Chapter 13 Concurrency

1 Introducing Concurrency

Concurrency

Concurrency is whenever things are happening "at the same time" or in parallel.

JS Engine is single-threaded, and it can only execute one task at a time.

The quick switching between tasks can give the illusion of concurrency, even though the single-thread characteristic.

Asynchronous Programming in JavaScript

Asynchronous programming is a programming paradigm that allows a program to perform tasks without blocking the main thread.

- The program can continue to execute other tasks while waiting for the async task to complete.
- The async task is executed in the background by the browser.
    - The browser is with the multi-threads capability.
- The JS engine will continue to execute the next task in the main thread.

Example 13-1: Get the user's geographical location

An example of async programming: getting the user's geographical location.

```
console.log('Start');
// get the user's geographical location
// off-load the task to the browser.
navigator.geolocation.getCurrentPosition(
  // callback function invoked by the Web API
  position => console.log(position),
  // error handling
  err => console.log(err)
);
console.log('Finish');
```

When you run the above code in the browser, you will see the following output:

```
Start
Finish
// the user's geographical location or an error message
```

while the `navigator.geolocation.getCurrentPosition` function run in the background (browser), the JS engine continues to execute the next task in the main thread.

```
> console.log('Start');
  // get the user's geographical location
  navigator.geolocation.getCurrentPosition(
    position => console.log(position),   // callback function invoked by the Web API
    err => console.log(err)
  );
  console.log('Finish');

  Start

  Finish

< undefined

  ▶ GeolocationPositionError {code: 1, message: 'User denied Geolocation'}
```

2 JS Engine and Browser

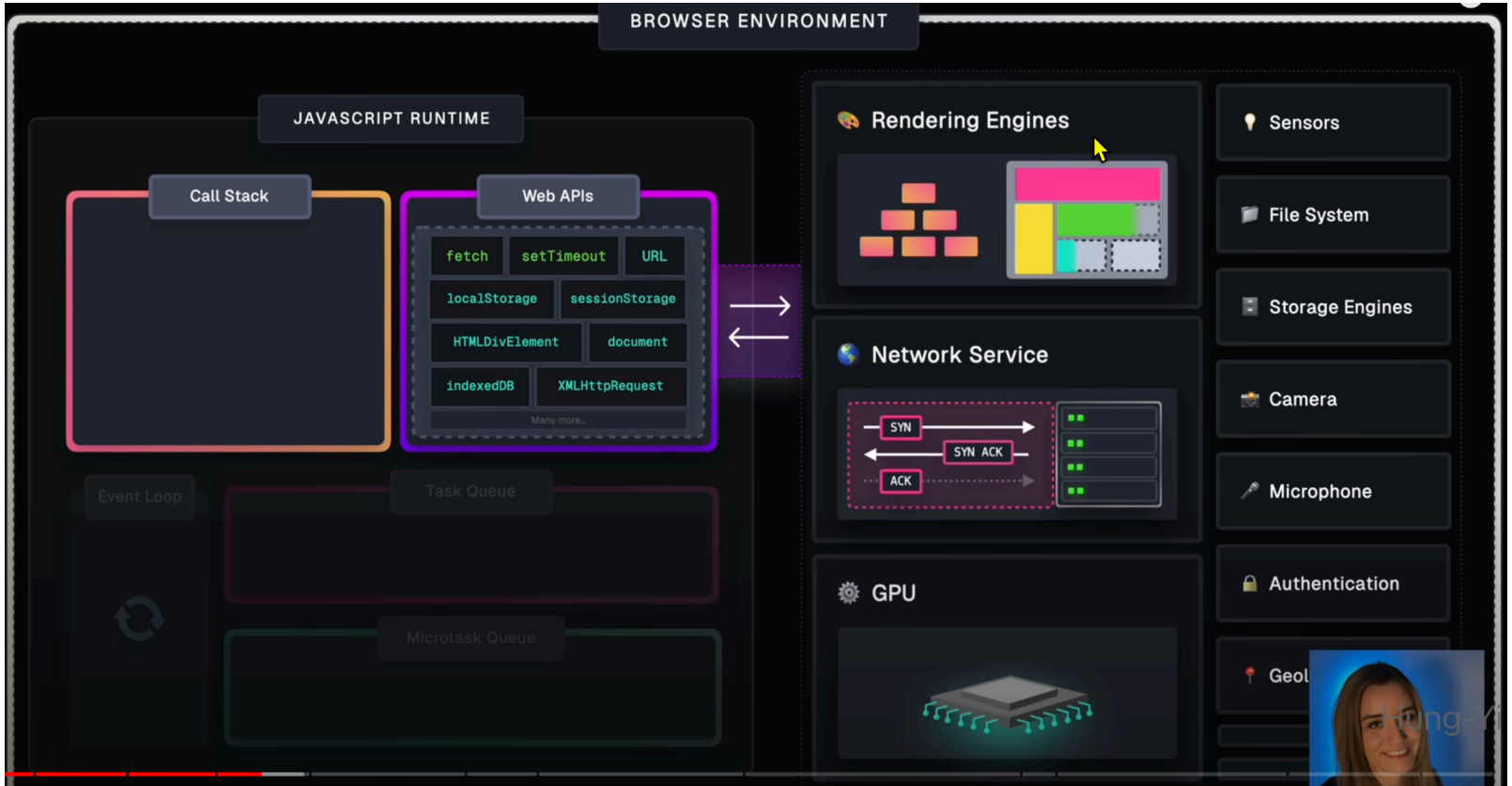
An interesting question arises from the above example:

- Who executes the task of getting the user's geographical location?
- Is it the JS engine or the browser?

3 JS engine and the browser are two different runtime environments.

A browser contains multiple engines to handle different tasks.

JavaScript Engine use Web APIs to use the services provided by the different engines.



The browser is implemented to have the multi-threaded capability.

So, the important concept to keep in mind:

- JS engine and the browser are two different runtime environments.

4 Asynchronous Programming

In JavaScript, concurrency is achieved through the use of asynchronous programming.

There are three ways to write asynchronous code in JavaScript:

- Callbacks
- Promises
- Async/Await

We will discuss each of them in the following slides.

5 Callbacks

Callbacks are functions passed as arguments to other functions.

- They are invoked by other functions.

An typical example of using callbacks is the `setTimeout` function.

- the `setTimeout` function is a Web API provided by the browser.

Example 13-2: Use the `setTimeout` function to delay the execution of a function

While the setTimeout function is running in the background by the browser, the JS engine continues to execute the next task in the main thread:

```
console.log('Hi there!');
function greeting(waitTimeSeconds) {
    console.log(`Sorry for the wait ${waitTimeSeconds} seconds.`)
}
setTimeout(greeting, 2000, 2); // async call; Execute the greeting function after 2 seconds
console.log('Please wait');
```

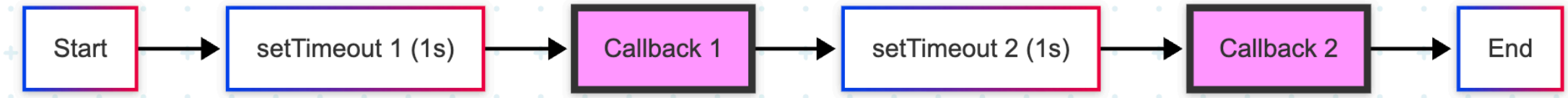
The outputs of the above code are:

```
Hi there!
Please wait
Sorry for the wait 2 seconds.
```

Callback Hell

When you want to execute multiple async tasks in a sequence by using callbacks, you need to nest the callback functions.

- The first callback function calls the second callback function.
  - The second callback function calls the third callback function.
    - continue nesting...



The nested callbacks leads to a problem called **callback hell**.

- make the code **hard to read and maintain**.

Example 13-3 : Logs messages every second for four seconds.

```
// ex_13_03.js
setTimeout(() => { // first callback
    console.log('First timeout');
    setTimeout(() => { // second callback
        console.log('Second timeout');
        setTimeout(() => { // third callback
            console.log('Third timeout');
            setTimeout(() => { // fourth callback
                console.log('Fourth timeout');
                // Continue nesting if needed
            }, 1000);
        }, 1000);
    }, 1000);
}, 1000);
```

The output of the above code is:

```
First timeout
Second timeout
Third timeout
Fourth timeout
```

To avoid the callback hell, we can use Promises or Async/Await (covered later).

6 Lab 13-1

Lab: Understanding Callback Hell in JavaScript

7 Why Promises?

Promises are a better way to handle asynchronous tasks than callbacks.

- avoid from the callback hell.
- convert the nested functions to a promise chain.

8 Promises: How do they work?

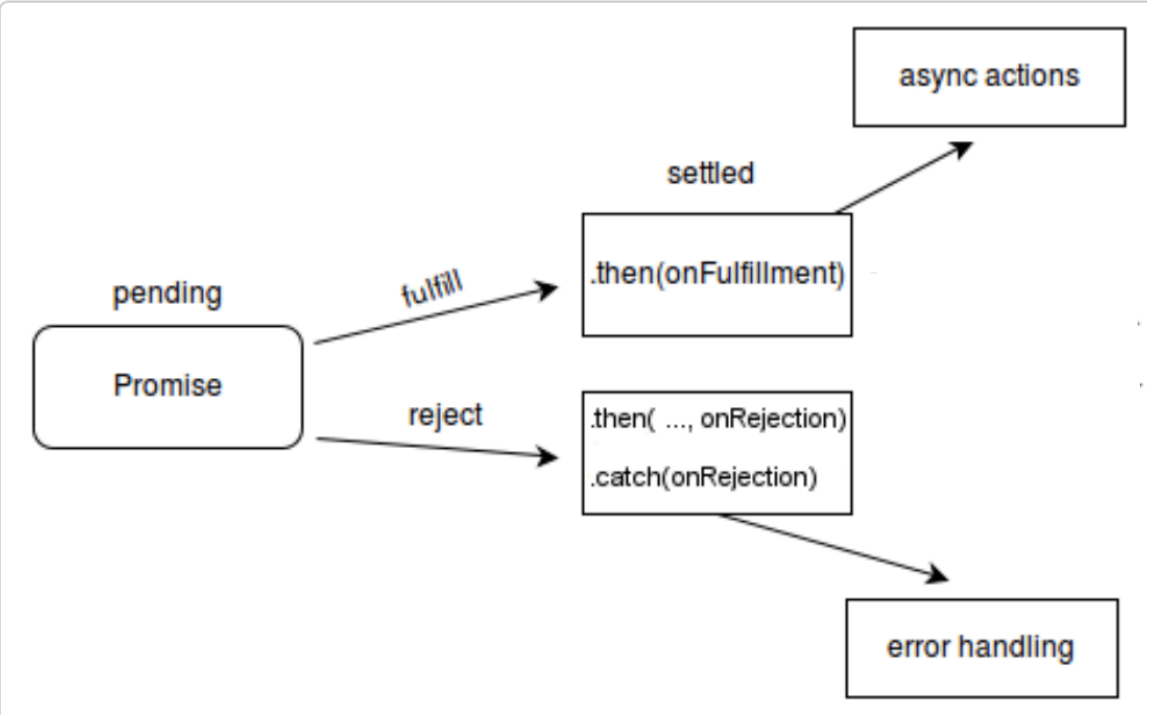
An async function returns a **Promise** object when it completes its task.

- (or the async function resolves the task and return the promise object as the result.)
- Then, the handler functions of the Promise object is placed in a special queue called the **Microtask Queue**.
- The **JS Engine** will find a suitable time to execute tasks in the Micro-task Queue.

9 Use the Promise object

A Promise object has the following possible states:

- Pending
- Settled
    - Fulfilled or Rejected



- Pending: The initial state of the promise object.
  - imply the async task is not completed yet.
- Settled: The promise object is either fulfilled or rejected.
- Fulfilled: The promise object is resolved.
  - imply that the async task is completed successfully.
- Rejected: The promise object is rejected.
  - imply that the async task is failed.

10 Pattern to write an async function using the promise

```
function asyncOperation() {
    return new Promise((resolve, reject) => {
        // code to execute either in the JS engine or in the browser

        // call resolve(value) to resolve the promise object if the operation is successful
        // Otherwise, call reject(reason) to reject the promise object
    });
}
```

1. Create a function that returns a new Promise object.
2. Pass an **executor** function as the argument to the `Promise` constructor.
    - the executor function will be called and invoked when the the JS engine construct the new Promise object.

3. The executor function has two parameters: `resolve` and `reject`.
    - `resolve` is a function that resolves the promise object.
    - `reject` is a function that rejects the promise object.
4. Call the `resolve(value)` function to resolve the promise object.
    - The value will be passed to the resolve handler.
        - The `value` can be another promise object.
    - The promise object will change to the fulfilled state after the `resolve` function is called.
    - Its resolve handler will be placed in the Micro-task Queue.
5. Call the `reject(reason)` function to reject the promise object.
    - The `reason` will be passed to the reject handler.
        - The `reason` is usually an error object.
    - The promise object will change to the rejected state after the `reject` function is called.
    - Its reject handler will be placed in the Micro-task Queue.

Example: Create a custom timeout function

You can also use the previous patten to warp a non-promise function to a promise one:

```
function startTimeouts(msg) {
    return new Promise((resolve, reject) => {
        setTimeout(() => {
            console.log(msg);
            resolve('Timeout completed');
        },  1000);
    });
}
```

Note: Code in the Promise constructor is executed by the main thread of the JS engine

- The main thread of the JS engine execute immediately the code in the Promise constructor when creating a new Promise object.
- Only the `resolve` and `reject` handlers are placed in the Micro-task Queue.
- The statements after the `resolve()` or `reject()` function still can be executed in the main thread.

Example: the code in the Promise constructor is executed by the main thread of the JS engine

```
console.log('1') ;
let promiseObject = new Promise((resolve, reject) => {
    console.log('2');
    resolve('3');
    console.log('4')
});
console.log('5');
```

The output of the above code is:

```
1
2
4
5
```

11 How to handle the returned promise: the promise handler

- The async function returns a promise object.
- We need to register a (promise) handle to handle the settled promise (either resolved or rejected).

Register the resolve and reject handlers

Resolve Handler:

- Use the `then` method of the Promise object to register the handler for the fulfilled promise.

```
promiseObject.then(onFulfilled_callback);
```

Reject Handler:

- Use the `catch` method of the Promise object to register the handler for the rejected promise.

```
promiseObject.catch(onRejected_callback);
```

Or, you can register both handlers using the `then` method:

```
promiseObject.then(onFulfilled_callback, onRejected_callback);
```

Example 13-4: Register a callback to handle the fulfilled promise

```
let fulfilledPromise = startTimeouts(2);
fulfilledPromise.then((msg) =>
    console.log('The promise is fulfilled with message:', msg);
);
```

Or, combine the two statements:

```
startTimeouts(2).then((msg) =>
    console.log('The promise is fulfilled with message:', msg);
);
```

Signature of the onFulfilled_callback and onRejected_callback functions

The `onFulfilled_callback` and `onRejected_callback` functions have the following signature:

```
function onFulfilled_callback(value) {
    // code to handle the fulfilled promise
    // value is the resolved value of the promise
}
function onRejected_callback(reason) {
    // code to handle the rejected promise
    // reason is the rejected reason of the promise
}
```

Example 13-X-3 Rewrite the nested callbacks using the Promise object

```
startTimeouts(2)
    // return a promise object
    .then(() => startTimeouts('First timeout'))
    // return another promise object
    .then(() => startTimeouts('Second timeout'))
    .catch(error => console.error('An error occurred:', error));
```

Lab 13-2

Lab: Rewrite the code in Lab 13-1 using the Promise object

12 Interacting with the browser with APIs

Fetch API

Use the Fetch API to fetch local or remote resources.

- e.g. get the data from a URL.

The HTTP request and response are represented by the following objects:

- The `request` object represents a resource request.
- The `response` object represents the response to the request.
- The `headers` object represents the HTTP headers of the request or response.

Syntax of the `fetch()` function

The syntax of the `fetch()` function is as follows:

```
fetch(url)
fetch(url, options)
```

- The `url` is the URL of the resource to fetch.
- the `options` is an optional object that contains the request options.
    - e.g. method, headers, body, etc.

Return value:

- The `fetch()` function returns a Promise object that resolves to the `response` object.

Example 13-5 : Use `fetch()` web API to get the data from a URL.

`fetch()` return a Promise object.

We register the handles using the `then` and `catch` methods of the Promise object.

```
fetch(url)
        // resolve the response object from the resolved promise object
        .then(response => {
            console.log("First handler for the fetch()'s promise")
            if (!response.ok) {
                throw new Error('Network response was not ok');
            }
            // response.text() is async fun.
            // It returns a promise that resolves with the response body
            return response.text();
        })
```

Continue from the last `then` method:

```
        // resolve the response body from the promise object
        .then(data => {
            console.log("Second handler for the response.text()'s promise");
            // data is the response body
            console.log('Data fetched:', data);
        })
        // catch the error from the promise object
        .catch(error => {
            console.error('Error fetching data:', error);
        });
```

Test your code with the url: `https://jsonplaceholder.typicode.com/posts/1`

The above code will print the response body of the URL to the console.

```
Fetching data from https://jsonplaceholder.typicode.com/posts/1
Please wait for the data to be fetched...
First handler for the fetch()'s promise
Second handler for the response.json()'s promise
Data fetched: {
  userId: 1,
  id: 1,
  title: 'sunt aut facere repellat provident occaecati excepturi optio reprehenderit',
  body: 'quia et suscipit\n' +
    'suscipit recusandae consequuntur expedita et cum\n' +
    'reprehenderit molestiae ut ut quas totam\n' +
    'nostrum rerum est autem sunt rem eveniet architecto'
}
```

13 Lab 13-3:

Fetch data from a URL and show the first N characters of the response body

14 Chain Promises

Promise objects are **thenable** objects

- Each Promise object has a `then` method that can return a new Promise object.
- The `then` method returning a new Promise object can be chained with another `then` method.
- This allows developers to control the flow of the asynchronous tasks.
    - Think the chained `then` method as a sequence of operations on returned Promise objects.

Patterns to chain Promise objects

Two patterns to chain Promise objects:

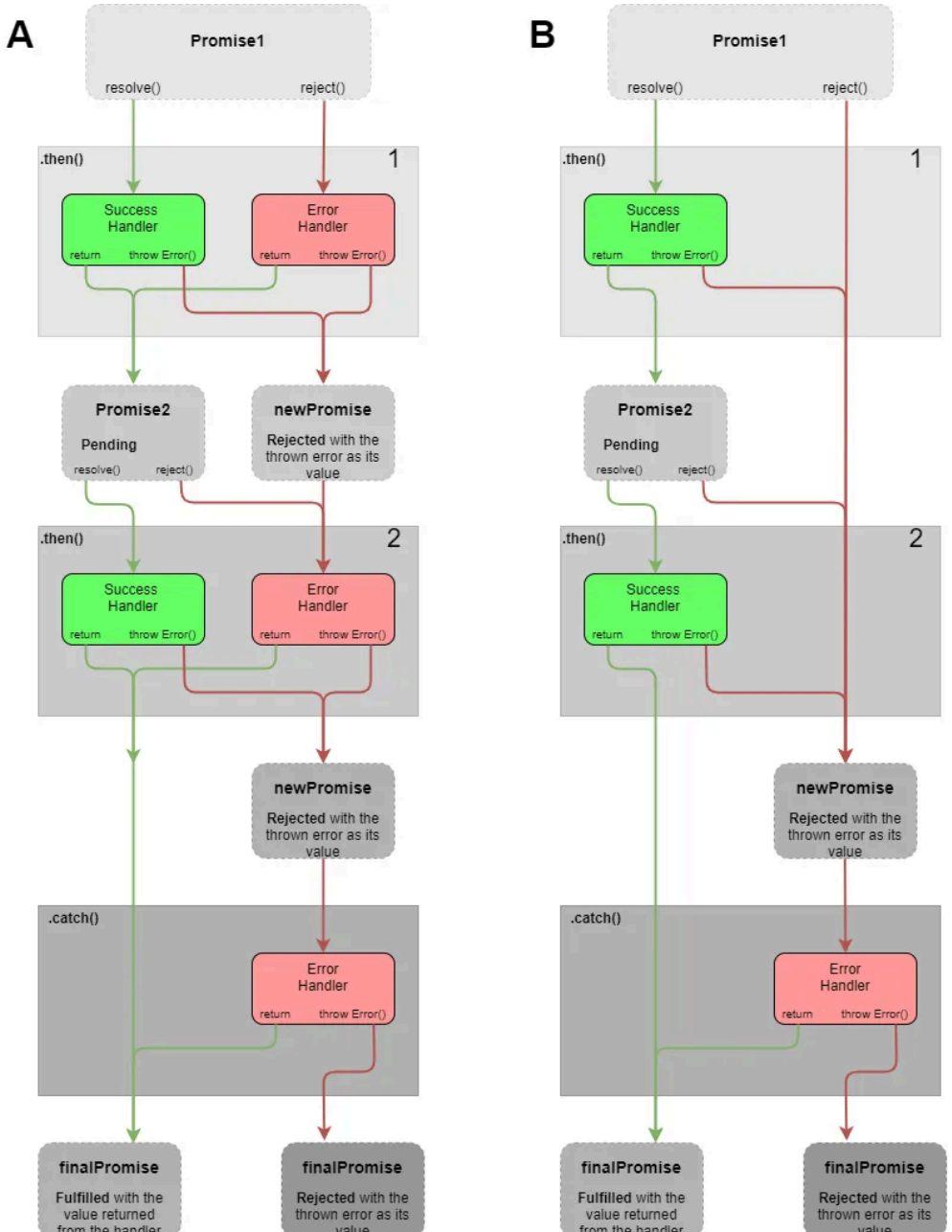
- Pattern A: A separated error handler for each Promise object.
- Pattern B: A single error handler for all Promise objects.

Pattern A: Separated error handler for each Promise object.

Feature:

- Go through all the `then` methods even if a Promise object is rejected.

```
promiseObject
    .then(onFulfilled_callback1, onRejected_callback1)
    .then(onFulfilled_callback2, onRejected_callback2)
    ...
    .catch(onRejected_callbackN);
```


A
Promise1
resolve()
reject()
.then()
1
Success Handler
return
throw Error()
Error Handler
return
throw Error()
Promise2
Pending
resolve()
reject()
newPromise
Rejected with the thrown error as its value
.then()
2
Success Handler
return
throw Error()
Error Handler
return
throw Error()
newPromise
Rejected with the thrown error as its value
.catch()
Error Handler
return
throw Error()
finalPromise
Fulfilled with the value returned
finalPromise
Rejected with the thrown error as its
B
Promise1
resolve()
reject()
.then()
1
Success Handler
return
throw Error()
Promise2
Pending
resolve()
reject()
.then()
2
Success Handler
return
throw Error()
newPromise
Rejected with the thrown error as its value
.catch()
Error Handler
return
throw Error()
finalPromise
Fulfilled with the value returned
finalPromise
Rejected with the thrown error as its

- Rejected Promise object are handled by the `onRejected_callback` function in the `then` method.
    - must return a resolved Promise to continue the chain.
- The `catch` method is used to handle the rejected Promise object that is not handled by the `then` method.
    - The last barrier in the chain.

Example 13-X-1: A separated error handler for each Promise object

Assume there are three async functions: `firstTask`, `secondTask`, and `thirdTask`.
The `secondTask` function returns a rejected Promise object.
We want to run the three tasks in sequence and handle the errors separately.

See ex_13_x_1.js for the complete example.

```
firstTask()
    .then(result => {
        console.log('First task completed with result:', result);
        return secondTask(result)
    },
        error => {
            console.log(`Handle the error in the first task: ${error}`);
            // try to handle the error
            // error handle successfully. Return a new promise to continue the chain
            return Promise.resolve(error);
        })  // The anonymous function returns a promise
    .then(result => {
        console.log('Second task completed with result:', result);
        return thirdTask(result)
    },
        error => {
            console.log('Handle the error in the second task', error);
            //handle the error unsuccessfully
            return Promise.reject(error); // Uncomment to handle the error and continue
        })
    .then(result => {
        console.log('Third task completed with result:', result);
    }, error => {
        console.log('Handle the error in the third task: ', error);
        // If not handled, will go to .catch()
        return Promise.reject(error);
    })
    .catch(error => {
        console.error('Final catch:', error);
    });
```

The output of the above code is:

```
'First task running...'
[ 'First task completed with result:', 1 ]
'Second task running...'
[ 'Handle the error in the second task', 2 ]
[ 'Handle the error in the third task: ', 2 ]
[ 'Final catch:', 2 ]
```

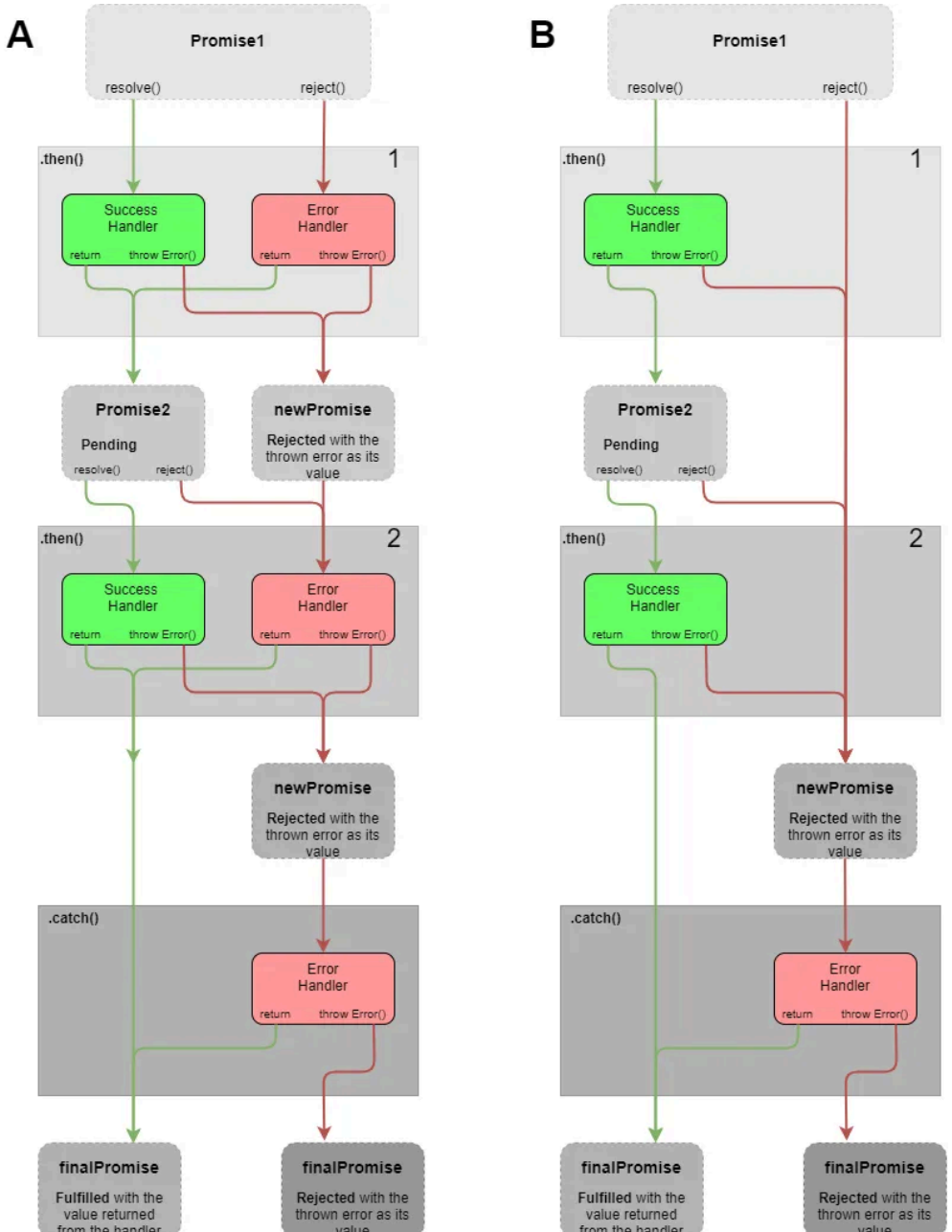
See example: ex_13_x_1.js

Pattern B: A single error handler for all Promise objects.

Feature: Any one of the rejected Promise objects stops the whole chain.

```
promiseObject
    .then(onFulfilled_callback1)
    .then(onFulfilled_callback2)
    ...
    .catch(onRejected_callback);
```

- The rejected Promise object go to the `catch` method directly.
- The `onRjected_callback` function is skipped in the `then` method.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Success Handler
return
throw Error()
Error Handler
return
throw Error()
newPromise
Rejected with the thrown error as its value
.catch()
Error Handler
return
throw Error()
finalPromise
Fulfilled with the value returned
finalPromise
Rejected with the thrown error as its
B
Promise1
resolve()
reject()
.then()
1
Success Handler
return
throw Error()
Promise2
Pending
resolve()
reject()
.then()
2
Success Handler
return
throw Error()
newPromise
Rejected with the thrown error as its value
.catch()
Error Handler
return
throw Error()
finalPromise
Fulfilled with the value returned
finalPromise
Rejected with the thrown error as its

Example 13-X-2: A single error handler for all Promise objects

Assume there are three async functions: `firstTask`, `secondTask`, and `thirdTask`.

The `secondTask` function returns a rejected Promise object.

```
firstTask()
    .then(result => secondTask(result))
    .then(result => thirdTask(result))
    .then(result => {
        console.log('Final result:', result);
    })
    .catch( error => {
        console.error('Final catch:', error);
    });
```

The output of the above code is:

```
'First task: resolved.'
'Second task: rejected'
[ 'Final catch:', 2 ]
```

15 Summary

- JavaScript is single-threaded but achieves concurrency through asynchronous programming.
- Asynchronous programming allows tasks to run without blocking the main thread.
- Callbacks are the basic way to handle async tasks but can lead to "callback hell" due to nested functions.
- Promises provide a cleaner, more manageable way to handle asynchronous operations and avoid callback hell.
- Promise objects have three states: pending, fulfilled, and rejected.

- The `then` and `catch` methods are used to handle fulfilled and rejected promises, respectively.
- Promises can be chained to control the sequence of asynchronous tasks, with different patterns for error handling.
- The Fetch API is a modern way to interact with remote resources and returns a Promise.
- Understanding the difference between the JS engine and browser environment is crucial for working with async code.
- Using Promises and chaining improves code readability and maintainability in asynchronous JavaScript.

References

1. Promise() constructor - JavaScript | MDN
2. async function - JavaScript | MDN