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Providing Real-Time and Fault Tolerance for CORBA Applications

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Outline

- Motivation
- Two standards for quality of service in CORBA
  - Real-Time CORBA and Fault-Tolerant CORBA
- Conflicts between real-time and fault tolerance
- Trade-offs between real-time and fault tolerance
- Resolving the trade-offs
  - Architecture
  - Mechanisms
- Conclusion

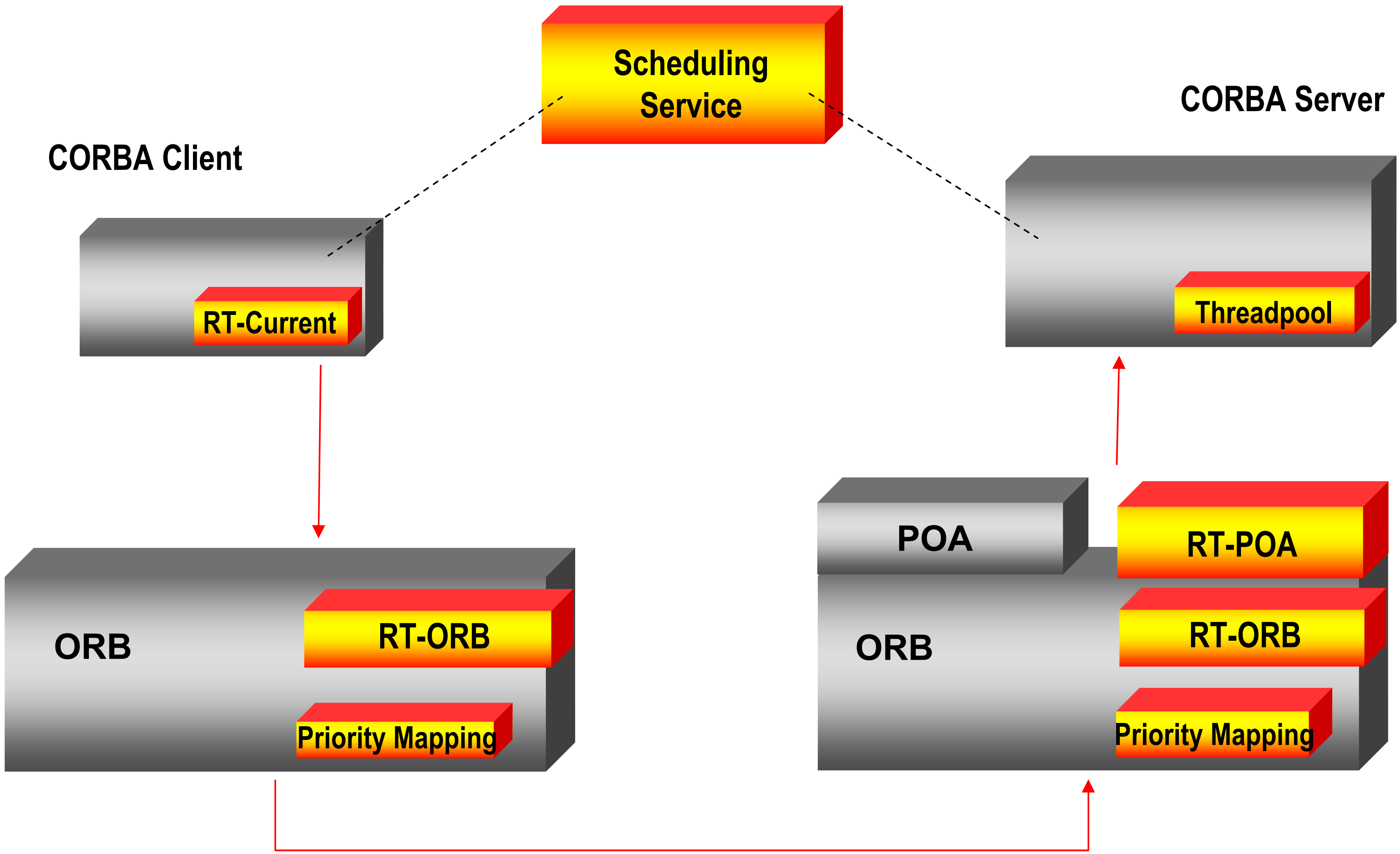
Motivation

- **CORBA is increasingly used for applications, where dependability and quality of service are important**
  - The Real-Time CORBA (RT-CORBA) standard
  - The Fault-Tolerant CORBA (FT-CORBA) standard
- **But ……**
  - Neither of the two standards addresses its interaction with the other
  - Either real-time support or fault-tolerant support, but not both
  - Applications that need both RT and FT are left out in the cold
- **Focus of talk**
  - Why real-time and fault tolerance do not make a good "marriage"
  - Overcoming these issues to build support for CORBA applications that require **both** real-time **and** fault tolerance

Quality of Service for CORBA Applications

- **The Real-time CORBA (RT-CORBA) standard**
  - Scheduling of entities (threads)
  - Assignment of priorities of tasks
  - Management of process, storage and communication resources
  - End-to-end predictability
- **The Fault tolerant CORBA (FT-CORBA) standard**
  - Replication of entities (CORBA objects or processes)
  - Management and distribution of replicas
  - Logging of messages, checkpointing and recovery
  - Strong replica consistency

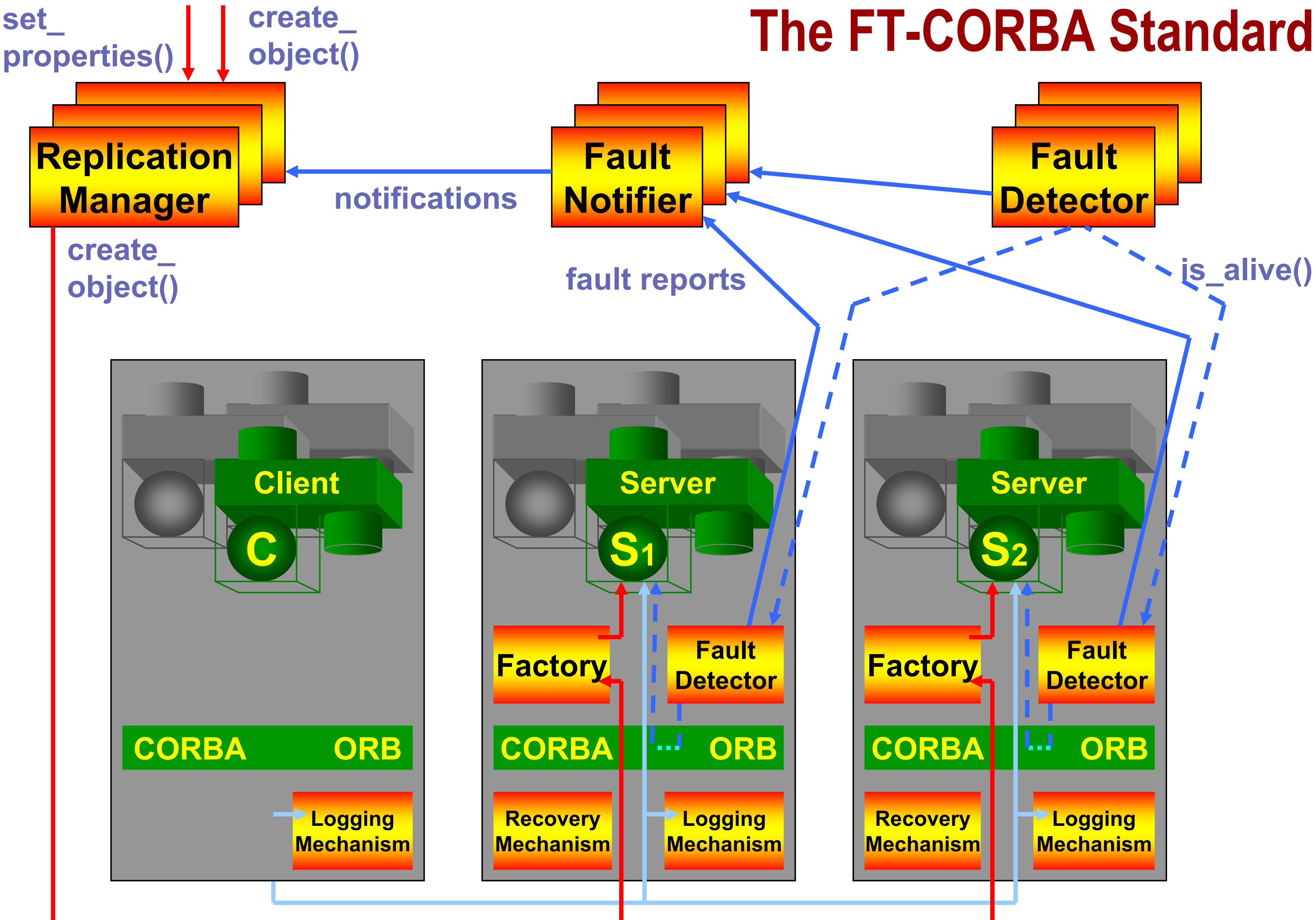
The RT-CORBA Standard



End-to-End Predictability

- The most important property of an RT-CORBA system
- Priorities attached to threads (execution entities) and invocations
  - Maps to native priorities on the operating system
- Bounds on temporal properties of application
  - Bounded message transmission latency across network
  - Bounded message processing time within ORB and application
- Schedule of various tasks computed ahead of time (offline)
  - Schedule respects task priorities and task deadlines
  - Fixed-priority scheduling
- Priority banding
  - Multiple client-to-server connections, each at a different priority
  - Client-dictated or server-dictated priority

The FT-CORBA Standard



Electrical & Computer ENGINEERING

Strong Replica Consistency

- The most important property of an FT-CORBA system
- Requires deterministic behavior of application objects
- Guarantees on message transmission and delivery
  - Same sequence of messages in the same order
  - No loss of messages over the communication medium
  - No delivery of duplicate invocations or responses
- State transfer to new and recovering replicas
- Essential for both active and passive replication
  - Debunks the myth that passive replication can cure non-determinism

Real-Time *vs.* Fault-Tolerance

Real-Time Systems	Fault-Tolerant Systems
Requires *a priori* knowledge of events	No advance knowledge of when faults might occur
Operations ordered to meet task deadlines	Operations ordered to preserve data consistency (across replicas)
Synchronous	Not necessarily synchronous
Multithreading for concurrency and efficient task scheduling	Determinism prohibits the use of multithreading
Use of timeouts and timer-based mechanisms	Determinism prohibits the use of local processor time

Real-Time *vs.* Fault-Tolerance - 1

- **RT and FT communities disagree even on basic terminology**
- **Determinism in the real-time sense**
  - Equivalent to predictability
  - Real-time invocation is deterministic if its execution and processing times are bounded and predictable ahead of time
  - Lack of RT determinism can result in missed deadlines
- **Determinism in the fault tolerance sense**
  - Equivalent to reproducibility
  - Fault-tolerant invocation is deterministic if its execution, by different replicas starting from the same initial state, on different processors, produce the same state changes and the same responses
  - Lack of FT determinism can result in replica inconsistency

Real-Time *vs.* Fault-Tolerance - 2

- **Real-time systems use multi-threading**
  - To allow concurrent tasks to execute simultaneously
- **Multi-threading is problematic for a fault-tolerant system**
  - Unrestricted multi-threading can lead to non-determinism
  - Server with two replicas S1 and S2 on two different processors
  - S1 and S2 might run two tasks on two different concurrent threads
  - Threads modifying shared state within the server can lead to inconsistency
  - Yes, shared state exists, inside the ORB (if not in the application)!
  - Need special scheduler to enforce single-threading for determinism
- **Task management**
  - Multithreading for task scheduling vs. single-threading for determinism

Real-Time *vs.* Fault-Tolerance - 3

- **Real-time systems use the notion of wall-clock time**
  - Timeouts and timers used to finesse real-time consensus issues
  - Clients can run a timeout if server doesn't respond in time
- **Wall-clock time is problematic in a fault-tolerant system**
  - Use of timeouts and timers can lead to non-determinism & inconsistency
  - Replicated (middle-tier) client with two replicas C1 and C2
  - C1's and C2's timeouts might expire at different times
  - C1 might think operation missed its deadline; C2 might think otherwise
  - Fault-tolerant systems use clock synchronization & global time service
- **Time management**
  - Maintaining determinism without making global time service a bottleneck

Real-Time *vs.* Fault-Tolerance - 4

- **Ordering in the real-time sense**
  - Tasks and invocations ordered to meet application deadlines
- **Ordering in the fault tolerance sense**
  - Tasks and invocations ordered to meet replica consistency
- **What if the two orders conflict?**
  - Processor P1 hosts replicas of objects A, B and C
  - Processor P2 hosts replicas of objects A and D
  - Schedules on the two processors might vary with current resources
  - P1's replica of A and P2's replica of A might see different orders
- **What if different machines need different task mixtures?**
  - Some tasks ordered *a la* real-time; others ordered *a la* fault tolerance

Real-Time *vs.* Fault-Tolerance - 5

- **Real-time assumes mostly synchronous operation**
  - Events, tasks, operations known ahead of time
  - Bounded latencies, bounded response time
- **Fault tolerance considers asynchronous environment**
  - Distributed asynchronous system
  - Unbounded latency, unbounded response time, unreliable fault detection
- **Fault tolerance assumes inherent unpredictability**
  - Faults cannot be predicted ahead of time; they are asynchronous events
  - What if faults “upset” the pre-computed real-time schedule?
- **Can we get synchronous operation in an asynchronous setting?**
  - Especially in the presence of transient faults

Real-Time *vs.* Fault-Tolerance - 6

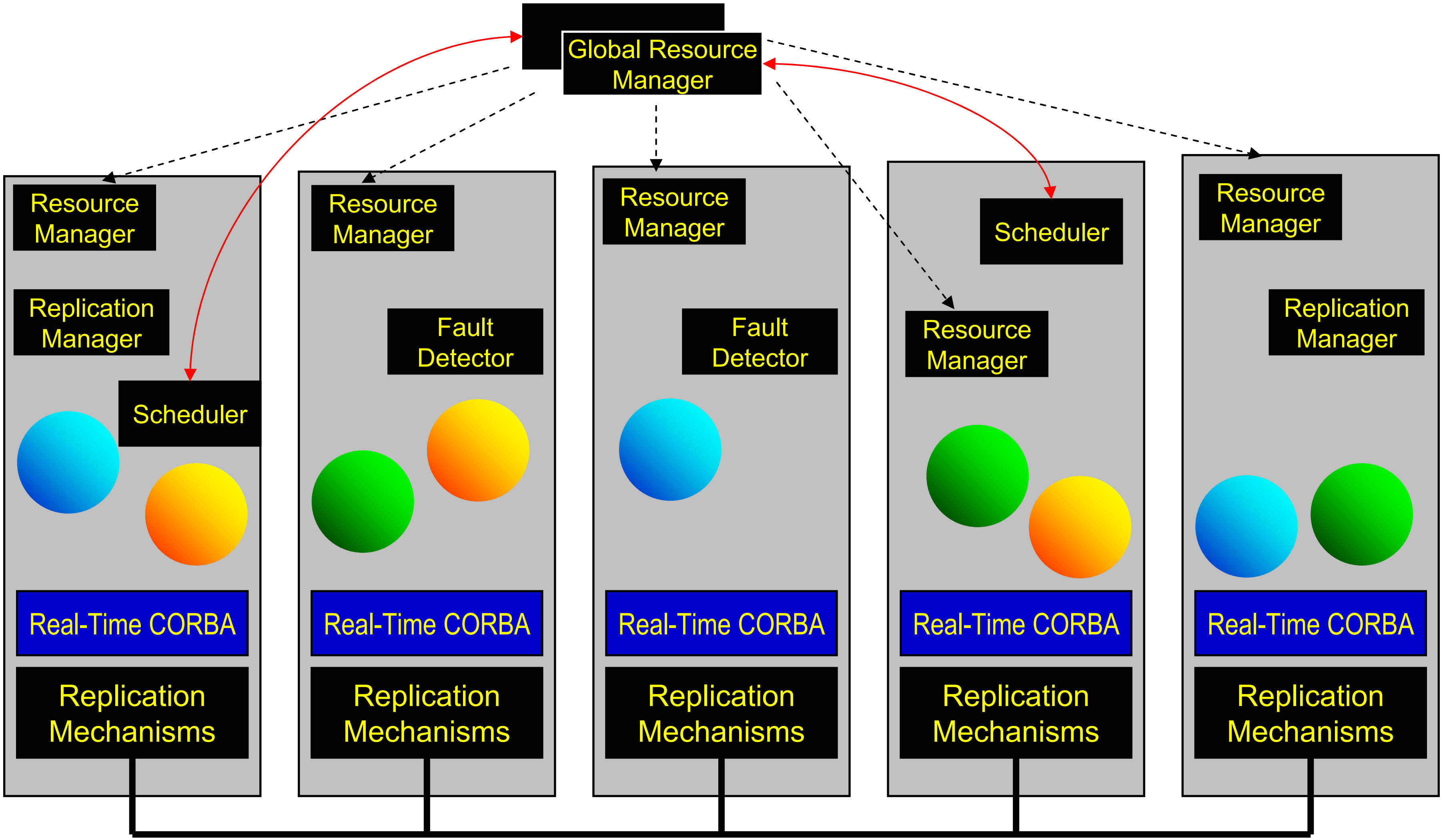
- **Real-time requires bounded operation time**
  - What about operations such as fault detection and recovery?
- **Time-consuming fault detection**
  - What of common-mode (correlated) faults?
    - Crash of processor hosting 100 objects can lead to 100 fault reports
- **Time-consuming recovery**
  - Recovery must account for ORB, application and infrastructure state
  - Recovery of trivial objects is straightforward (state=simple data structure)
  - What if recovery involves object instantiation?
    - Recovery of a process that requires 100 objects to be instantiated
  - FT-CORBA talks about object-centric recovery; shared state requires process-centric recovery

Combining Real-Time and Fault-Tolerance

- **Trade-offs between RT and FT for specific scenarios**
  - Effective ordering of operations to meet both RT and FT requirements
  - Resolution of non-deterministic conflicts (e.g., timers, multithreading)

- **Impact of fault-tolerance and real-time on each other**
  - Impact of a fault on real-time behavior
  - Impact of recovery (reboot) on real-time behavior
  - Replication of scheduling/resource management components
  - Scheduling (and bounding) recovery to avoid missing deadlines

RT-FT Architecture



Architectural Overview

- **Use replication to protect**
  - Application objects
  - Scheduler and global resource manager
- **Special RT-FT scheduler**
  - Real-time resource-aware scheduling service
  - Fault-tolerant-aware to decide when to initiate recovery
- **Resource management framework**
  - Local resource managers feed into a replicated global resource manager
  - Global resource manager coordinates with RT-FT scheduler
- **Ordering of operations**
  - Keeps replicas consistent in state despite faults, missed deadlines, recovery and non-determinism in the system

RT-FT Scheduler

- **Requires ability to predict and to control resource usage**
- **Needs input from the local and global resource managers**
  - Resources of interest: load, memory, network bandwidth
  - Parameters: resource limits, current resource usage, usage history profile
- **Uses resource usage input for**
  - Proactive action
    - Predict and perform new resource allocations
    - Migrate resource-hogging objects to idle machines before they start executing
  - Reactive action
    - Respond to overload conditions and transients
    - Migrate replicas of offending objects to idle machines even as they are executing invocations

RT-FT Scheduler

- **Requires prediction of faults and of recovery**
- **Needs input from a fault predictor**
  - To determine when, and what kinds of, faults can occur
  - To schedule fault detection time based on prediction
- **Needs input from a recovery predictor**
  - **Offline predictor**: Source code analysis for worst-case recovery time
    - Look at each object's data structures
    - Looks at the object's containing process and ORB interactions
    - Not comprehensive: unable to predict dynamic memory allocations
  - **Runtime predictor**: Object execution and memory allocation profile
    - Intercepts and observes runtime memory allocations (e.g., object instantiation, library loading), connection establishment, etc.
    - Prepares for the worst-case replica recovery time

Conclusion

- **Real-time and fault tolerance don't always make a good "marriage"**
  - Use of time and multithreading (non-determinism)
  - Ordering of tasks to meet replica consistency and task deadlines
  - Bounding fault detection and recovery times in asynchronous environment
- **RT-FT CORBA architecture requires**
  - Online fault profiler and predictor
  - Online and offline recovery predictor
  - FT-aware real-time scheduler that schedules recovery actions
  - New mechanisms to sanitize non-determinism
- **Ongoing research work with RT-CORBA implementations (TAO and Orbacus) and RTSJ reference implementation (Timesys)**

Thank You!

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