DAML Ontologies for Agent-Enabled Web Services

Sheila A. McIlraith

Knowledge Systems Laboratory (KSL)
Department of Computer Science
Stanford University

(with Tran Cao Son and Honglei Zeng)
Background

The Web is evolving from a provider of documents and images …
... to a provider of **services**
Knowledge Rep’n for the “Semantic Web”

XML (Extensible Markup Language)

RDF (Resource Description Framework)

RDFS (RDF Schema)

DAML+OIL (Ontology)

DAML-L (Logic)

[Background]

[Fensel+others, 2000]
Overview of Our Work

Today’s Web is designed primarily for human use.

**Problem:** The Web is not computer-interpretable

→ Precludes easy automation of tasks

We are developing:

- **semantic markup** to enable automation by making service capabilities, user constraints & procedures *computer-interpretable & use-apparent.*

- **agent technology** that exploits semantic markup to support automated Web service *discovery, execution, composition and interoperation.*
Goal

Automation of:

• Web service discovery
  *Find me an airline service that offers flights to Tuktoyuktuk*
Req’d Markup: declarative advertisements

• Web service execution
  *Buy me “Harry Potter and the Sorcerer’s Stone” at www.amazon.com*
Req’d Markup: declarative API (inputs & outputs)

• Web service selection, composition and interoperation
  *Make the travel arrangements for my WWW10 conference*
Req’d Markup: declarative use spec. (preconditions & effects)
Goal

Automation of:

• Web service discovery
  Find me an airline service to Tuktoyuktuk
  Req’d Markup: declarative

• Web service execution
  Buy me “Harry Potter and the Sorcerer’s Stone” at www.amazon.com
  Req’d Markup: declarative API (inputs &)

• Web service selection, composition, interoperation
  Make the travel arrangements for my WWW10 conference
  Req’d Markup: declarative use spec. (preconditions & effects)
Semantic Markup: DAML-S

DAML-S**: A DARPA Agent Markup Language for Services

- AI-Inspired markup language for Web services:
  - well-defined semantics
  - ontologies support reuse, mapping, succinct markup, ...

- Developed by a coalition of researchers from Stanford, SRI, CMU, BBN, and Nokia, under the auspices of DARPA.

- Pre-release of DAML-S version 0.5 scheduled for June, 2001

- Watch [http://www.daml.org/services/daml-s](http://www.daml.org/services/daml-s) for details

** (initiated 02/2001 following independent research efforts)
Layered Language Development

XML (Extensible Markup Language)

RDF (Resource Description Framework)

RDFS (RDF Schema)

DAML+OIL (Ontology)

DAML-S (Services)

DAML-L (Logic)

DAML-SL

[Fensel+others, 2000]
Semantic Markup of Web Services

Each Web site provides a set of services
  • information providing (e.g., flight schedules, camera views) &/or
  • world-altering (e.g., flight booking, home temp. adjustment)

Web service sites are annotated with DAML markup.

Service described as processes (sequence, if-then-else, while, iteration, ...) of
  • inputs & outputs (function metaphor)
  • preconditions & effects (action metaphor)
Function/Dataflow Metaphor

Input:
- customer name
- flight number
- credit card
- ...

www.acmeair.com
book flight service

Output:
- confirmation no.
- ...

flight available
+ valid credit card

- failure notification
- ...

Y
?
N
AI-inspired Action/Process Metaphor

Input:
- customer name
- flight number
- credit card
- ...

Preconditions:
- knowledge of the input
- own credit card
- ...

www.acmeair.com
book flight service

Effect:
- flight available + valid credit card
  - Y
  - N
  - ?

Output:
- failure notification
- ...

Effect:
- ticket purchased
- credit card debited
- ...

Effect:
- <no effect>
Web Services Markup Exploits Ontologies

Ontologies support sharing, reuse, succinct markup:

- **purchase**
  - `<input>` customer-name `</input>`
  - `<precond>` know(customer-name) `</precond>`

- **purchase-plane-ticket**
  - `<input>` flight-no `</input>`
  - `<input>` credit-card `</input>`
  - `<precond>` know(flight-no) `</precond>`
  - `<precond>` own(credit-card) `</precond>`

- **purchase-UAL-plane-ticket**
  - `<effect>` purchase(ticket) `</effect>`
  - `<effect>` debit(credit-card) `</effect>` ...

Collectively markup create a distributed KB of services.
Semantic Web Services

PDDL-like
- parameters
- input
- (conditional) output
- preconditions
- (conditional) effects within a process model
Objective

Problem: Automated Web Service Composition
E.g., Make the travel arrangements for my IJCAI’01 conference

Approach:
I. Plan a sequences of services that realize user’s objective.
   (NP complete or worse)

II. Customize reusable generic procedures
    - Define and archive reusable generic procedures
    - Customize with user’s constraints.
      (NP complete or worse in a reduced search space)

Advantages: efficiency, ease of use, customization
Generic Procedures

Desiderata for Generic Procedures

**Generic:** High degree of non-determinism to accommodate customization.

**Customizable:** Easily customizable by individual users.

**(Re)Usable:** Usable by agents w/ different levels of knowledge

⇒ *Self-sufficient* wrt required knowledge.

Claim:

Golog is natural formalism for creating generic procedures
Realizing Generic Procedures in Golog

Situation Calculus [McCarthy, 68] +
Golog [Levesque et al, 97] procedural constructs:
  • sequencing
  • if-then-else
  • nondeterministic choice
  • while-do, etc.

E.g.,
Book-travel(origin,dest,date-d,date-r,purpose)
  pick-one-of
    Book-plane(origin,dest) | Drive(origin,dest) | Book-train(origin,dest)
  end pick;
end
Customizing User Constraints

Generic procedures can be further constrained by DAML-defined user constraints

- personal constraints/preferences,
- group constraints, or
- instance-specific constraints.

E.g.,
- Bob would like to drive if the driving distance is less than 3 hours.
- KSL business air travel should be on an American carrier.

...
Deductive Instantiation

Web Services Model & User Constraints (Situation Calculus + State Constraints) + Generic Procedure (Golog)

Model-Based Program

nondeterministic ✓ constrains search

spectrum

theorem proving

Sequence of Web Services

deterministic ✓ eliminates search
Architecture

Web Procedures Ontologies ↔ Web Service Ontologies

DAML-enabled personal/company constraints and prefs

Agent Broker

E-mail...

DAML-enabled web pages
How it Works

Agent’s **KB is automatically constructed** relative to the generic procedure and user constraints.

**Deductive machinery** instantiates the generic procedure wrt. constraints and world state to generate Web service requests that the **agent broker** executes.

Middle ground interpreter balances information gathering services with delayed execution of world-altering services.

Agent’s KB is updated by Web service responses.
Properties of Our System

Logical-based approach enables us to enforce and/or prove properties of our system:
- safety constraints
- goal achievement
- maintenance constraints

Implementation of middle ground interpreter is sound & complete with respect to logical specification.

Characterization of classes of procedures that are knowledge self-sufficient. Proved properties wrt execution termination.
Status

- DAML = First-order logic and some DAML+OIL (soon to be DAML-S)
- Agent KB representation language = Situation Calculus
- Generic procedures representation language = Golog
- Deductive machinery = ConGolog interpreter written in Prolog
- Agent Broker = Open Agent Architecture [SRI]
- Web Service output = HTML + W4 info extraction (eventually DAML)
- Prototype agent/agent broker constructed.
- Preliminary service ontology constructed.
Demo: Dynamic UI with DAML+OIL

Knowledge Systems Laboratory
Stanford University

Welcome to the KSL DAML-markup agents page.

Please select User and Task. Click Submit if you would like to execute an agent associated with Task. Click Reset to cancel your choices. Click Back to go back to your previous page.

User: Son Cao Tran
Task: BookMeeting

Submit  Reset
Behind the Scenes

```
?- travel('Bob Chen','09/02/00','09/06/00','San Francisco','Monterey','DAML').

Contacting Web Service Broker:
  Request Driving Time [San Francisco] - [Monterey]
Result 2

Contacting Web Service Broker:
  Request Car Info in [San Francisco]
Result
  HERTZ Shuttle to Car Counter Economy Car Automatic...
  ACE Off Airport, Shuttle Provided Economy Car Autom...
  NATIONAL Shuttle to Car Counter Economy Car Autom...
  FOX Off Airport, Shuttle Provided Mini Car Autom...
  PAYLESS Off Airport, Shuttle Provided Mini Car Autom...
  ALL INTL Off Airport, Shuttle Provided Economy Car...
  HOLIDAY Off Airport, Shuttle Provided Economy Car...
  ABLE RENT Off Airport, Shuttle Provided Compact C...

Select
  HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

Contacting Web Service Broker:
  Request Hotel Info in [Monterey]
Result
  Travelodge Monterey, CA 55 Rooms / 2 Floors No...
  Econolodges MONTEREY, CA 47 Rooms / 2 Floors 1...
  Lexington Services Monterey, CA 52 Rooms Not A...
  Ramada Inns Monterey, CA 47 Rooms Not Available...
  Best Western Intl Monterey, CA 43 Rooms / 3 Floo...
  Motel 6 Monterey, CA 52 Rooms / 2 Floors Not A...
  Villager Lodge Monterey, CA 55 Rooms / 2 Floors...
  Best Western Intl Monterey, CA 34 Rooms / 2 Floo...
```
Behind the Scenes

| ?- travel('Bob Chen','09/02/00','09/06/00','San Francisco','Monterey','DAML'). |
| Contacting Web Service Broker: |
| Request Driving Time [San Francisco] - [Monterey] |
| Result 2 |
| Contacting Web Service Broker: |
| Request Car Info in [San Francisco] |
| Result |
| <B>HERTZ</B> Shuttle to Car Counter | <B>Economy Car Automatic...</B> |
| <B>ACE</B> Off Airport, Shuttle Provided | <B>Economy Car Automatic...</B> |
| <B>NATIONAL</B> Shuttle to Car Counter | <B>Economy Car Automatic...</B> |
| <B>FOX</B> Off Airport, Shuttle Provided | <B>Mini Car Automatic...</B> |
| <B>PAYLESS</B> Off Airport, Shuttle Provided | <B>Mini Car Automatic...</B> |
| <B>ALL INTL</B> Off Airport, Shuttle Provided | <B>Economy Car...</B> |
| <B>HOLIDAY</B> Off Airport, Shuttle Provided | <B>Economy Car...</B> |
| <B>ABLE RENT</B> Off Airport, Shuttle Provided | <B>Compact Car...</B> |

Select |
| HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage |

Contacting Web Service Broker: |
| Request Hotel Info in [Monterey] |
| Result |
| <B>Travelodge</B> Monterey, CA | <B>55 Rooms / 2 Floors</B>No... |
| <B>Econolodges</B> MONTEREY, CA | <B>47 Rooms / 2 Floors</B> 1... |
| <B>Lexington Services</B> Monterey, CA | <B>52 Rooms</B> Not A... |
| <B>Ramada Inns</B> Monterey, CA | <B>47 Rooms</B> Not Available... |
| <B>Best Western Intl</B> Monterey, CA | <B>43 Rooms / 3 Floors</B>... |
| <B>Motel 6</B> Monterey, CA | <B>52 Rooms / 2 Floors</B> Not A... |
| <B>Villager Lodge</B> Monterey, CA | <B>55 Rooms / 2 Floors</B>... |
| <B>Best Western Intl</B> Monterey, CA | <B>34 Rooms / 2 Floors</B>... |
Behind the Scenes

| ?. travel('Bob Chen', '09/02/00', '09/06/00', 'San Francisco', 'Monterey', 'DAML').
| Contacting Web Service Broker:
| Request Driving Time [San Francisco] - [Monterey]
| Result 2

| Contacting Web Service Broker:
| Request Car Info in [San Francisco]
| Result
| <B>HERTZ</B> Shuttle to Car Counter <B>Economy Car Automatic</B>
| <B>ACE</B> Off Airport, Shuttle Provided <B>Economy Car Automatic</B>
| <B>NATIONAL</B> Shuttle to Car Counter <B>Economy Car Automatic</B>
| <B>FOX</B> Off Airport, Shuttle Provided <B>Mini Car Automatic</B>
| <B>PAYLESS</B> Off Airport, Shuttle Provided <B>Mini Car Automatic</B>
| <B>ALL INTL</B> Off Airport, Shuttle Provided <B>Economy Car Automatic</B>
| <B>HOLIDAY</B> Off Airport, Shuttle Provided <B>Economy Car Automatic</B>
| <B>ABLE RENT</B> Off Airport, Shuttle Provided <B>Compact Car Automatic</B>

| Select
| HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

| Contacting Web Service Broker:
| Request Hotel Info in [Monterey]
| Result
| <B>Travelodge</B> Monterey, CA <B>55 Rooms / 2 Floors</B> No...
| <B>Econolodges</B> MONTEREY, CA <B>47 Rooms / 2 Floors</B> 1...
| <B>Lexington Services</B> Monterey, CA <B>52 Rooms</B> Not A...
| <B>Ramada Inns</B> Monterey, CA <B>47 Rooms</B> Not Available...
| <B>Best Western Intl</B> Monterey, CA <B>43 Rooms / 3 Floors</B>...
| <B>Motel 6</B> Monterey, CA <B>52 Rooms / 2 Floors</B> Not A...
| <B>Villager Lodge</B> Monterey, CA <B>55 Rooms / 2 Floors</B>...
| <B>Best Western Intl</B> Monterey, CA <B>34 Rooms / 2 Floors</B>...
Behind the Scenes

| ?- travel('Bob Chen', '09/02/00', '09/06/00', 'San Francisco', 'Monterey', 'DAML').
| Contacting Web Service Broker:
|   Request Driving Time [San Francisco] - [Monterey]
| Result 2

| Contacting Web Service Broker:
|   Request Car Info in [San Francisco]

   - HERTZ: Shuttle to Car Counter, Economy Car Automatic...
   - ACE: Off Airport, Shuttle Provided, Economy Car Automatic...
   - NATIONAL: Shuttle to Car Counter, Economy Car Automatic...
   - FOX: Off Airport, Shuttle Provided, Mini Car Automatic...
   - PAYLESS: Off Airport, Shuttle Provided, Mini Car Automatic...
   - ALL INTL: Off Airport, Shuttle Provided, Economy Car Automatic...
   - HOLIDAY: Off Airport, Shuttle Provided, Economy Car Automatic...
   - ABLE RENT: Off Airport, Shuttle Provided, Compact Car Automatic...

| Select
| HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

| Contacting Web Service Broker:
|   Request Hotel Info in [Monterey]
| Result

   - Travelodge, CA: 55 Rooms / 2 Floors
   - Econolodges, MONTEREY, CA: 47 Rooms / 2 Floors
   - Lexington Services, Monterey, CA: 52 Rooms
   - Ramada Inns, Monterey, CA: 47 Rooms
   - Best Western Intl, Monterey, CA: 43 Rooms / 3 Floors
   - Motel 6, Monterey, CA: 52 Rooms / 2 Floors
   - Villager Lodge, Monterey, CA: 55 Rooms / 2 Floors
   - Best Western Intl, Monterey, CA: 34 Rooms / 2 Floors
Behind the Scenes

Contacting Web Service Broker:
Request Driving Time [San Francisco] - [Monterey]
Result 2

Contacting Web Service Broker:
Request Car Info in [San Francisco]
Result
<B>HERTZ</B> Shuttle to Car Counter</B>Economy Car Automatic...
<B>ACE</B> Off Airport, Shuttle Provided</B>Economy Car Automatic...
<B>NATIONAL</B> Shuttle to Car Counter</B>Economy Car Automatic...
<B>FOX</B> Off Airport, Shuttle Provided</B>Mini Car Automatic...
<B>PAYLESS</B> Off Airport, Shuttle Provided</B>Mini Car Automatic...
<B>ALL INTL</B> Off Airport, Shuttle Provided</B>Economy Car...
<B>HOLIDAY</B> Off Airport, Shuttle Provided</B>Economy Car...
<B>ABLE RENT</B> Off Airport, Shuttle Provided</B>Compact Car...

Select
HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

Contacting Web Service Broker:
Request Hotel Info in [Monterey]
Result
<B>Travelodge</B> Monterey, CA</B>55 Rooms / 2 Floors</B>No...
<B>Econolodges</B> MONTEREY, CA</B>47 Rooms / 2 Floors</B> 1...
<B>Lexington Services</B> Monterey, CA</B>52 Rooms</B> Not A...
<B>Ramada Inns</B> Monterey, CA</B>47 Rooms</B> Not Available...
<B>Best Western Intl</B> Monterey, CA</B>43 Rooms / 3 Floors...
<B>Hotel 6</B> Monterey, CA</B>52 Rooms / 2 Floors</B> Not A...
<B>Villager Lodge</B> Monterey, CA</B>55 Rooms / 2 Floors...
<B>Best Western Intl</B> Monterey, CA</B>34 Rooms / 2 Floors...
Behind the Scenes

```
| ?- travel('Bob Chen','09/02/00','09/06/00','San Francisco','Monterey','DAML').

Contacting Web Service Broker:

  Request Driving Time [San Francisco] - [Monterey]

Result 2

Contacting Web Service Broker:

  Request Car Info in [San Francisco]

Result

  <B>HERTZ</B> Shuttle to Car Counter<Economy Car Automatic</B>
  <B>ACE</B> Off Airport, Shuttle Provided<Economy Car Automatic</B>
  <B>NATIONAL</B> Shuttle to Car Counter<Economy Car Automatic</B>
  <B>FOX</B> Off Airport, Shuttle Provided<Mini Car Automatic</B>
  <B>PAYLESS</B> Off Airport, Shuttle Provided<Mini Car Automatic</B>
  <B>ALL INTL</B> Off Airport, Shuttle Provided<Economy Car Automatic</B>
  <B>HOLIDAY</B> Off Airport, Shuttle Provided<Economy Car Automatic</B>
  <B>ABLE RENT</B> Off Airport, Shuttle Provided<Compact Car Automatic</B>

Select

  HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

Contacting Web Service Broker:

  Request Hotel Info in [Monterey]

Result

  <B>Travelodge</B> Monterey, CA <B>55 Rooms / 2 Floors</B>No...
  <B>EconoLodges</B> MONTEREY, CA <B>47 Rooms / 2 Floors</B> 1...
  <B>Lexington Services</B> Monterey, CA <B>52 Rooms</B>No A...
  <B>Ramada Inns</B> Monterey, CA <B>47 Rooms</B>No Available...
  <B>Best Western Intl</B> Monterey, CA <B>43 Rooms / 3 Floors</B>...
  <B>Motel 6</B> Monterey, CA <B>52 Rooms / 2 Floors</B>No A...
  <B>Villager Lodge</B> Monterey, CA <B>55 Rooms / 2 Floors</B>...
  <B>Best Western Intl</B> Monterey, CA <B>34 Rooms / 2 Floors</B>...```
Behind the Scenes

| ?- travel('Bob Chen', '09/02/00', '09/06/00', 'San Francisco', 'Monterey', 'DAML').
Contacting Web Service Broker:
  Request Driving Time [San Francisco] - [Monterey]
Result 2

Contacting Web Service Broker:
  Request Car Info in [San Francisco]
Result
  <B>HERTZ</B> Shuttle to Car Counter: <B>Economy Car Automatic</B>...
  <B>ACE</B> Off Airport, Shuttle Provided: <B>Economy Car Aut...</B>
  <B>NATIONAL</B> Shuttle to Car Counter: <B>Economy Car Autom...</B>
  <B>FOX</B> Off Airport, Shuttle Provided: <B>Mini Car Automa...</B>
  <B>PAYLESS</B> Off Airport, Shuttle Provided: <B>Mini Car Aut...</B>
  <B>ALL INTL</B> Off Airport, Shuttle Provided: <B>Economy Ca...</B>
  <B>HOLIDAY</B> Off Airport, Shuttle Provided: <B>Economy Car...</B>
  <B>ABLE RENT</B> Off Airport, Shuttle Provided: <B>Compact C...</B>

Select
  HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

Contacting Web Service Broker:
  Request Hotel Info in [Monterey]

  <B>Travelodge</B> Monterey, CA: <B>55 Rooms / 2 Floors</B> Not...
  <B>EconoLodges</B> MONTEREY, CA: <B>47 Rooms / 2 Floors</B> 1...
  <B>Lexington Services</B> Monterey, CA: <B>52 Rooms</B> Not A...
  <B>Ramada Inns</B> Monterey, CA: <B>47 Rooms</B> Not Available...
  <B>Best Western Intl</B> Monterey, CA: <B>43 Rooms / 3 Floo...</B>
  <B>Motel 6</B> Monterey, CA: <B>52 Rooms / 2 Floors</B> Not A...
  <B>Villager Lodge</B> Monterey, CA: <B>55 Rooms / 2 Floors</B>...
  <B>Best Western Intl</B> Monterey, CA: <B>34 Rooms / 2 Floo...</B>
Behind the Scenes

| ?- travel('Bob Chen', '09/02/00', '09/06/00', 'San Francisco', 'Monterey', 'DAML').
Contacting Web Service Broker:
  Request Driving Time [San Francisco] - [Monterey]
Result 2

Contacting Web Service Broker:
  Request Car Info in [San Francisco]
Result
  <B>HERTZ</B> Shuttle to Car Counter<br>Economy Car Automatic...
  <B>ACE</B> Off Airport, Shuttle Provided<br>Economy Car Automatic...
  <B>NATIONAL</B> Shuttle to Car Counter<br>Economy Car Automatic...
  <B>FOX</B> Off Airport, Shuttle Provided<br>Mini Car Automatic...
  <B>PAYLESS</B> Off Airport, Shuttle Provided<br>Mini Car Automatic...
  <B>ALL INTL</B> Off Airport, Shuttle Provided<br>Economy Car...
  <B>HOLIDAY</B> Off Airport, Shuttle Provided<br>Economy Car...
  <B>ABLE RENT</B> Off Airport, Shuttle Provided<br>Compact Car...

Select
  HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy Car Automatic with Air Conditioning, Unlimited Mileage

Contacting Web Service Broker:
  Request Hotel Info in [Monterey]
Result
  <B>Travelodge</B> Monterey, CA<br>55 Rooms / 2 Floors<br>No...
  <B>Econolodge</B> MONTEREY, CA<br>47 Rooms / 2 Floors<br>1...
  <B>Lexington Services</B> Monterey, CA<br>52 Rooms<br>No A...
  <B>Ramada Inns</B> Monterey, CA<br>47 Rooms<br>No Availability...
  <B>Best Western</B> Monterey, CA<br>43 Rooms / 3 Floors...
  <B>Motel 6</B> Monterey, CA<br>52 Rooms / 2 Floors<br>No A...
  <B>Villager Lodge</B> Monterey, CA<br>55 Rooms / 2 Floors...
  <B>Best Western</B> Monterey, CA<br>34 Rooms / 2 Floors...
Message 1:
From agent@stanford.edu Thu Aug 10 11:31:32 2000
Date: Thu, 10 Aug 2000 11:31:32 -0700 (PDT)
From: agent@stanford.edu
To: bob_chen@KSL.Stanford.EDU
Subject: Travel Arrangements

Dear Bob Chen,

Please find below the arrangements I have made for your trip:

Purpose of Trip: DAML
Date: [09/02/00] – [09/06/00]
Origin: [San Francisco]
Destination: [Monterey]

Rental Car Information:
ACE (San Francisco Airport), Location: Off Airport, Shuttle Provided, Economy Car Automatic with Air Conditioning, Unlimited Mileage
Daily Rate: 24.95

Accommodation:
Travelodge, Monterey, CA
Daily Rate: Not Available

It was a pleasure to serve you. Please let me know if you require any other assistance.

Your Personal Agent

PS: I have created an expense claim for your trip and have
Agent e-mails itinerary to customer

Message 1:
From agent@stanford.edu Thu Aug 10 11:31:32 2000
Date: Thu, 10 Aug 2000 11:31:32 -0700 (PDT)
From: agent@stanford.edu
To: bob_chen@KSL.Stanford.EDU
Subject: Travel Arrangements

Dear Bob Chen,

Please find below the arrangements I have made for your trip:

Purpose of Trip: DAHML
Date: [09/02/00] - [09/06/00]
Origin: [San Francisco]
Destination: [Monterey]

Rental Car Information:
  ACE (San Francisco Airport), Location: Off Airport, Shuttle Provided, Economy Car Automatic with Air Conditioning, Unlimited Mileage
  Daily Rate: 24.95

Accommodation:
  Travelodge, Monterey, CA
  Daily Rate: Not Available

It was a pleasure to serve you. Please let me know if you require any other assistance.

Your Personal Agent

PS: I have created an expense claim for your trip and have

---More---
Agent e-mails itinerary to customer

Message 1:
From agent@stanford.edu Thu Aug 10 11:31:32 2000
Date: Thu, 10 Aug 2000 11:31:32 -0700 (PDT)
From: agent@stanford.edu
To: bob_chen@KSL.Stanford.EDU
Subject: Travel Arrangements

Dear Bob Chen,

Please find below the arrangements I have made for your trip:

Purpose of Trip: DAML
Date: [09/02/00] – [09/06/00]
Origin: [San Francisco]
Destination: [Monterey]

Rental Car Information:
ACE (San Francisco Airport), Location: Off Airport, Shuttle Provided, Economy Car Automatic with Air Conditioning, Unlimited Mileage
Daily Rate: 24.95

Accommodation:
Travelodge, Monterey, CA
Daily Rate: Not Available

It was a pleasure to serve you. Please let me know if you require any other assistance.

Your Personal Agent

PS: I have created an expense claim for your trip and have

---More---
Agent e-mails itinerary to customer

```
Message 1:
From agent@stanford.edu Thu Aug 10 11:31:32 2000
Date: Thu, 10 Aug 2000 11:31:32 -0700 (PDT)
From: agent@stanford.edu
To: bob_chen@KSL.Stanford.EDU
Subject: Travel Arrangements

Dear Bob Chen,

Please find below the arrangements I have made for your trip:

Purpose of Trip: DAML
Date: [09/02/00] - [09/06/00]
Origin: [San Francisco]
Destination: [Monterey]

Rental Car Information:
ACE (San Francisco Airport), Location: Off Airport, Shuttle Provided, Economy Car Automatic with Air Conditioning, Unlimited Mileage
   Daily Rate: 24.95

Accommodation:
   Travelodge, Monterey, CA
   Daily Rate: Not Available

It was a pleasure to serve you. Please let me know if you require any other assistance.

Your Personal Agent

PS: I have created an expense claim for your trip and have
```
Agent e-mails itinerary to customer

Message 1:
From agent@stanford.edu Thu Aug 10 11:31:32 2000
Date: Thu, 10 Aug 2000 11:31:32 -0700 (PDT)
From: agent@stanford.edu
To: bob_chen@KSL.Stanford.EDU
Subject: Travel Arrangements

Dear Bob Chen,

Please find below the arrangements I have made for your trip:

Purpose of Trip: DAML
Date: [09/02/00] - [09/06/00]
Origin: [San Francisco]
Destination: [Monterey]

Rental Car Information:
ACE (San Francisco Airport), Location: Off Airport, Shuttle Provided, Economy Car Automatic with Air Conditioning, Unlimited Mileage
Daily Rate: 24.95

Accommodation:
Travelodge, Monterey, CA
Daily Rate: Not Available

It was a pleasure to serve you. Please let me know if you require any other assistance.

Your Personal Agent

PS: I have created an expense claim for your trip and have
Agent creates expense claim for customer

KSL Expense Claim Form

Traveler’s name: Bob Chen
Project to be billed: DAML
Destination: Monterey
Date of claim: 08/11/00
Dates of travel: From: 09/02/00 To: 09/06/00

Please submit receipts for all expenses over $25.

<table>
<thead>
<tr>
<th>Air Expenses</th>
<th>Airline</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No flights booked</td>
<td></td>
<td>$0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Taxi/Shuttle Expenses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$100</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rental Car</th>
<th>Daily Rate</th>
<th>Gas</th>
<th>Toll Charge</th>
<th>Parking</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$26.99</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$207.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lodging</th>
<th>Hotel Name</th>
<th>No. of Days</th>
<th>Daily Rate</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travelodge, Monterey, CA</td>
<td>4</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meals</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$0</td>
<td></td>
</tr>
</tbody>
</table>
Summary

1) DAML Markup of Web Services, User Constraints, Agent Procedures:
   • Computer-interpretable, use-apparent, agent-enabled services.
   • Ontologies facilitate construction, sharing, reuse, and composition; support succinct web site markup.
   • Markup not specific to particular agent implementation.

2) Agent Technology for Automated Web Service Composition:
   • Theme: usability and customization
   • Approach: Generic procedures and customizing user constraints
   • Deductive machinery instantiates procedures generating web service requests that are sent to the agent broker.
   • Procedures & deductive machinery provide middle ground between planning & programming.
   • Logic-based approach enables verification wrt. certain properties, soundness and completeness guarantees.
Related Work

Industrial Initiatives
- UDDI
- WSDL
- ebXML
- XLANG
- .Net, Biztalk, e-speak, etc.

Academic Research (incomplete)
- Golog variants [Levesque et al., 97], [de Giacomo & Levesque, 99]
- SRI work on Web services [Denker et al., 01], [Waldinger, 00]
- University of Washington softbot work [Etzioni et al., 94]
- IBROW3 [Benjamins et al., 98]
- Lark [Sycara et al., 99],
- Ubiquitous Computing [Weiser, 96], etc.
Want to Learn More?


**Papers:** [http://ksl.stanford.edu/people/sam/publications.html](http://ksl.stanford.edu/people/sam/publications.html)

**KSL’s DAML project:** [http://www.ksl.stanford.edu/Projects/DAML/](http://www.ksl.stanford.edu/Projects/DAML/)

**DAML-S:** [http://www.daml.org/services/daml-s/](http://www.daml.org/services/daml-s/)

**DAML Program:** [http://www.daml.org/](http://www.daml.org/)