

Natural Language Question-Answering with Visualizations

Bianca Yu, Hannah DeBalsi

CS 294W Spr 2020

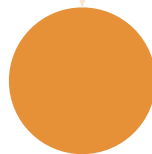
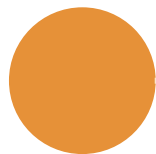
Outline

**Visualization
+
Natural
Language**

The Purpose of
Visualization

Natural Language
Interfaces for
Visualization

Application in
Conversational
Virtual Assistants



**Backend
Implementation**

NLP Query to
Database Query

From Answer
to Display

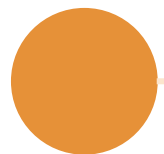
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What is **visualization**?

- “**Transformation** of the symbolic into the geometric”
(McCormick et al. 1987)

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- “**Transformation** of the symbolic into the geometric”
(McCormick et al. 1987)
- “... finding the **artificial memory** that best supports our **natural means of perception.**”
(Bertin 1967)

What is **visualization**?

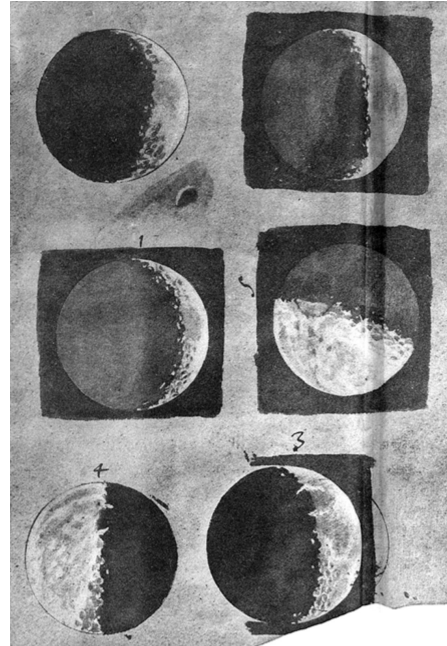
- “**Transformation** of the symbolic into the geometric”
(McCormick et al. 1987)
- “... finding the **artificial memory** that best supports our **natural means of perception.**”
(Bertin 1967)
- “The use of computer-generated, interactive, visual representations of data to **amplify cognition.**”
(Card, Mackinlay, and Shneiderman 1999)

We use visualization to ...

- **Record** information

We use visualization to ...

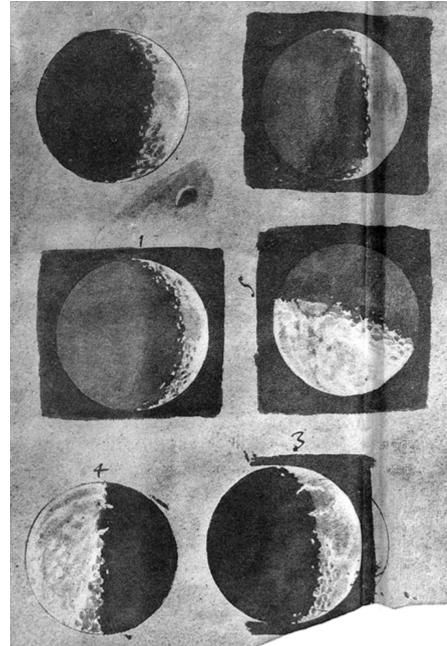
- **Record** information



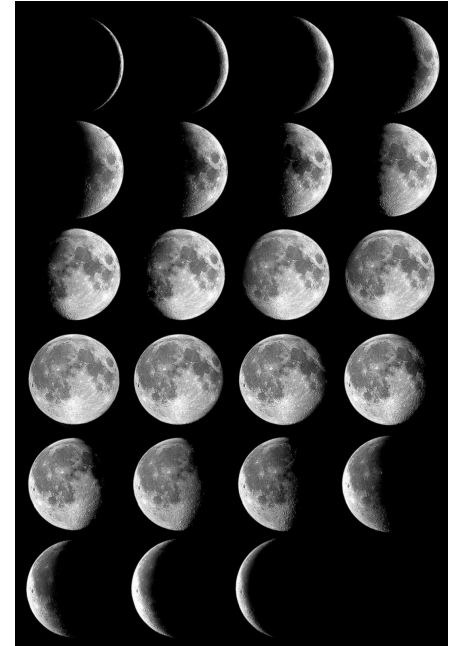
<http://galileo.rice.edu/sci/observations/moon.html>

We use visualization to ...

- **Record** information



<http://galileo.rice.edu/sci/observations/moon.html>



Getty Images

We use visualization to ...

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- **Analyze** information

We use visualization to ...

- **Record** information
- **Analyze** information
 - See data in context
 - Make a decision

See data in context

- Example: Cholera outbreak, 1854



See data in context

- Example: Cholera outbreak, 1854



Make a decision

- Example: Challenger space shuttle launch, 1986



Wikipedia

Make a decision

- Example: Challenger space shuttle launch, 1986

Blow By History

SRM-15 WORST BLOW-BY

- 2 CASE JOINTS (30'), (110°) ARE
- MUCH WORSE VISUALLY THAN SRM-22

SRM 22 BLOW-BY

- 2 CASE JOINTS (30-40°)

SRM-13A, 15, 16A, 18, 23A 24A

- NOZZLE BLOW-BY

HISTORY OF O-RING TEMPERATURES (DEGREES-F)

MOTOR	MBT	AMB	O-RING	WIND
DM-4	68	36	47	10 MPH
DM-2	76	45	52	10 MPH
QM-3	72.5	40	48	10 MPH
QM-4	76	48	51	10 MPH
SRM-15	52	64	53	10 MPH
SRM-22	77	78	75	10 MPH
SRM-25	55	26	29	10 MPH
			27	25 MPH

HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

SRM No.	Cross Sectional View			Top View		Clocking Location (deg)
	Erosion Depth (in.)	Perimeter Affected (deg)	Nominal Dia. (in.)	Length Of Max Erosion (in.)	Total Heat Affected Length (in.)	
61A LH Center Field**	22A	None	None	0.280	None	None
61A LH CENTER FIELD**	22A	NONE	NONE	0.280	NONE	NONE
61C LH Forward Field**	15A	0.010	154.0	0.280	4.25	5.25
61C RH Center Field (prim)***	15B	0.038	130.0	0.280	12.50	58.75
61C RH Center Field (sec)***	15B	None	45.0	0.280	None	29.50
410 RH Forward Field	13B	0.028	110.0	0.280	3.00	None
41C LH Aft Field*	11A	None	None	0.280	None	None
41B LH Forward Field	10A	0.040	217.0	0.280	3.00	14.50
STS-2 RH Aft Field	2B	0.053	116.0	0.280	--	--

*Hot gas path detected in putty. Indication of heat on O-ring, but no damage.

**Soot behind primary O-ring.

***Soot behind primary O-ring, heat affected secondary O-ring.

Clocking location of leak check port - 0 deg.

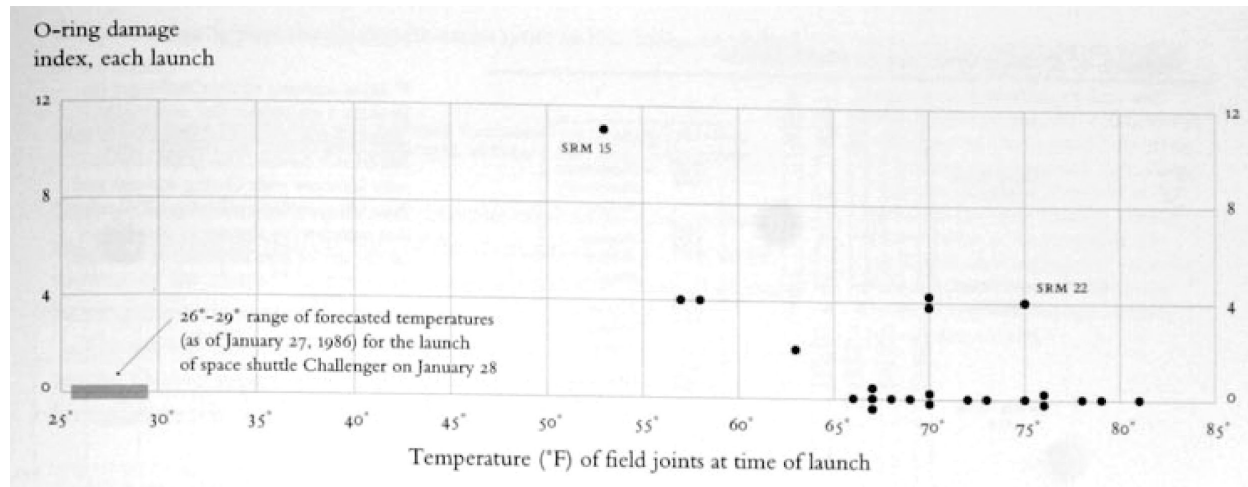
OTHER SRM-15 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY AND NO SOOT NEAR OR BEYOND THE PRIMARY O-RING.

SRM-22 FORWARD FIELD JOINT HAD PUTTY PATH TO PRIMARY O-RING, BUT NO O-RING EROSION AND NO SOOT BLOWBY. OTHER SRM-22 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY.

Tufte. Visual and Statistical Thinking 1997

Make a decision

- Example: Challenger space shuttle launch, 1986



Tufte. *Visual and Statistical Thinking* 1997

We use visualization to ...

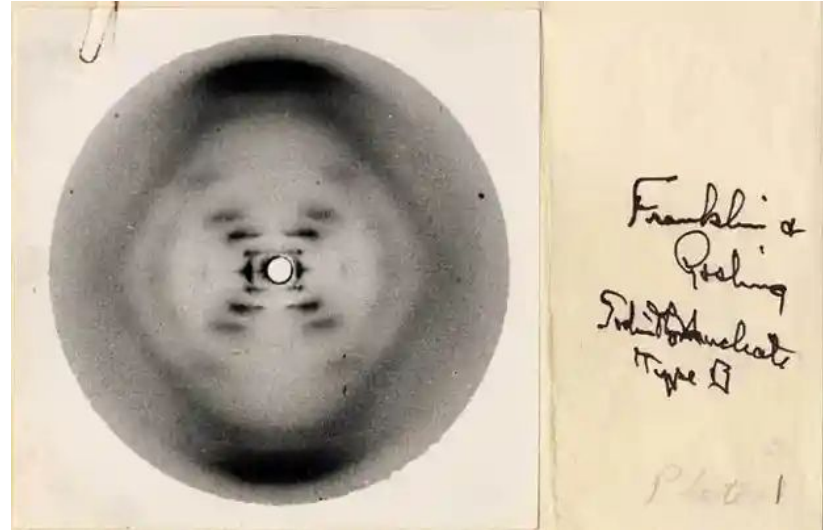
- **Record** information
- **Analyze** information
 - See data in context
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We use visualization to ...

- **Record** information
- **Analyze** information
 - See data in context
 - Make a decision
- **Convey** information

We use visualization to ...

- **Record** information
- **Analyze** information
 - See data in context
 - Make a decision
- **Convey** information



Rosalind Franklin and RG Gosling

Graphs in statistical analysis

“Graphs can have various purposes, such as:

- (i) to help us **perceive and appreciate** some broad features of the data,
- (ii) to let us look behind those broad features and **see what else is there.**”

(Anscombe 1973)

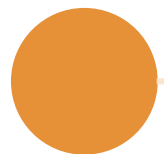
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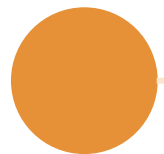
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Why implement natural language interaction?

Why implement natural language interaction?

- “Natural language interaction allows users to **ask questions directly** in complex programs **without having to learn how to use an interface.**”
(Gao et al.)
- Users of sophisticated visual analytic tools are “... usually domain experts with **marginal knowledge of visualization techniques.**”
(Sun et al.)

Types of current natural language interfaces

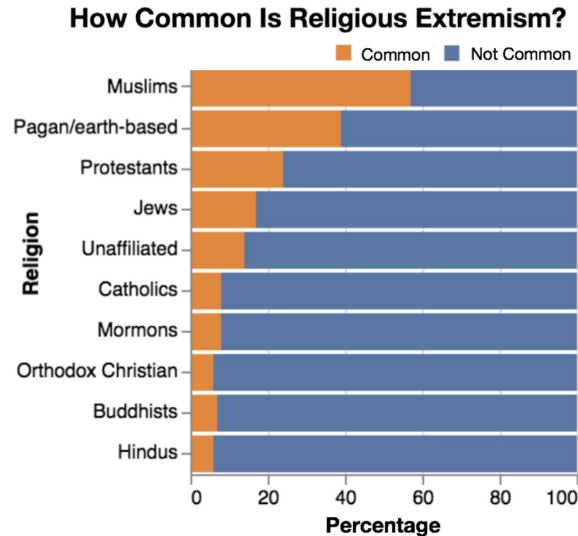
1

Those that
**answer questions
about existing
visualizations**

2

Those that
**create a new
visualization**

1) Answering questions about existing visualizations



Q1: *What is the percentage of response 'Common' for Catholics?*

A(Sempre): **92**

A(Ours): **8**. I looked up the length of the orange bar for 'Catholics'.

Q2: *Which religion has the longest orange component?*

A(Sempre): **Hindus**

A(Ours): **Muslims**. I looked up 'Religion' of the longest orange bar.

Q3: *What does the blue field represent?*

A(Sempre): **24**

A(Ours): **Not Common**. I looked up what blue represents by looking at the legend.

2) Creating new visualizations

2) Creating new visualizations

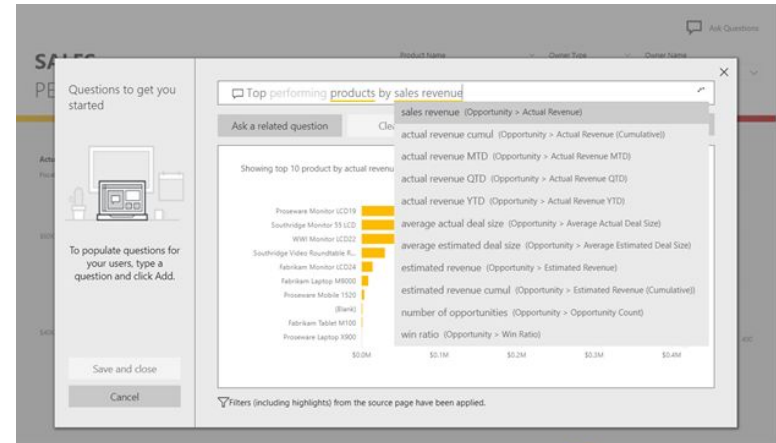
- Commercial
 - IBM
 - Microsoft
 - Wolfram Alpha



```
lim (sin x)/x as x-
lim (sin x)/x as x->0
lim (sin x)/x as x->infinity
```

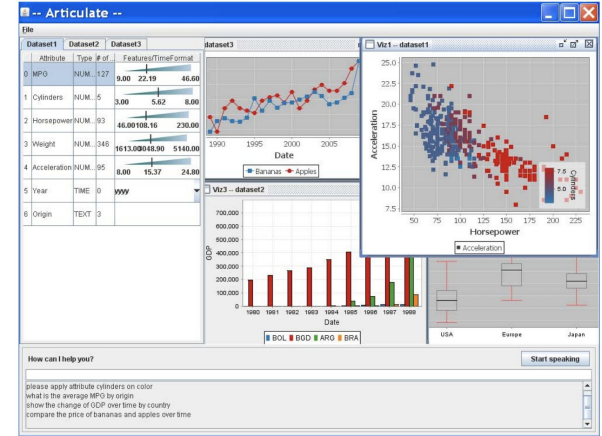
Compute expert-level answers using Wolfram's breakthrough algorithms, knowledgebase and AI technology

- Mathematics >
 - Step-by-Step Solutions
 - Elementary Math
 - x^2-1 Algebra
 - Plotting & Graphics
 - Calculus & Analysis
 - Geometry
- Science & Technology >
 - Units & Measures
 - Physics
 - Chemistry
 - Engineering
 - Computational Sciences
 - Earth Sciences
- Society & Culture >
 - People
 - Arts & Media
 - Dates & Times
 - Words & Linguistics
 - Money & Finance
 - Food & Nutrition
- Everyday Life >
 - Personal Health
 - Personal Finance
 - Surprises
 - Entertainment
 - Household Science
 - Household Math



2) Creating new visualizations

- Commercial
 - IBM
 - Microsoft
 - Wolfram Alpha
- Research Projects
 - Articulate
 - DataTone



Olympic Athletes

Data Overview:

Athlete: Michael Phelps, Natalie Coughlin, Sun Yang, ...

Age: 15-61

Country: United States, Australia, Russia, ...

Year: 2000-2012

Sport: Swimming, Diving, Cycling, ...

Gold Medal: 0-8

Silver Medal: 0-3

Bronze Medal: 0-3

Total Medal: 1-8

Chart Templates

- TotalMedals
- BronzeMedals
- SilverMedals
- GoldMedals

Dimensions

- Country | Sport
- Country

Color

- Color by Country
- Color by Sport
- Single Color

Group Order

- Group by Sport then by Country
- Group by Country then by Sport

Sample Queries:

show me medal for hockey and skating by country

Chart Templates

- TotalMedals
- BronzeMedals
- SilverMedals
- GoldMedals

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- Country | Sport
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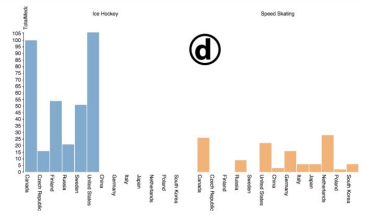
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Sum of TotalMedals (Sport: Speed Skating and Ice Hockey) by Sport, Country



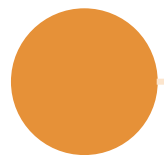
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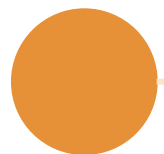
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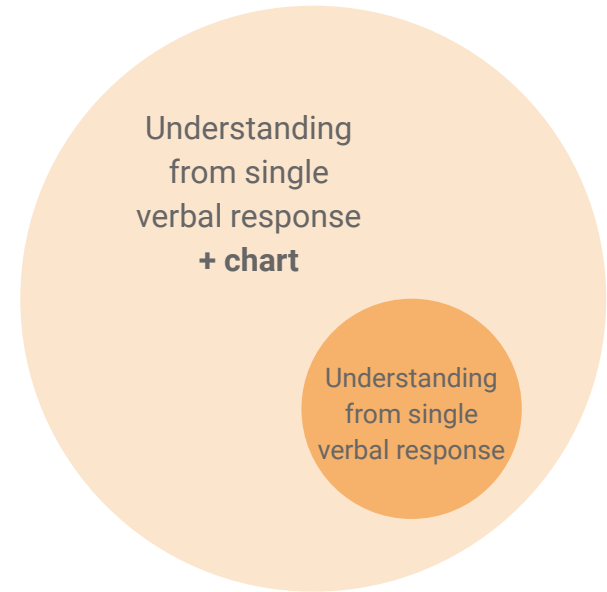
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Motivation

- Current tools created for data analysts, not the general, curious public
- “**Amplify cognition**” (Card, Mackinlay, and Shneiderman 1999)
- Provide **context** to numerical responses to increase comprehension
- Encourage **curiosity** and “see what else is there” (Anscombe 1973)



Challenges

- Ambiguity
 - What is the user asking for specifically?
- Inferring **when** to include a chart in the response
 - When does a user benefit from viewing a chart?
- Determining **what** to display
 - What kind of additional data should be displayed?
 - What kind of chart is most effective?
- CUI vs GUI



Question #1

Besides standard graphs, what other types of visualizations do you think would be helpful to integrate into a virtual assistant?

For what domain(s)?

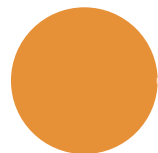
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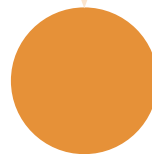
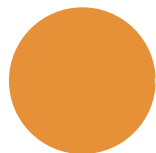
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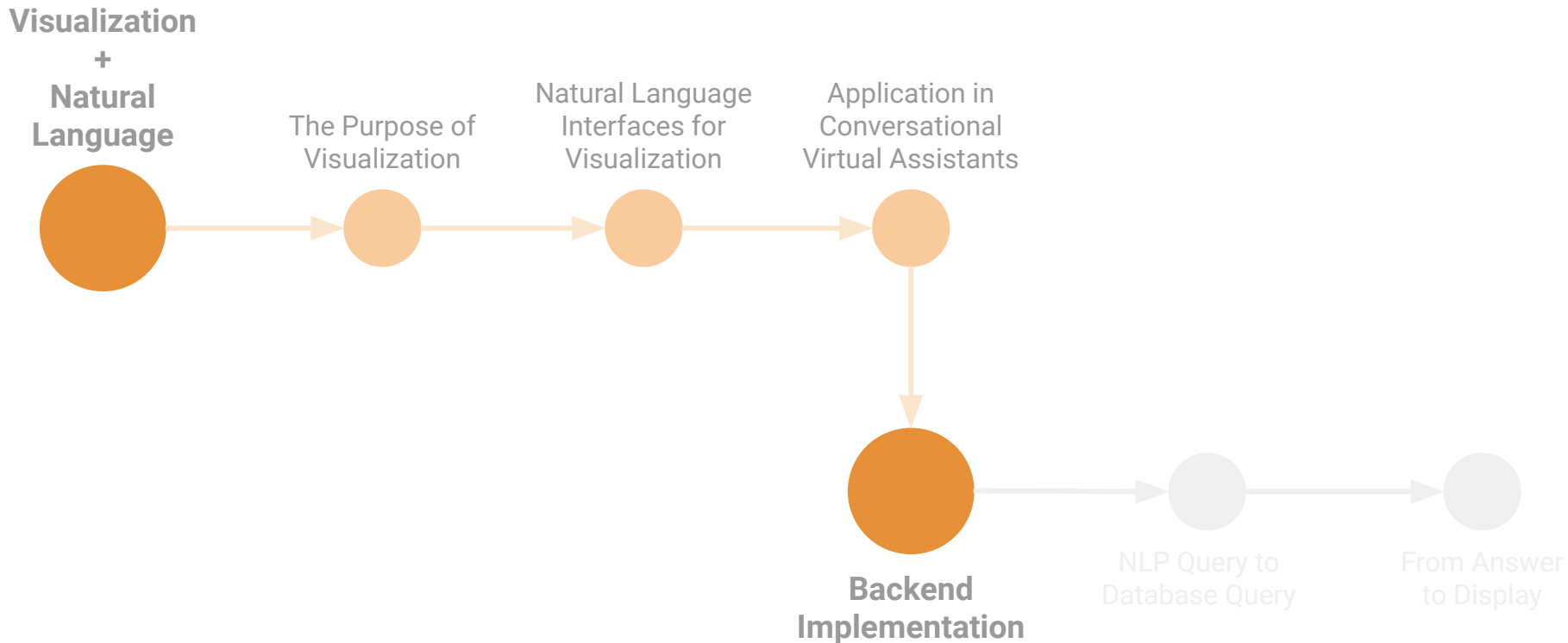
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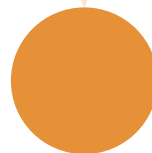
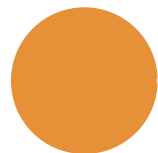
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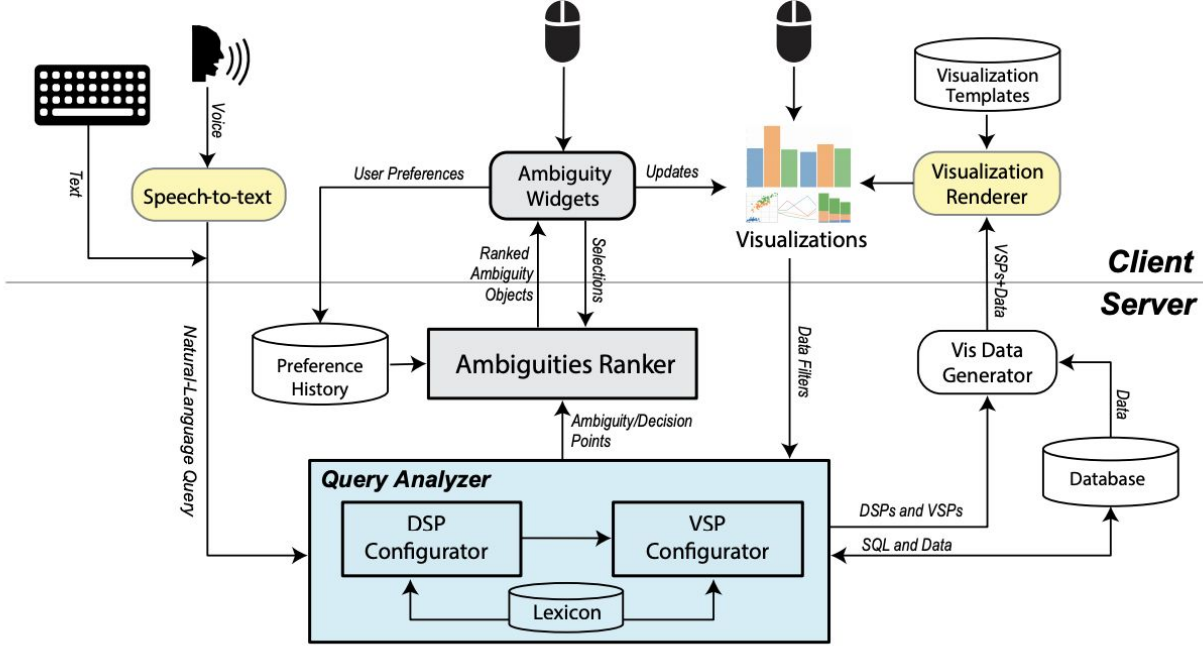


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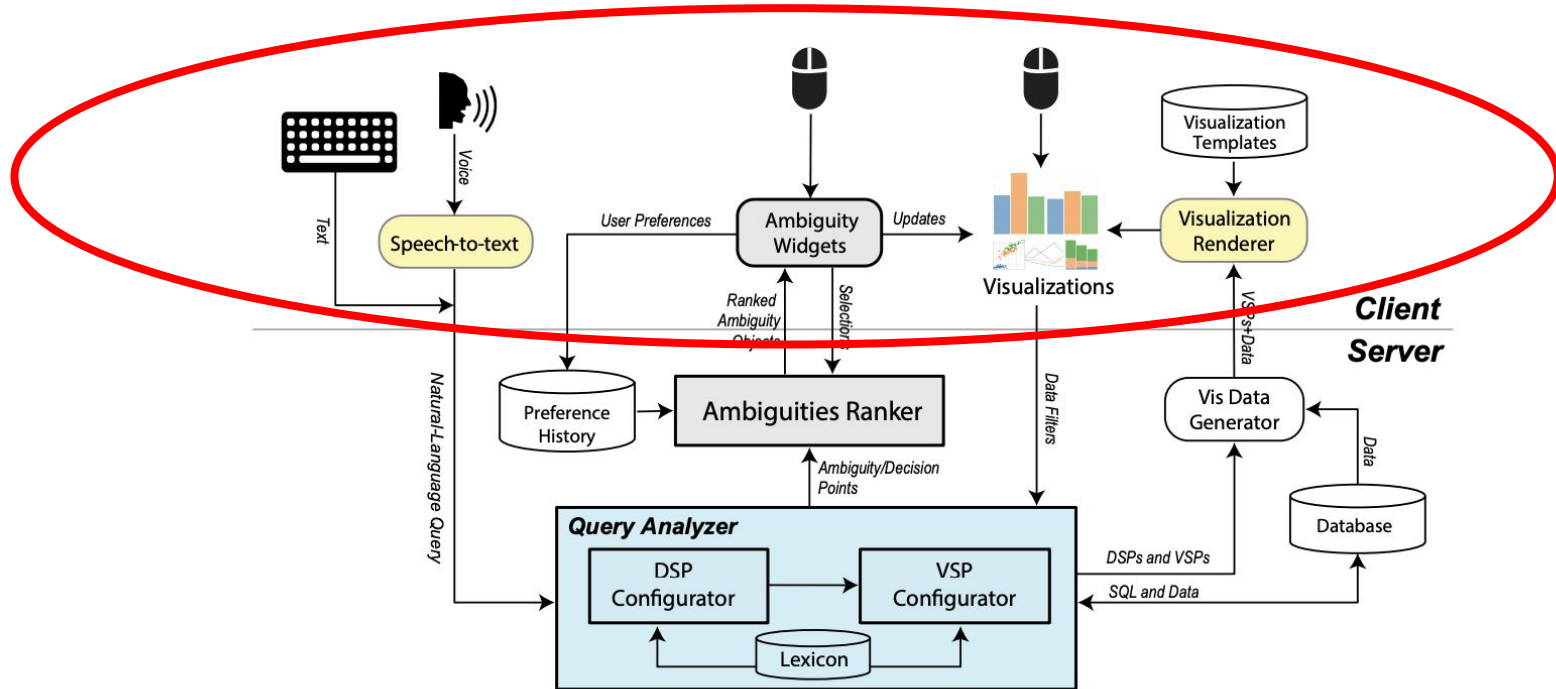
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DataTone System Architecture



Client Side: Web-based interface that operates in standard web browsers



Client Side Example

Olympic Athletes ⌵

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Total Medal: 1-8

a

Sample Queries:

show me medals for hockey and skating by country b Click to Speak Submit

⏪ ⏩

show me **medal** for **hockey** and **skating** by **country**

c

- TotalMedals
- BronzeMedals
- SilverMedals
- GoldMedals

Hockey (Sport)

IceHockey (Sport)

FigureSkating (Sport)

Short-TrackSpeedSkating (Sport)

SpeedSkating (Sport)

Dimensions

Country | Sport

Country

Chart Templates

e

Color

- Color by Country
- Color by Sport
- Single Color

Group Order

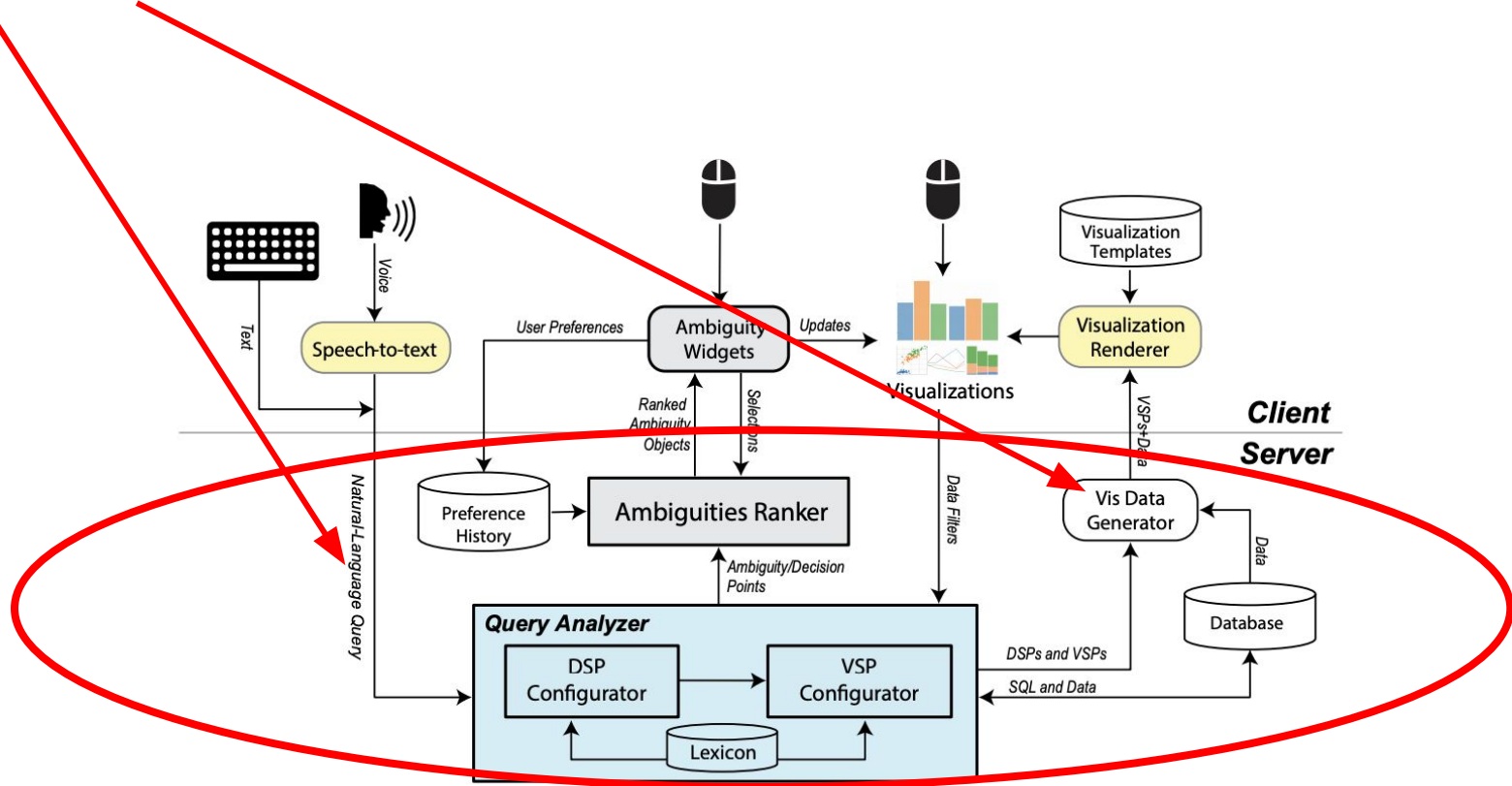
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Sum of TotalMedals (Sport: Speed Skating and Ice Hockey) by Sport, Country

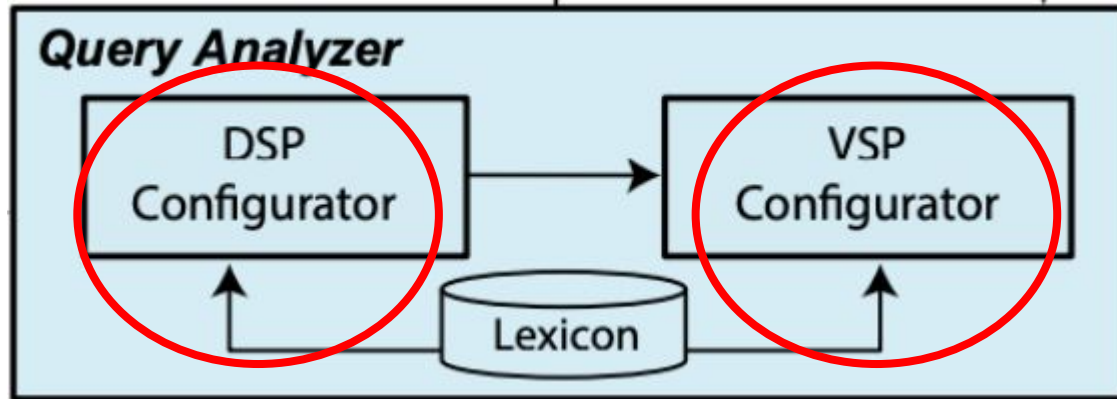
d

Sport	Country	Medals
Ice Hockey	Canada	100
	Finland	55
	Russia	30
	Sweden	50
	United States	100
Speed Skating	Canada	25
	Czech Republic	20
	United States	25
	China	15
	Germany	15
	Japan	10
	Netherlands	25
	South Korea	10

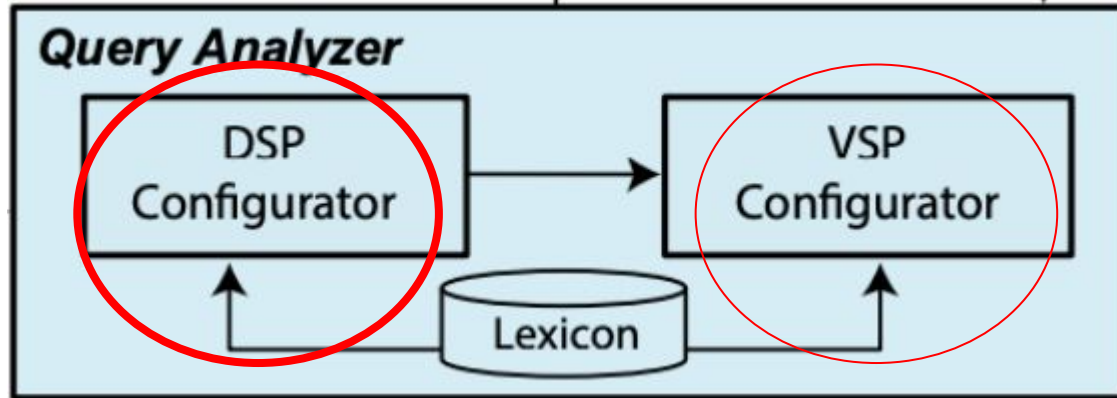
Server Side: handles translation of user input to a visualization



Query Analyzer



Query Analyzer



Tokenization

- Identify low-level language features (words and phrases) that have meaning within the context of the dataset and analysis tasks
 - Example: words that identify column names
1. Construct set of possible phrases
 - Extract all n-grams, ranging from 1 (single words) to k, the sentence length
 - Example: This is a sentence. => {this, is, a, sentence, this is, is a, a sentence, this is a, is a sentence, this is a sentence }
 2. Identify n-grams with relevance to dataset/query
 - comparing each n-gram to a set of regular expressions and a lexicon consisting of general phrases
 - tag each matched n-gram with one of eight category labels

Category Labels

1. database attributes (i.e., column names)
2. database cell values
3. numerical values
4. time expressions
5. data operators and functions (greater than, less than, equal, sum, average, sort)
6. visualization key phrases (trend, correlation, relationship, distribution, time series, bars, stacked bars, line graph)
7. boolean operators (e.g., and, or),
8. “direct manipulation” terms (e.g., color)

Example

Query: What is the relationship between unemployment and family income for those families earning more than 20000 and less than 150000 between 2007 and 2010 for California and Michigan?

1. Break into N-grams
2. Identify relevant N-grams by matching to categories

Example

Query: What is the relationship between unemployment and family income for those families earning more than 20000 and less than 150000 between 2007 and 2010 for California and Michigan?



Numerical Values

1. Break into N-grams
2. Identify relevant N-grams by matching to categories

Example

Query: What is the relationship between unemployment and family income for those families earning more than 20000 and less than 150000 between 2007 and 2010 for California and Michigan?

Numerical Value

Time

1. Break into N-grams
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Query: What is the relationship between unemployment and family income for those families earning more than 20000 and less than 150000 between 2007 and 2010 for California and Michigan?

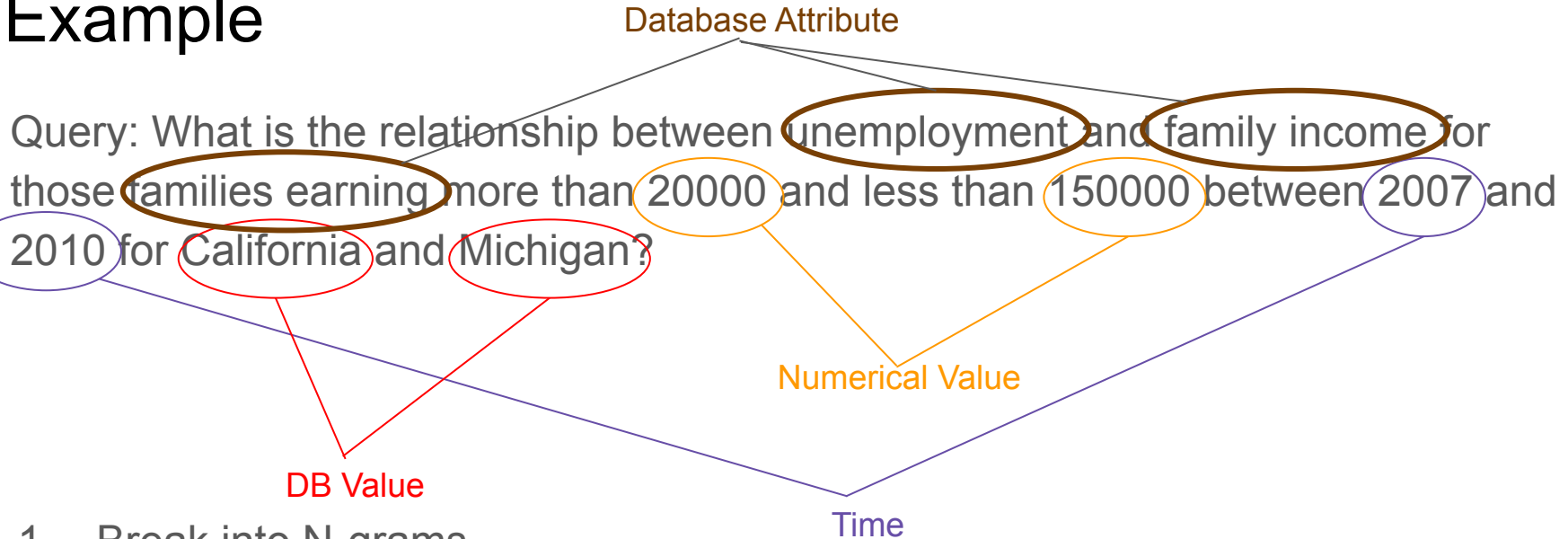
DB Value

Numerical Value

Time

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Example



1. Break into N-grams
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Query: What is the relationship between unemployment and family income for those families earning more than 20000 and less than 150000 between 2007 and 2010 for California and Michigan?

Operator

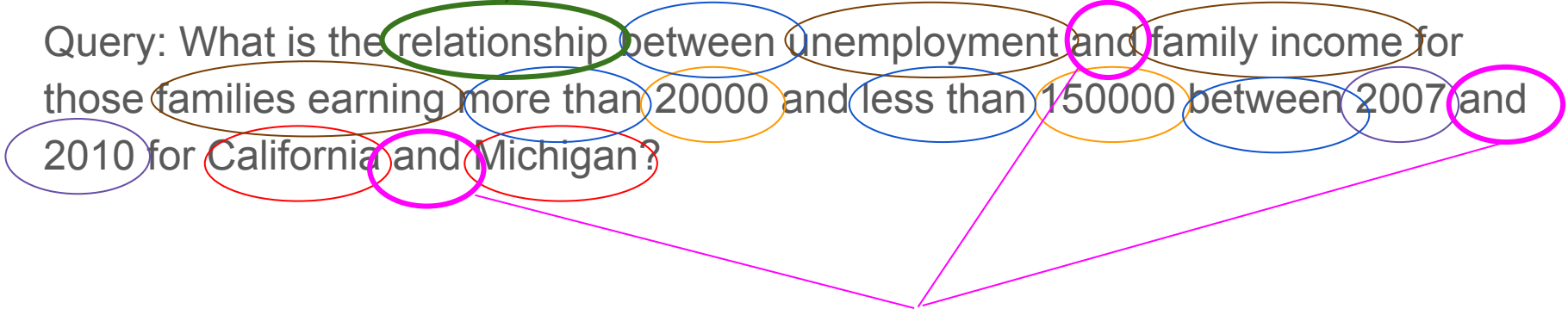


1. Break into N-grams
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Example

Visual Keyword

Query: What is the relationship between Unemployment and family income for those families earning more than 20000 and less than 150000 between 2007 and 2010 for California and Michigan?

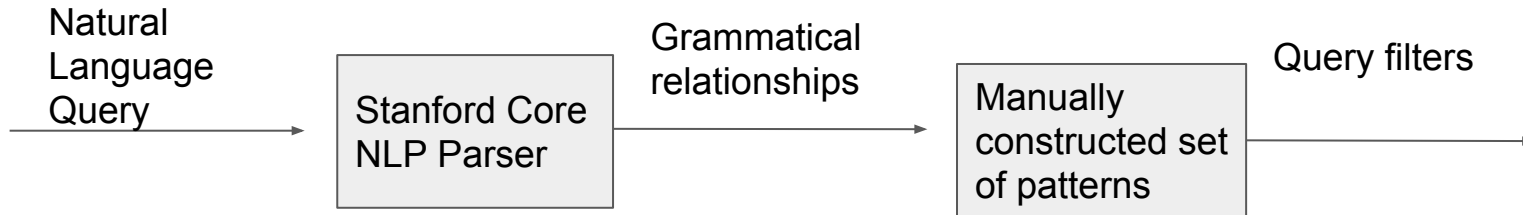
The diagram illustrates the analysis of the query text. Various words and phrases are enclosed in colored ovals: 'relationship' (green), 'Unemployment' (blue), 'and' (magenta), 'family income' (brown), 'more than' (blue), '20000' (orange), 'and' (blue), 'less than' (orange), '150000' (orange), 'between' (blue), '2007' (blue), 'and' (magenta), '2010' (blue), 'California' (red), 'and' (magenta), and 'Michigan?' (red). A green line connects the label 'Visual Keyword' to the green oval around 'relationship'. A magenta line connects the label 'Boolean Operator' to the magenta ovals around 'and'.

Boolean Operator

1. Break into N-grams
2. Identify relevant N-grams by matching to categories

Relation Identification

- We now have a set of tokens with category tags
- We need to define relationships between these tokens in order to construct a query



Relation Identification Example

“Show me the states
that had total sales
greater than than
20000.”

Stanford Core
NLP Parser

- “total sales”: noun phrase
- “greater than 20000”:
adjective phrase
NP and ADJP are
siblings of a sentence

Manually
constructed set
of patterns

Apply:

- SUM to Sales
- the operator “>” to 20000
- generate a filter `SUM(Sales) > 20000`.

Natural Language Parse \Rightarrow Data Specification (DSP)

- DSPs contain:
 - **Attributes:** all column names in the original query (ie **unemployment**, **family income**)
 - **Values:** all strings, numbers, times (ie **California**, **Michigan**, **20000**, **150000**)
 - **Filters:** as explained in the relation identification
 - **Aggregates:** “Show me average medal count by country per year” \rightarrow `AVG(MedalCount)`.
 - **Order:** “show me the sorted medal count by country from largest to smallest” \rightarrow `orderBy(MedalCount, DESC)`
- Generate one database query for each DSP

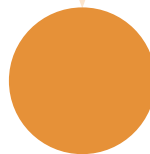
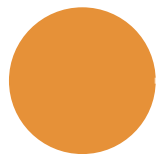
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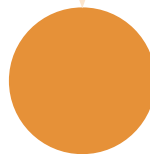
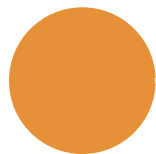
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Conversational
Virtual Assistants

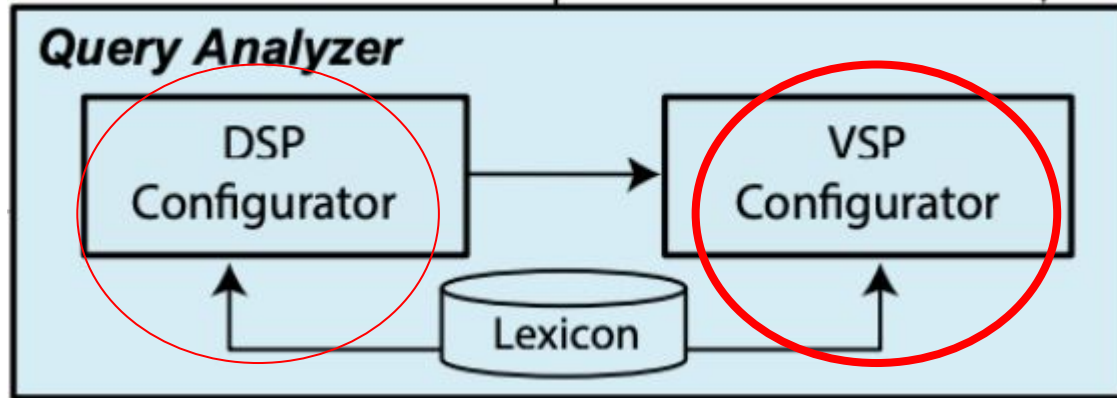


**Backend
Implementation**

NLP Query to
Database Query

From Answer
to Display

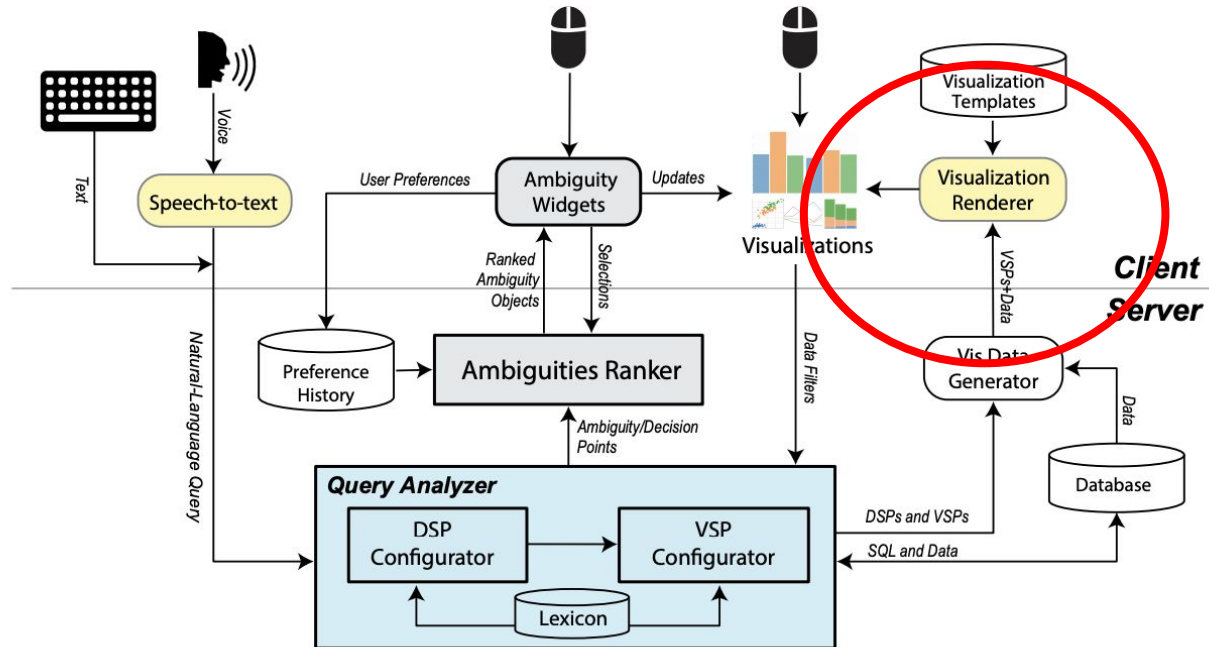
Query Analyzer



Visual Specification (VSP)

- Template for a graph
- Each template has constraints on how parameters can be filled
 - supported dimension and data types (categorical, quantitative, or time) for each parameter in the graph
- Map each DSP to the VSP template that can accept that specific DSP's configuration
- Bar Chart VSP:
 - x-axis: one categorical dimension
 - y-axis: one quantitative measure
 - color: a color encoding (mapping) of one dimension (optional)
- Given a DSP, there are may be several possible templates

VSP → Client → D3.js → Image



Question #2

What are some of the category labels for n-grams in this string? What type of graph would you use to represent the answer?

What were the trends of COVID-19 deaths in May between New York and California?

1. database attributes (i.e., column names)
2. database cell values
3. numerical values
4. time expressions
5. data operators and functions (greater than, less than, equal, sum, average, sort)
6. visualization key phrases (trend, correlation, relationship, distribution, time series, bars, stacked bars, line graph),
7. boolean operators (e.g., and, or)
8. “direct manipulation” terms (e.g., color)