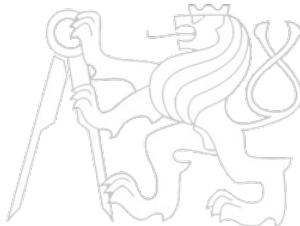


Middleware Architectures 2

Lecture 1: Asynchronous I/O

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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

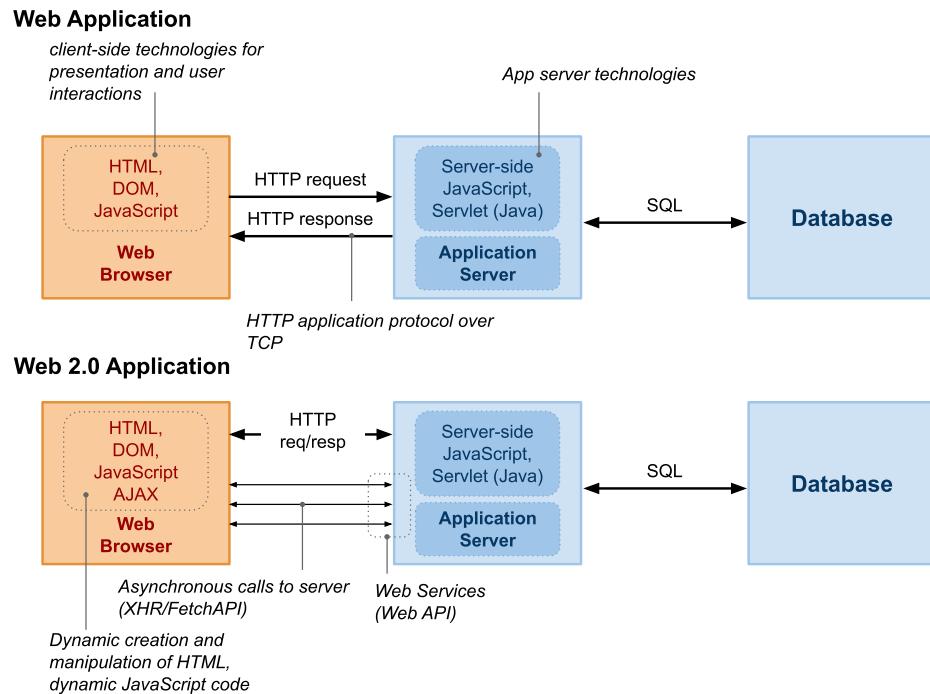
Asynchronous I/O

- 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 lets other tasks to run*
 - *Asynchronous code facilitates concurrent execution*
 - *It gives the "look and feel" of concurrent execution*

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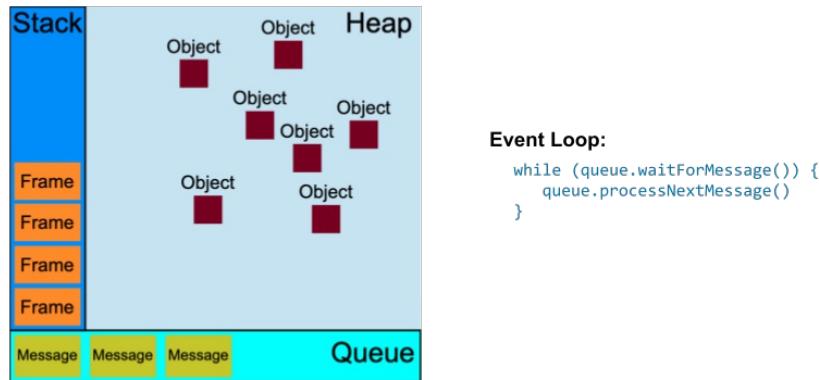
Web 2.0 Application Architecture



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



- **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

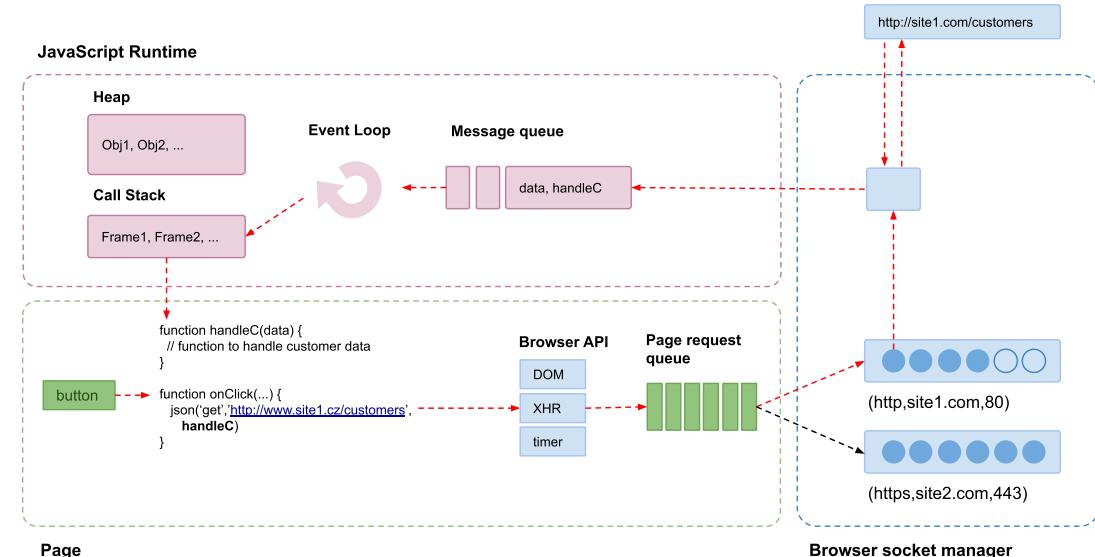
```
1 | while (queue.waitForMessage()) {  
2 |   queue.processNextMessage()  
3 | }
```

- 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

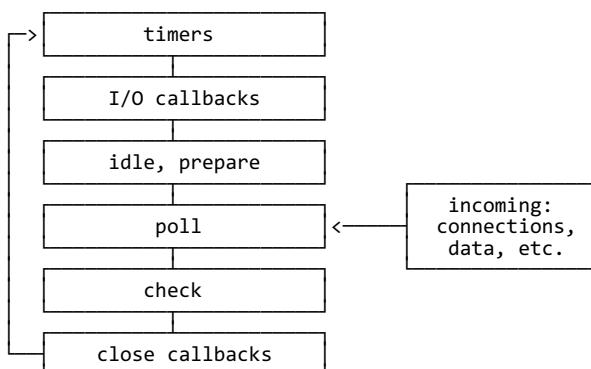
- Node.js ↗
 - Web server technology, very efficient and fast!
 - Event-driven I/O framework, based on JavaScript V8 engine
 - Any I/O is non-blocking (it is asynchronous)
 - One worker thread to process requests
 - You do not need to deal with concurrency issues
 - More threads to realize I/O
 - Open 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 }
```

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

– Complex asynchronous code is hard to understand and manage

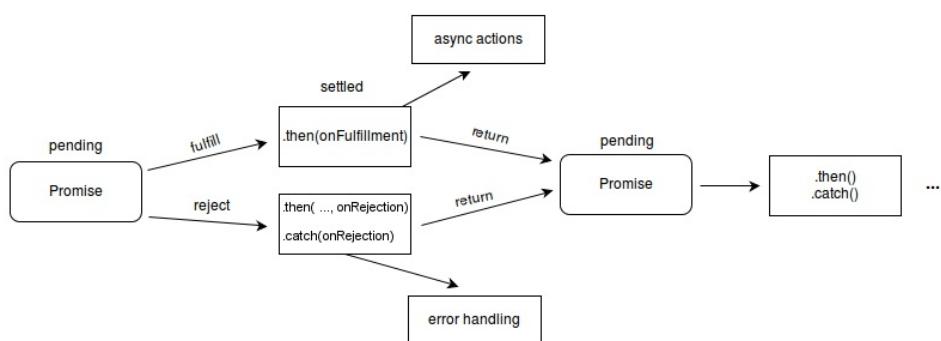
- Solution

– 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
- **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 |   return 1;  
3 | }  
4 | f().then((v) => alert(v));  
  
1 | async function f() {  
2 |   var promise = new Promise((resolve, reject) => {  
3 |     setTimeout(() => resolve("done!"), 1000)  
4 |   });  
5 |  
6 |   var result = await promise; // wait until the promise is resolved  
7 |  
8 |   alert(result);  
9 | }  
10| f();
```