Business 4720 - Class 2

Data Types and Data Sources

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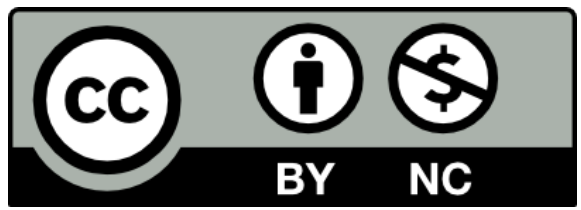

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This Class

What You Will Learn:

- Different data types
- Data quality and provenance
- Internal and external data sources

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Primitive Data Types

char	Individual Characters
string	A string of characters
byte	1 byte, $-128 \ldots 127$ or one Ascii characters
int (16 bit)	"Short", Integer numbers, $-32,768 \ldots 32,767$
int (32 bit)	"Long", Integer numbers, $-2,147,483,648 \ldots 2,147,483,647$
int (64 bit)	Integer numbers, $-9,223,372,036,854,775,808 \ldots 9,223,372,036,854,775$
float	Decimal numbers, 6 to 7 significant digits
double	Decimal numbers, 15 to 16 significant digits
boolean	Logical, true/false, 1 or 0

Not all tools use the same names, and not all tools make the same distinctions. For example, the R system uses `numeric` (which is actually a double type) and `integer` (which is a 32 bit integer).

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Missing Values

- Depends on software tool
- Different meanings (such as not applicable, not available)

R	NA
Python	None
SQL	Null

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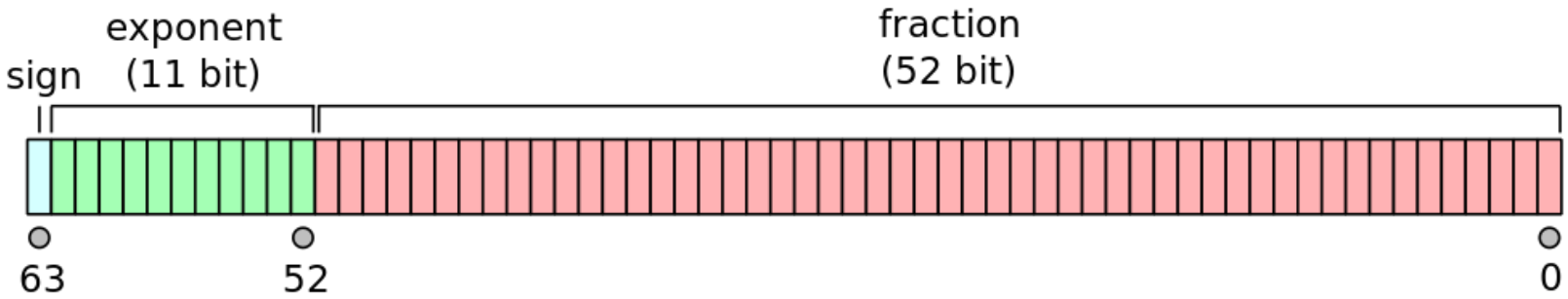
Floating Point Numbers (IEEE 754 Standard)



https://commons.wikimedia.org/wiki/File:IEEE_754_Double_Floating_Point_Format.svg

$$(-1)^{\text{sign}}(1.b_{51}b_{50}\ldots b_0)_2 \times 2^{\text{exp}-1023}$$

$$(-1)^{\text{sign}}\left(1+\sum_{i=1}^{52} b_{52-i}2^{-i}\right) \times 2^{\text{exp}-1023}$$

float	4 bytes, 1 bit for sign, 8 bits for exponent, 23 bits for significand, $\pm 3.40282347e+38$
double	8 bytes, 1 bit for sign, 11 bits for exponent, 52 bits for significand, $\pm 1.7976931348623157e+308$

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Floating Point Serialization to Text

Idiosyncrasies

- Thousands separator, grouping
- Negatives in brackets
- ”Scientific notation”

-1023476.56	
-1023476,56	some locales use comma as decimal sep
-1,023,476.56	some locales use comma for grouping
-1.023.475,56	some locales use comma as sep and points to group
(1,023,476.56)	some applications use brackets for neg
-1 023 476.56	some locales use space for grouping
-1.02347656e+06	”scientific notation”
-1023.47656e+03	also ”scientific notation”
...	

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Characters (Unicode ISO/IEC 8859)

- Covers all major alphabets and writing systems
- 149,813 symbols (V15.1), incl 3782 emojis, for 161 scripts

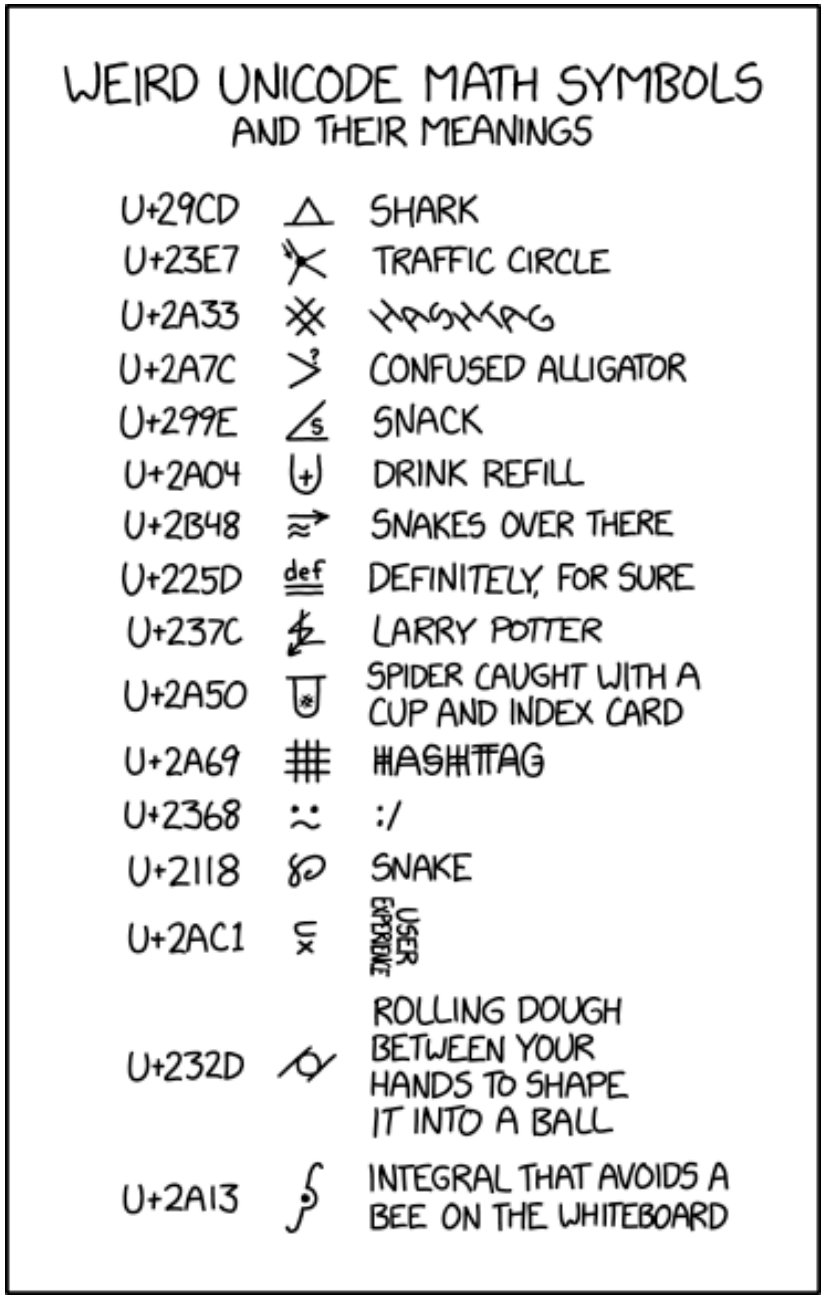
UTF-8

- Most widely used Unicode encoding standard
- Standardized 1998 as RFC 2277
- 1 to 4 byte variable length encoding for each character
- Initial 127 bytes backwards compatible with ASCII character set

```
Roman alphabet: Inuktitut

Written Inuktitut: ᐃᓄᒃᑎᑐᑦ
Unicode characters: \u1403 \u14c4 \u1483
                    \u144e \u1450 \u1466
UTF-8 Encoding: 0xE1 0x90 0x83 0xE1 0x93 0x84
                0xE1 0x92 0x83 0xE1 0x91 0x8E
                0xE1 0x91 0x90 0xE1 0x91 0xA6
```

Unicode



Source: `https://xkcd.com` (CC license)

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Hands-On Exercise

- Choose your favourite emoji
- Determine its Unicode number (”codepage”)
- Determine its UTF-8 encoding

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Dates and Times

Complexities

- Calendar formats (written)
  - DMY, YMD, MDY, YDM with different separators (”.”, ”-”, ”/”)
  - Not all software or data sets comply with standards
  - Difficult to parse and validate
- 12 hour (AM/PM) and 24 hour time formats
- Time zones
- Leap seconds, leap years
- Week numbering
- Precision (milliseconds, nanoseconds)
- Different written formats
- Arithmetic involving years, months, days

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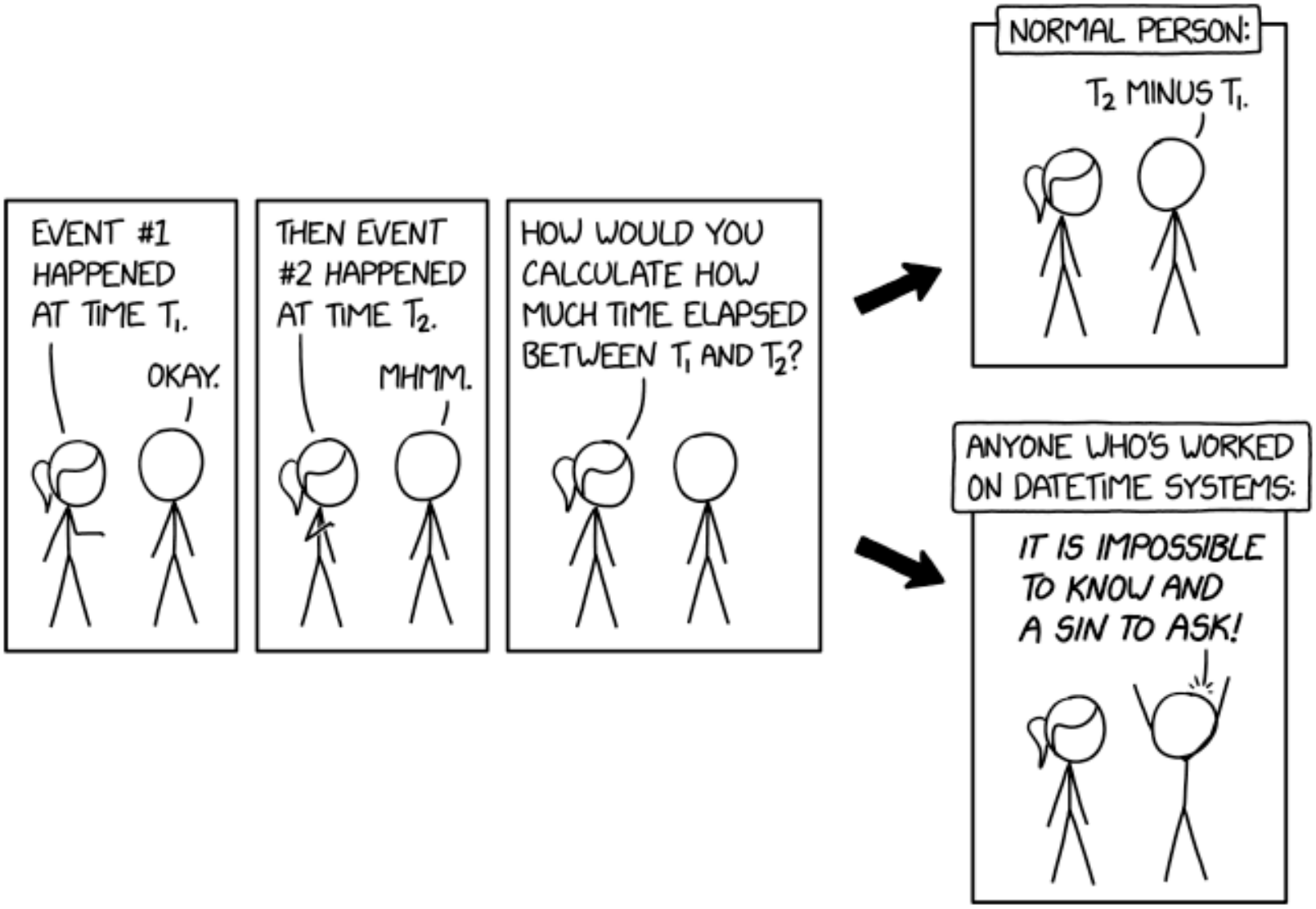
Dates and Times



Source: `https://xkcd.com` (CC license)

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ISO 8601 and RFC 3339 Date Format

Calendar dates	YYYY-MM-DD
Ordinal dates	*YYYY-DDD* (not in RFC 3339)
Week dates	*YYYY-Www-d* (not in RFC 3339)
Times	Thh:mm:ss.sss *(or Thhmmss.ss)* Thh:mm:ss *(or Thhmmss)* *Thh:mm.mmm or Thhmm.mmm* *Thh:mm or Thhmm* *Thh.hhh*
Time Zones	<time>Z or <time>±hh:mm or *(<time>±hhmm or <time>±hh)*
Combined	<date>T<time>
Periods	PnYnMnDTnHnMnS or P<date>T<time>

Leap Year Rule

(year % 4 == 0) and (year % 100 != 0 or year % 400 == 0)

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Hands-On-Exercises

The territory of Nunavut was created on April 1st, 1999.

- Express the date in RFC 3339
- Calculate the number of days since the creation of Nunavut
- Assume that a ceremony took place at 3PM that day in Iqaluit and express this date-time in RFC 3339
- Assume the ceremony lasted for 125 minutes and express this duration in RFC 3339

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Complex/Structured Data Types

Python

- list, `[1, 2, "a", "b", 2]`, mutable, ordered
- tuple, `(1, 2, "a", "b", 2)`, immutable
- set, `{1, 2, "a", "b"}`, mutable, unordered
- dict, `{"make": "Ford", "year": 2023}`, mutable

R

- list, `list(1, 2, "a", "b", 2)`, mutable, ordered
- vector, `c(1, 2, 3)`, mutable, same primitive type
- factor, `as.factor(c("Hot", "Med", "Cold"))`
- matrix, `matrix(c(1, 2, 3, 4), nrow=2)`
- array, `array(c(1, 2, 3), c(4, 5, 6))`

Data Types in Analytics

Structured Data

- Tables
- Key-Value pairs
- Documents (JSON, XML)
- Graphs

Unstructured Data

- Text
- Image
- Video

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Tables

- Columns, represent different variables
  - Each column is a vector, typically named
- Rows, represents values for different observations
- Cells, may be primitive or complex, e.g. sets or lists or tables

Name	**Area**	**Population**
Canada	9,984,670	38,781,292
Nigeria	923,768	223,804,632
Germany	357,600	83,294,633

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Table Interchange/Serialization

CSV format (RFC 4180)

- Plain text, Ascii or UTF-8 Unicode
- One record per line
- Fields separated by delimiter (typically: ”,”)
- Fields must be primitive
- Optional header with column/field names
- Fields *may* be enclosed by double quotes (” " ”)

```
"Name", "Area", "Population" <LF>
"Canada", "9984670", "38781292" <LF>
"Nigeria", "923768", "223804632" <LF>
"Germany", "357600", "83294633" <LF>
```

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Table Interchange/Serialization [cont'd]

Potential Problems with CSV Files

- Different delimiters (",", "tab", ";", " ^ ", etc.)
- Different line endings/terminators (CR/LF for Windows, LF for Mac & Unix)
- Different or inconsistent quoting
- Different decimal and thousand delimiters for numerics (depending on locale)
- Different date formats (depending on locale)

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Hands-On Exercise

- Search the internet for a CSV file of the population and areas of all countries of the world
- Examine the CSV file and answer the following questions:
  - What is the delimiter?
  - Which fields are quoted, and how?
  - What is the line ending character(s)?
  - What is the number format?
  - What is the date format (if there are dates)?
- Import the CSV file into your favourite spreadsheet tool
  - Does it recognize all information correctly? If not, what is not imported well?
- Export the CSV file from your tool under a different name.
  - Do you get an identical file to the one you imported? If not, what has changed?

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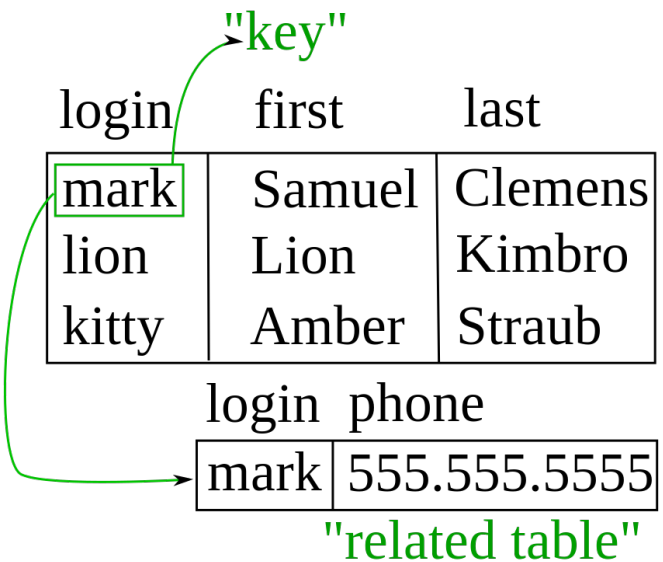
Relational Databases

Characteristics

- Records (”rows”) in tables (”relations”)
- Columns/fields are typed
- Records are identified by ”primary keys”
- Records can refer to other records, in the same or different relation/table



https://commons.wikimedia.org/wiki/File:Relational_key_SVG.svg

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Relational Databases [cont'd]

Advantages

- Normalization reduces redundancy, increases data integrity
- Enforcement of contraints such as types, referential integrity, non-nulls, etc. increases data integrity
- Intuitive schemas and queries

Prominent Examples

- *On-premises*: Oracle DBMS
- *Open source*: PostgreSQL
- *Cloud*: Amazon RDS, Google Cloud Database, Azure SQL

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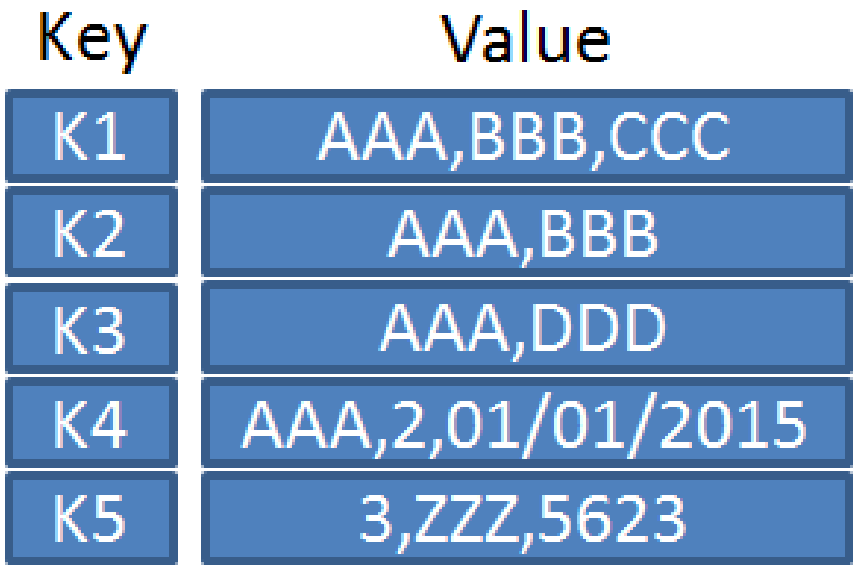
Key-Value Data Stores

Characteristics

- Records are sets of key-value pairs
- Key has multiple components (ordered list, ”minor keys”)
- Value is uninterpreted



https://commons.wikimedia.org/wiki/File:KeyValue.PNG

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Key-Value Data Stores [cont'd]

Advantages

- Fast retrieval/insertion/updating
- No relationships between entities/records
- Less memory use (does not store empty table cells)
- Untyped and no fixed schema increases flexibility
- Easy scalability and distribution

Prominent Examples

- *On-premises, open-source*: Apache Cassandra, Facebook RocksDB, Redis
- *Cloud*: AWS DynamoDB, Google LevelDB, Azure CosmosDB

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Documents (JSON)

JavaScript Object Notation (RFC 8259)

- Plain text, UTF-8
- Primitive Types:
  - Strings (in single or double quotations)
  - Number
  - Boolean
  - Null
- Structured Types:
  - Objects
    - unordered collection of zero or more name/value pairs)
    - Delimited by ”{” and ”}”
  - Arrays
    - Ordered sequence of zero or more values
    - Delimited by ”[” and ”]”

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JSON Example – Complex Object

```
{
  "Image": {
    "Width": 1060,
    "Height": 400,
    "Title": "Skyline of Iqualuit, Nunavut",
    "Url":
"https://upload.wikimedia.org/wikipedia/commons/b/b4/Iqaluit_skylin
    "Legal": {
      "Copyrighted": true,
      "License": "GNU Free Documentation License",
      "Inception": "2010-03-24",
      "Author": "Aaron Lloyd"
    },
  }
}
```

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JSON Example – List of Objects

```
[
  {
    "Latitude":  56.536389,
    "Longitude": -61.718889,
    "City":      "Nain",
    "Province":  "NL",
    "Postal":    "A0P",
    "Country":   "Canada"
  },
  {
    "Latitude":  53.512778,
    "Longitude": -60.135556,
    "City":      "Sheshatshiu",
    "Province":  "NL",
    "Postal":    "A0P",
    "Country":   "Canada"
  }
]
```

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Hands-On Exercise

Document yourself in a JSON object

- Identify information about yourself, such as names, addresses, dates, relationships (work, school, uni), etc.
- Structure the information in JSON Objects and Arrays
- Use nested structures, e.g. objects in arrays, or arrays in objects, or objects in objects, etc.

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Document Databases I

What makes them special

- *Nested* key-value data store
- All keys are *strings*
- No fixed schema, increases flexibility

Applications

- Content management
- Catalogs and product data
- Log and event data (IoT, sensors)

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Document Databases II

Prominent Examples

- *On-premises*: MongoDB, ArangoDB
- *Open source*: Apache CouchDB
- *Cloud*: AWS DocumentDB, Azure CosmosDB

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Extensible Markup Language – XML

- Document serialization format for structured data
- Nested **elements**
- Elements described by opening and closing **tag**
- Elements may have **attributes**, defined in opening tag
- Attributes can only hold simple data, elements can contain structured data.
- Arbitrary element and attribute names unqiuely defined within **namespaces** (typically URI, Uniform Resource Identifier)
- Element and attribute are defined using **XML Schema**

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XML Example

```
<People
      xmlns="https://www.example.com/peoples"
      xmlns:geo="http://www.example.com/geo"
      xmlns:hist="http://www.example.com/history">
    <GeneralInformation
            Name="Innu" Language="Innu-aimun">
        <geo:Location geo:Country="Canada"
                geo:Regions="Labrador, Quebec" />
    </GeneralInformation>
    <hist:History>
        <hist:Period hist:era="Pre-Colonial">
            <Description>
                Nomadic lifestyle, primarily
                hunting and fishing.
            </Description>
        </hist:Period>
```

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XML Example [cont'd]

```
    <hist:Period hist:era="Post-Colonial">
        <Description>
            Impact of colonization,
            including displacement and
            cultural changes.
        </Description>
    </hist:Period>
</hist:History>
<Culture>
    <Traditions>
        <Tradition>
            Hunting and fishing as cultural
            and subsistence activities.
        </Tradition>
        <Tradition>
            Use of the tepee for temporary
            shelter.
        </Tradition>
    </Traditions>
```

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XML Example [cont'd]

```
        <Art>
            <Form>Drum making</Form>
            <Form>Clothing with intricate beadwork
            </Form>
        </Art>
    </Culture>
    <Challenges>
        Issues like land rights, cultural preservation
    </Challenges>
</People>
```

XML Example – Key Points

- The `xmlns:geo` and `xmlns:hist` are namespace declarations. They are used to distinguish between geographical (geo) and historical (hist) data. Notice how element and attribute names may be prefixed by a namespace.
- The `xmlns` is the default namespace and applies to all elements and attributes without an explicit namespace.
- The `GeneralInformation` element has attributes for Name and Language. Attributes must be character strings
- The `Location` element includes attributes for Country and Regions, using the `geo` namespace.
- The `Location` does not include other elements and is defined with just one tag.
- Each `Period` element in the `History` element has an attribute `hist:era` to specify the era.
- Multiple elements with the same name can follow each other.

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Equivalent JSON Example

```
{ "Innu": {
    "GeneralInformation": {
       "Location": {
         "Country": "Canada",
         "Regions": "Labrador, Quebec"
       }
    },
    "History": {
      "Period": [
        {
          "era": "Pre-Colonial",
          "Description": "Nomadic lifestyle,
              primarily hunting and fishing."
        },
        {
          "era": "Post-Colonial",
          "Description": "Impact of colonization, ..."
        }
      ]
    },
```

XML — JSON

- Both are human and machine readable
- Both are system/language independent
- XML is more verbose/lengthy and very self-descriptive
- JSON is more compact/lightweight but not as descriptive
- XML supports more complex structures than JSON through
  - Attributes
  - Namspaces
  - More datatypes
- XML can be strictly defined using XML Schema, JSON always remains flexible

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Hands-On Exercise

Document yourself in an XML document

- Identify information about yourself, such as names, addresses, dates, relationships (work, school, uni), etc.
- Structure the information in Elements and Attributes
- Use nested elements where appropriate

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Graphs

Characteristics

- Nodes (also called ”vertices”)
- Edges (also called ”arcs”, ”relationships”) that connect vertices
  - Directed or undirected
- Vertices and Edges may be typed

Applications

- Social networks
- Logistics networks
- Financial networks
- Biological networks
- Resource descriptions (RDF)

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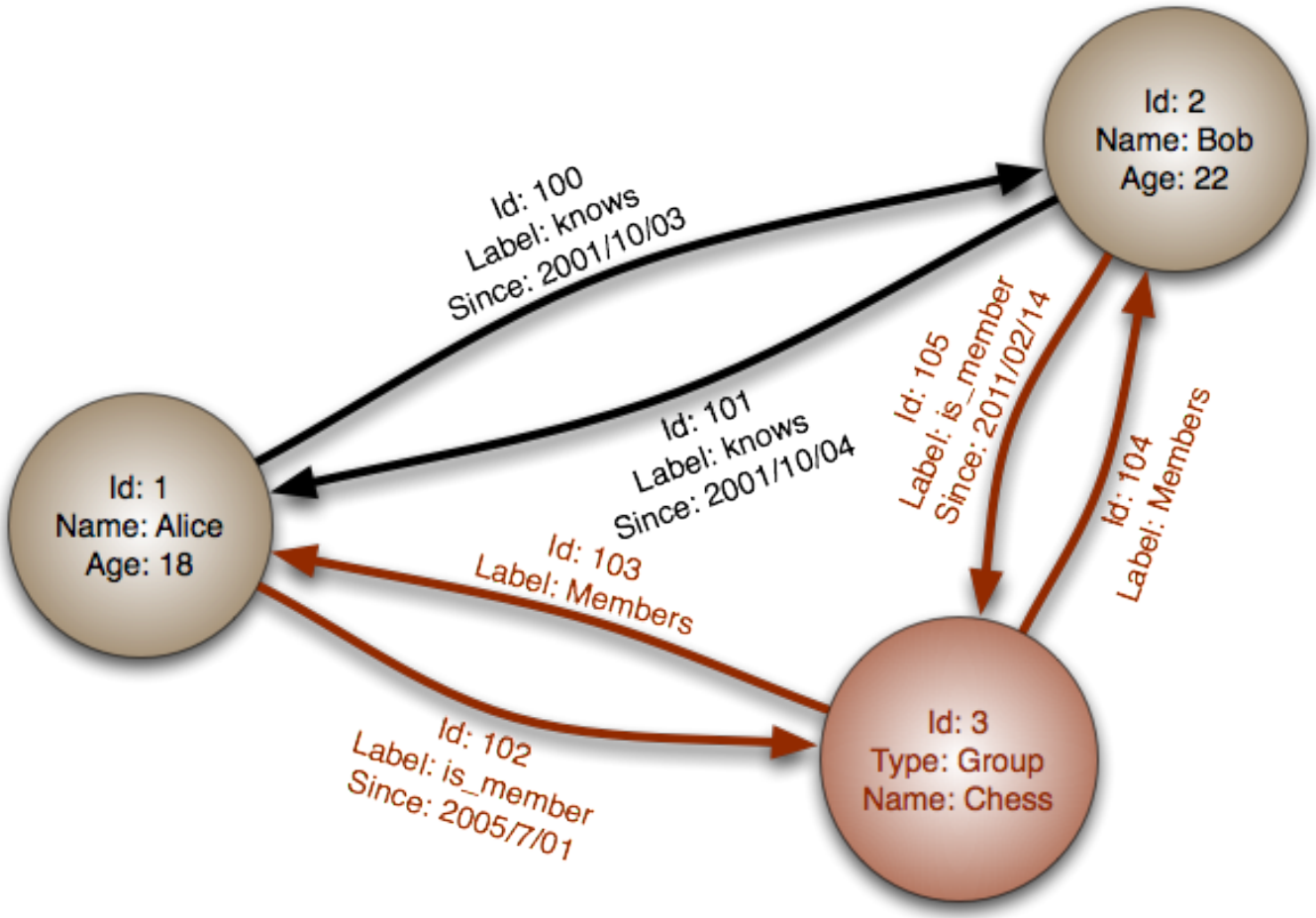
Property Graphs

- Vertices and Edges may have properties (e.g. key/value pairs of simple or complex data types, e.g. JSON objects)



https://commons.wikimedia.org/wiki/File:GraphDatabase_PropertyGraph.png

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RDF Graphs

- Resource Description Framework
- Subject – Verb/Predicate – Object triples

https://commons.wikimedia.org/wiki/File:Rdf_graph_for_Eric_Miller.png

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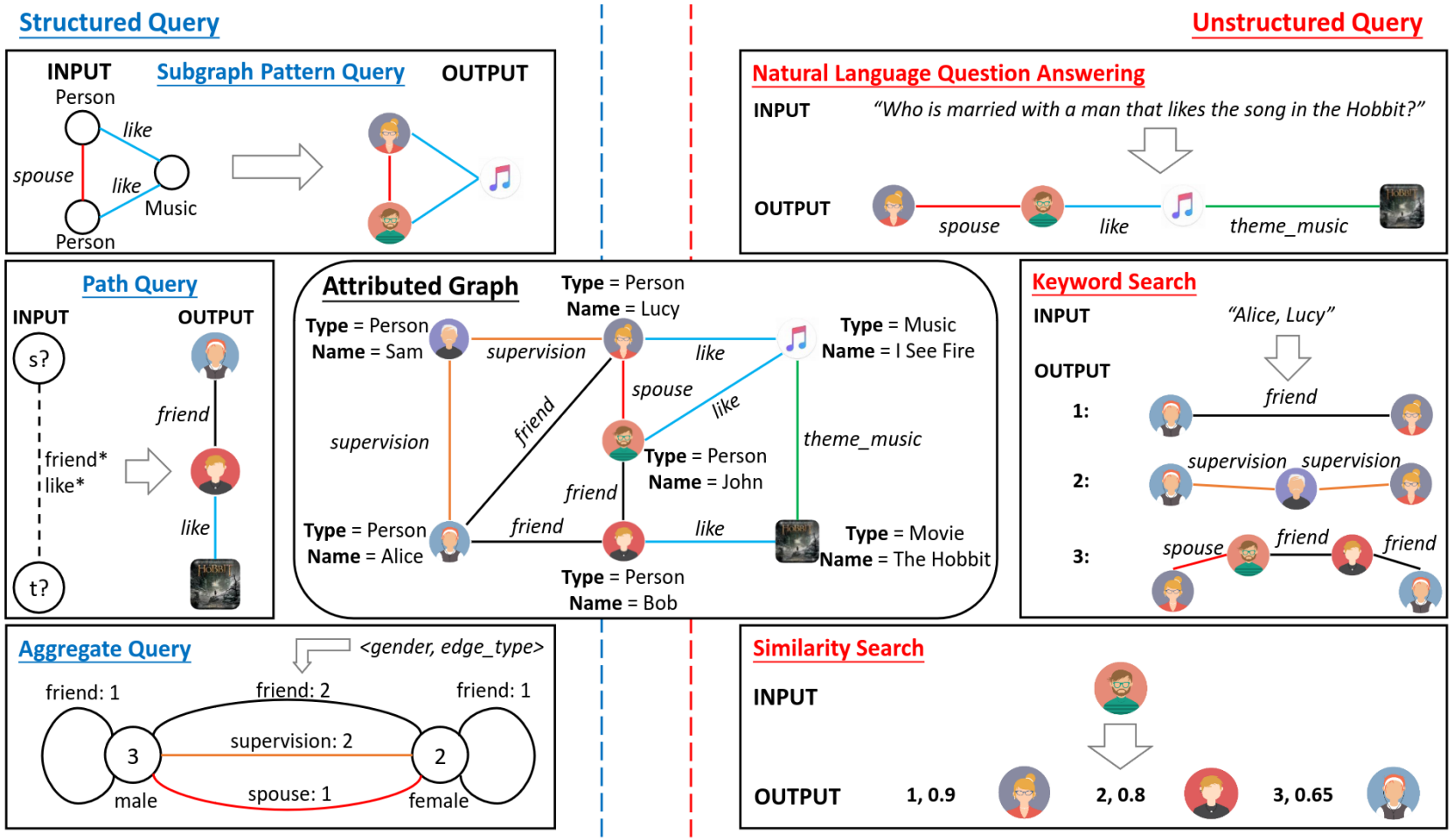
Graph Queries

- Path queries: Reachability, shortest-path, regular path
- Subgraph queries: Exact match, approximate match
- Aggregate queries
- Similarity search: path-based approaches, graph embedding-based approaches
- Keyword search: tree-based sematnics, subgraph-based semantics

Wang, Y., Li, Y., Fan, J., Ye, C., & Chai, M. (2021). A survey of typical attributed graph queries. World Wide Web, 24, 297-346.

Graph Queries



Wang, Y., Li, Y., Fan, J., Ye, C., & Chai, M. (2021). A survey of typical attributed graph queries. World Wide Web, 24, 297-346.

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Graph Databases

Prominent Examples

- *On-premises*: ArangoDB, Neo4J, OrientDB
- *Open-source*: JanusGraph
- *Cloud*: AWS Neptune, Azure CosmosDB

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PG-JSON Example


```
{
  "nodes":[
    {
     "id":101,
     "labels":["Person"],
     "properties":{"name":["Alice"], "age":[15], "country":["United
    },
    {
     "id":102,
     "labels":["Person", "Student"],
     "properties":{"name":["Bob"], "country":["Japan", "Germany"]}
    }
  ],
  "edges":[
    {
     "from":101,
     "to":102,
     "undirected":true,
     "labels":["sameSchool", "sameClass"],
     "properties":{"since":[2012]}
    },
    {
     "from":102,
     "to":101,
```

GraphSON Example

```
{
"graph": {
  "mode":"NORMAL",
  "vertices": [
    {
      "name": "lop",
      "lang": "java",
      "_id": "3",
      "_type": "vertex"
    },
    {
      "name": "vadas",
      "age": 27,
      "_id": "2",
      "_type": "vertex"
    },
    {
      "name": "marko",
      "age": 29,
      "_id": "1",
      "_type": "vertex"
    },
    {
      "name": "peter",
```

GraphSON Example [cont'd]

```
  "edges": [
    {
      "weight": 1,
      "_id": "10",
      "_type": "edge",
      "_outV": "4",
      "_inV": "5",
      "_label": "created"
    },
    {
      "weight": 0.5,
      "_id": "7",
      "_type": "edge",
      "_outV": "1",
      "_inV": "2",
      "_label": "knows"
    },
    {
      "weight": 0.4000000059604645,
      "_id": "9",
      "_type": "edge",
      "_outV": "1",
      "_inV": "3",
      "_label": "created"
```

N-Triples

```
<http://www.w3.org/People/EM/contact#me>
 <http://www.w3.org/2000/10/swap/pim/contact#fullName>
  "Eric Miller" .

<http://www.w3.org/People/EM/contact#me>
 <http://www.w3.org/2000/10/swap/pim/contact#mailbox>
  <mailto:e.miller123(at)example> .

<http://www.w3.org/People/EM/contact#me>
 <http://www.w3.org/2000/10/swap/pim/contact#personalTitle>
  "Dr." .

<http://www.w3.org/People/EM/contact#me>
 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
  <http://www.w3.org/2000/10/swap/pim/contact#Person> .
```

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Turtle Example (Terse RDF Triples)

```
@prefix eric:    <http://www.w3.org/People/EM/contact#> .
@prefix contact: <http://www.w3.org/2000/10/swap/pim/contact#> .
@prefix rdf:     <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .

eric:me contact:fullName "Eric Miller" .
eric:me contact:mailbox <mailto:e.miller123(at)example> .
eric:me contact:personalTitle "Dr." .
eric:me rdf:type contact:Person .
```

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Hands-On Exercise

Document yourself in a Turtle

- Identify information about yourself, such as names, addresses, dates, relationships (work, school, uni), etc.
- Structure the information in Turtle triples
- Make up appropppriate prefixes and appropriate verbs/predicates

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RDF/XML

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF xmlns:contact="http://www.w3.org/2000/10/swap/pim/contact#
xmlns:eric="http://www.w3.org/People/EM/contact#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
  <rdf:Description rdf:about="http://www.w3.org/People/EM/contact#m
    <contact:fullName>Eric Miller</contact:fullName>
  </rdf:Description>
  <rdf:Description rdf:about="http://www.w3.org/People/EM/contact#m
    <contact:mailbox rdf:resource="mailto:e.miller123(at)example"/>
  </rdf:Description>
  <rdf:Description rdf:about="http://www.w3.org/People/EM/contact#m
    <contact:personalTitle>Dr.</contact:personalTitle>
  </rdf:Description>
  <rdf:Description rdf:about="http://www.w3.org/People/EM/contact#m
    <rdf:type rdf:resource="http://www.w3.org/2000/10/swap/pim/cont
  </rdf:Description>
</rdf:RDF>
```

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Text Mining I

Example Text Analysis Tasks

- Named entity recognition
- Document clustering/similarity detection
- Co-reference analysis
- Relationship, fact, event extraction
- Sentiment analysis

Approaches

- Symbolic (1950s – 1990s)
- Statistical (1990s – 2010s)
- Neural networks (present)

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Text Mining II

Business Applications

- Marketing
- Customer relationship management
- Finance
- ...

Hands-On Exercise

1. Identify a specific business problem that can be addressed by analyzing text data
2. What text data would you need to address the problem?
3. What would you wish to do with the text data?
4. Where might you get this text data?

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Regular Expressions (RegEx)

- Important tool in analyzing text
- Sequence of characters specifying a match pattern in text
- Example (matches any number):

```
[+-]?(\d+(\.\d*)?|\.\d+)([eE][+-]?\d+)?.
```

https://en.wikipedia.org/wiki/Regular_expression

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Basic RegEx

Metacharacter	Description
^	Matches start of text
.	Matches any character; matches the dot character within brackets
[ ]	Matches any of the characters in the brackets; - can be used to specify ranges
[^]	Matches any character not in the brackets
$	Matches the end of text
( )	Marked subexpression
\n	Matches the n-th marked subexpression
*	Matches the preceding element zero or more times
{m,n}	Matches the preceding element at least m and not more than n times

All others are treated as literals

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Basic RegEx Examples

RegEx	Matches
.at	”hat”, ”cat”, ”bat”, ”4at”, etc.
[hc]at	”hat”, ”cat”
[^b]	all strings matched by .at except ”bat”
[^bc]	all strings matched by .at except ”bat” and ”cat”
^[bc]*at*	”bat” and ”cat” at start of text
[bc]*at*$	”bat” and ”cat” at end of text
\[.\]	any single charater surrounded by [and], e.g. ”[a]”, ”[7]”, etc.
s.*	character ”s” followed by zero or more characters, e.g. ”s”, ”saw”, ”s3w96.7”, etc.

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Extended RegEx

Metacharacter	Description
?	Matches preceding element zero or one time
+	Matches preceeding element one or more times
|	Matches either the expression before or after the choice operator

Extended RegEx Examples

RegEx	Matches
[hc]?at	”at”, ”hat”, ”cat”
[hc]*at	”at”, ”hat”, ”cat”, ”chat”, ”chchchat”, etc.
[hc]+at	”hat”, ”cat”, ”chat”, ”chchchat”, etc.
cat|dog	”cat” or ”dog”

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Different Types of RegEx

Differences

- Posix BRE requires ( ) { } to be escaped, ERE does not
- Perl RegEx is a popular ”dialect”
- Some RegEx dialects provide characterclasses

	Perl/Vim	**ASCII**	**Posix**
Digits	\d	[0-9]	[:digit:]
Non-digits	\D	[^0-9]	
Lowercase letters	\l	[a-z]	[:lower:]
Uppdercase letters	\u	[A-Z]	[:upper:]
Alphanumeric chars	\w	[A-Za-z0-9_]	
Non-word chars	\W	[^A-Za-z0-0_]	
Whitespace	\s	[\t\r\n\v\f]	[:space:]
Non-whitespace	\S	[^ \t\r\n\v\f]	

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Hands-On Exercises

1. Specify a RegEx to match Canadian postal codes

`https://www.canadapost-postescanada.ca/cpc/en/support/articles/addressing-guidelines/postal-codes.page`

2. Specify a RegEx to match a RFC 3339 date with timezone, such as ”2023-11-14T20:42:53-04:30”

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Levenshtein Distance

- Text similarity
- Type of string–edit distance
- Counts insertion, deletion, substitution operations to transform one text into the other
- May use differential cost for the operations

$$\operatorname{lev}(a,b) = \begin{cases} |a| & \text{if } |b| = 0, \\ |b| & \text{if } |a| = 0, \\ \operatorname{lev}\big(\operatorname{tail}(a), \operatorname{tail}(b)\big) & \text{if } \operatorname{head}(a) = \operatorname{head}(b), \\ 1 + \min \begin{cases} \operatorname{lev}\big(\operatorname{tail}(a), b\big) \\ \operatorname{lev}\big(a, \operatorname{tail}(b)\big) \\ \operatorname{lev}\big(\operatorname{tail}(a), \operatorname{tail}(b)\big) \end{cases} & \text{otherwise} \end{cases}$$

`https://en.wikipedia.org/wiki/Levenshtein_distance`

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Hands-On Exercise

Determine the Levenshtein distances between the following:

1. Last five digits of your student number and ”12345”
2. The words ”Nunavut” and ”Nunatsiavut”
3. The words ”Inuktitut” and ”Innuttitut”
4. The words ”Mikak” and ”Micock”

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Image Data

Vector Formats

- Examples are SVG, EPS, PDF
- Describe images in terms of graphics primitives such as rectangles, curves, polygons
- Infinitely scalable

Raster formats

- Describe images in terms of pixels and their colours
- Lossy compression formats such as PNG, JPEG
- Lossless compression formats such as TIFF
- Based on specific colorspace such as RGB (3 bytes) or CMYK (4 bytes) and resolution
- Conceptually a $3 \times X \times Y$ array of RGB values between $0 \ldots 255$ (or $0 \ldots 1$)

Image Analysis

https://commons.wikimedia.org/wiki/File:Persian_sand_CAT.jpg

Tasks

- Object detection and counting
- Object classification
- Image segmentation
- Image retrieval
- . . .

Image Analysis

Applications

- Robotics
- Character and handwriting recognition (process automation)
- Security (identity verification, fraud detection, etc.)
- Manufacturing (defect detection, etc.)
- ...

Hands-On Exercise

1. Identify a specific business problem that can be addressed by analyzing image data
2. What image data would you need to address the problem?
3. What would you wish to do with the image data?
4. Where might you get this image data?

Video Data

Codecs and Container Formats

- Conceptually a series of image *frames* in raster image format, i.e. a $T \times 3 \times X \times Y$ array of RGB values between $0 \ldots 255$ (or $0 \ldots 1$)
- Codecs ("coder/decoder") such as H.264, H.265, AVC, AV1 describe how frames are encoded in computer bytes and compressed
- Containers such as MPEG-4, Matroska, AVI, VOB, WebM describe how multiple video, audio, and text (subtitle) streams are arranged in a file

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Video Analytics

Typical Tasks

- Object detection
- Object recognition
- Object motion detection
- Object or background dynamic masking/blurring
- Event detection and classification (errors, exceptions)
- Activity detection and classification

Hands-On Exercise

1. Identify a specific business problem that can be addressed by analyzing video data
2. What video data would you need to address the problem?
3. What would you wish to do with the video data?
4. Where might you get this video data?

Metadata

- Data about data
- Embedded in data or external
- Examples
  - Authorship & ownership
  - Licensing & legal information
  - Information about collection (when, who, where, how, what)
  - Information about processing (when, who, where, how, what)
  - Technical information (e.g. encoding, serialization format, etc.)

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Hands-On Exercise

1. With your cell phone camera, take a selfie
2. Identify the meta-data for this photo

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Data Quality

Dimensions

- Accuracy (error rate)
- Availability (cost, ease of retrieval or collection, licensing)
- Completeness (omissions, bias)
- Conformity (with external standards)
- Consistency (no contradictions)
- Integrity (relationships within the data)
- Precision (measurement precision of values)
- Relevance (usefulness)
- Reliability (consistency of repeated data points)
- Timeliness (latency, currency, ”age”)
- Traceability (auditable provenance, verifiable source)

Based in part on Richard Y. Wang & Diane M. Strong (1996) Beyond Accuracy: What Data Quality Means to Data Consumers, Journal of Management Information Systems, 12:4, 5-33, DOI: 10.1080/07421222.1996.11518099

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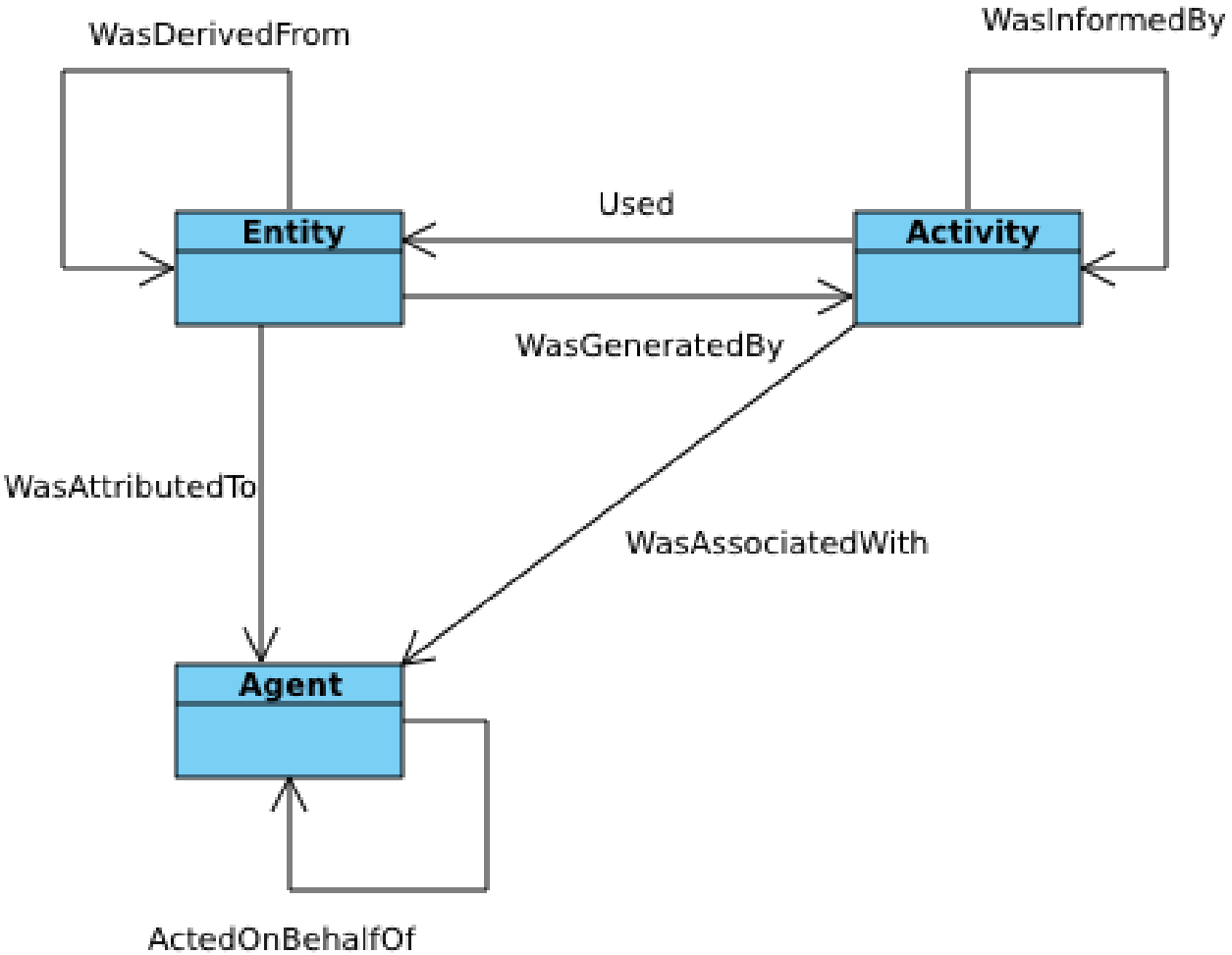
Data Provenance and Validity



https://commons.wikimedia.org/wiki/File:Prov_dm-essentials.png

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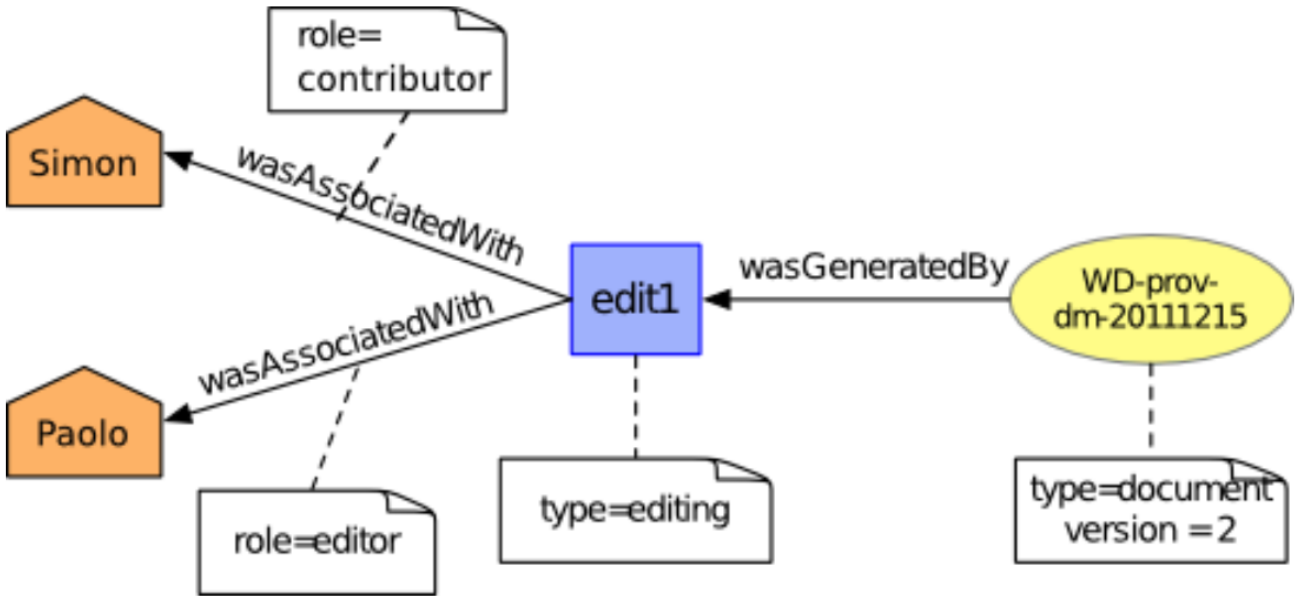
Data Provenance and Validity [cont'd]



urlhttps://www.w3.org/TR/prov-dm/#dfn-provenance

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Data Provenance and Validity [cont'd]

Collection

- How was the data collected? What errors could have happened?
- Who collected the data? Is it a trustworthy source?
- When were the data collected? Are they still valid?
- Are all the data collected? Are the data biased?
- Can the collection be verified/audited/repeated?

Processing

- How was the data processed? What mistakes could have been made?
- Was anything omitted or added?
- Who processed the data? Is it a trustworthy party?
- Can the processing be verified/audited/repeated?

Data Provenance and Validity [cont'd]

- What do different data fields mean?
- What are the units of measure?
- What is the level of aggregation?
- Were data sources combined? Are the different sources consistent with each other and of the same quality?
- Are the data accurate? How high are the error rates and the levels of precision?
- Can the data be validated? What are the validation rules for the data? Was the data validated?
- How can errors be detected and/or corrected?
- Are the data usable in a technical and legal way?

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Hands-On Exercises

1. Identify data on the consumer price index (excluding living and transportation expenses) for Newfoundland & Labrador for the last 10 years
   - How was it collected? By who? When?
   - How was it processed? By who? What was done to it?
   - Is there meta-data available for it?
   - How do you assess the quality of the data on the data quality dimensions?
   - Under what license is it available to you to use?
2. Identify some IoT devices or sensors in your household
   - What information can they measure?
   - How and when is the information being collected? By who?
   - How could the information be erroneous or biased?
   - How would you assess the quality of the data?

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Data Cleaning

Overview

- Critical step in the data analysis process
- Identification and rectification of errors and inconsistencies
- Improve data quality

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Data Cleaning

- Critical step in the data analysis process
- Identify and ”fix” errors and inconsistencies
- Improve data quality

Activities

1. **Auditing**: Identify anomalies and inconsistencies
2. **Validation**: Ensure data conforms to rules and constraints
3. **Cleaning:** Transform and correct data
4. **Duplicate Removal:** Ensure uniqueness of data.
5. **Harmonization:** Merge datasets from different sources and ensure consistent formats and scales.
6. **Standardization:** Bring data into a standard format.
7. **Quality Assessment:** Ensure cleaning has been effective.

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Data Validation

- Coding/serialization rules, e.g. with Regex
  - **Example** Are all phone numbers of the format:
    ```
    ^([0-9]{3})[ -]?[0-9]{3}[ -]?[0-9]{4}$
    ```
- Data type constraints
  - *Example*: Are all sales prices numbers?
- Range constraints
  - *Examples*: Are prices > 0? Are sales number < 1000?
- Cross-field validation
  - *Example*: If province is NL, then area code must be 709
- Uniformity of measures/scales
  - *Example*: All weights must be in kg, not pounds

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Data Validation [cont'd]

- Uniqueness constraints
  - Real duplicates and synonyms
  - *Example*: Rebekah Uqi Williams
    (Commissioner of Nunavut (2020–2021)
  - **Abbreviations**:
    Rebekah U. Williams; Rebekah Williams, R.U. Williams
  - **Order**:
    Williams, Rebekah Uqi; Williams, Rebekah U.; Williams, R.
  - **Spelling**:
    Rebekah; Rebecca; Rebeccah; Rebeckah; Rebecka
  - **Misspellings**:
    Reebkah, Rebkah, Wililams, Willaims, . . .
  - . . .

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Data cleaning

- **Data Transformation,** into proper format or structure.
  - One row for each observation, case, event, ...
  - Requires case or event identifiers
- **Data Imputation,** replacing missing values with estimated or default values, or removing missing values
  - Different meanings of missing values
  - Removal may bias data
  - Estimating values may be error-prone
- **Data Correction,** or removal of erroneous data.
  - Requires access to correct data

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Data Cleaning

Important

Cleaning, transformation, and correction of data is *subjective* and requires *expert knowledge* of the data, the validation rules, the metadata, and the application domain.

The 80/20 Rule of Data Science

Cleaning, transformation, and correction of data takes 80% of of the time, data analysis takes 20% of the time.

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