Tools and techniques for monitoring real-time distributed applications

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OMG Real-time, Embedded and Enterprise-Scale Time-Critical Systems workshop,
May 2010
Agenda

- The Challenge
- Infrastructure Monitoring
- Application Monitoring
- Future directions
Challenge

- Distributed systems are becoming larger…
  - composed of many independently-developed applications
  - by nature deployed on a network

- Understanding and management is a significant challenge
  - During System Integration/Testing
  - At deployment time

- Instrumentation and Monitoring are the key technologies that can address this:
  - What is running? Where?
  - How is it performing?
  - What is the application doing?

- Heisenberg challenge:
  - Do this without impacting the application
Example: DDS Systems

- DDS systems are decoupled and distributed
  - Dynamic
  - Highly scalable
  - Peer-to-peer
  - Real-Time

There is no central truth
Two dimensions to monitoring:

- **Infrastructure**
  - Middleware (e.g. DDS), Network, Operating system, Processor

- **Application**
  - Health
  - Internal state
  - Data

- These are not independent! System understanding requires correlation of all this data...
  - My tracking system is failing because is getting delayed data because network packets are dropped because the system is busy, because …
Agenda

- The Challenge
- **Infrastructure Monitoring**
- Application Monitoring
- Future directions
Monitoring Distributed Systems

- Faults come in many flavors
  - Hard faults (crash, hang etc.)
  - Violation of real-time constraints

- Hard to establish causality and chain of events
  - Can’t single step a distributed systems
  - Changing timing often changes event
  - Fault is often not reproducible

- Monitoring requires centralized access to distributed system state
  - For visualization
  - For regression against a baseline
Non-functional requirements

- Robust to network partitioning
- Minimally intrusive in resources (CPU, Memory, Network)
- Scalable to many applications
  - Traditional techniques such as SNMP not scalable
- Support for multiple consumers of the data
  - Recording
  - Logging
  - Visualization
  - Algorithmic supervision
Solution: Data-Centric Monitoring: Use DDS for Infrastructure Instrumentation

- **Application**
- **Middleware**
  - Middleware Instrumentation
- **Database Bridge**
  - SQL
- **Recording**
- **Event Processing**
- **Generic COTS Data-Visualization Tool**

The diagram illustrates the integration of DDS (Data Distribution Service) for infrastructure instrumentation, with components such as middleware, database, and visualization tools.
Benefits

- Leverage DDS performance and scalability to distribute collected data
- Leverage Discovery and Pub-Sub
  - Information available to all consumers
- Use Data-Centric model for Collected Data
  - Leverage DDS Data-Centric Qos
    - History to keep recent-values if each metric
    - Time filters to enabled sub-sampling
    - Deadline/Liveliness to monitor availability
Example: Monitoring DDS Middleware

DDS itself is an example infrastructure which can be monitored

- Data-Model based on DDS Status model

- Additions for:
  - DDS Entity resource usage
  - DDS-RTPS Wire Protocol entity model
    - RTPS Writer & Reader Statistics
    - RTPS Statistics

- Each DDS or RTPS entity becomes a separate data-object in the model
Example: Monitoring DDS Status

### DataReader Status

<table>
<thead>
<tr>
<th>DataReader Status</th>
<th>Sample Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requested Incompatible QoS Status</td>
<td>Sample Statistics</td>
</tr>
<tr>
<td>Total Count</td>
<td>Received Count: 1,135 (∆0)</td>
</tr>
<tr>
<td>Last Policy Id</td>
<td>Received Bytes: 122,590 (∆0)</td>
</tr>
<tr>
<td>Policies</td>
<td>Duplicates Count: 0 (∆0)</td>
</tr>
<tr>
<td>id = Deadline, count = 2</td>
<td>Duplicates Bytes: 0 (∆0)</td>
</tr>
</tbody>
</table>

### Heartbeat Statistics

<table>
<thead>
<tr>
<th>Heartbeat Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartbeat Count: 37 (∆0)</td>
</tr>
<tr>
<td>Gap Count: 660 (∆16)</td>
</tr>
</tbody>
</table>

### Sample Status

<table>
<thead>
<tr>
<th>Sample Count</th>
<th>Sample Count Peak: 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cache Samples Mean: 0.0</td>
<td>Cache Samples Minimum: 0</td>
</tr>
<tr>
<td>Cache Samples Maximum: 0</td>
<td>Cache Samples Variance: 0.0</td>
</tr>
</tbody>
</table>

### Total Count

<table>
<thead>
<tr>
<th>Total Count</th>
<th>Sample Sent Count: 36 (∆0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Rejected Status</td>
<td>Sample Sent Count: 1,009 (∆0)</td>
</tr>
</tbody>
</table>

### Last Relation

<table>
<thead>
<tr>
<th>Last Relation</th>
<th>Nacks Sent Count: 2 (∆0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last Instance Handle</td>
<td>Nacks Sent Bytes: 88 (∆0)</td>
</tr>
</tbody>
</table>
**DDS Topics used to monitor DDS itself**

- **EntityDescription** (QoS and other static information, published on creation, deletion and when QoS changes)
  - DomainParticipant
  - Publisher
  - Subscriber
  - Topic
  - DataReader
  - DataWriter

- **EntityStatistic** (Status, aggregated status and statistics, published periodically)
  - DomainParticipant
  - Topic
  - DataReader
  - DataWriter
  - DataReader with matched DataWriter
  - DataWriter with matched DataReader
  - DataWriter with matched locator
Agenda

- The Challenge
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- **Application Monitoring**
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Challenges of Application Instrumentation

- Access to application-specific data from remote locations
- Minimal intrusiveness
  - CPU, Memory, Network
- Access from many points
  - Live monitoring / HMIs
  - Logging
  - Real-Time analysis...

Same non-functional requirements than Infrastructure Instrumentation!
Solution: Use DDS for distribution of instrumented data

Application

Instrumentation API

DDS

Application

Instrumentation API

DDS

Application Instrumentation API

Database Bridge

SQL

Recording

Event Processing

Generic COTS

Data-Visualization Tool

Application Instrumentation Visualization Tool
Two aspects

- Instrumentation API
  - API used by developers to instrument their application
  - “the super printf()”

- Instrumentation Data-Model
  - How is the instrumented data modeled in DDS?
Why a different API and not just DDS?

- More focused on the instrumentation task
  - Lower learning curb
  - More easily adopted

- Enforces Instrumentation Data Model

- Enforces QoS sensible for instrumentation

- No need for compile-time type declarations or code-generation
  - Underneath it leverages DDS-X-TYPES spec.
Mapping to DDS

```
pkg MappingToDDS

ApplicationInstrumentation::ObservableClass
- name: string
- key: string
+ add_primitive_field(string, FieldType) : void
+ add_array_field(string, FieldType, long) : void
+ get_field_count() : long
+ get_field_info(long) : FieldInfo
+ create_object(string) : ObservableObject
+ set_consolidation_function(ConsolidationFunction) : void

ApplicationInstrumentation::ObservableObject
+ set_long_field_value(long, long) : void
+ set_double_field_value(long, double) : void
+ set_string_field_value(long, string) : void
+ set_long_array_field_value(long, long, long) : void
+ set_double_array_value(long, long, double) : void
+ set_string_array_value(long, long, string) : void
+ snapshot_observation() : void
+ get_observation(long) : Observation

DDS::DataWriter

DDS::ExtensibleTopics::DynamicType

DDS::ExtensibleTopics::DynamicObject

ApplicationInstrumentation::Observation
+ get_long_field_value(long) : long
+ get_double_field_value(long) : double
+ get_string_field_value(long) : string
+ get_long_array_value(long, long) : long
+ get_double_array_value(long, long) : double
+ get_string_array_value(long, long) : string
```
Two categories of Observations

- **Periodic Observations**
  - Sent at a specific, configured period

- **Event-based Observations**
  - Sent when “something interesting” happens
  - E.g. an observation exceeds a threshold
  - An observation changes “significantly” from the previously-reported value
# DDS QoS for Periodic Observations

<table>
<thead>
<tr>
<th>QoS Policy</th>
<th>Value</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>RELIABILITY</td>
<td>BEST EFFORT</td>
<td>It is sufficient to send the collected information best efforts because it is being collected periodically.</td>
</tr>
<tr>
<td>HISTORY</td>
<td>KEEP_LAST</td>
<td>Since data is being continually produced the system only needs to keep the most recent values</td>
</tr>
<tr>
<td>OWNERSHIP</td>
<td>EXCLUSIVE</td>
<td>At any one time there can only be one application publishing the instrumentation data of any given ObservableObject</td>
</tr>
<tr>
<td>DEADLINE</td>
<td>3X periodic rate</td>
<td>DEADLINE can be used to detect that a specific ObservableObject is no longer being produced. It should be set to match the periodicity of the disseminated observations.</td>
</tr>
<tr>
<td>DURABILITY</td>
<td>VOLATILE</td>
<td>There is no need to save data for late joiners because the fresh data will soon be produced</td>
</tr>
</tbody>
</table>
## DDS QoS for Event-Based Observations

<table>
<thead>
<tr>
<th>QoS Policy</th>
<th>Value</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RELIABILITY</strong></td>
<td>RELIABLE</td>
<td>Reliable communications are needed because the Observations are not updated continuously and losing one could cause the receivers to not receive some important change or state update and potentially never find out the correct values.</td>
</tr>
<tr>
<td><strong>HISTORY</strong></td>
<td>KEEP_LAST</td>
<td>Ensure that the system retains the last “history depth” Observations for each ObservableObject</td>
</tr>
<tr>
<td><strong>OWNERSHIP</strong></td>
<td>EXCLUSIVE</td>
<td>At any one time there can only be one application publishing the instrumentation data of any given ObservableObject</td>
</tr>
<tr>
<td><strong>DEADLINE</strong></td>
<td>INFINITE</td>
<td>Since Observations are not being sent continually published we cannot guarantee any deadline.</td>
</tr>
<tr>
<td><strong>DURABILITY</strong></td>
<td>TRANSIENT_LOCAL</td>
<td>Observations should be retained for late joiners because otherwise they may not receive date until the next significant event that causes the Observation to be published occurs. Depending on the system and ConsolidationFunction this might take an unbounded time.</td>
</tr>
</tbody>
</table>
Combined Solution: Middleware + Application Instrumentation

Application Instrumentation API

Middleware Instrumentation

Middleware Inst. Visualization Tool

Database Bridge

SQL

Recording

Application Inst. Viz Tool

Generic COTS
Agenda

• The Challenge

• Infrastructure Monitoring

• Application Monitoring

• Future directions
Scope of the RFP

- **Generic Instrumentation API**
  - Allows applications to instrument themselves and define the relevant internal state / measures to monitoring
    - This is application dependant

- **Monitoring Data Model for different middleware platforms: DDS, CORBA, …**
  - What internal state must the middleware report to understand its health

- **Mapping of the monitoring data to standard middleware (e.g. DDS) so that the information can be remotely accessed by recording and HMI tools.**
Proposed approach

- PIM on Application Instrumentation (AI)
- Three kinds of PSMs:
  - Application Instrumentation PSMs (AI-PSM)
  - Middleware Instrumentation PSMs (MI-PSM)
  - Middleware mapping of AI-PSM and MI-PSM
- AI-PSM
  - Concrete Platform/Language API to instrument applications
  - Mapping to middleware to access the collected data on a distributed system
- MI-PSM
  - What information should be collected on each middleware platform
AI-PSM Example:

- API that allows an application to define what data to collect and when:
  - Events
    - `InstrEventDeclare("Event Name", EventType, …)`
    - `InstrEventNotify("Event Name", EventValue)`
  - Continuous data.
    - `InstrMeasureDeclare("Measure Name", MeasureType, …)`
    - `InstrMeasuresCollect("Measure Name", MeasureValue);`
  - Triggers
    - `InstrTriggerDeclare("Measure Name", TriggerExpression)`

```
InstrTriggerDeclare("HostileTrackCount",
  "track_count > 1000");
```
MI-PSM Example:

- For DDS define relevant instrumentation data
  - Samples/sec received by a DataReader
  - Number of samples in a DataWriter cache
  - Number of NACKs received by a DataWriter
  - Number of Data samples that are un-acknowledged in a DataWriter Cache
  - ...

How is the Instrumentation API realized in terms of underlying data-model and how it is made available to other applications
  - E.g. map collected data to DDS Types and Topics

How is the Data-Collected from the middleware modeled and distributed
  - E.g. map middleware data to other DDS Types and Topics

NOTE: The middleware used for this PSM need not be the same as for the MI-PSM
  - E.g. it is possible to define a MI-PSM for CORBA and distributed the collected data via DDS.
Future Directions

- Monitor non-DDS system resources
  - e.g. CPU, memory, network
- Network topology with alerts
- Real-Time DDS Latency and Throughput statistics
- Integration with COTS tools
  - i.e. HP Openview
Thank You!

Q & A