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Asynchronous Programming in JS

“The” language of the Web

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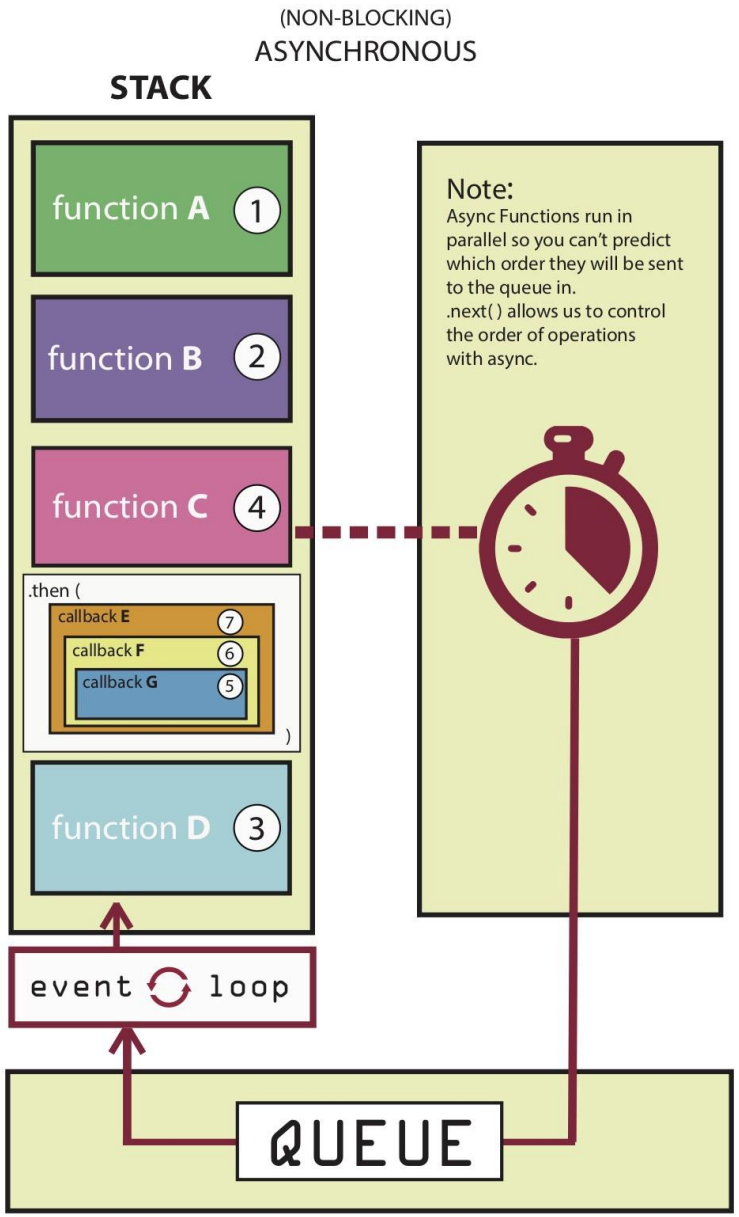


Outline

- Asynchronous Programming
- Database Access with SQLite
- Promises
- async/await

JavaScript: The Definitive Guide, 7th Edition
Chapter 11. Asynchronous JavaScript

Mozilla Developer Network

- Learn web development JavaScript » Dynamic client-side scripting » Asynchronous JavaScript
- Web technology for developers » JavaScript » Concurrency model and the event loop
- Web technology for developers » JavaScript » JavaScript Guide » Using Promises

JavaScript – The language of the Web

ASYNCHRONOUS PROGRAMMING

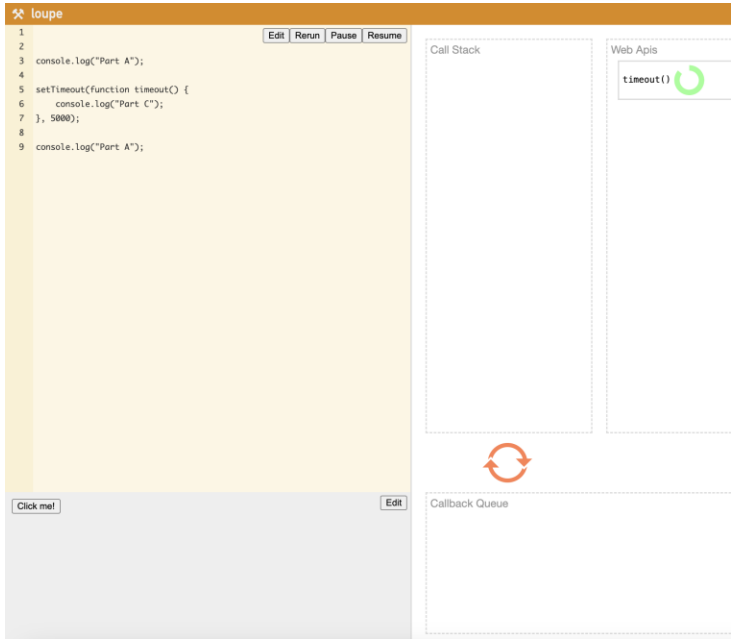
Asynchronicity

- JavaScript is single-threaded and inherently synchronous
  - i.e., code cannot create threads and run in parallel in the JS engine
- Callbacks are the most fundamental way for writing asynchronous JS code
- How can they work asynchronously?
  - e.g., how can setTimeout() or other async callbacks work?
- Thanks to the Execution Environment
  - e.g., browsers and Node.js
- and the Event Loop

```
const deleteAfterTimeout = (task) =>
{
  // do something
}
// runs after 2 seconds
setTimeout(deleteAfterTimeout, 2000,
task)
```

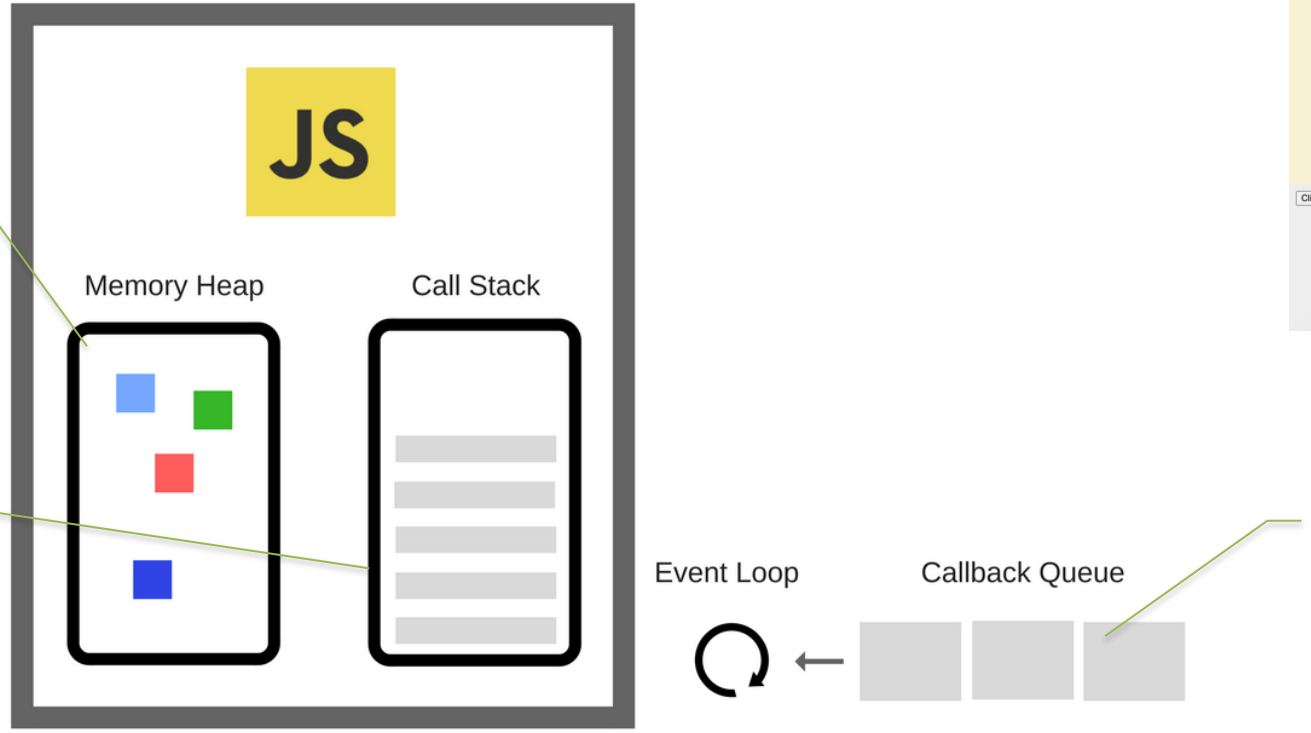
Execution Environment

[Try me!](#)



Allocated Objects

Running function calls



Pending callbacks to be executed

https://developer.mozilla.org/en-US/docs/Web/JavaScript/EventLoop

https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/#what-is-the-event-loop

Event Loop

- During code execution you may
  - Call functions → the function call is pushed to the call stack
  - Schedule events → the call to the event handler is put in the Message Queue
    - Events may be scheduled also by external events (user actions, I/O, network, timers, …)
- At any step, the JS interpreter:
  - If the call stack is not empty, pop the top of the call stack and executes it
  - If the call stack is empty, pick the head of the Message Queue and executes it
- A function call / event handler is **never** interrupted
  - Avoid blocking code!

https://developer.mozilla.org/en-US/docs/Web/JavaScript/EventLoop

https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/#what-is-the-event-loop

Non-Blocking Code!

- Asynchronous techniques are very useful, particularly for web development
- For instance: when a web app runs executes an intensive chunk of code without returning control to the browser, the browser can appear to be frozen
  - this is called **blocking**, and it **should be the exception**!
    - the browser is blocked from continuing to handle user input and perform other tasks until the web app returns control of the processor
- This may happen outside browsers, as well
  - e.g., reading a long file from the disk/network, accessing a database and returning data, accessing a video stream from a webcam, etc.
- Most of the JS execution environments are, therefore, deeply asynchronous
  - with non-blocking primitives
  - JavaScript programs are event-driven, typically

Asynchronous Callbacks

- The most fundamental way for writing asynchronous JS code
- Great for “simple” things!
- Handling user actions
  - e.g., button click
- Handling I/O operations
  - e.g., fetch a document
- Handling time intervals
  - e.g., timers
- Interfacing with databases

```
const readline = require('readline');

const rl = readline.createInterface({
    input: process.stdin,
    output: process.stdout
});

rl.question('How old are you? ', (answer) => {
    let description = answer;

    rl.close();
});
```

Timers

- Useful to delay the execution of a function. Two possibilities from the runtime environment
  - `setTimeout()` runs the callback function after a given period of time
  - `setInterval()` runs the callback function periodically

```
const onesec = setTimeout(()=> {
    console.log('hey') ; // after 1s
}, 1000) ;

console.log('hi') ;
```

Note: timeout value in ms, < 2^{31}-1 (about 24 days)

```
const myFunction = (firstParam,
secondParam) => {
  // do something
}
// runs after 2 seconds
setTimeout(myFunction, 2000,
firstParam, secondParam) ;
```

Timers

- `clearInterval()`: for stopping the periodical invocation of `setInterval`

```
const id = setInterval(() => {}, 2000) ;
// «id» is a handle that refers to the timer

clearInterval(id) ;
```

Handling Errors in Callbacks

- No “official” ways, only best practices!
- Typically, the first parameter of the callback function is for storing any error, while the second one is for the result of the operation
  - this is the strategy adopted by Node.js, for instance

```
fs.readFile('/file.json', (err, data) => {
  if (err !== null) {
    console.log(err);
    return;
  }
  //no errors, process data
  console.log(data);
});
```

Data Persistence

DATABASE ACCESS WITH SQLITE

Server-Side Persistence

- A web server should normally store data into a persistent database
- Node supports most databases
  - Cassandra, Couchbase, CouchDB, LevelDB, MySQL, MongoDB, Neo4j, Oracle, PostgreSQL, Redis, SQL Server, SQLite, Elasticsearch
- An easy solution for simple and small-volume applications is **SQLite**
  - in-process on-file relational database

SQLite

- Uses the '`sqlite`' npm module
- Documentation: https://github.com/mapbox/node-sqlite3/wiki

```
npm install sqlite3
```

```
const sqlite = require('sqlite3');
const db = new sqlite.Database('exams.sqlite', // DB filename
  (err) => { if (err) throw err; });

...
db.close();
```

SQLite: Queries

```
rows.forEach((row) => {
   console.log(row.name);
 });
```

- `const sql = "SELECT…";`

- `db.all(sql, [params], (err, rows) => { } )`
  - Executes sql and returns all the rows in the callback
  - If `err` is true, some error occurred. Otherwise, `rows` contains the result
  - `rows` is an array of objects. Each item contains the fields of the result

https://www.sqlitetutorial.net/sqlite-nodejs/

SQLite: Queries

```
rows.forEach((row) => {
   console.log(row.name);
 });
```

- `db.get(sql, [params], (err, row) => { } )`
  - Get only the first row of the result (e.g., when the result has 0 or 1 elements: primary key queries, aggregate functions, …)

- `db.each(sql, [params], (err, row) => { } )`
  - Executes the callback once per each result row (no need to store all of them)

https://www.sqlitetutorial.net/sqlite-nodejs/

SQLite: Other Queries

- `db.run(sql, [params], function (err) { } )`
  - For statement that do not return a value
  - INSERT
  - UPDATE
  - DELETE
  - In the callback function
    - `this.changes` == number of affected rows
    - `this.lastID` == number of inserted row ID (for INSERT queries)
    - Note: To make `this` work correctly in the callback, the **arrow function syntax cannot be used here**

https://www.sqlitetutorial.net/sqlite-nodejs/

Parametric Queries

- The SQL string may contain parameter placeholders: ?
- The placeholders are replaced by the values in the [params] array
  - in order: one param per each ?

```
const sql = 'SELECT * FROM course WHERE code=?';
db.get(sql, [code], (err, row) => {
```

- Always use parametric queries – **never** string+concatenation **nor** `template strings`

Example

Table: course

	code	name	CFU
	Filter	Filter	Filter
1	01TYMOV	Information systems security	6
2	02LSEOV	Computer architectures	10
3	01SQJOV	Data Science and Database Technology	8
4	01OTWOV	Computer network technologies and services	6
5	04GSPOV	Software engineering	8
6	01TXYOV	Web Applications I	6
7	01NYHOV	System and device programming	10

Table: score

	coursecode	score	laude	datepassed
	Filter	Filter	Filter	Filter
1	02LSEOV	25	0	2021-02-01

Example

transcript.js

```
const sqlite = require('sqlite3');
const db = new sqlite.Database('transcript.sqlite',
    (err) => { if (err) throw err; });

let sql = "SELECT * FROM course LEFT JOIN score ON course.code=score.coursecode" ;
db.all(sql, (err,rows)=>{
    if(err) throw err ;
    for (let row of rows) {
        console.log(row);
    }
});
```

Example

```
const sqlite = require('sqlite3');
const db = new sqlite.Database('transcript.sqlite',
    (err) => { if (err) throw err; });

let sql = "SELECT * FROM course LEFT JOIN score ON cou
db.all(sql, (err,rows)=>{
    if(err) throw err ;
    for (let row of rows) {
        console.log(row);
    }
});
```

```
{
  code: '01TYMOV',
  name: ' Information systems security ',
  CFU: 6,
  coursecode: null,
  score: null,
  laude: null,
  datepassed: null
}
{
  code: '02LSEOV',
  name: ' Computer architectures ',
  CFU: 10,
  coursecode: '02LSEOV',
  score: 25,
  laude: 0,
  datepassed: '2021-02-01'
}
```

But…

```
const sqlite = require('sqlite3');
const db = new sqlite.Database('transcript.sqlite', (err) => { if (err) throw err; });

let result = [];
let sql = "SELECT * FROM course LEFT JOIN score ON course.code=score.coursecode" ;
db.all(sql, (err,rows)=>{
    if(err) throw err ;
    for (let row of rows) {
        console.log(row);
        result.push(row);
    }
});
console.log('************');
for (let row of result) {
    console.log(row);
}
```

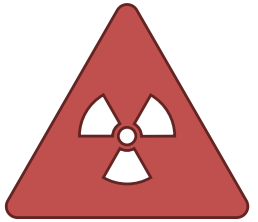
Queries Are Executed **Asynchronously**

```
CREATE TABLE IF NOT EXISTS "numbers" (
    "number"    INTEGER
);
INSERT INTO "numbers" ("number") VALUES (1);
```

```
insert into numbers(number) values(1);
-- Add a new line
```

```
select count(*) as tot from numbers;
-- Count how many lines we have
```

number
1



Queries Are Executed Asynchronously

```
const sqlite = require('sqlite3');
const db = new sqlite.Database('data.sqlite',
    (err) => { if (err) throw err; });

for(let i=0; i<100; i++) {
    db.run('insert into numbers(number) values(1)',
        (err) => { if (err) throw err; });

    db.all('select count(*) as tot from numbers',
    (err, rows) => {
        if(err) throw err;
        console.log(rows[0].tot);
    }) ;

}
db.close();
```

queries.js

```
…
389
390
391
392
396
396
396
397
398
399
399
400
400
…
```

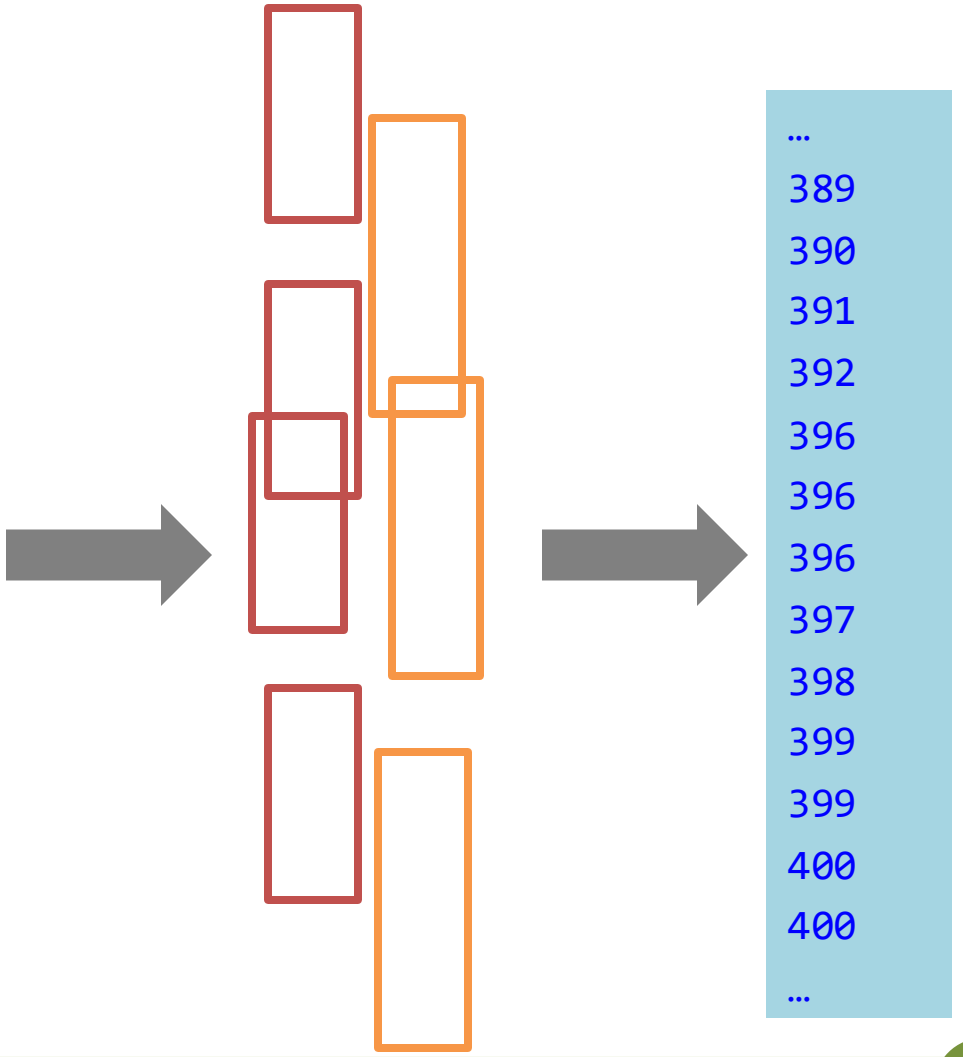
Queries are Executed Asynchronously

```
const sqlite = require('sqlite3');
const db = new sqlite.Database('data.sqlite',
    (err) => { if (err) throw err; });

for(let i=0; i<100; i++) {
    db.run('insert into numbers(number) values(1)',
        (err) => { if (err) throw err; });

    db.all('select count(*) as tot from numbers',
    (err, rows) => {
        if(err) throw err;
        console.log(rows[0].tot);
    }) ;

}
db.close();
```



Solution?


```
for(let i=0; i<100; i++) {

    db.run('insert into numbers(number) values(1)',
        (err) => { if (err) throw err;
                   else                                  })

    db.all('select count(*) as tot from numbers',
    (err, rows) => {
        if(err) throw err;
        console.log(rows[0].tot);
                                                         });

}
```

A possible solution is in `queries_sync.js`, but it's **not** recommended

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PROMISES

Beware: *Callback Hell*!

- If you want to perform multiple asynchronous actions in a row using callbacks, you must keep passing new functions to handle the continuation of the computation after the previous action
  - every callback adds a level of nesting
  - when you have lots of callbacks, the code starts to be complicated very quickly

```
const readline = require('readline');
const rl = readline.createInterface({
   input: process.stdin,
   output: process.stdout
});

rl.question('Task description: ', (answer) => {
  let description = answer;

  rl.question('Is the task important? (y/n)', (answer) => {
    let important = answer;

    rl.question('Is the task private? (y/n)', (answer) => {
      let privateFlag = answer;

      rl.question('Task deadline: ', (answer) => {
        let date = answer;
        ...
        rl.close();
      })
    })
  })
});
```

Promises

- A core language feature to "**simplify" asynchronous programming**
  - a possible solution to callback hell, too!
  - a fundamental building block for "newer" functions (`async`, ES2017)
- It is an **object** representing the eventual **completion** (or **failure**) of an asynchronous operation
  - i.e., an asynchronous function returns *a promise to supply the value* at some point in the future, instead of returning immediately a final value
- Promises standardize a way to handle errors and provide a way for errors to propagate correctly through a chain of promises

Promises

- Promises can be created or consumed
  - many Web APIs expose Promises to be consumed!
- When consumed:
  - a Promise starts in a pending state
    - the caller function continues the execution, while it waits for the Promise to do its own processing, and give the caller function some “responses”
  - then, the caller function waits for it to either return the promise in a fulfilled state or in a rejected state

Creating a Promise

- A Promise object is created using the **new** keyword
- Its constructor takes an *executor function*, as its parameter
- This function takes two *functions* as parameters:
  - `resolve`, called when the asynchronous task completes successfully and returns the results of the task as a value
  - `reject`, called when the task fails and returns the reason for failure (an error object, typically)

```
const myPromise =
  new Promise((resolve, reject) => {

    // do something asynchronous which
    // eventually call either:

      resolve(someValue); // fulfilled

    // or

      reject("failure reason"); // rejected

});
```

Creating a Promise

- You can also provide a function with “promise functionality”
- Simply have it return a promise!

```
function waitPromise(duration) {
  // Create and return a new promise
  return new Promise((resolve, reject) => {
      // If the argument is invalid,
      // reject the promise
    if (duration < 0) {
      reject(new Error('Time travel not yet
implemented'));
    } else {
      // otherwise, wait asynchronously and then
      // resolve the Promise; setTimeout will
      // invoke resolve() with no arguments:
      // the Promise will fulfill with
      // the undefined value
      setTimeout(resolve, duration);
    }
  });
}
```

Consuming a Promise

- When a Promise is fulfilled, the `then()` callback is used
- If a Promise is rejected, instead, the `catch()` callback will handle the error
- `then()` and `catch()` are instance methods defined by the Promise object
  - each function registered with `then()` is invoked only once
- You can omit `catch()`, if you are interested in the result, only

```
waitPromise().then((result) => {
  console.log("Success: ", result);
}).catch((error) => {
  console.log("Error: ", error);
});

// if a function returns a Promise...
waitPromise(1000).then(() => {
  console.log("Success!");
}).catch((error) => {
  console.log("Error: ", error);
});
```

Consuming a Promise

- `p.then(onFulfilled[, onRejected]);`
  - Callbacks are executed asynchronously (inserted in the event loop) when the promise is either fulfilled (success) or rejected (optional)
- `p.catch(onRejected);`
  - Callback is executed asynchronously (inserted in the event loop) when the promise is rejected
- `p.finally(onFinally);`
  - Callback is executed in any case, when the promise is either fulfilled or rejected.
  - Useful to avoid code duplication in then and catch handlers
- All these methods return Promises, too! ⇒ They can be chained

Promise: Create & Consume

```
const prom = new Promise(
   (resolve, reject) => {
      ...
      resolve(x);
      ...
      reject(y);
      ...
  }
)
```

```
prom
   .then((x) => {
      ...use x...
   } )
   .catch((y) => {
      ...use y...
   } ) ;
```

Chaining Promises

- One of the most important benefits of Promises
- They provide a natural way to express a sequence of asynchronous operations as a linear chain of `then()` invocations
  - without having to nest each operation within the callback of the previous one
    - the "callback hell" seen before
- **Important:** always return results, otherwise callbacks won't get the result of a previous promise

```
getRepoInfo()
  .then(repo => getIssue(repo))
  .then(issue => getOwner(issue.ownerId))
  .then(owner => sendEmail(owner.email,
'Some text'))
  .catch(e => {
    // just log the error
    console.error(e)
  })
  .finally(_ => logAction());
});
```

Example: Chaining

- Useful, for instance, with I/O API such as `fetch()`, which returns a Promise

```
const status = (response) => {
  if (response.status >= 200 && response.status < 300) {
    return Promise.resolve(response)   // static method to return a fulfilled Promise
  }
  return Promise.reject(new Error(response.statusText))
}

const json = (response) => response.json()    // return is implicit in this arrow function

fetch('/todos.json')
  .then(status)
  .then(json)
  .then((data) => { console.log('Request succeeded with JSON response', data) })
  .catch((error) => { console.log('Request failed', error) })
```

Promises… in Parallel

```
Promise.all(promises)
  .then(results => console.log(results))
  .catch(e => console.error(e));
```

- What if we want to execute several asynchronous operations in parallel?
- `Promise.all()`
  - takes an array of Promise objects as its input and returns a Promise
  - the returned Promise will be rejected if at least one of the input Promises is rejected
  - otherwise, it will be fulfilled with an array of the fulfillment values for each of the input promises
  - the input array can contain non-Promise values, too: if an element of the array is not a Promise, it is simply copied unchanged into the output array
- `Promise.race()`
  - returns a Promise that is fulfilled or rejected when the first of the Promises in the input array is fulfilled or rejected
  - if there are any non-Promise values in the input array, it simply returns the first one

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ASYNC/AWAIT

Simplifying Writing With async / await

- ECMAScript 2017 (**ES8**) introduces two new keywords, **`async`** and **`await`**
  - write promise-based asynchronous code that looks like synchronous code
- Prepend the `async` keyword to any function means that it will return a Promise
- Prepend `await` when calling an async function (or a function returning a Promise) makes the calling code stop until the promise is resolved or rejected

```
const sampleFunction = async () => {
  return 'test'
}
sampleFunction().then(console.log) // This will log 'test'
```

async Functions

- The `async` function declaration defines an asynchronous function
- Asynchronous functions operate in a separate order than the rest of the code (via the event loop), returning an **implicit Promise** as their result
  - but the syntax and structure of code using async functions looks like standard synchronous functions.

```
async function name([param[, param[, ...param]]]) {
   statements
}
```

https://developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Statements/async_function

await

- The `await` operator can be used to wait for a Promise. It can *only be used inside an async function*
- await **blocks** the code execution within the async function **until the Promise is resolved**
- When resumed, the value of the await expression is that of the fulfilled Promise
- If the Promise is rejected, the await expression **throws** the rejected value
  - If the value of the expression following the await operator is not a Promise, it is converted to a resolved Promise

```
returnValue = await expression ;
```

https://developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/await

Example: async / await

```
function resolveAfter2Seconds() {
  return new Promise(resolve => {
    setTimeout(() => {
      resolve('resolved');
    }, 2000);
  });
}
async function asyncCall() {
  console.log('calling');
  const result = await resolveAfter2Seconds();
  console.log(result);
}

asyncCall();
```

Return a promise

async is needed to use await

Looks like sequential code

```
> "calling"
//... 2 seconds
> "resolved"
```

Example: async / await

```
function resolveAfter2Seconds() {
  return new Promise(resolve => {
    setTimeout(() => {
      resolve('resolved');
    }, 2000);
  });
}
async function asyncCall() {
  console.log('calling');
  const result = await resolveAfter2Seconds();
  return 'end';
}

asyncCall().then(console.log);
```

Implicitly returns a Promise

Can use Promise methods

```
> "calling"
//... 2 seconds
> "end"
```

Examples… Before and After

```
const makeRequest = () => {
  return getAPIData()
    .then(data => {
      console.log(data);
      return "done";
    }
  );
}

let res = makeRequest();
```

```
const makeRequest = async () => {
  console.log(await getAPIData());
  return "done";
};

let res = makeRequest();
```

Examples… Before and After

```
function getData() {
  return getIssue()
    .then(issue => getOwner(issue.ownerId))
    .then(owner => sendEmail(owner.email, 'Some text'));
}

// assuming that all the 3 functions above return a Promise
```

```
async function getData = {
  const issue = await getIssue();
  const owner = await getOwner(issue.ownerId);
  await sendEmail(owner.email, 'Some text');
}
```

Chaining with async/await

- Simpler to read, easier to debug
  - debugger would not stop on asynchronous code

```
const getFirstUserData = async () => {
  const response = await fetch('/users.json'); // get users list
  const users = await response.json(); // parse JSON
  const user = users[0]; // pick first user
  const userResponse = await fetch(`/users/${user.name}`); // get user data
  const userData = await userResponse.json(); // parse JSON
  return userData;
}
getFirstUserData();
```

Promises or async/await? Both!

- If the output of `function2` is dependent on the output of `function1`, use `await`.
- If two functions can be run in parallel, create two different async functions and then run them in parallel `Promise.all(promisesArray)`
- Instead of creating huge async functions with many await asyncFunction() in it, it is better to create **smaller** async functions (not too much blocking code)
- If your code contains blocking code, it is better to make it an async function. The callers can decide on the level of asynchronicity they want.

https://medium.com/better-programming/should-i-use-promises-or-async-await-126ab5c98789

SQLite… revisited

```
function insertOne() {
    return new Promise( (resolve, reject) => {
        db.run('insert into numbers(number)
                values(1)', (err) => {
            if (err) reject(err);
            else resolve('Done');
        });
    }) ;
}
```

```
function printCount() {
    return new Promise( (resolve, reject) => {
        db.all('select count(*) as tot
                from numbers',
            (err, rows) => {
                if(err)
                    reject(err);
                else {
                    console.log(rows[0].tot);
                    resolve(rows[0].tot);
                }
            }) ;
        }) ;
}
```

SQLite… revisited

```
function insertOne() {
    return new Promise( (resolve, reject) => {
        db.run('insert into numbers(number)
                values(1)', (err) => {
            if (err) reject(err);
            else resolve('Done');
        });
    }) ;
}
```

```
function printCount() {
    return new Promise( (resolve, reject) => {
        db.all('select count(*) as tot
                from numbers',
            (err, rows) => {
                if(err)
                    reject(err);
                else {
                    console.log(rows[0].tot);
                    resolve(rows[0].tot);
                }
    }) ;
) ;
```

```
async function main() {
    for(let i=0; i<100; i++) {
        await insertOne();
        await printCount();
    }
    db.close();
}

main() ;
```

Beware The Bug!

```
async function main() {
    for(let i=0; i<100; i++) {
        await insertOne();
        await printCount();
    }
    db.close();
}

main() ;
```

```
async function main() {
    for(let i=0; i<100; i++) {
        await insertOne();
        await printCount();
    }
}

main() ;
db.close();
```

SQLite Libraries: Various Options

- **`sqlite3`**: the basic SQLite interface (JS wrapper of the SQLite C library)
- `sqlite`: This module has the same API as the original sqlite3 library, except that all its API methods **return ES6 Promises**.
  - internally, it wraps sqlite3; written in TypeScript
- `sqlite-async`: ES6 **Promise-based** interface to the sqlite3 module.
- `better-sqlite3`: Easy-to-use **synchronous** API (they say it's faster…)

- … search on https://www.npmjs.com/

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