A Data Centric Approach for Modular Assurance

Workshop on Real-time, Embedded and Enterprise-Scale Time-Critical Systems
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Agenda

- Introduction
  - Mixed criticality systems
  - The challenge

- Data Centric Architecture
  - Modularity
  - Separation Kernels
  - Data Distribution Service (DDS)

- Example

- Recommendations
Mixed Criticality Systems

- Any system that has multiple assurance requirements
  - Safety, at different assurance levels
  - Security, at different assurance levels
- Example: Unmanned Air Vehicle
  - Flight control is safety critical
  - Payload management is mission critical
- Ideally a system is built from components each with their own assurance requirements
The Challenge

- Design a modular plug-and-play architecture to reduce cost and reuse components
- Components must interact
  - The behavior of one component can affect another
  - It can be advantageous to have components at different criticality levels exchange data
  - Once a component interacts with another, then the whole system must be certified, not the individual components
The Solution

- Move from a component-interaction model to a data-centric model
- The data-centric model defines the data types and attributes in the system
- A component complies with the data model in terms of data it sends and receives
- This decouples the applications
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The Modular Approach

Monolithic Approach
- Certify whole system
- Connection oriented
- Tightly coupled
- Hard to evolve

Modular approach
- Certify components
- Data oriented
- Loosely coupled
- Evolvable

Smart Data Bus
Standardized Data Services
QoS Controlled Communication
The Data Contract

- First, all data in the system is defined
- Next, data characteristics are defined
  - For example “airspeed” is flagged as flight critical
- Then components define data delivery attributes
  - A flight critical component specifies data rate that flight critical data must be delivered
- This creates a “data contract”
Data Centric Approach for Layered Assurance

- Data contract includes
  - Data type
  - Name
  - Quality of Service

- Sender/Receiver of the data is anonymous

- Validation
  - Component validation – does it conform to the data model
  - System validation – is there a producer at correct assurance level for each required data
Realization in a Layered Assurance System

- **Separation Kernels**
  - Guarantees isolation of components
  - Controls data flow

- **Object Management Group (OMG) Data Distribution Service**
  - Used to implement the data model and distribute data
Separation Kernels

- Base of the solution for mixed-criticality systems certification

- Isolation and Control
  - Each guest operating system (OS) runs in its own partition
  - Each guest OS is isolated over both time and space
  - Information flows are tightly controlled
  - Components can be pre-certified and composed quickly into new configurations

- Caveat
  - Does not address interdependency between components or interactions between components on separate computers
Data Distribution Service (DDS)

- Data-centric publish-subscribe middleware for real-time communication
  - Strong data typing
  - Quality-of-Service (QoS) parameters
    - e.g., deadlines for message delivery, bandwidth control, reliability model control, failover and backup specification, data filtering etc.

- DDS QoS parameters characterize:
  - the data contracts between participants
  - the properties of the overall data model
  - real-time communication and delivery requirements on a per-data-stream basis
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Example: Wind River VxWorks MILS and RTI Data Distribution Service

Hardware (Processor + Board)

VxWorks MILS Separation Kernel
Wind River Hypervisor Technology
Example Demo Overview

UAV Components (SBC)

DDDS Bus

Ground control (laptop 1)  DDS provides location-independence!

Remote monitor (laptop 2)  DDS provides location-independence!

Flight critical

Logging

MILS Kernel

DDS

DDS

DDS

DDS

Alarm Viewer

DDS-Web Services bridge

High criticality

Lower criticality
Scenario 1: Failover of Lower Criticality

DDS Bus

Secondary Mission Plan

Primary Mission Plan

Flight critical

Logging

MILS Kernel

Alarm Viewer

DDS-Web Services bridge

High criticality

Lower criticality
Scenario 2: Lower Criticality Floods the Network

Filters excess data

DDS Bus

Secondary Mission Plan
Primary Mission Plan

Flight critical
Logging
MILS Kernel

Alarm Viewer
DDS-Web Services bridge

High criticality
Lower criticality

Floods network
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Tenets for Developing Safety-Critical Software

- Reduce code size
- Consider testability in design
- Enable verification
  - Avoid recursion
  - Set limits – for example limits on iterations
- Deterministic in time
- Deterministic in memory
  - No dynamic memory allocation after startup
Challenges DDS for in Safety-Critical Systems

- DDS is designed to be dynamic
  - Entities discovered at run-time
  - Number of nodes and endpoints can change
  - DDS adaptable to changes in the environment, for example increasing a sample queue

- DDS is feature rich
  - Implementations can have many lines of code, making certification costly
  - Many features either not suitable or not applicable to safety-critical systems
The process by which domain participants find out about each other’s entities
- Each participant maintains database on other participants in the domain and their entities

Happens automatically behind the scenes
- “anonymous publish-subscribe”

**Dynamic** discovery
- Participants must refresh their presence in the domain or will be aged out of database
- QoS changes are propagated to remote participants
DDS Discovery in Safety-Critical Systems

- **Do not want**
  - An a priori unknown number of participants connecting
  - An a priori unknown number of remote Data Writer/Data Readers

- **Do want**
  - To know if remote participants are up
  - A simple protocol

- **Solution**
  - Stage 1: the same, dynamic participant discovery
  - Stage 2: static loading of endpoints
In DDS, queue sizes can change
- Discovery queues grow when more nodes join the system
- Data queue sizes grow to accommodate more data

In a safety-critical system, memory must be deterministic

Solution
- Set all resource limits before creating entities
- Memory is only allocated during _create calls
- There is no memory growth policy
DDS Feature Set

- Support the same entities
  - Domain Participant, Publisher, Subscriber, Data Reader, Data Writer, Topic

- Need core DDS APIs
  - Create entities
  - Write/Read
  - Listener for data available
  - Get QoS and Entities

- RTPS wire protocol compatibility
QoS supported

QoS needed for safety-critical systems
- Best-effort communication
- Reliable communication
- History queue
- Reader and Writer Deadline
- Manual assertion of liveness by topic
- Time-based filter – Filter only on the reader
- Ownership
- Ownership strength
Conclusions

- Mixed-criticality systems certification can go a long way

- We can leverage:
  - Isolation and control capabilities through separation kernels
  - Modularity through a data-centric architecture

- It is possible to build mixed criticality systems that provide:
  - Modularity
  - Evolvability
  - Fault tolerance
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Thank You