UDP Programming

RES, Lecture 5

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SMTP review

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- Turn-by-turn, line-by-line protocols
- End of line markers
- Stateful vs stateless protocols
- Implementing a SMTP server
    - https://james.apache.org/
    - https://nodemailer.com/extras/smtp-server/
- Docker: services (daemons) vs "ephemeral" containers
- Docker compose

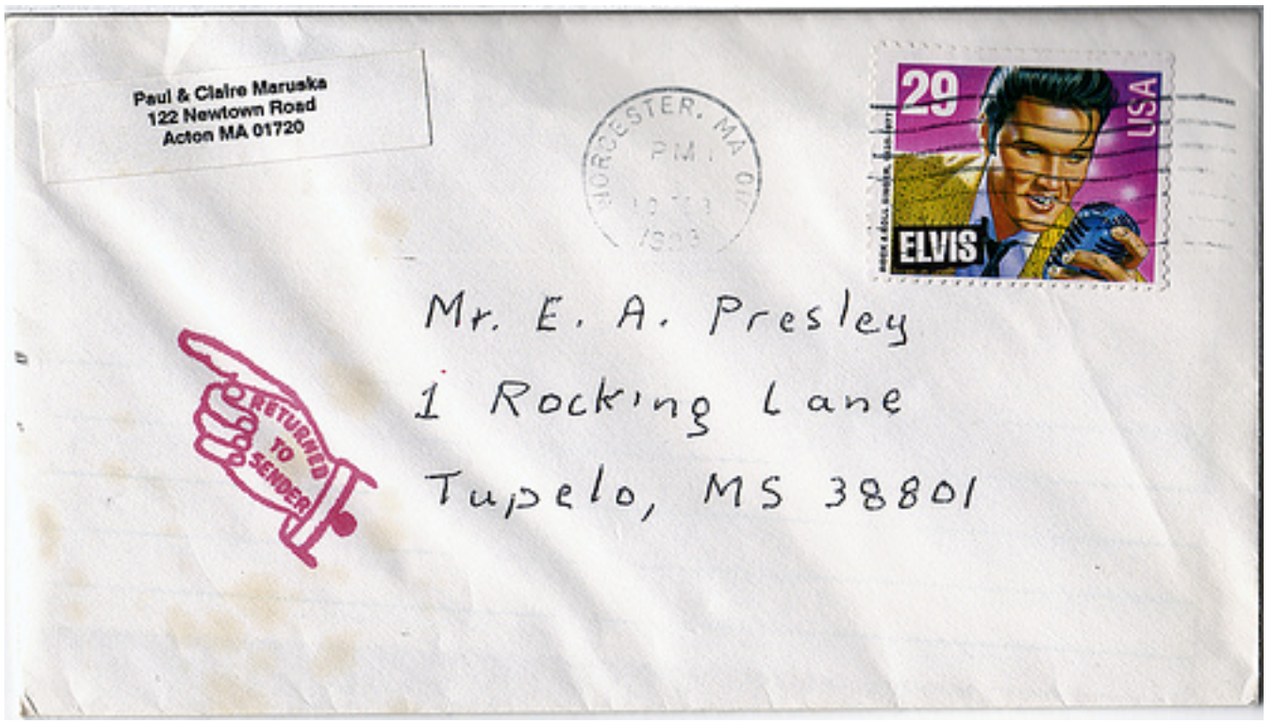
```yaml
version: '3.3'

services:
   db:
     image: mysql:5.7
     volumes:
       - db_data:/var/lib/mysql
     restart: always
     environment:
       MYSQL_ROOT_PASSWORD: somewordpress
       MYSQL_DATABASE: wordpress
       MYSQL_USER: wordpress
       MYSQL_PASSWORD: wordpress

   wordpress:
     depends_on:
       - db
     image: wordpress:latest
     ports:
       - "8000:80"
     restart: always
     environment:
       WORDPRESS_DB_HOST: db:3306
       WORDPRESS_DB_USER: wordpress
       WORDPRESS_DB_PASSWORD: wordpress
       WORDPRESS_DB_NAME: wordpress
volumes:
    db_data: {}
```

A lot of features are added to compose over time; make sure you specify the correct version here

This will start (at least) one container, using the mysql:5.7 image. It will be connected on the default network for this compose “topology”. It will be reachable via its IP address, but also via the “db” host name.

This is a “named” volume. It will persist data across restarts/re-creations of containers. It is not directly mapped to a folder on your file system. The volume is mounted on /var/lib/mysql in the container.

The UDP Protocol



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TCP

UDP

The UDP Protocol

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- When using UDP, **you do not work with the abstraction of an IO stream.**
- Rather, **you work with the abstraction of individual datagrams**, which you can send and receive. Every datagram is independent from the others.
- You **do not have any guarantee**: datagrams can get lost, datagrams can arrive out-of-order, datagrams can be duplicated.
- What do you put "**inside**" the datagram (i.e. what is the payload)?
  - A notification.
  - A request, a query, a command. A reply, a response, a result.
  - A portion of a data stream (managed by the application).
- What do you put "**outside**" of the datagram (i.e. what is the header)?
  - A destination address (IP address in the IP packet header + UDP port)
  - A source address (IP + port)

Unicast, Broadcast, Multicast

Destination Address

192.168.10.2

255.255.255.255

239.255.22.5

IANA Guidelines for IPv4 Multicast Address Assignments
http://tools.ietf.org/html/rfc5771

Messaging Patterns

Pattern: Fire-and-Forget

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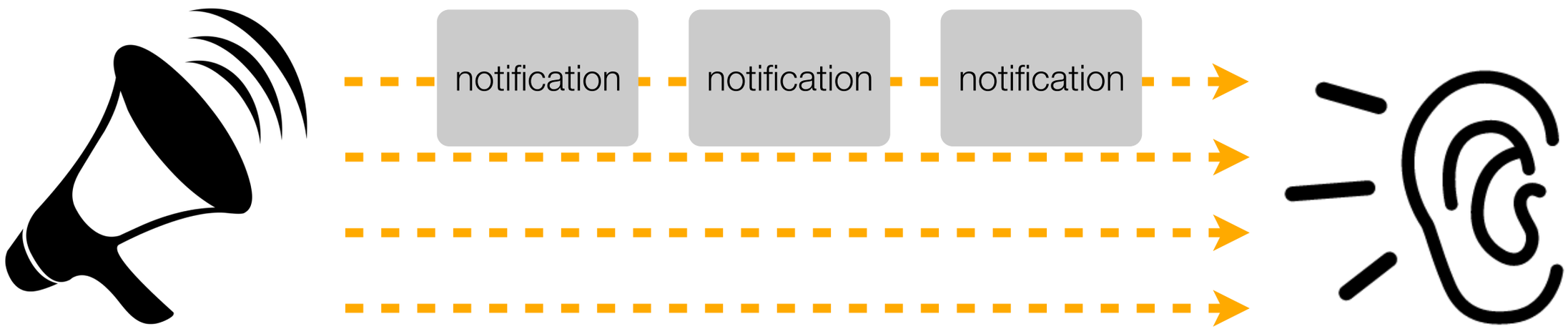
- The sender generates messages, sends them to a single receiver or to a group of receivers.
- The sender may do that on a **periodic** basis.
- The sender does not expect any answer. **He is telling, not asking**.



Pattern: Request-Reply

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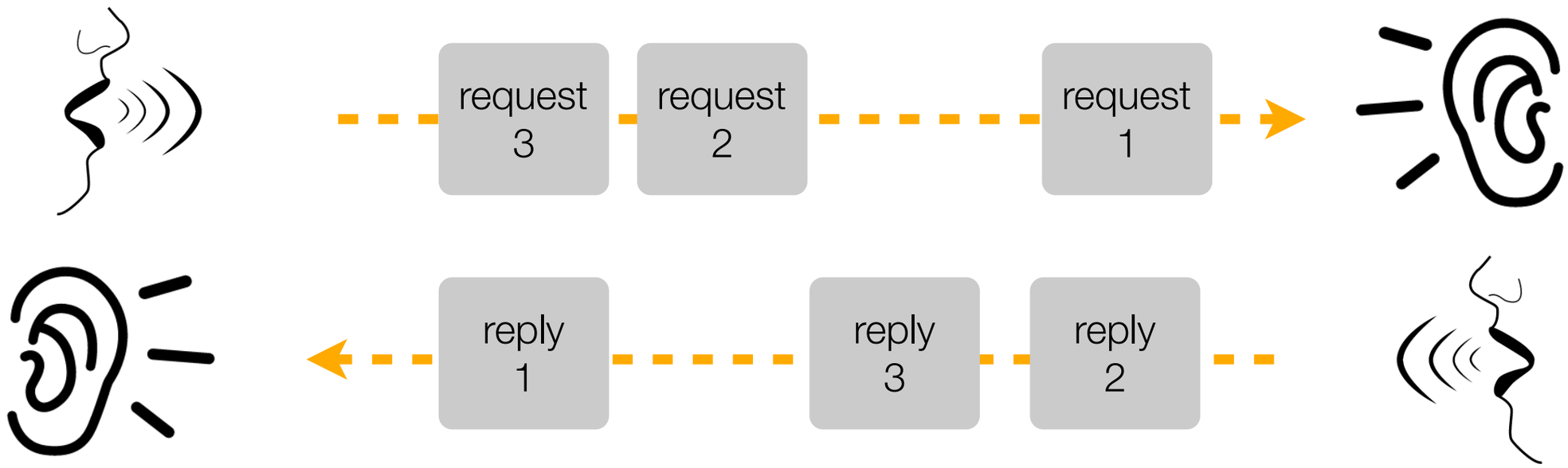
- This pattern is used to implement the **typical client-server model**. Both the client and the server **produce and consume** datagrams.
- **The client produces requests** (aka queries, commands). The client also listens for incoming replies (aka responses, results). The server listens for requests. **The server also sends replies back to the client**.
- Can the client send a new request, even if he has not received the response to the previous request yet? If yes, and because UDP datagrams can be delivered out of order, how can the client **associate a reply** with the corresponding request?



Service Discovery Protocols

Service Discovery Protocols

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- With **unicast** message transmission, the sender must know who the receiver is and must know how to reach it (i.e. know its address).
- With **broadcast** and **multicast**, this is not required. The sender knows that nodes that are either *nearby*, or that have *expressed their interest*, will receive a copy of the message.
- This property can be used to **discover the availability of services or resources** in a *dynamic environment*.

Model 1: Advertise Service Periodically

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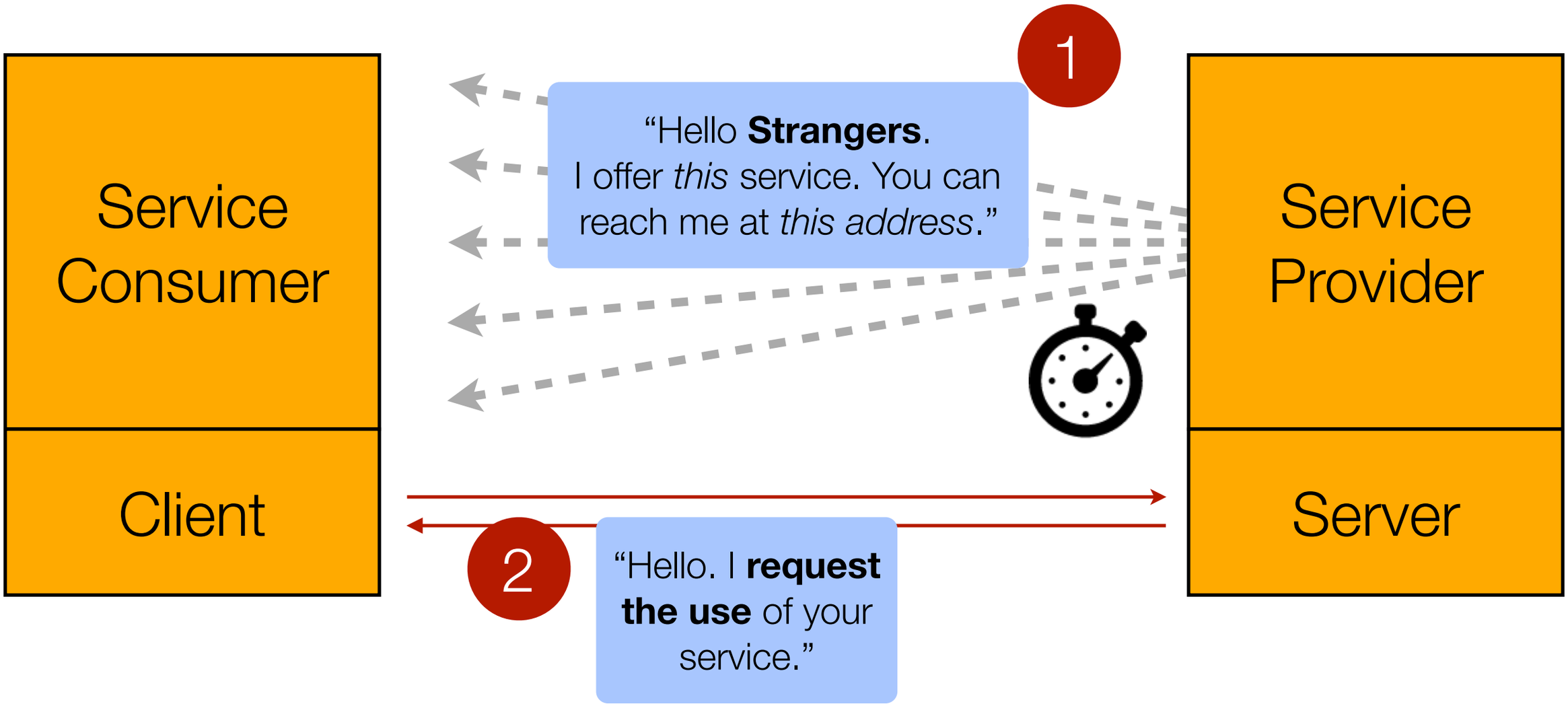

Model 2: Query Service Availability

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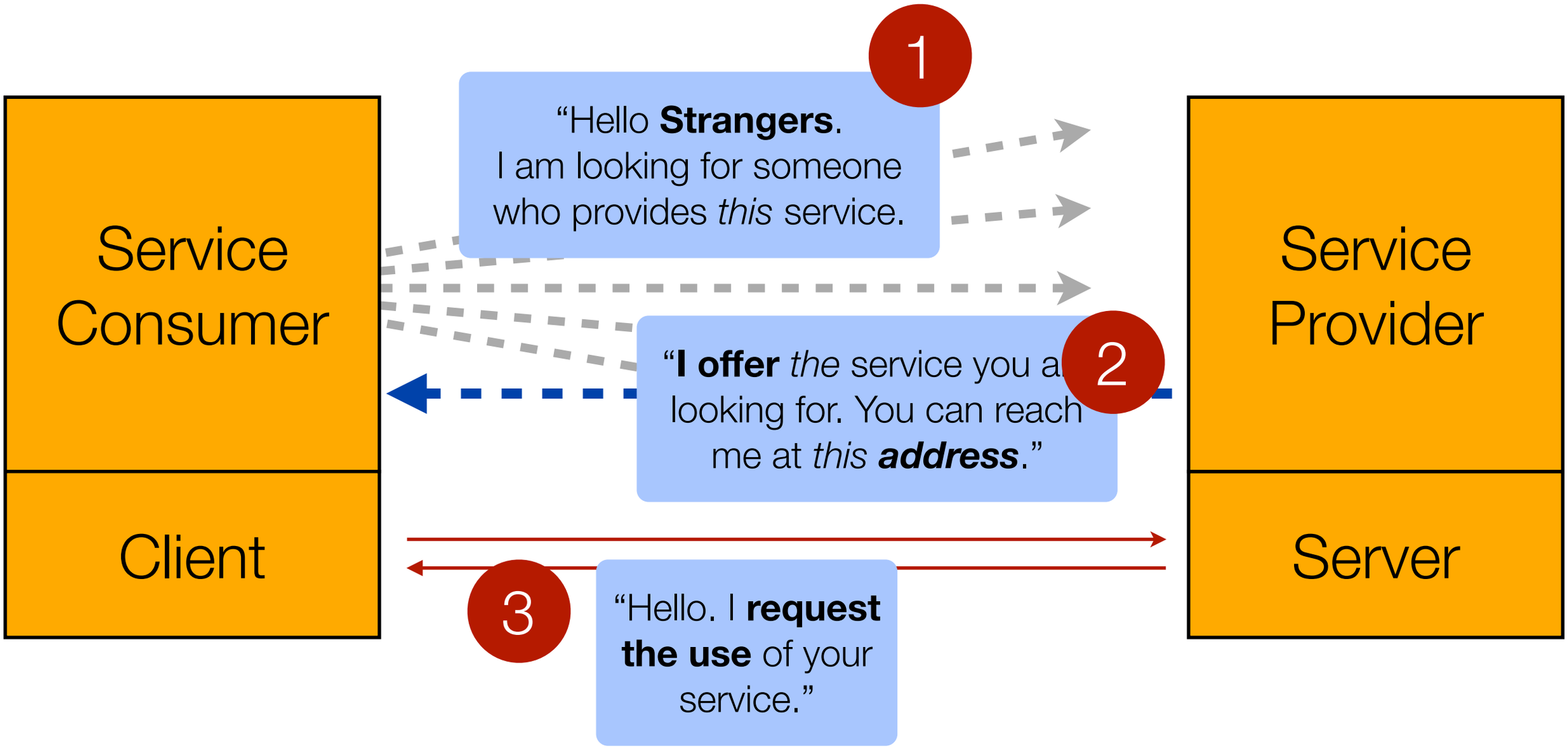

Reliability

Reliability

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- UDP is **not a reliable transport protocol**:
  - Datagrams can arrive in a different order from which they were sent.
  - Datagrams can get lost.
- For some application-level protocols, this is not an issue because they are **tolerant to data loss**. For example, think of a **media streaming** protocol.
- But **if no data loss can be tolerated at the application level** (which is typically the case for file transfer protocols), does it mean that it is impossible to use UDP?

Who Is Responsible for Reliability?

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- **It is actually possible** to implement reliable application-level protocols on top of UDP, but...
  - It is the **responsibility of the application-level protocol specification** to include appropriate mechanisms to overcome the limitations of UDP.
  - It is the **responsibility of the application developer** to implement these mechanisms.
- In other words, it is up to the application developer to "**do the kind of stuff that TCP usually does**".
- Do you remember about **acknowledgments**, **timers**, **retransmissions**, **stop-and-wait**, **sliding windows**, etc?

A First Example: TFTP

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- **Trivial File Transfer Protocol (TFTP)**
  - http://tools.ietf.org/html/rfc1350
  - "TFTP is a very simple protocol used to transfer files. It is from this that its name comes, Trivial File Transfer Protocol or TFTP. **Each nonterminal packet is acknowledged separately.** This document describes the protocol and its types of packets. The document also explains the reasons behind some of the design decisions."
  - "Any transfer begins with a request to read or write a file, which also serves to request a connection. If the server grants the request, the connection is opened and the file is sent in fixed length blocks of 512 bytes. Each data packet contains one block of data, and must be acknowledged by an acknowledgment packet **before** the next packet can be sent."

A Second Example: CoAP

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- **Constrained Application Protocol (CoAP)**
  - http://tools.ietf.org/html/draft-ietf-core-coap-18
  - "The Constrained Application Protocol (CoAP) is a **specialized web transfer protocol** for use with constrained nodes and constrained (e.g., low-power, lossy) networks. [...] The protocol is designed for **machine-to-machine (M2M) applications** such as smart energy and building automation."
  - "CoAP provides a **request/response interaction model** between application endpoints, supports built-in discovery of services and resources, and includes key concepts of the Web such as URIs and Internet media types."
  - "**2.1. Messaging Model**. The CoAP messaging model is based on the exchange of messages over UDP between endpoints. CoAP uses a short fixed-length binary header (4 bytes) that may be followed by compact binary options and a payload. This message format is shared by requests and responses. The CoAP message format is specified in Section 3. **Each message contains a Message ID used to detect duplicates and for optional reliability.** (The Message ID is compact; its 16-bit size enables up to about 250 messages per second from one endpoint to another with default protocol parameters.)
  - "**4.2. Messages Transmitted Reliably**. The reliable transmission of a message is initiated by marking the message as Confirmable in the CoAP header. [...] A recipient MUST **acknowledge** a Confirmable message with an Acknowledgement message [...].

Using the Socket API for a UDP **Sender**

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1. Create a datagram socket (without giving any address / port)

2. Create a datagram and put some data (bytes) in it

3. Send the datagram via the socket, specifying the destination address and port

If a reply is expected:

4. Accept incoming datagrams on the socket

If we do not specify the port when creating the socket, the operating system will **automatically assign a free one** for us.

This port will be in the "source port" field of the UDP header. The receiver of our datagram will extract this value and will use it to send us the reply (it is a part of the ***return address***.

Using the Socket API for a UDP **Receiver**

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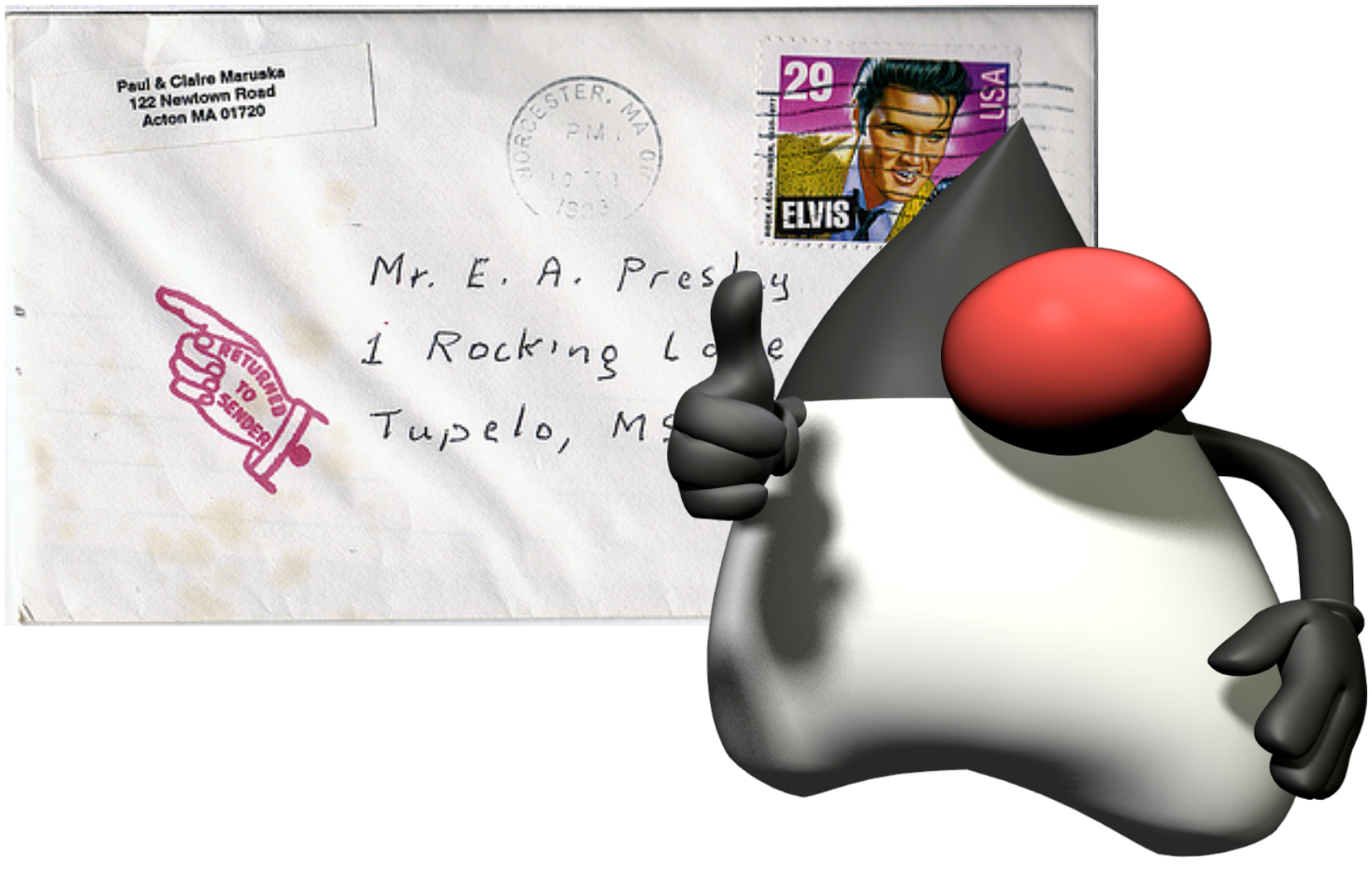
Application-level protocol specifications often define **a standard UDP port**, where the clients can send their requests. When this is the case, we have to specify the port number when creating the socket.

```
1. Create a datagram socket, specifying a particular port

2. Loop
   2.1. Accept an incoming datagram via the socket
   2.2. Process the datagram
   2.3. If a reply is expected by the sender
        2.3.1. Extract the return address from the request datagram
        2.3.2. Prepare a reply datagram
        2.3.3. Send the reply datagram via the socket
```

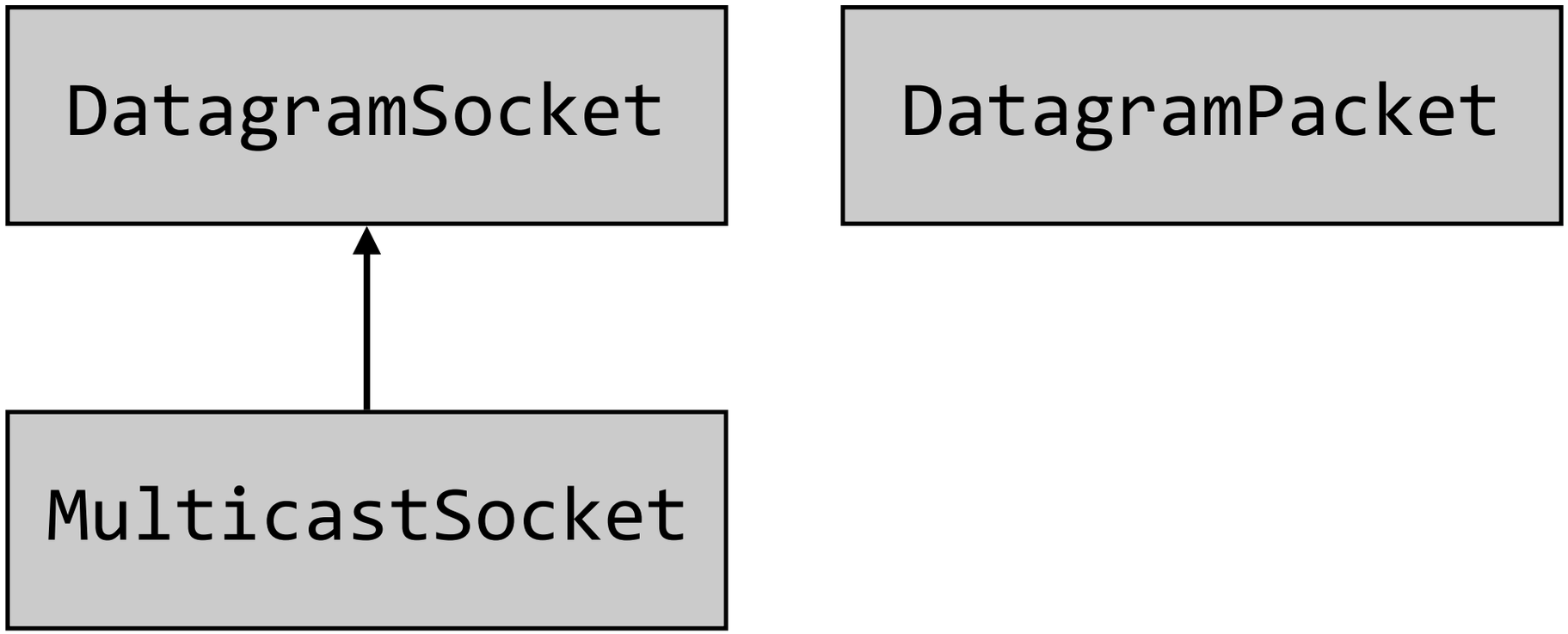
It is at this stage that we extract the source port and source IP address from the incoming datagram. We have found the ***return address***, so we know where to the send the response.

Using UDP in Java



Using UDP in Java

`java.net`



```
// Sending a message to a multicast group

socket = new DatagramSocket();
byte[] payload = "Java is cool, everybody should know!!".getBytes();

DatagramPacket datagram = new DatagramPacket(payload, payload.length,
InetAddress.getByName("239.255.3.5"), 4411);

socket.send(datagram);
```

Publisher (multicast)

Subscriber (multicast)

```
// Listening for broadcasted messages on the local network

MulticastSocket socket = new MulticastSocket(port);
InetAddress multicastGroup = InetAddress.getByName("239.255.3.5");
socket.joinGroup(multicastGroup);

while (true) {
    byte[] buffer = new byte[2048];
    DatagramPacket datagram = new DatagramPacket(buffer, buffer.length);
    try {
        socket.receive(datagram);
        String msg = new String(datagram.getData(), datagram.getOffset(), datagram.getLength());
        LOG.log(Level.INFO, "Received a datagram with this message: " + msg);
    } catch (IOException ex) {
        LOG.log(Level.SEVERE, ex.getMessage(), ex);
    }
}
socket.leaveGroup(multicastGroup);
```

```
// Broadcasting a message to all nodes on the local network

socket = new DatagramSocket();
socket.setBroadcast(true);

byte[] payload = "Java is cool, everybody should know!!".getBytes();

DatagramPacket datagram = new DatagramPacket(payload, payload.length,
InetAddress.getByName("255.255.255.255"), 4411);

socket.send(datagram);
```

Publisher

Subscriber

```
// Listening for broadcasted messages on the local network

DatagramSocket socket = new DatagramSocket(port);

while (true) {
    byte[] buffer = new byte[2048];
    DatagramPacket datagram = new DatagramPacket(buffer, buffer.length);
    try {
        socket.receive(datagram);
        String msg = new String(datagram.getData(), datagram.getOffset(), datagram.getLength());
        LOG.log(Level.INFO, "Received a datagram with this message: " + msg);
    } catch (IOException ex) {
        LOG.log(Level.SEVERE, ex.getMessage(), ex);
    }
}
```

JavaScript 101

JavaScript - End to End

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Client

Server

Experimenting with JavaScript

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What do I need to write, execute and debug JavaScript code?

- Should I work on the **server side** or on the **client side**?
- Should I use a **simple text editor** or a **complete IDE**?
- Should I rather use an **online programming environment**?
- What kinds of **developer tools**, such as debuggers, are available?

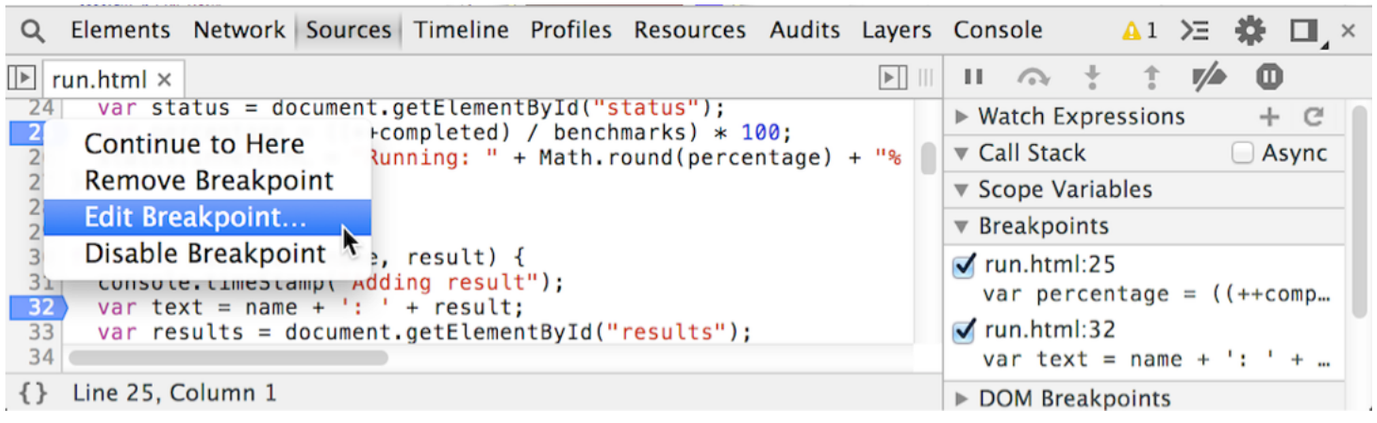
Browsers and Developers Tools

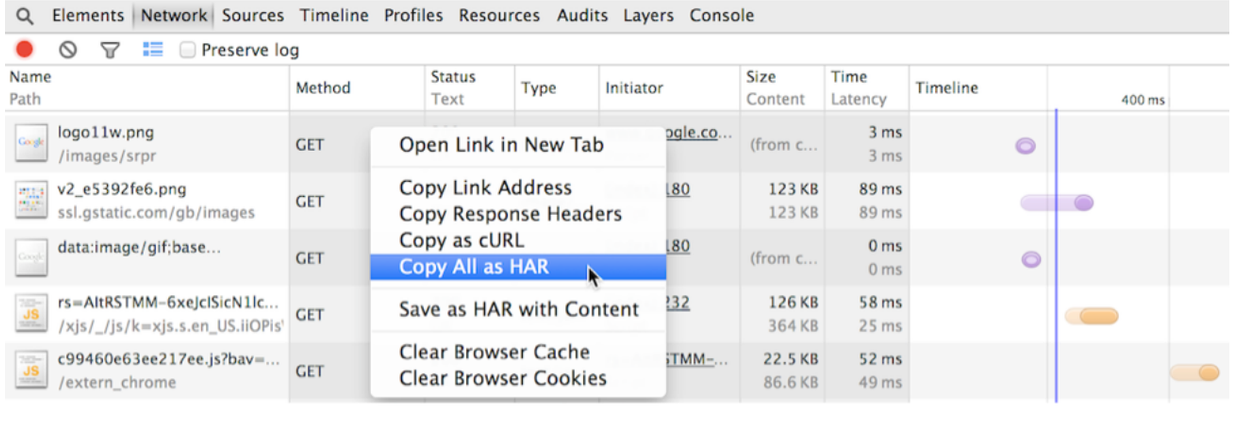
Chrome DevTools Overview

https://developer.chrome.com/devtools

The Chrome Developer Tools (DevTools for short), are a set web authoring and debugging tools built into Google Chrome. The DevTools provide web developers deep access into the internals of the browser and their web application. Use the DevTools to efficiently track down layout issues, set JavaScript breakpoints, and get insights for code optimization.

> **Note:** If you are a web developer and want to get the latest version of DevTools, you should use **Google Chrome Canary**.





How to access the DevTools

The DevTools window

Inspecting the DOM and styles

Working with the console

Debugging JavaScript

Improving network performance

Audits

Improving rendering performance

JavaScript CSS performance

Inspecting storage

Further reading

Further resources +

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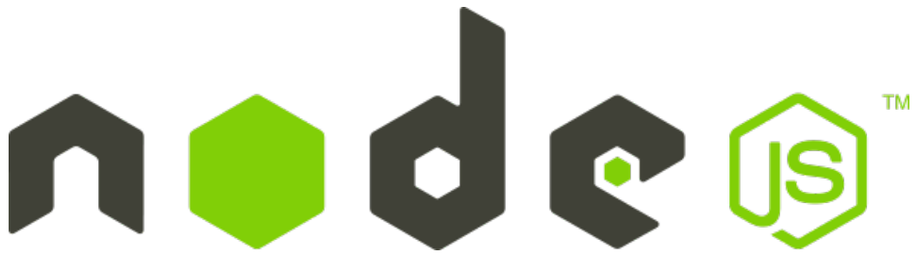

"Node.js is a **platform** built on Chrome's JavaScript runtime for easily building **fast**, **scalable network applications**.

not only!

Node.js uses an **event-driven**, **non-blocking I/O model** that makes it lightweight and efficient, perfect for **data-intensive real-time applications that run across distributed devices**."

Node.js v0.10.32 Manual & Documentation

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- Assertion Testing
- Buffer
- C/C++ Addons
- Child Processes
- Cluster
- Console
- Crypto
- Debugger
- DNS
- Domain
- Events
- File System
- Globals
- HTTP
- HTTPS
- Modules
- Net
- OS
- Path
- Process
- Punycode
- Query Strings
- Readline
- REPL
- Stream
- String Decoder
- Timers
- TLS/SSL
- TTY
- UDP/Datagram
- URL
- Utilities
- VM
- ZLIB

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```
console.log("hello");
```

index.js

```
$ node index.js
hello
```

JavaScript 101

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- Types
- Scopes
- Objects
- Prototypal inheritance
- Functions
- Constructors
- Arrays

Things are changing... we do not cover ES 6 in these slides

JavaScript defines 6 types

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```
const aNumber = 3.12;
const aBoolean = true;
const aString = "HEIG-VD";
const anObject = {
  aProperty: null
};

// t is true for all of these:
var t;
t = typeof aNumber === "number";
t = typeof aBoolean === "boolean";
t = typeof aString === "string";
t = typeof anObject === "object";
t = typeof anObject.aProperty ===
"object";
t = typeof anObject.foobar ===
"undefined";
```

http://codepen.io/wasadigi/full/tJFoy/

- The 6 types are:
  - number
  - boolean
  - string
  - object
  - undefined
  - null
- `null` is a type, but `typeof null === object`.
- JavaScript is a dynamic language: when you declare a variable, you don't specify a type (and the type can change over time).

Objects are dynamic bags of properties

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```
// let's create an object
const person = {
  firstName: 'olivier',
  lastName: 'liechti'
};

// we can dynamically add properties
person.gender = 'male';
person['zip'] = 1446;

// and delete them
delete person.zip;

for (let key in person) {
  console.log(key + " : " +
person[key]);
};
```

http://codepen.io/wasadigi/full/cmjGA

- There are different ways to **access properties** of an object.
- JavaScript is **dynamic**: it is possible to **add** and **remove** properties to an object at any time.
- Every object has a different list of properties (**no class**).

Before ES6, the language did not have support for classes.
There are 3 ways to create objects

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```
// create an object with a literal
const person = {
  firstName: 'olivier',
  lastName: 'liechti'
};

// create an object with a prototype
const child = Object.create(person);

// create an object with a constructor
const child = new Person('olivier',
'liechti');
```

- A **constructor** is function like any other (uppercase is a coding convention).
- It is the use of the **new** keyword that triggers the object creation process.

Arrays are objects

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```
var fruits = ["apple", "pear"];

fruits.push("banana");
console.log(Object.getPrototypeOf(fruits));

for (var i=0; i<fruits.length; i++) {
  console.log("fruits[" + i + "] = " + fruits[i]);
}

var transformedFruits = fruits.map( function(fruit) {
  return fruit.toUpperCase();
});
transformedFruits.forEach( function(fruit) {
  console.log(fruit);
});

var count = fruits.reduce( function(val, fruit) {
  console.log("reducer invoked with " + val);
  return val+1;
}, 0);
console.log("There are " + count + " fruits in the array");
```

http://codepen.io/wasadigi/full/LtnAp/

Functions are objects

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```
function aFunction() {
}

var f = function() {
}

var g = function g() {
  g(); // recursive call
}

var h = function(functionParam) {
  functionParam();
}

h(f);
h(g);
```

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#1 Functions are objects

```
var aFunction = function() {
  console.log("I am doing my job");
};
aFunction.aProperty = "aValue";
aFunction();
```

#2 Passing functions as arguments

```
var aFunction = function() {...};
var anotherFunction = function( f1 ) {... f1(); ...};
anotherFunction( aFunction );
```

#3 Return functions as values

```
var aFunction = function() {
  return function() {...}
  };
aFunction()();
```

Every object inherits from a prototype object

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```
var person = {
    firstName: "olivier",
    lastName: "liechti"
};
// person's prototype is Object.prototype

var father = {};
var child = Object.create(father);
// child's prototype is father

function Person(fn, ln) {
  this.firstName = fn;
  this.lastName = ln;
}
var john = new Person("John", "Doe");
// john's prototype is Person.prototype
```

http://codepen.io/wasadigi/full/nklil

Every object inherits from a prototype object

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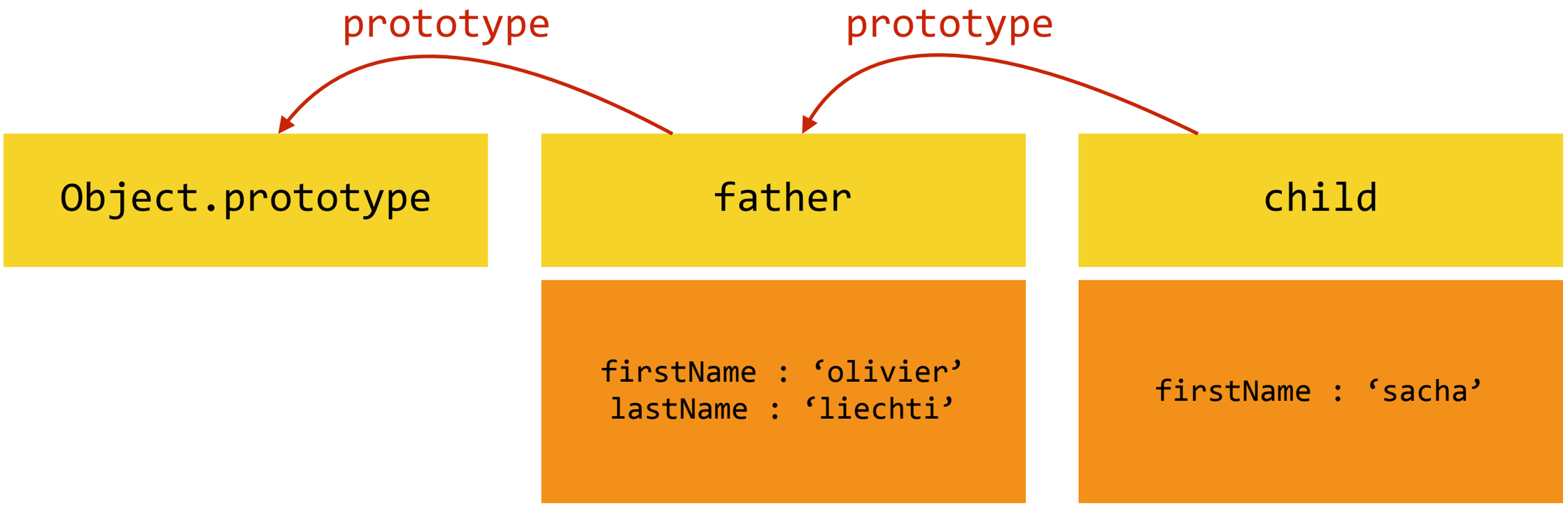


```
console.log(child.lastName);
// prints 'liechti' on the
console
```

- Every object inherits from a prototype object. **It inherits and can override its properties**, including its methods.
- Objects created with object literals inherit from **Object.prototype**.
- When you access the property of an object, JavaScript **looks up the prototype chain** until it finds an ancestor that has a value for this property.

With patterns, it is possible to implement class-like data structures

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```
function Person(fn, ln) {
  var privateVar;
  this.firstName = fn;
  this.lastName = ln;
  this.badGreet = function() {
    console.log("Hi " + this.firstName);
  };
};

Person.prototype.greet = function() {
  console.log("Hey " + this.firstName);
};

var p1 = new Person("olivier", "liechti");

p1.badGreet();
p1.greet();
```

http://codepen.io/wasadigi/full/FeiAd/

- **`badGreet`** is a property that will be replicated for every object created with the Person constructor:
  - poor memory management
  - not possible to alter behavior of all instances at once
- **`greet`** is a property that will be shared by all instances (because it will be looked up along the object inheritance chain).
- **`privateVar`** is not accessible outside of the constructor.
- **`fistName`** is publicly accessible (no encapsulation).

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Node.js 101

Let's look at a **first example** (**NOT** good)

```
/*global require */

var fs = require("fs");

/**
 * Simple function to test the synchronous readFileSync function provided by
 * Node.js
 * @param {string} filename - the name of the file we want to read in the test
 */
function testSyncRead(filename) {
  console.log("I am about to read a file: " + filename);
  var data = fs.readFileSync(filename);
  console.log("I have read " + data.length + " bytes (synchronously).");
  console.log("I am done.");
}

// We get the file name from the argument passed on the command line
var filename = process.argv[2];

console.log("\nTesting the synchronous call");
testSyncRead(filename);
```

This is for the Brackets editor

We use a standard **Node module** for accessing the file system

fs.readFileSync is synchronous: it blocks the main thread until the data is available.

process is a global object provided by Node.js

```
$ node sample2.js medium.txt

Testing the synchronous call
I am about to read a file: medium.txt
I have read 1024 bytes (synchronously).
I am done.
```

*Synchronous functions are easier to use, but they have **severe** performance implications!!*

Let's look at a **second example** (**BETTER**)

```
/*global require */

var fs = require("fs");

/**
 * Simple function to test the asynchronous readFile function provided by Node.js
 * @param {string} filename - the name of the file we want to read in the test
 */
function testAsyncRead(filename) {
  console.log("I am about to read a file: " + filename);

  fs.readFile(filename, function (err, data) {
    console.log("Nodes just told me that I have read the file.");
  });

  console.log("I am done. Am I really?????");
}
// We get the file name from the argument passed on the command line
var filename = process.argv[2];

console.log("\nTesting the asynchronous call");
testAsyncRead(filename);
```

```
$ node sample2.js medium.txt

Testing the asynchronous call
I am about to read a file: medium.txt
I am done. Am I?
Nodes just told me that I have read the file.
```

fs.readFile is asynchronous: it does not block the main thread until the data is available.

We must provide a **callback function**, which Node.js will invoke when the data is available.

Problems can happen when an (asynchronous) function is called.

*Node.js developers **have to** learn the asynchronous programming style.*

Let's look at a **third example**

```
/*global require */

var http = require("http");

/**
 * This function starts a http daemon on port 9000. It also
 * registers a callback handler, to handle incoming HTTP
 * requests (a simple message is sent back to clients).
 */
function runHttpServer() {
  var daemon = http.createServer();

  daemon.on("request", function (req, res) {
    console.log("A request has arrived: URL=" + req.url);
    res.writeHead(200, {
      'Content-Type': 'text/plain'
    });
    res.end('Hello World\n');
  });

  console.log("Starting http daemon...");
  daemon.listen(9000);
}

runHttpServer();
```

We use a standard **Node module** that takes care of the HTTP protocol.

Node can provide us with a **ready-to-use** server.

We can attach **event handlers** to the server. Node will notify us asynchronously, and give us access to the request and response.

We can **send back** data to the client.

We have wired everything, let's **welcome** clients!

HTTP Node.js v0.10.32 Ma ×

nodejs.org/api/http.html#http_event_request

NPM REGISTRY
DOCS
BLOG
COMMUNITY
LOGOS
JOBS

@nodejs

Node.js v0.10.32 Manual & Documentation

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These are the events that are **emitted** by the class. You can write callbacks and **react** to these events.

How does Node.js use an **event loop** to offer an asynchronous programming model?

```
on('request', function(req, res) { // my code});
```

```
on('data', function(data) { // my code});
```

Callback functions that **you** have written and registered

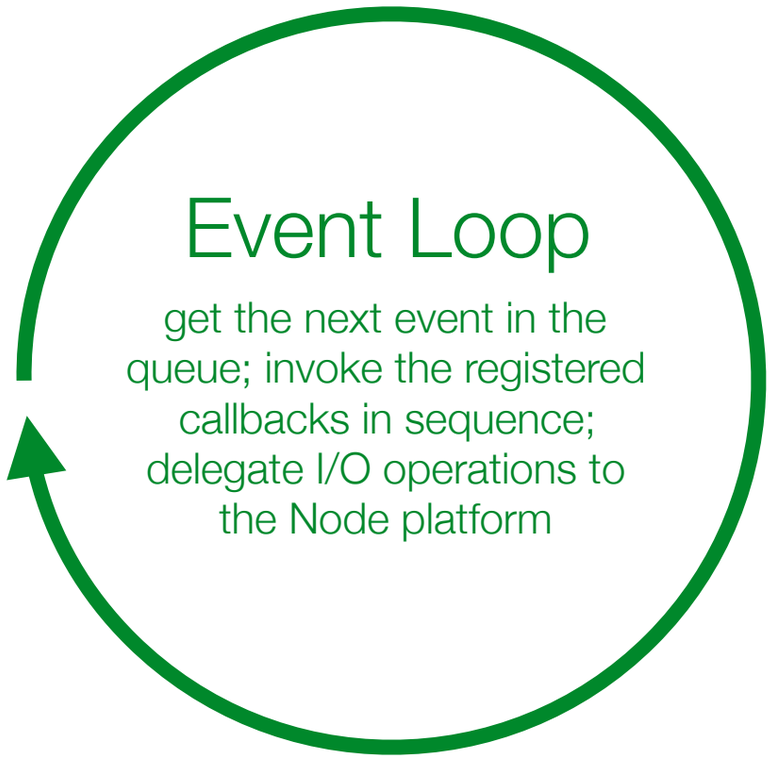
'request' **event**

'request' **event**

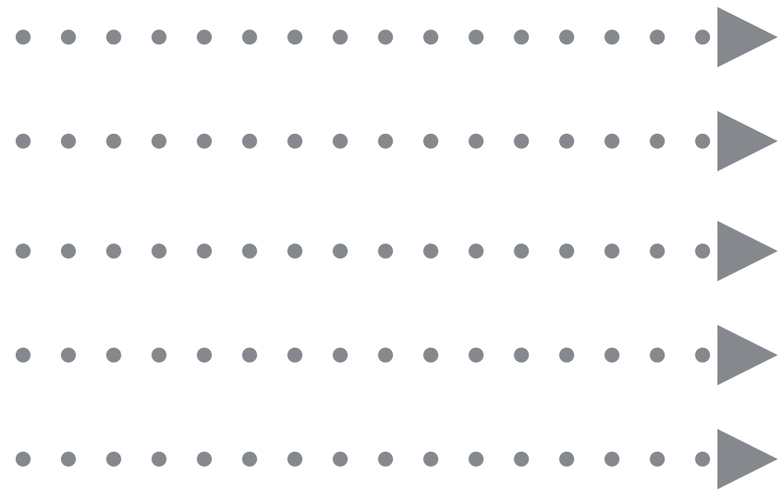
'data' **event**

'request' **event**

Queue of events that have been **emitted**

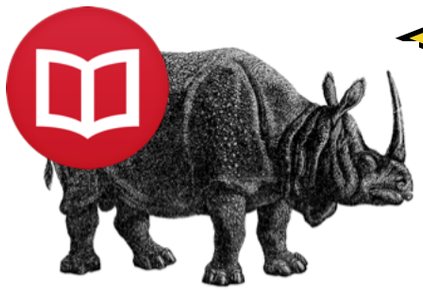


All the code that **you** write runs on a **single thread**



The **long-running tasks** (I/Os) are executed by Node in parallel; Node emits events to report progress (which triggers your callbacks).

Another pattern is to provide a callback to node when invoking an asynchronous function.



What is **npm**?

---

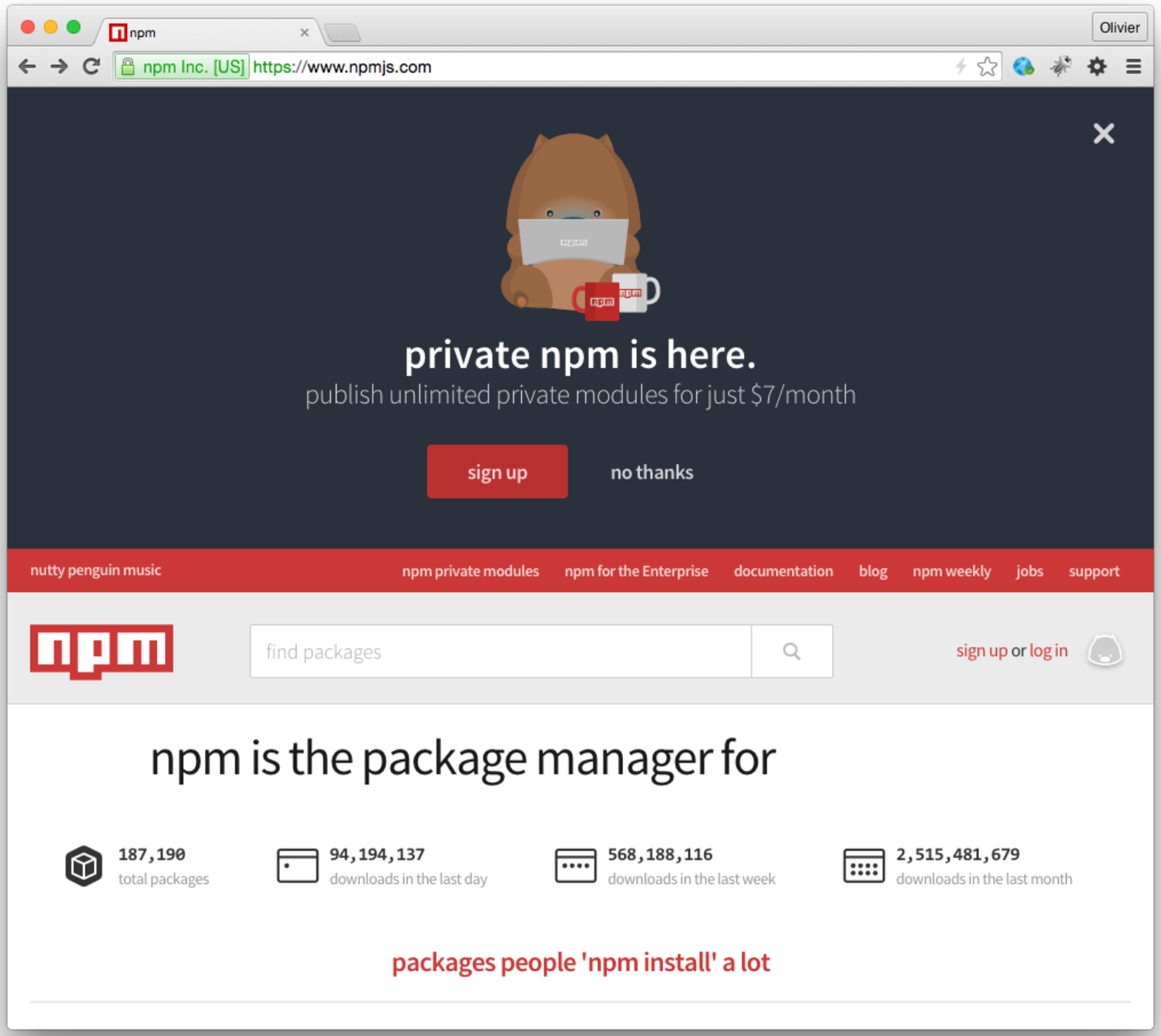
*”**npm** is the **package manager** for the Node JavaScript platform. It puts **modules** in place so that node can find them, and manages **dependency** conflicts intelligently.*

*It is extremely configurable to support a wide variety of use cases. Most commonly, it is used to **publish**, **discover**, **install**, and **develop** node programs.”*

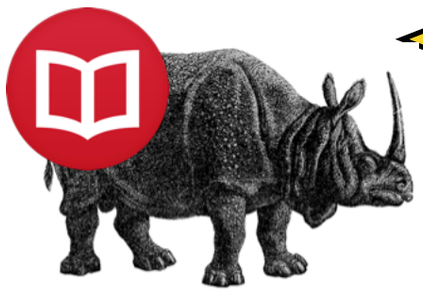
https://www.npmjs.org/doc/cli/npm.html

You **have to** read this:
https://www.npmjs.org/doc/misc/npm-faq.html

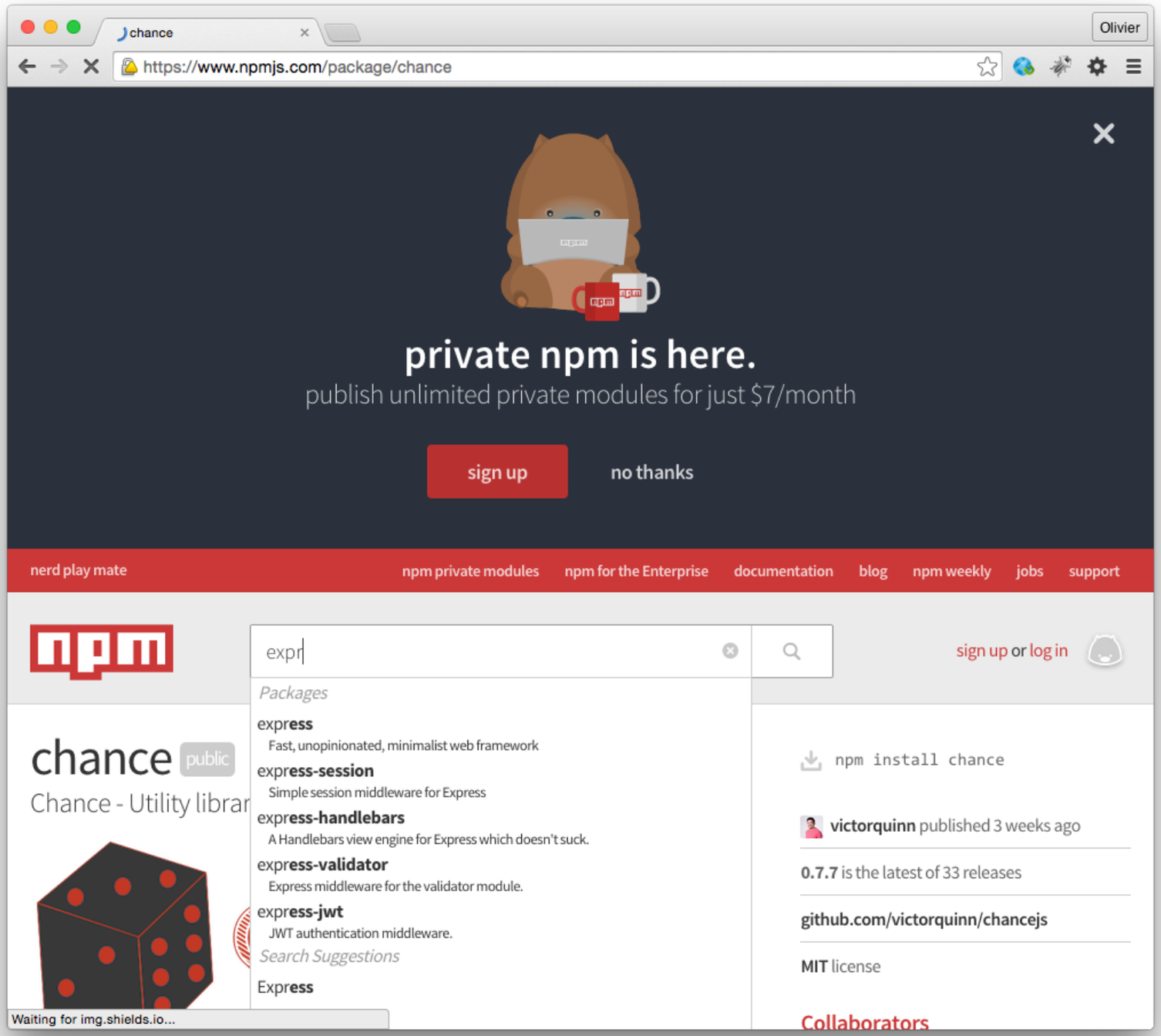
npm is a set of command line tools that work together with the **node registry**



https://www.npmjs.org



npm is a set of command line tools that work together with the **node registry**



https://www.npmjs.org

npm is a set of command line tools that work together with the **node registry**

---

express

Olivier

npm Inc. [US] https://www.npmjs.com/package/express

npm

find packages

sign up or log in

express public

Fast, unopinionated, minimalist web framework

express

npm install express

dougwilson published 2 months ago

4.13.3 is the latest of 272 releases

github.com/strongloop/express

MIT license

npm v4.13.3 | downloads 4M/month | linux invalid | windows passing | coverage 100%

```
var express = require('express')
var app = express()

app.get('/', function (req, res) {
  res.send('Hello World')
})

app.listen(3000)
```

Installation

```
$ npm install express
```

Features

- Robust routing

Collaborators

Stats

135,585 downloads in the last day

818,847 downloads in the last week

3,533,048 downloads in the last month

67 open issues on GitHub

28 open pull requests on GitHub

Keywords

https://www.npmjs.org

npm is a set of command line tools that work together with the **node registry**

---

admin — bash — 120×30

```
Last login: Wed Sep 23 19:59:09 on console
$ npm help

Usage: npm <command>

where <command> is one of:
    access, add-user, adduser, apihelp, author, bin, bugs, c,
    cache, completion, config, ddp, dedupe, deprecate, dist-tag,
    dist-tags, docs, edit, explore, faq, find, find-dupes, get,
    help, help-search, home, i, info, init, install, issues, la,
    link, list, ll, ln, login, ls, outdated, owner, pack,
    prefix, prune, publish, r, rb, rebuild, remove, repo,
    restart, rm, root, run-script, s, se, search, set, show,
    shrinkwrap, star, stars, start, stop, t, tag, test, tst, un,
    uninstall, unlink, unpublish, unstar, up, update, v,
    verison, version, view, whoami

npm <cmd> -h     quick help on <cmd>
npm -l           display full usage info
npm faq          commonly asked questions
npm help <term>  search for help on <term>
npm help npm     involved overview

Specify configs in the ini-formatted file:
    /Users/admin/.npmrc
or on the command line via: npm <command> --key value
Config info can be viewed via: npm help config

npm@2.5.1 /usr/local/lib/node_modules/npm
$
```

init
install
publish
update

Example: **09-thermometers**

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`node thermometer.js bedroom 17 2`

`node thermometer.js office 20 3`

Thermometer

Thermometer

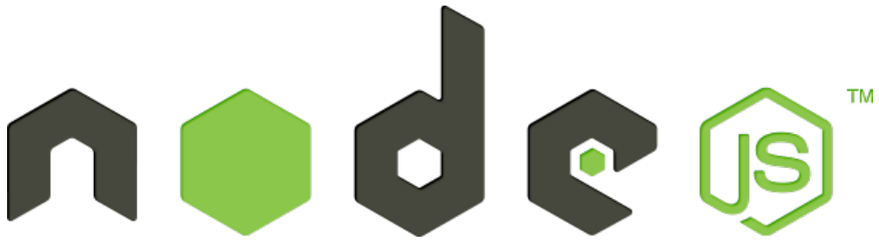
Thermometer

`node thermometer.js kitchen 20 5`

multicast
(239.255.22.5:9907)

Station

`node station.js`



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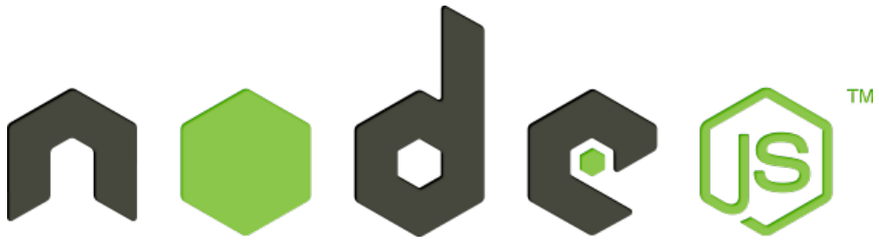
thermometer.js (fragment)

```
// We use a standard Node.js module to work with UDP
const dgram = require('dgram');

// Let's create a datagram socket. We will use it to send our UDP datagrams
const s = dgram.createSocket('udp4');

// Create a measure object and serialize it to JSON
const measure = new Object();
measure.timestamp = Date.now();
measure.location = that.location;
measure.temperature = that.temperature;
const payload = JSON.stringify(measure);

// Send the payload via UDP (multicast)
message = new Buffer(payload);
s.send(message, 0, message.length, protocol.PROTOCOL_PORT, protocol.PROTOCOL_MULTICAST_ADDRESS,
function(err, bytes) {
console.log("Sending payload: " + payload + " via port " + s.address().port);
});
```



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station.js (fragment)

```
// We use a standard Node.js module to work with UDP
const dgram = require('dgram');

// Let's create a datagram socket. We will use it to listen for datagrams published in the
// multicast group by thermometers and containing measures
const s = dgram.createSocket('udp4');
s.bind(protocol.PROTOCOL_PORT, function() {
  console.log("Joining multicast group");
  s.addMembership(protocol.PROTOCOL_MULTICAST_ADDRESS);
});

// This call back is invoked when a new datagram has arrived.
s.on('message', function(msg, source) {
        console.log("Data has arrived: " + msg + ". Source IP: " + source.address + ". Source
port: " + source.port);
});
```