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An Extensible Architecture for Avionics Sensor Health Assessment Using DDS

Sumant Tambe, Ph.D.
Senior Software Research Engineer
Real-Time Innovations, Inc.

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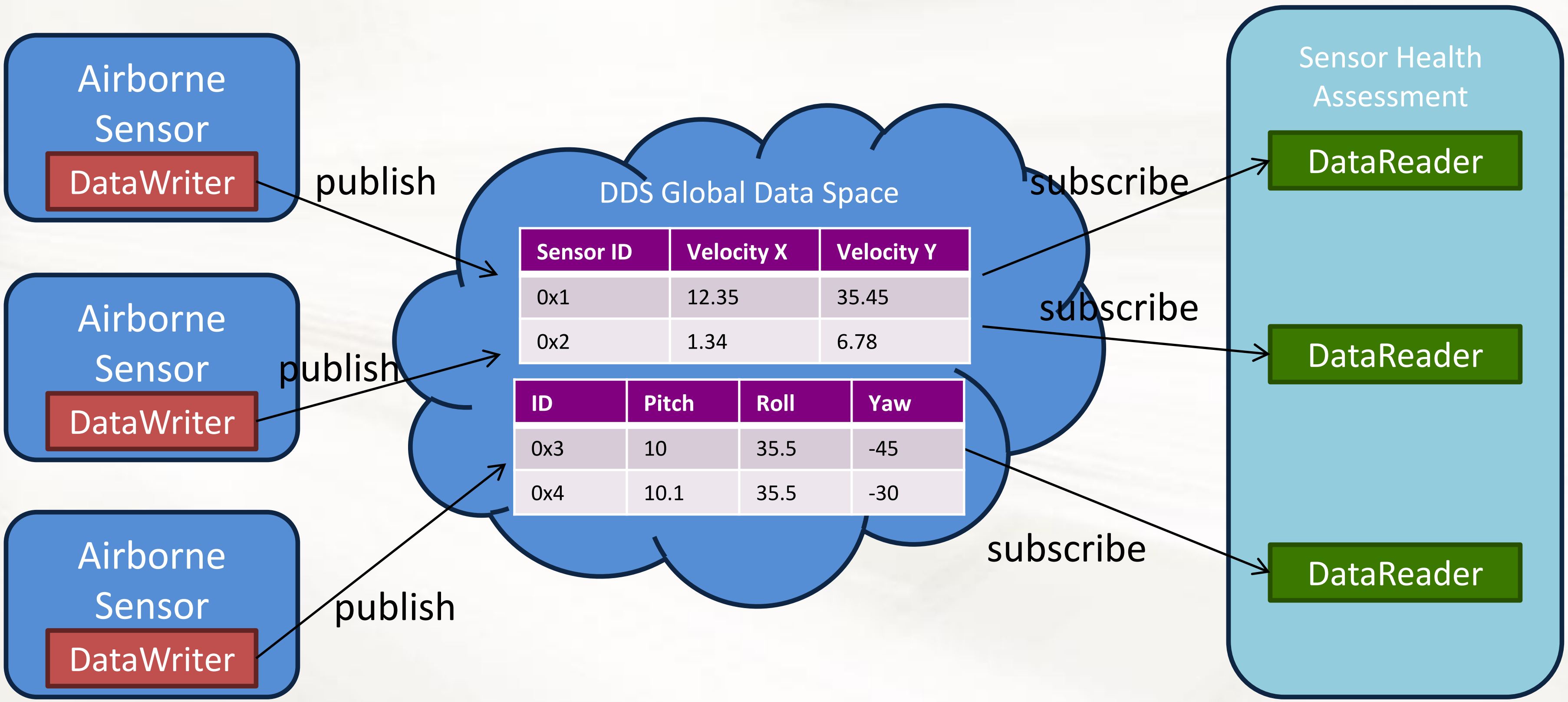
NASA K10 Rover:
Surface Telerobotics
Uses RTI Connext DDS

Why NASA Uses RTI Connext DDS

- NASA was looking for a software architecture and communications infrastructure that enabled **reliable**, **standards-based messaging** between the International Space Station and Earth.
- NASA relied on the RTI Connext DDS solution because of its ability to **tolerate time delay** and **loss of signal.**
- A **common, flexible, interoperable** data communications interface that would **readily integrate** across each robot's **disparate** applications and operating systems.

Data-Centric Architecture of DDS



Research: Cyber Situational Awareness

- Research is funded by the Air Force Research Laboratory, WPAFB, Dayton, OH

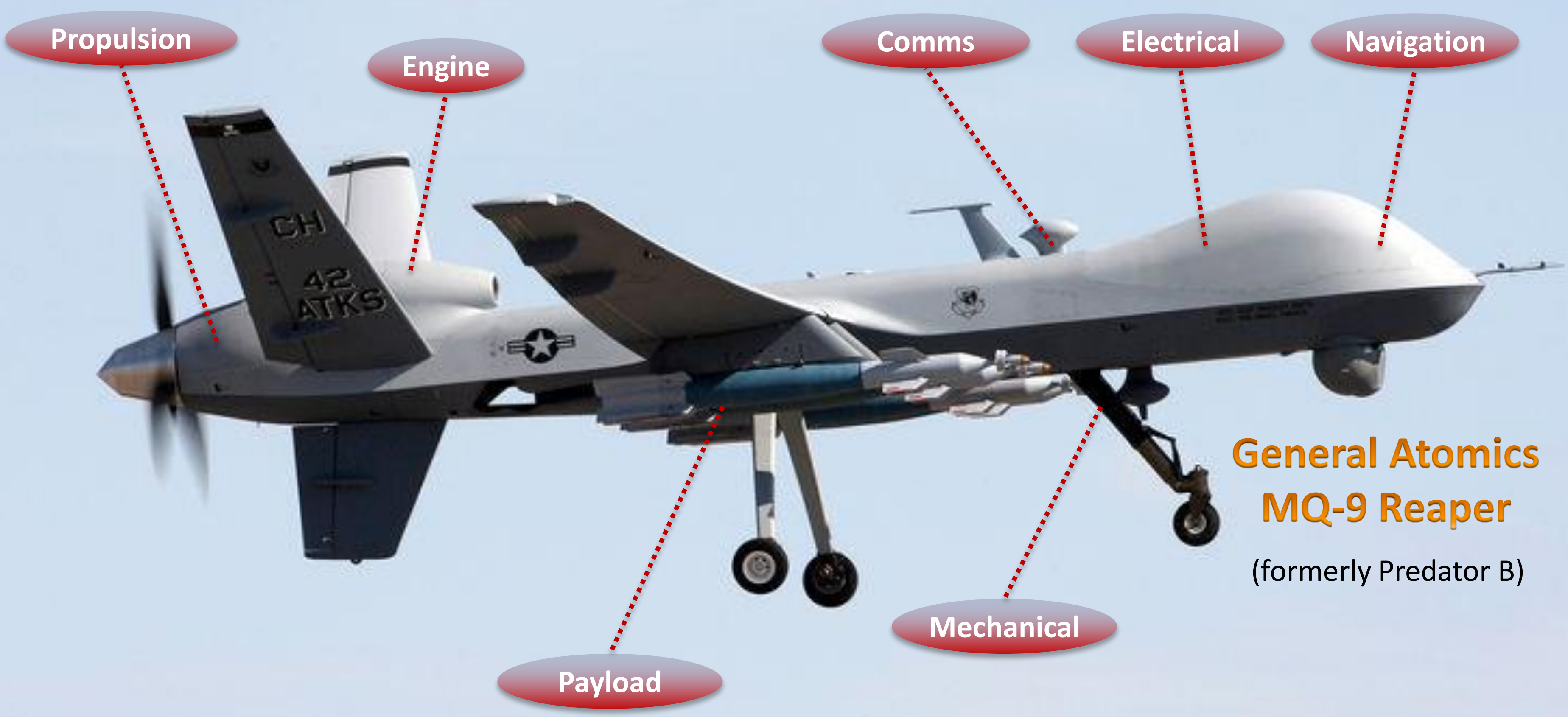
Context: Cyber Situational Awareness

- Enterprise Security Situational Awareness
- Sensor Health Management

	Security Situational Awareness	Sensor Health Management
Goal	Situation (Attack) recognition, comprehension, projection	Fault Detection, Isolation, Mitigation
Sensors	E.g., Host-based and network intrusion detection systems (OSSEC, Snort, Ganglia), malware detectors, firewalls, operating system, etc.	E.g., Accelerometer, fuel-flow sensors, altimeter, speedometer, etc.
Input to Analysis	Events and Alerts: log analysis, file integrity checking, policy monitoring, rootkit detection, real-time alerting and active response	Sensor readings, software status signals, software quality signals, operating system information
Analysis Techniques	Complex Event Processing, Classification (Naïve Bayes, SVM, linear classifiers), clustering (K-means), pattern matching etc.	Bayesian Networks, Hybrid Bayesian, Timed Fault Propagation Graphs (TFPG),
Tools/Libraries	R, Weka	Smile and Genie
Visualization	Histograms, heat maps, time series	Time series

Sensor Health Management

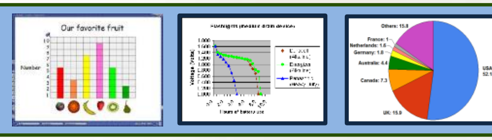
Cyber Health Analysis of Airborne Sensors



STANAG 4586 Message #1101: Subsystem Status Report
0 = No Status; 1 = Nominal; 2 = Caution; 3 = Warning; 4 = Emergency; 5 = Failed

Hardware-in-the-loop Simulation

Visualization

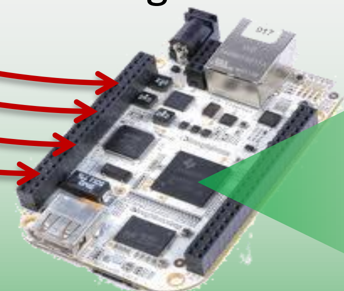


Sensor Health Estimates

Orientation Sensor (IMU)

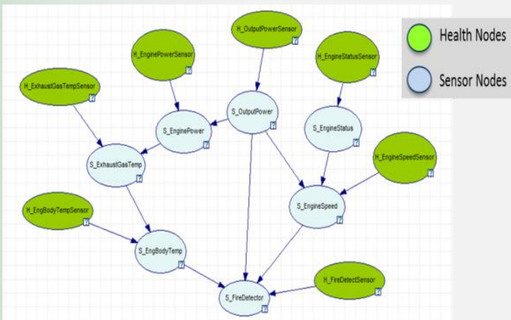
Pitch/Roll/Yaw updates over TTL UART1

BeagleBone



Sensor Health Analysis using Bayesian Network

Bayesian Network



Smile library

EngineOperatingStates

Simulated UAV Engine Data (STANAG 4586)

DDS

Simulated MQ-9 Reaper UAV

Flight Simulator

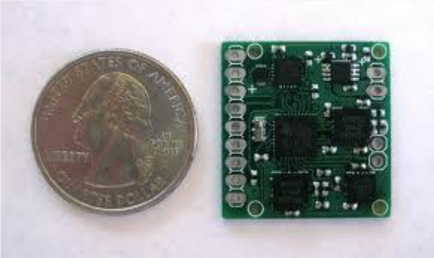
- Flight Simulator
  - E.g., Flight-Sim , X-Plane
  - Realistic aerodynamic simulation
  - Large number of model planes including UAVs
    - E.g., GD MQ-9 Reaper
  - Simulates sensor failures
    - E.g., Engine fire
- Using Simulator data
  - Publish using DDS
  - Drive the Bayesian Network
  - Inject artificial failure to evaluate BaysNet

Hardware-in-the-loop Simulation using Orientation Sensors

- Hardware Description
  - Beaglebone Rev A5 (700 MHz, 256 MB RAM)
  - CHR-6dm AHRS Orientation Sensor
  - Communication over TTL (3.3V) UART at 115200 Baud
  - Onboard Extended Kalman Filter (EKF) produces yaw, pitch, and roll angle estimates

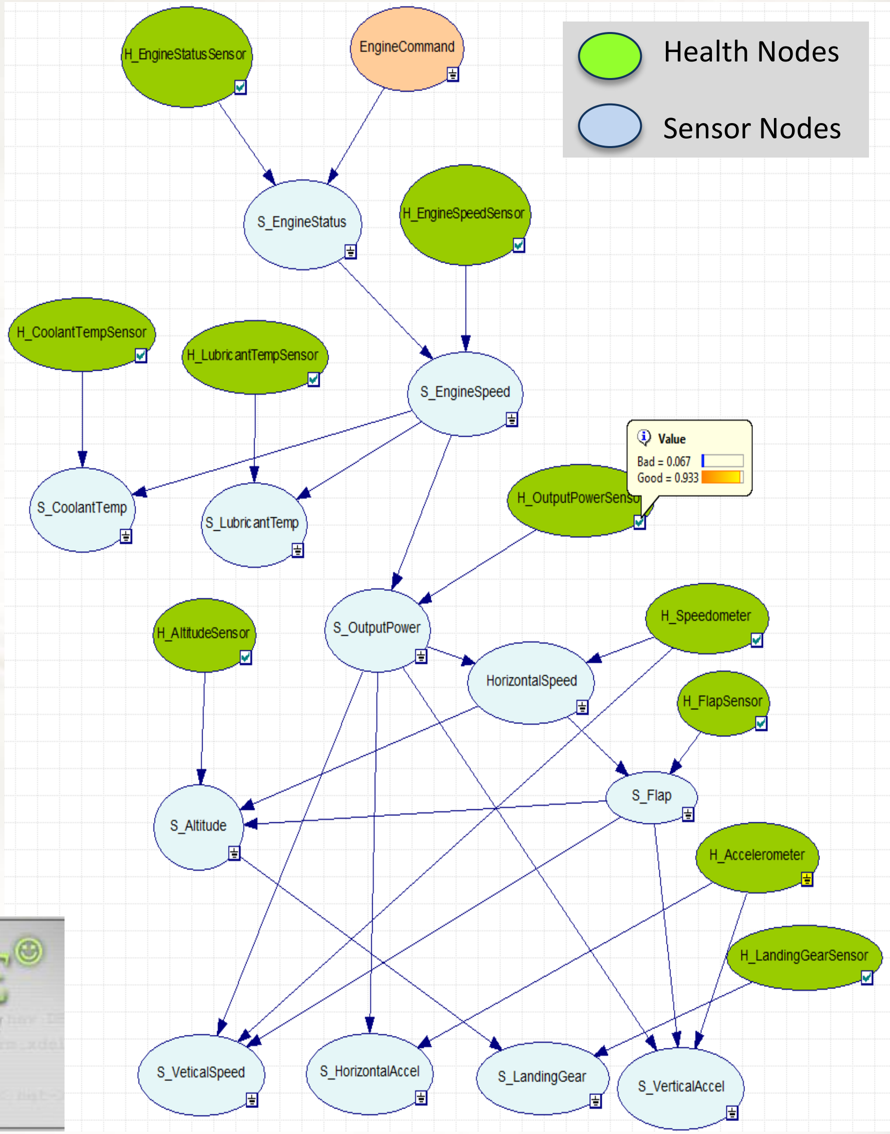
BeagleBone with CHR-6dm (above)

CHR-6dm orientation Sensor (below)



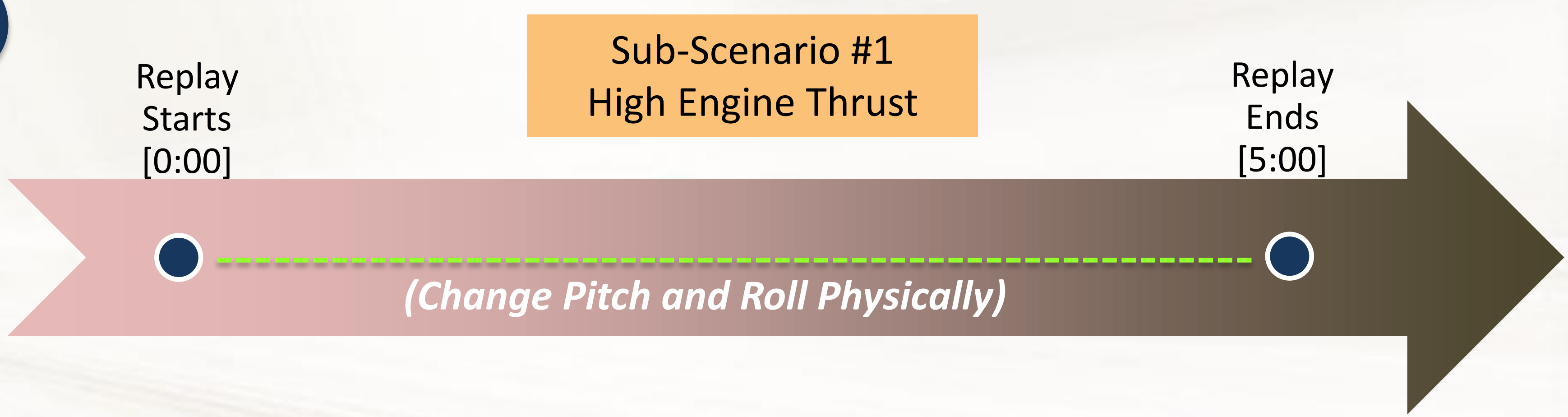
Sensor Health Analysis Using Bayesian Networks

- Bayesian Network based on STANAG 4586
- Sensor dependencies are modeled as an acyclic graphs
- Can learn the structure and parameters from raw data
- Each node has a probability distribution function with respect to its parents
- Raw values of sensor readings are discretized and plugged in
- Health nodes (H_*) give instantaneous probability of sensor being faulty
  - A real value between 0 to 1
  - A value above or below a threshold trigger an alert



IMU-in-the-loop Simulation (Failure Scenarios)

1



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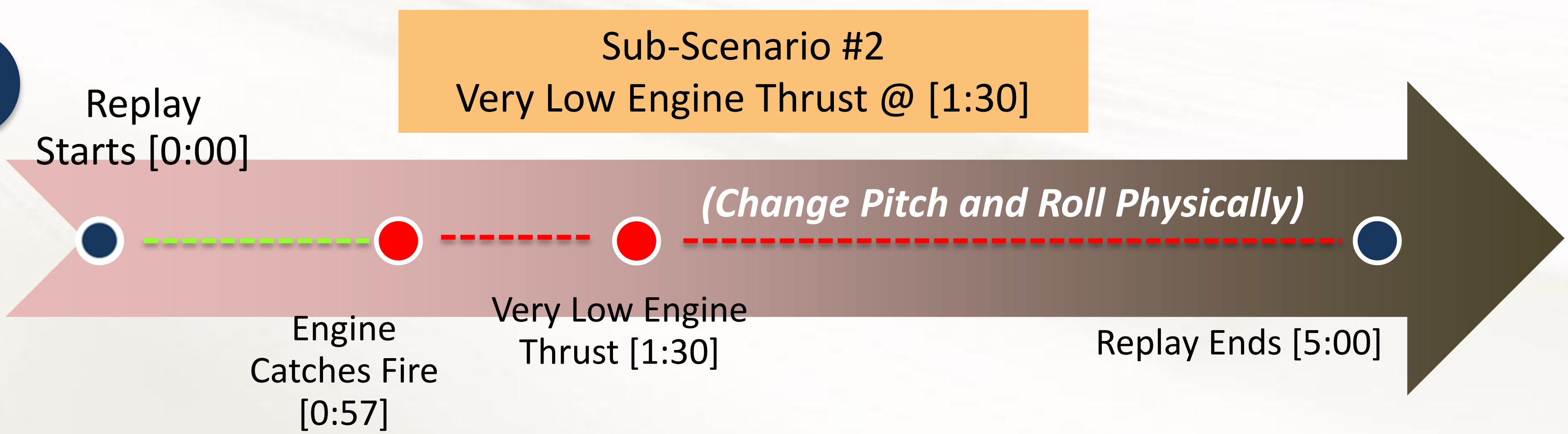


Extensibility Facilitates System Evolution

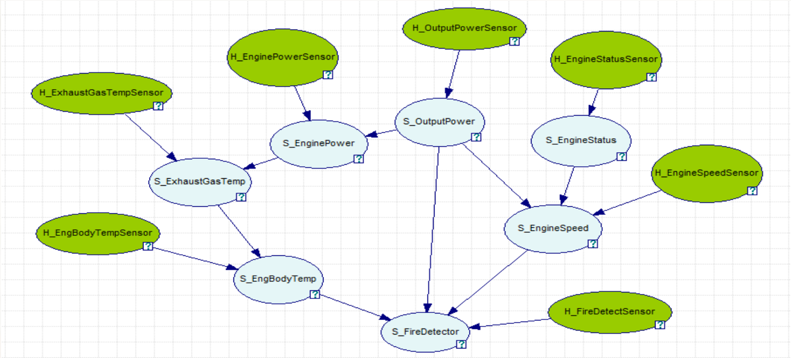
- Evolution
  - Hardware evolves → Software evolves → Data-types evolve
  - Evolved system components must continue to communicate with unevolved components
  - E.g., 2d point (X, Y) evolves to 3d point (X, Y, Z)
  - New radar that produces 3d points must work with old display that expects 2d
- Solution: OMG Extensible and Dynamic Topic Types Specification

```
struct EngineOperatingStates {
      double timestamp;
      string vehicleId; //@key
      long   engineStatus;
      double engineSpeed;
      double enginePower;
      double exhaustGasTemperature;
      double engineBodyTemperature;
      double outputPower;
      long   fireDetectionSensor;
};// Extensibility(EXTENSIBLE)
```

```
struct EngineOperatingStatesSensorsHealth {
      double p_engineSpeedSensor_good;
      double p_engineSpeedSensor_bad;
      double p_exhaustGasTempSensor_good;
      double p_exhaustGasTempSensor_bad;
      double p_fireDetectionSensor_good;
      double p_fireDetectionSensor_bad;
      . . .
};// Extensibility(EXTENSIBLE)
```

Take Home Points

- Bayesian Networks
  - A flexible and capable platform for fau detection and diagnosis
  - Fine-grain fault detection within a subsystem and across subsystems
  - Large number of COTS tools

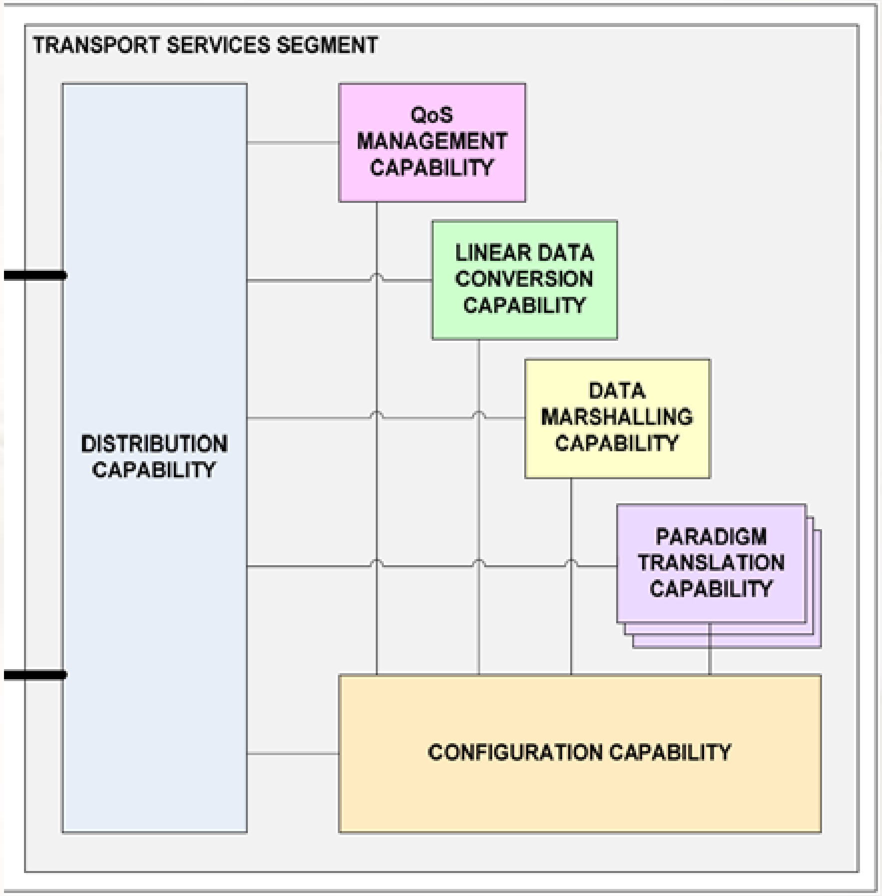


- RTI Connext DDS
  - Has small footprint
    - Runs on a ARM processors (700 MHz, 256MB RAM)
  - Has low latency
    - Supports hardware-in-the-loop simulation as well as Smart Systems
  - Standards-based support for system evolution

Future Work

1. Expanded Cyber Situational Awareness
   – Using independent ground-based sensors
2. Integrate portable and truly interoperable airborne software components
   – Use RTI Transport Services Segment (TSS) implementation
3. Semantic Interoperability
   – Use UAS Control Segment (UCS)
   – Protocol Interoperability using DDS (RTPS)

Future Airborne Capability Environment



Thank You!