Distributed Systems

RESTful APIs

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Definition 2

"We can identify two major classes of Web services:
REST-compliant Web services, in which the primary purpose of the service is to manipulate XML representations of Web resources using a uniform set of "stateless" operations; and arbitrary Web services, in which the service may expose an arbitrary set of operations."

— W3C, Web Services Architecture (2004)

Agenda

- REST
- HTTP
- RESTful Web Services

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Representational State Transfer

Representational State Transfer (REST) is an architectural style for distributed hypermedia systems.

Definition

"The name "Representational State Transfer" is intended to evoke an image of how a well-designed Web application behaves: a network of web pages (a virtual state-machine), where the user progresses through the application by selecting links (state transitions), resulting in the next page (representing the next state of the application) being transferred to the user and rendered for their use."

Defined in 2000 by Roy Fielding in his doctoral dissertation.

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  - A representation contains all necessary information to modify a **resource**
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  - The same data can have multiple representations (e.g., JSON, HTML, XML)
  - All changes to the state of a resource shall only happen via its representation

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- Transfer
  - Client-server architecture
  - Server acts as a **producer**, stores and provides the data
  - Client acts as a **consumer** and requests the data

What is REST?

- REST is an **architectural style**, not a standard
- It was designed for distributed systems to address **architectural properties** such as performance, scalability, simplicity, modifiability, visibility, portability, and reliability
- REST's architectural style is defined by **6 principles/architectural constraints** ($\rightarrow$ next slide)
- Systems and APIs that conforms to the constraints of REST can be called **RESTful**

REST Principles

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- Uniform interface
  - **Resource**-based
  - Manipulation of resource through representation
  - Self-descriptive messages
  - Hypermedia as the engine of application state

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- Code on Demand (optional)

Building RESTful API

- Can be built on top of existing web technologies
- Reusing semantics of HTTP 1.1 methods
- Safe and idempotent methods
- Typically called HTTP verbs in context of services
- Resource oriented, correspond to CRUD operations
- Satisfies uniform interface constraint
- HTTP Headers to describe requests & responses
- Content negotiation

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Recap

What do you remember about HTTP?

Hypertext Transfer Protocol (HTTP)

- HTTP is a stateless protocol for data transmission
  - Stateless means that every HTTP message contains all the information necessary to understand the message
  - The server does not maintain any information regarding the state or session for the client, and each request is a transaction, independent of other requests
- Specified in RFCs 1945, 2068, 7540, 9114, and many more
- Uses TCP via port 80 or 443 (HTTPS → HTTP over a secure channel)
- Originally developed by Roy Fielding, Tim Berners-Lee, and others at CERN from 1989 onwards
- Updated to version 2 (HTTP/2) in 2015
- Currently in version 3 (HTTP/3) and based on QUIC

World Wide Web

- Together with the concepts of URL[1] and HTML[2] it is the basis of the World Wide Web (WWW)
- Original main purpose: Loading web pages from webserver in a browser
- HTTP needs a reliable transport protocol → TCP
- Each HTTP message consists of:
  - *HTTP header*: Includes among others information about the encoding, desired language, browser, and content type
  - *Body*: Contains the payload, e.g., the HTML source code of a web page
- Today many application work on top of HTTP, e.g., using web sockets

[1] URL = Uniform Resource Locator
[2] HyperText Markup Language

HTTP Methods

- The HTTP protocol provides several requests messages

Request	Description
`PUT`	Upload a new resource to the web server
`GET`	Request a resource from the web server
`POST`	Upload data to the web server in order to generate resources
`DELETE`	Erase a resource on the web server

- Other commands like `HEAD` or `TRACE` exist.

About state

HTTP is a stateless protocol. But via cookies in the header information, applications can be implemented which require state or session information because they assign user information or shopping carts to clients.

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POST

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POST

- Request to the server to create a resource and return its name

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- Requesting client knows the name of the resource on the server
- Requests for the **attached entity** (in the request body)

POST

- Request to the server to create a resource and return its name
- Request that the origin server **accept the attached entity**

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- Requesting client knows the name of the resource on the server
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- **Idempotent**

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- Request to the server to create a resource and return its name
- Request that the origin server **accept the attached entity**
- **Not idempotent**

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- Requesting client knows the name of the resource on the server
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- Modify a **singular resource** that is a part of resources collection.

POST

- Request to the server to create a resource and return its name
- Request that the origin server **accept the attached entity**
- **Not idempotent**
- Add a **child resource** under **resources collection**

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PUT

- Requesting client knows the name of the resource on the server
- Requests for the **attached entity** (in the request body)
- **Idempotent**
- Modify a **singular resource** that is a part of resources collection.
- Use as **UPDATE**

POST

- Request to the server to create a resource and return its name
- Request that the origin server **accept the attached entity**
- **Not idempotent**
- Add a **child resource** under **resources collection**
- Use as **CREATE**

Safety and Idempotency

Which HTTP methods are idempotent?

Safety and Idempotency

HTTP Method	Safe	Idempotent
GET	✓	✓
PUT	✘	✓
DELETE	✘	✓
POST	✘	✘
HEAD	✓	✓
OPTIONS	✓	✓
TRACE	✓	✓
PATCH	✘	✘

HTTP Responses

- Each HTTP response contains a status code, which consists of three digits, and a text string, which describes the reason for the response

Status code	Meaning	Description
1xx	**Informational**	Request received, continuing process
2xx	**Success operation**	Action received, understood, accepted, and processed successfully
3xx	**Redirection**	Additional action must be taken by the client to complete the request
4xx	**Client error**	Request of the client caused an error situation
5xx	**Server error**	Server failed to fulfill a valid request $\Longrightarrow$ error was caused by server

Common HTTP Status Codes

Source: http.cat, Author: Tomomi Imura

- The table contains some common status codes of HTTP

Status code	Meaning	Description
200	`OK`	Request processed successfully. Result is transmitted in the response
204	`No Content`	Request executed successfully. Response intentionally contains no data
301	`Moved Permanently`	The old address is no longer valid
400	`Bad Request`	Request cannot be fulfilled due to bad syntax
401	`Unauthorized`	Request can not be executed without a valid authentication
403	`Forbidden`	Request is executed because of clients lack of privileges
404	`Not Found`	Server could not find the requested resource
500	`Internal Server Error`	Unexpected server error

HTTP Requests

- If an URL is accessed via HTTP (e.g., `http://example.teaching.dahahm.de/index.html`, the request for the resource `/index.html` is transmitted to the computer with hostname `example.teaching.dahahm.de`
- First, via DNS, the hostname is resolved to an IP address
- Next, this HTTP `GET` request is transmitted via TCP to port 80, where the web server usually operates

```
GET /index.html HTTP/1.1
Host: example.teaching.dahahm.de
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:96.0) Gecko/20100101 Firefox/96.0
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/avif,image/webp,*/
 *;q=0.8
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
Connection: keep-alive
...
```

Virtual Hosts (vhosts)

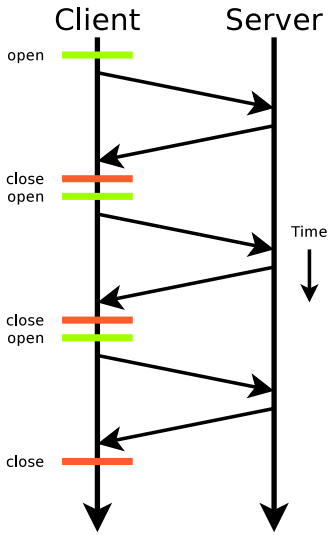
One server handles typically more than one domain, i.e., the same web server application may deliver multiple web pages at the same IP address for different domain names.

HTTP Response

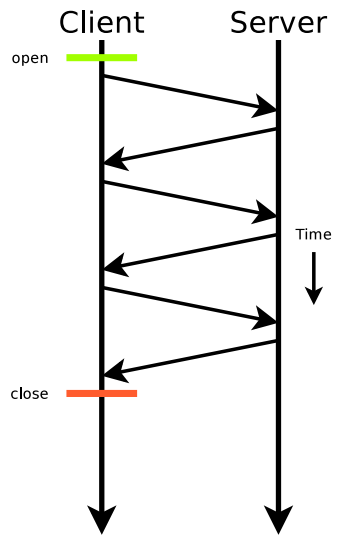
- The HTTP response of the web server consists of a message header and the message body with the actual message
  - In this case, the message body contains the content of the requested file `index.html`

```
HTTP/1.1 200 OK
Server: nginx/1.18.0
Date: Fri, 28 Jan 2022 18:05:47 GMT
Content-Type: text/html
Content-Length: 274
Last-Modified: Fri, 28 Jan 2022 17:55:45 GMT
Connection: keep-alive
ETag: "61f42e21-112"
Accept-Ranges: bytes
<!doctype html>
<html lang="en">
<head>
<meta charset="utf-8">
<meta name="viewport" content="width=device-width, initial-scale=1.0">
<title>Example Page for teaching computer networks</title>
</head>
<body>
<p>Happy networking!</p>
</body>
</html>
```

HTTP Protocol Versions (HTTP/1.0 and HTTP/1.1)



- HTTP/1.0 (RFC 1945): Prior to any request, a new TCP connection is established and closed by default by the server after the transmission of the reply



- HTTP/1.1 (RFC 2616): By default, no connection termination is done
  - So the connection can be reused for multiple requests
  - Interrupted transmissions can be resumed with `HTTP/1.1`

HTTP Protocol Versions (HTTP/2)

- HTTP/2 (RFC 7540): Changes from a text-based protocol to a binary one
  - Accelerates the data transfer by compressing the header with the **HPACK** algorithm (RFC 7541)
  - Enables aggregation (*Multiplex*) of requests and *Server Push* to send data automatically
    - Examples of such data are CSS files (Cascading Style Sheets), which specify the layout of web pages, or script files
  - Currently used by approx. 35 % of all web servers
- HTTP/3 (RFC 9114): Multiplexed transport via QUIC
  - Based on QUIC instead of TCP
  - Integrates TLS key negotiation and avoids head of line blocking
  - Currently used by approx. 30 % of all web servers and approx. 80 % of all browsers

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Addressability

- Every "thing" has a URI
  - `http://sales.com/customers/323421`
  - `http://sales.com/customers/323421/address`
- A URI provides information about ...
  - The protocol (how do we communicate)
  - The host/port (where it is on the network)
  - The resource path (what resource are we communicating with)

URI Syntax

- The generic syntax for URIs according to RFC 3986 comprises five elements:
  - $< scheme >:< scheme - specific - part >$
    or more detailed:
  - $URI = scheme" : "authority["?"query]["\#"fragment]$
    - Where $authority = [userinfo"@"]host[" : "port]$
  - **Examples:**
    - `ftp://ftp.is.co.za/rfc/rfc1808.txt`
    - `http://www.ietf.org/rfc/rfc2396.txt`
    - `ldap://[2001:db8::7]/c=GB?objectClass?one`
    - `mailto:John.Doe@example.com`
    - `tel:+1-816-555-1212`
    - `urn:oasis:names:specification:docbook:dtd:xml:4.1.2`

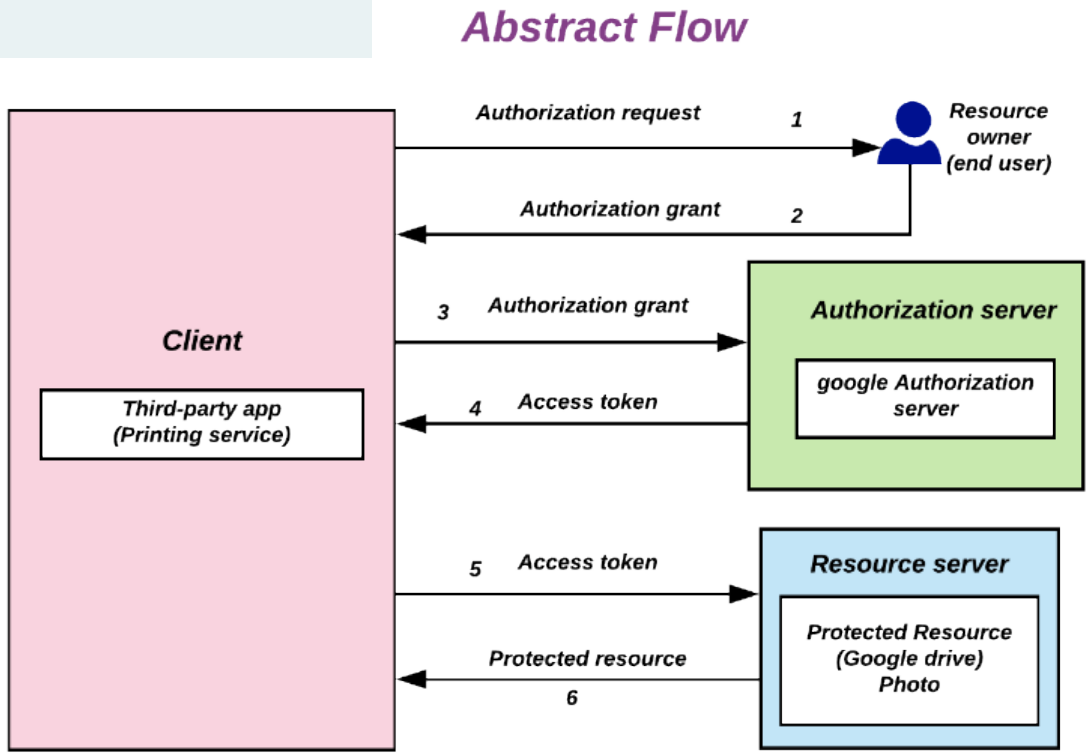
RESTful Services

- Resources as URI
  - Use unique URI to reference every resource on your API
- Operations as HTTP Methods
  - `GET` – Queries
  - `POST` – Queries
  - `PUT`, `DELETE` – Insert, update, and delete
- Connectedness and Discoverability
  - Like the Web, HTTP Responses contains links to other resources

Authentication via OAuth

Open Authorization

OAuth is a standard specified by the IETF in RFC 5849 (OAuth 1.0) and RFCs 6749 and 6750 (OAuth 2.0) for access delegation and is often used to authorize access to REST APIs.



Important takeaway messages of this chapter

- Many modern distributed systems are built as web services using HTTP as a transport protocol.
- REST is an architectural style to design such a system
- In RESTful systems resources are represented as URIs and operations as HTTP methods