Middleware Architectures 2

Lecture 4: Protocols for the Realtime Web

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Overview of APIs and Protocols

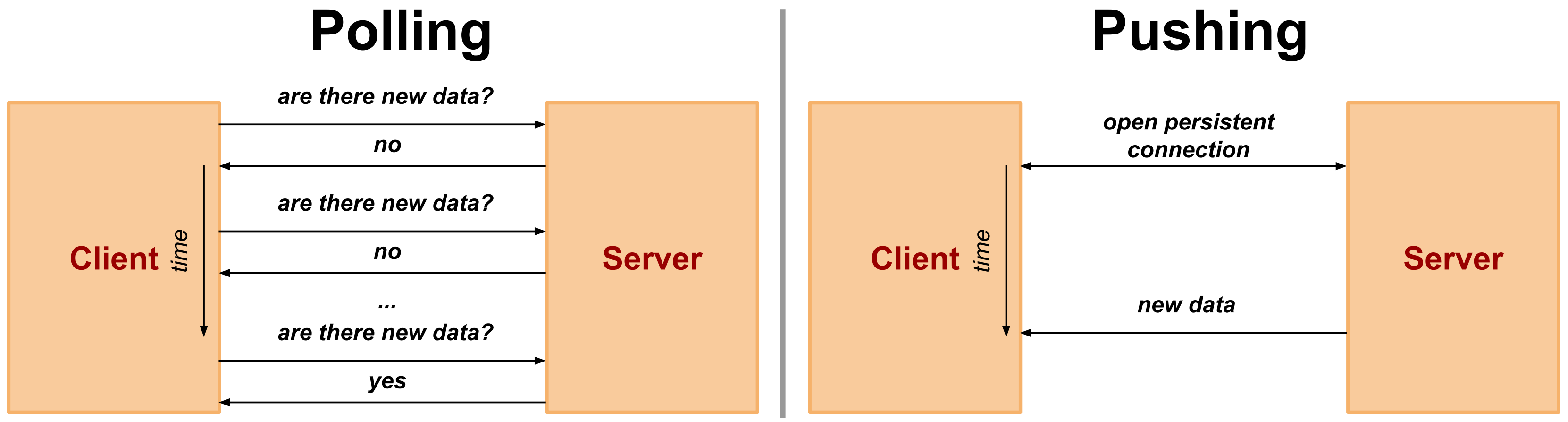
	XHR	Fetch API	Server-Sent Events	WebSocket
Request streaming	no	yes	no	yes
Response streaming	limited	yes	yes	yes
Framing mechanism	HTTP	HTTP	event stream	binary framing
Binary data transfers	yes	yes	no (base64)	yes
Compression	yes	yes	yes	limited
App. transport protocol	HTTP	HTTP	HTTP	WebSocket
Net. transport protocol	TCP	TCP	TCP	TCP

APIs and Protocols

Overview

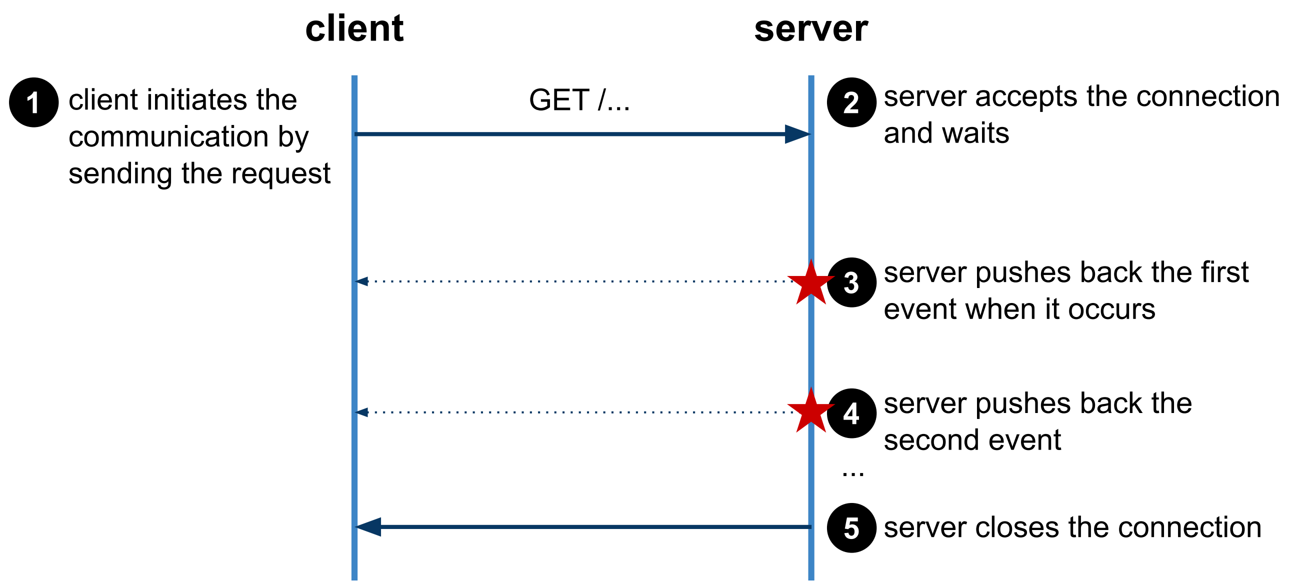
- Streaming and Long-polling
- WebSocket Protocol

Pushing and Polling



- Conceptual basis in messaging architectures
  – *event-driven architectures (EDA)*
- **HTTP is a request-response protocol**
  – *response cannot be sent without request*
  – *server cannot initiate the communication*
- **Polling** – client periodically checks for updates on the server
- **Pushing** – updates from the server (also called COMET)
  = **long polling** – server holds the request for some time
  = **streaming** – server sends updates without closing the socket

HTTP Streaming


client
server
1 client initiates the communication by sending the request
GET /...
2 server accepts the connection and waits
3 server pushes back the first event when it occurs
4 server pushes back the second event
...
5 server closes the connection

- server deffers the response until an event or timeout is available
- when an event is available, server sends it back to client as part of the response; this does not terminate the connection
- server is able to send pieces of response w/o terminating the conn.
  – *using* `transfer-encoding` *header in HTTP 1.1*
  – *using End of File in HTTP 1.0*
  (server omits `content-lenght` *in the response)*

Chunked Response

- Transfer encoding `chunked`
  - *It allows to send multiple sets of data over a single connection*
  - *a chunk represents data for the event*

```
HTTP/1.1 200 OK
Content-Type: text/plain
Transfer-Encoding: chunked

25
This is the data in the first chunk

1C
and this is the second one

0
```

  - *Each chunk starts with hexadecimal value for length*
  - *End of response is marked with the chunk length of 0*
- Steps:
  - *server sends HTTP headers and the first chunk (step 3)*
  - *server sends second and subsequent chunk of data (step 4)*
  - *server terminates the connection (step 5)*

Issues with Chunked Response

- Chunks vs. Events
  - *chunks cannot be considered as app messages (events)*
  - *intermediaries might "re-chunk" the message stream*
    → e.g., combining different chunks into a longer one
- Client Buffering
  - *clients may buffer all data chunks before they make the response available to the client application*
- HTTP streaming in browsers
  - *Server-sent events*

XHR Polling

- Client is making a period checks

```
  function checkUpdates(url) {
      var xhr = new XHMLHttpRequest();
      xhr.open('GET', url);
      xhr.onload = function() { ... };
      xhr.send()
  }

setInterval(function() { checkUpdates('/updates', 60000)});
```

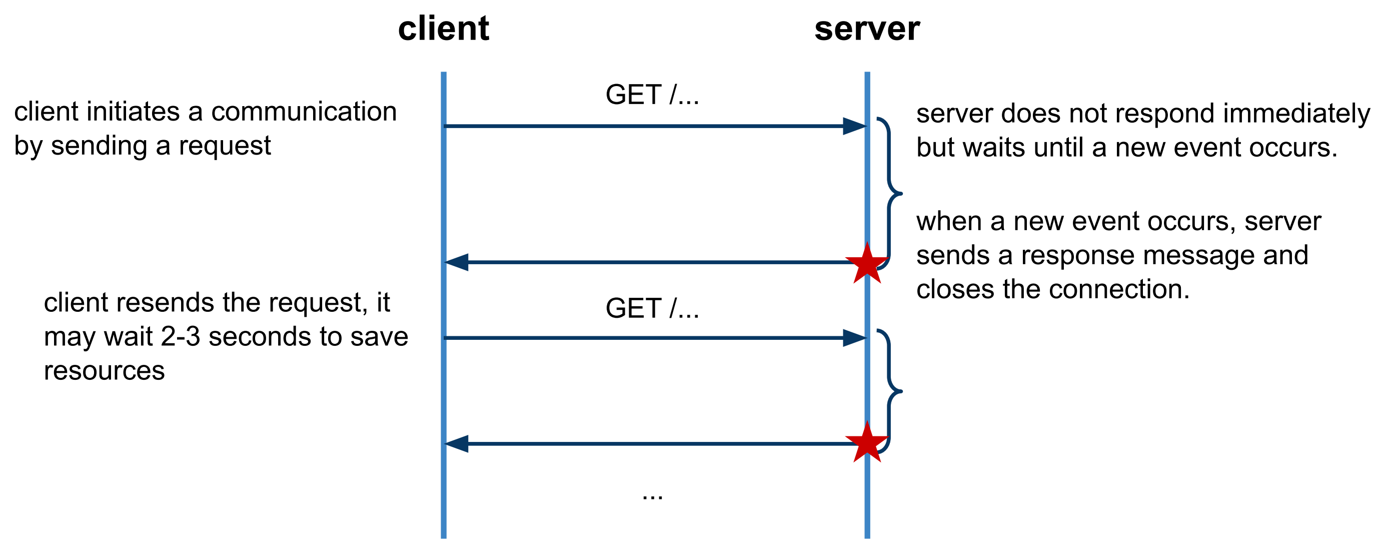
  – *When new data is available, data is returend*
  – *When no data is available, the response is empty*
  – *Simple to implement but very inefficient*

- Polling is expensive when interval is small
  – *Each XHR reqquest is a standalone HTTP request*
  – *HTTP incurs ~850 bytes of overhead for request/response headers*
  – *For example, 10 000 clients, each polling with 60 seconds interval:*

    `(850 bytes x 8 bits x 10000)/60 seconds = 1.13 Mbps`

    Server process 167 requests per second at a rate of 1.13 Mbps throughput
  – *Message latency*
    → *Depends on the interval, maximum is 60 seconds*
    → *Decreasing the interval will put more overhead on the server*

XHR Long Polling


client
server
client initiates a communication by sending a request
GET /...
server does not respond immediately but waits until a new event occurs.
when a new event occurs, server sends a response message and closes the connection.
client resends the request, it may wait 2-3 seconds to save resources
GET /...
...

- Server holds long-poll requests
  - *server responds when an event or a timeout occurs*
  - *saves computing resources at the server as well as network resources*
  - *can be applied over HTTP persistent and non-persistent communication*
- Advantages and Issues
  - *Better message latency when interval is not constant*
  - *concurrent requests processing at the server*
  - *Too many messages may result in worse results that XHR polling*

Server-Sent Events

- W3C specification
  - *part of HTML5 specs, see Server-Sent Events*
  - *API to handle HTTP streaming in browsers by using DOM events*
  - *transparent to underlying HTTP streaming mechanism*
    - → *can use both chunked messages and EOF*
  - *same origin policy applies*
- `EventSource` interface
  - *event handlers:* `onopen`, `onmessage`, `onerror`
  - *constructor* `EventSource(url)` *– creates and opens the stream*
  - *method* `close()` *– closes the connection*
  - *attribute* `readyState`
    - → `CONNECTING` *– The connection has not yet been established, or it was closed and the user agent is reconnecting.*
    - → `OPEN` *– The user agent has an open connection and is dispatching events as it receives them.*
    - → `CLOSED` *– The conn. is not open, the user agent is not reconnecting.*

SSE Example

- Initiating `EventSource`

```javascript
if (window.EventSource != null) {
  var source = new EventSource('your_event_stream.php');
} else {
  // Result to xhr polling :(
}
```

- Defining event handlers

```javascript
source.addEventListener('message', function(e) {
  // fires when new event occurs, e.data contains the event data
}, false);

source.addEventListener('open', function(e) {
  // Connection was opened
}, false);

source.addEventListener('error', function(e) {
  if (e.readyState == EventSource.CLOSED) {
    // Connection was closed
  }
}, false);
```

  – *when the conn. is closed, the browser reconnects every ~3 seconds*
    → *can be changed using* `retry` *attribute in the message data*

Event Stream Format

- Format
  - *response's* `content-type` *must be* `text/event-stream`
  - *every line starts with* `data:`*, event message terminates with 2* `\n` *chars.*
  - *every message may have associated* `id` *(is optional)*

```
id: 12345\n
data: first line\n
data: second line\n\n
```

- JSON data in multiple lines of the message

```
data: {\n
data: "msg": "hello world",\n
data: "id": 12345\n
data: }\n\n
```

- Changing the reconnection time
  - *default is 3 seconds*

```
retry: 10000\n
data: hello world\n\n
```

Auto-reconnect and Tracing

- When a connection is dropped
  - `EventSource` *will automatically reconnect*
  - *It may advertise the last seen message ID*
    → *The client appends* `Last-Event-ID` *header in the reconnect request*
  - *The stream can be resumed and lost messages can be retransmitted*
- Example

```
id: 43
data: ...

=> Request (after connection is dropped)
GET /stream HTTP/1.1
Host: example.com
Accept: text/event-stream
Last-Event-ID: 43

<= Response
HTTP/1.1 200 OK
Content-Type: text/event-stream
Connection: keep-alive
Transfer-Encoding: chunked

id: 44
data: ...
```

SSE Server-side implementation

- Node.js server

```javascript
const express = require('express')
const app = express()

app.get('/countdown', function (req, res) {
  res.writeHead(200, {
    'Content-Type': 'text/event-stream',
    'Cache-Control': 'no-cache',
    'Connection': 'keep-alive'
  })
  countdown(res, 10)
})

function countdown(res, count) {
  res.write("data: " + count + "\n\n")
  if (count)
    setTimeout(() => countdown(res, count - 1), 1000)
  else
    res.end()
}

app.listen(3000, () => console.log('SSE app  on http://127.0.0.1:3000'))
```

SSE Server-side implementation - output

- Node.js server

```
$ curl -vvv http://127.0.0.1:3000/countdown
*   Trying 127.0.0.1:3000...
* Connected to 127.0.0.1 (127.0.0.1) port 3000
> GET /countdown HTTP/1.1
> Host: 127.0.0.1:3000
> User-Agent: curl/8.4.0
> Accept: */*
>
< HTTP/1.1 200 OK
< X-Powered-By: Express
< Content-Type: text/event-stream
< Cache-Control: no-cache
< Connection: keep-alive
< Date: Mon, 25 Mar 2024 08:32:57 GMT
< Transfer-Encoding: chunked
<
data: 10

data: 9

...
```

Streams API

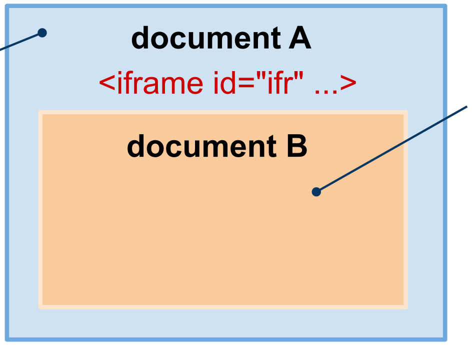
- JavaScript API to programmatically access streams of data
  - *Before, the whole resource had to be read*
  - *Now, you can process raw data as soon as it is available*
    - → *No need to generate string or buffer*
    - → *Detect streams start and end*
    - → *Chain streams together*
    - → *Handle errors, cancel streams*
- Streams usage
  - *Responses can be available as streams using Fetch API*
    - → *Response body returned by a* `fetch` *request and exposed as* `ReadableStream`
    - → *You can read it using* `ReadableStream.getReader()`
    - → *You can cancel it using* `ReadableStream.cancel()`

Other Technologies

- Cross-document messaging

script in document A

```
var o document.getElementById("ifr");
o.contentWindow.postMessage("Hello world",
   "http://example.org/")
```



script in document B

```
window.addEventListener('message', receiver, false);
function receiver(e) {
  if (e.origin == 'http://example.com') {
    if (e.data == 'Hello world') {
      e.source.postMessage('Hello', e.origin);
    } else {
      alert(e.data);
    }
  }
}
```

– *The use of Cross Document Messaging for streaming*
  1. *The client loads a streaming resource in a hidden* `iframe`
  2. *The server pushes a JavaScript code to the* `iframe`
  3. *The browser executes the code as it arrives from the server*
  4. *The embedded iframe's code posts a message to the upper document*

Overview

- Streaming and Long-polling
- WebSocket Protocol

WebSocket

- Specifications
  - *IETF defines WebSocket Protocol*
  - *W3C defines WebSocket API*
- Design principles
  - *a new protocol*
    - *→ browsers, web servers, and proxy servers need to support it*
  - *a layer on top of TCP*
  - *bi-directional communication between client and servers*
    - *→ low-latency apps without HTTP overhead*
  - *Web origin-based security model for browsers*
    - *→ same origin policy, cross-origin resource sharing*
  - *support multiple server-side endpoints*
- Custom URL scheme: `ws` and `wss` (TCP and TLS)
  - *WebSocket can be used over non-HTTP connections outside of browsers*
- Options to establish a WebSocket connection
  - *TLS and ALPN*
  - *HTTP/1.1 connection upgrade*

Connection Upgrade – Request

- Request
  - *client sends a following HTTP request to upgrade the connection to WebSocket*

```
GET /chat HTTP/1.1
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
Sec-WebSocket-Origin: http://example.com
Sec-WebSocket-Protocol: chat, superchat
Sec-WebSocket-Version: 7
```

  - `Connection` – *request to upgrade the protocol*
  - `Upgrade` – *protocol to upgrade to*
  - `Sec-WebSocket-Key` – *a client key for later validation*
  - `Sec-WebSocket-Origin` – *origin of the request*
  - `Sec-WebSocket-Protocol` – *list of sub-protocols that client supports (proprietary)*

Connection Upgrade – Response

- Response
  - *server accepts the request and responds as follows*

```
HTTP/1.1 101 Switching Protocols
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
Sec-WebSocket-Protocol: chat
```

  → `101 Switching Protocols` – *status code for a successful upgrade*

  → `Sec-WebSocket-Protocol` – *a sub-protocol that the server selected from the list of protocols in the request*

  → `Sec-WebSocket-Accept` – *a key to prove it has received a client WebSocket handshake request*

  - *Formula to compute* `Sec-WebSocket-Accept`

```
Sec-WebSocket-Accept = Base64Encode(SHA-1(Sec-WebSocket-Key +
  "258EAFA5-E914-47DA-95CA-C5AB0DC85B11"))
```

  → `SHA-1` – *hashing function*

  → `Base64Encode` – *Base64 encoding function*

  → `"258EAFA5-E914-47DA-95CA-C5AB0DC85B11"` – *magic number*

Data Transfer

- After a successful connection upgrade
  - *socket between the client and the "resource" at the server is established*
  - *client and the server can both read and write from/to the socket*
  - *No HTTP headers overhead*
- Data Framing
  - *Data transmitted in TCP packets (see RFC6455: Base Framing Protocol)*
  - *Contains payload length, closing frame, ping, pong, type of data (text/binary), etc. and payload (message data)*

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-------+-+-------------+-------------------------------+
|F|R|R|R| opcode|M| Payload len |    Extended payload length    |
|I|S|S|S|  (4)  |A|     (7)     |             (16/64)           |
|N|V|V|V|       |S|             |   (if payload len==126/127)   |
| |1|2|3|       |K|             |                               |
+-+-+-+-+-------+-+-------------+ - - - - - - - - - - - - - - - +
|     Extended payload length continued, if payload len == 127  |
+ - - - - - - - - - - - - - - - +-------------------------------+
|                               |Masking-key, if MASK set to 1  |
+-------------------------------+-------------------------------+
| Masking-key (continued)       |          Payload Data         |
+-------------------------------- - - - - - - - - - - - - - - - +
:                     Payload Data continued ...                :
+ - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - +
|                     Payload Data continued ...                |
+---------------------------------------------------------------+
```

Frame and Message

- Frame
  - *The smallest unit of communication, composed of a header and a paylod*
  - *Payload carries all or part of a message*
- Message
  - *A sequence of frames that map to a logical application message*
  - *Messages decomposition into frames is done by client and server framing code*
  - *Application is unaware of frames but only application messages*
- Frame on-the-wire
  - `FIN` – *indication whether the frame is final in the message*
  - `opcode` – *type of frame: (text, binary, control frame, ping, pong)*
  - *Mask bit indicates if the payload is masked (from client to server only)*
  - *Payload length*
  - *Masking key contains 32-bit key to mask the payload (if mask bit is set)*
  - *Payload application data*

Head-of-line Blocking

- Head-of-line blocking recall
  - *Second request needs to wait for the first request to finish*
  - *See HTTP Pipelining in AM1 for more details*
- WebSocket
  - *Large messages can cause the head of line blocking on the client*
  - *Messages can be split into more frames*
  - *But frames cannot be interleaved*

⇒ A large message with more frames may block frames of other messages

- You need to be careful of payload size of each message
  - *You should:*
    - → *split large message into multiple application messages*
    - → *monitor amount of messages in the client's buffer*
    - → *send data when buffer is empty*
- Each WebSocket connection requires a dedicated TCP connection
  - *Problem with HTTP/1.x due to a restricted number of connections per origin*

WebSocket Browser API

- Client-side API
  - *clients to utilize WebSocket, supported by all modern browsers*
  - *Hides complexity of WebSocket protocol for the developer*
- JavaScript example

```javascript
// ws is a new URL schema for WebSocket protocol; 'chat' is a sub-protocol
var connection = new WebSocket('ws://server.example.org/chat', 'chat');

// When the connection is open, send some data to the server
connection.onopen = function () {
  // connection.protocol contains sub-protocol selected by the server
  console.log('subprotocol is: ' + connection.protocol);
  connection.send('data');
};

// Log errors
connection.onerror = function (error) {
  console.log('WebSocket Error ' + error);
};

// Log messages from the server
connection.onmessage = function (e) {
  console.log('Server: ' + e.data);
};

...

// closes the connection
connection.close()
```

Avoid Head of Line Blocking

- Example code to monitor a client buffer size

```
var ws = new WebSocket('wss://example.com/socket');

ws.onopen = function () {
  subscribeToApplicationUpdates(function(evt) {
    if (ws.bufferedAmount == 0)
      ws.send(evt.data);
  });
};
```

  – *A call to* `send` *is asynchronous*
  – *Multiple calls to* `send` *will fill the client buffer*

WebSocket Infrastructure

- HTTP optimized for short transfers
  - *intermediaries are configured to timeout idle HTTP connections quickly*
  - *This can be a problem for long-lived WebSocket connections*
- We cannot control
  - *Client's network, some networks may block WebSocket traffic*
    - → *We need a fallback strategy*
  - *Proxies on the external network*
    - → *TLS may help, tunneling over secure end-to-end connection, WebSocket traffic can bypass intermediaries*
- We can control our infrastructure
  - *For example, set tunnel timeout to 1 hour on HAProxy*

```
defaults http
    timeout connect 30s
    timeout client  30s
    timeout server  30s
    timeout tunnel  1h
```