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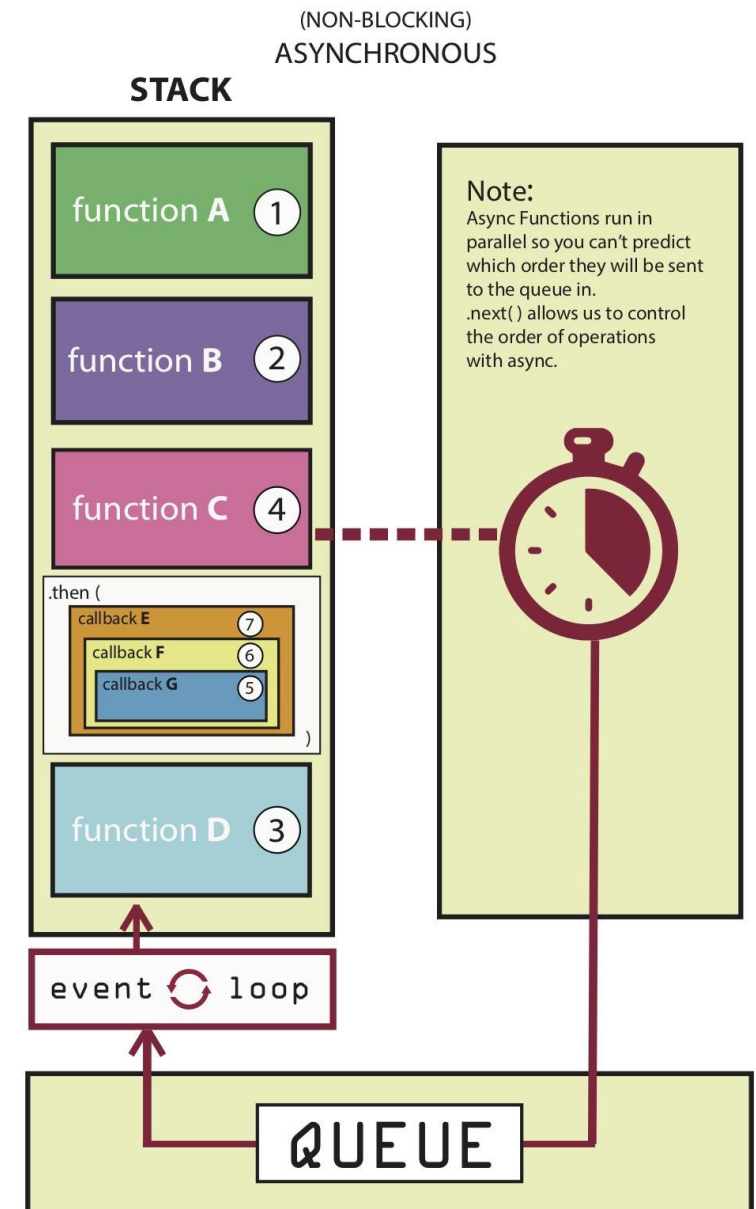
Asynchronous Programming in JS

“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

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JavaScript – The language of the Web

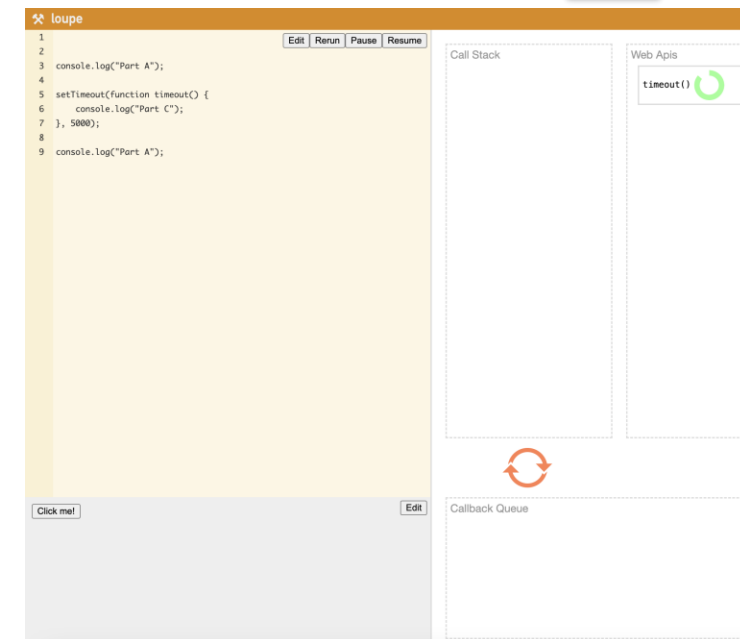
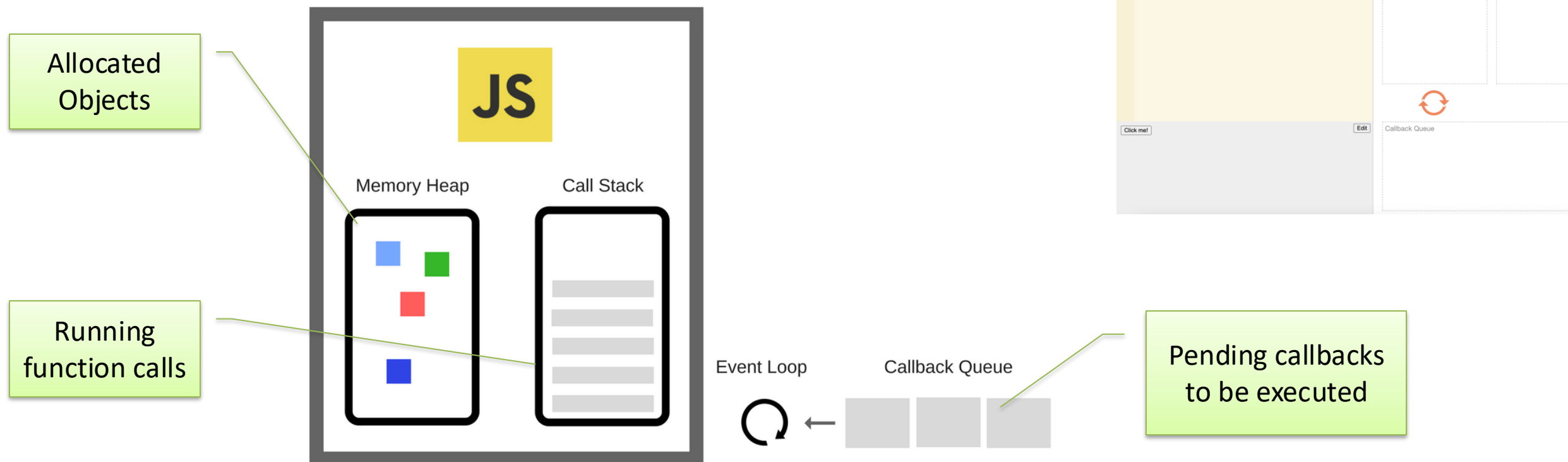
ASYNCHRONOUS PROGRAMMING

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



<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);
}
```

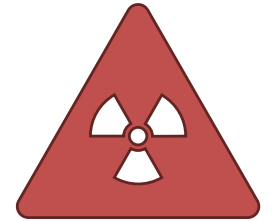
Queries Are Executed Asynchronously

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

number
1

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

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



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

...

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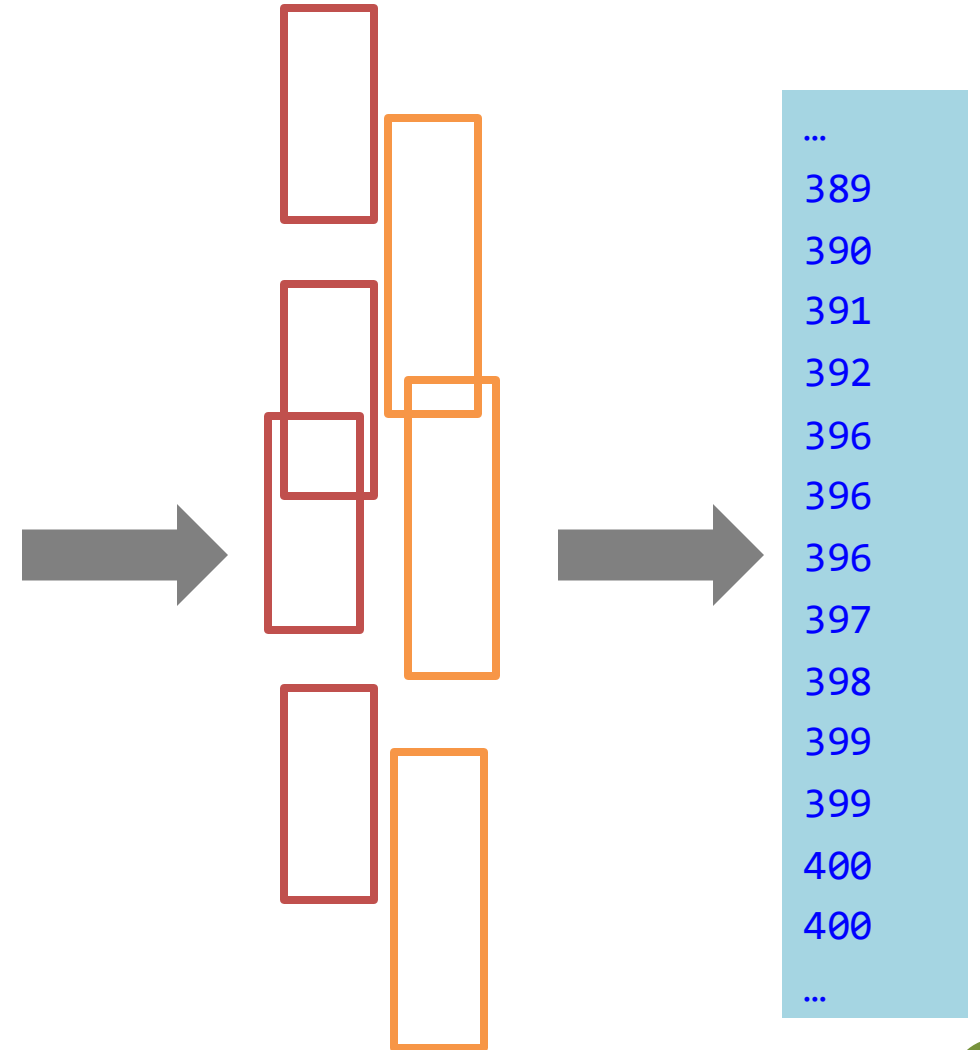
...

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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- [Web technology for developers » JavaScript » JavaScript Guide » Using Promises](#)

JavaScript – The language of the Web

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);
});
```

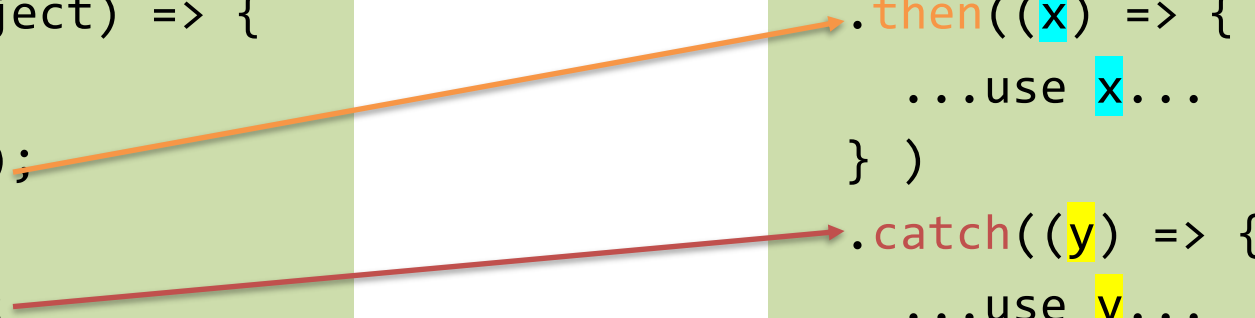
Consuming a Promise

- `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! \Rightarrow 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 user.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');  
        });  
    });  
}
```

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

```
main() ;
```

```
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);  
            }  
        });  
    });  
}
```

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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