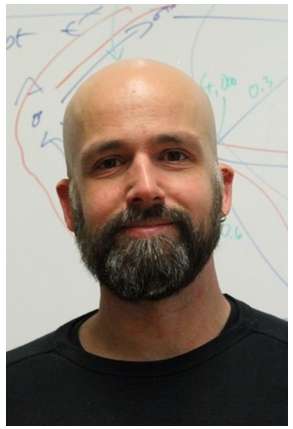
UNIVERSITÄT MANNHEIM

Knowledge Graphs Organization

Heiko Paulheim

Hello



- Prof. Dr. Heiko Paulheim
  - Chair for Data Science
- Research Interests:
  - Knowledge Graphs on the Web and their Applications
  - Data Quality and Data Cleaning on Knowledge Graphs
  - Using Knowledge Graphs in Data Mining
  - Societal Impact of Artificial Intelligence
- Room: B6 26, B0.22
- Consultation: Tuesdays 9-10
  - Please make an appointment with Bianca Lermer upfront
- Heiko will teach the lectures

Hello

- M.Sc. Sven Hertling
- Graduate Research Associate
- Research Interests:
  - Semantic Technologies / Semantic Web
  - Linked Data
  - Knowledge Graphs
- eMail: sven@informatik.uni-mannheim.de
- Sven will teach the exercises and co-supervise the projects.

Introduction and Course Outline

- Administration
- Introduction to Knowledge Graphs
- History of Knowledge Graphs
  - Vision of the Semantic Web
  - Building blocks of the Semantic Web
  - Technical foundations

Course Organization

- Lecture
  - Knowledge Graph standards and languages
  - Using public knowledge graphs
  - Creating knowledge graphs
- Exercise
  - Understand knowledge graphs and their principles, play with real data
- Project Work
  - teams of 3-4 students build a Knowledge Graph application
  - teams may choose their own data sets and tasks
    (in addition, we will propose some pointers for ideas)
  - write summary about project, present project results
  - **not graded, but mandatory**
- Final exam
  - **final grades are only based on written exam**

Course Organization

- Registration
  - you have registered via Portal2
  - you should have access to ILIAS
  - the course is fully booked with a waiting list
    - if you decide not to attend, please deregister in Portal2

- Important: course replacement
  - This course replaces IE 650 Semantic Web Technologies
  - You cannot get credits for both courses

Course Contents and Schedule

Week	Tuesday	Friday
12.09.2022	Lecture: Introduction	Exercise: Introduction
19.09.2022	Lecture: RDF	Exercise: RDF
26.09.2022	Lecture: RDFS	Exercise: RDFS
03.10.2022	Lecture: Linked Data, Semantic Web Programming	Exercise: Linked Data, Semantic Web Programming
10.10.2022	Lecture: SPARQL and other Query Paradigms	Exercise: SPARQL, Kick off Group Projects
17.10.2022	Lecture: Public Knowledge Graphs	Exercise: Public Knowledge Graphs
24.10.2022	Lecture: Labeled Property Graphs	Exercise: Labeled Property Graphs
31.12.2022	*Public holiday*	*No exercise*
07.11.2022	Lecture: OWL Part 1	Exercise: OWL Part 1
14.11.2022	Lecture: OWL Part 2	Exercise: OWL Part 2
21.11.2022	Lecture: Knowledge Modeling	Exercise: Knowledge Modeling
28.11.2022	Lecture: Data Quality and Interlinking	Exercise: Data Quality and Interlinking
05.12.2022	Project Presentations	

Deadlines

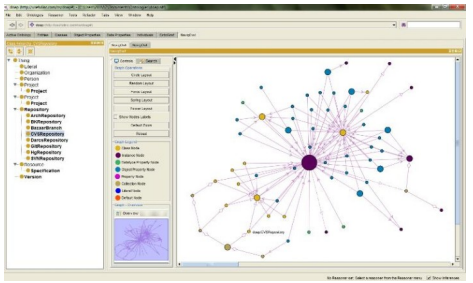
- Submission of project work proposal
  - Sunday, October 16th 23:59
- Submission of final project work report
  - Friday, December 9th, 23:59

Course Organization

- Lecture Webpage: Slides, Announcements, Web Links
  - hint: look at version tags of slides!
- Additional Material
  - ILIAS eLearning System, https://ilias.uni-mannheim.de/
- Time and Location
  - Lecture: Tuesday, 3.30 – 5.00, Room B6 30-32, E-F, room 209
  - Exercise: Friday, 12.00 - 13.30, Room B6 26, A1.04

Further Reading and Software

- Follow the links on the website
  - Most material is available online
- Programming environment
  - JENA framework (Java)
  - RDFlib (Python)
- Knowledge graph environment
  - Neo4j
- Ontology engineering environment
  - Protégé
  - http://protege.stanford.edu/



Warning

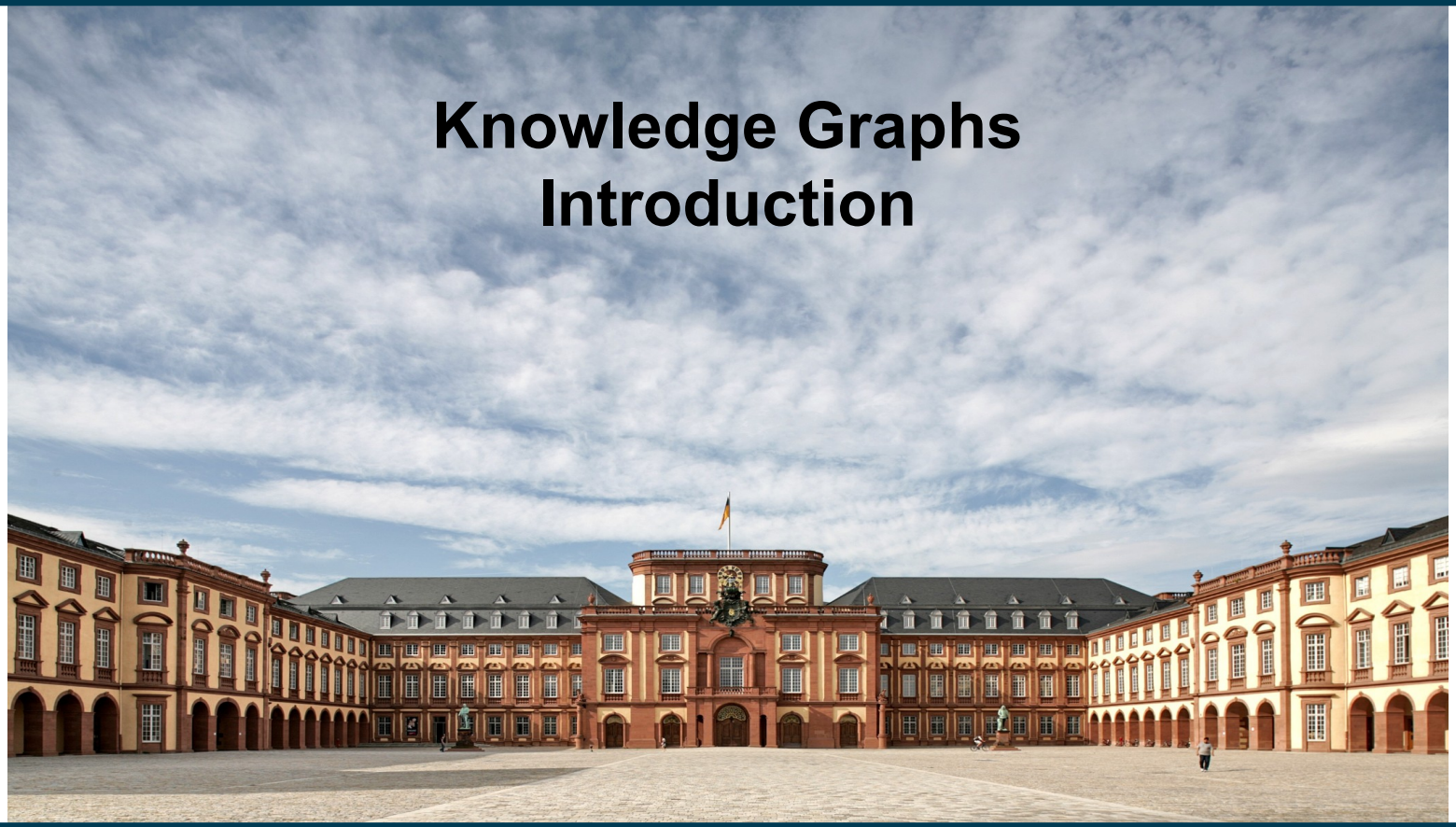
- This lecture contains
  - cartoons
  - Java and Python code
  - some digressions to philosophy

- Having said that:
  - have fun! :-)

Questions?

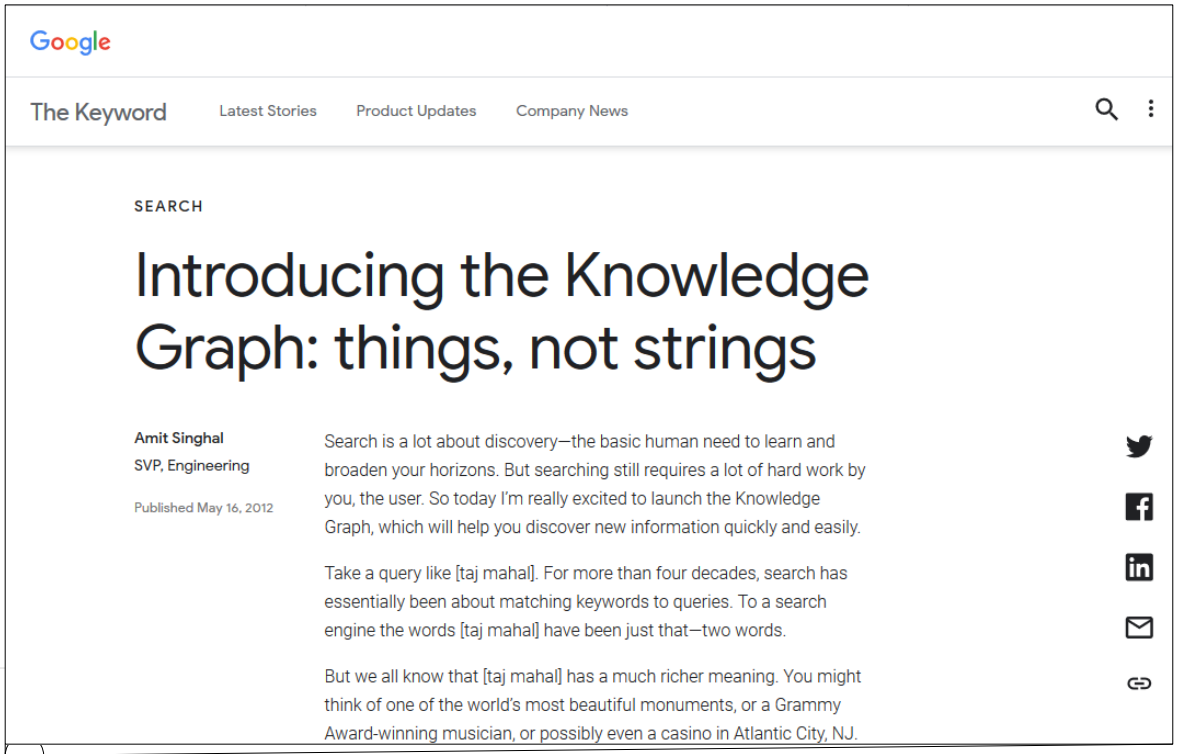
UNIVERSITÄT MANNHEIM

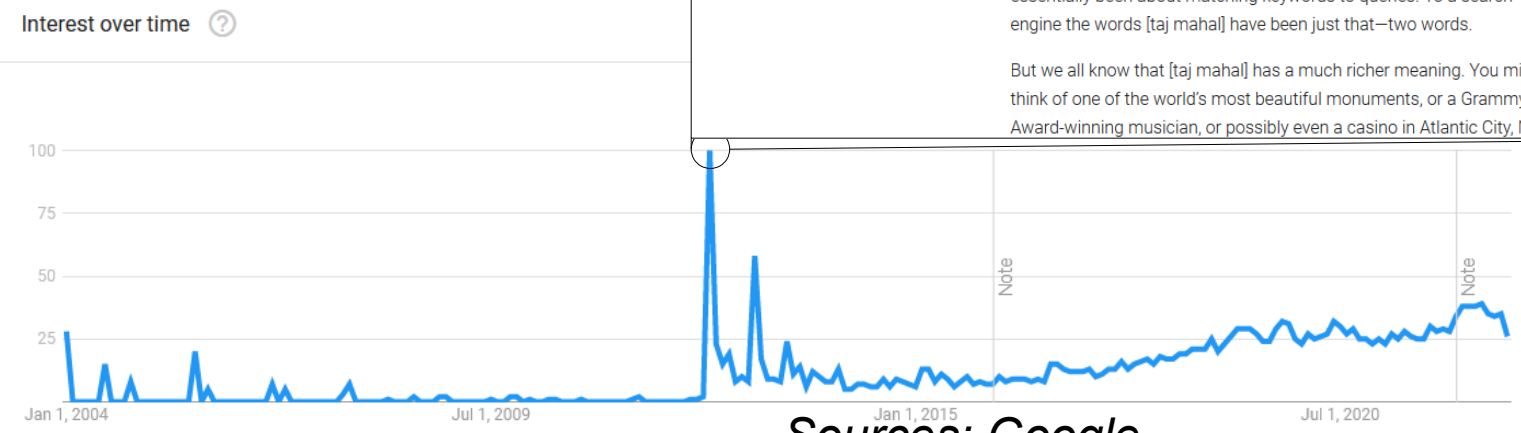
Knowledge Graphs
Introduction



Heiko Paulheim

The Birth of a Buzzword

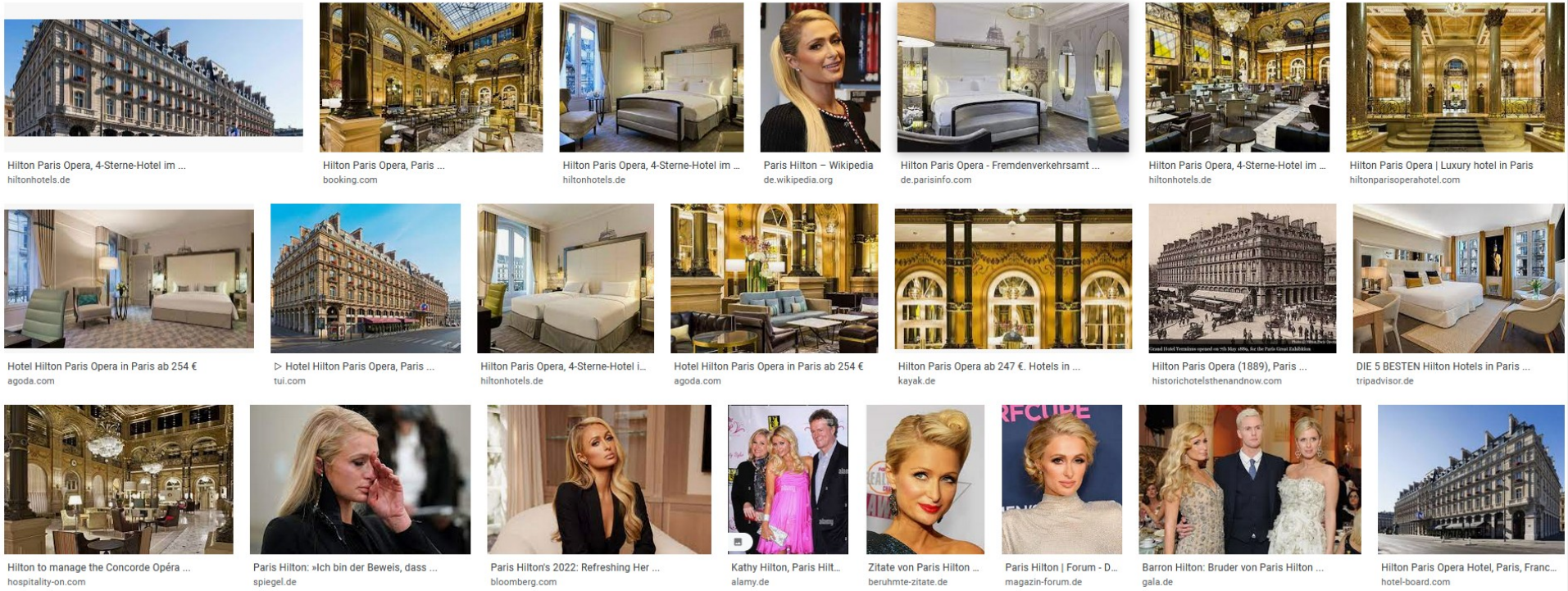




Sources: Google

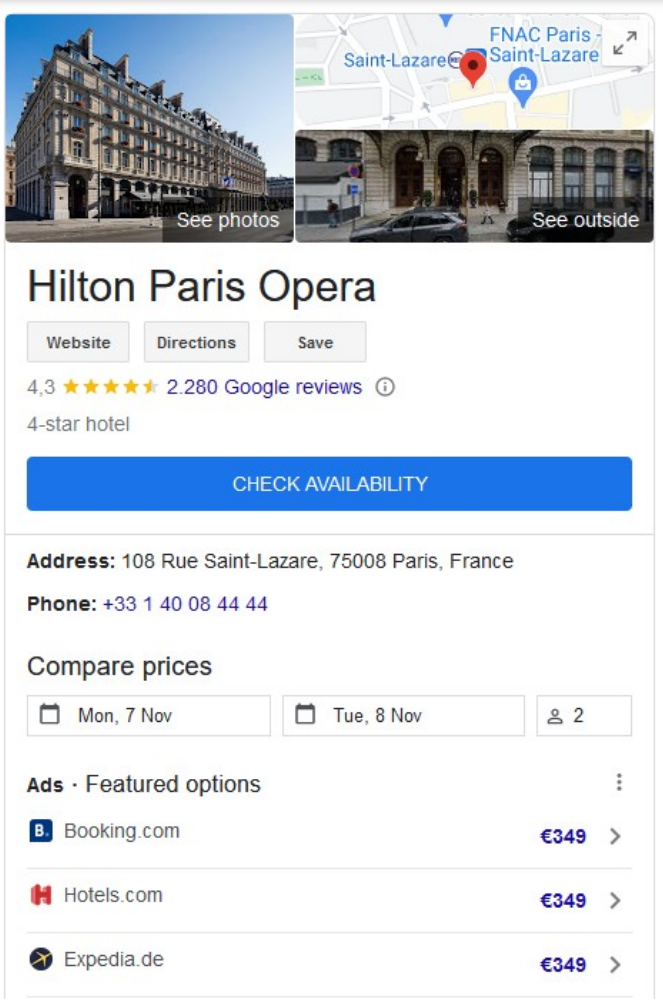
Idea of the Google Knowledge Graph

- Web search in the pre-knowledge graph age
  - Documents
  - Keywords (not: disambiguated entities)

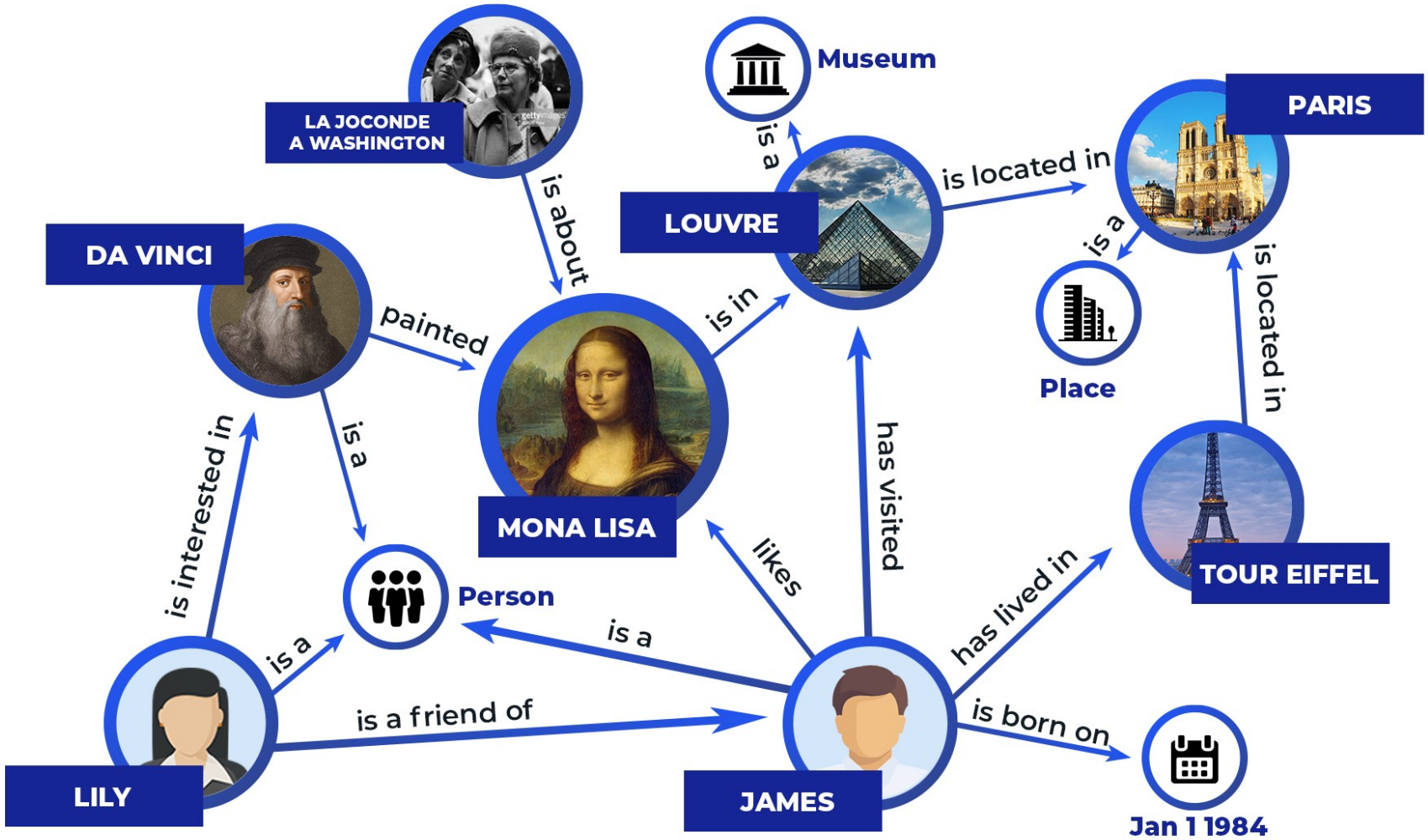


Idea of the Google Knowledge Graph

- Web search in the knowledge graph age
  - Backed by structured information
  - All entities are disambiguated
- Linked to other services
  - Ratings and reviews
  - Map information
  - External services (e.g., booking)
  - …



An Example for a Knowledge Graph



https://yashuseth.wordpress.com/2019/10/08/introduction-question-answering-knowledge-graphs-kgqa/

From Google to the World

- Documented list of companies using knowledge graphs
  - Courtesy of Frank van Harmelen, VU Amsterdam

Knowledge Graph Definitions

- Knowledge Graphs are a fairly new technology
  - Hence, there are few universally acclaimed definitions

- Some example definitions from the literature:
  - *Knowledge graphs could be envisaged as a **network of all kind things** which are **relevant to a specific domain or to an organization**. They are not limited to abstract concepts and relations but can also contain instances of things like documents and datasets.*
    (Blumauer, 2014)
  - *Knowledge graphs are **large networks of entities**, their semantic types, properties, and **relationships between entities**.*
    (Kroetsch and Weikum, 2016)

Ehrlinger and Wöß: Towards a Definition of Knowledge Graphs. 2016

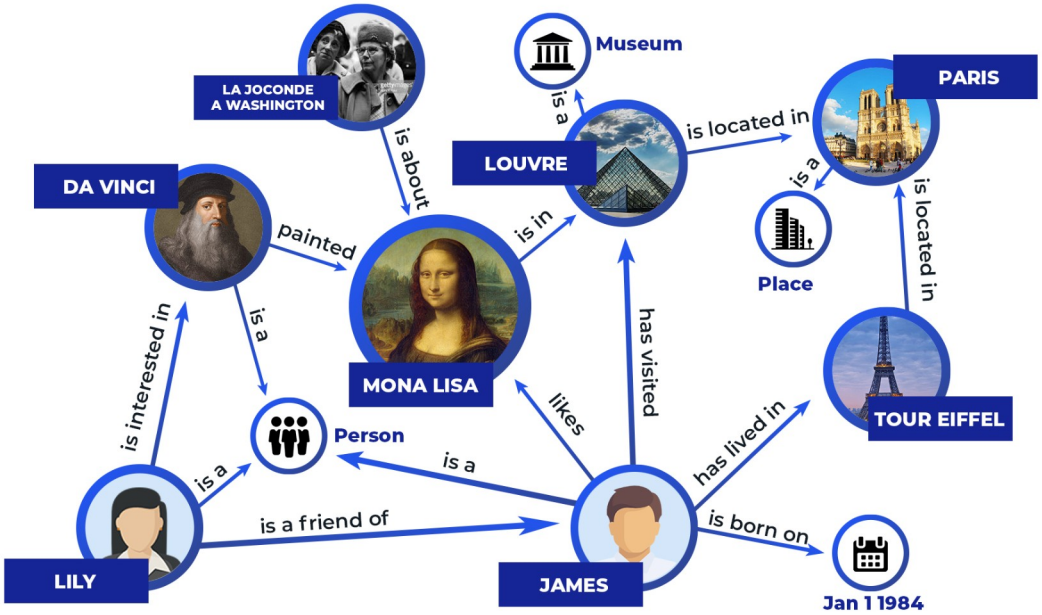
Knowledge Graph Definitions (ctd.)

- *[...] systems exist, [...], which use a variety of techniques to **extract new knowledge, in the form of facts**, from the web. These **facts are interrelated**, and hence, recently this extracted knowledge has been referred to as a knowledge graph.*
  (Pujara et al., 2013)
- *A Knowledge Graph (1) **mainly describes instances and their relations in a graph**, (2) defines possible classes and relations in a schema or ontology, (3) allows for **interlinking** arbitrary **entities with each other**, and (4) covers various domains.*
  (Paulheim, 2017)

Ehrlinger and Wöß: Towards a Definition of Knowledge Graphs. 2016

Knowledge Graph Definitions (ctd.)

- Common ground so far:
  - There are entities and relations that are connected and form a graph
  - There is a set of entity and relation *types*
    - those are often referred to as a *schema* or *ontology*
    - we will get back to this



Rewinding the Time Machine

- Google claim “things, not strings”
  - Entities instead of words in documents
  - Relations between entities explicitly modeled
  - Accessible to humans *and machines*
    - think: computers cannot read text

The Vision of the Semantic Web (2001)

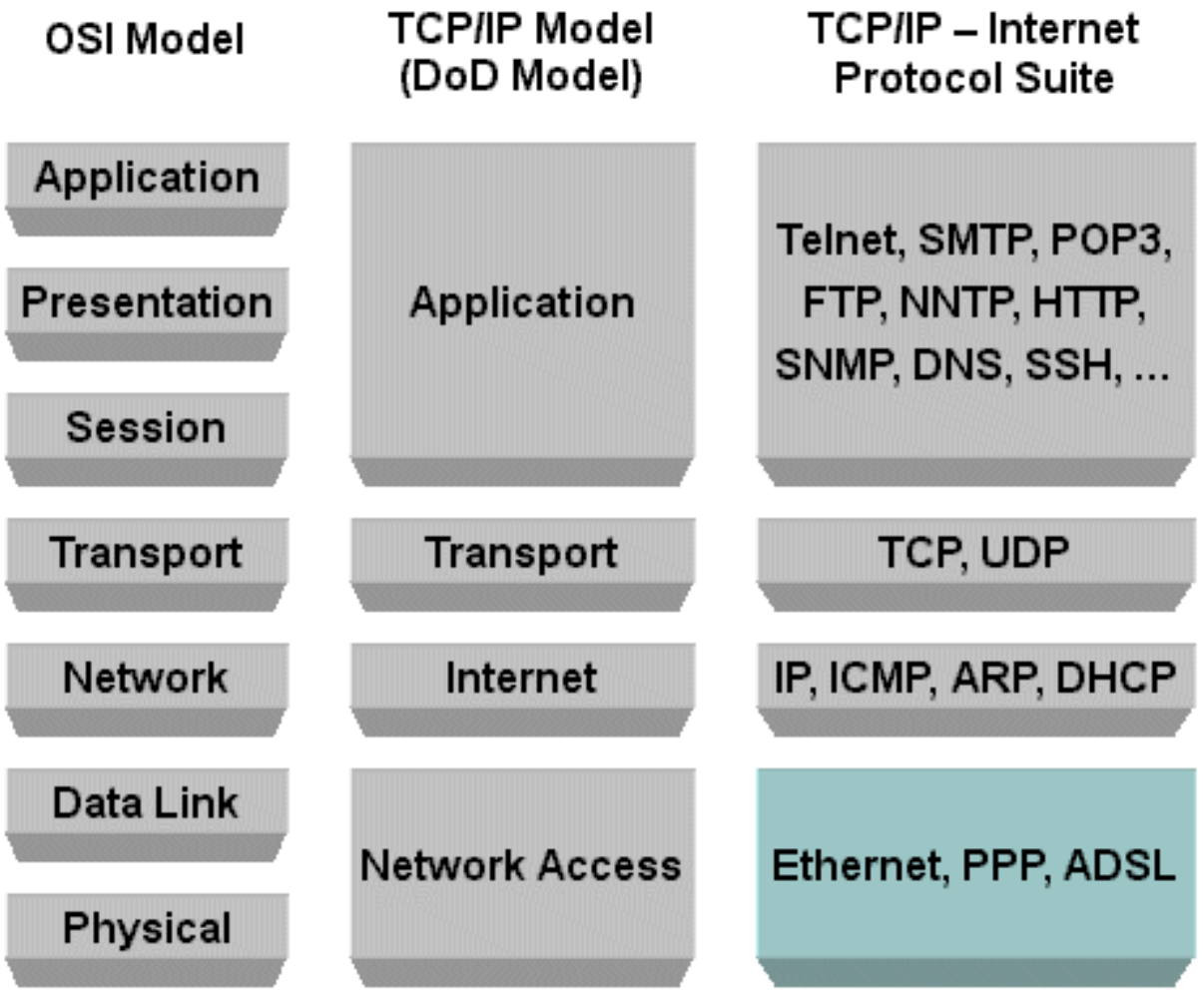
- 2001 article by Tim Berners-Lee, Jim Hendler, and Ora Lassila:

„The Web is the killer app of the Internet.

The Semantic Web is another killer app of that magnitude.“

Berners-Lee et al. (2001): *The Semantic Web.* In: Scientific American, Mai 2001.

Web vs. Internet?



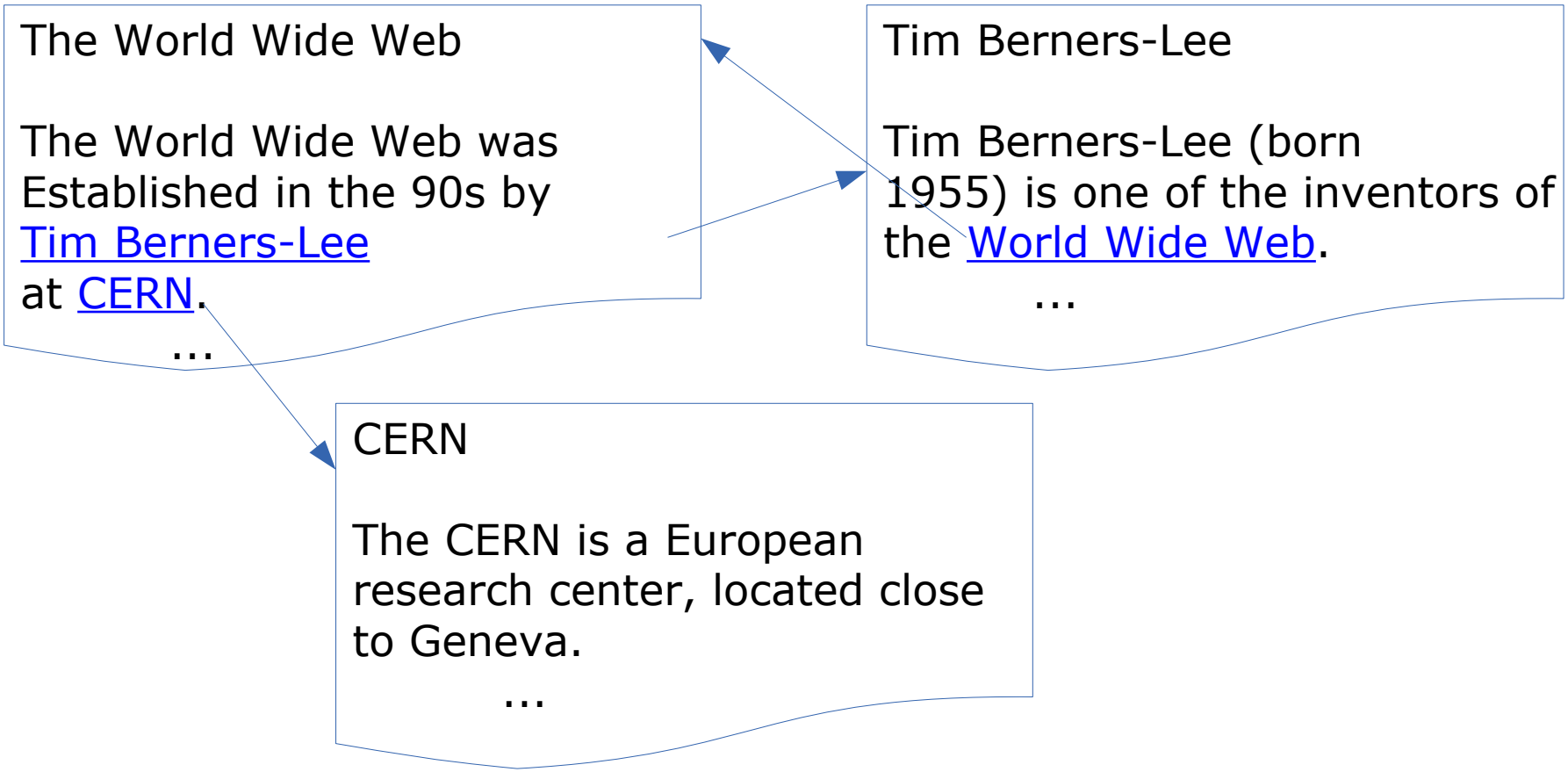
Chin-Shiuh Shieh (2000): *TCP/IP - Internet Protocol Suite and Ethernet.* http://bit.kuas.edu.tw/~csshieh/teach/np/tcpip/index.html

The “Classic” Web

- a.k.a. “World Wide Web”, “Document Web”
- Uses HTTP protocol and URLs
- HTML as a markup language
  - plus CSS, JavaScript, …
  - plus a few other, more or less standardized formats (GIF, JPEG, Flash, ...)
- Browser as a universal client
- Information is accessible to humans, but not to machines

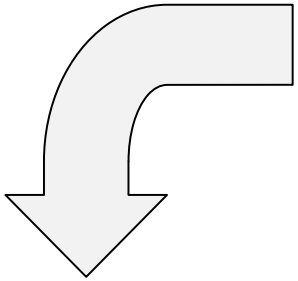
The “Classic” Web

- Hypertext: linked documents



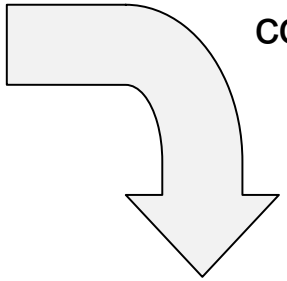
The “Classic” Web

In the eyes of a human



```
<html>
  …
  <b>Dr. Mark Smith</b>
  <i>Physician</i>
  Main St. 14
  Smalltown
  Mon-Fri 9-11 am
  Wed 3-6 pm
  …
</html>
```

in the eyes of a computer



Dr. Mark Smith
Physician
Main St. 14
Smalltown
Mon-Fri 9-11 am
Wed 3-6 pm

Print in bold: „hmf298hmmhudsa“
Print in italics: „mj2i9ji0“
Print normal: „fdsah
02hfadsh0um2m0adsmf0ihm
asdfjköfdsa298ndsfmij32mio
lk2mjpoimjiofdpmsajiomjm“

Searching for Information on the Web

Full text search by keywords (e.g., Google):

- „Mark Smith“
- „Physician in Smalltown“
- „Doctor in Smalltown“
- „Doctor in Smalltown with opening hours on Wednesday afternoon“
- „Somebody in Smalltown who can fix a broken leg“

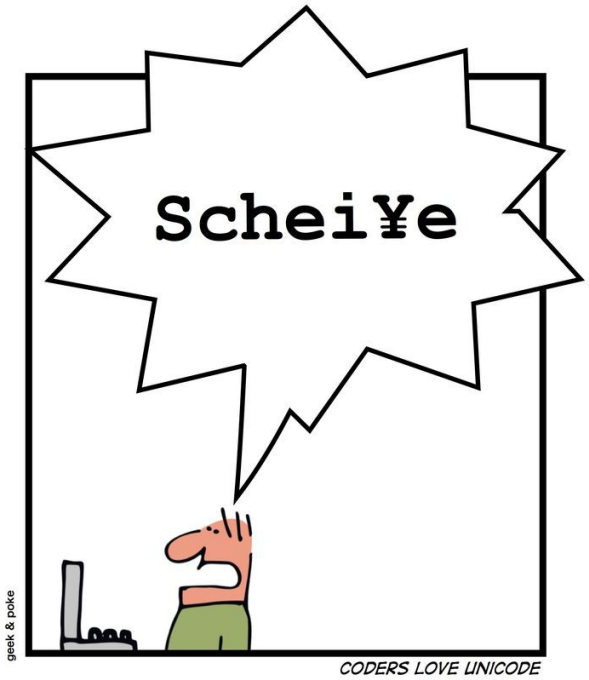
```
<html>
  …
  <b>Dr. Mark Smith</b>
  <i>Physician</i>
  Main St. 14
  Smalltown
  Mon-Fri 9-11 am
  Wed 3-6 pm
  …
</html>
```

→ “classic” Web is too inflexible for useful search

→ hard to use for intelligent agents

Problems of the “Classic” Web

- Finding information
  - Keyword based search instead of natural language questions
  - Different natural languages
  - Synonyms, homonyms and polysemous words
  - Ambiguity of natural language
- Processing information
  - Formats and encodings
- Making use of information
  - Distributed across pages
  - e.g., a book's author on the publishers site, address on his/her personal page



http://geekandpoke.typepad.com/geekandpoke/2011/08/coders-love-unicode.html

Homonyms and Polysemous Words

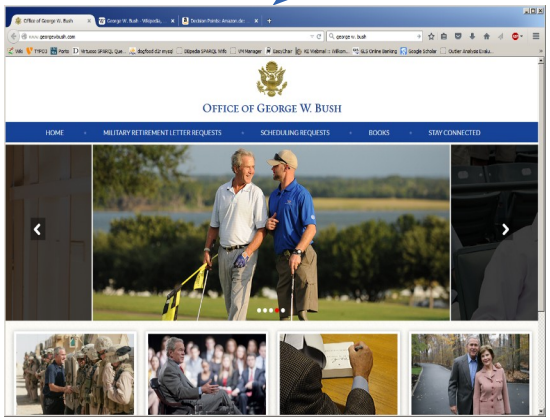
Untyped Links

Bush Era Law Could Get You 20 Years in Prison For Clearing Your Browser History

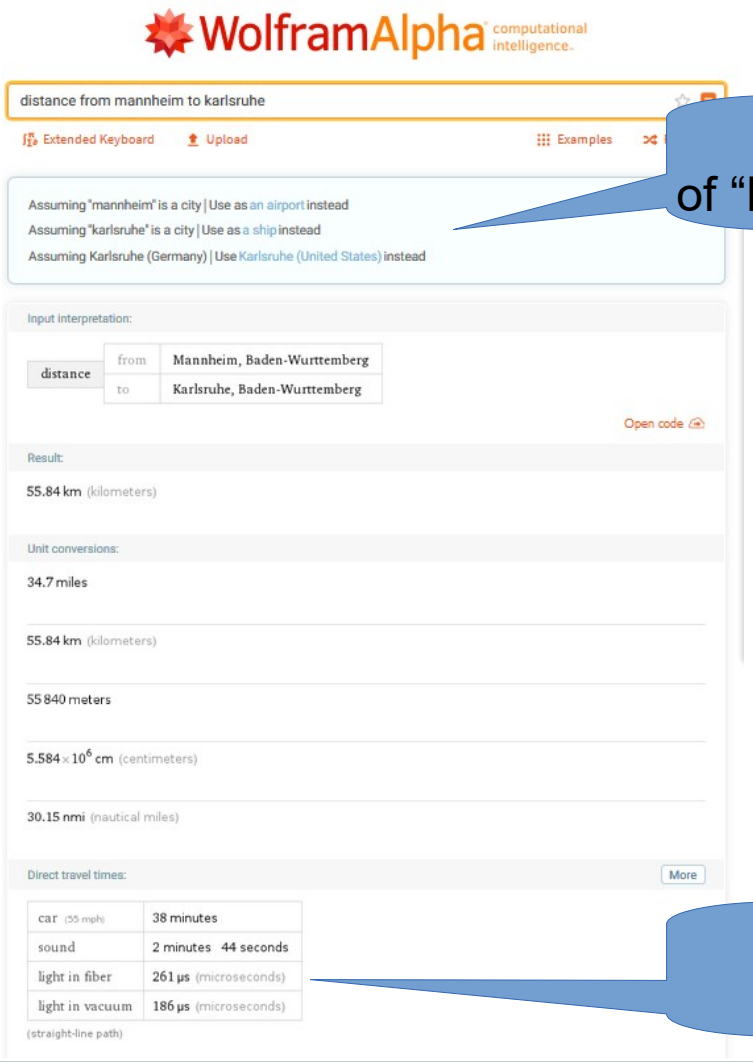
?

?

?



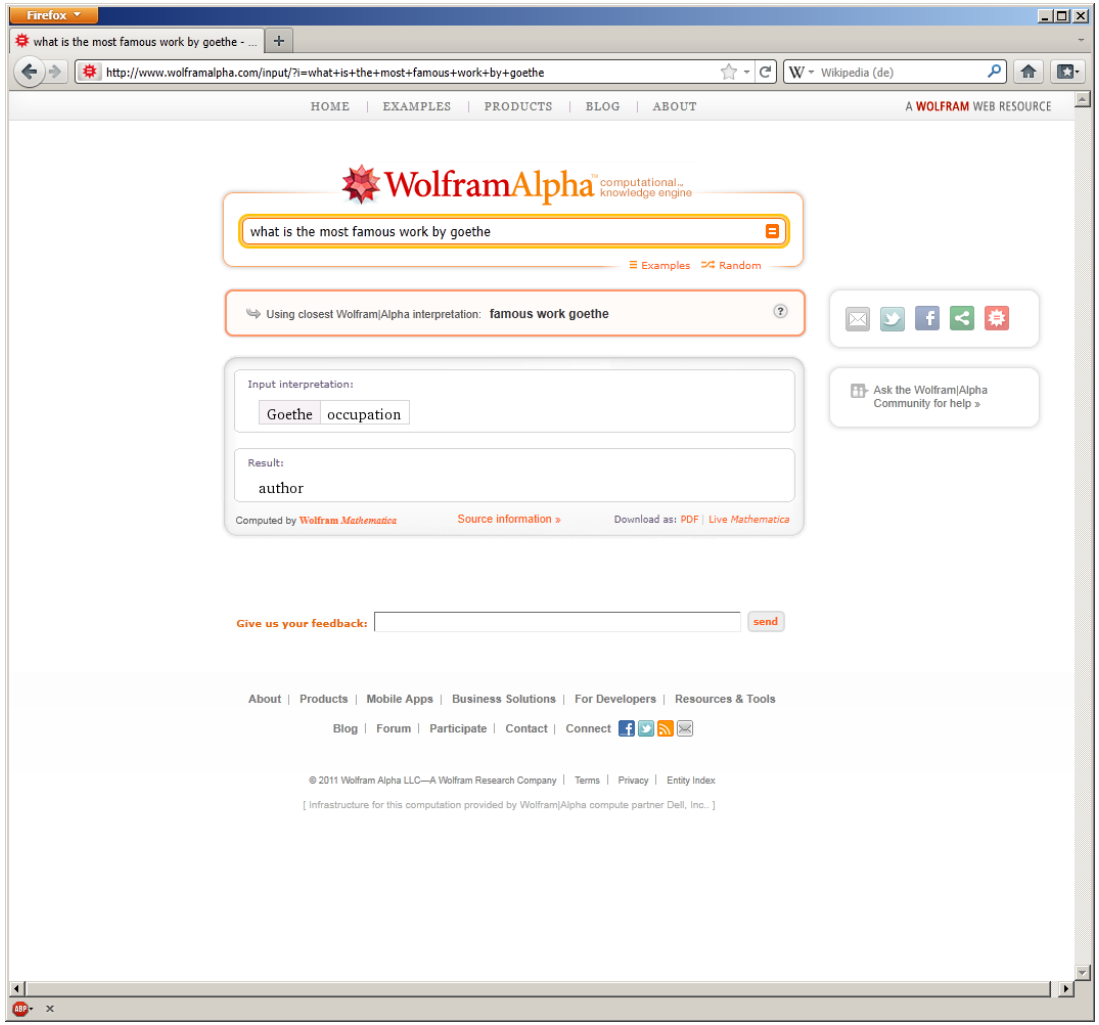
Example: Wolfram Alpha



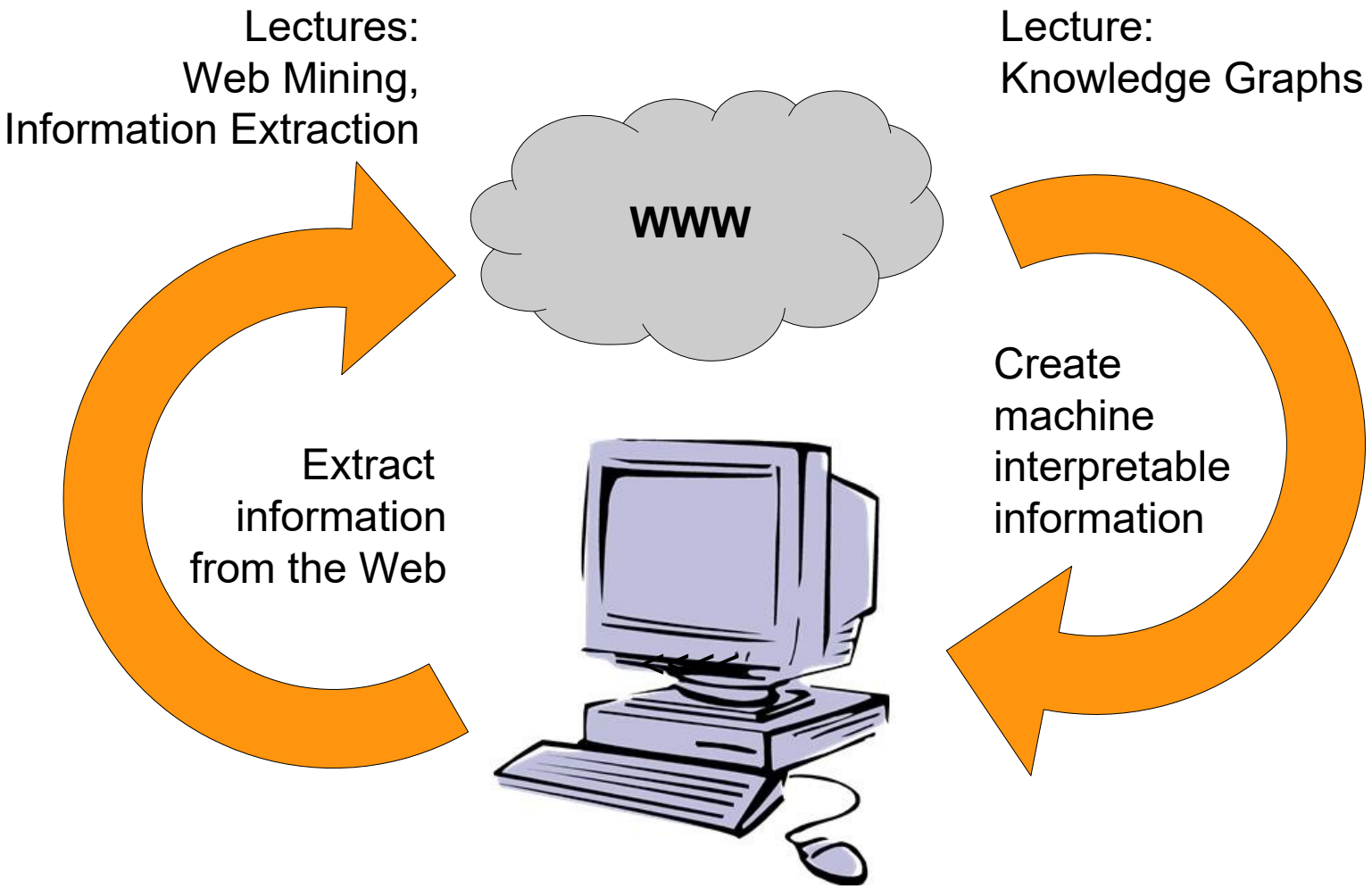
Multiple interpretations of “Mannheim” and “Karlsruhe”

Multiple interpretations of “distance”

Example: Wolfram Alpha



Solutions

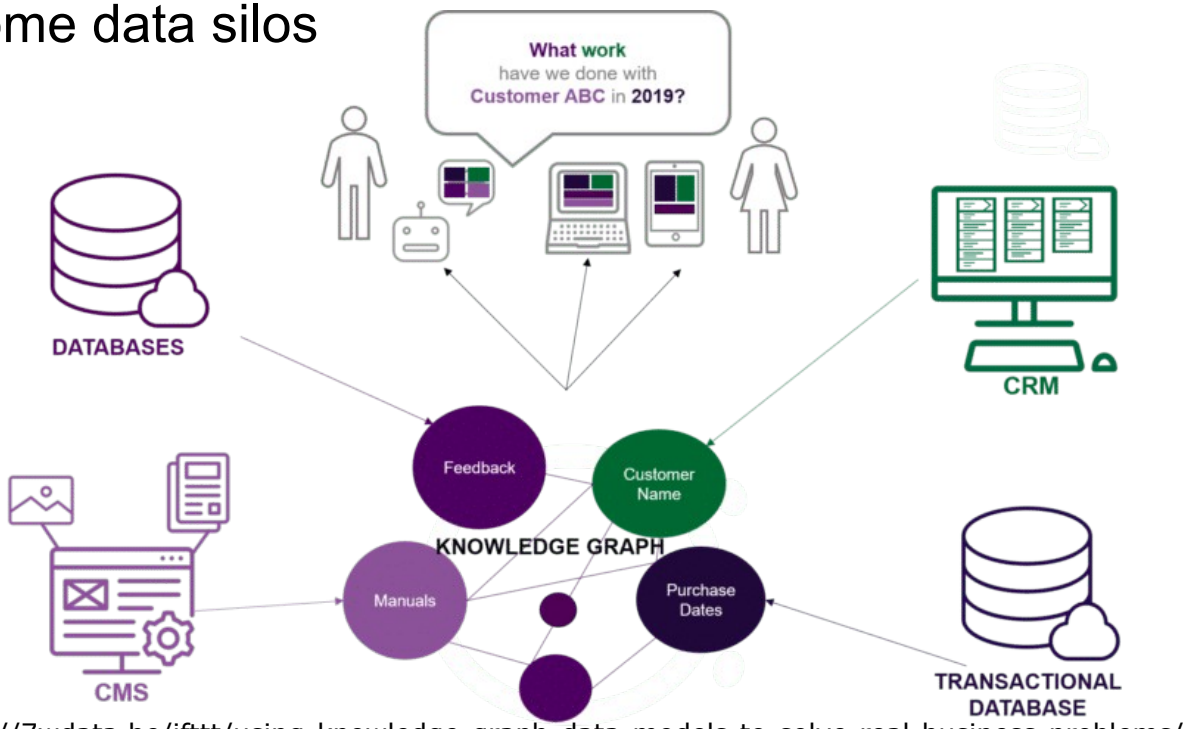

Lectures:
Web Mining,
Information Extraction
Lecture:
Knowledge Graphs
WWW
Extract
information
from the Web
Create
machine
interpretable
information

Semantic Web Vision

- Provide information in machine interpretable form
- Make (semantic) links between (data) documents us
- Facilitate useful (!) complex queries
- Allow logical reasoning

(Enterprise) Knowledge Graph Vision

- Integrate data from different sources
- Make connections between entities in those sources
- Facilitate cross data source queries
- Overcome data silos



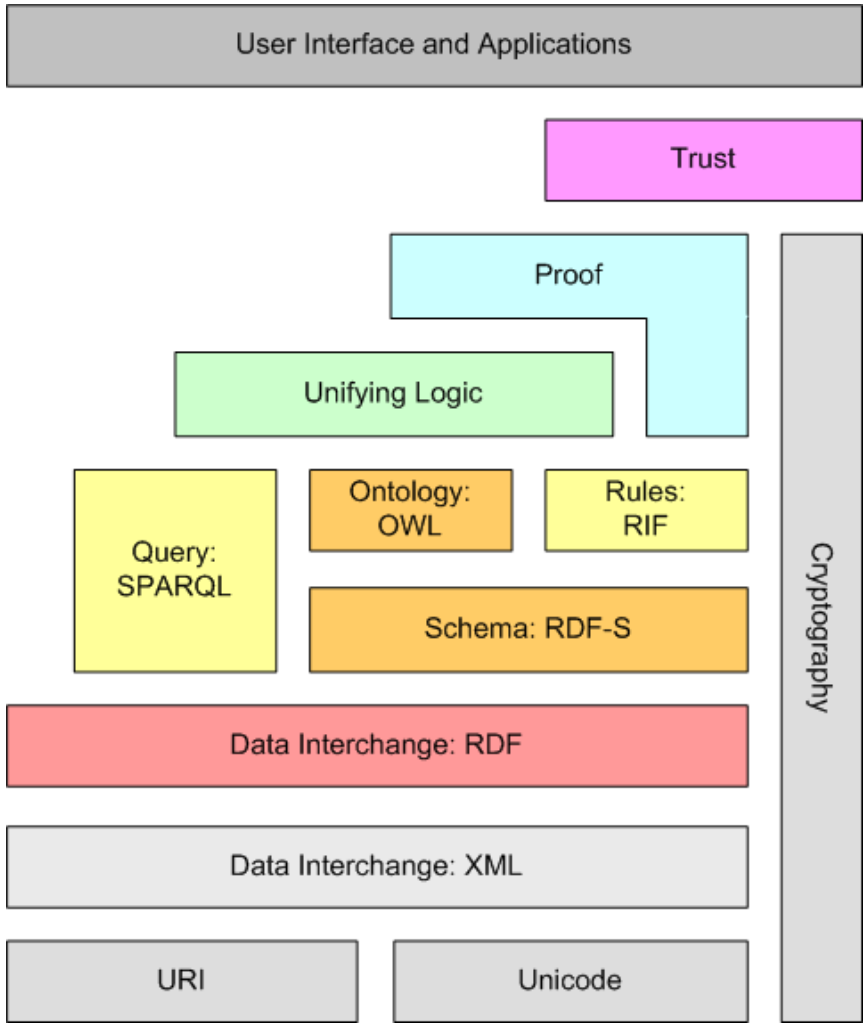
https://7wdata.be/ifttt/using-knowledge-graph-data-models-to-solve-real-business-problems/

Semantic Web – Architecture

here be dragons...

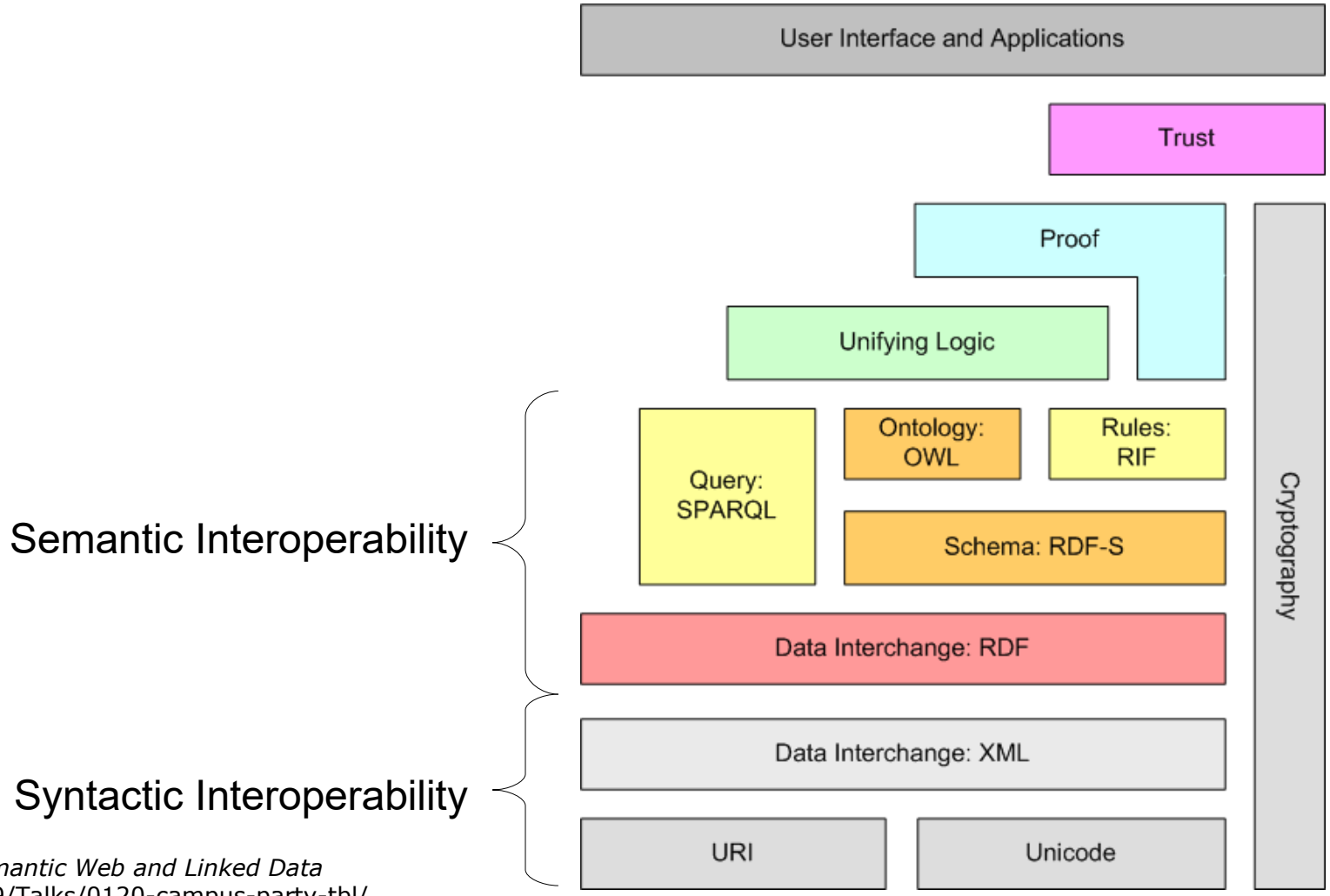
Knowledge Graph Technologies (This lecture)

Technical Foundations



Berners-Lee (2009): *Semantic Web and Linked Data*
http://www.w3.org/2009/Talks/0120-campus-party-tbl/

Data Interoperability with Knowledge Graphs



Berners-Lee (2009): *Semantic Web and Linked Data*
http://www.w3.org/2009/Talks/0120-campus-party-tbl/

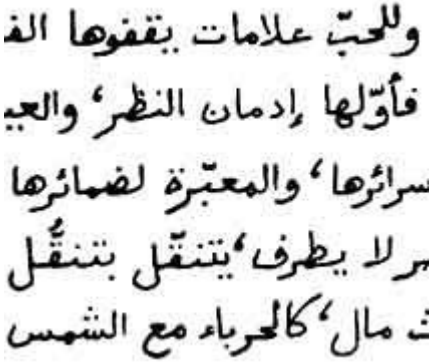
Syntactic Interoperability: Character Sets

- ASCII („American Standard Code for Information Interchange“)
  ISO 646 (1963), 127 characters, 95 of which are printable:

```
 !"#$%&'()*+,-./0123456789:;<=>?
@ABCDEFGHIJKLMNOPQRSTUVWXYZ[\]^_
`abcdefghijklmnopqrstuvwxyz{|}~
```

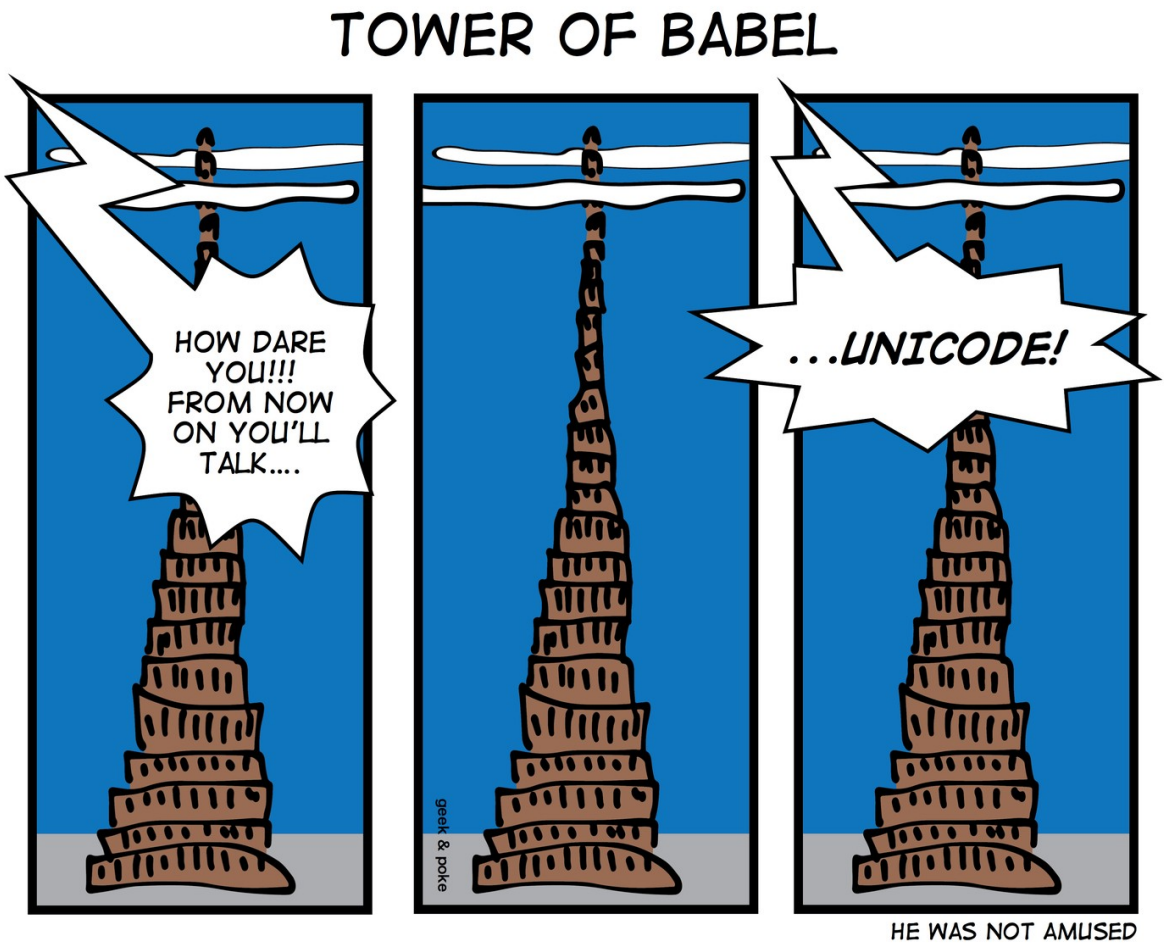
- Extension to 8 Bit: ISO 8859-1 to -16 (1998)
  - covers major European languages
  - most well known: 8859-1 („Latin-1“)

- The Web, however, speaks many more languages...



我爱中国
国中爱我

Syntactic Interoperability: Multilinguality

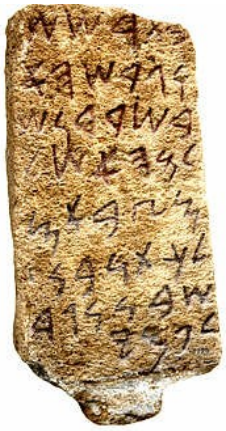


http://geek-and-poke.com/geekandpoke/2013/8/29/when-it-all-began

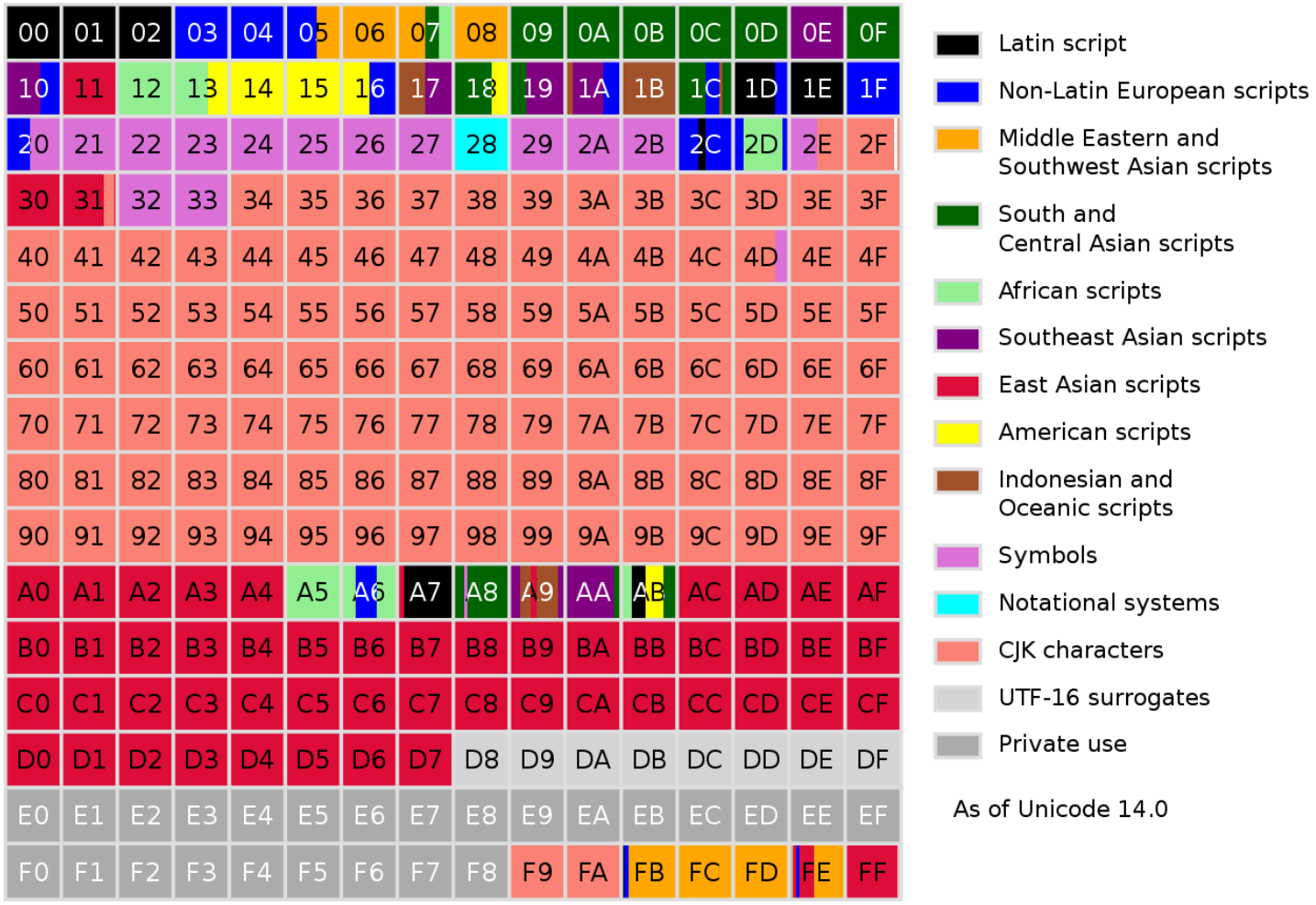
Syntactic Interoperability: Unicode

- ISO 10646
  - first version 1991 (Europe, Near East, India)
  - Unicode 14.0 (September 2021)
  - defines ~144,000 characters
  - covers even very exotic languages
  - Plus: currency symbols, emojis, sign language, music notation...

Klingon is still missing!!!



Syntactic Interoperability: Unicode



Source: Wikimedia Commons

Information Representation in XML

XML (eXtensible Markup Language)

- A W3C standard since 1998
- Universal format for data exchange and integration


```
<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

XML: Basic Concepts

- Tags (arbitrarily definable):
  - Form pairs:

    <physician> … </physician>
  - ...or empty element tags

    <young />

- Attributes:

  <physician location="Smalltown">

- Tags are nested (with *exactly one* root element):

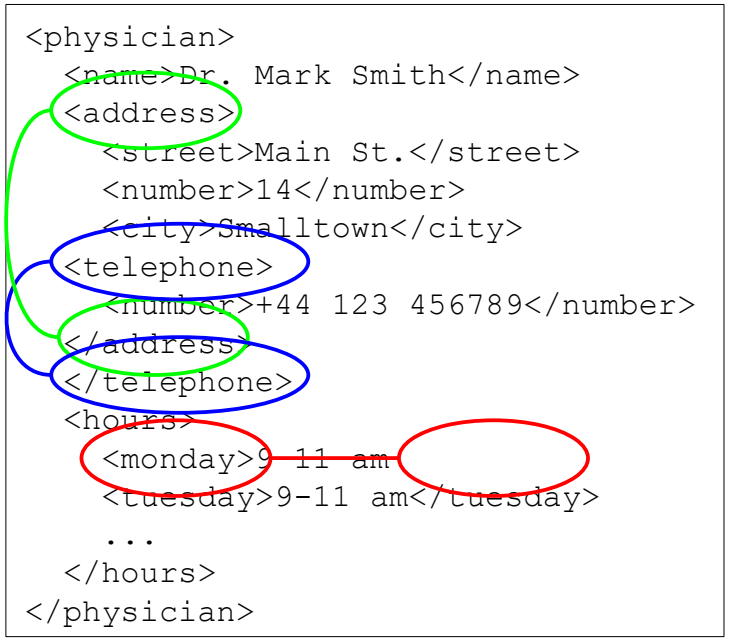
  <physician>

    <address> … </address>

  </physician>

XML: Well-formed Documents

```
<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```



HTML and XML

- HTML documents look like XML documents
  - ...but they are usually not well-formed!

```
<p>Look at this!<img src=smiley.gif> <br>
```

- XHTML: HTML as well-formed XML documents
- A W3C standard since 2000

```
<p>Look at this!<img src="smiley.gif"/> <br/> </p>
```

XPath: Accessing Information in XML

- Query language for XML
- A W3C standard since 1999 (Version 2.0: 2010)

```
/physician[name='Dr. Mark Smith']/telephone/number
```

```
<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

Namespaces in XML

- Elements with the same name can occur in different places
  - ...but the contents and semantics may differ
- How can we tell them apart?

```
<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

Namespaces in XML

- Namespace definition using prefixes (Notation: `prefix:name`)
- Each namespace itself is a URI
- Default namespaces may be defined

```
<physician xmlns      ="http://www.med.com/physician"
           xmlns:addr="http://www.med.com/addr">
  <name>Dr. Mark Smith</name>
  <addr:address>
    <addr:street>Main St.</addr:street>
    <addr:number>14</addr:number>
    <addr:city>Smalltown</addr:city>
  </addr:address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

XML: Document Type Definition (DTD)

- Defines valid elements for a class of XML documents
  - Names
  - allowed attributes
  - allowed nested child elements

- DTD is a part of the W3C's XML specification

- XML documents matching a DTD are called “valid”

XML: Document Type Definition (DTD)

```
<!DOCTYPE physician [

<!ELEMENT physician (
  name,
  address*,
  telephone?,
  fax?,
  hours)>

<!ELEMENT address (
  street,
  number,
  city)>

<!ELEMENT street (#PCDATA)>

  ...

]>
```

```
<!DOCTYPE physician SYSTEM
  "physician.dtd">

<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

XML: Document Type Definition (DTD)

- Definition of child elements and their order

```
<!ELEMENT address(street,no,line*,zip,city,state?)>
```

  - ?, + and * mark optional and possible multiple elements

- Definition of attribute lists

```
<!ATTLIST person title CDATA>
```

  - Allowed modifiers: #REQUIRED, #FIXED, #IMPLIED, "..."
  - Enumerating allowed values: (dr|prof)

- Definition of entities:

```
<!ENTITY sw "Semantic Web">
```

  - May be used as shortcuts in the XML document: `&sw;`

XML Schema

- W3C-Standard (since 2004)
- XML schemas are XML files themselves

- More flexible than DTDs:
  - Minimum and maximum number of elements
  - Combinations of elements (either/or, combinations w/out fixed order, …)
  - Data types (Numbers, dates, …), own types may be defined
  - Support for namespaces
  - Possibility to create modular schemas

XML Schema

```
<xs:schema elementFormDefault="qualified"
xmlns:xs="http://www.w3.org/2001/XMLSchema">

  <xs:element name="physician">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="name"
         type="xs:string">
        <xs:element name="address">
          <xs:complexType>
            <xs:sequence>
              <xs:element name="street"
               type="xs:string">
               ...
            </xs:sequence>
          </xs:complexType>
        </xs:element>
        ...
      </xs:sequence>
    </xs:complexType>
  </xs:element>
</xs:schema>
```

```
<physician xmlns:xsi=
"http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation=
"physician.xsd">
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

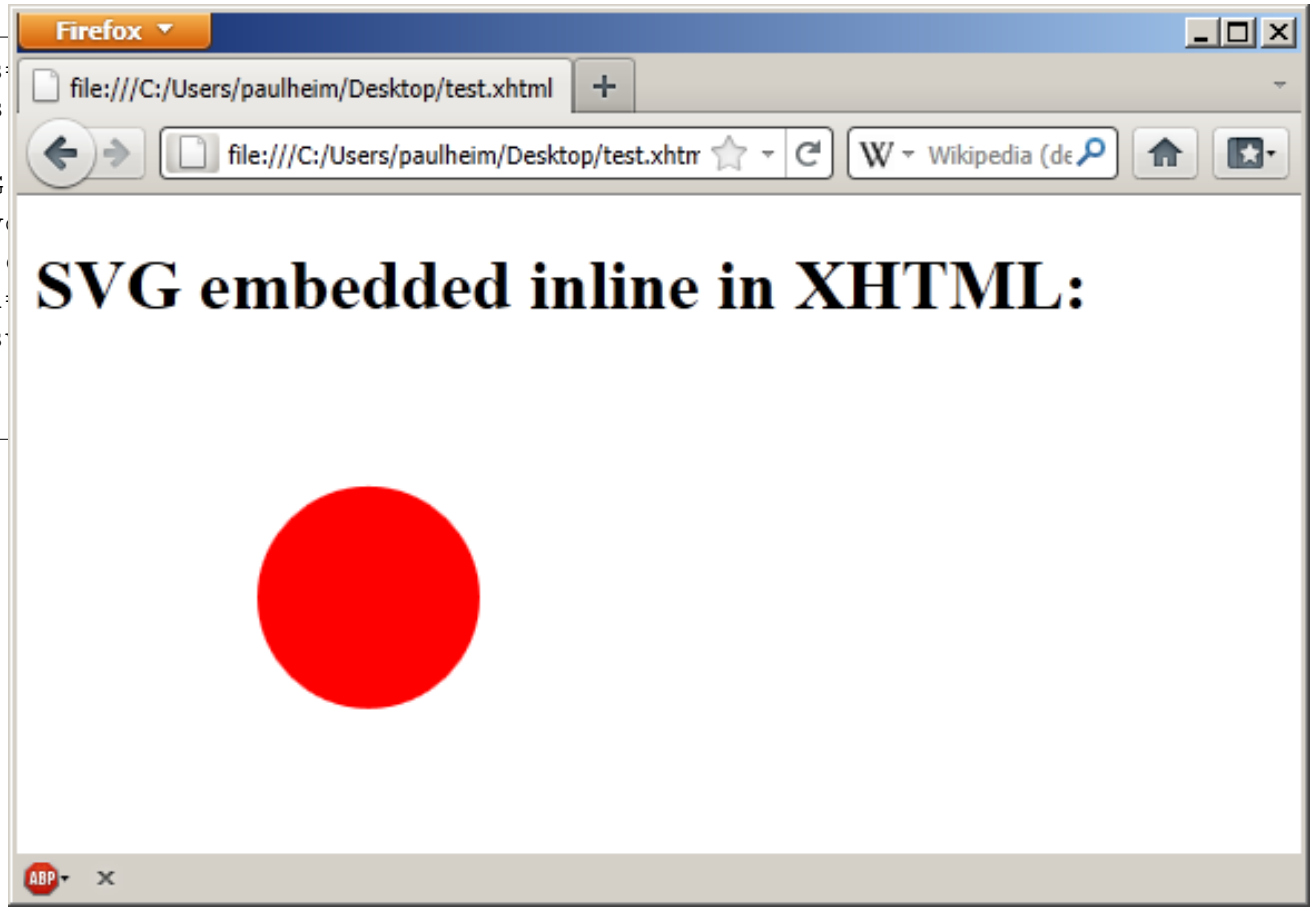
XML Schema – Modular Schemas

```
<xs:schema elementFormDefault="qualified"
xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:addr="http://www.address.com/">

  <xs:import
   namespace="http://www.address.com/"
   schemaLocation="address.xsd"/>
  <xs:element name="physician">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="name"
         type="xs:string">
        <xs:element ref="addr:address" />
        ...
      </xs:sequence>
    </xs:complexType>
  </xs:element>
</xs:schema>
```

```
<xs:schema elementFormDefault="qualified"
xmlns:xs="http://www.w3.org/2001/XMLSchema">

  <xs:element name="address">
     <xs:complexType>
        <xs:sequence>
           <xs:element name="street"
            type="xs:string">
            ...
         </xs:sequence>
      </xs:complexType>
   </xs:element>
</xs:schema>
```

Example: Modular Schemas in XHTML

```
<html xmlns=
      xmlns
  <body>
    <h1>SVG
    <svg:sv
      <svg:
       fill
    </svg:s
  </body>
</html>
```



https://developer.mozilla.org/En/SVG:Namespaces_Crash_Course

So, what does a DTD/Schema Define?

- Syntax – σύνταξις („together“ + „order“)
  - Which elements are there?
  - How are they arranged?
  - Which combinations are allowed?

- ...as opposed to: Semantics - σημαίνειν („denote“)
  - How to interpret the contents of an element?
  - What is their relation?

Syntax and Semantics: The Linguists' View

- Syntax: how are correct sentences formed?

  „This sentence no verb.“

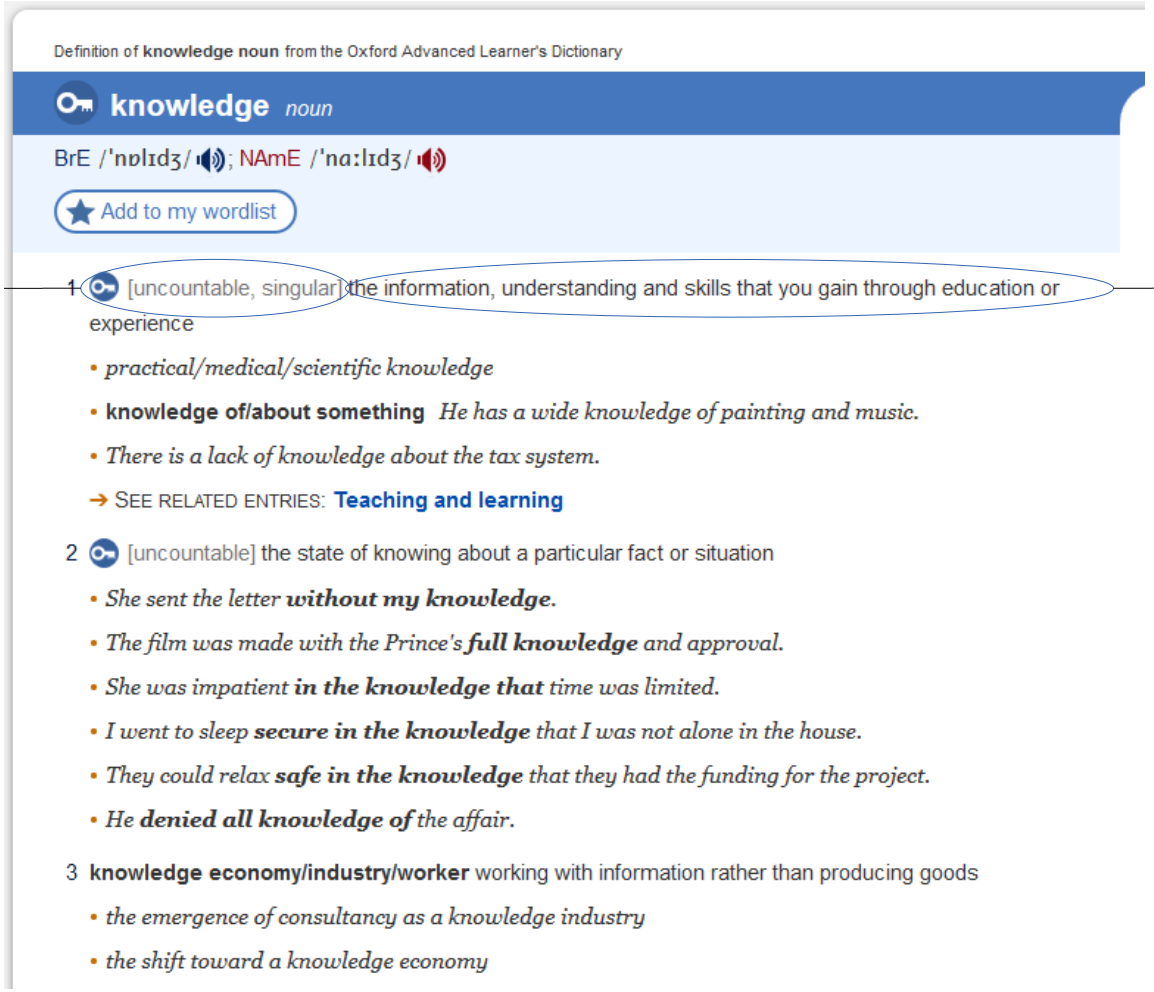
  „The dreaming lamp ~~give~~ gives a freshly cut ~~juices~~ juice to the ~~tire~~ tired sink.

- Semantics: what does a word and sentence *mean*?

- Notes
  - syntactic correctness does not guarantee semantic interpretability
  - semantic interpretability does not require syntactic correctness (for humans)

Syntax and Semantics: The Linguists' View

syntax



Definition of **knowledge noun** from the Oxford Advanced Learner's Dictionary

knowledge *noun*

BrE /ˈnɒlɪdʒ/; NAmE /ˈnɑːlɪdʒ/

Add to my wordlist

1 [uncountable, singular] the information, understanding and skills that you gain through education or experience

- *practical/medical/scientific knowledge*
- **knowledge of/about something** *He has a wide knowledge of painting and music.*
- *There is a lack of knowledge about the tax system.*

→ SEE RELATED ENTRIES: **Teaching and learning**

2 [uncountable] the state of knowing about a particular fact or situation

- *She sent the letter* ***without my knowledge****.*
- *The film was made with the Prince's* ***full knowledge*** *and approval.*
- *She was impatient* ***in the knowledge that*** *time was limited.*
- *I went to sleep* ***secure in the knowledge*** *that I was not alone in the house.*
- *They could relax* ***safe in the knowledge*** *that they had the funding for the project.*
- *He* ***denied all knowledge of*** *the affair.*

3 **knowledge economy/industry/worker** working with information rather than producing goods

- *the emergence of consultancy as a knowledge industry*
- *the shift toward a knowledge economy*

semantics

So, what does a DTD/Schema Define?

Employee catalog
of the hospital

```
<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

(probably)
the private address

?
=

Yellow Pages

```
<physician>
  <name>Dr. Mark Smith</name>
  <address>
    <street>Main St.</street>
    <number>14</number>
    <city>Smalltown</city>
  </address>
  <telephone>
    <number>+44 123 456789</number>
  </telephone>
  <hours>
    <monday>9-11 am</monday>
    <tuesday>9-11 am</tuesday>
    ...
  </hours>
</physician>
```

(probably)
the work address

So, what does a DTD/Schema Define?

- XML Schema / DTD defines the *syntax* of an XML document, but no its *semantics*

- Tag names are not interpretable by machines
  - i.e., they do not ease the information retrieval process...
  - Semantics of the data is hidden – usually hard wired in the application

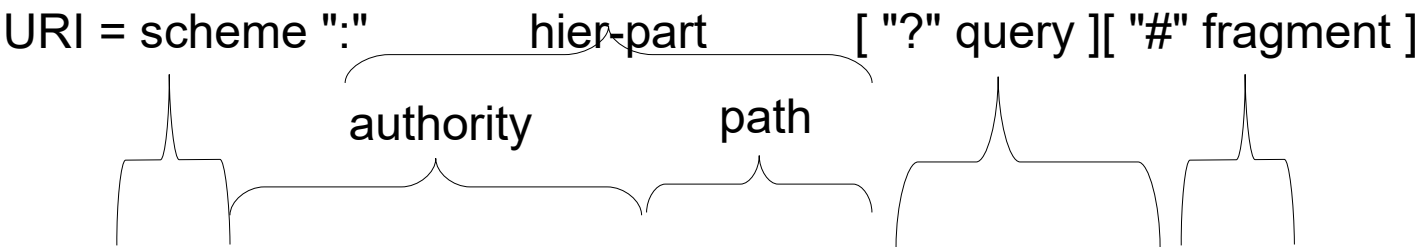
- The Semantic Web is meant as a remedy to that problem
  - *Semantic Web is/can do more than XML!*

```
<2nf3oiü*>
  <34f0>Dr. Mark Smith</34f0>
  <rmd4935r>
    <e2m4>Main St.</e2m4>
    <dur3>14</dur3>
    <jfa34>Smalltown</jfa34>
  </rmd4935r>
  <d24r3fmö>
    <deß5>+44 123 456789</deß5>
  </d24r3fmö>
  <vsfif>
    <f02>9-11 am</f02>
    <fj9>9-11 am</fj9>
    ...
  </vsfif>
</2nf3oiü*>
```

Uniform Resource Identifiers (URIs)

- “Things, not strings” requires identifiers for *things*
  - URIs: Proposed by Tim-Berners-Lee as „Universal Resource Identifier“ (IETF RFC 1630)
    - Standardized: IETF RFC 3986 (2005)

- Used for naming and finding resources on the Web



http://example.com:8042/over/there?name=ferret#nose

URIs vs. URLs

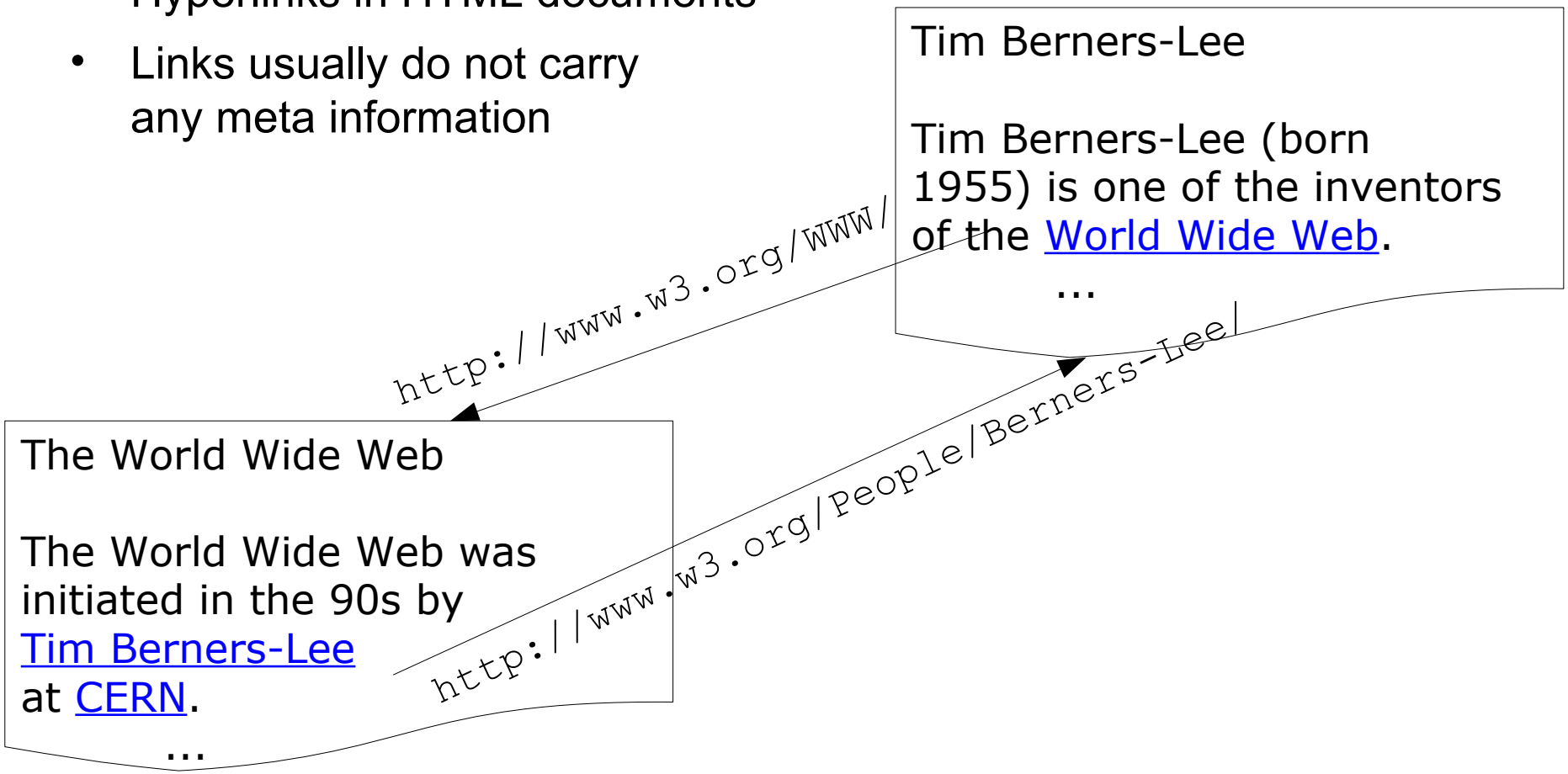
- Uniform Resource Locators (IETF RFC 1738, 1994) are a *subset* of URIs

- URIs can refer to *arbitrary* things
- A URL refers to a resource on the Web

- Typical URL prefixes
  - http
  - ftp
  - mailto
  - telnet
  - file
  - …

URLs on the Web

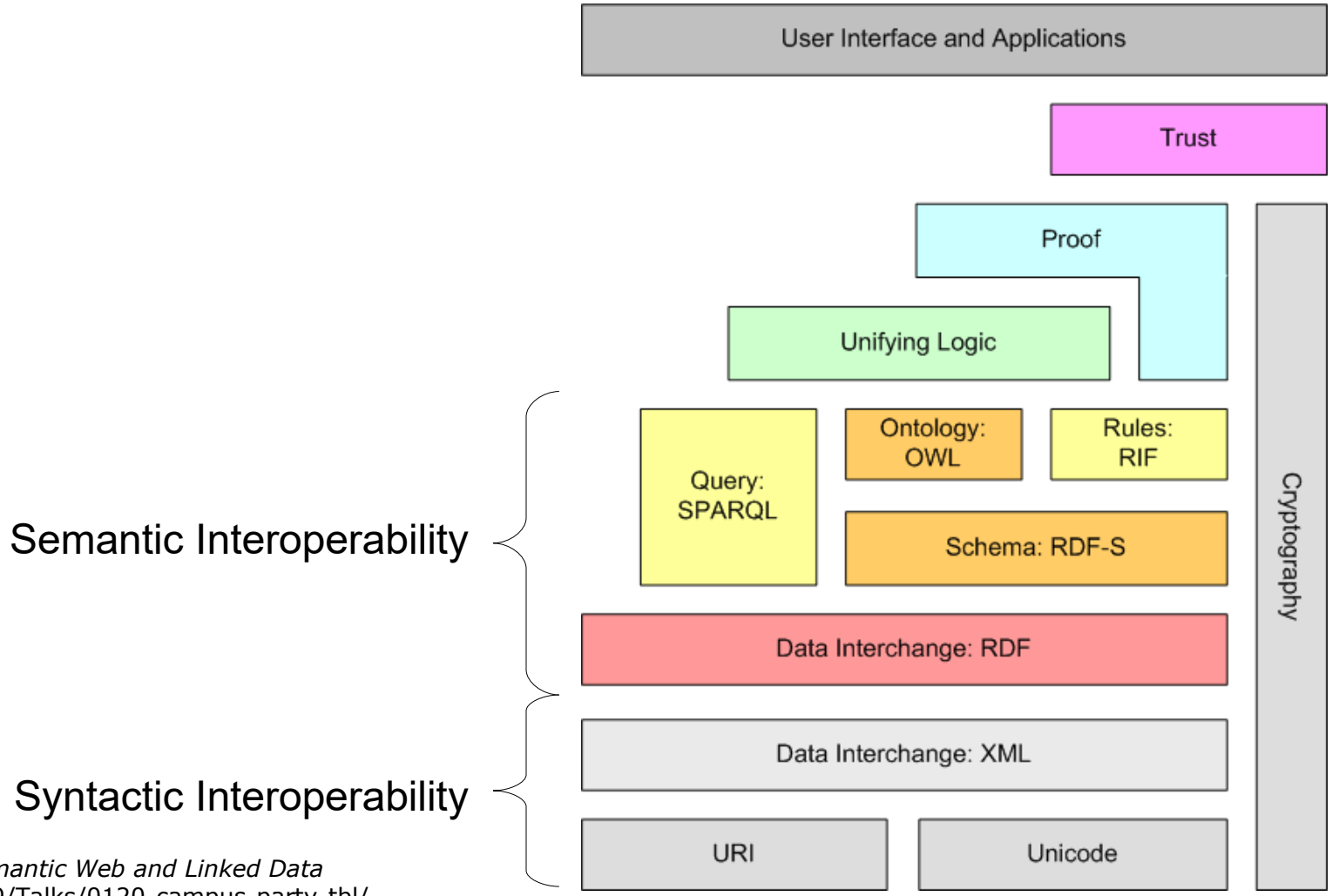
- Most common usage:
  Hyperlinks in HTML documents
- Links usually do not carry
  any meta information



Wrap Up

- Knowledge Graphs
  - Facilitate syntactic and semantic data interoperability
- Today, we have seen syntactic interoperability
  - Unicode: a character set for all languages
  - XML: a universal data exchange format
    - XPath
    - DTD
    - XML Schema
  - URIs
    - Unique identifiers for *things* (entities, resources, ...)
    - On the Web, URLs are dereferencable

Data Interoperability with Knowledge Graphs



Berners-Lee (2009): *Semantic Web and Linked Data*
http://www.w3.org/2009/Talks/0120-campus-party-tbl/

Questions?