DAML Ontologies for Agent-Enabled Web Services
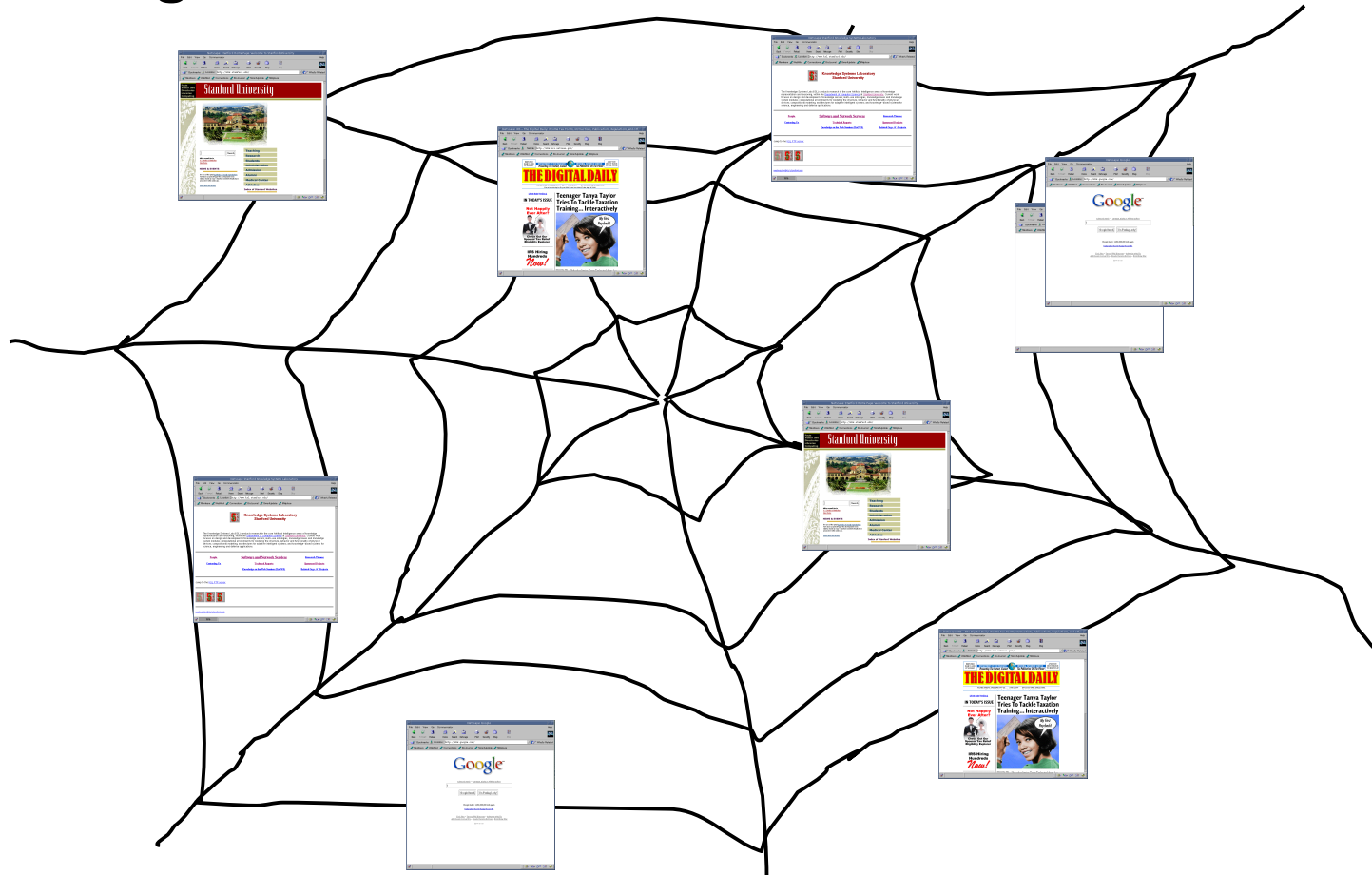
Sheila A. McIlraith

Knowledge Systems Laboratory (KSL)

Department of Computer Science
Stanford University
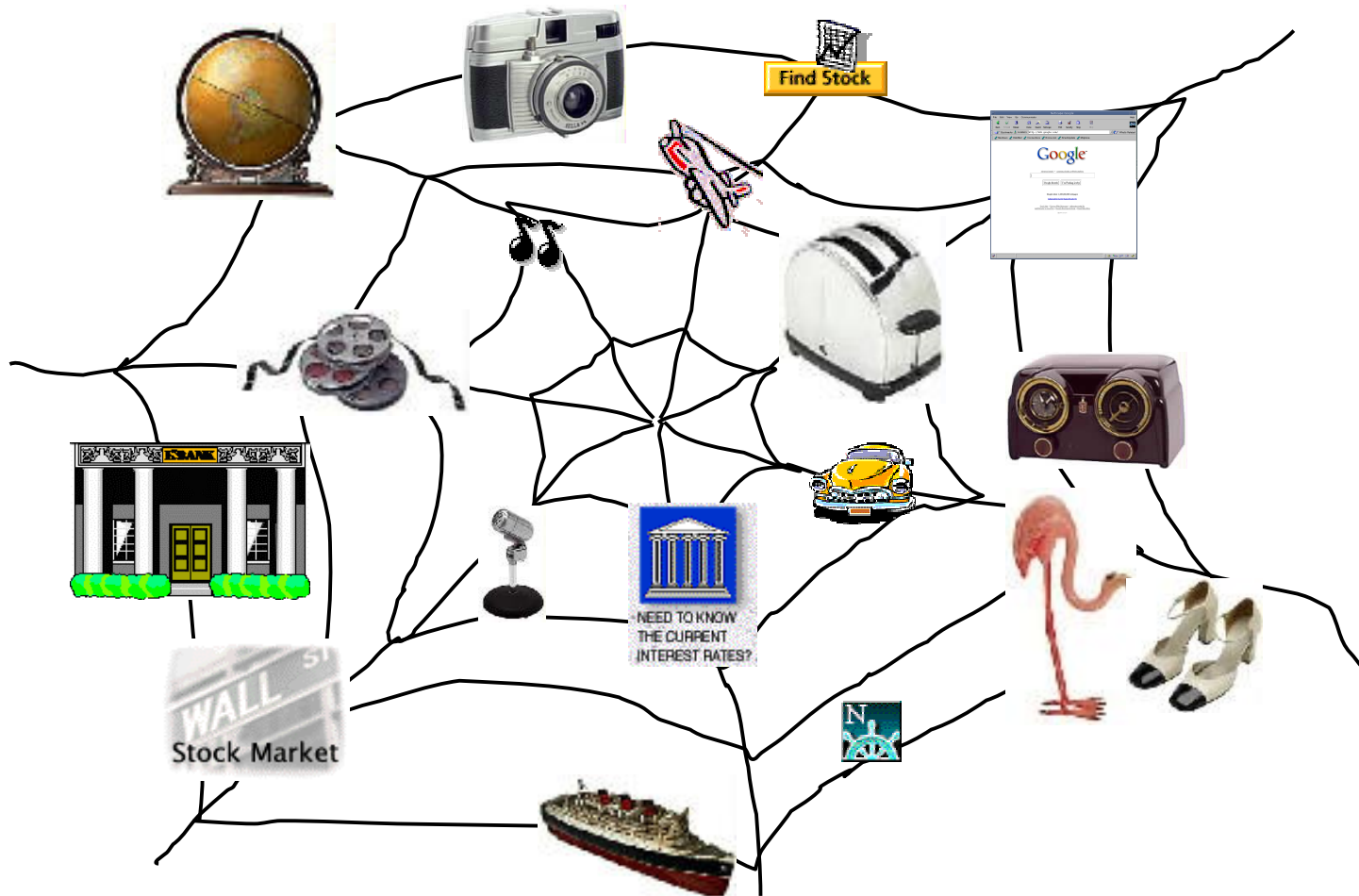
(withTran Cao Son and Honglei Zeng)

Background
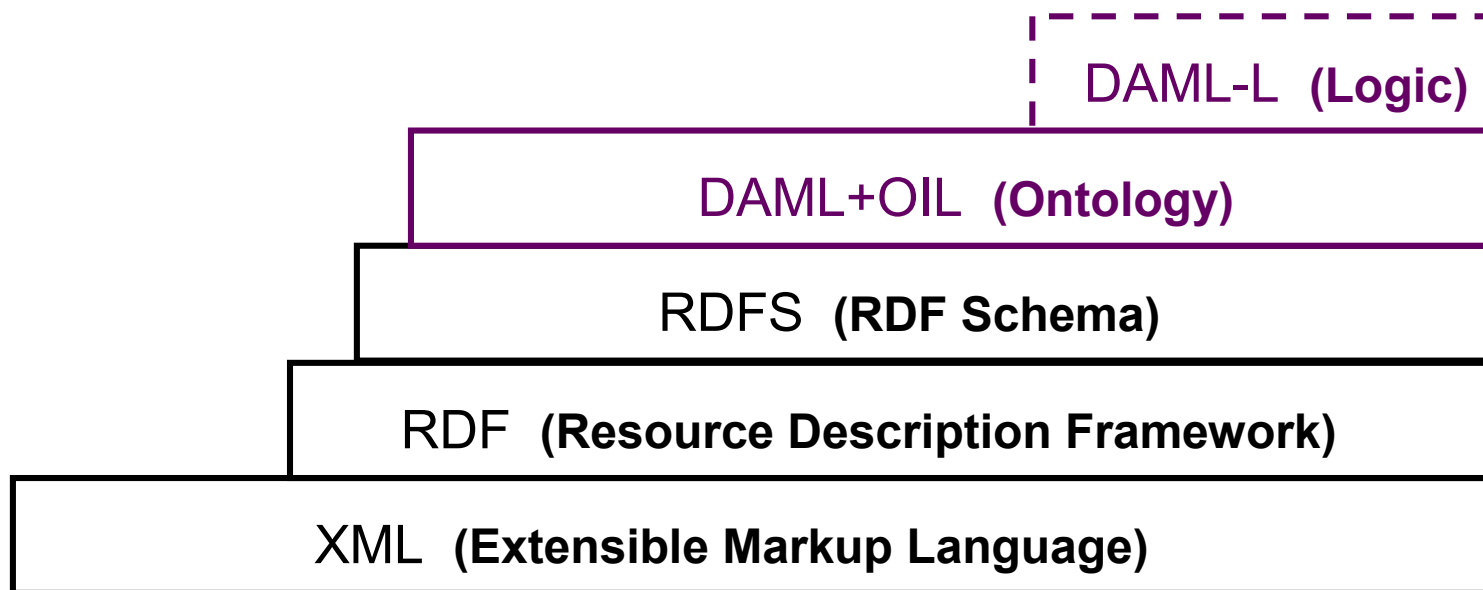
The Web is evolving from a provider of **documents and images …**

… to a provider of **services**

Knowledge Rep'n for the "Semantic Web"

DAML-L **(Logic)**

DAML+OIL **(Ontology)**

RDFS **(RDF Schema)**

RDF **(Resource Description Framework)**

XML **(Extensible Markup Language)**

[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 <u>discovery</u>

    Find me an airline service that offers flights to Tuktoyuktuk

    Req'd Markup: declarative advertisements

- Web service <u>execution</u>

    Buy me "Harry Potter and the Sorcerer's Stone" at www.amazon.com

    Req'd Markup: declarative API (inputs & outputs)

- Web service <u>selection</u>, <u>composition</u> and <u>interoperation</u>

    Make the travel arrangements for my WWW10 conference

    Req'd Markup: declarative use spec. (preconditions & effects)

Goal

Automation of:

- Web service <u>discovery</u>
  Find me an airline service t... ...o Tuktoyuktuk

  Req'd Markup: declara...

- Web service <u>execution</u>
  Buy me "Harry Potter ... ...orcerer's Stone" at www.amazon.com

  Req'd Markup: declarative API (inputs & ...

- Web service <u>selection</u>, <u>composition</u>, ...eration
  Make the travel arrangement... ...WWW10 conference

  Req'd Markup: declarative use spec. (preconditions & effects)

Industry efforts growing (we are improving with DAML)

Opportunity Area
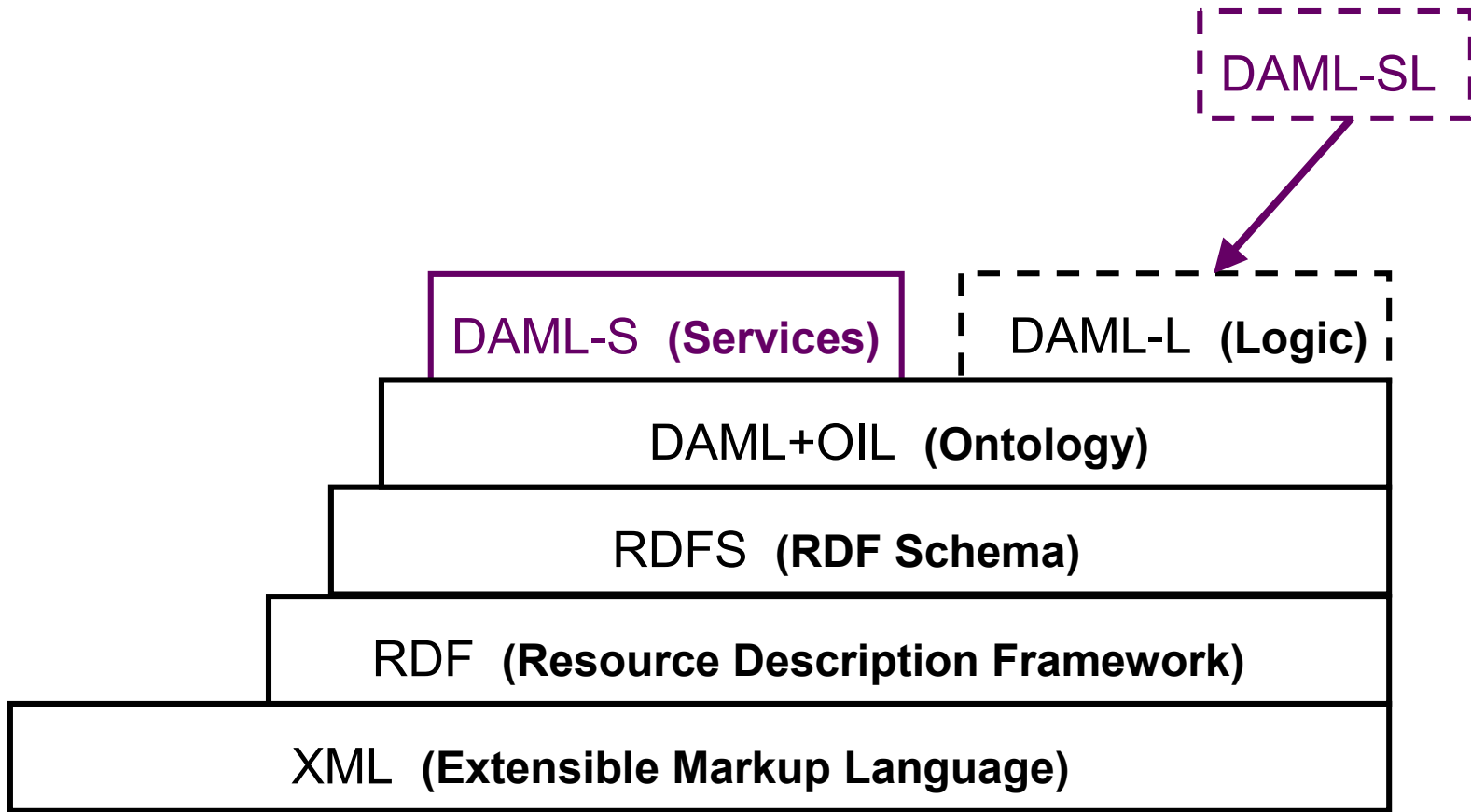
Semantic Markup: DAML-S

DAML-S[**]: A <u>D</u>ARPA <u>A</u>gent <u>M</u>arkup <u>L</u>anguage for <u>S</u>ervices

- 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 for details

 ** (initiated 02/2001 following independent research efforts)

Layered Language Development

DAML-SL

DAML-S **(Services)**   DAML-L **(Logic)**

DAML+OIL **(Ontology)**

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[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)
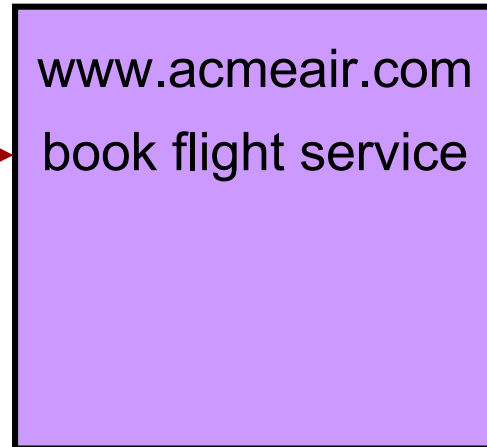
- preconditions & effects (**action** metaphor)
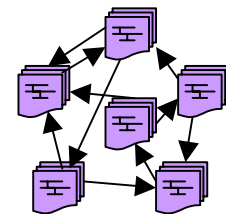
DAML-enabled web pages

Function/Dataflow Metaphor

Input:

Output:

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

www.acmeair.com

book flight service

**flight available
+
valid credit card**

?

Y

N

• confirmation no.
• ...

• failure notification
• …

AI-inspired Action/Process Metaphor

Output:
- confirmation no.
- ...

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

www.acmeair.com

book flight service

Preconditions:
- knowledge of the input
- own credit card
- ...
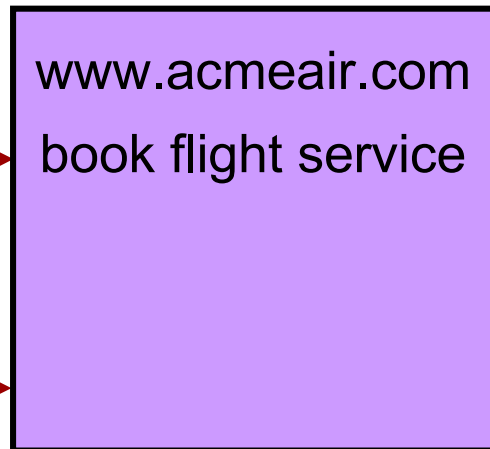
Effect:
- ticket purchased
- credit card debited
- ...

flight available + valid credit card

?

Y

N

Output:
- failure notification
- …

Effect:

Process of Processes

www.acmetravel.com
book travel service

- confirmation no.
- ...

- customer name
- location
- car type
- dates
- credit card no.
- ...

www.acmecar.com
book car service

?

- failure notification
- ...

- confirmation no.
- ...

- confirmation no.
- dates
- room type
- credit card no.
- ...

www.acmehotel.com
book hotel service

?

- confirmation no.
- ...

?

- failure notification
- ...

- customer name
- flight numbers
- dates
- credit card no.
- ...

www.acmeair.com
book flight service

?

- failure notification
- errror information
- ...
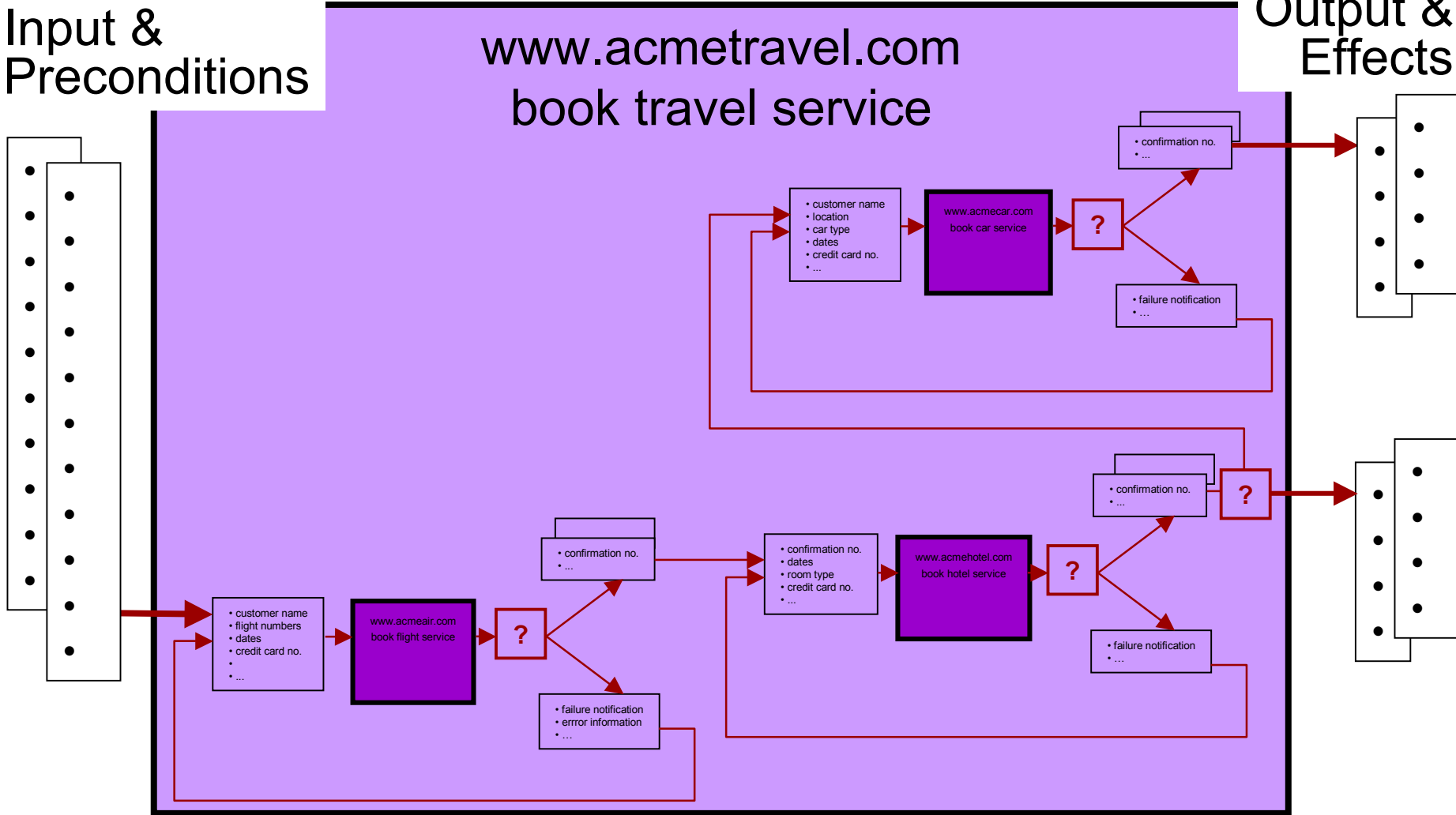
Web Services Markup Exploits Ontologies

Ontologies support sharing, reuse, succinct markup:

process

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> ...

Web Service Ontologies

DAML-enabled web pages
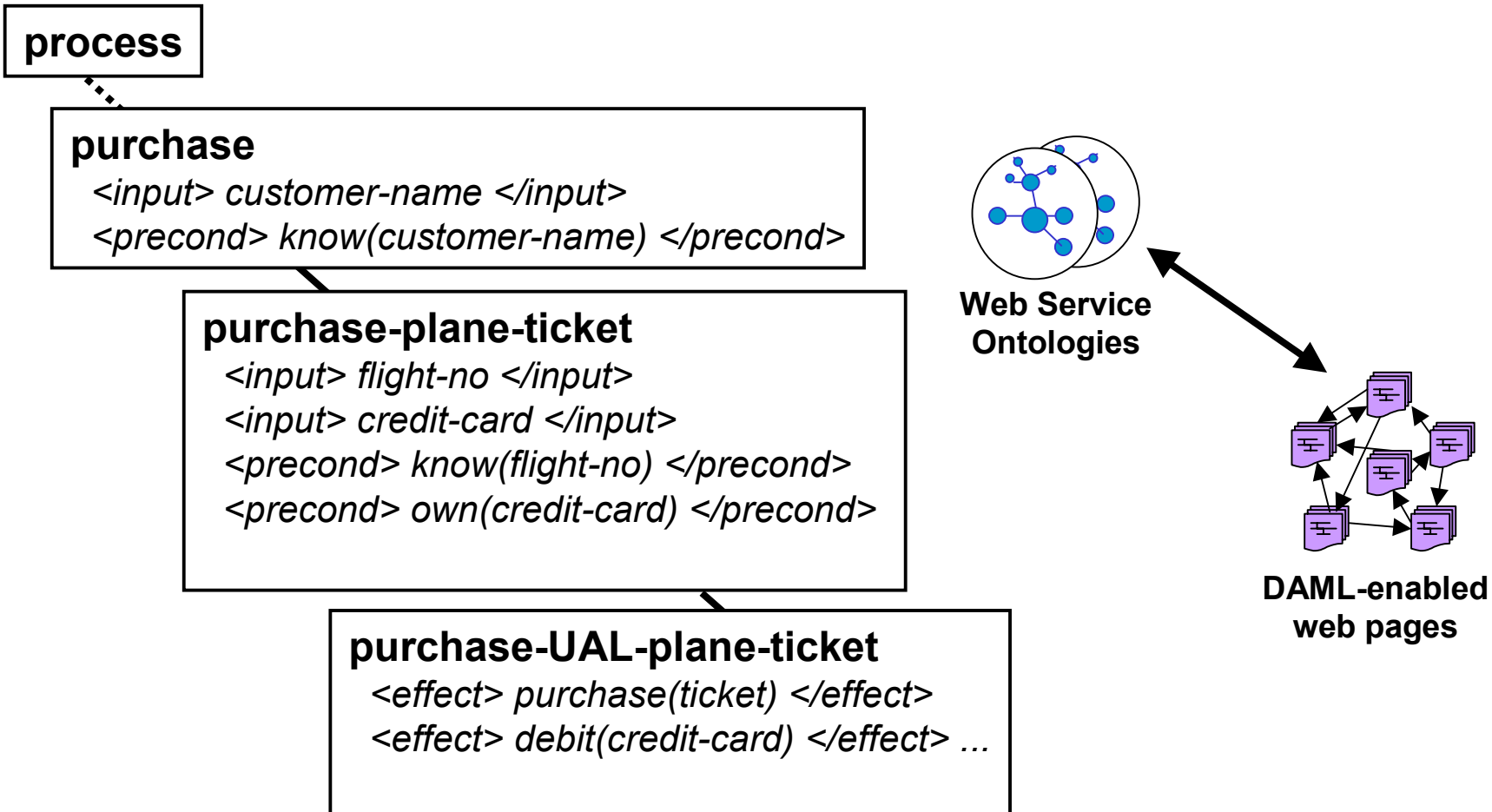
Collectively markup create a distributed KB of services.

Semantic Web Services

PDDL-like
- • parameters
- • input
- • (conditional) output
- • preconditions
- • (conditional) effects

within a process model

DAML
DAML
DAML
DAML
DAML
DAML
DAML
DAML
DAML
DAML
DAML
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DAML
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DAML
DAML
DAML
DAML

Find St

NEED TO KNOW THE CURRENT INTEREST RATES?

Stock Market
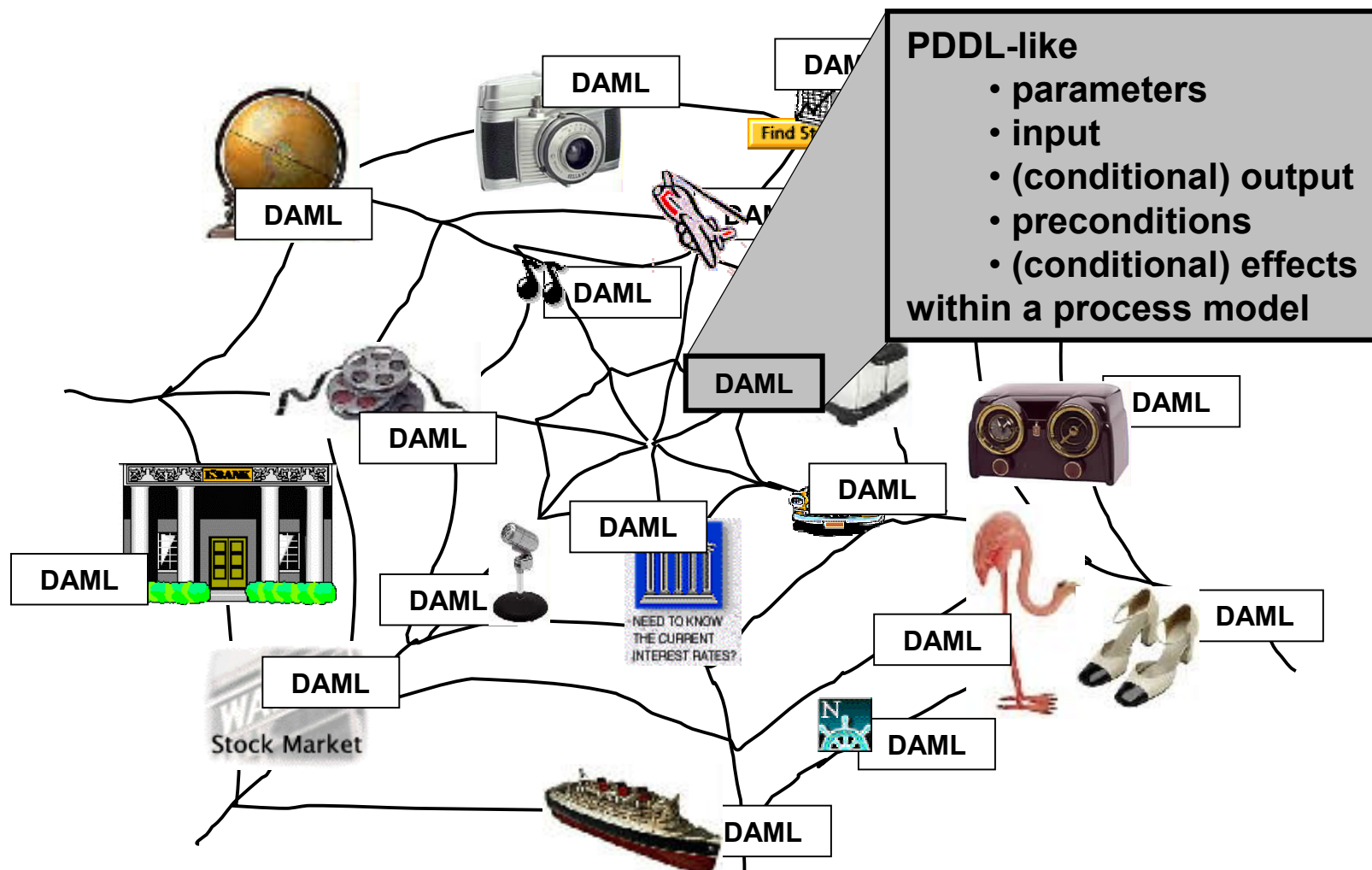
Objective

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

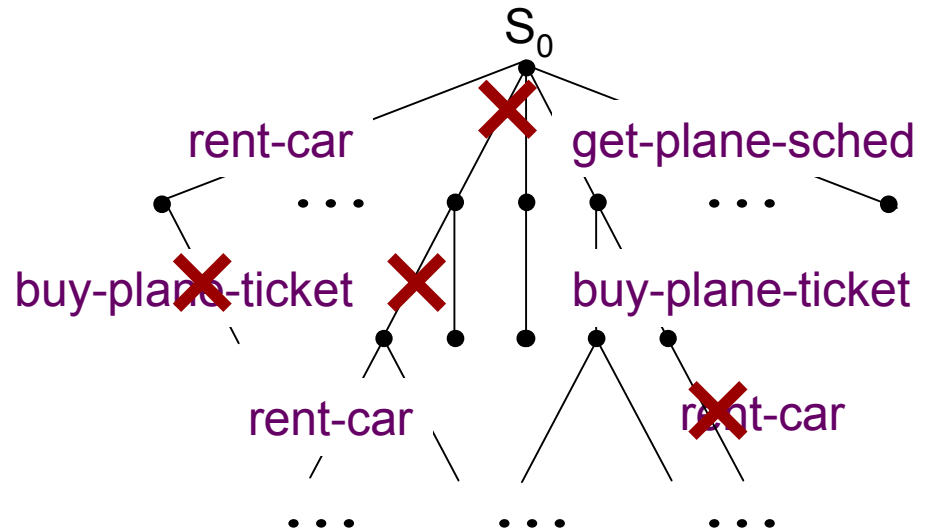# Realizing Generic Procedures in Golog

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
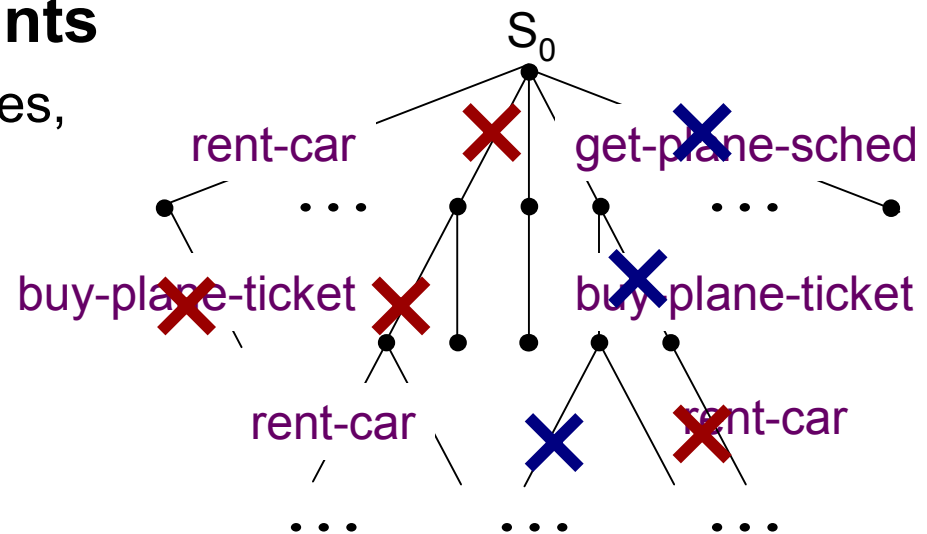   Book-plane(origin,dest) | Drive(origin,dest) | Book-train(origin,dest)
    end pick;
end

Customizing User Constraints

Generic procedures can be further constrained by

DAML-defined user constraints

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

S_0

rent-car   get-plane-sched

. . .   . . .

buy-plane-ticket   buy-plane-ticket

rent-car   rent-car

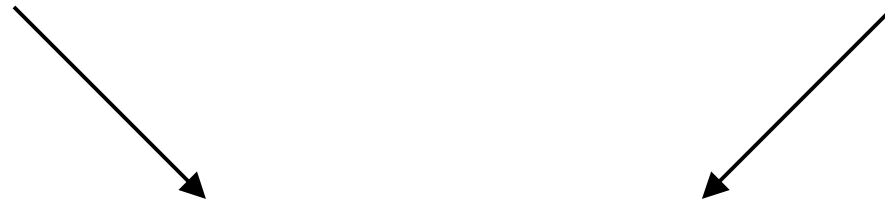. . .   . .

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   +   Generic Procedure
(Situation Calculus + State Constraints)   (Golog)

Model-Based Program

nondeterministic   *spectrum*   *deterministic*
✓ **constrains search**   ✓ **eliminates search**

theorem
proving

Sequence of Web Services

Architecture

Web Procedures Ontologies

Web Service Ontologies

Agent Broker

DAML-enabled personal/company constraints and prefs

DAML-enabled web pages

E-mail · · ·
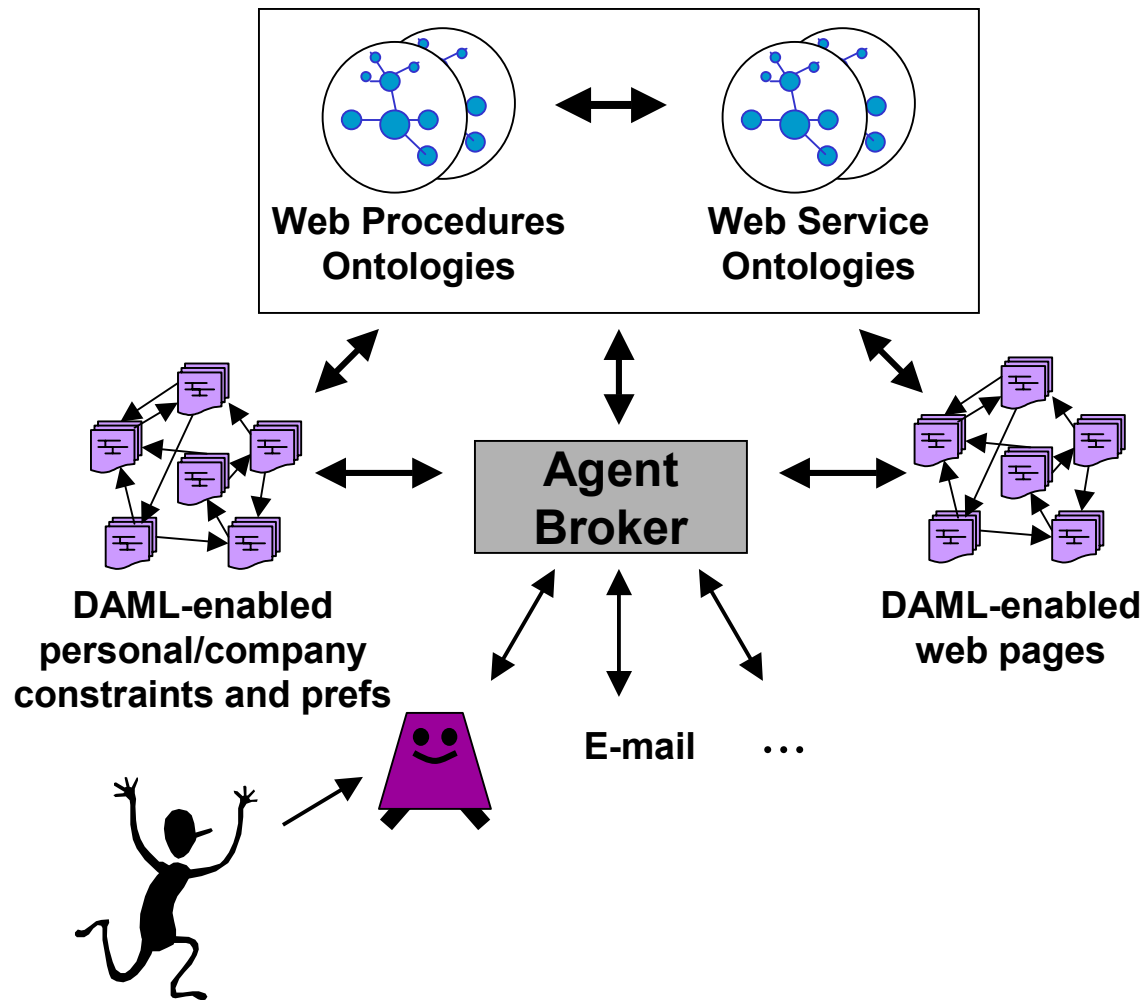
How it Works

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

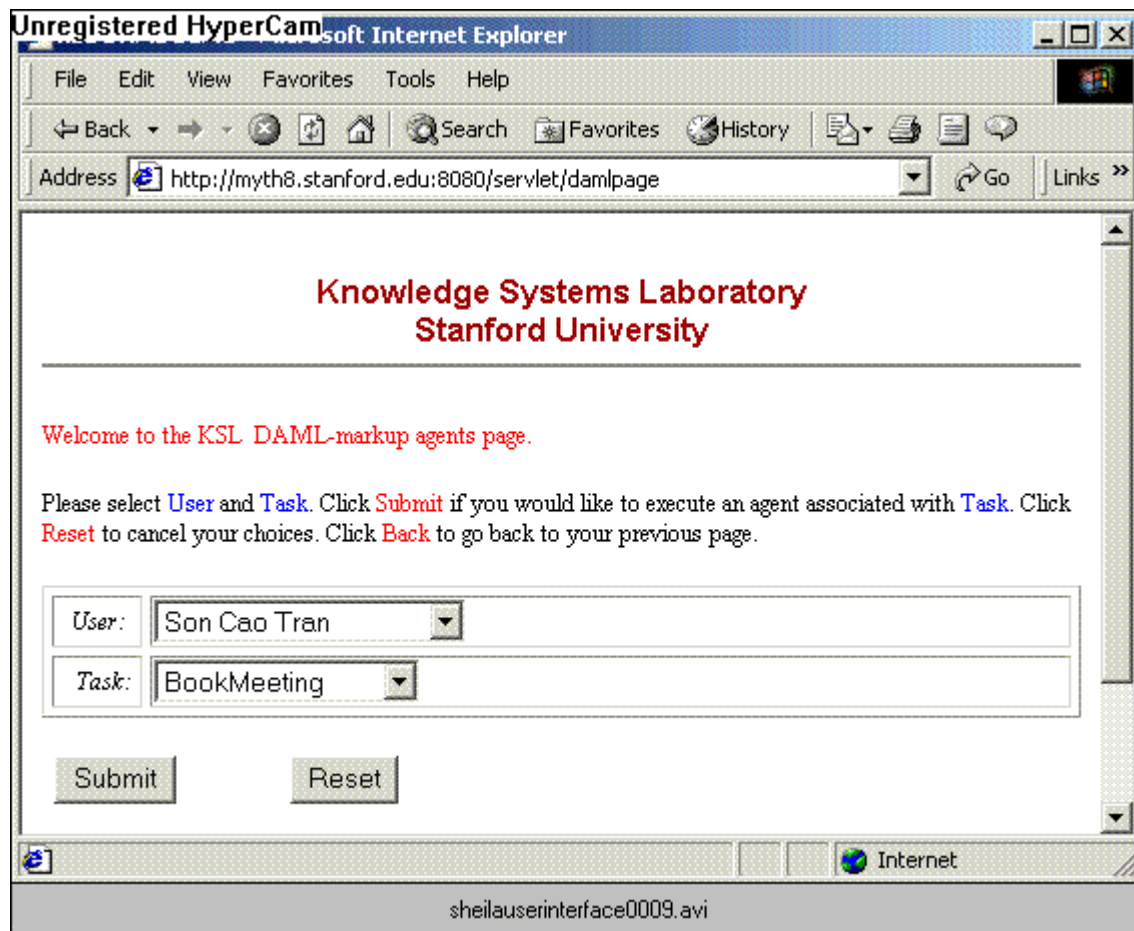Implementation of middle ground interpreter is sound & complete with respect to logical specification.

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.
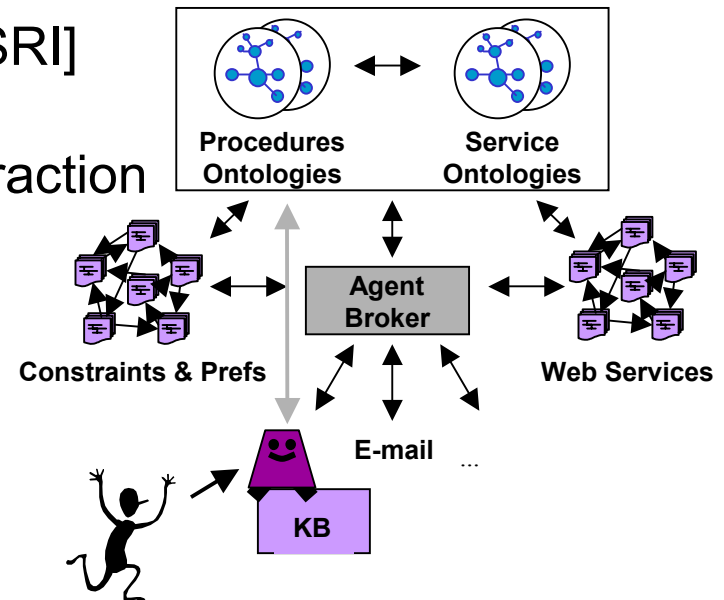
Demo: Dynamic UI with DAML+OIL

Behind the Scenes

```
                                    xterm
 ?- travel('Bob Chen','09/02/00','09/06/00','San Francisco','Monterey','DAML').
Contacting Web Service Broker:
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Result 2

Contacting Web Service Broker:
     Request Car Info in [San Francisco]
Result
   <B>HERTZ<B>Shuttle to Car Counter<B>Economy Car Automati...
   <B>ACE<B>Off Airport, Shuttle Provided<B>Economy Car Aut...
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Select
      HERTZ (San Francisco Airport), Location: Shuttle to Car Counter, Economy C
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Contacting Web Service Broker:
     Request Hotel Info in [Monterey]
Result
   <B>Travelodge<B> Monterey, CA<B>65 Rooms / 2 Floors<B>No...
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Contacting Web Service Broker:
      Request Hotel Info in [Monterey]
   <B>Travelodge<B> Monterey, CA<B>65 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 Availabl...
   <B>Best Western Intl<B> Monterey, CA<B>43 Rooms / 3 Floo...
   <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>Best Western Intl<B>  Monterey, CA<B>34 Rooms / 2 Flo...
```

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 Automati...
   <B>ACE<B>Off Airport, Shuttle Provided<B>Economy Car Aut...
   <B>NATIONAL<B>Shuttle to Car Counter<B>Economy Car Autom...
   <B>FOX<B>Off Airport, Shuttle Provided<B>Mini Car Automa...
   <B>PAYLESS<B>Off Airport, Shuttle Provided<B>Mini Car Au...
   <B>ALL INTL<B>Off Airport, Shuttle Provided<B>Economy Ca...
   <B>HOLIDAY<B>Off Airport, Shuttle Provided<B>Economy Car...
   <B>ABLE RENT<B>Off Airport, Shuttle Provided<B>Compact C...

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

Contacting Web Service Broker:
     Request Hotel Info in [Monterey]
Result
   <B>Travelodge<B> Monterey, CA<B>65 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...
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   <B>Best Western Intl<B>  Monterey, CA<B>34 Rooms / 2 Flo...
```

Agent e-mails itinerary to customer

```
                              xterm
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--
```

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Agent creates expense claim for customer

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?

High-level overview: McIlraith, Son and Zeng, "Semantic Web Services", *IEEE Intelligent Systems (special issue on the semantic web),* 16(2):46-53, 2001.

Some composition details: McIlraith and Son, "Adapting Golog for Programming the Semantic Web", *Proceedings Symposium on Logical Formalizations of Common Sense Reasoning (Common Sense 2001),* to appear, 2001.

Papers: http://ksl.stanford.edu/people/sam/publications.html

KSL's DAML project: http://www.ksl.stanford.edu/Projects/DAML/

DAML-S: http://www.daml.org/services/daml-s/

DAML Program: http://www.daml.org/