

I K N E X

# Knowledge Representation & Reasoning

Fall 2023

**Dr. Amna Basharat | Ms. Amna Binte Kamran**

# **Importance of 'Knowledge'**

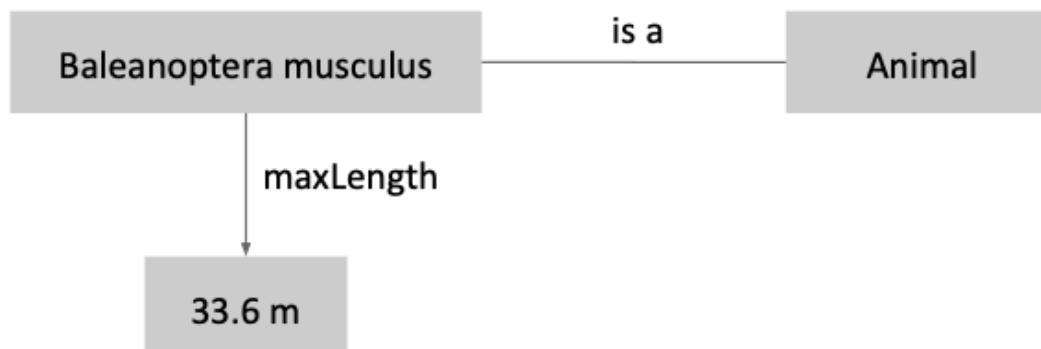
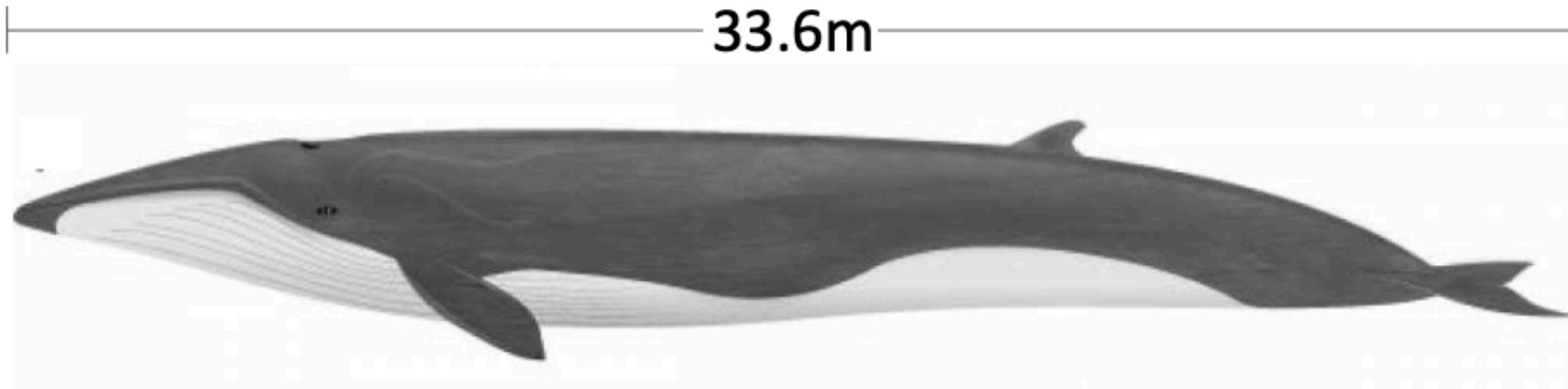
## **What is Knowledge?**

# **The Story of Knowledge**

# Data, Information & Knowledge

33.6

**33.6 m**



BaleanopteraMusculus ⊑ Animal  $\sqcap \forall \text{maxLength}.\leq 33.6$

# Data

- Data is raw.
- It simply exists and has no significance beyond its existence (in and of itself).
- It can exist in any form, usable or not.

# Information

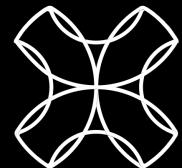
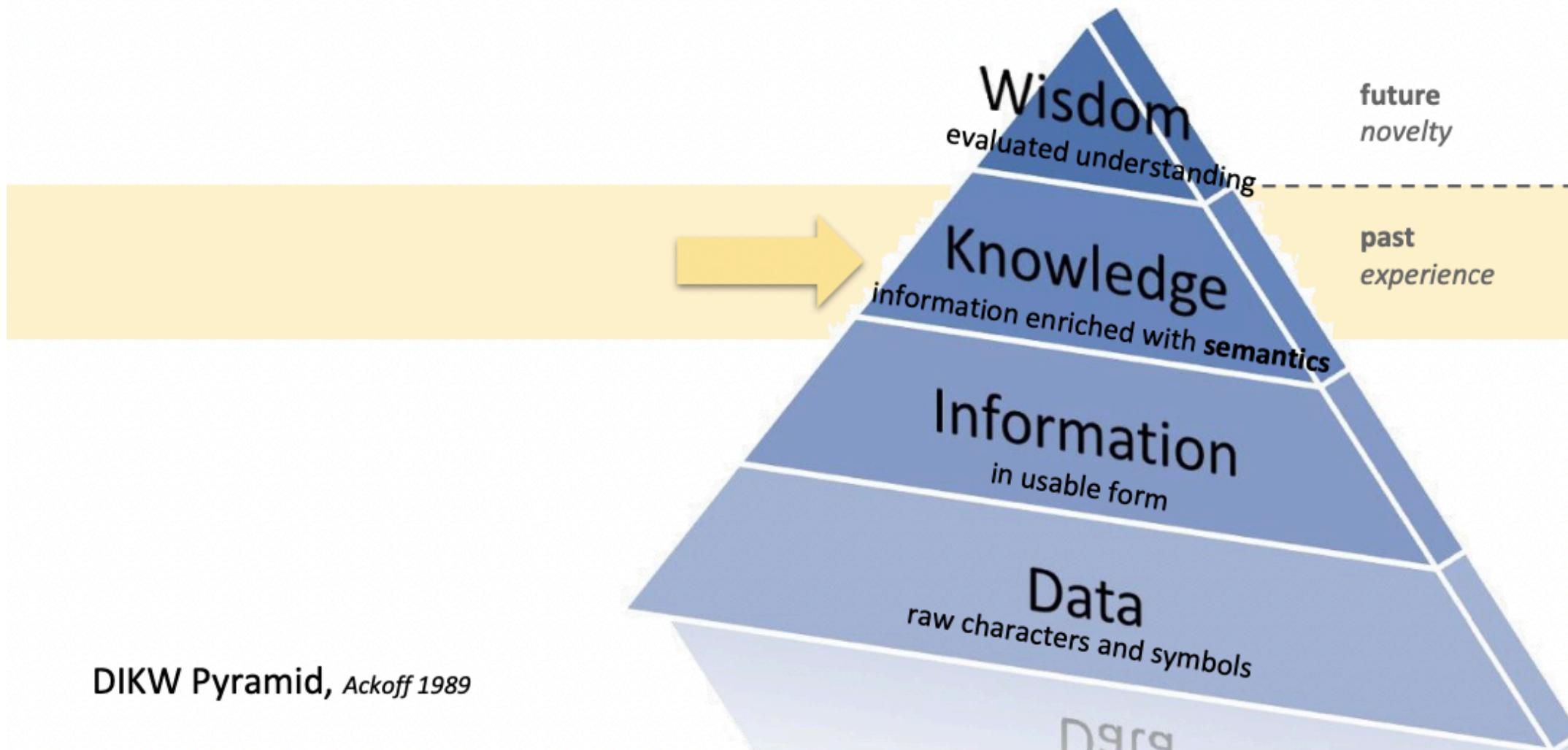
- Information is data that has been **given meaning by way of relational connection.**
- **This "meaning" can be useful, but does not have to be.**
- **Information is contained in descriptions.**
- **Information answers to questions that begin with such words as who, what, when, where, and how many.**

# knowledge

- **Knowledge** is the appropriate collection of information, such that it's intent is to be useful.
- **Wisdom** is the ability to make sound judgments and decisions.
- **Understanding** is a continuum that leads from **data**, through **information** and **knowledge**, and ultimately to **wisdom**.

Data transforms to information by convention, information to knowledge by cognition, and knowledge to wisdom by contemplation.

# From Data to Knowledge

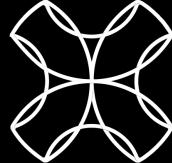


IK NEX

# Formal Knowledge Representation

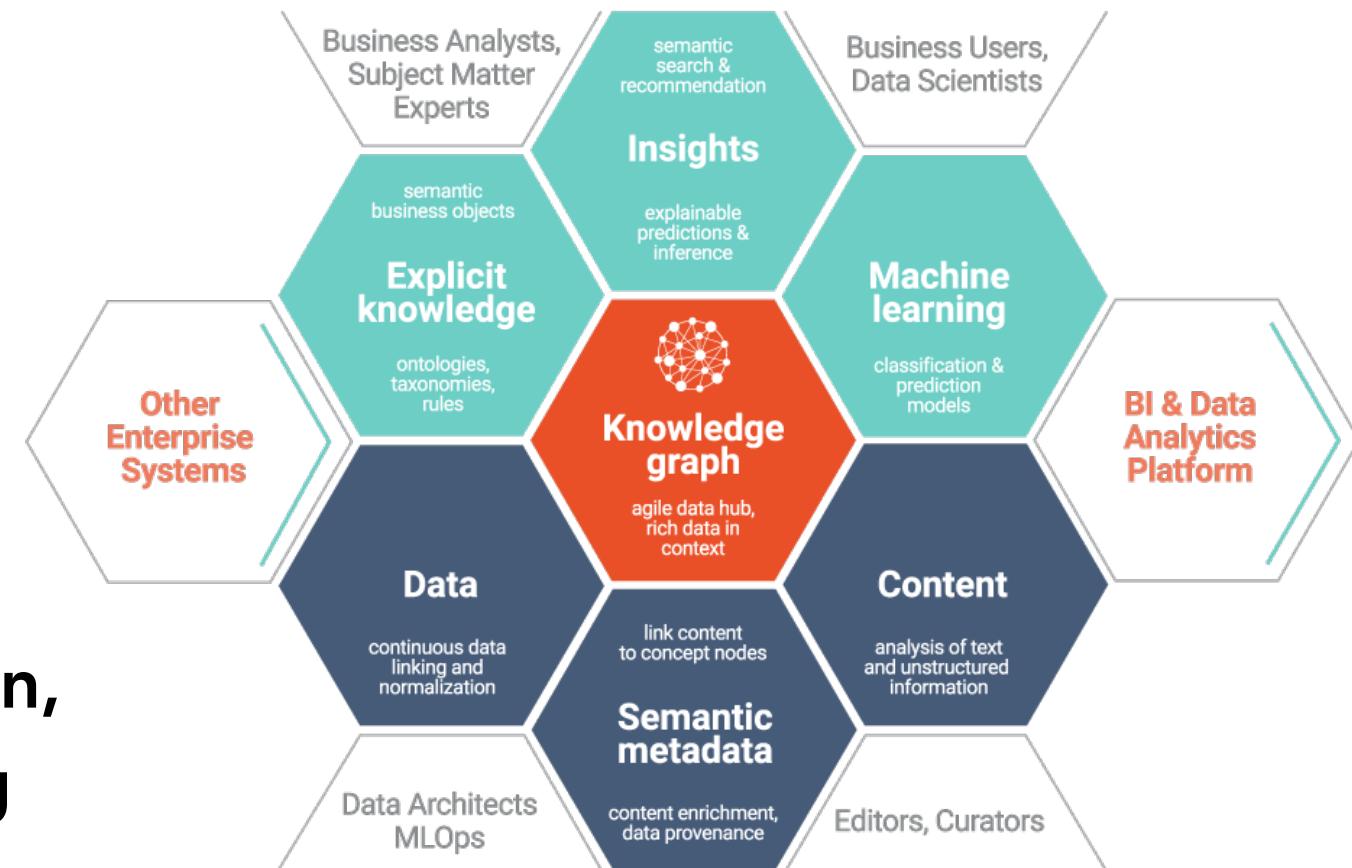
- **Formal Knowledge Representation**
  - is a field of **artificial intelligence (AI)**,
  - which (unambiguously) captures the **semantics (meaning)** of **concepts, properties, relationships, and entities**
  - of specific **knowledge domains**, i.e., fields of interest or areas of concern,
  - as **structured data**.
- **Machines (computers)** must be able to **understand** formal knowledge representations.
- To “**understand**” a knowledge representation, the machine must be able to **interpret it correctly**.

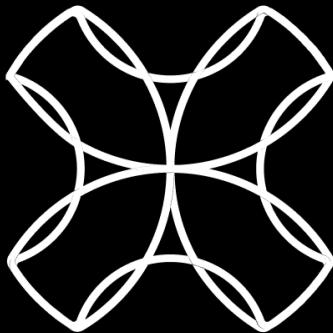
# Knowledge Graphs & Ontologies as Means of Formal Knowledge Representation



I K N E X

- Knowledge graphs put data in context via linking and semantic metadata
- Ontologies help provide the vocabulary for making the semantics of the data explicit
- A framework for data integration, unification, analytics and sharing



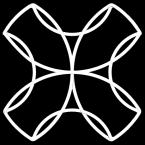


I K N E X

# The age of Intelligent Agents

**Knowledge Graphs, Ontologies, Semantics are some of the key enablers!**

# Google vs Siri



I K N E X

who is the father of imran khan

All News Images Videos More

About 8,420,000 results (0.73 seconds)

Imran Khan / Fathers

## Ikramullah Khan niazi

Feedback

People also ask

- Who is the father of actor Imran Khan?
- Who is the mother of Imran Khan?
- How rich is Imran Khan?
- Who is Imran Khan daughter?

**Imran Khan**  
Prime Minister of Pakistan



Imran Ahmed Khan Niazi HI PP is the 22nd and current Prime Minister of Pakistan and the chairman of the Pakistan Tehreek-e-Insaf. Before entering politics, Khan was an international cricketer and captain of the Pakistan national cricket team, which he led to victory in the 1992 Cricket World Cup.  
[Wikipedia](#)

**Born:** October 5, 1952 (age 67 years), Lahore  
**Height:** 1.88 m  
**Children:** Sulaiman Isa Khan, Kasim Khan

Hey Siri who is the father of Imran Khan  
Tap to Edit

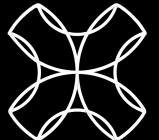
**Ikramullah Khan niazi** is Imran Khan's father.

**KNOWLEDGE**

**Ikramullah Khan niazi**  
Imran Khan's father

Spouse: Shaukat Khanum >  
Children: Imran Khan >

# Google vs Siri



IKNEX



Google how many women have won the nobel prize

All Images News Videos More Settings Tools

About 46,000,000 results (0.89 seconds)

**53 women**

Only **one woman**, Marie Curie, has been honoured twice, with the 1903 Nobel Prize in Physics and the 1911 Nobel Prize in Chemistry. This means that **53 women** in total have been awarded the Nobel Prize between 1901 and 2019.

[www.nobelprize.org/prizes/lists/nobel-prize-award...](http://www.nobelprize.org/prizes/lists/nobel-prize-award...)

[Nobel Prize awarded women](#)

About Featured Snippets Feedback



8:53 AM Hey Siri how many women have won the Nobel prize Tap to Edit

I found this on the web for 'how many women have won the Nobel prize'.

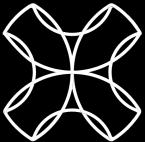
WEBSITES

**Nobel Prize awarded women**  
This means that 53 women in total have been awarded the Nobel Prize between...  
[nobelprize.org](http://nobelprize.org)

**List of female Nobel laureates - Wikipedia**  
As of 2019, Nobel Prizes have been awarded to 866 men, 53 women and 24...  
[en.wikipedia.org](https://en.wikipedia.org)

**Statistically speaking, 2019 Nobel Prize lineup of 11 men and one ...**  
15 Oct 2019 ... And half of the prizes that

# Google vs Siri



I K N E X



Google search results for "who killed John F Kennedy":

About 198,000,000 results (0.55 seconds)

[en.wikipedia.org › wiki › Assassination\\_of\\_John\\_F.\\_K... ▾](https://en.wikipedia.org/wiki/Assassination_of_John_F._Kennedy)

**Assassination of John F. Kennedy - Wikipedia**

John Fitzgerald Kennedy, the 35th President of the United States, was assassinated on Friday, November 22, 1963, at 12:30 p.m. Central Standard Time in ...

**Location:** Dealey Plaza, Dallas, Texas, USA    **Deaths:** John F. Kennedy; J. D. Tippit

**Date:** November 22, 1963; 56 years ago; 12:3...    **Weapons:** 6.5×52mm Italian Carcano M91/...

[Lee Harvey Oswald · Assassination of John F ...](#) · [Timeline of the John F ...](#) · [JD Tippit](#)

[www.history.com › this-day-in-history › john-f-kenned... ▾](https://www.history.com › this-day-in-history › john-f-kenned... ▾)

**John F. Kennedy Assassinated - HISTORY**

John Fitzgerald Kennedy, the 35th president of the United States, is assassinated by Lee Harvey Oswald while traveling through Dallas, Texas.

**Place of death:** Parkland Hospital

[www.history.com › topics › us-presidents › jfk-assassin... ▾](https://www.history.com › topics › us-presidents › jfk-assassin... ▾)

**Assassination of John F. Kennedy**



John Fitzgerald Kennedy, the 35th President of the United States, was assassinated on Friday, November 22, 1963, at 12:30 p.m. Central Standard Time in Dallas, Texas, while riding in a presidential motorcade through Dealey Plaza. [Wikipedia](#)

**Deaths:** John F. Kennedy; J. D. Tippit

**Start date:** November 22, 1963

**Location:** Dallas, Texas, United States

Hey Siri who killed John F. Kennedy  
Tap to Edit

**The answer I found is Lee Harvey Oswald.**

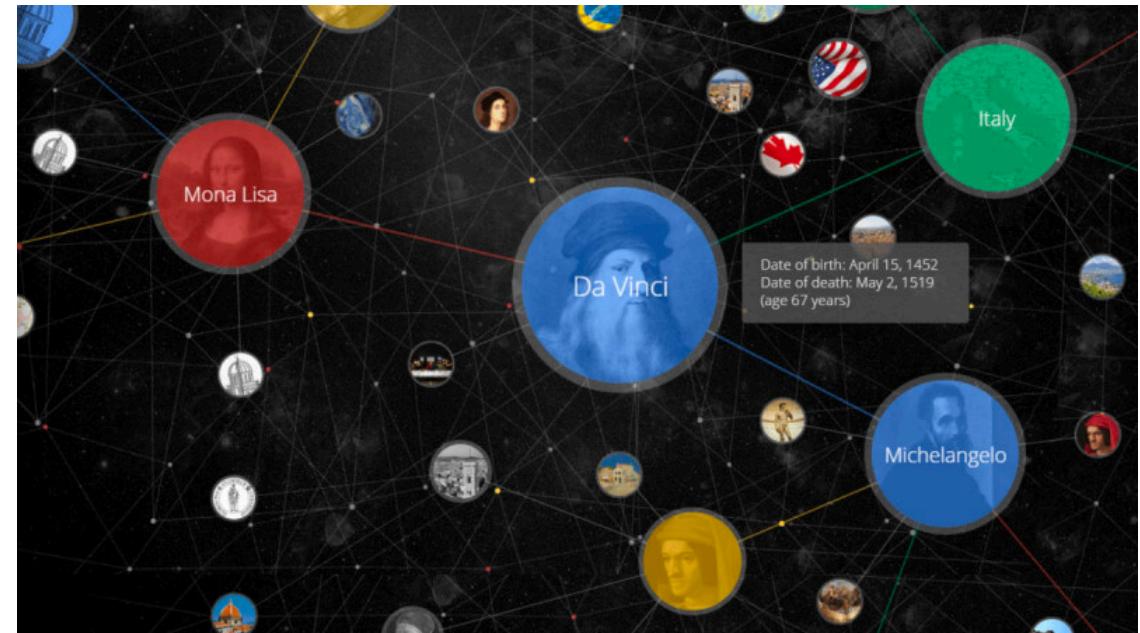
**KNOWLEDGE**

**Lee Harvey Oswald**  
American former marine who assassinated John F. Kennedy

 Lee Harvey Oswald was an American Marxist and former U.S. Marine who assassinated United States President John F. Kennedy on November 22, 1963. Oswald was honorably released from active duty in the Marine Corps into the reserve and defected to the Soviet Union in October 1959. He lived in Minsk until June 1962, when h... more

# The Google Knowledge Graph

- An "ontology" about everything
- Identifying entities in queries and presenting data about those entities as results



# Document Retrieval and Knowledge Graphs

The screenshot shows a Google search results page for the query "neil armstrong". The search bar at the top contains "neil armstrong". Below the search bar, there are navigation links for "Web", "Images", "News", "Videos", "Books", "More", and "Search tools". A message indicates "About 28,800,000 results (0.50 seconds)". The search results list several links:

- Neil Armstrong - Wikipedia, the free encyclopedia**  
https://en.wikipedia.org/wiki/Neil\_Armstrong ▾ Wikipedia ▾  
Neil Alden Armstrong (August 5, 1930 – August 25, 2012) was an American astronaut and the first person to walk on the Moon. He was also an aerospace ...  
Buzz Aldrin - Gemini 8 - Congressional Space Medal of - Space selfie
- Neil Armstrong - Astronaut, Explorer, Pilot - Biography.com**  
www.biography.com/people/neil-armstrong-9188943 ▾  
Learn more about famous astronaut Neil Armstrong military pilot, Korean War veteran, and first man on the moon on Biography.com.
- Biography of Neil Armstrong | NASA**  
https://www.nasa.gov/centers/glenn/about/bios/neillabio.html ▾ NASA ▾  
Biography of Neil Armstrong. National Aeronautics and Space Administration John H. Glenn Research Center Lewis Field Cleveland, Ohio 44135. Neil A.
- Who Was Neil Armstrong? | NASA**  
www.nasa.gov/audience/.../k.../who-was-neil-armstrong-k4.html ▾ NASA ▾  
Neil Armstrong was the first person to walk on the moon.
- Neil Armstrong, First Man on Moon, Dies at 82 - The New ...**  
www.nytimes.com/.../neil-armstrong-dies-first-man... ▾ The New York Times ▾  
Aug 25, 2012 - Neil Armstrong, as photographed by Buzz Aldrin, working near the Eagle lunar module after the landing on July 20, 1969. Credit NASA.
- Neil Armstrong's widow finds moon artifacts in closet - CNN ...**  
www.cnn.com/2015/02/09/us/neil-armstrong-moon-artifacts/ ▾ CNN ▾  
Feb 10, 2015 - Neil Armstrong, the first man to step foot on the moon, left some of his personal artifacts from his journey in a closet, his widow, Carol, ...
- Neil Armstrong - Facts & Summary - HISTORY.com**

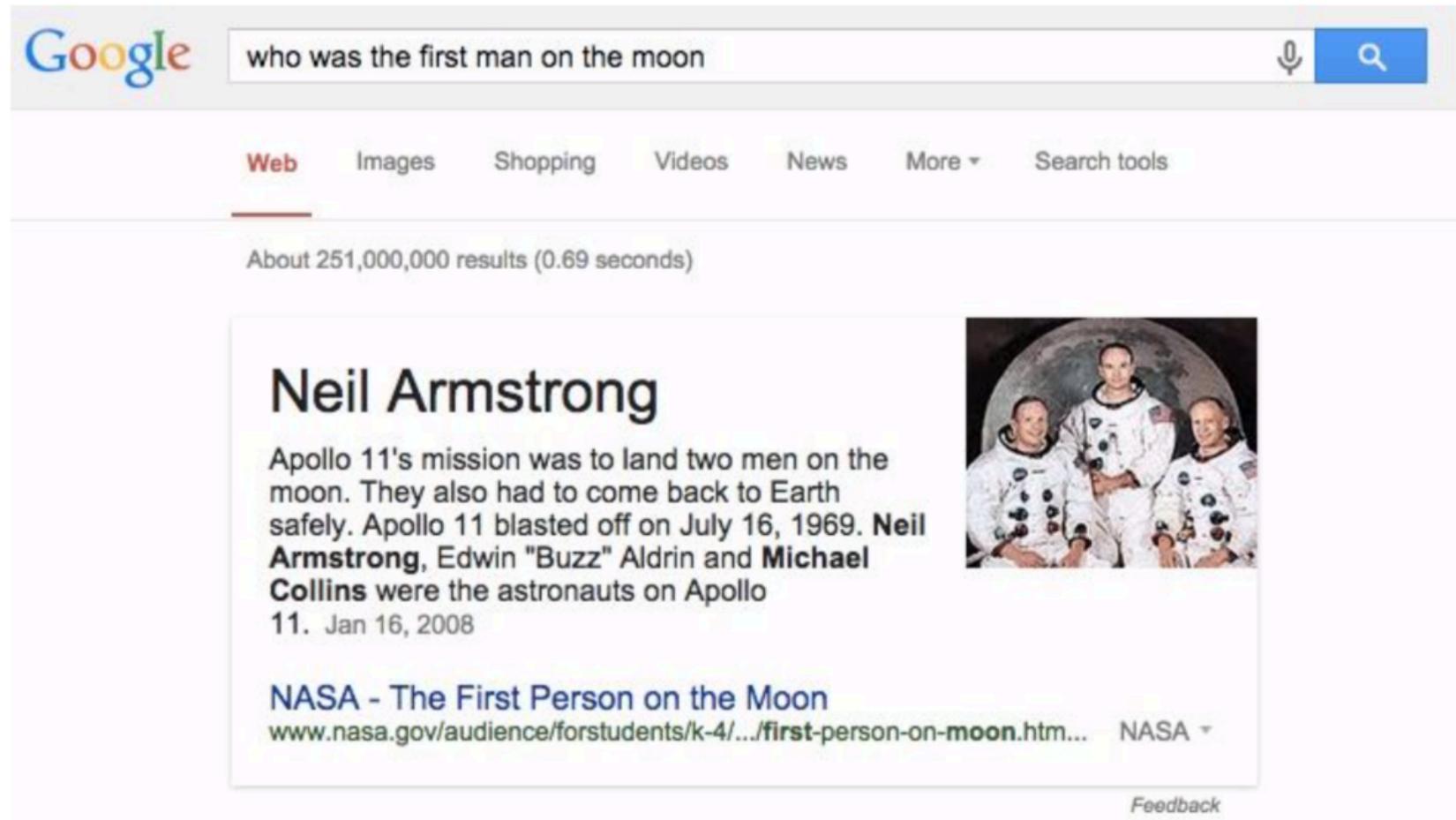
To the right of the search results, there is a detailed card for "Neil Armstrong" highlighted with a red circle. The card includes:

- A large portrait of Neil Armstrong in an astronaut suit.
- A grid of smaller images showing him in various spacesuits and environments.
- The name "Neil Armstrong" in bold.
- The title "Astronaut".
- A biography: "Neil Alden Armstrong was an American astronaut and the first person to walk on the Moon. He was also an aerospace engineer, naval aviator, test pilot, and university professor. Wikipedia"
- Birth and death information: "Born: August 5, 1930, Auglaize County, Ohio, OH" and "Died: August 25, 2012, Cincinnati, OH".
- Space missions: "Gemini 8, Apollo 11".
- Spouse: "Carol Held Knight (m. 1994–2012), Janet Shearon (m. 1956–1994)".
- Children: "Mark Armstrong, Karen Armstrong, Eric Armstrong".
- Parents: "Stephen Armstrong, Viola Armstrong".
- A section titled "People also search for" with thumbnails for Buzz Aldrin, Michael Collins, Yuri Gagarin, John Glenn, and Lance Armstrong.
- A "View 5+ more" link.
- A "Feedback" link at the bottom right of the card.

Red annotations on the right side of the card indicate its components:

- A red arrow points to the portrait and grid of images with the text "named entity".
- A red arrow points to the "People also search for" section with the text "structured data".
- A red arrow points to the "View 5+ more" link with the text "recommendations".

# From Document to Fact Retrieval



Google who was the first man on the moon

Web Images Shopping Videos News More Search tools

About 251,000,000 results (0.69 seconds)

**Neil Armstrong**

Apollo 11's mission was to land two men on the moon. They also had to come back to Earth safely. Apollo 11 blasted off on July 16, 1969. **Neil Armstrong**, Edwin "Buzz" Aldrin and **Michael Collins** were the astronauts on Apollo 11. Jan 16, 2008

NASA - The First Person on the Moon  
[www.nasa.gov/audience/forstudents/k-4/.../first-person-on-moon.htm...](http://www.nasa.gov/audience/forstudents/k-4/.../first-person-on-moon.htm...) NASA

Feedback

The screenshot shows a Google search results page for the query "who was the first man on the moon". The top navigation bar includes "Web", "Images", "Shopping", "Videos", "News", "More", and "Search tools". Below the search bar, it says "About 251,000,000 results (0.69 seconds)". The main result is a card for "Neil Armstrong" with a sub-card for the Apollo 11 mission. The sub-card contains text about the mission, a photo of the three astronauts (Neil Armstrong, Buzz Aldrin, and Michael Collins) in their space suits, and a link to the NASA website. At the bottom of the card, there is a "Feedback" button.

From an Information Engine ....to a .... Knowledge Engine!

# From Document to Fact Retrieval



WolframAlpha computational knowledge engine

Enter what you want to calculate or know about:

how far away is the moon from the earth in km

Input interpretation:  
convert Moon distance from Earth to kilometers

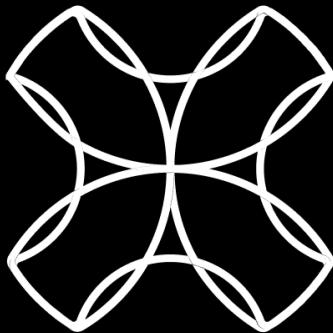
Result:  
398 078 km (kilometers)

Show details

Additional conversions:  
247 354 miles  
 $3.981 \times 10^8$  meters

Comparison as distance:  
≈ mean Moon-Earth distance ( $3.85 \times 10^8$  m)

Corresponding quantities:  
Light travel time  $t$  in vacuum from  $t = x/c$ :  
1.3 seconds

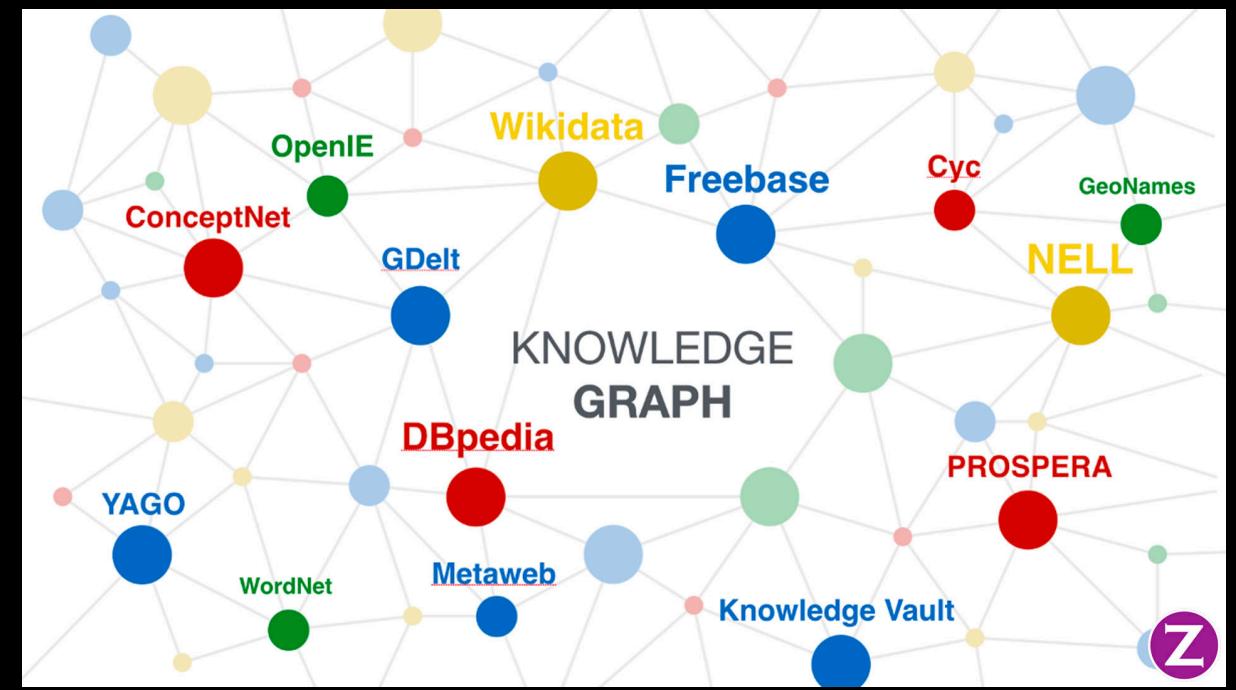


I K N E X

**Whats all the Hype about KGs?**

# Knowledge graphs constitute the backbone of today's state-of-the-art information systems & Intelligent Agents

- From improving search results over question answering and recommender systems up to explainable AI systems, the applications of knowledge graphs are manyfold.



# Knowledge Graphs - The Hype



- Knowledge graphs have emerged as a compelling abstraction for organizing world's structured knowledge over the internet
  - capturing relationships among key entities of interest to enterprises
  - a way to integrate information extracted from multiple data sources
- Knowledge graphs have also started to play a central role in machine learning and natural language processing
  - as a method to incorporate world knowledge
  - as a target knowledge representation for extracted knowledge
  - and for explaining what is being learned

# Knowledge Graphs - Emerging on the Hype Cycle

- Getting the Semantic Web and Knowledge Graph researchers excited!

Hype Cycle for Artificial Intelligence, 2021



gartner.com

Source: Gartner  
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Gartner®

**“By 2025, graph technologies will be used in 80% of data and analytics innovations, up from 10% in 2021, facilitating rapid decision making across the enterprise.”**

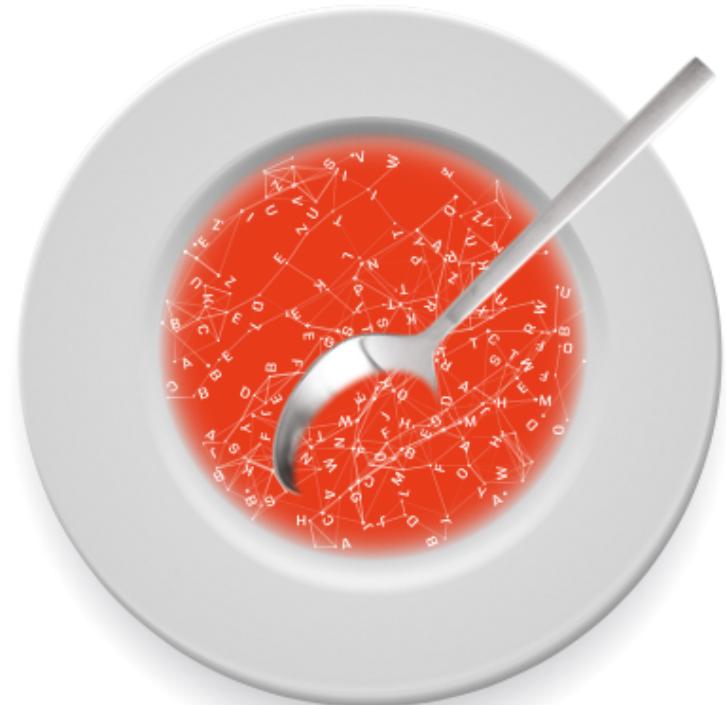
(Gartner®, “Market Guide for Graph Database Management Solutions”, Merv Adrian, Afraz Jaffri & Donald Feinberg, published 24 May 2021)

# More About Knowledge Graphs

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# THE KNOWLEDGE GRAPH COOKBOOK

## RECIPES THAT WORK



**ANDREAS BLUMAUER  
AND HELMUT NAGY**

1st edition, 2020

# WHY KNOWLEDGE GRAPHS?

How do you "cook" a knowledge graph? Before we discuss specific variants of recipes and dishes, examine the individual ingredients, tools and methods or classify recipes, I would like to explain the main reasons why you should learn how to cook knowledge graphs. This chapter will outline the excellent results you can achieve. Here is a brief preview:

- Knowledge graphs (KGs) solve well-known data and content management problems.
- KGs are the ultimate linking engine for enterprise data management.
- KGs automatically generate unified views of heterogeneous and initially unconnected data sources, such as Customer 360.
- KGs provide reusable data sets to be used in analytics platforms or to train machine learning algorithms.
- KGs help with the dismantling of data silos. A semantic data fabric is the basis for more detailed analyses.

## A BRIEF HISTORY OF KNOWLEDGE GRAPHS

Cooking is culture, and culture is based on history. History is not only what has happened, but also what has been piled up—the ground upon which we stand and build. Therefore, we should also have an understanding of where knowledge graphs come from if we want to become a maestro KG chef. Understanding the historical context is always paramount to understanding the possible paths one can take in the future.

## **FAST FORWARD**

- In 1736, graph theory was born: Leonhard Euler formulated the 'Königsberg Bridge Problem.'
- In 1976, John F. Sowa published his first paper on Conceptual Graphs.<sup>4</sup>
- In 1982, Knowledge Graphs were invented in the Netherlands. The theory of Knowledge Graphs was initiated by C. Hoede, a mathematician at the University of Twente, and F.N. Stokman, a mathematical sociologist at the University of Groningen.
- In 1999, Resource Description Framework (RDF) Model was published as a W3C Recommendation to lay a foundation for a Semantic Web.
- In 2001, Tim Berners-Lee, Jim Hendler and Ora Lassila published their ground-breaking article 'The Semantic Web'<sup>5</sup> in the Scientific American Magazine.
- In 2006, the DBpedia<sup>6</sup> project created a seed for the emergence of the Linked Open Data cloud by transforming Wikipedia content into linked data.
- In 2012, Google introduced their Knowledge Graph, and since then a lot of companies have started to build their own projects using knowledge graphs in various flavours.
- In 2018, The GQL Manifesto<sup>7</sup> was published to agree on a standard for a property graph query language.

- By the end of 2019 knowledge graphs had become mainstream. For example, Gartner states that "... a semantic knowledge graph can be used to power other data management tasks such as data integration in helping automate a lot of redundant and recurring activities."<sup>8</sup>
- After decades of developing KGs, the discipline has also been influenced by a lot of other knowledge domains including mathematical logic, graph theory, information retrieval, computer linguistics, knowledge representation and reasoning, and most recently, the Semantic Web and machine learning.

## **SEMANTIC WEB**

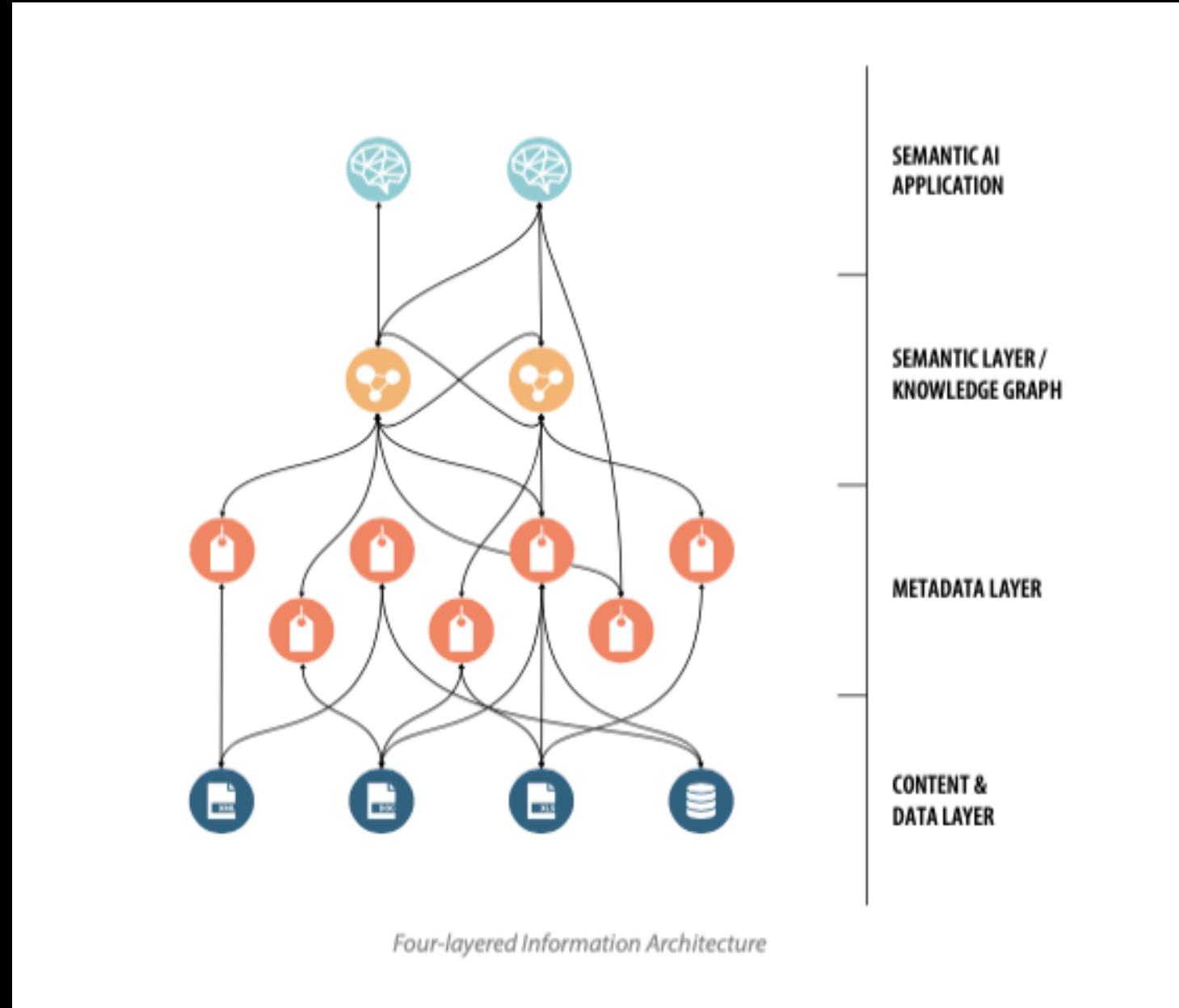
In 2001, when the WWW was still in its infancy, its founder Tim Berners-Lee was already talking about the next big step: "The Semantic Web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users."

20 years later, we all know that things have developed more slowly and somehow in a different direction than expected; nevertheless, the W3C has laid the groundwork for a Semantic Web by publishing several important recommendations:

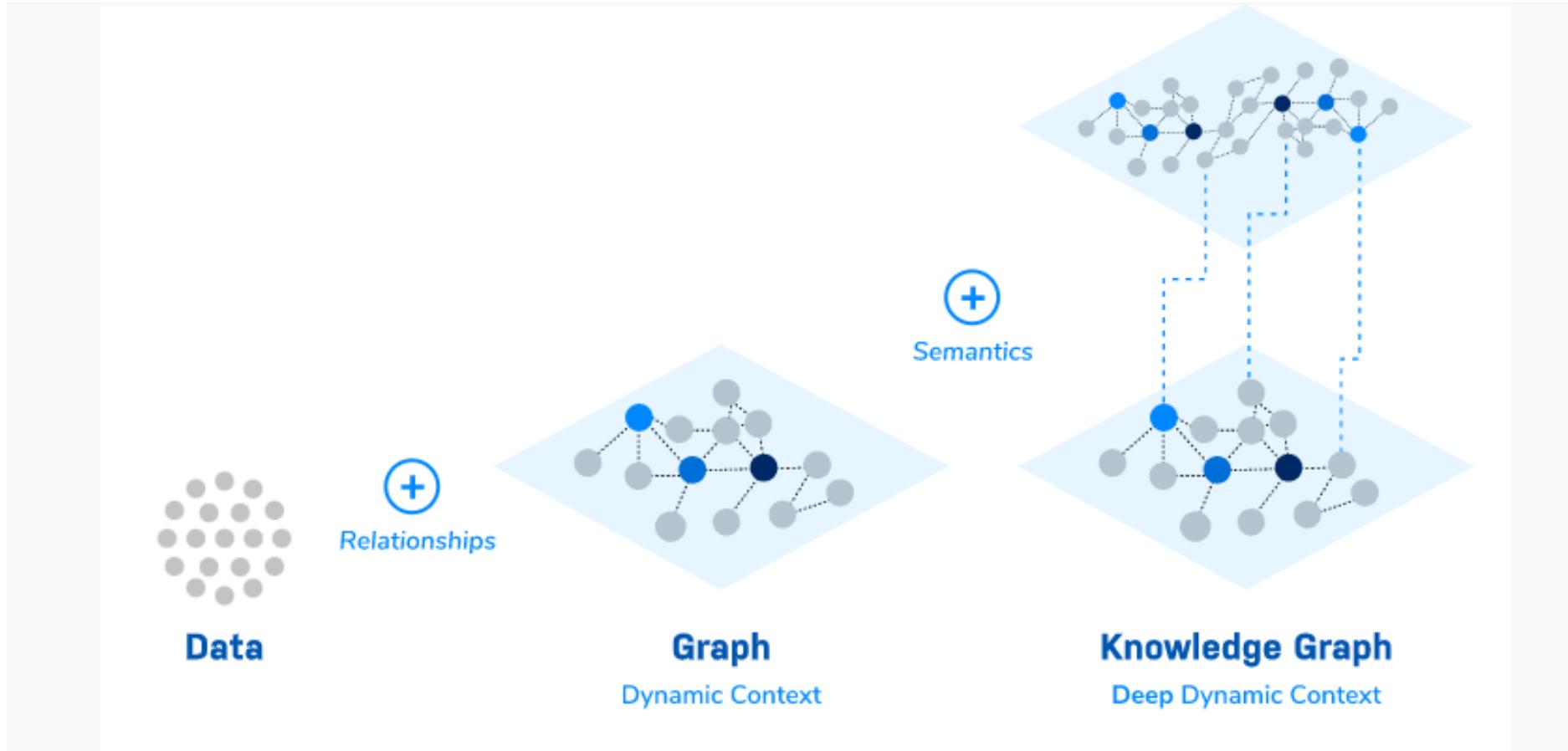
- 1999: Resource Description Framework (RDF) Model and Syntax Specification as a foundation for processing metadata to provide interoperability between applications that exchange machine-understandable information on the Web.
- 2004: Resource Description Framework (RDF) and RDF Vocabulary Description Language 1.0: RDF Schema (RDFS) as a standard for representing information about resources in the WWW. As a major update, RDF 1.1 was published in 2014.
- 2004: OWL Web Ontology Language as a language for defining and instantiating Web ontologies.
- 2008: SPARQL Protocol and RDF Query Language (SPARQL) to retrieve and manipulate data stored in RDF via so-called SPARQL endpoints. As a major update, SPARQL 1.1 was published in 2013.
- 2009: Simple Knowledge Organization System (SKOS) for representation of thesauri, classification schemes, taxonomies, subject-heading systems, or any other type of structured controlled vocabulary.

# Four Layered Information Architecture

- Powered by Knowledge Graphs



# Not all Graph Data is Knowledge Graphs!



## 1. Data

Bridge together diverse and disparate data silos regardless of data type, such as structured, unstructured, and semi-structured.

## 2. Graph

Map data and draw connections among them for the first layer of dynamic context, which provides immediate understanding.

## 3. Semantics

Apply semantics to provide deeper context to connected data. The deeper the context, the more powerful the insights.

- <https://neo4j.com/use-cases/knowledge-graph/>

# Better Knowledge Management



*DIKW Pyramid: From Data to Wisdom*

# Towards Explainable AI

# MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE: MAKE IT EXPLAINABLE

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"MACHINE LEARNING ALGORITHMS LEARN FROM HISTORICAL DATA, BUT THEY CANNOT DERIVE NEW INSIGHTS FROM IT"

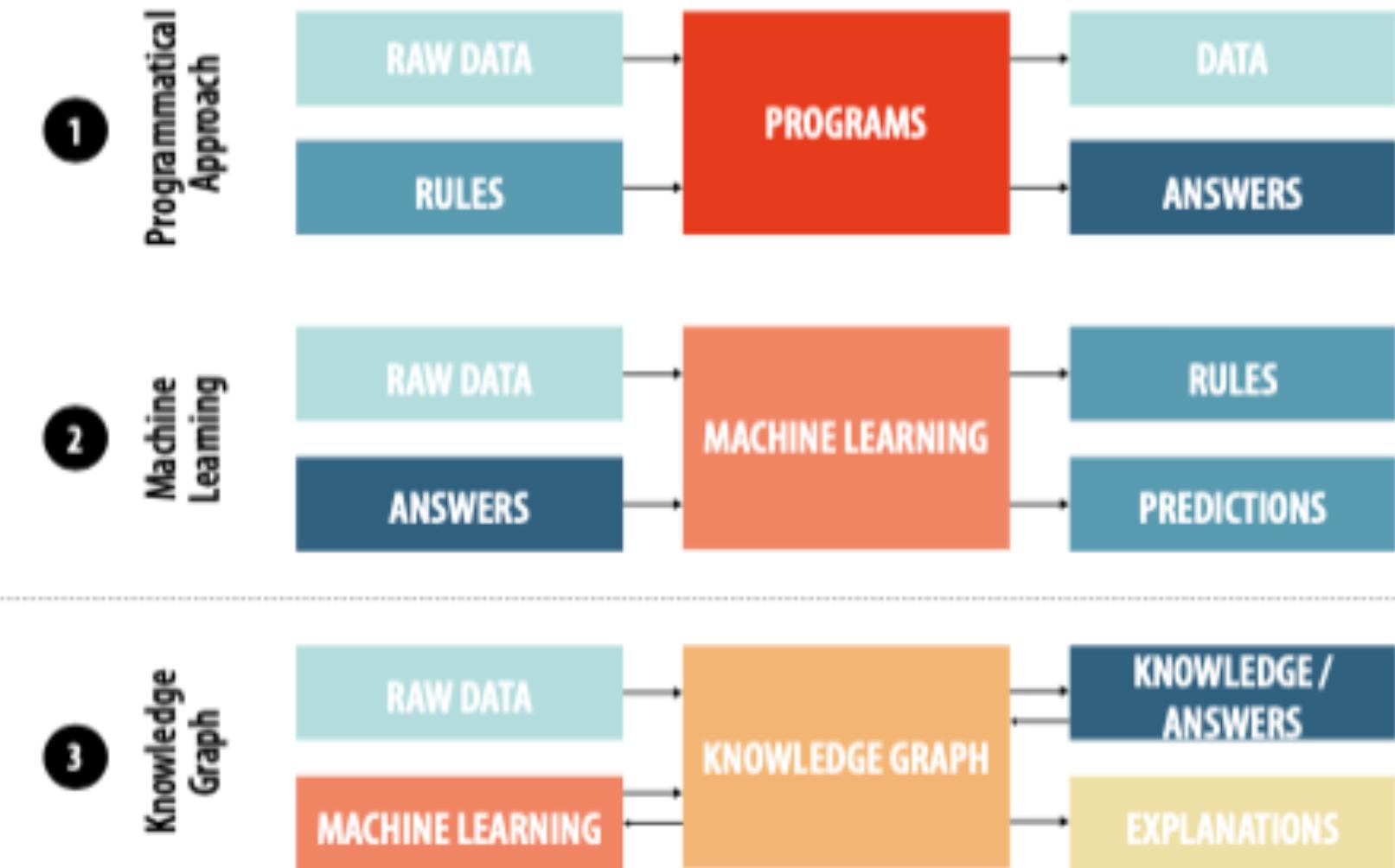
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While AI is becoming a part of our daily lives, many people are still skeptical. Their main concern is that many AI solutions work like black boxes and seem to magically generate insights without explanation.

In addition to the benefits they can bring to the area of enterprise data management, knowledge graphs are increasingly being identified as building blocks of an AI strategy that enables explainable AI following the Human-in-the-Loop (HITL) design principle.

*Why does artificial intelligence often work like a black box?*

# Towards Explainable AI



*Towards Explainable AI*



# Course Dynamics



# Course Overview

- In this course you will learn what is necessary to **design, implement, and use knowledge graphs.**
- The focus of this course will be on **basic semantic technologies** including the principles of knowledge representation and symbolic AI.
  - Information encoding via RDF triples
  - Knowledge representation via ontologies with OWL
  - Efficiently querying knowledge graphs via SPARQL
  - Knowledge graph applications in innovative information systems, as e.g., semantic and exploratory search



# Course Contents

- Knowledge Graphs in the Web of Data
- Basic Semantic Technologies
- Querying RDF with SPARQL
- Knowledge Representation with Ontologies
- Knowledge Graph Applications
- Advanced Knowledge Graph Applications
- Principles of Linked Data
- Publishing and Querying Linked Open Data



# Requirements

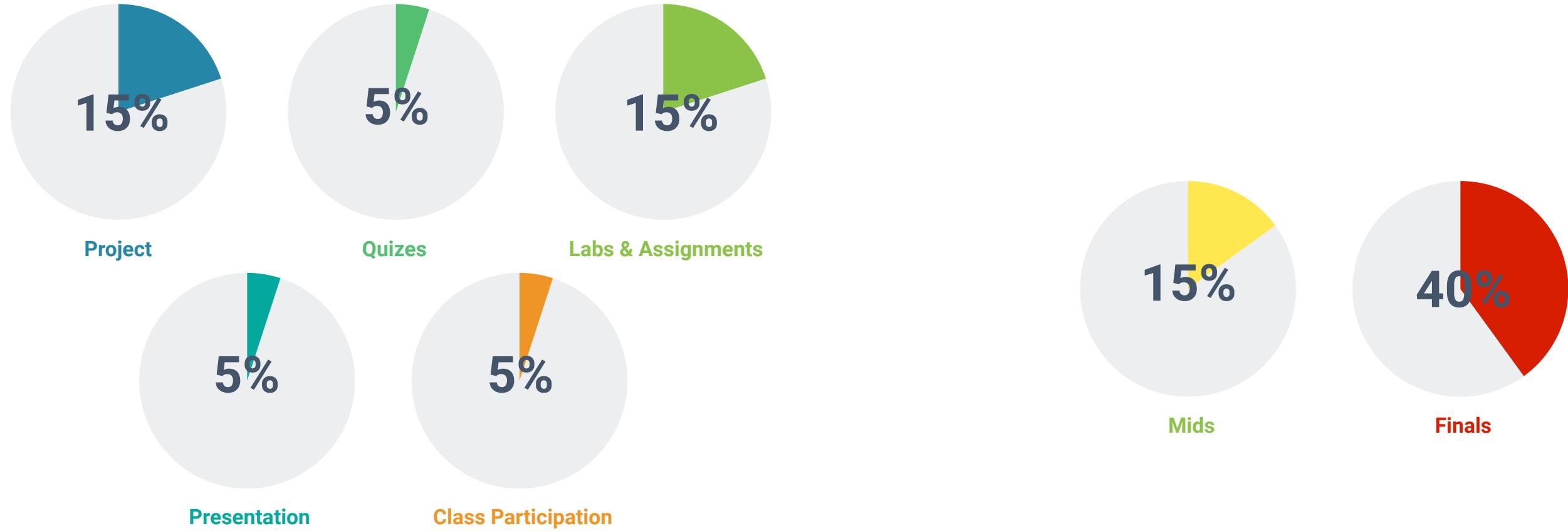
- Basic understanding of web technologies, such as URL and HTTP
- Basic knowledge of database technology, such as relational databases and SQL query language
- No prior knowledge of ML, AI, DM required as such, though it will be of benefit in helping co-relate and better appreciate the use of KGs



# The Driving Forces!



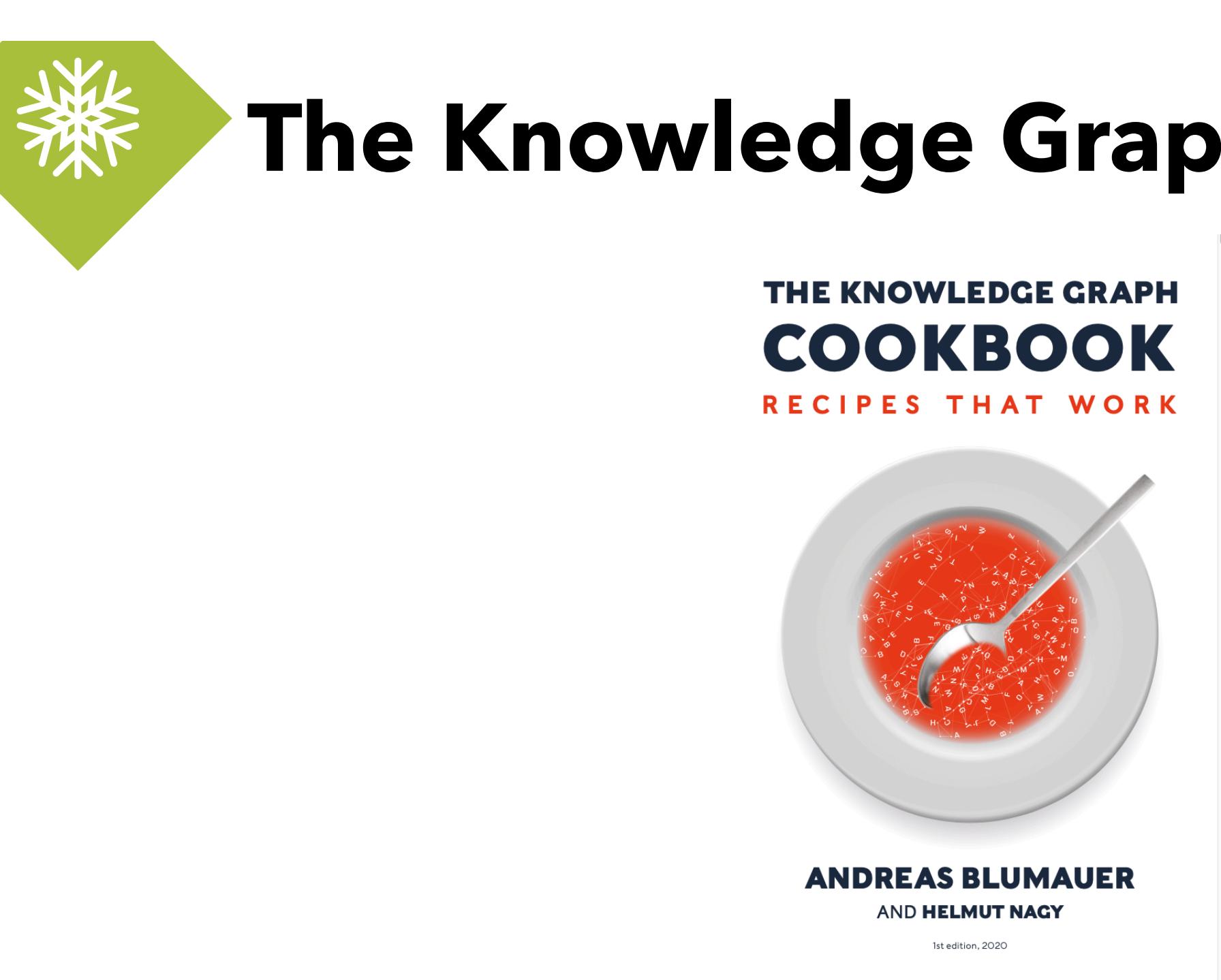
# The Key Driving Forces...?\*



\*Subject to Revision

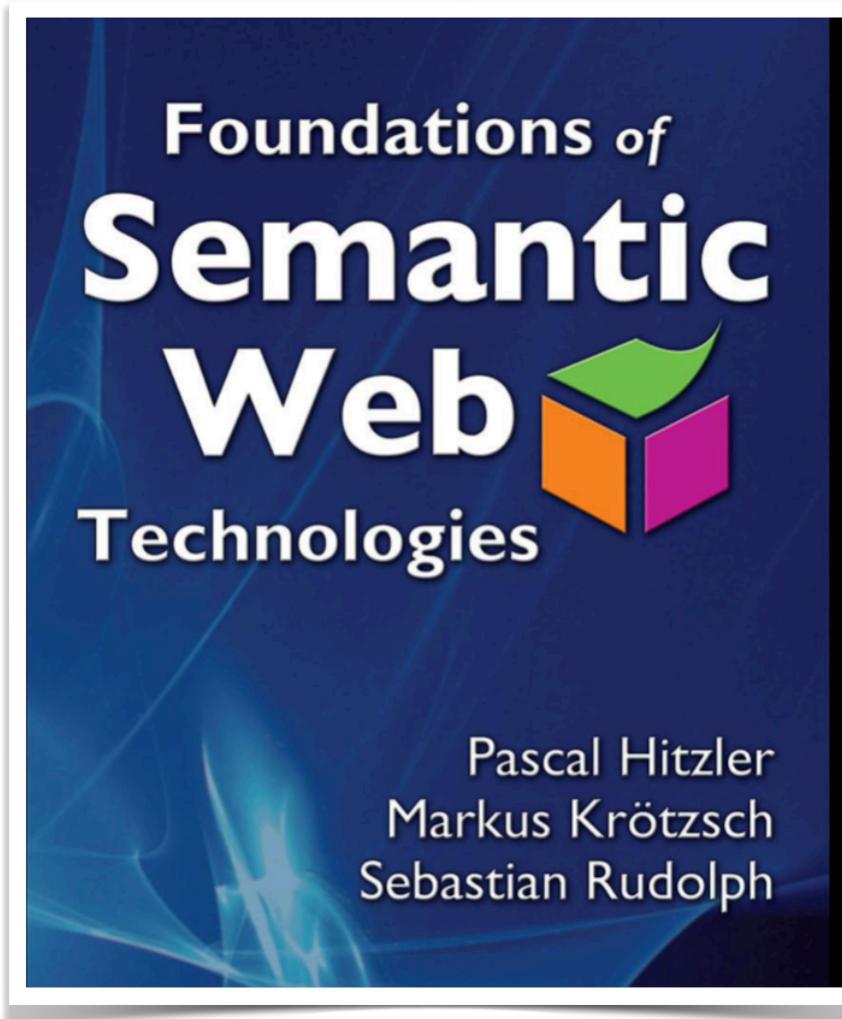


# **Books & Resources**



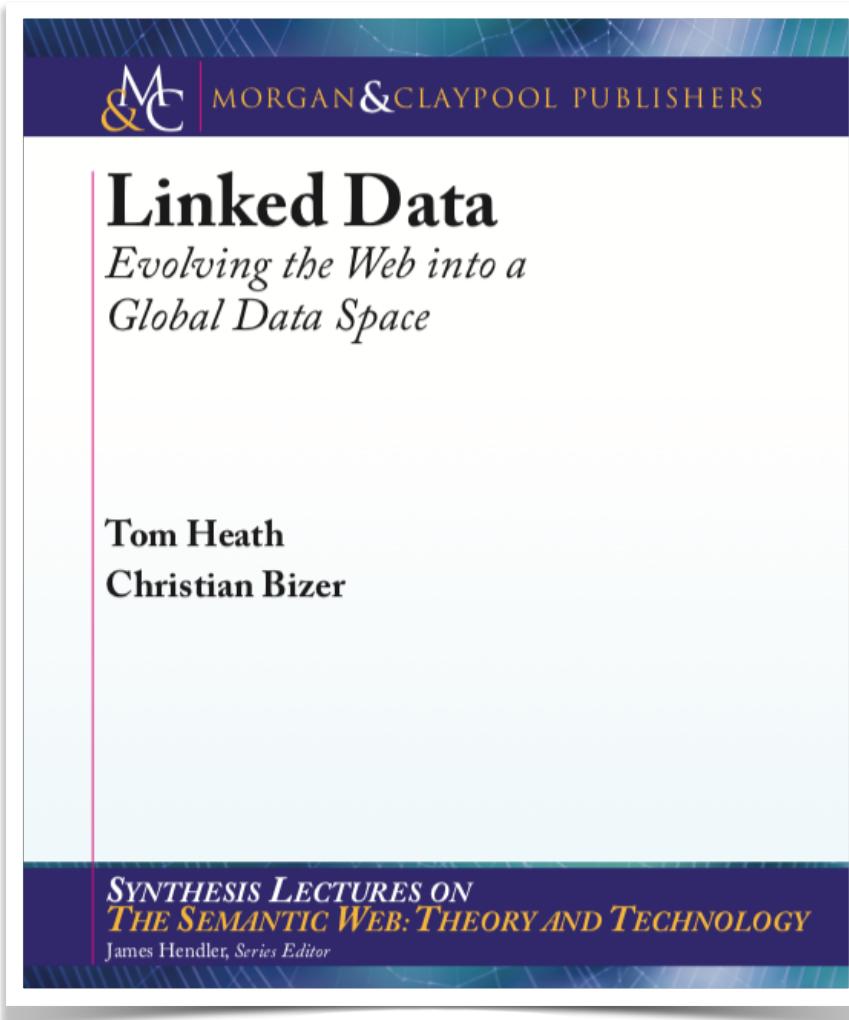


# Foundations of Semantic Web



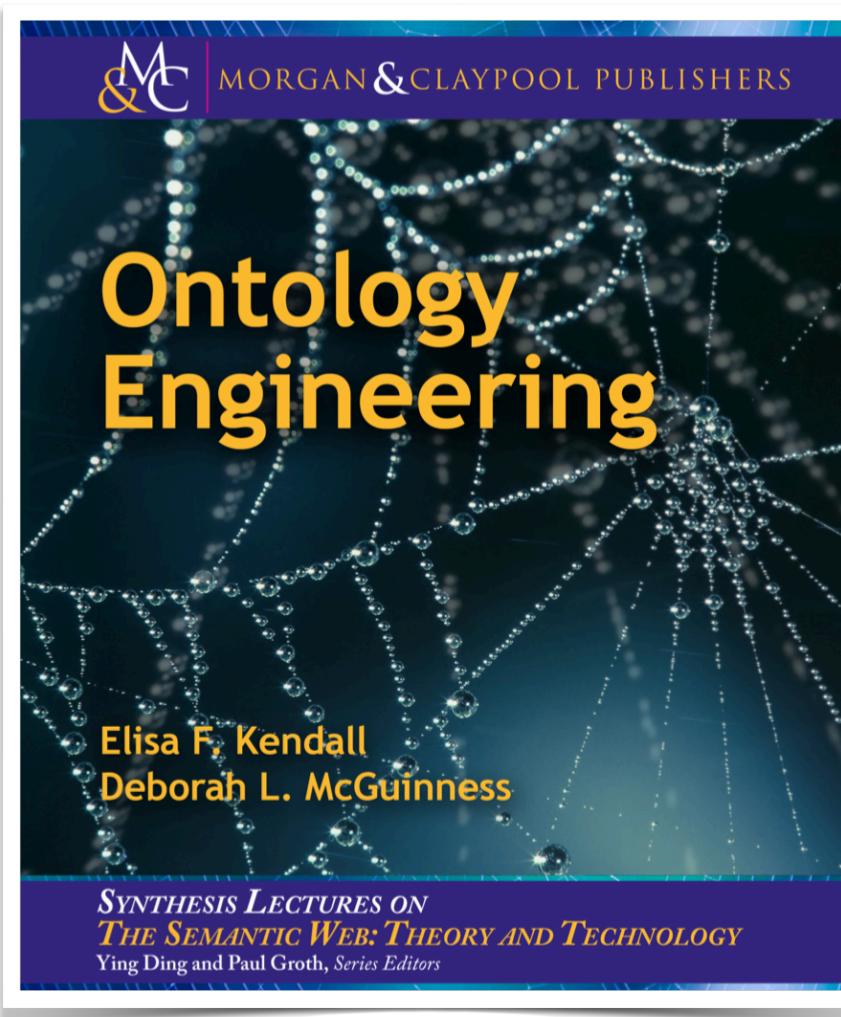


# Linked Data



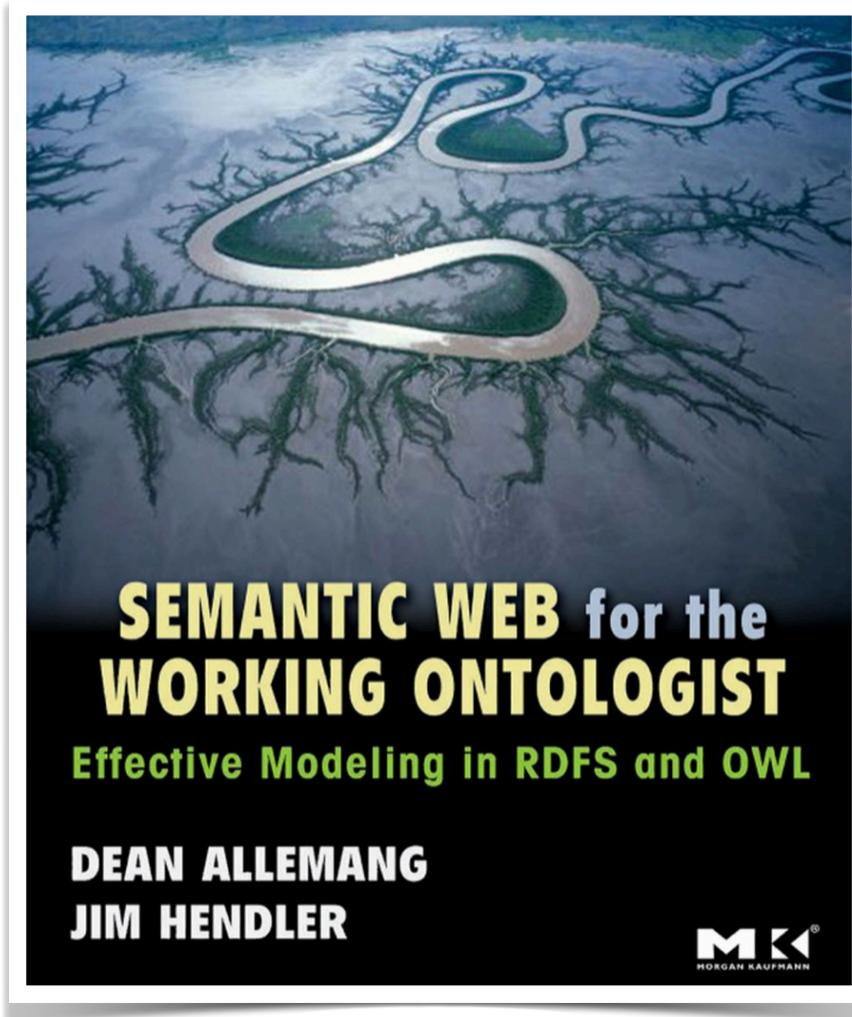


# Ontology Engineering



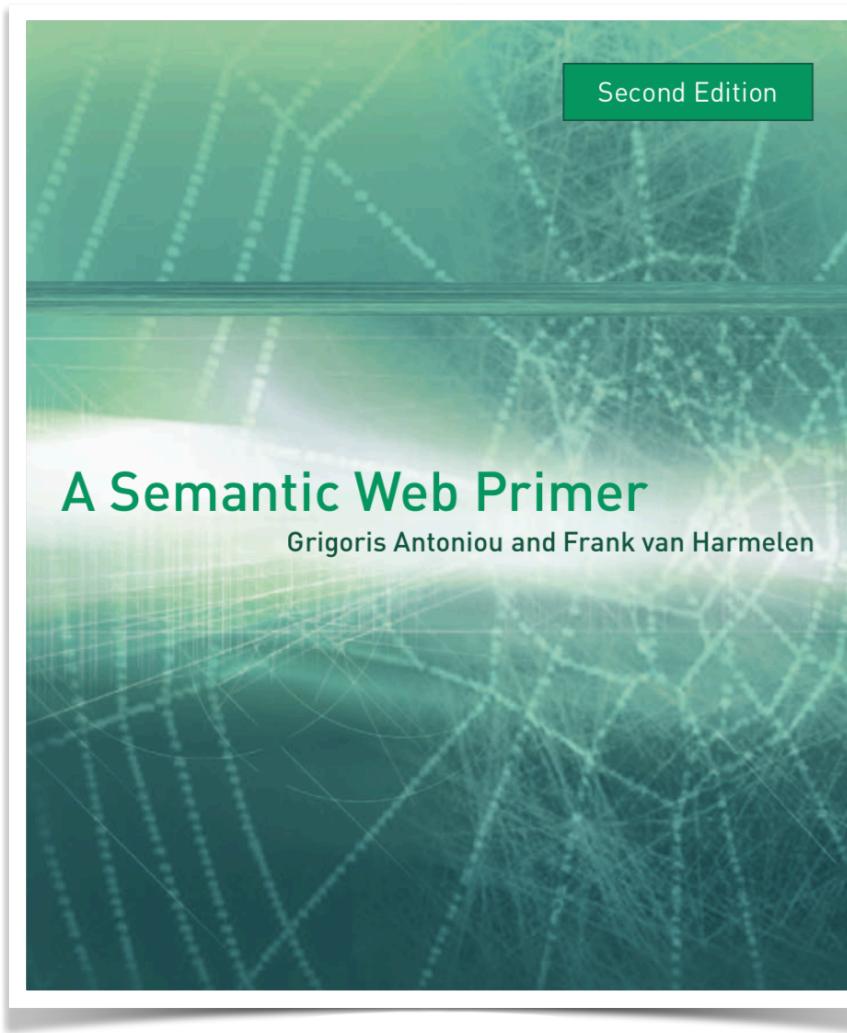


# Semantic Web for Working Ontologist





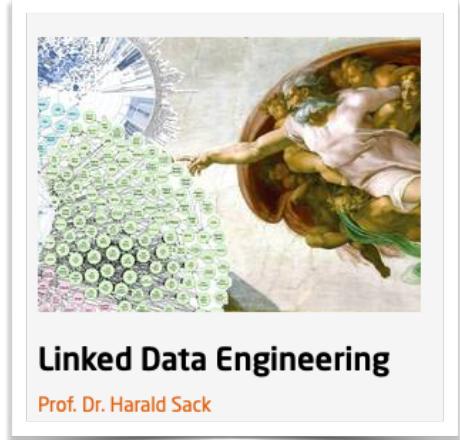
# Semantic Web Primer





# Other References:

- Lecture Material (Including slides) derived/taken from:
  - OPEN HPI MooC (<https://open.hpi.de>)
  - Knowledge Engineering with Semantic Web Technologies
  - Linked Data Engineering
    - by Prof Dr. Herald Sack
  - Semantic Web Course 2018 by Linkopings Universitet (<https://www.ida.liu.se/research/semanticweb/events/SemWebCourse2018/> )





# CS 520

## Knowledge Graphs

How should AI explicitly represent knowledge?

Department of Computer Science, Stanford University, Spring 2020

# Resources

- This class is a graduate level research seminar featuring prominent researchers and industry practitioners working on different aspects of knowledge graphs. It will showcase how latest research in AI, database systems and HCI is coming together in integrated intelligent systems centered around knowledge graphs.
- <https://web.stanford.edu/class/cs520/>