Data Handling: Import, Cleaning and Visualisation

Lecture 4:

"Big Data" from the Web

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Recap: Computer Code and Data Storage

Computer code

- Instructions to a computer, in a language it understands… (R)
- Code is written to **text files**
- Code is ‘translated’ into 0s and 1s which the CPU can process.

Data storage

- Data is usually stored in **text files**.
  - Read data from text files: data import.
  - Write data to text files: data export.

Inspect a text file

Interpreting `0`s and `1`s as text…

```
cat helloworld.txt; echo
```

```
## Hello World!
```

Inspect a text file

Directly looking at the `0`s and `1`s…

```
xxd -b helloworld.txt
```

```
## 00000000: 01001000 01100101 01101100 01101100 01101111 00100000  Hello
## 00000006: 01010111 01101111 01110010 01101100 01100100 00100001  World!
```

Inspect a text file

Directly looking at the `0`s and `1`s…

```
xxd -b helloworld.txt
```

```
## 00000000: 01001000 01100101 01101100 01101100 01101111 00100000  Hello
## 00000006: 01010111 01101111 01110010 01101100 01100100 00100001  World!
```

How does the computer know that `01001000` is `H`?

Encoding issues

```
cat hastamanana.txt; echo

## Hasta Ma?ana!
```

UTF encodings

- ‘Universal’ standards.
- Contain broad variety of symbols (various languages).
- Less problems with newer data sources…

Take-away message

- **Recognize an encoding issue when it occurs!**
- Problem occurs right at the beginning of the **data pipeline**!
  - Rest of pipeline affected…
  - … cleaning of data fails …
  - … analysis suffers.

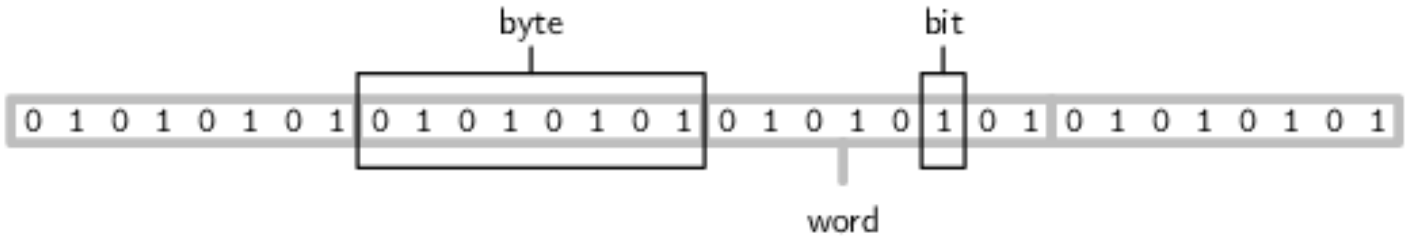
Structured Data Formats

- Still text files, but with standardized **structure**.
- **Special characters** define the structure.
- More complex **syntax**, more complex structures can be represented…

CSVs and fixed-width format

- Common format to store and transfer data.
  - Very common in a data analysis context.
- Natural format/structure when data represents a table.

Units of information/data storage: Bit, Byte, Word



Bit, Byte, Word. Figure by Murrell (2009) (licensed under CC BY-NC-SA 3.0 NZ)

Structures to work with…

- Data structures for storage on hard drive (e.g., csv).
- Representation of data in RAM (e.g. as an R-object)?
    - What is the representation of the ‘structure’ once the data is parsed (read into RAM)?

Structures to work with (in R)

We distinguish two basic characteristics:

1. Data **types**: integers; real numbers ('numeric values', floating point numbers); text ('string', 'character values').
2. Basic **data structures** in RAM:
   - **Vectors**
   - **Factors**
   - **Arrays/Matrices**
   - **Lists**
   - **Data frames** (very R-specific)

Complex Data Structures

A rectangular data set

father	mother	name	age	gender
		John	33	male
		Julia	32	female
John	Julia	Jack	6	male
John	Julia	Jill	4	female
John	Julia	John jnr	2	male
		David	45	male
		Debbie	42	female
David	Debbie	Donald	16	male
David	Debbie	Dianne	12	female

What is the data about?

A rectangular data set

father	mother	name	age	gender
		John	33	male
		Julia	32	female
John	Julia	Jack	6	male
John	Julia	Jill	4	female
John	Julia	John jnr	2	male
		David	45	male
		Debbie	42	female
David	Debbie	Donald	16	male
David	Debbie	Dianne	12	female

Which observations belong together?

A rectangular data set

father	mother	name	age	gender
		John	33	male
		Julia	32	female
John	Julia	Jack	6	male
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John	Julia	John jnr	2	male
		David	45	male
		Debbie	42	female
David	Debbie	Donald	16	male
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Can a parser understand which observations belong together?

Limitations of rectangular data

- Only **two dimensions**.
  - Observations (rows)
  - Characteristics/variables (columns)

Limitations of rectangular data

- Only **two dimensions**.
  - Observations (rows)
  - Characteristics/variables (columns)
- Hard to represent hierarchical structures.
  - Might introduce redundancies.
  - Machine-readability suffers (standard parsers won't recognize it).

Alternative formats

- JavaScript Object Notation (JSON)
- Extensible Markup Language (XML)
- and more…

Alternative formats

- JavaScript Object Notation (JSON)
- Extensible Markup Language (XML)
- Origin and most common domain of application: The Web!
  - Need to **transfer** complex data (between machines).
  - Need to **embed** complex data (in human friendly layout).

Deciphering XML

Revisiting Point Nemo

```
             VARIABLE : Monthly Surface Clear-sky Temperature (ISCCP) (Celsius)
             FILENAME : ISCCPMonthly_avg.nc
             FILEPATH : /usr/local/fer_data/data/
             BAD FLAG : -1.E+34
             SUBSET   : 48 points (TIME)
             LONGITUDE: 123.8W(-123.8)
             LATITUDE : 48.8S
            123.8W
16-JAN-1994 00  9.200012
16-FEB-1994 00  10.70001
16-MAR-1994 00  7.5
16-APR-1994 00  8.100006
```

Revisiting Point Nemo (in XML!)

```
<?xml version="1.0"?>
<temperatures>
<variable>Monthly Surface Clear-sky Temperature (ISCCP) (Celsius)</variable>
<filename>ISCCPMonthly_avg.nc</filename>
<filepath>/usr/local/fer_data/data/</filepath>
<badflag>-1.E+34</badflag>

<subset>48 points (TIME)</subset>
<longitude>123.8W(-123.8)</longitude>
<latitude>48.8S</latitude>
<case date="16-JAN-1994" temperature="9.200012" />
<case date="16-FEB-1994" temperature="10.70001" />
<case date="16-MAR-1994" temperature="7.5" />
<case date="16-APR-1994" temperature="8.100006" />

...
</temperatures>
```

Revisiting Point Nemo (in XML!)

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<?xml version="1.0"?>
<temperatures>
<variable>Monthly Surface Clear-sky Temperature (ISCCP) (Celsius)</variable>
<filename>ISCCPMonthly_avg.nc</filename>
<filepath>/usr/local/fer_data/data/</filepath>
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<subset>48 points (TIME)</subset>
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<case date="16-MAR-1994" temperature="7.5" />
<case date="16-APR-1994" temperature="8.100006" />

...
</temperatures>
```

What features does the format have? What is it's logic/syntax?

XML syntax

```
<?xml version="1.0"?>
  <temperatures>
    <variable>Monthly Surface Clear-sky Temperature (ISCCP) (Celsius)</variable>
    <filename>ISCCPMonthly_avg.nc</filename>
    <filepath>/usr/local/fer_data/data/</filepath>
    <badflag>-1.E+34</badflag>
    <subset>48 points (TIME)</subset>
    <longitude>123.8W(-123.8)</longitude>
    <latitude>48.8S</latitude>
    <case date="16-JAN-1994" temperature="9.200012" />
    <case date="16-FEB-1994" temperature="10.70001" />
    <case date="16-MAR-1994" temperature="7.5" />
    <case date="16-APR-1994" temperature="8.100006" />

...
  </temperatures>
```

XML syntax

The actual content we know from the csv-type example above is nested between the '`temperatures`'-tags:

```
  <temperatures>
...
  </temperatures>
```

XML syntax

Comparing the actual content between these tags with the csv-type format above, we further recognize that there are two principal ways to link variable names to values.

```
<variable>Monthly Surface Clear-sky Temperature (ISCCP) (Celsius)</variable>
<filename>ISCCPMonthly_avg.nc</filename>
<filepath>/usr/local/fer_data/data/</filepath>
<badflag>-1.E+34</badflag>
<subset>48 points (TIME)</subset>
<longitude>123.8W(-123.8)</longitude>
<latitude>48.8S</latitude>
<case date="16-JAN-1994" temperature="9.200012" />
<case date="16-FEB-1994" temperature="10.70001" />
<case date="16-MAR-1994" temperature="7.5" />
<case date="16-APR-1994" temperature="8.100006" />
```

XML syntax

1. Define opening and closing XML-tags with the variable name and surround the value with them, such as in `<filename>ISCCPMonthly_avg.nc</filename>`.
2. Encapsulate the values within one tag by defining tag-attributes such as in `<case date="16-JAN-1994" temperature="9.200012" />`.

XML syntax

Attributes-based:

```
<case date="16-JAN-1994" temperature="9.200012" />
<case date="16-FEB-1994" temperature="10.70001" />
<case date="16-MAR-1994" temperature="7.5" />
<case date="16-APR-1994" temperature="8.100006" />
```

XML syntax

Tag-based:

```
<cases>
  <case>
    <date>16-JAN-1994<date/>
    <temperature>9.200012<temperature/>
  <case/>
  <case>
    <date>16-FEB-1994<date/>
    <temperature>10.70001<temperature/>
  <case/>
  <case>
    <date>16-MAR-1994<date/>
    <temperature>7.5<temperature/>
  <case/>
  <case>
    <date>16-APR-1994<date/>
    <temperature>8.100006<temperature/>
  <case/>
<cases/>
```

Insights: CSV vs. XML

Note the key differences of storing data in XML format in contrast to a flat, table-like format such as CSV:

- Represent much more **complex (multi-dimensional)** data in XML-files than what is possible in CSVs.
  - Arbitrarily complex nesting structure.
  - Flexibility to label tags.

Insights: CSV vs. XML

Note the key differences of storing data in XML format in contrast to a flat, table-like format such as CSV:

- Self-explanatory syntax: **machine-readable and human-readable**.
  - Parsers/computers can more easily handle complex data structures.
  - Humans can intuitively understand what the data is all about just by looking at the raw XML file.

Insights: CSV vs. XML

Potential drawback of XML: **inefficient** storage.

- Tags are part of the syntax, thus, part of the actual file.
  - Tags (variable labels) are **repeated** again and again!
  - CSV: variable labels are mentioned once.
  - Potential solution: data compression (e.g., zip).
- If the data is actually two dimensional, a CSV is more practical.

Deciphering JSON

JSON syntax

- Key difference to XML: no tags, but **attribute-value pairs**.
- A substitute for XML (often encountered in similar usage domains).

XML:

```
<person>
  <firstName>John</firstName>
  <lastName>Smith</lastName>
  <age>25</age>
  <address>
    <streetAddress>21 2nd Street</streetAddress>
    <city>New York</city>
    <state>NY</state>
    <postalCode>10021</postalCode>
  </address>
  <phoneNumber>
    <type>home</type>
    <number>212 555-1234</number>
  </phoneNumber>
  <phoneNumber>
    <type>fax</type>
    <number>646 555-4567</number>
  </phoneNumber>
  <gender>
    <type>male</type>
  </gender>
</person>
```

XML:

```xml
<person>
  <firstName>John</firstName>
  <lastName>Smith</lastName>
  <age>25</age>
  <address>
    <streetAddress>21 2nd Street</st
    <city>New York</city>
    <state>NY</state>
    <postalCode>10021</postalCode>
  </address>
  <phoneNumber>
    <type>home</type>
    <number>212 555-1234</number>
  </phoneNumber>
  <phoneNumber>
    <type>fax</type>
    <number>646 555-4567</number>
  </phoneNumber>
  <gender>
    <type>male</type>
  </gender>
</person>
```

JSON:

```json
{"firstName": "John",
  "lastName": "Smith",
  "age": 25,
  "address": {
    "streetAddress": "21 2nd Street",
    "city": "New York",
    "state": "NY",
    "postalCode": "10021"
  },
  "phoneNumber": [
    {
      "type": "home",
      "number": "212 555-1234"
    },
    {
      "type": "fax",
      "number": "646 555-4567"
    }
  ],
  "gender": {
    "type": "male"
  }
}
```

XML:

```
<person>
  <firstName>John</firstName>
  <lastName>Smith</lastName>

</person>
```

JSON:

```
{"firstName": "John",
  "lastName": "Smith",

}
```

Parsing XML and JSON in R

Parsing XML in R

The following examples are based on the example code shown above (the two text-files `persons.json` and `persons.xml`)

```
# load packages
library(xml2)

# parse XML, represent XML document as R object
xml_doc <- read_xml("persons.xml")
xml_doc
```

```
## {xml_document}
## <person>
## [1] <firstName>John</firstName>
## [2] <lastName>Smith</lastName>
## [3] <age>25</age>
## [4] <address>\n  <streetAddress>21 2nd Street</streetAddress>\n  <city>New York</c
## [5] <phoneNumber>\n  <type>home</type>\n  <number>212 555-1234</number>\n</phoneNu
## [6] <phoneNumber>\n  <type>fax</type>\n  <number>646 555-4567</number>\n</phoneNur
## [7] <gender>\n  <type>male</type>\n</gender>
```

Parsing JSON in R

```
# load packages
library(jsonlite)

# parse the JSON-document shown in the example above
json_doc <- fromJSON("persons.json")

# check the structure
str(json_doc)
```

```
## Warning: package 'jsonlite' was built under R version 3.6.2
```

```
## List of 6
##  $ firstName  : chr "John"
##  $ lastName   : chr "Smith"
##  $ age        : int 25
##  $ address    :List of 4
##   ..$ streetAddress: chr "21 2nd Street"
##   ..$ city         : chr "New York"
##   ..$ state        : chr "NY"
##   ..$ postalCode   : chr "10021"
##  $ phoneNumber:'data.frame': 2 obs. of  2 variables:
##   ..$ type  : chr [1:2] "home" "fax"
##   ..$ number: chr [1:2] "212 555-1234" "646 555-4567"
##  $ gender     :List of 1
##   ..$ type: chr "male"
```

HTML: Computer Code Meets Data

HTML: Code to build webpages

HyperText Markup Language (HTML), designed to be read by a web browser.

HTML: Code to build webpages

HTML documents contain data!

HTML documents: code and data!

- Web designer's perspective: "HTML is a tool to design the layout of a webpage (and the resulting HTML document is **code**)."
- From a data scientist's perspective: "HTML gives the **data** contained in a webpage (the actual content) a certain degree of structure which can be exploited to systematically extract the data from the webpage."

HTML documents: code and data!

HTML documents/webpages consist of **'semi-structured data'**:

- A webpage can contain a HTML-table (**structured data**)…
- …but likely also contains just raw text (**unstructured data**).

```
<!DOCTYPE html>

<html>
    <head>
        <title>hello, world</title>
    </head>
    <body>
        <h2> hello, world </h2>
    </body>
</html>
```

Similarities to other formats?

Characteristics of HTML

1. **Annotate/'mark up'** data/text (with tags)
   - Defines **structure** and hierarchy
   - Defines content (pictures, media)

Characteristics of HTML

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   - Defines **structure** and hierarchy
   - Defines content (pictures, media)
2. **Nesting** principle
   - `head` and `body` are nested within the `html` document
   - Within the `head`, we define the `title`, etc.

Characteristics of HTML

1. **Annotate/'mark up'** data/text (with tags)
   - Defines **structure** and hierarchy
   - Defines content (pictures, media)
2. **Nesting** principle
   - `head` and `body` are nested within the `html` document
   - Within the `head`, we define the `title`, etc.
3. Expresses what is what in a document.
   - Doesn't explicitly 'tell' the computer what to do
   - HTML is a markup language, not a programming language.

HTML document as a ‘tree’

- ‘Root’: `<html>..</html>`
- ‘Children’ of the root node: `<head>...</head>`, `<body>...</body>`
- ‘Siblings’ of each other: `<head>...</head>`, `<body>...</body>`

HTML document as a ‘tree’

HTML (DOM) tree diagram (by Lubaochuan 2014, licensed under the Creative Commons Attribution-Share Alike 4.0 International license).

Two ways to read a webpage into R

In this example, we look at Wikipedia's Economy of Switzerland page.

Read the HTML line-by-line

```
swiss_econ <- readLines("https://en.wikipedia.org/wiki/Economy_of_Switzerland")
```

```
## Warning in readLines("https://en.wikipedia.org/wiki/Economy_of_Switzerland"): inco
## found on 'https://en.wikipedia.org/wiki/Economy_of_Switzerland'
```

```
head(swiss_econ)
```

```
## [1] "<!DOCTYPE html>"
## [2] "<html class=\"client-nojs\" lang=\"en\" dir=\"ltr\">"
## [3] "<head>"
## [4] "<meta charset=\"UTF-8\"/>"
## [5] "<title>Economy of Switzerland - Wikipedia</title>"
## [6] "<script>document.documentElement.className=\"client-js\";RLCONF={\"wgBreakFra
```

Navigate the raw HTML

Search for specific content

```
line_number <- grep('US Dollar Exchange', swiss_econ)
```

```
line_number
```

```
## [1] 216
```

```
swiss_econ[line_number]
```

```
## [1] "<th>US Dollar Exchange"
```

What are we missing here?

Parse the HTML!

- Navigate the document like an XML document!
  - Same logic (but tags are pre-defined)…
  - Traverse the tree.
- Access specific parts of the contained data directly.

Make use of the structure!

Parsing a Webpage with R

```
# install package if not yet installed
# install.packages("rvest")

# load the package
library(rvest)


# parse the webpage, show the content
swiss_econ_parsed <- read_html("https://en.wikipedia.org/wiki/Economy_of_Switzerland"
swiss_econ_parsed


## {html_document}
## <html class="client-nojs" lang="en" dir="ltr">
## [1] <head>\n<meta http-equiv="Content-Type" content="text/html; charset=UTF-8">\n<
## [2] <body class="mediawiki ltr sitedir-ltr mw-hide-empty-elt ns-0 ns-subject mw-ed
```

Parsing a Webpage with R

Now we can easily separate the data/text from the html code. For example, we can extract the HTML table containing the data we are interested in as a `data.frames`.

```
tab_node <- html_node(swiss_econ_parsed,
                      xpath = "//*[@id='mw-content-text']/div/table[2]")
tab <- html_table(tab_node)
tab
```

```
##    Year GDP (billions of CHF) US Dollar Exchange
## 1  1980                  184        1.67 Francs
## 2  1985                  244        2.43 Francs
## 3  1990                  331        1.38 Francs
## 4  1995                  374        1.18 Francs
## 5  2000                  422        1.68 Francs
## 6  2005                  464        1.24 Francs
## 7  2006                  491        1.25 Francs
## 8  2007                  521        1.20 Francs
## 9  2008                  547        1.08 Francs
## 10 2009                  535        1.09 Francs
## 11 2010                  546        1.04 Francs
## 12 2011                  659        0.89 Francs
## 13 2012                  632        0.94 Francs
## 14 2013                  635        0.93 Francs
## 15 2014                  644        0.92 Francs
## 16 2015                  646        0.96 Francs
```

Why should we care?

Source: https://www.sciencefocus.com/future-technology/how-much-data-is-on-the-internet/.

How much data is stored on the Web?

“One way to answer this question is to consider the sum total of data held by all the big online storage and service companies like Google, Amazon, Microsoft and Facebook. Estimates are that **the big four store at least 1,200 petabytes** between them. That is **1.2 million terabytes (one terabyte is 1,000 gigabytes)**.” (Gareth Mitchell, ScienceFocus)

Q&A

References

Murrell, Paul. 2009. **Introduction to Data Technologies**. London, UK: CRC Press.