Using Real-time CORBA Effectively
Patterns & Principles

Carlos O'Ryan & Douglas Schmidt
{coryan,schmidt}@uci.edu

Elec. & Comp. Eng. Dept.
University of California, Irvine

Irfan Pyarali
irfan@cs.wustl.edu

Comp. Sci. Dept.
Washington University, St. Louis

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

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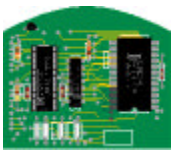
Motivation for Real-time Middleware

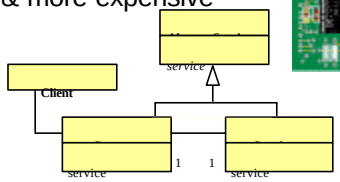
Trends

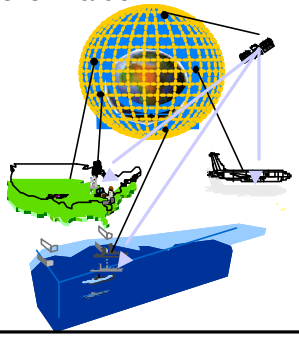
- Hardware keeps getting smaller, faster, & cheaper
- Software keeps getting larger, slower, & more expensive



Historical Challenges

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





New Challenges

- Many distributed applications require real-time QoS guarantees
  - e.g., avionics, real-time stock trading, telecom
- Building QoS-enabled applications manually is tedious, error-prone, & expensive
- Conventional middleware does not support real-time effectively

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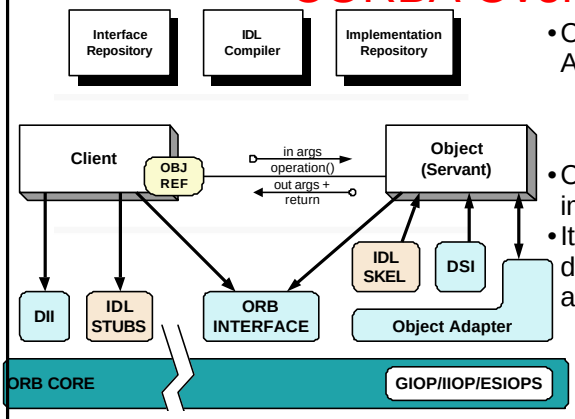
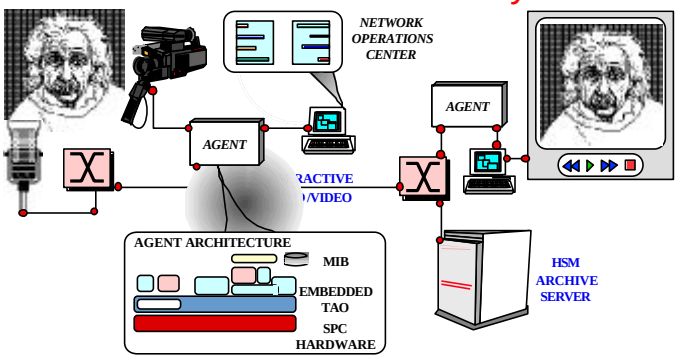
CORBA Overview



- CORBA shields applications from environment heterogeneity
  - *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
  - Object location
  - Connection management
  - Memory management
  - Parameter (de)marshaling
  - Event & request demultiplexing
  - Error handling
  - Object/server activation
  - Concurrency

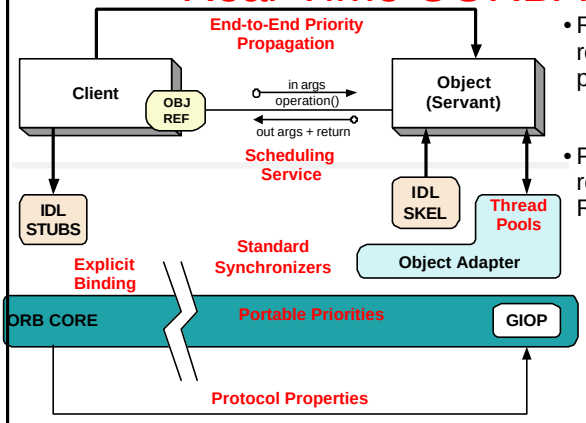
Caveat: Requirements & Historical Limitations of CORBA for Real-time Systems



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

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

Real-Time CORBA Overview

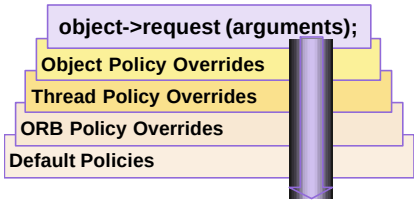


- RT CORBA adds QoS control to regular CORBA improve the predictability of applications, *e.g.,*
  - Bounding priority inversions &
  - Managing resources end-to-end
- Policies & mechanisms for resource configuration/control in RT-CORBA include:
  - **Processor Resources**
    - Thread pools
    - Priority models
    - Portable priorities
  - **Communication Resources**
    - Protocol policies
    - Explicit binding
  - **Memory Resources**
    - Request buffering
- These capabilities address some important (though by no means all) real-time application development challenges

Real-time CORBA leverages the CORBA Messaging QoS Policy framework

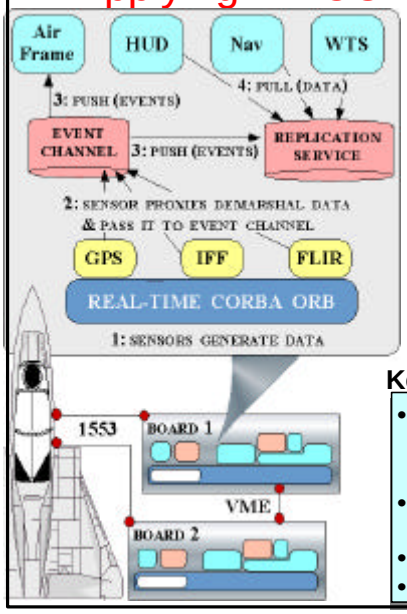
Overview of the CORBA QoS Policy Framework

- CORBA defines a QoS framework that includes policy management for *request priority, queueing, message delivery quality, timeouts, etc.*
- QoS is managed through interfaces derived from `CORBA::Policy`
  - Each QoS Policy has an associated `PolicyType` that can be queried
- A `PolicyList` is sequence of policies
- Client-side policies are specified at 3 "overriding levels":
  1. ORB-level through `PolicyManager`
  2. Thread-level through `PolicyCurrent`
  3. Object-level through overrides in an *object reference*



- Server-side policies are specified by associating QoS policy objects with a POA
  - *i.e.,* can be passed as arguments to `POA::create_POA()`
- Client-side QoS policies & overrides can be established & validated via calls to `Object::validate_connection()` & other CORBA APIs

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
  - www.cs.wustl.edu/~schmidt/TAO-boeing.html
- Also used on SOFIA project by Raytheon
  - sofia.arc.nasa.gov
- First use of RT CORBA in mission computing
- Drove Real-time CORBA standardization

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 (ACE+TAO)

Applying COTS to Hot Rolling Mills

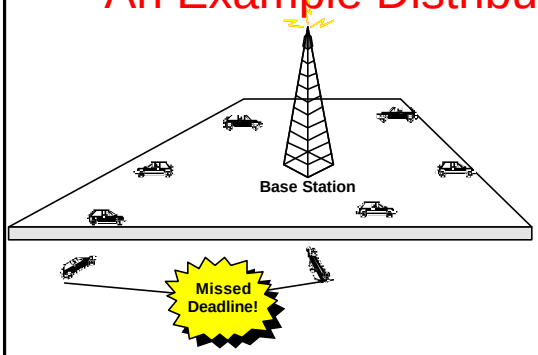
Goals
- Control the processing of molten steel moving through a hot rolling mill in real-time

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

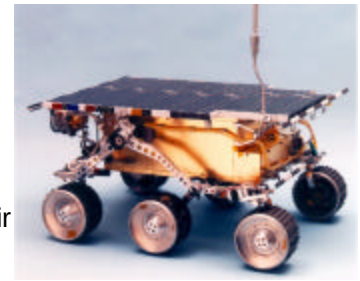
www.siroll.de

Key Software Solution Characteristics
- Affordable, flexible, & COTS
  - Product-line architecture
  - Design guided by patterns & frameworks
  - Windows NT/2000
  - Real-time CORBA (ACE+TAO)

An Example Distributed Application

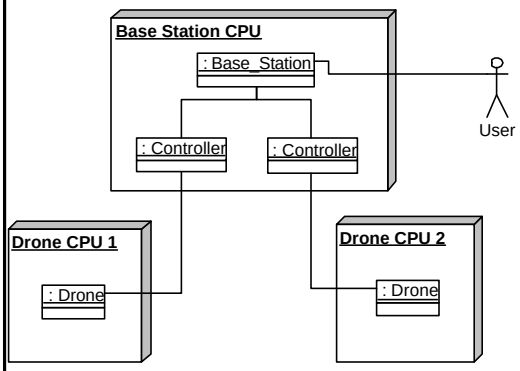


- Consider an application where cooperating drones explore a surface & report its properties periodically
  - *e.g.,* color, texture, etc.
- This is a simplification of various autonomous vehicle use-cases



- 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 **`Base_Station`** object
  - *e.g.,* they define high-level exploration goals for the drones
- The **`Base_Station`** 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 **`Base_Station`** via a **`Controller`** object
  - This interaction is an example of *Asynchronous Completion Token* & *Distributed Callback* patterns

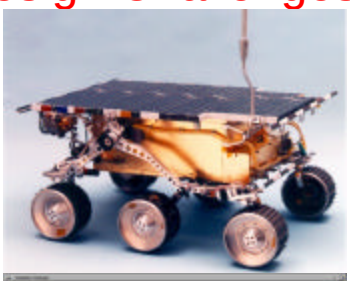
Defining Application Interfaces with CORBA IDL

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

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

exception Lack_Resources {};

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

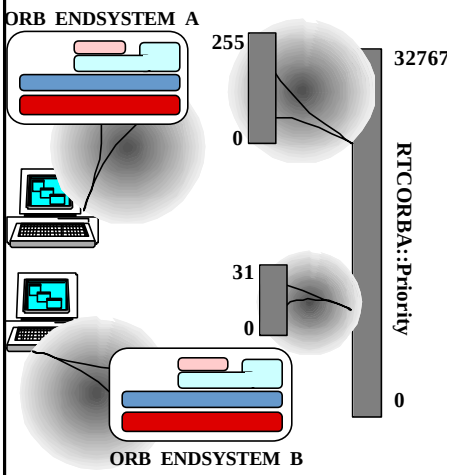
- Each **`Drone`** talks to one **`Controller`**
  - *e.g.,* **`Drones`** send alarm messages when they detect an edge
- The **`Controller`** should take corrective action if a **`Drone`** detects it's about to fall off an edge!
- The **`Base_Station`** interface is a **`Controller`** factory
  - **`Drones`**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

QoS-related Application Design Challenges

- Our example application contains the following QoS-related design challenges
  1. Obtaining portable ORB end-system 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 & end-system 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 End-system 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 ();
};
```

- **Problem**: How do we configure this new class?
- **Solution**: Use TAO's **`PriorityMappingManager`**

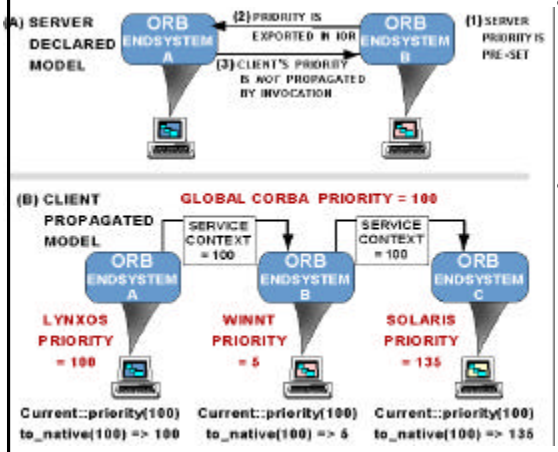
TAO's **`PriorityMappingManager`**

- TAO provides an extension that uses a *locality constrained* object to configure the priority mapping:

```
CORBA::ORB_var orb = ...; // the ORB
// Get the PriorityMappingManager
CORBA::Object_var obj =
   orb->resolve_initial_references ("PriorityMappingManager");
TAO::PriorityMappingManager_var manager =
   TAO::PriorityMappingManager::_narrow (obj);

// Create an instance of your mapping
RTCORBA::PriorityMapping *my_mapping =
   new MyPriorityMapping;

// Install the new mapping
manager->mapping (my_mapping);
```

- It would be nice if this feature were standardized in RT CORBA…
  - The current specification doesn't standardize this in order to maximize ORB implementer options, *e.g.,* link-time vs. run-time bindings

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)

Applying `CLIENT_PROPAGATED`

- Drones send critical messages to `Controllers` in the `Base_Station`
  - `edge_alarm()` runs at the highest priority in the system
  - `turn_completed()` runs at a lower priority in the system

```
CORBA::PolicyList policies (1); policies.length (1);
policies[0] = rtorb->create_priority_model_policy
   (RTCORBA::CLIENT_PROPAGATED,
    DEFAULT_PRIORITY /* For non-RT ORBs */);

// Get the ORB's policy manager
PortableServer::POA_var controller_poa =
   root_poa->create_POA
     ("Controller_POA",
      PortableServer::POAManager::_nil (),
      policies);

// Activate one Controller servant in <controller_poa>
controller_poa->activate_object (my_controller);
```

- Note that `CLIENT_PROPAGATED` policy is set on the server & exported to the client along with an object reference

Changing CORBA Priorities

- **Problem**: How can RT-CORBA applications change the priority of operations?
- **Solution**: Use the `RTCurrent` to change the priority of the current thread explicitly
  - The `RTCurrent` can also be used to query the priority
  - Values are 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 priority
rt_current->the_priority (VERY_HIGH_PRIORITY);

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


Design Interlude: The RTORB Interface

- **Problem:** How can the ORB be extended without changing the CORBA::ORB API?
- **Solution:** Use the *Extension Interface* pattern
  - 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 non-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);

// Get the ORB's policy manager
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, however!

Extended RT POA Interface

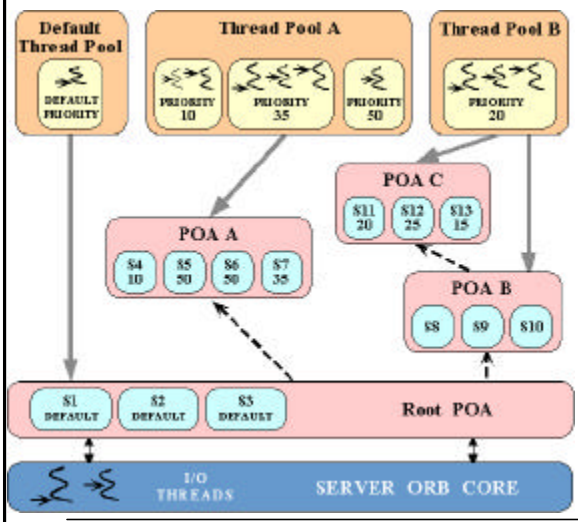
- RT CORBA extends the POA interface via inheritance

```
module RTPortableServer {
  local interface POA : PortableServer::POA {
    PortableServer::ObjectId activate_object_with_priority
     (in PortableServer::Servant servant_ptr,
      in RTCORBA::Priority priority)
    raises (ServantAlreadyActive, WrongPolicy);
  // ...
};
```

- Methods in this interface can override default `SERVER_DECLARED` priorities

```
// Activate object with default priority of RTPOA
MyBase_Station *station = new MyBase_Station;
base_station_poa->activate_object (station);

// Activate another object with a specific priority
RTPortableServer::POA_var rt_poa =
  RTPortableServer::POA::_narrow (base_station_poa);
rt_poa->activate_object_with_priority (another_servant,
                                       ANOTHER_PRIORITY);
```

Supporting Thread Pools Effectively



- **Problem**: Pre-allocating threading resources on the server *portably & efficiently*
  - *e.g.*, the `Base_Station` 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

Note that a thread pool can manage multiple POAs

Creating & Destroying Thread Pools

```
interface RTCORBA::RTORB {
   typedef unsigned long ThreadpoolId;

   ThreadpoolId create_threadpool (
      in unsigned long stacksize,
      in unsigned long static_threads,
      in unsigned long dynamic_threads,
      in Priority default_priority,
      in boolean allow_request_buffering,
      in unsigned long max_buffered_requests,
      in unsigned long max_request_buffer_size);

   void destroy_threadpool (in ThreadpoolId threadpool)
      raises (InvalidThreadpool);
};
```

There are factory methods for controlling the life-cycle of RT-CORBA thread pools

Creating Thread Pools with Lanes

```
interface RTCORBA::RTORB {
   struct ThreadpoolLane {
      Priority lane_priority;
      unsigned long static_threads;
      unsigned long dynamic_threads;
   };
   typedef sequence <ThreadpoolLane>
           ThreadpoolLanes;

   ThreadpoolId create_threadpool_with_lanes (
      in unsigned long stacksize,
      in ThreadpoolLanes lanes,
      in boolean allow_borrowing
      in boolean allow_request_buffering,
      in unsigned long max_buffered_requests,
      in unsigned long max_request_buffer_size );
};
```

- *Thread pools with lanes* can be used to partition the threads in a thread pool into different subsets, each with different priorities
- It's possible to "borrow" threads from lanes with lower priorities

Configuring Thread Pool Lanes

```
// Define two lanes
RTCORBA::ThreadpoolLane high_priority =
{ 10 /* Priority */,
   3 /* Static Threads */,
   0 /* Dynamic Threads */ };

RTCORBA::ThreadpoolLane low_priority =
{  5 /* Priority */,
   7 /* Static Threads */,
   2 /* Dynamic Threads */};

RTCORBA::ThreadpoolLanes lanes(2); lanes.length(2);
lanes[0] = high_priority; lanes[1] = low_priority;

RTCORBA::ThreadpoolId pool_id =
  rt_orb->create_threadpool_with_lanes (
     1024 * 10, // Stacksize
     lanes, // Thread pool lanes
     false, // No thread borrowing
     false, 0, 0); // No request buffering
```

When a thread pool is created it's possible to control certain resource allocations

- *e.g.,* stacksize, request buffering, & whether or not to allow "borrowing" across lanes

Installing Thread Pools on a RT-POA

```
// From previous page
RTCORBA::ThreadpoolId pool_id = // ...

// Create Thread Pool Policy
RTCORBA::ThreadpoolPolicy_var tp_policy =
   rt_orb->create_threadpool_policy (pool_id);

// Create policy list for RT-POA
CORBA::PolicyList RTPOA_policies(1); RTPOA_policies.length (1);
RTPOA_policies[0] = tp_policy;

// Create POAs
PortableServer::POA_var rt_poa_1 =
   root_poa->create_POA ("RT-POA_1", // POA name
                         PortableServer::POAManager::_nil (),
                         RTPOA_policies);  // POA policies
PortableServer::POA_var rt_poa_2 =
   root_poa->create_POA ("RT-POA_2", // POA name
                         PortableServer::POAManager::_nil (),
                         RTPOA_policies);  // POA policies
```

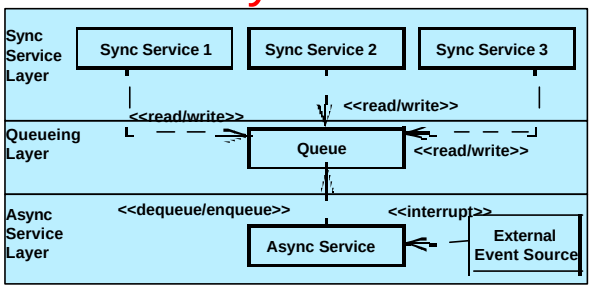
Note how multiple RT POAs can share the same thread pools

Thread Pools Implementation Strategies

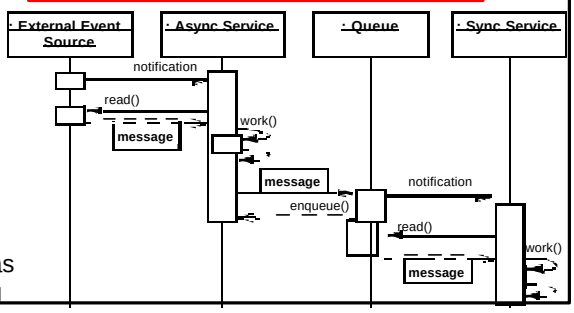
- There are two general strategies to implement RT CORBA thread pools:
  1. Use the *Half-Sync/Half-Async* pattern to have I/O thread(s) buffer client requests in a queue & then have worker threads in the pool process the requests
  2. Use the *Leader/Followers* pattern to demultiplex I/O events into threads in the pool *without* requiring additional I/O threads
- Each strategy is appropriate for certain application domains
  - *e.g.,* certain hard-real time applications cannot incur the non-determinism & priority inversion of additional request queues
- To evaluate each approach we must understand their consequences
  - Their pattern descriptions capture this information
  - Good metrics to compare RT-CORBA implementations

The Half-Sync/Half-Async Pattern

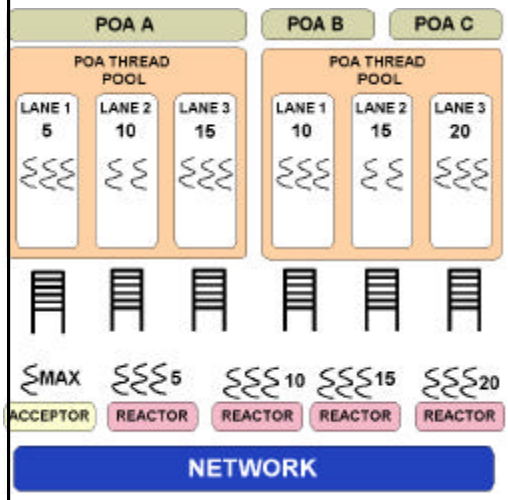
Intent
The *Half-Sync/Half-Async* architectural pattern decouples async & sync service processing in concurrent systems, to simplify programming without unduly reducing performance



- This pattern defines two service processing layers—one async and one sync—along with a queueing layer that allows services to exchange messages between the two layers
- The pattern allows sync services, such as servant processing, to run concurrently, relative both to each other and to async services, such as I/O handling & event demultiplexing



Queue-per-Lane Thread Pool Design



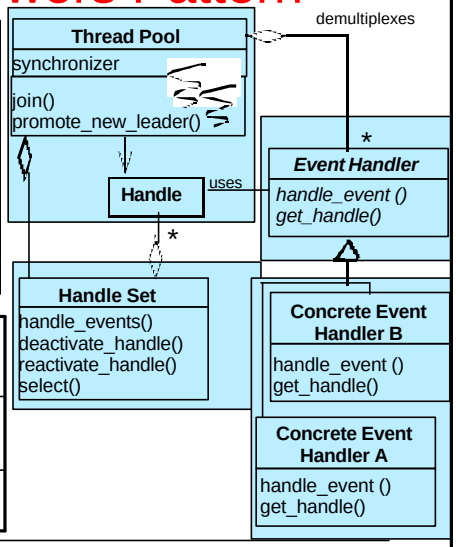
Design Overview
- Single acceptor endpoint
- One reactor for each priority level
- Each lane has a queue
- I/O & application-level request processing are in different threads

Pros
- Better feature support, *e.g.,*
  - Request buffering
  - Thread borrowing
- Better scalability, *e.g.,*
  - Single acceptor
  - Fewer reactors
  - Smaller IORs
- Easier piece-by-piece integration into the ORB

Cons
- Less efficient because of queuing
- Predictability reduced without _bind_priority_band() implicit operation

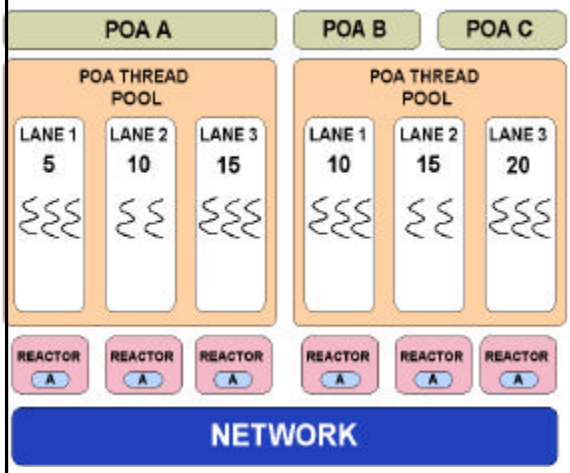
The Leader/Followers Pattern

Intent
The Leader/Followers architectural pattern provides an efficient concurrency model where multiple threads take turns sharing event sources to detect, demux, dispatch, & process service requests that occur on the event sources



Handles / Handle Sets	Concurrent Handles	Iterative Handles
Concurrent Handle Sets	UDP Sockets + `WaitForMultipleObjects()`	TCP Sockets + `WaitForMultpleObjects()`
Iterative Handle Sets	UDP Sockets + `select()/poll()`	TCP Sockets + `select()/poll()`

Reactor-per-Lane Thread Pool Design



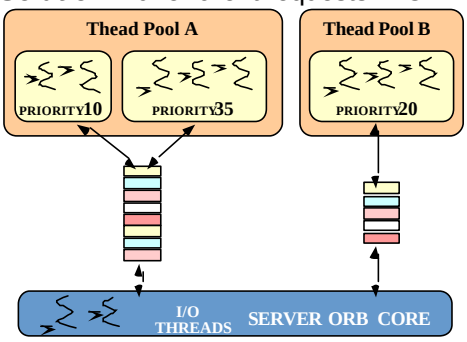
Design Overview
- Each lane has its own set of resources
  - *i.e.,* reactor, acceptor endpoint, etc.
- I/O & application-level request processing are done in the same thread

Pros
- Better performance
  - No context switches
  - Stack & TSS optimizations
- No priority inversions during connection establishment
- Control over ***all*** threads with standard thread pool API

Cons
- Harder ORB implementation
- Many endpoints = longer IORs

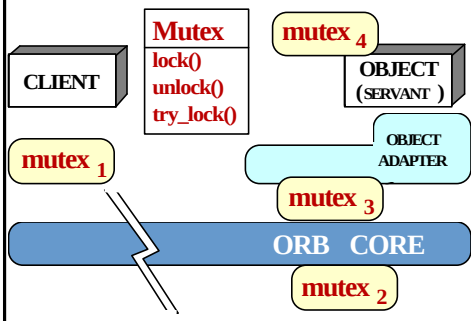
Buffering Client Requests

- **Problem**: Some types of applications need more buffering than is provided by the OS I/O subsystem
  - *e.g.,* to handle "bursty" client traffic
- **Solution**: Buffer client requests in ORB



- RT CORBA thread pool buffer capacities can be configured with:
  - Maximum number of bytes and/or
  - Maximum number of requests
- An ORB can reject a request to create a thread pool with buffers
- Some ORBs do not use queues to avoid priority inversions
  - This design is still compliant, however, since the maximum buffer capacity is always 0
  - Moreover, queueing can be done within the I/O subsystem of the OS

Synchronizing Objects Properly

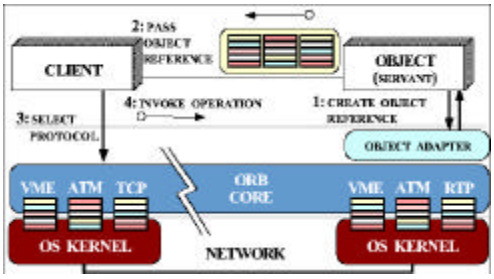


- **Problem**: An ORB & application may need to use the same *type* of mutex to avoid priority inversions
  - *e.g.,* using priority ceiling or priority inheritance protocols
- **Solution**: Use the `RTCORBA::Mutex` interface to ensure that consistent mutex semantics are enforced across ORB & application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

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

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 `Base_Station`, `Controllers`, & `Drones` must use a different protocol
    - *e.g.,* VME, 1553, shared memory, VIA, firewire, bluetooth, etc.
  - Moreover, communication between `Drone` & `Controller` cannot be queued
- **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



Oddly, RT-CORBA only specifies protocol properties for TCP!

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 */);
```

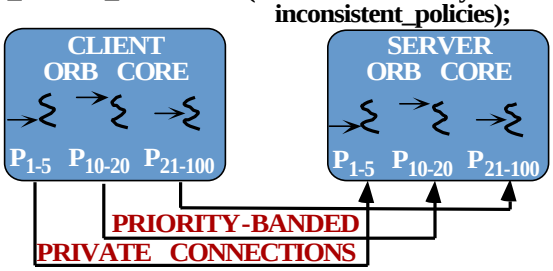
- Next, we configure the list of protocols to use

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

Controlling Network Resources

- **Problems**:
  - Avoiding request-level ("head-of-line") priority inversions
  - Minimizing thread-level priority inversions
  - Control jitter due to connection establishment

_validate_connection (out CORBA::PolicyList inconsistent_policies);



- **Solution**: Use explicit binding mechanisms, *e.g.,*
  - *Connection pre-allocation*
    - Eliminates a common source of operation jitter
  - *Private Connection Policy*
    - Guarantees non-multiplexed connections
  - *Priority Banded Connection Policy*
    - Invocation priority determines which connection is used

Pre-allocating Network Connections

- **Problem:** Dynamically establishing connections from the base station to/from the drones can result in unacceptable jitter, which can be detrimental to time-critical applications
- **Solution:** Pre-allocate one or more connections using the `Object::_validate_connection()` operation, which is defined in the CORBA Message specification

```
Drone_var drone = …; // Obtain reference to a drone

// Pre-establish connections using current
// policy overrides
CORBA::PolicyList_var inconsistent_policies;

// The following operation causes a _bind_priority_band()
// "implicit" request to be sent to the server
CORBA::Boolean successful =
   drone->_validate_connection (inconsistent_policies);
```

Private Connection Policy

- **Problem**: To minimize priority inversions, some applications cannot share a connection between multiple objects
  - *e.g.,* drones reporting `edge_alarm()` requests should use exclusive, pre-allocated resources
- **Solution**: Use the RT CORBA `PrivateConnectionPolicy` to guarantee non-multiplexed connections

```
// Use an exclusive connection to access the
// Controller objects
policies[0] =
   rtorb->create_private_connection_policy ();

CORBA::Object_var obj =
   controller->_set_policy_overrides
      (policies, CORBA::ADD_OVERRIDES);

CORBA::PolicyList_var inconsistent_policies;
CORBA::Boolean success =
   obj->_validate_connection (inconsistent_policies);
// If successful <obj> has a private connection
```


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);
bands[0].low = LOW_PRIO;      // We can have bands with
bands[0].high = MEDIUM_PRIO;  // a range of priorities or
bands[1].low = HIGH_PRIO;     // just a "range" of 1!
bands[1].high = HIGH_PRIO;

// Now create the policy…
CORBA::PolicyList policies (1); policies.length (1);
policies[0] =
   rtorb->create_priority_banded_connection_policy (bands);
// Use just like any other policies…
```

- This policy can be used on the client-side to pre-allocate connections

Simplifying Application Scheduling

- **Problem**: Although RT-CORBA gives developers control over system resources it has two deficiencies:
  - It can be tedious to configure all the various policies
  - Application developer must select the right priority values
- **Solution**: Apply the RT-CORBA Scheduling Service to simplify application scheduling
  - Developers just declare the current *activity*
  - Properties of an activity are specified using an (unspecified) external tool
  - Note that the Scheduling Service is an optional part of the RT-CORBA 1.0 specification

```
// Find the scheduling service
RTCosScheduling::ClientScheduler_var scheduler = … ;

// Schedule the 'edge_alarm' activity
scheduler->schedule_activity ("edge_alarm");

controller->edge_alarm ();
```

The client-side programming model Is simple

Server-side Scheduling

```
// Obtain a reference to the scheduling service
RTCosScheduling::ServerScheduler_var scheduler = … ;

CORBA::PolicyList policies; // Set POA policies

// The scheduling service configures the RT policies
PortableServer::POA_var rt_poa = scheduler->create_POA
  ("ControllerPOA",
   PortableServer::POAManager::_nil (),
   policies);

// Activate the servant, and obtain a reference to it.
rt_poa->activate_servant (my_controller);
CORBA::Object_var controller =
   rt_poa->servant_to_reference (my_controller);

// Configure the resources required for this object
// e.g., setup interceptors to control priorities
scheduler->schedule_object (controller, "CTRL_000");
```

Servers can also be configured using the Scheduling Service

Other Relevant CORBA Features

- RT CORBA leverages other advanced CORBA features to provide a more comprehensive QoS-enabled 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 1.0 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*****:** Currently in progress in the OMG (orbos/00-06-10), looks for RT-enhanced Notification Service
  - ***Dynamic Scheduling*****:** Currently in progress in the OMG (orbos/98-02-15) to address additional policies for dynamic & hybrid static/dynamic scheduling

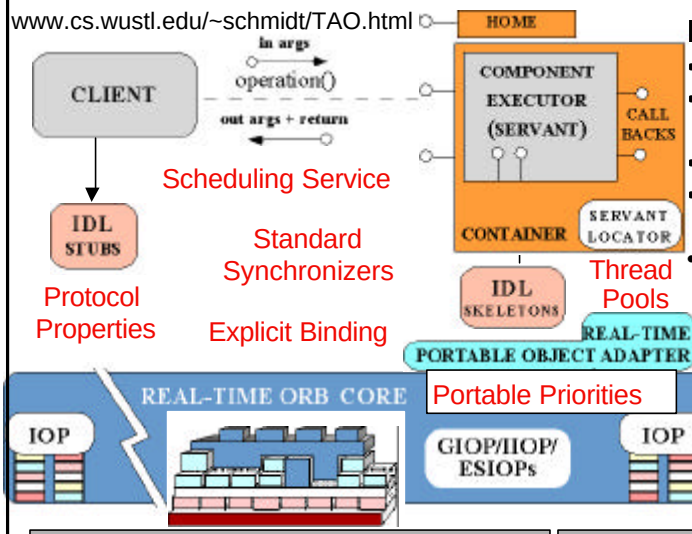
Controlling Request Timeouts

- **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 (100000000UL);

// 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);
drone_with_timeout->stop (); // Timeout takes effect here.
```

RT CORBA in Practice: The ACE ORB (TAO)

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



Features

- Open-source
- 500+ classes & 500,000+ lines of C++
- ACE-based
- Over 25 person-years of effort
- Ported to UNIX, Win32, MVS, & many RT & embedded OSs
  - *e.g.,* VxWorks, QNX, LynxOS, Chorus

- **Large open-source user community**
  www.cs.wustl.edu/~schmidt/TAO-users.html
- **Commercial support by OCI**
  - www.theaceorb.com/

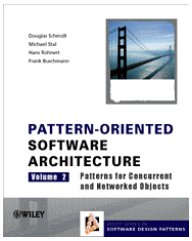
Open Issues with the Real-Time CORBA Specification

- No standard APIs for setting & getting priority mappings & priority transforms
- No compelling use-cases for server-set client protocol policies
- Semantic ambiguities
  - Valid policy configurations & their semantics
    - *e.g.,* should a protocol property affect all endpoints or just some?
  - Resource definition & allocation
  - Mapping of threads to connection endpoints on the server
- The bounds on priority inversions is a quality of implementation
  - No requirement for I/O threads to run at the same priority as request processing threads

Bottom-line: RT CORBA applications remain dependant on implementation details

Additional Information

- **Real-time CORBA spec**
  - `www.cs.wustl.edu/~schmidt/PDF/RT-ORB-std.pdf`
- **Patterns for concurrent & networked objects**
  - `www.posa.uci.edu`
- **ACE & TAO open-source middleware**
  - `www.cs.wustl.edu/~schmidt/ACE.html`
  - `www.cs.wustl.edu/~schmidt/TAO.html`



- **CORBA research papers**
  - `www.cs.wustl.edu/~schmidt/corba-research.html`
- **CORBA tutorials**
  - `www.cs.wustl.edu/~schmidt/tutorials-corba.html`

Concluding Remarks

- RT CORBA 1.0 is a major step forward for QoS-enabled middleware
  - *e.g.,* it introduces important capabilities to manage key ORB end-system/network resources
- We expect that these new capabilities will increase interest in--and applicability of--CORBA for distributed real-time & embedded systems
- RT CORBA 1.0 doesn't solve *all* real-time development problems, however
  - It lacks important features:
    - Standard priority mapping manager
    - Dynamic scheduling
      - Addressed in RT CORBA 2.0
  - Portions of spec are under-specified
    - Thus, developers must be familiar with the implementation decisions made by their RT ORB
- Our work on TAO has helped advance middleware for distributed real-time & embedded systems by implementing RT CORBA in an open-source ORB & providing feedback to the OMG