Building Large Simulations using Physics-Based Models

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Introduction

- The role of M&S within the Department of Defense is changing, today M&S can be, or is, a critical element in:
  - training
  - acquisition, analysis, T&E
  - technology can be an enabler across many domains
- M&S serves to support many goals:
  - Efficiency, planning, conceptualization
  - interoperability
  - re-use across , “domains”, components, functions
- There is almost certainly no technology that is exclusive to M&S
- There is almost certainly no technology that can’t help M&S

Examples of Embedded and Cross-Discipline uses of M&S

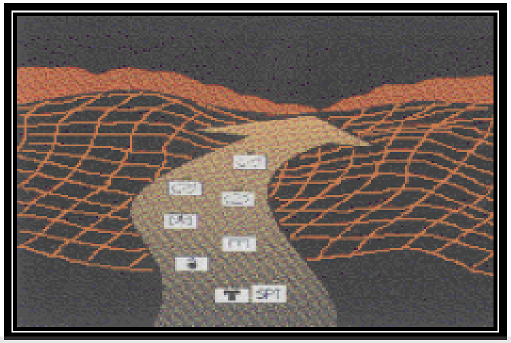
Simulation Domains

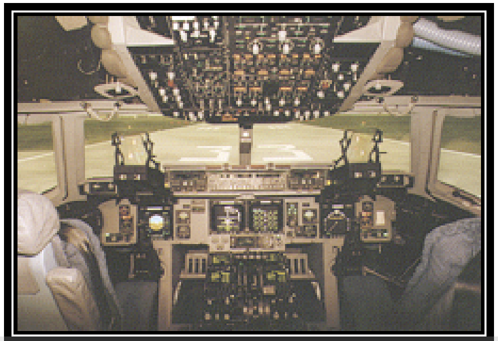
Live

Virtual

Constructive

Functional Areas





Acquisition *Analysis* *Experimentation* *Training* *Operations*

M&S Technology Applies in many Domains

- Information Environments & Infrastructures
  - Automated Software Development Environments
  - Integrated Data Environments
  - Integrated Product Data Environment
  - Digital System Model
  - Smart Product Model
- Tools
  - Engineering Tools
  - Program Management Tools
  - Technical Management Tools
  - Manufacturing Tools
  - Simulation Support Tools
- Databases
- Models & Simulations
  - Environmental Model
  - Combat Models (next chart)
  - Logistics Model
  - Engineering Design, Manufacturing Models
    - Virtual 3D layout / Mock up
    - Virtual Manufacturing Plant Simulation
    - Constructive Engineering Models
    - Constructive manufacturing Process Models
  - Training Models
    - Onboard Training Systems
    - Virtual Crew Simulators

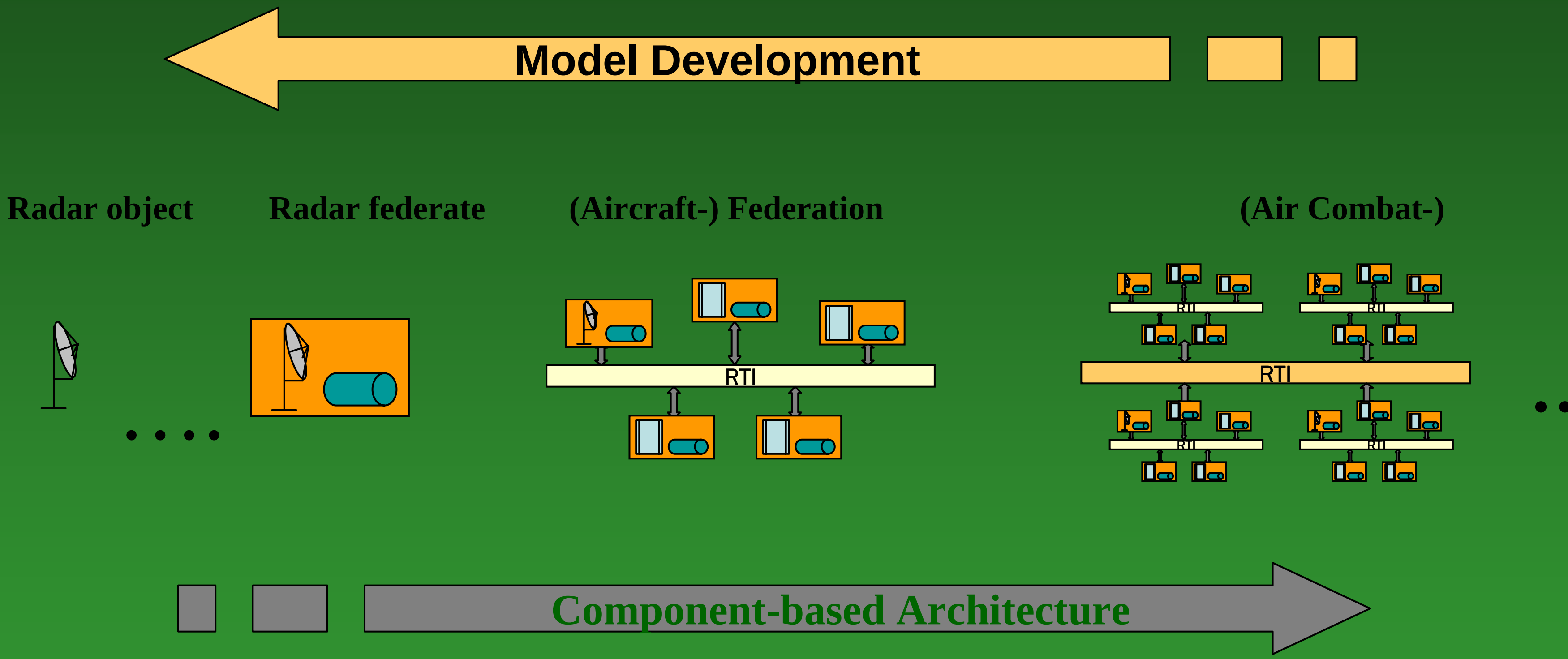
Taxonomy Of M&S Types & Applications In the System Acquisition Process, December 1998

M&S Technology Applies in many Domains (cont)

- **Combat Model**
  - Constructive Mission Models
  - Constructive Campaign & Theater Models
  - Constructive Engagement Models
  - Virtual Prototypes
  - Hardware in the Loop (HWIL) Test Tools
  - Constructive Threat Models
  - Man in the Loop (MIL) Test Tools
- **Combat Simulation**
  - Live Simulations

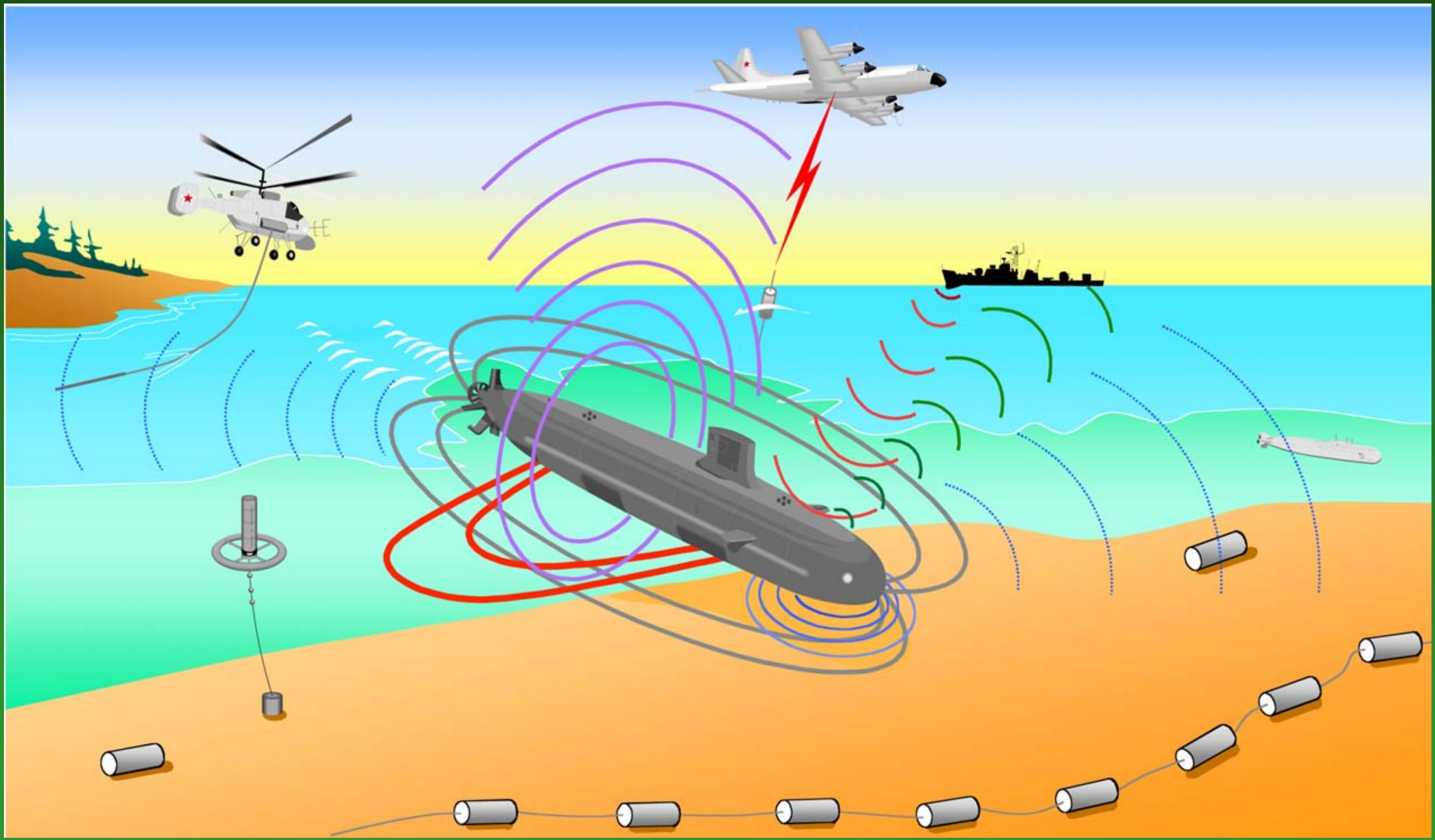
Taxonomy Of M&S Types & Applications In the System Acquisition Process, December 1998

Component-based M&S



- Composability, one of the key issues and main challenges

Context



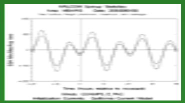
Fidelity, real/non real-time, resolution, bandwidth, frequency range etc are all a part of the context

Maritime Environment for FBEs

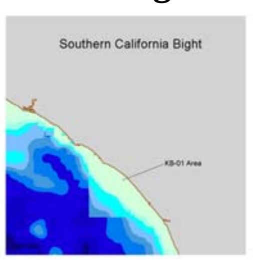
Assemble Archived Data Sources

Atmosphere

Ocean



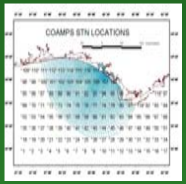
Wave Height



Bathymetry

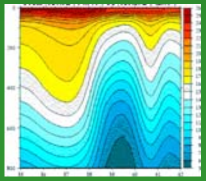
Initialize Model

Assimilate near Real time data



COAMPS Data

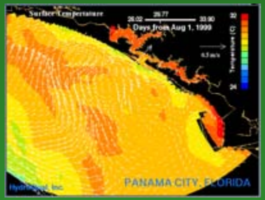
Buoy Data

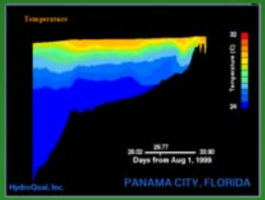


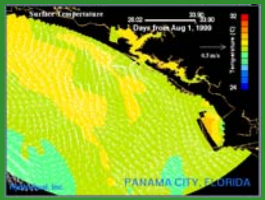
MODAS and POM For water column

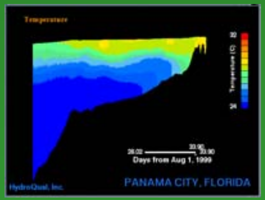
Daily Forecast/Nowcast Process
Creates Data for JSAF Simulation

0000: Receive COAMPS Forecasts
Receive Ocean Forecasts
0600: SERVE Maritime Environment to FBE
Replace prior forecasts with new data
2330: Prepare to repeat process









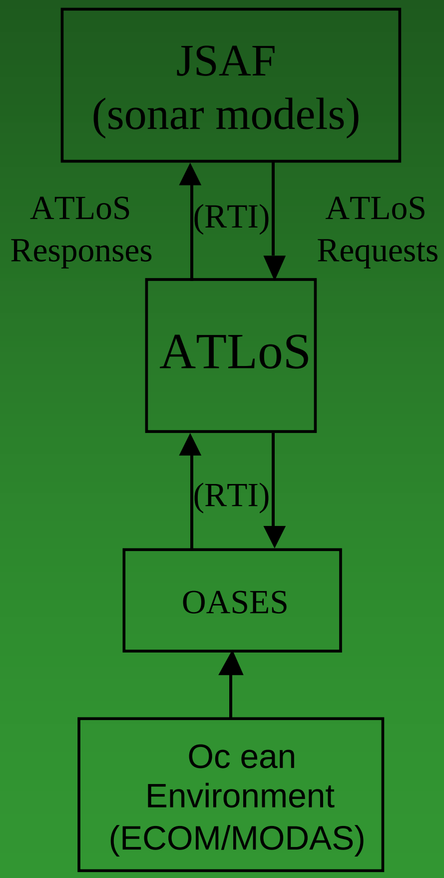
Weeks before FBE	Days/hours before FBE	Daily during FBE

Sources: NAVO, NRL/SSC, MEL

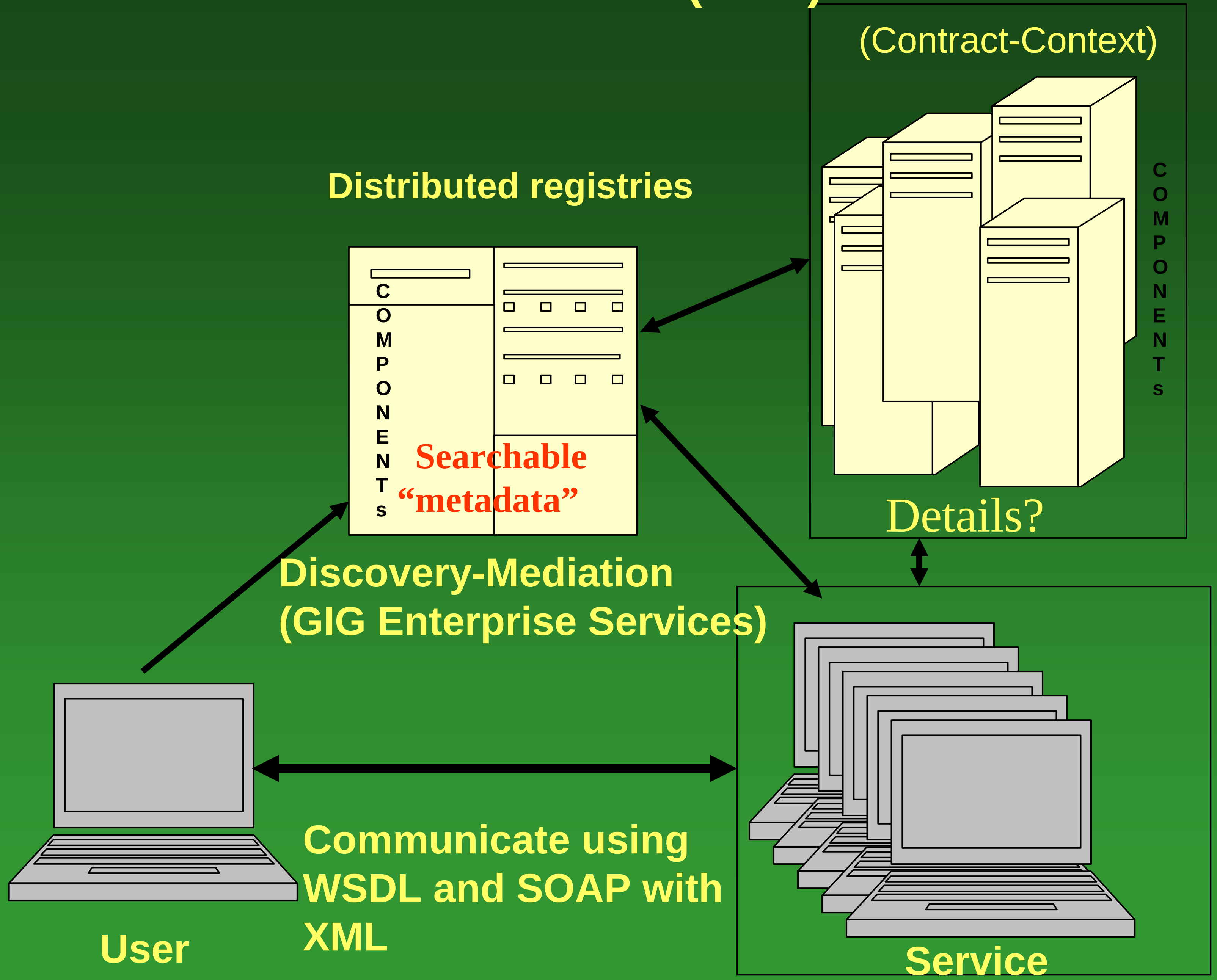
Sources: NAVO, NRL/SSC, any

ATLoS / OASES / JSAF Dataflow

- JSAF models: Northrup Grumman (Logicon)
- ATLoS: NRL, Anteon, Lockheed Martin-LMIS
- OASES Server: Northrup Grumman (TASC)
- Ocean Environment
  - MODAS, NCOM, (NAVY) ECOM (HydroQual)



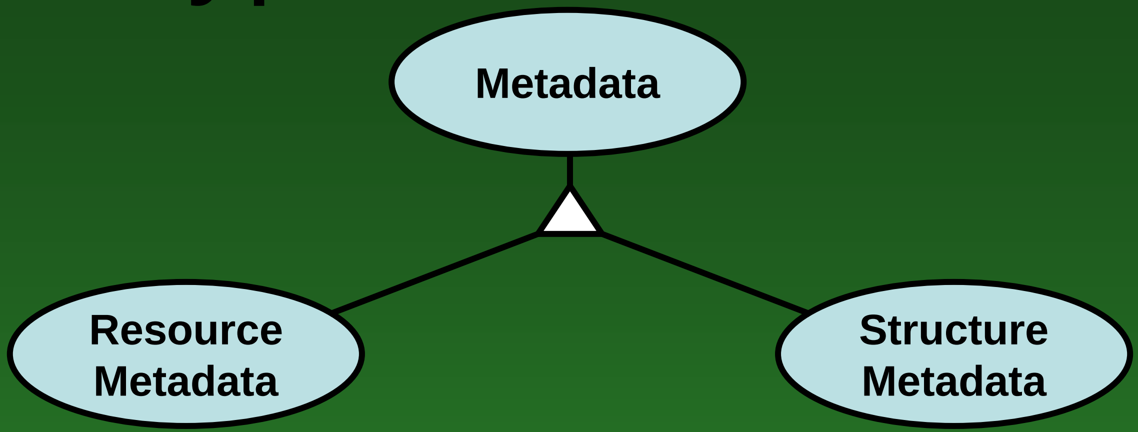
A Service Oriented Architecture (SOA)



Role of MetaData in Web Services and SOAs

- Support for loose coupling
  - Declarative Description vice Imperative Specification
- Building Registries and Repositories
  - Giving adequate description of what’s available
    - How much description is enough to decide what to use?
  - Support Discovery
  - Giving “complete” description of a model
  - Is one person’s registry another’s repository?
- Supporting Composability, Decomposition
  - Metadata must allow components to “know” if they match
  - Component building specs must match human talents
    - Can specified components be readily built?

Types of Metadata



Resource Metadata

- **Describes <u>individual</u> resources (datasets, simulations, services …)**
- **Example: MSRR catalog entries**
- **Necessary for the <u>discovery</u> of resources**
- **Resides in <u>COI Metadata Catalogs</u>**
- **Based on the DoD Discovery Metadata Specification (DDMS)**
- **Focus of the M&S COI <u>Metadata Focus Group</u>**

Structure Metadata

- **Describes the semantics and syntax for <u>types</u> of resources**
- **Examples: XML schemas, data models, etc.**
- **Necessary for the <u>understanding</u> of resources**
- **Resides in the <u>DoD Metadata Registry</u>**
- **Typically defined in XML, but not limited**
- **Necessary to facilitate the work of the M&S COI <u>Mediation Focus Group</u>**

What's Needed?

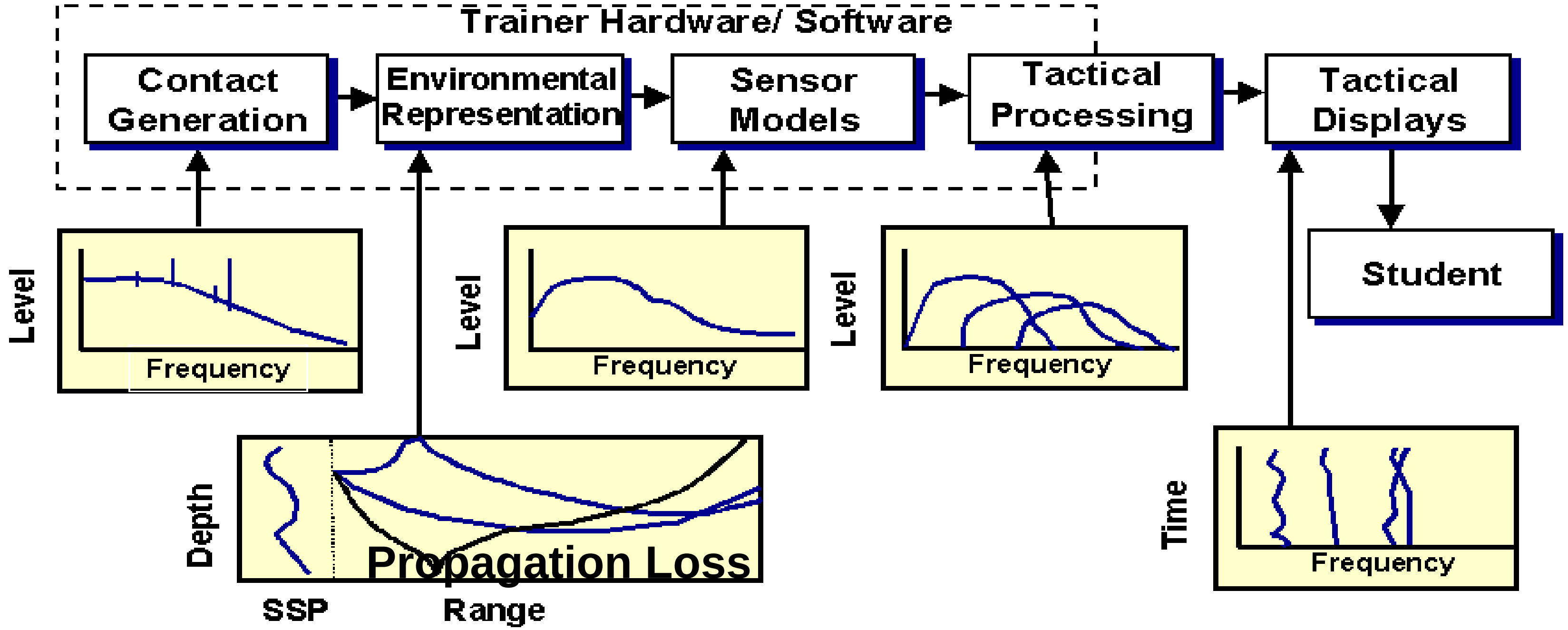
- Many tools identified
  - Are they adequate?
- Need use cases to identify capabilities and inadequacies
  - E.g.Model Definition
    - Equations provide sentences, a model is a collection of equations
- Need libraries -> at different levels

Benefits

- Support for Warfighter in building simulations, wargames
- Open access to models by non-experts
  - Search and retrieval
- Use of automation in model documentation
- Decision aids for simulation builders
  - Anticipate environmental effects in sim
- Animation engines and dead-reckoning
- Approach to true composability
  - Plug and play (not quite)

Use Case

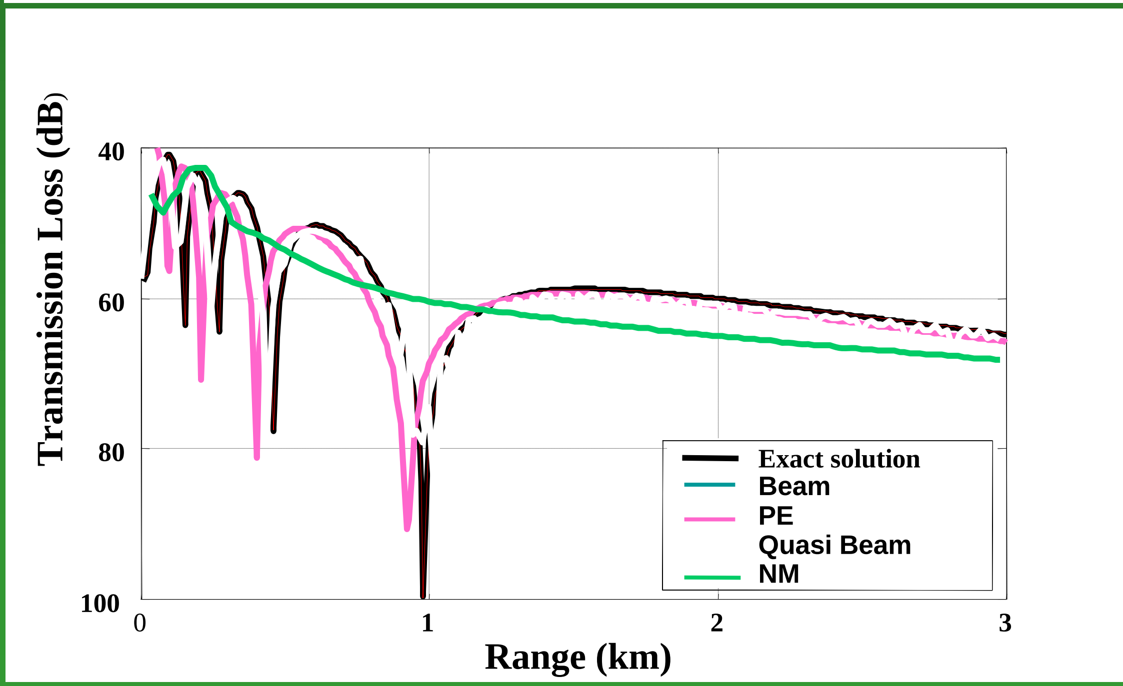
Train a sonar operator to detect a submarine



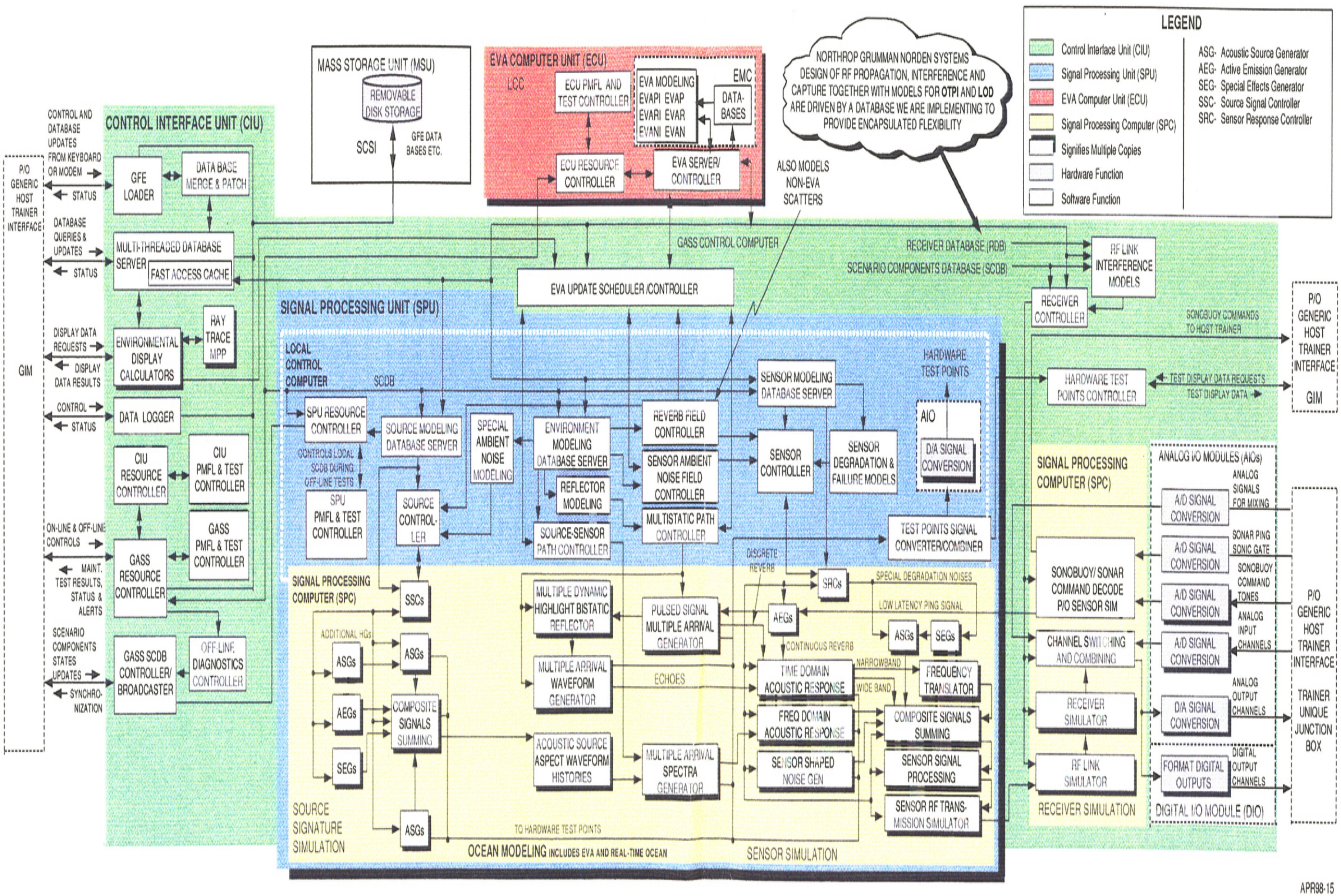
Training System

Real Time ASW Trainer Requirements/Context

- Arrival Structure
- Number of channels (contact-sensor pairs)
- Speed and timeliness
- Spatial Coverage
- Temporal Characteristics
- Accuracy and fidelity
- Computational fitness
- Interoperability
- Real time operation



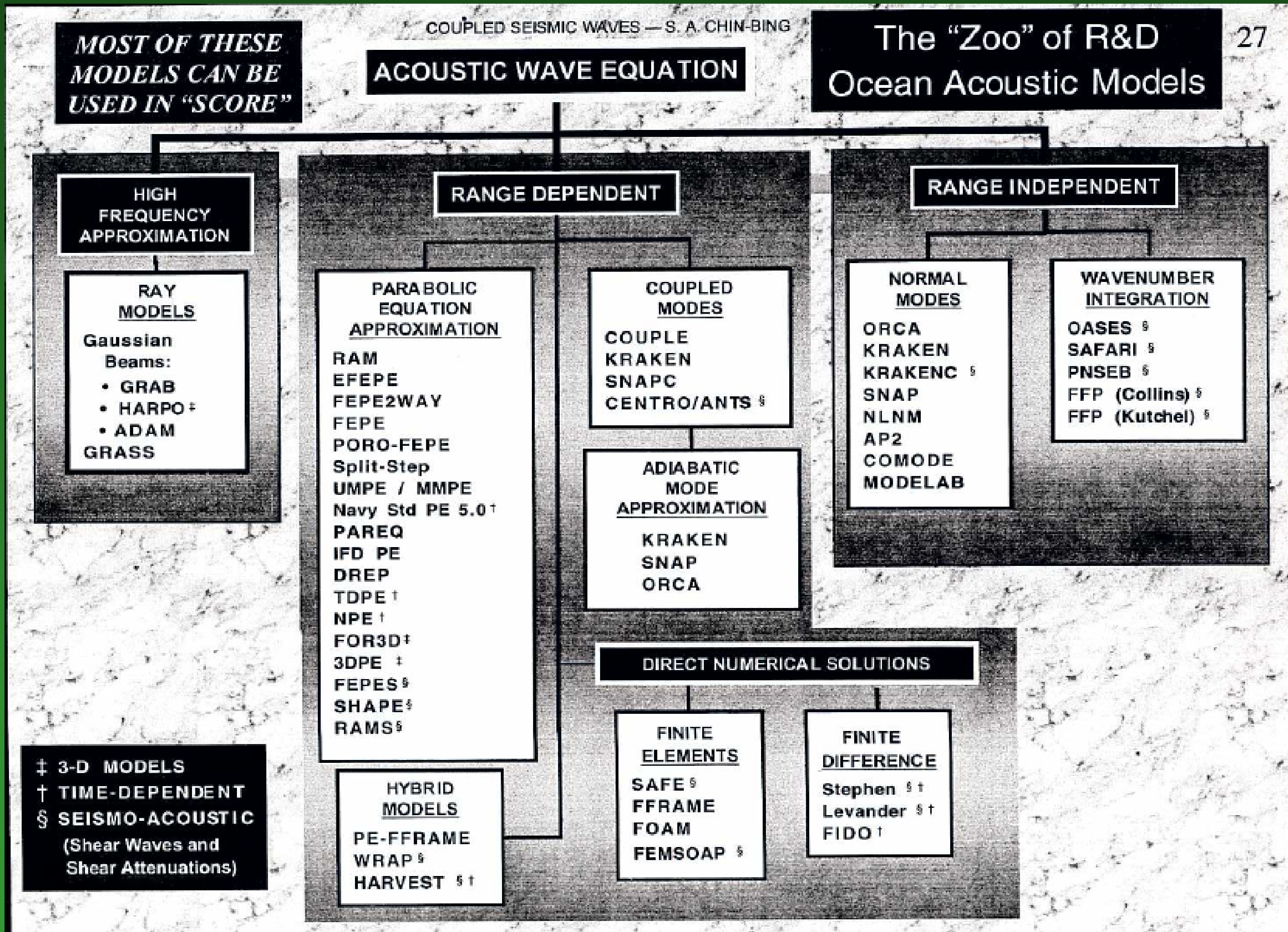
GASS Functional Block Diagram from Northrup Grumman



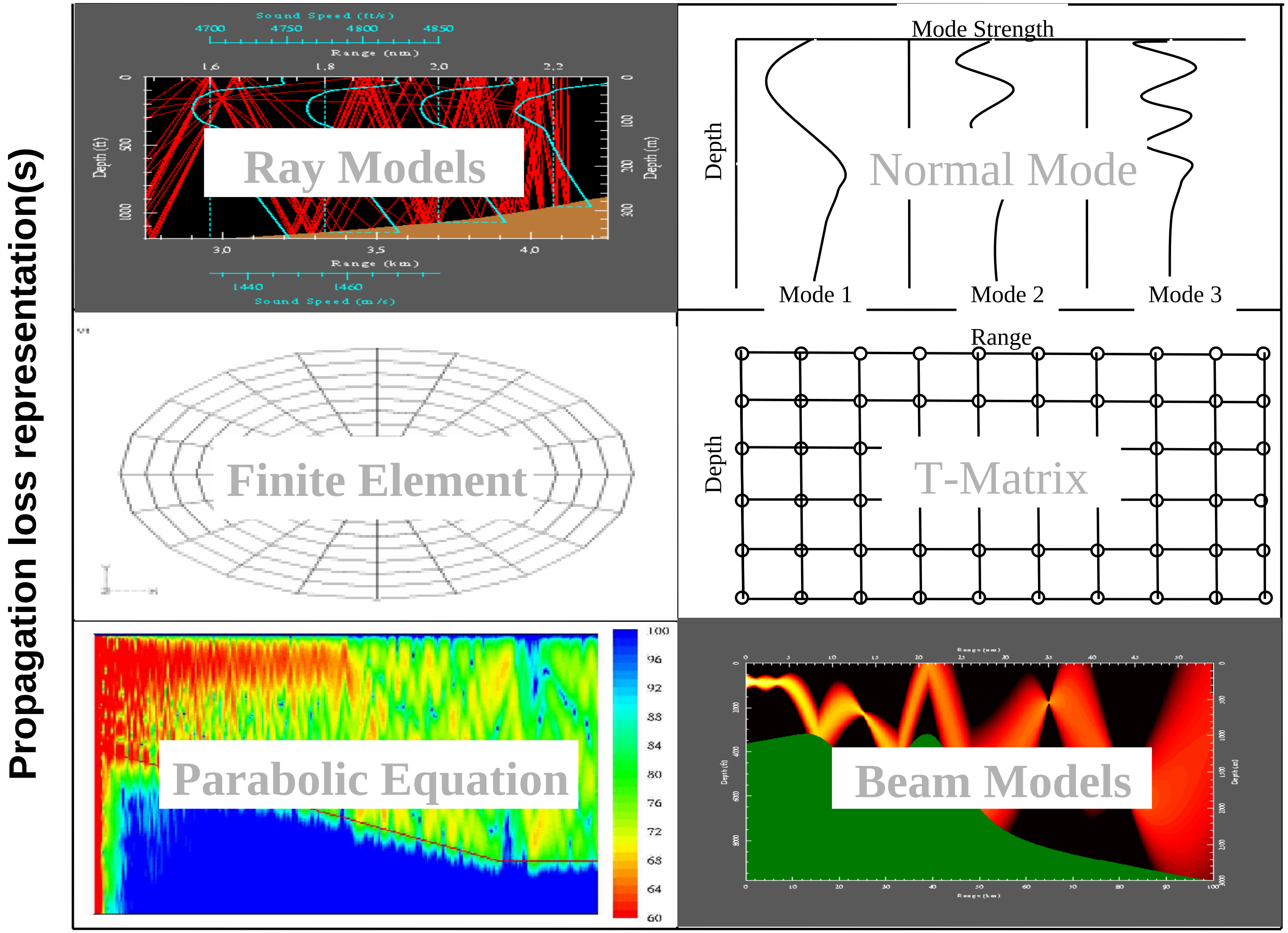
Assume the only unknown in the block diagram is the Propagation Loss Model

- How do we choose the mathematically and physics based based model (service/component)?
- What are our alternatives?
- What are the necessary metadata needed to help make the decision?
- How are the metadata, ontologies, and mathematics related

The Acoustic Model Zoo



Model Characteristics Summarized



The Propagation Model/service/component is physics, mathematically based

- What are the underlying equations?
- Why assumptions are important
- What metadata are needed to represent mathematically based? models/services/components?
- Is resource metadata enough?

Sample Model Metadata?

Parameter	Ray-Trace	Gaussian Beam	PE	Normal Mode	T Matrix	Finite Element
Run Time	Fast	Fast	Slow [1,2]	Slow [1,2]	Very slow [1,2]	Very slow [1,2]
Pre-computation potential	yes	yes	no(?)	yes	no	no
Speed with pre-computation	Very fast	Very fast	N/A	Fast	N/A	N/A
Memory for pre-computation	Mod.	Mod.	N/A	Large	N/A	N/A
Cost of beam forming	Low	Low	Very high [3]	Low to moderate	Very high [3]	Very high [3]
Frequency Range	High freq [4]	Mid to high freq [5]	Low freq [6]	Low to mid freq [7]	Low freq [6]	Low freq [6]
Broadband Model	Yes	Yes	No [8]	No [8]	No [8]	No [8]
Range dependence possible	Yes	Yes	Yes	Yes	Yes	Yes
Adiabatic Approximation	No, N/A	No, N/A	Not Req'd [9]	Not Req'd [9]	No	No
Steep Angle Performance	Good	Good	Poor	Good	Good	Good
Close Range	Good	Good	Poor [10]	Poor [10]	Good	Excellent
Diffraction and Duct Cut-off	No	Partial	Yes	Yes	Yes	Yes
Existing, adaptable model	Yes	Yes	Yes	Yes	No	No

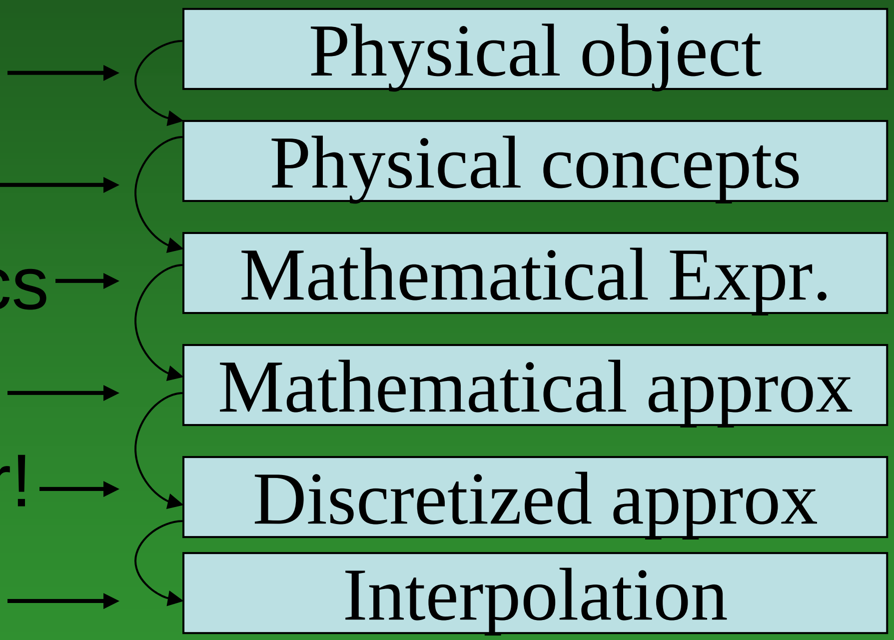
1 Run time increases in proportion to the number of discrete frequencies required.
2 Run time increases in proportion to the frequency.
3. Model produces complex pressure field, requiring beam former, inverse beam former implementation on a per sensor basis.
4. Model becomes inaccurate when feature size approaches several wave-lengths of sound.
5. Beam approach tends to compensate for weakness in ray-trace approach.
6. Limits primarily due to long run times.
8. Accuracy degrades with increasing frequency and water depth, unless number of modes used in the calculation increases. This degrades run times.
8. Broadband performance is achieved by making multiple runs at defined frequencies, and then inverse transforming on the signal (or construction a filter).
9. Both adiabatic approximation and coupled modes implementations exist. The later runs significantly slower than the former.
10. An overlay mode (e.g., ray-trace) model is often used to provide close in performance. Otherwise computational cost rise exponentially

Why Ontologies?

- An Ontology provides a framework for metadata to describe models
- Meaningful interoperability requires machine readable metadata, expressing modeling concepts
  - Intelligent Agents need ontologically based metadata
- Example: HLA does not support metadata
  - HLA supports executable-to-executable communication
  - Limited semantics are expressed in the computer
  - Agreements and assumptions stored primarily in human memory, accessible only to a few

A Physics-Based Model Ontology Layercake

- The thing modeled
- The Physics
- Language of physics
- The easier solution
- Let’s get an answer!
- The next guy’s grid



Each layer to layer, downward transition is **informal**, **one-to-many**

Can we infer the Physical Concept from the last layer? **No!**

Web-Based = XML Applications

- XML is the emerging baseline for knowledge representation on the Web
- Content MathML and OpenMath are XML applications for specification of mathematical content
- DocBook-MathML and OMDoc are XML applications capable of representing mathematical documents

MathML

- Two Flavors specified
  - Presentation MathML and Content MathML
- Provides concept names for basic math
- Provides a construct for extension
- Many current web-browsers display it
- Reasonably mature (the first!) W3C Recommendation

Presentation vs. Content: Example

- What does a superscript mean?

$$x^i = \pi$$

- Exponent, label, element? What content?

```
<apply>
  <eq/>
    <apply>
      <power/>
      <ci>x</ci>
      <ci>i</ci>
    </apply>
  <cn type=”constant”>&pi;</cn>
</apply>
```

```
<apply>
  <eq/>
    <apply>
      <selector/>
        <ci type=”vector”>x</ci>
        <ci>i</ci>
    </apply>
  <cn type=”constant”>&pi;</cn>
</apply>
```

Differential Equations

$$\nabla^2 G - \frac{\nabla \rho}{\rho} \bullet \nabla G + \frac{1}{c^2}\frac{\partial^2 G}{\partial t^2} = -\delta(r - r')\delta(t - t')$$

```
<apply>
   <divergence/>
   <apply>
      <gradient/>
      <ci type=”function”>G</ci>
   </apply>
</apply>
```

```
<apply>
   <scalarproduct/>
      <apply>
         <divide/>
         <apply>
            <gradient/>
            <ci type=”function”>&rho</ci>
         </apply>
         <ci>&rho</ci>
      </apply>
   <apply>
      <gradient/>
      <ci type=”function”>G</ci>
   </apply
</apply>
```

```
<apply>
   <multiply/>
   <apply>
      <power/> <ci type=”function”>c</ci>
      <cn>-2</cn>
   </apply>
   <apply>
      <partialdiff/>
      <bvar><degree><cn>2</cn></degree>
         <ci>t</ci>
      </bvar>
      <degree><cn>2</cn></degree>
      <ci type=”function”>G</ci>
   </apply>
</apply>
```

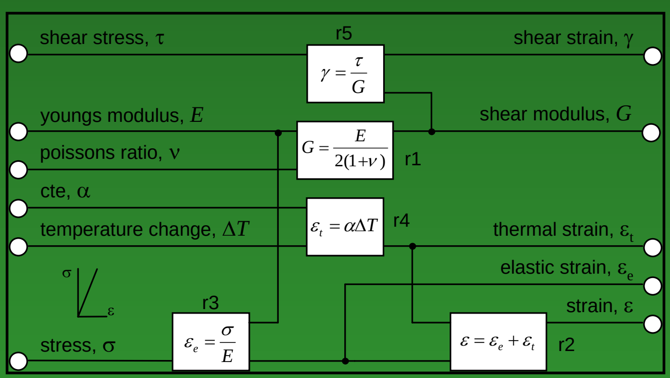
COB-based Libraries of Analysis Building Blocks (ABBs)

Material Model and Continuum ABBs - Constraint Schematic-S

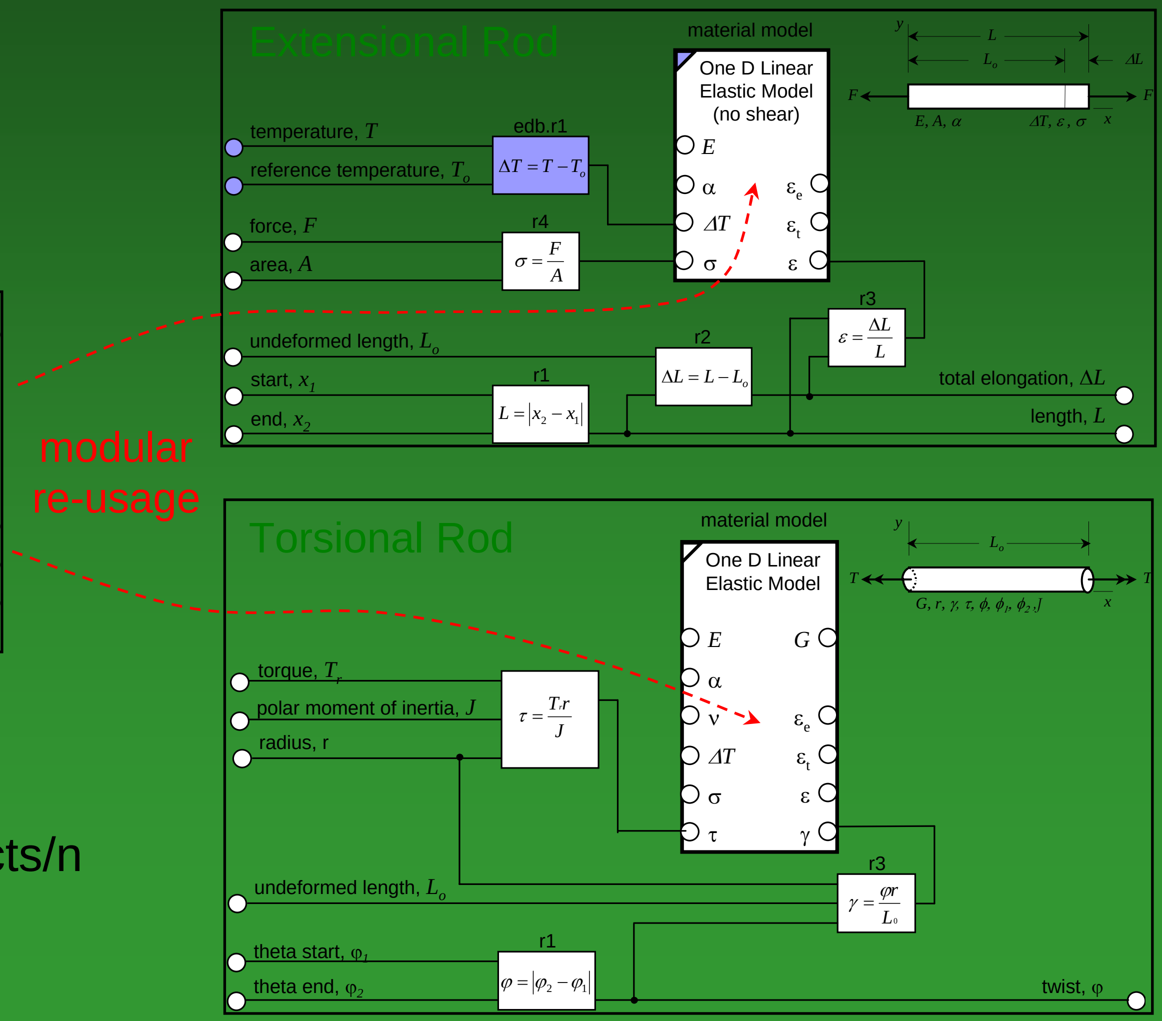
Continuum ABBs

Material Model ABB

1D Linear Elastic Model



modular re-usage



Prof. Russell Peak, GA Tech

http://eislab.gatech.edu/projects/nasa-ngcobs/ -2005-06-01

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