Towards Quality of Service in Distributed Systems with AOP and QoS Meta-Data

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(with BBN http://www.dist-systems.bbn.com/)

CptS 565/580 (Adv. Dist. Sys)
August 22, 2013 and on
Administrivia

• Papers for these 2 lectures:
  [1] Zinky JA, Bakken DE, Schantz R. Architectural Support for Quality of
      Service for CORBA Objects. Theory and Practice of Object Systems,
      3:1, April 1997
      Service Control Behaviors for Reuse. ISORC 2002, The 5th IEEE
      International Symposium on Object-Oriented Real-time distributed
      Computing, April 29 - May 1, 2002, Washington, DC.

Notes
– Not everything in the papers are covered in these slides
  and vice versa
– May not get to all the slides, maybe not last 1/3 or so

• I worked at BBN 1994-1999, co-architect of QuO
  – http://quo.bbn.com

• CptS 562, Fault-Tol. Computing, in “even” springs
580 Learning Objectives

• I expect 580 students to learn the following
  – Understanding of how the dynamic and unpredictable WAN environment makes distributed programming hard
  – Understand what QoS is for adaptive WAN applications, and what it is not
  – Understand the basics of what applications need to do to be able to adapt and/or take advantage of QoS using AOP-like techniques and QoS meta-data
  – How QuO languages are or are not AOP (discuss lots…)

• I do not expect anyone to learn
  – Details of WAN environments and their characteristics
  – Fine-grained details of QuO or its languages
Some Context...

“I have a cat named Trash. In the current political climate, it would seem that if I were trying to sell him (at least to a Computer Scientist), I would not stress that he is gentle to humans and is self-sufficient, living mostly on field mice. Rather, I would argue that he is object-oriented.”

*Prof. Roger King, University of Colorado, 1989*

“My cat is CORBA-compliant.”

*Dr. John Nicol, GTE Labs, 1995*

“My CORBA-compliant cat has great QoS.”

*Dr. Dave Bakken, BBN, 1997*

“My CORBA-compliant cat with great QoS is also an aspect-oriented, grid-enabled component for protecting sensor networks and the power grid against cyberterrorists, so your funding my research is a no-brainer.”

*Prof. Dave Bakken, Washington State University, 2005*
Outline of Talk

- **QoS: The problem, and basic definitions**
- QoS Implementation Issues
- Quality Objects (QuO) 2.0 Architecture
- QuO 2.0 Case Study
- QuO 3.0: Aspects and Reuse
- QuO 3.0 Case Study: UAV Multimedia adaptivity
The Problem: Wide-Area Distributed Applications Are Hard to Build and Maintain

- WANs are dynamic, unpredictable, and unreliable
- Hosts span a wide range of platforms
- Servers provide a variety of services and interfaces
- Changing requirements and configurations
- Complex interactions

Client just wants predictable behavior (as much as possible)!
Client programmer does not want to deal with managing the above details!
The Problem (cont.)

• Many distributed systems are too expensive to build and maintain, and
  – Cannot adapt sufficiently at runtime
  – Cannot evolve over lifetime to handle new requirements or work in new environments
• One reason: no systemic support for building distributed systems using shared resources
• Key challenge: how to create predictable distributed systems application programs which
  – Can operate acceptably when usage patterns or available resources vary over a wider spectrum and with much less predictability
  – Can be modified in a reasonable amount of time
  – Are reasonably affordable
• Needed: Middleware which makes a distributed application’s hidden quality of service assumptions (usage, resources) explicit, to
  – Help make the environment more predictable to the app, and
  – Help the app. to adapt when predictability fails
  – Note: this involves both distributed systems and software engineering issues!
QoS == the "how" to do the functional (IDL-described) "what"

- IDL tells "what" can or should be done
  - `void sort(inout long a[], in long n);`
  - `long lookup(in string name);`
- Quality of Service (QoS) is the non-functional "how" to do the above "what"
  - timeliness (delay, jitter)
  - throughput (volume)
  - availability/depenability
  - security (integrity, confidentiality)
  - cost
  - precision
  - accuracy
- No standard definition(s) of QoS yet, but progress being made towards implementing multiple QoS properties (a.k.a. QoS dimensions -- the "what" items: timeliness, etc. above) in one framework
QoS Basic Definitions (cont.)

• Premise 1: Different levels of service (not “all or nothing”) are possible and desirable under different conditions and costs
• Premise 2: The level of service in one dimension must be coordinated with and often traded off against the level of service in another
• Premise 3: Keep the functional and non-functional separate if possible
  – Let them be able to change independently (reuse)
  – Let them be managed by different people (QoS specialist, domain specialist)
• Question: How aware should client applications be of QoS:
  – Unaware (totally handled by something else)
  – “Awareness without pain”
  – Immersion (has to handle large amounts of QoS details and issues etc)
Different Views of QoS

- LAN multimedia with no adaptivity
- Bill Gates: end-user satisfaction
- “World Wide Wait”
- ISPs
- Power users
- IT Managers
- Dilbert Managers
- HP and other vendors (IWQoS ‘97, WebQoS, …)
- Builders of Big and Critical Systems
  - Cannot manage the “non-functional” behavior of their systems well
  - Cannot ride the technology curve over the lifecycle!
  - Examples
    - DARPA ITO Quorum program and Navy’s DD-21 ship program
    - Boeing (Commercial, Phantom Works, other)
Distributed QoS

QoS for Users: Adapting to Worsening Conditions or Different Configurations

- Program can be empowered to automatically adapt to worsening conditions (balance of supply of to demand on current shared resources)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Conferencing</th>
<th>Participants</th>
<th>Info Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Full color multimedia</td>
<td>Key and useful participants</td>
<td>Quick DB queries</td>
</tr>
<tr>
<td>Yellow</td>
<td>B&amp;W multimedia</td>
<td>Key and useful participants</td>
<td>Acceptable DB queries</td>
</tr>
<tr>
<td>Red</td>
<td>Audio</td>
<td>Key participants only</td>
<td>Acceptable DB queries</td>
</tr>
<tr>
<td>Black</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
QoS for ISPs & HW Suppliers: Multiple Levels of Service Enable Differentiated Products

- 3rd class: Best-effort
- 2nd class: Statistical performance guarantees
- 1st class: Absolute performance and availability guarantees
Distributed QoS Extensions is a Powerful Abstraction Layer on which to Build Applications

Diverse applications for geographically dispersed, heterogeneous environments – not just multimedia apps!

Distributed objects are the first abstraction layer that unifies CPU, storage, and communications

This interface needs to be hidden from applications

- It is too complicated
- It is changing too quickly
QoS is Not Just Multimedia over a LAN or MAN

Scheduling Algorithms

OpenMap™

Video Conf.

Schedule Map Face

Video Audio

OpenMap™

Video Conf.

Face Map Schedule

Shared Plans

Best-Effort

Predictable

Real-Time

Shared Workspace

Dave Bakken
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Users and application programmers need to be aware of their demand for resources, and be able to change!

Users/applications must understand the utility of their demand
- know their usage patterns and QoS requirements

Users/applications must be able to change demand based on volatility in the environment
- need to be able to determine utility of additional resources, and ability to do without

System infrastructure will improve its “transparency” over time, and its effectiveness of masking variability
“Awareness without Pain” II: Users Should See a “Graceful Degradation” of App, not a Hard Failure

- Functions marked with cost cues
- Middleware asks for more advice
- Middleware predicts long response times
- Application tolerates aborted operations with partial results
“Awareness without Pain” III: Needed---Higher-level QoS APIs and User Interfaces

• Most programmers and users of advanced distributed applications can’t deal with QoS because they
  – Are not very sophisticated in distributed systems issues (let alone QoS)
  – Have enough to do already providing/using the applications’ main job without worrying about QoS

• QoS contracts can give a high-level API for programmers to use, with the help of QoS framework implementers & QoS developers

• Simple (single-) application management user interfaces can help
  – User control:
    - QoS developer provides multiple implementations trading off multiple properties and resources, with a high-level mapping

  – User feedback:
QoS-Aware Resource Management I: Many Mechanisms Give the Correct Functionality, But Are Appropriate for a Small Set of Conditions

Applications
know Their Usage Pattern and QoS Requirements

Mechanism
given usage pattern and resources, yield QoS and Utilization

System Managers
setup resources and set usage policies

Resources
Capacity Reliability

Usage Pattern
Arrival Rate Priority

QoS
Performance Availability Security ...

Allocation Algorithms

Utilization
Cost Ownership
QoS-Aware Resource Management II: Control over Resource Allocation is Useless w/o Information on Usage Patterns & QoS Requirements

Information Detail
Quantitative

Qualitative

Waste of Time

Appropriate Control Band

Current Dist. Syst. Practice

Comm QoS Multimedia R+D

Controlling on Noise

Amount of Control

Little

Lots

Ad Hoc
Application-Level Adaptation Choices

• How can distributed applications become more predictable and adapt to changing system conditions?
  – Control and Reserve Resources
  – Utilize alternate Resources (redundancy)
  – Use an alternate mechanism (with different system properties)
  – Take longer
    • reschedule for later
    • tolerate finishing later than originally expected
  – Do less

• Note the multiple possible layers of adaptation:
  – Client application
  – Above the ORB core on client-side
  – Inside the ORB
  – Above the ORB core on server-side
  – Server

• Premise: supporting all the above choices is helpful!
QuO’s Philosophy: Support Monitoring of System Conditions & Adapting to Changes at All Levels

- QoS middleware needs to integrate disparate information (“QoS metadata”) over:
  - Providers
    - QoS API+middleware designer
    - QoS contract designer
    - application program (client)
    - remote object
    - operations staff (configure resources)
    - network management information, ...
  - Locations
    - client host
    - remote object host
    - network
  - Times
    - language design
    - application development
    - application initialization
    - contract setup
    - change in network conditions
    - invocation, ...
  - AOP-like languages provide policies across this space…
Guarantees/correctness versus Advice/Improvement for Predictable Behavior

- It is not feasible to provide absolute “guarantees” over WANs with an arbitrary mix of hosts, resources, operating systems, etc.
- It is useful to be able to
  - Organize information about an application’s requirements and expected usage
  - Reserve as much of the end-to-end resources as possible to make the application more predictable (lower variance)

QoS contracts are crucial for adaptivity, i.e., regions representing state of QoS expectations vs. actual conditions

Need to provide for a new role -- QoS engineer -- to help simplify the application developer’s task
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QuO History

- BBN Distributed Systems Dept had lots of experience since late 1970s
  - Distributed Applications over WANs
  - Middleware to support above (CORBA-like Cronus/Corbus)
- New Rome Lab Contract “Distributed Computing over New Technology Networks” for a study project, started in 8/1994
  - New networking technologies coming….  
  - But how can they help the application level?
  - (I was hired for this, right after PhD)
- Candidate technologies: multicast and reservations/QoS...
- QuO architecture requirements and initial design: Zinky and Bakken and Schantz (1995-6), a handful of others since
- Led to 7+ DARPA ITO and ISO QuO contracts
  - Flew in a Boeing military aircraft experiment, evaluated for use with UAVs
  - Approx 60-70 many-years of BBN labor invested in it by DARPA & USAF
- Used at a number of universities & companies to integrate their QoS research (CMU, GaTech, Cornell, U. Illinois, Wash. U. St. Louis., Columbia U, Trusted Information Systems(TIS), Boeing,...)
The Quality Objects (QuO) Framework Supports Development of Adaptive Distributed Applications

QuO is a reusable middleware framework that provides a common approach to adaptable QoS suitable for applying to any number of QoS dimensions.

The QuO framework provides:

- **Separation of concerns** between software functional properties and QoS needs:
  - Specify QoS desires, implementation alternatives separately from the functional application
- Monitor and measure QoS in the system
  - Consistent interfaces for QoS measurement and resource management control
- Facilities to enable application- and system-level adaptation
A QuO application contains additional components
(from traditional CORBA/DOC applications)

- **Contracts** summarize the possible states of QoS in the system and behavior to trigger when QoS changes
  - Regions can be nested, representing different epochs at which QoS information becomes available, e.g., *negotiated regions* represent the levels of service a client expects to receive and a server expects to provide, while *reality regions* represent observed levels of service
  - Regions are defined by *predicates* over system condition objects
  - *Transitions* specify behavior to trigger when the active regions change

- **System condition objects** are used to measure and control QoS
  - Provide interfaces to system resources, client and object expectations, mechanisms, managers, and specialized ORB functions
  - Changes in system condition objects observed by contracts can cause region transitions
  - Methods on system condition objects can be used to access QoS controls provided by resources, mechanisms, managers, and ORBs

- **Delegates** provide local QoS state for remote objects
  - Upon method call/return, delegate can check the current contract state and choose behavior based upon the current state of QoS
  - For example, delegate can choose between alternate methods, alternate remote object bindings, perform local processing of data, or simply pass the method call or return through
Contracts summarize system conditions into negotiated and reality regions and define transitions between them

- *Negotiated* regions represent the expected behavior of client and server objects, and *reality* regions represent observed system behaviors.
- Predicates using system condition objects determine which regions are valid.
- Transitions occur when a region becomes invalid and another becomes valid.
- Transitions might trigger adaptation by the client, object, ORB, or system.

### As_expected:
- **Normal:**
  - Expected capacity $\geq 10$
  - Measured capacity $\geq 10$

- **Degraded:**
  - Expected capacity $< 10$
  - Measured capacity $\geq 2$

- **Unused:**
  - Expected capacity $< 2$
  - Measured capacity $< 2$

### Insufficient_resources:
- **Normal:**
  - Measured capacity $< 10$
- **Degraded:**
  - Measured capacity $< 10$
  - Measured capacity $\geq 2$
- **Unused:**
  - Measured capacity $< 2$

### Extra_resources:
- **Normal:**
  - Measured capacity $< 10$
- **Degraded:**
  - Measured capacity $\geq 10$
- **Unused:**
  - Measured capacity $\geq 2$

---

= NegotiatedRegion

= Reality Region
System Conditions Project a Value to the Application, But also Must Maintain the Value

QuO Kernel

CORBA Object

Simple Value  Measured Value (Sensor)  Composed Value  Control Value  Control Value  Status Value

Application Developer

Qoskateer

QuO Kernel

CORBA Object

RSVP Controller

Device Status Service

Mechanism Developer

Specialized ORBs or Services
Contracts Need to integrate with System Condition Probes and Object Delegates

Client
  Object Ref

Overlay Delegate (expanded)
  MyContract
  MyLower

ORB Delegate
  network
  Object

Contract Object
  Allocated
    Normal
    Insufficient Resources
    Client Over Limit
    Client Asleep
  Measured
    Expected
      Throughput
      Capacity
    Measured
      Capacity
      Throughput
      Idleness
  Free
    Normal
    Extra Resources
    Client Not Sleeping

Environment
  Value
  Value

Key
  System Condition
  Attribute
  Region
  Reference
Delegates change their behavior based on their contract's current regions.
SDL code that supports choosing between replicated and non-replicated server objects

delegate behavior for Targeting and Replication is

call calculate_distance_to_target :
    region Available.Normal :
        pass to calculate_distance_to_target_multicast;
    region Low_Cost.Normal :
        pass to calculate_distance_to_target_multicast;
    region Available.Low :
        java_code { System.out.println("Remote call would fail");
            retval = -1; }
        cplusplus_code { cerr << "Remote call would fail");
            retval = -1; }
        return calculate_distance_to_target :
            pass_through;
    default : pass_through
end delegate behavior;

• SDL supports choosing between methods, run-time binding, and embedded Java or C++ code.
Contracts Summarize System Conditions into Regions, Each Appropriate for Different Situations

- Contract defines nested regions of possible states based on measured conditions
- Predicates using system condition objects determine which regions are valid
- Transitions occur when a region becomes invalid and another becomes valid
- Transitions trigger adaptation by the client, object, ORB, or system
QuO Adds Specification, Measurement, and Adaptation into the Distributed Object Model

Application Developer

Mechanism Developer

CorBA Doc Model

QuO Doc Model
**Measurement in QuO**

- **In-band** measurement handled by instrumentation
  - A structure is transparently passed along with the method call/return
  - Information can be inserted, read, and processed to record and evaluate method call statistics (e.g., the time spent in marshalling)
- **Out-of-band** measurement provided by system condition objects
Adaptation and Control in QuO

• **In-band** adaptation provided by the delegate and gateway
  – A delegate decides what to do with a method call or return based upon the state of its contract
  – Gateway enables control and adaptation at the transport layer

• **Out-of-band** adaptation triggered by transitions in contract regions
  – Caused by changes in the system observed by system condition objects
The QuO Toolkit Provides Tools for Building QuO applications (Note: QuO 3.0 different...)

- Quality Description Languages (QDL)
  - Support the specification of QoS contracts (CDL), delegates and their adaptive behaviors (SDL), connection, creation, and initialization of QuO application components (ConnDL)
  - QuO includes code generators that parse QDL descriptions and generates Java and C++ code for contracts, delegates, creation, and initialization

- QuO Runtime Kernel
  - Contract evaluator
  - Factory object which instantiates contract and system condition objects

- System Condition Objects, implemented as CORBA objects
QuO Development Steps, Tools, and Modules

**Client Functionality (CDC1)**
- Client ADA: Behavior (Callback Functionality) (CDC2)
- Client CDLs (QDC3c)
- Client SDLs (QDC4c)
- Client CSL (QDC5c)
- Client Connector Wrapper (QDC7c)

**Server Functionality (SDC1)**
- Server ADA: Behavior (Callback Functionality) (SDC2)
- Server CDLs (QDC3s)
- Server SDLs (QDC4s)
- Server CSL (QDC5s)
- Server Connector Wrapper (QDC7s)

**Quogen**
- IDL Compiler
- Java Compiler
- QuO Client-Side Library
- Property Package (PDCx) (OPTIONAL!!!)

**SysCond IDL (QDC2)**
- IDL Compiler
- Java Compiler
- QuO Runtime Library

**SysCond Implementations (QDC6)**
- Stubs & Skeletons
- QuO Client-Side Library

**Keys**
- Human-Written Code (LABEL)
- Computer-Generated Code
- Tool
- Coding “Step” or “Wave” by Developer or Provider:
  - Application (Client or Server)
  - QuO
  - COTS
  - QoS Mechanism

**Distributed QoS**

Dave Bakken
The QuO Gateway Manages IIOP Connections and Interfaces to Protocols which Manage QoS

- To the “Client” ORB, the QuO Gateway looks like the object
- To the “Server” ORB, the QuO Gateway looks like a client
- The two ends of the gateway are on the same LAN as the Client/Object and may be on the same host
- CORBA Objects are used to Control QuO Gateway halves, but do not touch in-band communication
  - Different for AQuA and DIRM, later some merging will occur...

![Diagram showing the relationship between Client, Server, IIOP Glue, and Control protocols.](image)

Specialize Protocols (Maestro Group Comm. for AQuA; RSVP for DIRM)
We can (and do! and must!) rewrite ObjKey and ReqID; we just have to restore them when we pass them back to the appropriate ORB so it can use them to demux the reply, lest the poor ORB choke on it. 

Mappings between {Process,Host} and GWs is flexible (~TBD):
- DIRM may want one per LAN/cluster to aggregate bandwidth
- AQuA may want one per client (replica) process or even every delegate/contract inside it
- OIT/Survivability/Security will have other constraints/preferences no doubt...

Some Naming issues to be resolved to describe the exact flexibility; mainly engineering issues with no show stoppers

Many research issues regarding the implications of different GW mappings on availability and performance/scalability
Layers of Managers Integrate Adaptation Policies at Different Levels & from Different Sources

- Functional Info (solid line) and "QoS meta-data" (dashed line)
- Translation between Manager Layers
- Centralized view vs. edge view
- Note: above is logical view, sometimes manager layers are merged...
Canonical QuO Architecture for Generic Property Package X

Adaptation by App. Client
- Appl. Client #1
- QuO Object Delegate
- QuO Contracts & SysConds involving Property X

Adaptation by QuO Above ORB
- CORBA/DCOM
- Network Services (RSVP, Group. Com, …)
- CORBA/DCOM

Adaptation Below ORB
- QuO Object Delegate
- Object #1 Impl.
- Object #2 Impl.
- Reconfig Mechanisms
- Status Services

Host A

Host B

Host C
- Property X (Middleware) Manager:
  - Maintains Property X of some objects for some clients
- (Property X Requested)
- (Property X Delivered)
- (Reconfig Mechanisms)
- (Status Info)

Other Reconfig Mechanisms
- Other Status Services
- (Other Clients, Objects, Contracts..)
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• QoS: The problem, and basic definitions
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• Quality Objects (QuO) 2.0 Architecture
• **QuO 2.0 Case Study: WSOA**
• QuO 3.0: Aspects and Reuse
• QuO 3.0 Case Study: UAV Multimedia adaptivity
Multiple Levels of QuO Coordination are Required!
Adaptive Behavior Integrated with Advanced Resource Management in WSOA

Distributed QoS

Collaboration

Client

Expected
Progress

Delegate

Progress
Contract

Measured
Progress

Processor
Resource
Manager

Soft Real-Time
Tasks

HUD

Hard Real-Time
Tasks

NAV

RMS or MUF scheduling of tasks

RT Event
Channel

TAO ORB

Network Monitor

Collaboration Task

get_image()

get_tile(n, q)

get_tile(N, Q)

VTF tile

Network

Adaptive Behavior Integrated with Advanced Resource Management in WSOA

QuO Components

RT-ARM components

TAO components

© 2000 Boeing
WSOA QoS Control Flow

QuO

- Manages application progress
  - Early, On-Time, or Late for each operation
- Defines operating regions
  - Range of rates for each operation
- Also handles image tiling (not shown)

RT-ARM

- Manages QoS parameters within the given operating regions
  - Adjust rates within defined ranges for each operation
- Reports when operating region is violated (or will be violated)
WSOA QoS Control Flow (cont’d)

RT-ARM
- Adjusts current available dispatch rate ranges for each operation
- Provides admission control policy
- Queries TAO Scheduler for monitored execution time results

TAO Scheduler
- Binds specific rate according to RT-ARM supplied admission control policy
- Queues operations and enforces hybrid static/dynamic scheduling policy
- Makes available to RT-ARM the actual execution times of each scheduled operation
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• QuO 2.0 Case Study
• **QuO 3.0: Aspects, Reuse, and Status Info**
  – Provided courtesy of BBN (after I left for WSU)
• QuO 3.0 Case Study: UAV Multimedia adaptivity
QuO 3.0 Components Are Packaged into Reusable Bundles of “Systemic Behavior” Called Qoskets

- The Qosket encapsulates a set of contracts (CDL), system condition objects (IDL), and QoS adaptive behavior (ASL)

- The Qosket exposes interfaces to access QuO controls and information (specified in IDL)

- The Qosket separates the functional adaptive behavior (business logic) from the QoS adaptive behavior and the middleware controls from the QoS mechanisms

- Greatly augmented and strengthened QuO 2.0 CSL
QuO 3.0 Aspects

• QuO provides hooks for different aspects specialized for application-level adaptivity

• Well-defined code join points in delegates
  – Pre-call to method
  – Post-call to method
  – After return from method
  – Extended and simplified QuO 2.0 SDL, made more regular, …
QuO 3.0 Resource Status Service (RSS) is an Integration Base for Observing Resource Status and Delivered QoS.
- Data is from many **sources**
- Data is from many **time horizons**
- **Common representations** are used to simplify the QoS Modeling
- **Collection and Integration** Details are hidden from QoS Modeling
RSS Helps Integrate Feedback Information from Different Locations

- Client
- Object
- Application Management
- Feedback
- End-to-End Feedback
- Local Feedback
- End-to-End Feedback
- Local Feedback

Distributed QoS
RSS Helps Integrate Feedback Information from Different Time Scales

Distributed QoS

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Resource Status Service

Act

Decide

Connections

Management

Development

Faster-Precise-Smaller

Slower-Broad-Bigger
QuO 3.0 has a Resource Status Service (RSS) Built into the QuO Java Kernel

- **Isolation**: The Quosketeer will work with a high level description of available resources
- **Integration**: Conflicting measurements will be resolved to always give the best guess.
- **Translation**: different standards for Resources MIBs will be translated into a QuO Resource Ontology
- **Collection**: interfacing details will be handled by Data Feed

**Expected QoS**

**Resource Status Service**
- Model Level
- Resource Level
- Integration Level

**Data Feeds**
- Translate
- Store
- Collect

- **Configuration**
  - (Base-Line)
- **Remos**
  - (Network)
- **StatusTEC**
  - (Host)

**Expected QoS**
New Integration Points were Added to QUO V3.0 to Manage Resource Information

- **QoS Model** can be built using a high-level representation of the underlying Resources and their structure.
- **Data Feeds** interface to the custom protocols used by distributed resource managers.
- **Status TEC** uses Push technology to publish resource status information without knowledge of the consumers or distribution channel.
- **Static Information** can be published via web pages, but in a QuO specific format.
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US Navy UAV Concept

UAV Basic Scenario

- Video feed from off-board source (unmanned aerial vehicle)
- Video Distributor sends video to hosts on ship’s network
- Users’ hosts receive video and display it
- Users interact with UAV in real time
Variations & Adaptations in UAV Scenario

Mission requirements of UAV scenario

**Fidelity**
- Highest fidelity frames (i.e., I frames) must be delivered

**Timeliness**
- Maintain an out-of-the-window view of UAV imagery

**Importance**
- Frames must be dropped in reverse order of importance (B, then P)

Dynamic Variations in Operating Conditions

**NETWORK RESERVATION**
- Condition: excessive Network load
- Action: Use IntServ to reserve bandwidth

**LOAD BALANCING**
- Condition: Excessive CPU load
- Action: Migrate distributor to a lightly loaded host

**DATA FILTERING**
- Condition: When excessive network or CPU load
- Action: Drop selective frames
UAV Architecture

• Features
  - Reused Off the Shelf Software
    - DVDView video player
  - Hand coded functionality
    - video forwarding
    - frame processing, filtering
    - timestamping and sequencing
    - connection, video transport

Many of these are intertwined aspects

Common middleware services
  - QuO adaptive middleware
  - Real-time CORBA ORB (TAO)
    - Naming Service
    - A/V Streaming Service
    - AQoS
Management and adaptation in UAV using the QuO adaptive middleware

Video Source Process

Video Distribution Host

Video Distributor

Video Display Proxy

Video Display

UAV File

UAV SIMULATION HOST

Video Stream

Video Stream

Filter

Rehost

Connect Stream

Reserve Bandwidth

Normal

Degraded

Unusable

Frame Rate

Display

A/V Streams

AQoSA

ORB

A/V Streams

AQoSA

ORB

Video Stream
Connecting and managing UAV video streams using the CORBA A/V Streaming Service

Video Source Process

Video Distributor

Video Display Proxy

Video Display

Source Stream Endpoint (Distributor)

Stream Interface Control Object

Stream Interface Control Object

Sink Stream EndPoint (Display)

Stream Adaptor

Stream Adaptor

QuO measurement and control

ORB

Video Stream

Video Stream

UAV SIMULATION HOST

UAV Video File

VIDEO DISTRIBUTION HOST

VIDEO DISPLAY HOST
Reserving network resources using the AQoSA API

- Video Source Process
  - UAV Video File
- Video Distributor
  - QuO
- Video Display Proxy
  - QuO
- Video Stream
- A/V Streaming Service
  - AQoSA API
    - request reservation
    - accept/reject
    - event notifications
    - flows
    - QoS updates
    - reservations
- Source Stream Endpoint (distributor)
- Sink Stream Endpoint (Display)
- Stream Adaptor
- Video Display
- UAV Simulation Host
- Video Distribution Host
- Video Display Host
- Video Display Proxy
- RSVP-enabled routers
Ability to Keep UAV Video Current using Middleware-based Adaptation

- UAV running on 3 200 MHz PCs (Linux), 128 MB memory, TCP/IP
- Additional 60% CPU load introduced on second stage (3 processes requesting 20% load each) starting at approx. 60 secs, removed at approx. 120 secs.

Under load

<table>
<thead>
<tr>
<th></th>
<th>Mean lateness</th>
<th>Max lateness</th>
</tr>
</thead>
<tbody>
<tr>
<td>No adaptation</td>
<td>5.400 sec</td>
<td>32.696 sec</td>
</tr>
<tr>
<td>Adaptation</td>
<td>0.067 sec</td>
<td>1.930 sec</td>
</tr>
</tbody>
</table>

Execution time (secs)

Additional latency (secs)

--

Without adaptation

With adaptation

Load
Functionality and aspects in the UAV application

Video Source Process
Base Functionality
• Read bytes from a file
• Convert into frames
• Send out pipe

Base Functionality
• Receive bytes
• Convert into frames
• Send frames to registered receivers

Adding a timestamp
Adding a sequence number
Measuring throughput
Measuring resource usage (CPU,NW)
Adapting to changes (e.g., filtering frames, load balancing)

Examining timestamp - handling late frames
Examining sequence nos. - handling frames out of sequence
Measuring throughput
Measuring resources

Video Distributor Process
Video Display Process
Base Functionality
• Receive bytes
• Convert into frames
• Display frames on the screen
Separating out Intertwined Aspects in the UAV Architecture

**Base Functionality**
- Read bytes from a file
- Convert into frames
- Send out pipe

**Timing:** periodic output of video frames

**Video Source Process**

**Video Distributor Process**
- Insert Timestamp
- Filter?
- Insert Seq. No.

**Filter?**
- Normal
- Degraded
- Unusable

**Base Functionality**
- Receive bytes
- Convert into frames
- Send frames to registered receivers

**Video Display Process**
- Remove Seq. No.
- Remove Timestamp

**Base Functionality**
- Receive bytes
- Convert into frames
- Display frames on the screen

**Adding a timestamp**

**Adding a sequence number**

**Measuring throughput**

**Measuring resource usage (CPU, NW)**

**Adapting to changes (e.g., filtering frames, load balancing)**

**Examining timestamp - handling late frames**

**Examining sequence nos. - handling frames out of sequence**

**Measuring throughput**

**Measuring resources**

**VIDEO DISPLAY HOST 2**
Specifying and Generating Code for QoS Aspects using QuO

**C++ Application Code**

```cpp
class Sender
{
public:
    int debug_level_; // Amount of debugging info to print out: 0 = none, 10 = lots
    Connection_Manager &connection_manager (void); // Accessor to the connection manager.
    void done (int); // Flag to know when we are done.
    int done (void) const; // Flag to know when we are done.
    int parse_args (int argc,  char **argv); // Parse args.
    int init (int argc,  char **argv, CORBA::Environment &); // Initialize data components.
}

/// Destructor.
~Distributor (void);

/// Constructor.
Distributor (void);

/// Method to parse the command line arguments.
int debug_level_; // Amount of debugging output to print out; 0 = none, 10 = lots
Connection_Manager &connection_manager (void); // Accessor to the connection manager.
int pace_data (CORBA::Environment &); // Method to pace and send data from a file.
```
Example Qoskets for the WSOA and UAV

F-15 collaboration client

ImageServerDelegate
- get_tile()
- change image quality

get_tile(number, quality)

C2 collaboration server

CollaborationQosket
- On Time
- Early
- Late

Request QoS

Processor Resource Manager

Measured Progress

Video Distributor

Send Frame

StreamEndpointDelegate
- reserve bandwidth()
- Filter?
- Timestamp
- Sequence no.

Normal
Degraded
Unusable

request reservation
reservation status

A/V Streaming Service

AQoSA

RSVP
Wrapping Up: Future QoS Directions

- Moving up towards application’s programming level
  - Design patterns and libraries (of contracts etc.) can help…

- More “multi-dimentional QoS” supported
  - Bandwidth “reservation”: performance
  - replication+caching : availability
  - Security
  - Mobile/wireless: minimize power consumption and memory footprint

- Broadening from just the classical multimedia & http apps
  - VPNs
  - Collaboration
  - Virtual Reality
  - Application managers with QoS

- More OS-level substrates to choose from
  - Intserv & Diffserv combined, eventually across domains / ISPs
  - MS QoS (W2K has hooks for it…)

- Industry-Academic partnerships
  - Industry does not have time/labor to experiment/evaluate research substrates
  - Academics don’t have time to learn industry products in depth
... so here are the quotations ...

“I have a cat named Trash. In the current political climate, it would seem that if I were trying to sell him (at least to a Computer Scientist), I would not stress that he is gentle to humans and is self-sufficient, living mostly on field mice. Rather, I would argue that he is object-oriented.”

Prof. Roger King, University of Colorado, 1989

“My cat is CORBA-compliant.”

Dr. John Nicol, GTE Labs, 1995

“My CORBA-compliant cat has great QoS.”

Dr. Dave Bakken, BBN, 1997

“My CORBA-compliant cat with great QoS is also an aspect-oriented, grid-enabled component for protecting sensor networks and the power grid against cyberterrorists, so your funding my research is a no-brainer.”

Prof. Dave Bakken, Washington State University, 2005
Conclusions

• Distributed QoS is a very broad area of research
  – Hot area, with lots of funding and cool problems!
  – Lots of issues that need to be dealt with systematically

• QuO provides end-to-end middleware support
  – Organizing end-to-end requirements
  – Collecting status inputs for adaptation
  – Providing adaptation at well-defined end-to-end locations
  – Reserving as many resources or as much QoS as possible
  – Adapting when you don’t get what you want
  – Reuse of all of the above application and system code

• QuO was designed from the start to integrate
  – Other researchers’ mechanisms to provide QoS
  – Other researchers’ status information sources
  – Multiple commercial and open-source middleware platforms
  – Has been very successful at this! (IMO; YMMV)
BACKUP SLIDES FOLLOW (some a tad obsolete)


**AQuA Handlers: Design Space has Many Variables!**

- Client group has leader or has no leader
  - how much do you trust client group?
- Server group has leader or has no leader
- Multicast strengths (total, causal, FIFO, ...) used in connection group
- Which members of client and server groups are in connection group
- Location and algorithm for voting
- How many rounds of multicasts (e.g., for byzantine)
- Location of buffering of requests/replies
  - Caveat: not shown in following diagrams
- Also: interaction with handler “upstream” or “downstream” in a nested call
  - A → B → C: handlers A → B and B → C need to be managed together, for reasons of performance and possibly correctness
AQuA Scheme1 Request Steps

(Leader)

1. C-Rep1
2. GW
3. ORB

GWs in Client Group

GWs in Connection Group

GWs in Server Group

1. C-Rep2
2. GW
3. ORB

1. C-RepN
2. GW
3. ORB
AQuA Scheme1 Reply Steps

(Leader)

C-Rep1
ORB

GW

C-Rep2
ORB

GW

... C-RepN
ORB

GW

GWs in Client Group

(All GWs are in Connection Group)

GW

GW

GW

GWs in Server Group

GW

ORB

S-Rep1

ORB

S-Rep2

... ORB

S-RepM
Implements the active protocol resembling that in Proteus design doc. Server-side Ldr GW votes on requests (H2), receiver-side GW Ldr votes on replies (H6). Assumes clients have no asynch. requests outstanding, so a gap in a reply sequence in H6 means a one-way request occurred (need trickier data structures to handle asynch replies: B, <n1,n2,…,nk>). Void where prohibited by law. YMMV.
D1. Sender ("client") ORB delivers IIOP msg.
D2. S-IIOPGW enqueues msg
D3. Dispatcher dequeues message
D4. Dispatcher looks up next sequence and calls Request()
D5. Dispatch handler looked up and dispatched to; stores local ReqID

H1. GW_Scheme1_Handler::SendRequest() does
   a. S-GWs send pt2pt msg #1 to Ldr S-GW
   b. NonLdr S-GWs buffer msg #1 (to be deleted in H3b).
H2. When recv msg #1, Ldr S-GW votes on requests. (in this case sends just the first one), and sends chosen request in msg #2 to connection group unordered
H3. When receive msg #2
   a. All NonLdr R-GWs store msg #2 in buffer (to be deleted in H4b)
   b. NonLdr S-GW delete msg #1 from buffer (stored in H1b)
   c. Ldr R-GW sends totally-ordered msg #3 to R-GWs to order across all client groups
H4. When receive msg #3
   a. R-GWs call Dispatcher->DeliverRequest()
   b. NonLdr R-GW deletes msg #2 from buffer (stored in H3c)

D6. Dispatcher places invocation msg in queue for IIOPGW
D7. IIOPGW removes msg from queue
D8. IIOPGW delivers msg to Receiver ("server") ORB
D9. "server" ORB sends back IIOP reply msg to R-IIOPGW
D10. R-IIOPGW queues reply message for R-GW
D11. R-GW dequeues reply msg
D12. R-W calls dispatch->Reply()
D13. R-GW Dispatcher->Reply() notes handler# from Msg, looks up wrapper, and calls Handler1->SendReply()

H5. GW_Scheme1_Handler::SendReply() does
   a. R-GWs send reply msg #4 pt2pt to Ldr R-GW
   b. NonLdr R-GW buffers msg #4 (to be deleted in H7a)
H6. When msg #4 arrives Ldr R-GW votes on replies and sends chosen reply (in this case the first msg #4 with this seq#) in msg #5 unordered to connection grp. Discards the rest of the replies with same seq#. Gaps in seq# may occur here, but if so this is due to a one-way request, since for now we assume no asynch client requests.
H7. When msg #5 received
   a. NonLdr R-GW can delete buffered reply msg #4 (stored in H5b) (note Ldr R-GW does not receive it because unordered; else it would just discard it)
   b. Ldr S-GW sends reply msg #6 ordered multicast to all S-GWs
   c. NonLdr S-GW stores reply msg #6 in buffer (deleated in H8b)
H8. When msg #6 arrives,
   a. S-GWs call dispatcher->DeliverReply() with this reply message.
   b. NonLdr S-GWs delete msg #5 from buffer (stored in H7c).

D14. S-GWs DeliverReply() queues msg for IIOPGW
D15. IIOPGW dequeues message
D16. IIOPGW sends IIOP message to sender “client” ORB