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Introduction to WebSockets

Session 1641

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InterConnect 2015
The Premier Cloud & Mobile Conference

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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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Before WebSockets...

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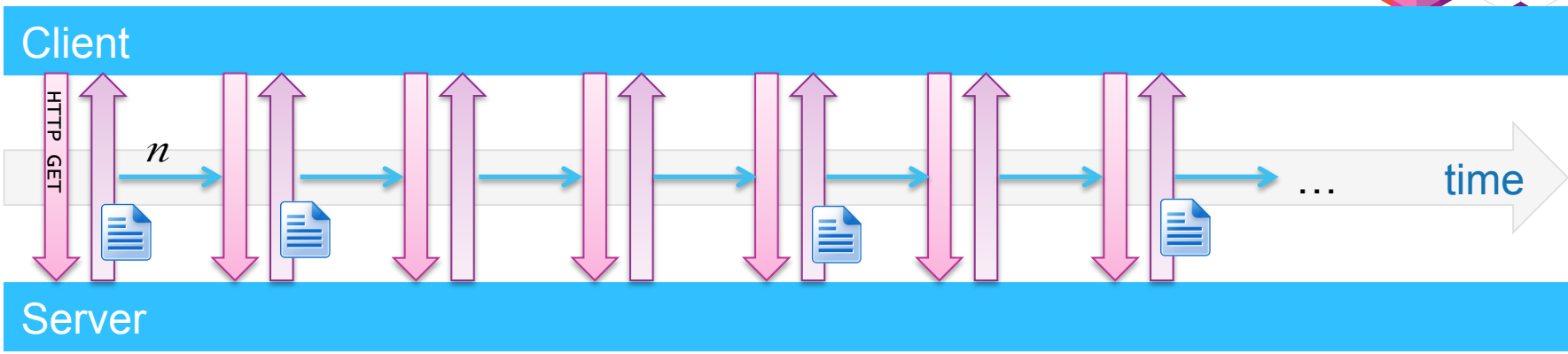
Options for two-way communication

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

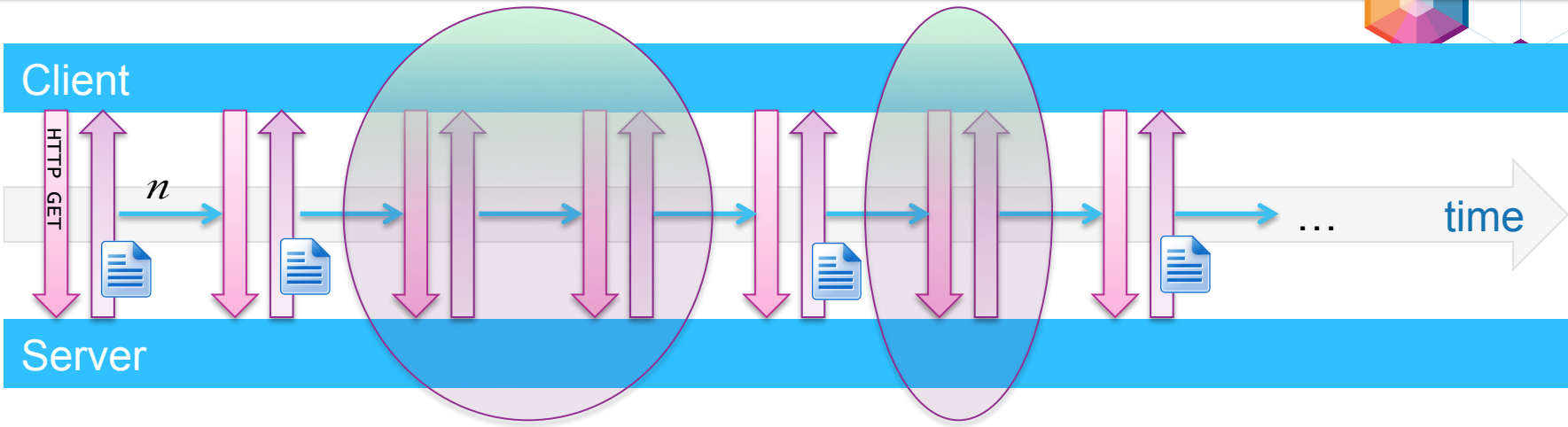
(1): Polling



- 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

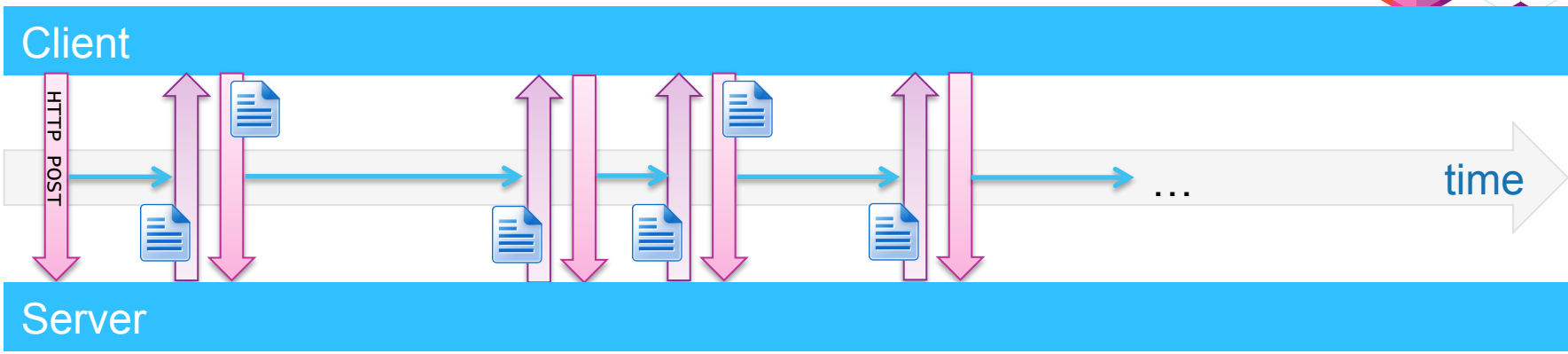
BUT…

(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*

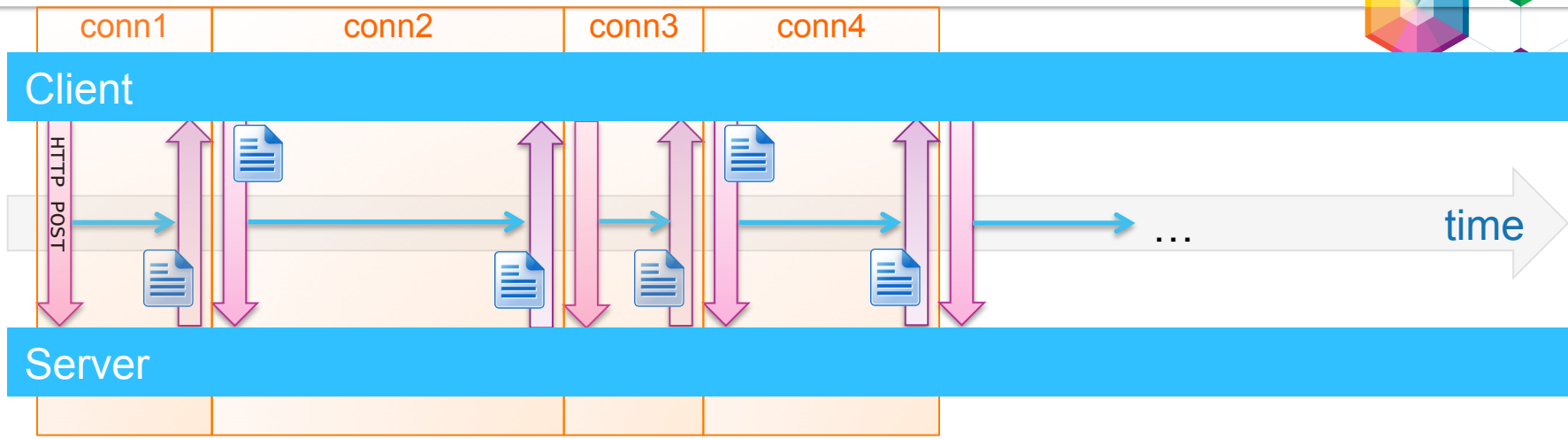
(2): Long Polling



- 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

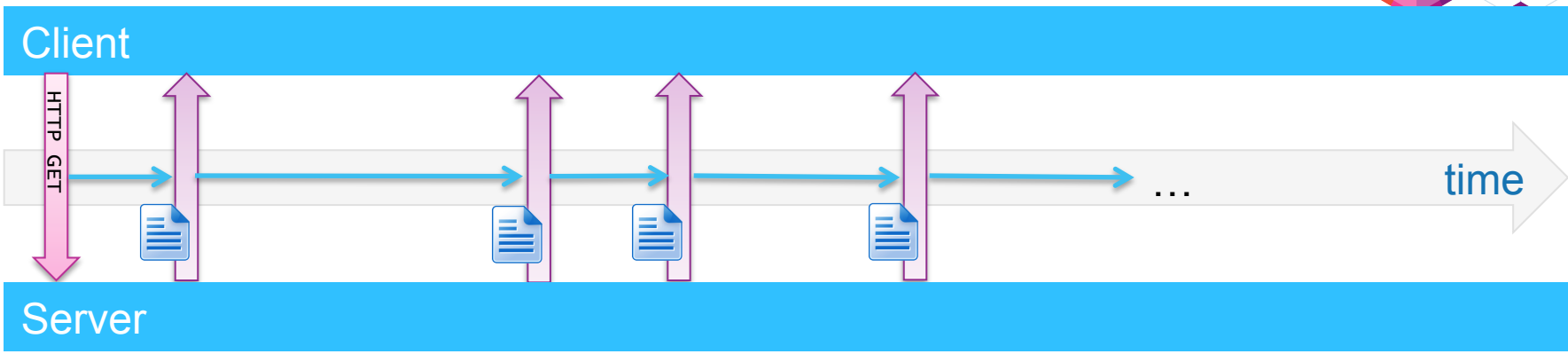
BUT…

(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*

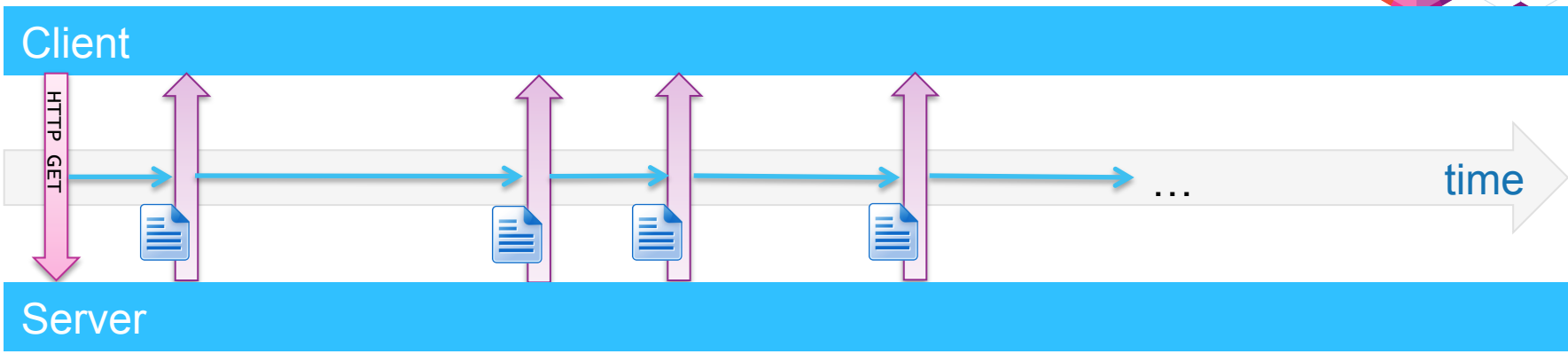
(3): Streaming / forever response



- 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

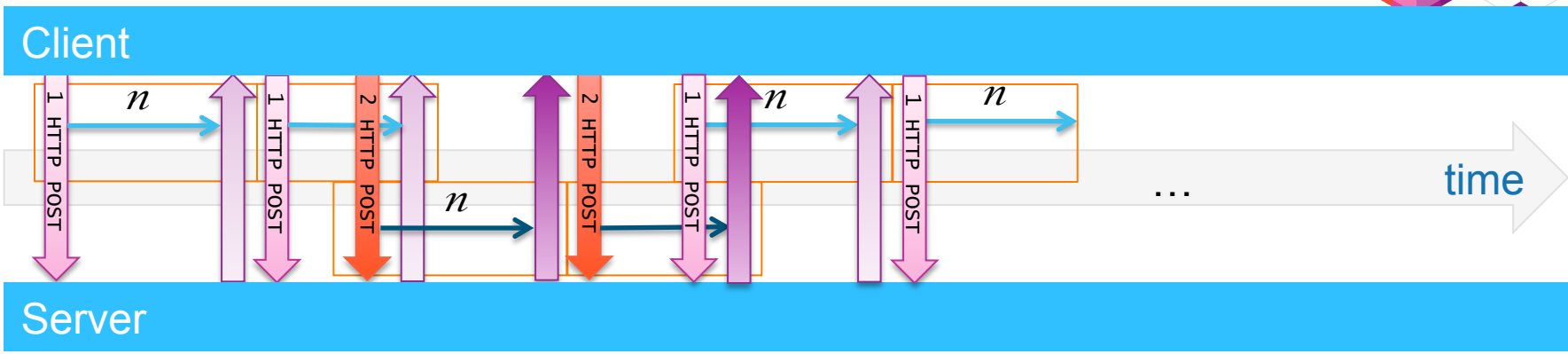
BUT…

(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*

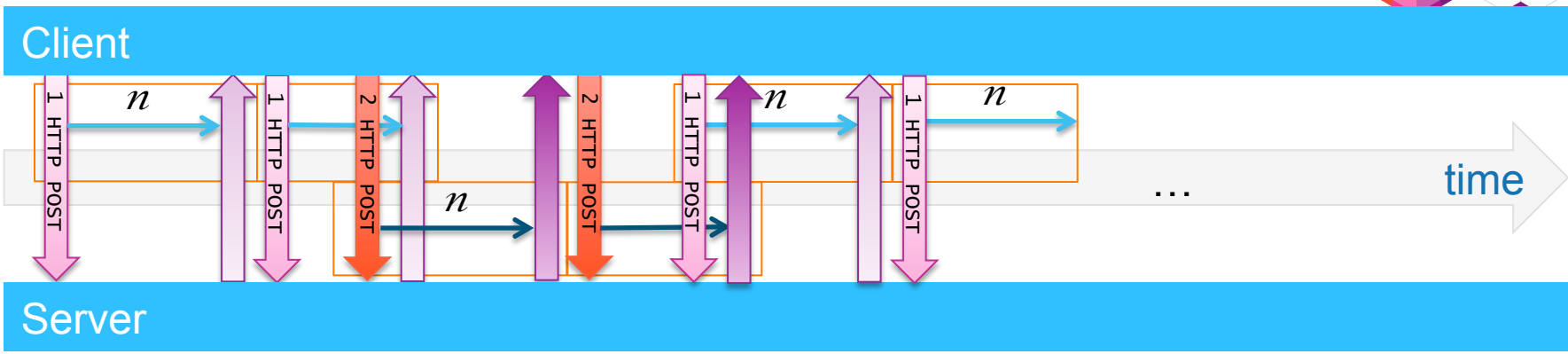
(4): Multiple connections



- 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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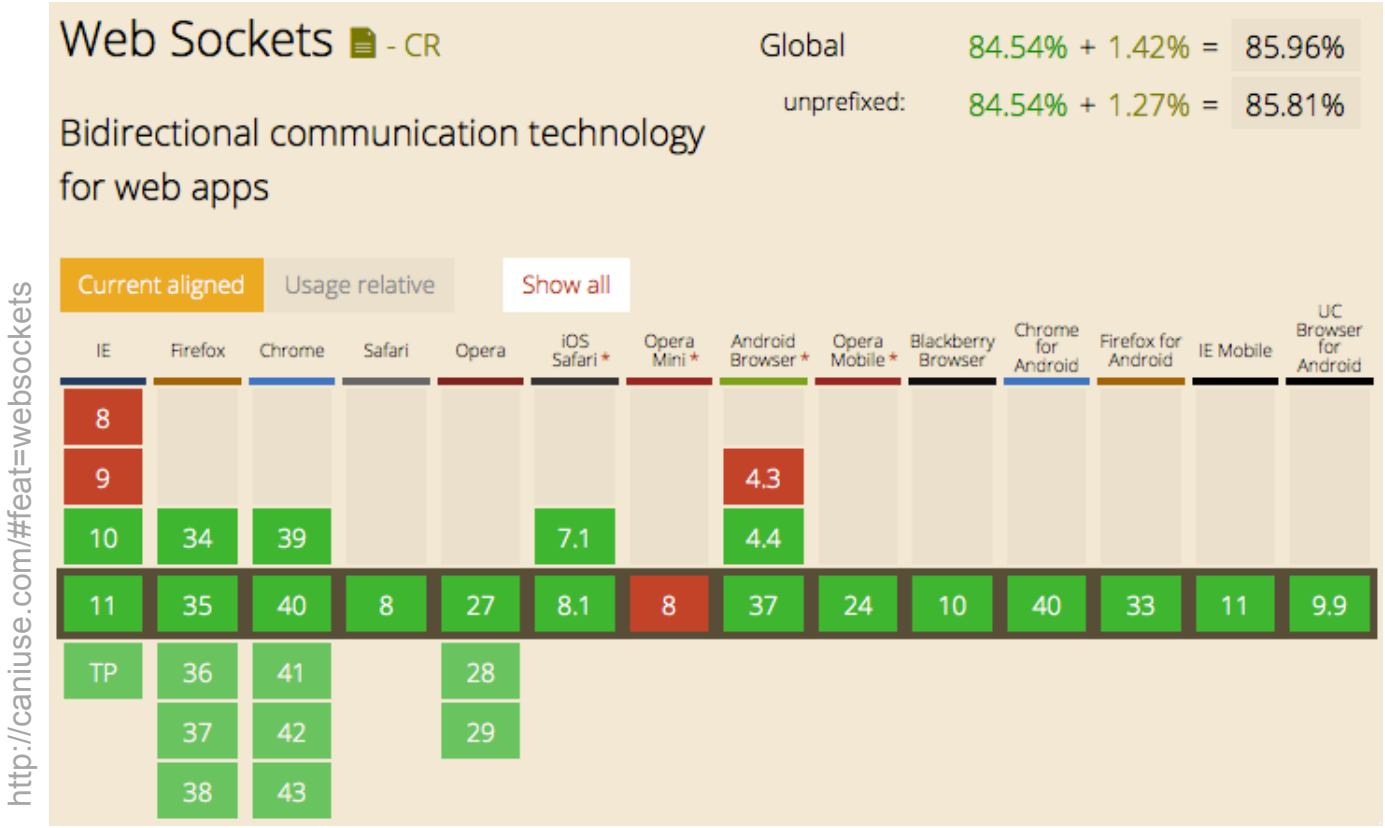
There is a better way: WebSockets

- 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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<background> How WebSockets work..

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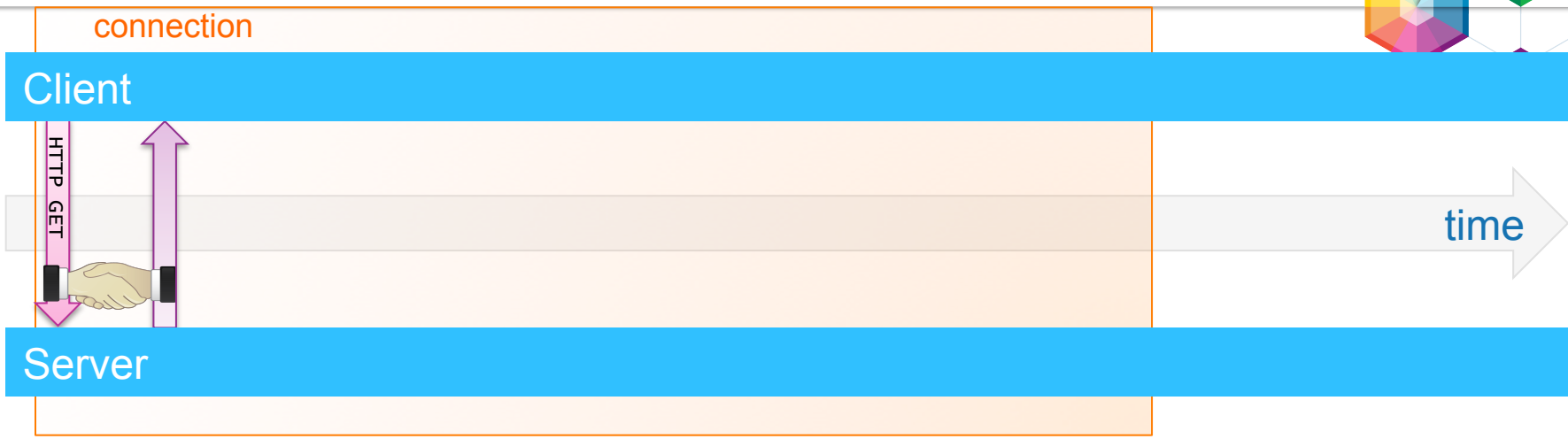
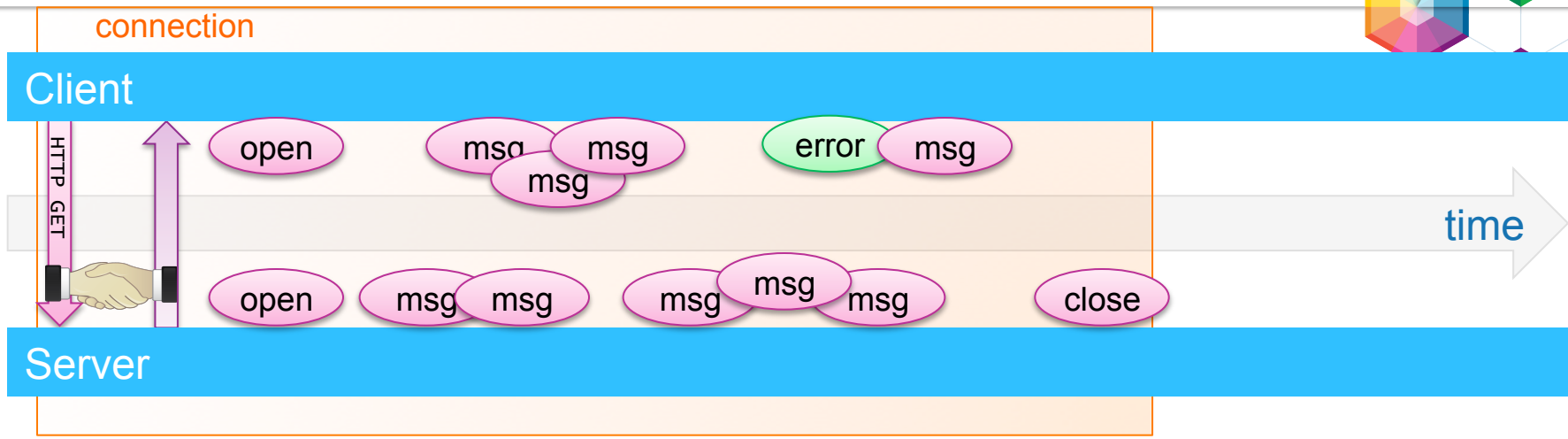
WebSocket connection



- 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: GhlIHNhbXBsZSBub25jZQ==
Sec-WebSocket-Version: 13
Sec-WebSocket-Protocol: custom
Sec-WebSocket-Extensions: compress
Origin: http://example.com
...
```

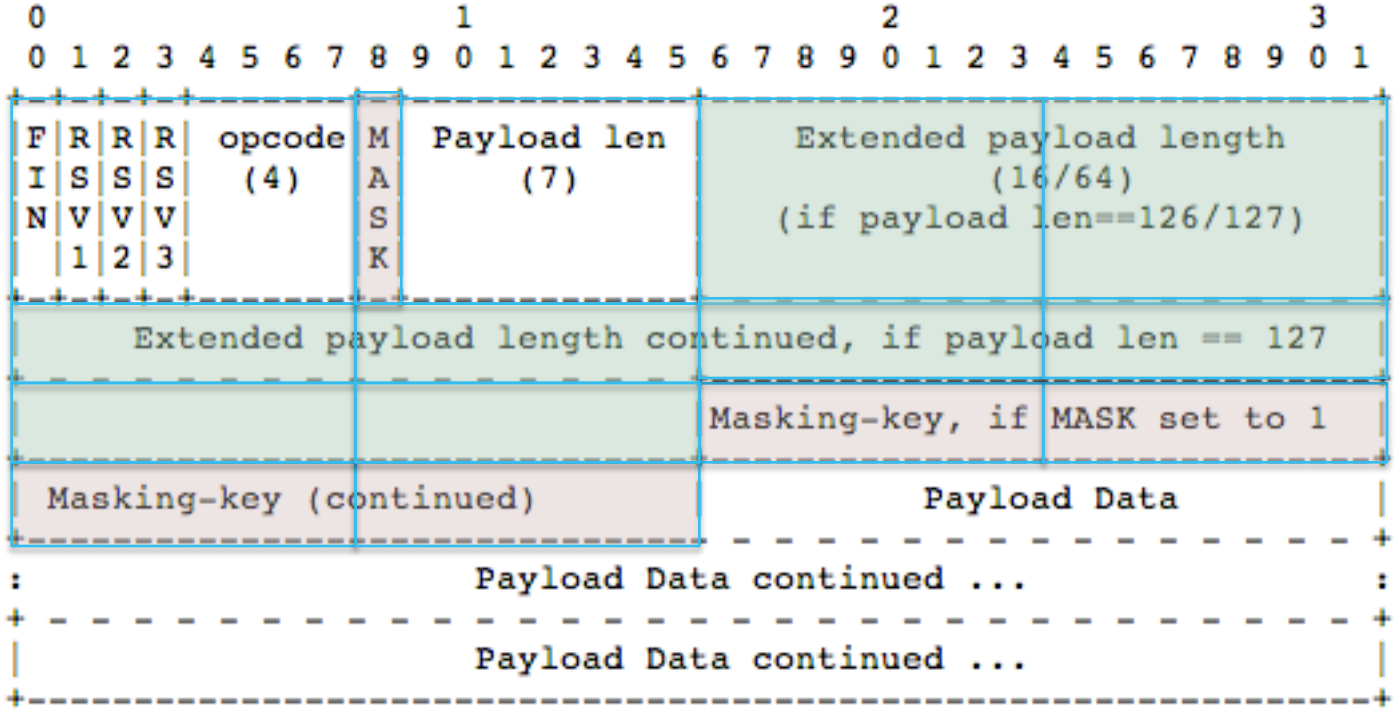
Request upgrade to WebSocket connection

WebSocket handshake headers

response

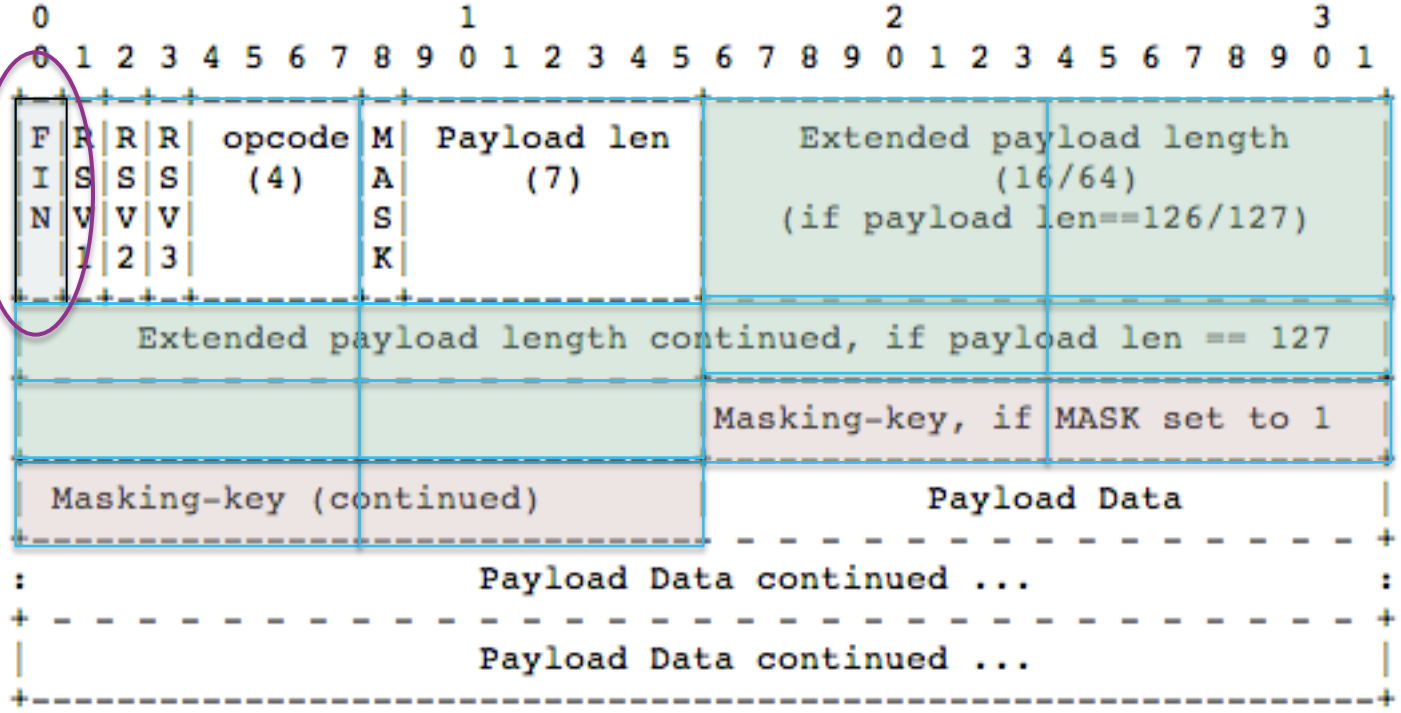
```
HTTP/1.1 101 Switching Protocols
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
Sec-WebSocket-Protocol: custom
Sec-WebSocket-Extensions: compress
```

... 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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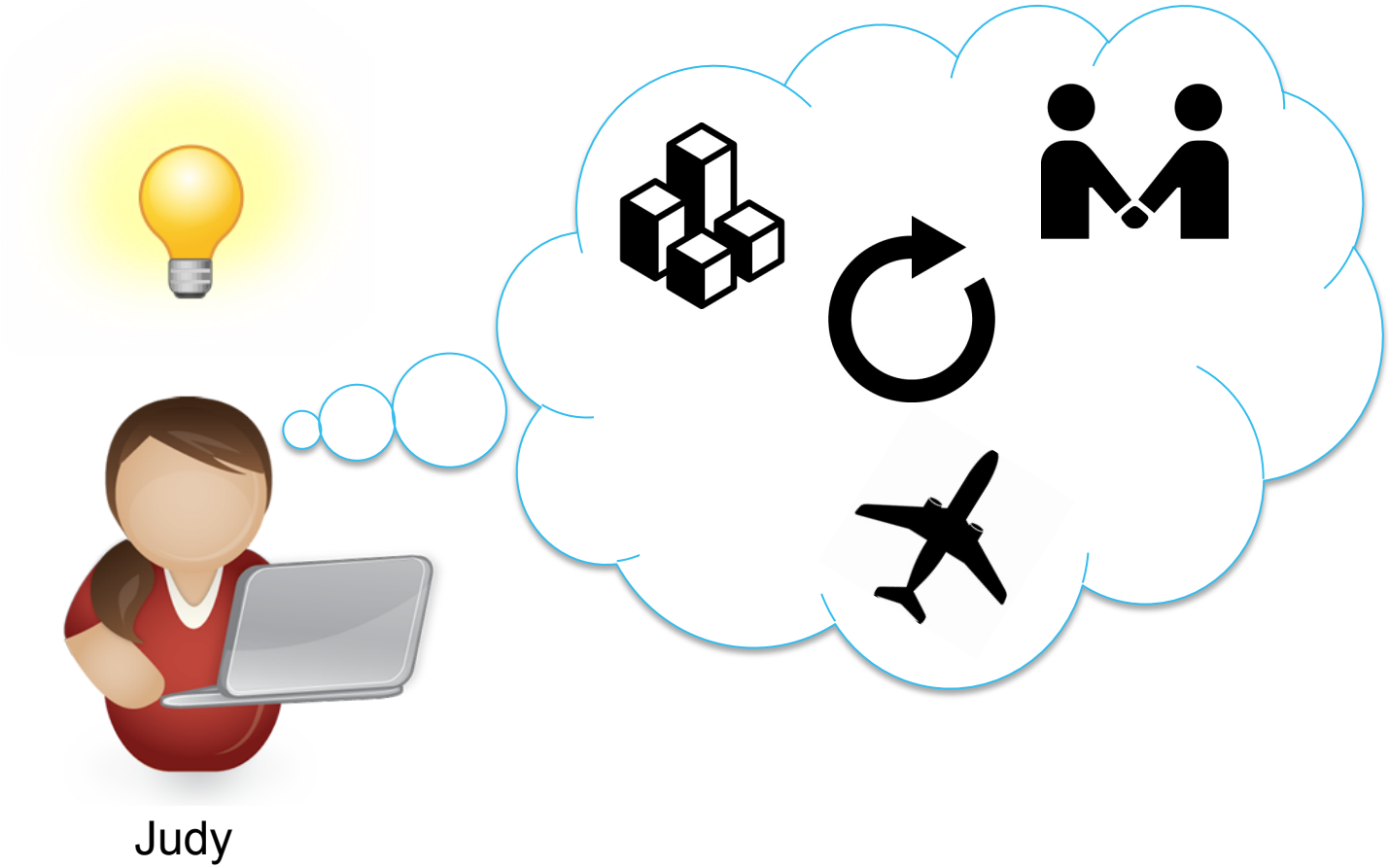
How do we use WebSockets in an application?



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...

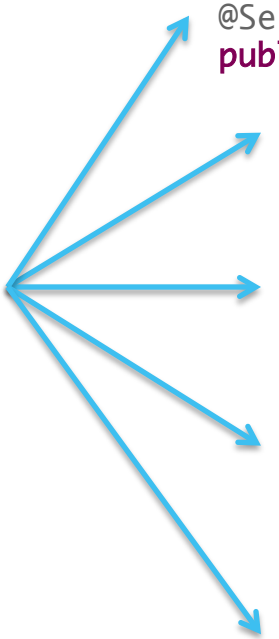
```
websocket = new WebSocket('ws://' +
                          window.document.location.host +
                          '/websocket/EchoEndpoint');

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 ←→Java Objects
- SPI: extensions and data frames

Server Endpoint: Annotated

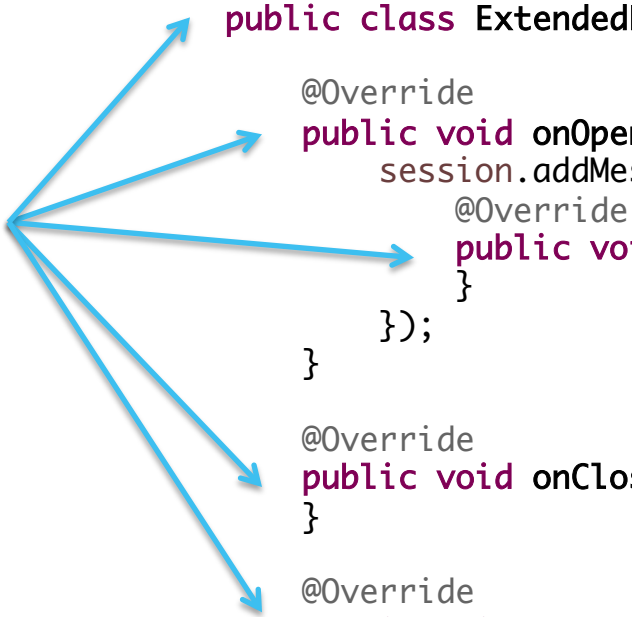
- Simple POJO with `@ServerEndpoint` annotation
  - value is the URI relative to your app's context root, e.g. ws://localhost/myapp/SimpleAnnotated
- Annotations for notifications: lifecycle and messages



```
@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`



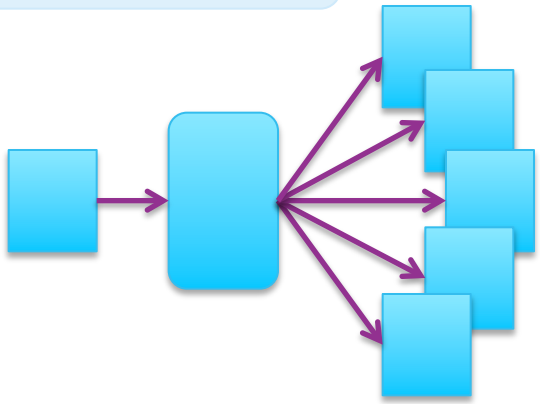
```
public class ExtendedEndpoint extends Endpoint {

    @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!

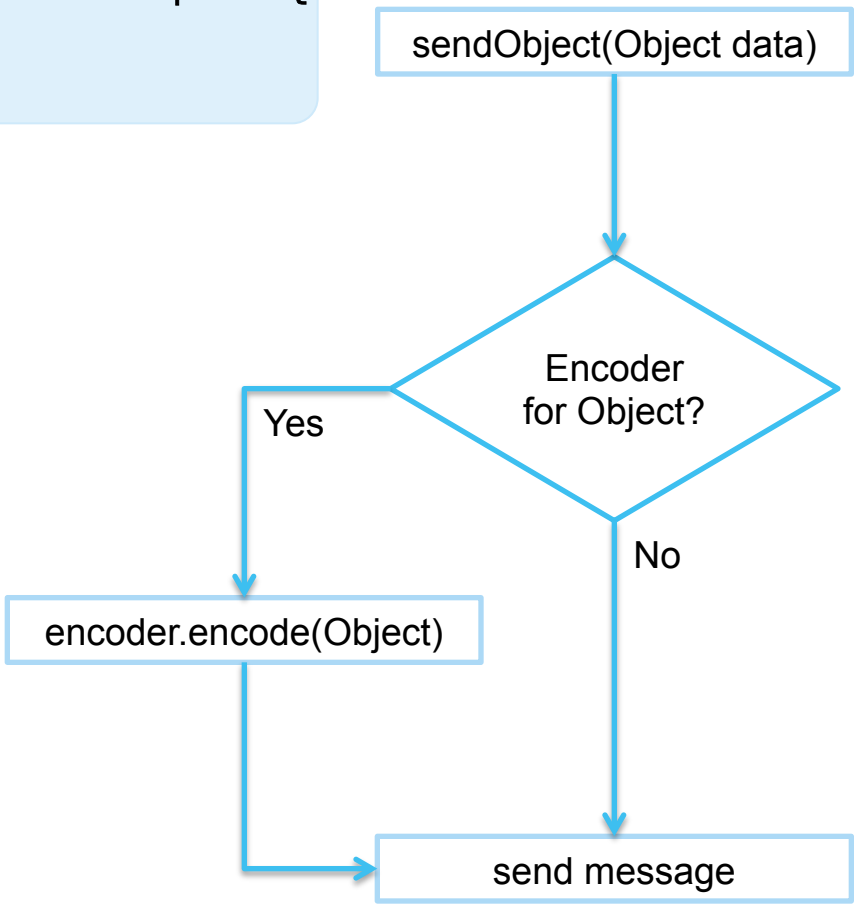
Encoder/Decoder: dealing with data

- 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);
            }
        }
    }

}
```

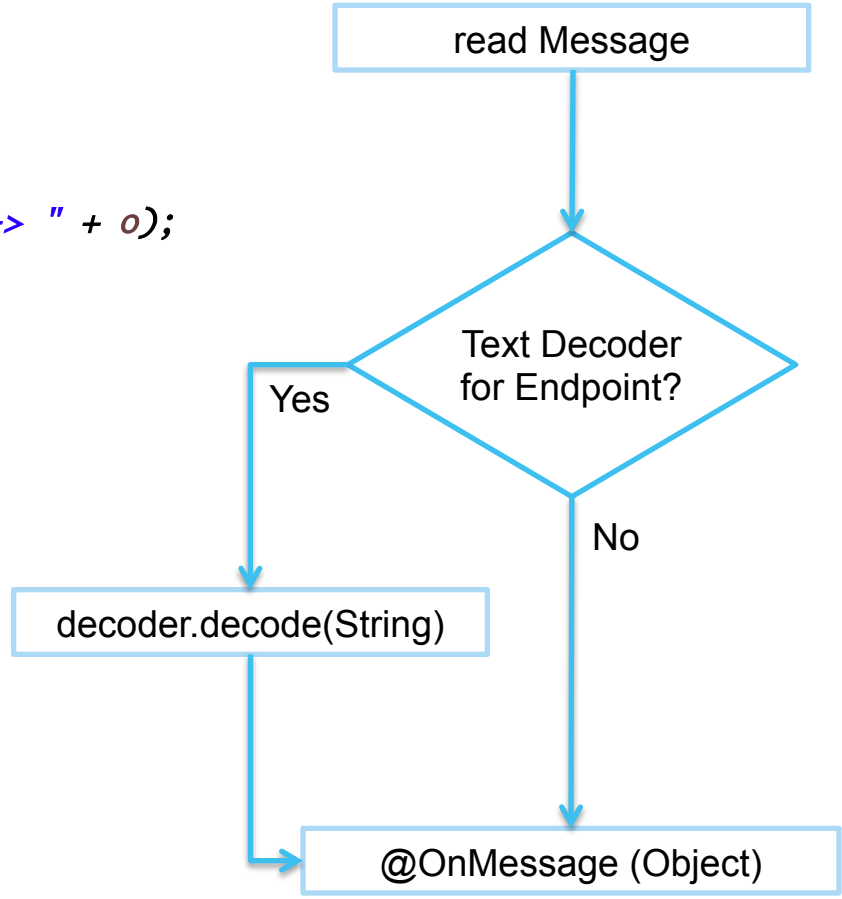
Encoder: dealing with data

```
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;

    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();
    }

    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"));
    }
}
```

decode

encode

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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2977A (lab)	Accelerate Your Business with Liberty's New HTML5 Real-Time Features Tuesday: 11:00 AM - 01:00 PM - Mandalay Bay, South Seas Ballroom A
1304A	Technical Deep Dive into IBM WebSphere Liberty Tuesday: 11:00 AM - 12:00 PM - Mandalay Bay, Reef Ballroom E
3085A	Don't Wait! Develop Responsive Applications with Java EE7 Instead Thursday: 10:30 AM - 11:30 AM - Mandalay Bay, Lagoon L