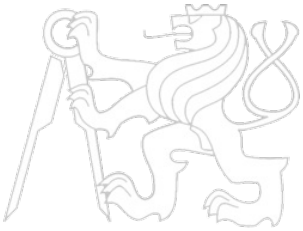
Middleware Architectures 2

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

Modified: Mon Feb 24 2025, 07:28:19
Humla v1.0

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*

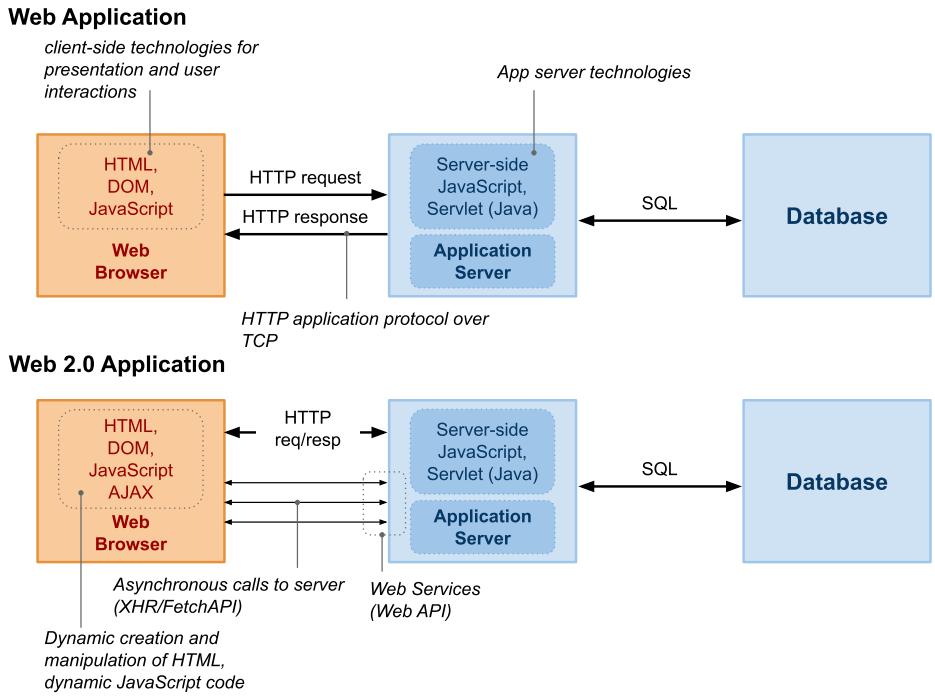
Asynchronous I/O

- 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

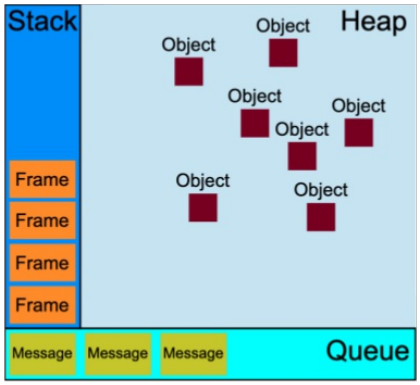
Web 2.0 Application Architecture



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



Event Loop:

```
while (queue.waitForMessage()) {
   queue.processNextMessage()
}
```

- 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.*

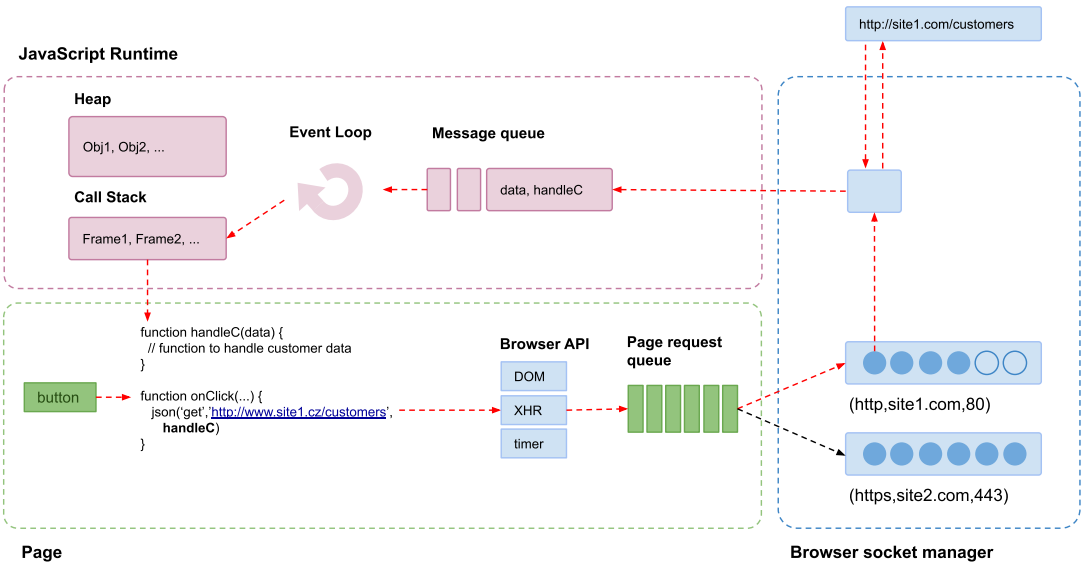
Event Loop

- Event loop

```
while (queue.waitForMessage()) {
  queue.processNextMessage()
}
```

  - *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()
```

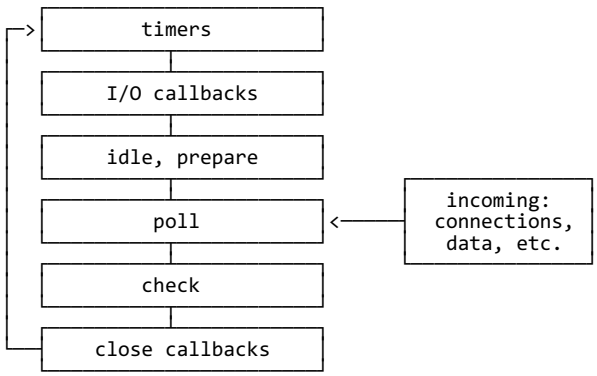
Node.js

- 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`*.*

```
1  const http = require('http');
2
3  const hostname = '127.0.0.1';
4  const port = 3000;
5
6  const server = http.createServer((req, res) => {
7    res.statusCode = 200;
8    res.setHeader('Content-Type', 'text/plain');
9    res.end('Hello World');
10 });
11
12 server.listen(port, hostname, () => {
13   console.log(`Server running at http://${hostname}:${port}/` );
14 });
```


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*

```
1  // create spreadsheet menu
2  function onOpen() {
3    var ss = SpreadsheetApp.getActiveSpreadsheet();
4    var menuEntries = [ {name: "Say Hi", functionName: "sayHi"},
5                        {name: "Say Hello", functionName: "sayHello"} ];
6    ss.addMenu("Tutorial", menuEntries);
7  }
8
9  function sayHi() {
10   Browser.msgBox("Hi");
11 }
12
13 function sayHello() {
14   Browser.msgBox("Hello");
15 }
```

Overview

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

Objects and Arrays

- Objects and Arrays

```
// objects - key/value pairs
var obj = { name: "Tomas", "main-city" : "Innsbruck", value : 3 };
obj.name = "Peter"; // assign the name property another value
obj["main-city"] = "Prague"; // another way to access object's values; it's not an array

// arrays
var a = ["Tomas", "Peter", "Alice"];
for (var i = 0; i < a.length; i++)
    // do something with a[i]

// combinations of arrays and objects
var obj_a = [
    { name: "Tomas", city: "Innsbruck" },
    { name : "Peter", city : "Prague" },
    { name : "Alice", cities : ["Prague", "Brno"] } ];

for (var j = 0; j < obj_a.length; j++)
    // do something with obj_a[j].name, ...
```

- Functions

```
// assign a function to a variable
var minus = function(a, b) {
    return a - b;
}

// call the function;
// now you can pass 'minus' as a parameter to another function
var r2 = minus(6, 4);
```

Functions

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

```
// function returns the result through a callback, not directly;
// this is not a non-blocking I/O, just demonstration of the callback
function add(a, b, callback) {
    callback(a + b);
}

// assign the callback to a variable
var print = function(result) {
    console.log(result);
};

// call the function with callback as a parameter
add(7, 8, print);
```

- Functions as values in object

```
var obj = {
    data : [2, 3, "Tomas", "Alice", 4 ],

    getIndexdOf : function(val) {
        for (var i = 0; i < this.data.length; i++)
            if (this.data[i] == val)
                return i;
        return -1;
    }
}

obj.getIndexOf(3); // will return 1
```


Closures

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

```
function adder() {
        var sum = 0;
        return function(x) {
                sum += x;
                return sum;
        }
}

var pos = adder();

console.log(pos(3)); // returns 3
console.log(pos(4)); // returns 7
console.log(pos(5)); // returns 12
```

Objects

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

```
function Person() {
  // The Person() constructor defines `this` as an instance of itself.
  this.age = 0;

  setInterval(function growUp() {
    // the growUp() function defines `this` as the global object,
    // which is different from the `this`
    // defined by the Person() constructor.
    this.age++;
  }, 1000);
}

var p = new Person();
```

  - *Solution*

```
function Person() {
  var that = this;
  that.age = 0;

  setInterval(function growUp() {
    // The callback refers to the `that` variable of which
    // the value is the expected object.
    that.age++;
  }, 1000);
}
```


Arrow Functions

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

```
function Person(){
  this.age = 0;

  setInterval(() => {
    this.age++; // |this| now refers to the person object
  }, 1000);
}

var p = new Person();
```

- Syntax, function body

```
// concise body syntax, implied "return"
var func = x => x * x;

// with block body, explicit "return" required
var func = (x, y) => { return x + y; };

// object literal needs to be wrapped in parentheses
var func = () => ({foo: 1});
```

Callback Hell

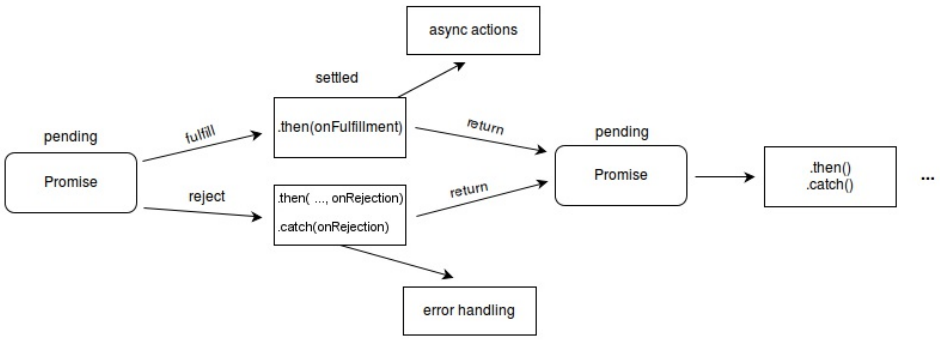
- Callback in callback

```
loadScript('/my/script1.js', function(script) {

  loadScript('/my/script2.js', function(script) {

    loadScript('/my/script3.js', function(script) {
      // ...continue after all script 1,2 and 3 are loaded
    });

  })

});
```

  - *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*

```
  async function f() {
    return 1;
  }

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*

```
async function f() {
  var promise = new Promise((resolve, reject) => {
    setTimeout(() => resolve("done!"), 1000)
  });

  var result = await promise; // wait untill the promise is resolved

  alert(result);
}

f();
```