Dynamic CPU Management for Real-Time, Middleware-Based Systems

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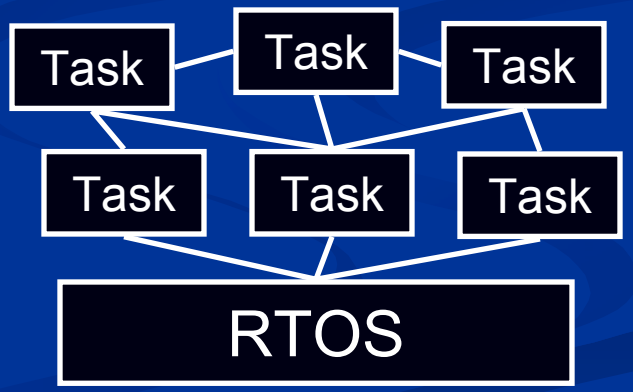
Monoliths → Modules

- Old: Monolithic RT systems
  - Made by one organization
  - One-off products
  - Closed and static

Hard to extend and integrate

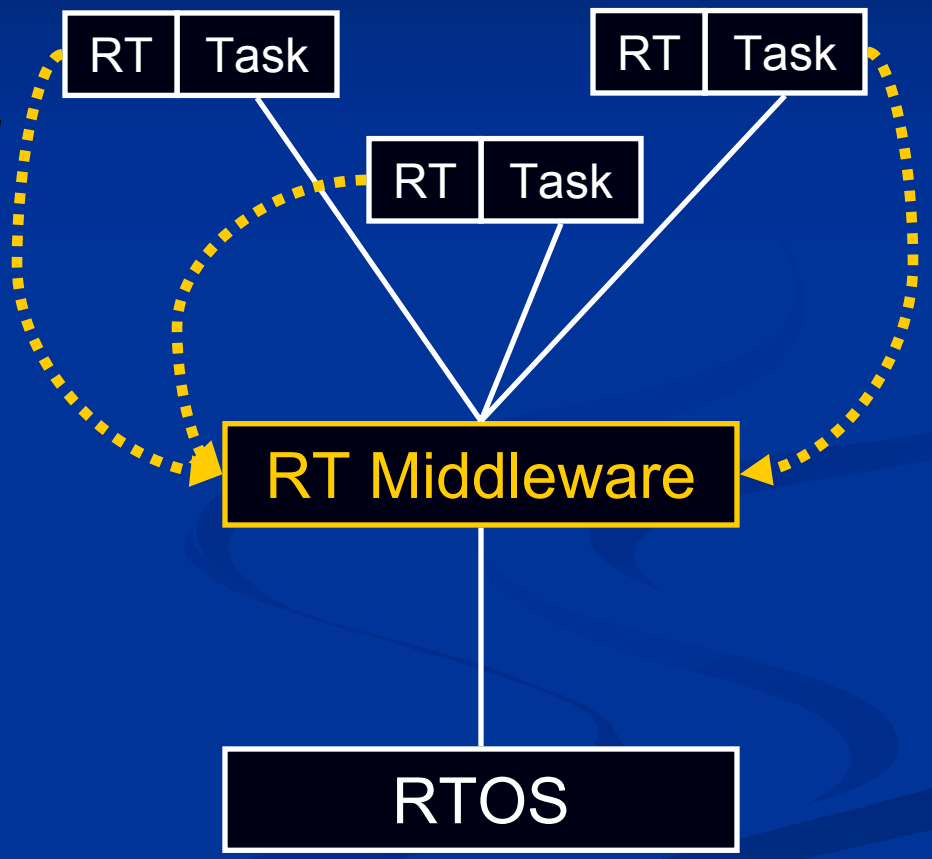
- New: Modular RT systems
  - Made by many organizations
  - Product lines and families
  - Open and dynamic



Hard to compose and control

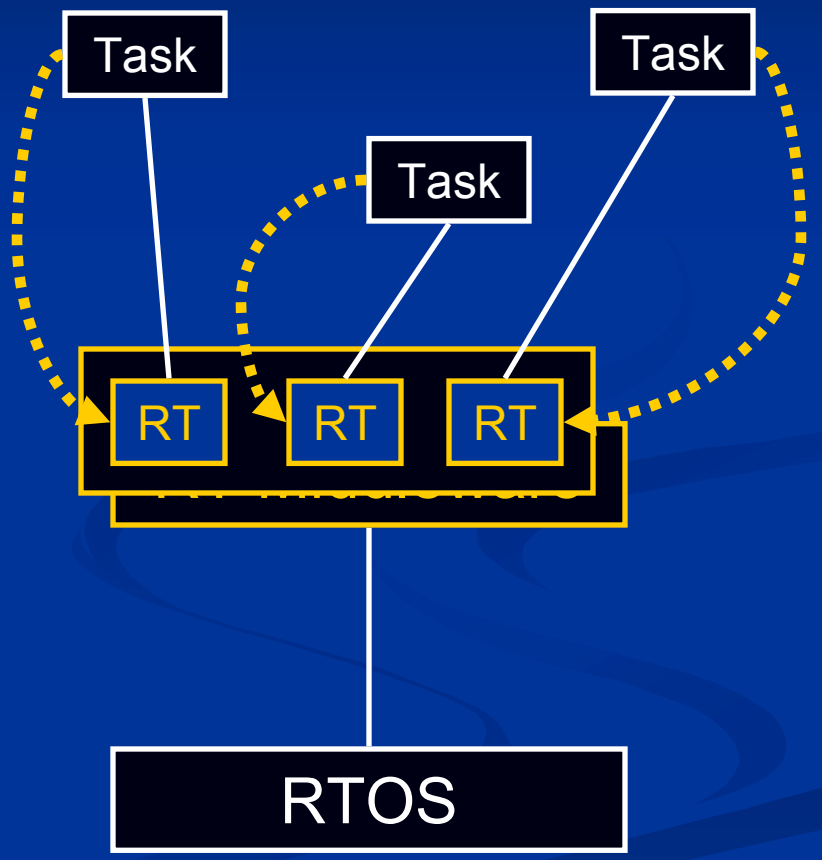
Modularity: Middleware

- Common backplane
- Relieve developers of tedious low-level detail
- Fewer bugs, shorter time to market
- Reusable across multiple products, product families



Modularity: Separate RT

- Separate application logic from RT logic
  - Reuse of task parts
  - Modularize RT parts for understandability
- Separation enables remodularization
- *But... how?*

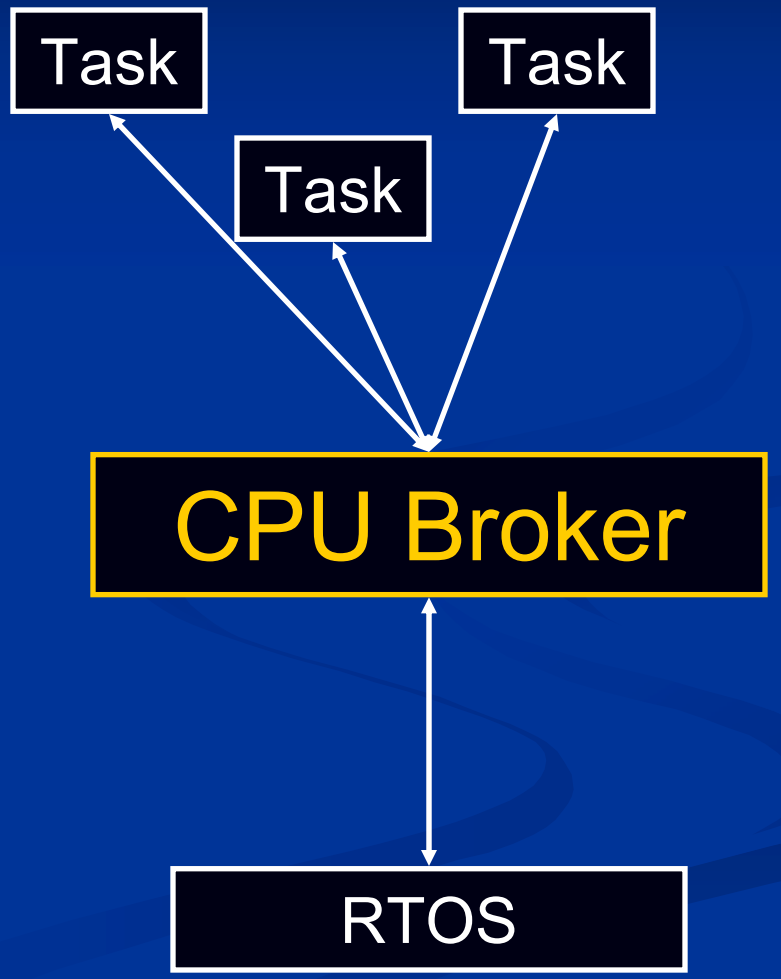


Modularity: Specifying RT

- Need composability
  - Reservations are composable, but not enough
- Need adaptability
  - …for complex parts
    - *data-, mode-, or configuration-dependent demand*
  - …for open systems
    - *unknown agents and resources before deployment*
  - …because prediction is hard

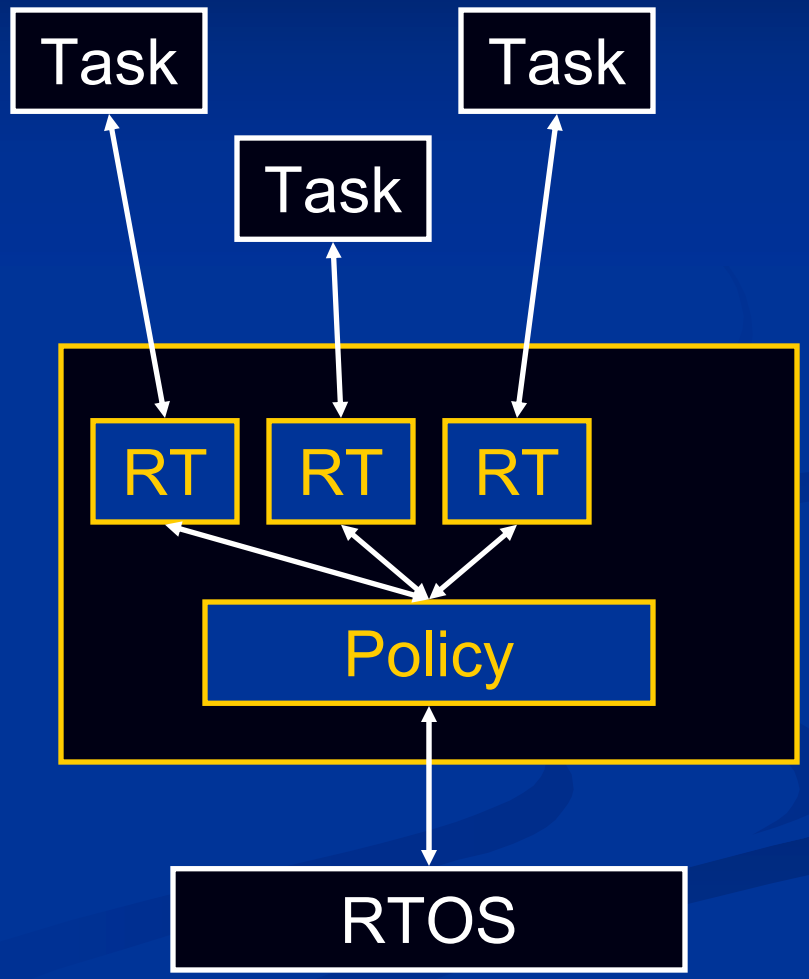
Idea: “CPU Broker”

- Service for managing processor resources on a host
- Mediates between RT tasks and RT OS
- *Broker is a negotiator, not a scheduler*



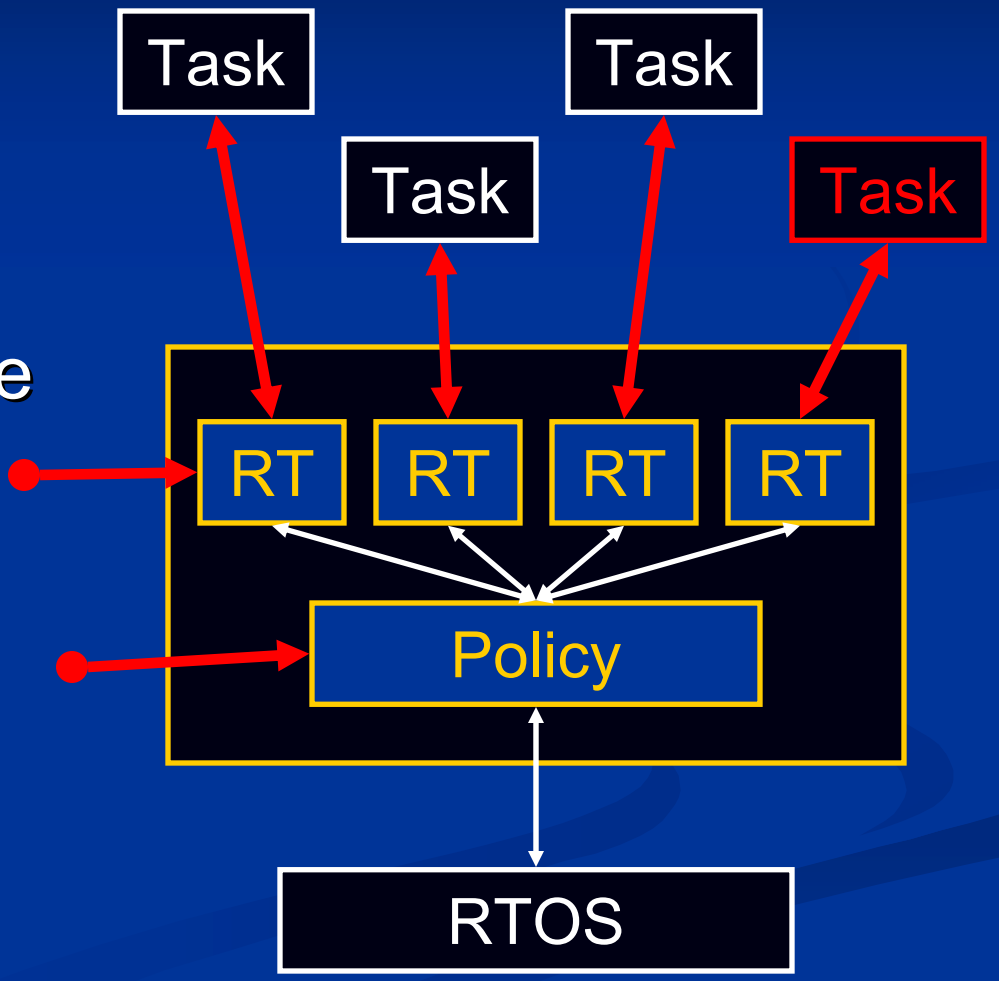
Idea 1: Separate Concerns

- Separate application logic from RT logic
- Separate per-task and global decision makers
- Separate negotiation from scheduling
- Manage both middleware-based and other applications



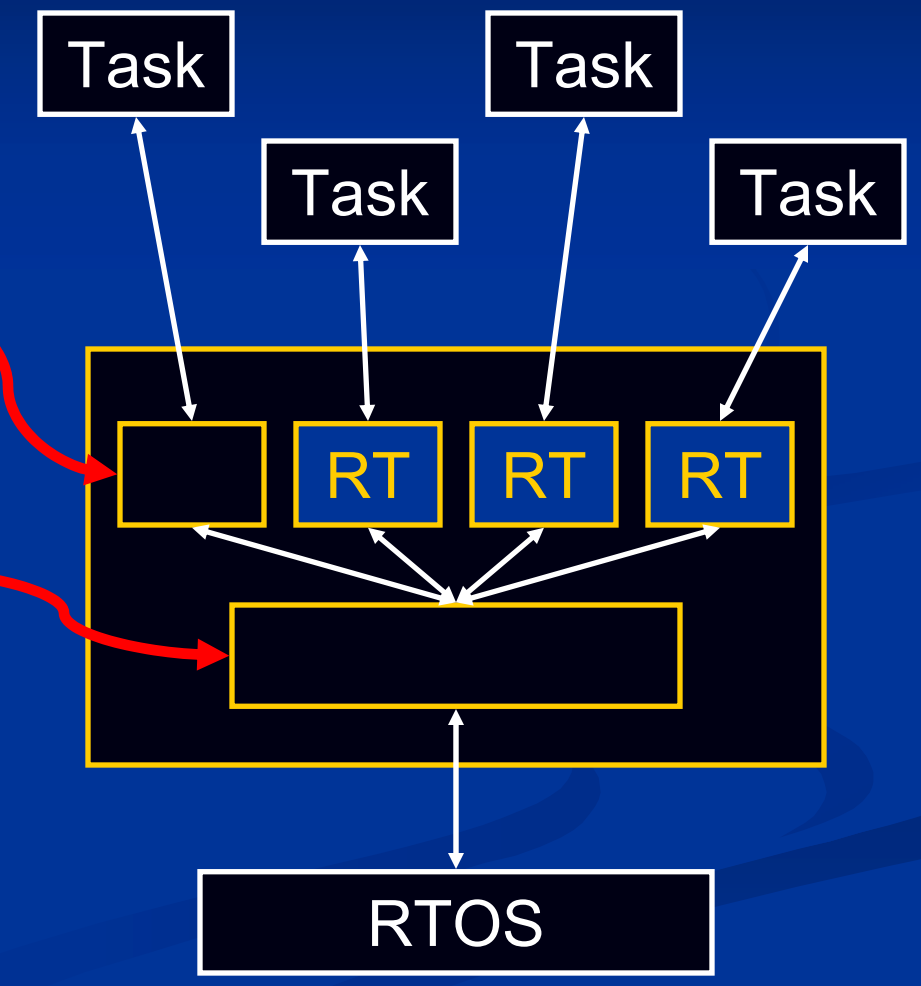
Idea 2: Dynamic/Adaptive

- Dynamic monitoring of applications
- Changing task sets
- External inputs to the broker at run time
- Set and change broker configuration at run time



Idea 3: Open Framework

- Parts are objects
  - Plug-in per-task "advocates"
  - Plug-in global policies
- Connect to other QoS management systems



Contributions

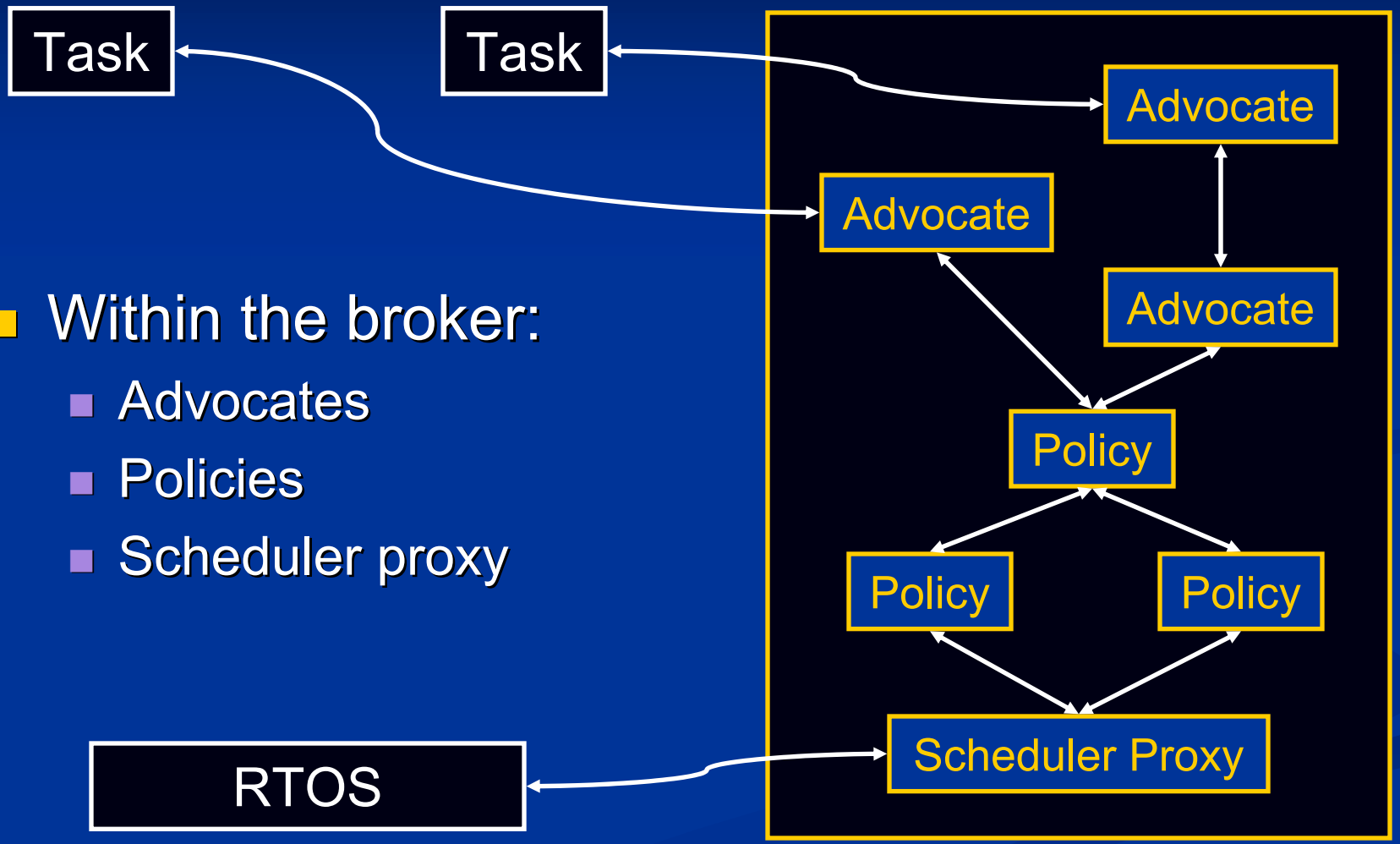
- Architecture addressing critical software engineering challenges
  - …moving from reservations to negotiations
  - …supporting more modular RT abstractions
- Implementation on COTS MW and RTOS
- Evaluation
  - …with synthetic RT applications
  - …with a distributed RT military application

Related Work

- Our focus: address SE challenges
- Build on previous work
  - Feedback-driven scheduling
    - *QoS Manager [Abeni and Buttazzo, '99]*
  - RT middleware
    - *RT CORBA [OMG], feedback [Lu et al., '03]*
  - MW-based QoS architectures
    - *DQM [Brandt et al., '98], QuO [Zinky et al., '97]*

Design Overview

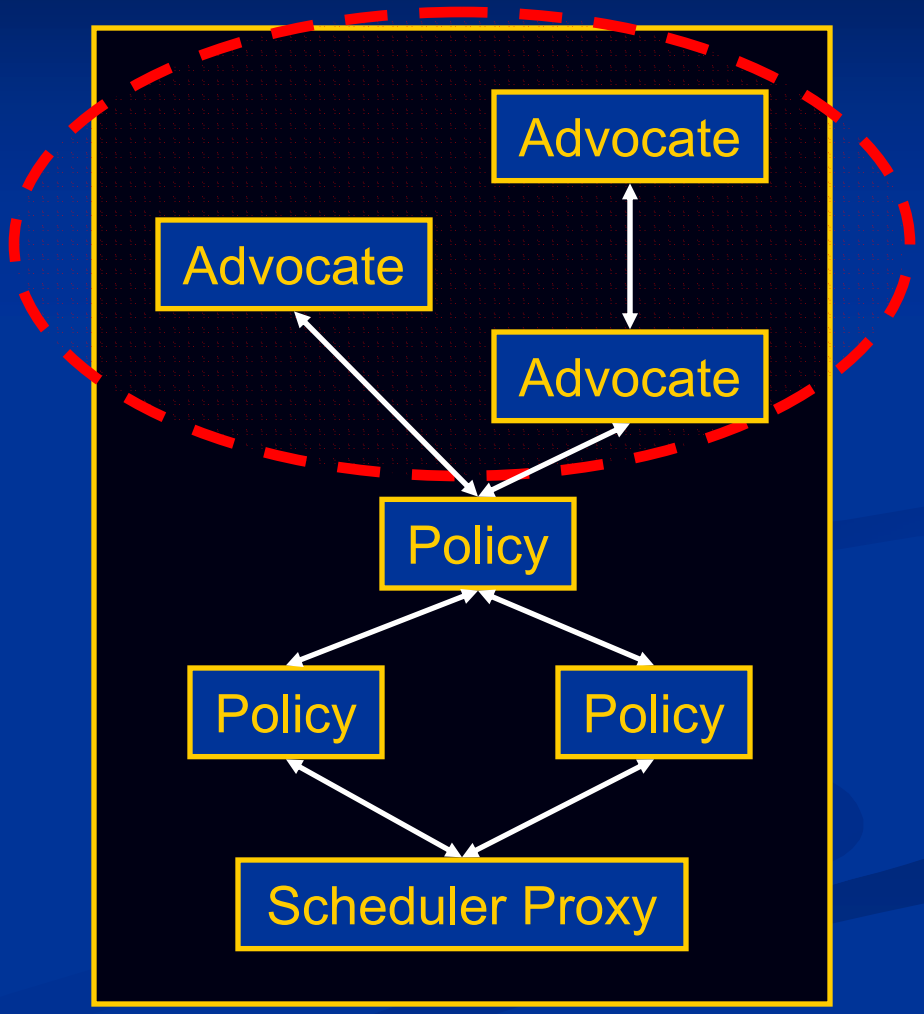
- Within the broker:
  - Advocates
  - Policies
  - Scheduler proxy



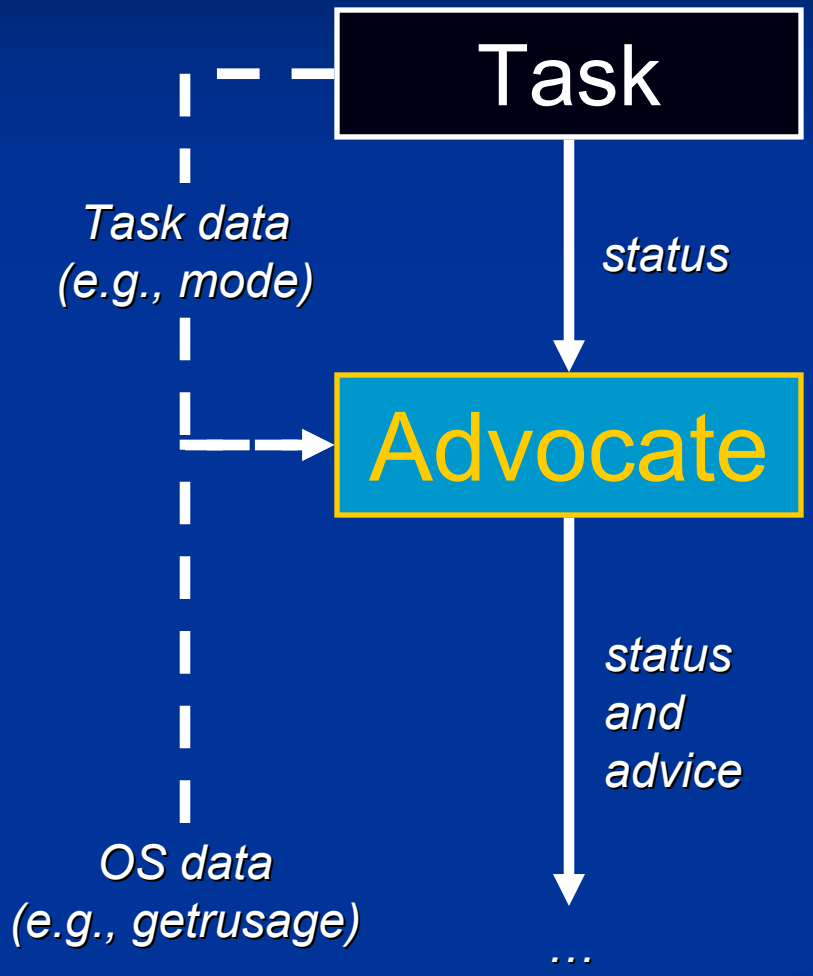
Advocates

- Per-application adaptation
- Request CPU resources for a task
- Chain to build up complex behaviors

- Goal: match expected task demand

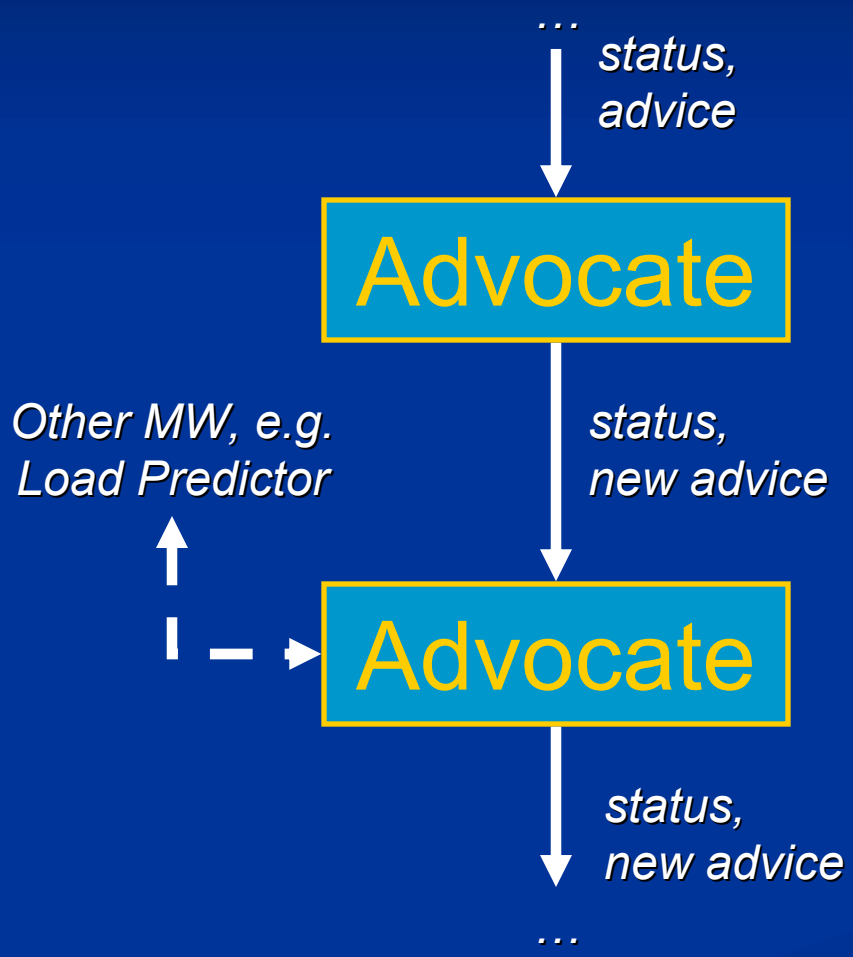


Topmost Advocate



- Input CPU consumed
  - "status"
- Output request for a periodic reservation
  - "advice" (C, P)
- Predict future need
  - …library of advocates
  - …or, write your own
  - can collocate with task

Subsequent Advocates

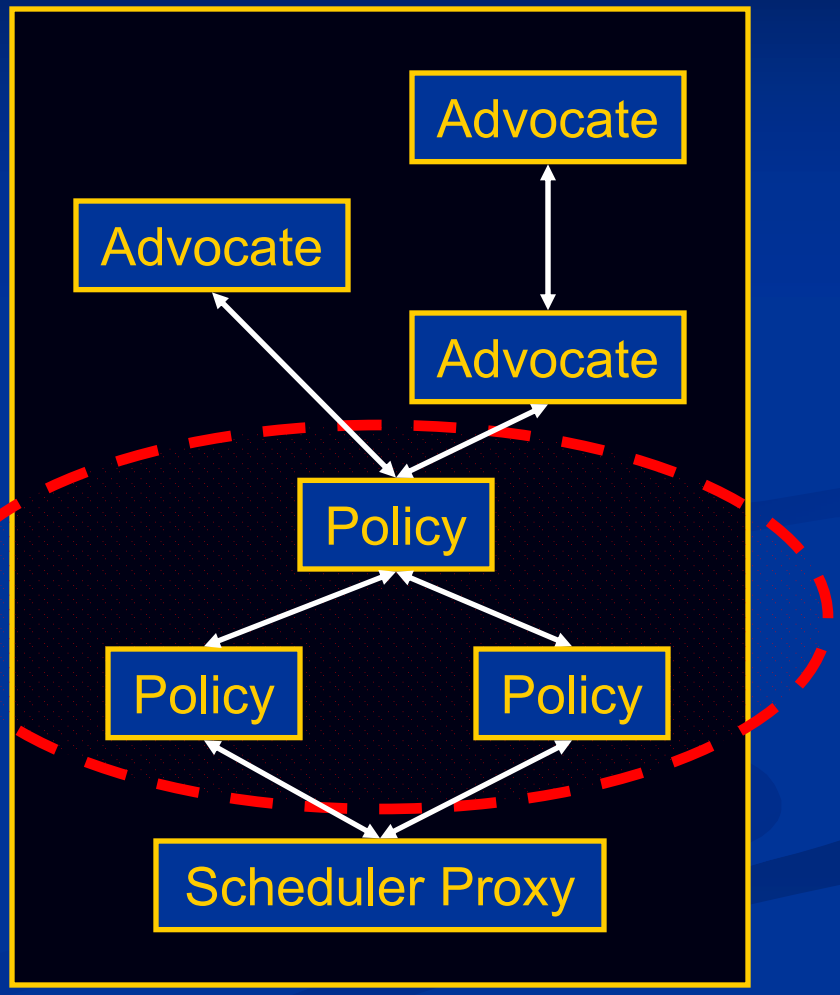


- Modify advice or perform side effect
  - cap request (min/max)
  - talk to other MW
  - watchdog timer
- Chaining allows
  - reuse of advocates
  - dynamic configuration
  - … and reconfiguration

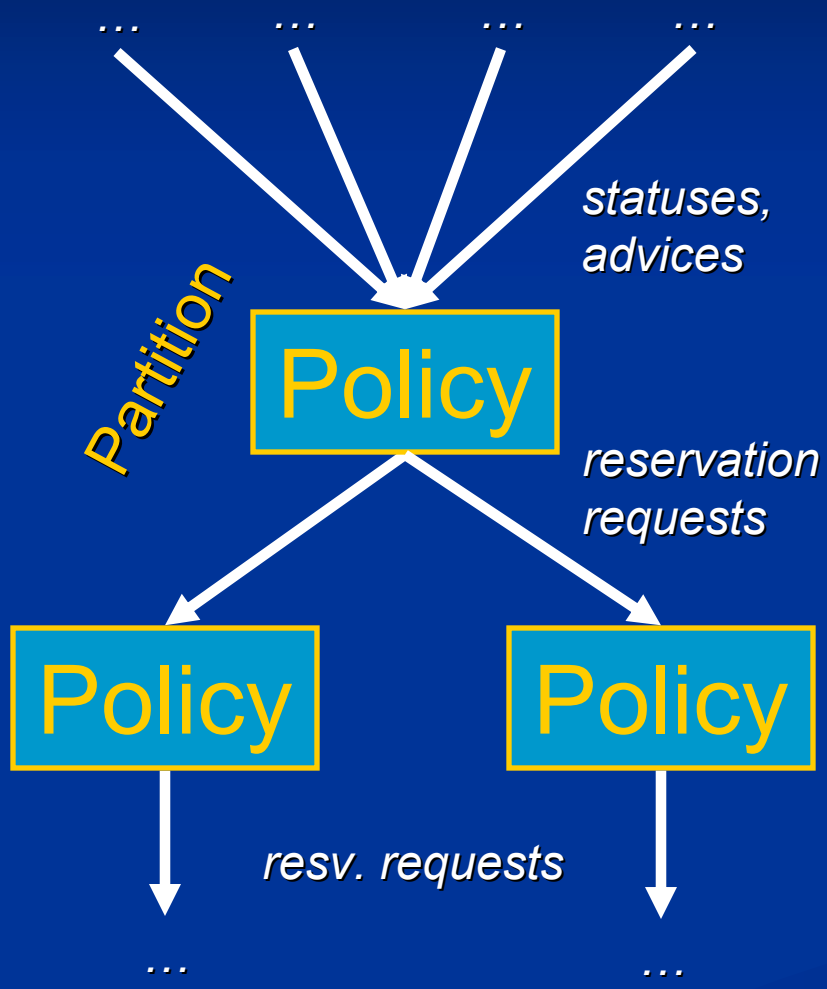
Policies

- Global adaptation
- Collect advice from advocates
- Request reservations
- Propagate information back to advocates

- Goal: negotiate to resolve contention



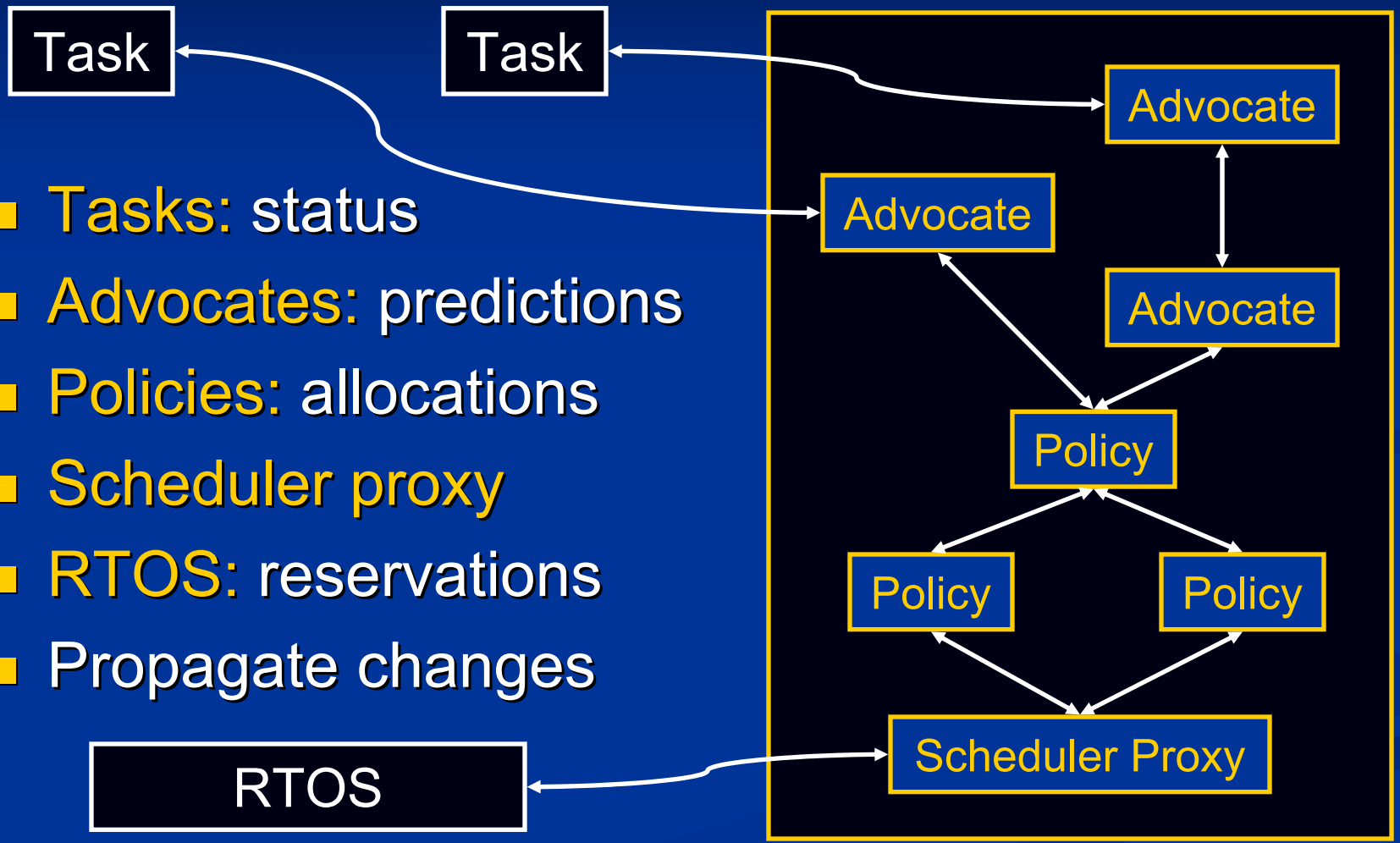
Policy Objects



- Encapsulate negotiation
  - …hard or soft RT
- Multiple policies via partitions
- Setting up policies
  - …use library policies
  - …or, write your own
- Set/reset policy data at run time, e.g.
  - …importances, weights

Putting It All Together

- Tasks: status
- Advocates: predictions
- Policies: allocations
- Scheduler proxy
- RTOS: reservations
- Propagate changes



Implementation

- COTS RT scheduling and accounting
  - *TimeSys Linux*
- Open architecture, dynamic control
  - *CORBA*
- Separate application and RT logic
  - *QuO*
  - *TimeSys Linux*

TimeSys Linux

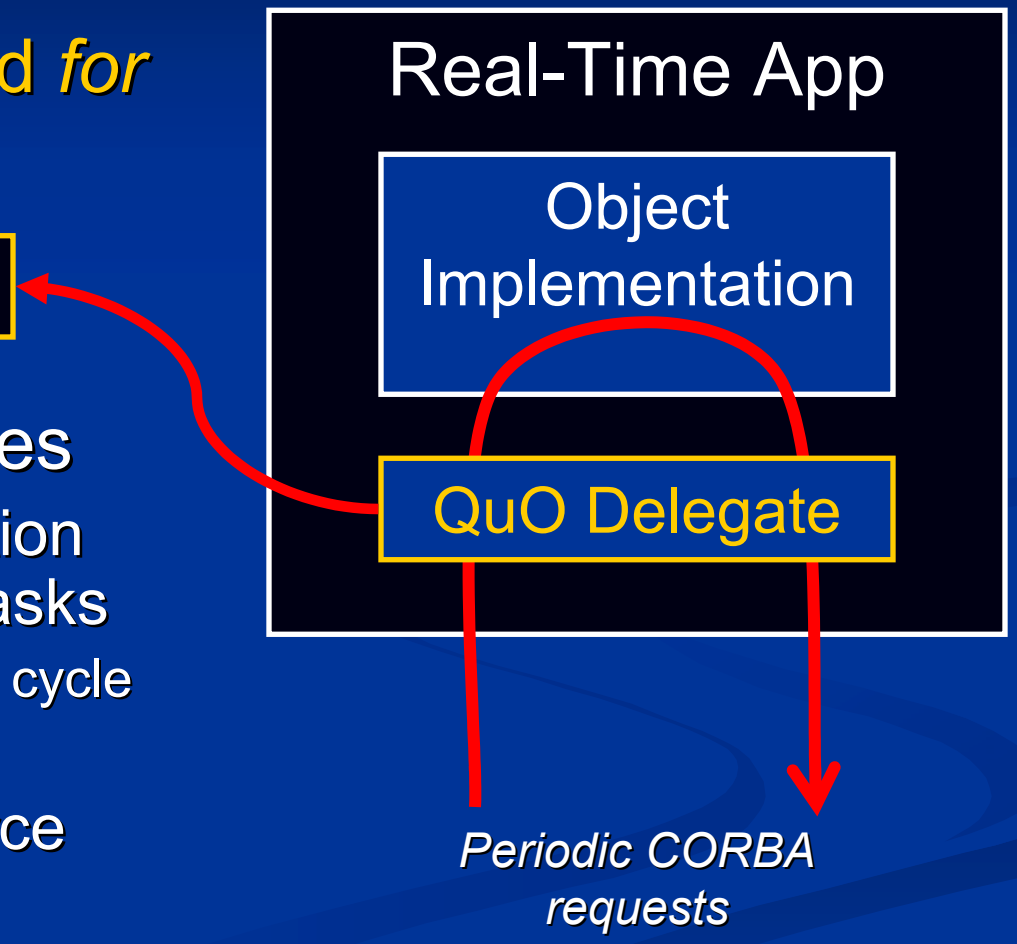
- Core services
  - Reservation-based scheduling
  - High-resolution CPU usage timers
- Good abstractions
  - Multiple threads can share one reservation
  - Reservations can be inherited
  - Thread→reservation associations can be created and manipulated “externally”
- …allow easy monitoring and manipulation

CORBA

- Advocates and policies: CORBA objects
  - Easy to assemble
  - Easy to invoke at run time
  - In one process or multiple processes
- Basis for custom advocates and policies
  - Dynamic loader for custom objects
- Basis for connecting to MW-based tasks
- …allows open and dynamic architecture

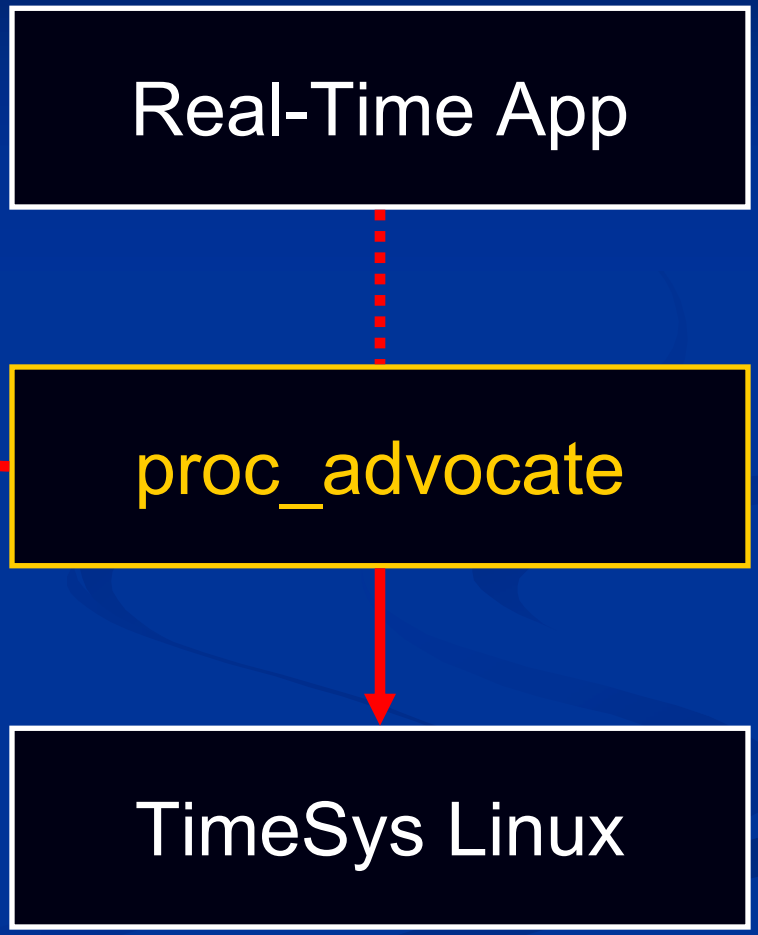
QuO

- Apps not designed *for* the CPU Broker
- Use QuO delegates
  - Improved integration with MW-based tasks
    - Sync'ed with task cycle
    - Customizable
  - … but, small source changes required



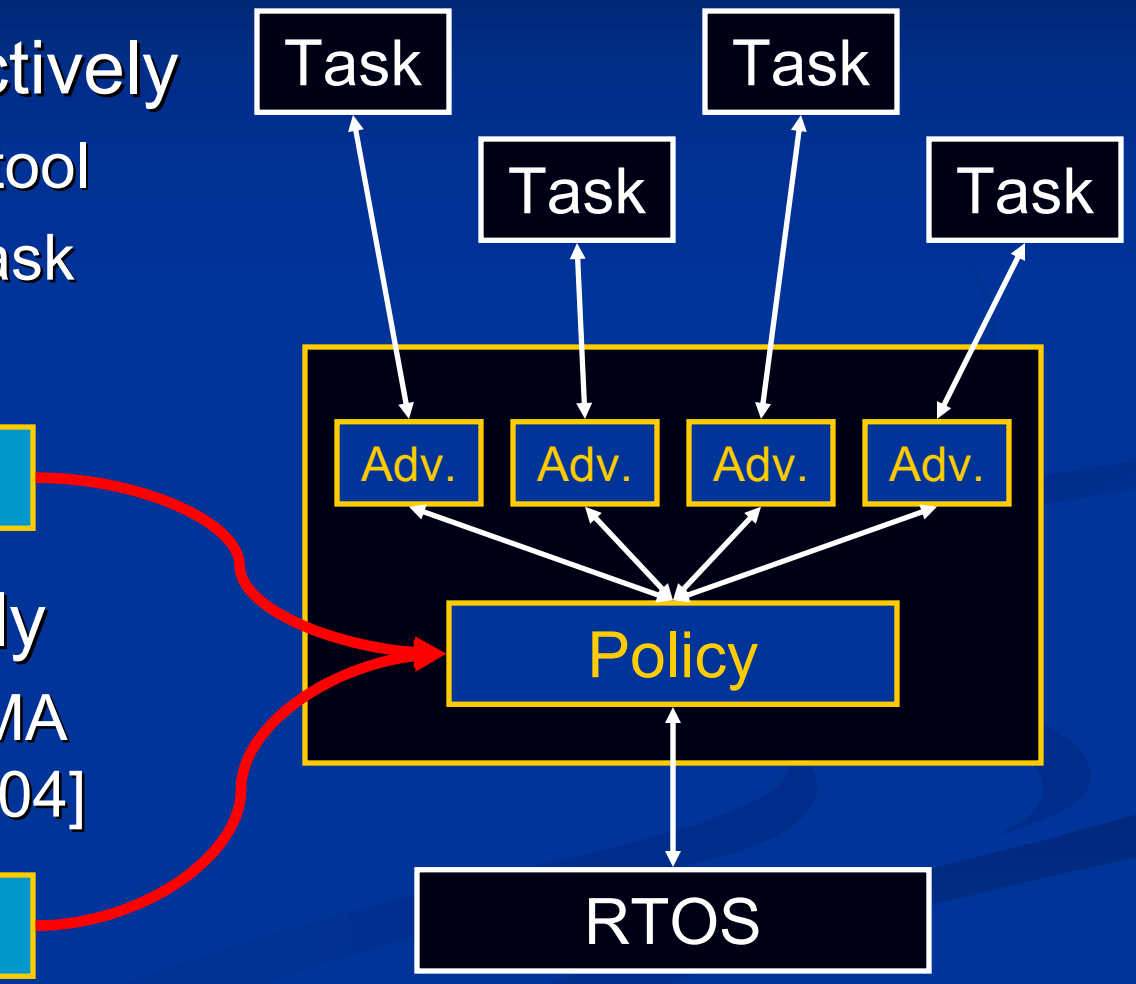
Process Advocate

- Need to manage non-MW applications, too
- Use “proc_advocate”
  - Transparent to task
    - No MW required
    - Entirely reusable
  - …but, less access to task state
    - E.g., period



Using the CPU Broker

- Scripted, interactively
  - Command-line tool
  - “set priority of task mplayer to 5”
- Programmatically
  - E.g., with QARMA [Gillen et al., 2004]



Evaluation

- Overhead
- *Synthetic applications (correct operation)*
- UAV application

- Experiments performed in Utah's Emulab
  - 850 MHz Pentium III, 512 MB RAM
  - TimeSys Linux/NET 3.1.214, Red Hat 7.3

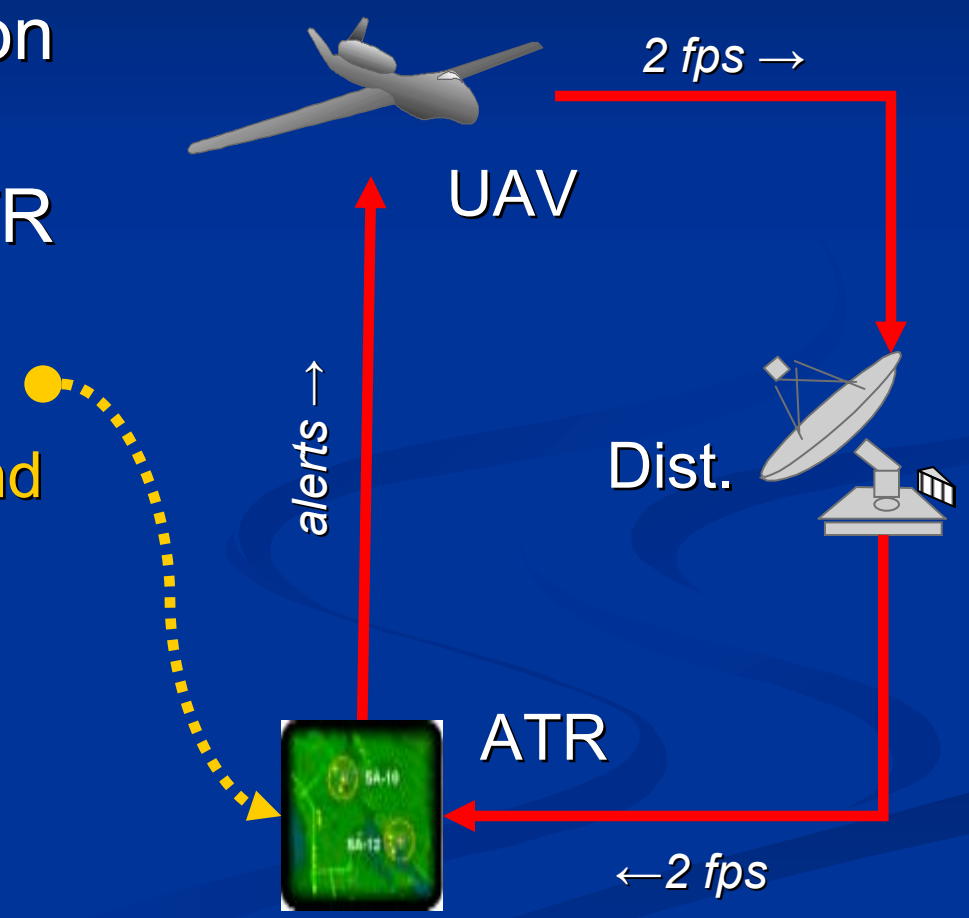
Measured Overhead

Configuration	Monitor+Broker CPU Time (µs)	Monitor Only Real Time (µs)
2-way QuO delegate	1742	1587
1-way QuO delegate	1716	660
In-broker proc. advocate	400	400
	"load"	*"latency"*

- Reasonable and small for many RT applications
- Further optimizations possible

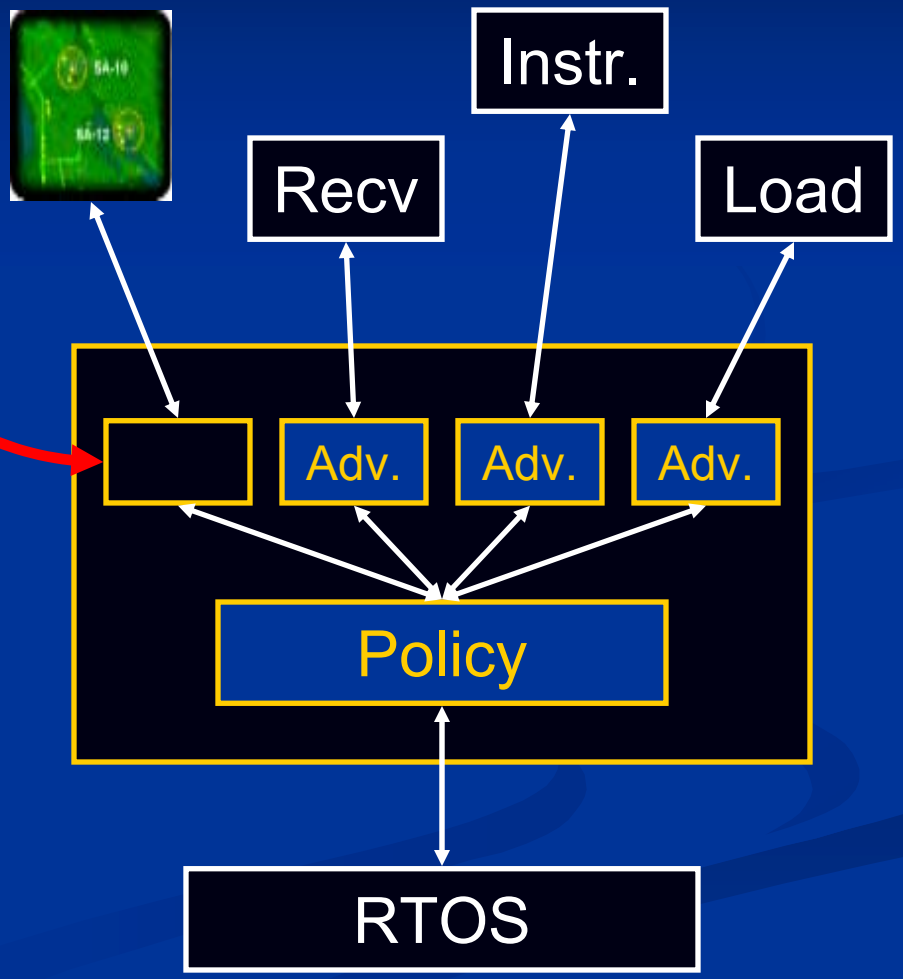
UAV Military Simulation

- Distributed application
  - Soft real-time
- Broker applied at ATR
  - Java process
  - Multi-threaded
  - Irregular CPU demand
- Goals
  - Ensure ATR meets deadlines
  - Allow high system utility

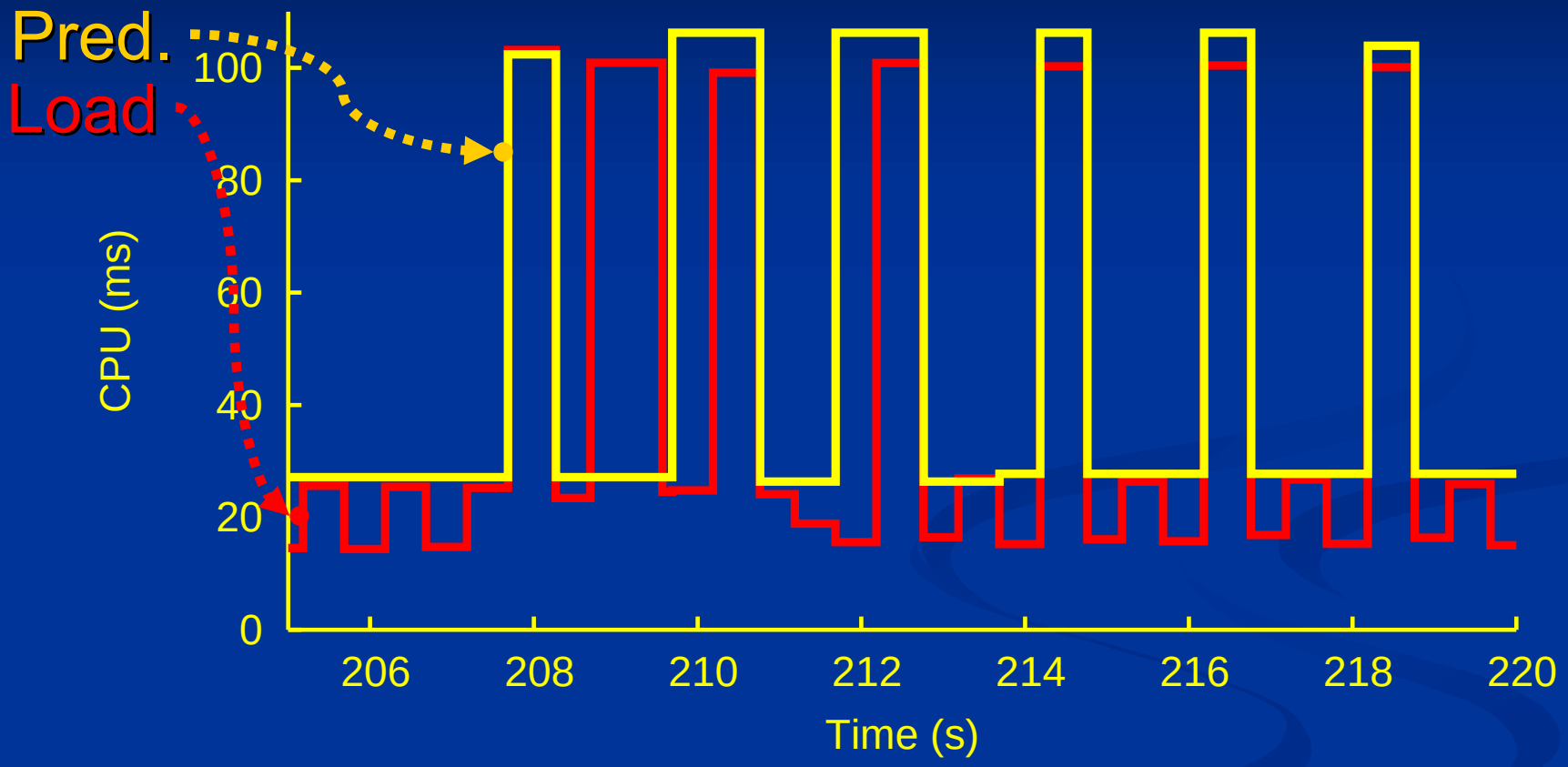


Broker Extension

- Custom advocate for ATR
  - Predict GC cycles from recent CPU demand
- Other broker objects from our library



Utility: Custom Advocate



- Custom advocate accurately predicts demand, allowing high system utility

Resilience to CPU Load

Metric	Unloaded, Baseline	CPU Load	CPU Load, With Broker
Frames processed	**432**	320	**432**
Avg. FPS	**1.84**	1.32	**1.81**
Min. FPS	1.67	0.45	1.11
Max. FPS	**2.00**	2.01	**1.99**
Std. Dev.	**0.09**	0.34	**0.09**
Alerts received	**76**	50	**76**
Avg. latency	127.67	1560.44	325.72
Min. latency (ms)	101.00	362.00	145.00
Max. latency (ms)	193.00	3478.00	**933.00**
Std. Dev.	33.46	961.62	153.60

Conclusions

- Dynamic RT systems face critical design-time and run-time challenges
- Our CPU Broker successfully addresses many of these challenges
  - specifications: separated and consolidated
  - dynamic: negotiations atop reservations
  - open framework: extension and integration
- →More modular and understandable RT

Open Source

- CPU Broker available online
- http://www.cs.utah.edu/flux/alchemy/