

# Concept Learning in Description Logics

## Motivation

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# Section 1

## Motivation

## Data Web

Charles III / Age

# 74 years

November 14, 1948



People also search for



**Queen  
Camilla**  
76 years



**Anne,  
Princess  
Royal**  
72 years



**William,  
Prince of  
Wales**  
41 years



### Charles III

King of the United Kingdom :



Charles III is King of the United Kingdom and 14 other Commonwealth realms. Charles was born in Buckingham Palace during the reign of his maternal grandfather, George VI, and was three years old when his mother, Elizabeth II, acceded to the throne in 1952, making him the heir apparent. [Wikipedia](#)

**Born:** November 14, 1948 (age 74 years), [Buckingham Palace, London, United Kingdom](#)

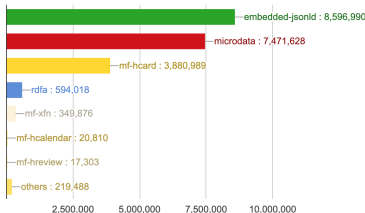
**Full name:** Charles Philip Arthur George

**Height:** 1.78 m

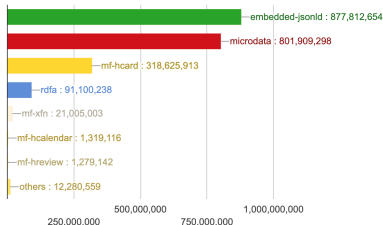
- ▶ Most popular application of knowledge graphs (KGs) is **Web search**
- ▶ Approx. 30% of search queries at Google answered by the Google Knowledge Graph
- ▶ Further **applications** in finance, health, e-commerce, and Industry 4.0
- ▶ Predominant portion of **open KGs** are in RDF

## Data Web

Domains with Triples



URLs with Triples

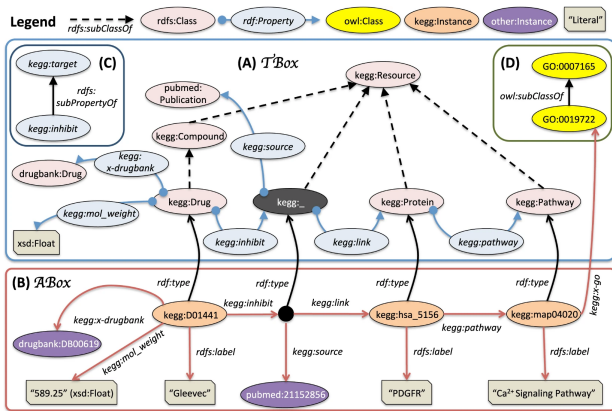


- ▶ RDF knowledge bases are now **first-class citizens** of the Web
- ▶ Approx. 50% of websites contain RDF<sup>1</sup>
- ▶ 2+ billion URLs contain RDF statements
- ▶ Ca. 100 billion statements in Linked Open Data

<sup>1</sup>See <http://webdatacommons.org/structureddata/#results-2022-1>

# Motivation

## Description Logics

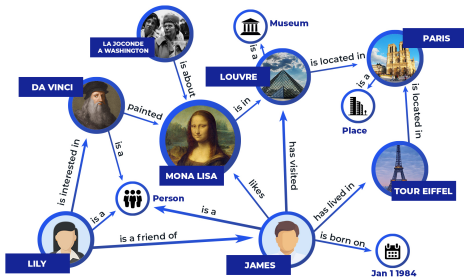


- ▶ Terminology of RDF datasets in description logics
- ▶ Popular DLs include  $\mathcal{ELH}$  (e.g., for biomedical domain),  $\mathcal{ALC}$  (e.g., for ML-driven applications), and  $\mathcal{SROIQ}$  (e.g., on the Web)

## Section 2

# Basic Setting

# Basic Setting Learning Problem



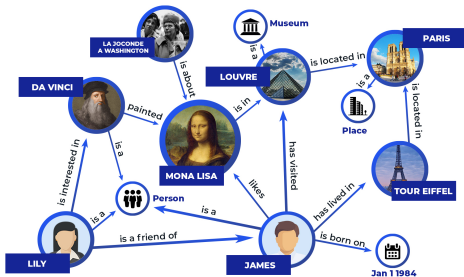
2

- ▶ Given
  - ▶ Knowledge base  $G$  (often called **background knowledge**)

<sup>2</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Learning Problem



2

### ► Given

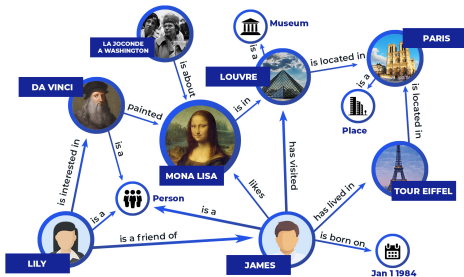
- Knowledge base  $G$  (often called **background knowledge**)
- Set of positive examples, e.g.,  $E^+ = \{Louvre, TourEiffel\}$

<sup>2</sup>Source: <https://bit.ly/3sxCj6e>



# Basic Setting

## Learning Problem



2

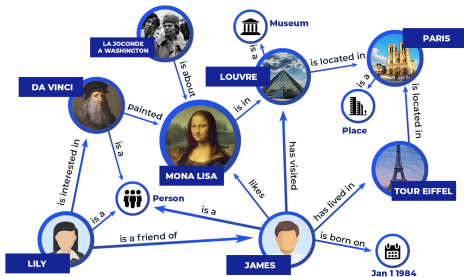
### ► Given

- Knowledge base  $G$  (often called **background knowledge**)
- Set of positive examples, e.g.,  $E^+ = \{\text{Louvre}, \text{Tour Eiffel}\}$
- Set of negative examples, e.g.,  $E^- = \{\text{Lily}, \text{James}\}$

<sup>2</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Learning Problem



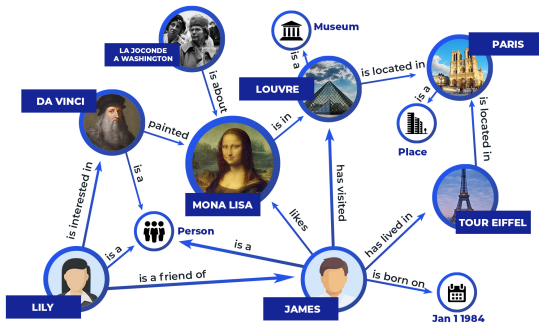
2

- ▶ Given
  - ▶ Knowledge base  $G$  (often called **background knowledge**)
  - ▶ Set of positive examples, e.g.,  $E^+ = \{Louvre, TourEiffel\}$
  - ▶ Set of negative examples, e.g.,  $E^- = \{Lily, James\}$
- ▶ **Goal:** Find **concept  $H$**  that “describes”  $E^+$  and “does not describe”  $E^-$ , e.g.,  $H = \exists isLocatedIn.Place$

<sup>2</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Symbolic Approaches



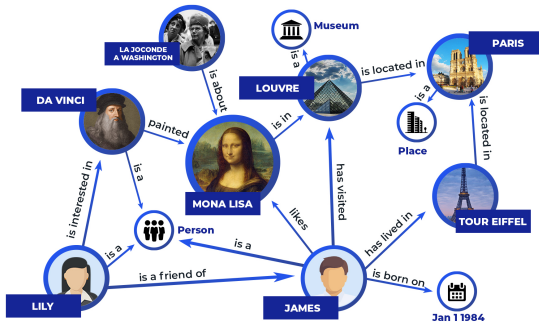
3

- Often based on refinement operators

<sup>3</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Symbolic Approaches



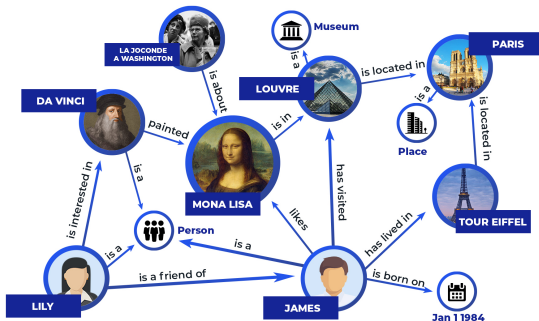
3

- ▶ Often based on refinement operators
- + Explainable, exploits background knowledge
- Slow :-)

<sup>3</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Neural Approaches



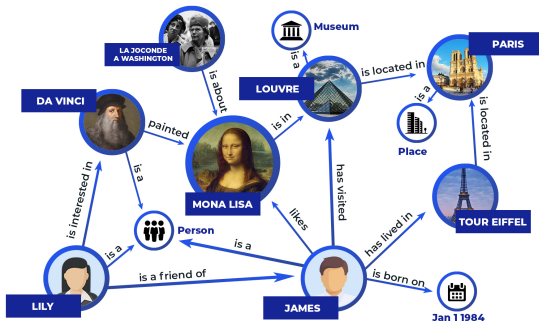
4

► **Deep Learning:** 
$$e(v_i) := \varphi \left( \bigoplus_{(v_i, p_k, v_j) \in G} e(p_k, v_j), e(v_i) \right)$$

<sup>4</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Neural Approaches



4

► **Deep Learning:**  $e(v_i) := \varphi \left( \bigoplus_{(v_i, p_k, v_j) \in G} e(p_k, v_j), e(v_i) \right)$

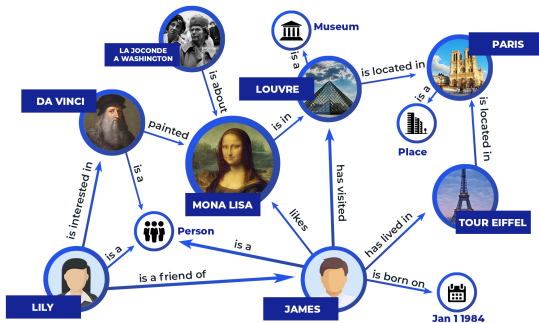
+ Time-efficient

- Unintelligible, does not exploits background knowledge

<sup>4</sup>Source: <https://bit.ly/3sxCj6e>

# Basic Setting

## Neuro-Symbolic Approaches



5

- + Exploit **time efficiency** of neural approaches
- + Keep **explainability** of symbolic approaches

<sup>5</sup>Source: <https://bit.ly/3sxCj6e>