

#ibminterconnect

Introduction to WebSockets

Session 1641

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About WebSockets...



- WebSocket network protocol
 - Data format
- WebSocket API (Javascript & Java EE)
 - Endpoint configuration
 - Session open/close
 - Message read/write
 - Error handling
 - Annotations
- Network architecture
 - Proxies / load balancers / routers...

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<tripDownMemoryLane>
Before WebSockets...



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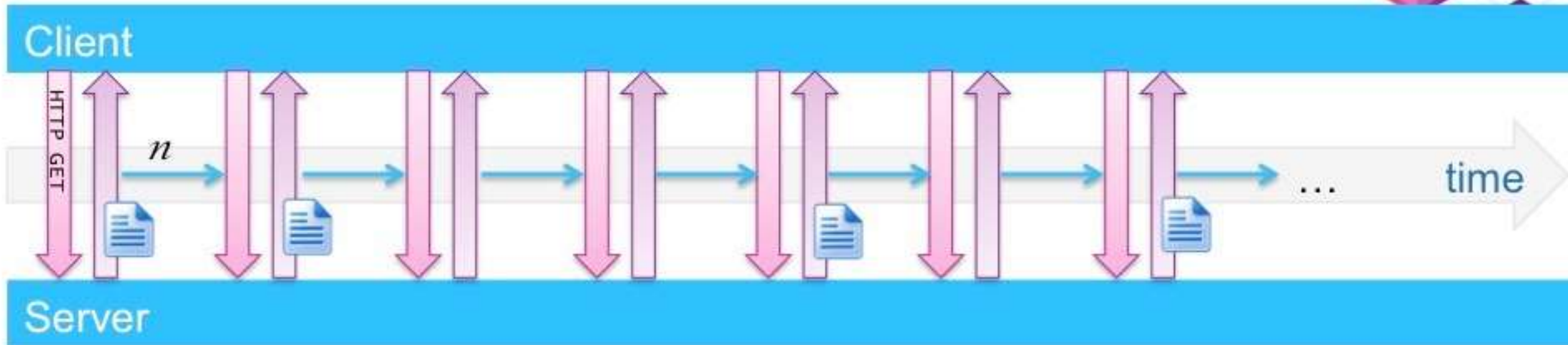
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Options for two-way communication

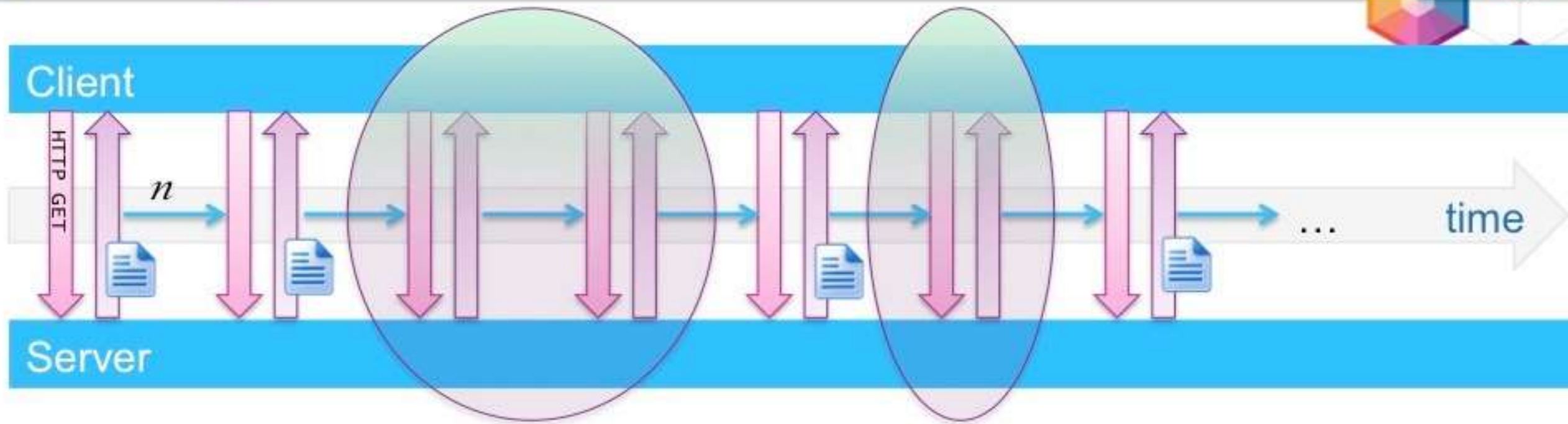
- Polling
- Long polling
- Streaming / forever response
- Multiple connections

(1): Polling



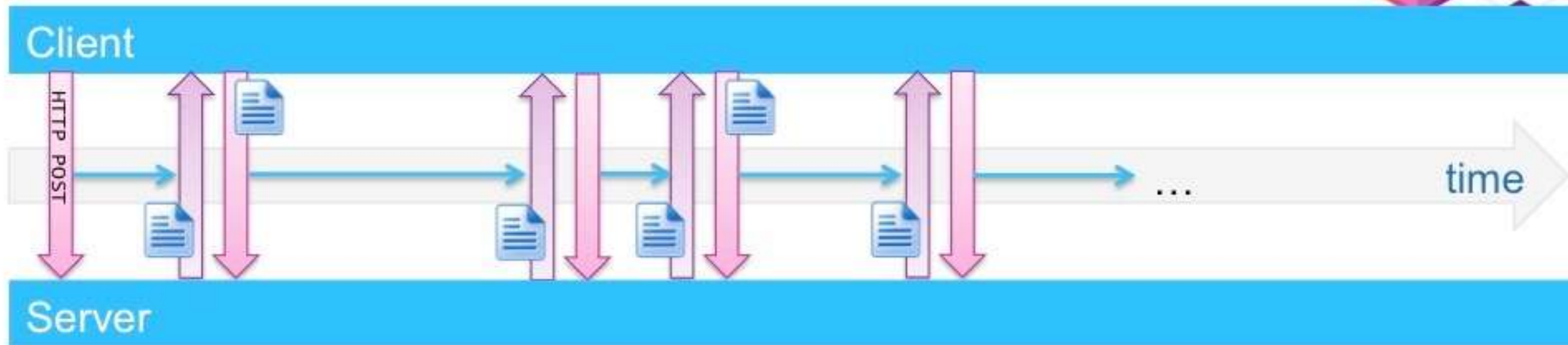
- Client polls the server every n ...
 - Server always immediately responds (with or without data)
 - Might work for periodic data where the period is known/constant
- BUT...

(1): Polling



- Client polls the server every n ...
- Server always immediately responds (with or without data)
- Might work for periodic data where the period is known/constant
- *Obvious waste (CPU and bandwidth) when there is no data*

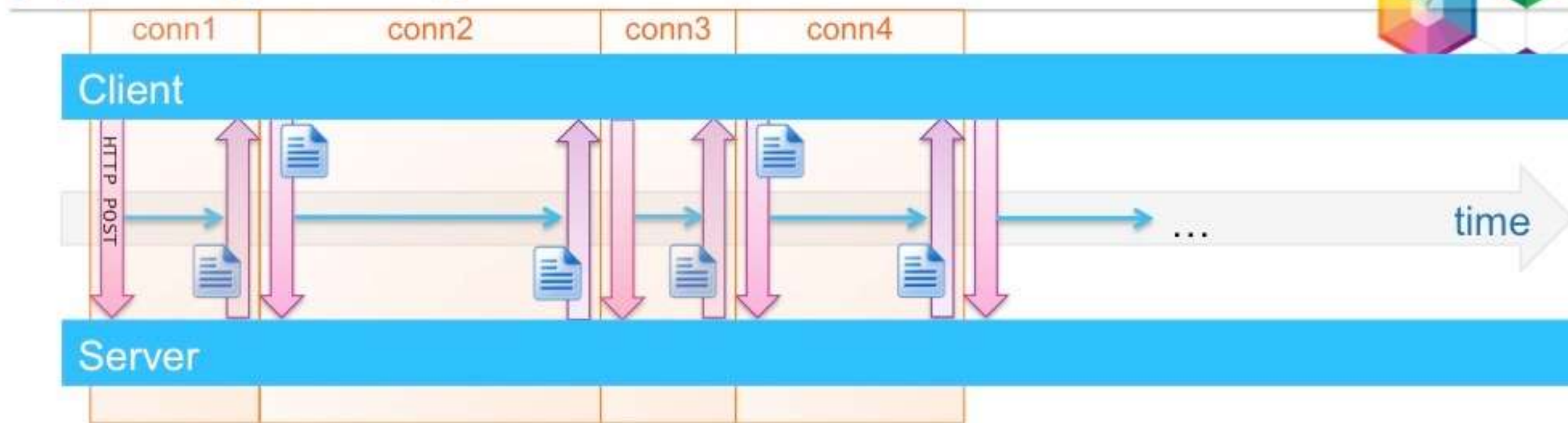
(2): Long Polling



- Client sends initial request
- Server waits until it has data to respond
- Client receives response, and immediately creates new request
- Obvious improvement over plain polling

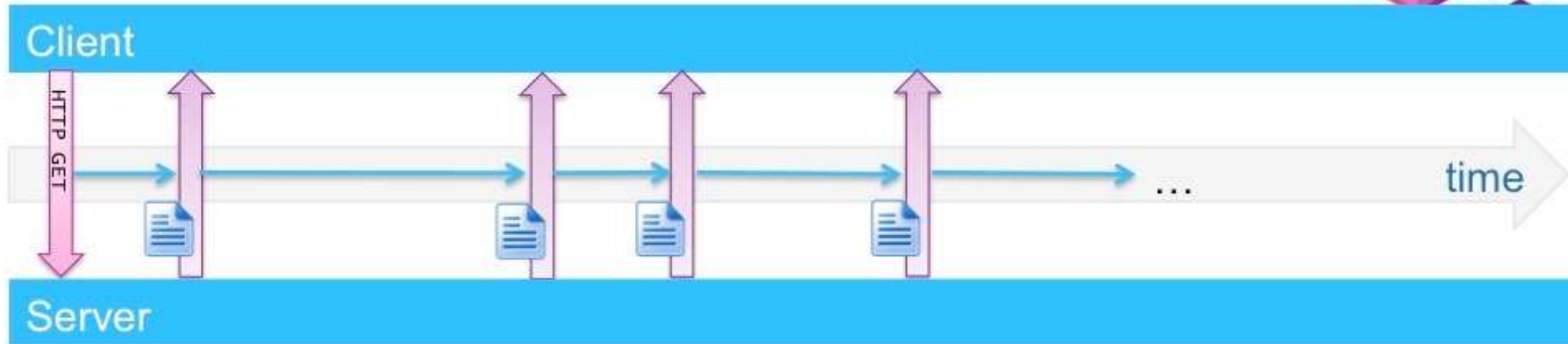
BUT...

(2): Long Polling



- Client sends initial request
- Server waits until it has data to respond
- Client receives response, and immediately creates new request
- Obvious improvement over plain polling
- *Each request/response creates and closes a connection*
- *Client has to wait to send new data until the server responds*

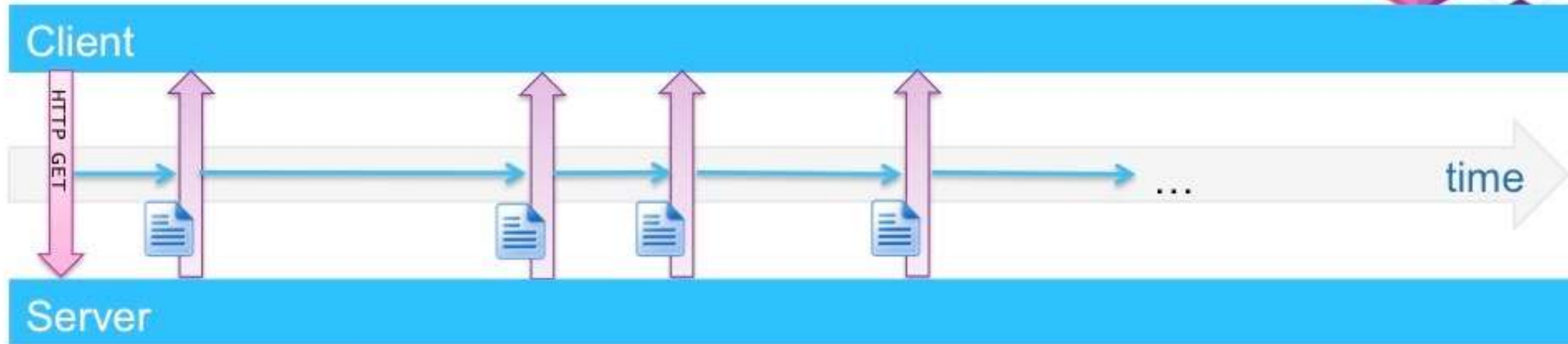
(3): Streaming / forever response



- Client sends initial request
- Server waits until it has data to respond
- Server responds by streaming data
 - Server has an open connection to *push* updates
- Connection is maintained

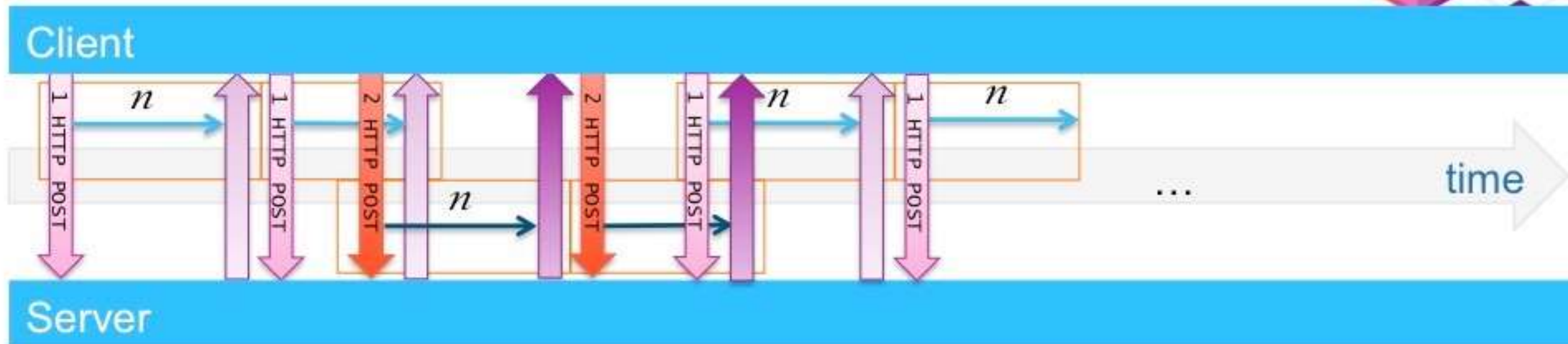
BUT...

(3): Streaming / forever response



- Client sends initial request
- Server waits until it has data to respond
- Server responds by streaming data
 - Server has an open connection to *push* updates
- Connection is maintained
- *It is half-duplex: only server to client*
- *User agents and proxies might not like partial responses*

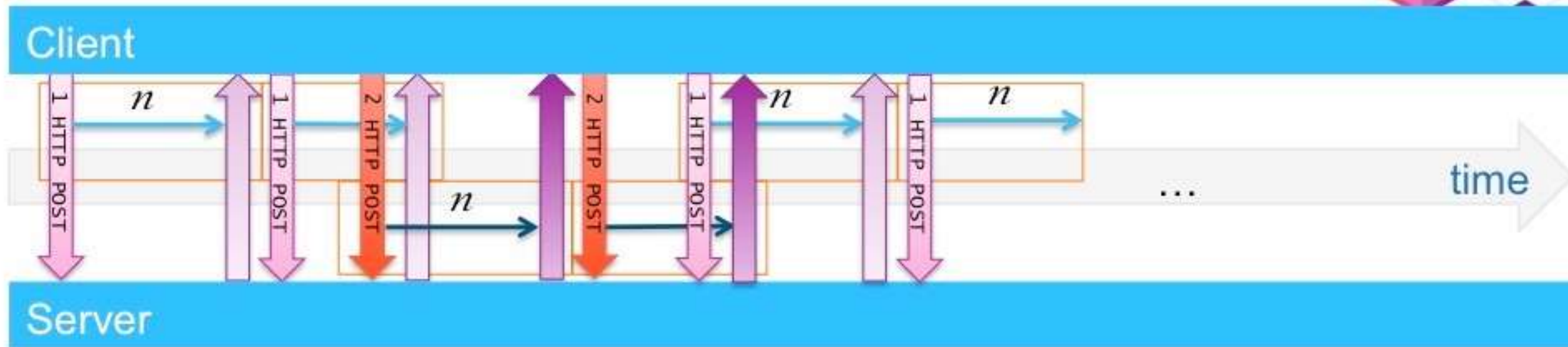
(4): Multiple connections



- Long polling over two separate HTTP connections
 - Approximation of bi-directional connection
 - Two connections are used (HTTP recommended max)
 - long polling
 - second connection allows client to send data to the server

BUT...

(4): Multiple connections



- Long polling over two separate HTTP connections
 - Approximation of bi-directional connection
 - Two connections are used (HTTP recommended max)
 - long polling
 - second connection allows client to send data to the server
- *Non-trivial connection coordination and management*
- *Two connections for every client*



Hidden cost of HTTP...

- TCP handshake when establishing new connection
 - Even worse for SSL...
- HTTP headers on every message
 - Always present, can vary in size and quantity

<http://www.websocket.org/quantum.html>

```
GET /PollingStock//PollingStock HTTP/1.1
Host: localhost:8080

User-Agent: Mozilla/5.0 (Windows; U; Windows NT 5.1; en-US; rv:1.9.1.5)
Gecko/20091102 Firefox/3.5.5

Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-us
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 300
Connection: keep-alive
Referer: http://www.example.com/PollingStock/
```

For small messages, you may end up pushing around more HTTP headers than data!

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There is a better way: WebSockets

- Bi-directional
 - Client and server can send messages at any time
- Full duplex
 - Client and server can send updates at the same time
 - No requirement for request/response pair or message ordering
- Single long running connection with established context
 - No connection management/coordination
- Connection upgraded from HTTP
 - No new connection protocol to build infrastructure for
- Efficient use of bandwidth and CPU
 - **Messages can focus on application data**



WebSockets have been standardized

- IETF RFC-6455: WebSocket Protocol Specification, 2011
- JSR 356: WebSocket API Specification, 2013
 - Part of Java EE 7



But...



- What about plain HTTP requests?
 - HTTP is still great for loading static resources!
- What about REST?
 - REST is still great for client-initiated CRUD operations
- What about MQTT?
 - Pub/Sub model, different QOS, different protocol
 - *Runs atop WebSockets!* (Liberty/Rtcomm, Paho.js, ...)

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How WebSockets
work..

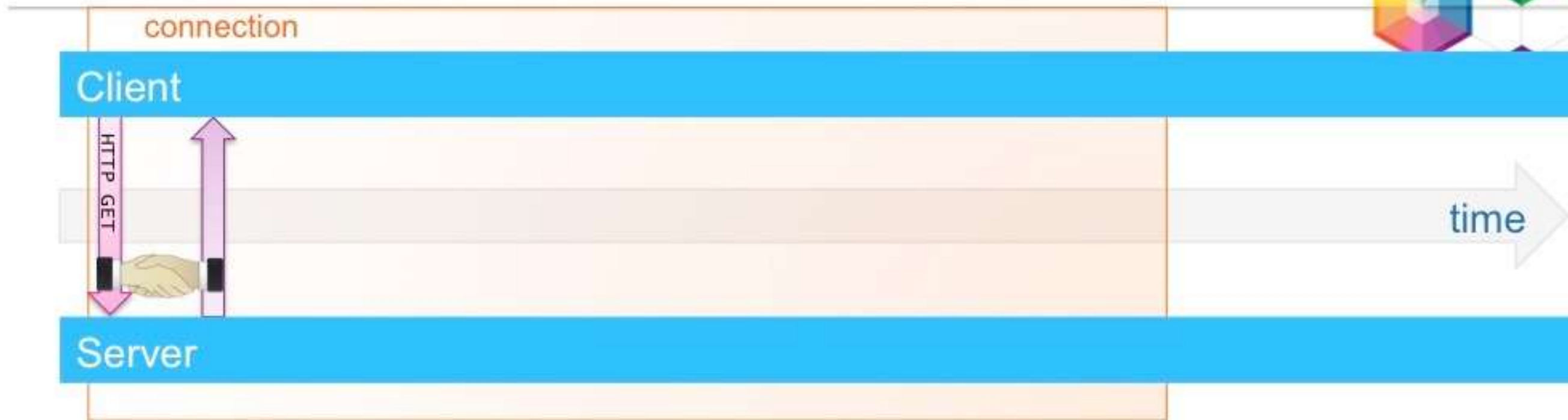


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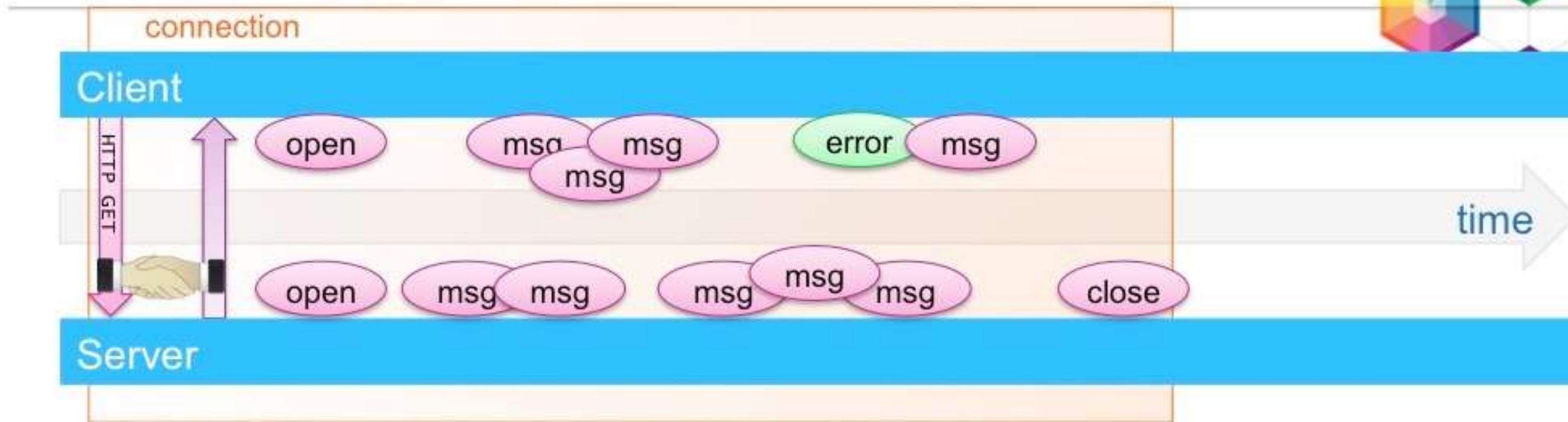
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WebSocket connection



- Handshake:
 - Client initiates connection
 - Server responds (accepts the upgrade)

WebSocket connection



- Handshake:
 - Client initiates connection
 - Server responds (accepts the upgrade)
- Once the WebSocket is established
 - both sides notified that socket is open
 - either side can send messages at any time
 - either side can close the socket

WebSocket Protocol: it starts with a handshake...



request

```
GET /myapp HTTP/1.1
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Key: Gh1IHNhbXBsZSBub25jZQ==
Sec-WebSocket-Version: 13
Sec-WebSocket-Protocol: custom
Sec-WebSocket-Extensions: compress
Origin: http://example.com
...
```

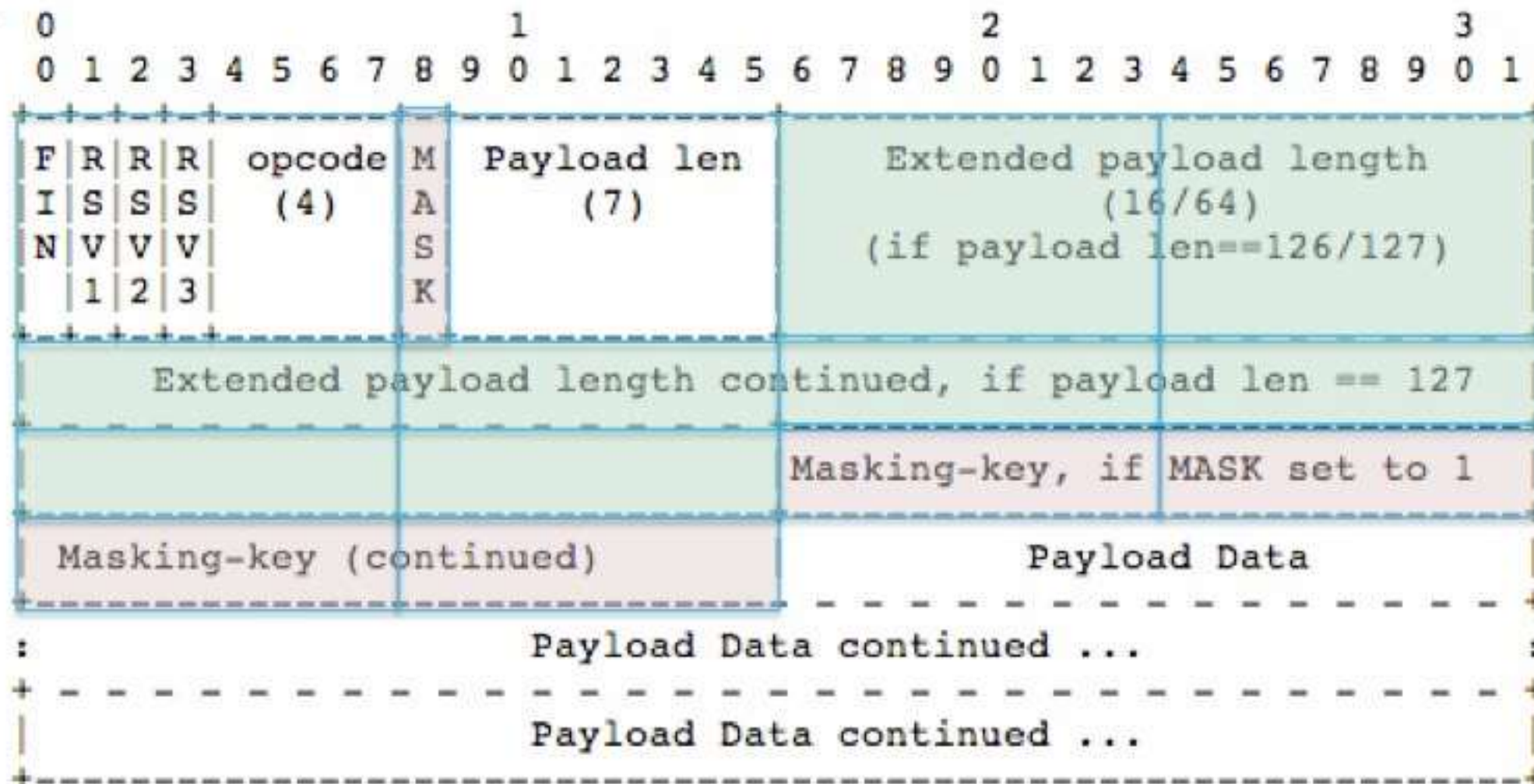
} Request upgrade to WebSocket connection

} WebSocket handshake headers

response

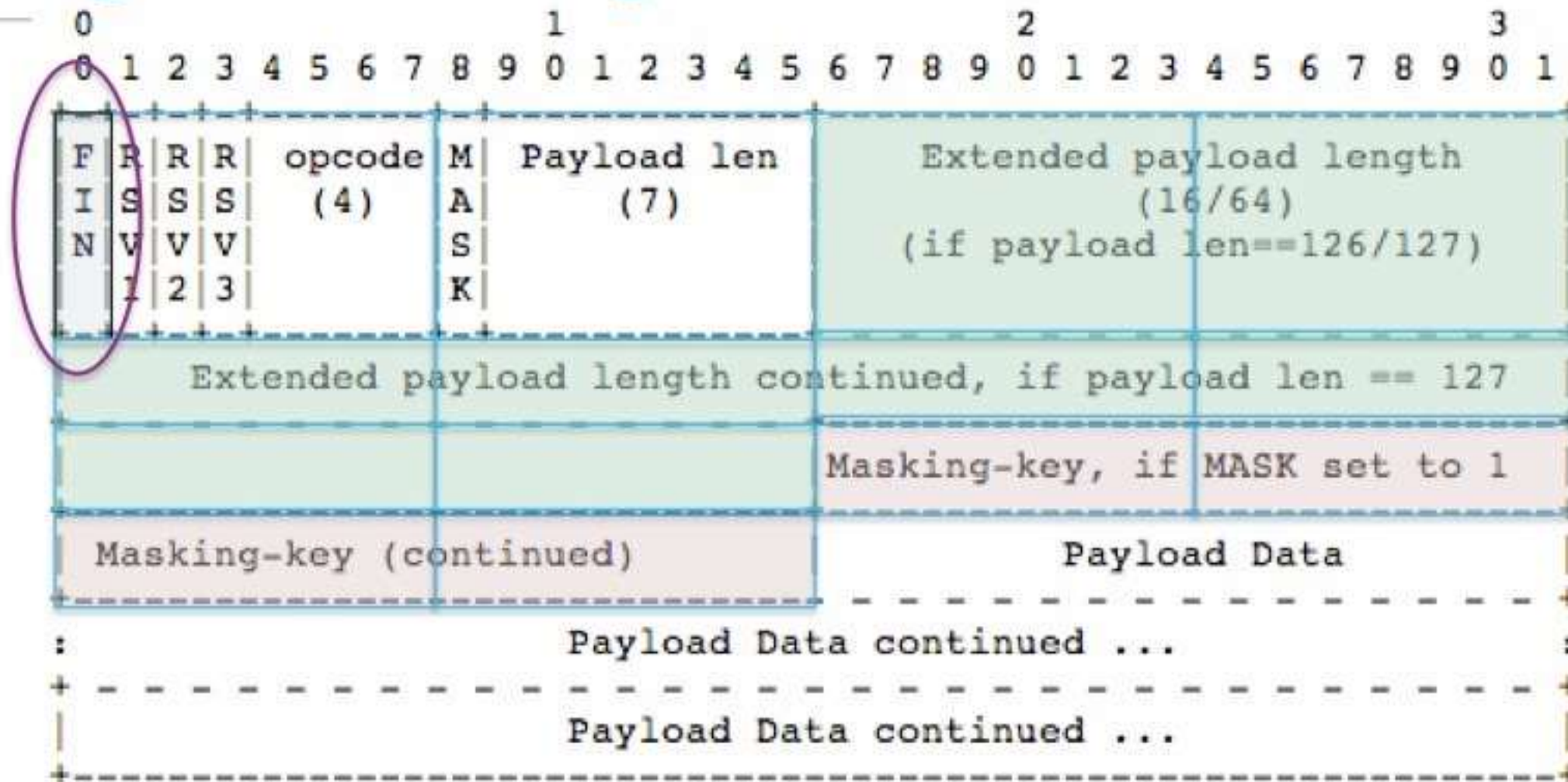
```
HTTP/1.1 101 Switching Protocols
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
Sec-WebSocket-Protocol: custom
Sec-WebSocket-Extensions: compress
```

... and then transitions to frames



- Data or text is transmitted in frames
 - Minimally framed: small header, then payload

Messages can be fragmented across frames



- Message can be in one or more frames
 - Continue until FIN
 - A frame contains data for only one message
 - Extensions can be used to multiplex connections



Op Codes: identifying messages

- Control frames
 - Ping – 0xA
 - Pong – 0x9
 - Close – 0x8
- Data frames
 - Text – 0x1
 - UTF-8
 - Binary – 0x2
 - Arbitrary content: up to the application layer to determine
- Additional op codes are defined by negotiated extensions
 - Use reserved flags in the header

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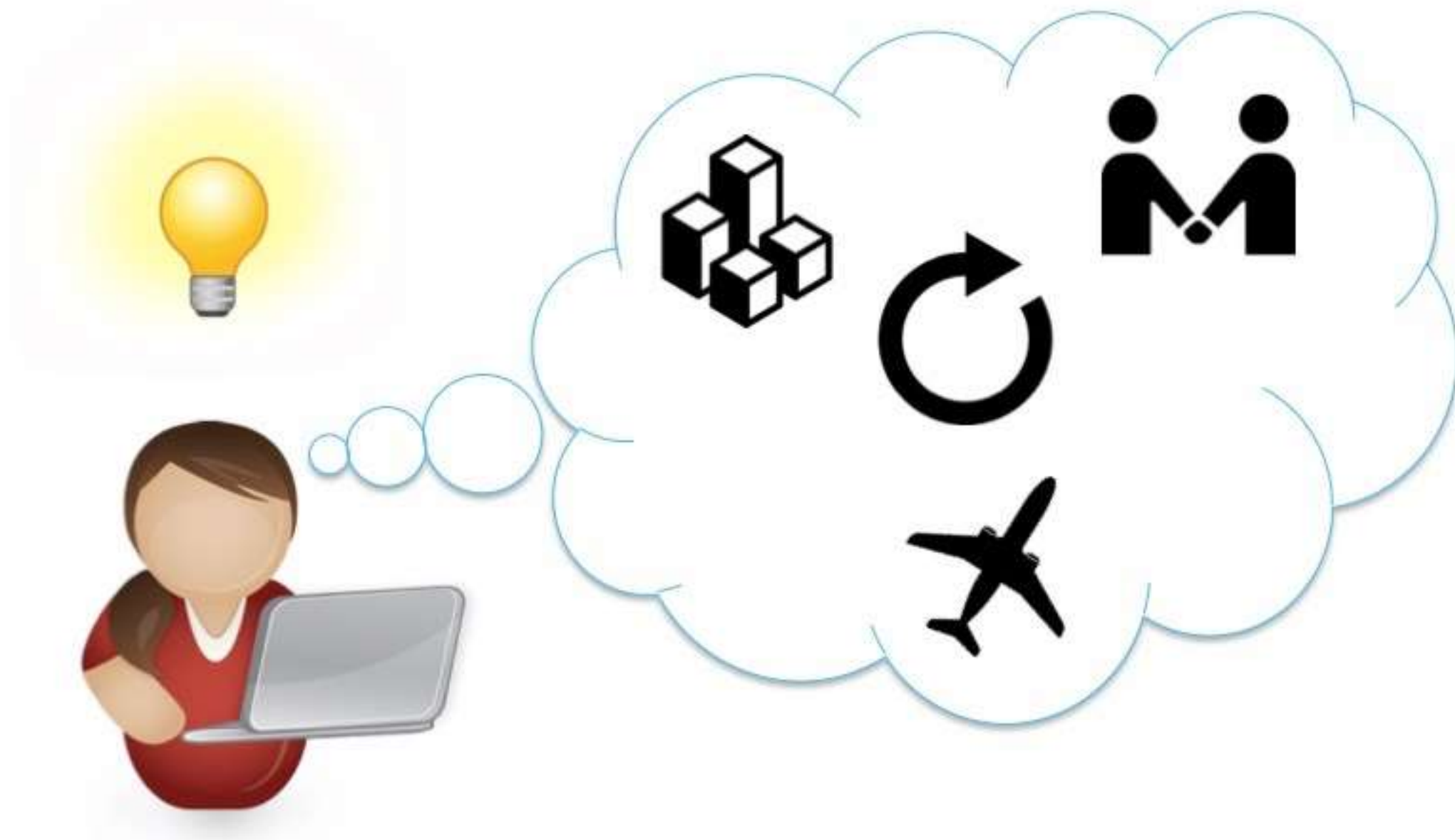


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How do we use WebSockets in an application?



Judy



WebSockets API (JavaScript)

- Developed as part of HTML5:
 - <http://dev.w3.org/html5/websockets/>

```
interface WebSocket : EventTarget {
  readonly attribute DOMString url;
  // ready state
  const unsigned short CONNECTING = 0;
  const unsigned short OPEN = 1;
  const unsigned short CLOSING = 2;
  const unsigned short CLOSED = 3;
  readonly attribute unsigned short readyState;
  readonly attribute unsigned long bufferedAmount;

  // networking attribute EventHandler onopen;
  attribute EventHandler onerror;
  attribute EventHandler onclose;
  readonly attribute DOMString extensions;
  readonly attribute DOMString protocol;
  void close([Clamp] optional unsigned short code, optional DOMString reason);

  // messaging
  attribute EventHandler onmessage;
  attribute BinaryType binaryType;
  void send(DOMString data);
  void send(Blob data);
  void send(ArrayBuffer data);
  void send(ArrayBufferView data);
};
```

JavaScript client invocation...



```
websocket = new WebSocket('ws://' +  
                           window.document.location.host +  
                           '/websocket/EchoEndpoint');  
  
websocket.onerror = function(event) {  
    ...  
}  
  
websocket.onopen = function(event) {  
    ...  
}  
  
websocket.onclose = function(event) {  
    ...  
}  
  
websocket.onmessage = function(event) {  
    ...  
}
```



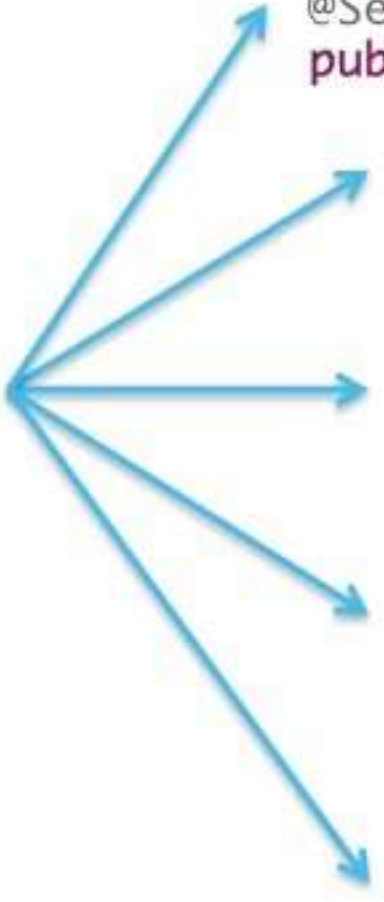
WebSockets API (Java EE)

- Programmatic or annotation-based approach
- Client and Server Endpoints
 - Have a lifecycle
 - onOpen
 - onClose
 - onError
 - Communicate using Messages
 - onMessage
 - send
 - Use sessions
- Encoders and Decoders deal with data formatting
 - Messages \leftrightarrow Java Objects
- SPI: extensions and data frames



Server Endpoint: Annotated

- Simple POJO with `@ServerEndpoint` annotation
 - value is the URI relative to your app's context root, e.g. `ws://localhost/myapp/SimpleAnnotated`
- Annotations for notifications: lifecycle and messages



```
@ServerEndpoint(value = "/SimpleAnnotated")
public class SimpleEndpoint {

    @OnOpen
    public void onOpen(Session session, EndpointConfig ec) {
    }

    @OnClose
    public void onClose(Session session, CloseReason reason) {
    }

    @OnMessage
    public void receiveMessage(String message, Session session) {
    }

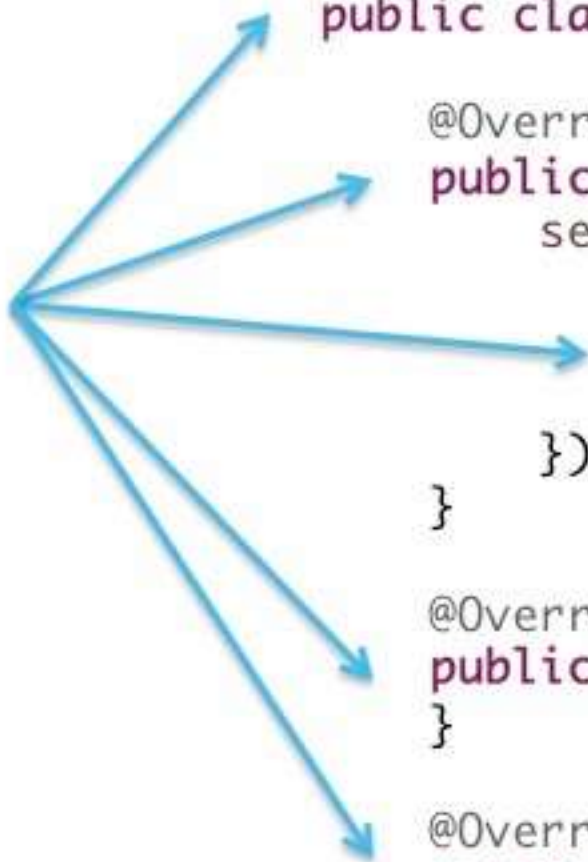
    @OnError
    public void onError(Throwable t) {
    }
}
```



Server Endpoint: Programmatic

- Class extends `Endpoint`
- Callback methods for lifecycle event notifications
- Message notifications require a `MessageHandler`

```
public class ExtendedEndpoint extends Endpoint {  
    @Override  
    public void onOpen(Session session, EndpointConfig ec) {  
        session.addMessageHandler(new MessageHandler.Whole<String>() {  
            @Override  
            public void onMessage(String message) {  
            }  
        });  
    }  
    @Override  
    public void onClose(Session session, CloseReason reason) {  
    }  
    @Override  
    public void onError(Session session, Throwable t) {  
    }  
}
```



Simple echo + server provided data

(using annotations)

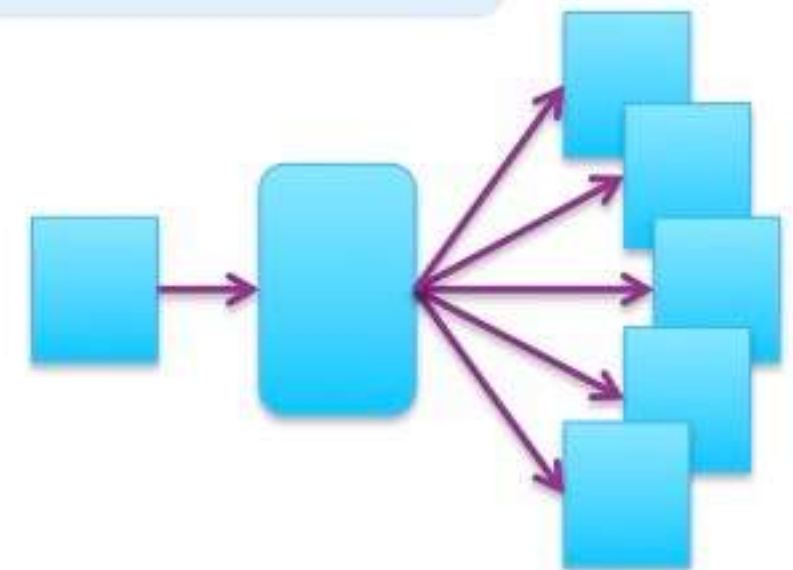


- `@OnMessage` method is called when a message is received
 - If message is 'stop': close the session
 - Otherwise, echo the message along with a hit count

```
int count = 0;
```

```
@OnMessage
public void receiveMessage(String message, Session session) throws IOException {
    if ( "stop".equals(message) ) {
        session.close();
    } else {
        int id = count++;
        for (Session s : session.getOpenSessions() ) {
            s.getBasicRemote().sendText("Echo " + id + ": " + message);
        }
    }
}
```

- Broadcast – iterate over open sessions



Invocation.. what happens?

- Let's see!





Encoder/Decoder: dealing with data

- Messages can be in text or binary format
- Encoders and Decoders translate between data on the socket and Java Objects

```
@ServerEndpoint(value = "/EchoEncoderEndpoint",  
                decoders = EchoDecoder.class,  
                encoders = EchoEncoder.class)
```

```
public class EchoEncoderEndpoint {
```

```
    @OnMessage
```

```
    public void receiveMessage(EchoObject o, Session session)
```

```
    throws IOException, EncodeException {
```

```
        if (o.stopRequest() ) {
```

```
            session.close();
```

```
        } else {
```

```
            for (Session s : session.getOpenSessions() ) {
```

```
                s.getBasicRemote().sendObject(o);
```

```
            }
```

```
        }
```

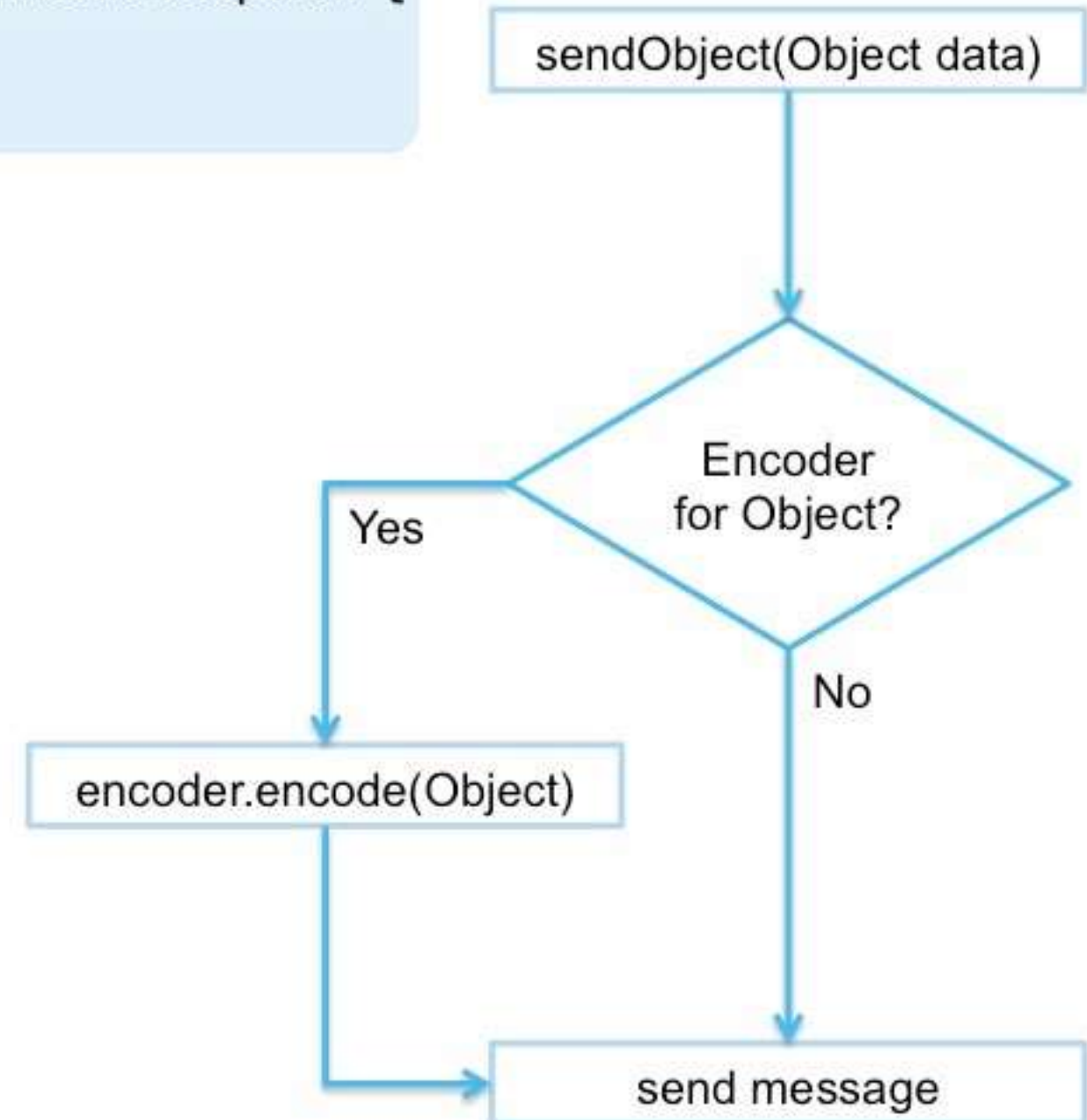
```
    }
```

```
}
```

Encoder: dealing with data



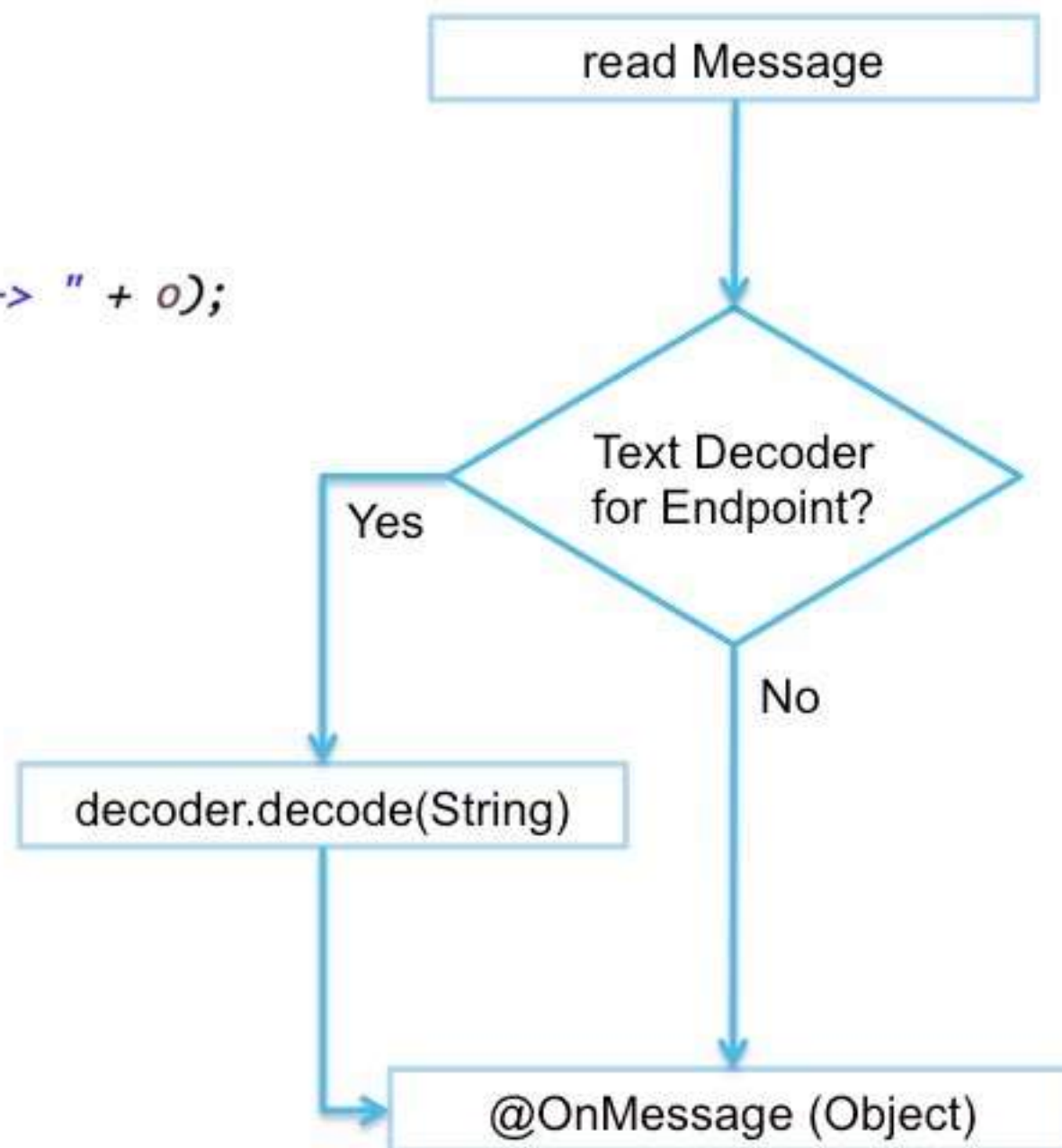
```
public class EchoEncoder implements Encoder.Text<EchoObject> {  
  
    @Override  
    public String encode(EchoObject o) throws EncodeException {  
        System.out.println("Encoding " + o);  
        return o.toString();  
    }  
  
    @Override  
    public void init(EndpointConfig ec) {}  
  
    @Override  
    public void destroy() {}  
}
```





Decoder: dealing with data

```
public class EchoDecoder implements Decoder.Text<EchoObject> {  
  
    @Override  
    public EchoObject decode(String msg) throws DecodeException {  
        EchoObject o;  
        try {  
            o = new EchoObject(msg);  
        } catch (Exception e) {  
            o = new EchoObject(e);  
        }  
        System.out.println("Decoded " + msg + " -> " + o);  
        return o;  
    }  
  
    @Override  
    public boolean willDecode(String msg) {  
        return true;  
    }  
  
    @Override  
    public void init(EndpointConfig ec) {}  
  
    @Override  
    public void destroy() {}  
}
```



EchoObject



```
public class EchoObject {  
    static final AtomicInteger count = new AtomicInteger();  
  
    final JsonObject obj;
```

decode

```
    public EchoObject(String msg) {  
        JsonReader r = Json.createReader(new StringReader(msg));  
        JsonObject in = r.readObject();  
  
        JsonObjectBuilder b = Json.createObjectBuilder();  
        b.add("count", count.getAndIncrement());  
        b.add("content", in.getString("content", "none provided"));  
        obj = b.build();  
    }
```

encode

```
    public String toString() {  
        return obj.toString();  
    }
```

```
    public EchoObject(Exception e) {  
        JsonObjectBuilder b = Json.createObjectBuilder();  
        b.add("content", e.toString());  
        b.add("count", -1);  
        obj = b.build();  
    }
```

```
    public boolean stopRequest() {  
        return "stop".equals(obj.getString("content"));  
    }
```



Invocation.. what happens?

- Let's see!

WebSockets have everything this application needs..



- Why wouldn't you use them?
 - Older devices / browsers don't support WebSockets
 - May be a challenge to degrade gracefully so older devices still have a decent experience
- Trouble with proxies..
 - wss:// recommended over ws://
 - Some proxy servers do not inspect encrypted traffic: just pass through

Challenges for Proxy servers



- WebSocket protocol is unaware of proxies / firewalls
- Relies on Upgrade header:
 - Hop-by-Hop Upgrade
 - Proxy server sends the request to the next hop
 - Upgrade header is only good for one link
- Proxy servers required to strip certain headers when forwarding
 - Some load balancers also mangle the Connection header
- HTTP CONNECT
 - Proxy to forward the TCP Connection to the destination
 - *Some proxies still analyze traffic: would choke on websocket frame*
 - *SSL tunnelling has a better shot:*
 - *Some proxies restrict CONNECT to SSL*
 - *BUT: SSL termination...*



WebSockets for Rich Clients

- Java API for a rich Client is similar to API for Server
- Annotations:

```
@ClientEndpoint
public class AnnotatedClient {
    @OnOpen
    public void onOpen(Session session, EndpointConfig ec) {
    }

    @OnClose
    public void onClose(Session session, CloseReason reason) {
    }

    @OnMessage
    public void processMessageFromServer(String message, Session session) {
        System.out.println("Message came from the server ! " + message);
    }

    @OnError
    public void onError(Throwable t) {
    }
}
```




WebSockets for Rich Clients

- Java API for a rich Client is similar to API for Server
- Programmatic:

```
final WebSocketContainer webSocketContainer = ContainerProvider.getWebSocketContainer();

Session session = webSocketContainer.connectToServer(new Endpoint() {
    @Override
    public void onOpen(Session session, EndpointConfig config) {
        session.addMessageHandler(new MessageHandler.Whole<String>() {
            @Override
            public void onMessage(String message) {
                System.out.println("Message came from the server ! " + message);
            }
        });
    }
}, URI.create("ws://some.uri"));
```

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Questions?



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