

# 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>



Evropský sociální fond  
Praha & EU: Investujeme do vaší budoucnosti

Modified: Sun Mar 14 2021, 11:18:53  
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 **preemptive 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 parallelism*
  - *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 facilitates 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*



## Web 2.0 Application



# JavaScript

- Lightweight, interpreted, object-oriented language
- Client-side (browser) and server-side (node.js, AppsScript)
- Standard
  - *Current stable release is ECMAScript 2020*
- 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

```
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*
- *Browser 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 preemptive 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 scheduled 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

```
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.getIndexdOf(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 asynchronous 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 used 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();
```