Question Answering on Web Data

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Commercial Assistants

Alexa

User hand-codes question/code 1 by 1

get me an upscale restaurants

What are the restaurants around here?

What is the best restaurant?

search for Chinese restaurants

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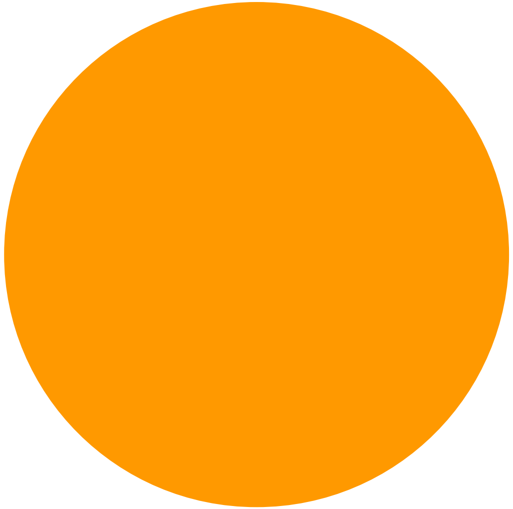

100K Alexa skills
Sep 2019

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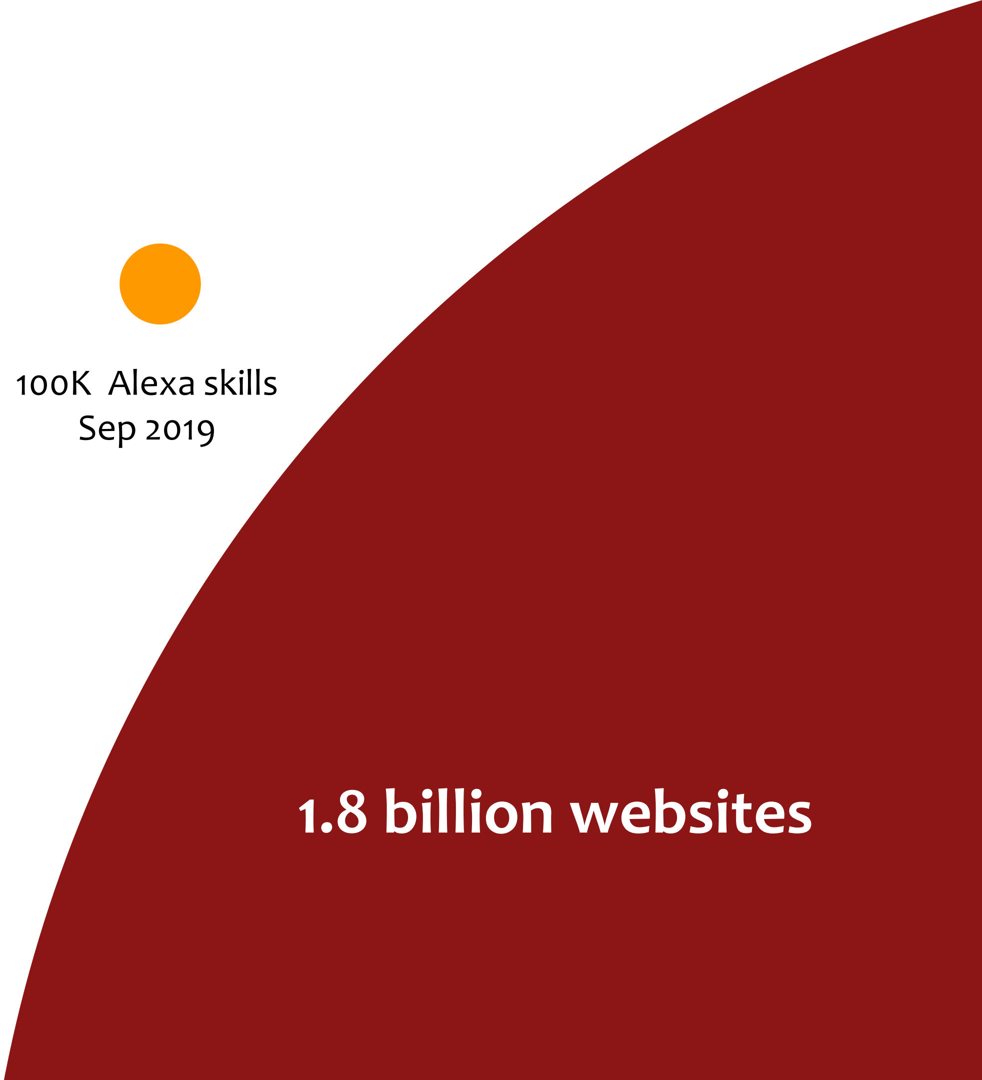
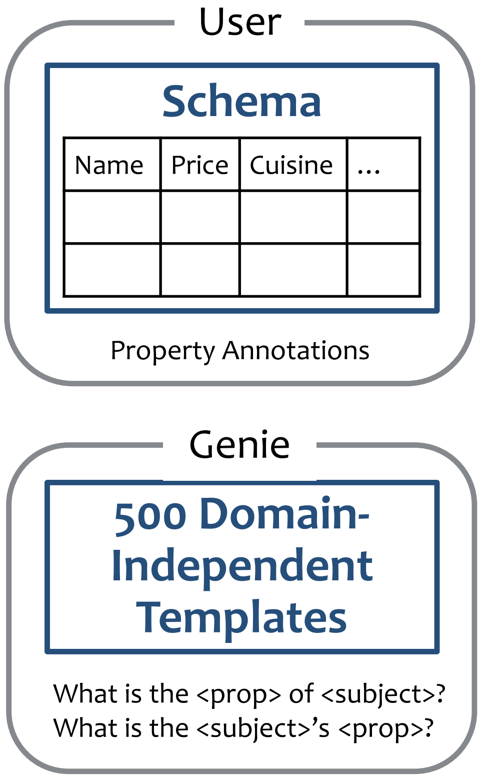


100K Alexa skills
Sep 2019

1.8 billion websites

Genie: Synthesize Question/Code from a Schema



User

Schema

Name	Price	Cuisine	…

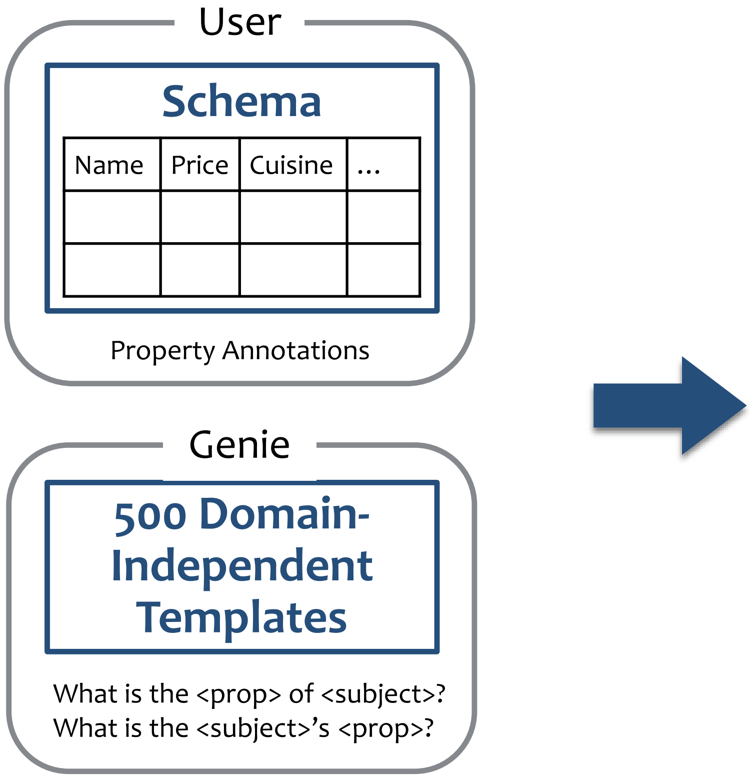
Property Annotations

Genie

500 Domain-Independent Templates

What is the <prop> of <subject>?
What is the <subject>'s <prop>?

Genie: Synthesize Question/Code from a Schema



User

Schema

Name	Price	Cuisine	…

Property Annotations

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500 Domain-Independent Templates

What is the <prop> of <subject>?
What is the <subject>’s <prop>?

get me an upscale restaurants

What are the restaurants around here?

What is the best restaurant?

search for Chinese restaurants

What is the best restaurant within 10 miles?

Find restaurants that serve Chinese or Japanese food

What is the best non-Chinese restaurant near here?

Show me a cheap restaurant with 5-star review.

Are there any restaurant with at least 4.5 stars?

What is the phone number of Wendy’s?

I’m looking for an Italian fine dining restaurant.

Give me the best Italian restaurant.

Find me the best restaurant with 500 or more reviews

Show me some restaurant with less than 10 reviews

The Web Has a Schema!

The Web Has a Schema!

- Schema.org
  - Structure data to mark up web pages
  - Mainly used by search engines
  - It covers many domains, including restaurants, hotels, people, recipes, products, news …

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```
<script type="application/ld+json">
{
  @type: "restaurant",
  name: "The French Laundry",
  servesCuisine: “French",
  aggregateRating: {
    @type: "AggregateRating",
    reviewCount: 2527,
    ratingValue: 4.5
  }
  ...
}
```

Schema.org markup on Yelp

The Web Has a Schema!

- Schema.org
  - Structure data to mark up web pages
  - Mainly used by search engines
  - It covers many domains, including restaurants, hotels, people, recipes, products, news …

40% of the websites use it!

```
<script type="application/ld+json">
{
  @type: "restaurant",
  name: "The French Laundry",
  servesCuisine: “French",
  aggregateRating: {
    @type: "AggregateRating",
    reviewCount: 2527,
    ratingValue: 4.5
  }
  ...
}
```

Schema.org markup on Yelp

Outline

- Introduction to Schema.org
- Represent Questions in ThingTalk
- LUINet: NL to ThingTalk
  - Training data generation
  - Experimental results
- Work in progress: automate everything!

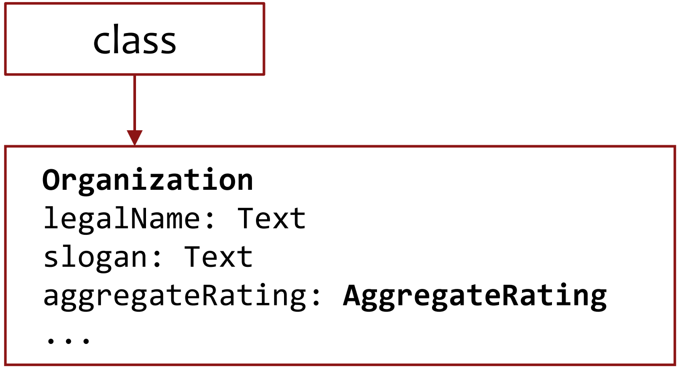
Introduction to Schema.org

Graph Data Model of Schema.org

Graph Data Model of Schema.org

```
Organization
legalName: Text
slogan: Text
aggregateRating: AggregateRating
...
```

Graph Data Model of Schema.org



```
Organization
legalName: Text
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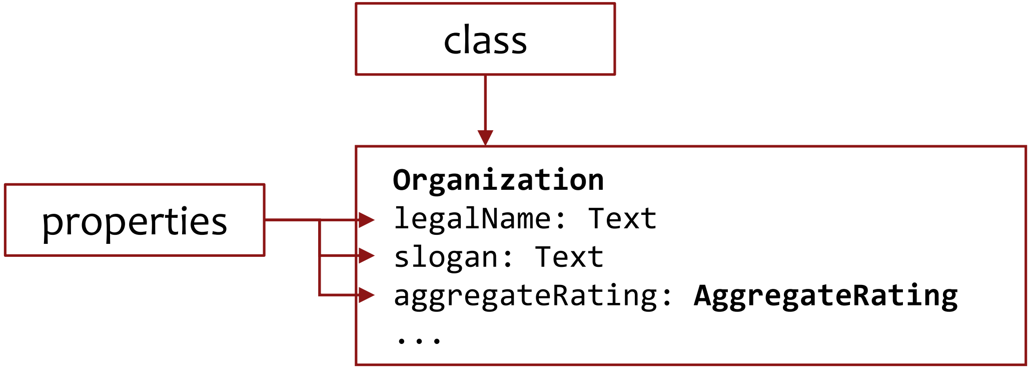
aggregateRating: AggregateRating
...
```

Graph Data Model of Schema.org

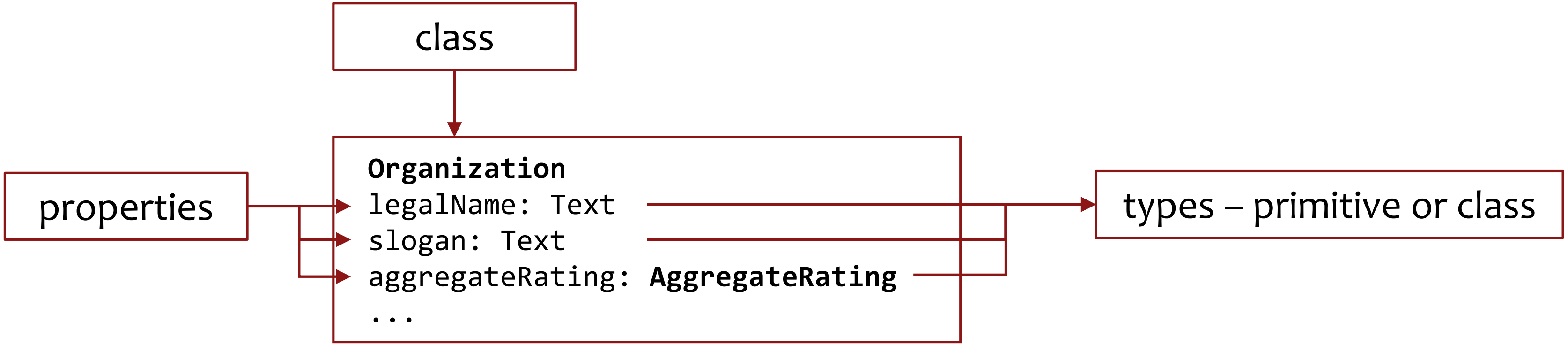


class

properties

```
Organization
legalName: Text
slogan: Text
aggregateRating: AggregateRating
...
```

Graph Data Model of Schema.org



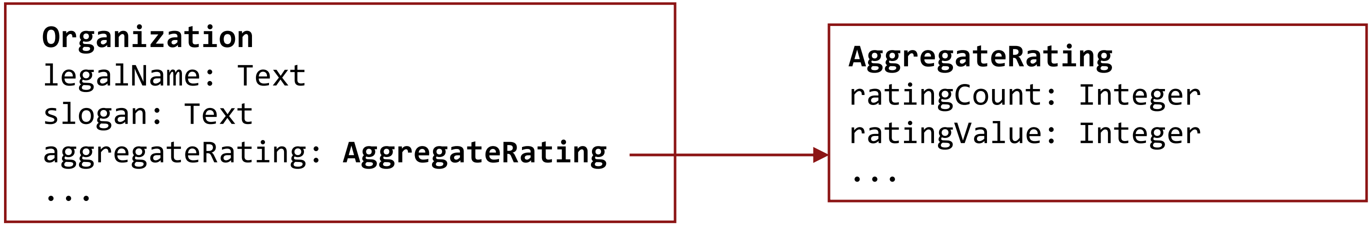
class

properties

types – primitive or class

```
Organization
legalName: Text
slogan: Text
aggregateRating: AggregateRating
...
```

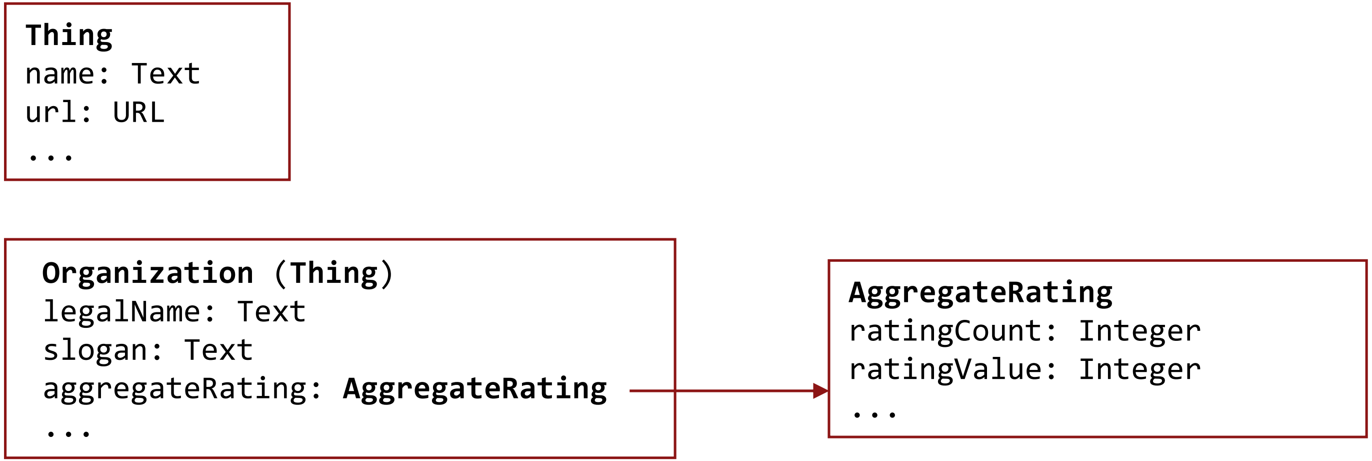
Graph Data Model of Schema.org



```
Organization
legalName: Text
slogan: Text
aggregateRating: AggregateRating
...
```

```
AggregateRating
ratingCount: Integer
ratingValue: Integer
...
```

Schema.org Hierarchy

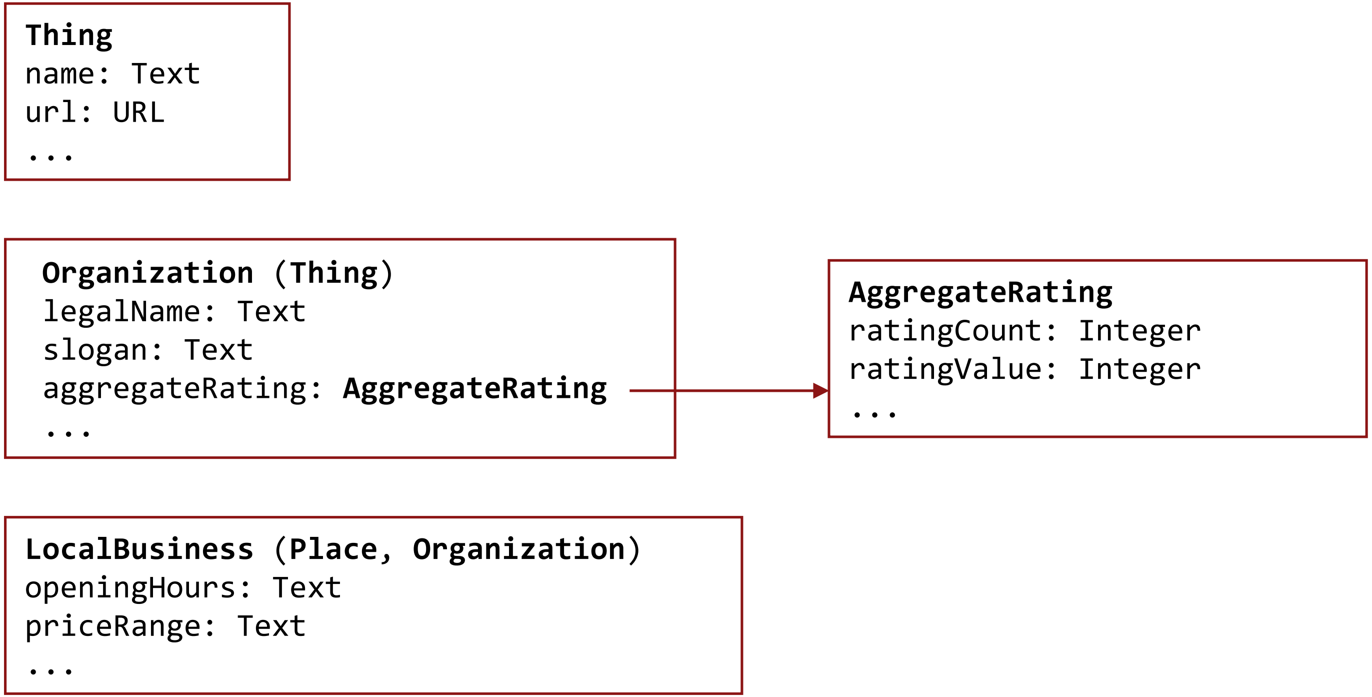


```
Thing
name: Text
url: URL
...
```

```
Organization (Thing)
legalName: Text
slogan: Text
aggregateRating: AggregateRating
...
```

```
AggregateRating
ratingCount: Integer
ratingValue: Integer
...
```

Schema.org Hierarchy



Thing
name: Text
url: URL
...

Organization (Thing)
legalName: Text
slogan: Text
aggregateRating: **AggregateRating**
...

AggregateRating
ratingCount: Integer
ratingValue: Integer
...

LocalBusiness (Place, Organization)
openingHours: Text
priceRange: Text
...

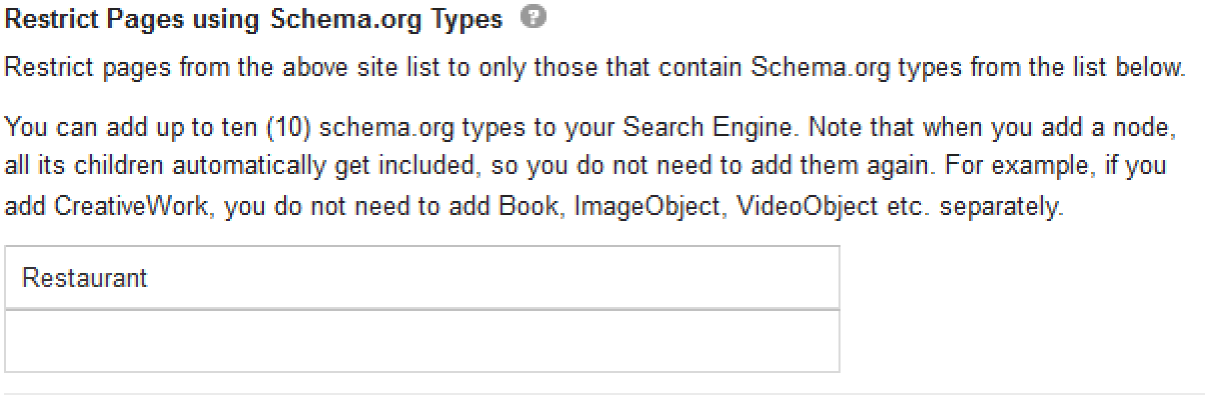
Some useful tools

- Google Structured Data Testing Tool

Google Structured Data Testing Tool

  - Show schema.org markups in a web page

- Google Custom Search
  - Search for pages that contain certain schema.org domains



Restrict Pages using Schema.org Types

Restrict pages from the above site list to only those that contain Schema.org types from the list below.

You can add up to ten (10) schema.org types to your Search Engine. Note that when you add a node, all its children automatically get included, so you do not need to add them again. For example, if you add CreativeWork, you do not need to add Book, ImageObject, VideoObject etc. separately.

Restaurant

ThingTalk for Questions

ThingTalk for QA

$$\mathit{table}\ [, \mathit{filter}]^?$$

ThingTalk for QA

$$\textit{table}\ [, \textit{filter}]^?$$

```
        @QA.restaurant(), geo == makeLocation(“Stanford”)
now =>                                                    => notify
```

Show me restaurants in Stanford

ThingTalk for QA

$$\mathit{table}\ [, \mathit{filter}]^{?}$$

```
         @QA.restaurant(), geo == makeLocation(“Stanford”)
now =>                    && servesCuisine =~ “Chinese”            => notify
```

Show me Chinese restaurants in Stanford

ThingTalk for QA

$$\texttt{sort}\ \mathit{fn}\ \texttt{asc|desc of}\ \ \mathit{table}\ [, \mathit{filter}]^{?}$$

```
         @QA.restaurant(), geo == makeLocation(“Stanford”)
now =>                && servesCuisine =~ “Chinese”             => notify
```

Show me Chinese restaurants in Stanford

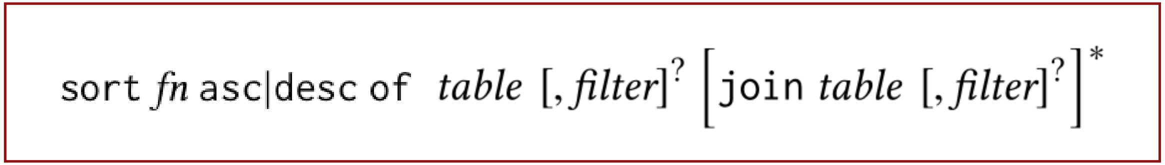
ThingTalk for QA

sort *fn* asc|desc of *table* [, *filter*]$^?$

```
               sort aggregateRating.ratingValue desc of (
              @QA.restaurant(), geo == makeLocation(“Stanford”)
now =>                  && servesCuisine =~ “Chinese” )            => notify
```

Show me top-rated Chinese restaurants in Stanford

ThingTalk for QA



$$\texttt{sort}\ \mathit{fn}\ \texttt{asc}|\texttt{desc of}\ \ \mathit{table}\ [,\mathit{filter}]^{?}\left[\texttt{join}\ \mathit{table}\ [,\mathit{filter}]^{?}\right]^{*}$$

```
now =>     sort aggregateRating.ratingValue desc of (
          @QA.restaurant(), geo == makeLocation(“Stanford”)
                           && servesCuisine =~ “Chinese” )        => notify
```

Show me top-rated Chinese restaurants in Stanford

ThingTalk for QA

$$\texttt{sort}\ \mathit{fn}\ \texttt{asc|desc of}\ \ \mathit{table}\ [,\mathit{filter}]^?\ \left[\texttt{join}\ \mathit{table}\ [,\mathit{filter}]^?\right]^*$$

```
             sort aggregateRating.ratingValue desc of (
            @QA.restaurant(), geo == makeLocation(“Stanford”)
now =>                       && servesCuisine =~ “Chinese” )             => notify
                      join ( @QA.Review(), in_array(id, review)
                             && author = “bob” )
```

Show me top-rated Chinese restaurants in Stanford reviewed by Bob

ThingTalk for QA

$$\texttt{sort}\ \mathit{fn}\ \texttt{asc|desc of}\ \ \mathit{table}\ [, \mathit{filter}]^?\ \left[\texttt{join}\ \mathit{table}\ [, \mathit{filter}]^?\right]^*$$

$$\left[\mathit{fn}^+\ \texttt{of}\right]^?\ \mathit{table}\ [, \mathit{filter}]^?$$

ThingTalk for QA

$$\texttt{sort}\ \mathit{fn}\ \texttt{asc|desc of}\ \ \mathit{table}\ [, \mathit{filter}]^{?} \left[\texttt{join}\ \mathit{table}\ [, \mathit{filter}]^{?}\right]^{*}$$

$$\left[\mathit{fn}^{+}\ \texttt{of}\right]^{?}\ \mathit{table}\ [, \mathit{filter}]^{?}$$

$$\texttt{aggregate}\ \mathrm{min|max|sum|avg|count}\ \mathit{fn}\ \texttt{of}\ \ \mathit{table}\ [, \mathit{filter}]^{?}$$

ThingTalk for QA

$$\texttt{sort}\ \mathit{fn}\ \texttt{asc}|\texttt{desc}\ \texttt{of}\ \ \mathit{table}\ [,\mathit{filter}]^{?}\left[\texttt{join}\ \mathit{table}\ [,\mathit{filter}]^{?}\right]^{*}$$

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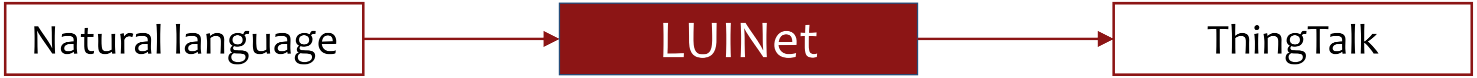
…

LUINet:
NL to ThingTalk

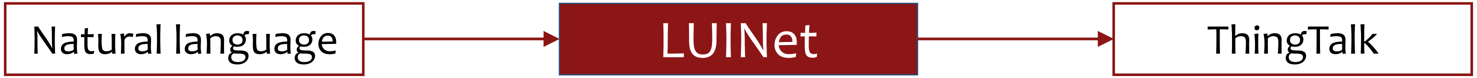
Natural Language Programming



What is the top-rated Chinese restaurant in Palo Alto?

```
sort aggregateRating.ratingValue desc of
(@QA.restaurant(),
geo == new MakeLocation(“Stanford”)
&& servesCuisine =~ “Chinese” )
```

Genie Pipeline



Genie Pipeline

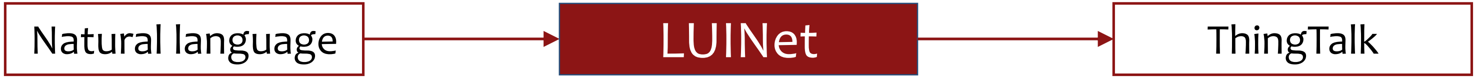
Thingpedia Manifest

Schema

Name	Price	Cuisine	…

Natural Language Annotations

cuisine of the restaurant
restaurant’s cuisine
cuisine served by the restaurant



Natural language → LUINet → ThingTalk

Genie Pipeline

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ThingTalk Grammar

Domain-independent Templates

What is the <prop> of <table>?
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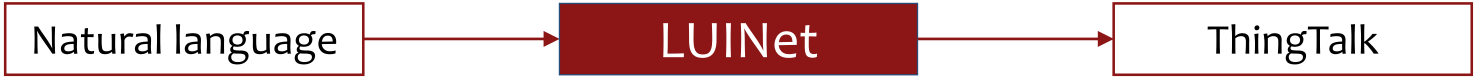

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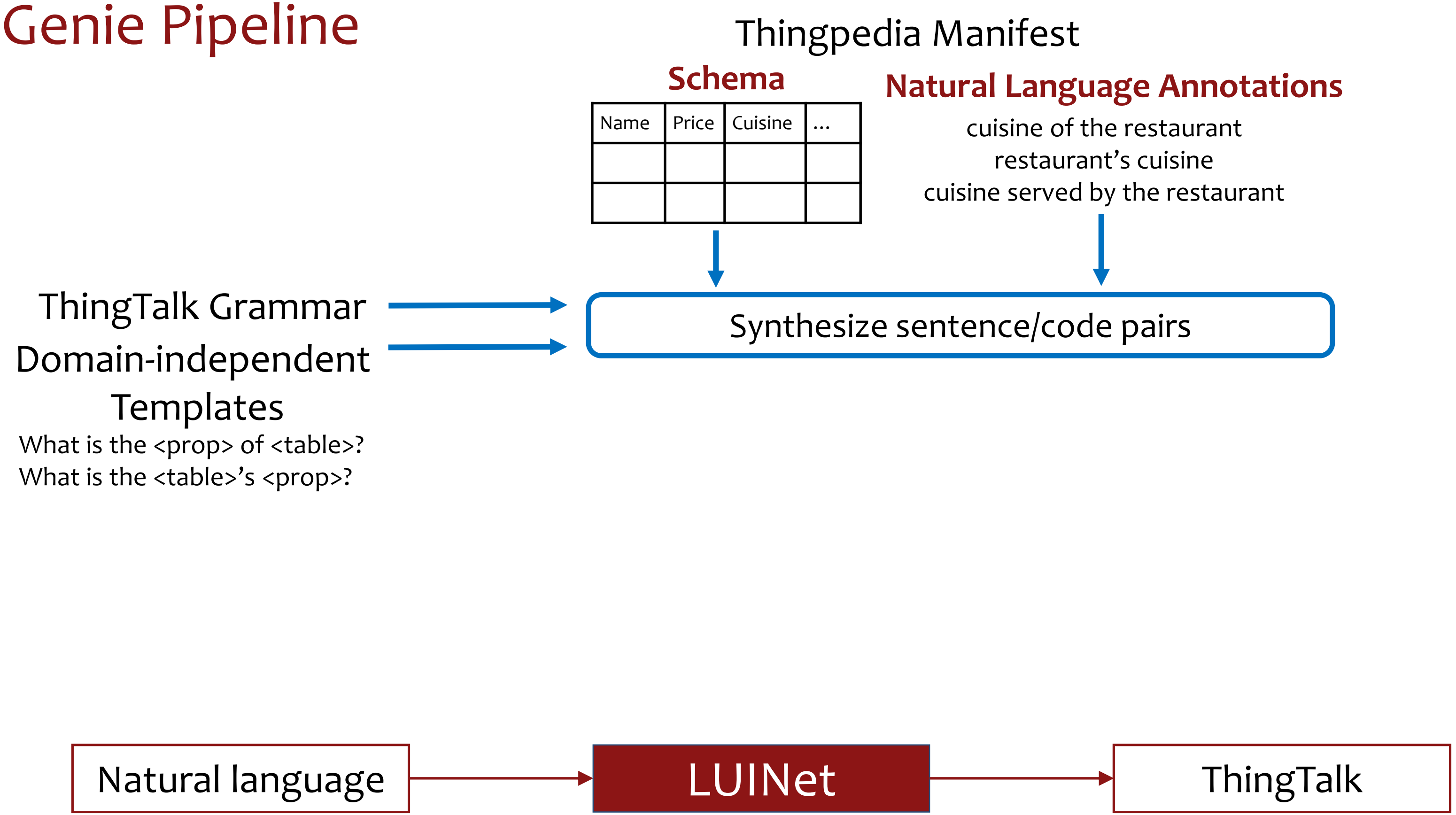

Thingpedia Manifest

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Synthesize sentence/code pairs

ThingTalk Grammar

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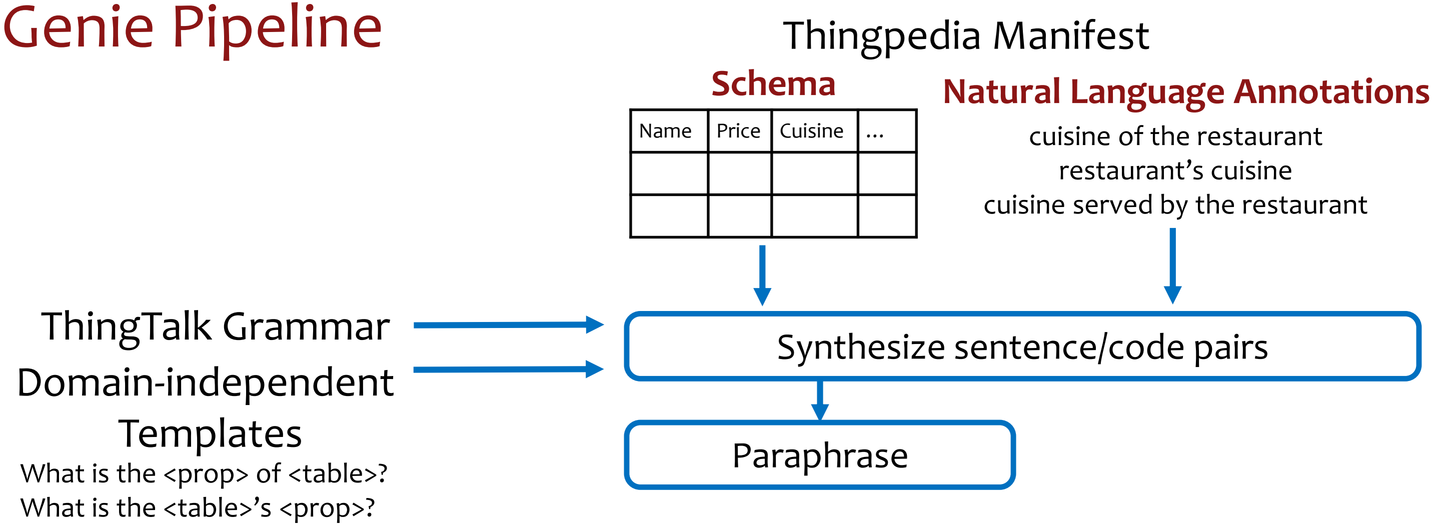

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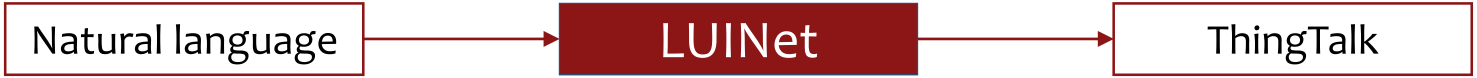

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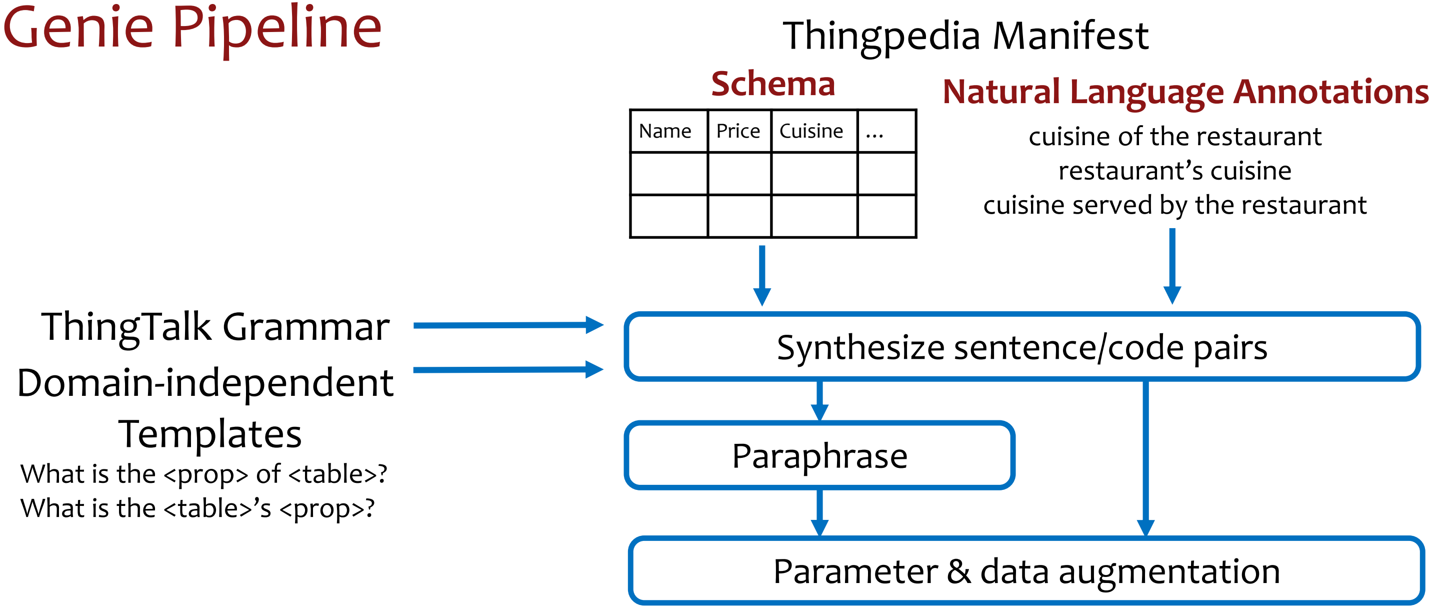

Thingpedia Manifest

Schema

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Natural Language Annotations

cuisine of the restaurant
restaurant's cuisine
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ThingTalk Grammar

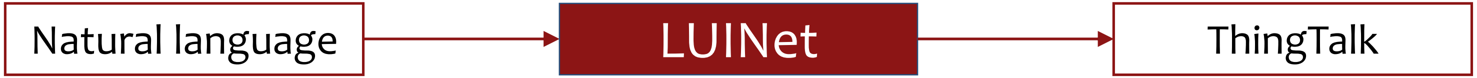
Domain-independent Templates

What is the <prop> of <table>?
What is the <table>'s <prop>?

Synthesize sentence/code pairs

Paraphrase

Parameter & data augmentation

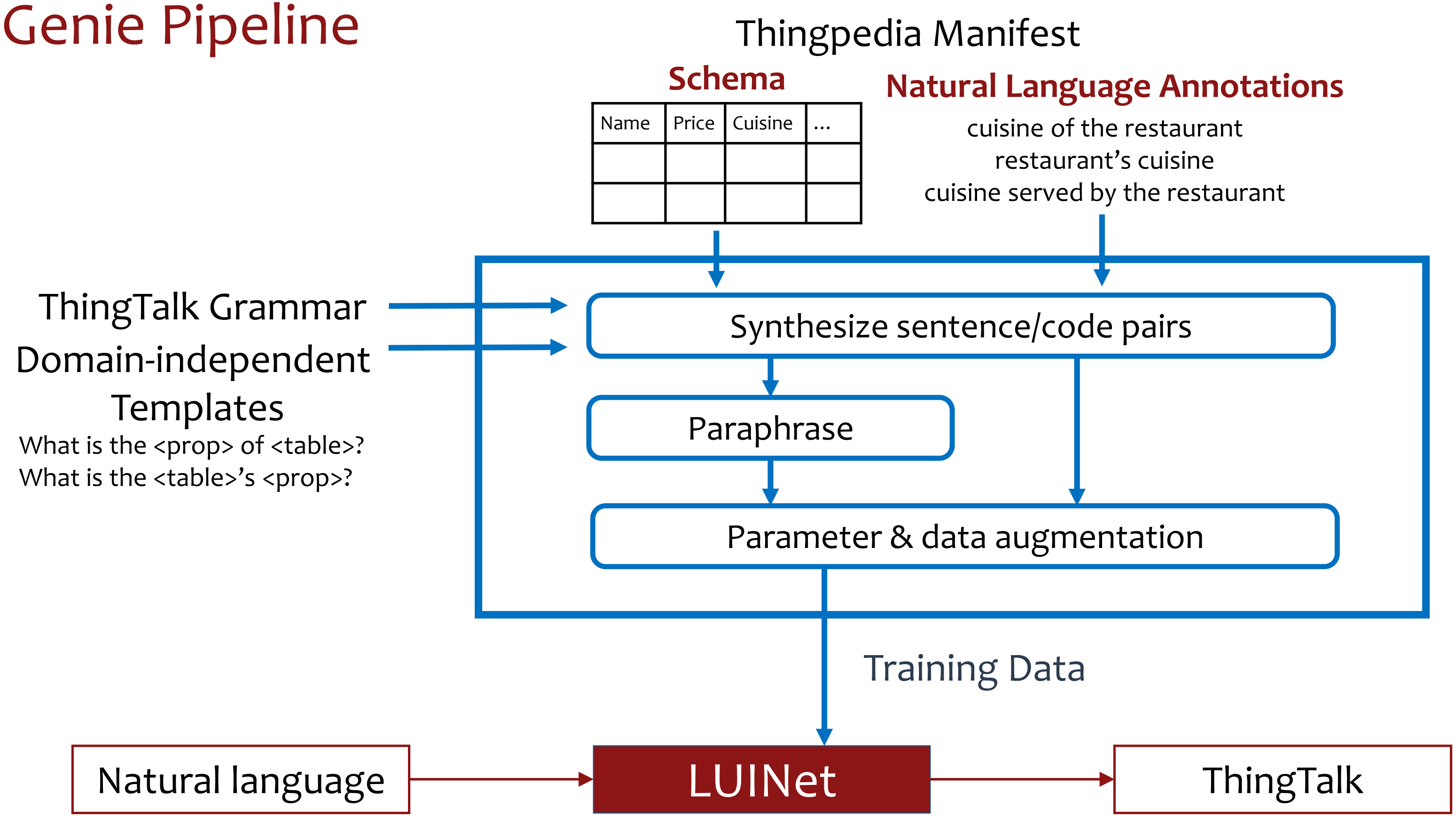


Natural language

LUINet

ThingTalk

Genie Pipeline



Thingpedia Manifest

Schema

Name	Price	Cuisine	…

Natural Language Annotations

cuisine of the restaurant
restaurant's cuisine
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What is the <prop> of <table>?
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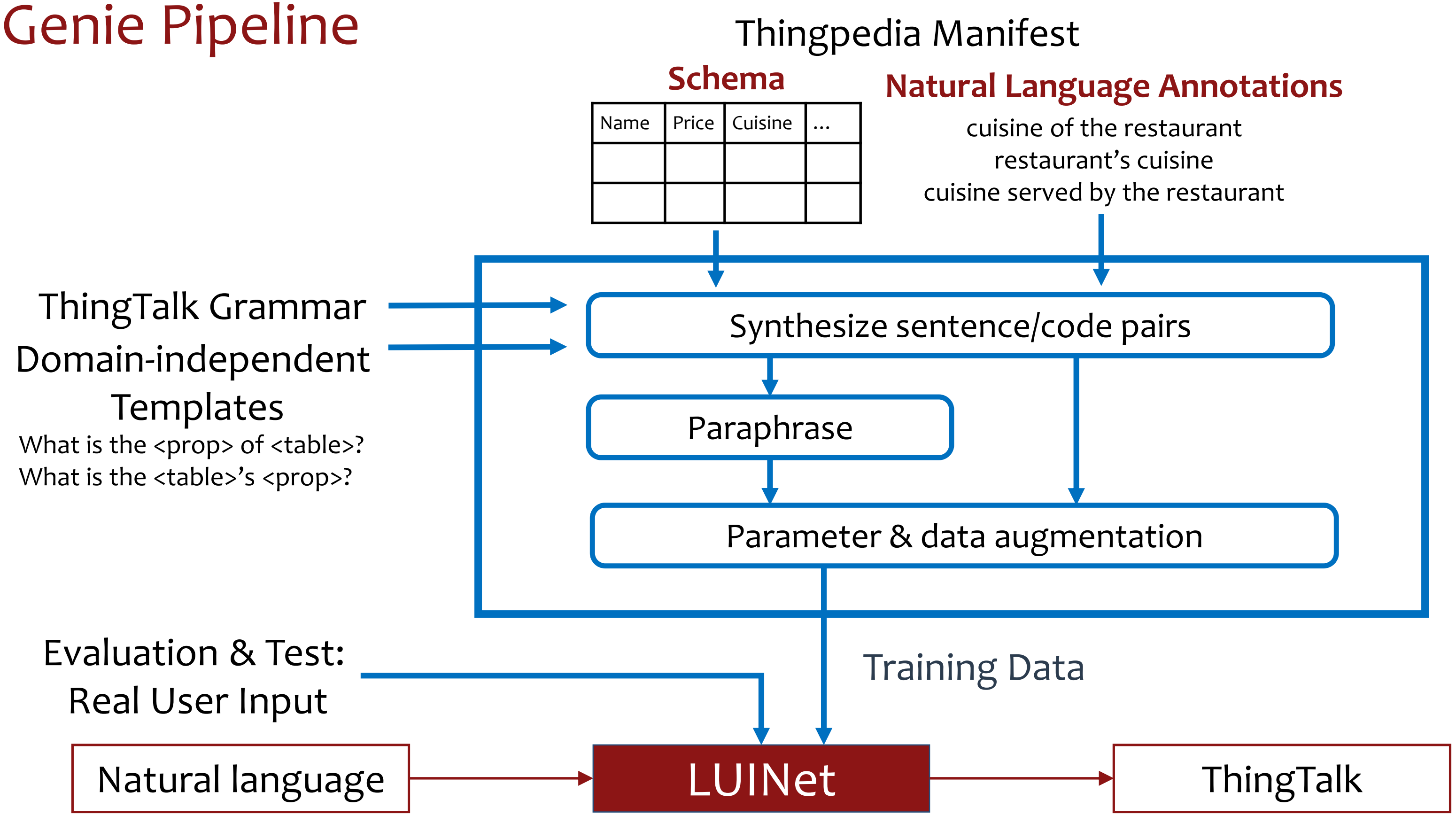
Genie Pipeline



Thingpedia Manifest

Schema

Name	Price	Cuisine	…

Natural Language Annotations

cuisine of the restaurant
restaurant’s cuisine
cuisine served by the restaurant

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Domain-independent Templates

What is the <prop> of <table>?
What is the <table>’s <prop>?

Synthesize sentence/code pairs

Paraphrase

Parameter & data augmentation

Training Data

Evaluation & Test: Real User Input

Natural language

LUINet

ThingTalk

Automatically Turn Schema.org into Thingpedia Manifest

- Tables with hierarchy
  - properties are inherited from parent tables
  - only keep classes & properties with data
  - decide types based on schema.org types and data

```
@org.schema {
  Restaurant extends FoodEstablishment {}
  FoodEstablishment extends LocalBusiness {
    acceptsReservation: Boolean,
    servesCuisine: String, ...
  }
  LocalBusiness extends Place, Organizations {
    priceRange: String,
    openingHours: String, ...
  }
  Organizations extends Thing {
    aggregateRating: {
      ratingCount: Number,
      ratingValue: Number,
    },
    review: Array(Review),
  }
  Thing {
    name: String, ...
  }
}
```

Map properties to natural language

Map properties to natural language

- Long, non-word, property names
  - E.g., ratingValue, servesCuisine
- Variety in natural language usage

Map properties to natural language

- Long, non-word, property names
  - E.g., ratingValue, servesCuisine
- Variety in natural language usage

servesCuisine	**ratingValue**
Chinese restaurant ✓	4.5 restaurant ✗
Restaurant with Chinese cuisine ✓	Restaurant with 4.5 rating ✓
Restaurant served Chinese cuisine ✗	Restaurant rated 4.5 ✓
Restaurant that serves Chinese cuisine ✓	Restaurant rates 4.5 ✗
Restaurant with Chinese ✗	Restaurant with 4.5 ✗
…	…

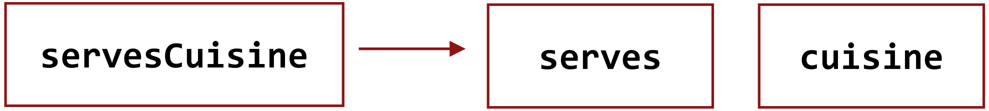
NL Annotations by Part-Of-Speech Categories

- “servesCuisine”
  - Noun phrase
    - “cuisine”: e.g., “the cuisine of the restaurant”, “restaurants with Chinese cuisine”
  - Verb phrase
    - “serves # cuisine”, “serves #” : e.g., “restaurant that serves Chinese cuisine”, “what does the restaurant serve”
  - Adjective-phrase value (with no property name)
    - E.g., “Chinese restaurants”

NL Annotation Generation

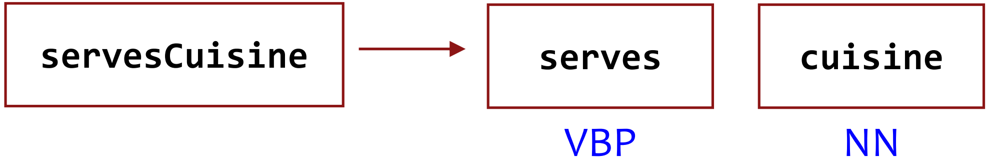
```
servesCuisine
```

NL Annotation Generation



servesCuisine → serves cuisine

NL Annotation Generation

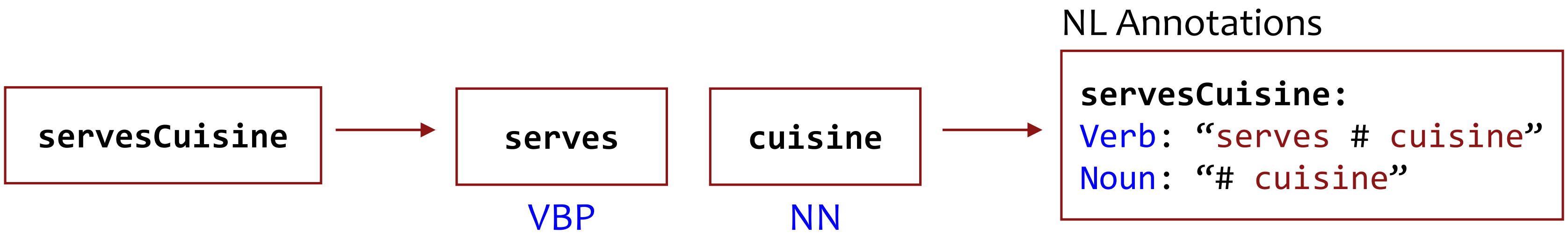


servesCuisine → serves cuisine

serves: VBP

cuisine: NN

NL Annotation Generation



servesCuisine → serves cuisine →

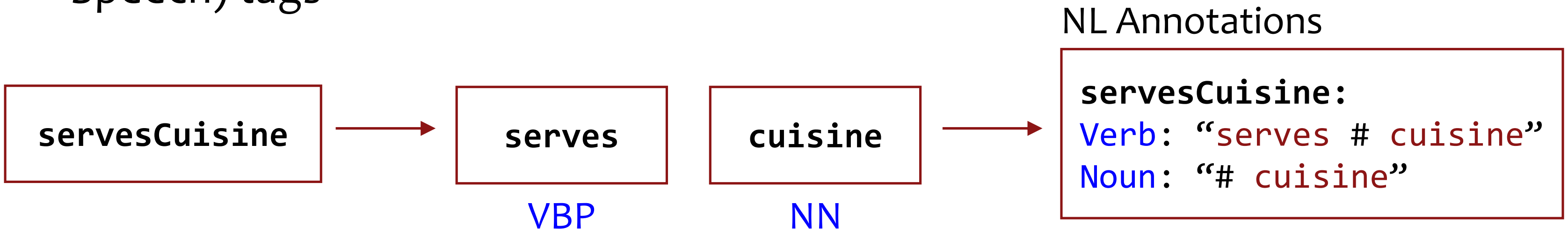
VBP NN

NL Annotations

```
servesCuisine:
Verb: “serves # cuisine”
Noun: “# cuisine”
```

NL Annotation Generation

- Automatic: Heuristics based on POS (Part-Of-Speech) tags

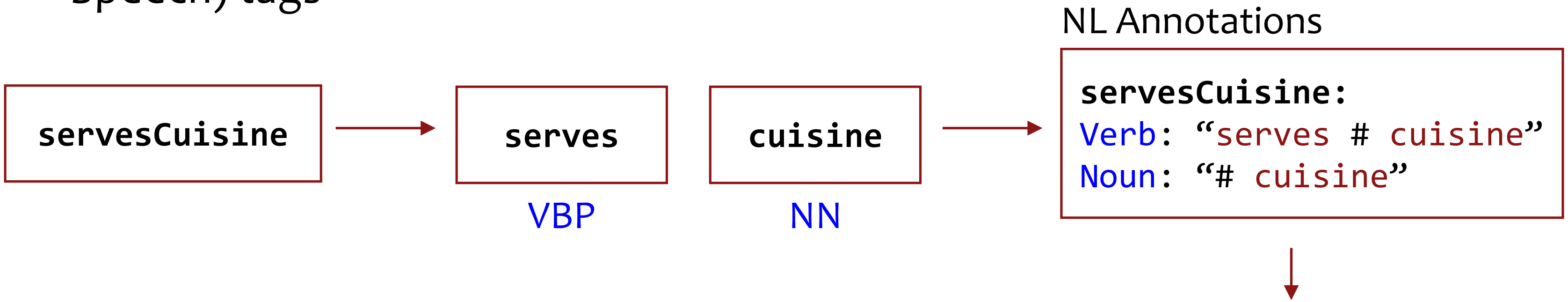


```
servesCuisine:
Verb: “serves # cuisine”
Noun: “# cuisine”
```

- Manual:
  - Provides additional synonyms, and annotations in different POS categories

NL Annotation Generation

- Automatic: Heuristics based on POS (Part-Of-Speech) tags



```
servesCuisine:
Verb: “serves # cuisine”
Noun: “# cuisine”
```

- Manual:
  - Provides additional synonyms, and annotations in different POS categories

```
servesCuisine:
Verb: “serves # cuisine”
      “offers # food”
Noun: “# cuisine”
      “# food”
Adjective: “#”
```

Domain-independent Templates

```
servesCuisine:
Verb: “serves # cuisine”
      “offers # food”
Noun: “# cuisine”
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Adjective: “#”
```

Domain-independent Templates

```
servesCuisine:
Verb: “serves # cuisine”
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```

Show me <table> that <verb>.
Show me <table> with <noun>.
Show me <adjective> <table>.

Domain-independent Templates

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servesCuisine:
Verb: “serves # cuisine”
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```

Show me <table> that <verb>.
Show me <table> with <noun>.
Show me <adjective> <table>.

→

```
now => @QA.restaurant(),
servesCuisine =~ “Chinese” => notify;
```

Show me restaurants that serve Chinese cuisine.
Show me restaurants with Chinese food.
Show me Chinese restaurants.

Domain-independent Templates

```
servesCuisine:
Verb: “serves # cuisine”
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```

```
now => @QA.restaurant(),
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Show me <table> that <verb>.
Show me <table> with <noun>.
Show me <adjective> <table>.

→

Show me restaurants that serve Chinese cuisine.
Show me restaurants with Chinese food.
Show me Chinese restaurants.

Show me <table> with <noun:NUMBER> greater than <value>.

→

Show me restaurants with rating greater than 4

Domain-independent Templates

```
servesCuisine:
Verb: “serves # cuisine”
      “offers # food”
Noun: “# cuisine”
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Adjective: “#”
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now => @QA.restaurant(),
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Show me <table> that <verb>.
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Show me <adjective> <table>.

→

Show me restaurants that serve Chinese cuisine.
Show me restaurants with Chinese food.
Show me Chinese restaurants.

Show me <table> with <noun:NUMBER> greater than <value>. → Show me restaurants with rating greater than 4

Show me <table> with <noun:MEASURE(m)> longer than <value>. → Show me surfboard with length longer than 3m

Domain-dependent Templates

Domain-dependent Templates

- Some natural sentences cannot be generated by domain-independent templates:
  - "the top-rated restaurant", "the best restaurant"
- We allow developers to improve the accuracy by providing domain-dependent templates

Domain-dependent Templates

- Some natural sentences cannot be generated by domain-independent templates:

ThingTalk	Sentence by domain-independent templates
`sort aggregateRating.ratingValue desc of @QA.restaurant()`	restaurant with the highest rating
	restaurant that have the highest rating
	…

  - "the top-rated restaurant", "the best restaurant"
- We allow developers to improve the accuracy by providing domain-dependent templates

Domain-dependent Templates

- Some natural sentences cannot be generated by domain-independent templates:

ThingTalk	Sentence by domain-independent templates

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ThingTalk	Domain-dependent templates

`sort aggregateRating.ratingValue desc`
`of @QA.restaurant()`
	the top-rated restaurant

	the best restaurant
	…

Experiments

Experimental Results

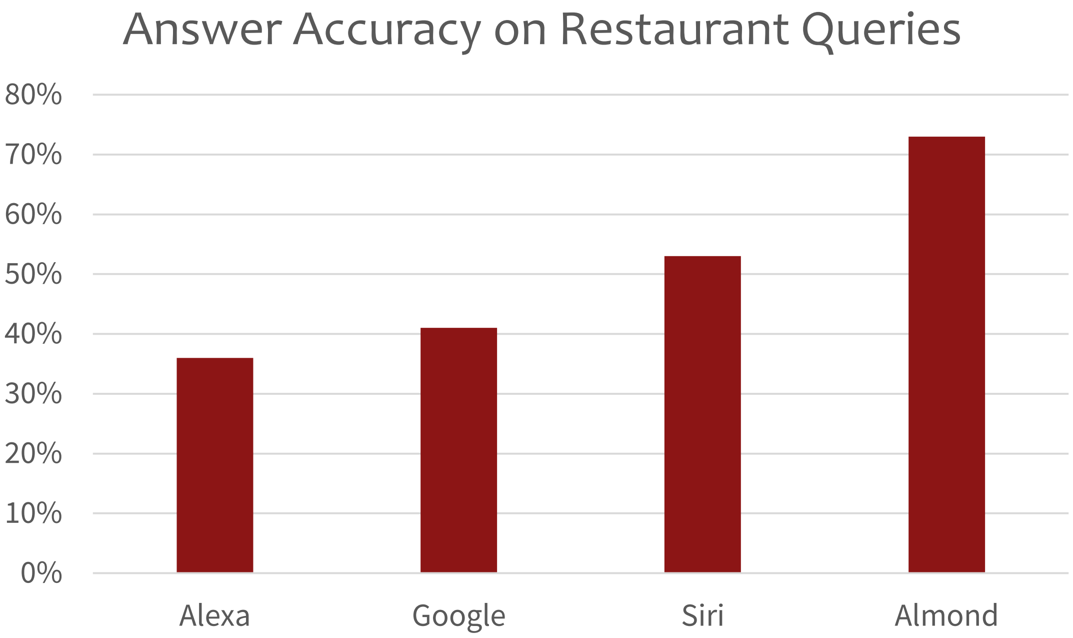
- Domains
  - Restaurants: data from Yelp
  - Person: data from LinkedIn
- Training set

	Restaurant	Person
Synthetic	1,294,278	553,067
Paraphrase	6,288	6,000
Total (augmented)	**1,809,109**	**930,564**

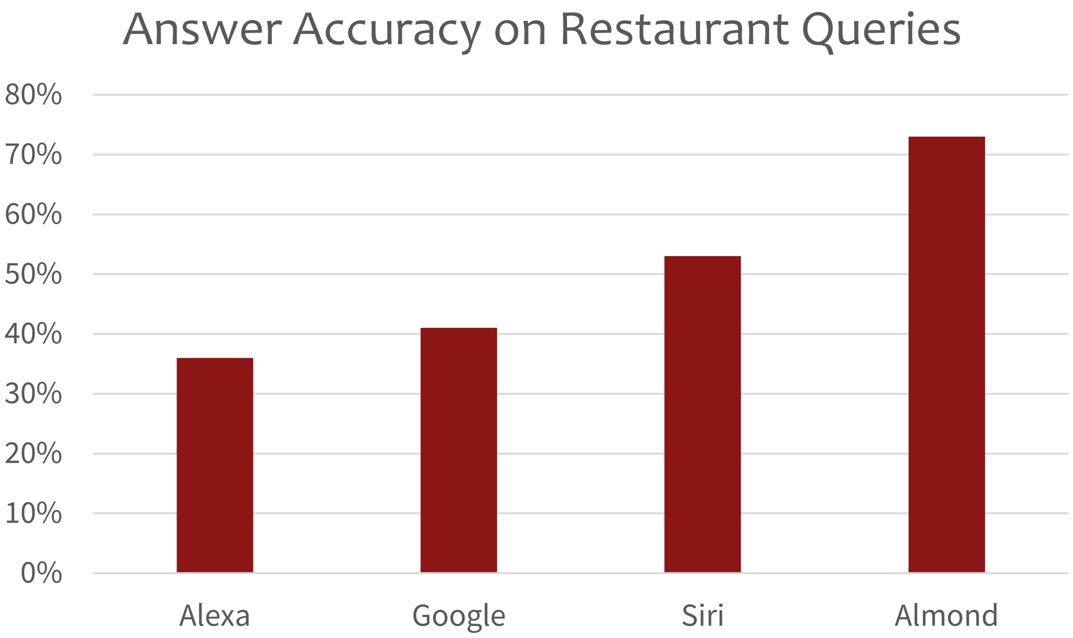
- Realistic evaluation set

		Restaurant	**Person**
Dev	1 property	134	6
	2 properties	47	144
	3+ properties	59	0
	Total	**240**	**160**
Test	1 property	96	127
	2 properties	79	106
	3+ properties	40	0
	Total	**215**	**233**

Comparison with Commercial Virtual Assistants

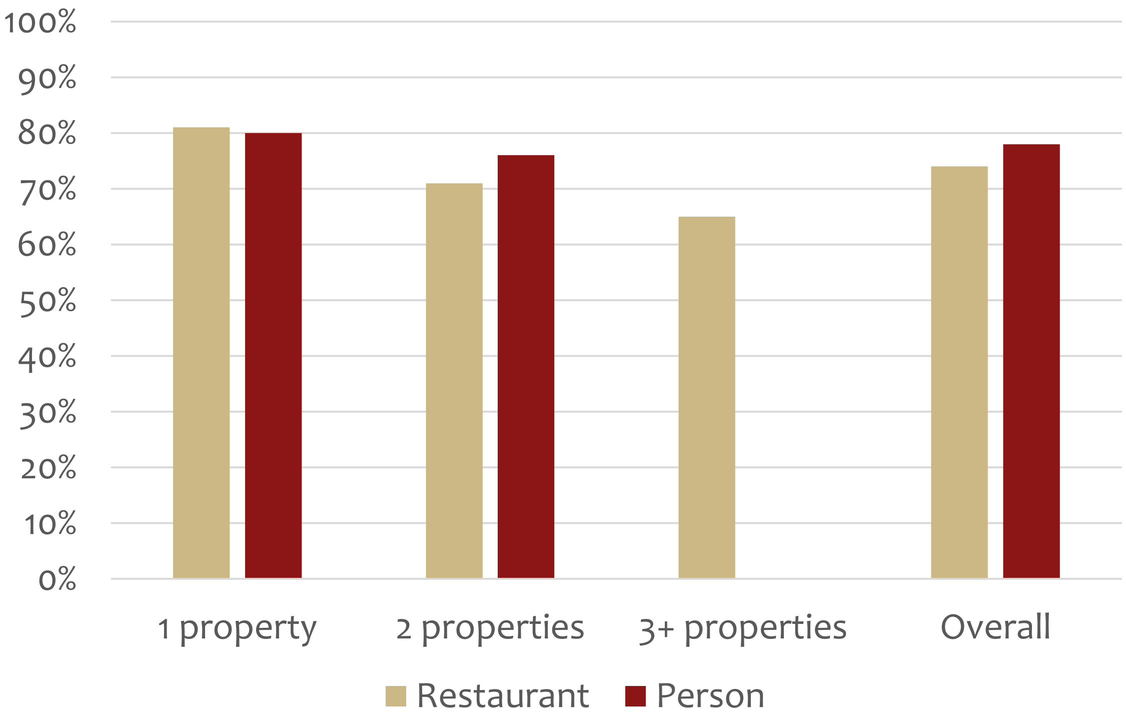


Comparison with Commercial Virtual Assistants



Trained with no real data!

Experimental Results



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Can We Do Better?

Manual Effort in Genie Pipeline

Manual Effort in Genie Pipeline

- Natural language annotations
  - The heuristics based on part-of-speech doesn't provide good variety, and sometimes unnatural
- Paraphrase
  - We ask crowdworkers to manually paraphrase synthetic sentences
  - We can only do this for a small sample of synthetic because of cost

- Can we replace them with something automatic?

Automatic NL Annotation Generation

- Generate context-aware synonyms by a language model

Automatic NL Annotation Generation

- Generate context-aware synonyms by a language model

A Sample Sentence
Automatically Constructed based on POS

Show me restaurants with Italian cuisine.

Automatic NL Annotation Generation

- Generate context-aware synonyms by a language model

A Sample Sentence
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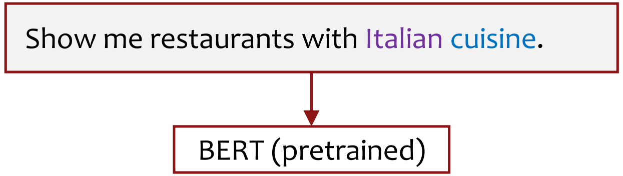
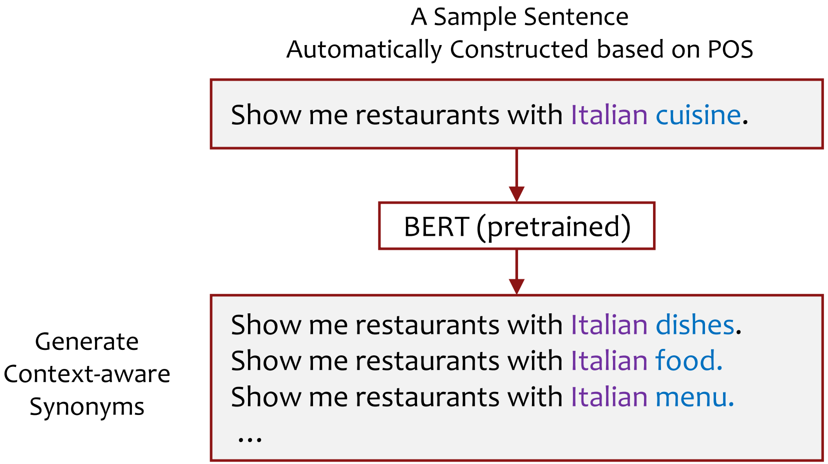


Show me restaurants with Italian cuisine.

BERT (pretrained)

Automatic NL Annotation Generation

- Generate context-aware synonyms by a language model



A Sample Sentence
Automatically Constructed based on POS

Show me restaurants with Italian cuisine.

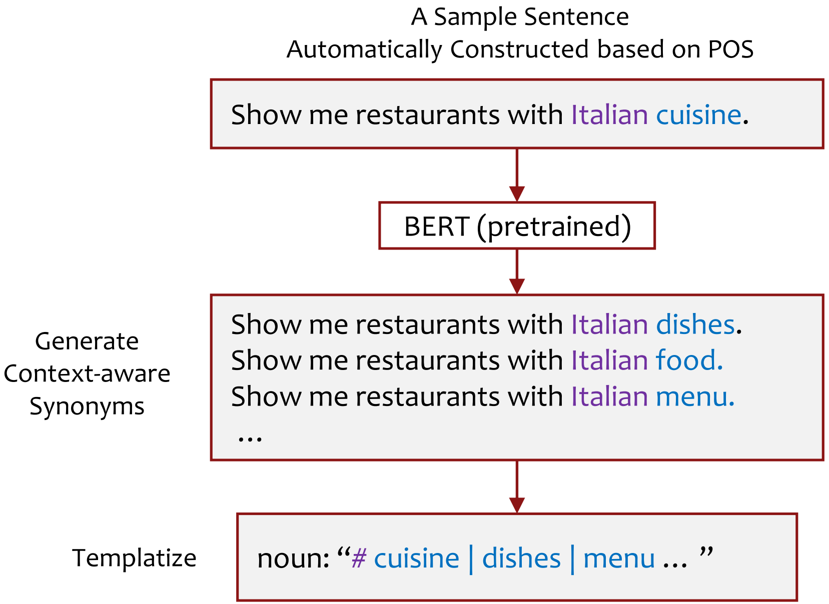
BERT (pretrained)

Generate
Context-aware
Synonyms

Show me restaurants with Italian dishes.
Show me restaurants with Italian food.
Show me restaurants with Italian menu.
…

Automatic NL Annotation Generation

- Generate context-aware synonyms by a language model



A Sample Sentence
Automatically Constructed based on POS

Show me restaurants with Italian cuisine.

BERT (pretrained)

Generate Context-aware Synonyms

Show me restaurants with Italian dishes.
Show me restaurants with Italian food.
Show me restaurants with Italian menu.
…

Templatize

noun: “# cuisine | dishes | menu … ”

Automatic NL Annotation Generation (cont.)

- Predict adjective properties by a language model

Automatic NL Annotation Generation (cont.)

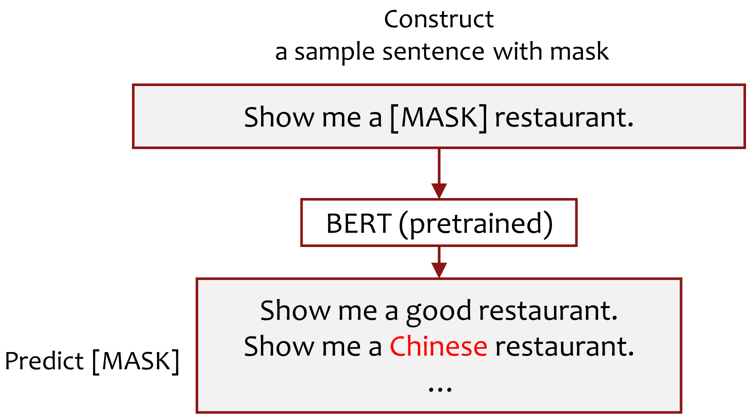
- Predict adjective properties by a language model

Construct
a sample sentence with mask

Show me a [MASK] restaurant.

Automatic NL Annotation Generation (cont.)

- Predict adjective properties by a language model



Construct
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Show me a [MASK] restaurant.

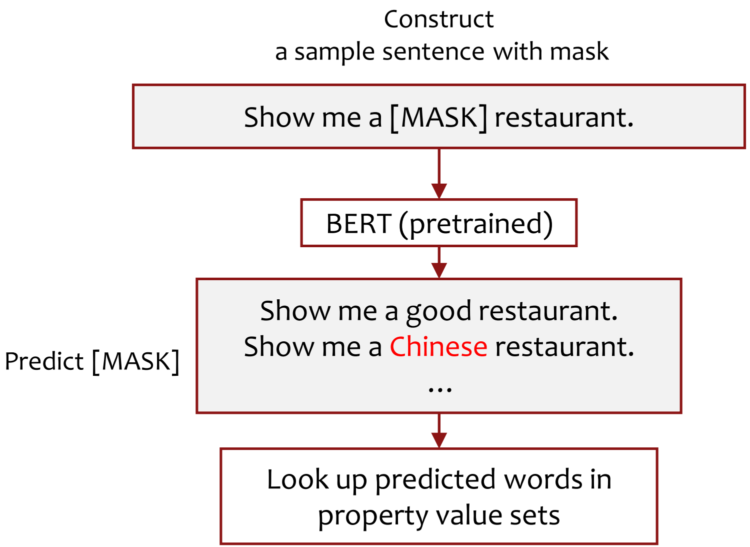
BERT (pretrained)

Predict [MASK]

Show me a good restaurant.
Show me a Chinese restaurant.
…

Automatic NL Annotation Generation (cont.)

- Predict adjective properties by a language model



Construct
a sample sentence with mask

Show me a [MASK] restaurant.

BERT (pretrained)

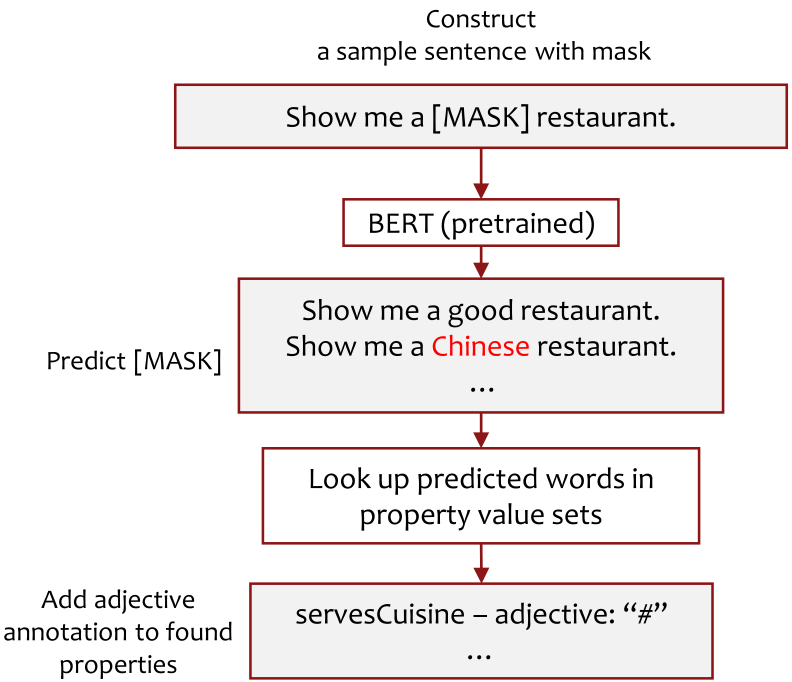
Predict [MASK]

Show me a good restaurant.
Show me a Chinese restaurant.
…

Look up predicted words in property value sets

Automatic NL Annotation Generation (cont.)

- Predict adjective properties by a language model



Construct
a sample sentence with mask

Show me a [MASK] restaurant.

BERT (pretrained)

Predict [MASK]

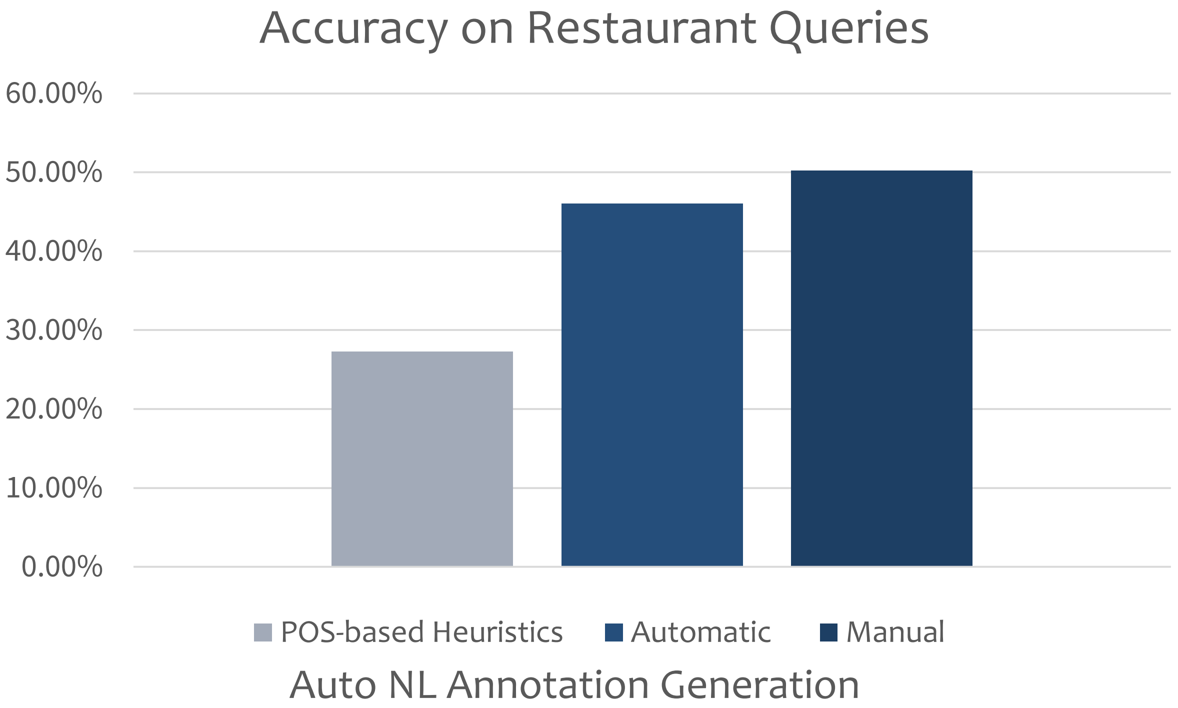
Show me a good restaurant.
Show me a Chinese restaurant.
…

Look up predicted words in property value sets

Add adjective annotation to found properties

servesCuisine – adjective: “#”
…

Preliminary Experimental Result



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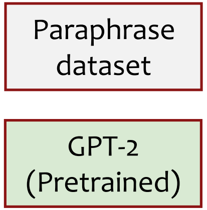
Automatic Paraphrasing

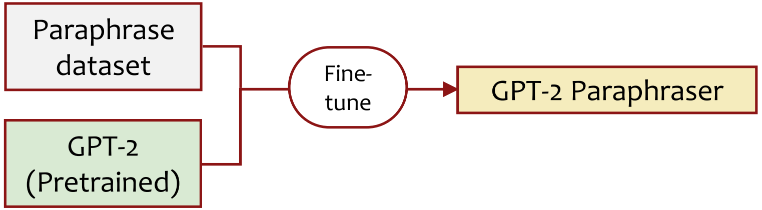
Automatic Paraphrasing



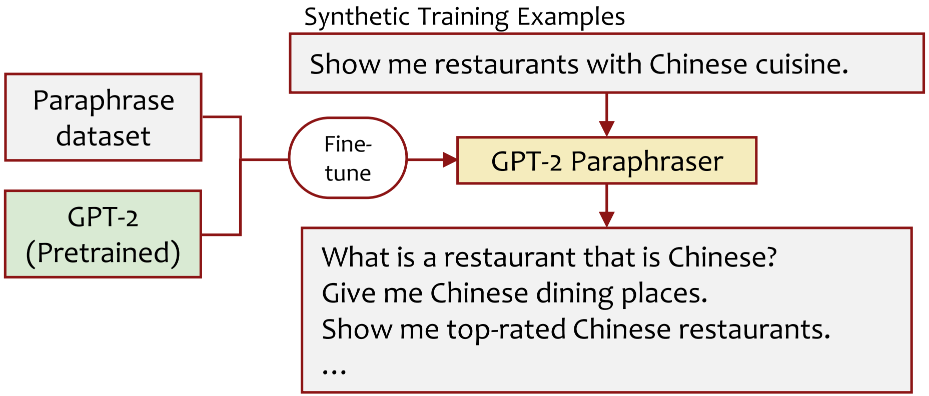
Paraphrase dataset

GPT-2 (Pretrained)

Automatic Paraphrasing



Automatic Paraphrasing



Synthetic Training Examples

Show me restaurants with Chinese cuisine.

Paraphrase dataset

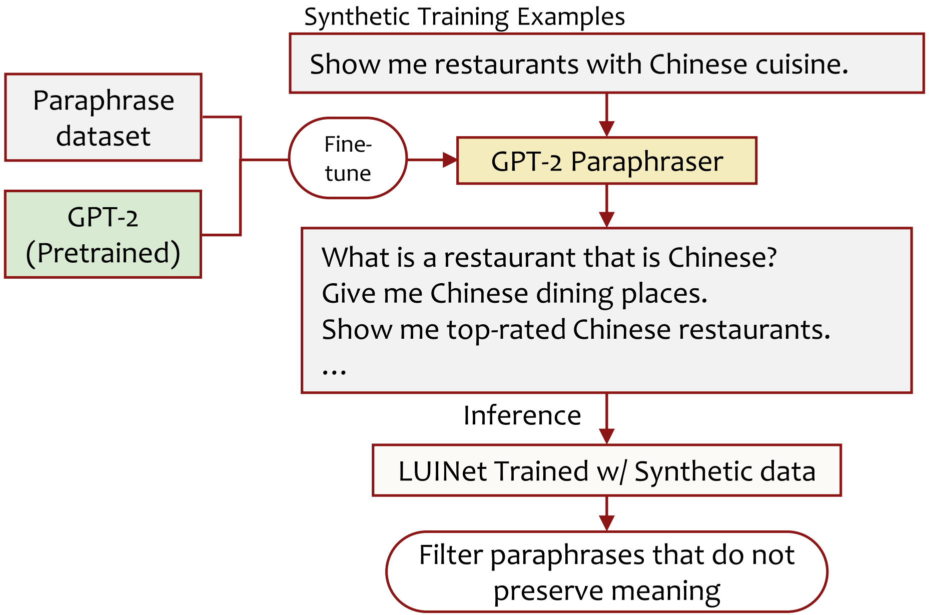
GPT-2 (Pretrained)

Fine-tune

GPT-2 Paraphraser

What is a restaurant that is Chinese?
Give me Chinese dining places.
Show me top-rated Chinese restaurants.
…

Automatic Paraphrasing



Synthetic Training Examples

Show me restaurants with Chinese cuisine.

Paraphrase dataset

GPT-2 (Pretrained)

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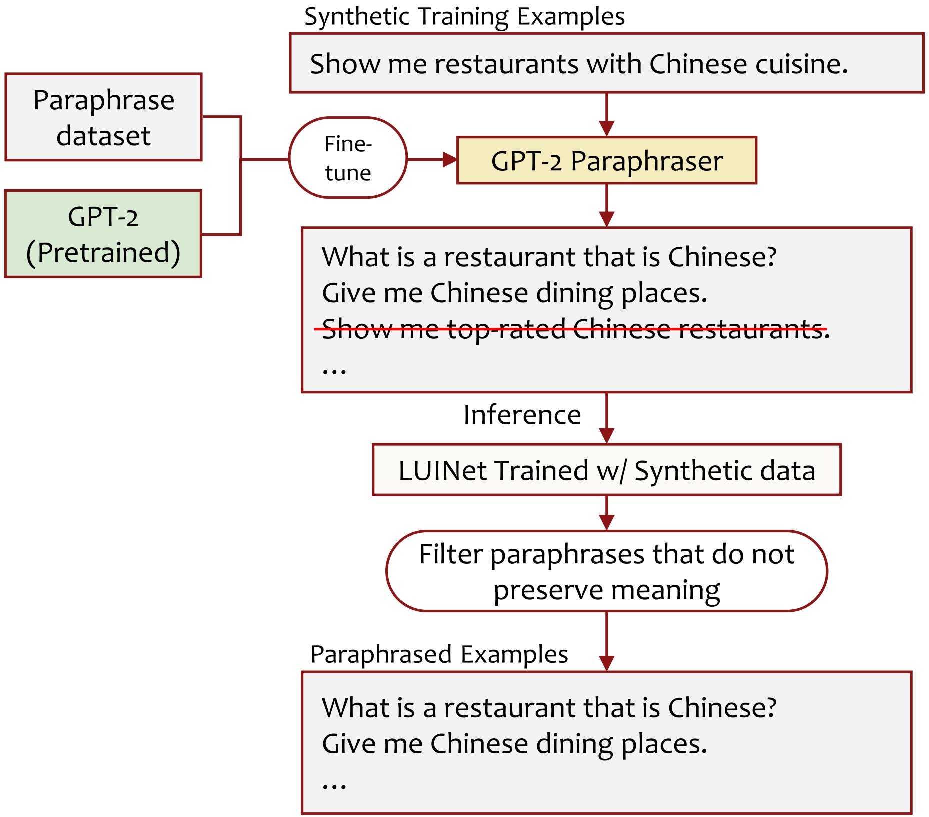
Inference

LUINet Trained w/ Synthetic data

Filter paraphrases that do not preserve meaning

Automatic Paraphrasing



Synthetic Training Examples

Show me restaurants with Chinese cuisine.

Paraphrase dataset
GPT-2 (Pretrained)
Fine-tune
GPT-2 Paraphraser

What is a restaurant that is Chinese?
Give me Chinese dining places.
~~Show me top-rated Chinese restaurants.~~
…

Inference
LUINet Trained w/ Synthetic data
Filter paraphrases that do not preserve meaning

Paraphrased Examples

What is a restaurant that is Chinese?
Give me Chinese dining places.
…

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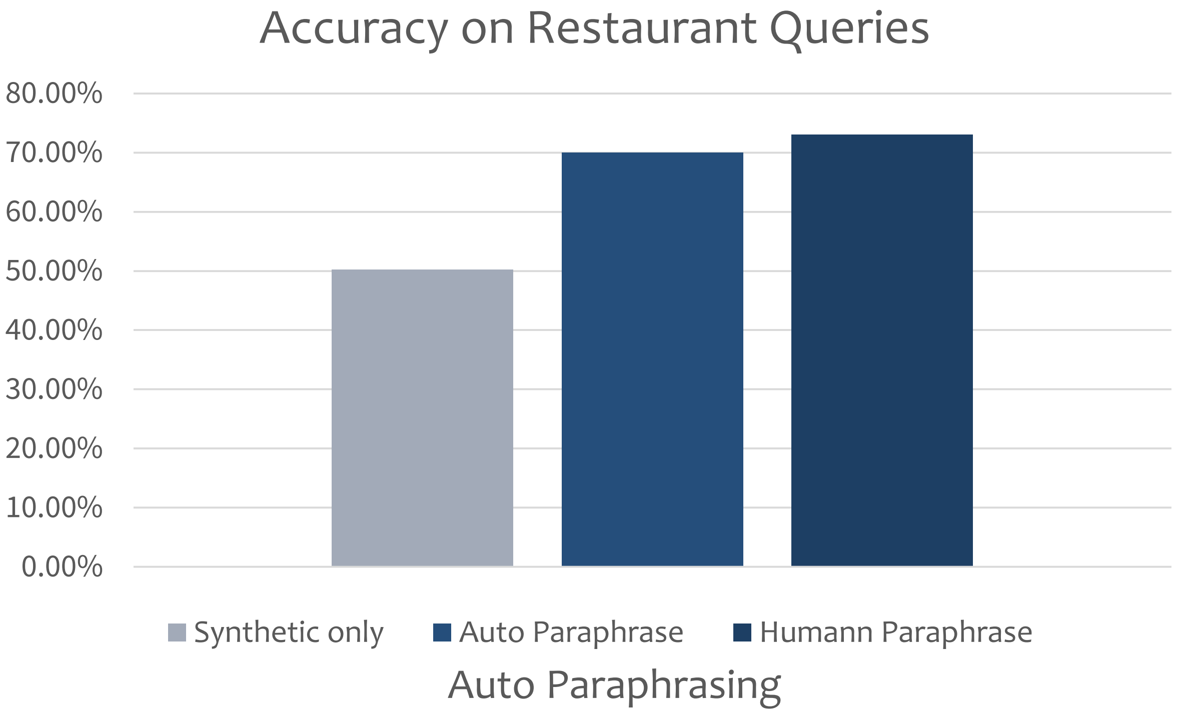
Preliminary Experimental Result



Thank you!

Hope you will enjoy your homework ☺