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Automatically Constructing Semantic Web Services from Online Sources

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Goal

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- 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
  - Such models would make the existing semantic web tools and techniques more widely applicable
- 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

Approach

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- 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

Outline

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- Integrated Approach
  - Discovering related sources
  - Constructing syntactic models of the sources
  - Determining the semantic types of the data
  - Building semantic models of the sources
- Experimental Results
- Related Work
- Discussion

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Seed Source

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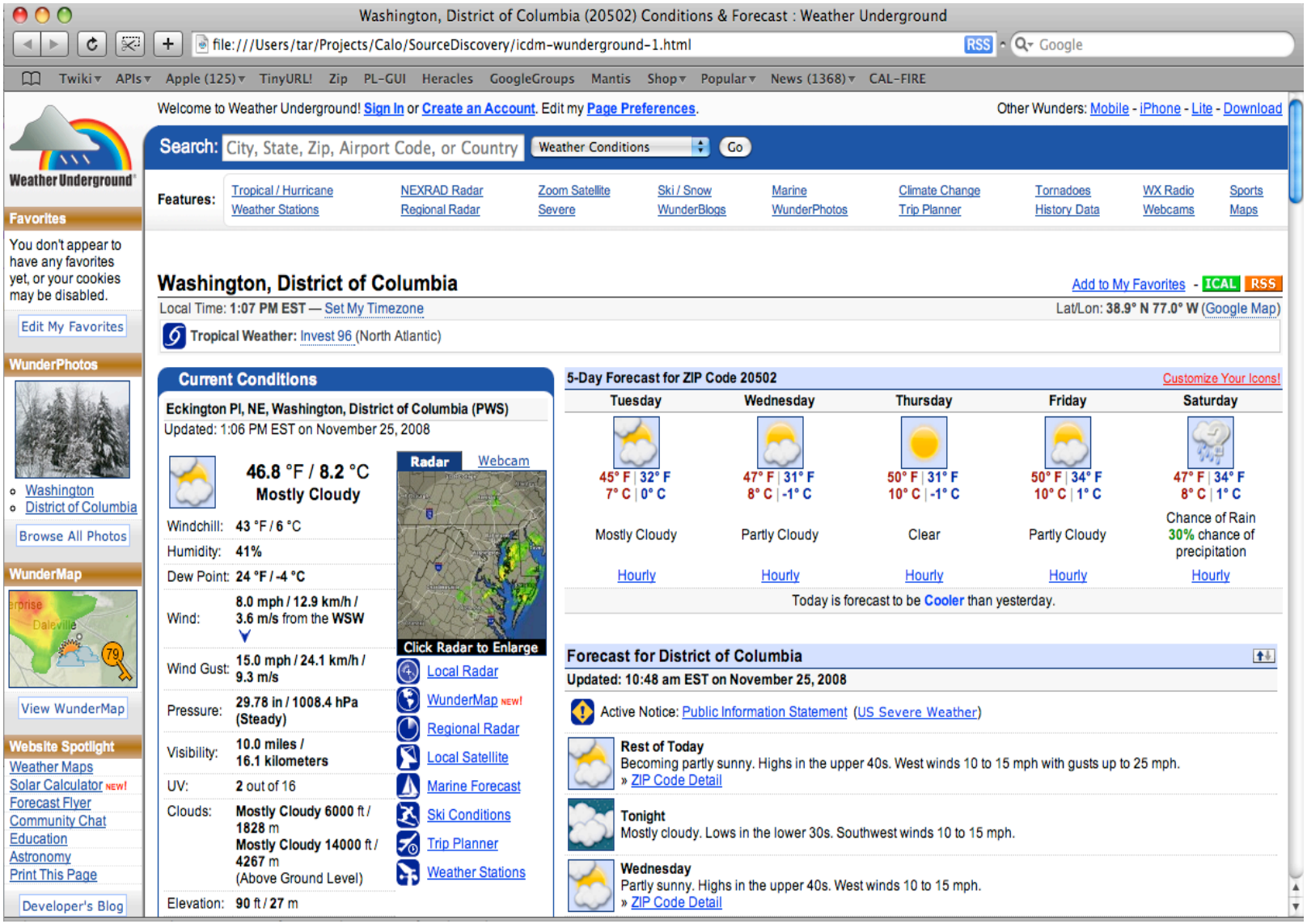

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Automatically Discover and Build Semantic Web Services for Related Sources

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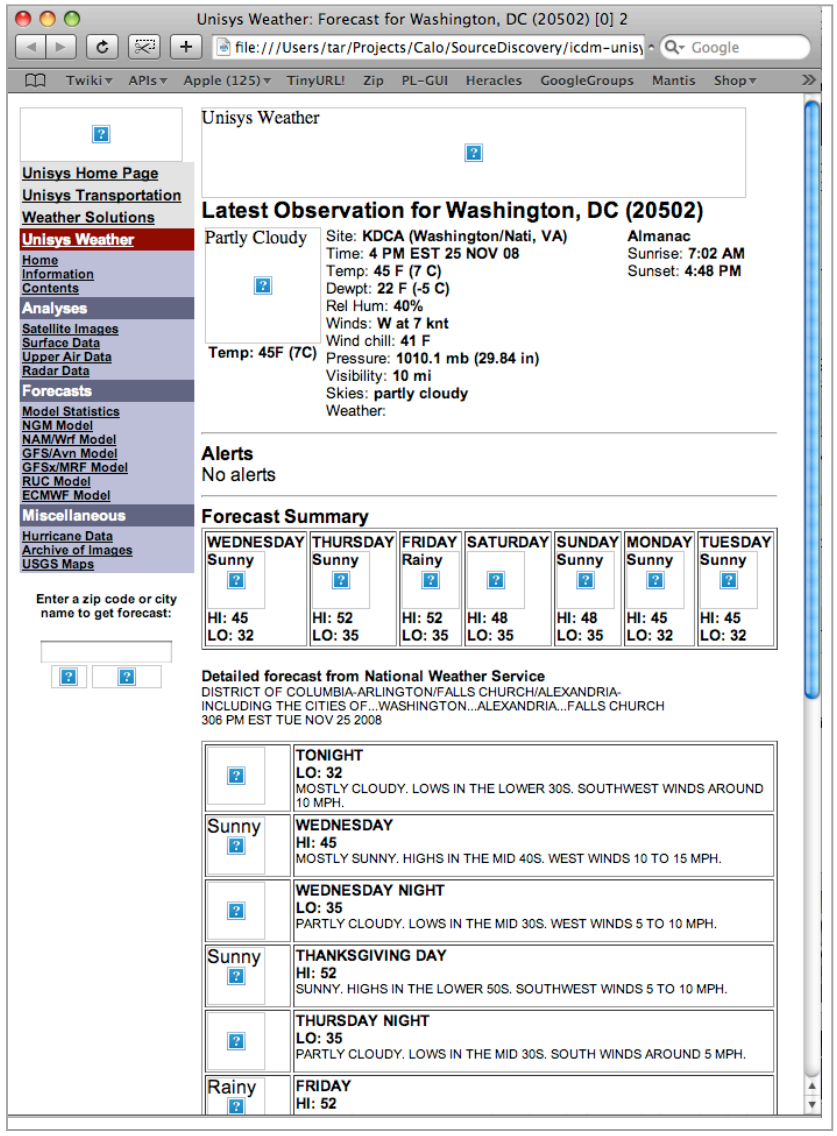
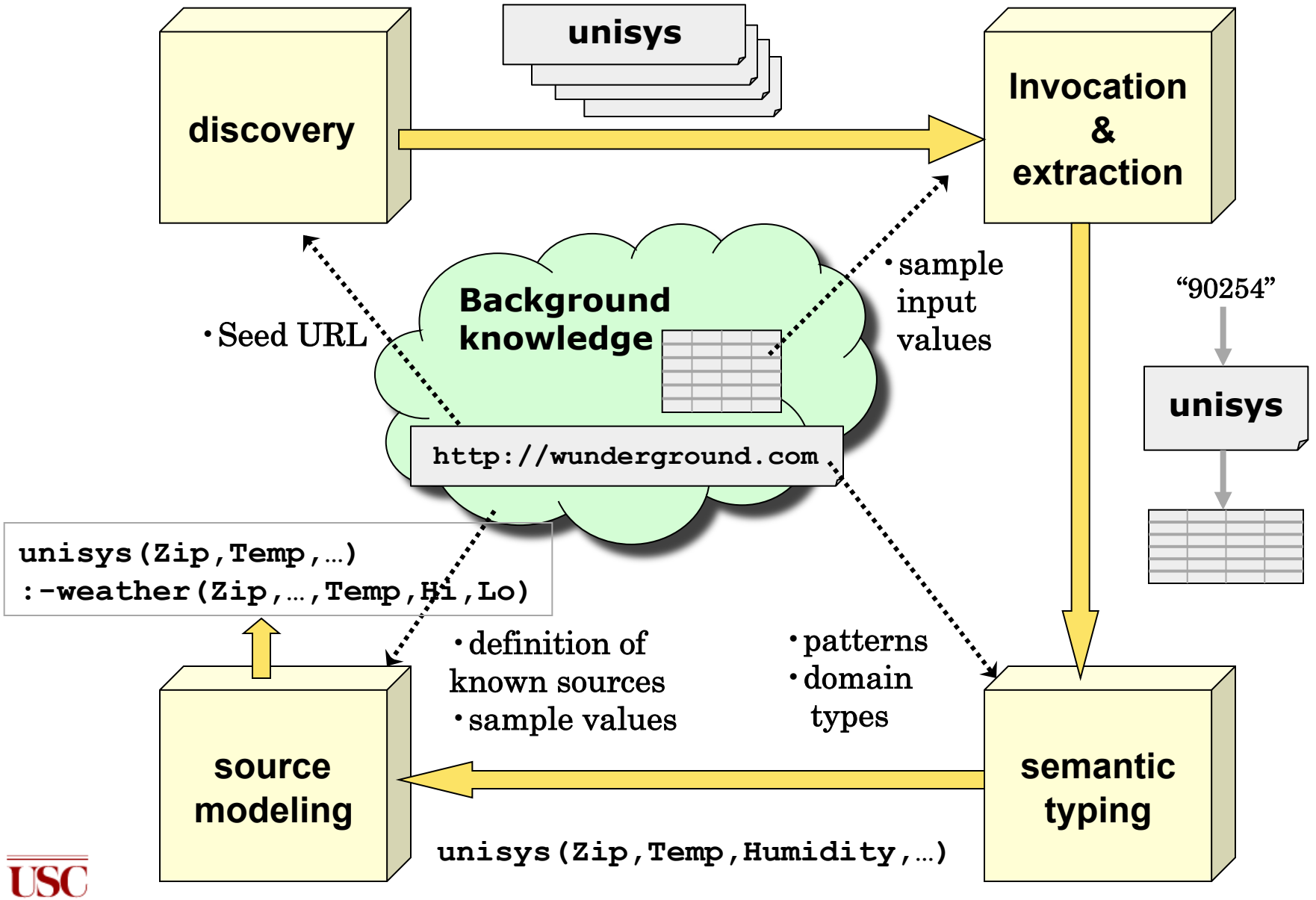
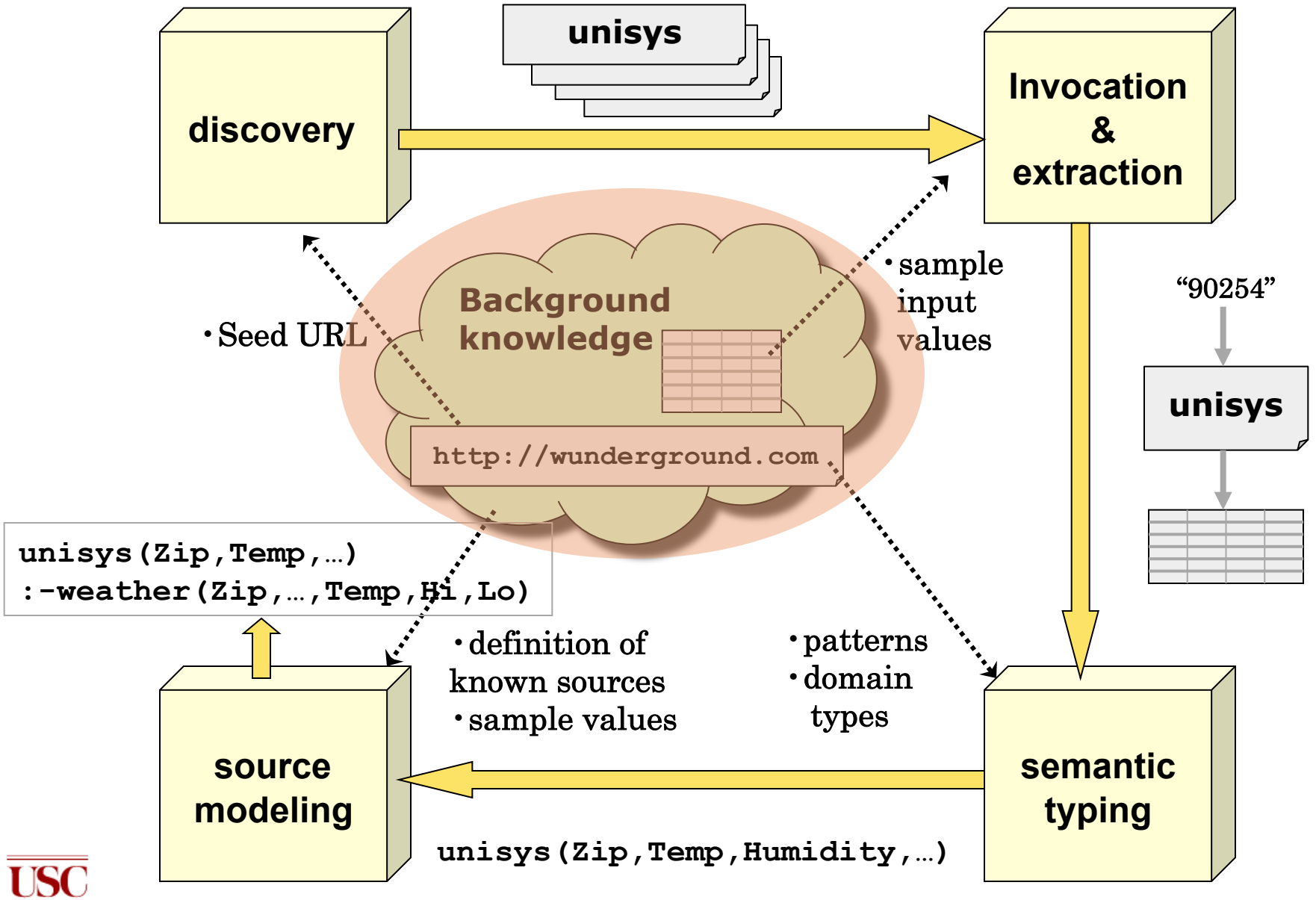


Integrated Approach



Background Knowledge



Background Knowledege

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- 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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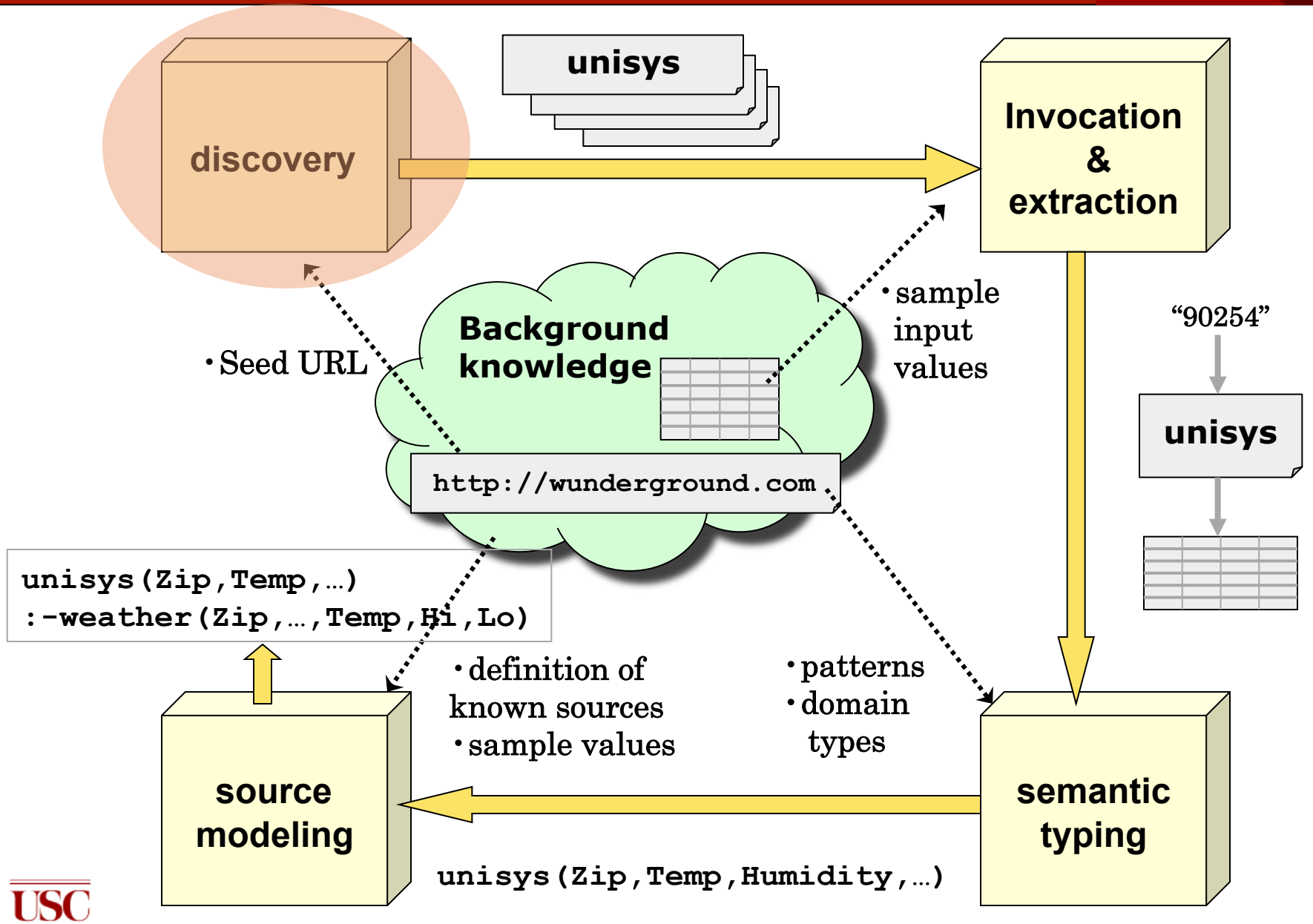
Source Discovery



Source Discovery [Plangprasopchok and Lerman]

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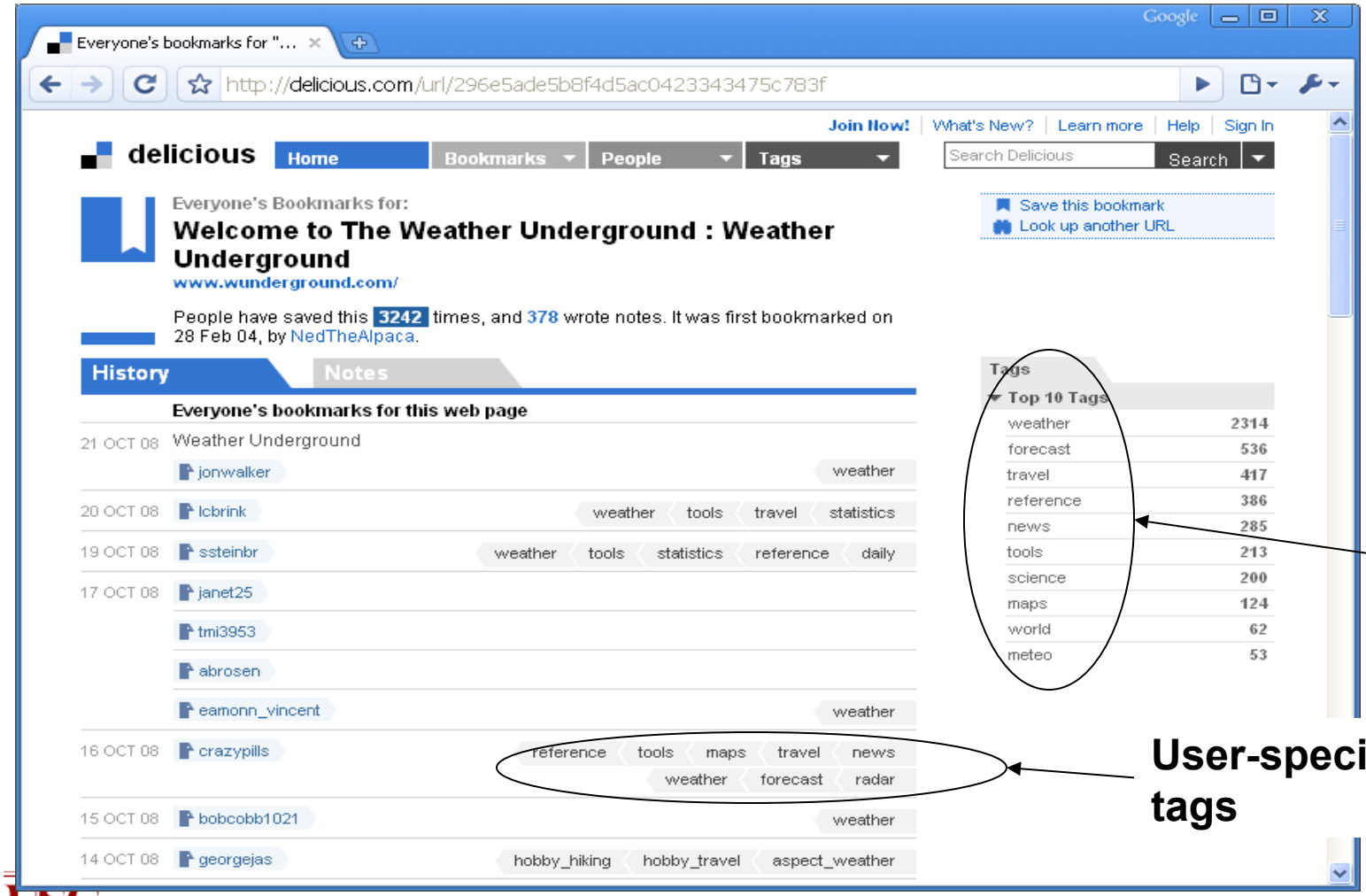
- Leverage user-generated tags on the social bookmarking site del.icio.us to discover sources similar to the seed



Exploiting Social Annotations for Resource Discovery

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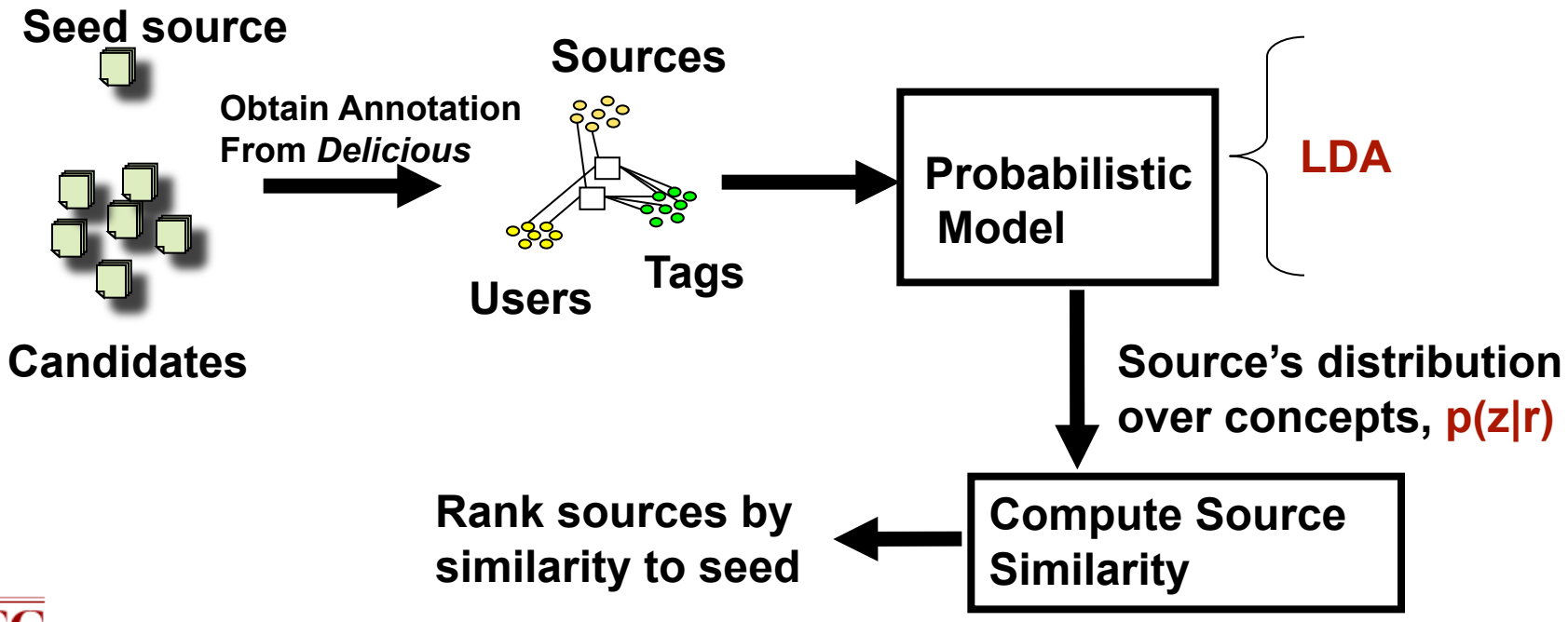
- Resource discovery task : "*given a seed source, find other most similar sources*"
  - Gather a corpus of <user, source, tag> bookmarks from del.icio.us
  - Use probabilistic modeling to find hidden topics in the corpus
  - Rank sources by similarity to the seed within topic space



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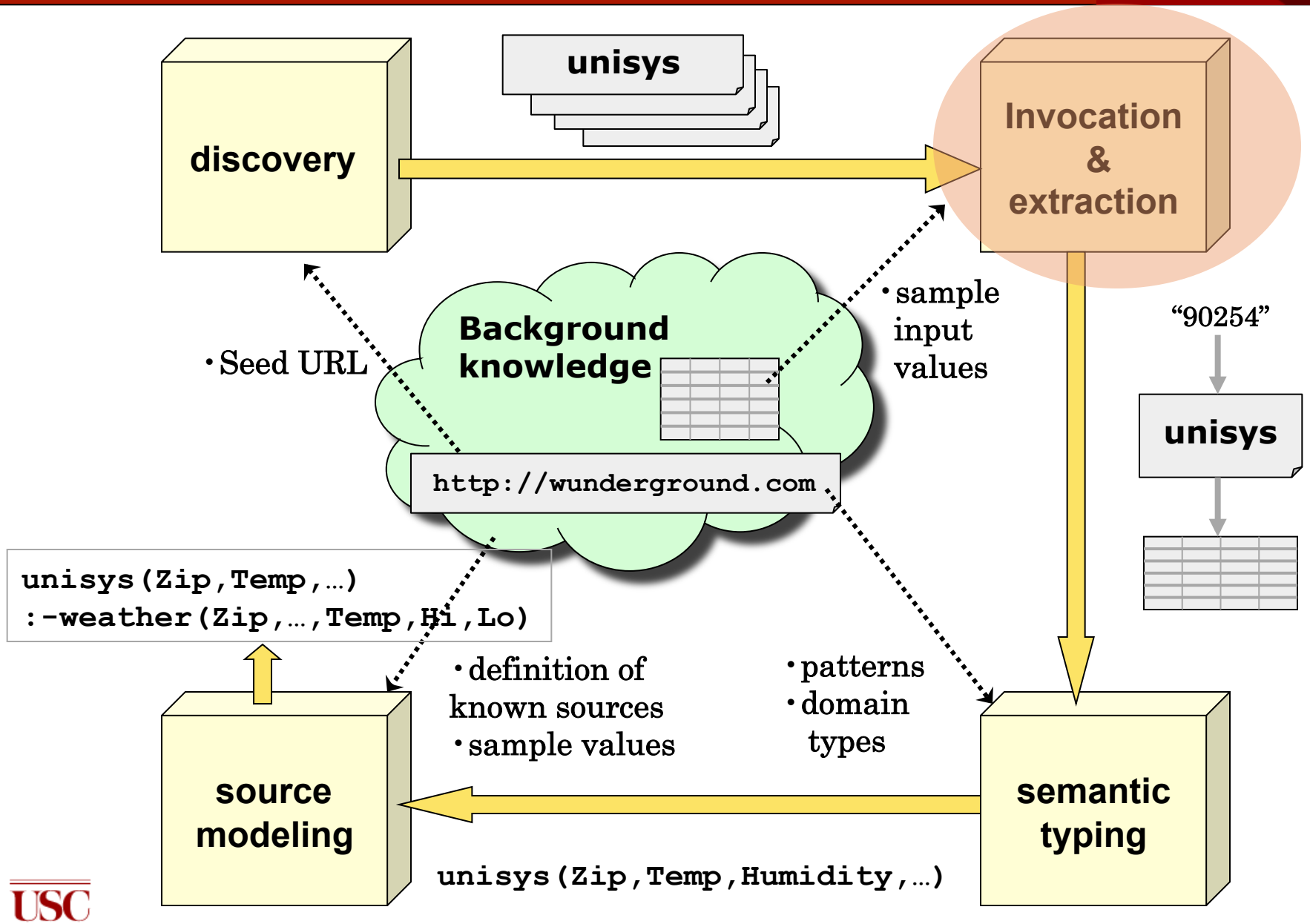
Source Invocation & Extraction



Target Source Invocation

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- 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

Form Input

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Inducing Extraction Templates

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- 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

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- 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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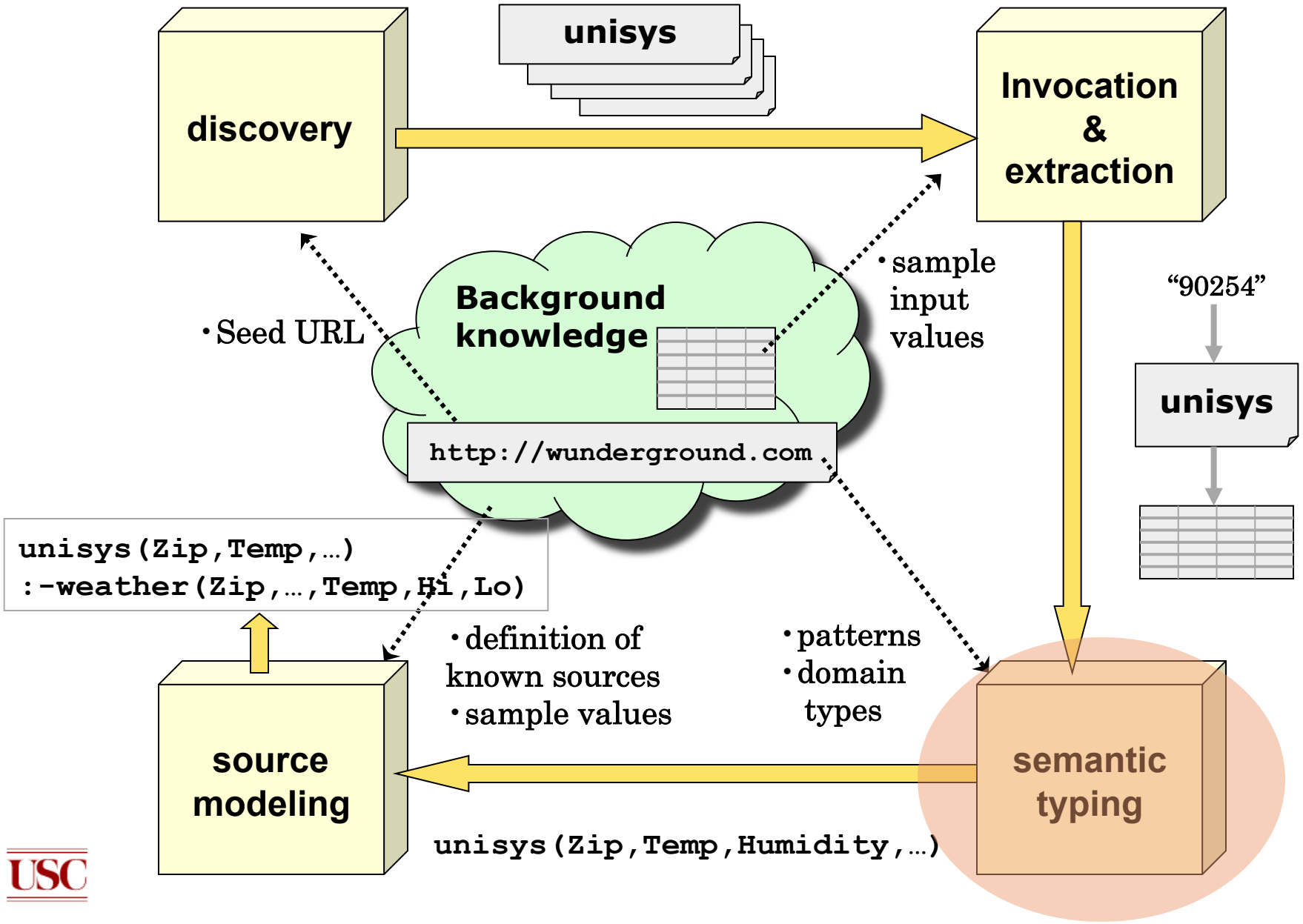
Semantic Typing



Semantic Typing [Lerman, Plangprasopchok, & Knoblock]

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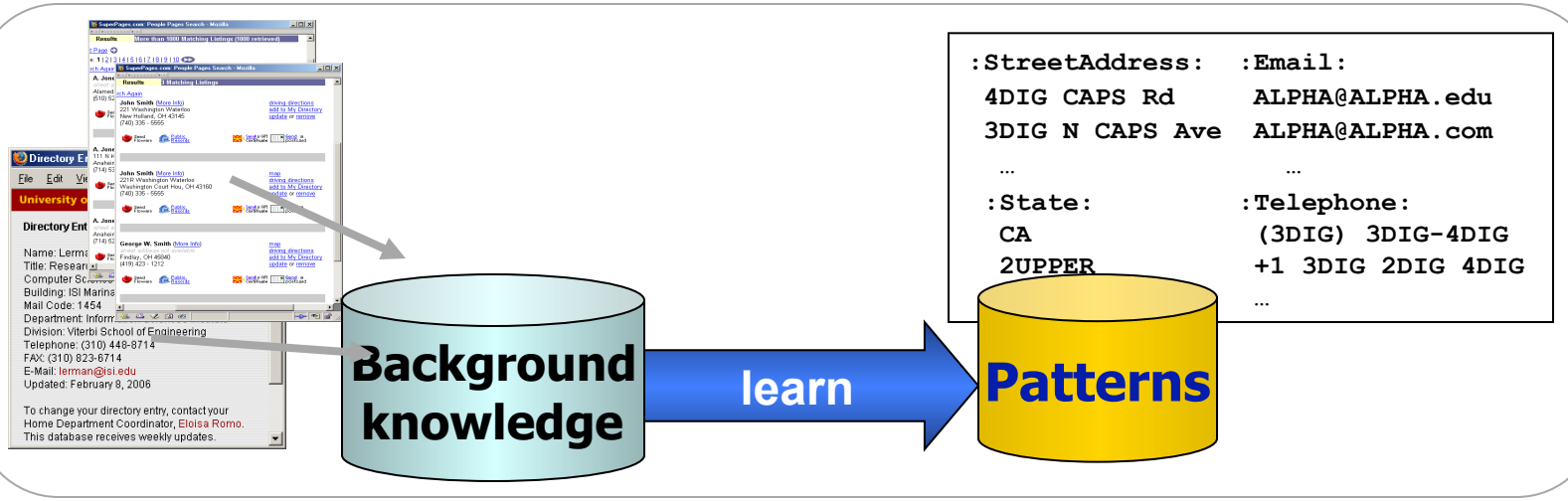
✓**Idea: Learn a model of the content of data and use it to recognize new examples**



Person	Address	Work
E Lewis	3518 Hilltop Rd	(419) 531 - 0504
Andrew Lewis	3543 Larchmont Pkwy	(518) 474 -
C. S. Lewis	555 Willow Run Dr	(612) 578 -
Carmen Jones	355 Morgan Ave N	(612) 522 -
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

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- 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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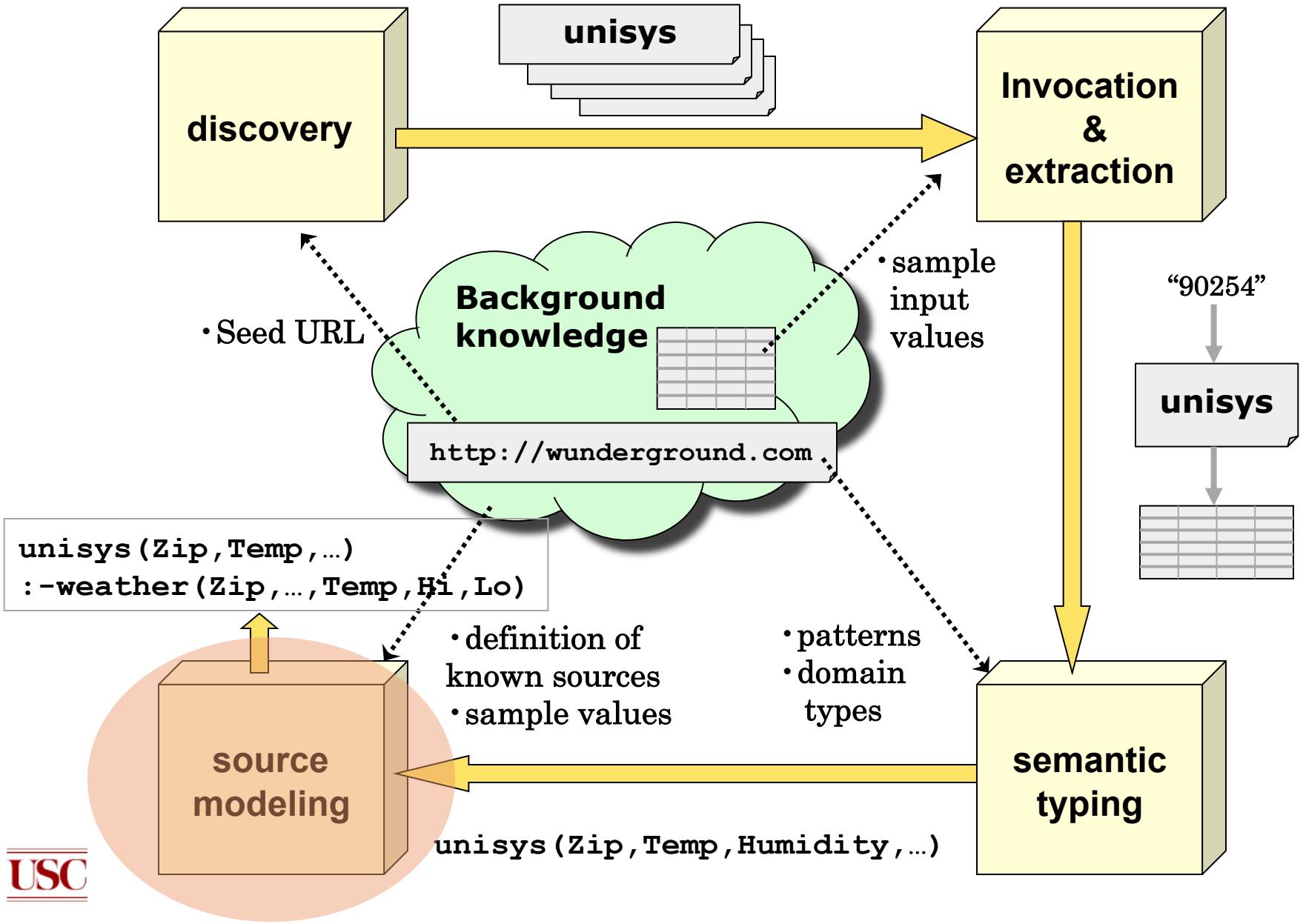
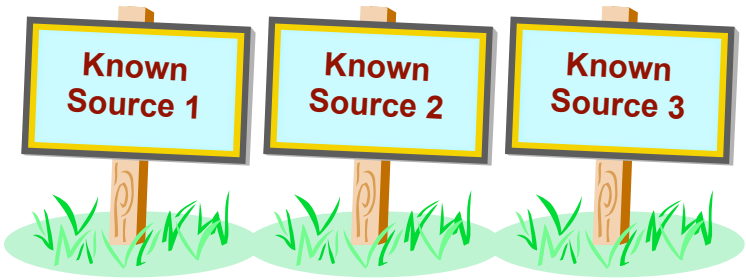
Source Modeling [Carman & Knoblock]

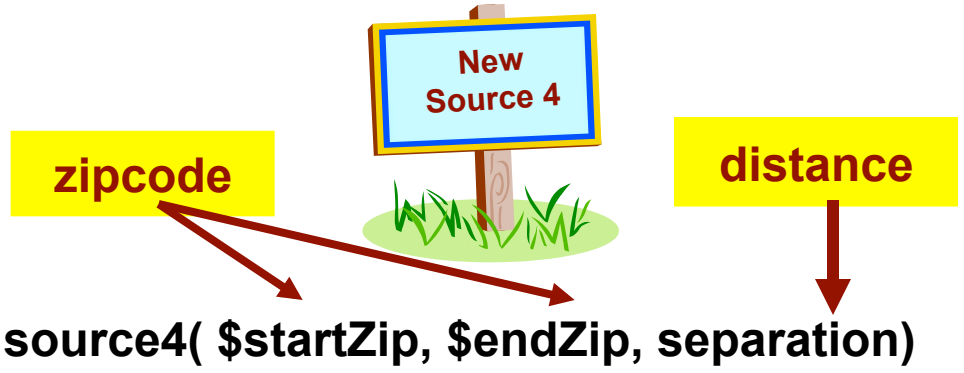


Inducing Source Definitions

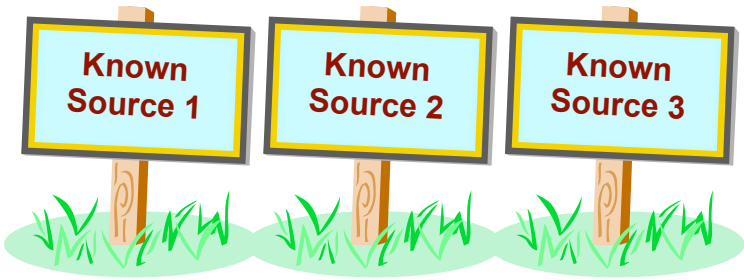



```
source1($zip, lat, long) :-
    centroid(zip, lat, long).

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



Generating Plausible Definition




```
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
- 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

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- 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

Constructing the Semantic Web Service

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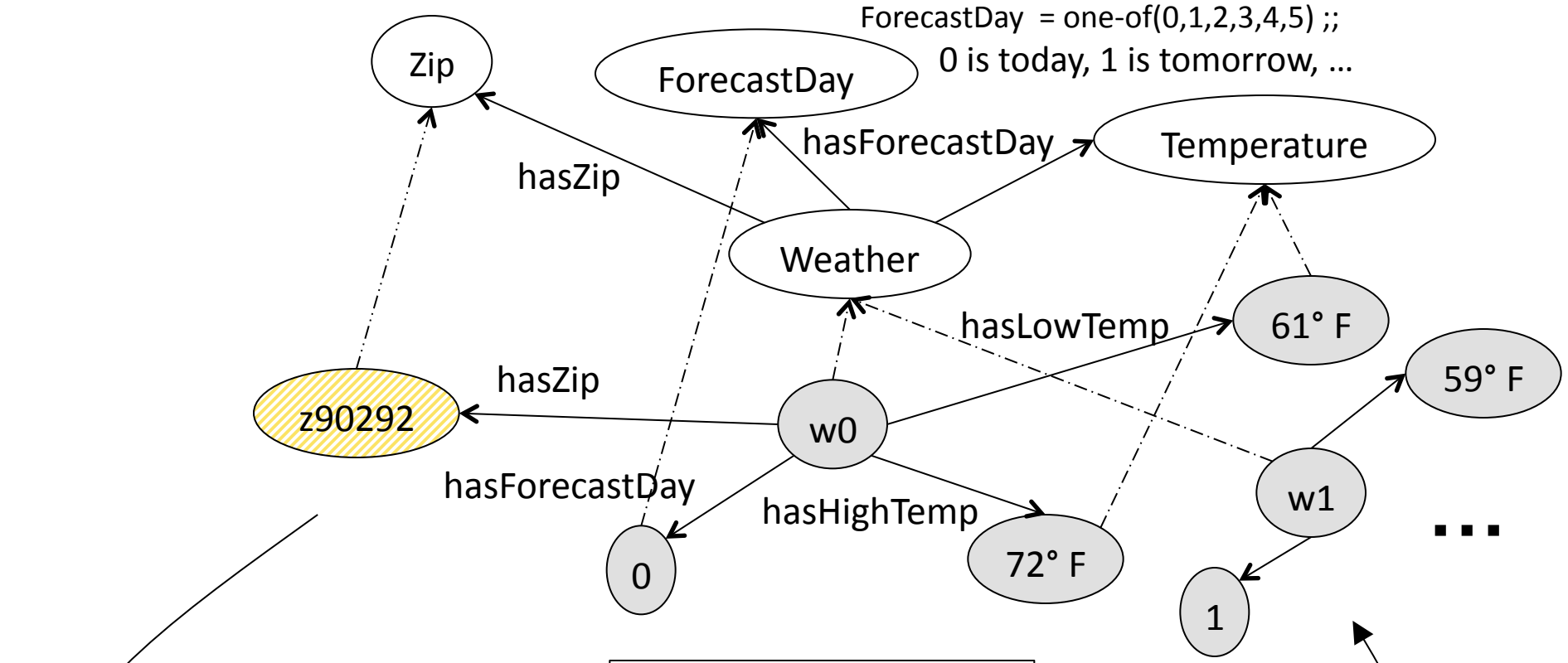

z90292 hasName 90292 .

DEIMOS generated Web Service

w1 hasZIP z90292 .
w1 hasTemp 61° F .
…
w1 hasZIP z90292 .
w2 hasLowTemp 59° F .

Legend:

ontology

RDF Input

RDF output

Background Source Descriptions

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```
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)
```

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Target explained using background sources

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```
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)
```

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Learned Target Source Description

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```
unisys($Z,_,_,_,_,_,_,_,F9,_,C,_,F13,F14,Hu,_,F17,_,_,_,_,S22,_,S24,_,_,_,
        _,_ ,_,_,_,_,_,_,S35,S36,_,_,_,_,_,_,_,_,_,_) :-
   Weather(_w0),hasForecastDay(_w0,0),hasZIP(_w0,Z),
     hasCurrentTemperatureFarenheit(_w0,F9), centigrade2farenheit(C,F9),
     hasCurrentTemperatureCentigrade(_w0,C), hasHumidity(_w0,Hu0),
  Weather(_w1),hasForecastDay(_w1,1), hasZIP(_w1,Z),
     hasCityState(_w1,CS), hasTimeWZone(_w1,T),
     hasLowTemperatureFarenheit(_w1,F14),
     hasHighTemperatureFarenheit(_w1,F17), hasSkyConditions(_w1,S24),
  Weather(_w2),hasForecastDay(_w2,2), hasZIP(_w2,Z),
     hasSkyConditions(_w2,S22),
  Weather(_w3),hasForecastDay(_w3,3), hasZIP(_w3,Z),
     hasSkyConditions(_w3,S35),
  Weather(_w4),hasForecastDay(_w4,4), hasZIP(_w4,Z),
     hasSkyConditions(_w4,S36),
  Weather(_w5),hasForecastDay(_w5,5), hasZIP(_w5,Z),
      hasLowTemperatureFarenheit(_w5,F13).
```

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Web Service Invocation

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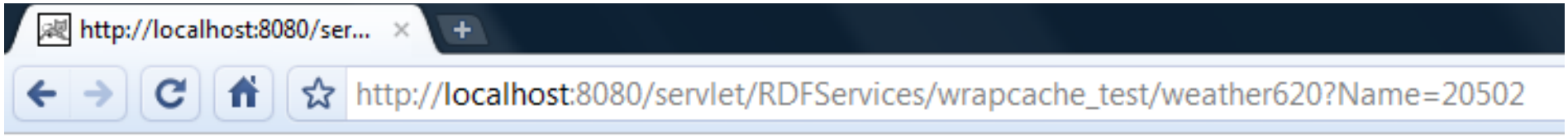


```
weatherforecast7709080 rdf:type WeatherForecast .
weatherforecast7709080 hasZIP "20502" .
weatherforecast7709080 hasCurrentTemperatureFarenheit "71F" .
windspeed7365415 rdf:type WindSpeed .
weatherforecast7709080 hasWindSpeed windspeed7365415 .
weatherforecast8455262 rdf:type WeatherForecast .
weatherforecast8455262 hasLowTemperature "49 F (9 C)" .
weatherforecast3087280 rdf:type WeatherForecast .
weatherforecast3087280 hasHighTemperature "71 F (21 C)" .
```

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  - Determining the semantic types of the data
  - Building semantic models of the sources
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Experimental Evaluation

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- 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

Candidate Sources after Each Step

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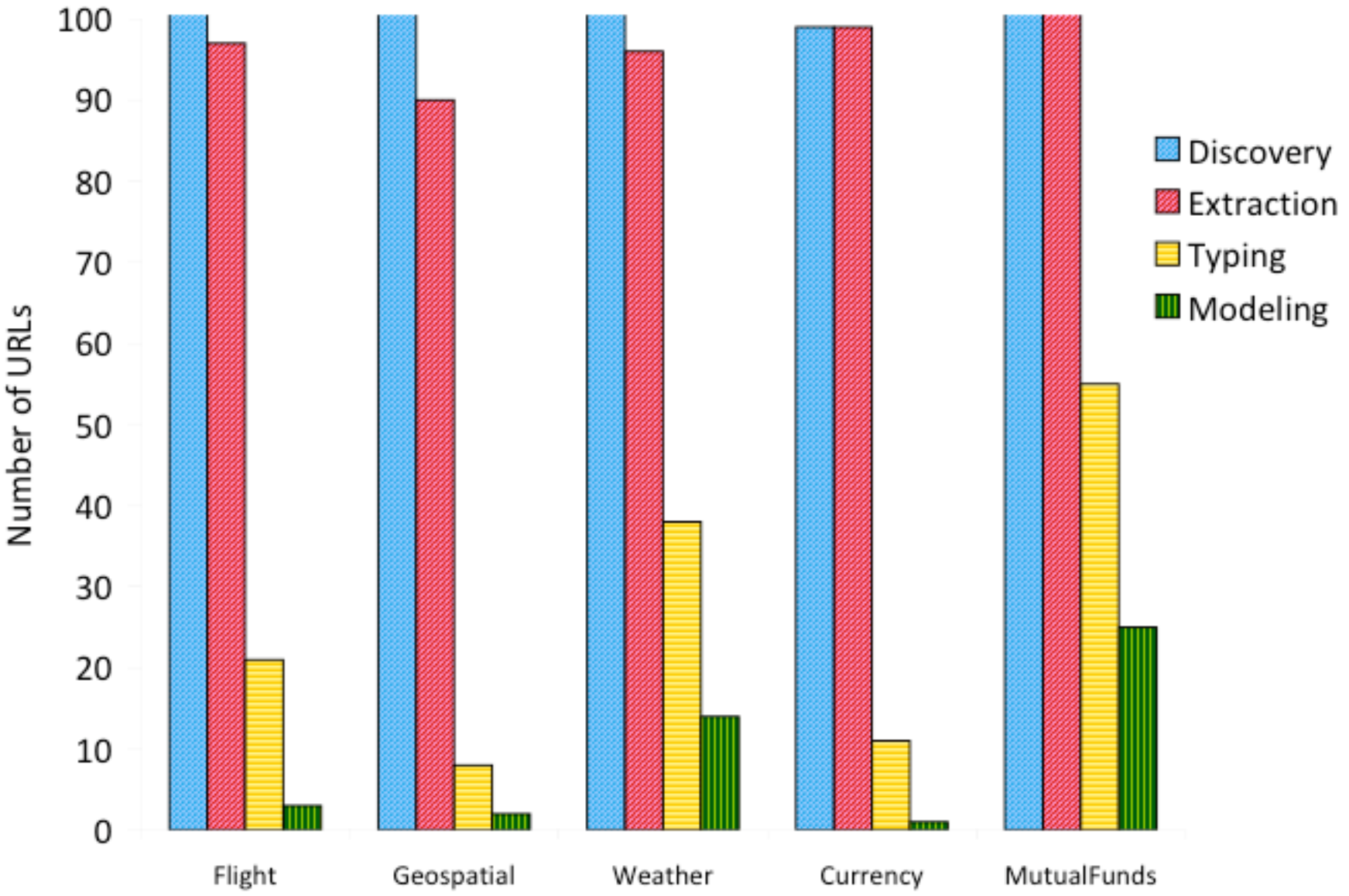

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Evaluation of the Models

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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

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Related Work

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- ILA & Category Translation (Perkowitz & Etzioni 1995)
  - Learn functions describing operations on internet
  - Assumes single input and single tuple as output
- Metadata-based classification of data types used by Web services and HTML forms (Hess & Kushmerick, 2003)
  - Naïve Bayes classifier
  - Only classified the source type, no model
- Use NLP to learn source descriptions (Afzal et al, 2009)
  - Extract type and function provided by service
  - Only provides high-level service type (ex: algorithm, application, data)
- Mining existing workflows (Belhajjame et al, 2008)
  - Connections in parameters of workflows use to infer semantic types
  - Limited semantic description of a web service

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Discussion

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- Integrated approach to discovering and modeling online sources and services:
  - *Discover new sources*
  - *How to invoke a source*
  - *Discovering the template for the source*
  - *Finding the semantic types of the output*
  - *Learning a definition of what the service does*
- Provides an approach to generate services and data for the Semantic Web
  - Little motivation for providers to annotate services
  - Instead we can generate metadata automatically

Future Work

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- Coverage, Precision, & Recall
  - Difficult to invoke sources with many inputs
    - *Hotel reservation sites*
  - Hard to learn sources that have many attributes
    - *Some weather sources could have 40 attributes*
- Learning beyond the domain model
  - Learn new semantic types
    - *Discover barometric pressure*
  - Learn new source attributes
    - *Learn about 6-day high and low temperatures*
  - Learn new source relations
    - *Learn conversion between Fahrenheit and Celsius*
  - Learn the domain and range of the sources
    - *Learn that a source provides world weather vs. US weather*
- Linking the Deep Web to the Linked Data Web
  - Use linked data ontologies as domain model
  - Perform entity linkage from web source URI to linked data URI

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Acknowledgements & Papers

- Sponsors
  - DARPA CALO Program, AFOSR, & NSF

- Papers
  - Integrated Approach
    - *[Ambite, Darbha, Goel, Knoblock, Lerman, Parundekar, Russ, ISWC 2009]*
  - Source discovery
    - *[Plangprasopchok and Lerman, WWW, 2009]*
  - Source extraction
    - *[Gazen, CMU Ph.d. thesis, 2008]*
  - Semantic typing
    - *[Lerman, Plangprasopchok, & Knoblock, IJSWIS, 2008]*
  - Source modeling
    - *[Carman & Knoblock, JAIR, 2007]*