Jim Hendler
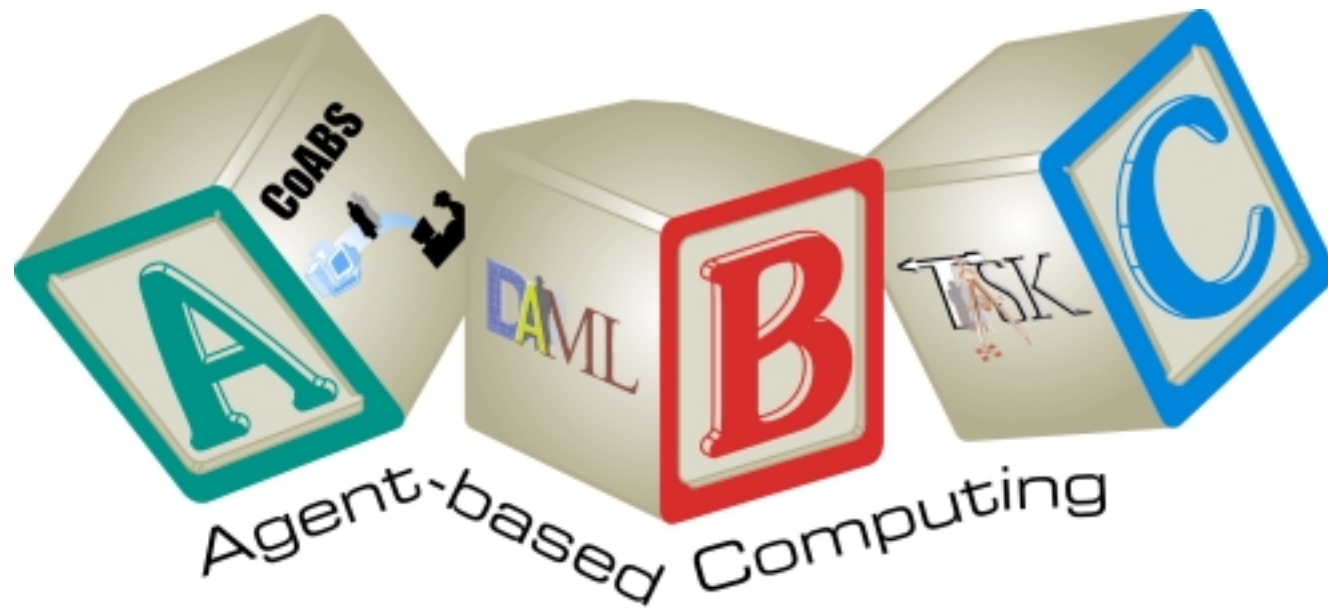*Information Systems Office*

1

"Agent" is used for many things...

Mobile Code

"Disembodied" Code

"Intelligent" Interfaces

Semantic Brokering

Applets

Information Filtering

Negotiation Protocols

Distributed Component Libraries

Information Extraction

Auction Mechanisms

Dynamic Middleware

UAV Ops

Search Tools

Active Messaging   Robots
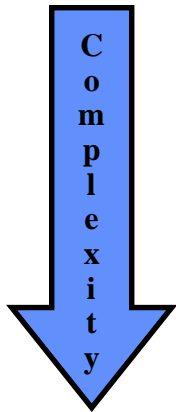
Mobile Networking

...And the DoD needs all of them!

- ● **These capabilities map to critical military problems**
  - ◆ Asset assignment in real-time <-> e-comm auction mechanisms
  - ◆ Bandwidth restrictions <-> active messaging
  - ◆ Comm QoS problems <-> mobile code
  - ◆ Data visualization <-> interface agents
  - ◆ Elint filtering <-> disembodied "monitor" code
  - ◆ Field upgradable software <-> applets
  - ◆ Gathering open source intelligence <-> Info agents
  - ◆ High speed, small unit ops <-> autonomous behaviors
  - ◆ Information assurance <-> agent wrappers
  - ◆ Joint force & coalition interoperability <-> agent middleware
  - ◆ Zero casualty ops <-> UAVs, robots

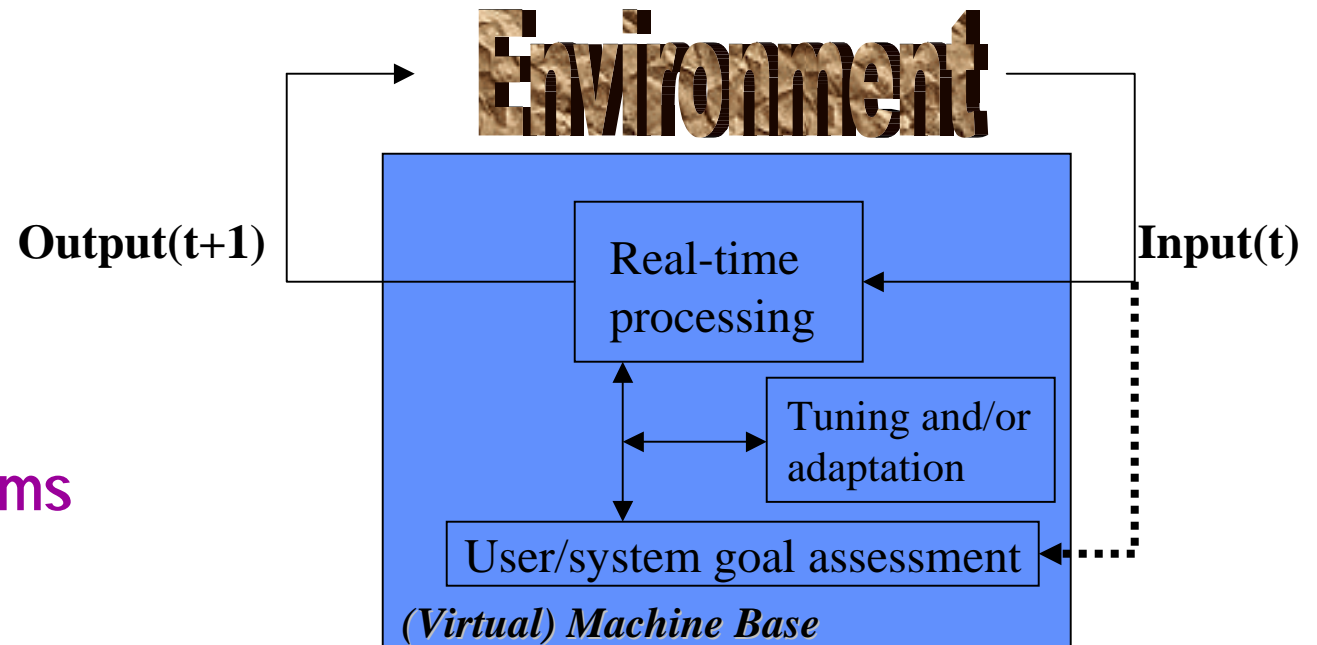# Which grow out of the definition of agency

- **An agent is a software component or system that is:**
  - ◆ Dynamic in its behaviors (not single I/O mapping)
  - ◆ Embedded in, and "aware" of, an environment
  - ◆ User enabled/steered, but "empowered" to act for user
  - ◆ Able to improve its behavior over time

C
o
m
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x
i
t
y

Autonomous

Communicative

Capable

Adaptive

These are important properties for software systems

Environment

Output(t+1)

Input(t)

Real-time processing

Tuning and/or adaptation

| User/system goal assessment |
|---|

(Virtual) Machine Base

DARPA's ABC programs merge science and practice

- **Military TIEs stress *interoperability***
  - ◆ OOTW
    - NEO Challenge Problem
  - ◆ Theater Ballistic Missile Defense
    - Used in Fleet Battle Experiments
  - ◆ Coalition Force Interoperability
    - DERA/AFRL/DARPA Project underway
  - ◆ Others
    - Air Mobility Command, JIATF-E

Site j "costs" c_j to visit and has probability p_j of success.

Visit sites until none left or successful.

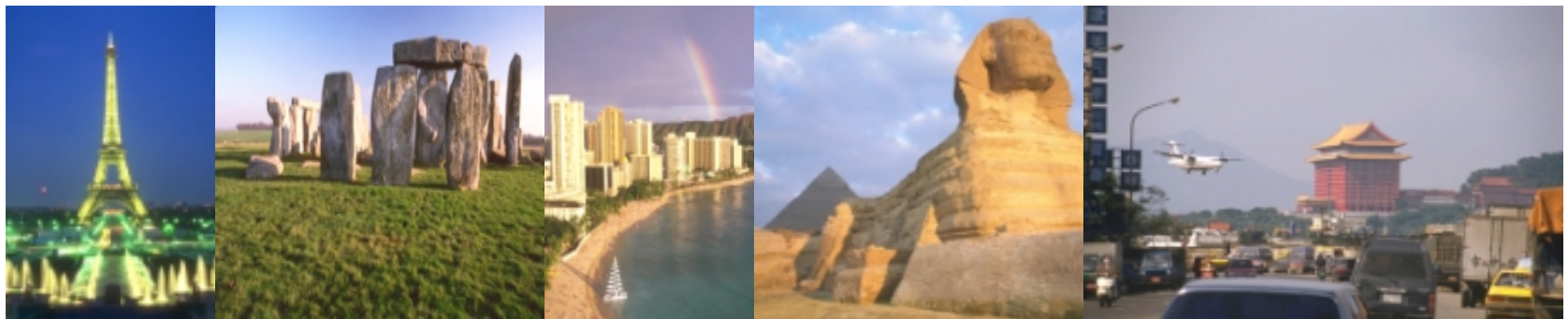Expected cost $= c_j + (1-p_j)c_k + (1-p_k)(1-p_j)c_m + ...$
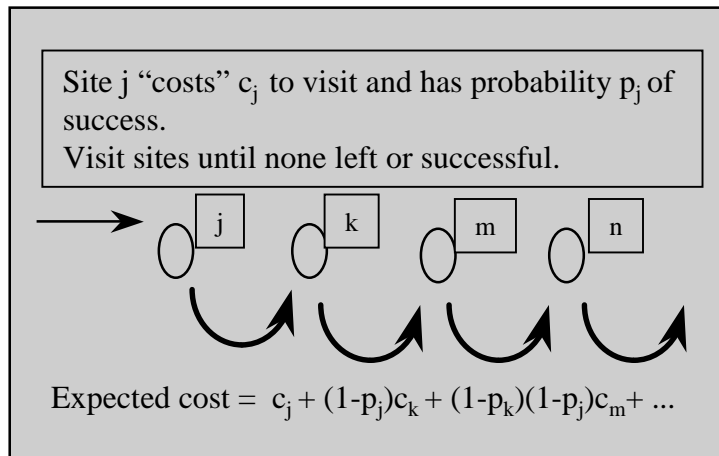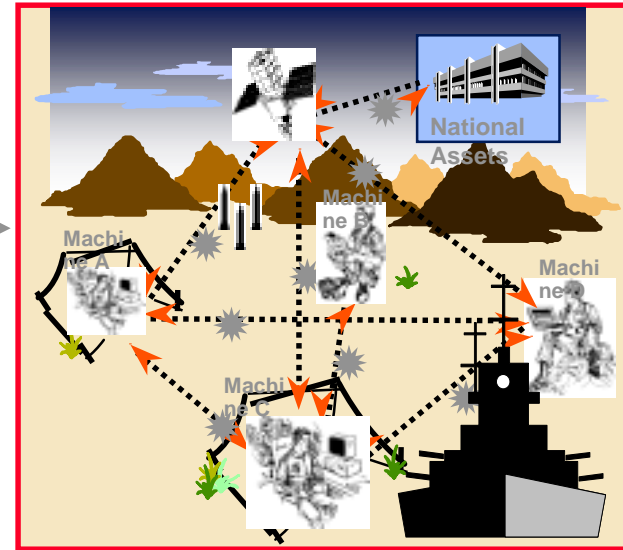
- **Scientific TIEs stress *scaling***
  - ◆ Negotiation Experiments
    - 1st results favor auctions
  - ◆ Mathematical Analyses
    - New results for agent mobility
  - ◆ Control Scheme Comparison
    - Analysis of time/ Experiments designed

Common Architecture
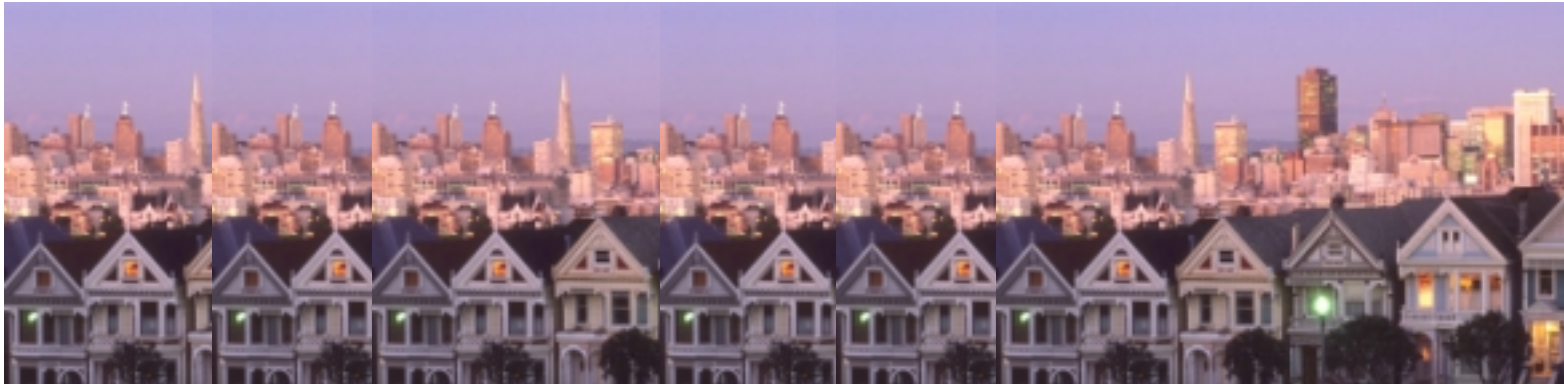
vs

Heterogeneity

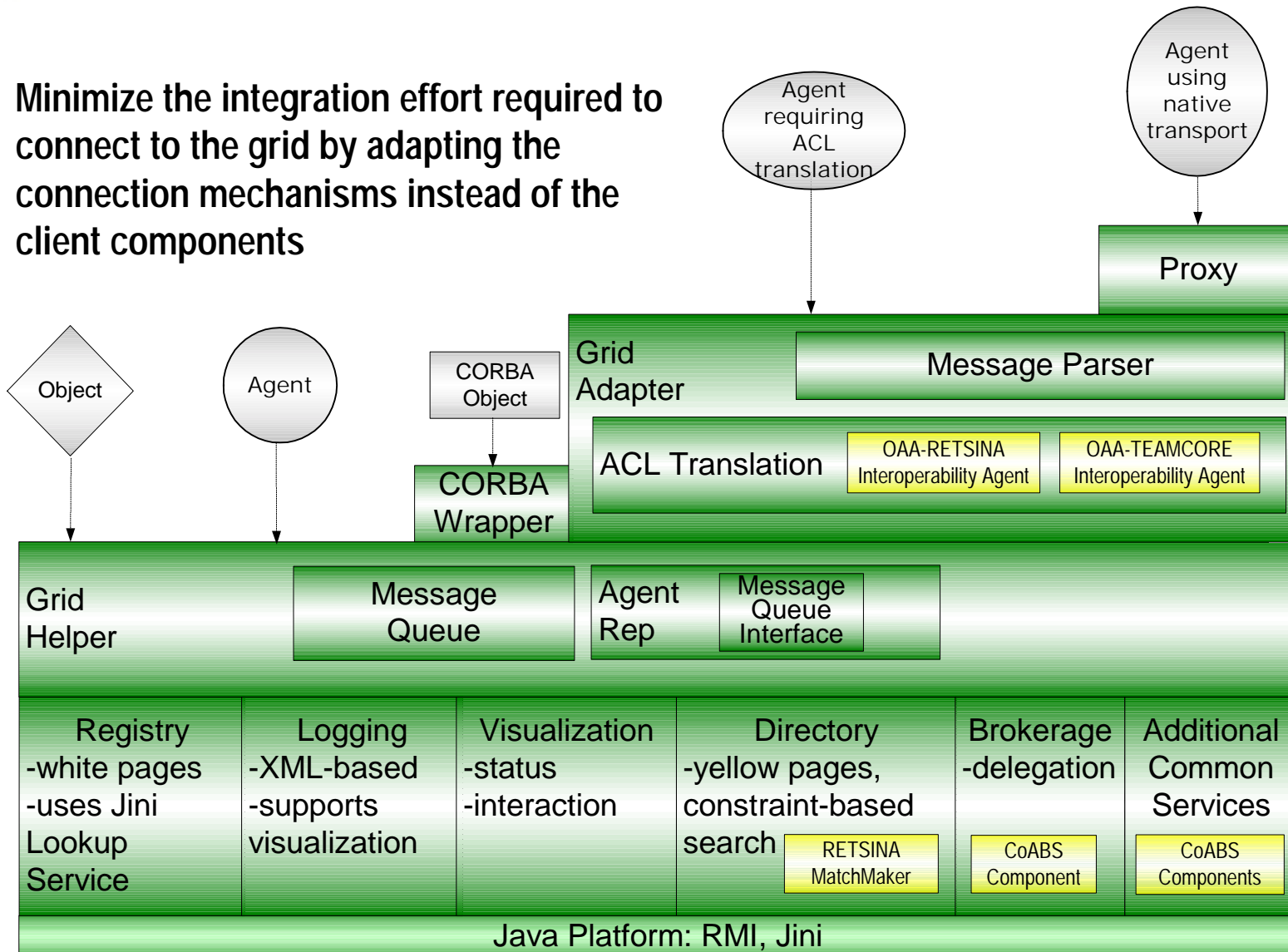# CoABS Feasibility Demo: Heterogeneous Systems Interoperability Challenge
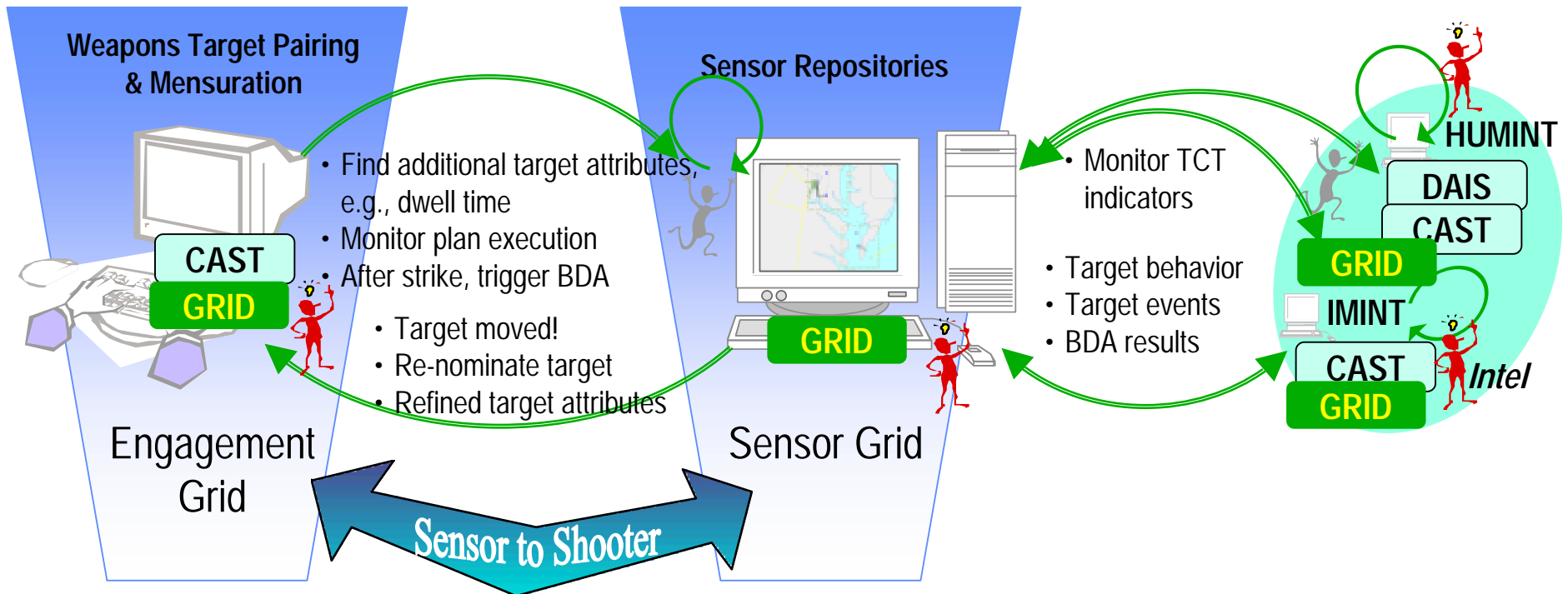
- **21 different agent systems and services integrated in 2 weeks**
  - ◆ Distributed development
    - 9+ organizations/sites
  - ◆ Six implementation languages
    - Java, Lisp, C++, Prolog, Soar, C
  - ◆ Multiple platforms
    - Windows NT, UNIX Solaris
  - ◆ Three Agent Communication Languages
    - e.g., OAA ICL, KQML, FIPA ACL

CoABS Grid "Architecture"

- **Minimize the integration effort required to connect to the grid by adapting the connection mechanisms instead of the client components**

Agent requiring ACL translation

Agent using native transport

Proxy

Object

Agent

CORBA Object

CORBA Wrapper

Grid Adapter

Message Parser

ACL Translation

| OAA-RETSINA Interoperability Agent | OAA-TEAMCORE Interoperability Agent |

Grid Helper

Message Queue

Agent Rep

Message Queue Interface

| Registry -white pages -uses Jini Lookup Service | Logging -XML-based -supports visualization | Visualization -status -interaction | Directory -yellow pages, constraint-based search | Brokerage -delegation | Additional Common Services |
| | | | RETSINA MatchMaker | CoABS Component | CoABS Components |

Java Platform: RMI, Jini

Agents CAST/Grid used in Missile Defense Cell, Fleet Battle Experiment - Foxtrot, Dec 1999

Weapons Target Pairing & Mensuration

Sensor Repositories

HUMINT

DAIS

CAST

GRID

IMINT

CAST

GRID

Intel

CAST

GRID

• Find additional target attributes, e.g., dwell time
• Monitor plan execution
• After strike, trigger BDA

• Target moved!
• Re-nominate target
• Refined target attributes

• Monitor TCT indicators

• Target behavior
• Target events
• BDA results

GRID

Engagement Grid

Sensor Grid

Sensor to Shooter

Agents Analysis of Bandwidth Usage
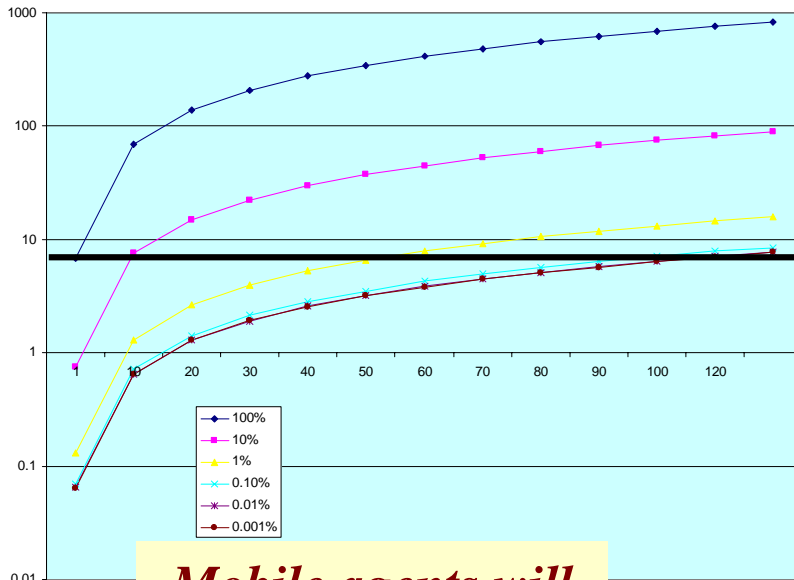
Mobile agents will decrease bandwidth usage. More powerful servers help, not hurt, scaling possibilities when bandwidth limited.

- Analyzed scaling of mobile-agents based on performance parameters from FBE-Echo

- Developed mathematical model of bandwidth trade-offs for mobile-agent vs. broadcast of information (limitation: assuming homogeneous information needs across space)

...e computational resources allocated to agent j from client i is S_{ij}^s, ...sing on the server machine is:

$$T_{ap}(i,j) = \frac{c_{ij}(D, R'_{ij}, R_{ij})}{\alpha^s S_{ij}^s}.$$

...sing, only the relevant data is sent back to the client machines. The ba... ...mmunication channel is b_{ij}^s. The data transmission time is therefore gi...

$$T_{at}(i,j) = \frac{\beta_a D R'_{ij} R_{ij}}{b_{ij}^s}.$$

...count overlapping between computation time and transmission time fo... ...me is

$$\begin{aligned}
T_{ar} &= \max_{i=1,\dots,n} \max_{j=1,\dots,m_i} \left(\frac{c_{ij}(D, R'_{ij}, R_{ij})}{\alpha^s S_{ij}^s} + \gamma_a \frac{\beta_a D R'_{ij} R_{ij}}{b_{ij}^s} \right) \\
&= \max_{i=1,\dots,n} \max_{j=1,\dots,m_i} (T_{ap}(i,j) + \gamma_a T_{at}(i,j))
\end{aligned}$$

Grid Transition Plan

DARPATECH 2000 ISO

- ● **Beta Release of Grid (FY99- 3QFY00)**
  - ◆ CoABS demo described previously
  - ◆ Working with other DARPA Programs (ALP, CPoF, AIA)
- ● **Military Transitions Focus of 3QFY00-FY02**
  - ◆ Navy Fleet Battle Experiments (Funded by CoABS)
  - ◆ Air Mobility Command (Funded by AFRL, uses Grid)
  - ◆ Bilateral Air Planning (Funded by UK DERA, AFRL; uses Grid)
  - ◆ Intelink Management Office (Funded by IMO, DARPA)
  - ◆ Possibility of use for CC21 ACTD (ONR lead)

```
<Title> Beyond XML
    <subtitle> agent semantics </subtitle>      </title>
<USE-ONTOLOGY ID="PPT-ontology" VERSION="1.0" PREFIX="PP" URL=
"http://iwp.darpa.mil/ppt..html">
<CATEGORY NAME="pp.presentation" FOR="http://iwp.darpa.mil/jhendler/agents.html">
 <RELATION-VALUE POS1 = "Agents" POS2 = "/jhendler">
```

DAML:

Create technologies to enable software agents to identify, communicate with, and understand other software agents dynamically (i.e., on the fly at run time, not built in at development time).

```
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powerpoint presentations">

<DEF-CATEGORY NAME="Title" ISA="Pres-Feature" >
<DEF-CATEGORY NAME="Subtitle" ISA="Pres-Feature" >

<DEF-RELATION NAME="title-of"
          SHORT="was written by">
        <DEF-ARG POS=1 TYPE="presentation">
        <DEF-ARG POS=2 TYPE="presenter" >
```

DARPA Agent Markup Language

- **DARPA is working on the development of the DARPA Agent Markup Language (DAML)**
  - A "semantic" language that ties the information on a page to machine readable semantics (ontology)
    - Currently being explored at University level
      - SHOE (Maryland), Ontobroker (Karlsruhe),OWL (Washington Univ)
      - Largely grows from past DARPA programs (I3, ARPI)
    - But not transitioning
      - W3C focused on short-term gain: HTML/XML

```
<Title> Beyond XML

    <subtitle> agent semantics </subtitle>      </title>

<USE-ONTOLOGY ID="PPT-ontology" VERSION="1.0"
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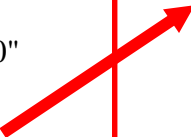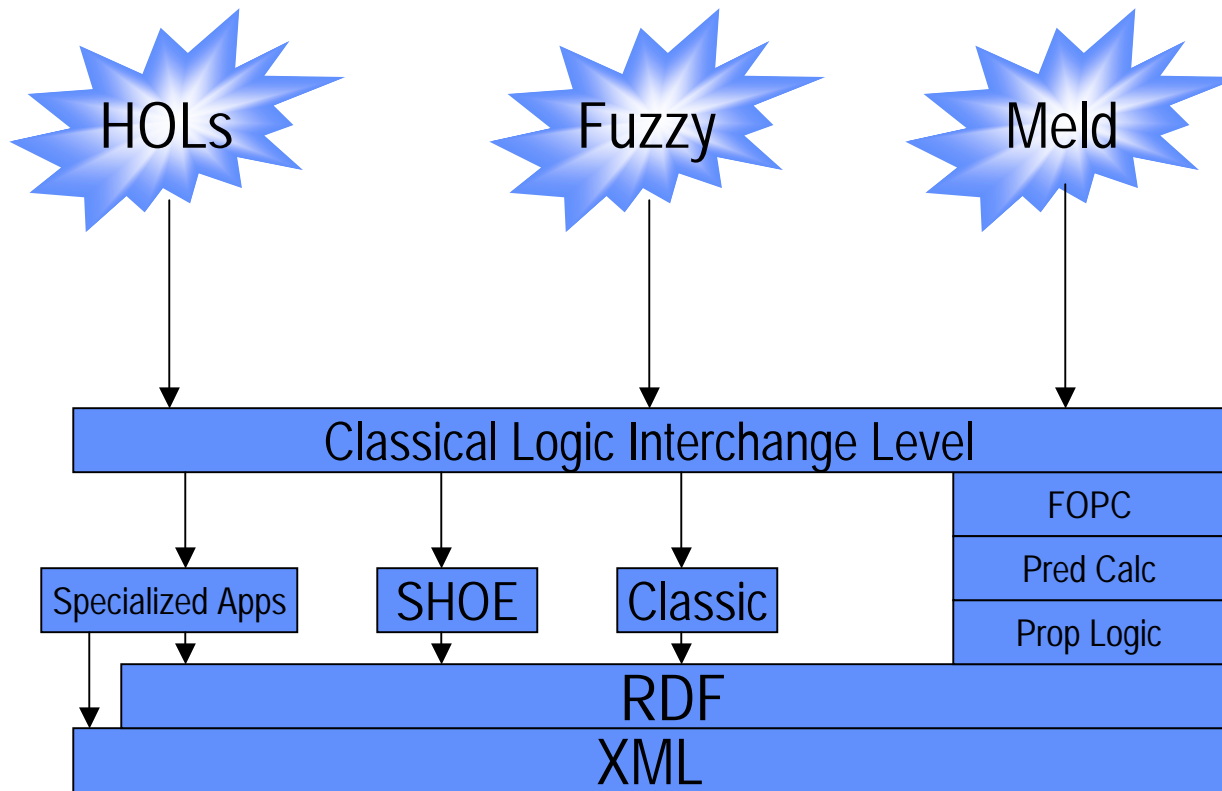
DoD and W3C working together

DAML and the "Semantic Web"

DARPATECH 2000 ISO

Taskable Agent Software Kit

Create the engineering discipline of agent-based computing

Infinite-horizon problems: $V_t = V_{t'}$ for any t and t'.

1. Expected value per time step
2. Expected cumulative value until goal reached (e.g., $E(\tau)$)
3. Expected discounted cumulative value for discount $0 \leq \gamma \leq 1$

Discounted case

- The value of being in state x after n stages is $\gamma^n V(X = x)$.
- Let $\Omega_X = \{1, 2, \ldots\}$ and the state transition probabilities

$$P_{ij}(d) = \Pr(X_t = j \mid X_{t-1} = i, D_t = d) \qquad i, j \in \Omega_X \qquad d \in \Omega_D$$

- A policy δ maps states Ω_X to actions Ω_D
- Expected discounted cumulative value for policy δ and state i

$$E_\delta(\Sigma_\eta \mid X = i) = V(X = i) + \gamma \sum_{j \in \Omega_x} P_{ij}(\delta(X = i)) \, E_\delta(\Sigma_\eta \mid X = j) \qquad i \in \Omega_X$$

- The *optimal expected discounted cumulative value*

$$E(\Sigma_\eta \mid X = i) = \max_\delta E_\delta(\Sigma_\eta \mid X = i) \qquad i \in \Omega_X$$
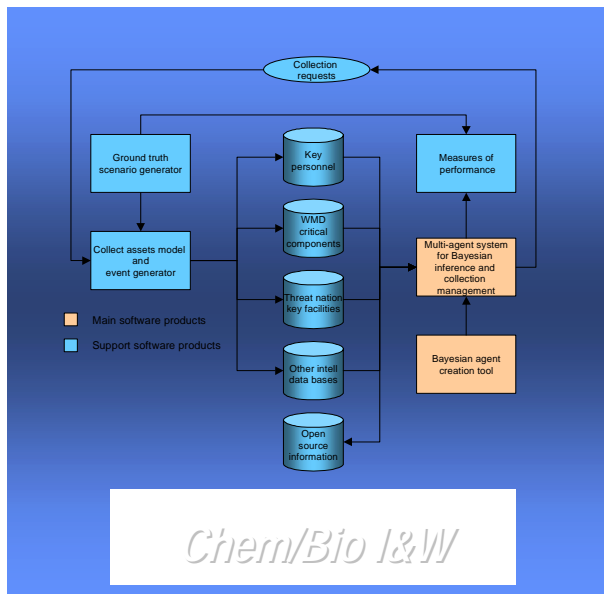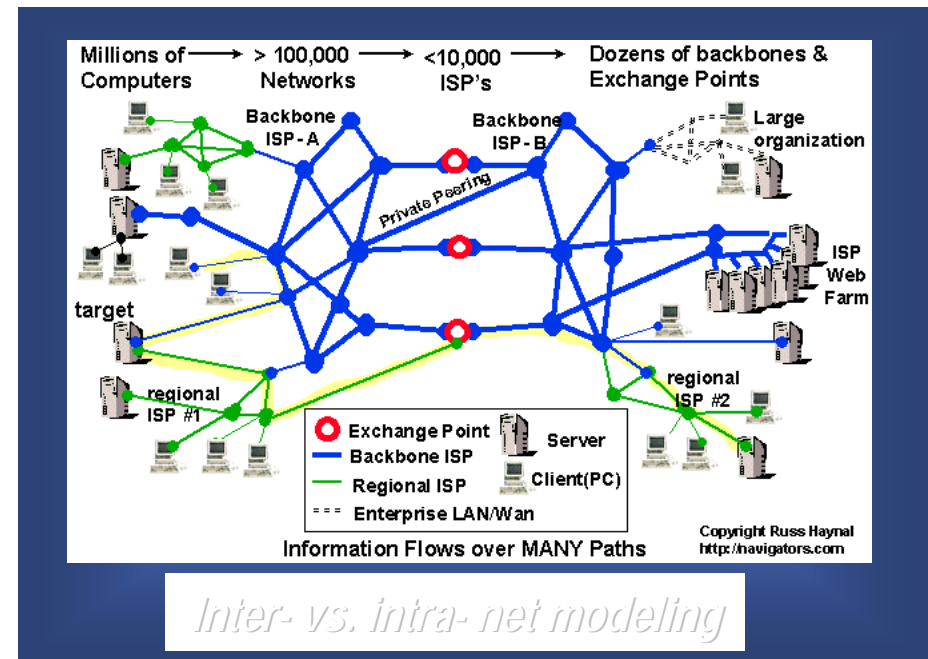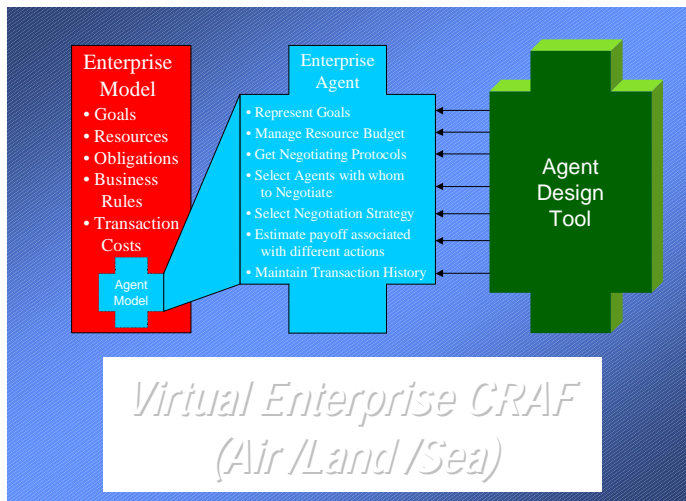
- Which satisfies the *optimality equation*

$$E(\Sigma_\eta \mid X = i) = \max_d \left[V(X = i) + \gamma \sum_{j \in \Omega_x} P_{ij}(d) \, E_\delta(\Sigma_\eta \mid X = j) \right] \qquad i \in \Omega_X$$

Optimal Bayesian State Estimator

$$\pi(t)(x) = \frac{\Pr(y(t) \mid X_t = x) \sum_{x' \in \Omega_x} \Pr(X_t = x \mid X_{t-1} = x', u(t)) \pi(t-1)(x')}{\sum_{x'' \in \Omega_x} \left[\Pr(y(t) \mid X_t = x'') \sum_{x' \in \Omega_x} \Pr(X_t = x'' \mid X_{t-1} = x', u(t)) \pi(t-1)(x') \right]}$$

15

Virtual Enterprise CRAF (Air /Land /Sea)

Chem/Bio I&W

Inter- vs. intra- net modeling

Task PIs will "strut their stuff" against three currently unsolvable problems

Conclusions

- **Agents are important to the military...**
  - ◆ Across a wide variety of problems
    - Early results already exciting

- **... But much R&D remains to be done**
  - ◆ Just because it is software, it does not have to be soft science...
    - Solid experimental studies can be performed
  - ◆ … But the theory of computing needs fixing
    - Largely based on a 40-year old model of computation

- **DARPA is taking the DoD lead in understanding this new form of computation**
  - ◆ CoABS: Ongoing program (3rd year)
  - ◆ DAML/TASK: New Starts, BAA still open (16 DAML projects & 15 TASK projects already funded)

"Press clippings"

From DSB "21st Century Defense Technology Strategies", Nov. 1999
"A key program at DARPA in this technology area is called CoABS. The goal of this program is to design, implement, and test a prototype 'agent grid'...[the DoD] must continue to fund the science and technology initiatives that will lead to the intellgent agents envisioned herein. DARPA and the Service laboratories have focused their resources on developoing intelligent agent technology that leverages and supplements private-sector technologies in order to meet warfighter needs."

Figure 5-4 shows one approach to building such a grid of agents, currently under development in DARPA's Control of Agent-Based Systems (CoABS) initiative ... This combination of agent-based codes, agent mark-up languages, and an interoperability infrastructure that enhances agent (and legacy) communication provides an "information web" structure that goes beyond the specific needs of the JBI. However, the study team sees this infrastructure as a military necessity, and the study team joins the Defense Science Board and others in endorsing the military development of such an approach ... transition of DARPA agent technology to AFRL has begun, and the study team recommend high priority be given funds for this transition -- **From AF SAB, "Building the Joint Battlespace Infosphere", Nov. 1999**

"An effort is about to begin to establish a new agent language intended to progress well beyond current Web languages (HTML, XML) that will provide readable (interoperable) semantics." **From NSB, "Network-Centric Naval Forces", 2000**

"DAML could take search to a new level",
PC Week, Feb. 7, 2000

"A new language known as DAML addresses an important unmet need --- making Web sites more understandable to programs and nontraditional browsing devices...One advantage DAML may have over other emerging web technologies is the involvement of DARPA, which has been instrumental in the creation of the Internet and many Internet technologies."

Fleet Battle Experiment (FBE) reviews by CDR, USN
"I believe we have made significant strides in application of the agent technology to the Navy future warfighting concepts. I view CAST as a long term investment--the acorn that may grow into a giant oak tree 5-10 FBEs down the road. FBEs are conducted every six months and are iterative, incremental concept development events and we are very supportive of continued CAST involvement in future FBEs."