System of System Integration Technology and Experimentation (SoSITE)  
The Future of Interoperability

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15 September 2016

Abstract # 18869
We Need to Rethink how to Maintain Air Dominance

- Manned platforms alone cannot defeat networked proliferated threats
  - Survivability is THE dominant cost driver for manned combat aircraft
  - Imposes an impediment to upgrading in stride with pace of technology
- Mix of high- and low-end platforms can avoid obsolescence better than high-end platforms alone
  - What does interoperability need to be in order to stay apace of technology?

<table>
<thead>
<tr>
<th>Platform</th>
<th>1st Priority</th>
<th>2nd Priority</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manned</td>
<td>Survivability</td>
<td>Lethality</td>
<td>Human Life and $$$$$$ Vehicle</td>
</tr>
<tr>
<td>Attritable UAV</td>
<td>Lethality</td>
<td>Survivability</td>
<td>Mission Needs, then $$$ Vehicle</td>
</tr>
<tr>
<td>Expendable UAV</td>
<td>Lethality</td>
<td>Cost</td>
<td>Mission needs and $ Vehicle</td>
</tr>
</tbody>
</table>
Opportunity: Composable Architectures to Avoid Obsolescence

PED: Processing, Exploitation, Dissemination

Courtesy of Dr. Joshua Bernstein, Northrop Grumman Electronic Systems

Distribution A. Approved for public release: distribution unlimited.
Systems Have Short Effective Lifetimes Once Adversaries Discover Their Countermeasures

- Time to develop a system usually longer than the time to develop its countermeasure
- Response time quickens as Combat Darwinism kicks in
- The best is the enemy of the good
  - We may be able to approach the best with informed assemblies of the good
- What principles for composability might we adopt to achieve this?
What Do I mean by Composable Systems of Systems and Why Should We Care?

**Global Interoperability without Global Consensus**

Not necessary for parties to agree globally on capabilities their systems will provide or how they will interact

**Compose then Optimize**

Ability to optimize the systems and their inter-relationships to fulfill your need after you have selected those systems

**Float and Flow**

Don’t settle on the capabilities you need, the systems you will use, and the roles they will play until you must fulfill that need

We should be able to create capabilities when we need them from whatever we have in the Nation’s S&T portfolio
Open Architectures Helpful, but Rethink Them

- Today’s Open Architectures all require global consensus on message interfaces or data models (e.g., Link-16, Link-11, DAML)
  - Consensus has to work for all: company-specific variations discouraged
  - Consensus takes time, creating barriers to new technologies

- How do we preserve OSAs when technological change outpaces them?

![How Standards Proliferate](https://xkcd.com/1158/)

Courtesy of XKCD
• Organization A uses Geodetic coordinates in its systems to report \textit{Location}.

• Organization B uses Earth-Centered-Inertial to report \textit{Position}.

• Organization C uses the Military Grid Reference System to report \textit{Place}.

• A and B agree on precise rules to translate to and from Geodetic and ECI.

• B and C develop precise rules to translate to and from ECI and MGRS.

Can Local Consensus Replace Global Consensus? Baby Steps
Local Consensus **CAN** Replace Global Consensus

- Use the pair-wise agreements to achieve interoperability between A & C

A: Location  
ECI to Geodetic  
Geodetic to ECI

B: Position

C: Place

MGRS to ECI

ECI to MGRS

- **A Consensus Network!**
Extending a Consensus Network is Not Hard

- Organization D, a British company, uses British National Grid for *Spot*
- D simply agrees on translations with *one* of the three, e.g. Organization A, to attain interoperability with *all* of the three:

\[ \begin{align*}
\text{A: Location} & \quad \text{ECI to Geodetic} \quad \text{Geodetic to ECI} \\
\text{B: Position} & \quad \text{MGRS to ECI} \\
\text{D: Spot} & \quad \text{BNG to Geodetic} \\
\text{C: Place} & \quad \text{ECI to MGRS} \\
\text{Geodetic to BNG} & \\
\end{align*} \]
A Few Observations

- Software will easily assemble translation steps
  - An expression such as D.Spot == C.Place can instruct software to the sequence of translations from one to the other and back

- We don’t need to write code to assemble interoperable interfaces
  - Code generators will do this

- We don’t need to select translation sequences until we need to connect specific systems
  - Code generators will locate and assemble the translation steps for us
  - *Float and Flow!*

- Chaining translations doesn’t imply we get inefficient interfaces
  - Compliers will eliminate unnecessary or redundant computations when they compile the auto-generated code into machine binaries
  - *Compose then Optimize!*
Achieving Extendibility

- Systems designed to be upgraded frequently often use extendible datatype messages
- Example: conveying Time, Latitude, and Longitude within a Position message using Xtendible Markup Language (XML):

```xml
<Message>
  <Name>Position</Name>
  <FieldType>
    <Name>Time</Name>
    <FieldCode>4 byte</FieldCode>
  </FieldType>
  <FieldType>
    <Name>Latitude</Name>
    <FieldCode>8 Byte</FieldCode>
  </FieldType>
  <FieldType>
    <Name>Longitude</Name>
    <FieldCode>8 byte</FieldCode>
  </FieldType>
</Message>
```

- The message provides all the information needed to understand what it is conveying, but it is verbose!
Achieving Efficiency

- Systems designed to run in real-time use bit-packed messages to achieve high throughput, low latency
- Conveying the same 20 bytes for Time, Latitude, and Longitude in a 160-bit message.....

- ....and conveying the same information with even fewer bits using compression
Extending Consensus Networks to Bit-Packed Messages

- Interoperability between systems using *Different* bit-packed schemes without either developer knowing the representation used by the other!
Can We Achieve Extendibility & Efficiency?

<Message>
  <Name>Position</Name>
  <FieldType>
    <Name>Time</Name>
    <FieldCode>4 byte</FieldCode>
  </FieldType>
  <FieldType>
    <Name>Latitude</Name>
    <FieldCode>8 Byte</FieldCode>
  </FieldType>
  <FieldType>
    <Name>Longitude</Name>
    <FieldCode>8 byte</FieldCode>
  </FieldType>
</Message>

Extensibility

Efficiency

Distribution A. Approved for public release: distribution unlimited.
Do I have an Existence Proof? Yes!!

- SoSITE has delivered a prototype tool to the Air Force, Navy, SEI
- Locates the transforms needed to achieve interoperability between messages that aren’t designed to a common standard
- Auto-generate the interface code (Java, C++) from those transforms
- Compiles the interface code into compact, highly-efficient executable binaries
- Navy is using on the CNO’s Interoperability Demo for Task Force Netted Navy
- Software Engineering Institute is evaluating for new missile defense architectures
Prototype Training Sessions at MITLL
Experiment To Test Efficiency Hypothesis

• Subsystems (All Subsystems Are C++ Cores and Use Packed Interfaces)
  – R: Radar Source SS, uses R.PackedMessage with Time and Dets
  – T1: Tracker Destination SS, uses R.PackedMessage (no transform needed)
  – T2: Tracker Destination SS, uses T2.PackedMessage (only changes Time units)
  – T3: Tracker Destination SS, uses T3.PackedMessage (switches Lat and Lon in Dets)
  – T4: Tracker Destination SS, uses T4.PackedMessage (change Time and Dets units)

• Each Interface Has both a Packed and Unpacked FTG Node with (Painful) Transforms between them

• We Consider Two Pathways through the FTG
  – PUUP: Packed\textsubscript{Source} → Unpacked\textsubscript{Source} → Unpacked\textsubscript{Destination} → Packed\textsubscript{Destination}
  – PP: Packed\textsubscript{Source} → Packed\textsubscript{Destination}

• Hypotheses that We Are Looking to Test:
  – Can we Compile the PUUPs to an acceptable level of performance?
  – How does the performance of the Optimized PUUPs compare to the hand-generated PP transforms?
## Comparison Run-Time Performance

[Sorted by Connection]  

<table>
<thead>
<tr>
<th>Connection</th>
<th>PUUP vs PP</th>
<th>Java HCALS</th>
<th>C++ HCALs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Speed Mbps</td>
<td>Latency ms</td>
</tr>
<tr>
<td>R1 -&gt; T1 (No Transform)</td>
<td>PUUP</td>
<td>3000±35</td>
<td>1.1±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T1 (No Transform)</td>
<td>PP</td>
<td>3005±18</td>
<td>1.0±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T2 (Only Change Time)</td>
<td>PUUP</td>
<td>1972±18</td>
<td>1.1±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T2 (Only Change Time)</td>
<td>PP</td>
<td>1967±22</td>
<td>1.2±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T3 (Switch Order Lat, Lon)</td>
<td>PUUP</td>
<td>1100±9</td>
<td>1.5±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T3 (Switch Order Lat, Lon)</td>
<td>PP</td>
<td>1058±9</td>
<td>1.6±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T4 (Change All Fields)</td>
<td>PUUP</td>
<td>685±5</td>
<td>2.0±0.1</td>
</tr>
<tr>
<td>R1 -&gt; T4 (Change All Fields)</td>
<td>PP</td>
<td>755±7</td>
<td>1.9±0.1</td>
</tr>
</tbody>
</table>