynamic thread limit
    - 0 = no limit. same value as static = no dynamic threads
  - thread stacksize
  - default thread priority

Laned Threadpools

- Alternate way of configuring a Threadpool
  - for applications with detailed knowledge of priority utilization
  - preconfigure ‘lanes’ of threads with different priorities
  - ‘borrowing’ from lower priority lanes can be permitted



without lanes

priority = 5
static = 15
dynamic = 15

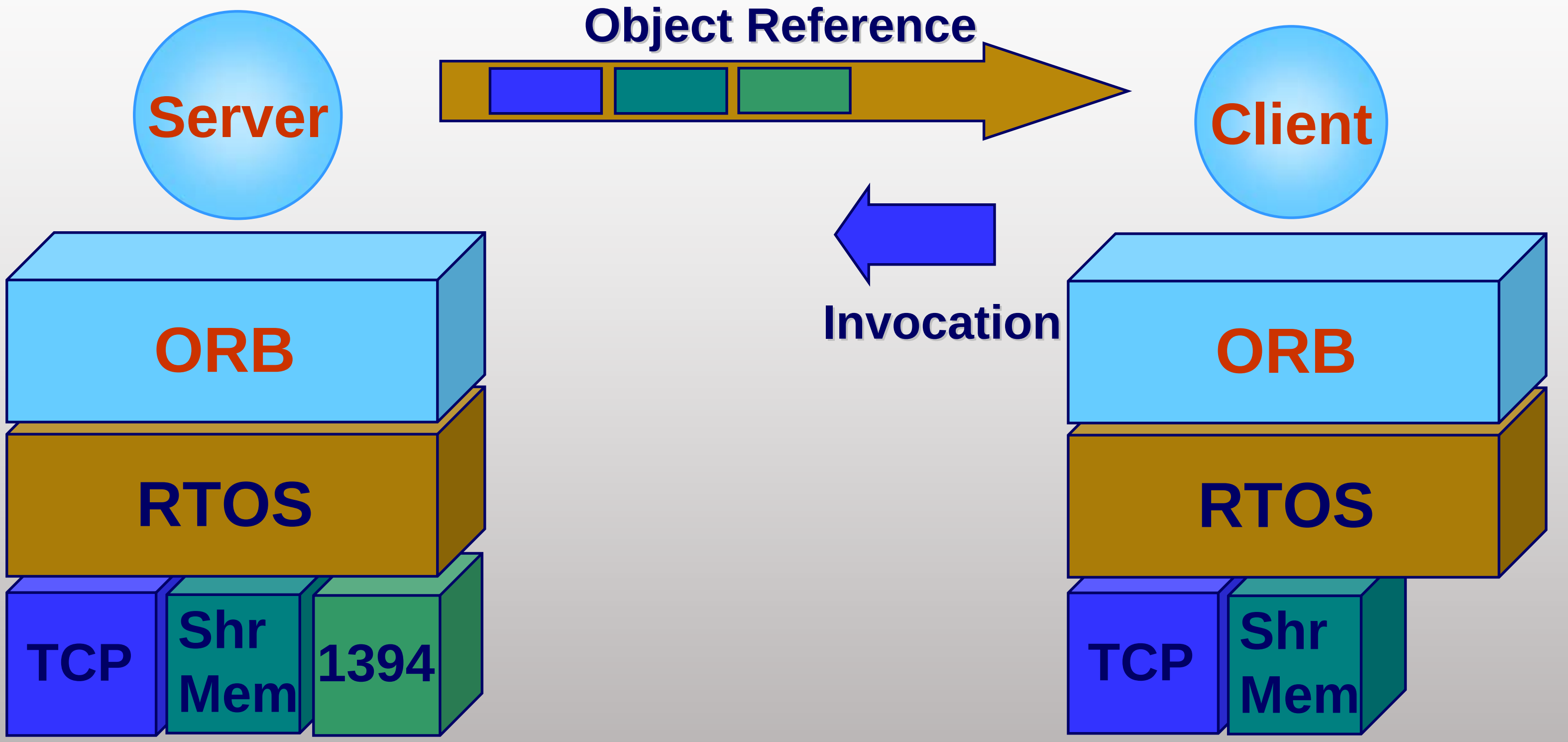
p = 5
s = 5
d = 5

p = 6
s = 5
d = 5

p = 8
s = 5
d = 5

with lanes

Protocol Selection and Configuration



On Server, this policy indicates which protocols to publish in Object Reference

On Client, this policy Indicates which protocol to use to connect

Protocol Properties

- A Protocol Properties interface to be provided for each configurable protocol supported
  - allows support for proprietary and future standardized protocols
- Real-Time CORBA only specifies Protocol Properties for TCP
- TCP Protocol Properties

```
module {
  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;
  };
};
```

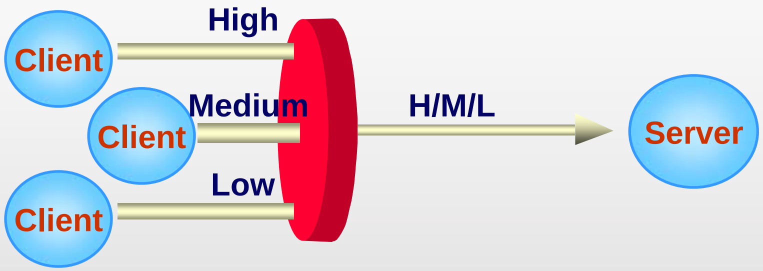
Client and Server Protocol Policies

- Server Protocol Policy
  - Enables selection and configuration of communication protocols on a per-POA basis
  - Protocols are represented
    - By a unique id
    - And by Protocol Properties defined as ORB/transport level protocol pairs
  - RTCORBA::ProtocolList allows multiple protocols to be supported by one POA
    - Order of protocols in list indicates order of preference
- Client Protocol Policy
  - Same syntax as server-side
  - On client, RTCORBA::ProtocolList specifies protocols that may be used to make a connection
    - order indicates order of preference
  - If Protocol Policy not set, order of protocols in target object’s IOR used as order of preference

Connection Management

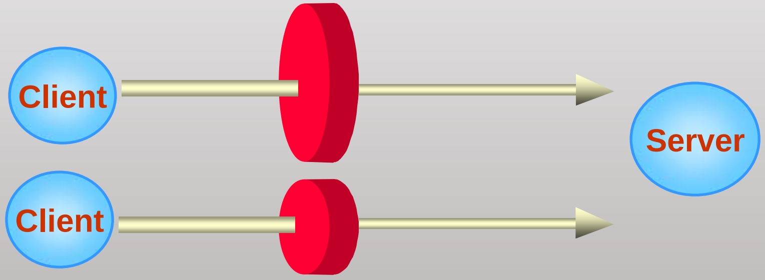
Connection Multiplexing

- Offered by many ORB’s for resource conservation
- Can contribute to priority inversion



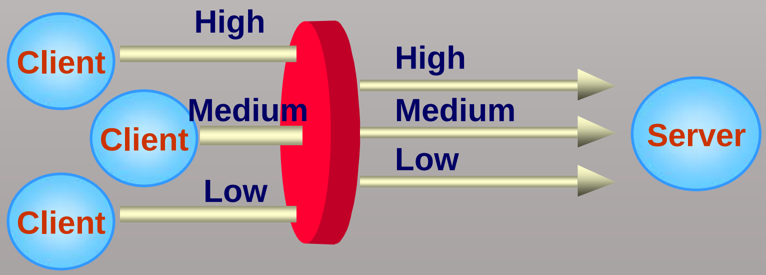
Private Connection

- Dedicated connection per object



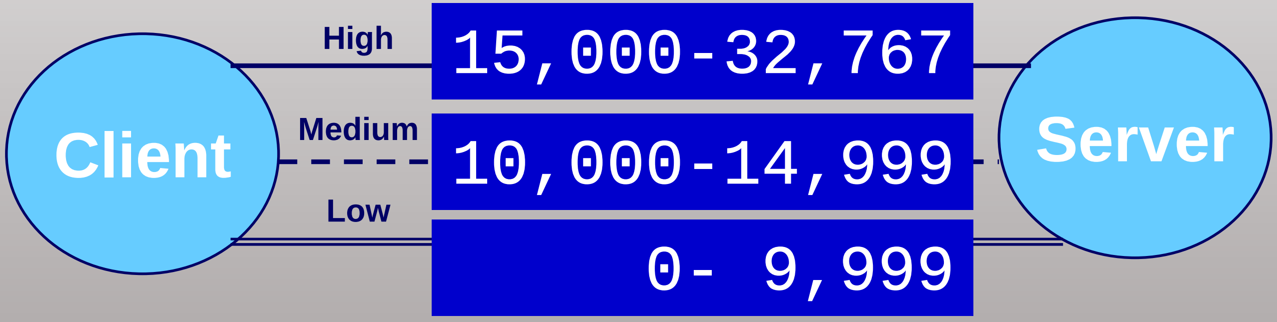
Priority Banding

- Several connections between nodes
- Connection to be used based on priority
- Can avoid O/S and transport priority inversions



Priority Banding Connection Policy

- Multiple connections, to reduce priority inversion
  - each connection may represent a range of priorities
  - may have different ranges in each band, including range of 1



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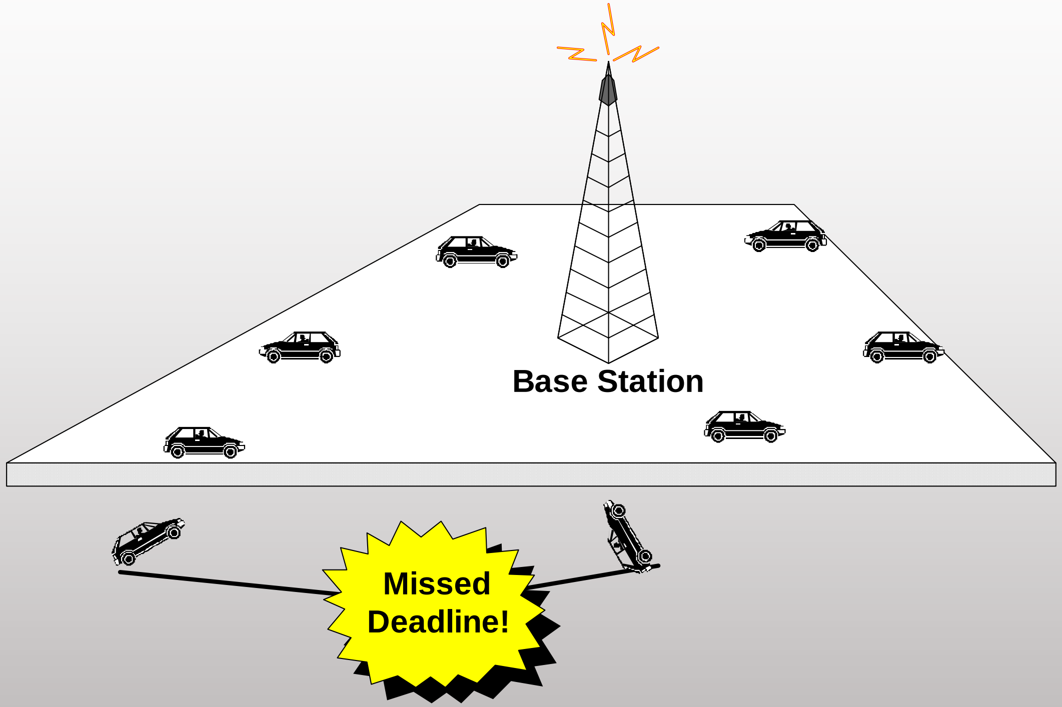
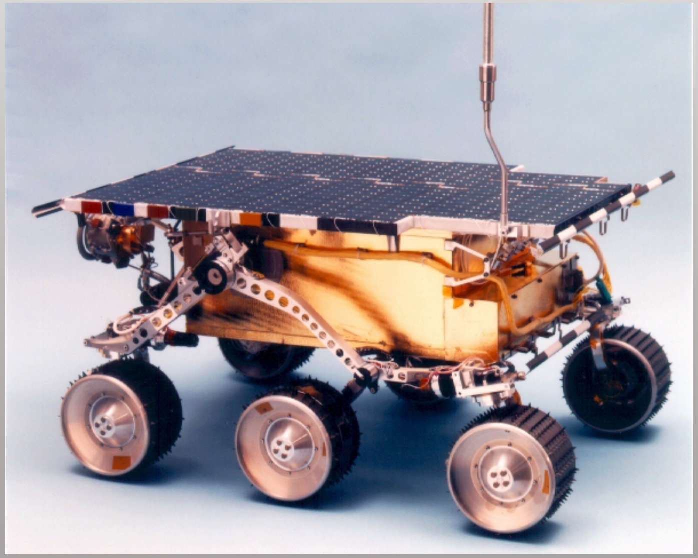
An Example Distributed Application

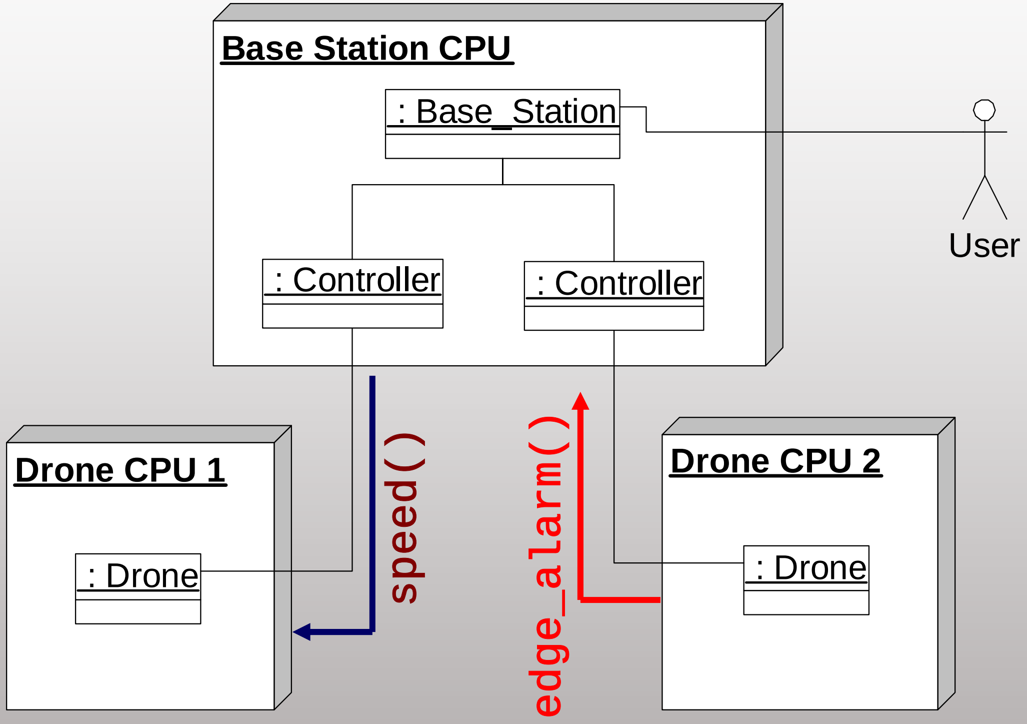


- Consider an application where cooperating *drones* explore a surface & report its properties periodically
  - *e.g.,* color, texture, etc.
- This is a simplification of various autonomous vehicle use-cases



- Drones aren’t very “smart,”
  - *e.g.,* they can fall off the “edge” of the surface if not stopped
- Thus, a *controller* is used to coordinate their actions
  - *e.g.,* it can order them to a new position

Designing the Application



- End-users talk to a **BaseStation** object
  - *e.g.*, they define high-level exploration goals for the drones
- The **BaseStation** object controls the drones remotely using **Drone** objects
- **Drone** objects are proxies for the underlying drone vehicles
  - *e.g.*, they expose operations for controlling & monitoring individual drone behavior

- Each drone sends information obtained from its sensors back to the **BaseStation** via a **Controller** object

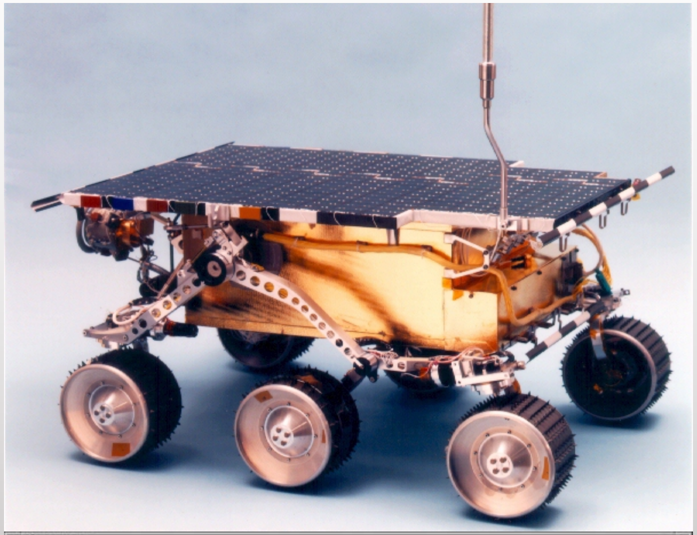
Defining Application Interfaces with CORBA IDL

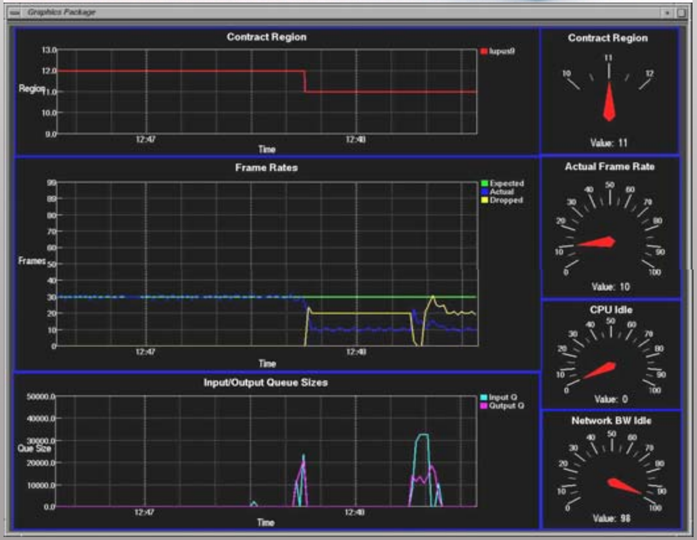
```
interface Drone
{
  void turn  (in float degrees);
  void speed (in short mph);
  void reset_odometer ();
  short odometer ();
  // …
};

interface Controller
{
  void edge_alarm();
  void battery_low();
};

exception Lack_Resources {};

interface BaseStation
{
  Controller new_controller(in string name)
    raises (Lack_Resources);
  void set_new_target (in float x, in float y);
  //……
};
```

- Each `Drone` talks to one `Controller`
  - *e.g.*, `Drones` send hi-priority alarm messages when they detect an edge
- The `Controller` should take corrective action if a `Drone` detects it's about to fall off an edge!
- The `BaseStation` interface is a `Controller` factory
  - `Drones` use this interface to create their `Controllers` during power up
  - End-users use this interface to set high-level mobility targets

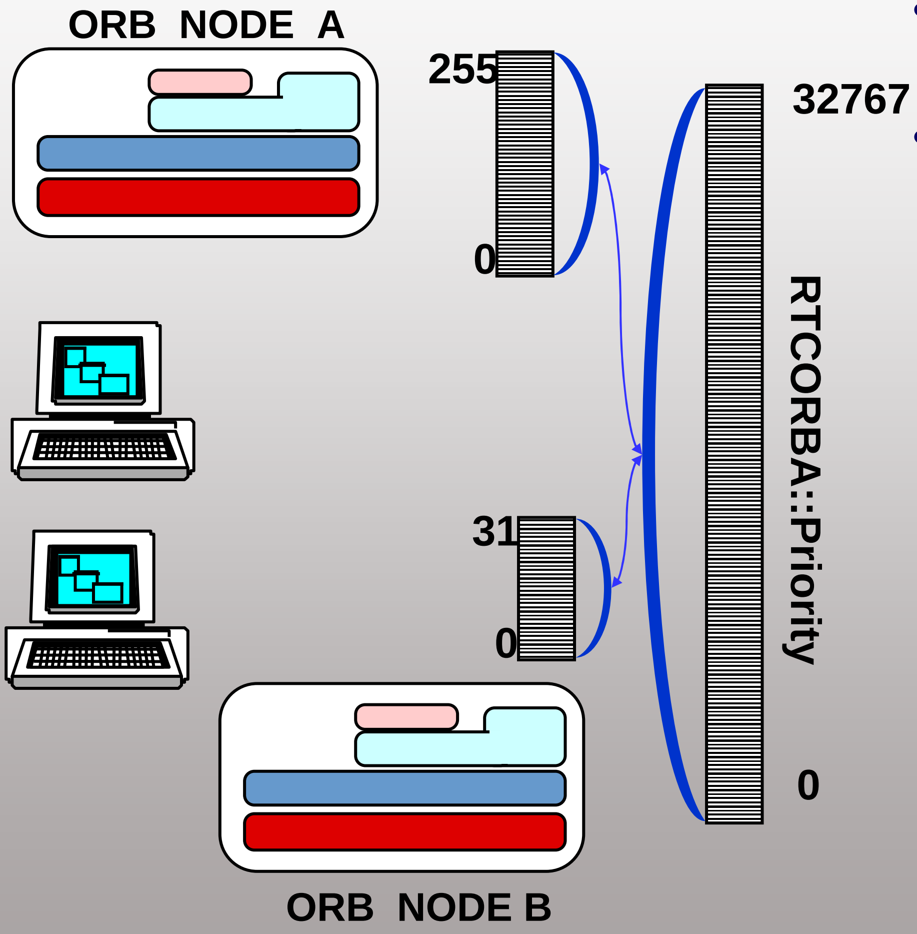
Real-time Application Design Challenges

- Our example application contains the following real-time design challenges
  1. *Obtaining portable ORB node priorities*
  2. *Preserving priorities end-to-end*
  3. *Enforcing certain priorities at the server*
  4. *Changing CORBA priorities*
  5. *Supporting thread pools effectively*
  6. *Buffering client requests*
  7. *Synchronizing objects correctly*
  8. *Configuring custom protocols*
  9. *Controlling network & node resources to minimize priority inversion*
  10. *Avoiding dynamic connections*
  11. *Simplifying application scheduling*
  12. *Controlling request timeouts*
- The remainder of this tutorial illustrates how these challenges can be addressed by applying RT CORBA capabilities





Obtaining Portable ORB Node Priorities



- **Problem**: Mapping CORBA priorities to native OS host priorities
- **Solution**: Standard RT CORBA priority mapping interfaces
  - –OS-independent design supports heterogeneous real-time platforms
  - –CORBA priorities are “globally” unique values that range from 0 to 32767
  - –Users can map CORBA priorities onto native OS priorities in custom ways
  - –No silver bullet, but rather an “enabling technique”
  - –*i.e.*, can’t magically turn a general-purpose OS into a real-time OS!

Priority Mapping Example

- Define a priority mapping class that always uses native priorities in the range 128-255
  - *e.g.*, this is the top half of LynxOS priorities

```
class MyPriorityMapping : public RTCORBA::PriorityMapping {
  CORBA::Boolean to_native (RTCORBA::Priority corba_prio,
                            RTCORBA::NativePriority &native_prio)
  {
    native_prio = 128 + (corba_prio / 256);
    // In the [128,256) range…
    return true;
  }

  // Similar for CORBA::Boolean to_CORBA ();
};
```

Preserving Priorities End-to-End

- Problem: Requests could run at the wrong priority on the server
  - e.g., this can cause major problems if edge_alarm() operations are processed too late!!
- Solution: Use RT CORBA priority model policies
  - SERVER_DECLARED
    - Server handles requests at the priority declared when object was created
  - CLIENT_PROPAGATED
    - Request is executed at the priority requested by client (priority encoded as part of client request)

Creating PriorityBands Policies

- Drones send critical messages to `Controllers` in the `BaseStation`
  - `edge_alarm()` called by and runs at high priority
  - `battery_low()` called by and runs at low priority
- So first we set up a PriorityBands Policy

```
// ----- Obtain a reference to the RTORB
RTCORBA::RTORB_var rt_orb = RTCORBA::RTORB::_narrow(
    orb->resolve_initial_references("RTORB"));

// ----- Obtain the ORB's PolicyManager
CORBA::PolicyManager_var orb_pol_mgr = CORBA::PolicyManager::_narrow(
    orb->resolve_initial_references("ORBPolicyManager"));

RTCORBA::PriorityBands priority_bands(3);
priority_bands.length(3);
priority_bands[0].low  =     0;
priority_bands[0].high = 10000;
priority_bands[1].low  = 10001;
priority_bands[1].high = 20000;
priority_bands[2].low  = 20001;
priority_bands[2].high = 32767;

CORBA::PolicyList policy_list(1);
policy_list.length(1);
policy_list[0] =
    rt_orb->create_priority_banded_connection_policy(priority_bands);

orb_pol_mgr->set_policy_overrides(policy_list, CORBA::ADD_OVERRIDE);
```

Overridding IOR with PriorityBands

- Then we override and use the new object reference

```
Controller_var controller = // get from naming service, etc.

// Override the object reference with banding policies
CORBA::Object_var temp_object =
    controller->_set_policy_overrides(
        policy_list, CORBA::ADD_OVERRIDE);

Controller_var rt_ controller = Controller::_narrow(temp_object);

// Real-time invocation using priority banding.
// Controller servant runs at equivalent of this
// threads priority (high or low) in server.

rt_controller->edge_alarm();

// Normal invocation without priority banding. (BAD!)
// Controller servant runs at undefined priority
// (ORB default typically) in server.

controller->edge_alarm();
```

Changing CORBA Priorities at the Client

- **Problem**: How can RT-CORBA client applications change the priority of operations?
- **Solution**: Use the `RTCurrent` to change the priority of the current thread explicitly
  - An `RTCurrent` can also be used to query the priority
  - Values are expressed in the *CORBA priority* range
  - Behavior of `RTCurrent` is *thread-specific*

```
// Get the ORB’s RTCurrent object
obj = orb->resolve_initial_references (“RTCurrent”);

RTCORBA::RTCurrent_var rt_current =
   RTCORBA::RTCurrent::_narrow (obj);

// Change the current CORBA priority
rt_current->base_priority (VERY_HIGH_PRIORITY);

// Invoke the request at <VERY_HIGH_PRIORITY> priority
// The priority is propagated (see previous page)
rt_controller->edge_alarm();
```

Design Interlude: The RTORB Interface

- **Problem:** How can the ORB be extended without changing the CORBA::ORB API?
- **Solution:**
  - Use `resolve_initial_references()` interface to obtain the extension
  - Thus, non real-time ORBs and applications are not affected by RT CORBA enhancements!

```
CORBA::ORB_var orb = CORBA::ORB_init (argc, argv);

CORBA::Object_var obj =
   orb->resolve_initial_references (“RTORB”);

RTCORBA::RTORB_var rtorb =
   RTCORBA::RTORB::_narrow (obj);
// Assuming this narrow succeeds we can henceforth use RT
// CORBA features
```

Applying SERVER_DECLARED

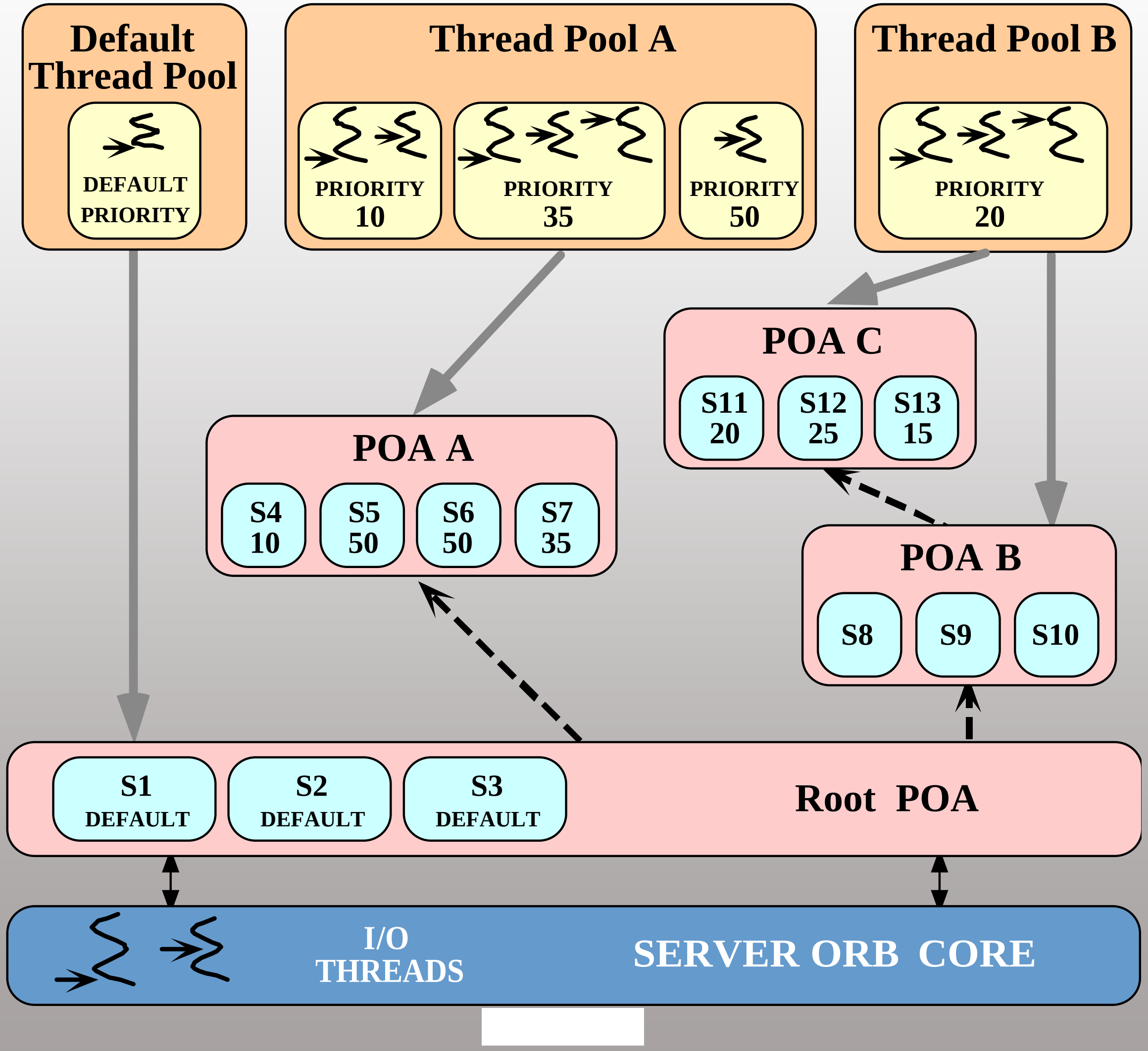
- **Problem**: Some operations must always be invoked at a fixed priority
  - *e.g.*, the `Base_Station` methods are not time-critical, so they should always run at lower priority than the `Controller` methods
- **Solution**: Use the RT CORBA SERVER_DECLARED priority model

```
CORBA::PolicyList policies (1); policies.length (1);
policies[0] = rtorb->create_priority_model_policy
   (RTCORBA::SERVER_DECLARED, LOW_PRIORITY);

// Create a POA with the correct policies PortableServer::POA_var
base_station_poa =
   root_poa->create_POA (“Base_Station_POA”,
                         PortableServer::POAManager::_nil (),
                         policies);

// Activate the <Base_Station> servant in <base_station_poa>
base_station_poa->activate_object (base_station);
```

- By default, SERVER_DECLARED objects inherit the priority of their RTPOA
  - It’s possible to override this priority on a per-object basis

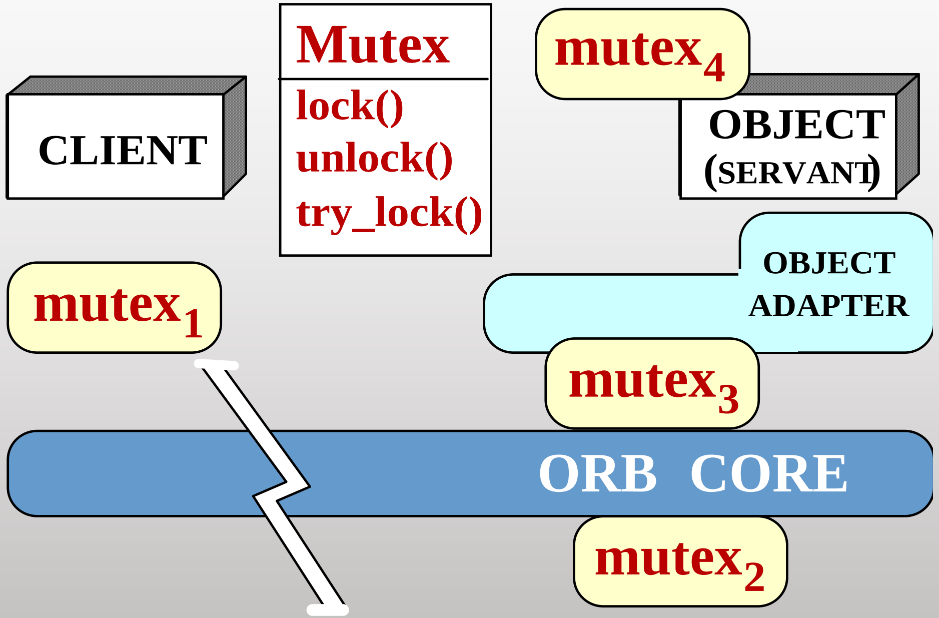
Warning: SERVER_DECLARED does not specify what priority the client and server ORB processing should occur at.

Supporting Thread Pools Effectively



- **Problem**: Pre-allocating threading resources on the server *portably* & *efficiently*
  - *e.g.*, the `BaseStation` must have sufficient threads for all its priority levels
- **Solution**: Use RT CORBA thread pools to configure server POAs to support
  - Different levels of service
  - Overlapping of computation & I/O
  - Priority partitioning

Synchronizing Objects Consistently



- **Problem**: An ORB & application may need to use the same *type* of mutex to avoid priority inversions
  - *e.g.*, using priority ceiling or priority inheritance protocols
- **Solution**: Use the `RTCORBA::Mutex` interface to ensure that consistent mutex semantics are enforced across ORB & application domains

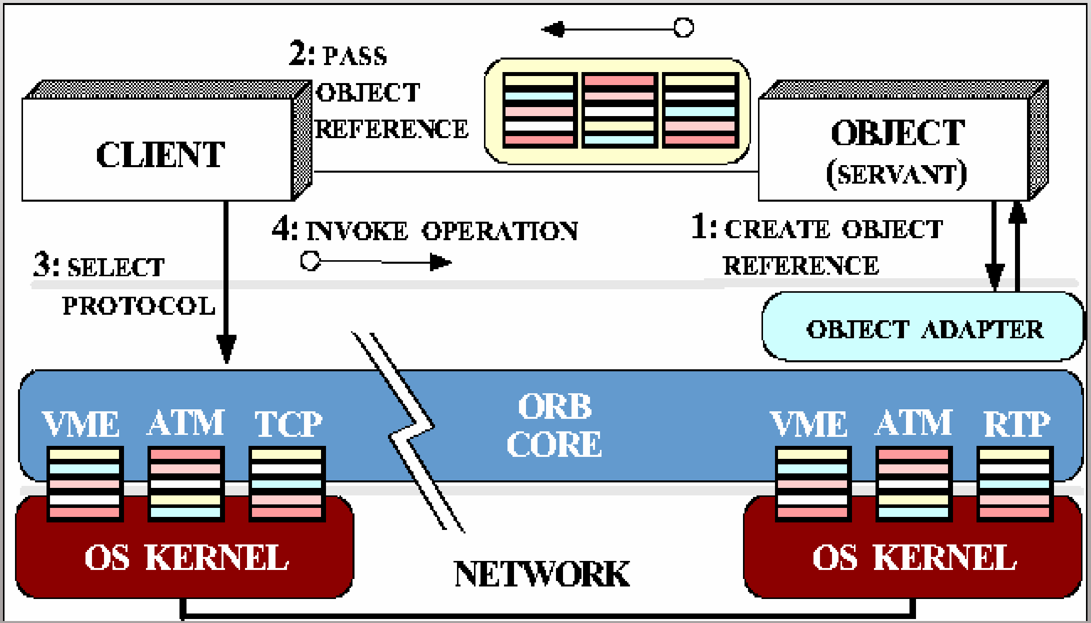
```
RTCORBA::Mutex_var mutex = rtorb->create_mutex();
...
mutex->lock();
// Critical section here…
mutex->unlock();
...
rtorb->destroy_mutex(mutex);
```

`create_mutex()` is a factory method

Configuring Custom Protocols

- **Problems**: Selecting communication protocol(s) is crucial to obtaining QoS
  - –TCP/IP is inadequate to provide end-to-end *real-time* response
  - –Thus, communication between `BaseStation`, `Controllers`, & `Drones` must use a different protocol
  - –Moreover, some messages between `Drone` & `Controller` cannot be delayed

- **Solution**: Protocol selection policies
  - Both server-side & client-side policies are supported
  - Some policies control protocol selection, others configuration
  - Order of protocols indicates protocol preference
  - Some policies are exported to client in object reference



Example: Configuring protocols

- First, we create the protocol properties

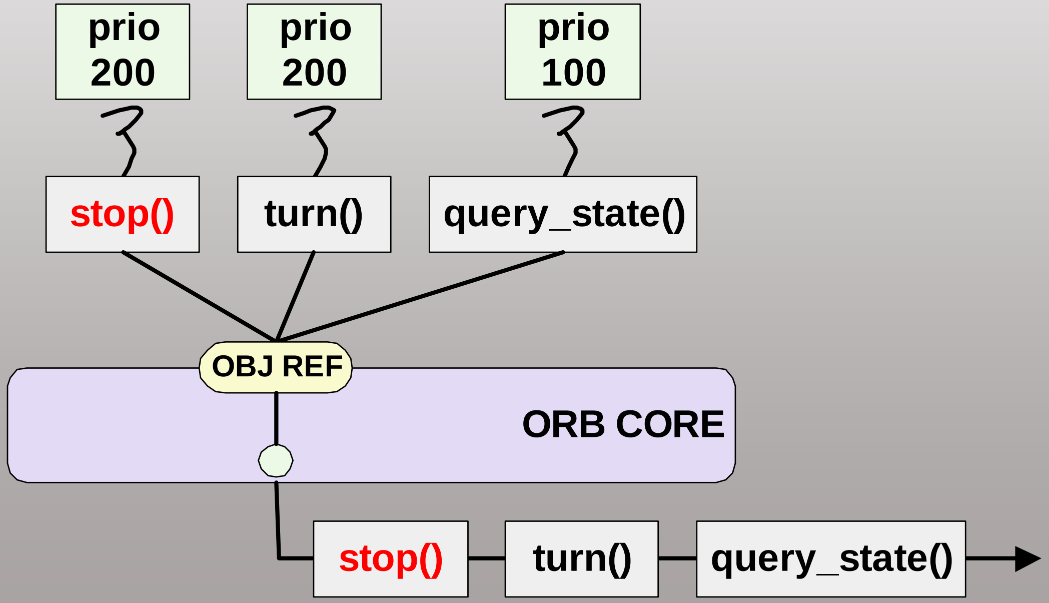
```
RTCORBA::ProtocolProperties_var tcp_properties
   = rtorb->create_tcp_protocol_properties (
        64 * 1024, /* send buffer */
        64 * 1024, /* recv buffer */
        false,     /* keep alive  */
        true,      /* dont_route  */
        true);     /* no_delay    */
```

- Next, we configure the list of protocols to use

```
RTCORBA::ProtocolList plist; plist.length (2);
plist[0].protocol_type = MY_PROTOCOL_TAG;
plist[0].trans_protocol_props =
    /* Use implementation specific interface */
plist[1].protocol_type = IOP::TAG_INTERNET_IOP;
plist[1].trans_protocol_props = tcp_properties;
RTCORBA::ClientProtocolPolicy_ptr policy =
   rtorb->create_client_protocol_policy(plist);
```

Controlling Network Resources

- **Problems**:
  - –Control jitter due to connection setup
  - –Avoiding request-level (“head-of-line”) priority inversions
  - –Minimizing thread-level priority inversions

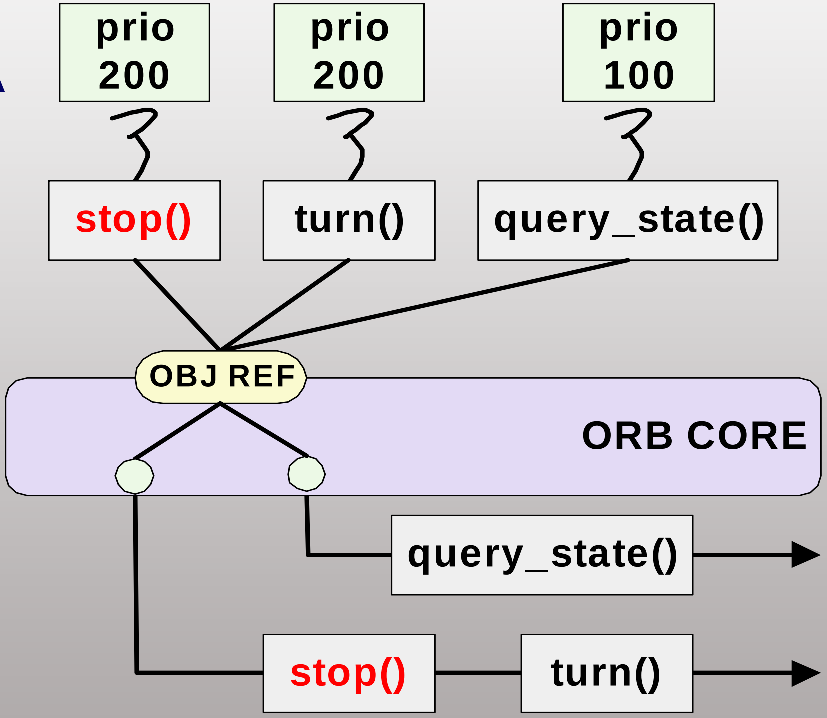


- **Solution**: Use explicit binding mechanism
  - *Priority Banded Connection Policy*
    - Invocation priority determines which connection is used

Priority Banded Connection Policy

- **Problem**: To minimize priority inversions, high-priority operations should not be queued behind low-priority operations
- **Solution**: Use different connections for different priority ranges via the RT CORBA `PriorityBandedConnectionPolicy`

```
// Create the priority bands.
RTCORBA::PriorityBands bands (2);
bands.length (2);
// We can have bands with a range
// of priorities...
bands[0].low  = 0;
bands[0].high = 9999;
// ... or just a “range” of 1!
bands[1].low  = 10000;
bands[1].high = 19999;

CORBA::Policy_var policy = rtorb->
create_priority_banded_connection_policy (bands);
```



Other Relevant CORBA Features

- RT CORBA leverages other advanced CORBA features to provide a more comprehensive real-time ORB middleware solution, *e.g.:*
  - ***Timeouts***: CORBA Messaging provides policies to control roundtrip timeouts
  - ***Reliable oneways***: which are also part of CORBA Messaging
  - ***Asynchronous invocations***: CORBA Messaging includes support for type-safe asynchronous method invocation (AMI)
  - ***Real-time analysis & scheduling***: The RT CORBA Scheduling Service is an optional compliance point for this purpose
    - However, most of the problem is left for an external tool
  - ***Enhanced views of time*****:** Defines interfaces to control & query "clocks" (orbos/1999-10-02)
  - ***RT Notification Service*****:** In progress in the OMG orbos/00-06-10, looks for RT-enhanced Notification Service
  - ***Dynamic Scheduling*****:** OMG ptc/01-08-34, addresses additional policies for dynamic & hybrid static/dynamic scheduling

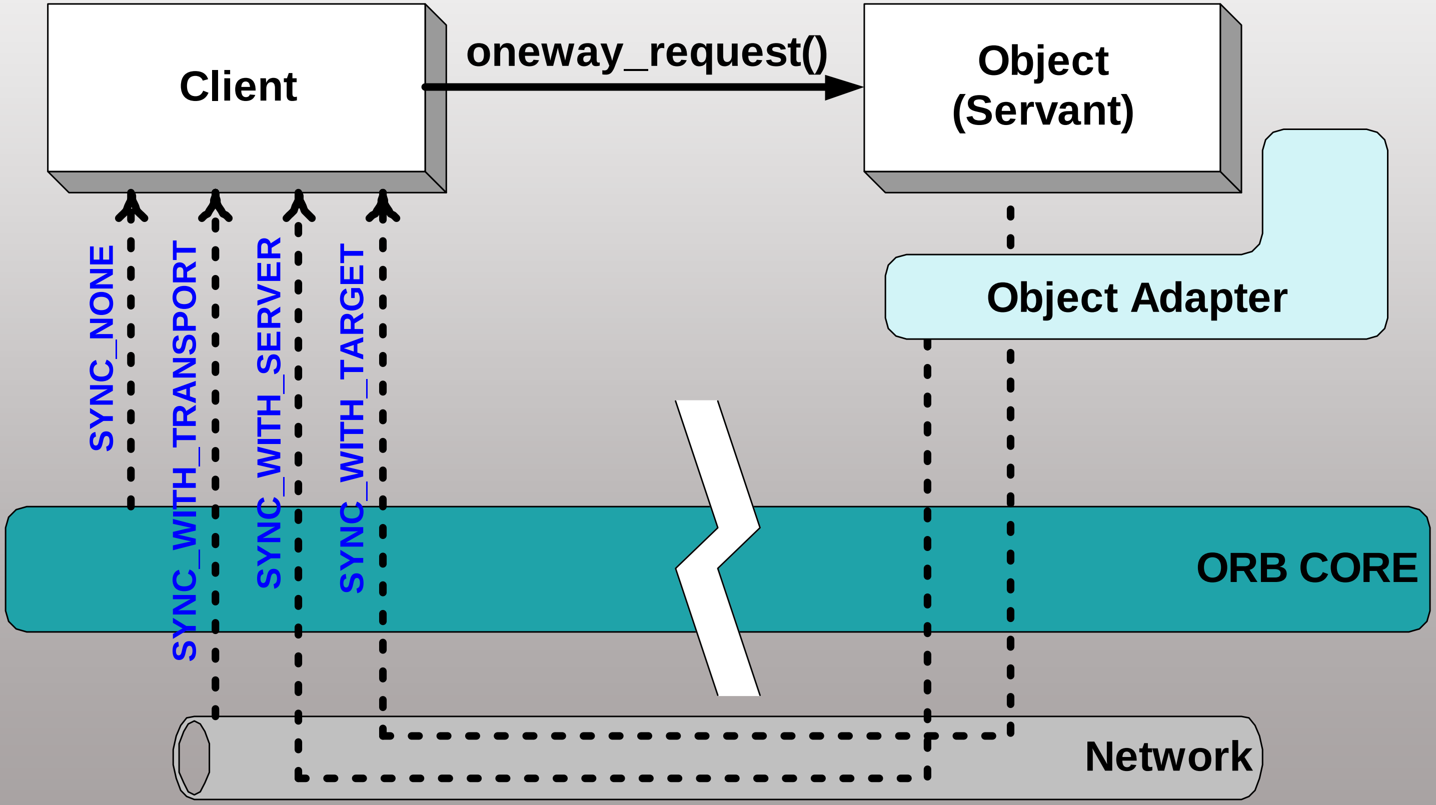
Controlling Request Timeouts

- **Problem**: Our `Controller` object should not block indefinitely when trying to stop a drone that's fallen off an edge!
- **Solution**: Override the timeout policy in the `Drone` object reference

```
// 10 milliseconds (base units are 100 nanosecs)
CORBA::Any val; val <<= TimeBase::TimeT (100000UL);

// Create the timeout policy
CORBA::PolicyList policies (1); policies.length (1);
policies[0] = orb->create_policy
   (Messaging::RELATIVE_RT_TIMEOUT_POLICY_TYPE, val);

// Override the policy in the drone
CORBA::Object_var obj = drone->_set_policy_overrides
   (policies, CORBA::ADD_OVERRIDE);

Drone_var drone_with_timeout = Drone::_narrow (obj);
try {  drone_with_timeout->speed (0); }
catch (const CORBA::TIMEOUT &e) { // Handle exception }
```

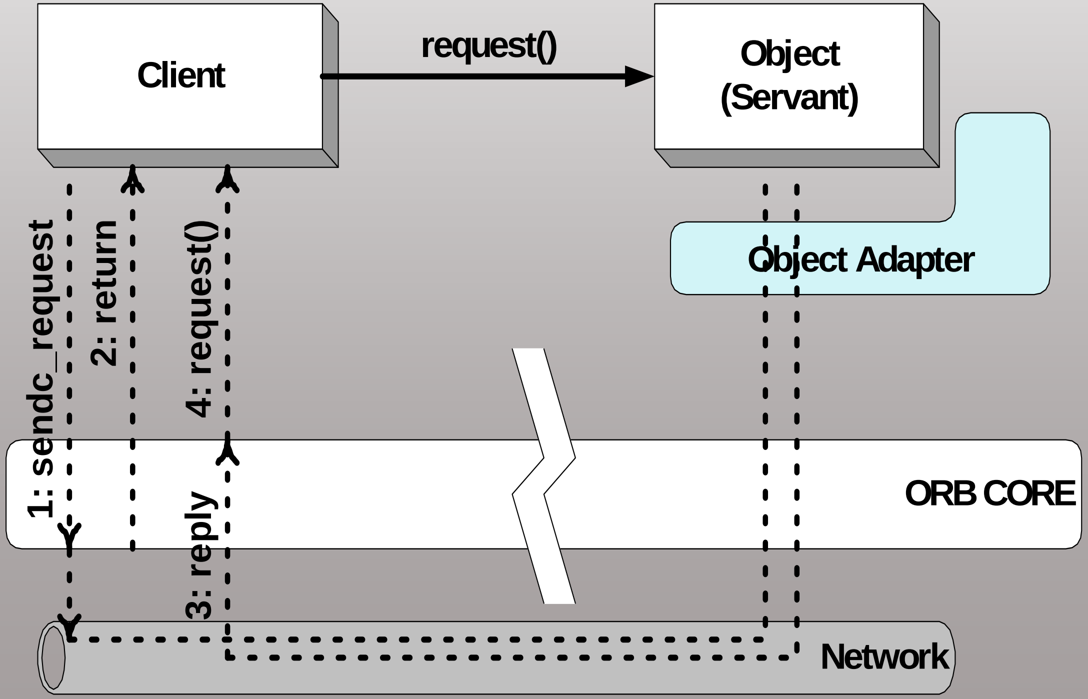
Reliable Oneways

- **Problem**: Traditional CORBA one-way operation semantics are not precise enough for real-time applications
- **Solution**: Use the SyncScope policy to control one-way semantics



Asynchronous Method Invocation

- **Problem**: clients block waiting for requests to complete, yet some requests take too long, or many requests must be issued simultaneously
- **Solution**: use the AMI interfaces to separate (in time and space) the thread issuing the request from the thread processing the reply



Agenda

- Motivation
- Introduction to Real-time Principles
- Challenges in Distributing Real-time Systems
- Overview of Real-time CORBA
- Applying Real-time CORBA to problem domains
- Real-time CORBA Architecture
- Example Application
- Dynamic Scheduling
- Future Directions
- Summary

Goals of Dynamic Scheduling

- Generalizes Real-Time CORBA scheduling
  - Any scheduling discipline may be employed
  - The scheduling parameters may be changed at any time
  - The schedulable entity is a distributable thread
    - Builds upon RT CORBA 1.0 activity concept
    - Spans node boundaries carrying its scheduling context with it

Scope

- Provides
  - A scheduling framework upon which schedulers can be built
  - Mechanism used for passing information between scheduler instances via GIOP service contexts
    - Does not specify format and content of service contexts
    - On-the-wire interoperability of scheduler implementations is left to future specifications
    - A foundation for future full interoperability
  - An abstraction for distributed real-time programming (distributable thread)

Scope 2

- Adds interfaces for a small set of well known scheduling disciplines
  - optional compliance points
  - includes interfaces for these disciplines that will allow the development of portable applications
  - interfaces for other scheduling disciplines is left to future specifications
- Does not provide all interfaces necessary for interoperability
  - between scheduling disciplines
  - between different scheduler implementations

Scope 3

- Does not address
  - fault tolerance
  - content of information propagated along the path of a distributable thread
- Defines ORB/scheduler interfaces for development of portable schedulers
  - Scheduler use of O/S is outside scope of submission
  - Does not provide portability of schedulers except with respect to ORB interactions

Scheduler

- Realized as a extension to Real-time CORBA
- Utilizes the scheduling needs and resource requirements of one or more applications
- Manages the order of execution on the distributed nodes
- Provides operations for applications to announce their requirements
- Runs in response to specific application requests
  - Defining a new scheduling parameter
  - CORBA invocations (via Portable Interceptor interfaces)

Scheduler 2

- Utilizes the information provided in these interfaces to execute threads
- Scheduler control of threads
  - Via whatever interfaces the operating system provides
  - Outside of the scope of RTCORBA
- Premise: dist application = set of dist threads
  - May interact in a number of ways
  - Sharing resources via mutexes
  - Sharing transports
  - Parent/offspring relationships
  - etc.

Scheduler 3

- Interact with Distributable Threads
  - Provides a vehicle for carrying scheduling information across the distributed system
  - Interact with the scheduler at specific scheduling points
    - Application calls
    - Locks and releases of resources
    - Pre-defined locations within CORBA invocations
      - Required because distributable thread may transition to another processor
      - Scheduling information must be reinterpreted on the new processor
    - Creation and termination of a distributable thread

Scheduler Characteristics

- Does not assume a single scheduling discipline
- Schedulers developed to implement a particular scheduling discipline
- Defines only the interface between the ORB/application and the scheduler
- Intended to foster the development of schedulers that are not dependent on any particular ORB
- While schedulers will likely be dependent on O/S
  - this submission does not address these O/S interfaces

Scheduler Characteristics 2

- Addresses schedulers that will optimize execution for the application scheduling needs on a processor-by-processor basis
  - ... as the execution of an application distributable thread moves from processor to processor, its scheduling needs are carried along and honored by the scheduler on each processor
  - Doesn't preclude development global optimization schedulers
    - But this specification does not specifically address that type of scheduler.
- Scheduler APIs for a small set of scheduling disciplines is provided

Scheduler Characteristics 3

- What's missing from the spec that's required for full interoperability?
  - Fully define the semantics of the example scheduling disciplines
  - Define the service contexts to propagate execution context with distributable threads
- Implementation experience is needed before full interoperability is possible

Scheduling Parameter Elements

- Scheduling parameter = a container of potentially multiple values called scheduling parameter elements
  - the values needed by a scheduling discipline in order to make scheduling decisions for an application
  - A scheduling discipline may have no elements, only one, or several
  - The number and meaning of the scheduling parameter elements is scheduling discipline specific
  - A single scheduling parameter is associated with an executing distributable thread via the begin_scheduling_segment operation
  - A thread executing outside the context of a scheduling segment has no scheduling parameter associated with it

Pluggable Scheduler and Interoperability

- Specification provides a "pluggable" scheduler
- A particular ORB in the system
  - may have any scheduler installed or
  - may have no scheduler
- Applications run on that ORB with a scheduler are "under the purview" of that scheduler

Pluggable Scheduler and Interoperability 2

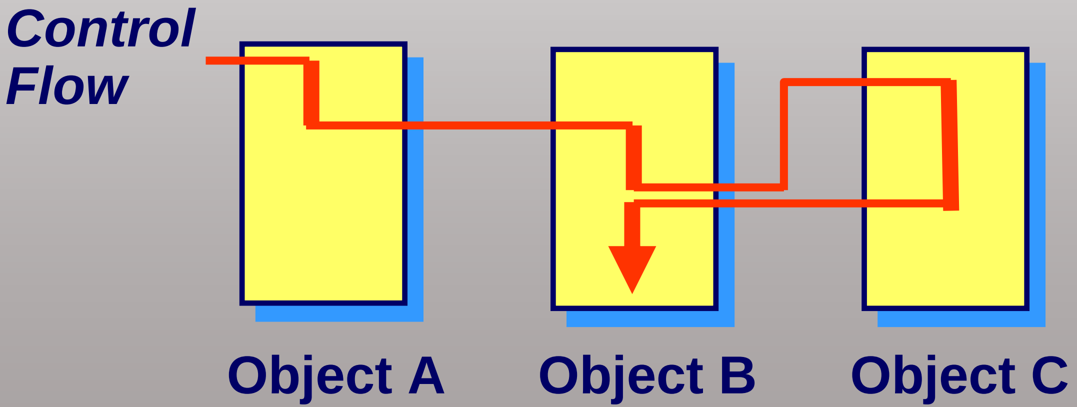
- Application components may interoperate as long as:
  - their ORBs have compatible schedulers installed
    - the schedulers implement the same discipline
    - follow a CORBA standard for that discipline
    - the scheduler implementations use a compatible service context
  - The current specification does not define any standard service contexts
  - Future specifications are anticipated in this area
- A scheduler may choose to support multiple disciplines, but the current specification does not address this

Distributable Thread

- End-to-end schedulable entity
- Cost-effectiveness demands application-specific knowledge
- Much of this knowledge can be best captured in the scheduling discipline
- Application-specific scheduling disciplines can be implemented by a pluggable scheduler
- An end-to-end execution model is essential to achieving end-to-end predictability of timeliness
- This is especially important in dynamically scheduled systems

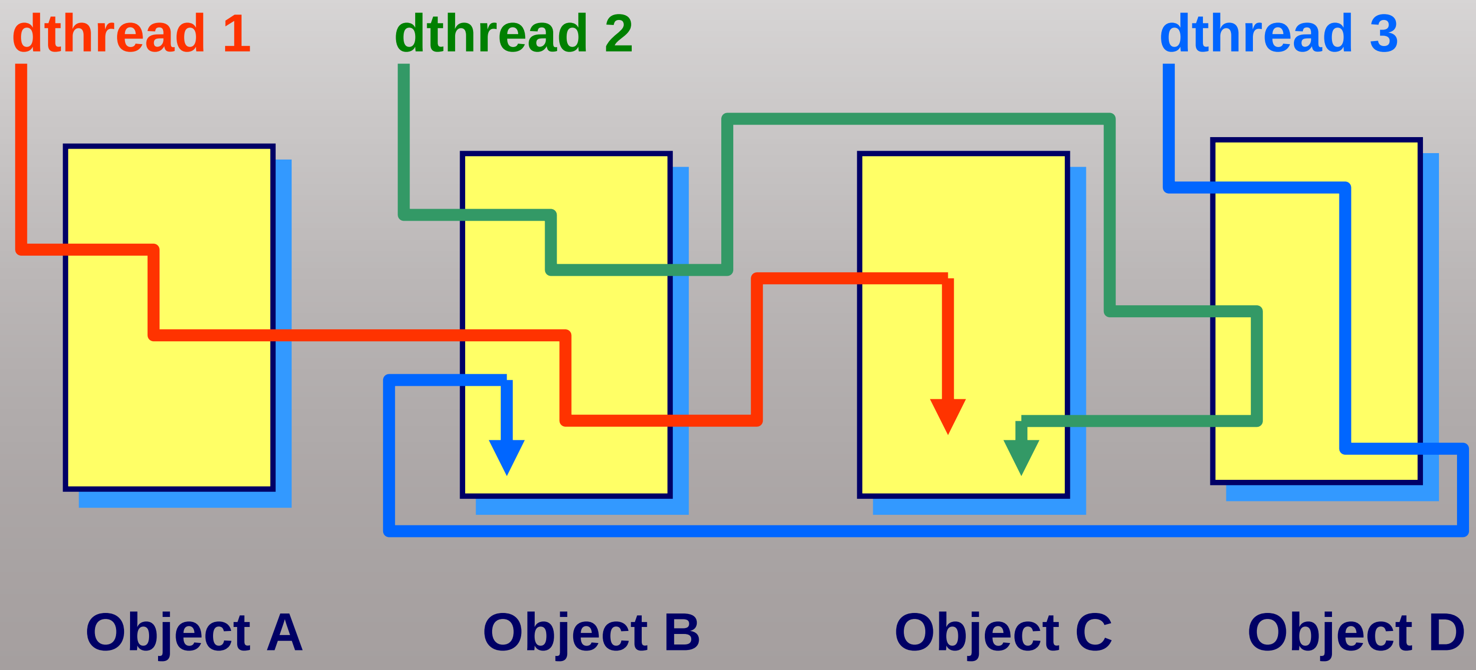
Distributable Thread 2

- The fundamental abstraction of application execution
- Incorporates the sequence of actions
  - associated with a user-defined portion of the application
  - may span multiple processing nodes
  - but that represents a single logical thread of control



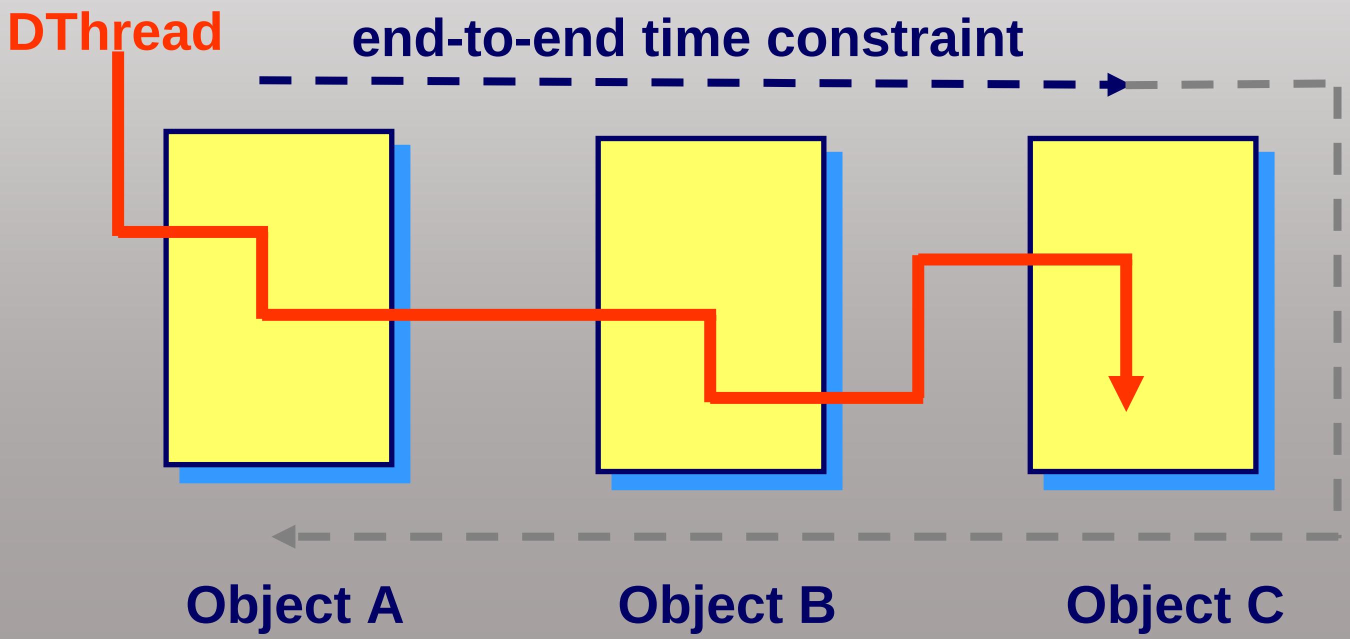
Distributable Thread 3

- Distributed applications will typically be constructed as several distributable threads that execute logically concurrently
- Locus of execution between significant points in the application



Distributable Thread 4

- Carries the scheduling context from node to node as control passes through the system
- Might encompass part of the execution of a local (or native) thread or multiple threads executing in sequence on one or more processors



Distributable Thread 5

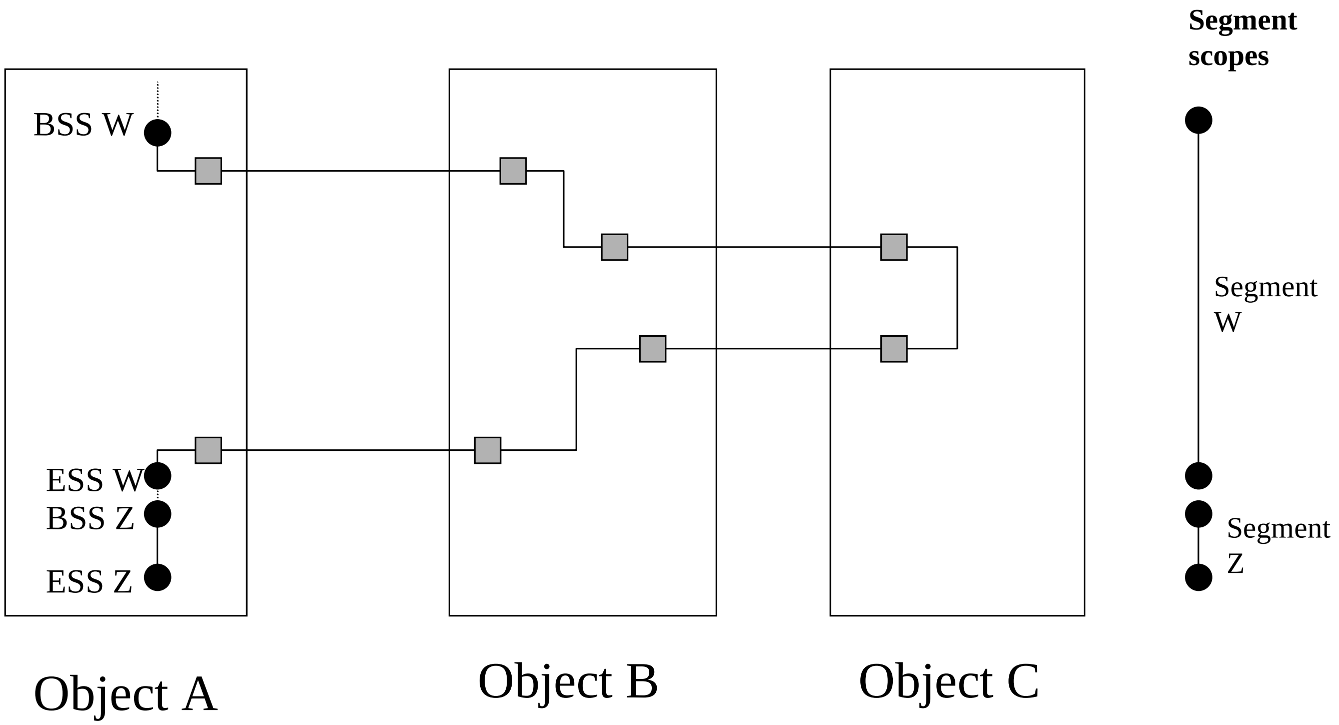
- At most one head (execution point) at any moment in time
- CORBA exceptions unwind the distributable thread back to the origin unless caught
- May have a scheduling parameter containing multiple element values associated with it
- These scheduling parameter elements become the scheduling control factor for the distributable thread and are carried with the distributable thread via CORBA requests and replies

Distributable Thread 6

- The scheduling parameter elements for a DT are
  - associated with begin_scheduling_segment() or spawn()
  - updated with update_scheduling_segment()
- Branch of control (fork), as occurs with a CORBA oneway invocation
  - The originating distributable thread remains at the client and continues execution according to its eligibility
- Has a globally unique id within the system
  - Fundamental difference from chains of RPCs
  - Via get_current_id() operation
  - Reference a distributable thread via lookup() operation

Distributable Thread 7

Distributable Thread Traversing CORBA Objects



BSS - *begin_scheduling_segment*

USS - *update_scheduling_segment*

ESS - *end_scheduling_segment*

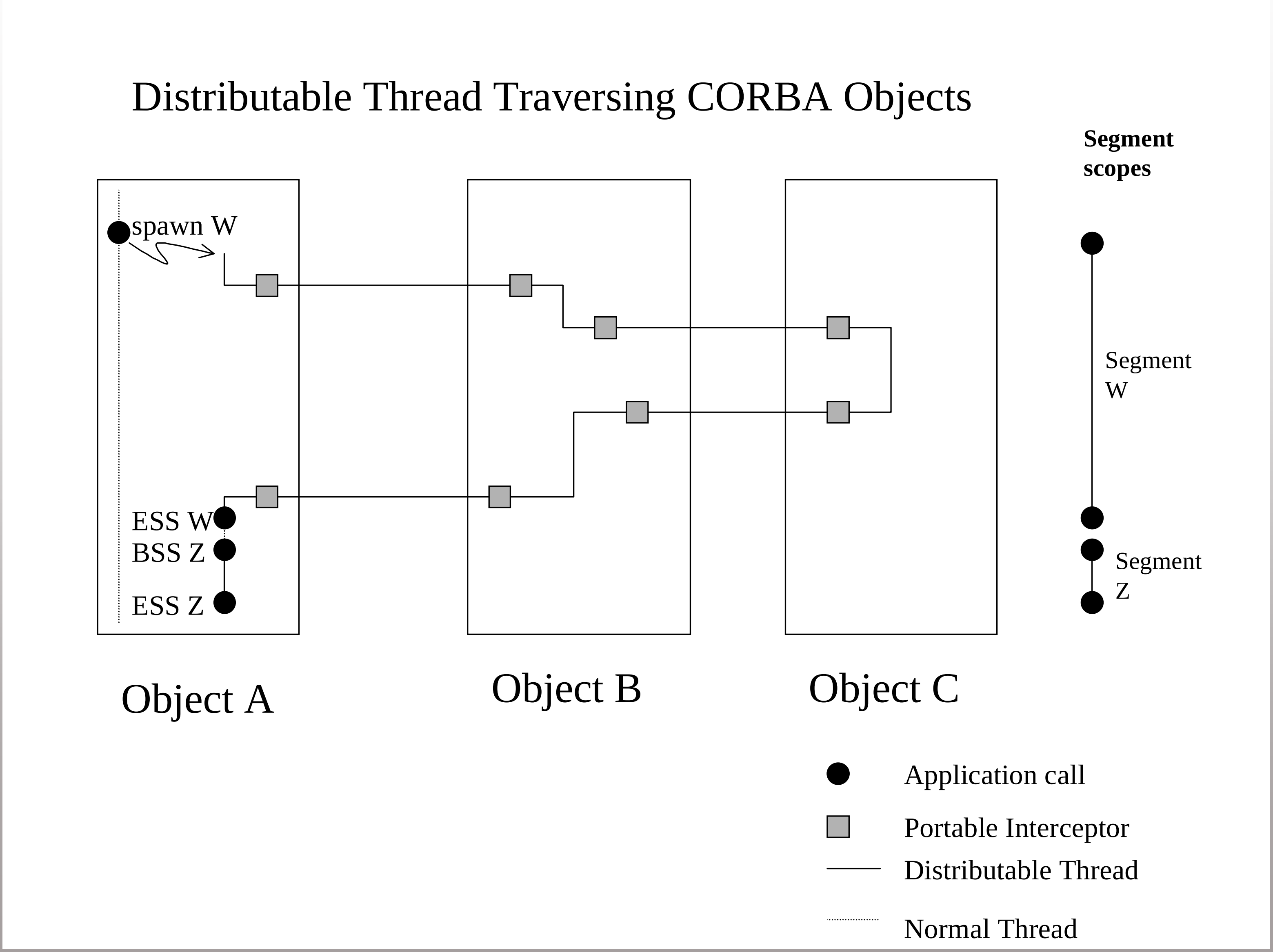
● Application call

▨ Portable Interceptor

— Distributable Thread

┈ Normal Thread

Distributable Thread 8



DistributableThread - IDL

```
module RTScheduling
{
   local interface DistributableThread
   {
    void cancel();
             // raises CORBA::OBJECT_NOT_FOUND if
             // the distributable thread is
             // not known to the scheduler
    };
};
```

Current – IDL

```
module RTScheduling
{
   local interface Current : RTCORBA::Current
   {
        DistributableThread
            spawn
                (in ThreadAction   start,
                 in unsigned long  stack_size,
                         // zero means use the O/S default
                 in RTCORBA::Priority base_priority);


        …
   };
};
```

Current – IDL 2

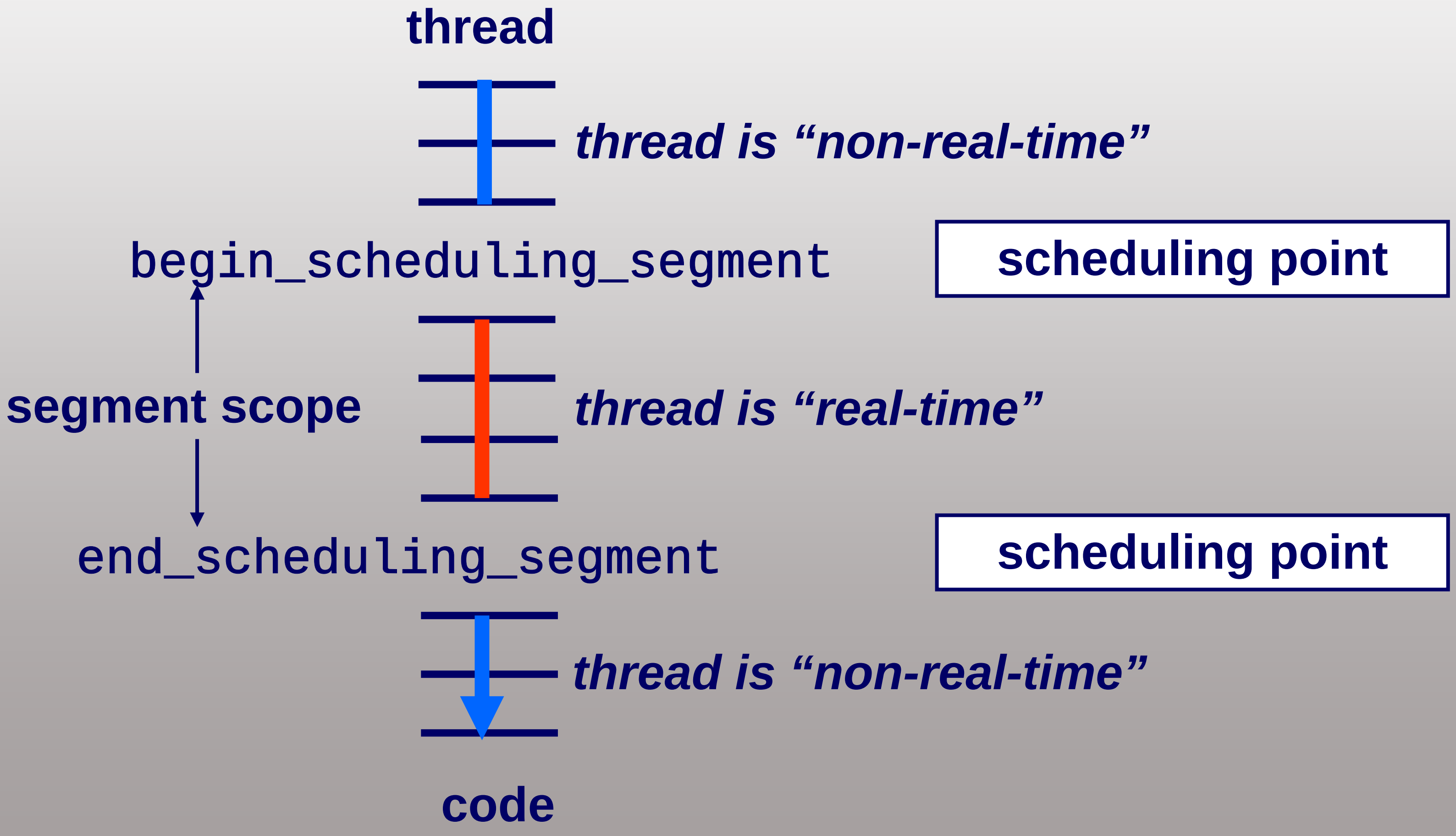
```
module RTScheduling
{
    local interface Current : RTCORBA::Current
    {
        …
        typedef sequence<octet> IdType;
        readonly attribute IdType id;
            // a globally unique id

        IdType get_current_id();
            // id of running thread

        DistributableThread lookup(in IdType id);
            // returns a null reference if
            // the distributable thread is
            // not known to the local scheduler
        …
    };
};
```

Current – IDL 3

```
module RTScheduling
{
   local interface Current : RTCORBA::Current
   {
    …
    readonly attribute CORBA::Policy
                              scheduling_parameter;

    readonly attribute CORBA::Policy
                              implicit_scheduling_parameter;

    typedef sequence<string> NameList;

    readonly attribute NameList

    current_scheduling_segment_names;
   };
};
```

Scheduling Segments

- Distributable threads consist of one or more (potentially nested) scheduling segments



thread

thread is "non-real-time"

`begin_scheduling_segment`

scheduling point

segment scope

thread is "real-time"

`end_scheduling_segment`

scheduling point

thread is "non-real-time"

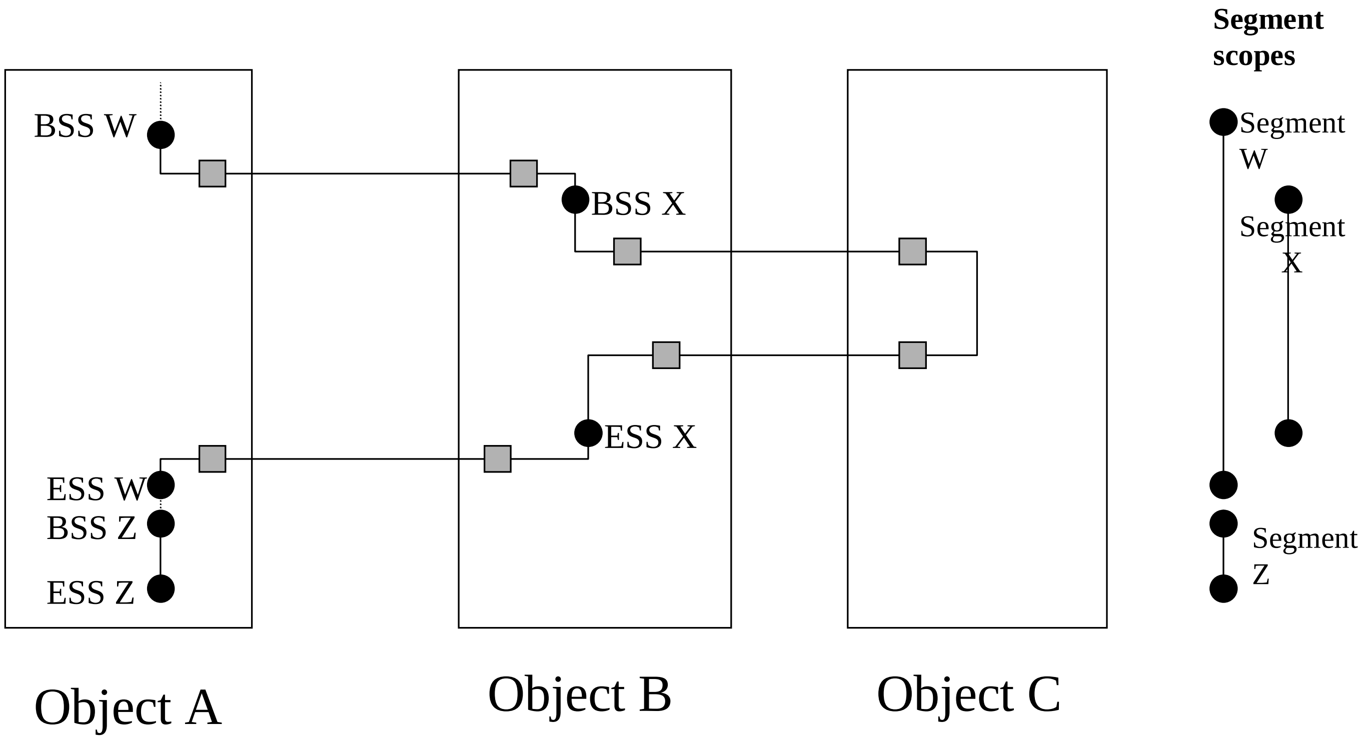
code

Scheduling Segments 2

- Represents a sequence of control flow with which a scheduling parameter is associated
- Can be sequential and nested
- Life cycle
  - Starts with begin_scheduling_segment
  - Updated with update_scheduling_segment (optional)
  - Ends with end_scheduling_segment
- May have a segment name
  - Of use by scheduling tools
  - Optional on end statement, allows for error check of nesting

Scheduling Segments 3

Distributable Thread Traversing CORBA Objects



● Application call

▨ Portable Interceptor

— Distributable Thread

⋯ Normal Thread

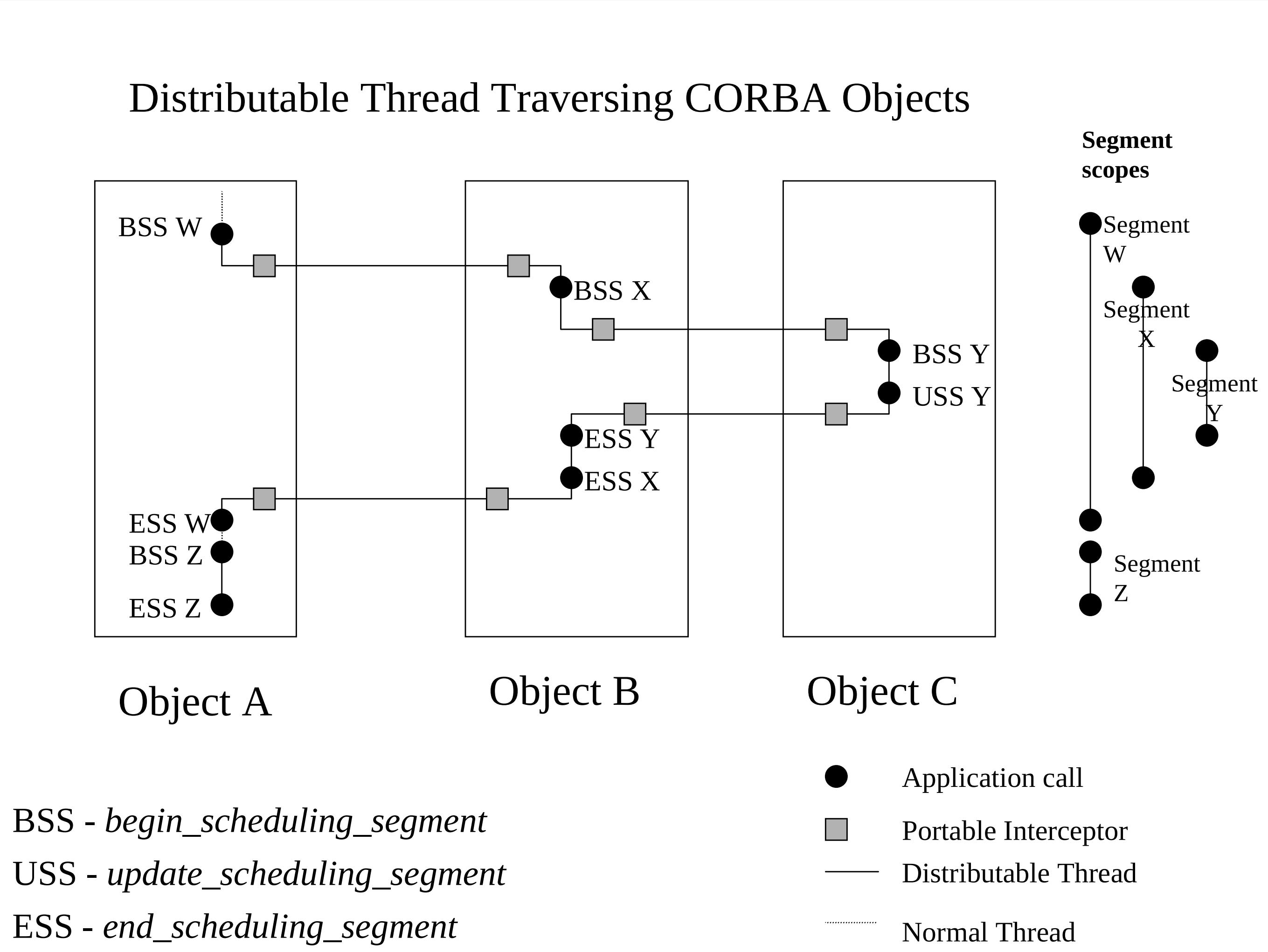
BSS - *begin_scheduling_segment*

USS - *update_scheduling_segment*

ESS - *end_scheduling_segment*

Scheduling Segments 4

- May span processor boundaries



BSS - *begin_scheduling_segment*

USS - *update_scheduling_segment*

ESS - *end_scheduling_segment*

Scheduling Segments - IDL

```
module RTScheduling
{
   local interface Current : RTCORBA::Current
   {
        exception UNSUPPORTED_SCHEDULING_DISCIPLINE {};
        void begin_scheduling_segment
            (in string        name,
             in CORBA::Policy sched_param,
             in CORBA::Policy implicit_sched_param)
            raises ( UNSUPPORTED_SCHEDULING_DISCIPLINE );

        void update_scheduling_segment
            (in string        name,
             in CORBA::Policy sched_param,
             in CORBA::Policy implicit_sched_param)
            raises ( UNSUPPORTED_SCHEDULING_DISCIPLINE );

        void end_scheduling_segment(in string name);
   … };
};
```

Scheduling Points

- Opportunities for scheduler to decide what runs:
  - Creation of a distributable thread (via begin_scheduling_segment or spawn)
  - Termination or completion of a distributable thread
  - begin_scheduling_segment
  - update_scheduling_segment
  - end_scheduling_segment
  - A CORBA operation invocation, specifically the request and reply interception points provided in the Portable Interceptor specification
  - Creation of a resource manager
  - Blocking on a request for a resource via a call to RTScheduling::ResourceManager::lock or RTScheduling::ResourceManager::try_lock
  - Unblocking as a result of the release of a resource via a call to RTScheduling::ResourceManager::unlock

Scheduler-Aware Resources

- The application to create a scheduler-aware resource locally via the create_resource_manager operation in a ResourceManager
- These resources can have scheduling information associated with them via the register_resource operation
  - A servant thread could have a priority ceiling if the application were using fixed priority scheduling
  - The scheduler will run when these resources are locked or released, so that the scheduling discipline is maintained
- Any scheduling information associated with these resources is scheduling discipline-specific

Scheduler & Resources - IDL

```
module RTScheduling
{
   local interface ResourceManager : RTCORBA::Mutex
   {
   };
};
```

Scheduler & Resources – IDL 2

```
module RTScheduling
{
   local interface Scheduler
   {
        exception INCOMPATIBLE_SCHEDULING_DISCIPLINES {};
        attribute CORBA::PolicyList scheduling_policies;
        readonly attribute CORBA::PolicyList poa_policies;
        readonly attribute string scheduling_discipline_name;

        ResourceManager
                 create_resource_manager
                         (in string        name,
                          in CORBA::Policy scheduling_parameter);

        void set_scheduling_parameter
                 (inout PortableServer::Servant resource,
                  in    string        name,
                  in    CORBA::Policy scheduling_parameter);
   };
};
```

Exceptions

- CORBA::SCHEDULER_FAULT
  - Indicates that the scheduler itself has experienced an error
- CORBA::SCHEDULE_FAILURE
  - Indicates that DT violated the constraints of scheduling parameter
  - Could occur when a deadline has been missed or a segment has used more than its allowed CPU time
- CORBA::THREAD_CANCELLED
  - Indicates that the DT receiving the exception has been cancelled
  - May occur because a distributable thread cancels another DT thereby causing the CORBA::THREAD_CANCELLED exception to get raised at the subsequent head of the cancelled DT
- RTScheduling::DistributableThread::UNSUPPORTED_SCHEDULING_DISCIPLINE
  - Indicates that the scheduler was passed a scheduling parameter inappropriate for the scheduling discipline(s) supported by the current scheduler

Well Known Scheduling Disciplines

- Fixed Priority Scheduling
- Earliest Deadline First (EDF)
- Least Laxity First (LLF)
- Maximize Accrued Utility (MAU)

Fixed Priority Scheduling - IDL

```
module FP_Scheduling
{
    struct SegmentSchedulingParameter
    {
        RTCORBA::Priority base_priority;
    };

    local interface SegmentSchedulingParameterPolicy
        : CORBA::Policy
    {
        attribute SegmentSchedulingParameter value;
    };

    struct ResourceSchedulingParameter
    {
        RTCORBA::Priority resource_priority_ceiling;
    };
```

Fixed Priority Scheduling – IDL 2

```
    local interface ResourceSchedulingParameterPolicy
        : CORBA::Policy
    {
        attribute ResourceSchedulingParameter value;
    };

    local interface Scheduler : RTScheduling::Scheduler
    {
        SegmentSchedulingParameterPolicy
             create_segment_scheduling_parameter
                 (in SegmentSchedulingParameter value);

        ResourceSchedulingParameterPolicy
             create_resource_scheduling_parameter
                 (in ResourceSchedulingParameter value);
    };
};
```

Earliest Deadline First - IDL

```
module EDF_Scheduling
{
    struct SchedulingParameter
    {
        TimeBase::TimeT deadline;
        long            importance;
    };

    local interface SchedulingParameterPolicy : CORBA::Policy
    {
        attribute SchedulingParameter value;
    };

    local interface Scheduler : RTScheduling::Scheduler
    {
        SchedulingParameterPolicy
            create_scheduling_parameter
                (in SchedulingParameter value);
    };
};
```

Least Laxity First - IDL

```
module LLF_Scheduling
{
    struct SchedulingParameter
    {
        TimeBase::TimeT deadline;
        TimeBase::TimeT estimated_initial_execution_time;
        long            importance;
    };
    local interface SchedulingParameterPolicy : CORBA::Policy
    {
        attribute SchedulingParameter value;
    };

    local interface Scheduler : RTScheduling::Scheduler
    {
        SchedulingParameterPolicy
            create_scheduling_parameter
                 (in SchedulingParameter value);
    };
};
```

Maximize Accrued Utility - IDL

```
module Max_Utility_Scheduling
{
    struct SchedulingParameter
    {
        TimeBase::TimeT deadline;
        long            importance;
    };

    local interface SchedulingParameterPolicy : CORBA::Policy
    {
        attribute SchedulingParameter value;
    };

    local interface Scheduler : RTScheduling::Scheduler
    {
        SchedulingParameterPolicy
            create_scheduling_parameter
                (in SchedulingParameter value);
    };
};
```

Conformance

- Makes no changes to the Real-time CORBA 1.0 non-optional IDL (ie. other than changes to Scheduling Service IDL)
- Implementation of this specification is optional for implementations of the Real-time CORBA 1.0 specification
  - Implementation of the basic Dynamic Scheduling infrastructure is the most basic form of compliance
  - Implementation of each scheduler is optional and separate compliance point

Changes to core

- Adds three system exceptions to core CORBA
  - CORBA::SCHEDULER_FAULT
  - CORBA::SCHEDULE_FAILURE
  - CORBA::THREAD_CANCELLED

Summary

- Extends Real-time CORBA to dynamic systems
- Provides replaceable scheduling
- Allows users to control timeliness of distributed real-time applications

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Future Directions

- CORBA and Real-time CORBA success lead to additional computing environments
  - Minimum CORBA 2.0 (realtime/2005-05-01)
    - A reduced set of CORBA and Real-time CORBA functionality for resource constrained systems
    - Has multiple profiles
  - High-Assurance ORB (realtime/2005-05-02)
    - High-Assurance – failure causes loss of life
    - Extending the reach of CORBA to high-assurance systems

Minimum CORBA

- Many features of the full CORBA specification come at a cost to the system architect (resources)
- Subsets of CORBA specifically designed for embedded systems
  - Minimize the resource requirements
  - Maximize code portability
  - Full interoperability

Minimum CORBA 2.0

- Extends CORBA's reach to resource constrained systems (deeply embedded systems)
  - Subsets of the CORBA Standard
    - CORBA/e
    - Minimal
- Includes Parts of Real-time CORBA within the CORBA subsets
- Suggests that other CORBA subsets would be possible (High-Assurance ORB)

High-Assurance ORB

- Many systems today require software that must meet stringent criteria (Safety-Critical or High-Assurance systems)
  - Safety
  - Security
  - Reliability
- Traditionally these systems have been custom designed, with the rapid expansion of this type of system, stove-pipe designs are impractical
- The CORBA, Minimum CORBA and Real-Time CORBA specifications provide a solid foundation to begin addressing the needs of High-Assurance and Safety-Critical systems.

High-Assurance ORB

- Addresses Systems that require certification
  - ARINC 653
  - DO178B
  - EAL-7
  - IEC 61608
- Language Subsets, two involved
  - Target Language (Ada, C++)
  - IDL
- Leverage Past Research
  - Subset work has been done with Ada, C and C++

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Further Information

- Real-time CORBA 1.2
  - Latest revision, formal/2005-01-04
- High Assurance ORB
  - Latest revision, realtime/2005-05-02
- Minimum CORBA 2.0
  - Latest revision, realtime/2005-05-01
- Tests of various communication technologies
  - Lockheed Martin Advanced Technology Labs' Agent and Distributed Objects Quality of Service (QoS)
  - http://www.atl.external.lmco.com/projects/QoS/
- Information about CORBA for Real-time, Embedded, and High Performance Applications
  - http://www.ois.com/resources/corb-1.asp