Multiagent Infrastructure for Agent Interoperability in Open Computational Environments



Katia P. Sycara School of Computer Science Carnegie Mellon University Pittsburgh, PA. 15213 http://www.cs.cmu.edu/~softagents



School of Computer Science

Talk Outline

- Motivations for Interoperability
- Multiagent Infrastructure
- Agent Discovery: ANS and Middle Agents
- Semantic Markup and DAML-S
- **RETSINA** Infrastructure
- **RETSINA** Applications
- Conclusions

Motivations for Dynamic Interoperability

- Challenges
 - Dynamic Environment
 - Transitory Execution Environment for Agent applications
 - Undependable Infrastructure
 - Systems
 - Networks/Connectivity
 - Services
- Goals
 - Automatic / Self Configuring Agents and Infrastructure
 - Fault Tolerance and Dynamic Reconfiguration
 - Scalability in Quantity, Loading and Dispersing into Groups or over WANS

(while still allowing systems to "find" each other)

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The Many Faces of Interoperability

- Syntactic and Static via known Registries
 - At the component Level
 - At the connector Level
 - At the Software Architecture Level
- Semantic and Dynamic (Agents)
 - Agent/component Discovery over LANs and WANs (Discovery Mechanisms)
 - Ontological Understanding of Agent Behaviors (Ontologies, Languages, e.g. DAML-S)
 - Interacting in Meaningful Ways (Conversational Policies)

MAS Infrastructure Requirements

MAS Infrastructure

MAS Interoperation

Translation Services Interoperator Services

Capability to Agent Mapping

Middle Agents, Ontologies

Name to Location Mapping

Agent Name Service

Security

Certificate Authority Cryptographic Service

Performance Services

MAS Monitoring Reputation Services

Multi-Agent Management Services

Logging Activity Visualization Launching

ACL Infrastructure

Public Ontology Protocol Servers

Communications Infrastructure

Discovery Message Transfer

Individual Agent Infrastructure

Interoperation

Interoperation Modules

Capability to Agent Mapping

Middle Agent Components

Name to Location Mapping

ANS Component

Security

Security Module

Private/Public Keys

Performance Services

Performance Service Modules

Management Services

Logging and Visualization Components

ACL Infrastructure

Parser, Private Ontology, Protocol Engine

Communication Modules

Discovery Message Transfer Modules

Operating Environment

Machines, OS, Network, Multicast Transport Layer, TCP/IP, Wireless, Infrared, SSL

Agents with Middle/Infrastructure Agents



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Discovery Mechanisms

- Agent Discovery:
 - Static: a priori knowledge of agent's IP address
 - Dynamic Local: based on RMI or SSDP
 - Dynamic Widearea: Retsina A2A
 - Informed: Facilitated through Infrastructure/Middle Agents (e.g. ANS, JINI, Matchmakers, Brokers)
- Discovery of Middle Agent Infrastructure
 - Static: a priori knowledge of Middle Agent's address (e.g. UDDI)
 - Dynamic Local:
 - RMI-based (e.g. JINI/GRID)
 - SSDP-based: Retsina ANS, Retsina Matchmakers and Brokers
 - Dynamic Widearea: Retsina A2A

Agent Name Service v.2 (ANS)

The ANS is a name registration and lookup service to facilitate communication among agent applications.



Agent Communications





ANS Client Initialization active servers reply that they are available











Branching Nature of Extended ANS Lookup



DAML-S: Interoperability Language

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MAS Interoperation

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Agent Discovery

By capability advertisement and Request through Middle Agents

Service Transaction

- Providers and requesters interact with each other directly
 - a negotiation phase to find out service parameters and preferences (if not taken into account in the locating phase)
 - delegation of service
- Providers and requesters interact through middle agents
 - middle agent finds provider and delegates
 - hybrid protocols
- Reasons for interacting through middle agents
 - privacy issues (anonymization of requesters and providers)
 - trust issues (enforcement of honesty; not necessarily keep anonymity of principals); e.g. NetBill

Matchmaker



Classified Ads



Facilitator

Combines Agent Location and Transaction Phases



Discovery Over the Internet

• Problem:

How to quickly and broadly implement a solution to allow discovery and lookup communication between widely dispersed systems...

• Our Solution:

Piggy-back on top of an existing nonproprietary and popular (widely utilized) communications framework that provides global connectivity - Gnutella. Copyright Katia Sycara

Wide-Area Discovery, Affinity, and Community Aggregation

- Gnutella Peer-to-Peer (P2P) networks provide random connectivity to a large range of other systems over a wide-area: the Internet.
- Agent-to-Agent (A2A) adds task identifiers to messages; these are used to classify hosts into specific communities of specific interests.
- A2A prefers connectivity partners that share the same interests. This affinity causes congregations of Agents in P2P networks to be formed.
- A2A attempts to maintain certain levels of connectivity to related Agents, and to hosts that have higher confidence/probability of providing needed information (either directly, or through their peers.)
- A2A reduces random P2P connectivity, in favor of these links with higher probability for satisfying directed or background discovery and lookup processes.

A2A Agent Architecture



Gnutella Peer-to-Peer (P2P) and CMU's Agent-to-Agent (A2A)



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Agent Languages and Ontologies

- Formal Languages that have well defined syntax and Semantics
- To be used both as languages for Web page markup (semantic Web), and
- As agent communication content languages

Semantic Markup for Internet Pages

- HTML is markup for making pages viewable by humans
- XML has more rigorous syntax and allows semantics by agreement
- **DAML** is XML+semantics (provided by RDF)

Ontological Reasoning in RDF



Type constraint violation: The range of owns is Fish.

OR There is no inconsistency: Wanda is a fish! Mermaid? Copyright Katia Sycara 30



Cardinality constraint violation: George can't have two majors OR There is no inconsistency: Engineering = Arts & Sciences Copyright Katia Sycara 31

Consequences of Semantic Markup

- Semantic markup allows the Web to be used as a vast knowledge base
- Semantic markup facilitates distributed inference
- Semantic markup allows pages to be viewed as "services"

Industry Efforts in Web-Based Services

- UDDI (Universal Description, Discovery and Integration)
- WSDL (Web Service Description language)
- E-speak
- ebXML

DAML-S: A DARPA Agent Markup Language for Services

• DAML-S Objectives:

Provide an upper ontology for describing properties of agents & (Web) services in a semantically meaningful, computer interpretable markup language.

- AI-inspired markup language:
 - tailored to the representational needs of Services
 - expressive power
 - well-defined semantics
 - supports interoperation
- Release of DAML-S version 0.5 June,2001
 <u>http://www.daml.org/services/</u>

Automation Enabled by DAML-S

• Web service <u>discovery</u>

Find me a shipping service that transports goods to Somalia

- Web service selection and execution Buy me 500 lbs. rice from www.acmemoo.com
- Web service <u>composition</u> Arrange food for 100 people for 2 weeks in Somalia.
- Web service <u>execution monitoring</u> Has the rice been ordered and paid for yet?

Upper Ontology of Services



DAML-S Service Profile

- High-level description of a service and its provider
 - description of service (human readable)
 - specification of functionalities service provides
 - functional attributes (requirements and capabilities)
- Profile used for
 - populating service registries
 - automated service discovery via middle agents
 - matchmaking

DAML-S Service Model

Service Model may be used to

- 1) to perform a more in-depth analysis of whether the service meets a requester's needs;
- 2) to compose service descriptions from multiple services to perform a specific task;
- 3) during the course of the service enactment, to coordinate the activities of the different participants;
- 4) to monitor the execution of the service.

For non-trivial services, the first two tasks require a model of action and process, the last two involve, in addition, an execution model.

Process Model

- Subclass of ServiceModel and composed of:
 - *process*, which describes a service in terms of its actions
 - *process control model* to allow agents to monitor execution of a service request
- The top level class is Process
 - Subclass of Process is CompositeProcess
 - Properties of Process are: *parameter*, *input*, *output*, *participant*, *precondition*, *effect*

Composite Process

- CompositeProcess has an additional property
 - *components*, to indicate ordering and conditional execution of processes
- Subclasses of CompositeProcess are:
 - Sequence: list of processes to be executed in order
 - **Split**: bag of subprocesses to be executed concurrently
 - Unordered: bag of processes executed in any order; all of them must be executed
 - Split+Join: concurrent execution of a bag of sub-processes with some partial synchronization

Composite Process (cont)

- Subclasses of CompositeProcess are:
 - Choice: a composite process with additional properties "chosen" and "chooseFrom" –these are useful in specifying new subclasses, such as "choose at least n from m"
 - Condition: composite process with an output proerty (conditionValue) that has a binary range. Useful for specifying test actions
 - If-Then-Else: composite process with intended semantics
 "Test If-condition; if True do *Then*, if False do *Else*"
 - **Iterate:** composite process whose *next process* property has the same value as current process.
 - Repeat-Until: subclass of If-Then-Else class

Supporting a Service Grounding



DAML-S:

• Service Process

Service Profile

- Provides a specification of service access information.
- Specifies:
 - communication protocols, transport mechanisms at varying levels etc.
 - E.g., SOAP, HTTP forms, KQML, OAA ACL, Java RMI, RPC, etc.

Current Status of DAML-S

- Initial version of DAML-S on www.daml.org/services/daml-s
- Intended for review and comment from the DAML community
- To be added later
 - Semantics for DAML-S: DAML-S is defined in DAML+OIL and inherits its semantics. Semantics for DAML-S will also be produced
 - Service Grounding Ontology
 - Process Control Ontology to support service execution monitoring
 - Conversational Protocols: current definitions are limited in specifying messages to be exchanged between service participants in carrying out a service Copyright Katia Sycara 43

RETSINA - REusable Task-based System of Intelligent Network Agents

- Adaptive, self-configuring collection of distributed heterogeneous autonomous agents that interact with humans and each other over WANs in real-time in a dynamic environment:
 - find each other through discovery in open environments where network connections, information sources and agents can unpredictably appear and disappear
 - access, filter, aggregate and distribute information
 - integrate information management and decision support
 - interleave planning, information management, execution and monitoring
 - anticipate and satisfy human information processing and problem solving
 - notify users and each other about significant changes in the environment
 - discover and interoperate semantically
 - adapt to user, task and situation
 - include "agentified" legacy systems

RETSINA Functional Organization



Some RETSINA Applications

- Aiding Human Teams in joint mission planning (using ModSAF as a simulated battlefield)
- Robot teams for de-mining
- Team Rescue Scenario (NEO)
- Agent-based "on the move" collaboration on mobile devices
- Agent-aided aircraft maintenance
- Agent-based financial portfolio management
- E-commerce in wholesale markets (agent-based auctions and negotiation)
- Agent-based Supply Chain Management

RETSINA Agent Architecture



Distributed Agents Supporting Different Functions





Applet



- 🗆 ×

Applet started.



Anytime Anywhere Agents



RETSINA Agent Visualization Tool



Air-Force Aircraft Maintenance -Current Situation

- Aircraft (e.g. F-15) arrive at maintenance airbase
- Periodical maintenance must be completed in 60 days (varies for different aircraft types)
- Mechanics inspect aircraft. For a discrepancy:
 - If repair method is unknown to mechanic:
 - Consults: experienced mechanics, manuals. Else,
 - A 202a form is filled (by hand). Sent to experts
 - Reply (202b) includes repair instructions
- Mechanic repairs and files a report (and the 202)

Aircraft Maintenance Agent Organization



		Form	Interface Agent	
File				
Form 202A				Search Results
Fields To: Date: Noun: NationalStockNo: Location: WorkStoppage: PhoneNo: OrganicallyCaused: Memo Fields Eng mount support on not clean up. Holes of .36312578257030	LFLEA Feb. 6, 1995 Eng Mount Support Dock 2 Yes 5622 No Encode State Sta	From: ControlNo: PartNo: SerialTailNo: ToDwgNo: Initiator: NotifiedTCM: MaintenancePlan ciency: f tolerance, which to (95021) 37 38 39 40 mendation:	LFPB LFPLP95002B 68A332028-2008 C80-048 LFPLP #000101 Norwood ner: first over size vill 41 42 43 .2599 .2690	 /afs/cs/usr/gitars/data/data1/A/Wed-f
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Matching News Articles for NSCP

- [1] ****Silicon Graphics/Sun/Netscape To Merge Web Technologies 12/05/95 [Tue Dec 5 16:00:41 1995]
- [2] Netscape Stock Surges on JavaScript Plans [Tue Dec 5 18:00:16 1995]
- [3] Sun Microsystems Unit To Offer Netscape Pdts >SUNW NSCP [Wed Dec 6 08:31:13 1995]
- [4] *Smith Barney Starts Netscape Communications At Sell >NSCP [Thu Dec 7 08:55:38 1995]
- [5] Smith Barney–Internet Stks –2: Initiates 6 Cos>AMER NSCP [Thu Dec 7 09:23:22 1995]
- [6] CA Announces Internet Products, Partnership With Netscape 12/07/95 [Thu Dec 7 16:00:35 1995]
- [7] Netscape, Other Internet Shares Pressured [Fri Dec 8 15:00:20 1995]
- [8] Netscape vows "dog-fight" vs Microsoft [Fri Dec 8 15:00:32 1995]
- [9] Netscape, other Internet shares pressured [Fri Dec 816:50:081995]
- [10] Netscape Vows "Dog-Fight" vs Microsoft [Fri Dec 8 18:20:26 1995]
- [11] Netscape Gives 2 \$1,000 Apiece [Fri Dec 8 20:30:24 1995]
- [12] Netscape, Other Internet Shares Pressured [Sat Dec 9 07:50:12 1995]
- [13] Hot Stocks In Barron's: CPQ TBCCITW NSCP MSFT IBM T [Mon Dec 11 10:17:31 1995]
- [14] H-P, Microsoft, Netscape Sign Pact To Develop Web Standards [Tue Dec 12 06:05:22 1995]
- [15] *****HP Teams With Netscape & Microsoft On Internet Printing 12/12/95 [Wed Dec 13 14:20:32 1995]
- [16] *****Netscape Creates Java Conference 12/20/95 [Wed Dec 20 18:11:05 1995]
- [17] Worldview Sys To Use Netscape Software To Create Travel Svc [Thu Dec 21 11:33:43 1995]

Written by the Stock Display Agent, Fri Dec 22 17:03:01 1995

Coalition Formation for Volume Discounts



Conclusions

- Agent Technology is key to important aspects of interoperability
- Provide completed specification of DAML-S
- Provide algorithms for matchmaking and service composition for DAML-S
- Applications built using A2A discovery and interaction
- Experimental investigation of A2A scheme regarding scalability, reachability, network congestion and security