Intelligent Agents on the Web and in the Aether

Tim Finin
University of Maryland Baltimore County

Presentation given at the U. of Pittsburgh on Sept. 19, 2001

Joint work with Anupam Joshi, Yun Peng, Scott Cost, Yelena Yesha and many students.

This work was partially supported by DARPA contract F30602-97-1-0215 and NSF grants CCR007080 and IIS9875433.

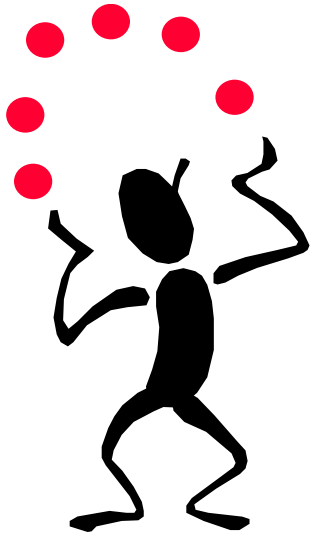
Overview

- Big picture
- Intelligent agents
- Semantic web
- Some current research at UMBC
  - Systems: Centaurus, DReggie, ESDP
  - Infrastructure: Distributed trust
  - Applications: Agents2Go, ITtalks
- Comments
- Conclusion

The Big Picture

- Mobile/pervasive computing and software agents are a good match
- The combination offers new challenges for each
- Attempts are being made to bridge the gap to connect the two
- **Pervasive computing** is a good target and will require an integrated model to support both wired and wireless computing

Today: Life is Good.



Tomorrow: We Got Problems!

Mobile and Agents are a Good Match

- The agents community has relatively advanced approaches to many of the problems faced by mobile computing, since we have assumed a very dynamic, ad hoc environment, open environment. Some common issues:
  - Service description, discovery, composition.
  - Negotiation for services and information
  - Authentication, authorization, and trust
  - Delegation and degrees of autonomy
  - Coordination and teamwork models
- Mobile/pervasive computing will provide good justification for an agent oriented approach.

Special challenges for agents

- Today's mobile computing environment offers special challenges for us. Mobile systems have:
  - Low/variable bandwidth, limited CPU, memory, disk, power etc.
    - Resource poor systems connected over thin pipes.
    - "Resource gap" is (mostly) indifferent to absolute values.
  - (Elective) disconnections, dynamically changing network topology …

Special challenges for mobile computing

- Current technologies being used for mobile computing (e.g., Bluetooth) or likely to be adopted (e.g., Jini, UDDI) have problems.
  - The languages for describing and matching services are much too simple.
  - No or poor support for shared ontologies beyond those selected for us by business consortia.
  - No or poor support for evolution and maintenance in such an open environment.
- Envisioned pervasive computing environments must be "context aware".

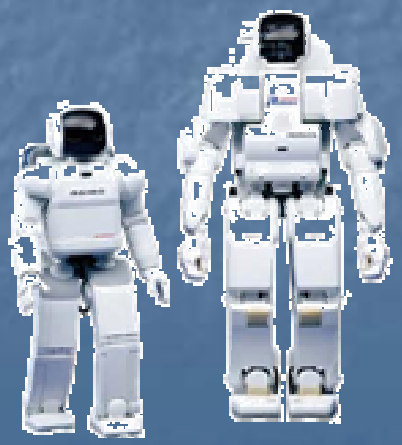
Rest of Talk

- The agent paradigm
- The semantic web as a common model for both wired and mobile knowledge sharing
- Several UMBC ongoing projects addressing issues at different levels: systems, infrastructure and application:
- Comments and conclusion

What is an agent?

An agent is a powerful and ubiquitous abstraction in computer science

- Daemons (e.g., ftp agent)
- User interface clients (e.g., mail agent)
- Physical agents (e.g., robotics)
- Believable agents (e.g., VR and graphics)
- Intelligent HCI
- Personal (expent) assistants
- Mobile software technology
- Multiagent systems

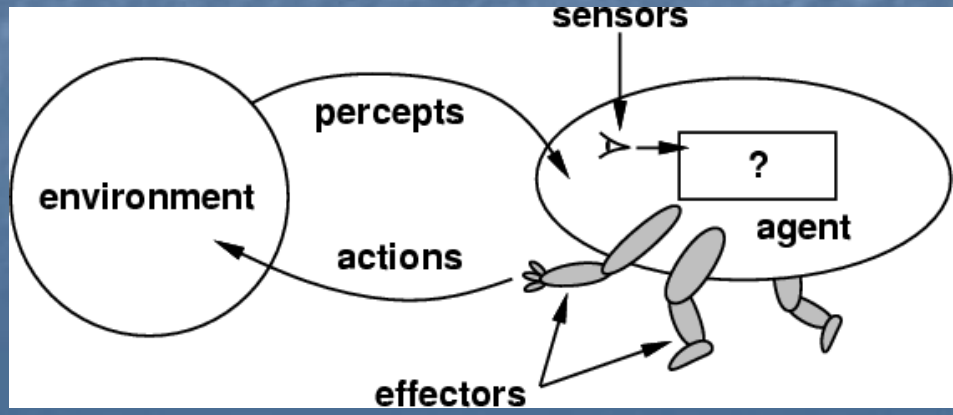


So, what's a software agent?

No crisp definition, but several key concepts are

- **Autonomous**, taking the initiative as appropriate through delegation
- **Goal-directed**, maintaining an agenda of goals which it pursues until accomplished or believed impossible.
- **Situated** in an environment (computational and/or physical) which it is aware of and reacts to.
- **Cooperative** with other agents (software or human) to accomplish its tasks.
- **Communicative** with other agents (human or software)
- **Adaptive**, modifying beliefs & behavior based on experience

Still an emerging paradigm….



The BDI model

- BDI architectures describe the internal state of an agent by the mental states of beliefs, desires, and intentions
- BDI theories provide a conceptual model of the knowledge, goals, and commitments of an agent
- BDI agents have some (implicit or explicit) representations of the corresponding attitudes.
- BDI models provide a theory to underlie and guide communication.

Agent Communication

- Agent-to-agent communication is key to realizing the potential of the agent paradigm, just as the development of human language was key to the development of human intelligence and societies.
- Agents use an ***Agent Communication Language*** or ACL to communication information and knowledge.
- Genesereth (CACM, 1994) defined a software agent as any system which uses an ACL to exchange information.

Knowledge Sharing Effort

- Framework developed by DARPA program in early 90's
- Knowledge sharing requires a communication which requires a common language
- We can divide a language into syntax, semantics, and pragmatics
- Some existing components, used independently or together:

1. **KIF** - knowledge interchange format *(syntax)*
2. **Ontolingua** - a language for defining sharable ontologies *(semantics)*
3. **KQML** - a high-level interaction language *(pragmatics)*

Propositional

Propositional attitudes

Common Ontologies

- *Ontology*: A common vocabulary and agreed upon meanings to describe a subject domain.
- A conceptual schema specifies the intended meaning of concepts used in a data base

Data Base:

139	74.50
140	77.60
…	…

Data Base Schema:

Table: price
***stockNo: integer; cost: float**

Conceptual Schema:

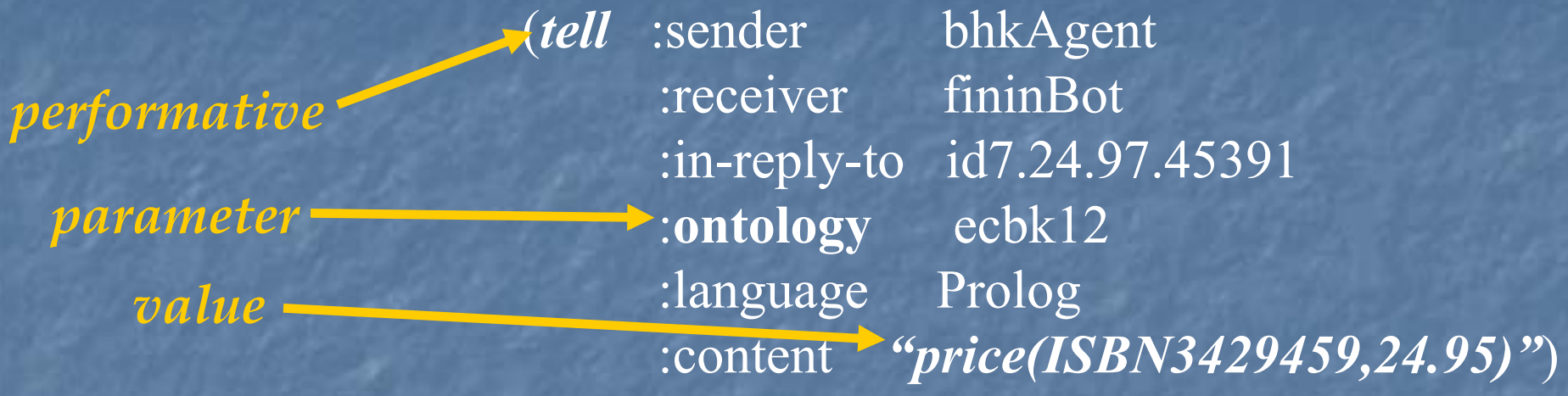
price(x, y) =>
∃ (x', y') [auto_part(x')
& part_no(x') = x
& retail_price(x', y', Value-Inc)
& magnitude(y', US_dollars) = y]

Auto Product Ontology

Product Ontology

Units & Measures Ontology

A KQML Message



Represents a single *speech act* or *performative*

ask, tell, reply, subscribe, achieve, monitor, ...

with an associated *semantics and protocol*

$$\text{tell}(\, i,j,\, B_i\phi\,) = \text{fp}[B_i\, B_i\phi \wedge \neg\, B_i(\, \text{Bif}_j\, B_i\phi \vee \text{Uif}_j\, B_i\phi\,)] \wedge \text{re}[B_j\, B_i\phi] \ldots$$

and a list of *attribute/value pairs*

:content, :language, :from, :in-reply-to

FIPA

- Foundation for Intelligent Physical Agents
  - International standards body with ~60 members.
  - Three suites of specification published (97, 98, 00)
  - Carrying forward the ideas of the Knowledge Sharing Effort
  - **http://www.fipa.org/**
- Standards in the following main areas
  - Agent communication (language, content language, interaction protocols)
  - Message transport
  - Directory services (DF)
  - Management and naming services (AMS)
- Software
  - ~10 FIPA compliant systems (2 open sourced)

The FIPA ACL

```
(request
   :sender (:name moniqueagent@liawww.epfl.ch:8080)
   :receiver (:name movenpick-
         hotel@tcp://movenpick.com:6600)
   :ontology personal-travel-assistant
   :language FIPA-SL
   :protocol fipa-request
   :content
    (action movenpick-hotel@tcp://movenpick.com:6600
     (book-hotel (:arrival 25/11/2000)      (:departure
   05/12/2000) ...) )
```

Where are the agents?

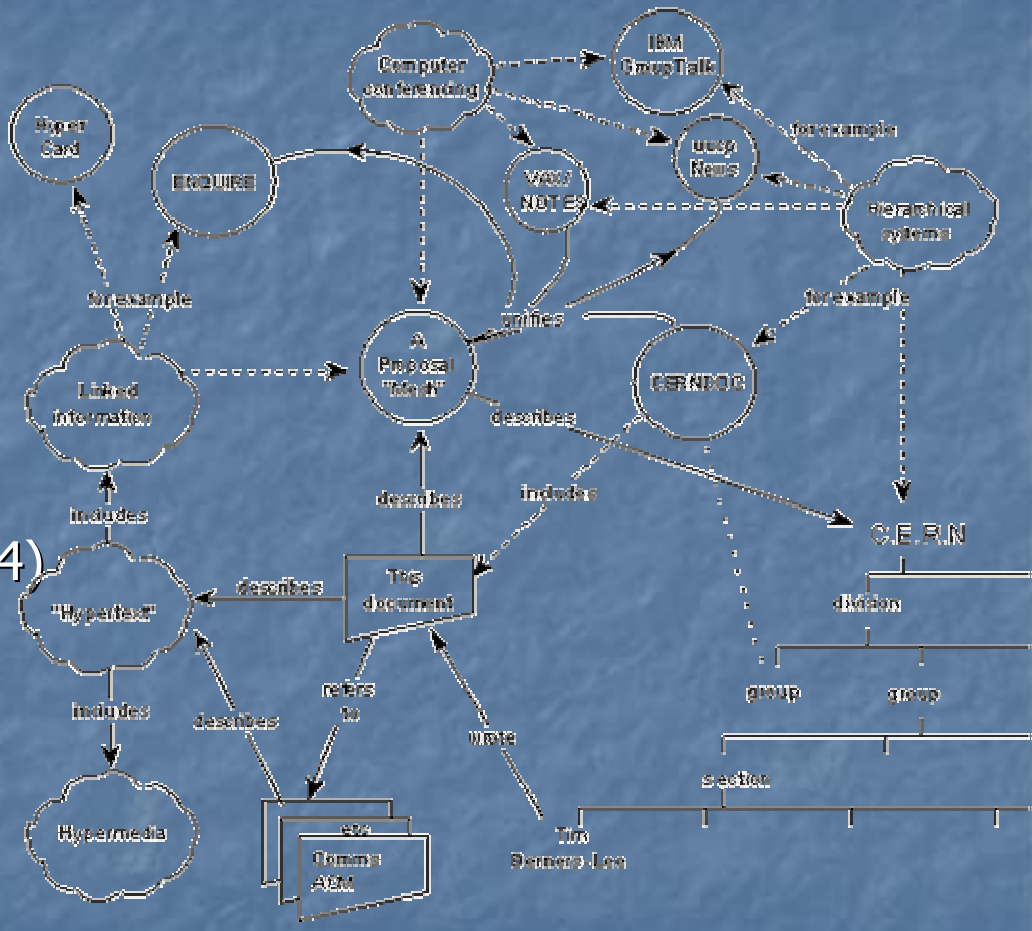
- The communicating agent paradigm was articulated about the same time as the Web.
- Both leveraged the Internet, but
  - Agents have not yet made a significant impact, either personal or commercial.
  - The Web has changed the world.
- There may be many reasons for this
- But, we should consider trying to import web oriented ideas and approaches into the agent world.

Semantic Web?

- I'll argue that the semantic web provides a good approach, language and tools to support agents as well as mobile and pervasive computing.
- This isn't obvious, since the SW seems grounded in the "traditional" wired web.
- But, the principles which drive it are the right ones for agents as well as pervasive computing.
- And, by grounding agents in web technology, they may make it out of the lab.
- Next: overview of Semantic Web

Origins of the Semantic Web

- Tim Berners-Lee's original 1989 WWW proposal described a Web of relationships among named objects that unified many information management tasks.
- Guha designed MCF at Apple (~94)
- XML+MCF=>RDF (~96)
- RDF+OO=>RDFS (~99)
- RDF+KR=>DAML+OIL (00)
- W3C's SW activity (01)

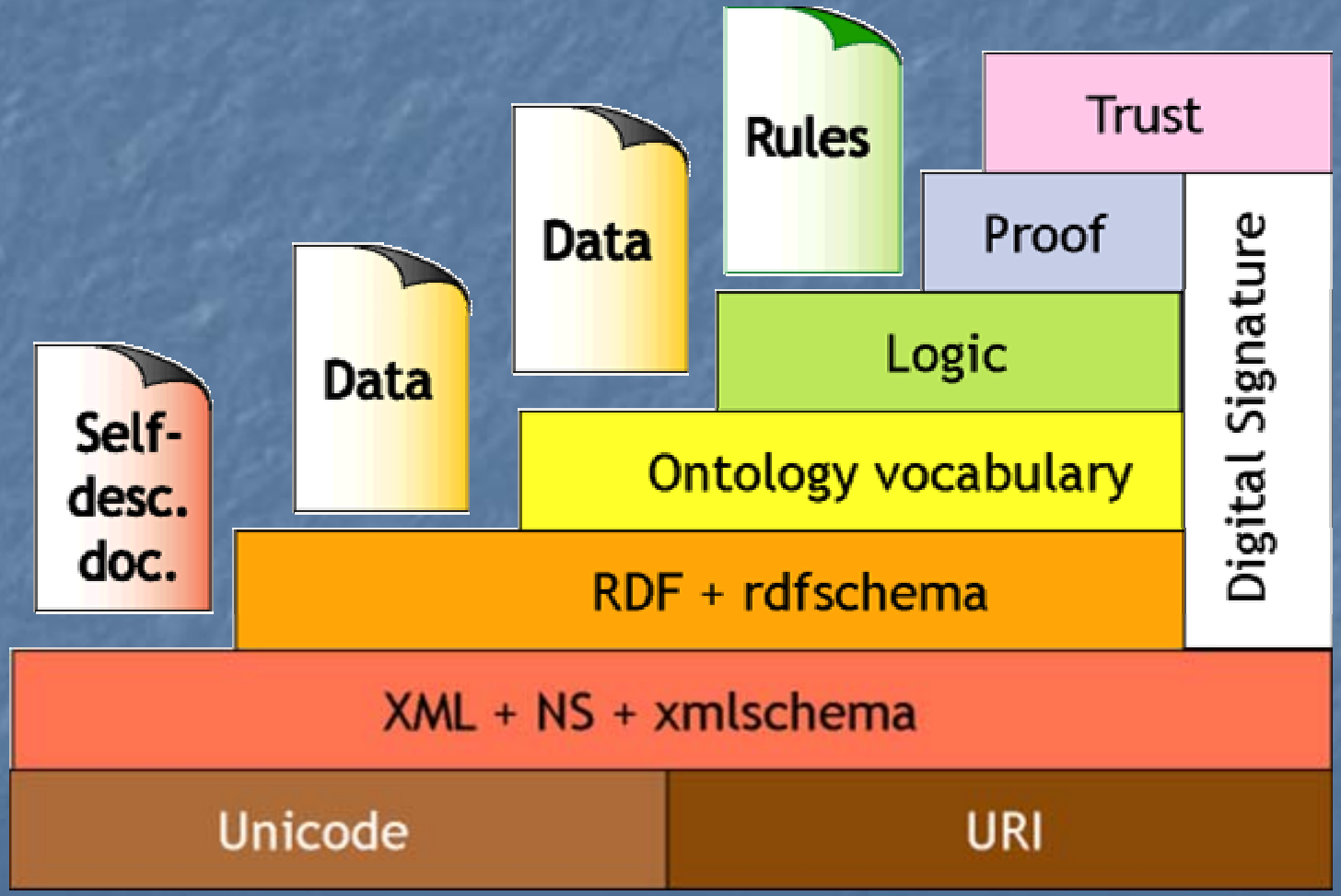


http://www.w3.org/History/1989/proposal.html

W3C's Semantic Web Goals

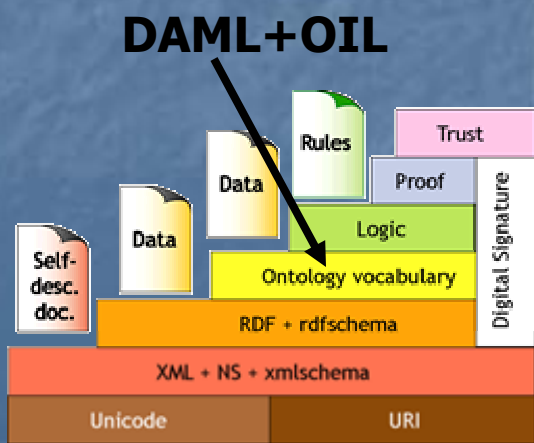
- Realizing the full potential of the Web
- Making it cost-effective for people to effectively record their knowledge
- Focus on machine consumption.
  - *"The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation."* -- Berners-Lee, Hendler and Lassila, The Semantic Web, Scientific American, 2001
- Ultimate goal - effective and efficient global knowledge exchange

Tbl's semantic web vision



DAML+OIL as a Semantic Web Language

- DAML = Darpa Agent Markup Language
  - DARPA program with 17 projects & an integrator developing language spec, tools, applications for SW.
- OIL = Ontology Inference Layer
  - An EU effort aimed at developing a layered approach to representing knowledge on the web.
- Process
  - Joint Committee: US DAML and EU Semantic Web Technologies participants
  - DAML+OIL specs released 01/01 & 03/01
  - See http://www.daml.org/
  - New W3C SW activity started 08/01.



DAML in One Slide

DAML is built on top of XML and RDF

It allows the definition, sharing, composition and use of ontologies

DAML is ~= a frame based knowledge representation language

It can be used to add metadata about anything which has a URI.

URIs are a W3C standard generalizing URLs

everything has URI

```
<rdf:RDF xmlns:rdf ="http://w3.org/22-rdf-syntax-ns#"
   xmlns:rdfs="http://w3.org/rdf-schema#"
   xmlns:daml="http://daml.org/daml+oil#“>
<daml:Ontology rdf:about="">
    <daml:imports rdf:resource="http://daml.org/daml+oil"/>
</daml:Ontology>
<rdfs:Class rdf:ID="Person">
 <rdfs:subClassOf rdf:resource="#Animal"/>
 <rdfs:subClassOf>
  <daml:Restriction>
   <daml:onProperty rdf:resource="#hasParent"/>
   <daml:toClass rdf:resource="#Person"/>
  </daml:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <daml:Restriction daml:cardinality="1">
   <daml:onProperty rdf:resource="#hasFather"/>
  </daml:Restriction>  </rdfs:subClassOf> </rdfs:Class>
<Person rdf:about=“http://umbc.edu/~finin/">
<rdfs:comment>Finin is a person.</rdfs:comment>
</Person>
```

We're going down a familiar road

KR trends

- 55-65: arbitrary data structures
- 65-75: semantic networks
- 75-85: simple frame systems
- 85-95: description logics
- 95-??: logic

Web trends

- 95-97: XML as arbitrary structures
- 97-98: RDF
- 98-99: RDF schema as a frame-like system
- 00-01: DAML+OIL
- 02-??: DAML-L

Only much faster!

Semantic Web Principles

- Everything is on the web
- Partial information
- Web of trust
- Support information evolution
- Minimalist design
- Common data model

Adapted from Eric Miller, W3C

Some UMBC Work

I'll briefly describe several ongoing projects involving mobile/pervasive computing and the semantic web.

(1) Centaurus communication infrastructure

(2) Enhancing Jini with DAML for service description and discovery

(3) Enhancing Bluetooth's SDP with DAML

(4) A model of distributed authorization and trust

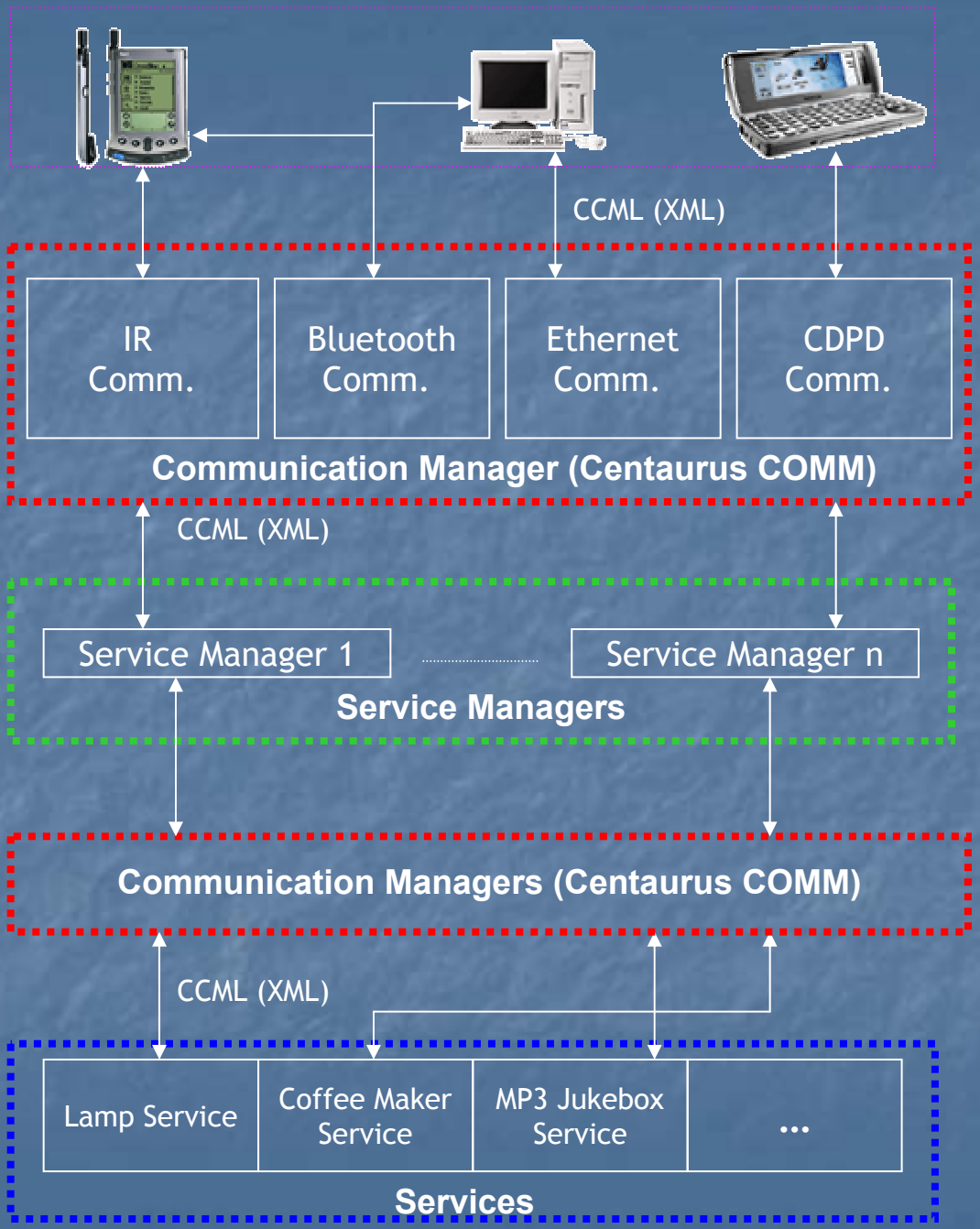
(5) Agents2go -- a simple mobile application

(6) ITtalks – a semantic web application

(1) Centaurus

Centaurus Communication (Centaurus COMM) provides a message passing network architecture that allows heterogeneous devices to communicate through varied communication mediums in a uniform fashion

Runs on PDAs and other small devices



(2) Enhancing Jini's registration server

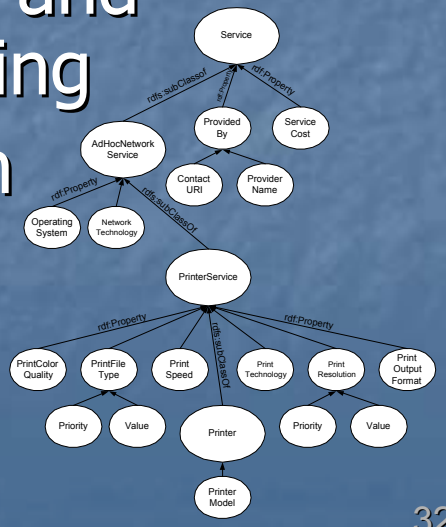
- Jini is Sun's technology for building "self describing and self organizing" distributed systems.
- Jini is a very attractive collection of ideas and components.
- One deficiency is the Jini registration server's inexpressive approach to describing services offered and sought.
- We've produced a modified Jini registration server which allows agents to use DAML+OIL to describe services offered or sought
- Supports reasoning during matching (e.g., constraint satisfaction)

(3) Enhancing Bluetooth's SDP

- Bluetooth is a short-range RF wireless technology that supports ad-hoc networks and uses P2P protocols.
- Bluetooth Service Discovery Protocol:
  - Simple service discovery mechanism
  - Services and attributes represented by UUIDs
  - UUID-based matching (128 bit number!)
  - No registration, aggregation, multicasting, event notification
- Not very expressive!

Prototyped Solution

- Assume Bluetooth ad-hoc networks with at least one resource rich device (e.g., each room has a facilitator).
- Enhanced SDP
  - Services and attributes described in DAML using a "standard" ontology
  - All available information from service and attribute descriptions used for matching
  - Tries to obtain *closest* possible match
  - Support service registration facility



(4) Delegation Based Model for Distributed Trust

- We are developing a delegation based model for distributed authorization and trust for use in both wired and wireless scenarios.
- Focus on trust from a "security perspective"
- Building on concepts like authentication, authorization, role-based access control, public key infrastructure, digital signatures, authoritative sources of information, etc.
- Agents make speech acts about and reason over these properties and relations.
- Grounded in an ontology represented in DAML

What is Distributed Trust

- Issues
  - No central authority
  - *logging in* is not possible
  - Access control for entities never encountered before

- We use *Distributed Trust* to solve these issues
- trust = policies + credentials + delegation actions + proofs of deontic properties

Three Scenarios

- Supply Chain Management System
  - ✓ Already implemented
- Dynamic Wireless Environment
  - ✓ Ongoing work
- Distributed Trust for Web Services
  - ✓ Future work
  - ✓ To be applied to ITTALKS (http://www.ittalks.org/)

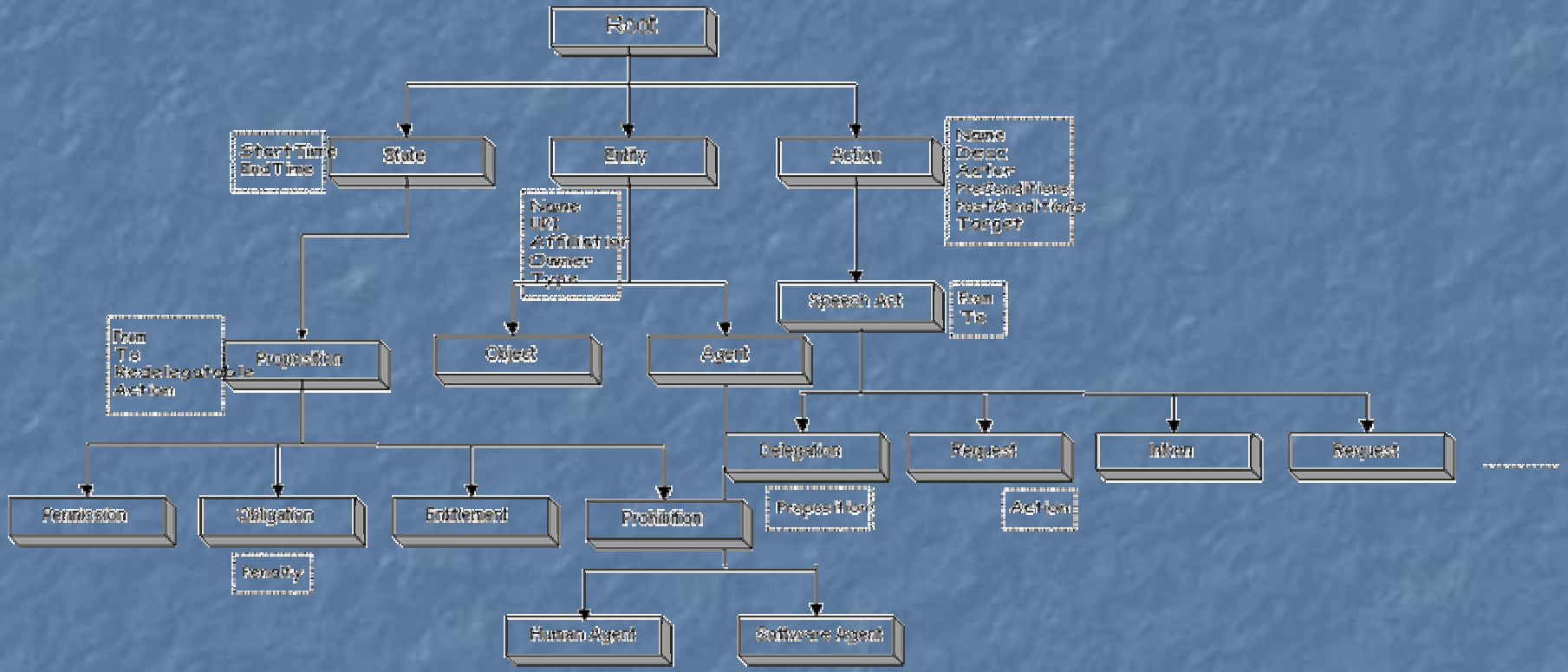
Distributed Belief

- A policy specified that "UMBC CSEE faculty are allowed to do X", but how do we determine who they are?
- Our dtrust language allows us to say

  "We accept http://www.csee.umbc.edu/faculty.html as a trusted source of information about membership in the class http://umbc.edu/ontologies/people#faculty"
- *faculty.html* has a human-readable faculty list (in HTML) and (possibly signed) statements (in DAML) asserting who the faculty are.
- Beliefs can be delegated as well

  "I delegate belief of phdAdvisee(X,Y) to X if X is a CSEE faculty member"

Dtrust Ontology

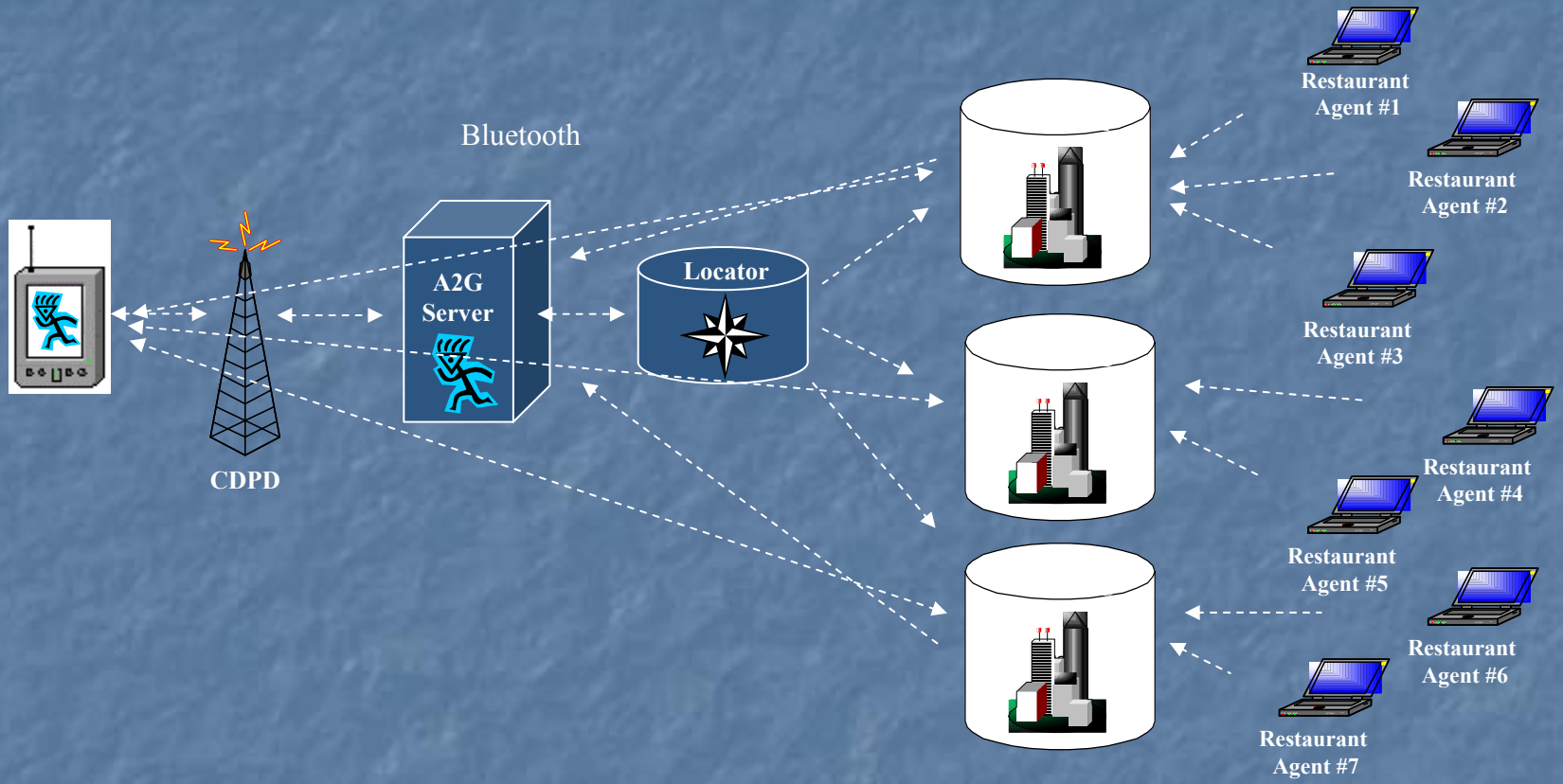


A DAML ontology for describing authorization and trust actions, states and policies.

(5) The Agents2Go Platform

- Location dependent services discovery
  - Location dependent information retrieval
  - The search results contain information about restaurants that are local to the requesting user.
- Distributed services
  - Distributed Information
  - Service information is distributed and grouped by regions.
  - Information about the restaurant is stored locally.
- Automatic location detection
  - Cell tower ids are mapped to the geographical region name.
- Service provider representation
  - Service Agents reside at the service provider locations.
  - Restaurant Agents reside at the restaurant locations.

The Agents2Go Infrastructure

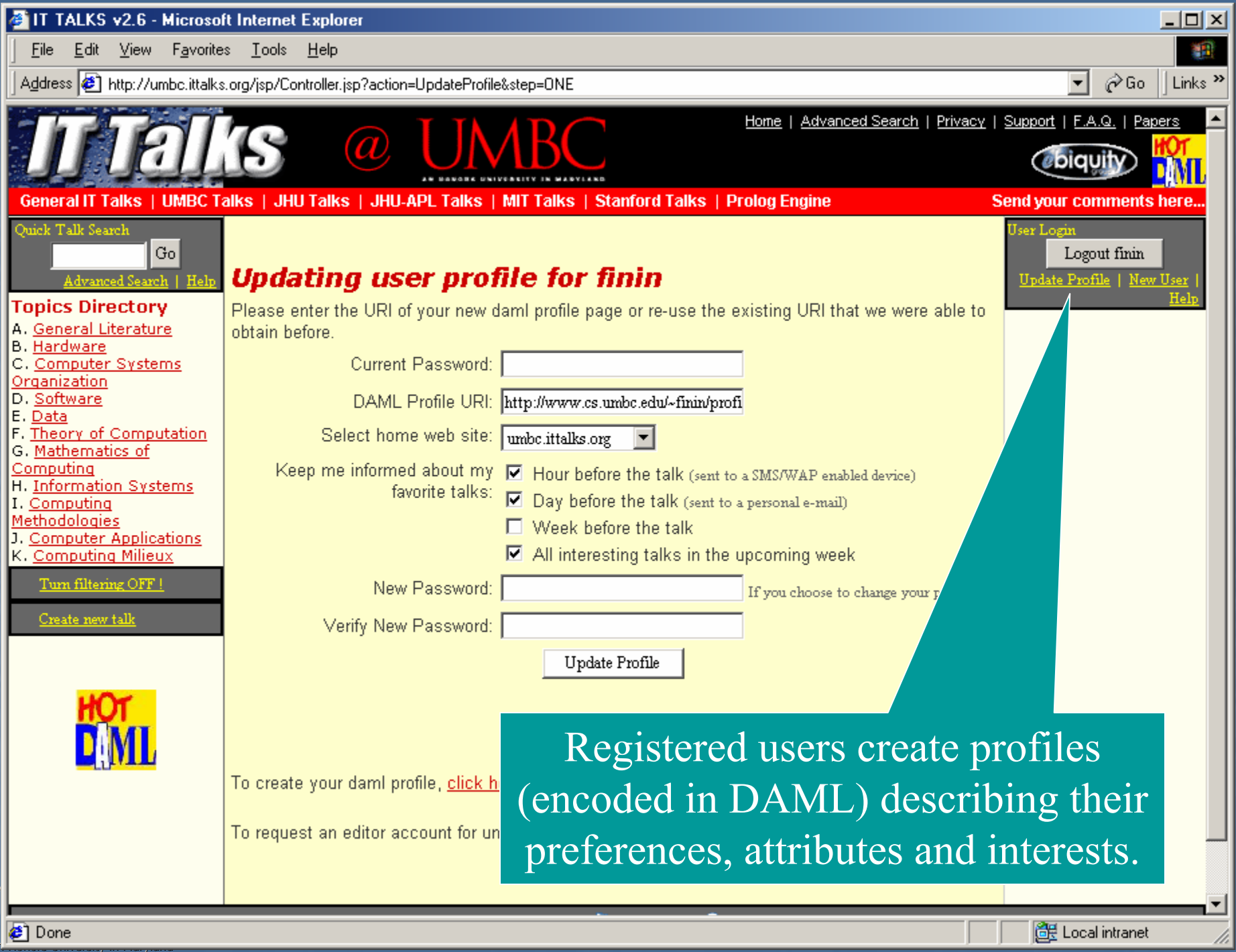


(6) ITTALKS

- **ITTALKS** is a database driven web site of IT related talks at UMBC and other institutions. The database contains information on
  - Seminar events
  - People (speakers, hosts, users,…)
  - Places (rooms, institutions,…)

http://ittalks.org/

- This database is used to dynamically generate web pages and DAML descriptions for the talks and related information.
- Notifications are sent to registered users and/or their agents via email, SMS, WAP, and/or KQML for talks matching their interests, location and schedule.


IT TALKS v2.6 - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://umbc.ittalks.org/jsp/Controller.jsp?action=UpdateProfile&step=ONE
Go Links
IT Talks @ UMBC
Home | Advanced Search | Privacy | Support | F.A.Q. | Papers
ebiquity
HOT DAML
General IT Talks | UMBC Talks | JHU Talks | JHU-APL Talks | MIT Talks | Stanford Talks | Prolog Engine
Send your comments here...
Quick Talk Search
Go
Advanced Search | Help
Topics Directory
A. General Literature
B. Hardware
C. Computer Systems Organization
D. Software
E. Data
F. Theory of Computation
G. Mathematics of Computing
H. Information Systems
I. Computing Methodologies
J. Computer Applications
K. Computing Milieux
Turn filtering OFF !
Create new talk
HOT DAML
Updating user profile for finin
Please enter the URI of your new daml profile page or re-use the existing URI that we were able to obtain before.
Current Password:
DAML Profile URI: http://www.cs.umbc.edu/~finin/profi
Select home web site: umbc.ittalks.org
Keep me informed about my favorite talks:
Hour before the talk (sent to a SMS/WAP enabled device)
Day before the talk (sent to a personal e-mail)
Week before the talk
All interesting talks in the upcoming week
New Password:
If you choose to change your p
Verify New Password:
Update Profile
To create your daml profile, click h
To request an editor account for un
User Login
Logout finin
Update Profile | New User | Help
Registered users create profiles (encoded in DAML) describing their preferences, attributes and interests.
Done
Local intranet

IT TALKS v2.6 - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://umbc.ittalks.org/jsp/Controller.jsp?action=NextPage&page=3 Go Links

IT Talks @ UMBC

AN HONORS UNIVERSITY IN MARYLAND

Home | Advanced Search | Privacy | Support | F.A.Q. | Papers

ebiquity HOT DAML

General IT Talks | UMBC Talks | JHU Talks | JHU-APL Talks | MIT Talks | Stanford Talks | Prolog Engine

Send your comments here...

Quick Talk Search

Go

Advanced Search | Help

Welcome to IT Talks

This site is designed to be your single portal to the world of IT colloquia and seminars. ... Read more

HOT DAML

DOC Coo!a SYNC TO PALM

Click above to synchronise talk information to your palm.

Date	Talk Title	Speaker	Action
2001-02-14	The Face of the New Engineer	Eleanor Baum	View
2001-02-16	Fast, Low-Cost Checkpointing and Recovery Techniques for Mobile Computing Systems	Mukesh Singhal	View
2001-02-16	Visualization of Large Graph	Stephen Kobourov	View
2001-02-16	How to Build a Trusted Database System on Untrusted Storage	Bill Shapiro	View
2001-02-17	Acoustic-optical Phonetics and Audiovisual Speech Perception	Lynne Bernstein	View
2001-02-18	Impacts of Information Technology on Society	Anupam Joshi	View
2001-02-18	Impacts of Information Technology on Society	Jacob Slonim	View
2001-02-19	Noun Phrase Coreference for Information Extraction	Claire Claudie	View
2001-02-20	Electric Elves: Towards an Agent Facilitaed Human Organization	Milind Tambe	View
2001-02-22	Optimization of Stuffing Santa's Sack	James C. Spall	View

Page | 1 | 2 | <<< 3 >>> | 4 | 5 | 6

ACMTopic Expand Directory

User Login

User:

Passwd:

Login

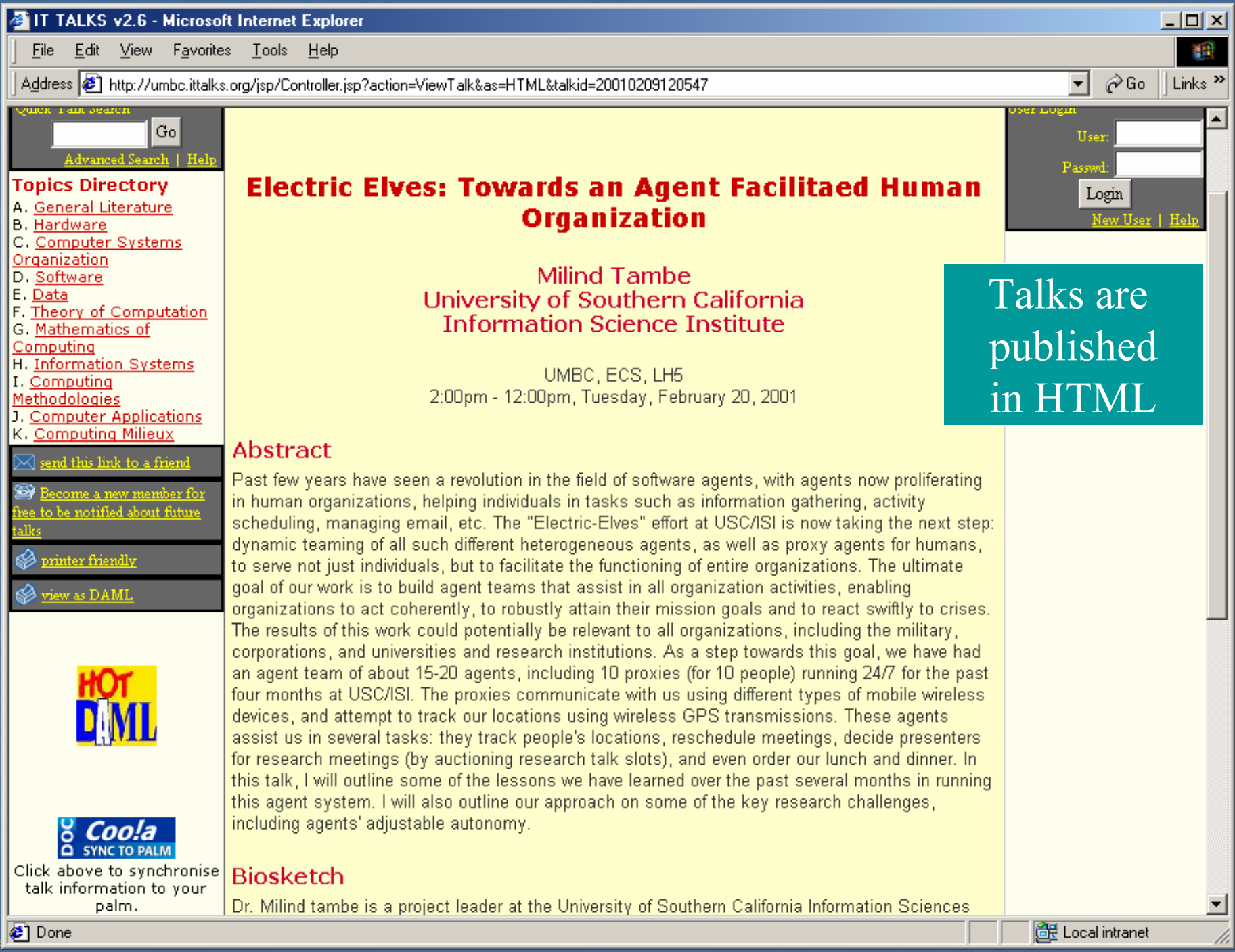
New User | Help

New Features

To read about our exciting new features, click here.

personalize | ? help

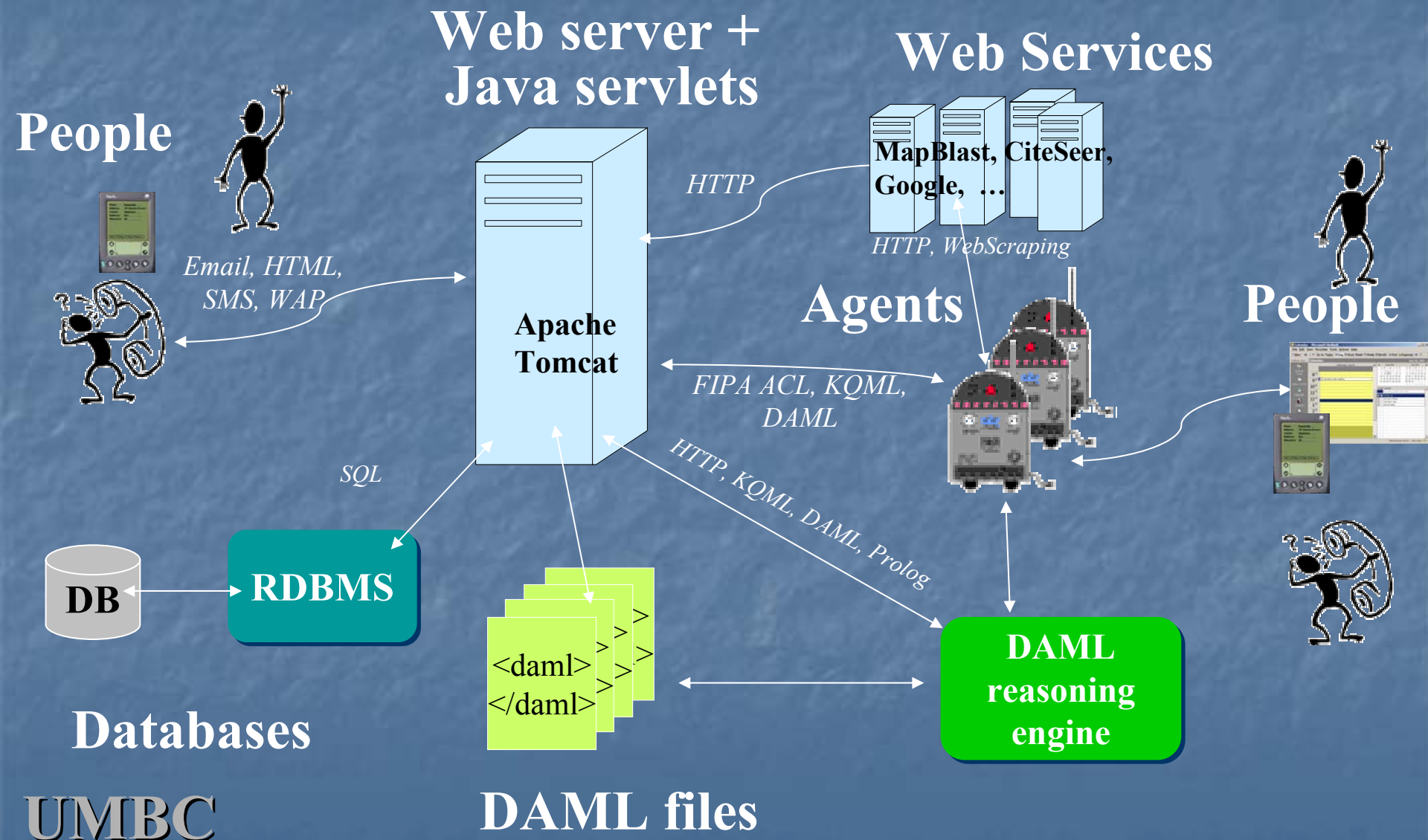
Done Local intranet


IT TALKS v2.6 - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://umbc.ittalks.org/jsp/Controller.jsp?action=ViewTalk&as=HTML&talkid=20010209120547
Go
Links
Go
Advanced Search | Help
Topics Directory
A. General Literature
B. Hardware
C. Computer Systems Organization
D. Software
E. Data
F. Theory of Computation
G. Mathematics of Computing
H. Information Systems
I. Computing Methodologies
J. Computer Applications
K. Computing Milieux
send this link to a friend
Become a new member for free to be notified about future talks
printer friendly
view as DAML
HOT DAML
Coo!a SYNC TO PALM
Click above to synchronise talk information to your palm.
User:
Passwd:
Login
New User | Help
Electric Elves: Towards an Agent Facilitaed Human Organization
Milind Tambe
University of Southern California
Information Science Institute
UMBC, ECS, LH5
2:00pm - 12:00pm, Tuesday, February 20, 2001
Abstract
Past few years have seen a revolution in the field of software agents, with agents now proliferating in human organizations, helping individuals in tasks such as information gathering, activity scheduling, managing email, etc. The "Electric-Elves" effort at USC/ISI is now taking the next step: dynamic teaming of all such different heterogeneous agents, as well as proxy agents for humans, to serve not just individuals, but to facilitate the functioning of entire organizations. The ultimate goal of our work is to build agent teams that assist in all organization activities, enabling organizations to act coherently, to robustly attain their mission goals and to react swiftly to crises. The results of this work could potentially be relevant to all organizations, including the military, corporations, and universities and research institutions. As a step towards this goal, we have had an agent team of about 15-20 agents, including 10 proxies (for 10 people) running 24/7 for the past four months at USC/ISI. The proxies communicate with us using different types of mobile wireless devices, and attempt to track our locations using wireless GPS transmissions. These agents assist us in several tasks: they track people's locations, reschedule meetings, decide presenters for research meetings (by auctioning research talk slots), and even order our lunch and dinner. In this talk, I will outline some of the lessons we have learned over the past several months in running this agent system. I will also outline our approach on some of the key research challenges, including agents' adjustable autonomy.
Biosketch
Dr. Milind tambe is a project leader at the University of Southern California Information Sciences
Talks are published in HTML
Done
Local intranet


http://umbc.ittalks.org/jsp/Controller.jsp?action=ViewTalk&as=DAML&talkid=20010209120547 - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://umbc.ittalks.org/jsp/Controller.jsp?action=ViewTalk&as=DAML&talkid=20010209120547
Go
<?xml version="1.0" ?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:daml="http://www.daml.org/2000/10/daml-ont#"
xmlns="http://daml.umbc.edu/ontologies/talk-ont#"
xmlns:time="http://daml.umbc.edu/ontologies/calendar-ont#">
<rdf:Description about="http://umbc.ittalks.org/jsp/Controller.jsp?
action=ViewTalk&as=HTML&talkid=20010209120547">
<imports resource="" />
<Talk rdf:parseType="Resource">
<Title>Electric Elves: Towards an Agent Facilitaed Human Organization</Title>
<X-URI>http://umbc.ittalks.org/jsp/Controller.jsp?
action=ViewTalk&as=HTML&talkid=20010209120547</X-URI>
<DAML-URI>http://umbc.ittalks.org/jsp/Controller.jsp?
action=ViewTalk&as=DAML&talkid=20010209120547</DAML-URI>
<Abstract>Past few years have seen a revolution in the field of software agents, with agents now proliferating in human organizations, helping individuals in tasks such as information gathering, activity scheduling, managing email, etc. The "Electric-Elves" effort at USC/ISI is now taking the next step: dynamic teaming of all such different heterogeneous agents, as well as proxy agents for humans, to serve not just individuals, but to facilitate the functioning of entire organizations. The ultimate goal of our work is to build agent teams that assist in all organization activities, enabling organizations to act coherently, to robustly attain their mission goals and to react swiftly to crises. The results of this work could potentially be relevant to all organizations, including the military, corporations, and universities and research institutions. As a step towards this goal, we have had an agent team of about 15-20 agents, including 10 proxies (for 10 people) running 24/7 for the past four months at USC/ISI. The proxies communicate with us using different types of mobile wireless devices, and attempt to track our locations using wireless GPS transmissions. These agents assist us in several tasks: they track people's locations, reschedule meetings, decide presenters for research meetings (by auctioning research talk slots), and even order our lunch and dinner. In this talk, I will outline some of the
Internet

… and in DAML

ITTALKS Architecture



ITAALKS and agents current working prototype

ITTALKS app

mapquest

ITTALKS agent

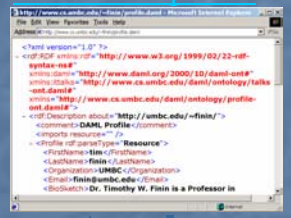
Travel agent

Communication protocol

KQML

API

user's daml profile



User agent

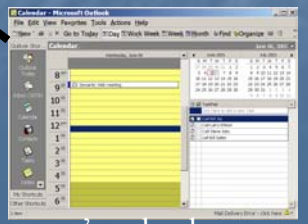
Calendar agent

DAML reasoning engine

Broker Agent

Agent Name Server

Common agent infrastructure



user's calendar app e.g. MS Outlook

DAML reasoner

Today's Conclusions

- Different mobile environments
- Rethinking agent communication
- How do we get there from here?
- Final thoughts

Current coordination infrastructure

- There are many current systems for service registration and coordination
  - UDDI at the internet level
  - Jini at a more local level
  - Bluetooth SDP
  - And others like eSpeak, Salutation, …
- All are characterized by their relatively inexpressive languages for describing services offered and sought.
- This is where the agents/AI/KR/SW communities have something to offer.

Rethinking the agent communication paradigm

- Much multi-agent systems work is grounded in Agent Communication Languages (e.g., KQML, FIPA) and associated software infrastructure.
- This paradigm was articulated ~1990, about the same time as the WWW was developed.
- Our MAS approach has not yet left the laboratory yet the Web has changed the world.
- Maybe we should try something different?

Rethinking the agent communication paradigm

- The communication MAS paradigm has been peer-to-peer message oriented communication mediated by brokers and facilitators.
- This approach was, I think, inherited from the dominant software paradigms at the time: client-server and OO systems.
- The semantic web invites different paradigms which will require some changes in ACLs and their associates software systems.

Rethinking the agent communication paradigm

- New paradigm?
  - Agents "publish" beliefs, requests, and other "speech acts" on web pages.
  - Brokers "search" for and "index" published content
  - Agents "discover" what peers have published on the web and browse for more details
  - Agents "speak for" content on web pages by
    - Answering queries about them
    - Accepting comments and assertions about them

Context aware computing

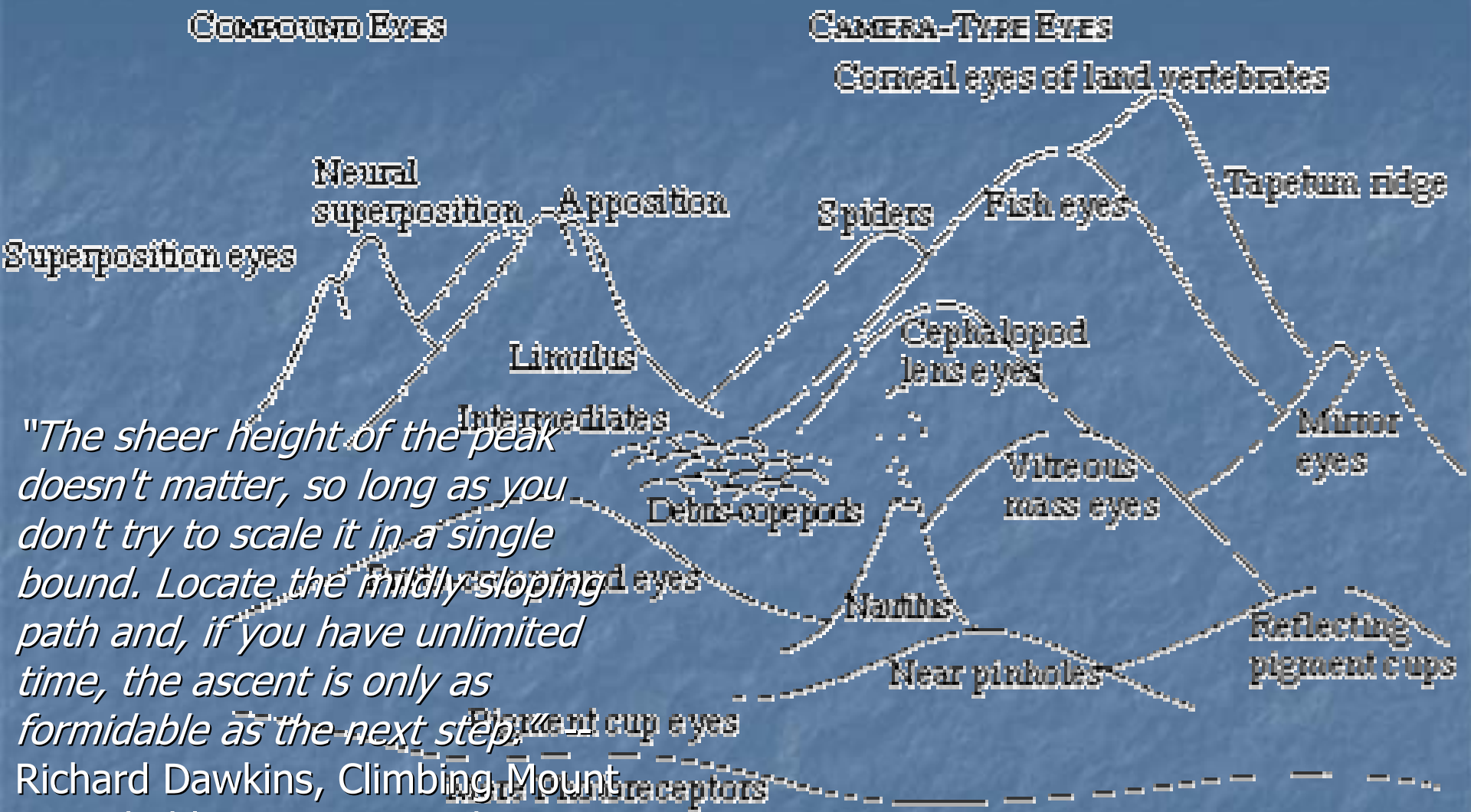
- An exciting general view of the new mobile/pervasive computing environment goes under the name of "context aware computing".
- This inherits from work in intelligent HCI
- The computing devices in our environment are aware of each other and also of the people and things in their vicinity.
- Awareness of people entails inferring their internal states and individual and joint activities.
- They "share information" to compile a common model of the context.

Context aware computing

- This is a promising area which can draw on lots of the things we know:
  - Interpreting sensor inputs
  - Sensor and data fusion
  - Abductive reasoning and belief revision
  - Machine learning
  - Plan recognition
  - User modeling
  - Using shared ontologies
  - Models of coordination and teamwork

How do we get there from here?

- It will take some time to really deliver on the agent paradigm, either on the Internet or in a pervasive computing environment.
- The development of complex systems is basically an evolutionary process.
- Random search carried out by tens of thousands of researchers, developers and graduate students.

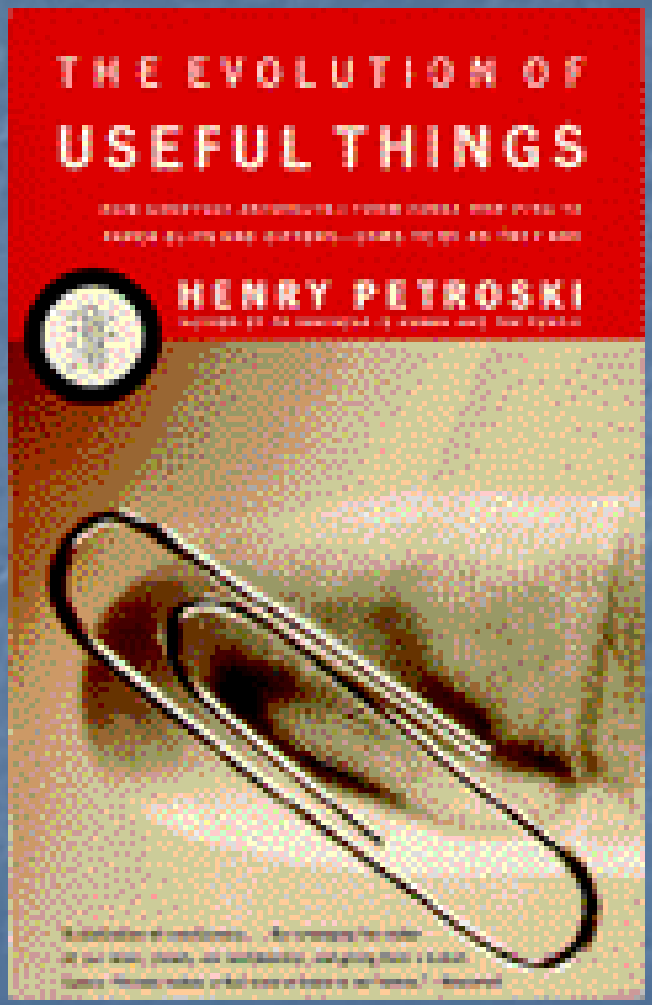


"The sheer height of the peak doesn't matter, so long as you don't try to scale it in a single bound. Locate the mildly sloping path and, if you have unlimited time, the ascent is only as formidable as the next step."

Richard Dawkins, Climbing Mount Improbable, Penguin Books, 1996.

Climbing Mount Improbable

The Evolution of Useful Things



- The Evolution of Useful Things, Henry Petroski, 1994.
- Prior to the 1890's, papers were held together with straight pens.
- The development of "spring steel" allowed the invention of the paper clip in 1899.
- It took about 25 years (!) for the evolution of the modern "gem paperclip", considered to be optimal for general use.

Final thoughts

- Agents and mobile computing may be a good marriage.
- The semantic web offers some ideas that may help realize the agent vision.
- As usual, only time will tell and all will be obvious in hindsight.
- See http://research.ebiquity.org/ for more information and papers on our work at UMBC.