

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: Sun Mar 14 2021, 11:18:53
Humla v0.3

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 control 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 processed 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

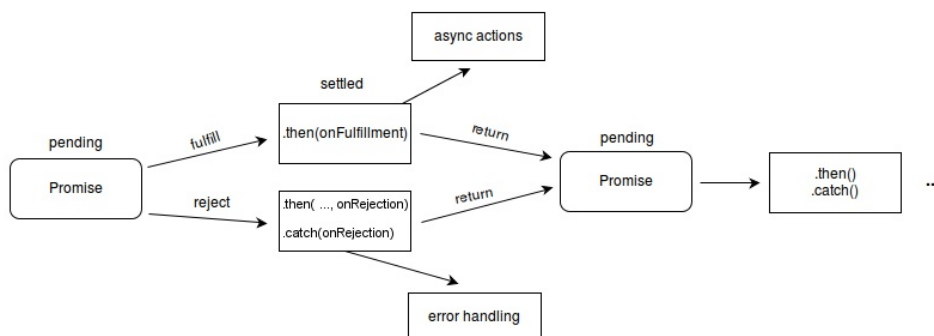
- Solution

- 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();
```