Applying Adaptive & Reflective Middleware to Optimize Distributed Embedded Systems

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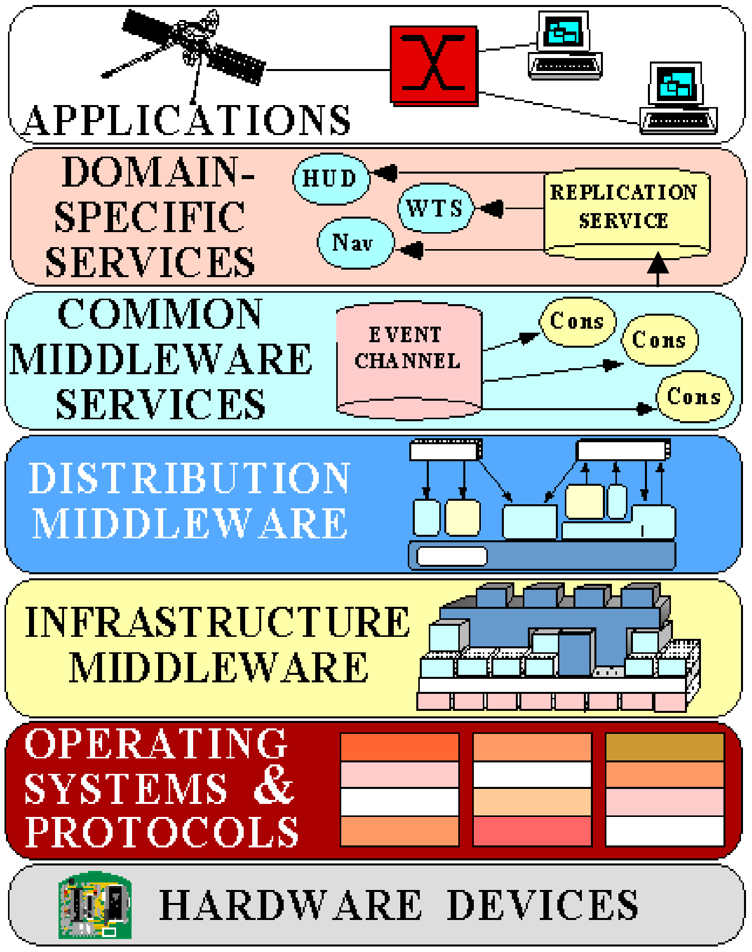
R&D Challenges for COTS-based Mission-Critical Distributed Systems



Historically, mission-critical apps were built directly atop hardware & OS

- Tedious, error-prone, & costly over lifecycles

Standards-based COTS middleware helps:

- Manage end-to-end resources
- Leverage HW/SW technology advances
- Evolve to new environments & requirements

The domain-specific services layer is where system integrators can provide the most value & derive the most benefits

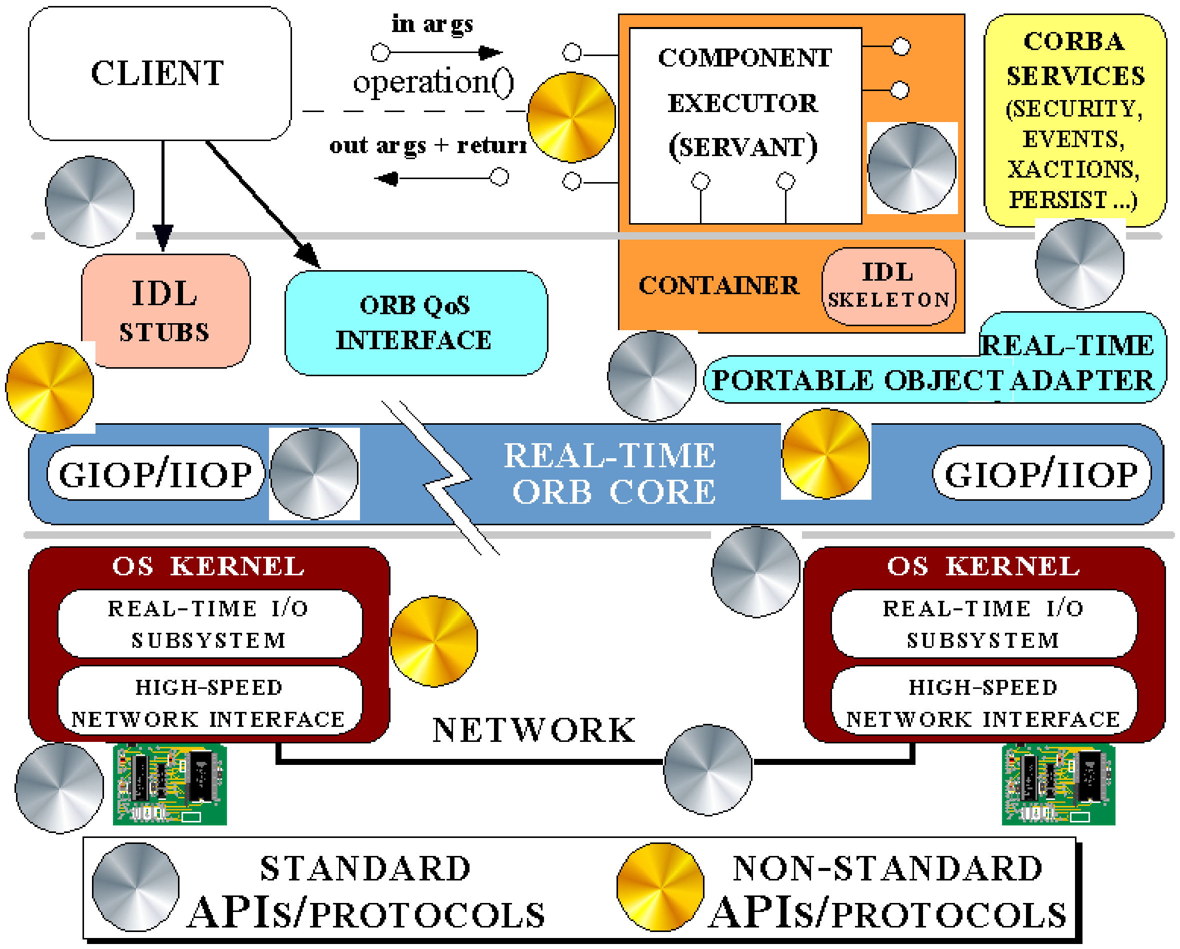
There are multiple COTS layers & research/ business opportunities

Key R&D challenges include:

- **Layered QoS specification & enforcement**
- **Separating policies & mechanisms across layers**
- **Time/space optimizations for middleware & apps**
- **Layered resource management & optimization**
- **High confidence**
- **Stable & robust adaptive systems**

Prior R&D programs have address some, *but by no means all*, of these issues

Pros & Cons of COTS



Historically, COTS tightly couples *functional* with *QoS* aspects

- *e.g.*, due to lack of "hooks"

Many hardware & software APIs and protocols are now standardized, *e.g.:*

- Intel x86 & Power PC chipsets
- TCP/IP, ATM
- POSIX & JVMs
- CORBA ORBs & components
- Ada, C, C++, RT Java

COTS standards promote reuse via "narrow-waist" architectures

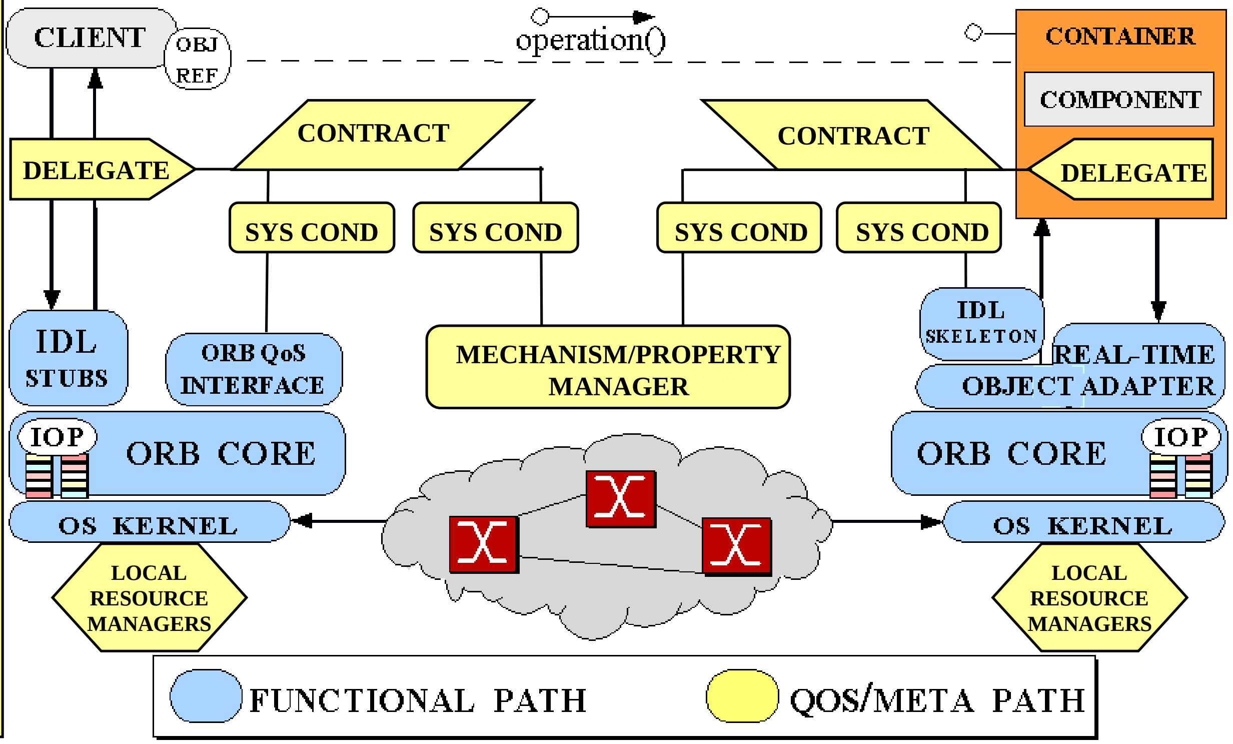
However, they also limit design choices, *e.g.:*

- Networking protocols
- Concurrency & scheduling
- Demultiplexing
- Caching
- Fault tolerance
- Security

Promising New Approach: Adaptive & Reflective Middleware

Adaptive & reflective middleware is middleware whose functional or QoS-related properties can be modified either

- *Statically*, *e.g.*, to better allocate resources that can optimized *a priori* or
- *Dynamically*, *e.g.*, in response to changes in environment conditions or requirements

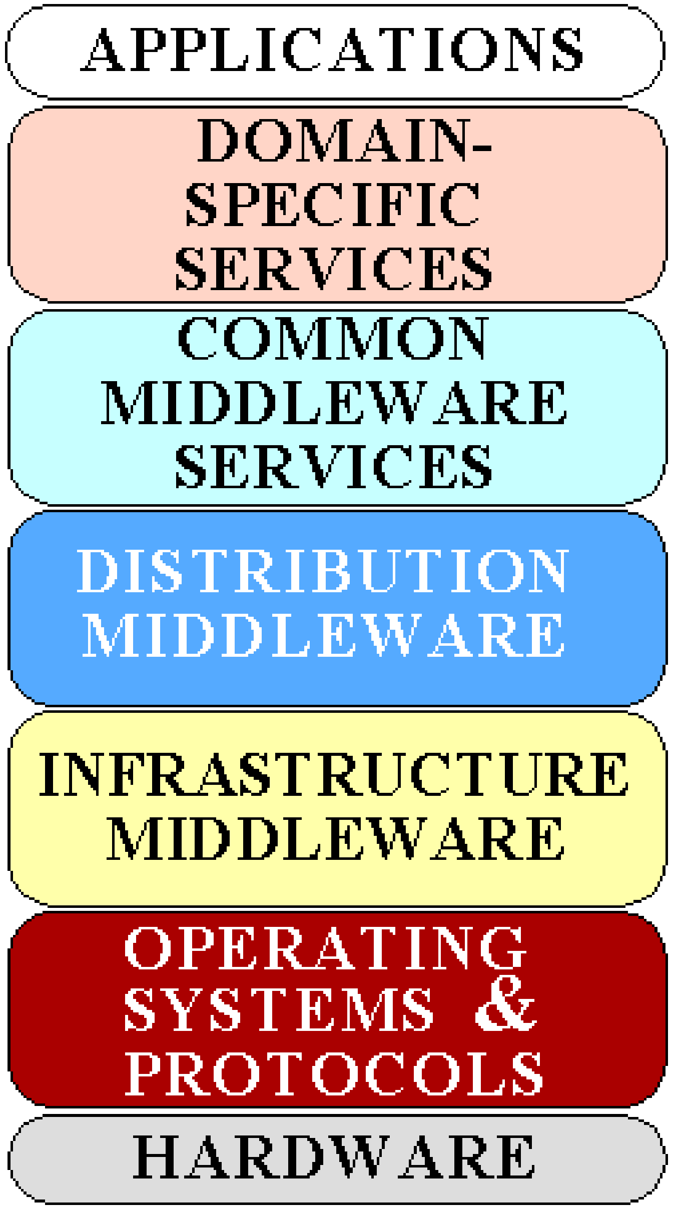


Research Challenges

- Preserve *critical set* of application QoS properties end-to-end
  - *e.g.*, efficiency, predictability, scalability, dependability, & security
- Achieve *load invariant* performance & system *stability*

- Maximize *longevity* in wireless & mobile environments
  - *e.g.*, control power-aware hardware via power-aware middleware
- Automatically generate & integrate *multiple QoS properties*

COTS Challenges for Embedded Systems


APPLICATIONS
DOMAIN-SPECIFIC SERVICES
COMMON MIDDLEWARE SERVICES
DISTRIBUTION MIDDLEWARE
INFRASTRUCTURE MIDDLEWARE
OPERATING SYSTEMS & PROTOCOLS
HARDWARE

COTS middleware has historically been unsuited for embedded systems due to

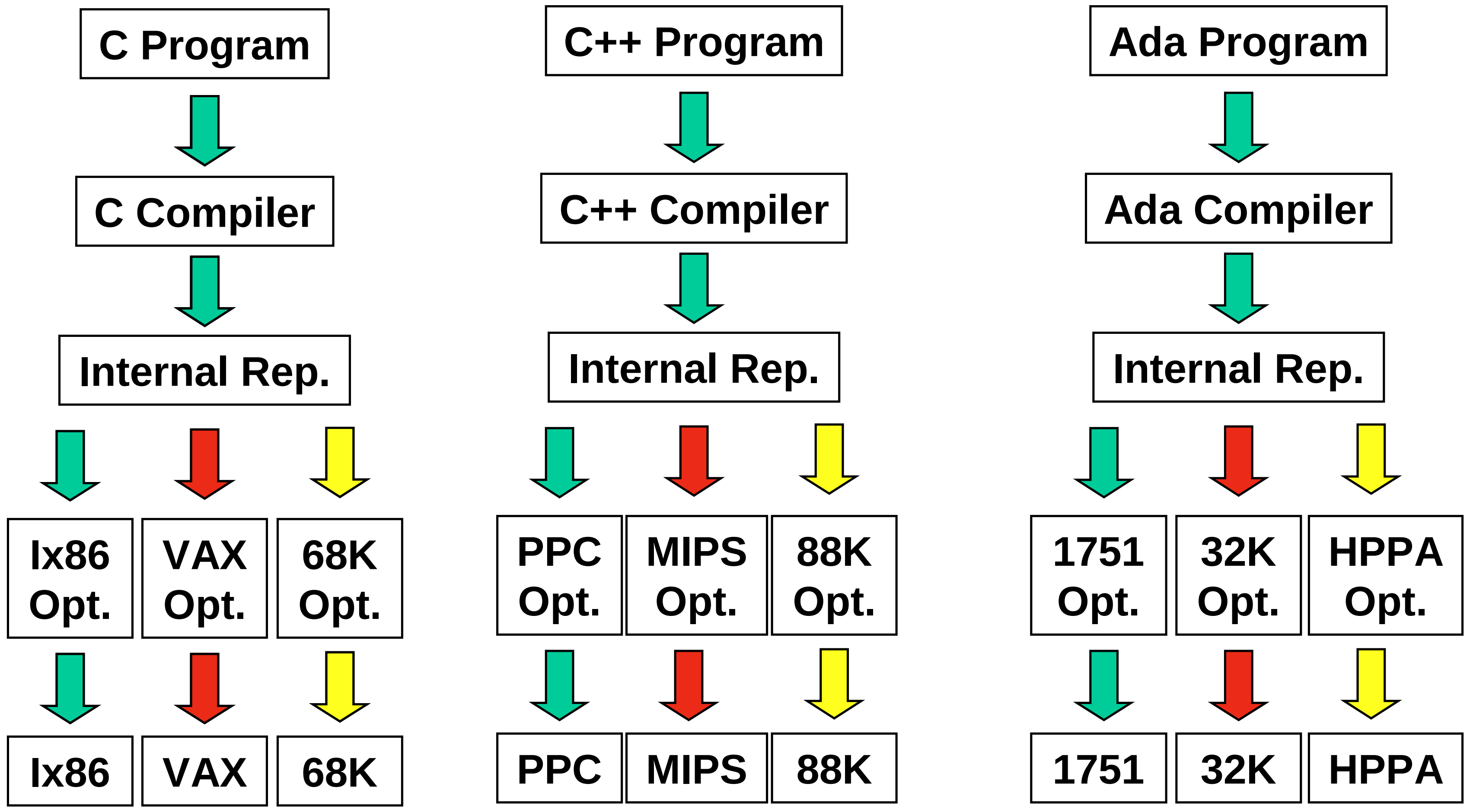
- Inadequate support for QoS specification & enforcement
- Inadequate time/space optimizations
- Inadequate flexibility & customizability

Conventional solutions to this problem are either

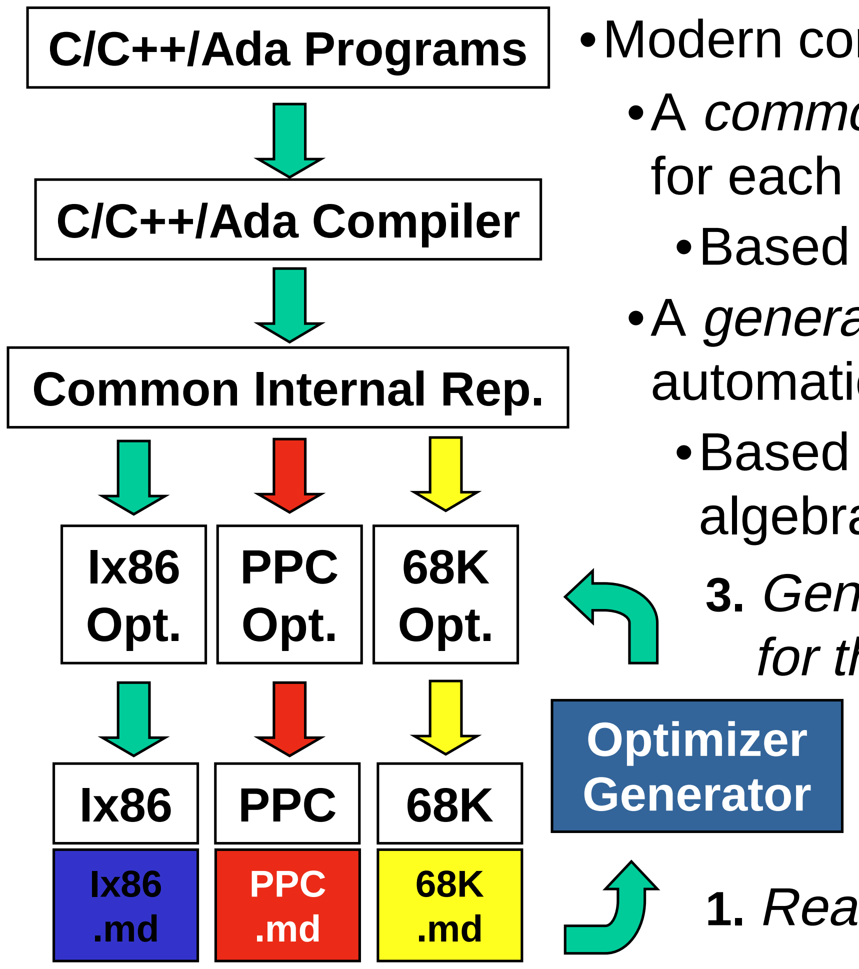
- *Tedious*
  - *e.g.*, reimplement application from scratch
- *Proprietary*
  - *e.g.*, reimplement middleware from scratch
- *Manual & ad hoc*
  - *e.g.*, subset existing COTS middleware

Applying Reflection as an Optimization Technique

To illustrate the benefits of reflection as an optimization technique, consider the evolution of compiler technology:



Applying Reflection as an Optimization Technique



- Modern compilers, such as GNU GCC, support
  - A *common* internal representation (still hand-written) for each programming language
    - Based on *generalizing the language semantics*
  - A *generated* optimizer that is customized automatically for each target backend
    - Based on *reflective* assessment of algebraic target machine description

3. *Generate an optimizer that is customized for the particular platform/language*

2. *Use discrimination network to analyze the optimization rules & opportunities*

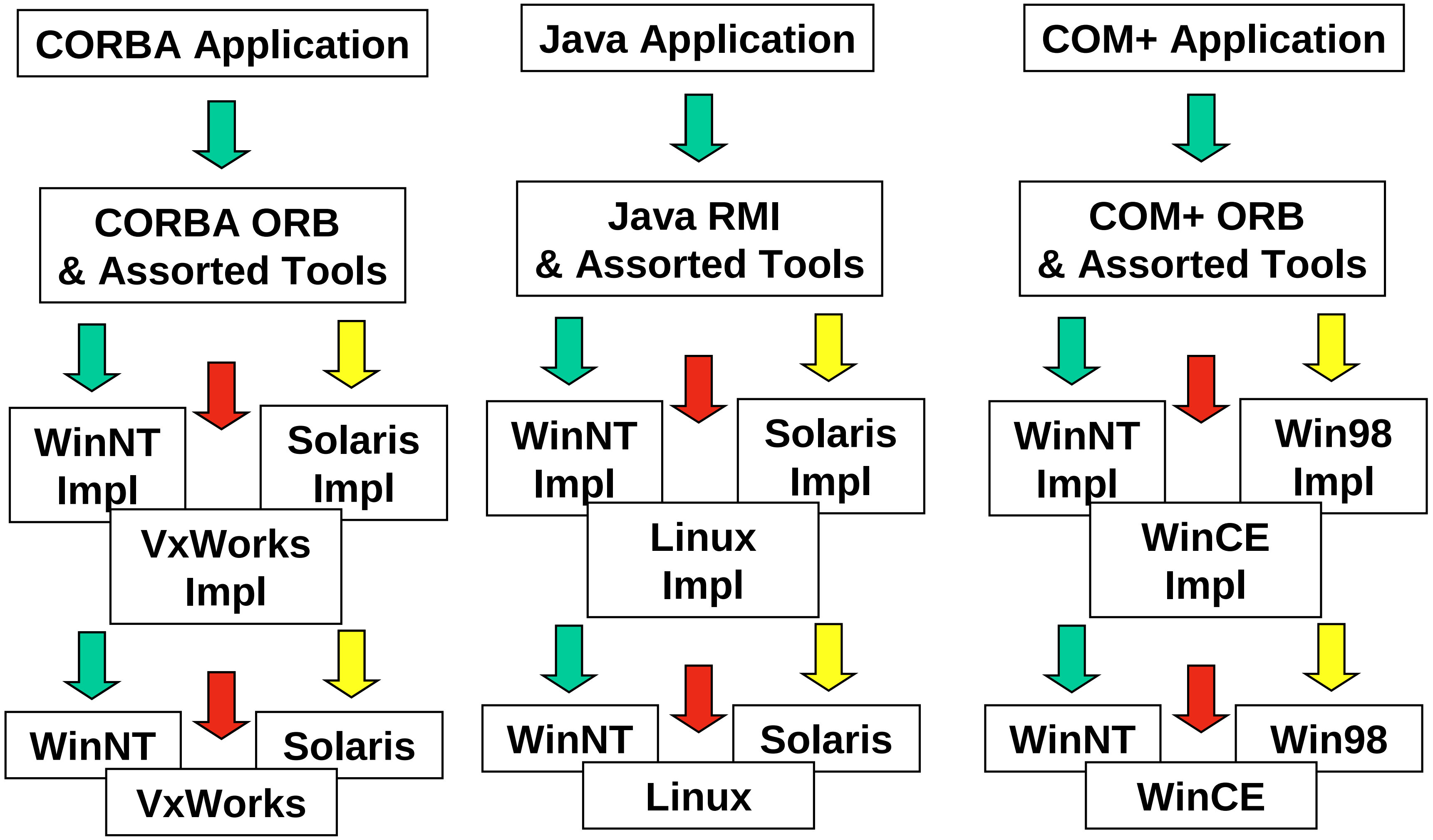
1. *Read the target machine description*

Key Benefit of "Static" Reflection

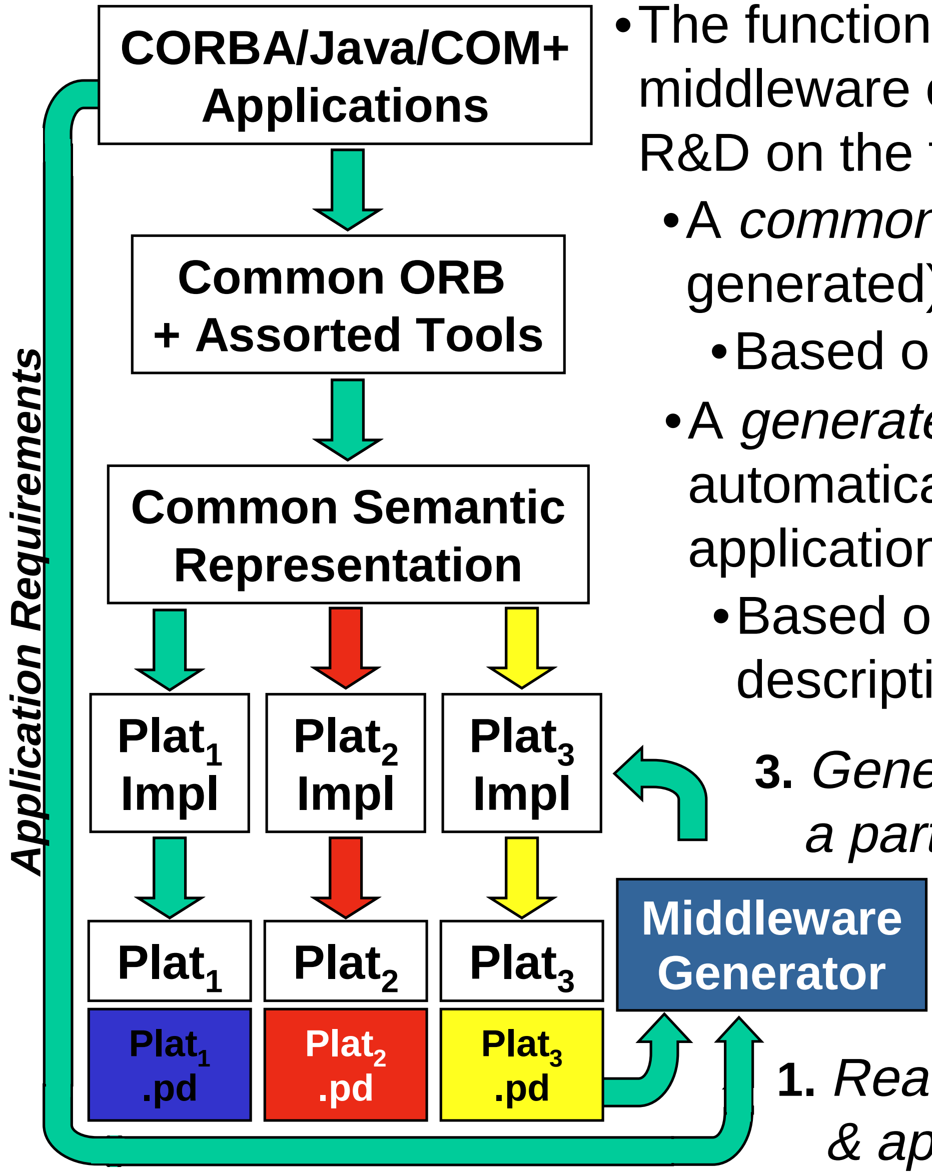
- New targets can be supported by writing a new machine description, rather than writing a new code generator/optimizer

Applying Reflection to Optimize Middleware Statically

Conventional middleware for embedded systems is developed & optimized in a manner similar to early compiler technologies:



Applying Reflection to Optimize Middleware Statically



- The functional and QoS-related aspects of middleware can be improved greatly by advanced R&D on the following topics:
  - A *common* internal representation (ideally auto-generated) for each middleware specification
    - Based on *generalizing the middleware semantics*
  - A *generated* implementation that is optimized automatically for each target platform & application use-case
    - Based on *reflective* assessment of platform descriptions & application use-case

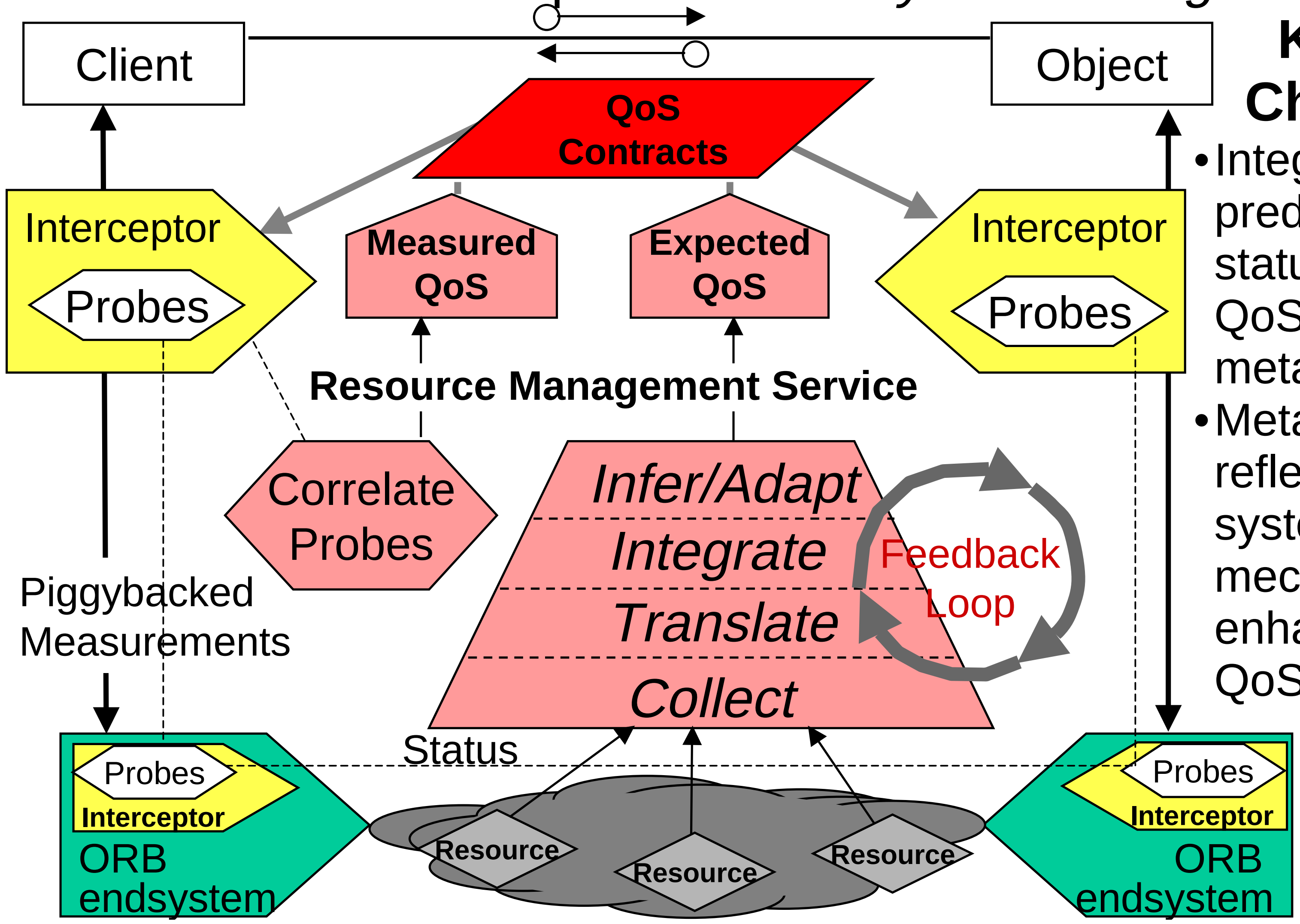
3. *Generate middleware that is customized for a particular platform & application use-case*

2. *Use discrimination network to analyze the optimization rules & opportunities*

1. *Read the target platform description & application requirements*

Applying Reflection to Optimize Middleware Dynamically

Applying reflection as an optimization is even more relevant to middleware than compilers due to *dynamism* & *global resources*:

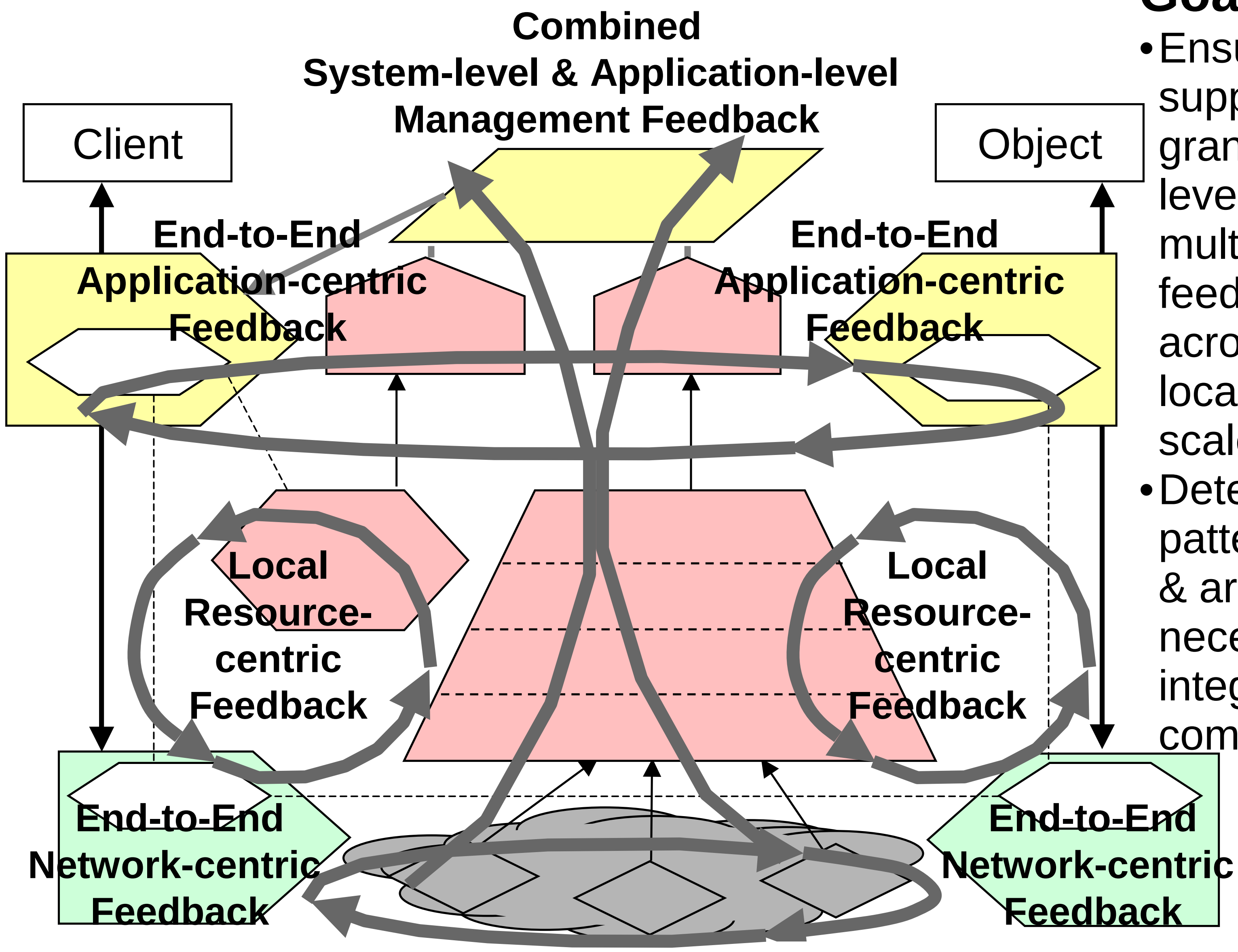


Key System Characteristics

- Integrate observing & predicting of current status & delivered QoS to inform the meta-layer
- Meta-layer applies reflection to adapt system policies & mechanisms to enhance delivered QoS

Key Research Challenge:

Providing QoS Guarantees for Multiple Adaptive Feedback Loops

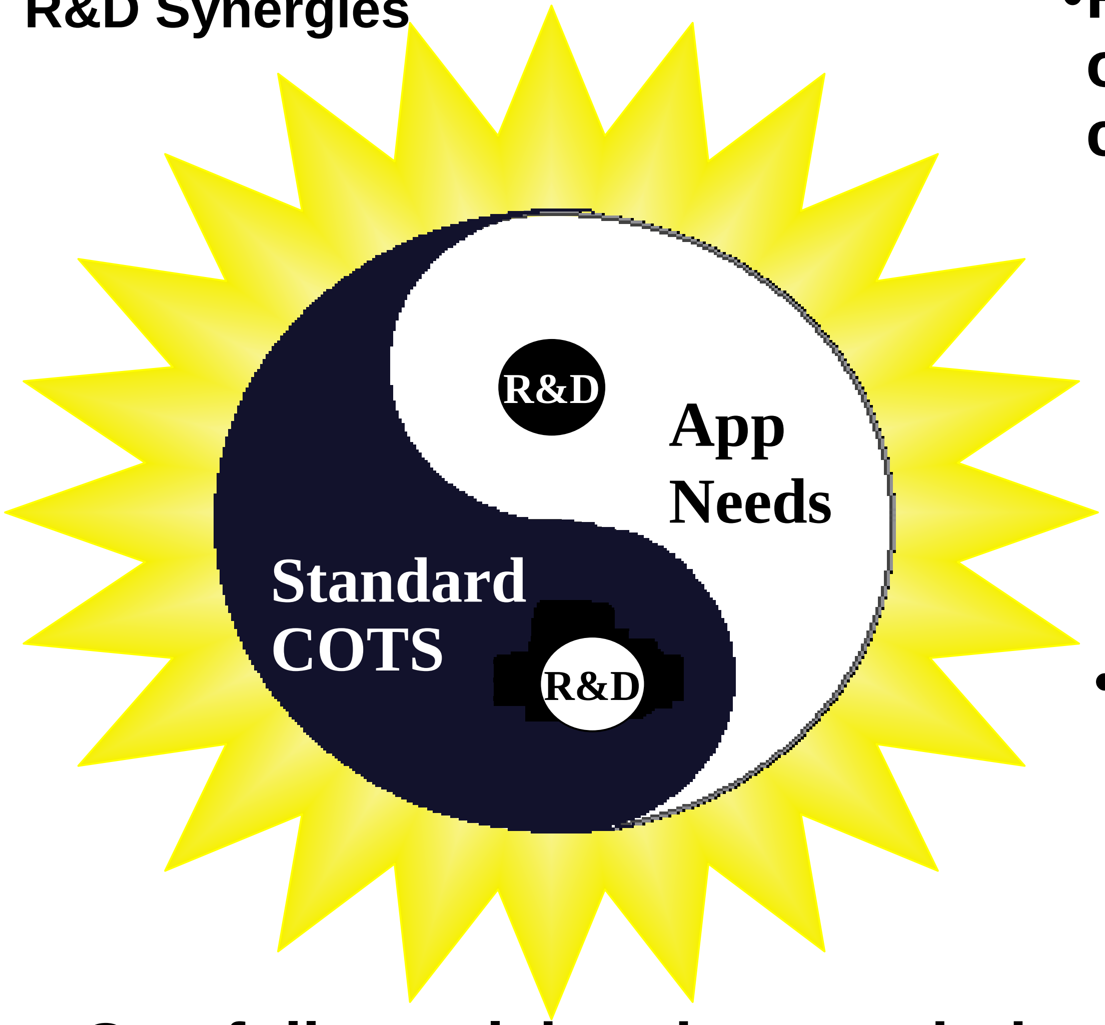


Goals

- Ensuring stable QoS support at varying granularity & scope levels for integrated, multi-property feedback paths across different locations & time scales
- Determining patterns, protocols, & architectures necessary to integrate COTS components

Concluding Remarks

R&D Synergies



- **Researchers & developers of distributed systems face common challenges, *e.g.:***
  - ***Connection management, service initialization, error handling, flow control, event demuxing, distribution, concurrency control, fault tolerance synchronization, scheduling, & persistence***
- **The application of *formal methods* along with *patterns*, *frameworks*, & *components* can help to resolve these challenges**
- **Carefully applying these techniques can yield efficient, scalable, predictable, & flexible middleware & applications**