

# Quality Connector

## A Pattern Language for Provisioning and Managing Quality-Constrained Services in Distributed Real-time and Embedded Systems

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### Abstract

*Over the past decade, substantial progress has been made in the specification and implementation of well-defined and increasingly standardized functional services for distributed real-time and embedded (DRE) systems. Less advanced are mechanisms for specifying and implementing the required qualities of those services in DRE systems. The Quality Connector pattern language consists of a collection of patterns that enable service qualities to be specified and provided in DRE systems, together with constraints and recommendations on how they may be combined. A subset of these patterns are described in this paper.*

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The Quality Connector pattern language consists of patterns and relations among patterns that serve to define and provide constrained qualities of service (QoS) in distributed real-time and embedded (DRE) systems. When applied in appropriate combinations, these patterns serve to

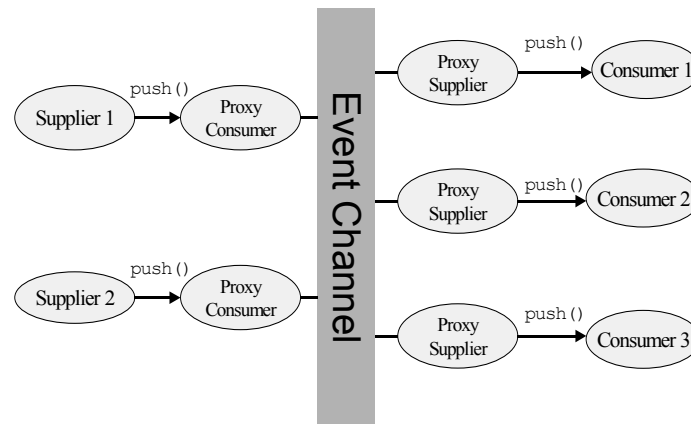
- Provide standard interfaces to non-standard QoS control interfaces
  - Connect applications to QoS control mechanisms transparently to application developers
  - Configure/select services according to application QoS requirements, where the requirements are permitted to depend on environmental conditions and constraints, and on the system's mode
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### Example

CORBA *event channels* [2] decouple communication between suppliers and consumers of data, as shown in Figure 1. An event channel logically mediates the communication from each supplier to all consumers, where by “logical” mediation we mean that the actual communication may use some type of unicast, broadcast, or multicast protocol. In many implementations, however, the event channel object *physically* mediates these communications, *i.e.*, all events are routed through a process where the event channel

object resides. In either case, the communication between suppliers and consumers is decoupled in the sense that

- It is asynchronous, *i.e.*, consumers will receive data some time after a supplier has completed its `push ()` operation, and
- The suppliers and consumers must be aware of the event channel's identity, but need not be aware of each other's identities.



**Figure 1. A Simple CORBA Event Channel**

There is no pre-defined limit on the number of suppliers and consumers that can be connected to a CORBA event channel at any time. Moreover, they can connect and disconnect at any time. There may be many event channels active at one time in a distributed system.<sup>1</sup>

The CORBA specification intentionally leaves many aspects of event channel behavior unspecified. For example, the following properties of event delivery are not specified:

- Latency of event delivery
- Where and how often event data are copied
- Threading and synchronization policies for event dispatching
- What communication mechanism is used to convey the event data from the supplier to the consumers; *e.g.*, which of several radio channels will be used
- How and where event data are buffered, and how large the event data buffers are
- What happens when an event data buffer overflows
- Reliability of event delivery

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<sup>1</sup> Our discussion focuses on the “push” model of event delivery, where a supplier invokes a `push (data)` operation to supply any type of data, and the event channel causes `push (data)` operations to be invoked on the consumers registered with that event channel. In addition to the “push” model, there is also a “pull” model of event delivery, which we do not address in this paper.

- Whether events from one supplier will be delivered to each consumer in the order in which they were supplied, and whether event delivery is causally ordered
- If a consumer connects to an event channel, and if an event is supplied to that channel one minute later, will that consumer receive that event? Does the answer depend on whether the supplier and consumer are on different continents?

Consider a DRE application that uses the CORBA Event Service and that will meet or not meet its requirements depending on the value of one or more of the event delivery properties outlined above. It should be possible to determine whether a given Event Service implementation will successfully support the application. It should also be possible to port the application easily from one implementation of the Event Service to another. Finally, it should be possible to modify the service implementation – including making changes to hardware and revising support software – and retain confidence that the application will continue to function correctly and with the appropriate quality of service.

Most of the preceding desiderata are facilitated if the Event Service implementation exposes configuration controls by which required QoSs can be obtained. On the other hand, unless such configuration controls are standardized across implementations, portability is inhibited.

### **Context**

The Quality Connector pattern language can be applied in a DRE system that has the following characteristics:

- It uses services provided by components, and the qualities of those services are critical to the system's conformance to its requirements,
- The qualities of the services provided by those components can be affected from outside the components (i.e., the components have “knobs” for adjusting QoSs), and
- The cost of maintaining and porting the system over many years is an important determinant of the system's success.

### **Problem**

Many implementations of infrastructure services provide standardized *functional* interfaces, but they expose only non-standard *QoS* interfaces for controlling the qualities of the services provided, such as throughput, latency, jitter, scalability, dependability, and security. When an application uses such a service implementation, three forces arise:

- A quality-sensitive application should be able to monitor, control, and configure the qualities of its supporting services. The required qualities should be permitted to depend on the current system mode (see Sidebars 1 and 2).
- An application that undergoes multiple portings should be capable of executing *without manual modifications* on multiple implementations of infrastructure services with standard functional interfaces.
- For time-critical mode transitions, infrastructure resources, by which we mean resources such as ATM virtual circuits, processors, or radios, must be reallocated quickly to provide the services required in the new mode.

### Sidebar 1: System Modes, Informally

Complex hardware/software systems are often capable of operating in different modes or states. The differences between modes may be based on the different purposes that the system fulfills, as an aircraft that can operate in taxiing mode, takeoff mode, and cruising mode, and the differences between modes may be based on the physical conditions of parts of the system, as a nuclear reactor may be in over-temperature mode.

The value of a mode can change abruptly. For example, the failure of a component can change the mode of a system.

The qualities of distributed communication services that applications require may differ in different modes. Consider the example of a crew entertainment video whose priority drops when the ship enters battle mode. Similarly, the importance of processes within a nuclear reactor control system might be expected to change when the reactor enters the over-temperature mode. The requirement to change provided QoSs when the system changes its mode can be addressed by permitting applications to specify their QoS requirements as a function of mode. This provides the opportunity for the system to plan resource allocations before the resources are needed.

A related problem arises when a mode changes but QoS requirements do not change. When the failure of a resource, such as a LAN, occurs and requirements which that LAN had been supporting remain in effect, then new resources must be identified and configured into operation as quickly as possible. This operation is often called "fault reconfiguration."

### Sidebar 2: System Modes, Formally

Let the hierarchy of parts that constitute a system be called *configuration items*. A configuration item may be *small* (such as a motherboard in a computer) or *large* (such as a ship). A configuration item may exist statically (as does a router) or may be created and destroyed dynamically (as is a thread within a process). Configuration items may contain other configuration items; this containment relation forms a *directed acyclic graph* (the containment relation on configuration items need not form a tree or set of trees since some configuration items may be part of several others, e.g., a LAN may be part of the combat system configuration item and part of the command and control system configuration item).

We assume that every configuration item is always in one of a fixed, finite set of states; different types of configuration items may have different sets of states. For example, a workstation may be in a training state or an operational state, and a radar may be in a search state, tracking state, self-test state, or off-line state. The state of a configuration item may (but need not) be a function of the states of its contained configuration items.

We can now define a system *mode* as a Boolean function on the states of its constituent configuration items. For example, "the ship is in battle state" is a mode, and "all ATM backbone configuration items are in their operational states" is a mode. Since many Boolean functions have the value true on any given set of states of configuration items, it follows that a system is simultaneously in many modes.

## Solution

Implement a *Quality Connector* pattern for each infrastructure component<sup>2</sup> that provides only a non-standard QoS-control interface. The Quality Connector pattern configures the infrastructure component to provide, if possible, the requested QoS in the specified system modes. The interface between the application and the components of the Quality Connector should be independent of the choice of infrastructure component implementation and should be concerned only with

- The qualities of the service provided
- The load that will be imposed on the service and
- The modes of the system.

*In detail:* Before the application source code is compiled, a *static application connector* acts on that code (or on some higher-level representation of it, such as a model), inserting hooks through which the *dynamic connector* will act at application run-time to configure the infrastructure components. In addition, a *static infrastructure connector* selects and configures the implementations of infrastructure services before the system is linked.

If a new infrastructure component implementation is employed, then a corresponding Quality Connector component will be required that provides the same interface to the application as before. The application will therefore not require manual changes to its functionality. The runtime interface between the Quality Connector component and the component implementation depends on the infrastructure component's QoS-control interface.

## Structure

The Quality Connection pattern language consists of three broad categories of components:

### Static Application Connector

A *Static Application Connector* component acts on the application source code before it is compiled and may operate similarly to “aspect weaving” tools, such as AspectJ [12], or using a code generation approach as in QuO [6]. For example, a Static Application Connector may scan the application source code to detect statements and declarations that are related to the service being provided. This detection process may be as sophisticated as that used in globally optimizing compilers or as simple as the detection of flags embedded in comments. A Static Application Connector then modifies the source code at certain of these locations, generating new source code.

- ↳ For example, consider an application that intends to supply events to the Event Service as described in the Example section above, and whose QoS requirements are known statically. Such an application must first create an Event Service access point called a `ProxyPushConsumer` by invoking the standard `obtain_push_consumer()` method. The Static Application Connector

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<sup>2</sup> An “infrastructure component” is any hardware or software component of the deployable system whose function is to provide infrastructure services to the application; an ORB together with its supporting computing and communication hardware is an example.

component of the Quality Connector locates these method invocations in the application source code, and modifies that code so that, at run-time, the modified code will behave as follows: first it will obtain, instead of a `ProxyPushConsumer`, an object of a subclass thereof, perhaps called `ProxyPushQoSConsumer`; and second, it will invoke methods on that object to specify QoSs, such as `ProxyPushQoSConsumer.setMaxLatency()`.

<p><i>Class</i></p> <p>Static Application Connector</p>	<p><i>Collaborator</i></p> <p>/ Dynamic Connector</p>
<p><i>Responsibility</i></p> <p>/ Accepts QoS specifications for infrastructure services</p> <p>/ Modifies the application source code as required by the Dynamic Connector</p>	

### Static Infrastructure Connector

A *Static Infrastructure Connector* component acts on the underlying middleware components before they are linked into the deployed system. This action can be as simple as selecting one of several implementations of an interface. It can also be as complex as recompiling and relinking the middleware component using appropriately chosen values for configuration parameters, such as include file search paths, macro symbol definitions, and compiler options.

The Static Infrastructure Connector has a similar function to that of the Component Configurator [26] and Virtual Component [37] patterns, although the latter two patterns emphasize both installation-time and run-time activity. Also, QuO [6] has System Condition Objects that provide some of the characteristics in the Static Infrastructure Connector; QuO's System Condition objects use the Snapshot pattern [38].

- ↳ For example, the TAO ORB [19] provides a Real-time Event Service [31] that is highly configurable by both runtime and compile-time mechanisms [2]. We can exploit the efficiencies available when the target system is known to be homogeneous by enabling a macro in an include file that streamlines the TAO Real-time Event Service's marshaling and demarshaling processing.

<p><b>Class</b></p> <p>Static Infrastructure Connector</p>	<p><b>Collaborators</b></p> <p>/ Middleware Components</p> <p>/ Dynamic Connector</p>
<p><b>Responsibility</b></p> <p>/ Accepts QoS specifications for infrastructure services</p> <p>/ Selects or modifies the middleware components that will be available to the Dynamic Connector</p>	

## Dynamic Connector

A *Dynamic Connector* component is linked in with the application and acts during its operation. This component allocates infrastructure resources to data flows. When a dynamic connector component receives a request for a specific QoS, it may use the Configuration pattern (see below) or similar mechanism to discover the infrastructure components that might be used to provide the requested service in the specified mode. It may then negotiate with the infrastructure resources in an attempt to obtain support for the requested service. If these negotiations are successful, the Dynamic Connector component records the successful strategy, for use if and when the system enters the applicable mode, and directs the resources involved to record their commitments to this QoS in this mode.

If the allocation of resources is made in advance of their need, then this is an instance of the Proactive Resource Allocation pattern, and if the allocation is in response to an immediate need, then this is an instance of the Reactive Resource Allocation pattern, both of which appear in [32]. While nothing in these patterns prevents their use in a reactive style, the division of effort between in-band and out-of-band processing is optimized for the proactive style; specifically, the task of determining the “best means” may be quite slow in a large system, and is therefore designed to be performed before the need arises – i.e., proactively.

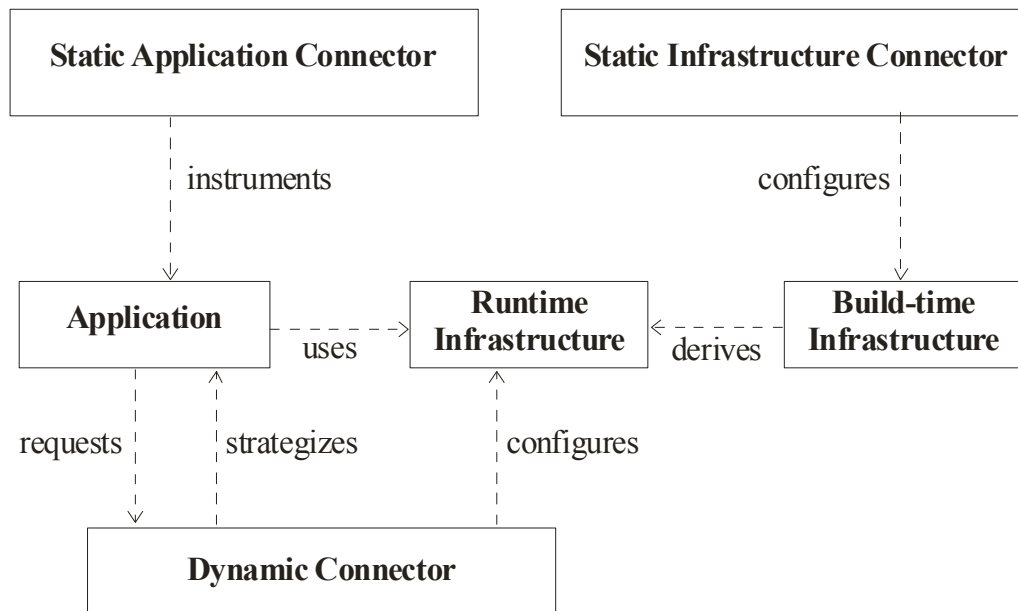
- ↳ For example, since an Event Service is permitted by the CORBA specification to use any mechanism to propagate events from suppliers to consumers, the Dynamic Connector component can (and should) examine the available communication resources to determine the best means to propagate events, where “best means” refers to the set of resources that can provide the requested QoS while minimizing some system-dependent measure of cost<sup>3</sup>.

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<sup>3</sup> Note that this cost presumably includes the opportunity cost of potentially denying access to the selected resources to some other users. Note also that the “best means” may change as loads change and as resource availabilities change.

<b>Class</b> Dynamic Connector	<b>Collaborators</b> / Infrastructure resources (or their proxies) / Middleware components
<b>Responsibility</b> / Negotiates with infrastructure resources (or their proxies) / Allocates infrastructure resources to data flows / Configures middleware components during application execution	

The relations among the patterns in the Quality Connector pattern language are shown in the following figure:



In addition to the participants of the Quality Connection pattern language components described above, there are several related collections of patterns, including:

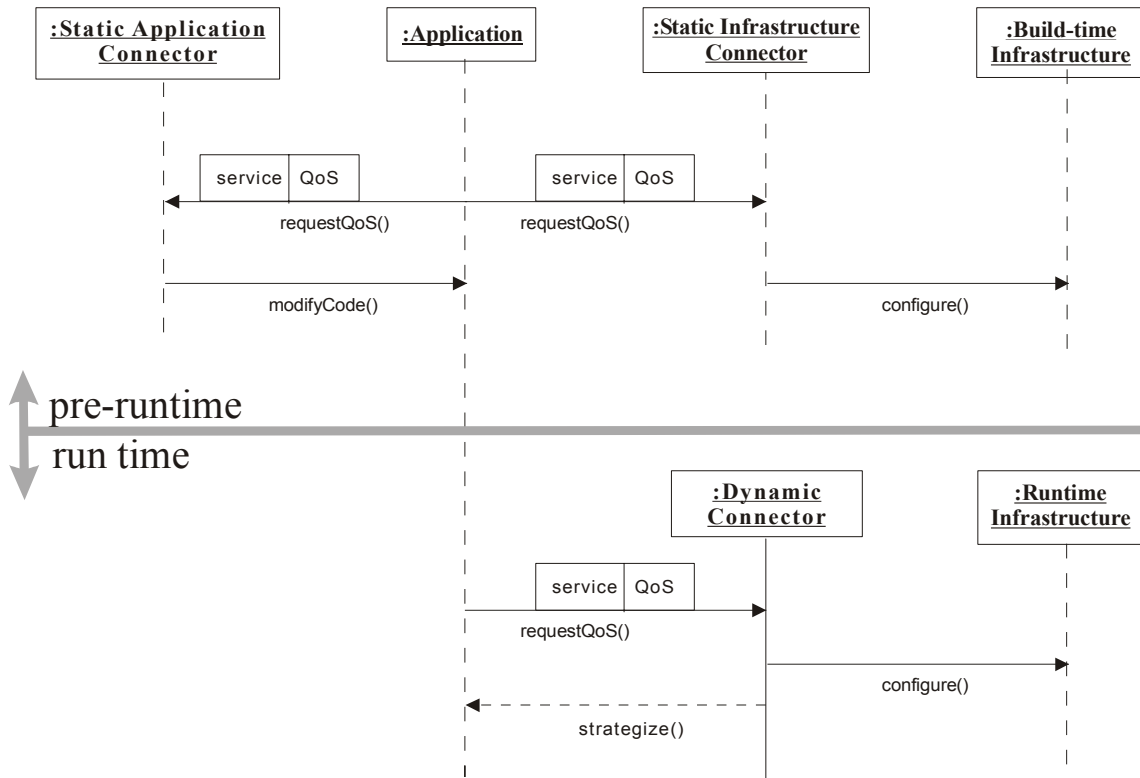
- Configuration tools that assist system builders in selecting compatible sets of infrastructure components that implement required services,
- Simulation tools to determine whether locally specified qualities of service will combine to meet system-level requirements, and
- A Configuration pattern that provides visibility at run-time of the set of configuration items that currently comprise the executing system.

These related patterns are not addressed further in this paper.

## Dynamics

As a broad generality, the dynamic interactions of the participants in the Quality Connection pattern language are illustrated in the figure below and can be divided into the three phases as described below:

1. **Pre-runtime.** When the identities of the services to which QoS requests will be made are known, the application source code can be modified automatically to insert the code that makes the runtime requests. Infrastructure components are selected and constructed using whatever information is known about the QoS requirements and load imposed on the service.
  - ↳ For example, if the service to which QoS requests will be made is determined to be the CORBA Event Service, then the pre-runtime operation of the Quality Connector is as described above in the *Structure* section's overview of the Static Application Connector.
2. **Runtime preparation.** The runtime dynamics of the Quality Connector are illustrated in Figure 2. At runtime, the application requests a QoS in a specified mode, including the specification of a load. The code included by the Quality Connector determines whether that request could be satisfied using the presently available infrastructure, considering any extant QoS agreements. If the request would be feasible, the QoS request is granted, and the *strategy* by which the application must access the service is recorded. Moreover, listeners are attached to the configuration items whose mode changes might signal transition to or from the relevant mode.
  - ↳ Continuing the CORBA Event Service example, the runtime preparation would entail an examination of the resources available for propagating events from suppliers to consumers – LANs, radios, etc., and selecting a “best means,” in the sense described above. Strategies that encapsulate this choice are distributed to the applicable components.
3. **Runtime employment.** After a QoS agreement has been established and the system enters the mode in which that agreement applies, the code included by the Quality Connector receives notification of the mode change and reallocates infrastructure resources immediately according to its pre-computed strategy.
  - ↳ In the CORBA Event Service example, the runtime employment would result in the transition to the use of the selected resources to propagate events.

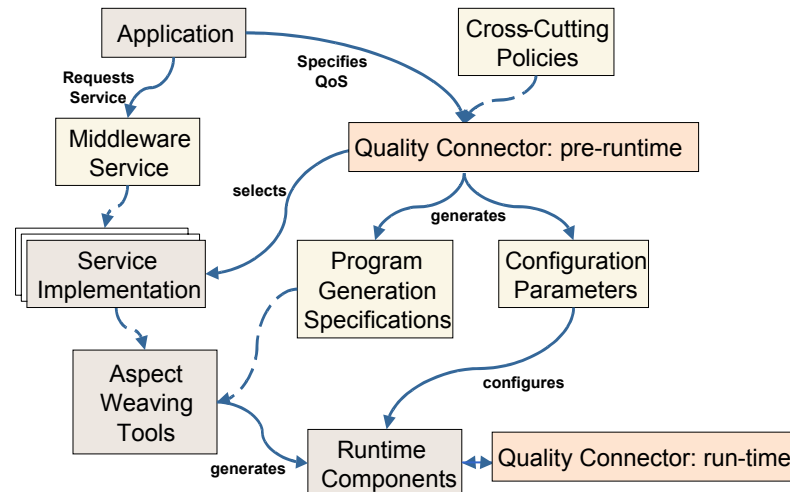


## Implementation

After a configurable infrastructure service has been selected, a quality connector for that service can be implemented as follows:

1. **Define a language** in which acceptable values (or sets of acceptable values) of the service's qualities can be specified, depending on the system mode. This language is the form in which data flows over the "Specifies QoS" arrow in the figure below. Consider defining this language using XML so that it can be understood readily by humans and parsed easily by COTS tools. This activity can take place even in advance of the system design; ideally the language will be defined by an open standard, such as UML and XML.
2. **Provide configuration-time tools** to check for feasibility and consistency of the requested quality values, and to set the properties of the Runtime Components to provide the required qualities, as illustrated below.
3. **Implement a Dynamic Connector.** This is the Dynamic Connector component of the Quality Connector, described above; it carries out the runtime allocation of resources. This function is performed in the Middleware Service box below.

The following figure outlines how these activities interact when implementing the Quality Connector pattern language:



We describe each of these implementation activities below.

### Step 1: Define the Quality Connector QoS Language

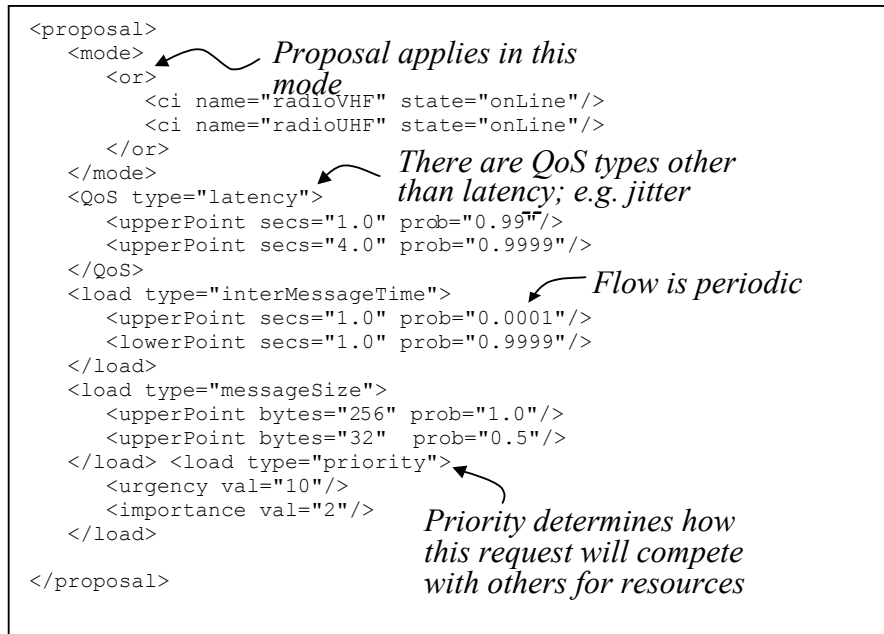
Define a Quality Connector QoS language that is capable of specifying

- Values for all qualities of the service that are of interest in the system
- Values for all relevant parameters of the load that the clients will impose on the service
- Relative priorities of clients, for use when not all requests can be supported and
- System modes in which quality requests apply.

↳ A QoS language that applies to a CORBA Event Service is illustrated in Figure 3. We have not used worst-case bounds for qualities such as latency, on the ground that if “worst case” is interpreted literally, then resource utilization may be too low to be effective for production DRE applications. Rather, we assume that latencies will be constrained by a conjunction of one or more conditions of the form “<proportion> of latencies shall be less than or equal to <time-interval>.” For example, a QoS specification for latency might be “99% of latencies less than or equal to 1.0 seconds and 99.99% of latencies less than or equal to 4.0 seconds.”<sup>4</sup>

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<sup>4</sup> It should be noted that the preceding is a special case of a much more general and powerful technique, which we call *density intervals*. A density interval specifies a distribution of values by the assertion that its cumulative density function lies entirely between an upper bounding function and a lower bounding function. In the preceding example, only an upper bounding function is specified, and it is a step function. Since the generality of density intervals is not essential to the present discussion, this subject will not be treated in detail here.



The load that will be imposed by the event service is specified in terms of a distribution of event sizes, in bytes, and a distribution of the times between event-push invocations.

Relative priorities of clients are specified by the following two integral values:

- The *urgency* of a request determines which of several simultaneously eligible requests will get access to a shared resource. For example, if either of two packets of data could be sent over a communication link, the packet with the higher urgency will be sent.
- The *importance* of a request determines which of two requests not both of which can be supported will be accepted. For example, if both of two requests for event data propagation cannot be supported on the present infrastructure, then the request with the higher importance will be accepted and the other will be rejected. Moreover, if a new request for service is received, and that request can be accommodated only if some currently operating, lower importance service is shut down, then that will be done; in this case, we say that the lower importance request is abrogated.

Urgency and importance are system-level properties, in the sense that they may affect the allocation of any resource. The urgency and importance of a resource request may be expected to remain constant within one mode, although as system state changes, modes change, and hence the priority of resource requests may change.

The proposal shown above applies only when either of a pair of tactical military or emergency response team radios is on-line. In that case, the time between a supplier's push() call and all consumers' corresponding push() calls for every event are to be less than 1.0 second 99% of the time and less than 4 seconds 99.99% of the time. The sizes of the event data are always at most 256 bytes and 50% of the time are less than or equal to 32 bytes. The supplier's push() calls occur periodically, once per second. Note that the priority of the request consists of the two integral values defined above.

## Step 2: Provide Configuration-time Tools

Procure or build tools to help the programmers conduct the configuration-time and runtime Quality Connector activities. The decisions concerning which tools to use, if any, are subject to cost/benefit tradeoffs, such as the cost to build or buy the tool plus the tool maintenance cost vs. the anticipated productivity improvement and risk reduction from its use. Consider using design tools, such as design-tool interfaces, QoS language checkers, simulators, and source code generators, such as AspectJ [12] or scripts.

↳ For our Event Channel service, our QoS language is in XML, so schemas are a natural mechanism for language checking. Our application is written in C++, so we explicitly mark locations in the source code where modifications are to be applied, and we use a Perl script to insert the QoS requests automatically.

## Step 3: Implement the Dynamic Connector

The Dynamic Connector component implements the runtime functionality of the Quality Connector. This component is therefore responsible for

- Receiving QoS requests from the application,
- Negotiating with the available infrastructure resources for support,
- Replying to the application's request for QoS with either acquiescence or an explicit denial, and, if acquiesced, then
- Distributing strategies to the components that will employ them when the applicable mode is entered.

↳ In our CORBA Event Service, QoS requests are made by the application through the `ProxyPushSupplier` and `ProxyPushConsumer` objects. These forward the request to the event channel object, which negotiates with the infrastructure resources.

The event channel object first requests service from the infrastructure components with a parameter called `disruptExistingQoS` set to `false`, which has the effect of attempting to provide the requested service without disrupting any existing QoS agreements. If this negotiation fails, then the event channel object tries the negotiation again but with `disruptExistingQoS` set to `true`; which has the effect that if this second round of negotiation succeeds, then at the time when the presently negotiated QoS is required, then agreements of less importance than the present request may be abrogated.

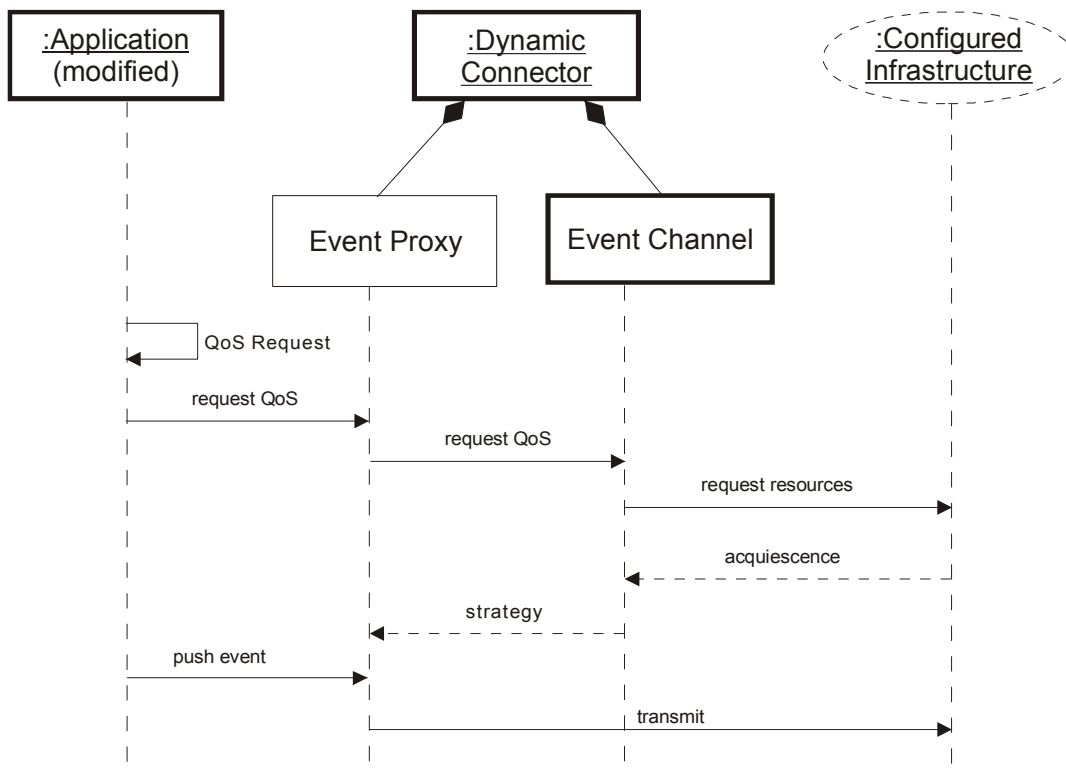
If the negotiation process succeeds, then a collection of resources will be allocated for the event flow in the specified mode. The event channel object distributes strategy objects, represented as XML strings, to the affected service objects. For example, the strategy given to a `ProxyPushConsumer` might direct the immediate creation of a socket with specified parameters to which supplied events should be written.

## Example Resolved

We can apply the Quality Connector pattern language to enhance the CORBA Event Service so applications can control qualities of the event service without being unduly affected by its implementation. To accomplish this, we permit the application to submit a QoS request of the form shown in the previous figure with each consumer and supplier proxy. These requests support the requirement that QoS be permitted to depend on system mode.

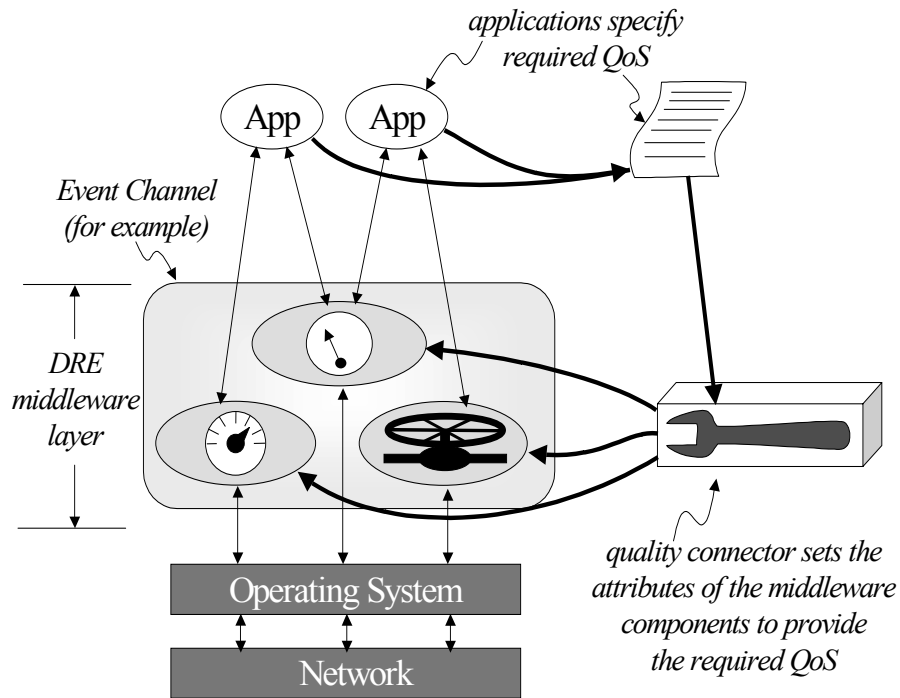
To avoid manual modifications to the application source code, we can apply automatic tools possessing aspect-oriented programming (AOP) [4] capabilities to insert the required calls to request QoSs, following the creation of each Event Service proxy. The rejection of a QoS request raises an exception. As a result, no manual modification of application code is required when a different event service implementation is used.

The runtime result of a QoS request is that the request is forwarded from the Event Service proxy to the Event Channel object, where the negotiation for infrastructure support takes place with the infrastructure resources or their proxies. If the mode specified in the request is not the current mode, then the strategy for the specified mode is retained in the proxy object, for use when the specified mode is entered. As a result, the infrastructure resources are reallocated quickly when the mode is entered, as required for time-critical mode transitions. These interactions are shown in the following figure:



In summary, the following figure illustrates the runtime component interactions (pre-runtime activities, such as instrumentation and weaving of aspects, are not shown).

- ↳ For our Event Channel service example, the figure illustrates the Dynamic Connector accepting the application's QoS requirements, determining the resources that will be used to provide that QoS, and distributing strategies to provide that service.



## Known Uses

**Meta-INterface for Real-time Embedded Systems (MINERS).** There is an ongoing independent research and development project at Lockheed Martin Tactical Systems in Eagan, Minnesota, USA, called MINERS. MINERS is investigating the use of meta-programming techniques to provide DRE applications with an open interface through which they can configure and control the underlying middleware as they require. The goal of MINERS is to develop and demonstrate means whereby applications programs can be made fully independent of the infrastructure on which they execute. This goal, together with the stringent requirements of DRE systems for efficient use of resources, requires the use of the following components:

- **Static Application Connector** to free programmers from the need to adapt their source code to each new infrastructure
- **Static Infrastructure Connector** to select and configure infrastructure components for the available hardware and the QoS requirements of the applications and
- **Dynamic Connector**, in the proactive style, to provide rapid resource reallocations in response to system mode changes.

**QuO.** The BBN Quality Objects (QuO) framework [6] uses QoS definition languages [7] that are based on the separation of concerns promoted by AOP [4]. In particular, QuO

includes the notion of a *connection* between a client and an object, which encapsulates QoS requirements and intended usage patterns; this is analogous to MINERS QoS requests. QuO provides *system condition* objects, which are similar to MINERS modes, and provide some of the characteristics of the Static Infrastructure Connector category. QuO provides a Quality Description Language (QDL) that includes two aspect languages:

1. A *contract description language* (CDL) that describes contracts as outlined above,
2. An *adaptation specification language* (ASL) that describes the internal structure of object implementations and the amount of resources they require.

These languages perform functions similar to the MINERS QoS language described above.

QuO includes code generators, which are instances of the Static Application Connector category above; QuO uses both wrapping and weaving to achieve the static connection effect. QuO's contracts and delegates fulfill much of the Dynamic Connector characteristics.

QuO has in the past emphasized reactive resource allocation [32], which monitors the QoS being provided and acting to correct contract violations or anticipated violations. There is nothing inherent in the structure of QuO, however, that prohibits implementing the proactive resource allocation style described in this paper.

QuO defines contracts and delegates that fulfill much of the Dynamic Connector characteristics; QuO's contracts are described in the QoS Contract pattern [38].

**Human uses.** Applications behave analogously to an executive who gives a package to his staff with direction that it must be delivered by a specified time. The Quality Connector acts, analogously to the staff, by selecting mechanisms for transport and setting the controllable parameters of those mechanisms.

## Consequences

The Quality Connector pattern language has the following benefits:

- ***Infrastructure independence.*** The Quality Connector decouples an application from dependencies on the infrastructure it executes upon, even when that infrastructure requires explicit configuration to provide the QoS that the application requires.
- ***Fast response to mode changes.*** The Quality Connector negotiates requests for service in modes other than the current mode, and in so doing performs the possibly long and difficult determination of the necessary resource allocations. When the new mode in fact arises, the resources can then be reallocated quickly.
- ***Separation of Quality concerns.*** Moving QoS-related concerns out of the functional code of the program enables the division of developer roles into functional and QoS developers.

The Quality Connector pattern language also has the following liabilities:

- ***Reimplementation.*** When a new infrastructure is deployed, a new Quality Connector component may be required.
- ***Potential for low utilization.*** Resource utilization may be low if the Quality Connector implementations are unduly conservative in rejecting QoS requests. (Note

that this is more likely to be an issue in the Proactive resource allocation style, since this is where the luxury of conservatism may be tolerated.)

- **Requires source code.** This pattern requires access to the source code of the application and/or infrastructure implementation in order to modify it.

### See Also

Portions of the Quality Connector pattern language are related to the Component Configurator [26] and the Virtual Component [37] patterns, which permit component implementations to be linked into and unlinked from a running application without shutting down the application. Both the Quality Connector pattern language and these other two patterns provide a means to change the behavior of a service during application execution. The Component Configurator and Virtual Component patterns are concerned with one mechanism – dynamic linking – for doing so, while the Quality Connector focuses on broader policies and mechanisms that ensure rapid response to changing system state by switching present components among pre-computed strategies.

One of the goals of the Quality Connector pattern language is similar to that of the Interceptor pattern [26], in that both adjust infrastructure behavior without modifying the application manually. The Interceptor pattern accomplishes this by a highly flexible method of adding services that are triggered automatically when specified events occur. The Interceptor pattern applies to the design of a framework, specifying that the framework expose application-callback interfaces, and that it open aspects of its internal state and behavior to control by the application. The Quality Connector imposes no design requirements on its constituent components (although if the service components expose only weak configuration controls, then the Quality Connector will be unable to provide good resource utilization). The Quality Connector is concerned with service quality, while the Interceptor pattern is more general, and can provide functions such as event logging.

The Reflection pattern [30] provides for the inclusion in a running application of meta-objects that provide information about, and control over, the objects that implement the application “logic.” This pattern is clearly a basis on which the Quality Connector pattern language depends since the latter requires that the infrastructure services support reflective capabilities.

The Proxy pattern [29] shields an application from details of the implementation of a service, *e.g.*, it hides the physical location of a service implementation from its clients. The Quality Connector pattern language serves to modify the behavior of existing, fully visible, service-providing components.

The Quality Connector is related to the Adapter pattern [29]. The Adapter serves to adapt an existing implementation to the interface required by an application, and the Quality Connector adapts the disparate quality control interfaces of existing components.

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