Information Agents

(Based on an invited talk at IJCAI’03)

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Introduction

- The Web is a tremendous resource, but designed for browsing
  - Sites provide limited capabilities for personalization
  - Few sites are designed to be integrated with others
- Goal: Develop technology to rapidly construct personal software agents
  - Build agents that can perform retrieval, integration, and monitoring tasks on any online source
Outline

- The Electric Elves: Information agents for monitoring travel
- Wrapping online sources
- Linking records across sources
- Efficiently executing agent plans
- Conclusions
Outline

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Electric Elves Project
[Chalupsky et al, 2001]

Elves project goal: Apply agent technology to support human organizations

- Develop software agents that automate routine tasks
- Enable software agents and humans to work together
- Support coordination of tasks

Applications: Office Elves and Travel Elves
Agents for Monitoring Travel

[Ambite et al, 2002]

• Office Elves created as an application of the Electric Elves
• Given travel itinerary, generates set of agents for anticipating travel-related failures and opportunities:
  • Price changes
  • Schedule changes
  • Flight delays & cancellations
  • Earlier and close connections
  • Finding the closest restaurant given GPS coordinates
Travel Assistant
Monitoring Travel Plans

**Monitoring Tasks**

- **Monitor Flight Status**
  - Monitor Flights
  - Stop Monitoring
  - Status:
    - Active
    - Outbound flight 1
- **Monitor Flight Schedule**
  - Monitor Schedule
  - Stop Monitoring
  - Status:
    - Active
- **Monitor Earlier Flights**
  - Monitor Earlier Flights
  - Stop Monitoring
  - Status:
    - Active
- **Monitor Connecting Flights**
  - Monitor Connecting Flights
  - Stop Monitoring
  - Status (Outbound):
    - Active
  - Status (Inbound):
    - Active
- **Monitor Airfare**
  - Monitor Airfare
  - Stop Monitoring
  - Mode:
    - Decrease only
  - Status:
    - Active

Notify Hotel (Fax):
7038128516

Notify Car Rental Counter (Fax):
7034948462
Agents Deployed to Monitor Travel Itinerary

Travel Itinerary

Agents Proxies

Ontology-Based Matchmakers

Agent Information Agents

People

GRID

Flight Prices & Schedules

Flight Status

Weather

Restaurants

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Monitoring Agents

- **Flight-Status Agent:**
  - **Flight delayed message:**
    Your United Airlines flight 190 has been delayed. It was originally scheduled to depart at 11:45 AM and is now scheduled to depart at 12:30 PM. The new arrival time is 7:59 PM.
  - **Flight cancelled message:**
    Your Delta Air Lines flight 200 has been cancelled.
  - **Fax to hotel message:**
    Attention: Registration Desk
    I am sending this message on behalf of David Pynadath, who has a reservation at your hotel. David Pynadath is on United Airlines 190, which is now scheduled to arrive at IAD at 7:59 PM. Since the flight will be arriving late, I would like to request that you indicate this in the reservation so that the room is not given away.
Monitoring Agents

- **Airfare Agent: Airfare dropped message**
  The airfare for your American Airlines itinerary (IAD – LAX) dropped to $281.

- **Earlier-Flight Agent: Earlier flights message**
  The status of your currently scheduled flight is:
  # 190 LAX (11:45 AM) – IAD (7:29 PM) 45 minutes Late
  If you would like to return earlier, the following United Airlines flights will arrive earlier than your scheduled flights:
  # 946 LAX (8:31 AM) – IAD (3:35 PM) 11 minutes Late
  -------
  # 388 LAX (9:25 AM) – DEN (12:25 PM) 10 minutes Late
  # 1534 DEN (1:20 PM) – IAD (6:06 PM) On Time
Learning to Make Predictions: To Buy or Not To Buy

- Agents can go beyond gathering and monitoring online sources
  - They can help make decisions by exploiting the wealth of online information

![Graph showing price changes with dates and price levels ranging from 250 to 2250.]

American Airlines flights 192 & 223, LAX-BOS, departing on Jan. 2 & 9
Learning to Make Predictions: To Buy or Not To Buy

- Agents can go beyond gathering and monitoring online sources
  - They can help make decisions by exploiting the wealth of online information
- Developed a learning system, Hamlet, to predict whether it is better to wait or buy [Etzioni, Knoblock, Tuchinda, Yates, KDD’03]
- Collected data on airline prices over several months
- Learned a model of the pricing
- In our simulation on collected data, Hamlet saved $198,074 out of a possible $320,572 (61.8% of optimal)
Related Agent Systems

- Some notable deployed systems
  - Internet Softbot [Etzioni & Weld, ’94]
  - BargainFinder [Krulwich, ’96]
  - ShopBot [Perkowitz et al. ’96]
  - Warren [Decker et al., ’97]
  - Electric Elves [Chalupsky et al., ’01]
  - and many others...
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  - Wrapping online sources
- Linking records across sources
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- Conclusions
Wrappers for Live Access to Online Sources

- HTML sources turned into agent-friendly sources

Wrapper

```html
<YAHOO_WEATHER>
- <ROW>
  <TEMP>25</TEMP>
  <OUTLOOK>Sunny</OUTLOOK>
  <HI>32</HI>
  <LO>19</LO>
  <APPARTEMP>25</APPARTEMP>
  <HUMIDITY>35%</HUMIDITY>
  <WIND>E/10 km/h</WIND>
  <VISIBILITY>20 km</VISIBILITY>
  <DEWPOINT>9</DEWPOINT>
  <BAROMETER>959 mb</BAROMETER>
</ROW>
</YAHOO_WEATHER>
```
Extraction Rules

- Wrapper defined by a set of extraction rules
- Extraction rule: sequence of landmarks
  - Define both beginning and end of required information on the page

Name: Joel’s  Phone: (310) 777-1111  Review: …
Learning the Extraction Rules

[Muslea, Minton, & Knoblock, 01]

- Hierarchical wrapper induction
  - Decomposes a hard problem into several easier ones
  - Extracts items independently of each other
Example of Rule Induction

**Training Examples:**

Name: Del Taco
Phone (toll free): (<b>800</b>) 123-4567
Cuisine ...

Name: Burger King
Phone: (310) 987-9876
Cuisine: ...

**Search Space:**

SkipTo( () )

SkipTo( <b>Phone</b> ) SkipTo( () ) ... SkipTo(:) SkipTo( )
Active Learning

- Problem: May require large number of examples to achieve high accuracy
- Exploit active learning
  - System selects most informative examples to label
  - Want to achieve 100% accuracy with as few examples as possible
Which Example to Label Next

Training Examples

Name: Joel’s  <p> Phone: (310) 777-1111  <p> Review: The chef...
Name: Kim’s  <p> Phone: (213) 757-1111  <p> Review: Korean ...

Unlabeled Examples

Name: Chez Jean  <p> Phone: (310) 666-1111  <p> Review: ...
Name: Burger King  <p> Phone: (818) 789-1211  <p> Review: ...
Name: Café del Rey  <p> Phone: (310) 111-1111  <p> Review: ...
Name: KFC  <p> Phone: (800) 111-7171  <p> Review: ...
Multi-view Learning
[Muslea, Minton, Knoblock ’00]

- Two ways to find start of the phone number:

  SkipTo( **Phone:** )

  **Name:** KFC  
  **Phone:** (310) 111-1111  
  **Review:** Fried chicken ...

  BackTo( **Nmb** )
Multi-view Learning: Co-Testing

RULE 1

RULE 2

Labeled data

Unlabeled data
Co-Testing for Wrapper Induction

Name: Joel’s  Phone: (310) 777-1111  Review: ...

Name: Kim’s  Phone: (213) 757-1111  Review: ...

Name: Chez Jean  Phone: (310) 666-1111  Review: ...

Name: Burger King  Phone: (818) 789-1211  Review: ...

Name: Café del Rey  Phone: (310) 111-1111  Review: ...

Name: KFC  Phone: (800) 111-7171  Review: ...
Not All Queries are Equally Informative
Weak Views
[Muslea, Minton, Knoblock ’03]

- Learn “content description” for item to be extracted
  - Too general for extraction
    - ( Nmb ) Nmb – Nmb can’t tell a phone number from a fax number
  - Useful at discriminating among query candidates
  - Learned content descriptions
    - Starts with: ( Nmb )
    - Ends with: Nmb – Nmb
    - Contains: Nmb Punct
    - Length: [6,6]
Naïve & Aggressive Co-Testing

- **Naïve Co-Testing:**
  - Query: randomly chosen contention point
  - Output: rule with fewest mistakes on queries

- **Aggressive Co-Testing:**
  - Query: contention point that most violates weak view
  - Output: committee vote (2 rules + weak view)
Results for Random Sampling

- 33 most difficult of the 140 tasks from [Kushmerick ’97]

![Bar chart showing Examples to 100% accuracy for extraction tasks]
Results for Active Learning

Naïve Co-Testing  Random sampling

Extraction Tasks

Examples to 100% accuracy

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Results for Active Learning with Weak Views

Extraction Tasks

Examples to 100% accuracy

Aggressive Co-Testing
Naïve Co-Testing
Random sampling
Outline

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### Zagat’s Restaurants

<table>
<thead>
<tr>
<th>Name</th>
<th>Street</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art’s Deli</td>
<td>12224 Ventura Blvd.</td>
<td>818-756-4124</td>
</tr>
<tr>
<td>Teresa’s</td>
<td>80 Montague St.</td>
<td>718-520-2910</td>
</tr>
<tr>
<td>Steakhouse The</td>
<td>128 Fremont St.</td>
<td>702-382-1600</td>
</tr>
<tr>
<td>Les Celebrites</td>
<td>155 W. 58th St.</td>
<td>212-484-5113</td>
</tr>
</tbody>
</table>

### Dept. of Health

<table>
<thead>
<tr>
<th>Name</th>
<th>Street</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art’s Delicatessen</td>
<td>12224 Ventura Blvd.</td>
<td>818/755-4100</td>
</tr>
<tr>
<td>Teresa’s</td>
<td>103 1st Ave. between 6th and 7th Sts.</td>
<td>212/228-0604</td>
</tr>
<tr>
<td>Binion’s Coffee Shop</td>
<td>128 Fremont St.</td>
<td>702/382-1600</td>
</tr>
<tr>
<td>Les Celebrites</td>
<td>160 Central Park S</td>
<td>212/484-5113</td>
</tr>
</tbody>
</table>
**Active Learning to Determine Matched Records**

[Tejada, Knoblock, Minton ’01,’02]

- Learn importance of attributes for matching records

<table>
<thead>
<tr>
<th>Name</th>
<th>Street</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zagat’s</td>
<td>Art’s Deli 12224 Ventura Boulevard</td>
<td>818-756-4124</td>
</tr>
<tr>
<td>Dept of Health</td>
<td>Art’s Delicatessen 12224 Ventura Blvd.</td>
<td>818/755-4100</td>
</tr>
</tbody>
</table>

**Mapping rules:**

- Name > .9 & Street > .87 => mapped
- Name > .95 & Phone > .96 => mapped
Mapping Rule Learner

Choose initial examples

Generate committee of learners

Learn Rules

Classify Examples

Votes

Learn Rules

Classify Examples

Votes

Learn Rules

Classify Examples

Votes

Choose Example

Set of Mapped Objects

USER

Label

Label
Committee Disagreement

- Chooses an example based on the disagreement of the query committee

<table>
<thead>
<tr>
<th>Examples</th>
<th>Committee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art’s Deli, Art’s Delicatessen</td>
<td>Yes  Yes  Yes</td>
</tr>
<tr>
<td>CPK, California Pizza Kitchen</td>
<td>Yes  No   Yes</td>
</tr>
<tr>
<td>Ca’Brea, La Brea Bakery</td>
<td>No   No   No</td>
</tr>
</tbody>
</table>

- CPK, California Pizza Kitchen is the most informative example
Exploiting Secondary Sources for Record Linkage

[Michalowski, Thakkar, Knoblock ’03]

- Primary data source may be insufficient to determine mappings
- Secondary sources can help reduce the uncertainty
- Examples of secondary sources
  - Geocoder
    - Maps street addresses into lat/long coordinates
  - Business directories
    - Provide company officers and locations
  - Area code updates
    - Provide changes in area codes over time
Missing Matches

Record Linkage

Matched Records

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Name</th>
<th>Address</th>
<th>City</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zagats</td>
<td>Chart House</td>
<td>13950 Panay Way</td>
<td>Marina del Rey</td>
<td>CA</td>
</tr>
<tr>
<td>Dinesite</td>
<td>Chart House</td>
<td>13950 Panay Way</td>
<td>Marina del Rey</td>
<td>CA</td>
</tr>
<tr>
<td>Zagats</td>
<td>Killer Shrimp</td>
<td>523 Washington Blvd.</td>
<td>Marina del Rey</td>
<td>CA</td>
</tr>
<tr>
<td>Dinesite</td>
<td>Killer Shrimp</td>
<td>523 Washington Boulevard</td>
<td>Marina del Rey</td>
<td>California</td>
</tr>
<tr>
<td>Zagats</td>
<td>CAFE DEL REY</td>
<td>4451 Admiralty Way</td>
<td>Marina del Rey</td>
<td>CA</td>
</tr>
<tr>
<td>Dinesite</td>
<td>Cafe Del Rey</td>
<td>4451 Admiralty Way</td>
<td>Marina del Rey</td>
<td>California</td>
</tr>
<tr>
<td>Zagats</td>
<td>Koo Koo Roo</td>
<td>4325 Glencoe Ave.</td>
<td>Marina del Rey</td>
<td>CA</td>
</tr>
<tr>
<td>Dinesite</td>
<td>Koo Koo Roo</td>
<td>4325 Glencoe Avenue</td>
<td>Marina del Rey</td>
<td>California</td>
</tr>
</tbody>
</table>
Exploiting a Geocoder

Matched Records

Record Linkage

Secondary Source

26 Beach Cafe
26 Washington St.
Venice, CA

26 Beach Cafe
26 Washington Boulevard
Marina Del Rey, Calif
## Preliminary Results: Secondary Sources

Secondary source reduces the depth of the decision tree that needs to be learned.

<table>
<thead>
<tr>
<th># Labeled Examples</th>
<th>Total Correct Matches</th>
<th>Without Secondary Source</th>
<th>With Secondary Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Precision</td>
<td>Recall</td>
</tr>
<tr>
<td>25</td>
<td>109</td>
<td>51%</td>
<td>33%</td>
</tr>
<tr>
<td>35</td>
<td>109</td>
<td>73%</td>
<td>57%</td>
</tr>
<tr>
<td>50</td>
<td>109</td>
<td>83%</td>
<td>81%</td>
</tr>
</tbody>
</table>
Outline

- The Electric Elves: Information agents for monitoring travel
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Efficiently Executing Agent Plans

Problem

• Information gathering may involve accessing and integrating data from many sources
• Total time to execute these plans may be large

Why?

• Slow remote sources
• Unpredictable network latencies
• Binding patterns
  ◆ Source cannot be queried until a previous query has been answered
• Result: execution is often I/O-bound
Theseus Agent Execution System
[Barish & Knoblock, JAIR’05]

- **Plan language** and **execution system** for Web-based information integration
  - Expressive enough for monitoring a variety of sources
  - Efficient enough for real-time monitoring

```
PLAN myplan {
  INPUT: x;
  OUTPUT: y;
  BODY {
    Op (x : y);
  }
}
```
Streaming Dataflow

- Plans consist of a network of operators
  - Examples: Wrapper, Select, etc.
  - Operators produce and consume data
  - Operators “fire” upon any input data
- Data passed as tuples of a relation
Parallelism in Streaming Dataflow

**Dataflow**
- Operations scheduled by data availability
  - Independent operations execute in parallel
  - *Maximizes horizontal parallelism*
- Example: computing \((a*b) + (c*d)\)

**Streaming**
- Operations emit data as soon as possible
  - Independent data processed in parallel
  - *Maximizes vertical parallelism*
CarInfo Agent

- Agent for recommending used cars:
  - Combine information from
    - Prices of used cars
    - Safety ratings
    - Reviews
  - Example:
    - 2002 Midsize coupe/hatchback
    - $4K-$12K
    - No Oldsmobiles
1. Locate cars that meet criteria
   - Edmunds.com
The CarInfo agent

1. Locate cars that meet criteria
   - Edmunds.com

2. Filter out Oldsmobiles
The CarInfo agent

1. Locate cars that meet criteria
   - Edmunds.com

2. Filter out Oldsmobiles

3. Gather safety reviews for each
   - NHSTA.gov
The CarInfo agent

1. Locate cars that meet criteria - Edmunds.com
2. Filter out Oldsmobiles
3. Gather safety reviews for each - NHSTA.gov
4. Gather detailed reviews of each - ConsumerGuide.com
Requires navigating through multiple pages
Dataflow-style CarInfo agent plan

(Midsize coupe/hatchback, $4000 to $12000, 2002)

((Midsize coupe/hatchback, $4000 to $12000, 2002))

JOIN

WRAPPER ConsumerGuide Full Review

WRAPPER ConsumerGuide Summary

WRAPPER ConsumerGuide Search

SELECT maker != "Oldsmobile"

WRAPPER Edmunds Search

search criteria

(((http://cg.com/summ/20812.htm), other summary review URLs))

((http://cg.com/full/20812.htm), other full review URLs)

NHTSA Search

((Dodge Stratus), (Pontiac Grand Am), (Mercury Cougar))

((Oldsmobile Alero), (Dodge Stratus), (Pontiac Grand Am), (Mercury Cougar))
Speculative Execution
[Barish & Knoblock ’02, ’03]

- Basic idea
  - Exploit idle resources to execute future instructions in advance of when they are normally issued

- Challenges
  - How to augment plans for speculation
  - How to ensure correctness and fairness
  - How to decide what to speculate on
How to speculate?

- **General problem**
  - Means for issuing and confirming predictions

- **Two new operators**
  - **Speculate**: Makes predictions based on "hints"
  - **Confirm**: Prevents errant results from exiting plan

![Diagram](image-url)
How to speculate?

- **Example: CarInfo**
  - Predict cars based on search criteria
  - Makes practical sense:
    - Same criteria yields same cars

BEFORE

```
BEFORE
```

```
W S W W W J W W
```
How to speculate?

- Example: CarInfo
  - Predict cars based on search criteria
  - Makes practical sense:
    - Same criteria yields same cars
Detailed example

2002
Midsize coupe
$4000-$12000

W Speculate S W W J W W

Confirm

Time = 0.0 sec
Issuing predictions

Oldsmobile Alero T1
Dodge Stratus T2
Pontiac Grand Am T3
Mercury Cougar T4

Speculate

W
S

W
W
J
W

Confirm

Time = 0.1 sec
Speculative parallelism

Time = 0.2 sec
Answers to hints

Time = 1.0 sec

Speculate

Oldsmobile Alero
Dodge Stratus
Pontiac Grand Am
Mercury Cougar

W

S

W

W

J

W

Confirm
Continued processing

Additions (corrections), if any

Time = 1.1 sec
Generation of final results

Time = 3.2 sec

Dodge Stratus (safety) (review) T2
Pontiac Grand Am (safety) (review) T3
Mercury Cougar (safety) (review) T4
Confirmation of results

Dodge Stratus (safety) (review)
Pontiac Grand Am (safety) (review)
Mercury Cougar (safety) (review)

Time = 3.3 sec
Safety and fairness

❖ **Safety**
  • **Confirm** blocks predictions (and results of) from exiting plan before verification

❖ **Fairness**
  • **CPU**
    ◆ Speculative operations use "speculative threads"
      • Lower priority threads
  • **Memory and bandwidth**
    ◆ Speculative operations allocate "speculative resources"
      • Drawn from "speculative pool" of memory / objects
Cascading Speculation

- Use predicted cars to speculate about the ConsumerGuide summary and full URLs

- Optimistic performance
  - Execution time: \( \text{max} \{1.2, 1.4, 1.5, 1.6\} = 1.6 \text{ sec} \)
  - Speedup over streaming dataflow: \( \frac{4.2}{1.6} = 2.63 \)
Automatic plan transformation

- Agent plans are automatically modified for speculative execution
  - Successive runs of the plan benefit
    - Even with different input data

- Leverage Amdahl's Law:
  - Consider optimizing only the most expensive path (MEP)

- Algorithm continually refines MEP
  - Until overhead of further optimization outweighs benefits
Learning for Speculative Execution

- **Caching**
  - Associate a hint with a predicted value
    - 2002 Midsize coupe 4K-12K
      → Olds Alero, Dodge Stratus, Pontiac Grand Am, Mercury Cougar

- **Classification**
  - Use features of a hint to predict value
    - **EXAMPLE**: Predicting car list from Edmunds

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Min</th>
<th>Max</th>
<th>Car list</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Midsize</td>
<td>8000</td>
<td>15000</td>
<td>(Oldsmobile Alero, Dodge Stratus)</td>
</tr>
<tr>
<td>2002</td>
<td>Midsize</td>
<td>7500</td>
<td>14500</td>
<td>(Oldsmobile Alero, Dodge Stratus)</td>
</tr>
<tr>
<td>2002</td>
<td>SUV</td>
<td>14000</td>
<td>20000</td>
<td>(Nissan Pathfinder, Ford Explorer)</td>
</tr>
<tr>
<td>2001</td>
<td>Midsize</td>
<td>11000</td>
<td>18000</td>
<td>(Honda Accord, Toyota Camry)</td>
</tr>
<tr>
<td>2002</td>
<td>SUV</td>
<td>18000</td>
<td>22000</td>
<td>(Nissan Pathfinder, Ford Explorer)</td>
</tr>
</tbody>
</table>

**Decision list**

- type = SUV : (Nissan Pathfinder, Ford Explorer)
- type = Midsize :
  - ...min <= 10000 : (Olds Alero, Dodge Stratus)
  - min > 10000 : (Honda Accord, Toyota Camry)
Learning for Speculative Execution

Transduction

- Transducers are FSM that translate hints into predictions

To create full review URL:

1. Insert "http://cg.com/full/"
2. Extract & insert the dynamic part of the summary URL (e.g., 20812)
3. Insert ".htm"
Speculation Results: Last Tuple

Bar chart showing the time to last tuple in milliseconds for different information sources. The x-axis represents CarInfo, RepInfo, TheaterLoc, FlightStatus, and StockInfo. The y-axis represents the time in milliseconds, ranging from 0 to 8000.

Legend:
- No speculation
- 50% correct
- 100% correct
Related Work

- **Wrapper learning**
  - Supervised [Kushmerick ’97, Hsu & Dung ’98]
  - Unsupervised [Lerman et al. ’01, Crescenzi ’01]

- **Record linkage**
  - Learning [Cohen ’00, Sarawagi & Bhamidipaty ’02]
  - Statistics [Winkler ’98]
  - Name matching [Bilenko et al. ’03, Cohen et al. ’03]

- **Efficient plan execution**
  - Network query engines [Ives et al. 1999, Naughton et al. 2000, Hellerstein et al. 2001]
  - Agent execution systems [Firby ’94, Myers et al. 1996]
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Conclusions

- Web provides the ideal environment for developing and testing software agents
  - Noted by Etzioni, AAAI’96 in his talk on Softbots
- Yet few have seized this opportunity...why?
- Like robotics, wide variety of hard technical problems
- With Web Services, the Semantic Web, etc. the infrastructure is improving
- Great opportunity for AI
  - Ability to demonstrate and test technologies in a real-world setting
  - Opportunity to apply technologies to make a difference in people’s lives
Many interesting technical challenges for building software agents:

- Wrapping online sources
- Linking records across sites
- Efficiently executing agent plans
- Extraction from text documents
- Aligning ontologies across sources
- Planning to integrate data sources
- Learning to improve performance and capabilities
- Integrating these capabilities in a robust architecture that can:
  - Respond to failures
  - Explain its behavior
  - Communicate appropriately
Want to Learn More?

- I teach a course on Information Integration on the Web
- Syllabus, readings, and slides available from:
  - http://www.isi.edu/info-agents/courses/csci548/
The End