Extending Real-Time CORBA for Next-Generation Distributed Real-Time Mission-Critical Systems

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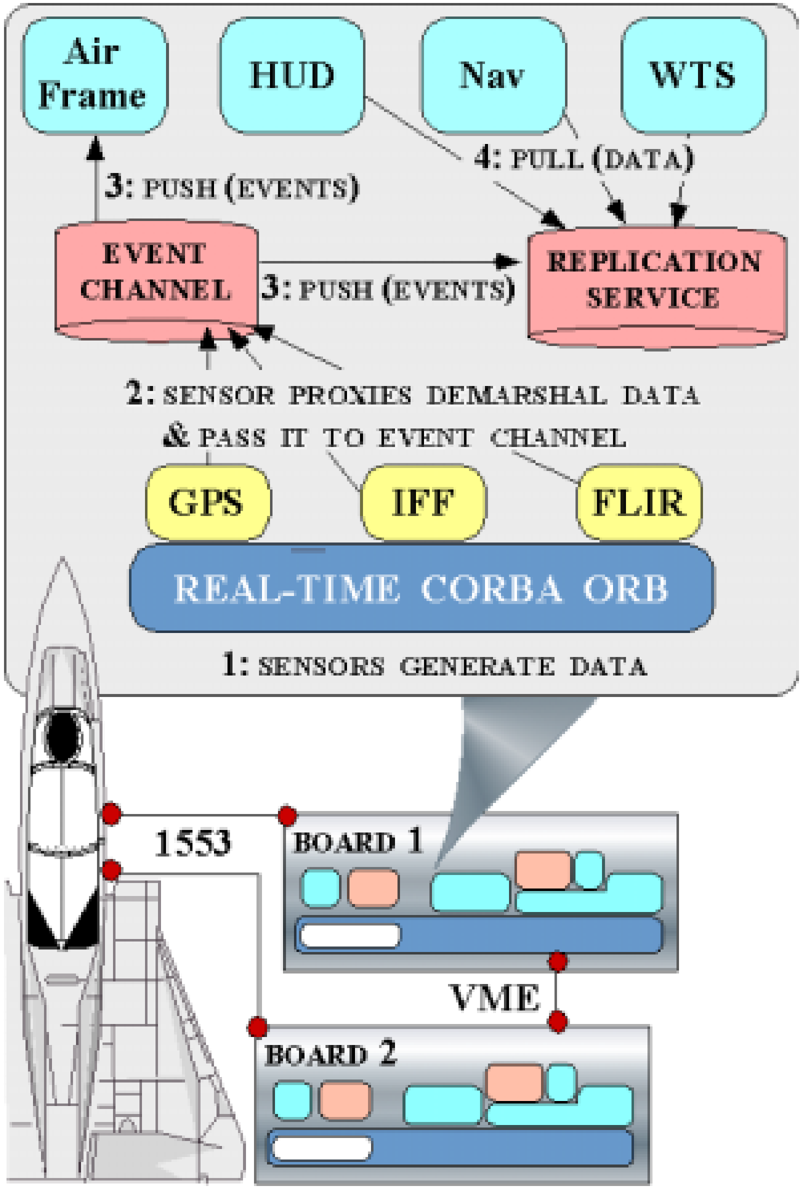
Motivating Application



Boeing Bold Stroke Middleware Infrastructure Platform

- Used on CRAD, IRAD, and production systems
- Research conduit to production systems

Operations Well Defined

- Harmonic rates, bounded execution times
- Need criticality isolation assurances

Event Mediated Middleware Solution

- RT Enhanced TAO Event Channel
- Precedence DAG, scheduler per endsystem

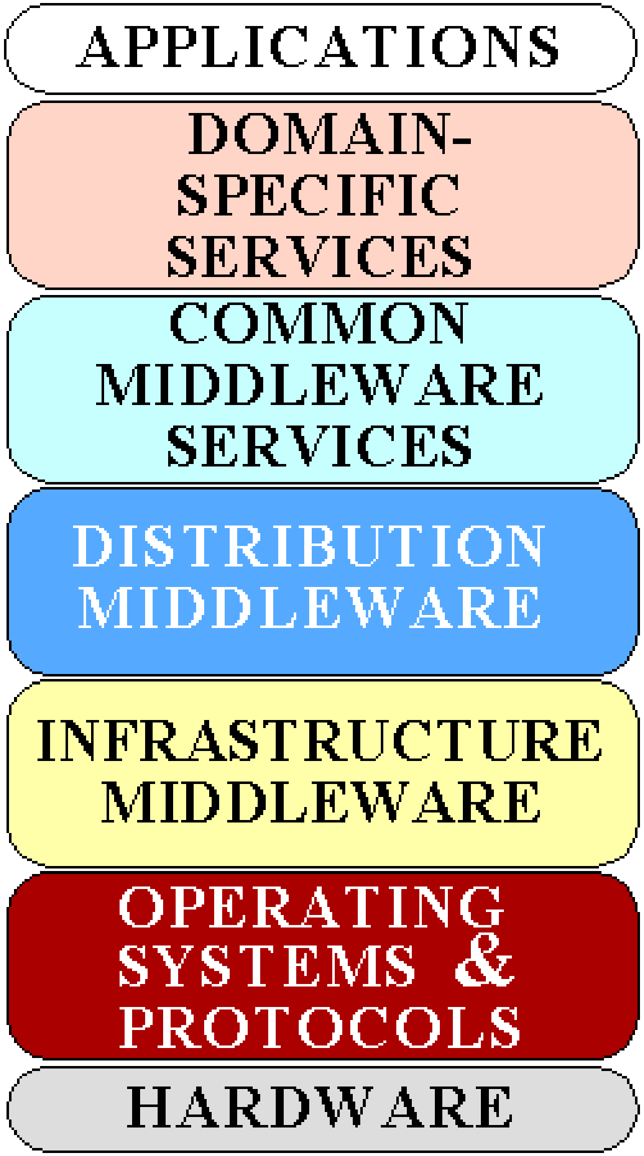
Previous Generation Systems

- Fixed environment, static modes
- Used cyclic exec or RMS scheduling

Next Generation Systems

- Highly variable environment
- Large # of system states, dynamic modes
- Need *dynamic* & *adaptive* resource mgmt
- Need coordinated closed-loop QoS control
  - –Across time-scales, system layers
  - –*E.g.,* ACE+TAO, QuO, RT-ARM

Limitations With Existing Approaches



Historically, distributed and embedded RT systems built directly atop hardware/OS

- **Tedious, error-prone, & costly over lifecycles**

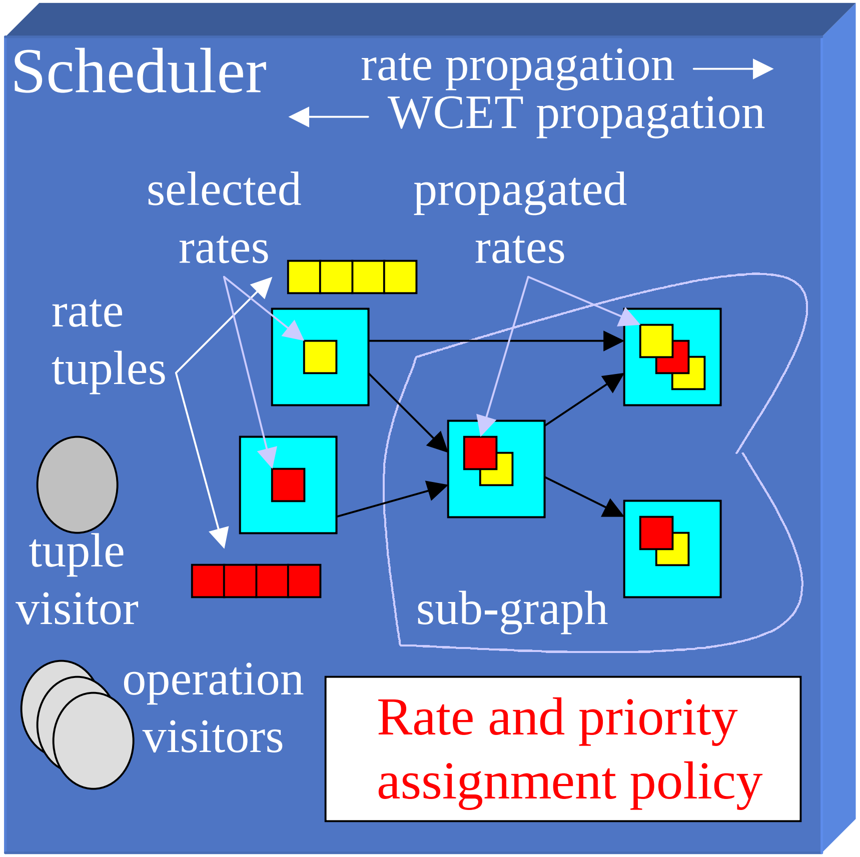
COTS middleware (*e.g.*, CORBA) increasingly used to lower cost/time in real-world systems:

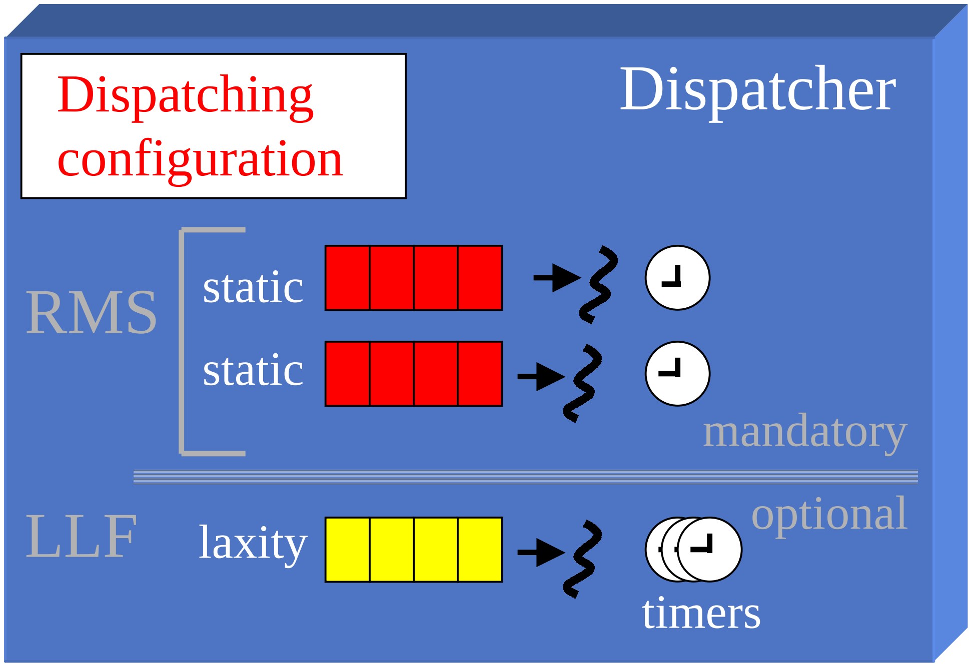
Domain	Company
Avionics mission computing	Boeing, Raytheon
Mass storage devices	SUTMYN, StorTek
Medical Information Systems	Siemens, GE
Satellite Control	LMCO COMSAT
Telecommunications	Motorola, Lucent, Nortel, Cisco, Siemens
Missile & Radar Systems	LMCO Sanders, Raytheon
Steel Manufacturing	Siemens ATD
Beverage Bottling Automation	Krones AG

However, current COTS middleware lacks hooks for key domain-specific features, *e.g.*:

- **Optimized integration w/ higher level managers**
- **Hybrid static-dynamic scheduling strategies**
- **Composition of scheduling strategies & dispatching mechanisms from primitive elements**
- **Adaptive domain-specific & run-time optimizations**

Research Approach: the *Kokyu* Flexible Middleware Scheduling/Dispatching Framework





Application specifies *characteristics*
- *e.g.*, criticality, periods, dependencies

Scheduler assigns *rates & priorities* per topology, scheduling policy
- Defines necessary dispatch configuration

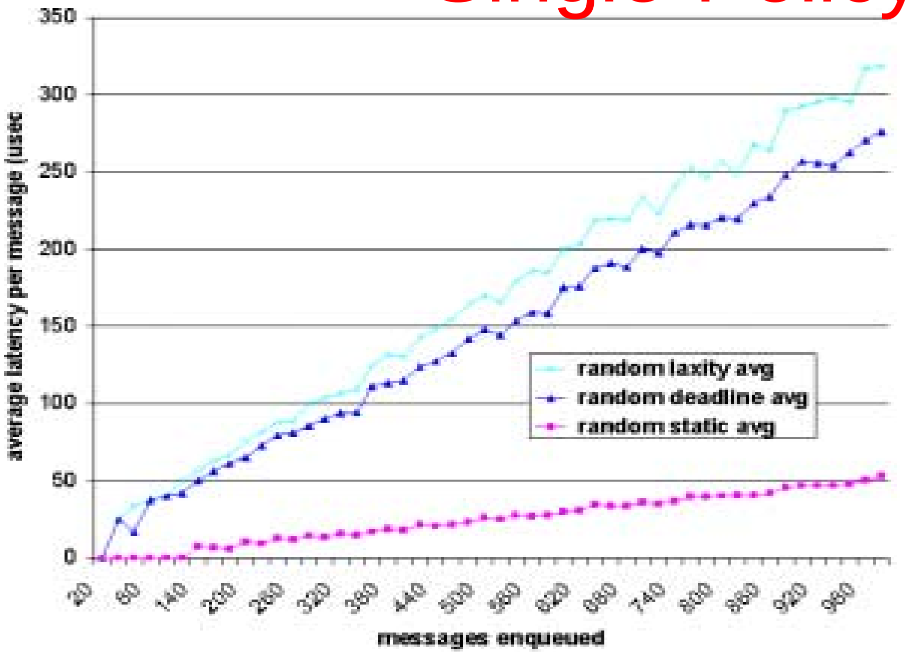
Dispatcher is (re)configurable
- Multiple priority lanes
- *Queue, thread, timers* per lane
- Starts repetitive timers once
- Looks up lane on each arrival

Implicit *projection*
- Of specific scheduling policy into generic dispatch infrastructure

Tailoring Scheduling Heuristic to Domain/State

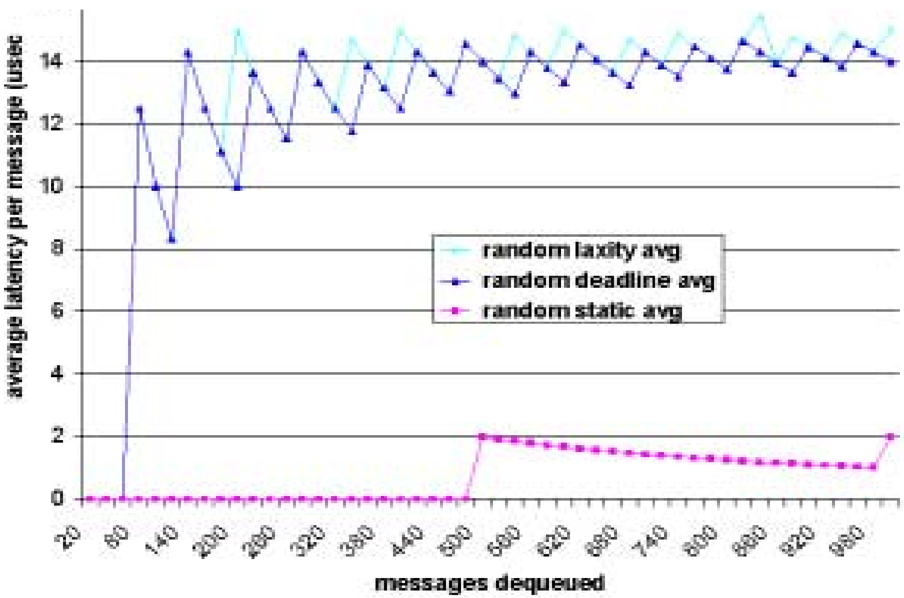
Technical Challenge	Research Approach	Research Impact
No one strategy optimal for every resource “niche”	Dispatching composed from primitive elements	Supports tailored “fit” of scheduling/dispatching
Co-scheduling resource managers and application	Decision lattice joining *a priori* analysis with empirical measurement	Allows run-time reflective and adaptive policy selection (in-progress)

Problem: Limitations with Existing Single-Policy Approaches



Optimal Heuristic Depends on Application-Specific Details:

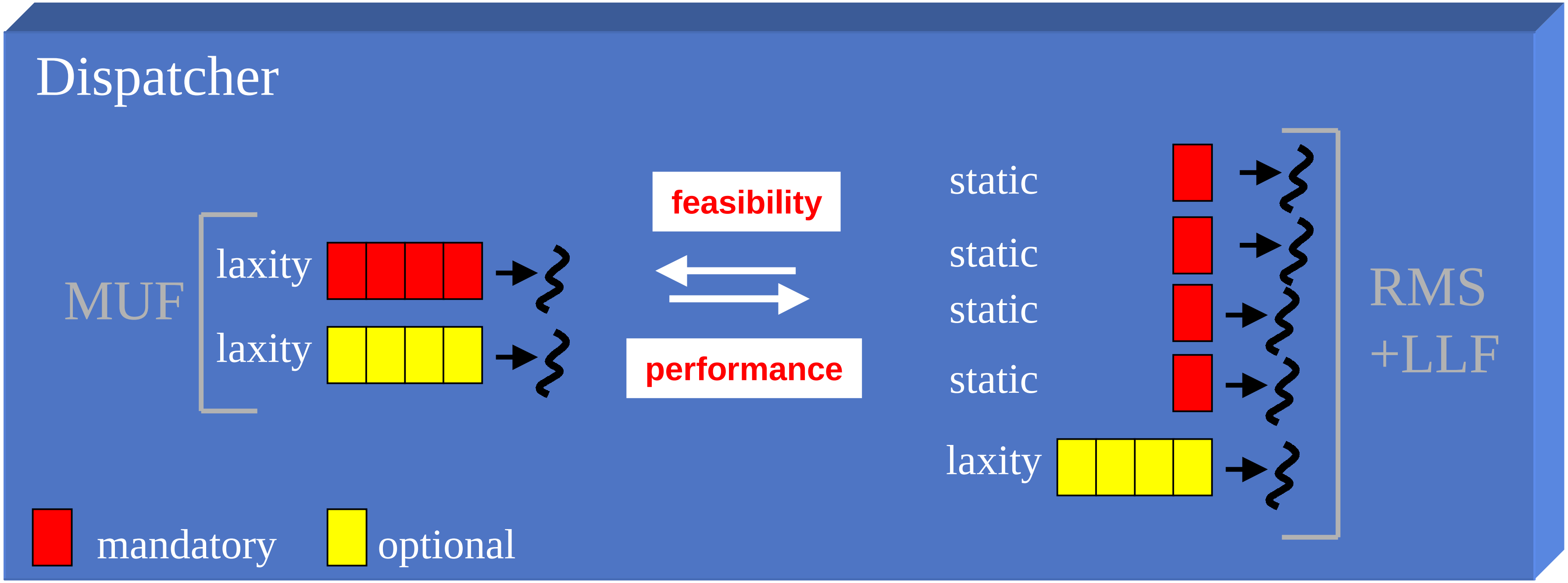
- Example: RMS+LLF vs. MUF when rates are harmonic vs. non-harmonic
  - –Feasibility vs. performance



Performance of Three Canonical Queue Ordering Disciplines

- Simple test with queue classes
- Randomly ordered enqueues
- Static → fixed sub-priority
- Deadline → time to deadline
- Laxity → time to deadline – WCET
- Enqueue overhead worse with > load
- Overhead: static << deadline < laxity

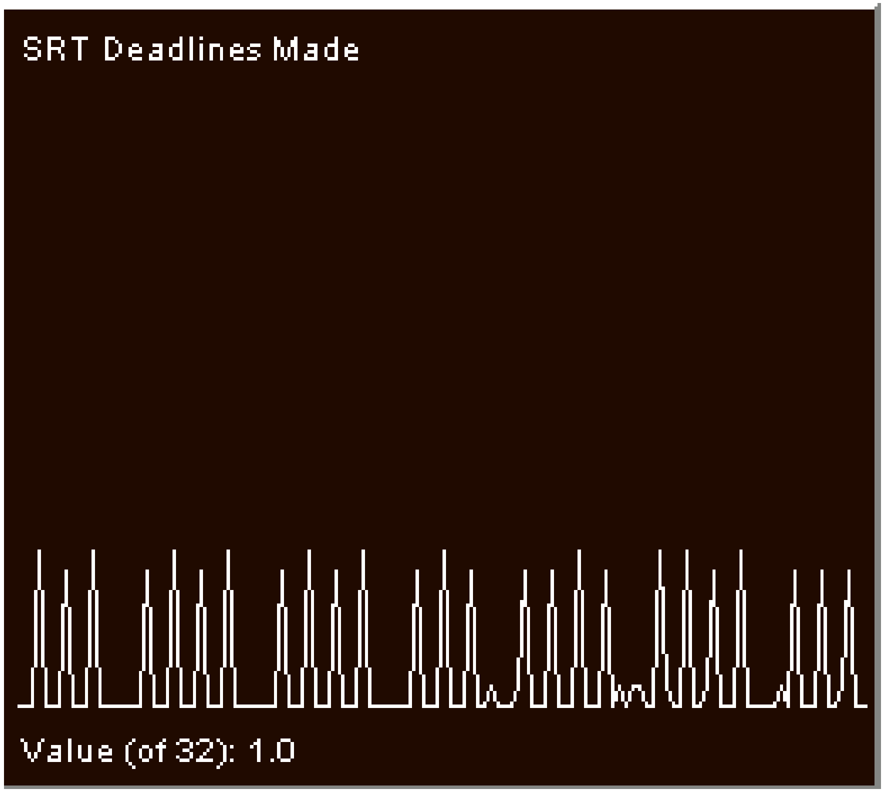
Solution: Composition of Scheduling Heuristics from Dispatching Primitives



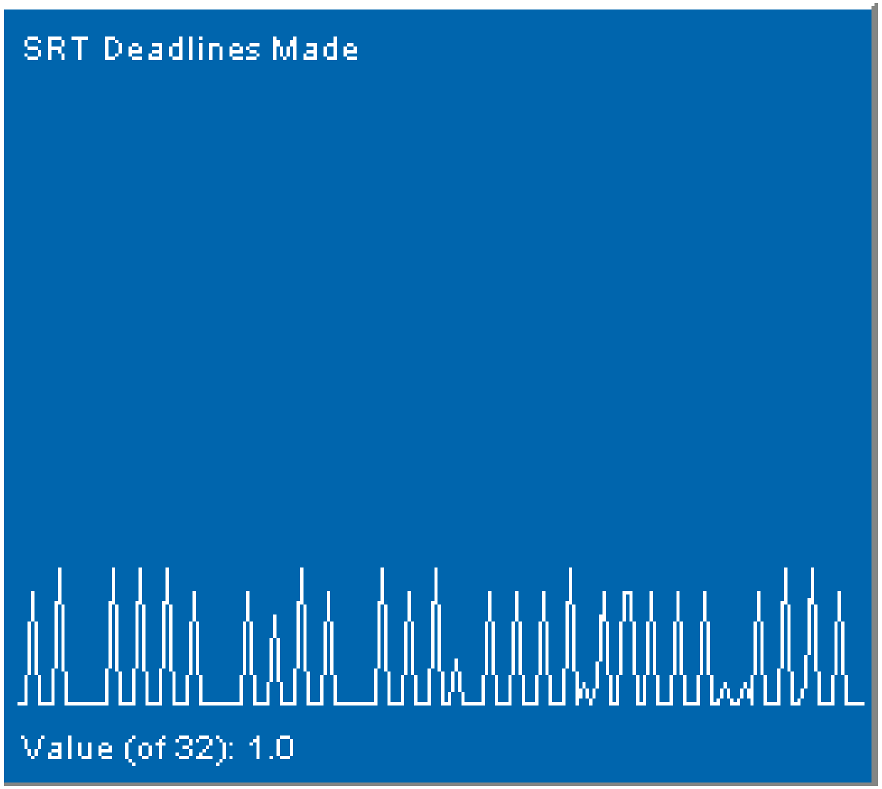
Gives Fine Grain Control over Feasibility / Performance Trade-Off

- With non-harmonic rates MUF may be feasible but RMS+LLF infeasible
- However MUF dispatching overhead is expected to be worse
  - Only 2 threads, but queue management/contention likely dominates
  - mandatory - 1 laxity queue, optional - 1 laxity queue
- RMS+LLF performance is expected to be better, if feasible
  - 5 threads but greater fan-out of critical operations = lower contention
  - Mandatory – 4 static queues, optional - 1 laxity queue

Empirical Results: Tailored Policy Improves Deadline Success of Optional Operations



RMS+LLF Optional Operations



MUF Optional Operations

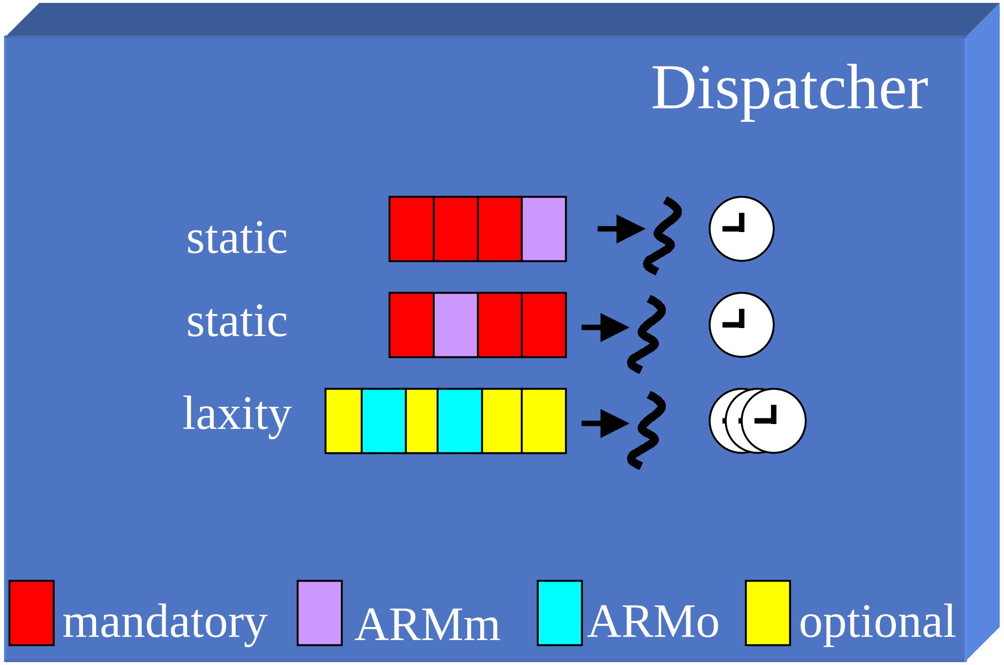
ASFD: Expectations from Theory and Measurement Confirmed

- **Some improvement of RMS+LLF over MUF in practice**
  - **Made more optional operation deadlines under same overload conditions**
- **Lower overhead/queue & greater fan-out across queues in RMS+LLF**

Co-Scheduling Resource Managers & Application

Technical Challenge	**Research Approach**	**Research Impact**
No one strategy optimal for each resource "niche"	Dispatching composed from primitive elements	Supports tailored "fit" of scheduling/dispatching
Co-scheduling resource managers and application	Decision lattice joining *a priori* analysis with empirical measurement	Allows run-time reflective and adaptive policy selection (in-progress)

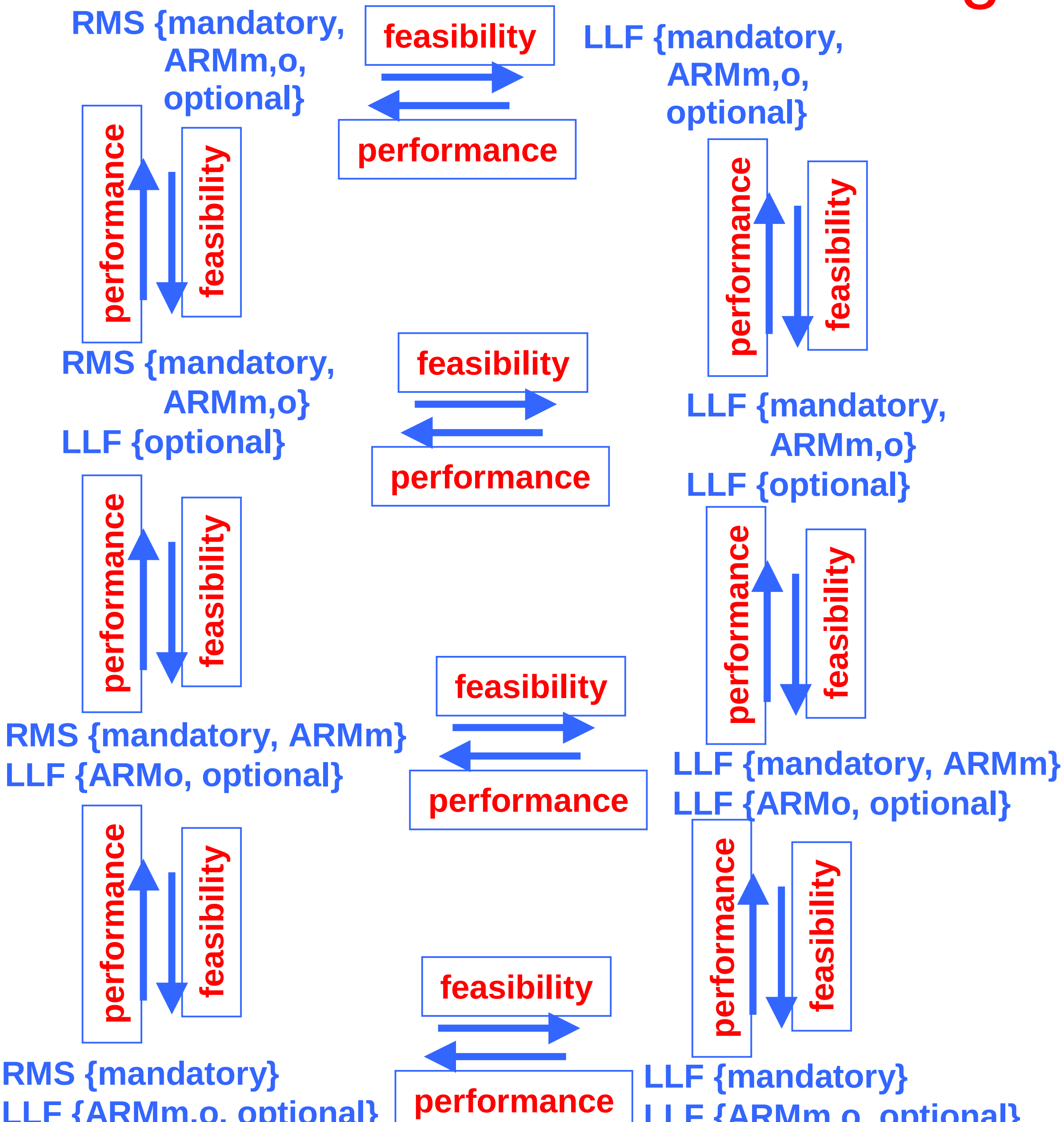
Problem: Limitations with Existing Approaches to Co-Scheduling ARM and Application



Previously *ad hoc*

- **Scheduled entire RT-ARM in a single priority lane**
- **However, RT-ARM is also divisible into mandatory and optional sets**
  - **Mandatory: could we adapt?**
  - **Optional: perform adaptation**
- **Key: mandatory + ARMm feasible**
  - **Or, no assurance of coherency**
- **Natural criticality partition over the set of all operations**
  - **Application mandatory**
  - **ARM mandatory**
  - **ARM optional**
  - **Application optional**
- **Given all this, we can do better**

Solution: Use Empirical & *A Priori* Information to Co-Schedule Resource Mgrs & Applications



Preserve Invariant, but Optimize Performance

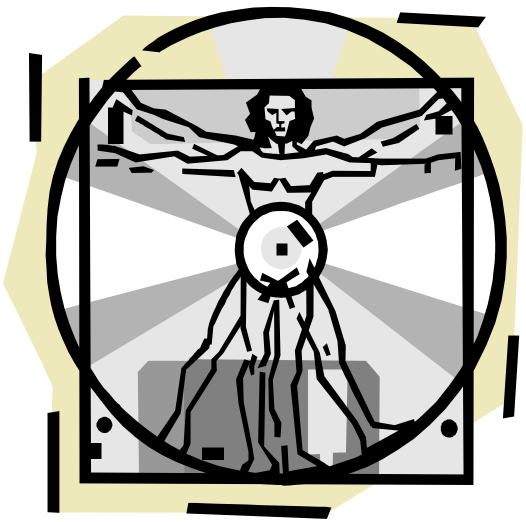
- Criticality: values partition ops for deadline isolation
- Definition: system schedulable if highest partition feasible
- Invariant: no lower partition can make a higher one infeasible
- Key: invariant strength
  - *e.g.,* 1:1 criticality to priority over-constrains
  - Want safe optimizations

Decision Lattice (experiments in progress)

- A rich optimization space: topological? geometric?
- Spans criticality → prio/queue mappings
- *E.g.,* over 4 partitions: {mandatory},{ARMm}, {ARMo},{optional}

Concluding Remarks

The Kokyu research project provides solutions to key challenges for optimized and adaptive QoS support in middleware



Empirical Evaluation

- **Validates adaptive/hybrid scheduling approach**
- **Quantifies costs/benefits of discrete alternatives**
- **Powerful when combined with theoretical view**
  - ***"Mining"* technique for problems & properties**

Composable Dispatching

- **Enables domain-specific optimizations, *especially* when design decisions are aided by empirical data**

Heuristic Space Experiments

- **Will offer a quantitative blueprint for co-scheduling RT-ARM with OFP applications**
- **Will demonstrate a general co-scheduling technique where theory & empirical studies meet**

Open-Source Code

- **All software described here that is uniquely a part of my research will be made available in the ACE_wrappers distribution**
  - **First within TAO, then as a distinct *Kokyu* directory (summer 2001)**