Data Formats

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Outline

- We will look into several formats for **encoding data**

- **CSV** – Comma-Separated Values
- **XML** – Extensible Markup Language
- **JSON** – JavaScript Object Notation
- **BSON** – Binary JSON
- **RDF** – Resource Description Framework
- **Protocol Buffers**

Data encoding

- Software applications inevitably **change** over time.
  - In most cases, this also requires a change to data.
  - Old and new versions of the code, and old and new data formats, may potentially all coexist in the system at the same time.
- For the system to continue running smoothly, we need to maintain compatibility in both directions:
  - **Backward compatibility** - newer code can read data that was written by older code.
  - **Forward compatibility** - older code can read data that was written by newer code. It requires older code to ignore additions made by a newer version of the code.

Data encoding

- Programs usually work with data …
  - In memory, data is kept in objects, structs, lists, arrays, hash tables, trees and so on.
  - Out of memory, to write data to a file, or send it over the network (i.e., a different sequence of bytes).
- The translation from the in-memory representation to a byte sequence is called **encoding** (also known as **serialization** or marshalling),
- The reverse is called **decoding** (parsing, **deserialization**, unmarshalling).

Language-specific formats

- Many programming languages come with built-in support for encoding in-memory objects into byte sequences.
  - Java (*Serializable*), Ruby (*Marshal*), Python (*pickle*), ...
- These encoding libraries are very convenient, but…

- … reading the data in another language is very difficult.
  - using such kind of encoding commits to the current programming language.
- So, it is a bad idea to use these built-in encoding for anything other than **transient purposes**.

Textual Formats

- Main advantage: human-readable
  - Examples: CSV, JSON, XML and RDF
- But they bring some **issues**:
- **Ambiguity** between a **number** and a **string**
  - JSON handles this, but not integers # floating-point, i.e., lacks to specify precision.
- CSV does **not** have any **schema**
  - It is up to the application to define the meaning of each row and column.

- Despite some flaws, JSON, XML and CSV are good enough for many purposes.

Binary Encoding

- Binary encoding
- More compact, faster to parse.
  - For a small dataset, the gains are negligible, but once you get into the terabytes, the choice of data format can have a big impact.
- Some binary encodings for JSON
  - MessagePack, BSON, BJSON, UBJSON, BISON, and Smile, …
- But none of them is as widely adopted as the textual versions of JSON and XML.

CSV

- **CSV – Comma-Separated Values**
- XML – Extensible Markup Language
- JSON – JavaScript Object Notation
- BSON – Binary JSON
- RDF – Resource Description Framework
- Protocol Buffers

CSV – Comma-Separated Values

- Unfortunately, not fully standardized
  - Different field separators (commas, semicolons)
  - Different escaping sequences
  - No encoding information
- File extension: *.csv
- RFC 4180, RFC 7111
  - URI Fragment Identifiers for the text/csv Media Type
- Media type (MIME)
  - Content type: text/csv

Example

- Document
  - A header line (optional) + records

```
firstname,lastname,year
Ana,Katrina,1974
Paul,Machado,1956
Luis,Morais,1974
Sofia,Silvasky,1986
Maria,Marinova,1976
```

XML

- CSV – Comma-Separated Values
- **XML – Extensible Markup Language**
- JSON – JavaScript Object Notation
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XML – Extensible Markup Language

- Representation of semi-structured data
  - + a family of related technologies, languages, specifications, …
- Derived from SGML, developed by W3C, since 1996
- Design goals
  - Simplicity, generality and usability across the Internet
- File extension: *.xml, content type: text/xml
- Versions: 1.0 and 1.1
- W3C recommendation
  - http://www.w3.org/TR/xml11/
- XML formats = particular languages
  - **XSD**, XSLT, XHTML, DocBook, ePUB, SVG, RSS, SOAP, …

Example

```xml
<?xml version="1.1" encoding="UTF-8"?>
<movie year="2007">
    <title>The Great Marnoto</title>
    <actors>
        <actor>
            <firstname>Jakim</firstname>
            <lastname>Dalmeida</lastname>
        </actor>
        <actor>
            <firstname>Sofia</firstname>
            <lastname>Ravara</lastname>
        </actor>
        </actors>
    <director>
        <firstname>Paulo</firstname>
        <lastname>Castanho</lastname>
    </director>
</movie>
```

Constructs – Element

- Marked using <opening> and </closing> tags
  - … or an abbreviated tag in case of empty <elements/>
- Each element can have a set of attributes
- Well-formedness is required
- Types of content
  - Empty content
  - Text content
  - Element content
    - Sequence of nested elements
  - Mixed content
    - Elements arbitrarily interleaved with text

JSON

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- XML – Extensible Markup Language
- **JSON – JavaScript Object Notation**
- BSON – Binary JSON
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JSON – JavaScript Object Notation

- Open standard for data interchange
- Design goals
  - Simplicity: text-based, easy to read and write
  - Universality: object and array data structures
    - Supported by majority of modern programming languages
- Derived from JavaScript (but language independent)
- Started in 2002
- File extension: *.json
- Content type: application/json
- http://www.json.org/

JSON structure

- JSON is built on two structures:

- A **collection of name/value pairs**.
  - In various languages, this is realized as an *object*, record, struct, dictionary, hash table, keyed list, or associative array.
- An **ordered list** of values.
  - In most languages, this is realized as an *array*, vector, list, or sequence.

Example

```json
{
   "title":"The Great Marnoto",
   "year":2007,
   "actors":[
      {
         "firstname":"Jakim",
         "lastname":"Dalmeida"
      },
      {
         "firstname":"Sofia",
         "lastname":"Ravara"
      }
   ],
   "director":{
      "firstname":"Paulo",
      "lastname":"Castanho"
   }
}
```

Data Structure – Object

- Unordered collection of name-value pairs (properties)
  - Correspond to structures such as objects, records, structs, dictionaries, hash tables, keyed lists, associative arrays, …

- Example

```
{ "name" : ”Manuel Sliav", "year" : 2000 }
{ }
```

Data Structure – Array

- Ordered collection of values
  - Correspond to structures such as arrays, vectors, lists, sequences, ...
- Values can be of different types, duplicate values are allowed
- Example

```
[ 2, 7, 7, 5 ]
[ "Some person", 1979, 77 ]
[ ]
```

Data Structure – Value

- Unicode string
  - Enclosed with double quotes
  - Backslash escaping sequences
    - Example: `"a \n b \" c \\ d"`
- Number
  - Decimal integers or floats
    - Examples: `1`, `-0.5`, `1.5e3`
- Nested object
- Nested array
- Boolean value: `true`, `false`
- Missing information: `null`

```
{
  "stuff": {
     "onetype": [
        {"id":1,"name":"John"},
        {"id":2,"name":"Don"}
     ],
     "othertype":
        {"id":2,"company":"ACME"}
  },
  "otherstuff": {
     "thing": [[1,42],[2,2]]
  }
}
```

BSON

- CSV – Comma-Separated Values
- XML – Extensible Markup Language
- JSON – JavaScript Object Notation
- **BSON – Binary JSON**
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BSON – Binary JSON

- Binary-encoded serialization of JSON documents
  - Design characteristics: lightweight, **traversable**, efficient
  - **convenient storage of binary information**:
    - better suitable for exchanging **images** and **attachments**
  - designed for **fast in-memory manipulation**
  - **extra data types (then JSON)**:
    - double, date, byte array, JavaScript code, …
- Used by MongoDB
  - Document NoSQL database for JSON documents
  - Data storage and network transfer format
- File extension: *.bson
- http://bsonspec.org/

Example

- JSON

```
{
  "title" : "Marnoto",
  "year" : 2007
}
```

- BSON

```
            t   i t   l e               M
2200 0000 0274 6974 6c65 0008 0000 004d
a r  n o  t o       y e  a r   2007      // = 0x07d7
6172 6e6f 746f 0010 7965 6172 00d7 0700
0000
```

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Document Structure

- **Document**
  - serialization of one JSON object or array
- JSON object is serialized directly
- JSON array is first transformed to a JSON object
  - Property names correspond to position numbers , e.g.

    `[ "Some", "Another" ] → { "0" : "Some", "1" : "Another" }`
- Structure
  - Document size (total number of bytes)
  - Sequence of elements
  - Terminating hexadecimal 00 byte

```
               t  i t  l e               M
2200 0000 0274 6974 6c65 0008 0000 004d
a r  n o  t o       y e  a r    2007  // = 0x07d7
6172 6e6f 746f 0010 7965 6172 00d7 0700
0000
```

Document Structure

- **Element**
  - serialization of one JSON property
- Structure
  - Type selector
    - 02 (string), 03 (object), 04 (array)
    - 01 (double), 10 (32-bit integer), 12 (64-bit integer)
    - 08 (boolean), 09 (datetime), 11 (timestamp)
    - 0A (null)
    - …
  - Property name
    - Unicode string terminated by 00
  - Property value

```
                 t  i t  l e            M
2200 0000 0274 6974 6c65 0008 0000 004d
a r  n o  t o       y e  a r   2007  // = 0x07d7
6172 6e6f 746f 0010 7965 6172 00d7 0700
0000
```

RDF

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RDF – Resource Description Framework

- Language for representing information about resources in the World Wide Web
  - \+ a family of technologies, languages, specifications, …
  - Used in graph databases and in the context of the Semantic Web, Linked Data, …
- Developed by W3C
  - Started in 1997
- Versions: 1.0 and 1.1
- W3C recommendations
  - https://www.w3.org/TR/rdf11-concepts/
    - Concepts and Abstract Syntax
  - https://www.w3.org/TR/rdf11-mt/
    - Semantics

Statements

- RDF is based on the concept that every **resources** can have different **properties** which have **values**.
- Resource - Any real-world entity
  - **Referents** = resources identified by IRI (Internationalized Resource Identifier)
    - E.g. physical things, documents, abstract concepts, …

      `http://db.pt/movies/Marnoto`
      `http://db.pt/terms#actor`
      `mailto:somegirl@nowhere.com`
      `urn:issn:0167-6423`

  - **Values** = resources for literals
    - E.g. numbers, strings, …

Statements

- Example of a **statement** about a web page:

  `http://www.example.org/index.html has an author whose name is Pete Maravich.`

- A RDF statement is a **triple** that contains a:
  - **Resource**, the **subject** of a statement
  - **Property**, the **predicate** of a statement
  - **Value**, the **object** of a statement

- Several properties for this web page could be:

  `http://www.example.org/index.html has an author whose name is Pete Maravich.`

  `http://www.example.org/index.html has a language which is English.`

  `http://www.example.org/index.html has a title which is Example_Title.`

RDF example

```
<?xml version="1.0"?>

<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:foaf="http://xmlns.com/foaf/0.1/"
         xmlns:edu="http://example.org/education#">

  <!– Resource Descriprion: João -->
  <rdf:Description rdf:about="http://example.org/people/Joao">
    <foaf:name>João Silva</foaf:name>
    <foaf:age>30</foaf:age>
    <foaf:mbox rdf:resource="mailto:joao.silva@example.org"/>
    <foaf:knows rdf:resource="http://example.org/people/Maria"/>
    <edu:studiedAt rdf:resource="http://example.org/university/ABC"/>
  </rdf:Description>

  <!-- Resource Descriprion: Universidade -->
  <rdf:Description rdf:about="http://example.org/university/ABC">
    <foaf:name>Universidade ABC</foaf:name>
    <foaf:location>Lisboa, Portugal</foaf:location>
  </rdf:Description>
</rdf:RDF>
```

Resource

Value

Property

Resource

Value

Serialization approaches

- RDF/XML notation
  - XML syntax for RDF (.rdf, .rdfs, .owl, .xml)
  - https://www.w3.org/TR/rdf-syntax-grammar/
- Turtle notation (Terse RDF Triple Language)
  - .ttl extension
  - https://www.w3.org/TR/turtle/
- N-Triples notation
  - .nt extension
  - https://www.w3.org/TR/n-triples/
- JSON-LD notation
  - JSON-based serialization for Linked Data
  - https://www.w3.org/TR/json-ld/

Protocol Buffers

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Protocol Buffers

- Protocol Buffers is a **binary** encoding library that require a **schema** for any data that is encoded.
- Extensible mechanism for serializing structured data
  - Used in communication protocols, data storage, …
- Developed (and widely used) by Google
  - Mostly for server-side communication
- Design goals
  - Language-neutral, platform-neutral
  - **Small**, **fast**, **simple**
- File extension: *.proto
- https://developers.google.com/protocol-buffers/

Protocol Buffers

- Intended usage
  - Schema creation
    → automatic source code generation
      → sending messages between applications
- Components
  - Interface description language
  - Source code generator (`protoc` compiler)
  - Supported languages
    - Official: C++, C#, Java, Python, Ruby …
    - 3rd party: Perl, PHP, Scala, …
  - Binary serialization format
  - Compact, not self-describing

Schema: encoding examples

```
message Person {
    required string  user_name = 1;
    optional int64   favorite_number = 2;
    repeated string  interests = 3;
}
```

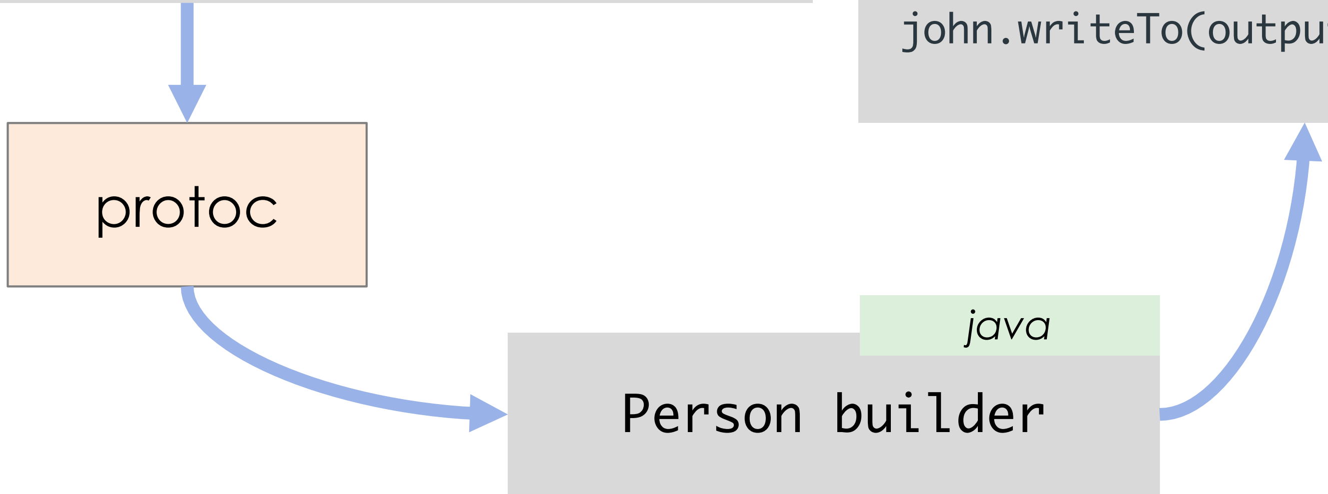
```
syntax = "proto3";
message Actor {
    string firstname = 1;
    string lastname = 2;
}
message Movie {
    string title = 1;
    int32 year = 16;
    repeated Actor actors = 17;
    enum Genre {
        UNKNOWN = 0;
        COMEDY = 1;
    }
    repeated Genre genres = 2048;
}
```

Example: ProtoBuf to Java

```
message Person {
  required string name = 1;
  required int32 id = 2;
  optional string email = 3;
}
```

java

```java
Person john = Person.newBuilder()
    .setId(1234)
    .setName("John Doe")
    .setEmail("jdoe@example.com")
    .build();
output = new
FileOutputStream(args[0]);
john.writeTo(output);
```



Summary

Data encoding formats:

- **Programming-language-specific**
  - restricted to a single programming language.
- **Textual** formats
  - widespread, and its compatibility depends on the use.
  - Somewhat vague about datatypes, namely numbers and binary strings.
- **Binary** schema-driven formats
  - More compact and efficient encoding, with clearly defined forward and backward compatibility semantics.
  - The schema can be useful for documentation and code generation in statically typed languages.

Summary

Data formats

- **Relational**: CSV
- **Tree**: XML, JSON
- **Graph**: RDF
- **Binary**: BSON, Protocol Buffers

Other binary formats

- **Avro**
  - Apache
- **Thrift**
  - Facebook + Apache
- MessagePack

… *and many others*

- A good comparison is available at:
  - https://en.wikipedia.org/wiki/Comparison_of_data_serialization_formats

Resources

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- Eric Redmond, Jim R. Wilson. ***Seven databases in seven weeks***, Pragmatic Bookshelf, 2012.
- Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom, ***Database systems: the complete book*** *(2nd Ed.)*, Pearson Education, 2009.