CS 4530: Fundamentals of Software Engineering
Lesson 4.2: Asynchronous Programming in TypeScript

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Learning Goals for this Lesson

- At the end of this lesson, you should be able to:
  - Be able to write asynchronous code in TypeScript using both Promises and async/await
  - Understand how to achieve concurrency through asynchronous operations in TypeScript

Not all Asynchronous Code uses Await

Both code snippets are identical once JS engine compiles them

Using async/await

```
async function makeOneGetRequest(){
    const response = await axios.get('https://rest-example.covey.town');
    console.log('Heard back from server');
    console.log(response.data);
}
makeOneGetRequest();
console.log('Made Request');
```

We pass a function to ".then", which is called after the promise is resolved

Directly using Promise

```
axios.get('https://rest-example.covey.town/')
    .then((response) =>{
      console.log('Heard back from server');
      console.log(response.data);
    });
console.log('Made Request');
```

Promises Enforce Ordering Through "Then"

Code after the async call runs *immediately*

```
1. console.log('Making requests');
2. axios.get('https://rest-example.covey.town/')
     .then((response) =>{
        console.log('Heard back from server');
        console.log(response.data);
    });
3. axios.get('https://www.google.com/')
     .then((response) =>{
         console.log('Heard back from Google');
     });
4. axios.get('https://www.facebook.com/')
     .then((response) =>{
        console.log('Heard back from Facebook');
     });
5. console.log('Requests sent!');
```

Sample Output:

```
Making requests
Requests sent!
Heard back from Google
Heard back from server
This is GET number 6 on the current server
Heard back from Facebook
```

These 2 lines ALWAYS first (same listener)

These 2 lines ALWAYS together (same listener)

No guarantee on order of hearing back from Google, our server, or Facebook

Each Listener Returns a Promise for Itself

Both examples produce the exact same output

```
async function makeOneGetRequest(){
  const response = await axios.get('https://rest-
example.covey.town');
  console.log(response.data);
}
```

```
console.log('Making first request');
makeOneGetRequest().then( () =>{
  console.log('Making second request');
  return makeOneGetRequest();
}).then(() => {
  console.log('Making third request');
  return makeOneGetRequest();
}).then(()=>{
  console.log('All done!');
});
```

```
async function makeThreeSerialRequests(){
1.  console.log('Making first request');
2.  await makeOneGetRequest();
3.  console.log('Making second request');
4.  await makeOneGetRequest();
5.  console.log('Making third request');
6.  await makeOneGetRequest();
7.  console.log('All done!');
}
makeThreeSerialRequests();
```

Syntax for Writing Asynchronous Code

For Async/Await and for Promises

- You can only call **await** from a function that is **async**
- You can only **await** on functions that return a **Promise**
- Beware: **await** makes your code synchronous (this is what we want it for)!
- Handle errors using try/catch instead of “catch” (common gotcha with promises)

```
async function makeOneGetRequest(): Promise<void> {
  console.log("Making Request");
  try {
    const response = await axios.get("https://rest-
example.covey.town");
    console.log("Heard back from server");
    console.log(response.data);
  } catch(err){
    console.log('Uh oh!');
    console.trace(err);
  }
}
```

```
function makeOneGetRequestNoAsync(): Promise<void> {
  console.log("Making Request");
  return axios.get("https://rest-
example.covey.town").then((response) => {
    console.log("Heard back from server");
    console.log(response.data);
  }).catch(err => {
    console.log('Uh oh!');
    console.trace(err);
  });
}
```

Promise.all Allows for Concurrency

Promise.all creates one Promise for many

```
async function makeOneGetRequest(){
  const response = await axios.get('https://rest-example.covey.town');
  console.log(response.data);
}
```

```
async function makeThreeSerialRequests():
Promise<void> {
  await makeOneGetRequest();
  await makeOneGetRequest();
  await makeOneGetRequest();
  console.log('Heard back from all of the
requests');
}

makeThreeSerialRequests();
```

Output:

This is GET number 1 on the current server
This is GET number 2 on the current server
This is GET number 3 on the current server
Heard back from all of the requests

```
async function makeThreeGetRequests() {
  await Promise.all([
    makeOneGetRequest(),
    makeOneGetRequest(),
    makeOneGetRequest(),
  ]);
  console.log('Heard back from all of the requests');
}
makeThreeGetRequests();
```

Output:

This is GET number 3 on the current server
This is GET number 1 on the current server
This is GET number 2 on the current server
Heard back from all of the requests

Promise.all lets us leverage concurrency

Sequential version: ~200msec

```
async function makeThreeSerialRequests():
Promise<void> {
  await makeOneGetRequest();
  await makeOneGetRequest();
  await makeOneGetRequest();
}

makeThreeSerialRequests();
```

"Don't make another request until you got the last response back"

Concurrent version: ~70msec

```
async function makeThreeGetRequests() {
  await Promise.all([
    makeOneGetRequest(),
    makeOneGetRequest(),
    makeOneGetRequest(),
  ]);
}
makeThreeGetRequests();
```

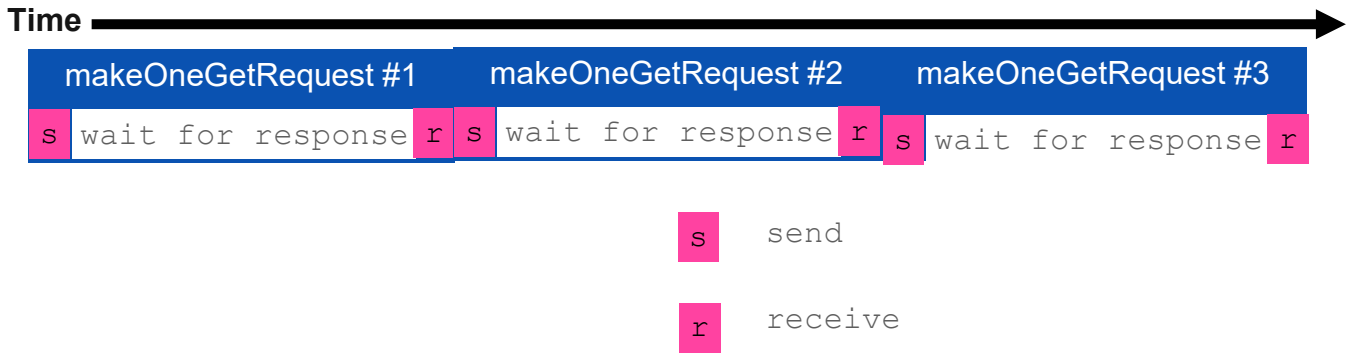
"Make all of the requests at the same time, then wait for all of the responses"

Masking Latency With Concurrency

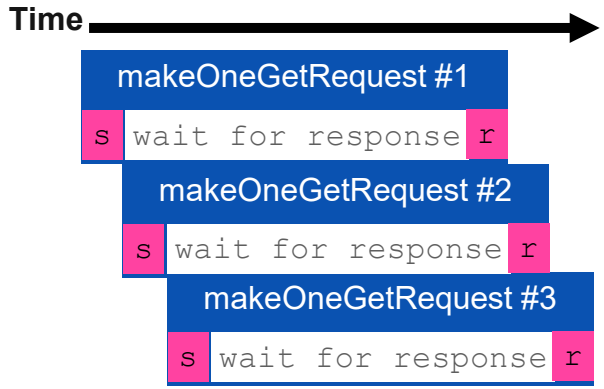
```
async function makeThreeSerialRequests():
Promise<void> {
  await makeOneGetRequest();
  await makeOneGetRequest();
  await makeOneGetRequest();
  console.log('Heard back from all of the
requests');
}

makeThreeSerialRequests();
```

```
async function makeThreeGetRequests() {
  await Promise.all([
    makeOneGetRequest(),
    makeOneGetRequest(),
    makeOneGetRequest(),
  ]);
  console.log('Heard back from all of the requests');
}
makeThreeGetRequests();
```

Sequential version: ~200msec



Concurrent version: ~70msec



Don't Perform Long-Running Computation in Synchronous Code

```
axios.get('https://rest-example.covey.town/')
  .then((response) =>{
  console.log('Heard back from server');
  console.log(response.data);
});
axios.get('https://www.google.com/')
  .then((response) =>{
    console.log('Heard back from Google');
    fs.writeFileSync("google-
response.txt",response.data);
  });
axios.get('https://www.facebook.com/')
  .then((response) =>{
    console.log('Heard back from Facebook');
    fs.writeFileSync("facebook-
response.txt",response.data);
  });
```

Write a file *synchronously* (write it in this event handler)

3 seconds

```
axios.get('https://rest-example.covey.town/')
  .then((response) =>{
  console.log('Heard back from server');
  console.log(response.data);
});
axios.get('https://www.google.com/')
  .then((response) =>{
    console.log('Heard back from Google');
    return fsPromises.writeFile("google-response.txt",
       response.data);
  });
axios.get('https://www.facebook.com/')
  .then((response) =>{
    console.log('Heard back from Facebook');
    return fsPromises.writeFile("facebook-response.txt",
       response.data);
  });
```

Write a file a*synchronously* (Ask NodeJS to write it in the background, this returns a new Promise to tell us when it's done)

2.1 seconds

Good news: You usually have to go out of your way to use synchronous I/O in NodeJS (the methods all have the word "Sync" in them)

Don’t Perform Long-Running Computation in Asynchronous Code

For large values of count, this will prevent anything from happening in JS until it’s done!

```
function approximatePi(count) {
  let inside = 0;
  const r = 5;
  console.log(`Approximating Pi using ${count} iterations`)
  for (let i = 0; i < count; i++) {
    const x = Math.random() * r * 2 - r;
    const y = Math.random() * r * 2 - r;
    if ((x * x + y * y) < r * r) {
      inside++
    }
  }
  const ret = 4.0 * inside / count;
  console.log(`Computed: ${ret}`);
  return ret;
}
```

What could we do here?

- We could turn the loop body into an async…

```
async function approximatePiAsync(count:number) {
    let inside = 0;
    const r = 5;
    async function generatePoint (r:number): Promise<boolean> {
        const x = Math.random() * r * 2 - r;
        const y = Math.random() * r * 2 - r;
        return ((x * x + y * y) < r * r);
    }
    console.log(`Approximating Pi using ${count} iterations`)
    for (let i = 0; i < count; i++) {
      if(await generatePoint(r)) { inside++ }
    }
    const ret = 4.0 * inside / count;
    console.log(`Computed: ${ret}`);
    return ret;
  }
```

General Rules for Writing Asynchronous Code

- Don’t perform long-running computations or synchronous IO
- Leverage concurrency when possible
  - Remember that events are processed in the order they are ***received***
  - But events may arrive in unexpected order!
- Always check for errors (try/catch for async/await, “.catch” for promises)

A Full-Featured Asynchronous Example

“The Transcript Server” – A web service for us to play with

```
POST /transcripts
 -- adds a new student to the database,
 -- returns an ID for this student.
 -- requires a body parameter 'name'
 -- Multiple students may have the same name.
GET  /transcripts/:ID
 -- returns transcript for student with given ID.  Fails if no such student
DELETE /transcripts/:ID
 -- deletes transcript for student with the given ID, fails if no such student
POST /transcripts/:studentID/:courseNumber
 -- adds an entry in this student's transcript with given name and course.
 -- Requires a body parameter 'grade’
 -- Fails if there is already an entry for this course in the student's transcript
GET  /transcripts/:studentID/:courseNumber
 -- returns the student's grade in the specified course.
 -- Fails if student or course is missing.
GET  /studentids?name=string
 -- returns list of IDs for student with the given name
```

Example: Writing Asynchronous Tasks

Calculating Statistics Using the Transcript Server

- From an array of StudentIDs:
  - Request each student's transcript, and save it to disk so that we have a copy
  - Once all of the pages are downloaded and saved, print out the total size of all of the files that were saved

Generating a promise for a student

```
async function promiseForTranscript(studentID: number) {
        const response = await axios.get(`https://rest-example.covey.town/transcripts/${studentID}`)


}
```

Here is something we plan to do later

The promise is to call axios and wait for the result.

Generating a promise for a student (cont'd)

```
async function promiseForTranscript(studentID: number) {
        const response = await axios.get(`https://rest-example.covey.town/transcripts/${studentID}`)
        await fsPromises.writeFile(`transcript-${response.data.student.studentID}.json`,
            JSON.stringify(response.data))
    }
```

After we get the response, make a new promise: this time to write the result to a file. Then wait for that to finish.

When the file-writing promise is fulfilled, then the whole original promise is fulfilled.

Now, actually generate all the promises

```
async function runClientAsync(studentIDs:number[]) {
    console.log('Making requests for ${studentIDs}');

    async function promiseForTranscript(studentID: number) { .. }

    const promisesForTranscripts = studentIDs.map(promiseForTranscript)
    console.log('Requests sent!');


}
```

map applies the function specified to each element in the array and returns a new array containing the result of each of those functions

Wait for all the promises to resolve

```
async function runClientAsync(studentIDs:number[]) {
    console.log('Making requests for ${studentIDs}');

    async function promiseForTranscript(studentID: number) { .. }

    const promisesForTranscripts = studentIDs.map(promiseForTranscript)
    console.log('Requests sent!');
    await Promise.all(promisesForTranscripts);




}
```

Asynchronously stat all the files

```
async function runClientAsync(studentIDs:number[]) {
    console.log('Making requests for ${studentIDs}');

    async function promiseForTranscript(studentID: number) { .. }

    const promisesForTranscripts = studentIDs.map(promiseForTranscript)
    console.log('Requests sent!');
    await Promise.all(promisesForTranscripts);
    const stats = await Promise.all(studentIDs.map(studentID => fsPromises.stat(`transcript-
${studentID}.json`)));



  }
```

..and total the sizes

```
async function runClientAsync(studentIDs:number[]) {
    console.log('Making requests for ${studentIDs}');

    async function promiseForTranscript(studentID: number) { .. }

    const promisesForTranscripts = studentIDs.map(promiseForTranscript)
    console.log('Requests sent!');
    await Promise.all(promisesForTranscripts);
    const stats = await Promise.all(studentIDs.map(studentID => fsPromises.stat(`transcript-
${studentID}.json`)));
    const totalSize = stats.reduce((runningTotal, val) => runningTotal + val.size, 0);
    console.log(`Finished calculating size: ${totalSize}`);
    console.log('Done');
  }
```

'reduce' is what you called 'foldl' back in Fundies 1.

Leverage Concurrency When Possible

Where you place awaits can make a big difference!

For each student: make an async handler to fetch their transcript and save it

The code we've seen on past slides:

```
async function runClientAsync() {
  console.log('Making a requests');
  const studentIDs = [1, 2, 3, 4];
  const promisesForTranscripts = studentIDs.map(
    async (studentID) => {
      const response = await axios.get(`https://rest-example.covey.town/transcripts/${studentID}`)
      await fsPromises.writeFile(`transcript-${response.data.student.studentID}.json`, JSON.stringify(response.data))
    });
  console.log('Requests sent!');
  await Promise.all(promisesForTranscripts);
  const stats = await Promise.all(studentIDs.map(studentID => fsPromises.stat(`transcript-${studentID}.json`)));
  const totalSize = stats.reduce((runningTotal, val) => runningTotal + val.size, 0);
  console.log(`Finished calculating size: ${totalSize}`);
}
```

Running time: 1.5 sec

For each student: wait to fetch their transcript, then wait to write it, then go on to the next student

This accomplishes the same function, but without concurrency:

```
async function runClientAsyncSerially() {
  console.log('Making a requests');
  const studentIDs = [1, 2, 3, 4];
  for(let studentID of studentIDs){
    const response = await axios.get(`https://rest-example.covey.town/transcripts/${studentID}`);
    await fsPromises.writeFile(`transcript-${response.data.student.studentID}.json`, JSON.stringify(response.data))
  }
  let totalSize = 0;
  for(let studentID of studentIDs){
    const stats = await fsPromises.stat(`transcript-${studentID}.json`);
    totalSize += stats.size;
  }
  console.log(`Finished calculating size: ${totalSize}`);
}
```

Running time: 2.2 sec

This is what we mean by "your code can become synchronous"

Async/Await Programming Activity

Transcript Server: Create a student, then post their grades

1. Create a new student in the transcript server

```
await client.addStudent('test student');
```

then…

2. Assign several grades for that student

```
await client.addGrade(studentID, 'demo course', 100);
```

then…

3. Fetch the transcript for that student

```
await client.getTranscript(studentID)
```

Your task will be to take a list of students with a list of grades, post them, and return all of the resulting transcripts

Download the activity (includes instructions in README.md):
Linked from course webpage for week 4, or at https://bit.ly/34GbcN6

Learning Goals for this Lesson

- At the end of this lesson, you should be able to:
  - Be able to write asynchronous code in TypeScript using both Promises and async/await
  - Understand how to achieve concurrency through asynchronous operations in TypeScript