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School of Engineering

Automatic Source Modeling

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Based on slides by Mark Carman, Craig Knoblock
Jose Luis Ambite and Kristina Lerman

Source Modeling vs. Schema Matching

- Schema Matching/Mapping
  - Align schemas between data sources
  - Assumes static sources and complete access to data
  - Schema Mapping does provide queries to map between sources
- Source Modeling
  - Incrementally build models from partial data (e.g., web services, html forms, programs)
  - Model not just the fields but the source types and even the function of a source
  - Support richer source models (a la Semantic Web) that describe the contents of sources

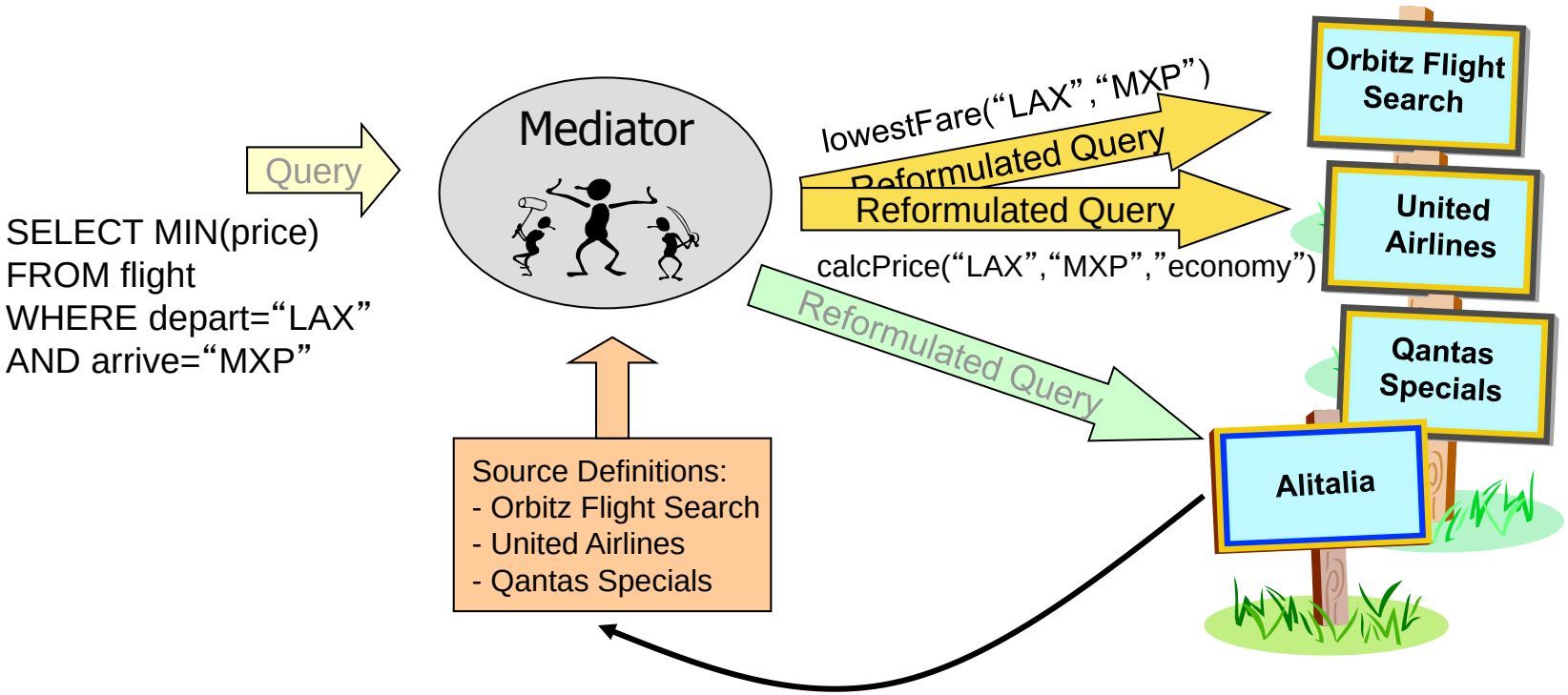
Overview

- **Learning Semantic Descriptions of Web Information Sources**
  - Integrated approach to learning semantic definitions of a source
  - Needs to invoke the source
  - Learn Datalog description of the source: LAV mapping

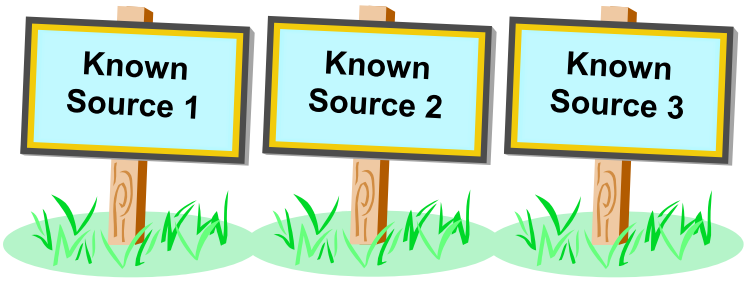
- **Automatically Constructing Semantic Web Services from Online Sources**
  - Deimos: End to end system for discovering and modeling sources
  - Uses system above to automatically discover semantic definitions of discovered sources

Mediators Require Source Definitions

- New service => no source definition!
- Can we discover a definition automatically?



Inducing Source Definitions by Example

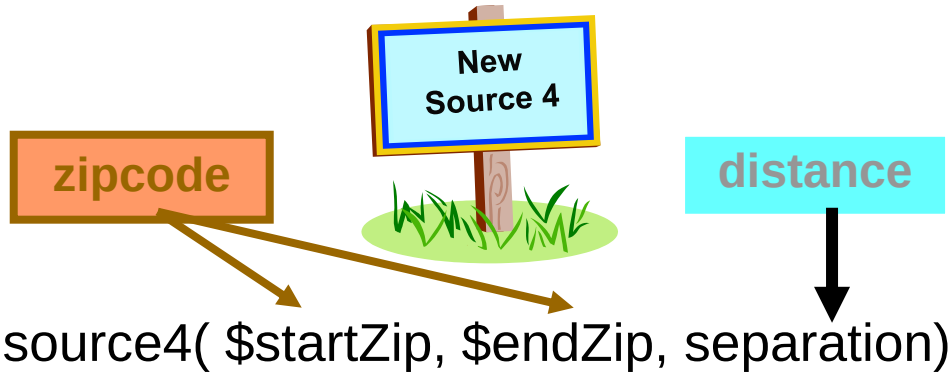



```
source1($zip, lat, long) :-
    centroid(zip, lat, long).

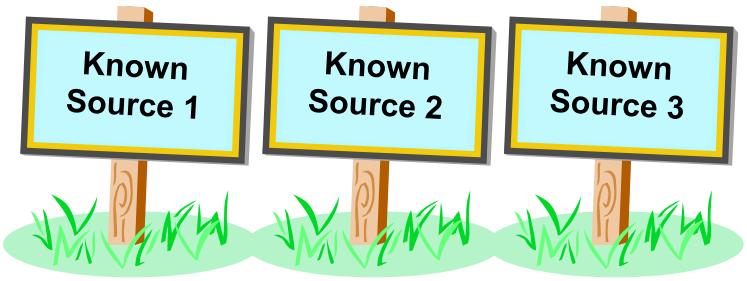
source2($lat1, $long1, $lat2, $long2, dist) :-
    greatCircleDist(lat1, long1, lat2, long2, dist).

source3($dist1, dist2) :-
    convertKm2Mi(dist1, dist2).
```

- Step 1: classify input & output semantic types



Inducing Source Definitions - Step 2



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convertKm2Mi(dist1, dist2).

- Step 1: classify input & output semantic types
- Step 2: generate plausible definitions

source4($zip1, $zip2, dist):-
source1(zip1, lat1, long1),
source1(zip2, lat2, long2),
source2(lat1, long1, lat2, long2, dist2),
source3(dist2, dist).

source4($zip1, $zip2, dist):-
centroid(zip1, lat1, long1),
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convertKm2Mi(dist1, dist2).

Inducing Source Definitions – Step 3

- Step 1: classify input & output semantic types
- Step 2: generate plausible definitions
- Step 3: invoke service & compare output

```
source4($zip1, $zip2, dist):-
    source1(zip1, lat1, long1),
    source1(zip2, lat2, long2),
    source2(lat1, long1, lat2, long2, dist2),
    source3(dist2, dist).
```

```
source4($zip1, $zip2, dist):-
    centroid(zip1, lat1, long1),
    centroid(zip2, lat2, long2),
    greatCircleDist(lat1, long1, lat2, long2, dist2),
    convertKm2Mi(dist1, dist2).
```

match

$zip1	$zip2	dist *(actual)*	dist *(predicted)*
80210	90266	842.37	843.65
60601	15201	410.31	410.83
10005	35555	899.50	899.21

Searching for Definitions

- Search space of *conjunctive queries:*

  target(X) :- source1(X_1), source2(X_2), …
- For scalability don't allow negation or union
- Perform Top-Down Best-First Search

Expressive Language
Sufficient for modeling most online sources

1. First sample the New Source

Invoke ***target*** with set of random inputs;
Add empty clause to ***queue***;
while (***queue*** not empty)
v := best definition from ***queue***;
forall (***v'*** in **Expand(*v*)**)
if (**Eval(*v'*)** > **Eval(*v*)**)
insert ***v'*** into ***queue***;

2. Then perform best-first search through space of candidate definitions

Invoking the Target

Generate Input Tuples: *<zip1, dist1>*

Invoke

source5($zip1, $dist1, zip2, dist2)

Invoke source with *representative* values

- Try randomly generating input tuples:
  - Combine examples of each type
  - Use distribution if available

Randomly Combined Example Values

Input <zip1, dist1>	**Output** <zip2, dist2>
<07307, 50.94>	{<07097, 0.26>, <07030, 0.83>, <07310, 1.09>, ...}
<60632, 10874.2>	{}

Non-empty Result

Empty Result

Invoking the Target

Generate Input Tuples: *<zip1, dist1>*

Invoke

source5($zip1, $dist1, zip2, dist2)

Invoke source with *representative* values

- Try randomly generating input tuples:
  - Combine examples of each type
  - Use distribution if available
- If *only empty invocations* result
  - Try *invoking other sources* to generate input
- Continue until sufficient non-empty invocations result

Top-down Generation of Candidates

Start with empty clause & generate specialisations by

- Adding one predicate at a time from set of sources
- Checking that each definition is:
  - Not logically redundant
  - Executable (binding constraints satisfied)

source5($zip1,$dist1,zip2,dist2)

source5(_,_,_,_).

Expand

source5(zip1,_,_,_) :- **source4**(zip1,zip1,_).
source5(zip1,_,zip2,dist2) :- **source4**(zip2,zip1,dist2).
source5(_,dist1,_,dist2) :- **<**(dist2,dist1).
…

Best-first Enumeration of Candidates

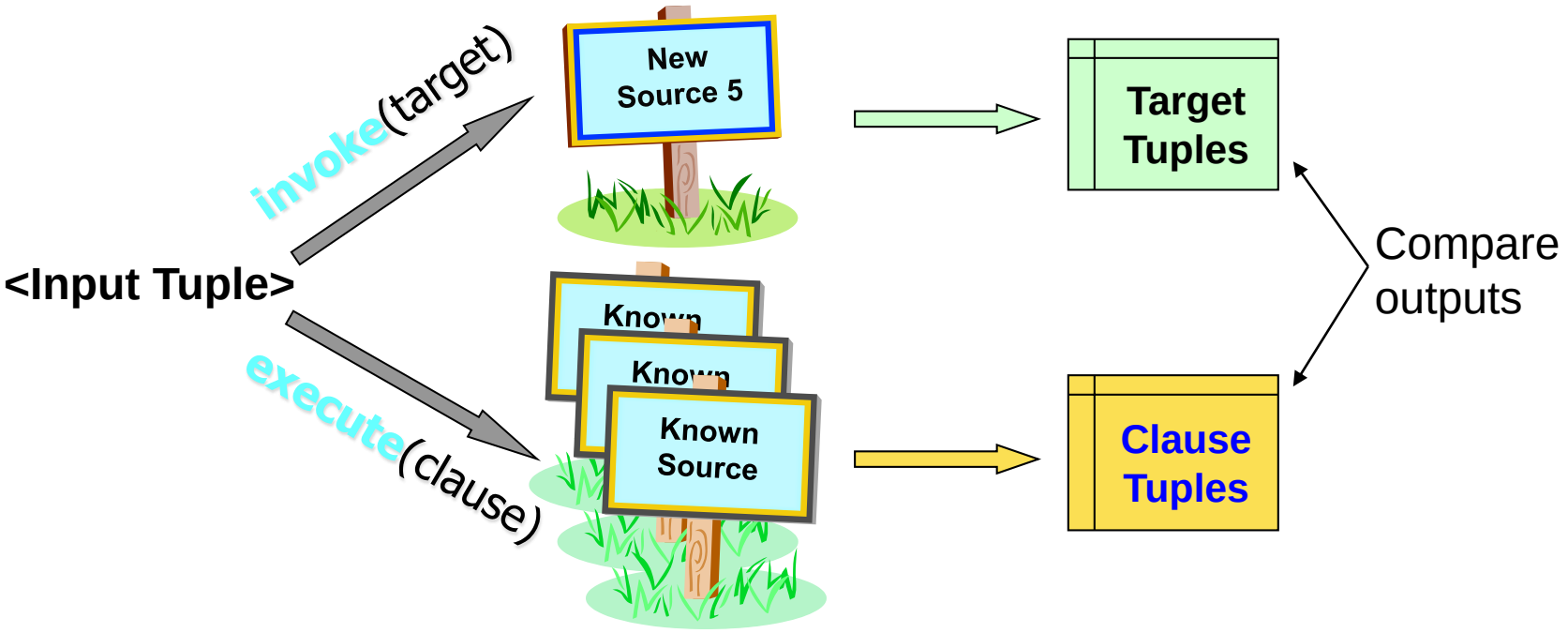
- Evaluate each clause produced
- Then expand best one found so far
- Expand high-arity predicates incrementally

source5(zip1,_,zip2,dist2) :- **source4**(zip2,zip1,dist2).

Expand

source5(zip1,dist1,zip2,dist2) :- **source4**(zip2,zip1,dist2), **source4**(zip1,zip2,dist1).
source5(zip1,dist1,zip2,dist2) :- **source4**(zip2,zip1,dist2), **<**(dist2,dist1).
…

Evaluating Candidates



- Compare output of clause with that of target.
- Average the results across different input tuples.

Evaluating Candidates II

Candidates may return multiple tuples per input

- Need measure that compares sets of tuples!

Input <$zip1, $dist1>	Target Output <zip2, dist2>	Clause Output <zip2, dist2>
<60632, 874.2>	{}	{<60629, 2.15>, <60682, 2.27>, <60623, 2.64>, ..}
<07307, 50.94>	{<07097, 0.26>, <07030, 0.83>, <07310, 1.09>, ...}	{}
<28041, 240.46>	{<28072, 1.74>, <28146, 3.41>, <28138, 3.97>,...}	{<28072, 1.74>, <28146, 3.41>}

No Overlap

No Overlap

Overlap!

Approximating Equality

Allow flexibility in values from different sources

- Numeric Types like *distance*

  10.6 km ≈ 10.54 km

  Error Bounds (eg. +/- 1%)

- Nominal Types like *company*

  Google Inc. ≈ Google Incorporated

  String Distance Metrics (e.g. JaroWinkler Score > 0.9)

- Complex Types like *date*

  Mon, 31. July 2006 ≈ 7/31/06

  Hand-written equality checking procedures.

Next …

Automatically build semantic models for data and services available on the larger Web

- Construct models of these sources that are sufficiently rich to support querying and integration
- Current focus:
  - Build models for the vast amount of structured and semi-structured data available
    - *Not just web services, but also form-based interfaces*
    - *E.g., Weather forecasts, flight status, stock quotes, currency converters, online stores, etc.*
  - Learn models for information-producing web sources and web services

Integrated Approach

- Start with an some initial knowledge of a domain
  - Sources and semantic descriptions of those sources
- Automatically
  - Discover related sources
  - Determine how to invoke the sources
  - Learn the syntactic structure of the sources
  - Identify the semantic types of the data
  - Build semantic models of the source
  - Construct semantic web services

Seed Source

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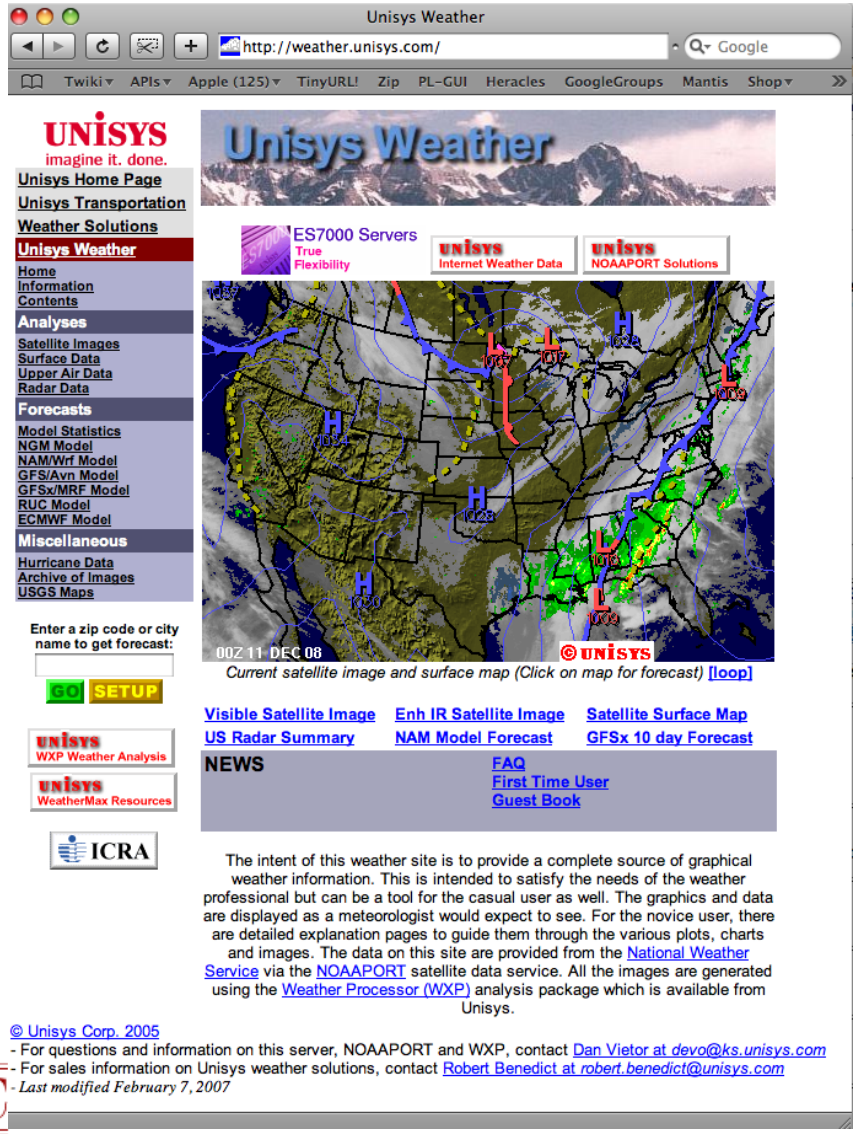
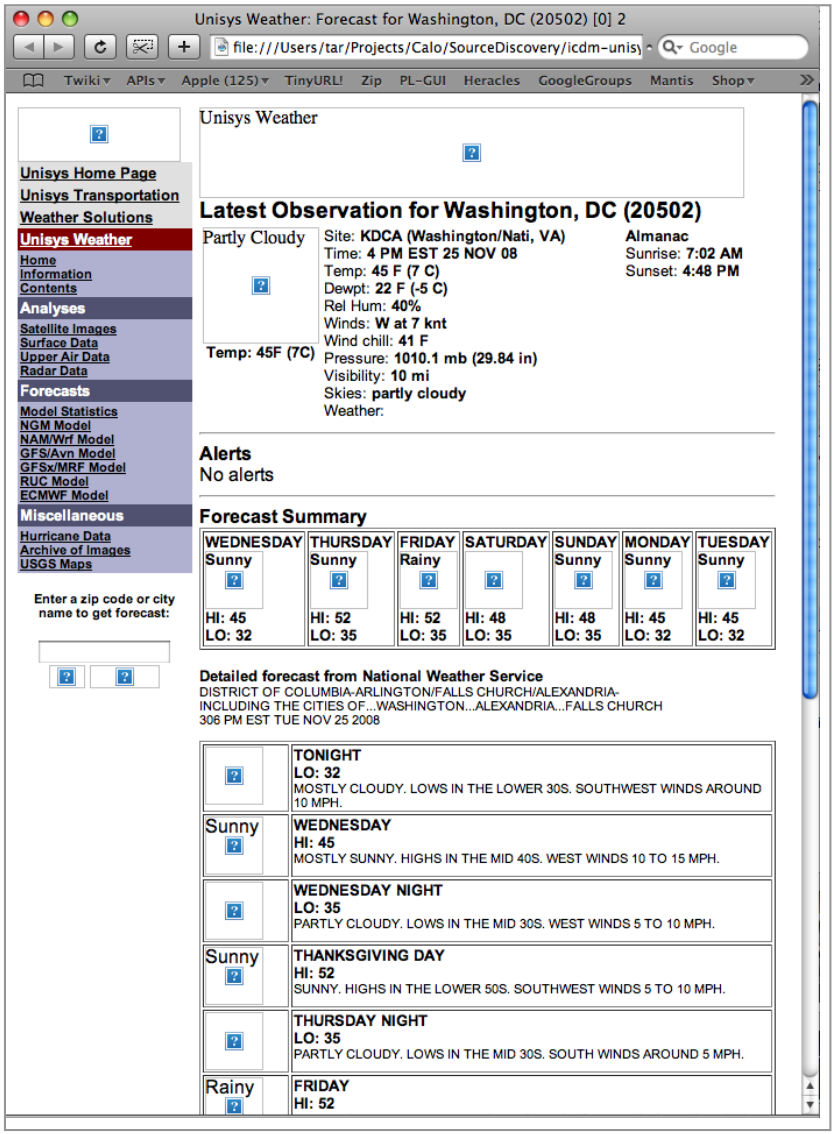
Automatically Discover and Build Semantic Web Services for Related Sources





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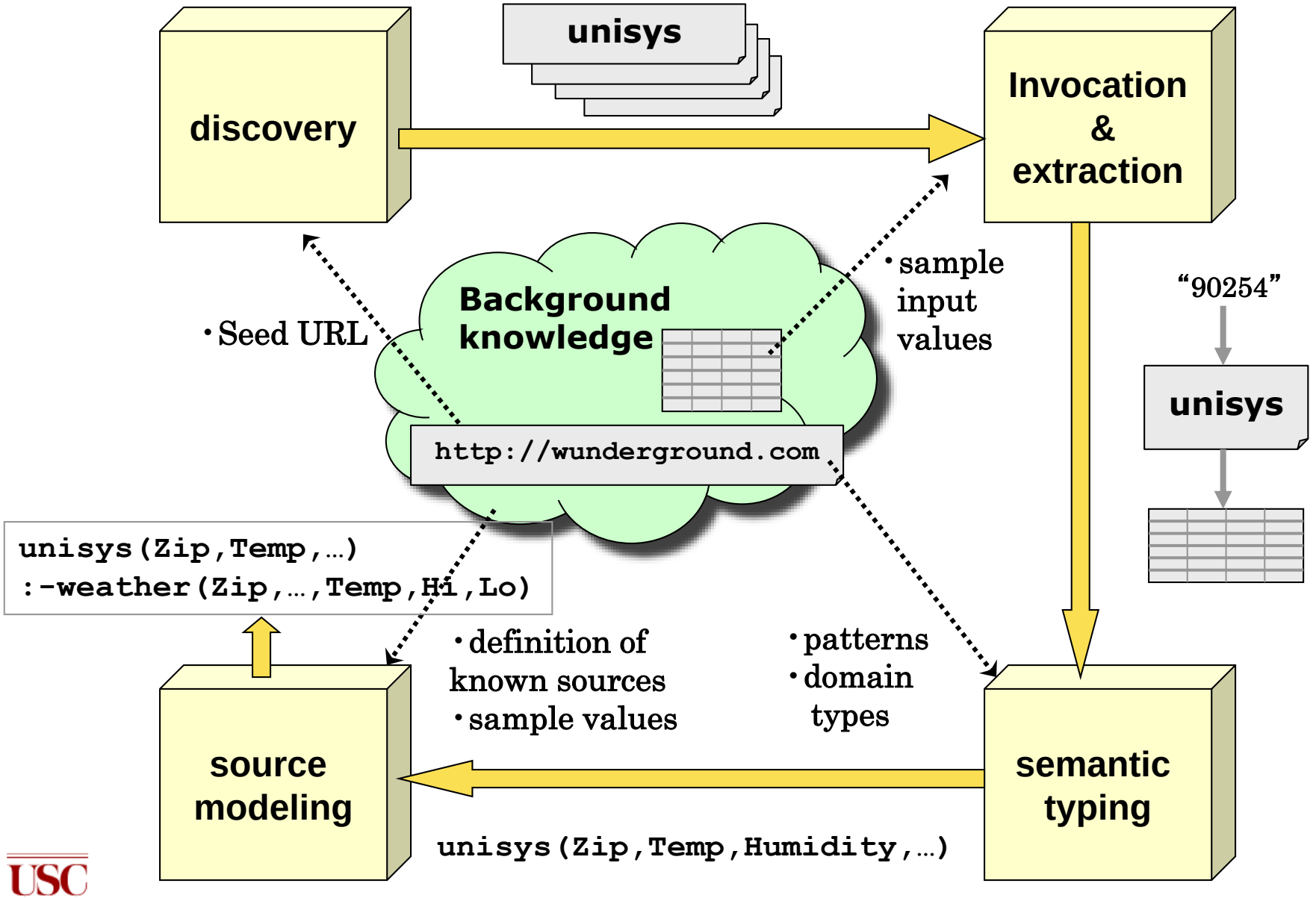
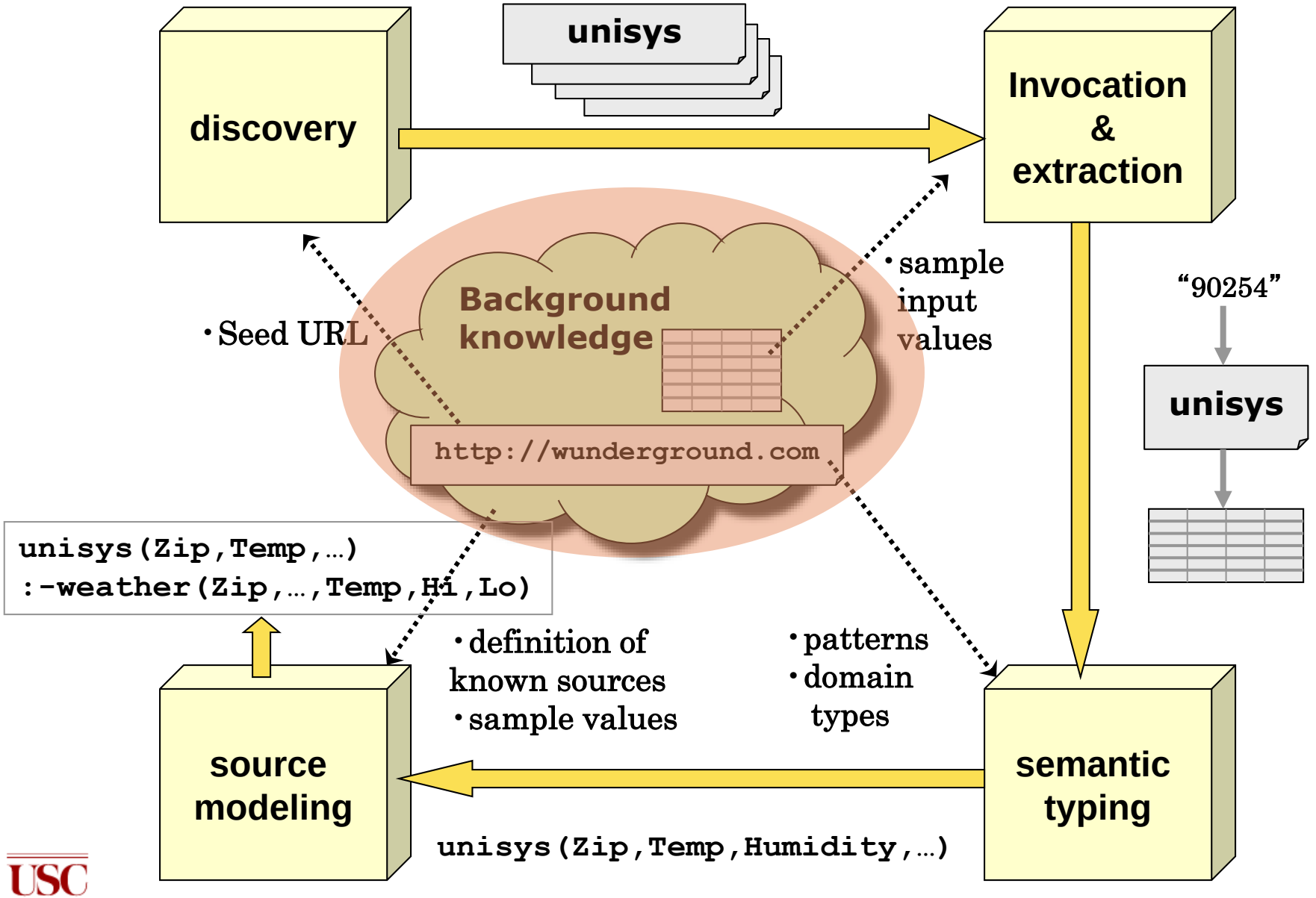
Integrated Approach



Background Knowledge



Background Knowledege

- Ontology of the inputs and outputs
  - e.g., TempF, Humidity, Zipcode;
- Sample values for each semantic type
  - e.g., “88 F” for TempF, and “90292” for Zipcode
- Domain input model
  - a weather source may accept Zipcode or City and State as input
  - Sample input values
- Known sources (seeds)
  - e.g., http://wunderground.com
- Source descriptions in Datalog or RDF
  - wunderground($Z,CS,T,F0,S0,Hu0,WS0,WD0,P0,V0,FL1,FH1,S1,FL2,FH2,S2,
    FL3,FH3,S3,FL4,FH4,S4,FL5,FH5,S5) :-
    weather(0,Z,CS,D,T,F0,_,_,S0,Hu0,P0,WS0,WD0,V0)
    weather(1,Z,CS,D,T,_,FH1,FL1,S1,_,_,_,_,_),
    weather(2,Z,CS,D,T,_,FH2,FL2,S2,_,_,_,_,_),
    weather(3,Z,CS,D,T,_,FH3,FL3,S3,_,_,_,_,_),
    weather(4,Z,CS,D,T,_,FH4,FL4,S4,_,_,_,_,_),
    weather(5,Z,CS,D,T,_,FH5,FL5,S5,_,_,_,_,_).

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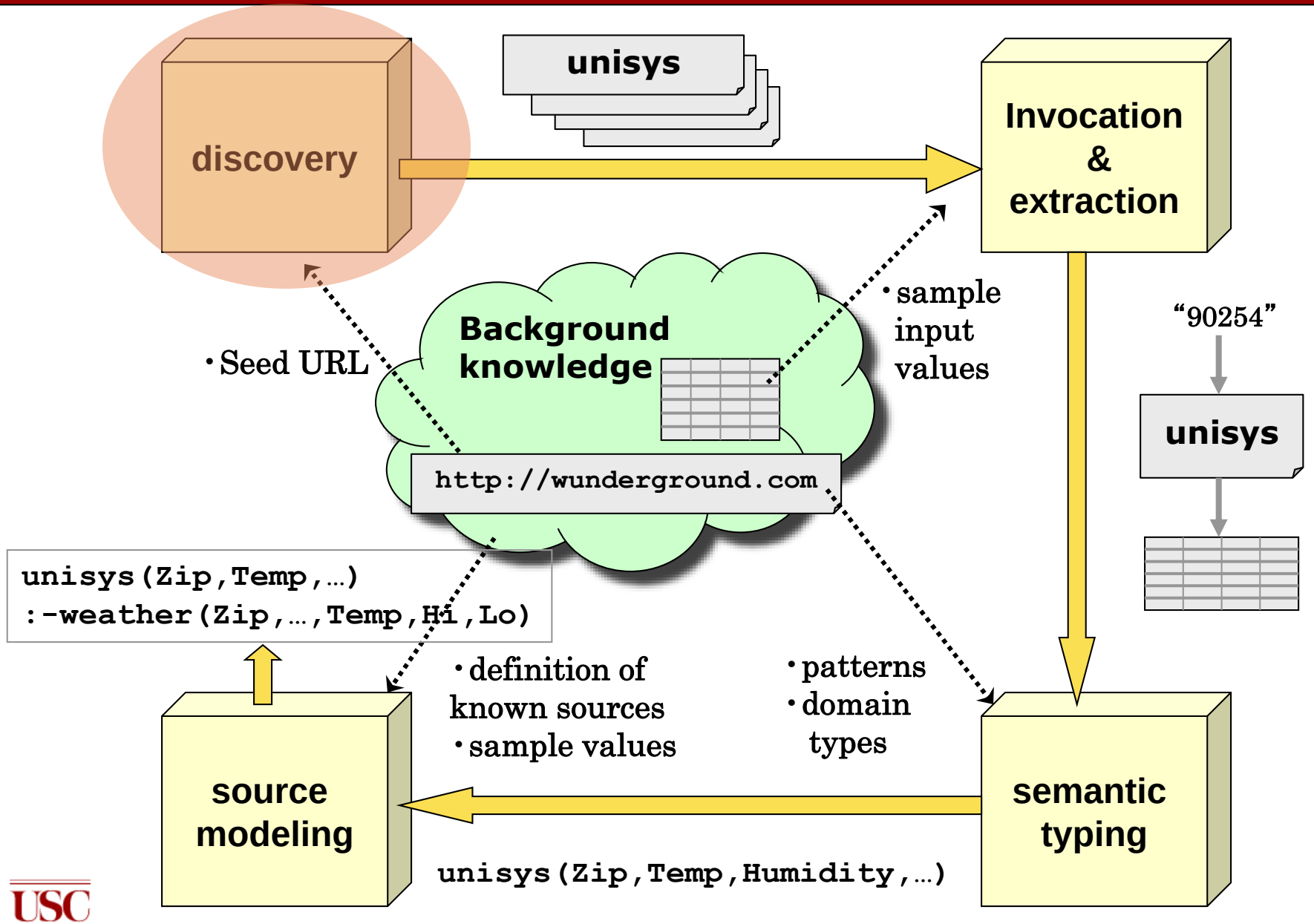
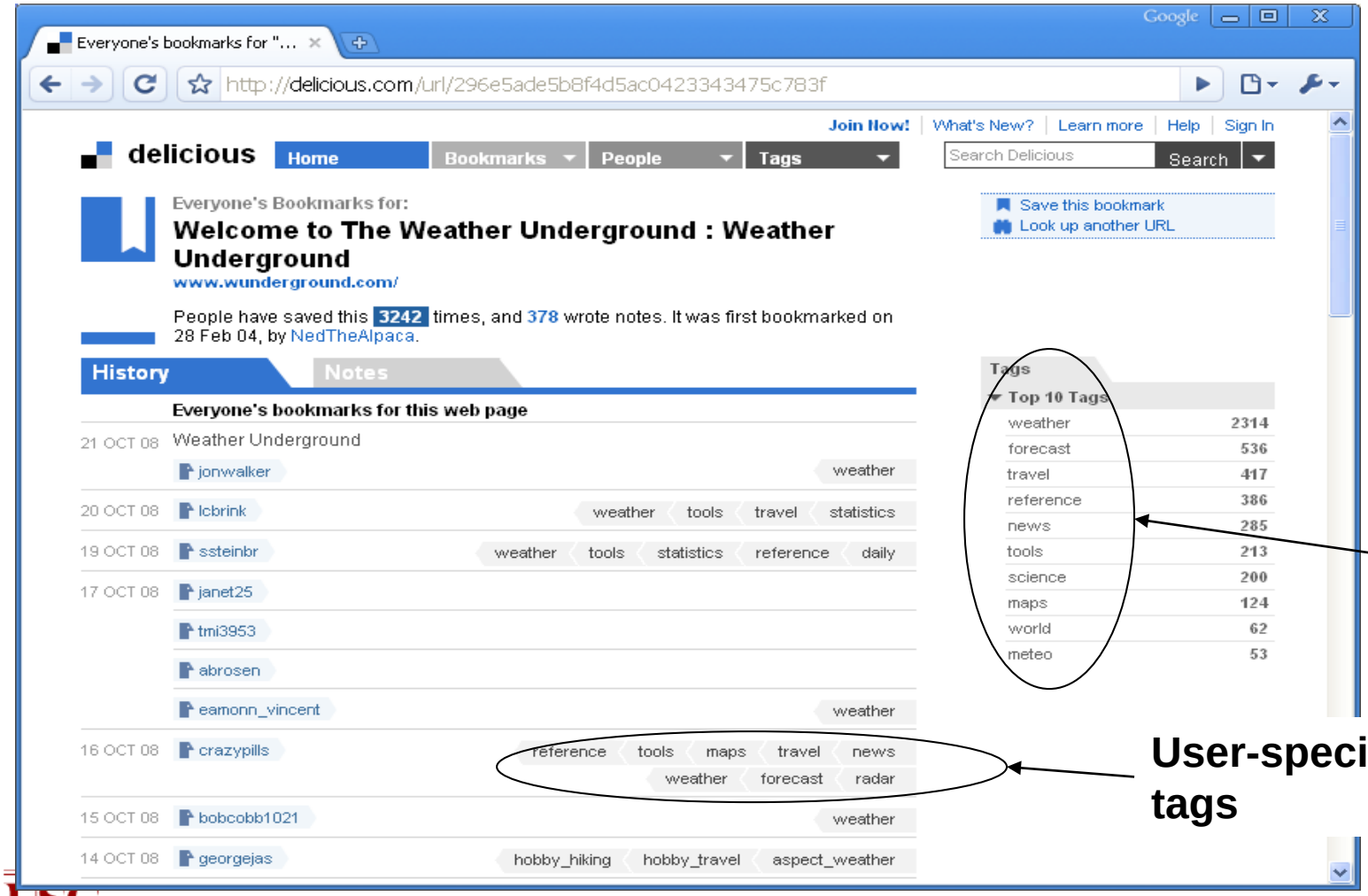
Source Discovery



Source Discovery [Plangprasopchok and Lerman]

- Leverage user-generated tags on the social bookmarking site del.icio.us to discover sources similar to the seed

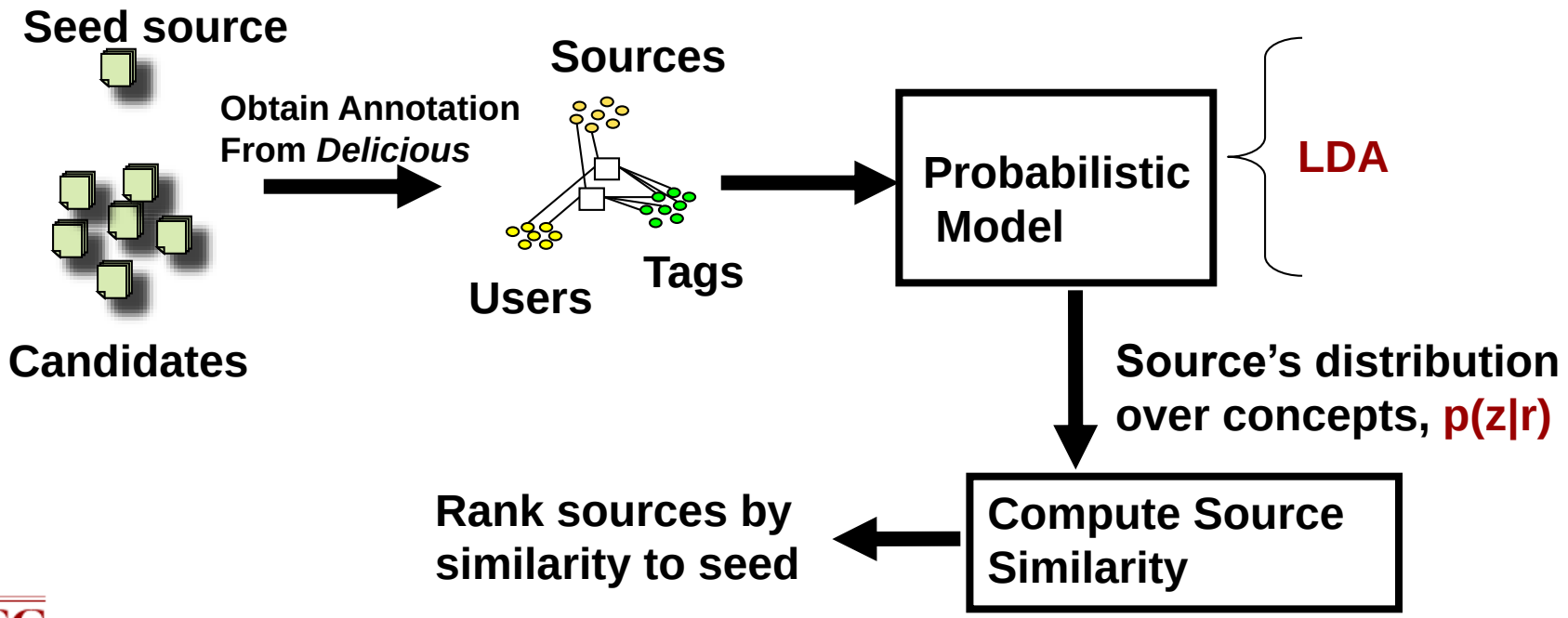


Most common tags

User-specified tags

Exploiting Social Annotations for Resource Discovery

- Resource discovery task : "*given a seed source, find other most similar sources*"
  - Gather a corpus of <user, source, tag> bookmarks from del.icio.us
  - Use probabilistic modeling to find hidden topics in the corpus
  - Rank sources by similarity to the seed within topic space



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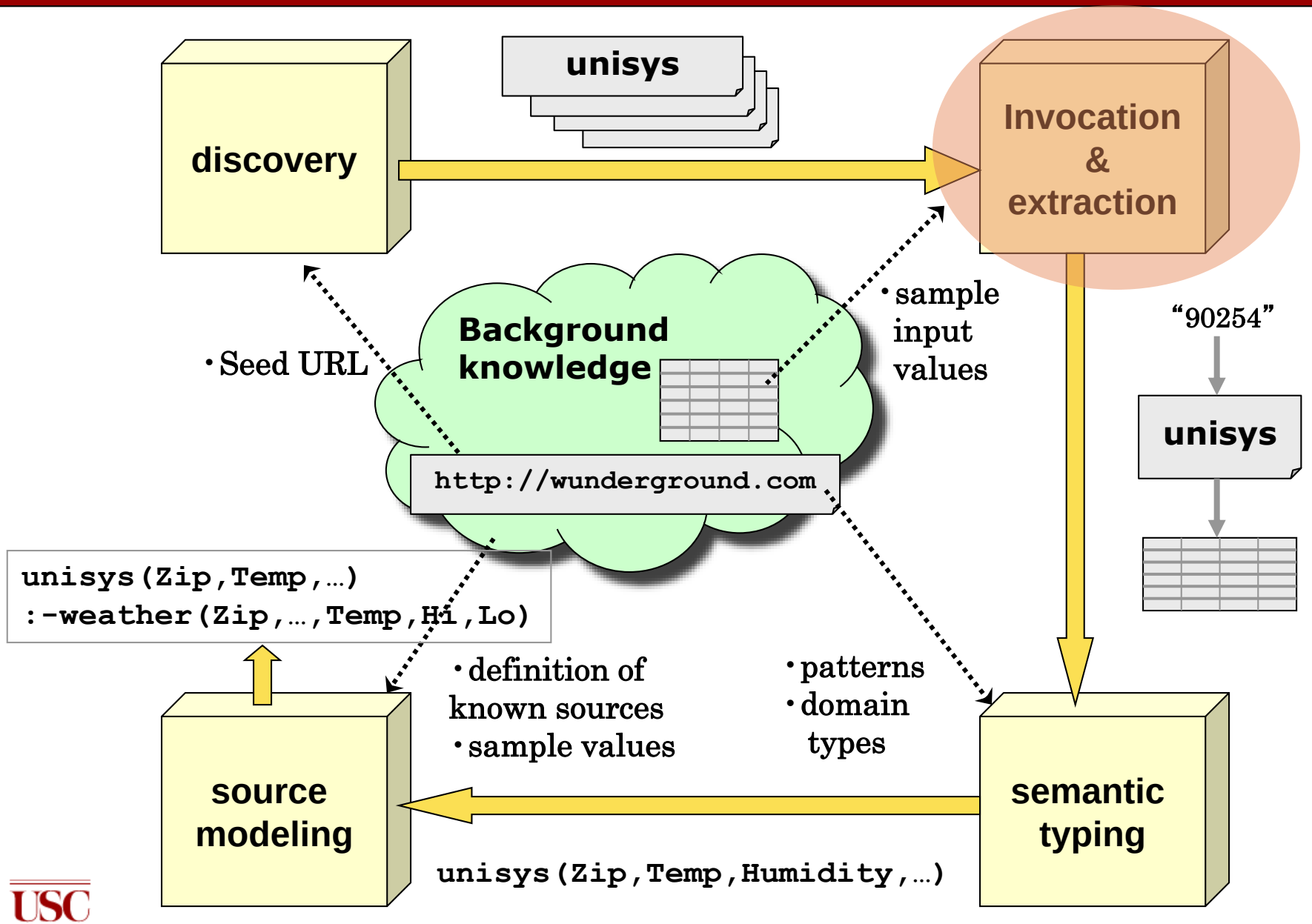
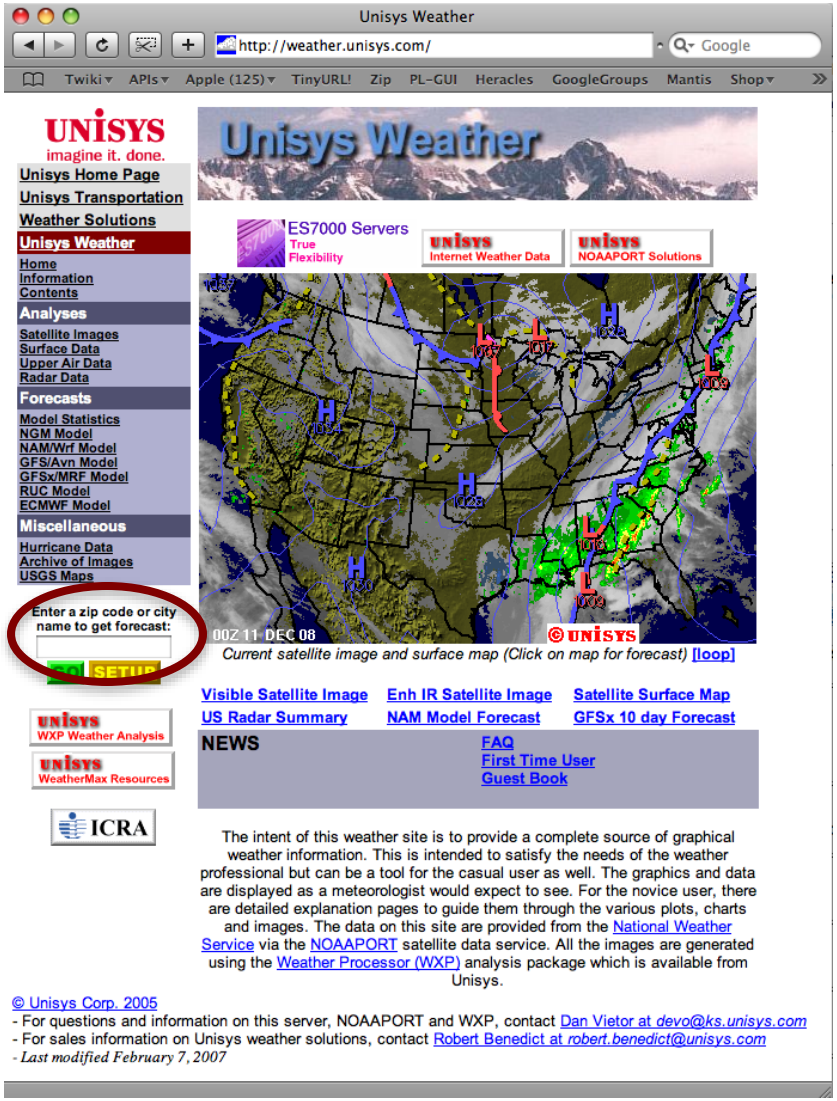
Source Invocation & Extraction



Target Source Invocation

- To invoke the target source, we need to locate the form and determine the appropriate input values
  1. Locate the form
  2. Try different data type combinations as input
     - *For weather, only one input - location, which can be zipcode or city/state*
  3. Submit Form
  4. Keep successful invocations



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Inducing Extraction Templates

- Template: a sequence of alternating slots and stripes
  - stripes are the common substrings among all pages
  - slots are the placeholders for data
- Induction: Stripes are discovered using the Longest Common Subsequence algorithm

Sample Page 1

```
<img src="images/Sun.png" alt="Sunny"><br>
<font face="Arial, Helvetica, sans-serif">
  <small><b>Temp: 72F (22C)</b></small></font>
<font face="Arial, Helvetica, sans-serif">
  <small>Site: <b>KSMO (Santa_Monica_Mu, CA)</b><br>
       Time: <b>11 AM PST 10 DEC 08</b>
```

Sample Page 2

```
<img src="images/Clouds.png" alt="Cloudy"><br>
<font face="Arial, Helvetica, sans-serif">
  <small><b>Temp: 37F (2C)</b></small></font>
<font face="Arial, Helvetica, sans-serif">
  <small>Site: <b>KAGC (Pittsburgh/Alle, PA)</b><br>
       Time: <b>2 PM EST 10 DEC 08</b>
```

Induction

Template

```
<img src="images/✱.png" alt="✱"><br>
<font face="Arial, Helvetica, sans-serif">
  <small><b>Temp: ✱ (✱)</b></small></font>
<font face="Arial, Helvetica, sans-serif">
  <small>Site: <b>✱ (✱, ✱)</b><br>
       Time: <b>✱ 10 DEC 08</b>
```

Slot

Stripe

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Data Extraction with Templates [Gazen& Minton]

- To extract data: Find data in slots by locating the stripes of the template on unseen page:

Unseen Page

```
<img src="images/Sun.png" alt="Sunny"><br>
<font face="Arial, Helvetica, sans-serif">
  <small><b>Temp: 71F (21C)</b></small></font>
<font face="Arial, Helvetica, sans-serif">
  <small>Site: <b>KCQT (Los_Angeles_Dow, CA)</b><br>
       Time: <b>11 AM PST 10 DEC 08</b>
```

Induced Template

```
<img src="images/*.png" alt="*"><br>
<font face="Arial, Helvetica, sans-serif">
  <small><b>Temp: * (*)</b></small></font>
<font face="Arial, Helvetica, sans-serif">
  <small>Site: <b>* (*, *)</b><br>
       Time: <b>* 10 DEC 08</b>
```

Extracted Data

Sun	Sunny	71F	21C	KCQT	Los_Angeles_Dow	CA	11 AM PST

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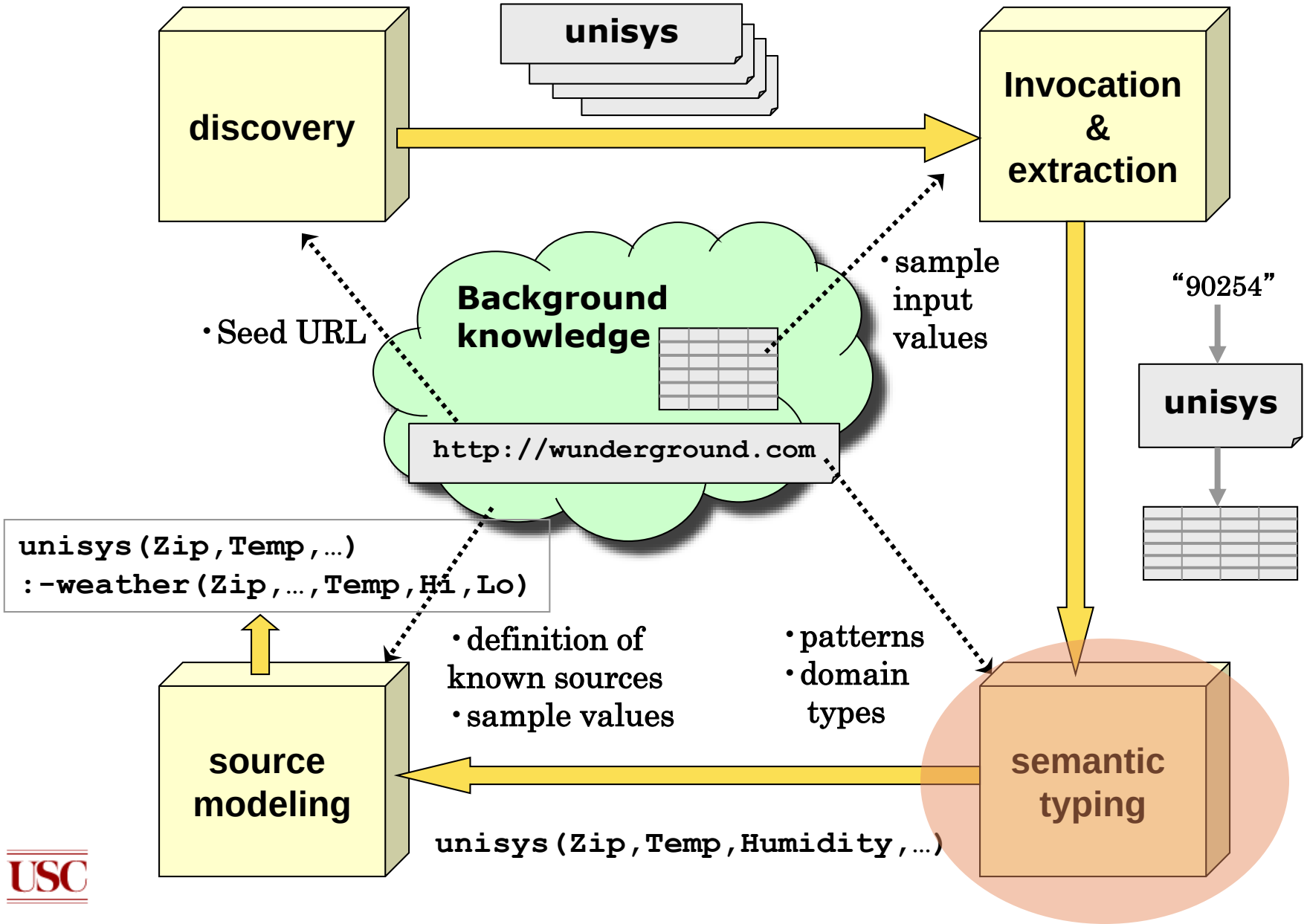
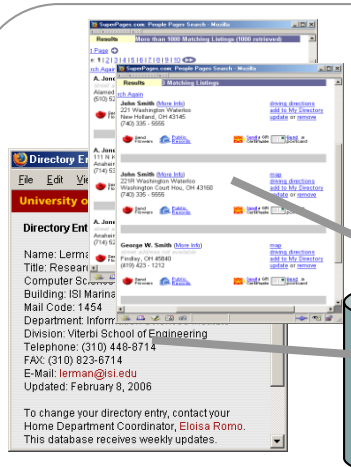
Semantic Typing



Semantic Typing
[Lerman, Plangprasopchok, & Knoblock]

✓**Idea: Learn a model of the content of data and use it to recognize new examples**



Background knowledge

learn

```
:StreetAddress:   :Email:
 4DIG CAPS Rd      ALPHA@ALPHA.edu
 3DIG N CAPS Ave   ALPHA@ALPHA.com
  …                  …
 :State:           :Telephone:
  CA                (3DIG) 3DIG-4DIG
  2UPPER            +1 3DIG 2DIG 4DIG
                    …
```

Patterns

Person	Address	Work
E Lewis	3518 Hilltop Rd	(419) 531 - 0504
Andrew Lewis	3543 Larchmont Pkwy	(518) 474 - [illegible]
C. S. Lewis	555 Willow Run Dr	(612) 578 - [illegible]
Carmen Jones	355 Morgan Ave N	(612) 522 - [illegible]
John Jones	3574 Brookside Rd	(555) 531 - 9566
Location	**State_prov**	**Postal_code**
Toledo	OH	64325-3000
Toledo	OH	64356
Seattle	WA	8422
Seattle	WA	8435
Omaha	NE	52456-6444

label

:FullName:	:StreetAddress:	:Telephone:
E Lewis	3518 Hilltop Rd	(419) 531 - 0504
drew Lewis	3543 Larchmont Pkwy	(518) 474 - 4799
Lewis	555 Willow Run Dr	(612) 578 - 5555
rmen Jones	355 Morgan Ave N	(612) 522 - 5555
John Jones	3574 Brookside Rd	(555) 531 - 9566
:City:	**:State:**	**:Zipcode:**
Toledo	OH	64325-3000
Toledo	OH	64356
Seattle	WA	8422
Seattle	WA	8435
Omaha	NE	52456-6444

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Labeling New Data

- Use learned patterns to link new data to types in the ontology
  - Score how well patterns describe a set of examples
    - *Number of matching patterns*
    - *How many tokens of the example match pattern*
    - *Specificity of the matched patterns*
  - Output top-scoring types

Person	Address	Work
E Lewis	3518 Hilltop Rd	(419) 531 - 0504
Andrew Lewis	3543 Larchmont Pkwy	(518) 474 - 4799
C. S. Lewis	555 Willow Run Dr	(612) 578 - 5555
Carmen Jones	355 Morgan Ave N	(612) 522 - 5555
John Jones	3574 Brookside Rd	(555) 531 - 9566
Location	**State_prov**	**Postal_code**
Toledo	OH	64325-3000
Toledo	OH	64356
Seattle	WA	8422
Seattle	WA	8435
Omaha	NE	52456-6444

patterns

```
:StreetAddress:    :Email:
 4DIG CAPS Rd       ALPHA@ALPHA.edu
 3DIG N CAPS Ave    ALPHA@ALPHA.com
  …                   …
 :State:           :Telephone:
  CA                 (3DIG) 3DIG-4DIG
  2UPPER             +1 3DIG 2DIG 4DIG
  …                  …
```

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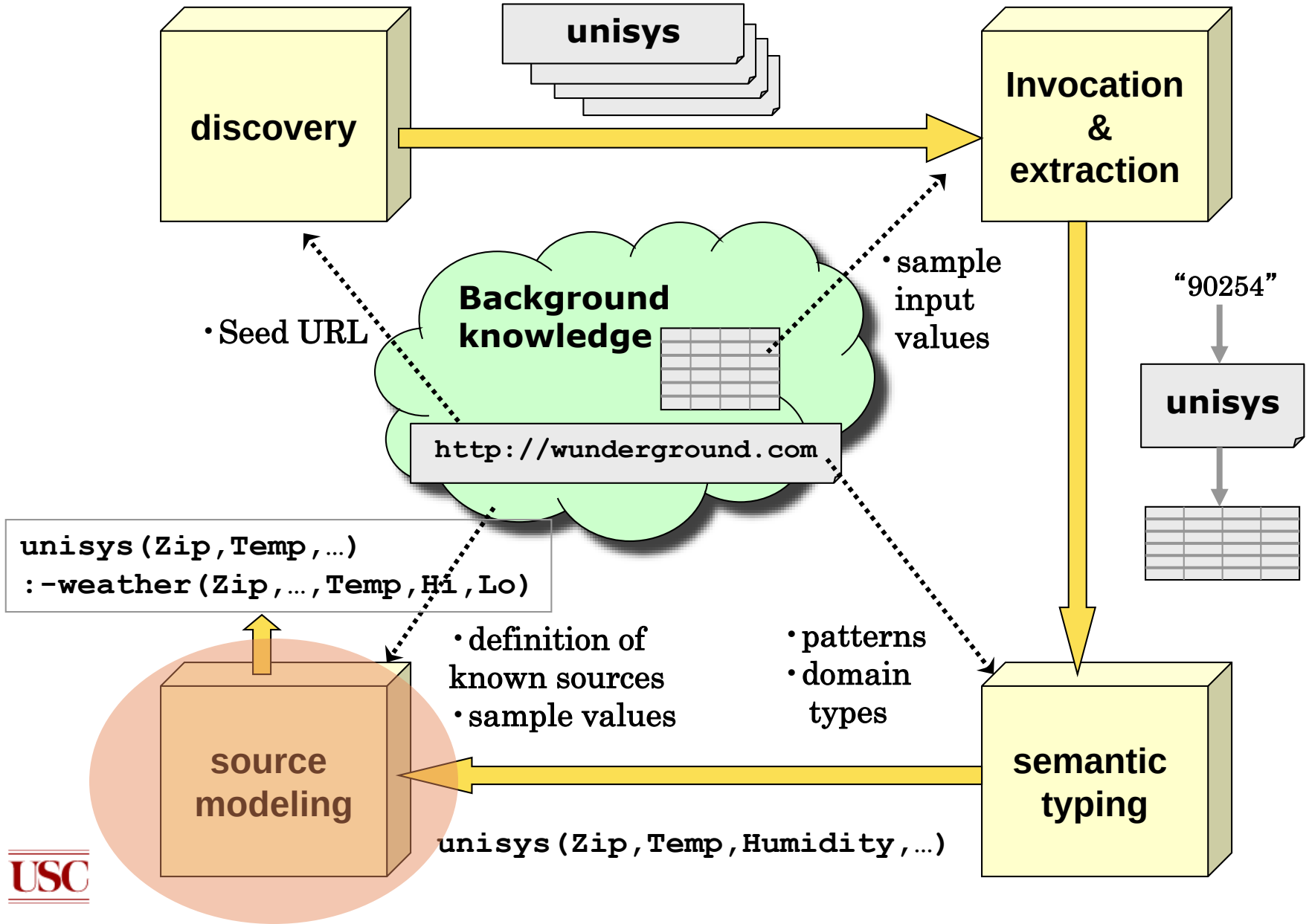
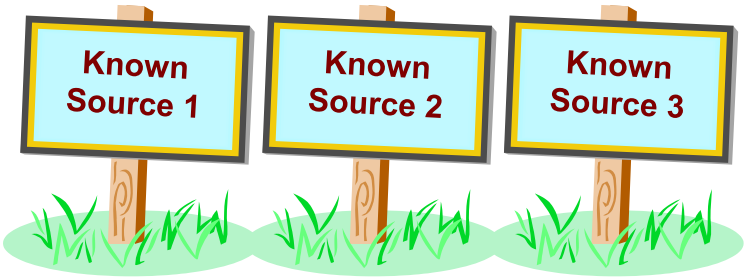
Source Modeling [Carman & Knoblock]



Inducing Source Definitions



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source2($lat1, $long1, $lat2, $long2, dist) :-
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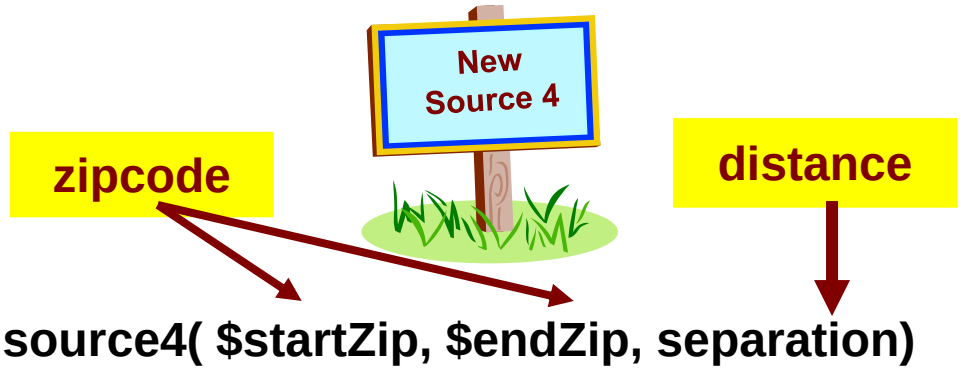
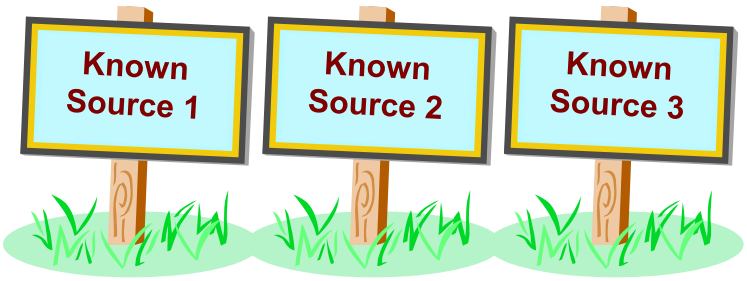
source3($dist1, dist2) :-
convertKm2Mi(dist1, dist2).

- Step 1: classify input & output semantic types



Generating Plausible Definition

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```

- Step 1: classify input & output semantic types
- Step 2: generate plausible definitions

```
source4($zip1, $zip2, dist):-
    source1(zip1, lat1, long1),
    source1(zip2, lat2, long2),
    source2(lat1, long1, lat2, long2, dist2),
    source3(dist2, dist).
```

```
source4($zip1, $zip2, dist):-
    centroid(zip1, lat1, long1),
    centroid(zip2, lat2, long2),
    greatCircleDist(lat1, long1, lat2, long2, dist2),
    convertKm2Mi(dist1, dist2).
```

Invoke and Compare the Definition

- Step 1: classify input & output semantic types
- Step 2: generate plausible definitions
- Step 3: invoke service & compare output

```
source4($zip1, $zip2, dist):-
    source1(zip1, lat1, long1),
    source1(zip2, lat2, long2),
    source2(lat1, long1, lat2, long2, dist2),
    source3(dist2, dist).
```

```
source4($zip1, $zip2, dist):-
    centroid(zip1, lat1, long1),
    centroid(zip2, lat2, long2),
    greatCircleDist(lat1, long1, lat2, long2,dist2),
    convertKm2Mi(dist1, dist2).
```

match

$zip1	$zip2	dist *(actual)*	dist *(predicted)*
80210	90266	842.37	843.65
60601	15201	410.31	410.83
10005	35555	899.50	899.21

Example of a Learned Source Model for Weather Domain

- Given a set of known sources and their descriptions
  - wunderground($Z,CS,T,F0,S0,Hu0,WS0,WD0,P0,V0) :-
    weather(0,Z,CS,D,T,F0,_,_,S0,Hu0,P0,WS0,WD0,V0)
  - convertC2F(C,F) :- centigrade2farenheit(C,F)
- Learn a description of a new source in terms of the known sources
  - unisys($Z,CS,T,F0,C0,S0,Hu0,WS0,WD0,P0,V0) :-
    wunderground(Z,CS,T,F0,S0,Hu0,WS0,WD0,P0,V0),
    convertC2F(C0,F0)

Background Source Descriptions

```
wunderground( $Z,CS,T,F0,C0,S0,Hu0,WS0,WD0,P0,V0,FL1,FH1,S1,
                    FL2,FH2, S2,FL3,FH3,S3,FL4,FH4,S4,FL5,FH5,S5):-
   Weather(_w0),hasForecastDay(_w0,0),hasZIP(_w0,Z),
      hasCityState(_w0,CS),hasTimeWZone(_w0,T),
      hasCurrentTemperatureFarenheit(_w0,F0),
      hasCurrentTemperatureCentigrade(_w0,C0),
      hasSkyConditions(_w0,S0),hasHumidity(_w0,Hu0),
      hasPressure(_w0,P0), hasWindSpeed(_w0,_ws1),
      WindSpeed(_ws1), hasWindSpeedInMPH(_ws1,WS0),
      hasWindDir(_ws1,WD0), hasVisibilityInMi(_w0,V0),
   Weather(_w1), hasForecastDay(_w1,1), hasZIP(_w1,Z),
      hasCityState(_w1,CS), hasLowTemperatureFarenheit(_w1,FL1),
      hasHighTemperatureFarenheit(_w1,FH1), hasSkyConditions(_w1,S1),
   …

convertC2F($C,F) :- centigrade2farenheit(C,F)
```

Target explained using background sources

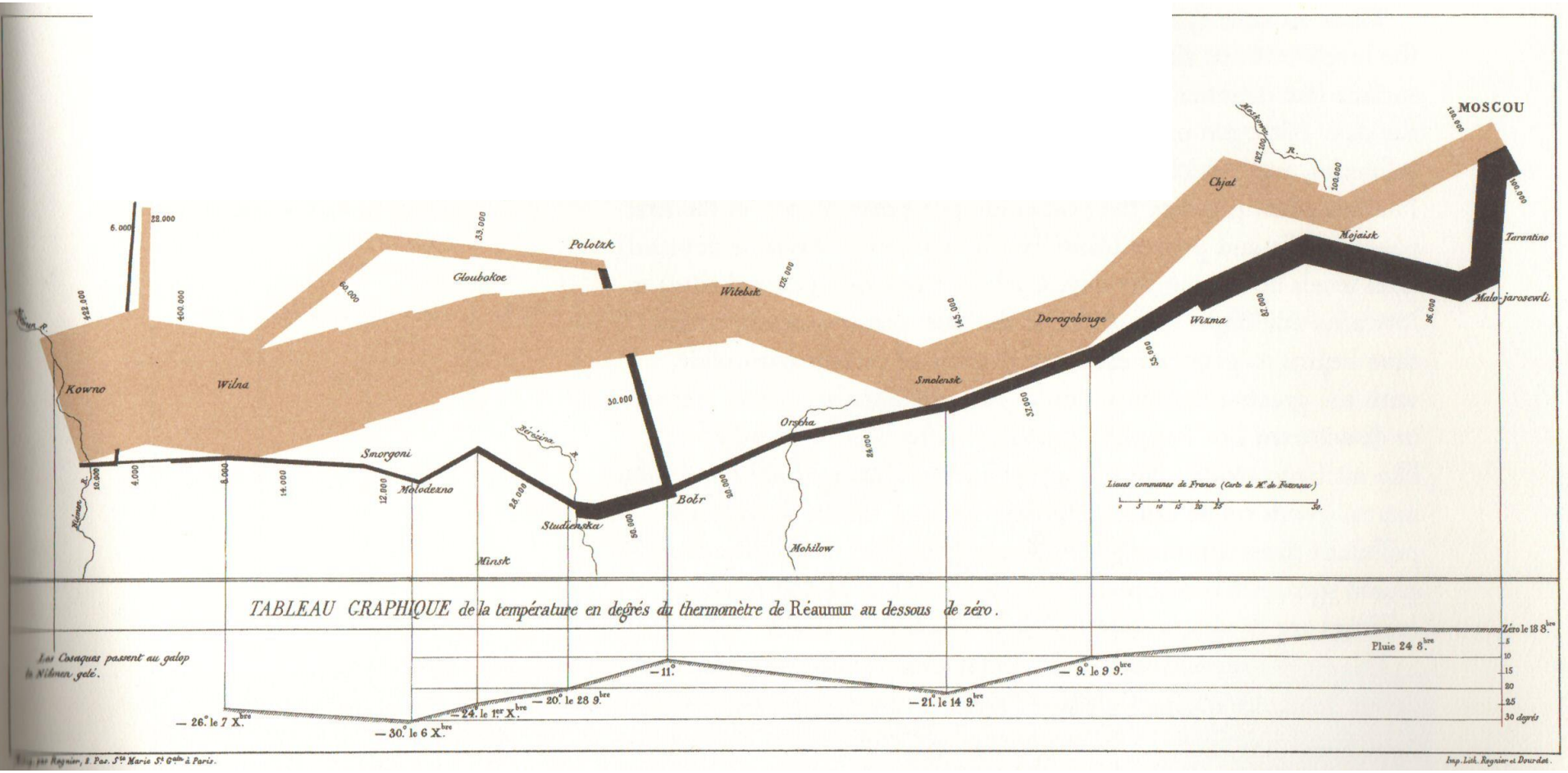
```
unisys($Z,_,_,_,_,_,_,_,_,F9,_,C,_,F13,F14,Hu,_,F17,_,_,_,_,S22,_,S24,
        _,_,_,_,_,_,_,_,_,_,_,S35,S36,_,_,_,_,_,_,_,_,_) :-
    wunderground(Z,_,_,F9,_,Hu,_,_,_,_,F14,F17,S24,_,_,S22,_,_,
                 S35,_,_,S36,F13,_,_),
    convertC2F(C,F9)
```

USC

Experimental Evaluation

- Experiments in 5 domains
  - Flight – lookup the current status of a flight
  - Geospatial – map streeet addresses into lat/long coordinates
  - Weather – find the current and forecasted weather
  - Currency – convert between various currencies
  - Mutual Funds – look up current data on a mutual fund

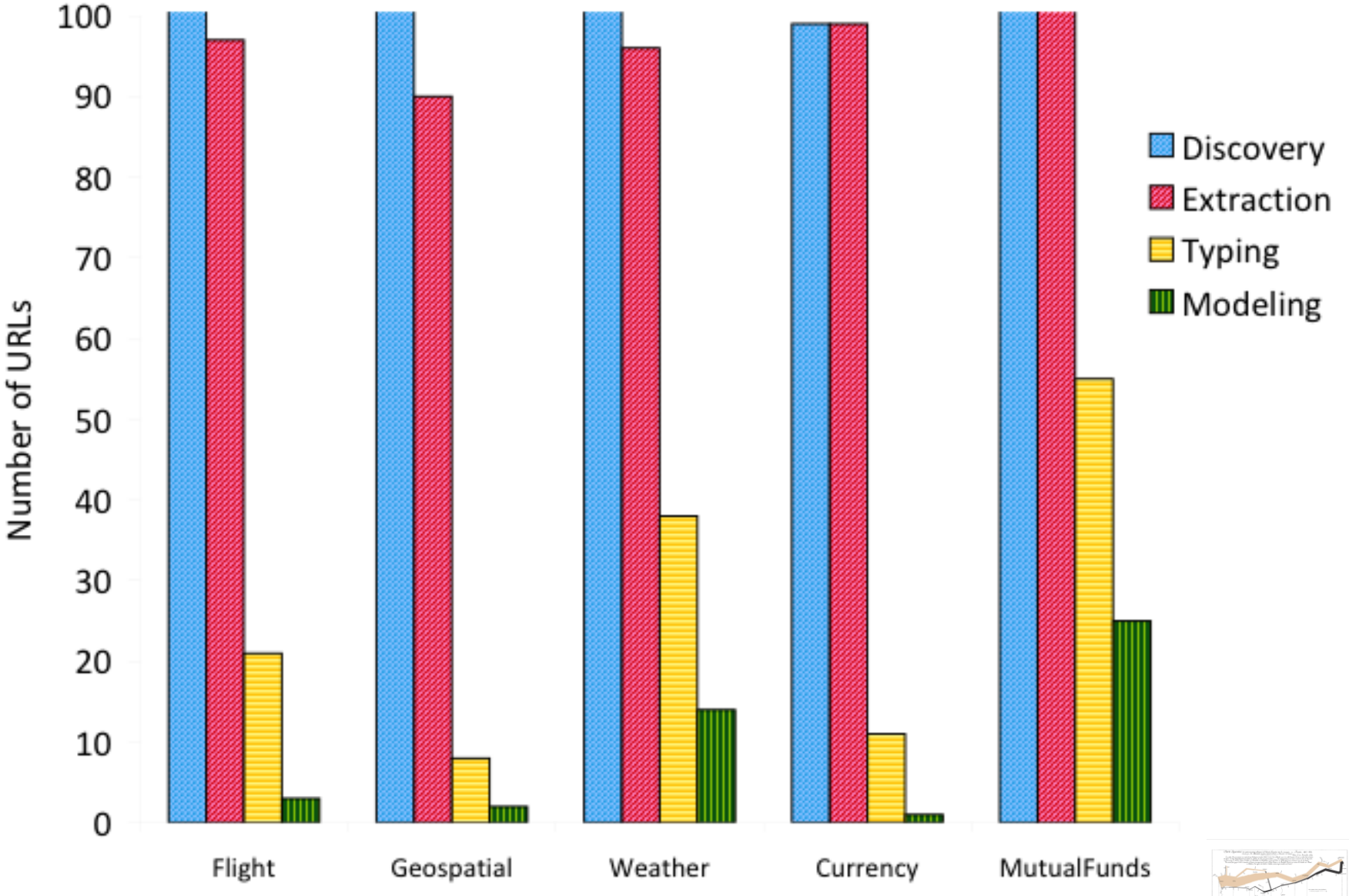
- Evaluation:
  - 1) Can the system correctly learn a model for those sources that perform the same task
  - 2) What is the precision and recall of the attributes in the model



[Edward Tufte, *The Visual Display of Quantitative Information*]

USC

Candidate Sources after Each Step



Evaluation of the Models

domain	Precision	Recall	F_1-measure
weather	0.64	0.29	0.39
geospatial	1.00	0.86	0.92
flights	0.69	0.35	0.46
currency	1.00	1.00	1.00
mutualfund	0.72	0.30	0.42

Conclusions

- Integrated approach to learning:
  - *How to invoke a web service*
  - *The semantic types of the output*
  - *A definition of what the service does*
- Provides an approach to generate source descriptions for the Semantic Web
  - Little motivation for providers to annotate services
  - Instead we generate metadata automatically
- Also provides an approach to automatically discover new sources of data