Deploying Information Agents on the Web

Craig A. Knoblock

University of Southern California
and
Fetch Technologies

agents@USC

Acknowledgements

- Information Agents Research Group
  - Steve Minton, Fetch Tech.
  - Jose Luis Ambite, USC
  - Greg Barish, Fetch Tech.
  - Kristina Lerman, USC
  - Martin Michalowski, USC
  - Ion Muslea, SRI
  - Maria Muslea, USC
  - Sheila Tejada, UNO
  - Snehal Thakkar, USC
  - Rattapoom Tuchinda, USC
- Electric Elves
  - Hans Chalupsky, USC
  - Yolanda Gil, USC
  - Jean Oh, CMU
  - David V. Pynadath, USC
  - Thomas A. Russ, USC
  - Milind Tambe, USC
- Funding
  - DARPA
  - AFOSR
  - NSF
  - Microsoft

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
- Current and related work
- Conclusions

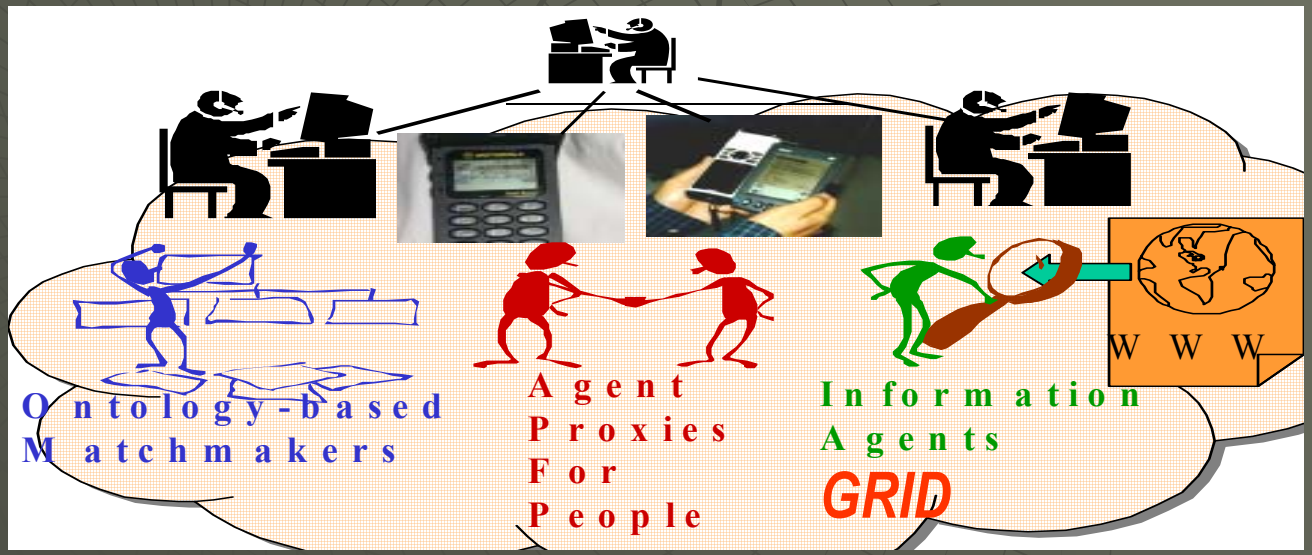
Outline

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

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

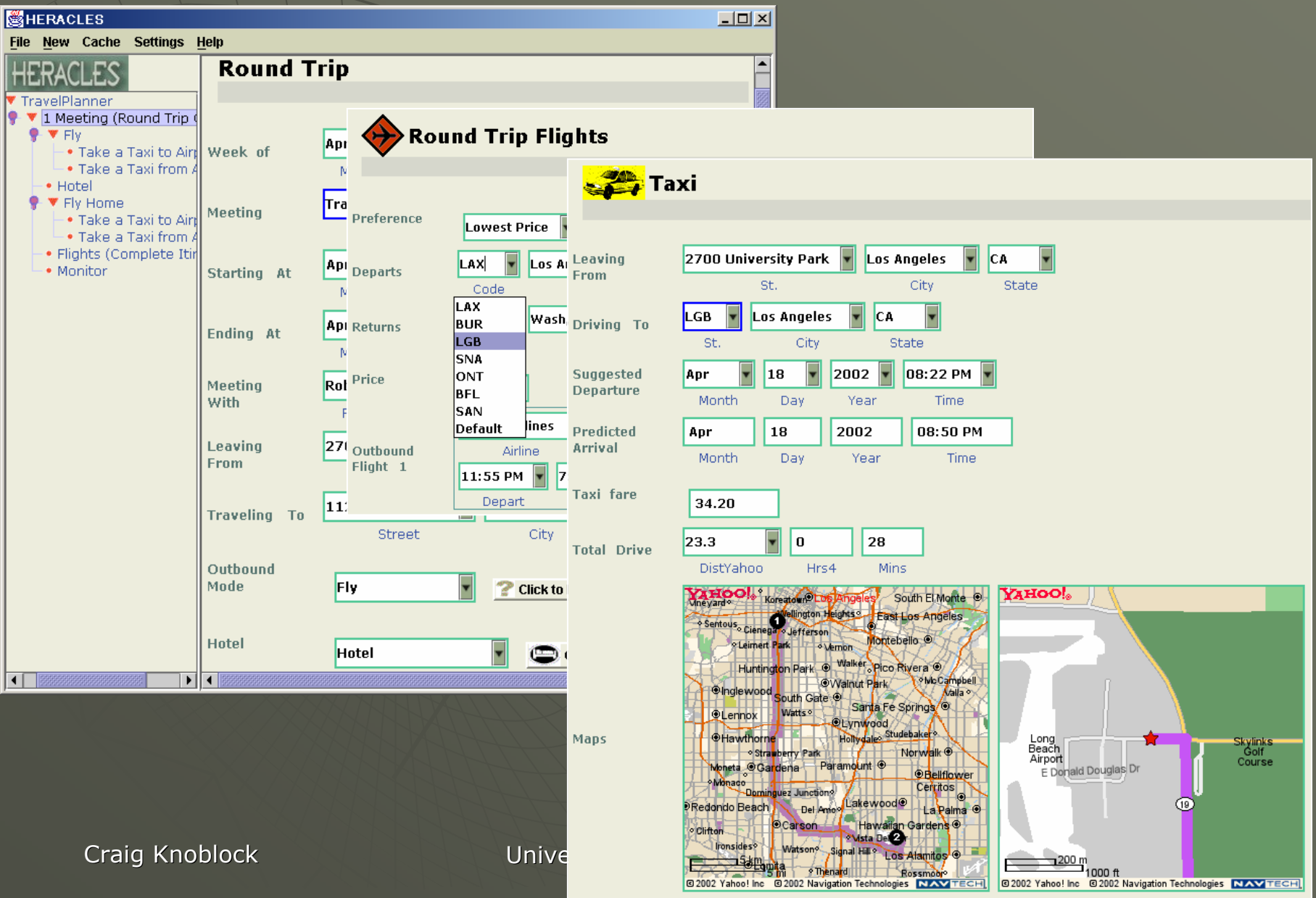


Agents for Monitoring Travel
[Ambite et al, 2002]

- 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

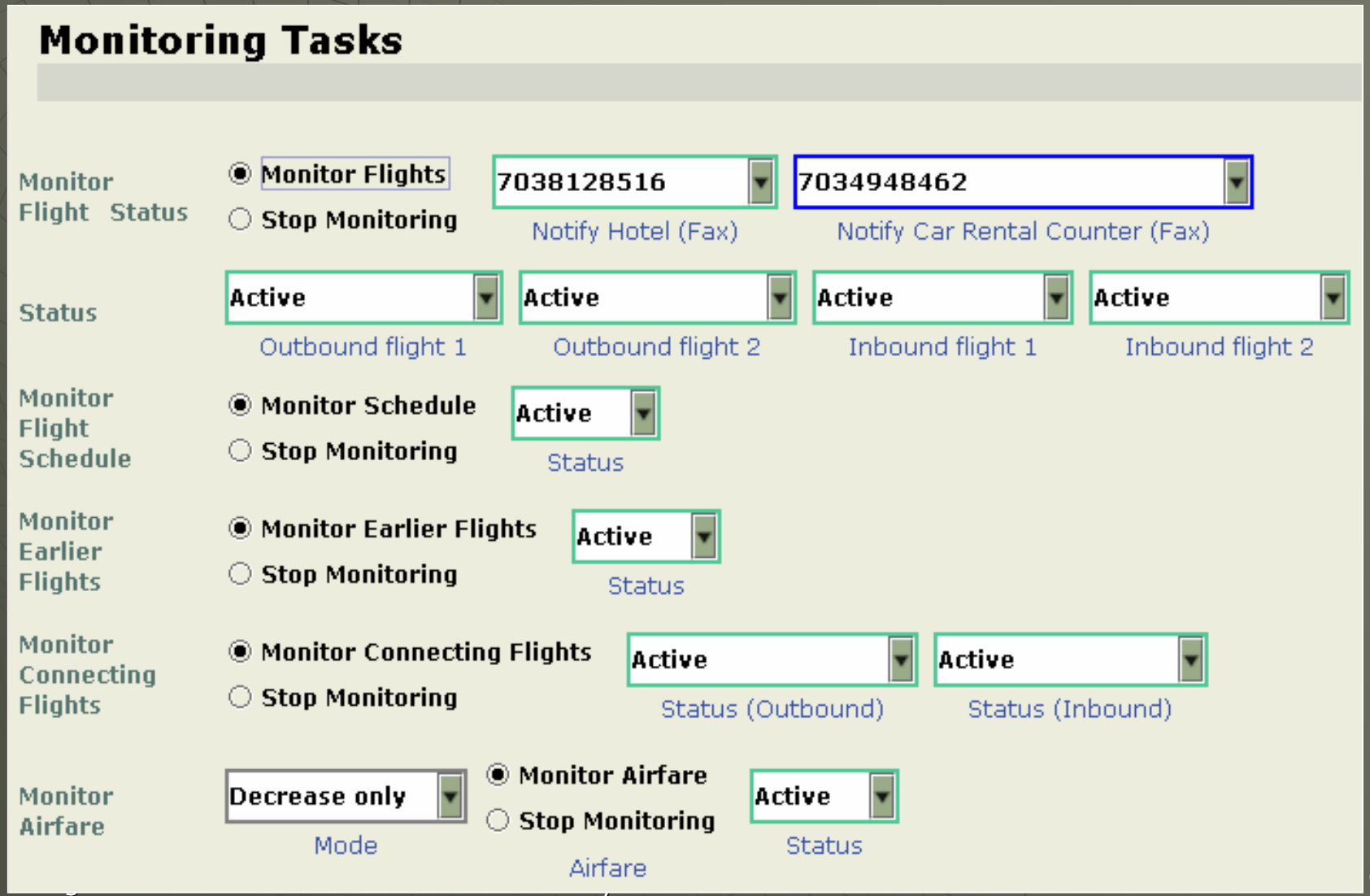
agents@USC



Craig Knoblock

Unive

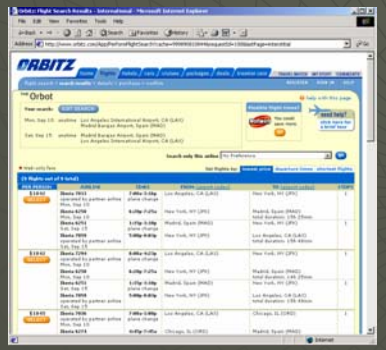
Monitoring Travel Plans



agents@USC

Agents Deployed to Monitor Travel Itinerary

Travel Itinerary



Flight Prices & Schedules

Flight Status

Weather

Restaurants

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
```

Outline

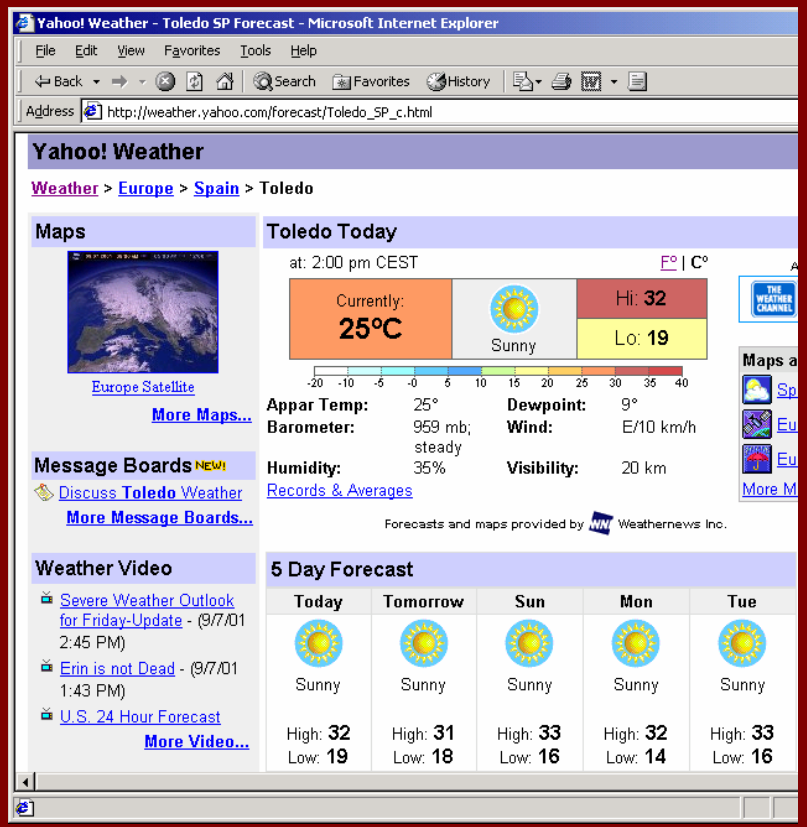
- The Electric Elves: Information agents for monitoring travel
- Wrapping online sources
- Linking records across sources
- Efficiently executing agent plans
- Current and related work
- Conclusions

Wrappers for Live Access to Online Sources

agents@USC

- HTML sources turned into agent-friendly sources

Wrapper




```
<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

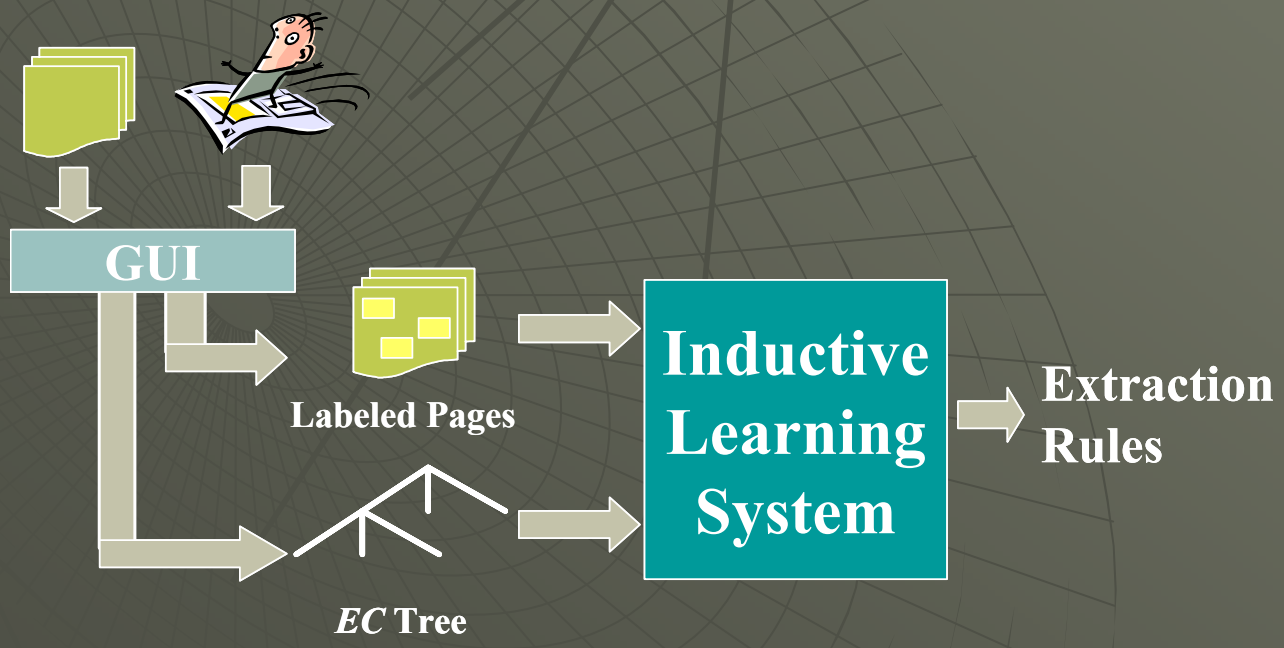
- Wrapper defined by a set of extraction rules
- Extraction rule: sequence of landmarks
  - Define both beginning and end of required information on the page

Learning the Extraction Rules

agents@USC

[Muslea, Minton, & Knoblock, 01]

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



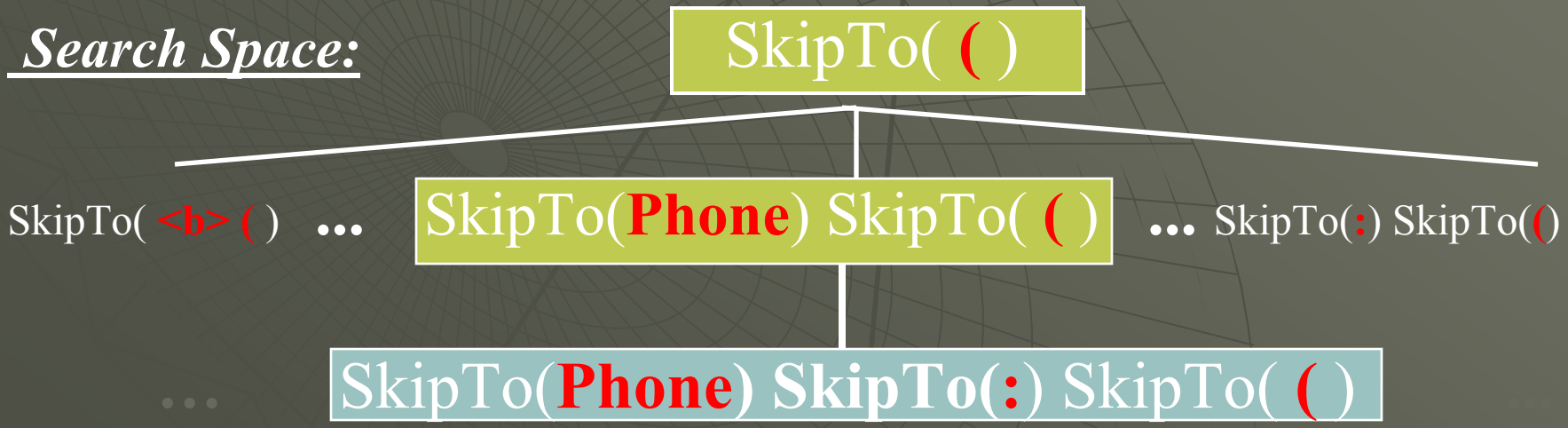
Example of Rule Induction

Training Examples:

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

Name: Burger King <p> Phone : (310) 987-9876 <p> Cuisine: …

Search Space:



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

SkipTo(Phone:)

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: …

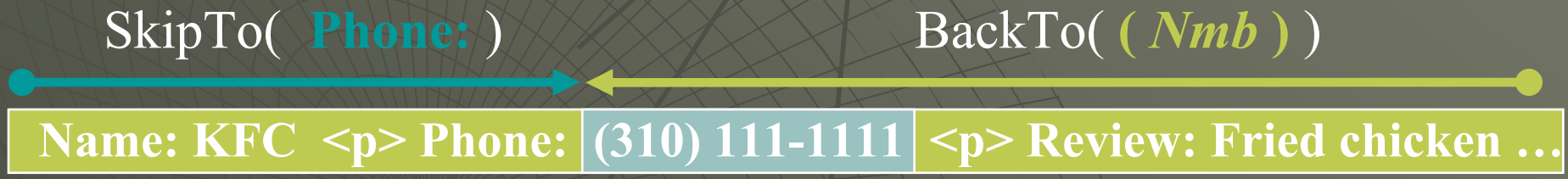
Name: Burger King <p> Phone:(818) 789-1211 <p> Review: ...

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

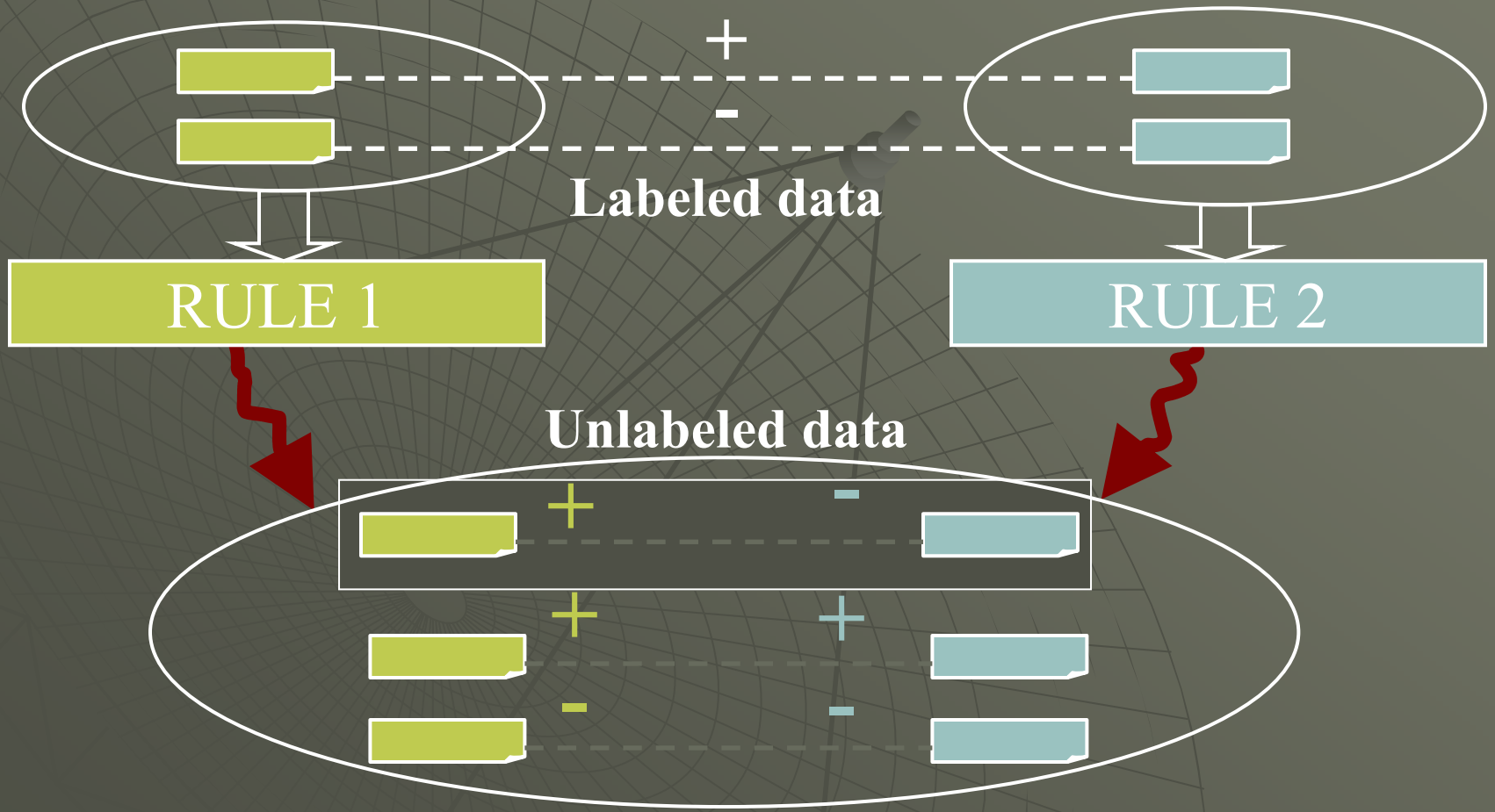
Name: KFC <p> Phone: (800) 111-7171 <p> Review:...

Multi-view Learning
[Muslea, Minton, Knoblock '00]

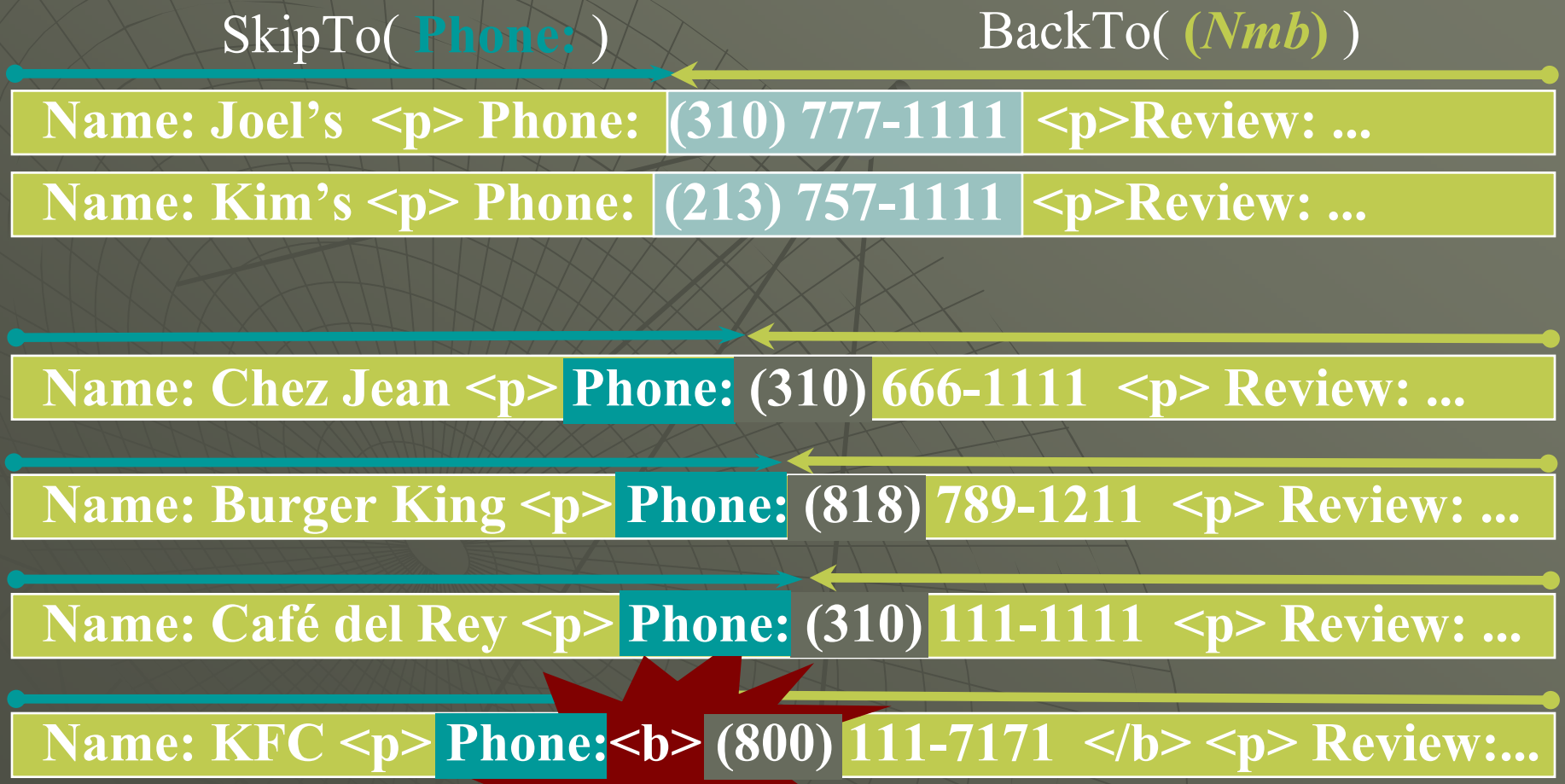
- Two ways to find start of the phone number:



Multi-view Learning: Co-Testing

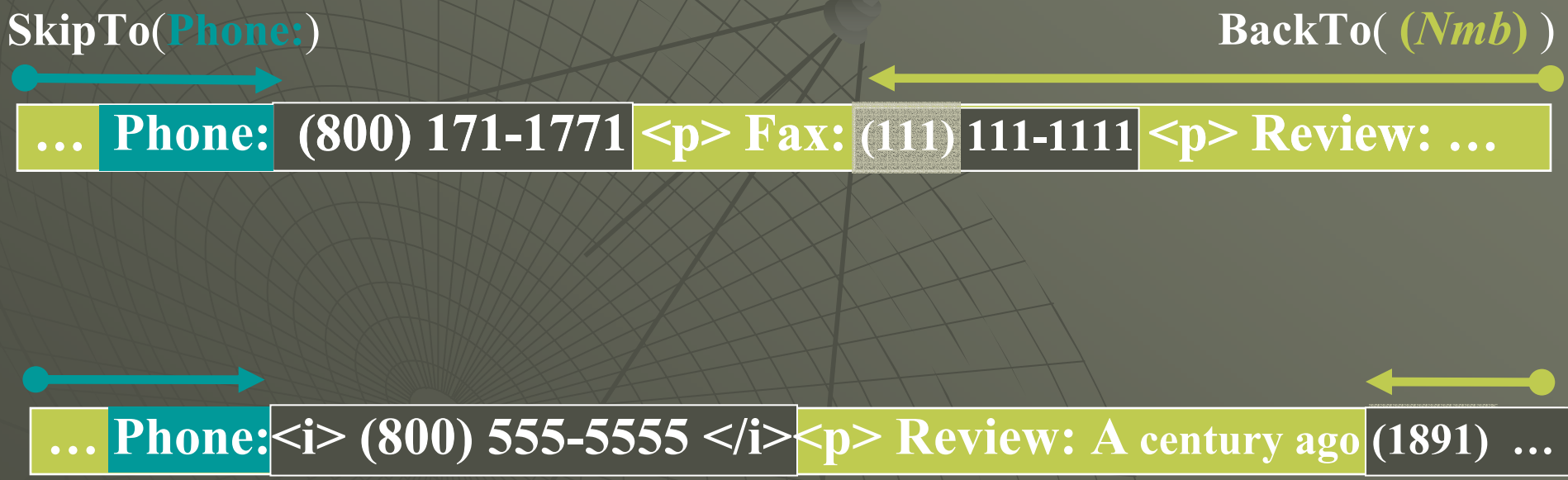


Co-Testing for Wrapper Induction



Not All Queries are Equally Informative

agents@USC



Weak Views
[Muslea, Minton, Knoblock '03]

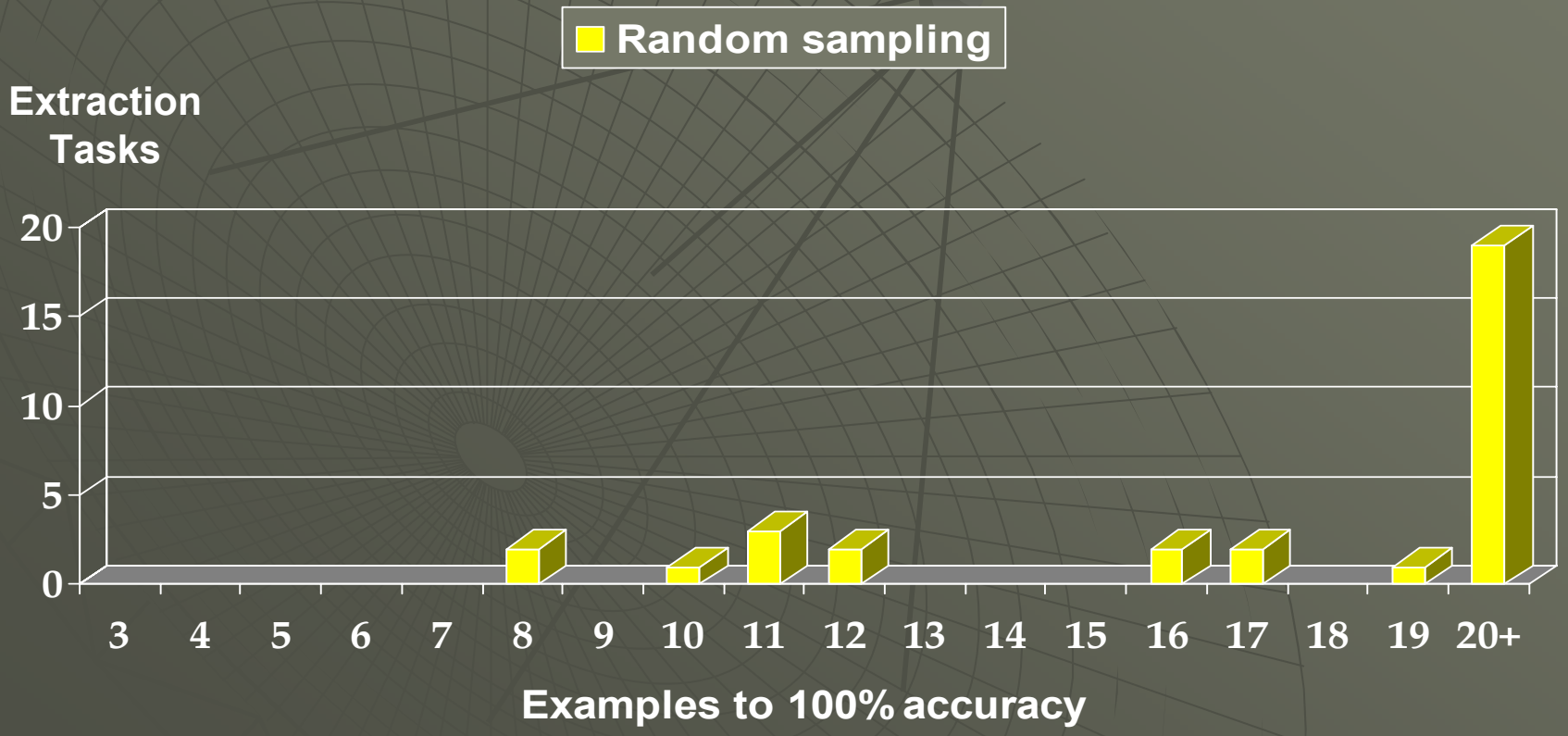
- Learn "content description" for item to be extracted
  - Too general for extraction
    - ***(Nmb) Nmb – Nmb*** can't tell a ***phone number*** from a ***fax number***
  - Useful at ***discriminating*** among ***query candidates***
  - Learned content descriptions
    - Starts with: ***(Nmb)***
    - Ends with: ***Nmb – Nmb***
    - Contains: ***Nmb Punct***
    - Length: **[6,6]**

Naïve & Aggressive Co-Testing

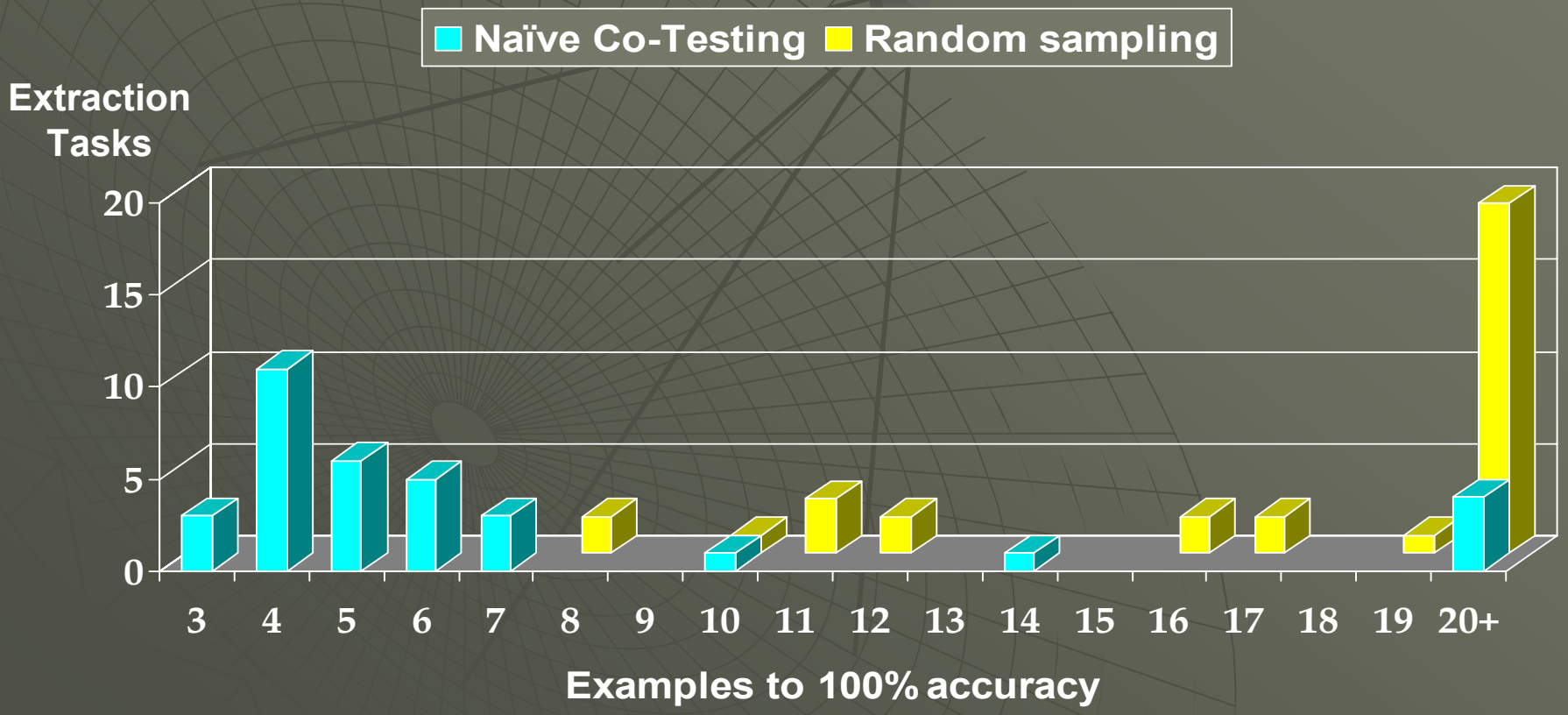
- Naïve Co-Testing:
  - Query: randomly chosen contention point
  - Output: rule with fewest mistakes on queries
- Aggressive Co-Testing:
  - Query: contention point that most violates weak view
  - Output: committee vote (2 rules + weak view)

Results for Random Sampling

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

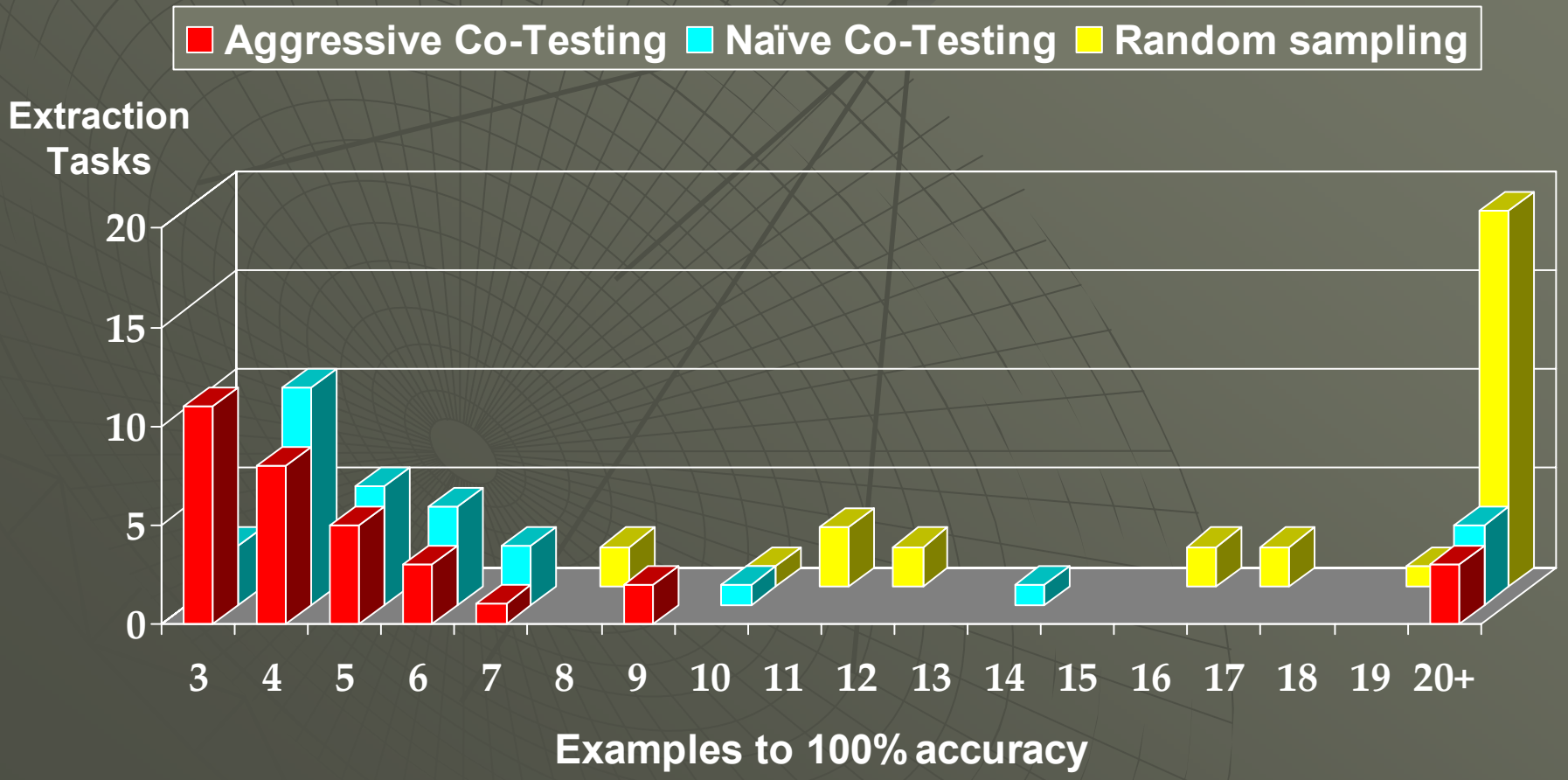


Results for Active Learning



Results for Active Learning with Weak Views

agents@USC



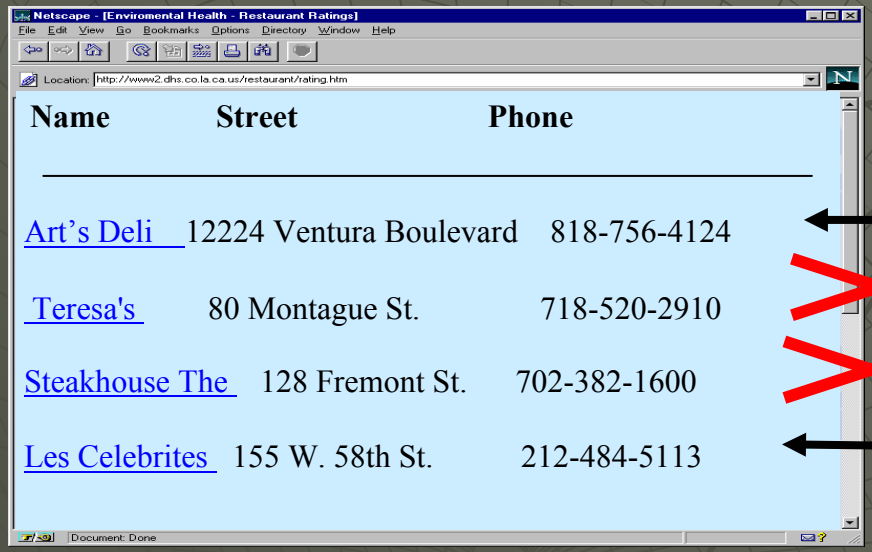
Outline

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

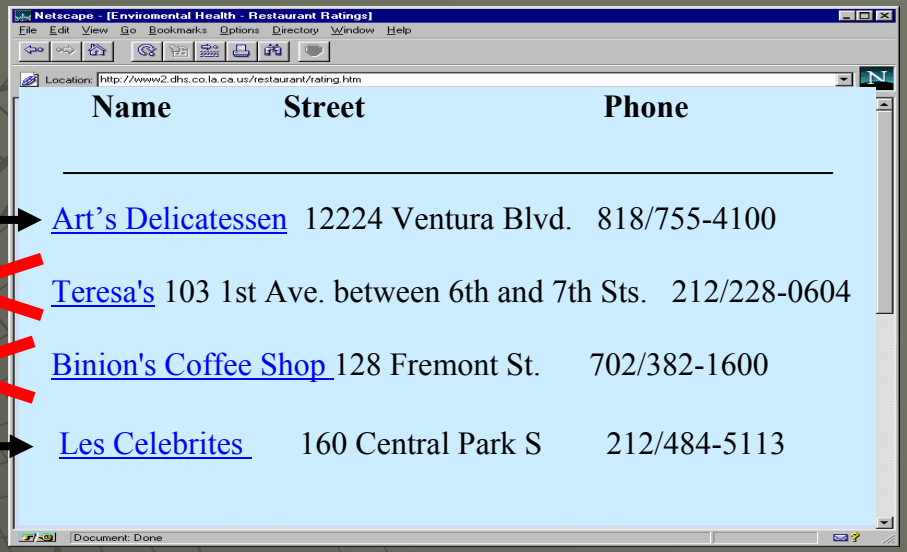
Record Linkage (Object Consolidation)

agents@USC

Zagat's Restaurants



Dept. of Health



Active Learning to Determine Matched Records

[Tejada, Knoblock, Minton '01,'02]

agents@USC

- Learn importance of attributes for matching records

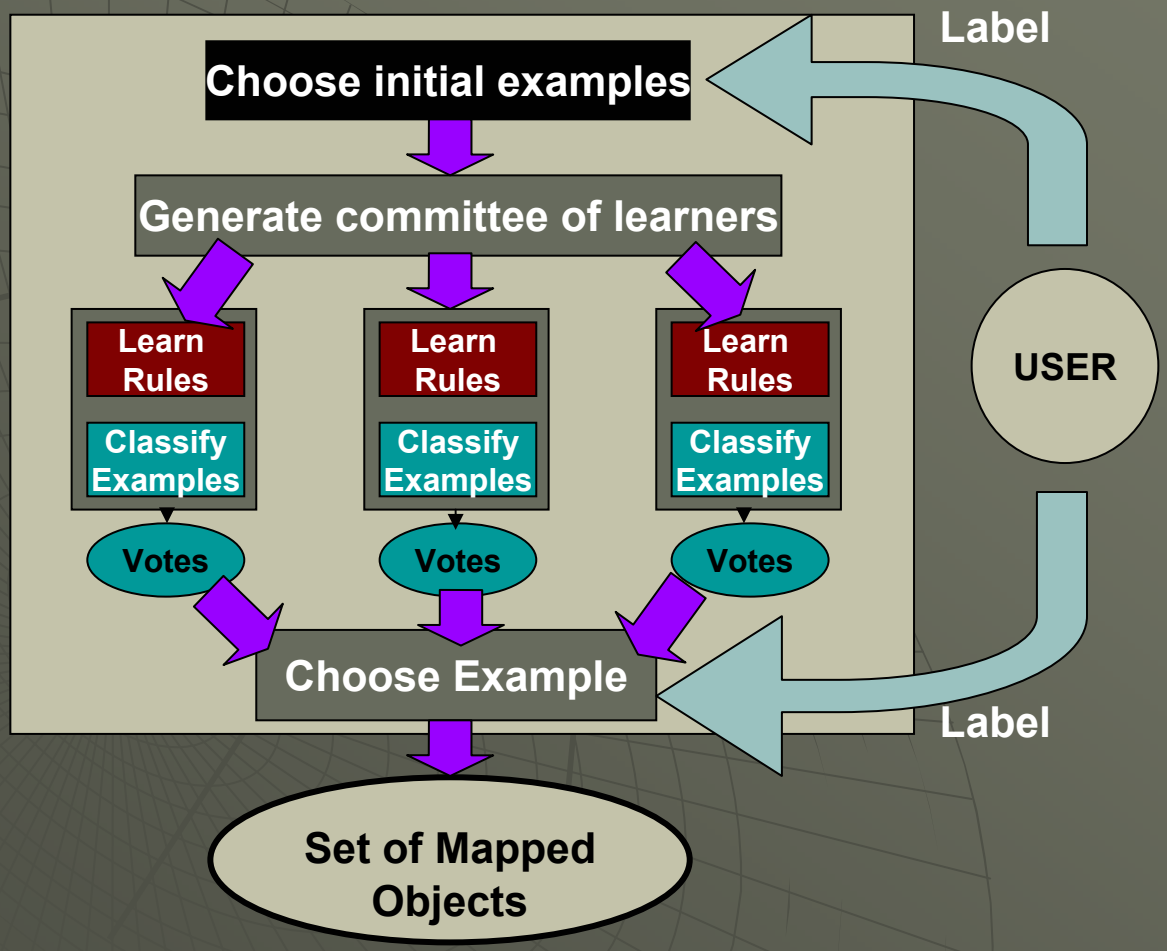
	Name	Street	Phone
Zagat's	Art's Deli	12224 Ventura Boulevard	818-756-4124
Dept of Health	Art's Delicatessen	12224 Ventura Blvd.	818/755-4100

Mapping rules:

Name > .9 & Street > .87 => mapped

Name > .95 & Phone > .96 => mapped

Mapping Rule Learner



Committee Disagreement

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

Examples	Committee M1	M2	M3
Art's Deli, Art's Delicatessen	Yes	Yes	Yes
CPK, California Pizza Kitchen	Yes	No	Yes
Ca'Brea, La Brea Bakery	No	No	No

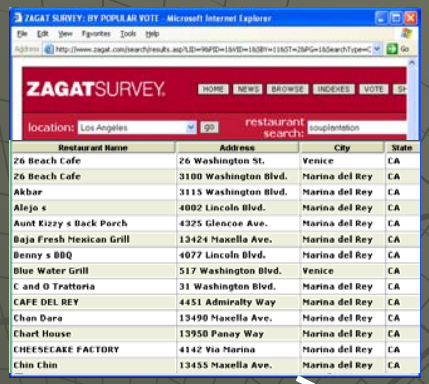
- CPK, California Pizza Kitchen is the most informative example

Exploiting Secondary Sources for Record Linkage
[Michalowski, Thakkar, Knoblock '03]

agents@USC

- 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

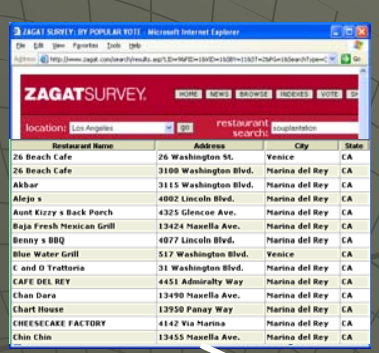


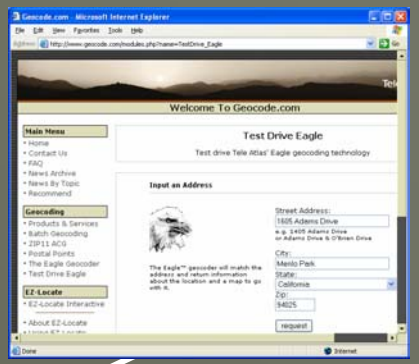
Record Linkage

Matched Records

Data Source	Name	Address	City	State
Zagats	Chart House	13950 Panay Way	Marina del Rey	CA
Dinesite	Chart House	13950 Panay Way	Marina Del Rey	California
Zagats	Killer Shrimp	523 Washington Blvd.	Marina del Rey	CA
Dinesite	Killer Shrimp	523 Washington Boulevard	Marina Del Rey	California
Zagats	CAFE DEL REY	4451 Admiralty Way	Marina del Rey	CA
Dinesite	Cafe Del Rey	4451 Admiralty Way	Marina Del Rey	California
Zagats	Koo Koo Roo	4325 Glencoe Ave.	Marina del Rey	CA
Dinesite	Koo Koo Roo	4325 Glencoe Avenue	Marina Del Rey	California

Exploiting a Geocoder





Secondary Source

Record Linkage

Matched Records

Consolidated Restaurants

Data Source	Name	Address	City	
Zagats	CAFE DEL REY	4451 Admiralty Way	Marina del Rey	CA
Dinesite	Cafe Del Rey	4451 Admiralty Way	Marina Del Rey	Calif
Zagats	Benny s BBQ	4077 Lincoln Blvd.	Marina del Rey	CA
Dinesite	Benny s Bar-B-Q	4077 Lincoln Boulevard	Marina Del Rey	Calif
Zagats	Alejo s	4002 Lincoln Blvd.	Marina del Rey	CA
Dinesite	Alejo Presto Trattoria	4002 Lincoln Boulevard	Marina Del Rey	Calif
Zagats	Aunt Kizzy s Back Porch	4325 Glencoe Ave.	Marina del Rey	CA
[illegible]			Marina Del Rey	Calif
Zagats	26 Beach Cafe	26 Washington St.	Venice	CA
Dinesite	26 Beach Cafe	26 Washington Boulevard	Marina Del Rey	Calif
[illegible]			Marina del Rey	CA
Dinesite	Chart House	13950 Panay Way	Marina Del Rey	Calif
Zagats	Killer Shrimp	523 Washington Blvd.	Marina del Rey	CA
Dinesite	Killer Shrimp	523 Washington Boulevard	Marina Del Rey	Calif
Zagats	Koo Koo Roo	4325 Glencoe Ave.	Marina del Rey	CA
Dinesite	Koo Koo Roo	4325 Glencoe Avenue	Marina Del Rey	Calif

26 Beach Cafe
26 Washington St.
Venice, CA

26 Beach Cafe
26 Washington Boulevard
Marina Del Rey, Calif

Preliminary Results: Secondary Sources

# Labeled Examples	Total Correct Matches	Without Secondary Source			With Secondary Source		
		Precision	Recall	Average DT Depth	Precision	Recall	Average DT Depth
25	109	51%	33%	5	66%	51%	1
35	109	73%	57%	8	81%	68%	3
50	109	83%	81%	10	85%	85%	3

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

Outline

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

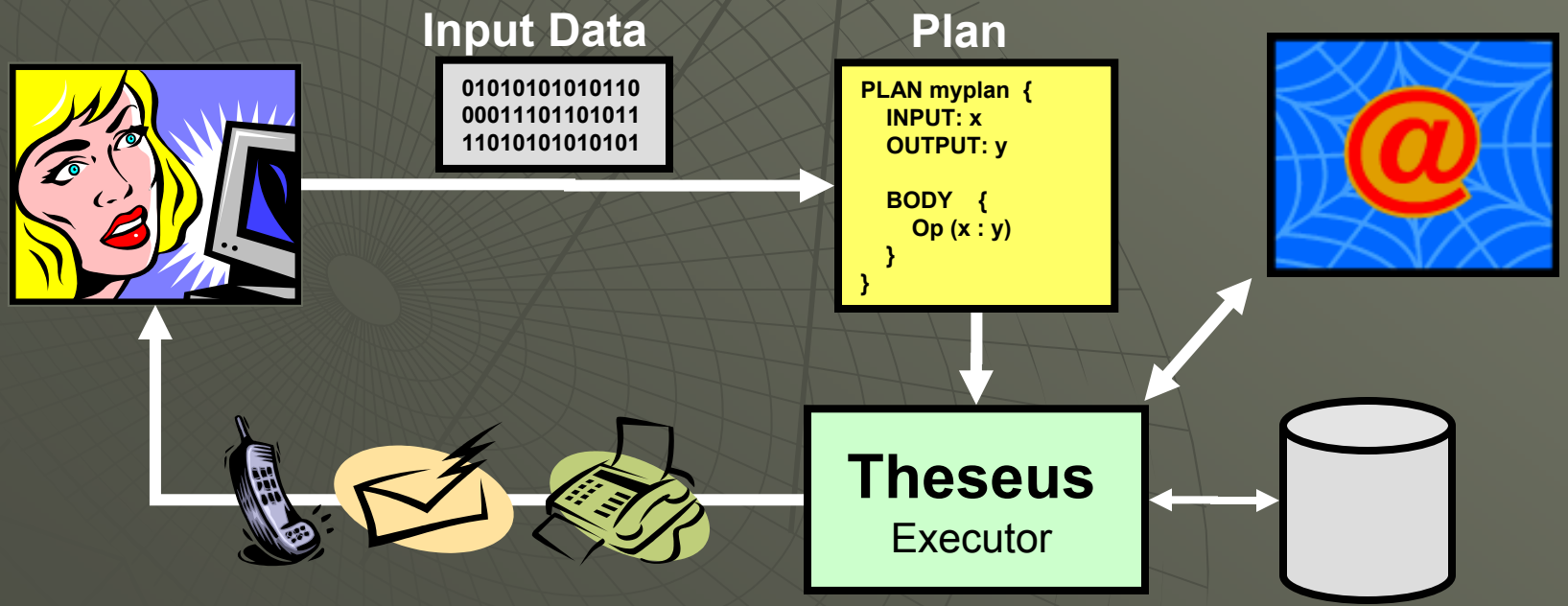
Efficiently Executing Agent Plans

agents@USC

- **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

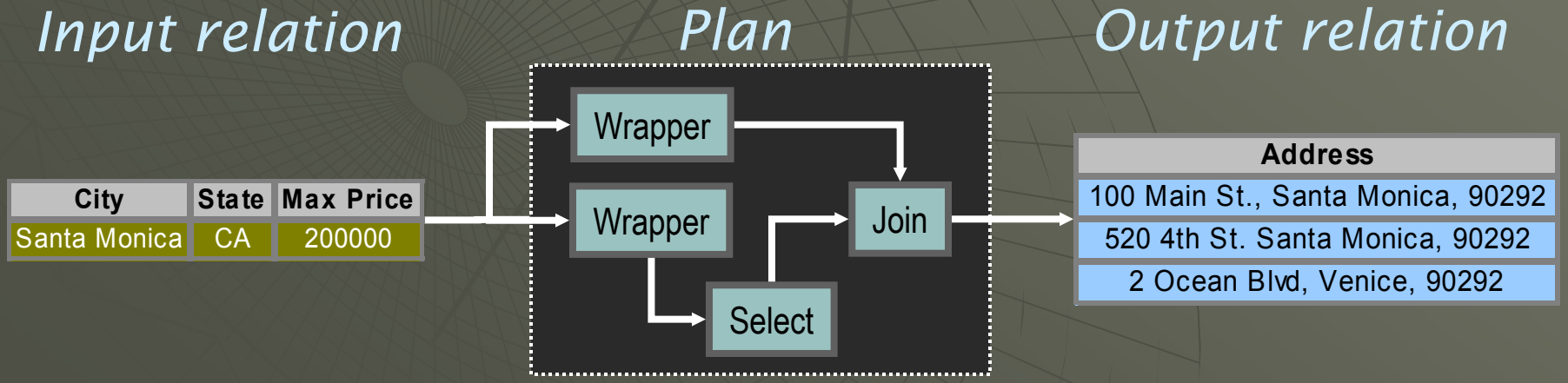
Theseus Agent Execution System
[Barish & Knoblock, '02]

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



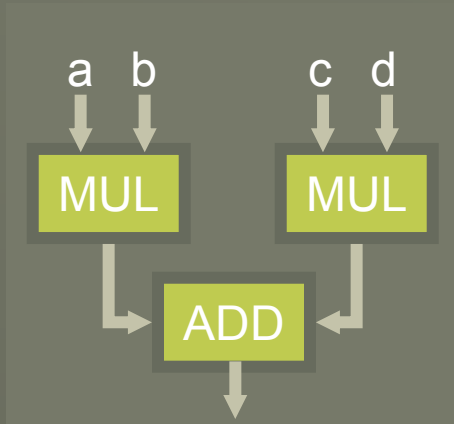
Streaming Dataflow

- 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

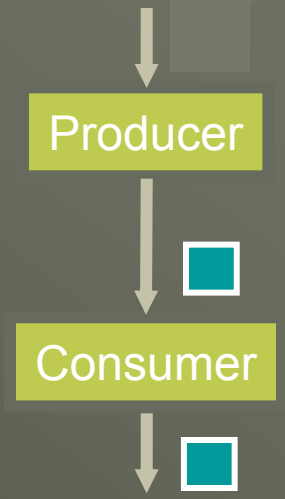


Parallelism in Streaming Dataflow

- **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

The CarInfo agent

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

agents@USC

1. **Locate cars that meet criteria**
   - Edmunds.com
2. **Filter out Oldsmobiles**
3. **Gather safety reviews for each**
   - NHSTA.gov

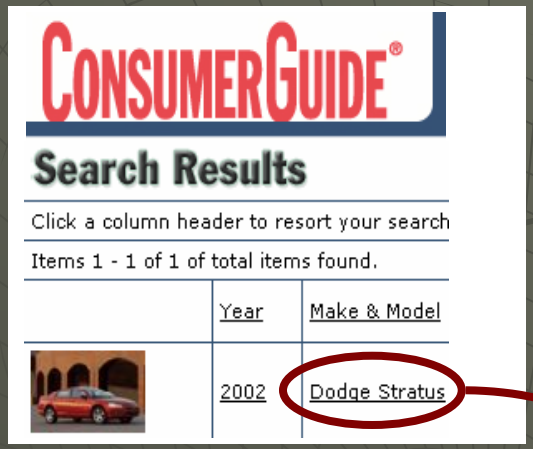
The CarInfo agent

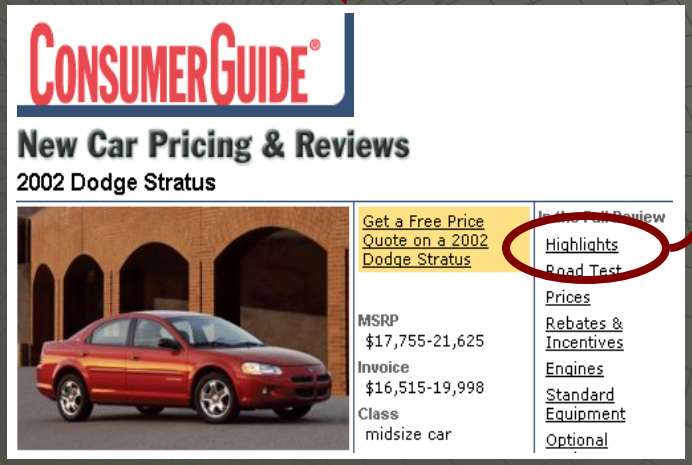
agents@USC

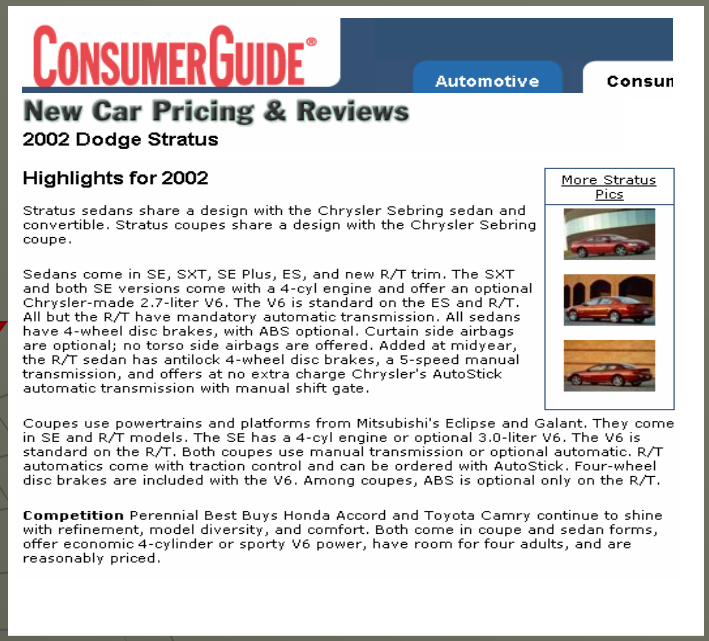
1. **Locate cars that meet criteria**
   - Edmunds.com
2. **Filter out Oldsmobiles**
3. **Gather safety reviews for each**
   - NHSTA.gov
4. **Gather detailed reviews of each**
   - ConsumerGuide.com

ConsumerGuide Navigation

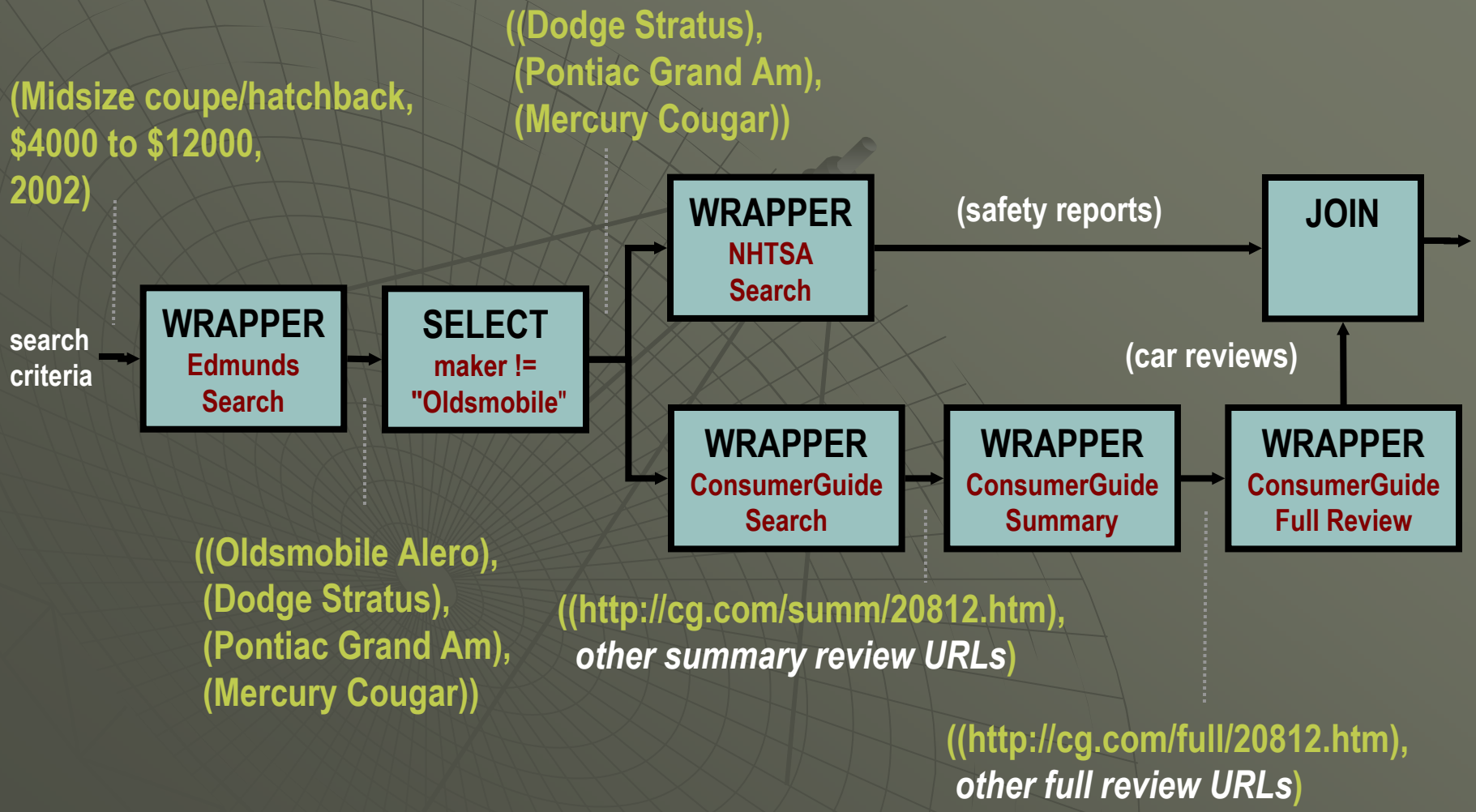
- Requires navigating through multiple pages







Dataflow-style CarInfo agent plan

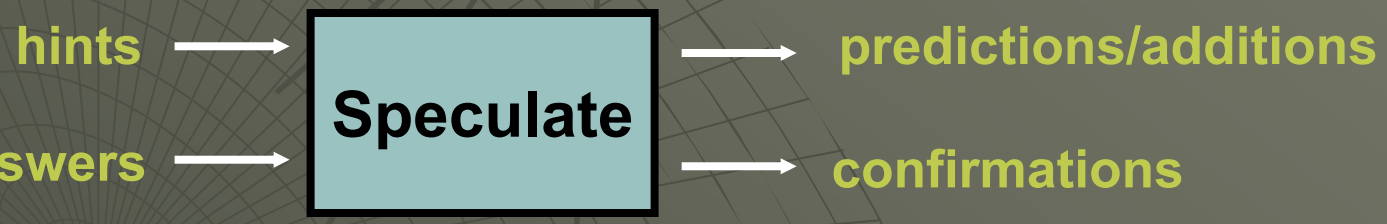


Speculative Execution
[Barish & Knoblock '02, '03]

- 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"

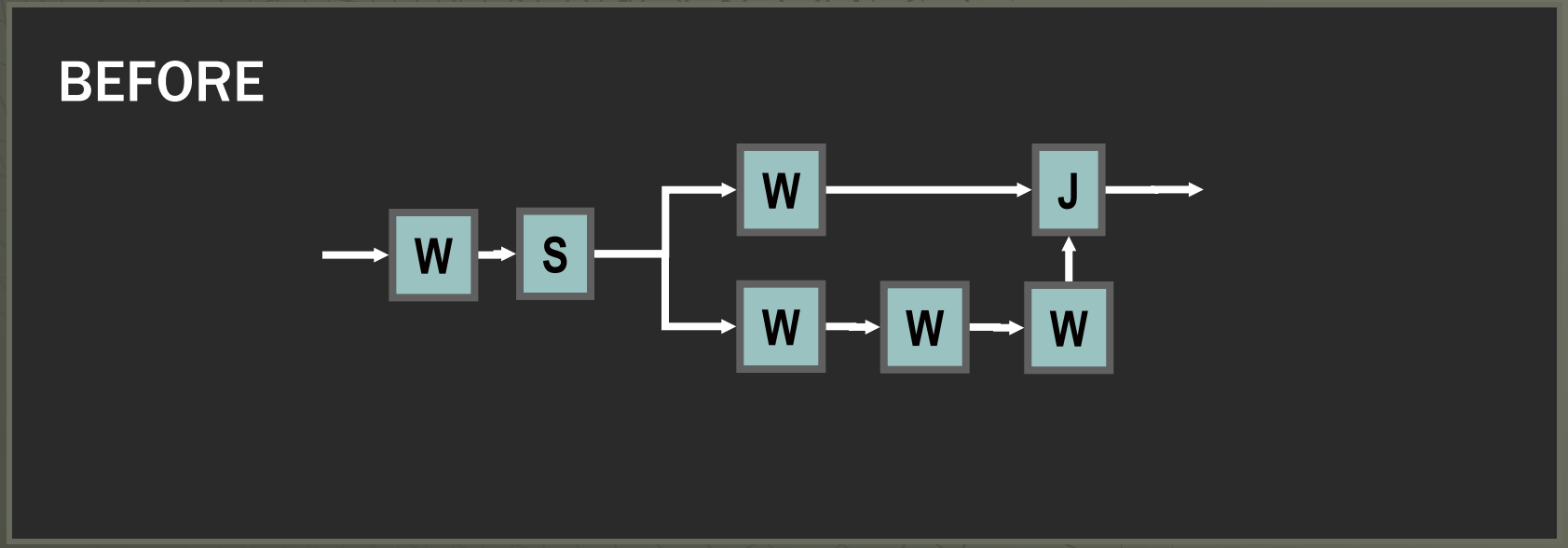


  - **Confirm**: Prevents errant results from exiting plan

How to speculate?

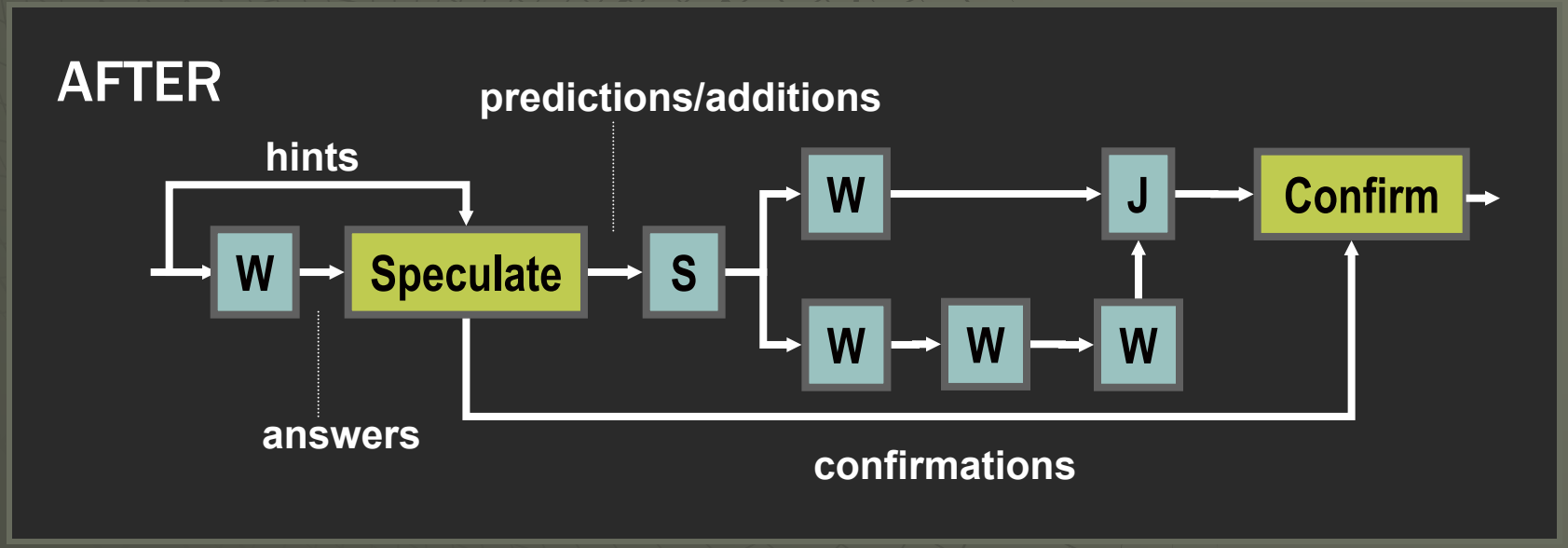
agents@USC

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

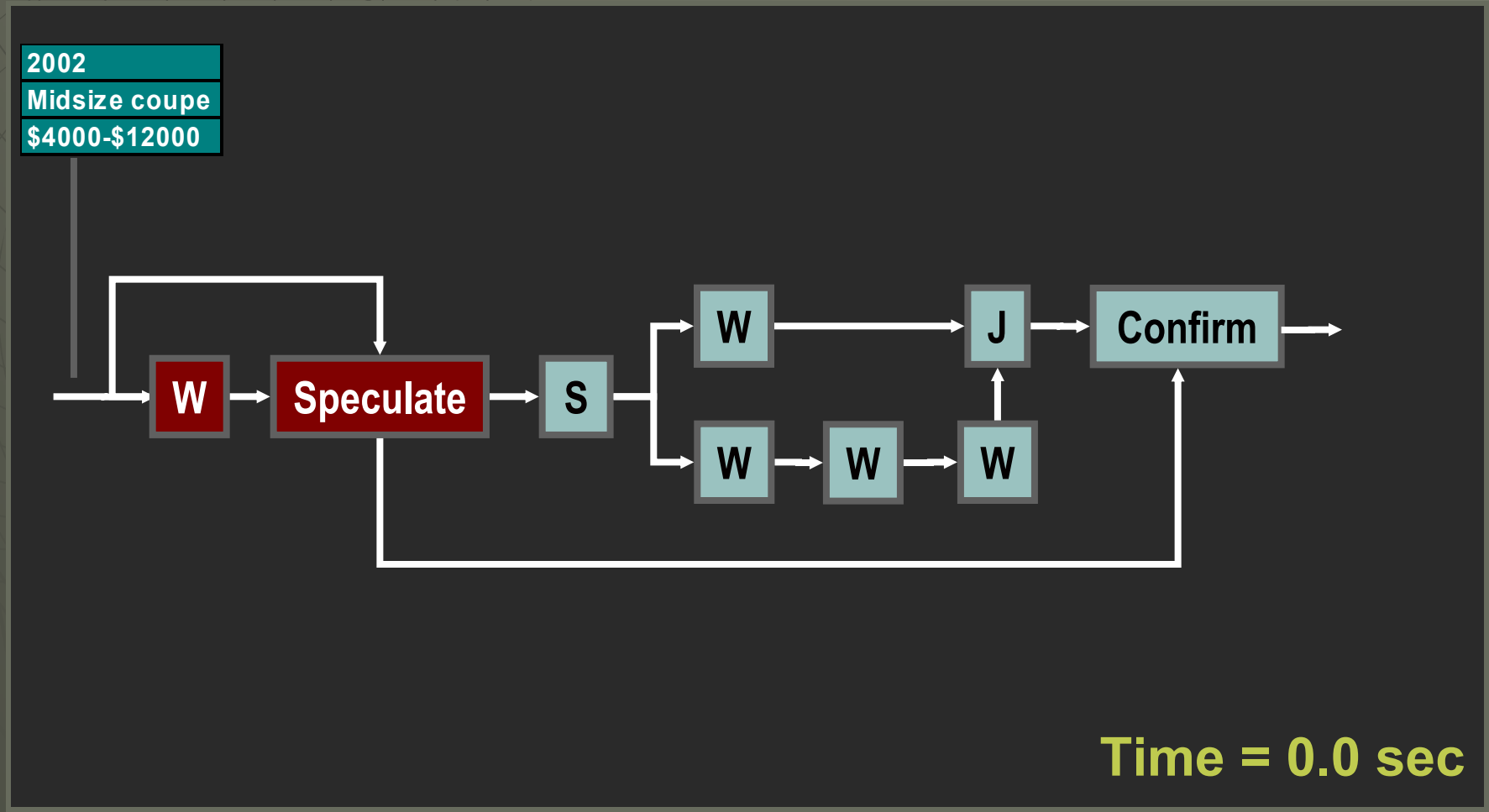


How to speculate?

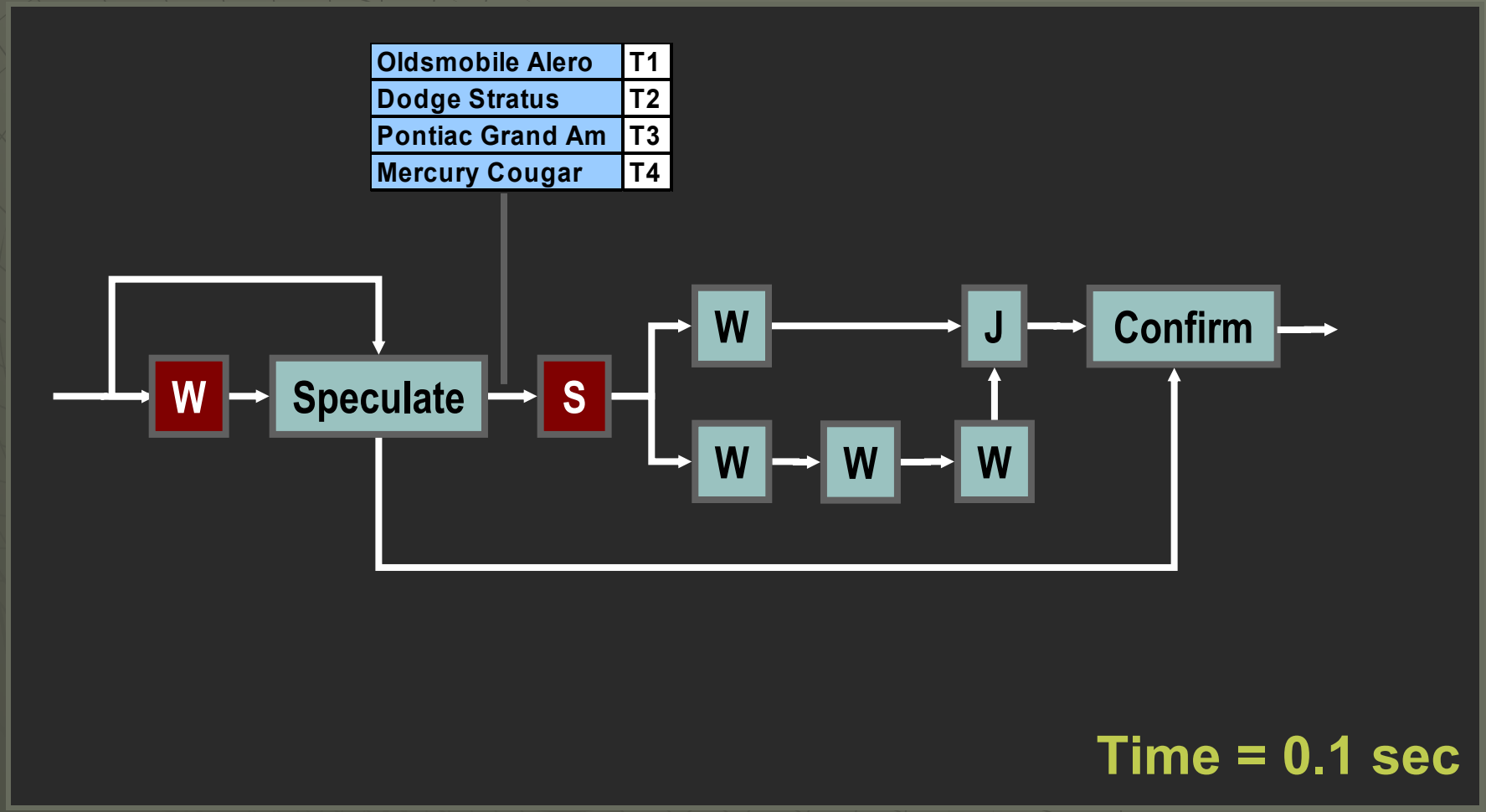
- Example: CarInfo
  - Predict cars based on search criteria
  - Makes practical sense:
    - Same criteria yields same cars



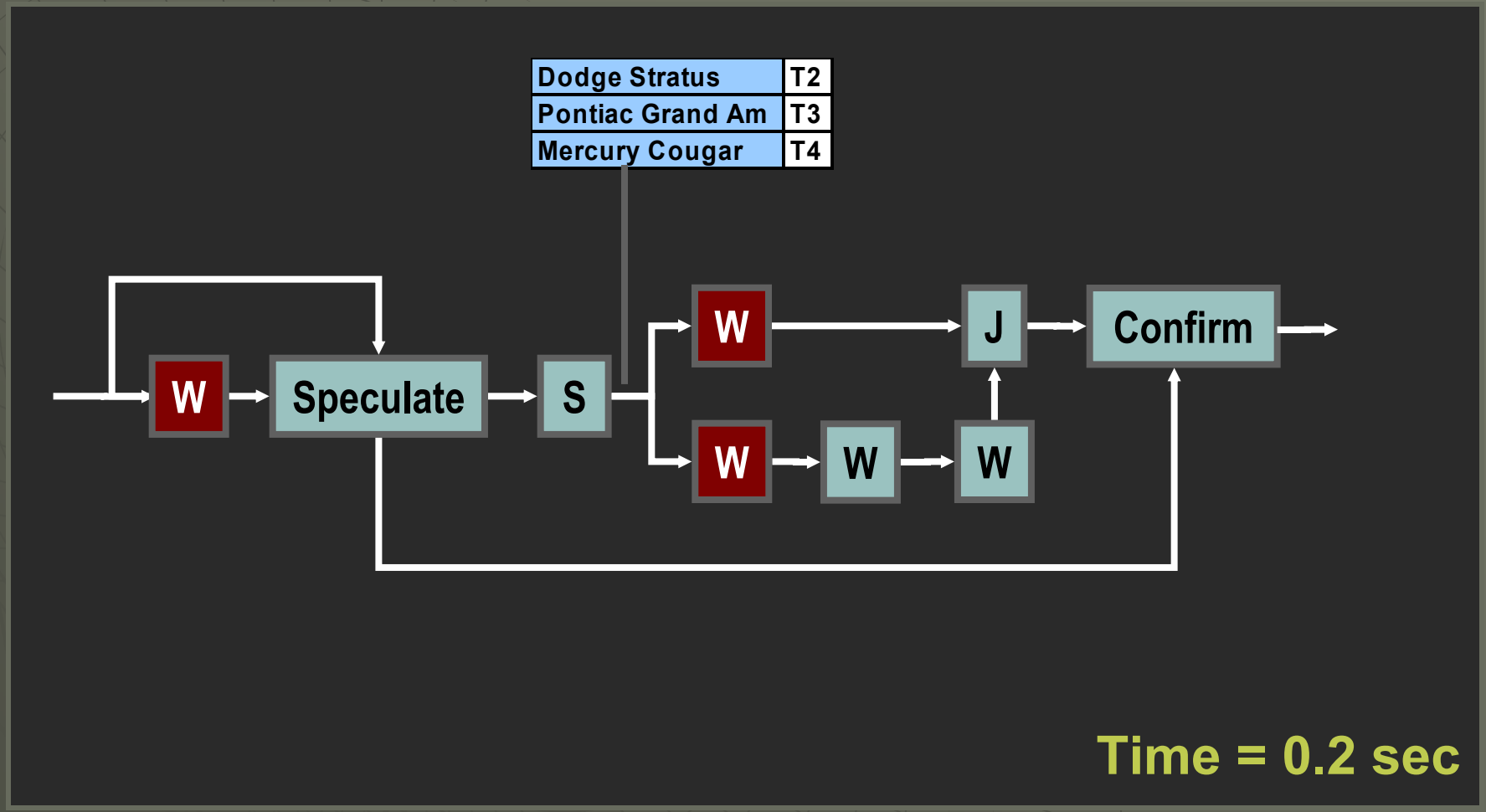
Detailed example



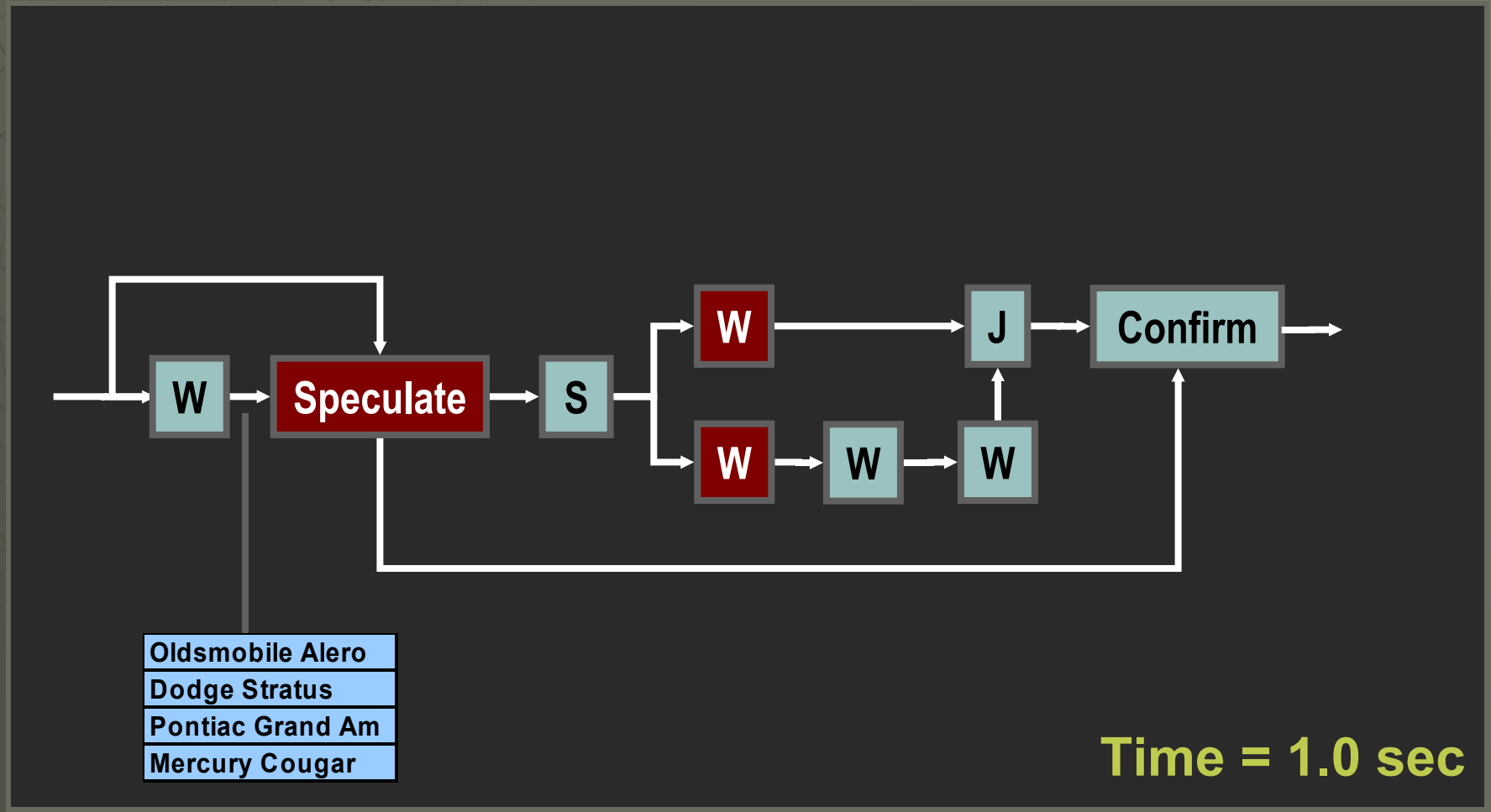
Issuing predictions



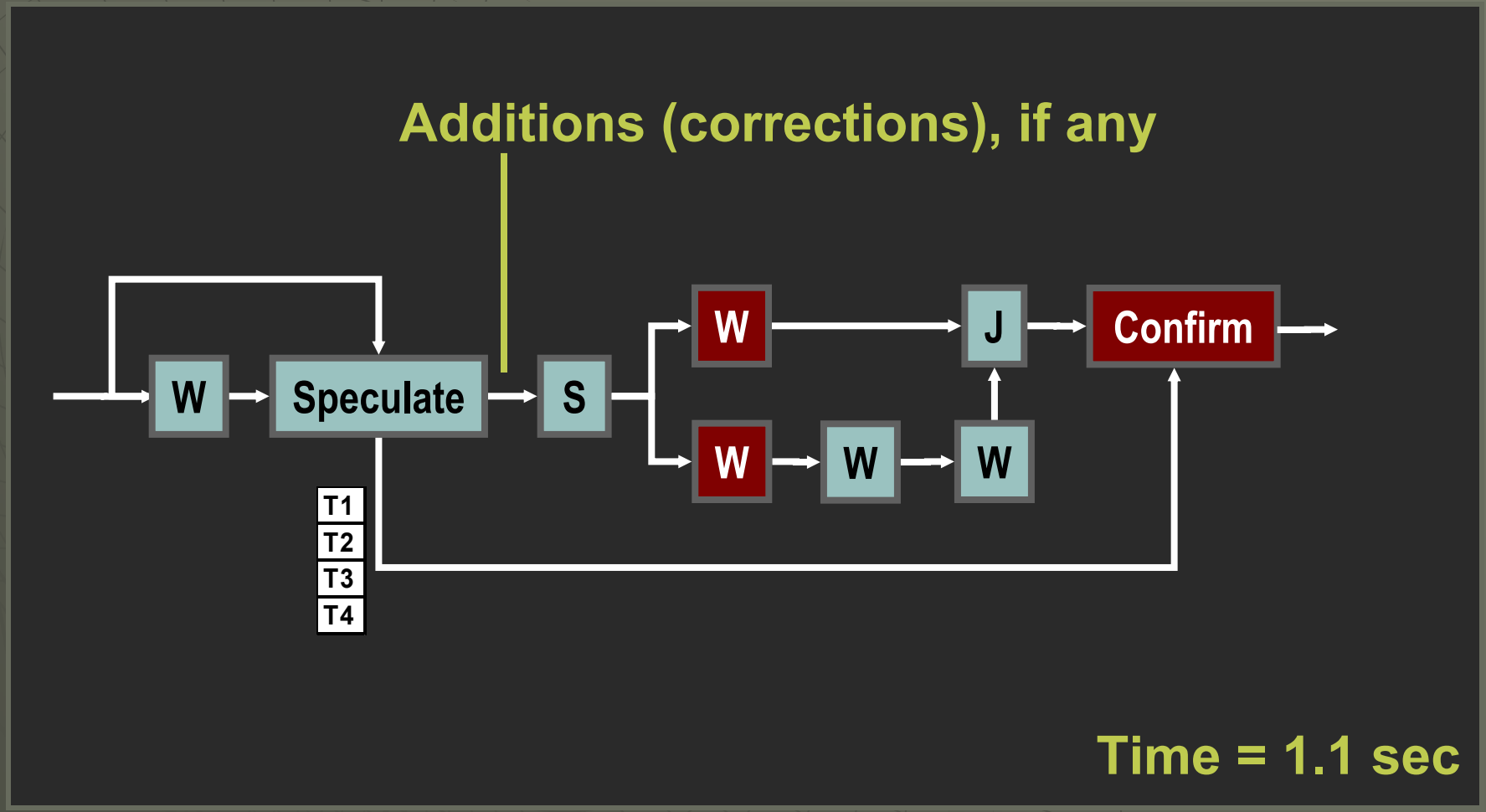
Speculative parallelism



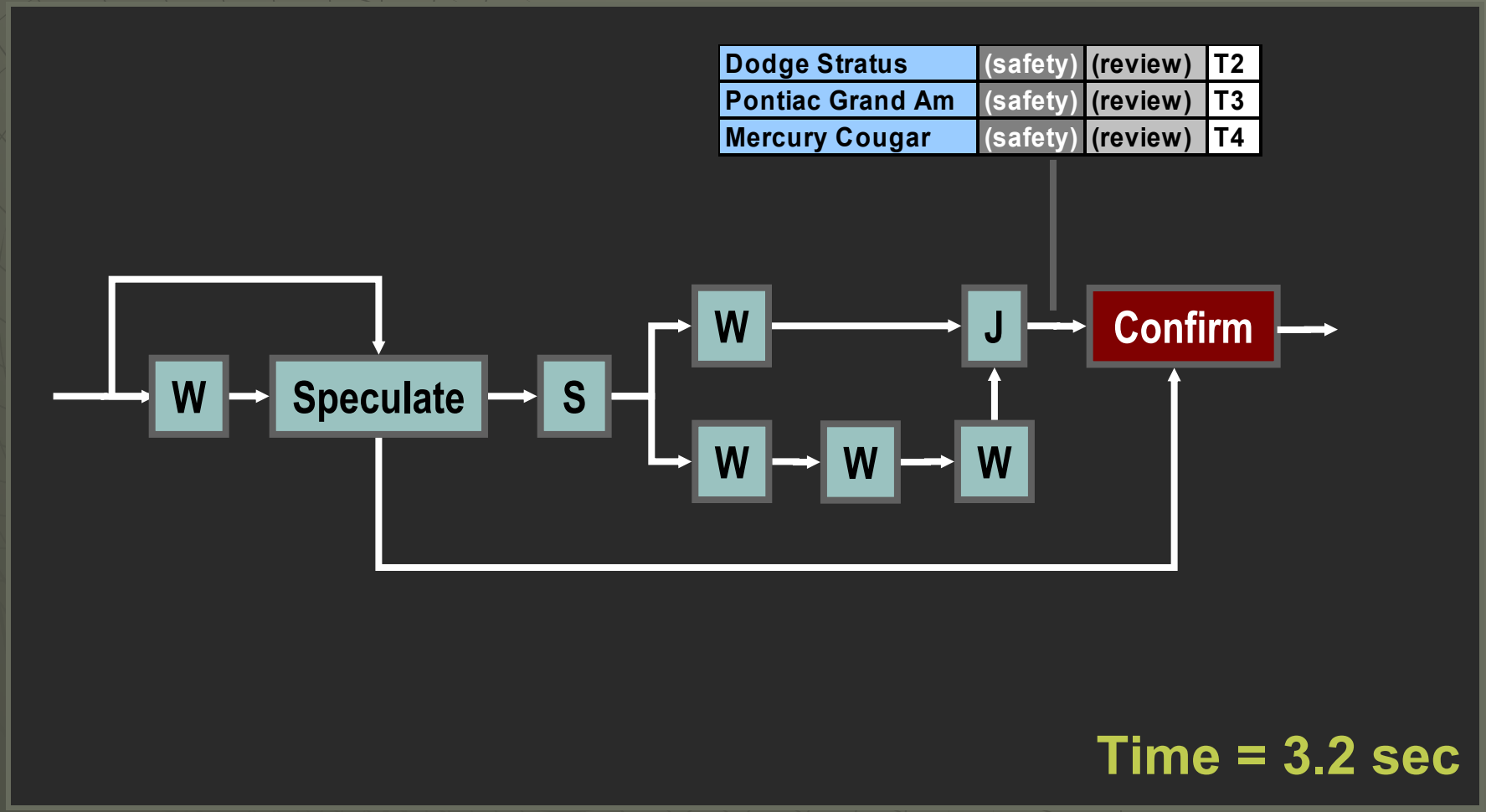
Answers to hints



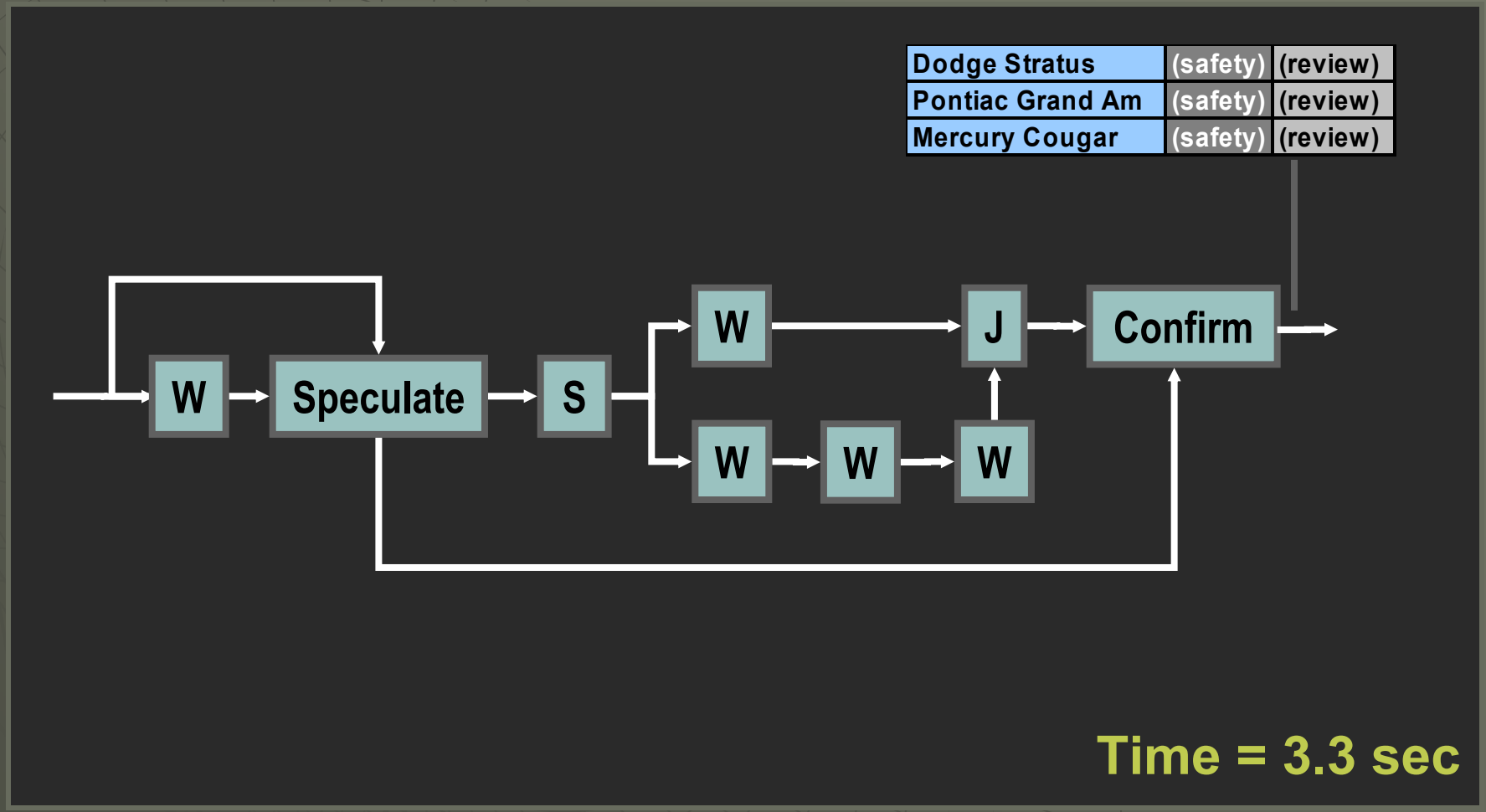
Continued processing



Generation of final results



Confirmation of results

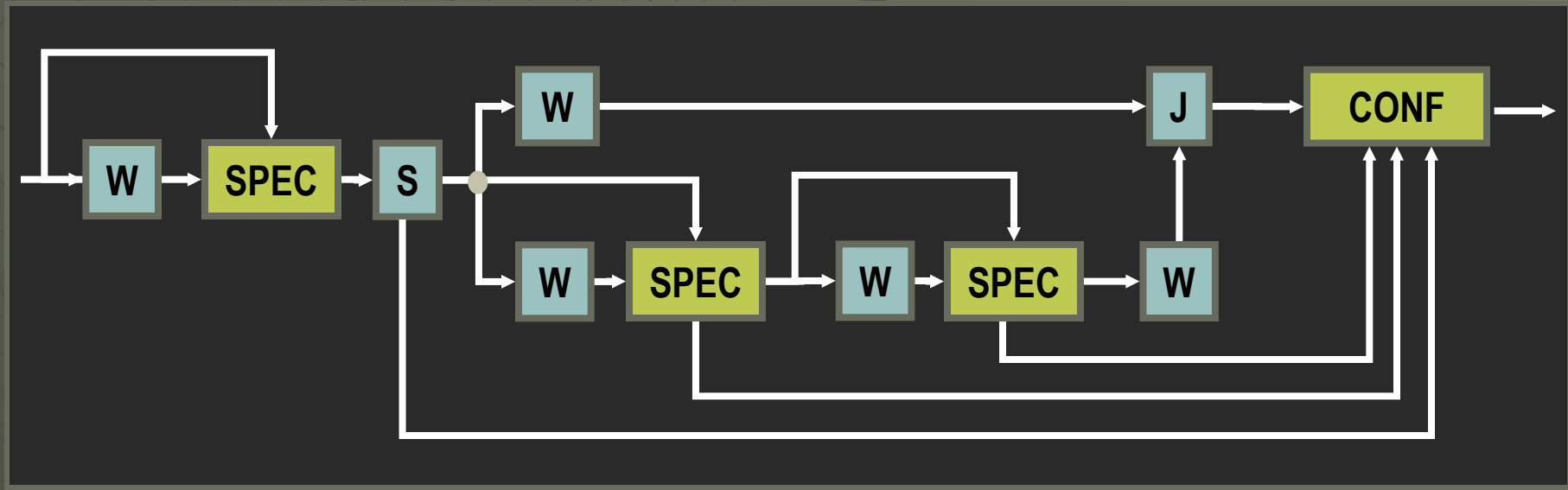


Safety and fairness

- 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: **max** {1.2, 1.4, 1.5, 1.6} = **1.6 sec**
  - Speedup over streaming dataflow: (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

Year	Type	Min	Max	Car list
2002	Midsize	8000	15000	(Oldmobile Alero, Dodge Stratus)
2002	Midsize	7500	14500	(Oldmobile Alero, Dodge Stratus)
2002	SUV	14000	20000	(Nissan Pathfinder, Ford Explorer)
2001	Midsize	11000	18000	(Honda Accord, Toyota Camry)
2002	SUV	18000	22000	(Nissan Pathfinder, Ford Explorer)

Cache

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

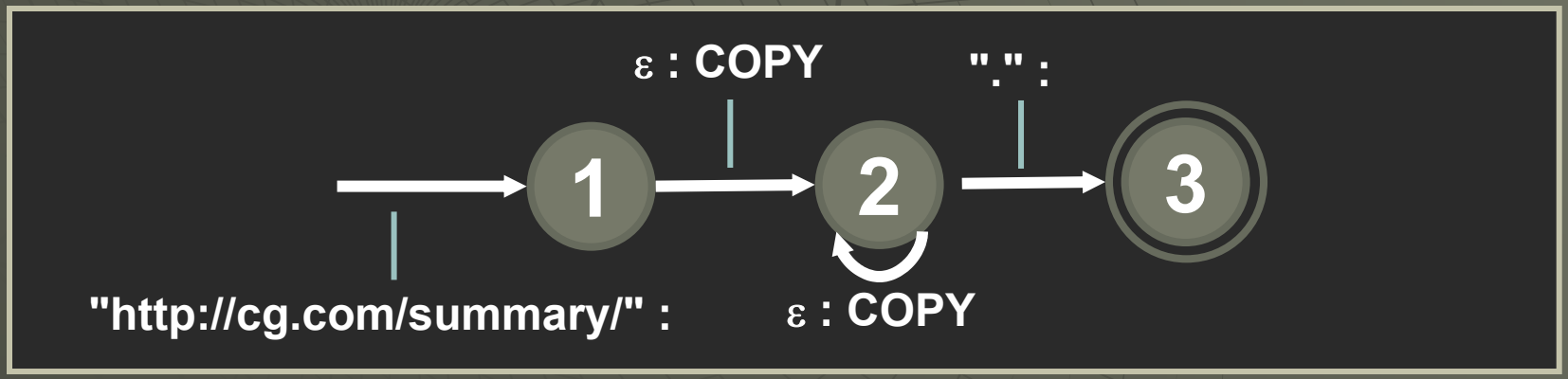
- Transduction
  - Transducers are FSM that translate hints into predictions

http://cg.com/summary/20812.htm

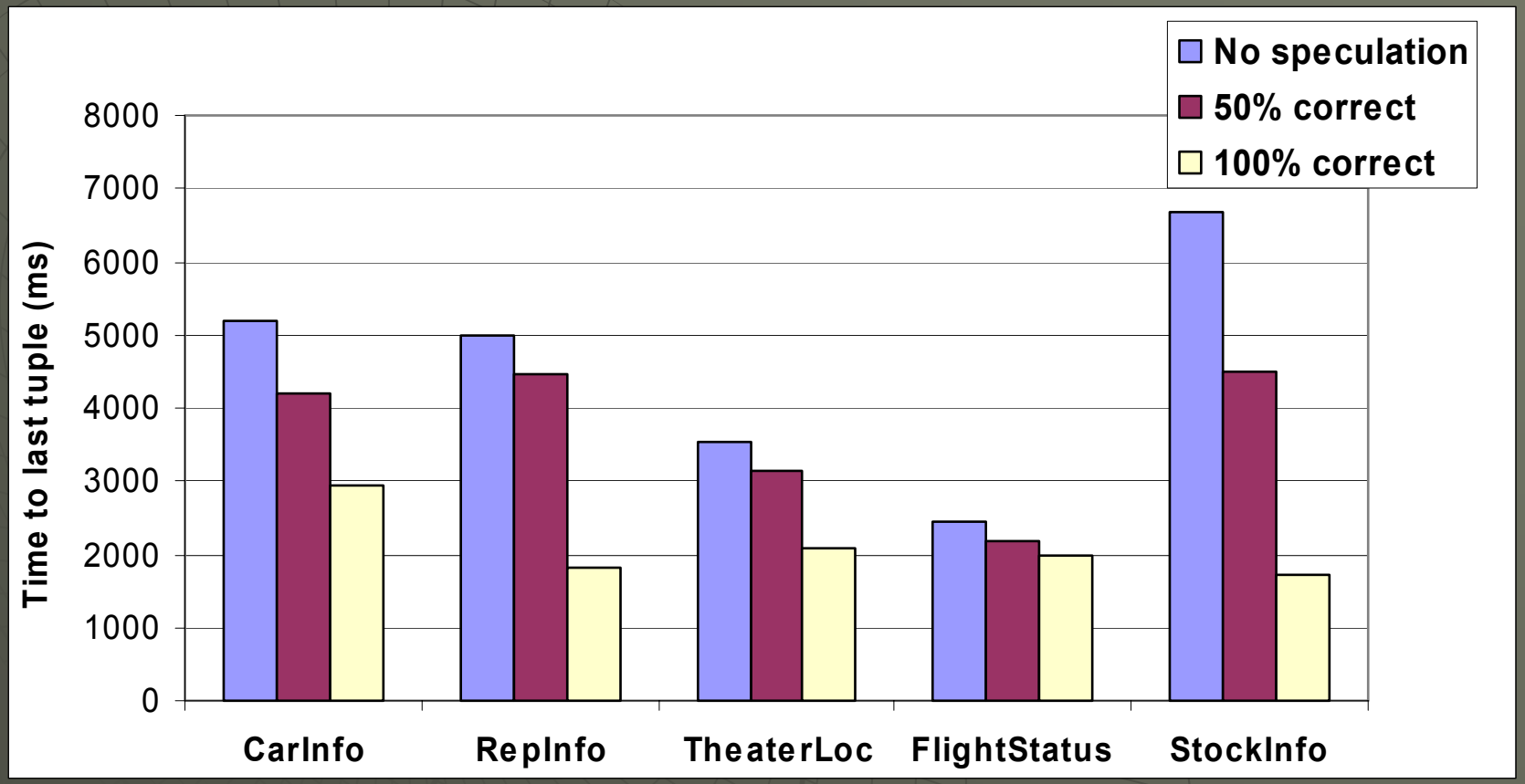
http://cg.com/full/20812.htm

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



Outline of talk

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

Planning to Compose Web Services

[Thakkar, Knoblock, & Ambite, '03]

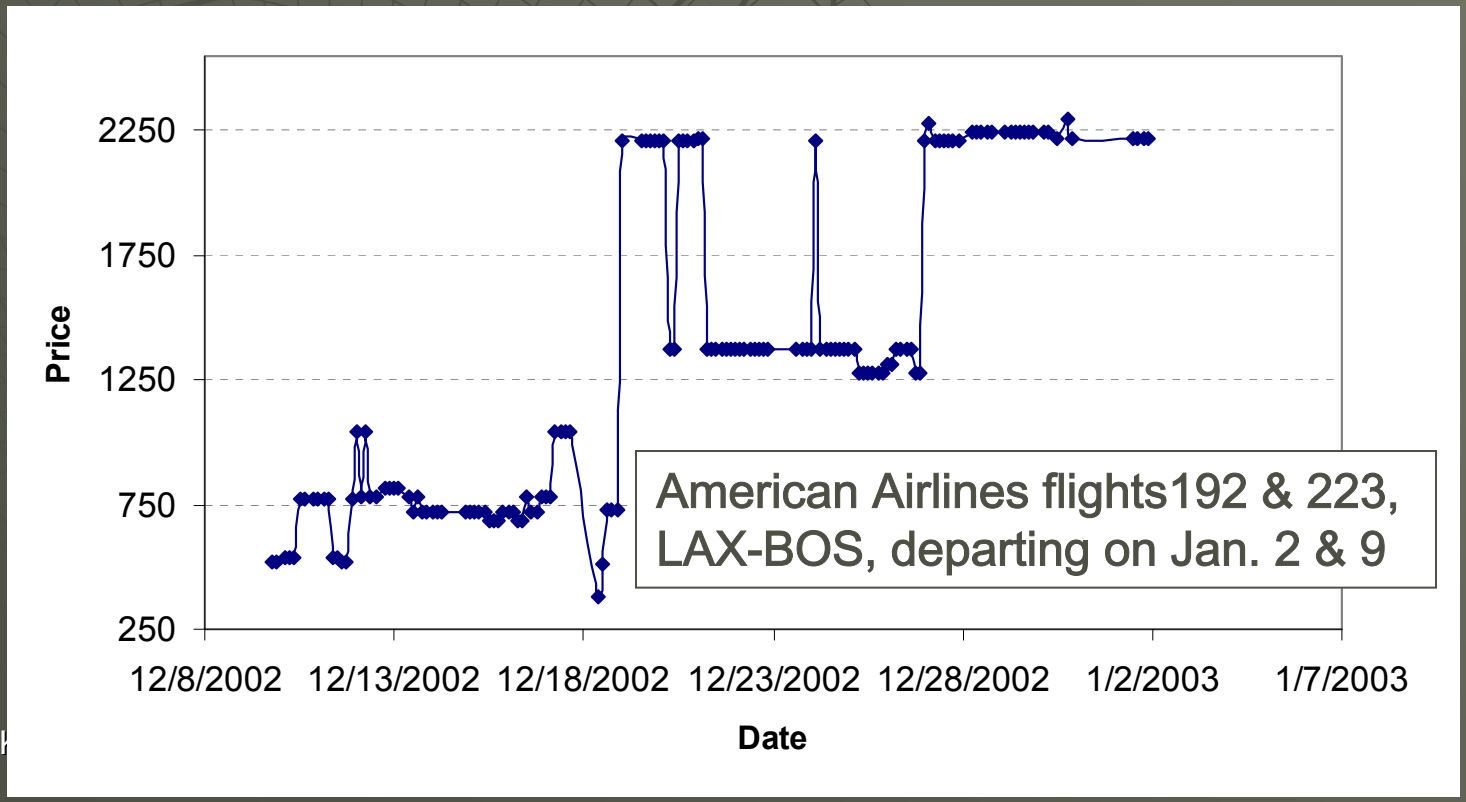
agents@USC

- Goal: Automatically compose new services from existing web services
- We developed services that can dynamically compose information producing services
  - Builds on data integration techniques to construct plans
  - Turns the plans into Theseus plans for efficient execution
- We are extending this work to more complex services that can change the world (side effects)

Learning to Make Predictions: To Buy or Not To Buy

agents@USC

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



Learning to Make Predictions: To Buy or Not To Buy

agents@USC

- 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…

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]

Outline of talk

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

Conclusions

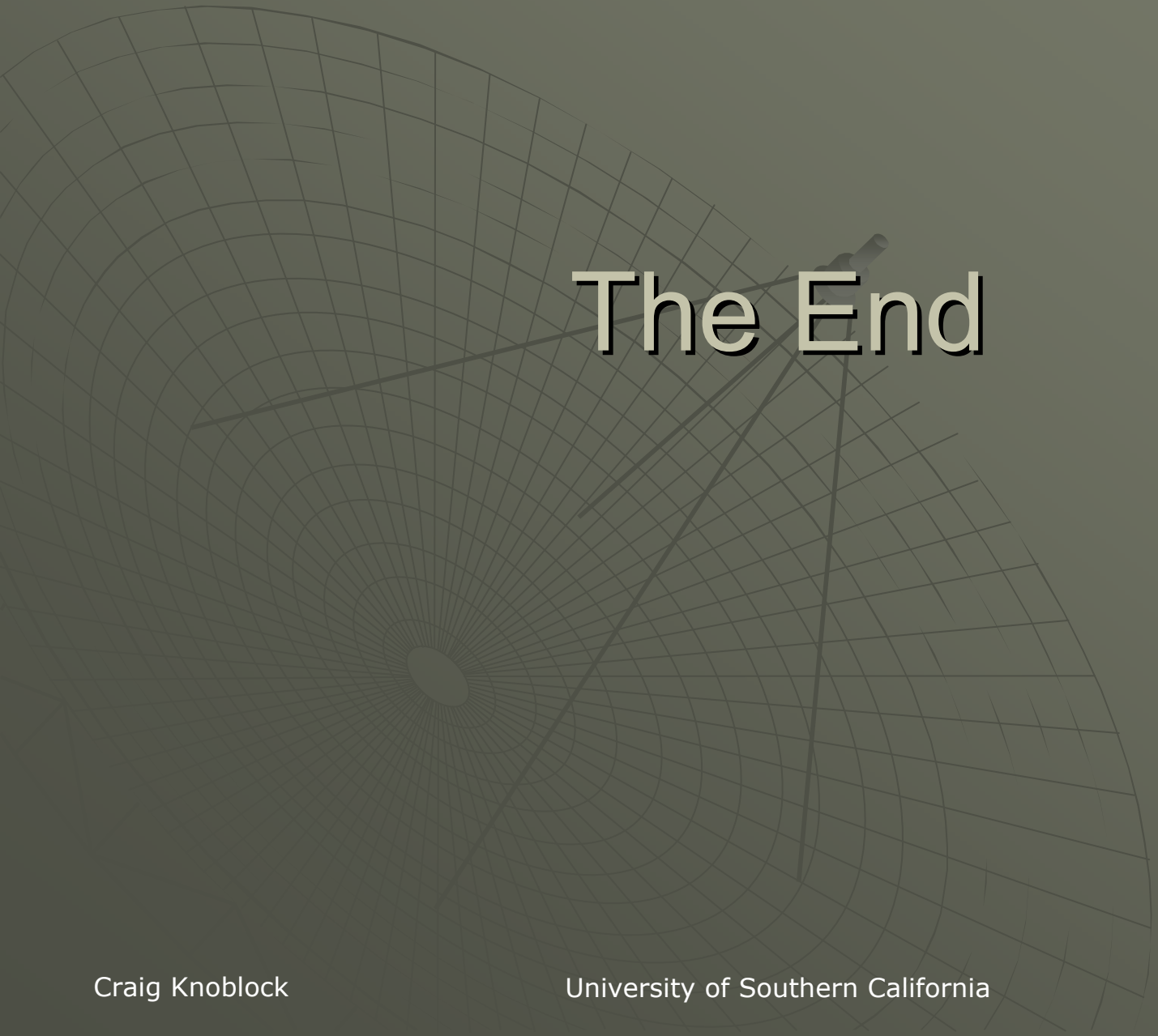
- Web provides the ideal environment for developing and testing software agents
  - Noted by Etzioni, AAAI'96 in his talk on Softbots
- Yet few have seized this opportunity…why?
- Like robotics, wide variety of hard technical problems
- With Web Services, the Semantic Web, etc. the infrastructure is 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

Conclusions (cont.)

- 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

More Information

- My home page: http://www.isi.edu/~knoblock
- IJCAI'03 Workshop on Information Integration on the Web
  - Proceedings available online (pointer from my homepage)



The End