Examining the Use of Java Technologies for Real-Time in a Prototype U.S. Surface Navy Combat System Application

Naval Surface Warfare Center Dahlgren Division

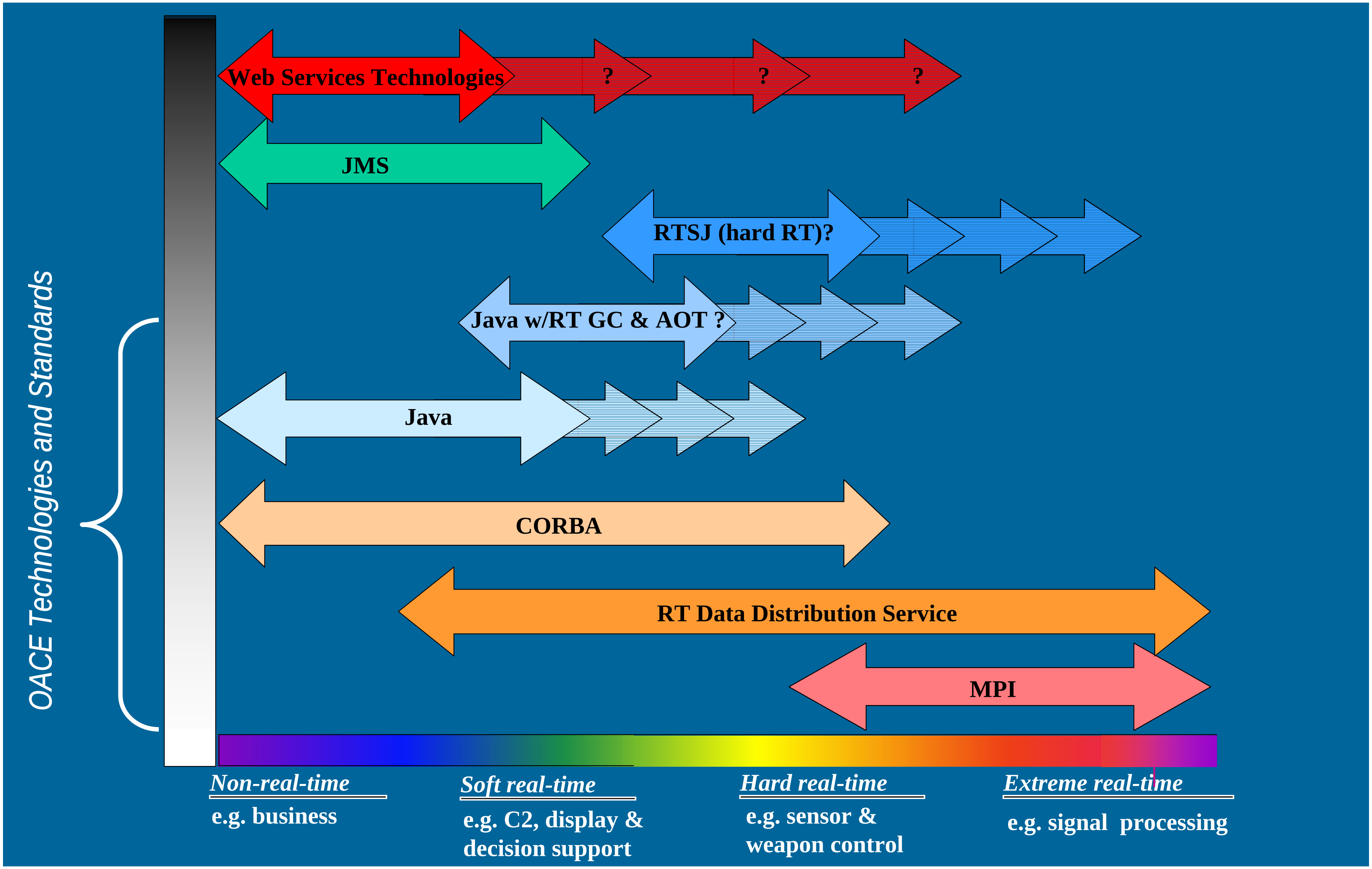
Fred Weindelmayer and Tim Childress

Disclaimer: The testbed and scenarios described represent notional US Navy Combat System capabilities for technology evaluation purposes.

The OA Surface Application Domain

- Large distributed real-time weapon system applications
- Both soft and hard real-time applications
- Timescale for deadlines typically in the O(10) – O(100) millisecond range
- Long system life spans, often for several decades
- Consequences of not meeting requirements for time-deterministic behavior could be severe

Standards Support for Real-Time



Java Considerations in the Real-Time Domain

Potential Benefits	Concerns
Enabling of SOA & Web Services for Cross-Domain & Fn Integration ◆ Java provides support for SOA and Web Services technologies such as SOAP, XML, UDDI, J2EE, etc.	**Can Java meet real-time, mission-critical, and safety requirements of combat systems?** ◆ The ability of Java technologies to meet required combat system performance has not yet been proven ◆ Insufficient information whether Java will pass Weapons Systems and Explosives Safety Review Board (WSESRB) certification using mainstream features – VLS briefed WSESRB regarding their use of RTSJ with a RAVENSCAR-like profile
Increased Productivity ◆ Large programmer base ◆ Standardized APIs ◆ Many libraries available to implement commonly required capabilities e.g. string manipulation, data structures, graphics, etc. ◆ Automatic memory management (less debugging)	**Will Java technologies for real-time deliver the same productivity gains of standard Java?** ◆ Appropriate use of RTSJ features requires additional training and introduces complexity ◆ RT garbage collectors require additional understanding of underlying application memory allocation behavior that is not made apparent by the language – tools not available to support a priori analysis ◆ Real-time programming knowledge is required regardless of the language. Java does not alleviate this requirement ◆ Some standard Java APIs are incompatible with RTSJ memory management for RT apps; Porting of some APIs has been done, but inconsistent across RTSJ implementations
Portability of Java Applications ◆ *"Write once, run anywhere"*	**Using Java in the real-time domain requires a tighter coupling to the computer platform** ◆ RTSJ slogan "*Write once carefully, run anywhere conditionally*"? – not yet proven ◆ JVMs implementing RT technologies (e.g., RTSJ, RTGC, AOT, etc) are part of a product eco-system (JVM, OS, processor), currently having limited availability ◆ May require additional standards-related guidance for OS, e.g. which scheduling algorithms must be supported, minimum clock resolution
Product availability ◆ Java is widely supported with many products available for virtually any computing platform ◆ Many support products available that support Java, including development environments, middleware, etc.	**Will Java products for real-time have the same availability?** ◆ Vendors are still limited in the diversity of platforms that they support; very few supported products – several available in beta. ◆ Differences between Java products for RT are significant at this time – cost of switching products may be significant if a computing platform port is required. ◆ Significantly smaller market for RT to drive development of Java and support products

Java Technologies for Real-Time

- **Standard Java**
  - Sun, IBM, and BEA J2SE 5.0 JVMs
  - Can be used for some real-time applications if features that impact determinism are restricted, e.g.
    - Employ memory pools to reduce / eliminate dynamic allocation of objects
    - Constrain use of standard Java libraries
    - Avoid multi-threading to eliminate possible priority inversion
- **The Real-Time Specification for Java (RTSJ)**
  - Sun Java RTS and IBM J9 RT JVM (J2SE)
  - Apogee (J2ME)
- **Real-Time Garbage Collectors**
  - Implementations exist for both Standard Java and RTSJ products
  - Metronome GC (IBM), Lund GC (Sun), Deterministic GC (BEA)
- **"Java-Like" Virtual Machines with Real-Time GC**
  - Aonix PERC and AICAS Jamaica VMs

Objectives of the Experiment

- **Obtain information on which technologies, and which subsets of features within them, are appropriate for different regions of the real-time Navy Enterprise application space**
  - For example: Is there a class of soft real-time applications for which real-time garbage collection is sufficient, without having to use RTSJ-specific features (even if using an RTSJ JVM)?
- **Gain insight on appropriate techniques and design patterns for application of real-time Java technology**
  - Languages typically provide many alternative ways to implement solutions, but which are best suited to the problems we encounter?
- **Identify possible deficiencies in existing real-time Java technologies for Navy real-time applications**
  - Such knowledge could be applied toward the development of a Mission-Critical Java standard
- **Gain sufficient insight on RT Java usage to determine how standards might be changed in support of Navy RT requirements**

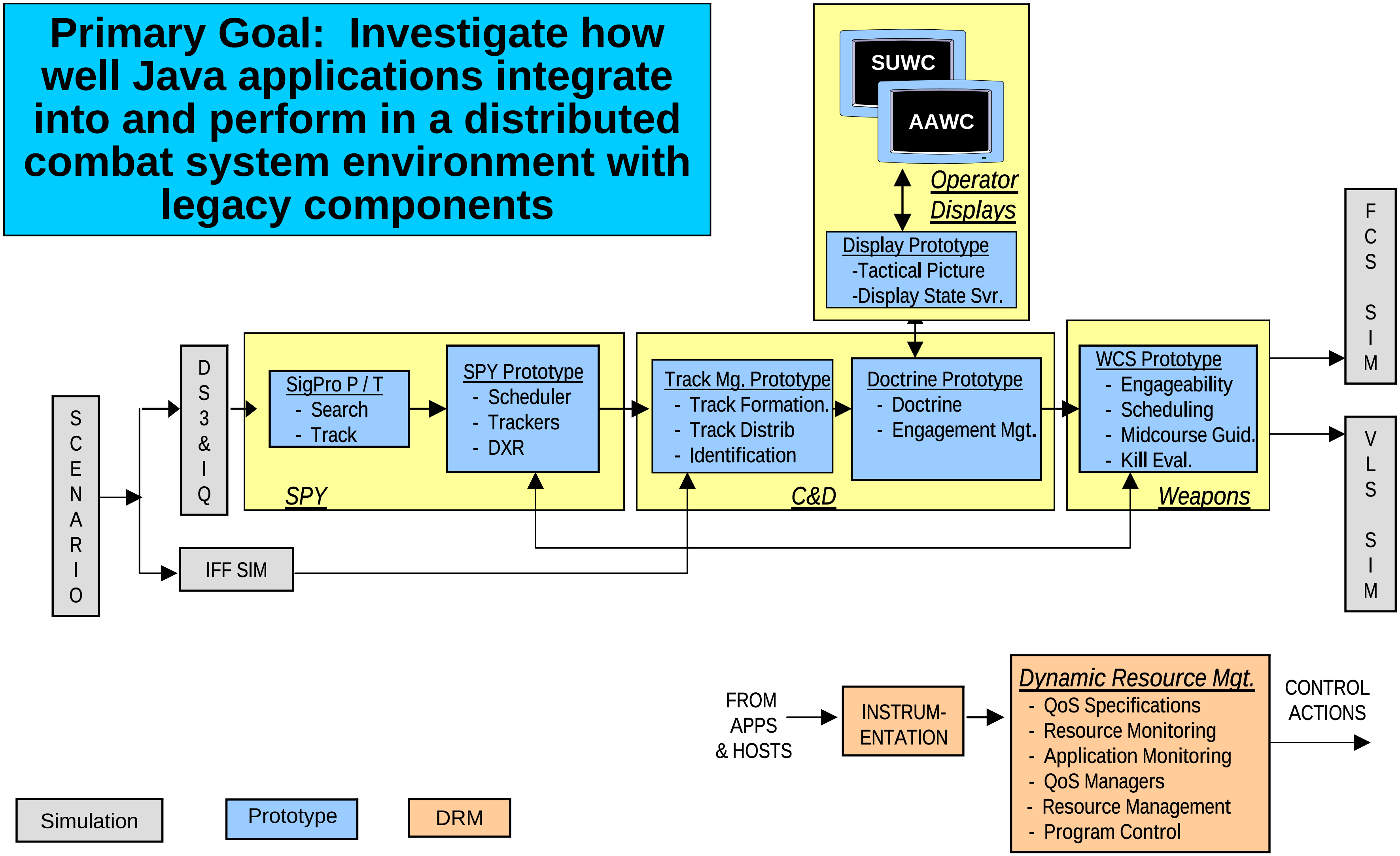
Metrics of Interest

- **Timeliness**
  - Degree to which application meets real-time deadlines
  - Track generator will simulate a variety of different message traffic patterns, allowing us to evaluate timeliness under different load scenarios
- **Jitter**
  - Difference between longest and shortest observed latencies
  - Lower jitter means more consistent real-time behavior and consequently more predictability
- **Performance**
  - Performance impacts which deadlines can be feasibly met with the technology
- **Relevant characteristics associated with application development:**
  - Portability
  - Maintainability
  - Scalability
  - Ease of development

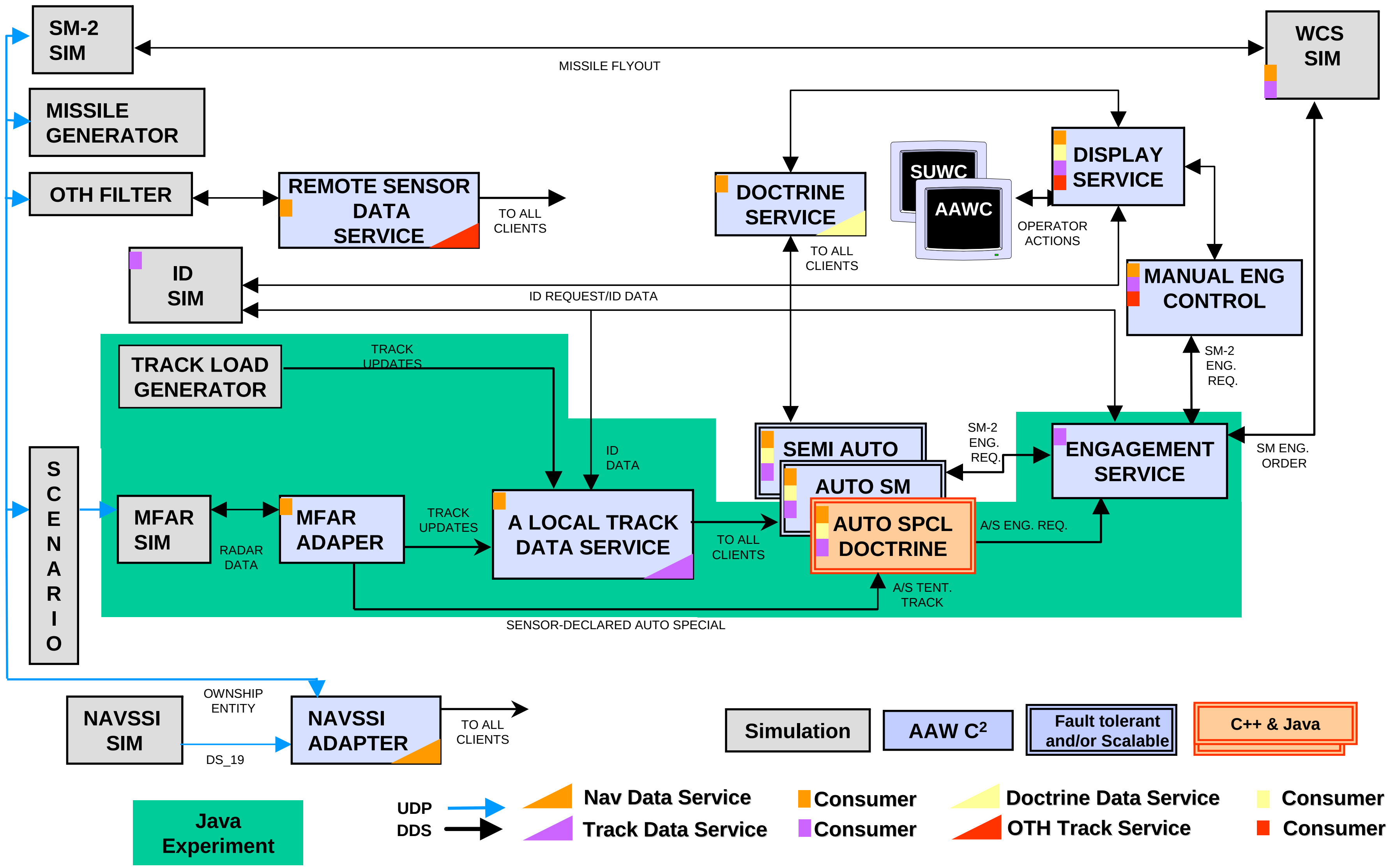
Evaluation Description

OACE Prototype

Primary Goal: Investigate how well Java applications integrate into and perform in a distributed combat system environment with legacy components



OACE Prototype Functional Block Diagram

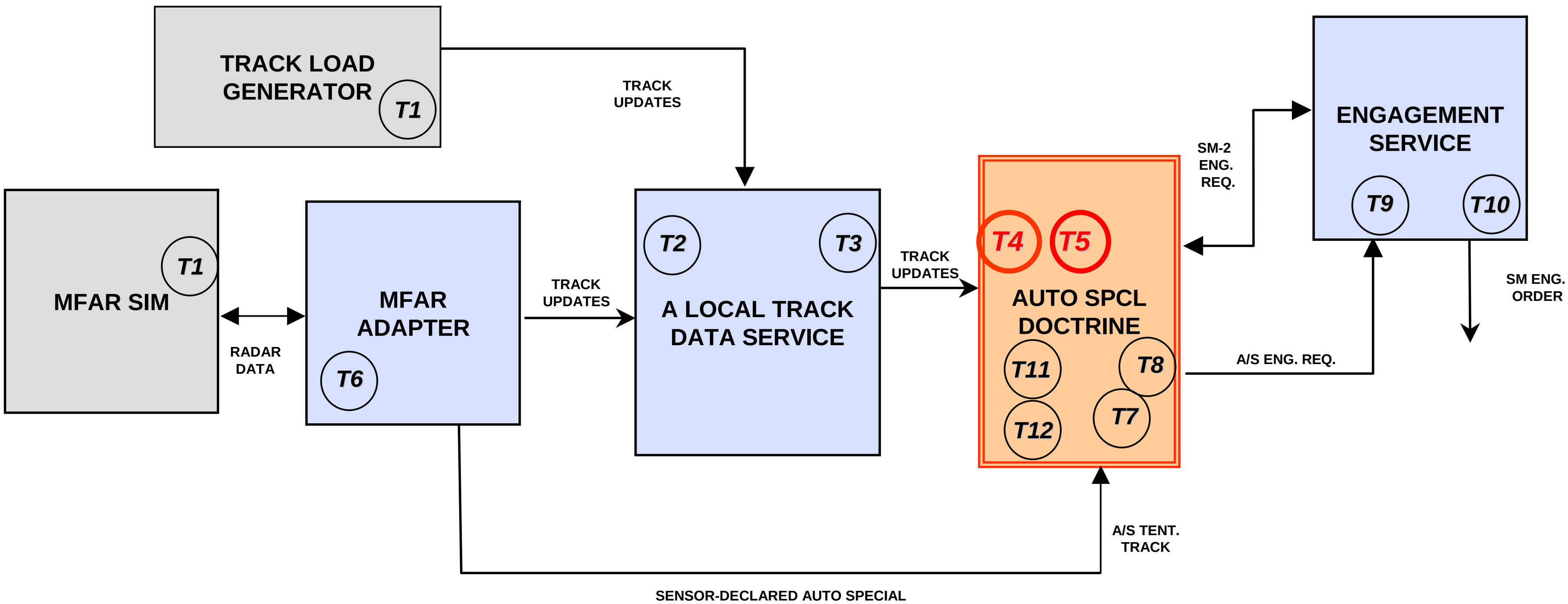


Experiment Construction

- C++ and standard Java implementations of OACE Auto Special prototype using same high-level design
- "Reasonable decisions" principle for Java implementation – e.g. memory pools for fixed sized objects*
- Identical test harness, procedures, and scenario
- Instrumentation points inserted at identical points in the processing
- Language Implementations:
  - C++: GCC 3.4.4
  - Standard Java: J2SE 5.0 (various vendor JVMs)
- Computing Platform:
  - Intel Xeon 3.06 GHz, 4 CPUs, 1GB RAM
  - Red Hat Linux 3.4.3-9.EL4 with RT patches
  - NDDS 4.0

** Lesson learned from Aegis Open Architecture*

Sensor-To-Shooter Instrumentation



T1 - Valid Time of Sensor Kinematic Data
T2 - Time Track Data Received at Service
T3 - Time Track Data Sent from Service
T4 - Time Track Data Received at Consumer
T5 – Time Track Data Processed at Consumer

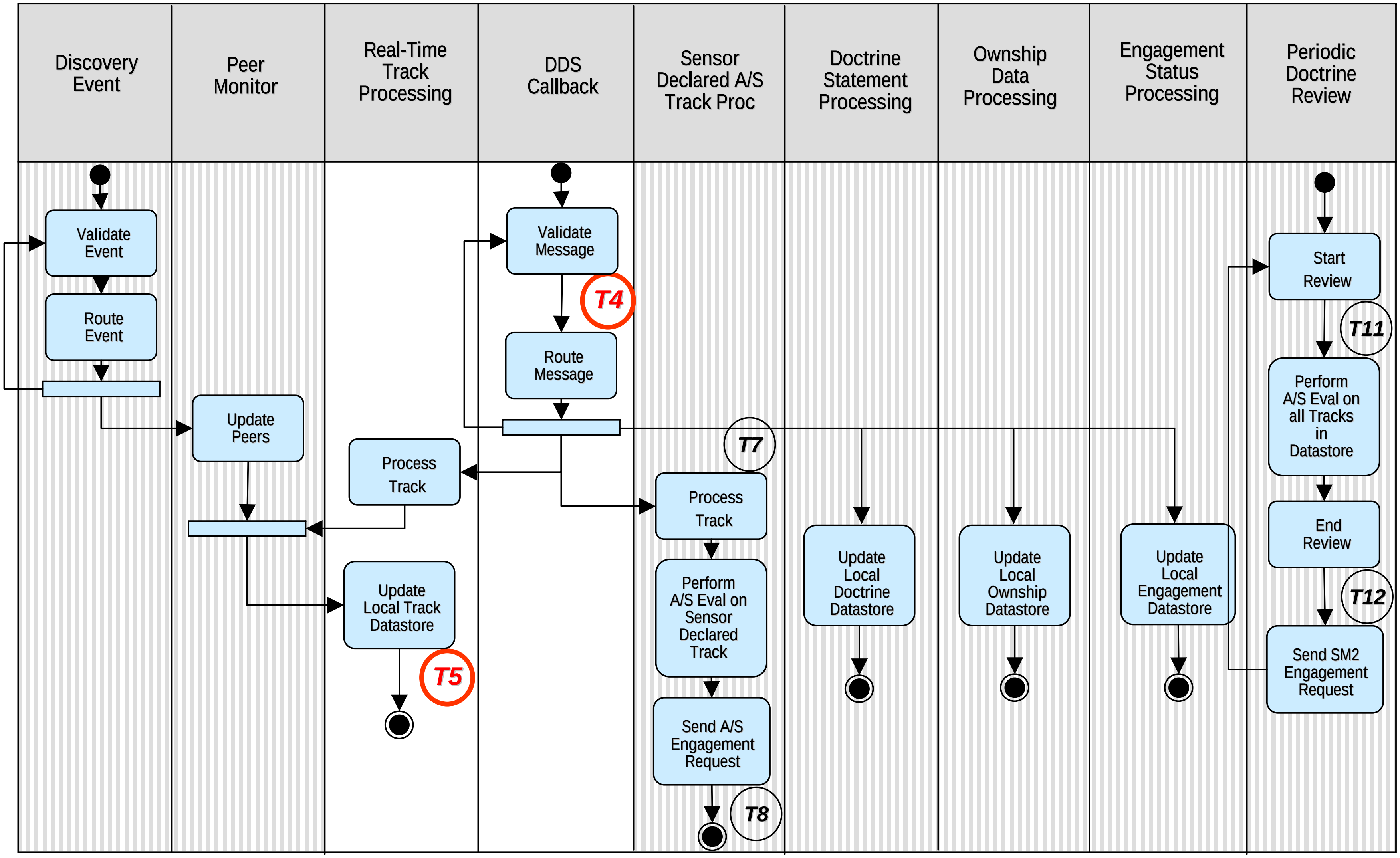
T6 - Valid Sensor A/S Message Initiated
T7 - A/S Message Received at Consumer
T8 - A/S Engagement Request Sent
T9 - A/S Engagement Request Received
T10 - A/S Engage Order Sent

T11 - A/S Periodic Processing Start
T12 - A/S Periodic Processing Complete

Tn – Instrumentation point in OACE Prototype
Tm – Instrumentation point used for Java/C++ Comparison

Simulation | AAW C^2 | Fault tolerant and/or Scalable | C++ & Java

Auto Special Activity Diagram



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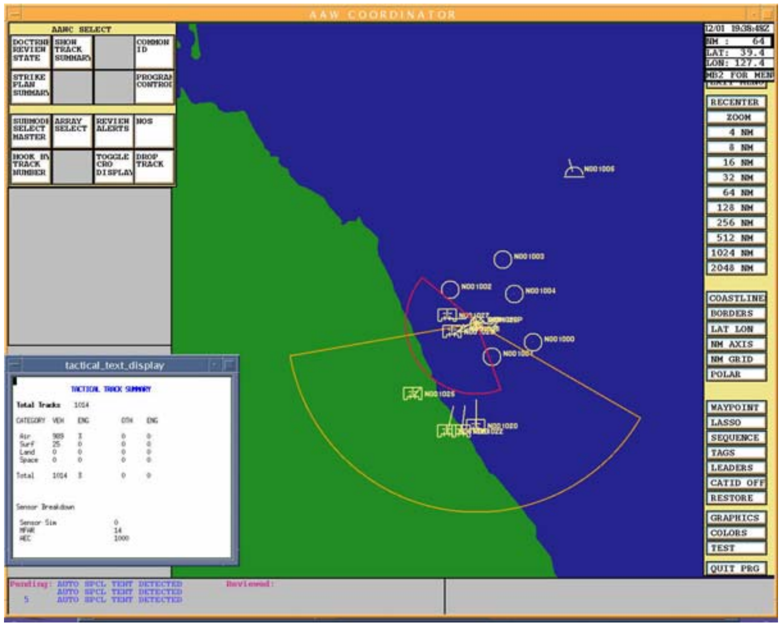
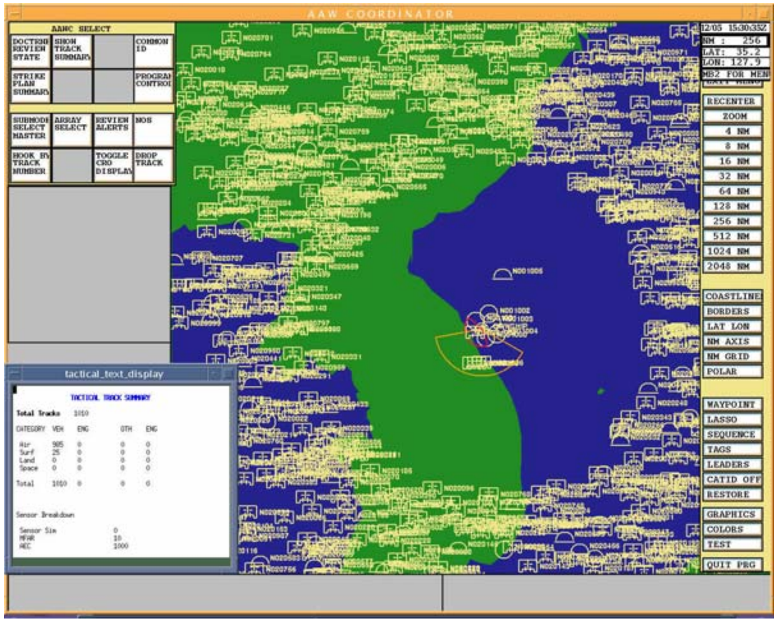
Scenario



- One hour data collection period for each configuration
- Common test harness & track scenario for C++ and Java
- Six surface tracks updated at 2Hz rate
- Seven pop-up tracks updated at 2Hz rate – included 3 A/S engageable tracks
- 1000 background track load – updated at ½ Hz rate



Results

Metrics

Data will be provided

Conclusions

Evaluation Findings To Date

- **Language selection appears to have a greater effect on overall processing time than the language implementation**
  - **C++ performance is highly predictable throughout the test**
  - **Both Java products in this experiment exhibit some degree of unpredictable performance – unknown how they will scale to larger processing loads or how outliers will affect the ability to meet end-to-end performance requirements**
  - **RT garbage collection technology is promising - exhibits fewer outliers that tend to be smaller in magnitude**
- **Cause of Java outliers is currently unknown – candidates include:**
  - **RT Garbage Collection technology is immature**
  - **Garbage collection effects**
    - **May be able to further optimize application using standard Java features**
    - **May be able to tune GC products to significantly reduce number or size of outliers**
  - **Just In Time (JIT) compilation**
    - **May introduce processing delays when a code path is traversed for the first time**
  - **Secondary effects of Java implementation or other language features e.g. thread control**
    - **May be able to use RTSJ thread control features in combination to reduce effects**
  - **Suitability of high-level design for optimal Java performance**
    - **Redesign may improve overall performance and enhance understanding of RT design patterns for Java**
- **Predicting and tuning performance will be a key concern when using RTGC and AOT technologies – analysis will require methodologies and tools not currently available**

Observations

- Java products for real-time are a potential solution for allowing Java applications to meet Navy deterministic mission needs. A number of products now exist; all are immature at this point.
- Real-Time Garbage Collection technology is generally immature. Because no standards exist for garbage collection, behavior and performance can vary significantly.
- Java technologies for real-time are often tied to the underlying computing infrastructure. Use of Java technologies for real-time may ease code portability, but may also require additional standards-related guidance to support reuse and technology refresh while meeting performance requirements.
- It is not clear at this point how widely-accepted Java technologies for real-time will become. Need to continue working with Java vendors to improve their products' viability within the Navy (performance, tools, standardization approach, business model, product licensing etc.).

- Additional experiments needed to fully understand performance and its effect on meeting real-time end-to-end system requirements

Questions?

Backup