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
 - \rightarrow 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

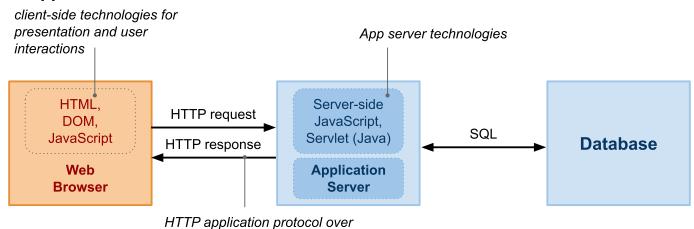
- Asynchronous I/O
 - A style of concurrent programming; it is not a parellelism
 - Single-threaded, single process design
 - It uses cooperative multitasking
- Asynchronous processing of a task
 - Tasks are running in so called event loop
 - A task is able to "pause" when they wait for some result
 - \rightarrow A task let other tasks to run
 - Asynchronous code faciliates concurrent execution
 - → It gives the "look and feel" of concurrent execution

Overview

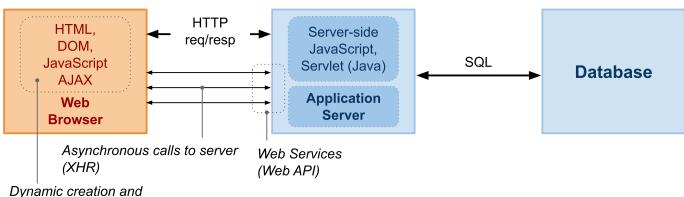
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Web 2.0 Application Architecture

Web Application



Web 2.0 Application

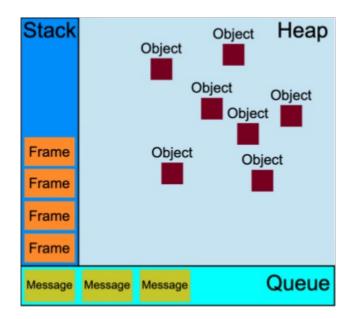


Dynamic creation and manipulation of HTML, dynamic JavaScript code

JavaScript

- Lightweight, interpreted, object-oriented language
- Client-side (browser) and server-side (node.js, AppsScript)
- Standard
 - Current stable release is ECMAScript 2020
- Major characteristics
 - Function is an Object
 - → passing functions as arguments to other functions
 - → returning functions as values from other functions
 - \rightarrow assigning functions to variables
 - \rightarrow 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...

```
function foo(b) {
  let a = 10
  return a + b + 11
}

function bar(x) {
  let y = 3
  return foo(x * y)
}

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

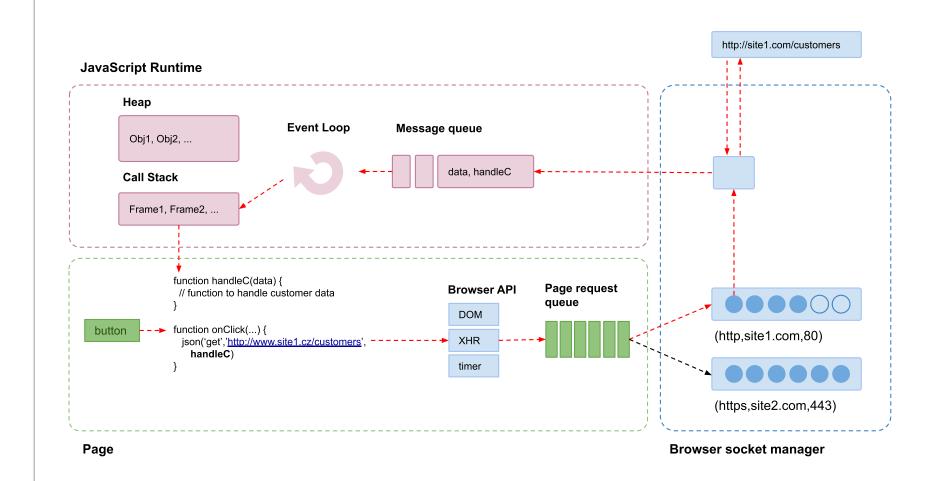
```
while (queue.waitForMessage()) {
   queue.processNextMessage()
}
```

- -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

```
// main.js
var myWorker = new Worker('worker.js');

something.onchange = function() {
   myWorker.postMessage([value1,value2]);
}

// worker.js
onmessage = function(e) {
   var workerResult = 'Result: ' + (e.data[0] * e.data[1]);
   postMessage(workerResult);
}

// ... and terminate
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

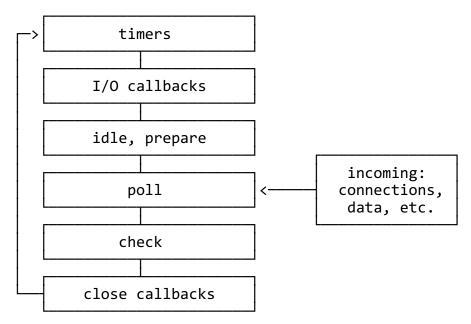
• Every I/O as an event

- reading and writing from/to files
- reading and writing from/to sockets

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

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()
 - \rightarrow I/O callbacks executes all I/O callbacks except close callbacks.
 - \rightarrow *idle/prepare used internally*
 - \rightarrow *poll* retrieve new I/O events
 - → check invokes setImmediate() callbacks
 - \rightarrow 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.

```
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');
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

```
// 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");
10
11
12
13
    function sayHello() {
14
      Browser.msgBox("Hello");
15
```

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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++)</pre>
        // do something with a[i]
10
    // combinations of arrays and objects
11
12
   var obj a = [
        { name: "Tomas", city: "Innsbruck" },
13
        { name : "Peter", city : "Prague" },
         { name : "Alice", cities : ["Prague", "Brno"] } ];
15
16
17 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</pre>
```

Closures

Closures

- A function value that references variables from outside its body

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;
 4
       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++;
10
       }, 1000);
11
12
     var p = new Person();
- Solution
     function Person() {
       var that = this;
       that.age = 0;
 4
       setInterval(function growUp() {
         // The callback refers to the `that` variable of which
 6
         // the value is the expected object.
         that.age++;
       }, 1000);
 10
```

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

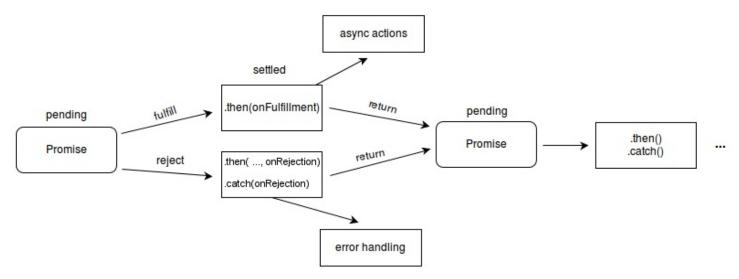
• Callback in callback

- 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

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

Promise Example

• A chain of Promise objects

```
const request = require('request');
    function get json(url) {
      return new Promise((resolve, reject)=>{
4
        request(url, { json: true }, (err, res, body) => {
           if (err)
             reject(err)
           else
             resolve(body)
10
        })
11
      })
12
    };
13
    get json('http://w20.vitvar.com/toc.json')
14
    .then((data)=>{
15
16
      console.log(data)
      return get json('http://mdw.vitvar.com/toc.json')
17
18
19
    .then((data)=>{
      console.log(data)
20
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

```
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();
```