TDA357/DIT621 – Databases

Lecture 10 – Semi-structured Data Model, NoSQL, XML and JSON

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Stepping outside the box

- Data does not have to be in tables. How else can we do it?
- Graph databases
  - Our data is a graph with nodes
- Key/value stores
  - Store all data in a big map, lookup keys and get values
  - Simple, efficient, but kind of limited
- Document databases
  - Store *documents*, that in turn contain structures
  - Inefficient, weak integrity, but lightweight and portable

We will focus on this

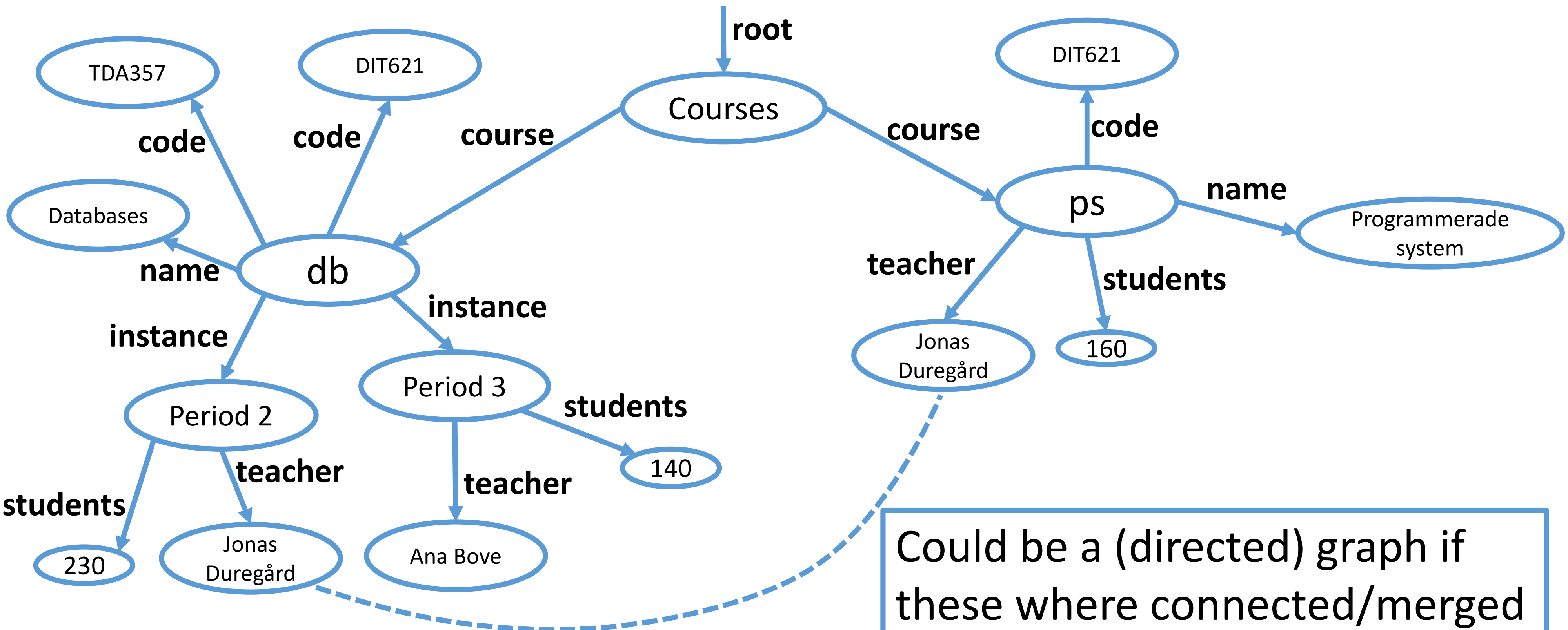
Semi-structured data (SSD)

- The relational model has a very rich structure
  - Allows us to have strong constraints on data
- This structure also limits flexibility
  - Much of the design work is centered on deliberately preventing users from being flexible (by enforcing constraints)
- In semi-structured data models, the schema is flexible
  - Data is still structured

  … but the structure is not necessarily uniform across the data
  - E.g. data does not fit in tables where every row has the same columns

A different way of structuring data

- Here as a tree of objects, with attribute-labels on edges and data in nodes
- Note how the "attributes" of courses differ (db has multiple instances)

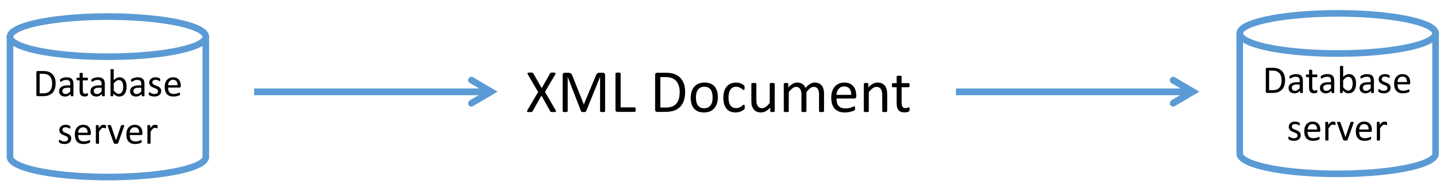


Examples of document-based SSD standards

- XML
  - Extensible Markup Language
  - Created in the 1990's
  - Syntax: <tag attribute="value"><other_tag/>also some text</tag>
- JSON
  - JavaScript Object Notation
  - Created in the 2000's
  - Collections of key/value pairs, very simple syntax
  - Used to various extents in lots of modern DBMS
- Both these are *document based*, a data set is most naturally described by a text document rather than a table
- Both are hierarchical, the documents have a tree-structure

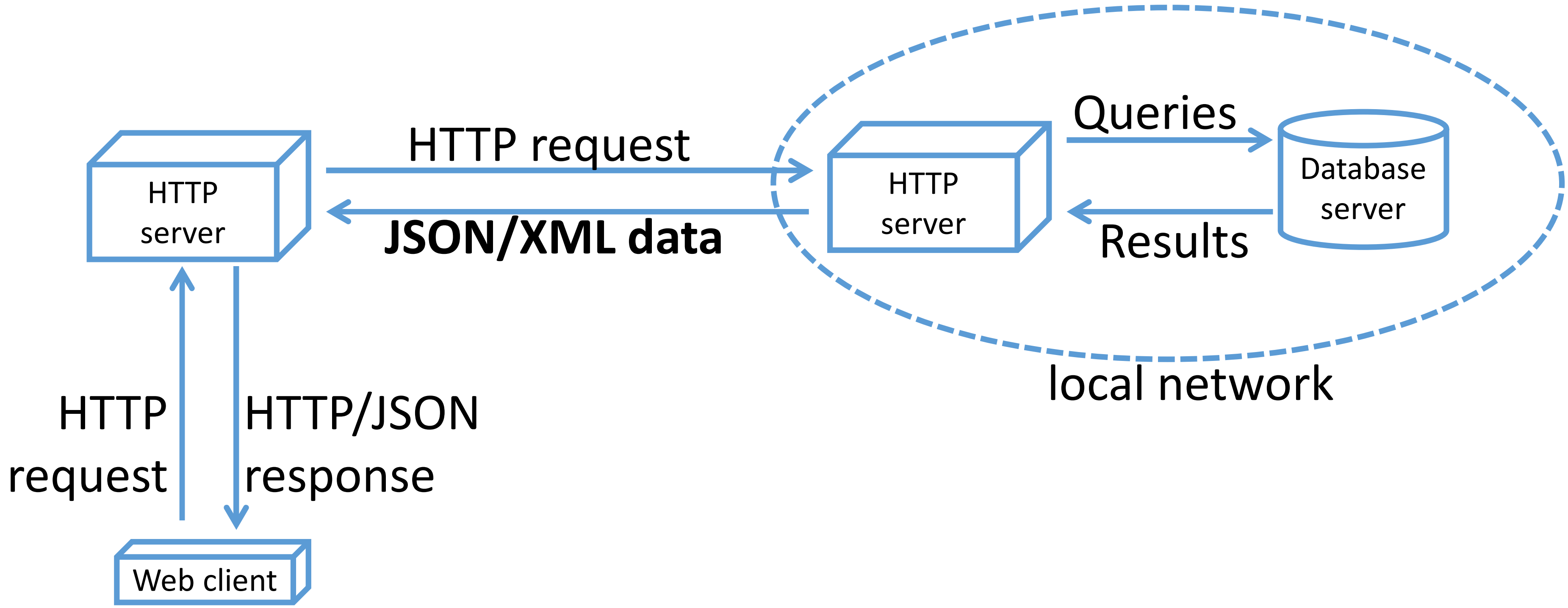
Data interchange formats

- Data interchange formats facilitate the transfer of data from one database to another
- Transforms data from one schema to another, via an intermediate format
- The interchange format must be flexible enough to conveniently represent data from both schemas



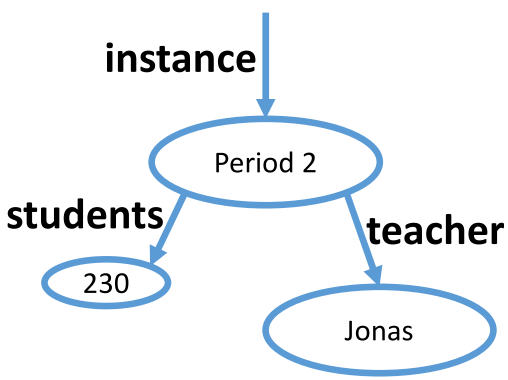
Cross domain communication

- When modern web services build web pages, it is not uncommon that they request information from other web servers
- Direct access to database servers over the Internet is not advisable



XML

- Derived from pre-existing document markup languages
  - Compare with HTML: HTML uses tags to format a web-page, XML uses tags to describe data
- Documents are built from elements, attributes and text



One way to express this tree in XML:

```
<instance name="Period 2">
  <teacher>Jonas</teacher>
  <students>230</students>
</instance>
```

Closing tags

Contains 3 elements (instance, teacher, and students), 1 attribute (name), and 2 element texts (Jonas, 230)

Hierarchical structure of xml

- XML documents always have a single root element, that in turn may contain other elements with attributes/elements of their own etc.
- All tags must be closed
  - Allowed: `<grades><grade>G</grade><grade>VG</grade></grades>`
  - Not allowed: `<grades><grade>G<grade>VG</grades>`
  - Special case, self closing tag: `<tag/>` or `<tag att="val"/>`
- Tags must be properly nested
  - Allowed: `<a><b><c>text</c></b></a>`
  - Not allowed: `<a><b><c>text</b></c></a>`

Uses to close <c>

Mixing texts and elements

- It is valid to have text and subelements in the same element:
  `<tag>`**`text`**`<subtag></subtag></tag>`
- This is considered bad practice, especially when you have things like `<tag>`**`text`**`<subtag></subtag>`**`more text`**`</tag>`
  - What is the semantic difference between the text before/after the subtag?
  - In the hierarchical structure the two texts are on the same level

Attributes vs elements

- Two ways of representing a person in XML:

```
<Teacher>
     <Firstname>Jonas</Firstname>
     <Lastname>Duregård</Lastname>
     <Course>Databases</Course>
</Teacher>
```

Element-centric

Attribute-centric

```
<Teacher firstname="Jonas" lastname="Duregård" course="Databases"/>
```

- Attributes and elements can be mixed however we want. What should we use?
  - Having firstname as an attribute and lastname as en element seems odd
  - Maybe firstname/lastname should be attributes, and courses elements (the names feel "attributy" whereas a course feels more "entityish")

Not technical terms...

Attributes vs elements

- Suppose we want Jonas to have two courses, and each course to have both a name and a code?
- Elements are easy to extend, attributes are very limited

```
<Teacher>
    <Firstname>Jonas</Firstname>
    <Lastname>Duregård</Lastname>
    <Course>Databases</Course>
</Teacher>
```

```
<Teacher>
    <Firstname>Jonas</Firstname>
    <Lastname>Duregård</Lastname>
    <Course>
        <Name>Databases</Name>
        <Code>TDA357</Code>
    </Course>
    <Course>
        <Name>Programmerade system</Name>
        <Code>TDA143</Code>
    </Course>
</Teacher>
```

Extra name element to avoid mixing text and elements

Summary: Attributes vs elements

- Advantages of attributes:
  - Compact syntax
  - Correspond naturally to attributes in relational databases
- Advantages of elements:
  - Can represent complex objects (with attributes, subelements etc.)
  - Can have arbitrarily many elements with the same tag
  - Easily extensible (remember: we are using XML for flexibility!)
- Compare with ER-modelling: Anything that needs to have attributes of its own can never be an attribute
- Often, elements are used to represent the actual data, while attributes are used to describe "modifiers" of tags

Is an XML document a database?

- Yes, in a wide sense
- It contains data in a structured, (sort of) persistant manner
- It is very unlike a relational database:
  - There is no "XML-server" corresponding to PostgreSQL
  - There is no insert operation that adds data into a document
    - Documents are either generated by a program or written by hand
  - We typically do not write queries on our documents (but we can)
    - Documents are processed by programs, using library functions etc.
  - We do not have constraints on documents (but they can be *validated*)

JSON

- Think of JSON documents as Java(Script) objects without any methods
  - Objects that can have variables (that are objects or primitive types)
  - The "variable names" are called keys in JSON
- This document contains an object that has a single variable/key, "Teacher"
- The value of "Teacher" is an object containing three variables of type String

```
{
  "Teacher": {
    "Firstname": "Jonas",
    "Lastname": "Jonas",
    "Course": "Databases"
  }
}
```

Start/end object

key: value

This (and all JSON) is actual JavaScript code!

XML or JSON

- Here is a tiny XML document, and a tiny JSON document
  - Notice how they are doing pretty much the same thing?

```xml
<Teacher>
    <Firstname>Jonas</Firstname>
    <Lastname>Duregård</Lastname>
    <Course>Databases</Course>
</Teacher>
```

Four elements and three strings

```json
{
  "Teacher": {
    "Firstname": "Jonas",
    "Lastname": "Jonas",
    "Course": "Databases"
  }
}
```

Two objects, four keys, and three strings

XML or JSON

- Both XML and JSON can be used as semi-structured data formats
  - E.g. to receive data from a web server, for data exchange etc.
- Both are used in practice and there are good arguments for using either
- Traditionally this course has taught only XML, the last few year we are switching focus towards JSON
  - It has simpler syntax
  - It is growing quickly into the standard data format of the web
  - JSON is now used in the Assignment (Task 4)

So what will I need to know for the exam?

- *Read* and understand XML documents (already done)
- *Read*, *write*, *validate* and *query* JSON documents (rest of this weeks lectures, and the exercise on Friday)
- Most old exam questions (pre-2018 or so) about XML can be translated into corresponding JSON questions (replacing DTD with JSONSchema and XPath with JSONPath)

Full syntax of JSON

Every JSON document is built from a combination of six types:

Structures:

- Objects: **{** "key1" **:** JSON**,** "key2" **:** JSON**, ...}**
  Can have 0 or more key:value pairs, values can be any JSON value
- Arrays/lists: **[**JSON**,** JSON**, ...]**
  Can have 0 or more items, each can be any JSON value

Literals (usually the "leaves" in the document tree):

- Java-esque strings: `"Hello world!\n"`
- Numbers: 7, 5.3
- Booleans: **true** or **false**
- **null**

Recursive definition

An example document

```
[{"city":"Boston", "population":700000}
,{"city": "New York",
  "boroughs": [
           "The Bronx",
           "Brooklyn",
           "Manhattan",
           "Queens",
           "Staten Island"
         ]
 }
]
```

- An array containg two objects
- First object has two keys:
  city (string) and population (number)
- Second object has two keys:
  city (string) and boroughs (array)
- The array in boroughs contains five strings

Simple paths in JSON

```
[{"city":"Boston", "population":700000}
,{"city": "New York",
  "boroughs": [
         "The Bronx",
         "Brooklyn",
         "Manhattan",
         "Queens",
         "Staten Island"
       ]
 }
]
```

- We can use Java-like object syntax to address sub-values in documents
- If we call this document d,
  what is the value of d[1].boroughs[2]?
  - Answer: `"Manhattan"`
- What about d[0]?
  - Answer: `{"city":"Boston", "population":700000}` (an object)
- What about d[0].city.population?
  - Answer: d[0].city is not an object, so applying .population is an error
    (or maybe null depending on your philosophical beliefs)

JSON and types

- Arrays in JSON are heterogenous, this is allowed:

```
[1, "string", {"key":0}, true, [1,2]]
```

- It's an array containing a number, a string, an object, a boolean and an array
    - In practice we may want to limit ourselves to homogenous arrays, where all values have the same type

JSON Documents do not need to be objects

- Often, the top level of a document is an object
- Sometimes it's an array
- It can in principle be just a number, a string, or a boolean
- Examples, all of these are valid JSON documents:
  - 42
  - true
  - null
  - "hello world"

Which are well formed JSON documents?

`[[[1]]]`

- Yes, this is an array containing an array containing an array containing 1

`{{"city" : "Gothenburg"}}`

- No! The outer object is not on the form key:value

`{"city" : "population" : 3000}`

- No! This is on the form x:y:z which is never allowed in objects

`{"city":{"boston"}}`

- No! The object `{"boston"}` is not valid (contents should be key:value)

`[{}, [], ""]`

- Yes, it's an array containing the empty object, array and string

Building JSON documents using Postgres

Try it out

- All the code from this slide on is available on the course homepage in jsonpostgres.sql
- Run it, modify it to do something different, use part of it as a base for the information part of Task 4 …

https://www.postgresql.org/docs/current/functions-json.html
https://www.postgresql.org/docs/current/datatype-json.html

JSON support in Postgres

Postgres (especially version 12+) has extensive support for JSON

- Covered this lecture:
  - Two SQL types for: JSON (text format) and JSONB (faster binary format)
    - You can have JSON documents in table cells, views, query results, …
  - Functions for building JSON documents
  - Operators for extracting values from JSON documents
    (e.g. turn a JSON string to an SQL string to use it in a WHERE-clause)
- Covered next lecture:
  - Writing JSON Path queries to extract more advanced data from JSON

A very flexible table

- This could be a table in some social media application
- It has three regular old columns with regular old constraints, and a fourth column containing JSONB
- The idea is that the JSON can contain data in a more flexible format that can be extended without changing the DB design

```
CREATE TABLE Posts(
  id SERIAL PRIMARY KEY,
  author TEXT NOT NULL REFERENCES Users(uname),
  created TIMESTAMP NOT NULL,
  content JSONB NOT NULL
);
```

The only new stuff on this slide!

Inserting data

`Posts(id, author, created, content)`

- One way of encoding a link post and a picture post

Sometimes, we need to use `::TYPE` to convert values to different SQL types

```
INSERT INTO Posts VALUES (
  DEFAULT,
  'Jonas',
  CURRENT_TIMESTAMP,
  '{"link" : "https://xkcd.com/327/", "preview":true}' :: JSONB
);

INSERT INTO Posts VALUES (
  DEFAULT,
  'Jonas',
  CURRENT_TIMESTAMP,
  '{"picture" : "funnycat.gif", "prop":{"size":15434}}' :: JSONB
  );
```

JSON values written as `string :: JSONB`

`Posts(id, author, created, content)`

Basic querying with JSON

```
SELECT * FROM Posts;

 id | author |          created           |                           content
----+--------+----------------------------+------------------------------------------------------------------
  1 | Jonas  | 2019-11-28 15:01:31.247316 | {"link": "https://xkcd.com/327/", "preview": true}
  2 | Jonas  | 2019-11-28 15:01:31.252545 | {"prop": {"size": 15434}, "picture": "funnycat.gif"}
```

```
SELECT id, content->'link' AS url FROM Posts;

 id |           url
----+--------------------------
  1 | "https://xkcd.com/327/"
  2 |
```

Gives content.link as a JSONB value

This is a JSON string (not an SQL string)

This is a (SQL) null value (not a JSON null value!)

`Posts(id, author, created, content)`

Using JSON in WHERE-clauses

- Find all picture posts:

```sql
SELECT id, content FROM Posts
  WHERE content->'picture' IS NOT NULL;
```

```
 id |                    content
----+---------------------------------------------
  2 | {"prop": {"size": 15434}, "picture": "funnycat.gif"}
```

As a shorthand, Postgres allows: `WHERE content ? 'picture';`

Even more JSON querying

- Two ways of finding all posts with enabled previews

Compare to the JSON true value

```
SELECT * FROM Posts
  WHERE (content->'preview') = 'true';
```

Convert the JSON boolean to an SQL boolean

```
SELECT * FROM Posts
  WHERE (content->'preview') :: BOOLEAN ;
```

Always remember the difference between e.g. a JSON number and an SQL number

Nested access

- Select the size property of all posts

```
SELECT id, content, content->'prop'->'size' AS postsize
 FROM Posts;
```

```
 id |                      content                       | postsize
----+----------------------------------------------------+----------
  1 | {"link": "https://xkcd.com/327/", "preview": true}  |
  2 | {"prop": {"size": 15434}, "picture": "funnycat.gif"} | 15434
```

A tiny JSON document (type JSONB), not an SQL number

Use what you already know

- All the new JSON features can be combined with the SQL feature we already know to express even more!
- Example: Select all post sizes, replace nulls with 0's and convert to SQL numbers

```
SELECT
  id,
  COALESCE(content->'prop'->'size','0') :: NUMERIC AS postsize
 FROM Posts;
```

```
 id | postsize
----+----------
  1 |        0
  2 |    15434
```

We can create a view from this, aggregate with SUM to compute total size for each user etc.

SQL numbers

Building JSON in query results

- Even if you have no tables with JSON values, you can still use JSON in postgres
  - We can run queries that construct JSON documents from table data
  - This is what you will be doing in the lab (Task 4) so pay attention ☺

Building objects: jsonb_build_object

- A built in stored procedure (function) for creating JSON objects:

`jsonb_build_object(key1,value1,key2,value2,…)`

- Example (three rows in Posts):

```
SELECT id, jsonb_build_object(
                 'user',author,
                 'postid',id
                 ) AS jsondata
  FROM Posts;
```

Selects id, and also a little JSON object for each row in Post

```
 id |               jsondata
----+--------------------------------
  1 | {"user": "Jonas", "postid": 1}
  2 | {"user": "Jonas", "postid": 2}
  3 | {"user": "sanoJ", "postid": 3}
```

Table: Posts

id	author	…
1	Jonas	…
2	Jonas	…
3	sanoJ	…

Strings, numbers etc. are automatically converted from SQL to JSON

Aggregating into JSON arrays: jsonb_agg

- jsonb_agg is an aggregation function (like SUM, COUNT, …)
  - Must either be the only thing selected, or have a GROUP BY
- Simple example, build an array with all post authors (3 rows in Posts):

```
SELECT jsonb_agg(author) AS jsonarray
  FROM Posts;
```

```
          jsonarray
-------------------------------
 ["Jonas", "Jonas", "sanoJ"]
(1 row)
```

Groups together all rows and takes the author value from each row in the group

Always gives a single row (without GROUP BY)

Example using group by

Table: Posts

<u>id</u>	author	…
1	Jonas	…
2	Jonas	…
3	sanoJ	…

- Task: For each user in Posts, create a JSON array containing JSON objects for every post the user has
- Desired output for our table:

```
 author |                        jsondata
--------+---------------------------------------------------------
 Jonas  | [{"user":"Jonas","postid":1},{"user":"Jonas","postid": 2}]
 sanoJ  | [{"user":"sanoJ","postid":3}]
```

Plan:

- Group rows by their author
- for each group use jsonb_agg to create a JSON array item for every post
- use jsonb_build_object to create objects in the array

Example continued

Table: Posts

id	author	...
1	Jonas	...
2	Jonas	...
3	sanoJ	...

- Group rows by their author
- for each group use jsonb_agg to create a JSON array item for every post
- use jsonb_build_object to create objects in the array

```
SELECT author, jsonb_agg(jsonb_build_object(
                    'postid',id,
                    'user',author)) AS jsondata
  FROM Posts
  GROUP BY author;
```

```
 author |                    jsondata
--------+------------------------------------------------------
 sanoJ  | [{"user":"sanoJ","postid":3}]
 Jonas  | [{"user":"Jonas","postid":1},{"user":"Jonas","postid": 2}]
```

Going nuts with correlated queries

- This beautiful query creates a JSON object for each user, containing their basic information and an array of posts

```
SELECT
  json_build_object(
    'uid', uname,
    'email', email,
    'posts', (SELECT COALESCE(jsonb_agg(jsonb_build_object(
              'postid',id,
              'time',created)
            ),'[]') FROM Posts WHERE author = U.uname)
  )
  FROM Users U;
```

A single item in the SELECT, building a massive JSON object for each row in Users

Refers to outer query

jsonb_agg gives (SQL) null for empty sets, so coalesce to []

- One row from the result of the query on the last slide:

```
{"uid" : "Jonas",
 "email" : "jonas.duregard@chalmers.se",
 "posts" :
    [{"time": "2021-11-02T14:52:37.451796",
      "postid": 1}
    ,{"time": "2021-11-02T14:52:37.453225",
      "postid": 2}
    ]
 }
```

A number in an object in an array in an object ☺
This is at position x.posts[1].postid
Tells us that one of the posts for user Jonas has ID 2

Regarding the assignment

- In the assignment you are supposed to create a JSON object for a given student containing lots of information, including lists of passed courses and such
- Hey, that sounds a lot like the thing on the last slide!
  - It is possible to solve the whole information part of Task 4 using one glorious query
  - Experiment in a .sql file until you get it working, then move it into Java
- You don’t have to use the JSON features of Postgres at all in the lab, but I highly recommend it

Tomorrow

- JSON Schema
  - Final piece of the puzzle for the assignment!
- JSON Path