Nuts and Bolts of WebSocket

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Agenda

- Introduction
- WebSocket and Node.js
- WebSocket using JSR 356
  - Server
  - Client
- Securing WebSocket
- Embedded WebSocket
- Load Balance WebSocket
- Pub/Sub over WebSocket
  - STOMP over WebSocket
  - MQTT over WebSocket
- REST and SSE
- Scalability
- Debugging
- Production Tips

The “long” story of WebSocket

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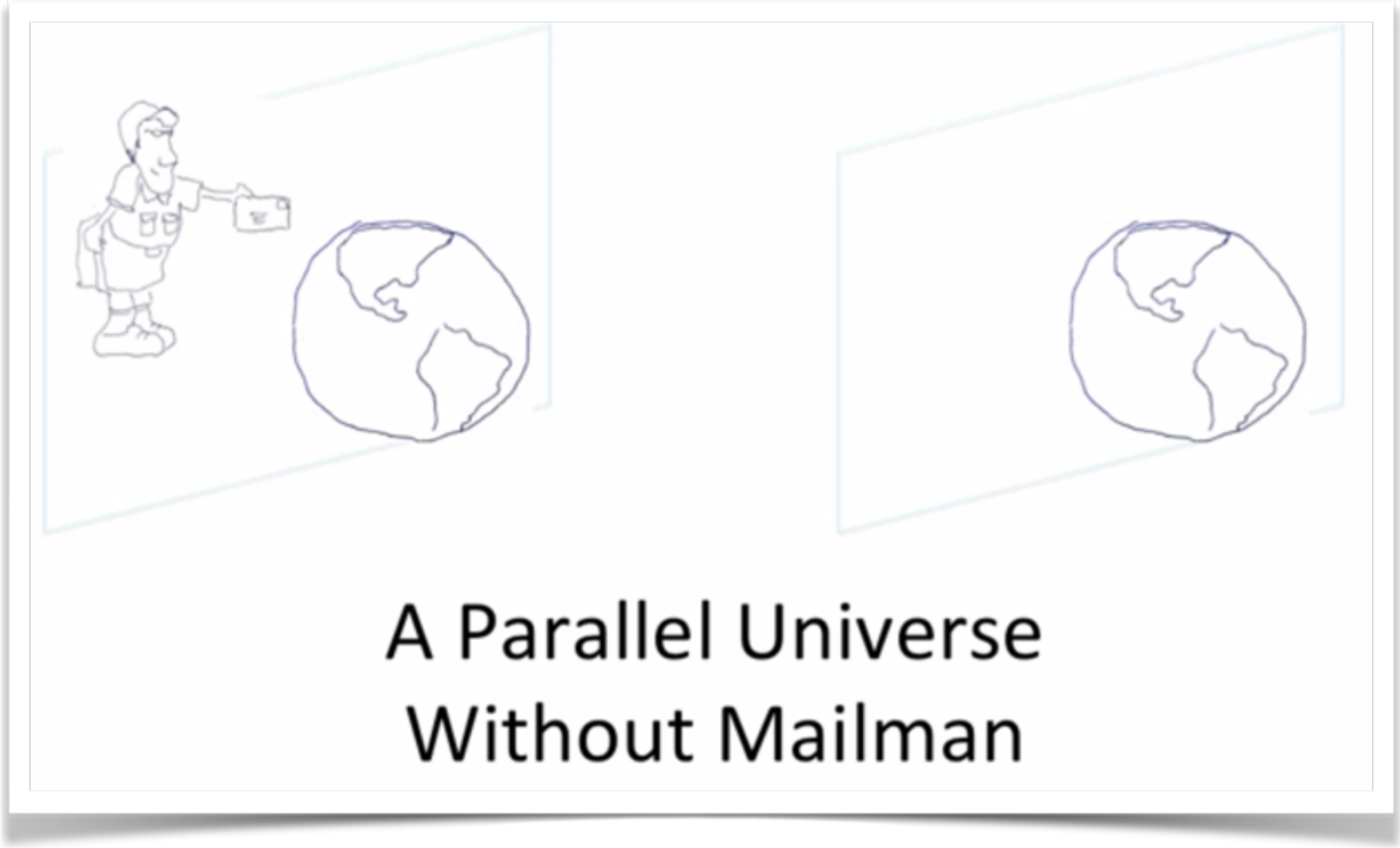

“Limitations” of HTTP

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- Client-driven
- Half-duplex
- Verbose
- New TCP connection

“Hello World” HTTP


```
POST /websocket-vs-rest-payload/webresources/rest HTTP/1.1\r\n
Host: localhost:8080\r\n
Connection: keep-alive\r\n
Content-Length: 11\r\n
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_9_1) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/32.0.1700.107 Safari/537.36\r\n
Origin: chrome-extension://hgmloofddffdnphfgcellkdfbfbjeloo\r\n
Content-Type: text/plain \r\n
Accept: */*\r\n
Accept-Encoding: gzip,deflate,sdch\r\n
Accept-Language: en-US,en;q=0.8\r\n
\r\n
```

663 bytes

```
HTTP/1.1 200 OK\r\n
Connection: keep-alive\r\n
X-Powered-By: Undertow 1\r\n
Server: Wildfly 8 \r\n
Content-Type: text/plain\r\n
Content-Length: 11 \r\n
Date: Fri, 21 Feb 2014 21:27:53 GMT \r\n
\r\n
```

How WebSocket solves it ?

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- Bi-directional (client-driven)
- Full-duplex (half-duplex)
- Lean protocol (verbose)
- Single TCP connection (new TCP)

What is WebSocket ?

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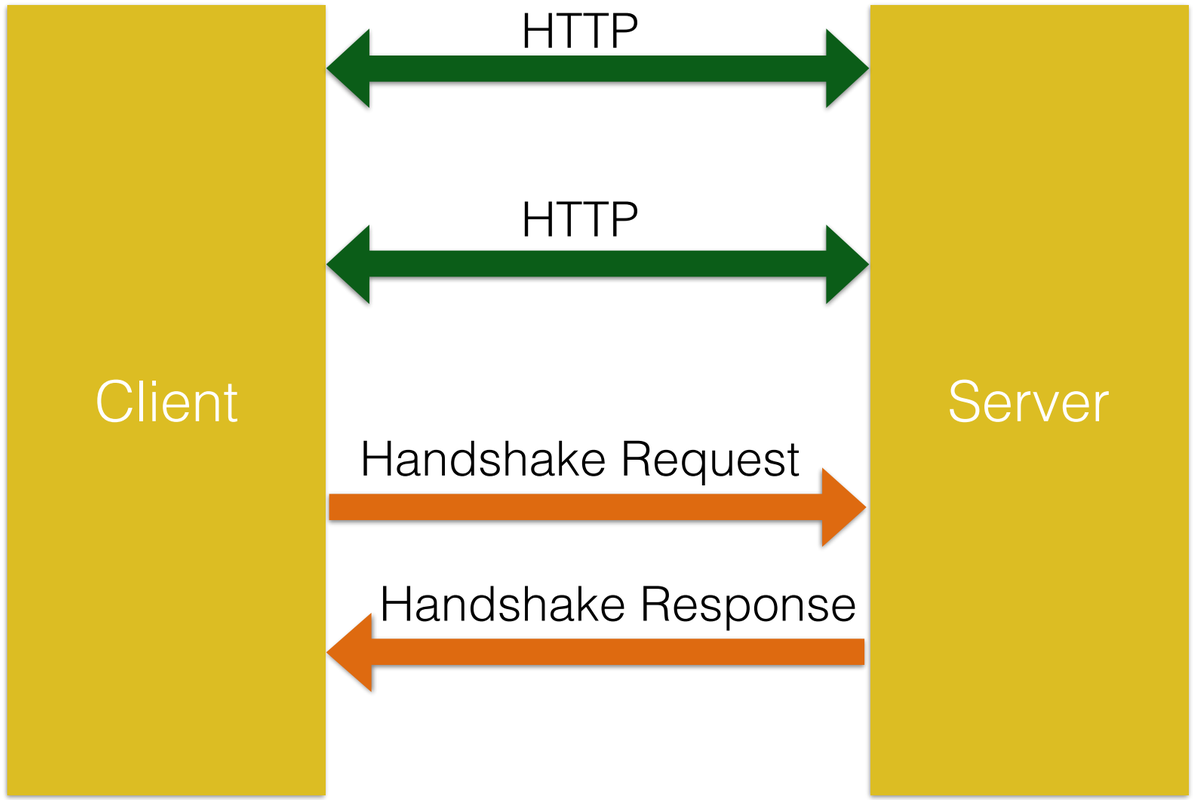
- Bi-directional, full-duplex, communication channel over a single TCP connection
- Originally proposed as part of HTML5
- IETF-defined **Protocol**: RFC 6455
- W3C-defined **JavaScript API**

How does it work ?

- Upgrade HTTP to WebSocket (single TCP connection)
- Send data frames in both direction (bi-directional)
- Send messages independent of each other (full-duplex)
- End the connection

How does it work ?



Handshake Request

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```
GET /chat HTTP/1.1
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Origin: http://example.com
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
Sec-WebSocket-Protocol: chat, superchat
Sec-WebSocket-Version: 13
```

Handshake Response

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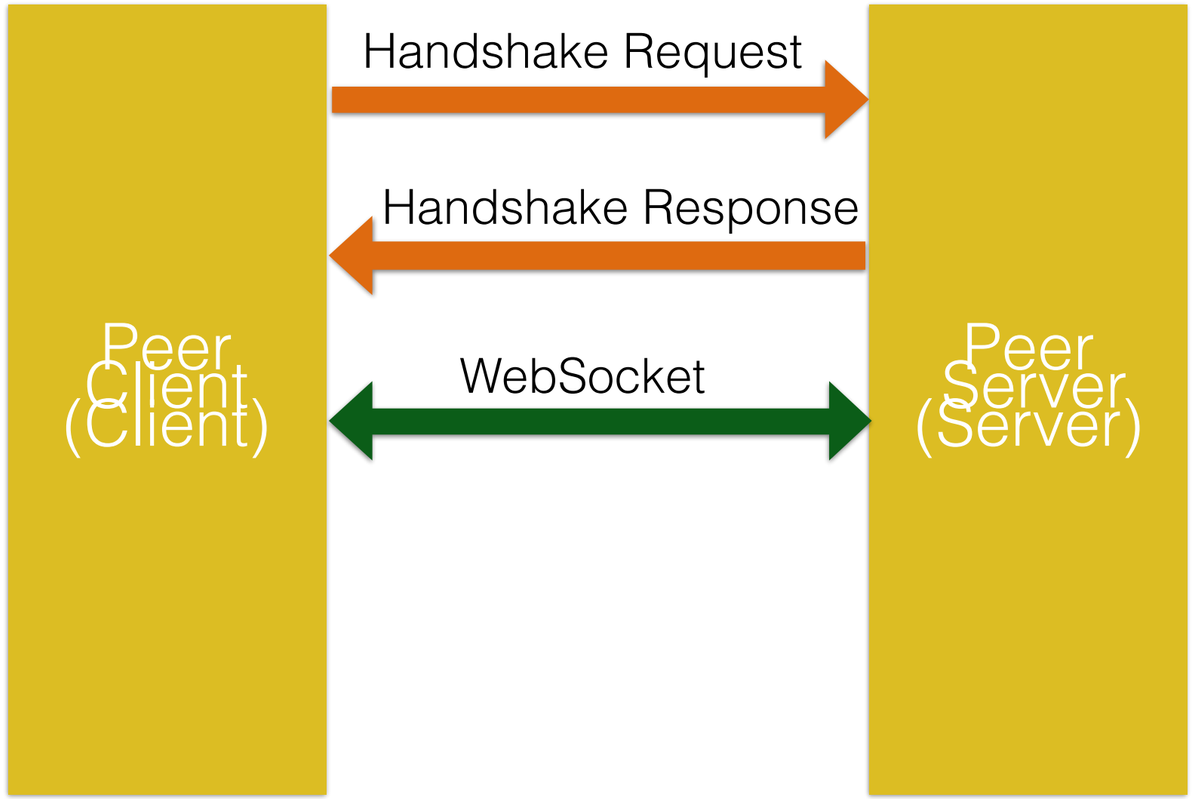
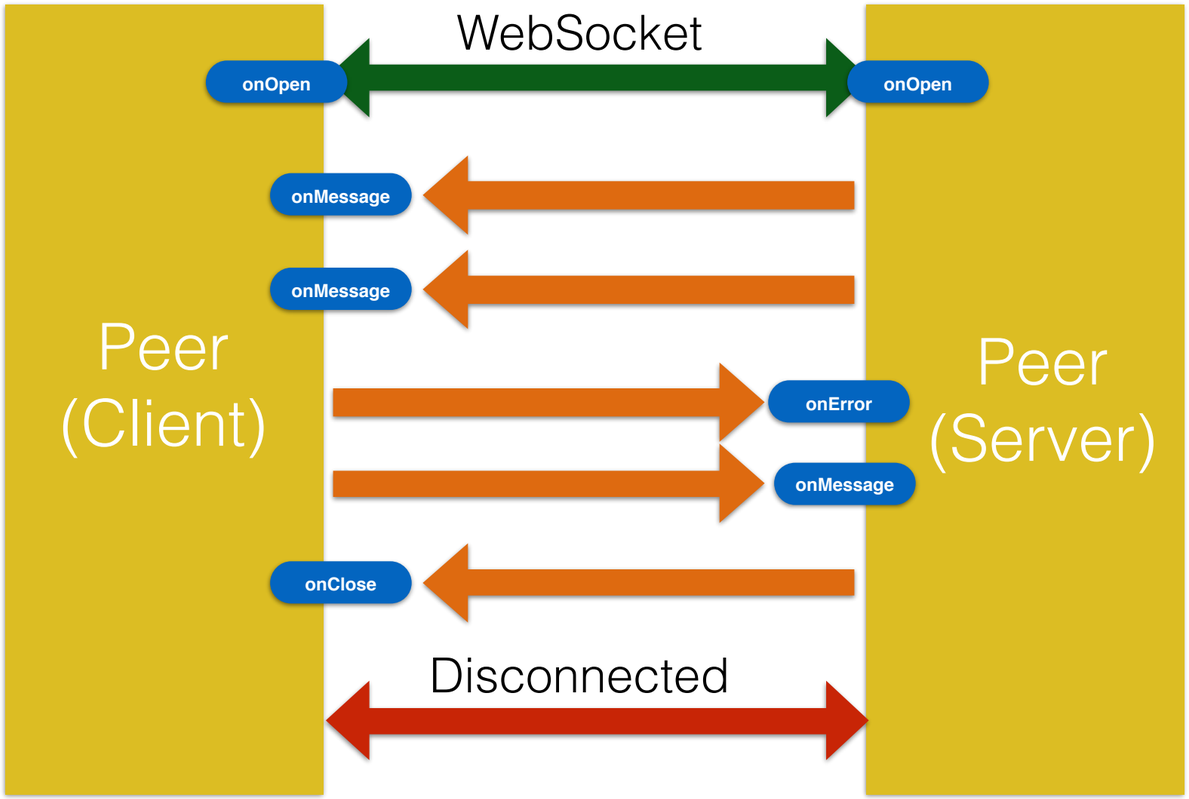
```
HTTP/1.1 101 Switching Protocols
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
Sec-WebSocket-Protocol: chat
```

How does it work ?



How does it work ?



WebSocket Subprotocols

- Facilitates application layer protocols
- Registered in a Subprotocol name registry
  - Identifier, common name, definition
  - www.iana.org/assignments/websocket/websocket.xml#subprotocol-name
    - STOMP, XMPP, MQTT, SOAP, …

WebSocket Extensions

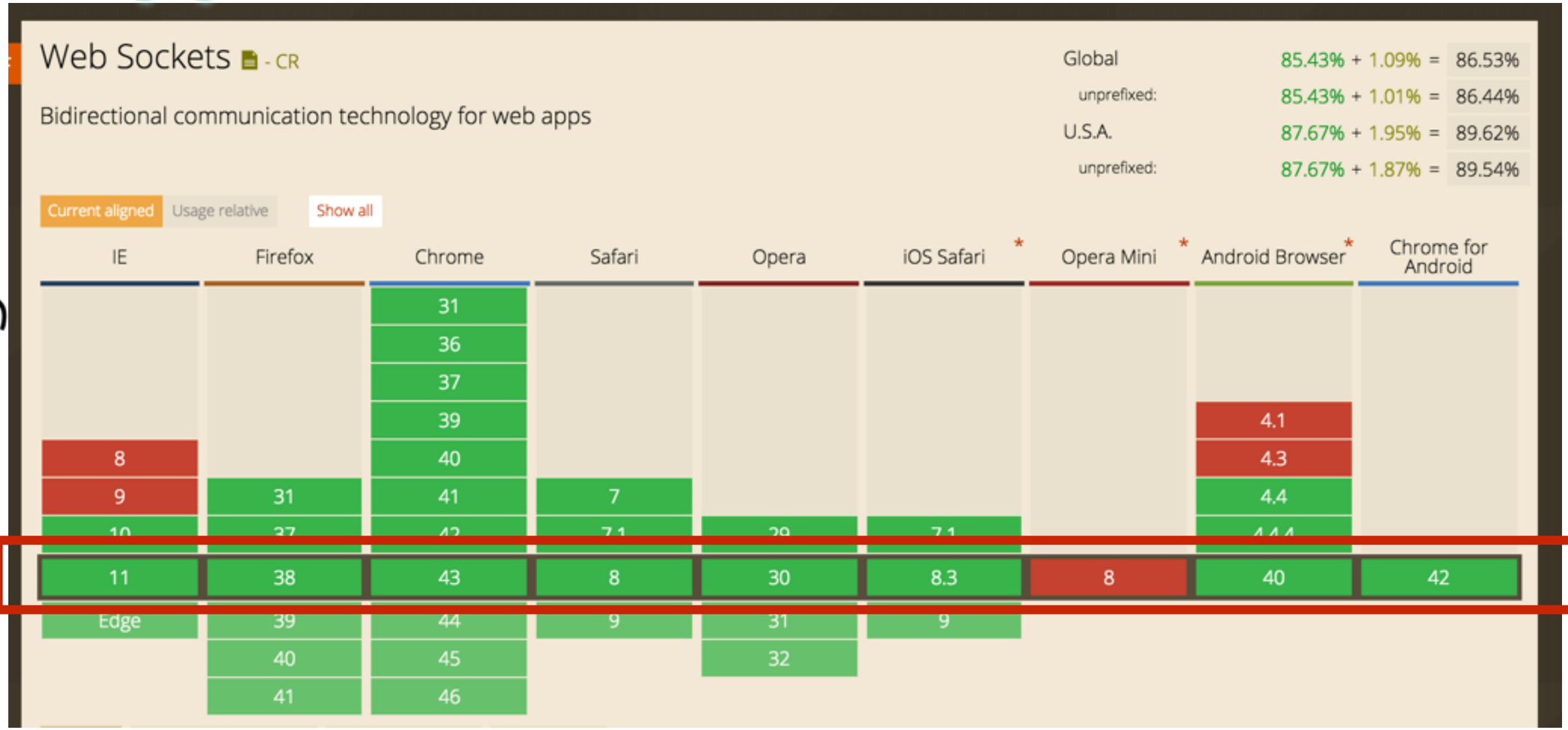
- Add capabilities to the base protocol
- Multiplexing
  http://tools.ietf.org/html/draft-tamplin-hybi-google-mux
- Compression: Only non-control frames/messages
  - Per-frame
    http://tools.ietf.org/html/draft-tyoshino-hybi-websocket-perframe-deflate
  - Per-message
    http://tools.ietf.org/html/draft-ietf-hybi-permessage-compression

WebSocket JavaScript API


```
[Constructor(DOMString url, optional (DOMString or DOMString[]) protocols)]
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 DOMString binaryType;
  void send(DOMString data);
  void send(Blob data);
  void send(ArrayBuffer data);
  void send(ArrayBufferView data);
};
```

www.w3.org/TR/websockets

Support in Browsers



caniuse.com/websockets

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Developer Tools

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Java API for WebSocket

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- API for WebSocket server and client endpoint
  - Annotated: `@ServerEndpoint, @ClientEndpoint`
  - Programmatic: `Endpoint`
    - WebSocket opening handshake negotiation
- Lifecycle Callback methods
- Integration with Java EE technologies

Annotated Endpoint

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```
import javax.websocket.*;

@ServerEndpoint("/hello")
public class HelloBean {
  @OnMessage
  public String sayHello(String name) {
    return "Hello " + name;
}
```

WebSocket Annotations

- Class-level annotations
  - `@ServerEndpoint`: Turns a POJO in a server endpoint
  - `@ClientEndpoint`: Turns a POJO in a client endpoint

WebSocket Annotations

- Method-level annotations
  - `@OnMessage`: Intercepts WebSocket messages
  - `@OnOpen`: Intercepts WebSocket open events
  - `@OnClose`: Intercepts WebSocket close events
  - `@OnError`: Intercepts WebSocket error events

WebSocket Annotations

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- Parameter-level annotations
  - `@PathParam`: Matches path segment of a URI-template

@ServerEndpoint attributes

- `value`: Relative URI or URI template e.g. '/hello' or '/chat/{subscriber-level}'
- `decoders`: list of message decoder classnames
- `encoders`: list of message encoder classnames
- `subprotocols`: list of the names of the supported subprotocols

Chat Server

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```
@ServerEndpoint("/chat")
public class ChatBean {
  static Set<Session> peers = Collections.synchronizedSet("...");

  @OnOpen
  public void onOpen(Session peer) {
    peers.add(peer);
  }

  @OnClose
  public void onClose(Session peer) {
    peers.remove(peer);
  }

  @OnMessage
  public void message(String message) {
    for (Session peer : peers) {
      peer.getBasicRemote().sendObject(message);
    }
  }
}
```

Chat Server Simplified

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```
@ServerEndpoint("/chat")
public class ChatBean {
  @OnMessage
  public void message(String message, Session endpoint) {
    for (Session peer : endpoint.getOpenSessions()) {
      peer.getBasicRemote().sendObject(message);
    }
  }
}
```

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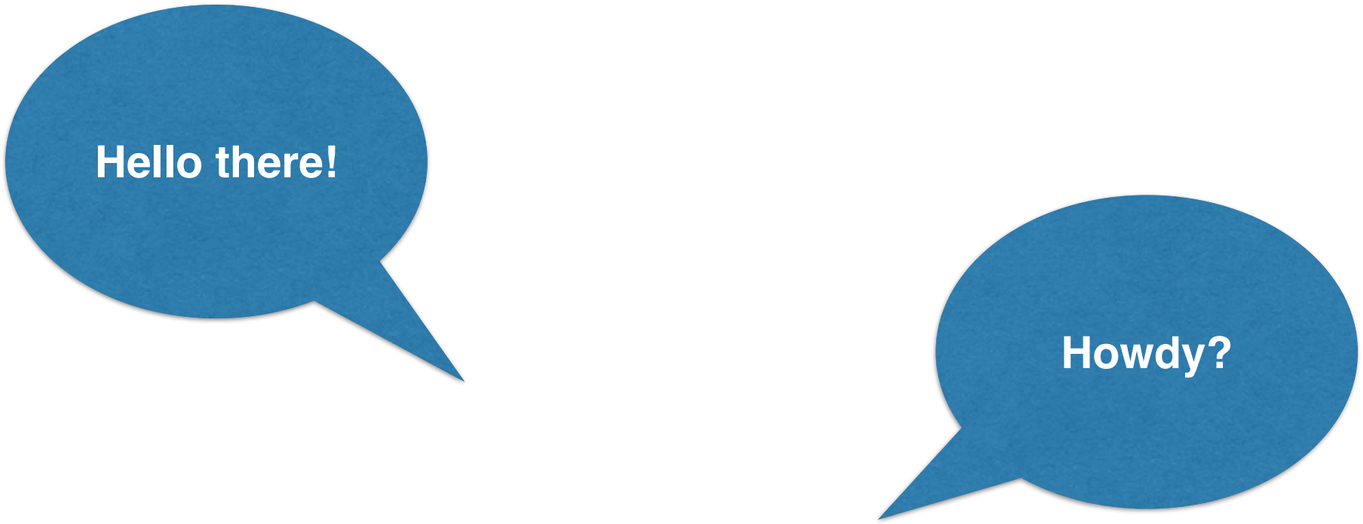

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/chat

Custom Payloads

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```
@ServerEndpoint(
  value="/hello",
  decoders={MyMessageDecoder.class},
  encoders={MyMessageEncoder.class}
)
public class MyEndpoint {
  . . .
}
```

Custom Payloads: Text decoder

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```
public class MyMessageDecoder implements Decoder.Text<MyMessage> {
  public MyMessage decode(String s) {
    JsonObject jsonObject = Json.createReader("...").readObject();
    return new MyMessage(jsonObject);
  }

  public boolean willDecode(String string) {
    . . .
    return true;
  }

  . . .
}
```

Custom Payloads: Text encoder

```
public class MyMessageDecoder implements Encoder.Text<MyMessage> {
  public String encode(MyMessage myMessage) {
    return myMessage.jsonObject.toString();
  }

  . . .
}
```

Custom Payloads: Binary decoder

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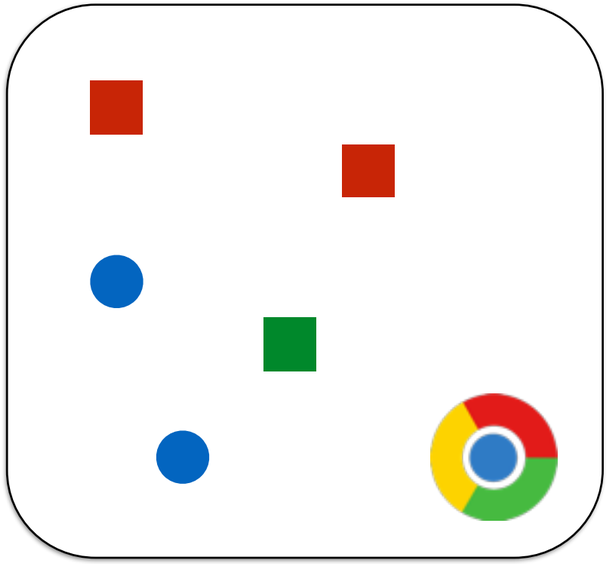
```
public class MyMessageDecoder implements Decoder.Binary<MyMessage> {
  public MyMessage decode(byte[] s) {
    . . .
    return myMessage;
  }

  public boolean willDecode(byte[] string) {
    . . .
    return true;
  }

  . . .
}
```

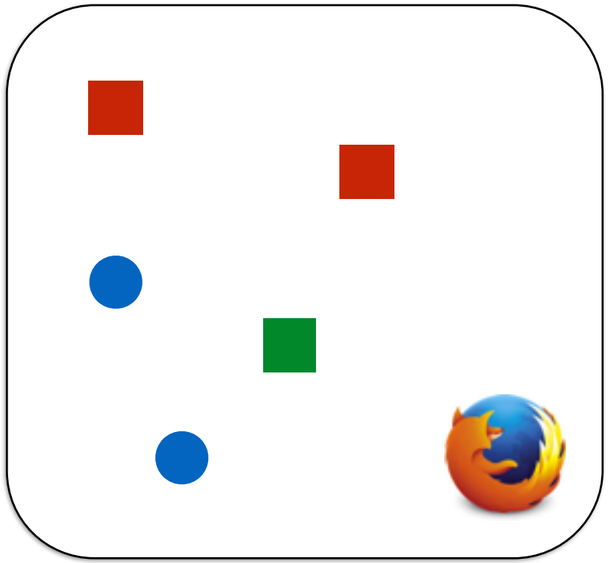
Method Signatures

- Exactly one of the following
  - **Text**: `String`, `boolean`, Java primitive or equivalent class, `Reader`, any type for which there is a decoder
  - **Binary**: `byte[]`, `ByteBuffer`, `byte[]` and `boolean`, `ByteBuffer` and `boolean`, `InputStream`, any type for which there is a decoder
  - **Pong** messages: `PongMessage`
- An optional **Session** parameter
- 0..n String parameters annotated with **@PathParam**

Sample Messages

- `void m(String s);`
- `void m(Float f, @PathParam("id")int id);`
- `Product m(Reader reader, Session s);`
- `void m(byte[] b); or void m(ByteBuffer b);`
- `Book m(int i, Session s, @PathParam("isbn")String isbn, @PathParam("store")String store);`





https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/whiteboard

URI Template Matching

```
@ServerEndpoint("/chat/{roomid}")
public class ChatServer {
  @OnMessage
  public void receiveMessage(
    @PathParam("roomid")String roomId) {
    . . .
  }
}
```

Client Endpoint


```
@ClientEndpoint
public class HelloClient {
  @OnMessage public void message(
    String message,
    Session session) {
    //. . .
  }
}

WebSocketContainer c = ContainerProvider.getWebSocketContainer();
c.connectToServer(HelloClient.class, "hello");
```

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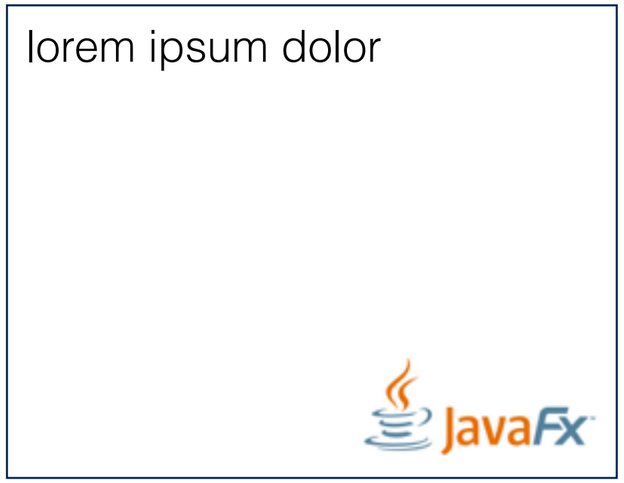

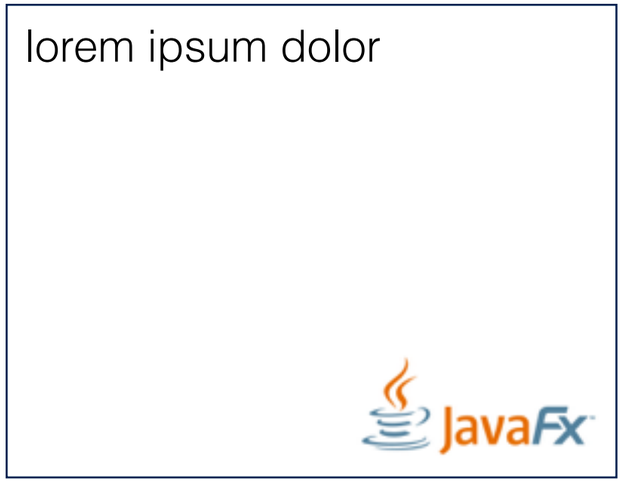

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/google-docs

Programmatic Endpoint

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```
public class ChatServer extends Endpoint {
  @Override
  public void onOpen(Session session) {
    session.addMessageHandler(new MessageHandler.Text() {
      public void onMessage(String message) {
        try {
          session
           .getBasicRemote()
           .sendText(message);
        } catch (IOException ex) { }
      }
    });
  }
}
```

Programmatic Endpoint Config


```
public class MyEndpointConfig implements ServerApplicationConfig {

    @Override
    public Set<ServerEndpointConfig> getEndpointConfigs(
        Set<Class<? extends Endpoint>> set) {
        return new HashSet<ServerEndpointConfig>() {
            {
                add(ServerEndpointConfig.Builder
                    .create(ChatServer.class, "/chat")
                    .build());
            }
        };
    }

    @Override
    public Set<Class<?>> getAnnotatedEndpointClasses(Set<Class<?>> set) {
        return Collections.emptySet();
    }
}
```

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https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/endpoint-singleton

Securing WebSockets

- Origin-based security model
- Sec-xxx keys can not be set using XMLHttpRequest
  - Sec-WebSocket-Key, Sec-WebSocket-Version
- User-based security using Servlet security mechanism
  - Endpoint mapped by **ws://** is protected using security model defined using the corresponding http:// URI
  - Authorization defined using `<security-constraint>`
- Transport Confidentiality using **wss://**
  - Access allowed over encrypted connection only

Cross-Origin Resource Sharing

- Relaxes same-origin restrictions to network requests
- Servers include `Access-Control-Allow-Origin` HTTP header
- Access-Control-* headers
  - Max-Age
  - Allow-Methods
  - Allow-Headers
  - …
- www.w3.org/TR/cors/

User-based Security

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/endpoint-security

TLS-based Security

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/endpoint-wss

Embedded WebSocket

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- **Undertow** New web server in WildFly 8
- Blocking and non-blocking based on NIO
- Composition/handler-based architecture
- Lightweight and fully embeddable
- Supports Servlet 3.1 and HTTP Upgrade
- mod_cluster supported

Undertow is awesome!

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```
techempower@lg01:~$ wrk -d 30 -c 256 -t 40 http://10.0.3.2:8080/byte
Running 30s test @ http://10.0.3.2:8080/byte
  40 threads and 256 connections
  Thread Stats   Avg      Stdev     Max   +/- Stdev
    Latency   247.05us    3.52ms 624.37ms   99.90%
    Req/Sec    27.89k     6.24k   50.22k    71.15%
  31173283 requests in 29.99s, 3.83GB read
  Socket errors: connect 0, read 0, write 0, timeout 9
Requests/sec: 1039305.27
Transfer/sec:    130.83MB
```

This is output from Wrk testing a single server running Undertow using conditions similar to Google's test (1-byte response body, no HTTP pipelining, no special request headers) **1.039 million requests per second**.

http://www.techempower.com/blog/2014/03/04/one-million-http-rps-without-load-balancing-is-easy/

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git@github.com:undertow-io/undertow.git

Load Balance WebSocket

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- Reverse proxy
  - Apache module: `mod_proxy_wstunnel`
- Only vertical scaling
- No session replication

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http://blog.arungupta.me/2014/08/load-balance-websockets-apache-httpd-techtip48/

STOMP over WebSocket

- STOMP: **S**imple **T**ext **O**riented **M**essaging **P**rotocol
- Interoperable wire format: any client, any broker
- Messaging interoperability among languages and platforms
  - Unlike JMS
- REST for messaging: CONNECT, SEND, SUBSCRIBE, . . .
- Map STOMP frames to WebSocket frames

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https://github.com/arun-gupta/wildfly-samples/tree/master/websocket-stomp

MQTT over WebSocket

Stomp 

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- Light-weight pub/sub messaging over TCP
- Designed for "small foot print" or limited bandwidth
- MQTT 3.1.1 is now an OASIS standard
- Plain byte array message payload
- Quality-of-Service: 0 (TCP), 1 (at least once), 2 (missed messages)
- "Last will and testament" publish a message after client goes offline

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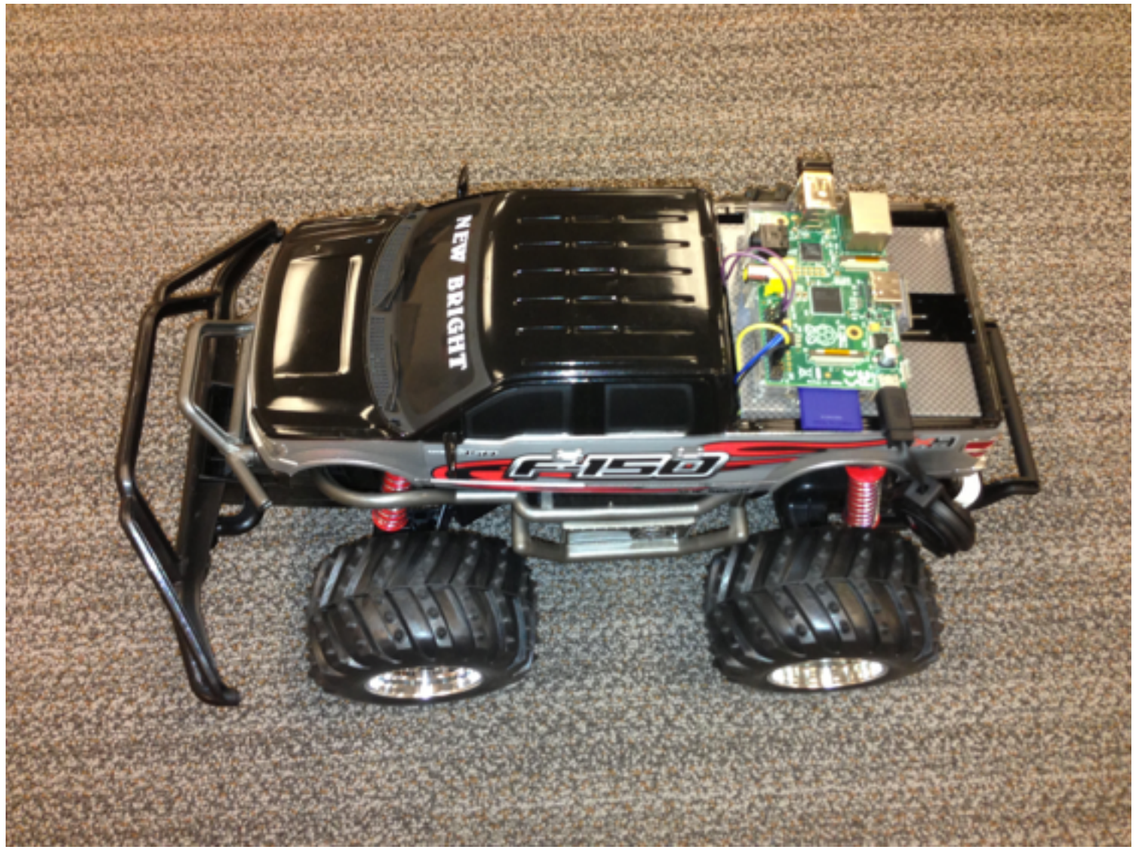

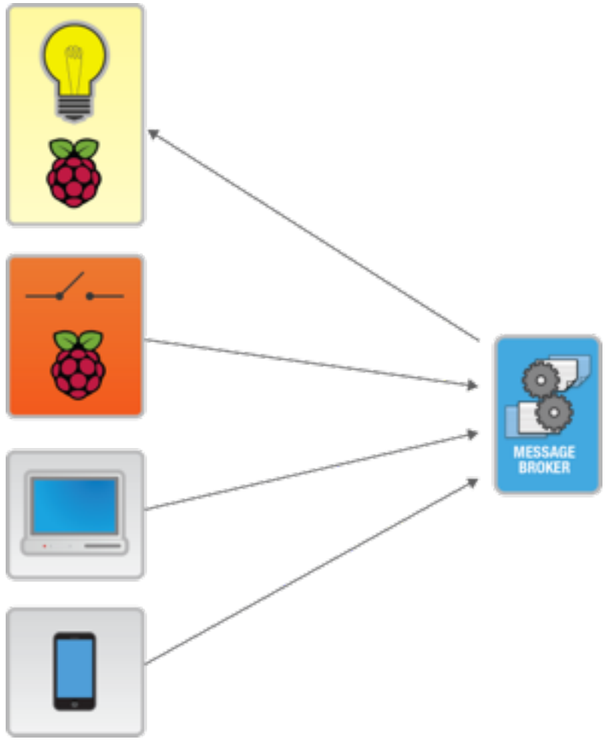

http://blog.kaazing.com/2013/10/01/controlling-physical-devices-on-the-real-time-web-kaazing-iot-talk-at-javaone-2013/

Compare with REST

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/websocket-vs-rest-payload

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/websocket-vs-rest

Server-Sent Events

- Part of HTML5 Specification
- Server-push notifications
- Cross-browser JavaScript API: `EventSource`
- Message callbacks
- MIME type: `text/eventstream`

EventSource API


```
[Constructor(DOMString url, optional EventSourceInit eventSourceInitDict)]
interface EventSource : EventTarget {
  readonly attribute DOMString url;
  readonly attribute boolean withCredentials;

  // ready state
  const unsigned short CONNECTING = 0;
  const unsigned short OPEN = 1;
  const unsigned short CLOSED = 2;
  readonly attribute unsigned short readyState;

  // networking
  [TreatNonCallableAsNull] attribute Function? onopen;
  [TreatNonCallableAsNull] attribute Function? onmessage;
  [TreatNonCallableAsNull] attribute Function? onerror;
  void close();
};

dictionary EventSourceInit {
  boolean withCredentials = false;
};
```

WebSockets and SSE ?

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WebSocket	Server-Sent Event
Over a custom protocol	Over simple HTTP
Full-duplex, bi-directional	Server-push only, client-server OOB
Native support in most browsers	Can be poly-filled to backport
Not straight forward protocol	Simpler protocol

WebSockets and SSE ?

WebSocket	Server-Sent Event
Application-specific reconnection	Built-in support for reconnection and event id
Require server and/or proxy configurations	No server or proxy change required
Text and Binary	Text only
Pre-defined message handlers	Pre-defined and arbitrary

What makes them scalable ?

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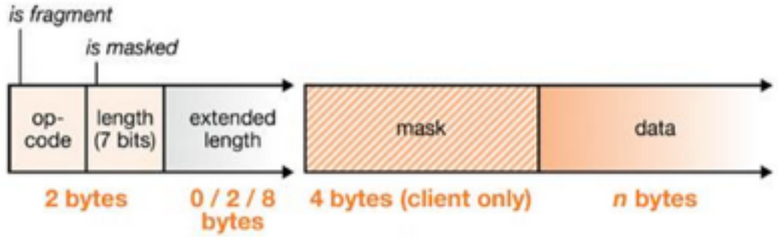
- No HTTP/TCP opening/closing connections
  - Handshake over a single TCP connection
  - HTTP connections have short connection timeout (5 secs for Apache)
- Elimination of HTTP headers (cookies, content-type, user-agent, …)
  - Reduces bandwidth dramatically

What makes them scalable ?



- Minimal data framing
  - 2-14 bytes overhead after handshake
- Maintaining a TCP connection on server is relatively inexpensive
- Smaller data fragments can be sent without out a request/ response
  - Live pushes, e.g. stock sticker
  - Lower latency

What makes them scalable ?

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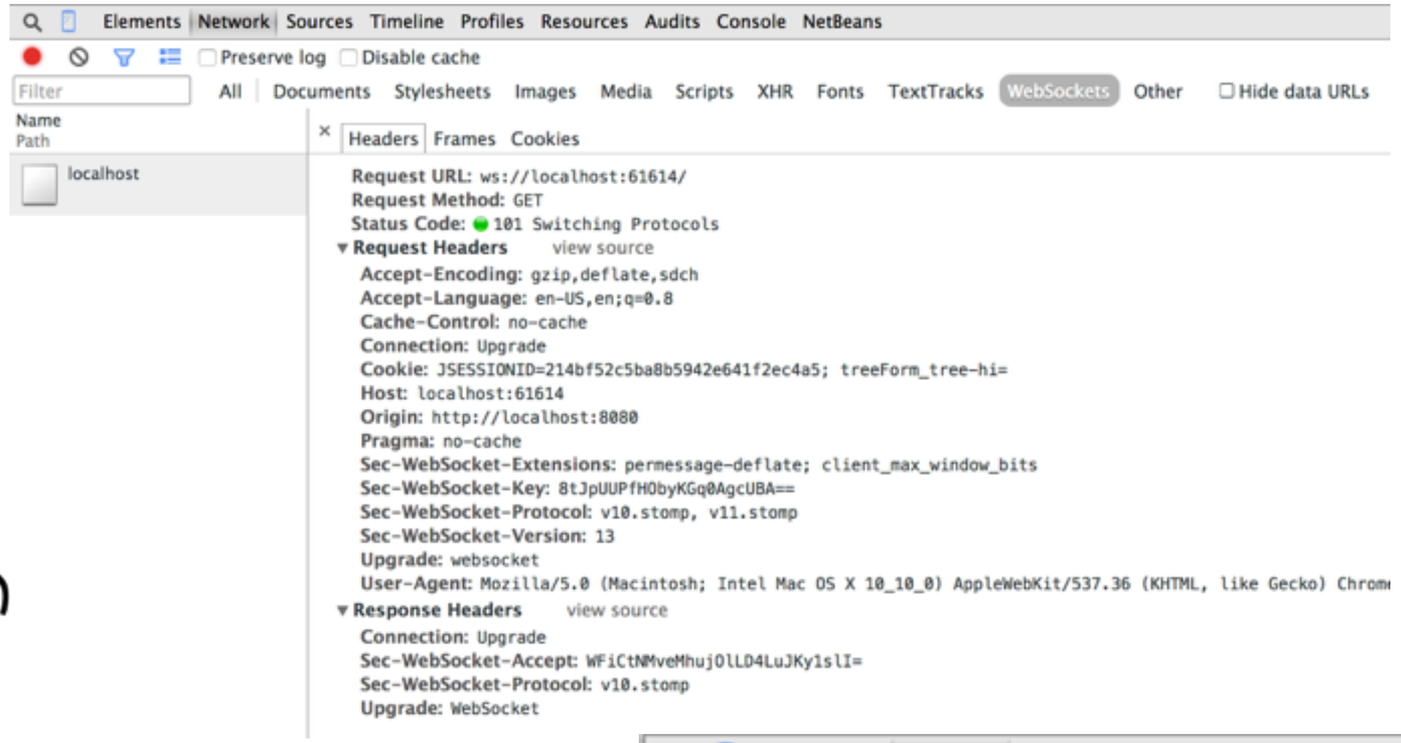
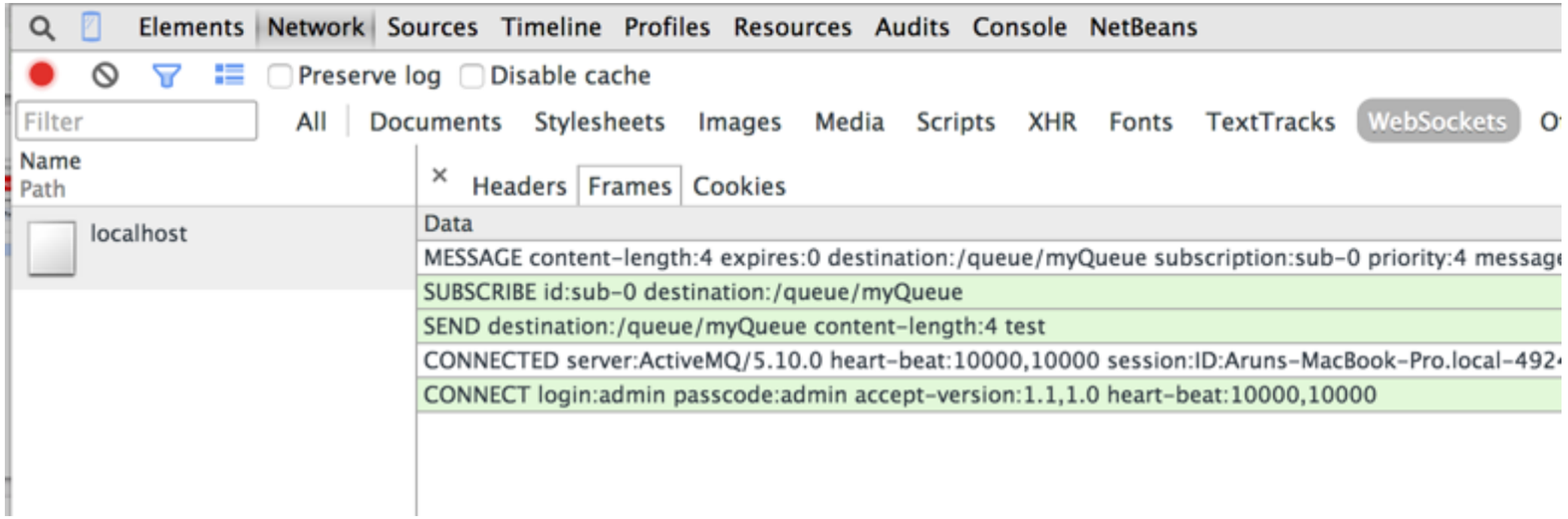
- WebSockets are good at scaling vertically
- HTTP servers are typically configured to log start/completion of HTTP request, not so for WebSocket
- Polling and Long-polling is a waste of bandwidth, WebSockets are more elegant
- Number of concurrent clients depend upon FD settings

Debugging WebSockets





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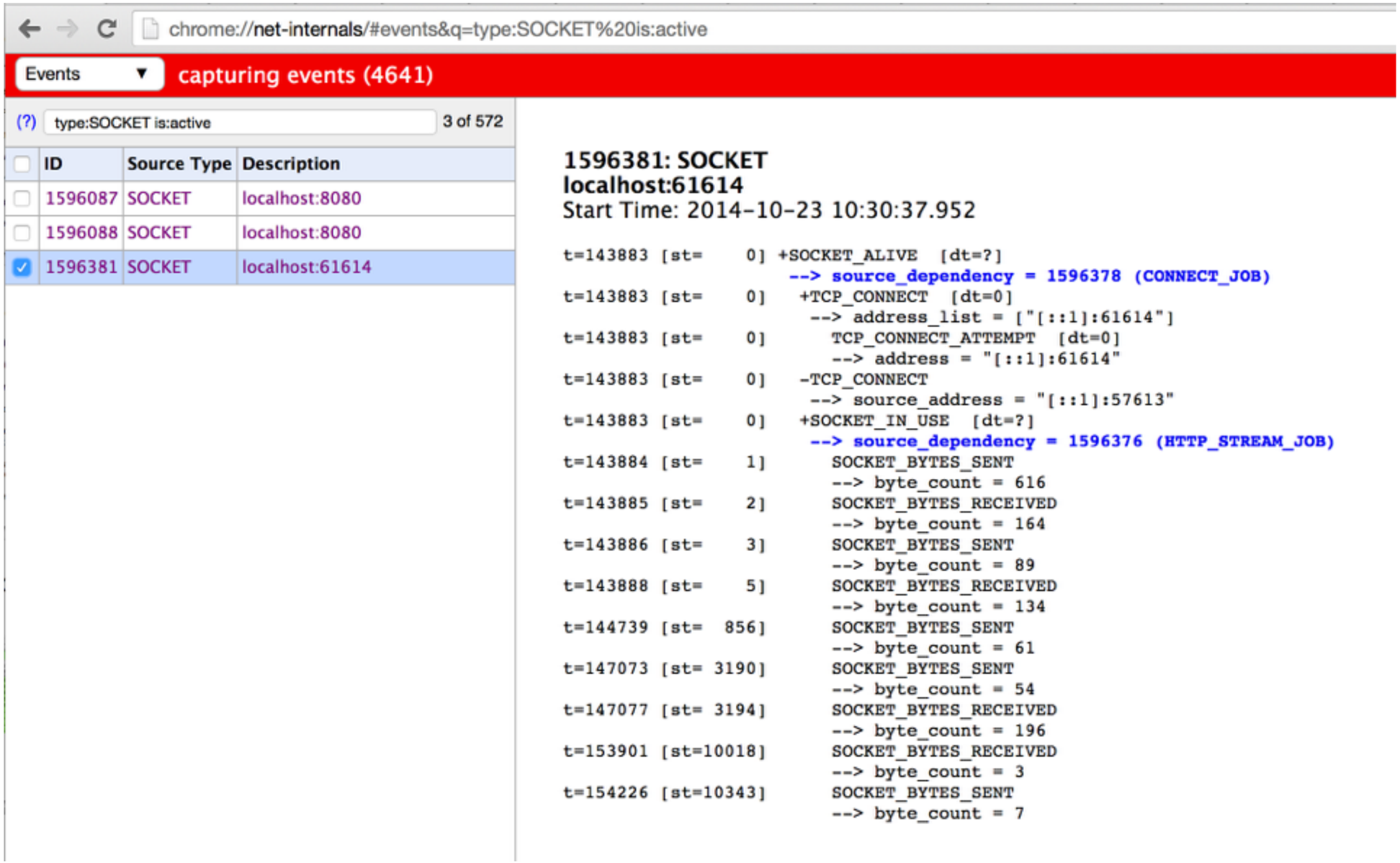

Debugging WebSockets

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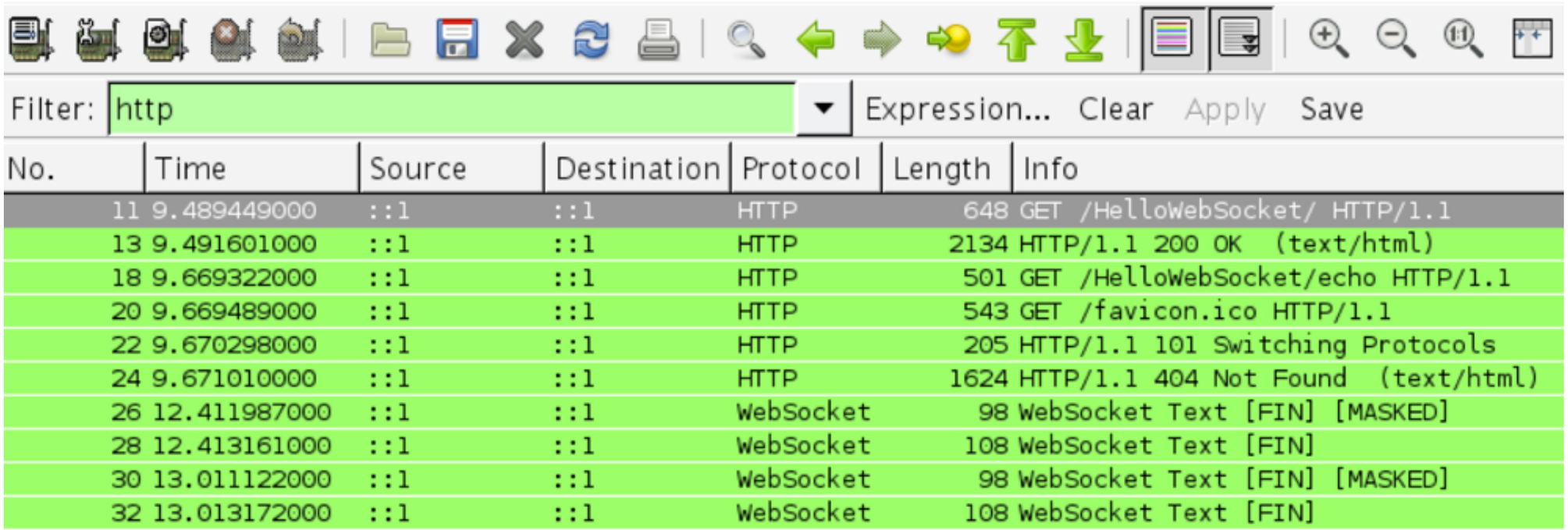
WIRESHARK



Filter: http — Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
11	9.489449000	::1	::1	HTTP	648	GET /HelloWebSocket/ HTTP/1.1
13	9.491601000	::1	::1	HTTP	2134	HTTP/1.1 200 OK (text/html)
18	9.669322000	::1	::1	HTTP	501	GET /HelloWebSocket/echo HTTP/1.1
20	9.669489000	::1	::1	HTTP	543	GET /favicon.ico HTTP/1.1
22	9.670298000	::1	::1	HTTP	205	HTTP/1.1 101 Switching Protocols
24	9.671010000	::1	::1	HTTP	1624	HTTP/1.1 404 Not Found (text/html)
26	12.411987000	::1	::1	WebSocket	98	WebSocket Text [FIN] [MASKED]
28	12.413161000	::1	::1	WebSocket	108	WebSocket Text [FIN]
30	13.011122000	::1	::1	WebSocket	98	WebSocket Text [FIN] [MASKED]
32	13.013172000	::1	::1	WebSocket	108	WebSocket Text [FIN]

Production Tips

- Proxy can be evil and make WebSockets unusable
  - **Issue**: Remove "Upgrade" header
  - **Fix**: Set timeout, remove after `onOpen` called
  - **Issue**: Close connection after X idle time
  - **Fix**: Application-level heartbeat
  - **Issue**: Not allow to pass through at all
  - **Fix**: Fall back on long-polling

Production Tips

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- Load Balancer
  - **Issue**: Don't work with WebSocket, e.g. Amazon ELB
  - **Fix**: ELB configured to use TCP, but no session affinity
- Browsers
  - **Issue**: IE 6, 7, 8, 9 and Safari 5 do not support WebSocket
  - **Fix**: Fallback using Atmosphere, Socket.IO, SockJS
- Inconsistencies in JSR 356

Atmosphere

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- Java/JavaScript framework
- Portable asynchronous applications
- Fallback to long-polling in absence of WebSocket
- Containers: Netty, Jetty, GlassFish, Tomcat, JBoss, WildFly, WebLogic, Resin, WebSphere
- Browsers: Firefox, Chrome, IE (6x+), Opera, Safari, Android

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/atmosphere-chat

Resources

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- Material: github.com/arun-gupta/nuts-and-bolts-of-websocket