Middleware Architectures 2
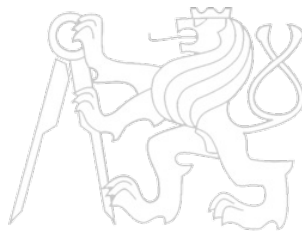## Lecture 1: Asynchronous I/O

doc. Ing. Tomáš Vitvar, Ph.D.

tomas@vitvar.com • @TomasVitvar • https://vitvar.com

Czech Technical University in Prague

Faculty of Information Technologies • Software and Web Engineering • https://vitvar.com/lectures

Overview

- Asynchronous I/O Overview
- Asynchronous I/O in JavaScript
- JavaScript Language Overview

Recall: Application Server

- Environment that runs an application logic
  - *Client communicates with AS via an application protocol*
  - *Client – Browser, application protocol – HTTP*

- Terminology
  - *Application Server × Web Server × HTTP Server*
    - → *AS is a modular environment; provides technology to realize enterprise systems*
    - → *AS contains a Web server/HTTP server*
  - *We will deal with Web server only*

- Two major models to realize communication
  - *Blocking I/O (also called synchronous I/O)*
  - *Non-blocking I/O (also called asynchronous I/O)*

- A technology we will work with
  - *Node.js – runs server-side Javascript*

Programming Models

- Concurrency
  - *Multiple tasks have the ability to run in an overlapping manner*
  - *Concurrency does not imply parallelism!*

- Multiprocessing
  - *CPU-bounded tasks*
  - *Allows to process multiple processes on different CPUs*

- Multithreading
  - *I/O bound tasks*
  - *Multiple threads execute tasks*
  - *A process may contain multiple threads*
  - *It uses **preemtive multitasking***
    - → *OS decides how long a task should run (no tasks cooperation)*
    - → *context switching*
  - *Threads can access shared memory; you need to controll this*

Asynchronous I/O

- Asynchronous I/O
  - *A style of concurrent programming; it is not a parellelism*
  - *Single-threaded, single process design*
  - *It uses **cooperative multitasking***

- Asynchronous processing of a task
  - *Tasks are running in so called **event loop***
  - *A task is able to "pause" when they wait for some result*
    - → *A task let other tasks to run*
  - *Asynchronous code faciliates concurrent execution*
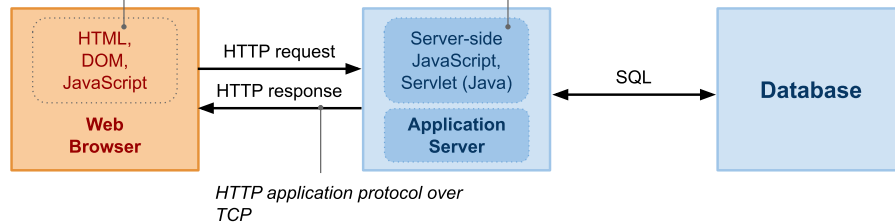   - → *It gives the "look and feel" of concurrent execution*

Overview

- Asynchronous I/O Overview
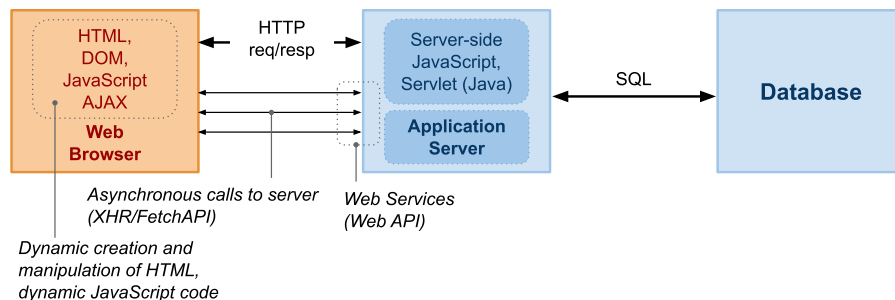- Asynchronous I/O in JavaScript
- JavaScript Language Overview

Web 2.0 Application Architecture

Web Application

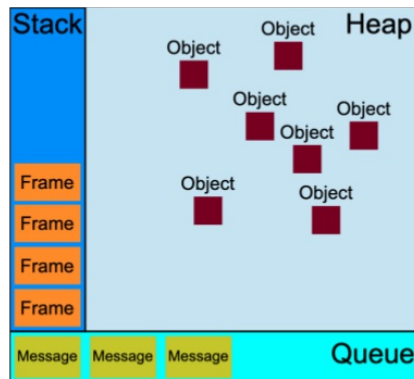*client-side technologies for presentation and user interactions*

App server technologies

HTML, DOM, JavaScript

Web Browser

HTTP request

HTTP response

Server-side JavaScript, Servlet (Java)

Application Server

SQL

Database

HTTP application protocol over TCP

Web 2.0 Application

HTML, DOM, JavaScript AJAX

Web Browser

HTTP req/resp

Server-side JavaScript, Servlet (Java)

Application Server

SQL

Database

Asynchronous calls to server (XHR/FetchAPI)

Web Services (Web API)

Dynamic creation and manipulation of HTML, dynamic JavaScript code

---

JavaScript

- Lightweight, interpreted, object-oriented language
- Client-side (browser) and server-side (node.js, AppsScript)
- Standard
  – *Current stable release is ECMAScript 2024/June 2024*
- Major characteristics
  – *Function is an Object*
    → *passing functions as arguments to other functions*
    → *returning functions as values from other functions*
    → *assigning functions to variables*
    → *storing functions in data structures.*
  – *Anonymous functions*
    → *declared without any named identifier to refer to it*
  – *Arrow functions*
  – *Closures*

Javascript Runtime

- Stack
  - *Contains frames, i.e. function parameters and local variables*
- Heap
  - *Objects are allocated in a heap, a region of memory.*
- Queue
  - *A list of messages to be processed*
  - *Message is data and callback to be processed*

Stack

- When running a program...

```
1  function foo(b) {
2    let a = 10
3    return a + b + 11
4  }
5
6  function bar(x) {
7    let y = 3
8    return foo(x * y)
9  }
10
11 console.log(bar(7)) //returns 42
```

1. *calling* bar*: a frame is created with bar's arguments and variables.*
2. bar *calls* foo*: a new frame with foo's args and vars is created.*
3. foo *returns: the top frame element is popped out of the stack.*
4. bar *returns: the stack is empty.*

Event Loop

- Event loop

```
1  while (queue.waitForMessage()) {
2     queue.processNextMessage()
3  }
```

  – *Message = data + callback to be processed*
  – *Messages are process completely one by one*
     → *No "clashes" across messages' processing*
     → *Processing should not block for a long time – Workers*
  – *Brwoser adds a new message when an event occurs and there is an event listener*

- Run-to-completion
  – *Each message is processed fully before any other message is processed.*
  – *A function runs entirely before any other code runs*
     → *unlike in preemtive multitasking*
  – *If a message takes much time to complete, all work can be blocked!*

Handling Request
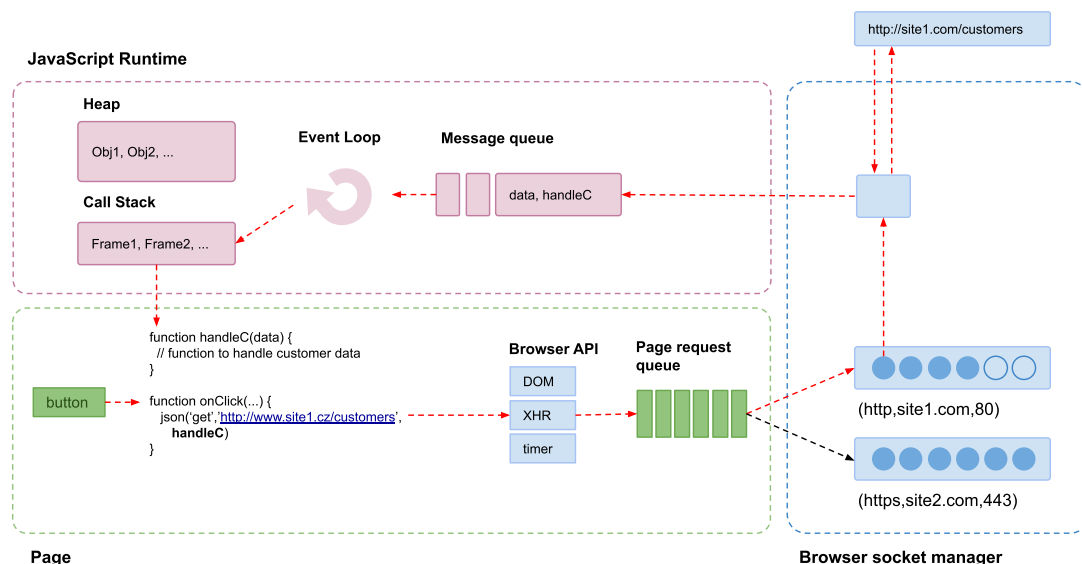
Multiple Runtimes

- Runtime
  - *Stack, Heap, Message Queue*
  - `iframe` *and a Web worker has its own runtimes*

- Communication between runtimes
  - *Runtimes communicate via* `postMessage`
  - *A runtime can receive a message if it listens to message events*

Web Workers

- A code that runs in a worker thread
  - *Every worker runs event loop; communicate via posting messages*
  - *Can do anything, but manipulate DOM*
  - *Can spawn a new workers*
  - *They are thread-safe*

- Workers Types
  - *Dedicated workers – accessible by scripts that created them*
  - *Shared workers – accessible by multiple scripts (iframes, windows, workers)*

- Example

```
1   // main.js
2   var myWorker = new Worker('worker.js');
3
4   something.onchange = function() {
5     myWorker.postMessage([value1,value2]);
6   }
7
8   // worker.js
9   onmessage = function(e) {
10    var workerResult = 'Result: ' + (e.data[0] * e.data[1]);
11    postMessage(workerResult);
12  }
13
14  // ... and terminate
15  myWorker.terminate()
```

Node.js

- Node.js ⊡
  - *Web server technology, very efficient and fast!*
  - *Event-driven I/O framework, based on JavaScript V8 engine*
    - → *Any I/O is non-blocking (it is asynchronous)*
  - *One worker thread to process requests*
    - → *You do not need to deal with concurrency issues*
  - *More threads to realize I/O*
  - *Open sourced, @GitHub ⊡, many libraries ⊡*
  - *Future platform for Web 2.0 apps*

- Every I/O as an event
  - *reading and writing from/to files*
  - *reading and writing from/to sockets*

```
1  // pseudo code; ask for the last edited time of a file
2  stat( 'somefile', function( result ) {
3    // use the result here
4  } );
```

Node.js Event Loop

- Allows Node.js to perform asynchronous I/O operations.
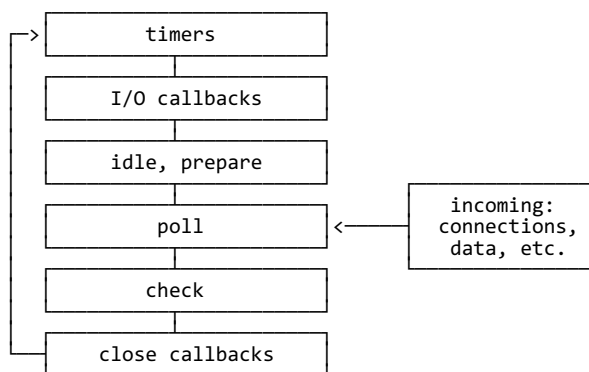
  - *Six phases, each phase has a FIFO queue of callbacks to execute.*
    - → *timers* – *executes callbacks sheduled by* `setTimeout()` *and* `setInterval()`
    - → *I/O callbacks* – *executes all I/O callbacks except close callbacks.*
    - → *idle/prepare* – *used internally*
    - → *poll* – *retrieve new I/O events*
    - → *check* – *invokes* `setImmediate()` *callbacks*
    - → *close callbacks* – *executes close callback, e.g. socket.on('close', ...).*

HTTP Server in Node.js

- HTTP Server implementation
  - *server running at* 127.0.0.1, *port* 8080.

```javascript
const http = require('http');

const hostname = '127.0.0.1';
const port = 3000;

const server = http.createServer((req, res) => {
  res.statusCode = 200;
  res.setHeader('Content-Type', 'text/plain');
  res.end('Hello World');
});

server.listen(port, hostname, () => {
  console.log(`Server running at http://${hostname}:${port}/`);
});
```

Google Apps Script

- Google Apps Script
  - *JavaScript cloud scripting language*
  - *easy ways to automate tasks across Google products and third party services*
- You can
  - *Automate repetitive processes and workflows*
  - *Link Google products with third party services*
  - *Create custom spreadsheet functions*
  - *Build rich graphical user interfaces and menus*

```javascript
// create spreadsheet menu
function onOpen() {
  var ss = SpreadsheetApp.getActiveSpreadsheet();
  var menuEntries = [ {name: "Say Hi", functionName: "sayHi"},
                      {name: "Say Hello", functionName: "sayHello"} ];
  ss.addMenu("Tutorial", menuEntries);
}

function sayHi() {
  Browser.msgBox("Hi");
}

function sayHello() {
  Browser.msgBox("Hello");
}
```

Overview

- Asynchronous I/O Overview
- Asynchronous I/O in JavaScript
- JavaScript Language Overview

Objects and Arrays

- Objects and Arrays

```
1   // objects - key/value pairs
2   var obj = { name: "Tomas", "main-city" : "Innsbruck", value : 3 };
3   obj.name = "Peter"; // assign the name property another value
4   obj["main-city"] = "Prague"; // another way to access object's values; it's not an array
5
6   // arrays
7   var a = ["Tomas", "Peter", "Alice"];
8   for (var i = 0; i < a.length; i++)
9       // do something with a[i]
10
11  // combinations of arrays and objects
12  var obj_a = [
13      { name: "Tomas", city: "Innsbruck" },
14      { name : "Peter", city : "Prague" },
15      { name : "Alice", cities : ["Prague", "Brno"] } ];
16
17  for (var j = 0; j < obj_a.length; j++)
18      // do something with obj_a[j].name, ...
```

- Functions

```
1   // assign a function to a variable
2   var minus = function(a, b) {
3       return a - b;
4   }
5
6   // call the function;
7   // now you can pass 'minus' as a parameter to another function
8   var r2 = minus(6, 4);
```

Functions

- Function Callbacks
  - *You can use them to handle asynchronous events occurrences*

```
1   // function returns the result through a callback, not directly;
2   // this is not a non-blocking I/O, just demonstration of the callback
3   function add(a, b, callback) {
4       callback(a + b);
5   }
6
7   // assign the callback to a variable
8   var print = function(result) {
9       console.log(result);
10  };
11
12  // call the function with callback as a parameter
13  add(7, 8, print);
```

- Functions as values in object

```
1   var obj = {
2       data : [2, 3, "Tomas", "Alice", 4 ],
3
4       getIndexdOf : function(val) {
5           for (var i = 0; i < this.data.length; i++)
6               if (this.data[i] == val)
7                   return i;
8           return -1;
9       }
10  }
11
12  obj.getIndexOf(3); // will return 1
```

Closures

- Closures
  - *A function value that references variables from outside its body*

```
1   function adder() {
2       var sum = 0;
3       return function(x) {
4           sum += x;
5           return sum;
6       }
7   }
8
9   var pos = adder();
10
11  console.log(pos(3)); // returns 3
12  console.log(pos(4)); // returns 7
13  console.log(pos(5)); // returns 12
```

Objects

- `this` problem
  - *A new function defines its own `this` value.*

```
1   function Person() {
2     // The Person() constructor defines `this` as an instance of itself.
3     this.age = 0;
4
5     setInterval(function growUp() {
6       // the growUp() function defines `this` as the global object,
7       // which is different from the `this`
8       // defined by the Person() constructor.
9       this.age++;
10    }, 1000);
11  }
12
13  var p = new Person();
```

  - *Solution*

```
1   function Person() {
2     var that = this;
3     that.age = 0;
4
5     setInterval(function growUp() {
6       // The callback refers to the `that` variable of which
7       // the value is the expected object.
8       that.age++;
9     }, 1000);
10  }
```

Arrow Functions

- Arrow function expression
  - *defined in ECMAScript 2015*
  - *shorter syntax than a function expression*
  - *non-binding of `this`*

```
1   function Person(){
2     this.age = 0;
3
4     setInterval(() => {
5       this.age++; // |this| now refers to the person object
6     }, 1000);
7   }
8
9   var p = new Person();
```

- Syntax, function body

```
1   // concise body syntax, implied "return"
2   var func = x => x * x;
3
4   // with block body, explicit "return" required
5   var func = (x, y) => { return x + y; };
6
7   // object literal needs to be wrapped in parentheses
8   var func = () => ({foo: 1});
```

Callback Hell

- Callback in callback

```
1    loadScript('/my/script1.js', function(script) {
2
3      loadScript('/my/script2.js', function(script) {
4
5        loadScript('/my/script3.js', function(script) {
6          // ...continue after all script 1,2 and 3 are loaded
7        });
8
9      })
10
11   });
```

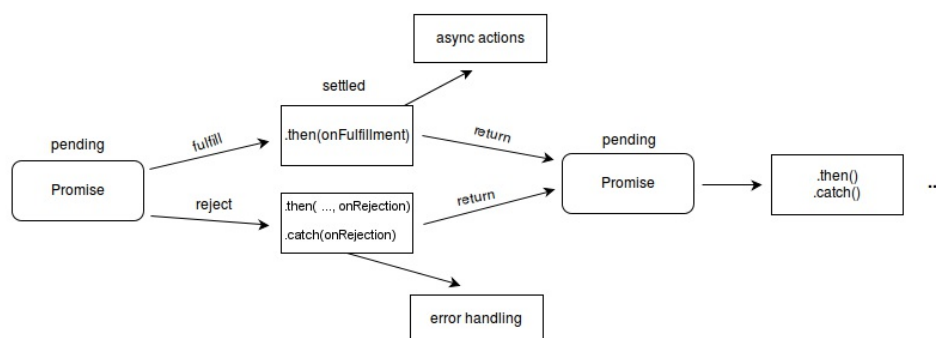 – *Complex asnychronous code is hard to understand and manage*
- Solution
  – *Promise – a proxy to a "future" value of the function*
  – *Async/await – language constructs to work with asynchronous code*

Promise Object

- Promise
  – *An object representing completion or failure of an asynchronous operation.*
  – *A proxy for a value not necessarily known when the promise is created.*

Callback Hell Example

- A callback in a callback

```
1   const request = require('request');
2
3   request("http://w20.vitvar.com/toc.json", { json: true },
4   (err, res, body) => {
5     if (err)
6       console.log("error: " + err)
7     else {
8       console.log(body)
9       request("http://mdw.vitvar.com/toc.json", { json: true },
10      (err, res, body) => {
11        if (err)
12          console.log("error: " + err)
13        else
14          console.log(body)
15      })
16    }
17  })
```

Promise Example

- A chain of Promise objects

```
1   const request = require('request');
2
3   function get_json(url) {
4     return new Promise((resolve,reject)=>{
5       request(url, { json: true }, (err, res, body) => {
6         if (err)
7           reject(err)
8         else
9           resolve(body)
10      })
11    })
12  };
13
14  get_json('http://w20.vitvar.com/toc.json')
15  .then((data)=>{
16    console.log(data)
17    return get_json('http://mdw.vitvar.com/toc.json')
18  })
19  .then((data)=>{
20    console.log(data)
21  })
22  .catch((err)=>{
23    console.log("error: " + err)
24  })
```

async/await

- **async**
  - *the function always returns a Promise*
  - *if there is no Promise, the returned value is wrapped into Promise*

```
1    async function f() {
2        return 1;
3    }
4
5  f().then((v) => alert(v));
```

- **await**
  - *makes program to wait until the promise is resolved or rejected*
  - *it returns the resolved value and throws an exception when the promise is rejected*
  - *can only be usded inside* **async** *function*

```
1  async function f() {
2    var promise = new Promise((resolve, reject) => {
3      setTimeout(() => resolve("done!"), 1000)
4    });
5
6    var result = await promise; // wait untill the promise is resolved
7
8    alert(result);
9  }
10
11  f();
```