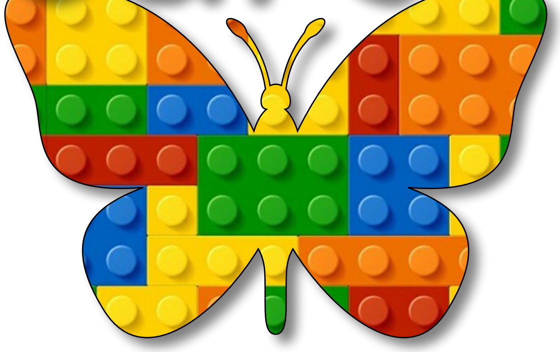
Artificial Intelligence Module C Unit #3 neuro evolution smart cars



Content

Module C Unit #3 smart cars

Introduction to smart cars neuroevolution

We are going to give these cars a smart brain (ml5.js), they have to learn to chase after a moving target. All they do is get a reward according to how well they do. This uses a Genetic Algorithm to select those who perform best. We aren't going to train the algorithm but select the ones that perform better, for every car will have its own neural network based on random weights.

Over time we select the best ones (that get closest to the target) and breed them, think natural selection, evolution. After many populations have come and gone we are left with ones that have succeeded in breeding the right attributes (weights) to follow a moving target.

We are going to create two classes, target and vehicle, for these we put them in two new files and add them to the index.html file. This was covered in the `coding snippets part 4` so you will be familiar with the process of adding files and the purposes of classes. However, I will still emphasise their purpose and function so that you become more familiar with them.

It goes without saying that you will also need to have the line of code for ml5.js in the index.html file. You will also note that we will be switching from one file to another and back again. This means that you might want to keep the side panel open as you code. This way you can switch quickly from one to the other.

If you don't want the fuss of going from file to file then you can add the classes in the sketch.js file and just have one long line of code.

The index.html file

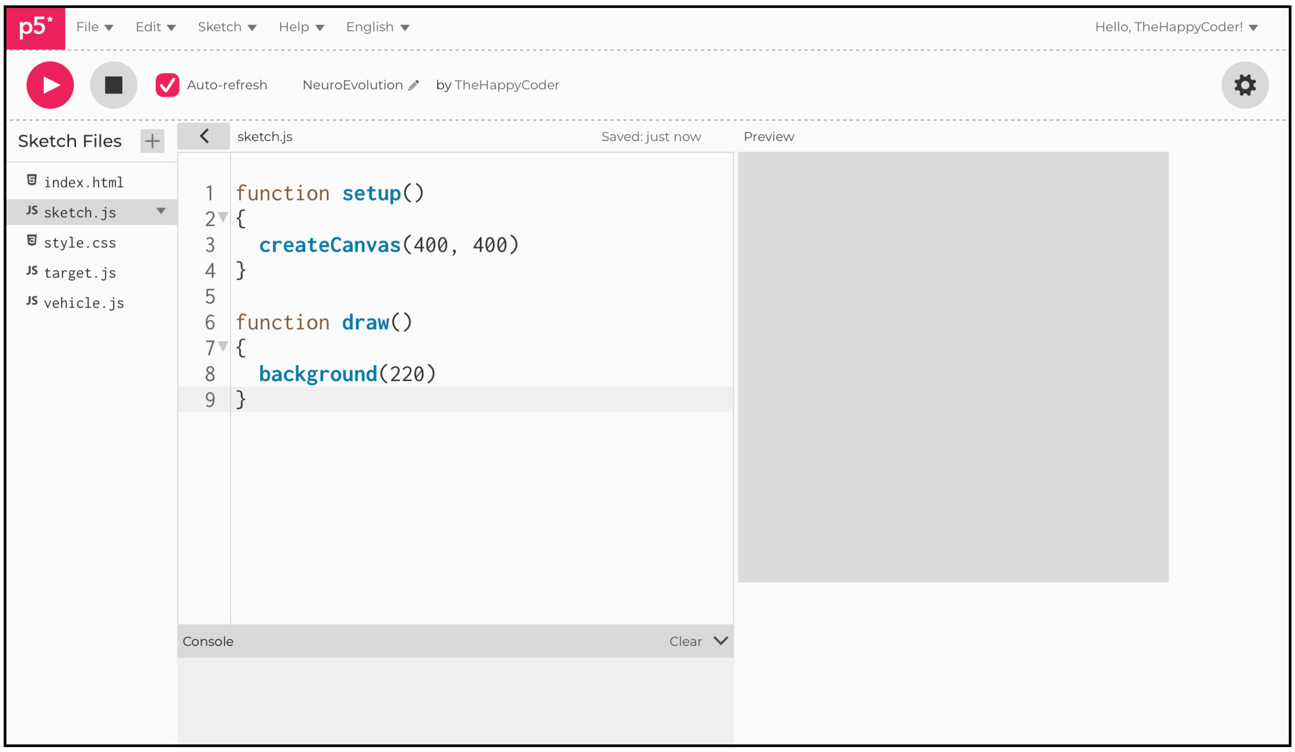
Adding ml5.js as per usual

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <script src="https://cdnjs.cloudflare.com/ajax/libs/p5.js/
1.11.0/p5.js"></script>
    <script src="https://cdnjs.cloudflare.com/ajax/libs/p5.js/
1.11.0/addons/p5.sound.min.js"></script>
    <script src="https://unpkg.com/ml5@1/dist/ml5.min.js"></
script>
    <link rel="stylesheet" type="text/css" href="style.css">
    <meta charset="utf-8" />

  </head>
  <body>
    <main>
    </main>
    <script src="sketch.js"></script>
  </body>
</html>
```

Adding target.js and vehicle.js files

Now we are going to add the next two files `target.js` and `vehicle.js` to our list of files, see `figure 1`

Figure 1 adding the files

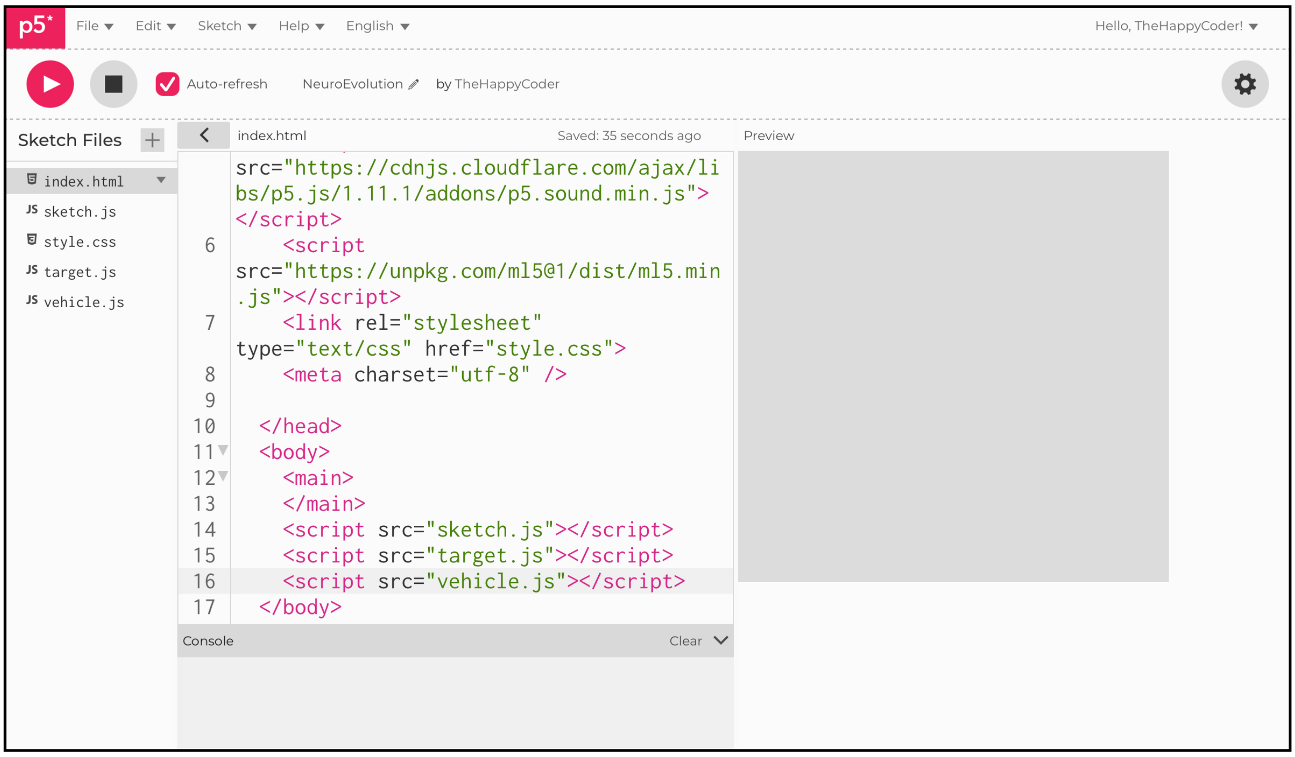


```
function setup()
{
  createCanvas(400, 400)
}

function draw()
{
  background(220)
}
```

Adding them to the index.html file

This step is easy to forget. Just copy and paste sketch.js and change the names to `target` and `vehicle`. To access the files just click on them but these two new ones should be completely empty. See figure 2.

Figure 2 adding files in index.html



```
src="https://cdnjs.cloudflare.com/ajax/libs/p5.js/1.11.1/addons/p5.sound.min.js">
</script>
    <script
src="https://unpkg.com/ml5@1/dist/ml5.min.js"></script>
    <link rel="stylesheet"
type="text/css" href="style.css">
    <meta charset="utf-8" />

  </head>
  <body>
    <main>
    </main>
    <script src="sketch.js"></script>
    <script src="target.js"></script>
    <script src="vehicle.js"></script>
  </body>
```

Sketch C3.1 starting sketch

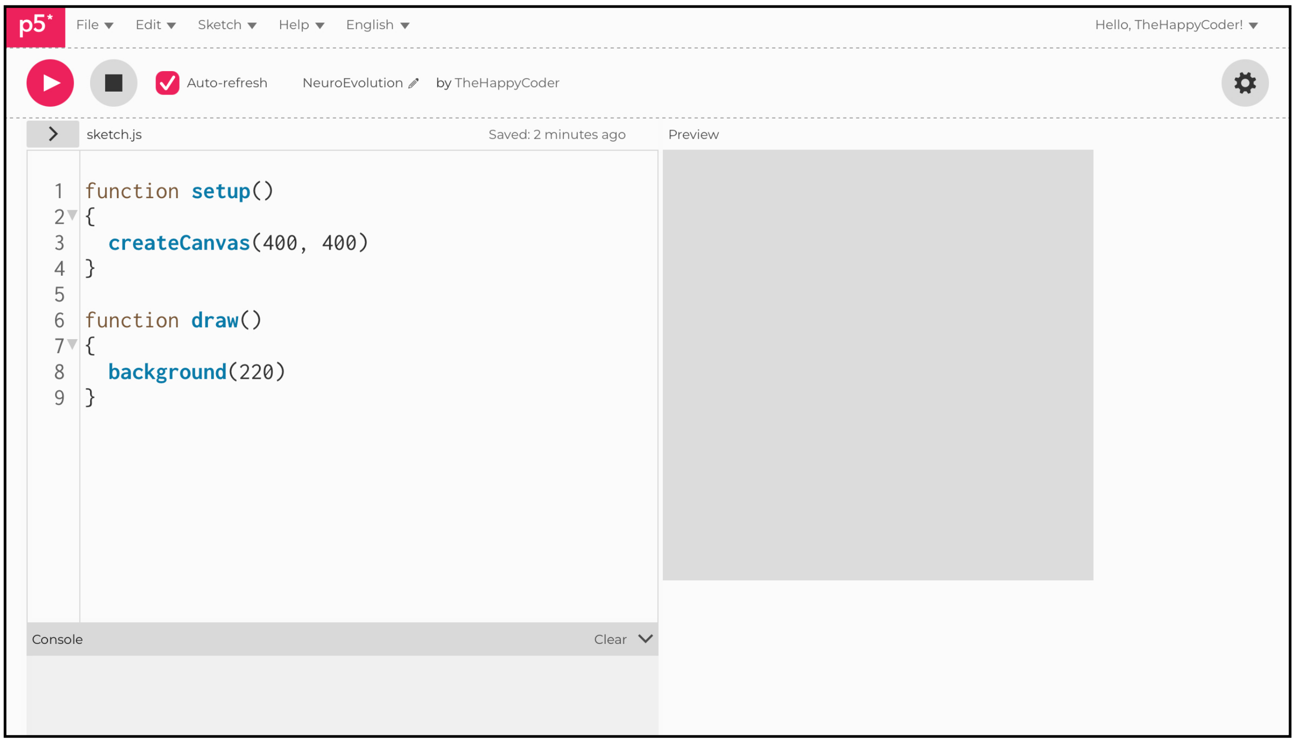
❗ starting sketch in `sketch.js`

Our starting sketch, note that this is for the `sketch.js` file (see the heading).

sketch.js

```
function setup()
{
  createCanvas(400, 400)
}

function draw()
{
  background(220)
}
```

Figure C3.1



```
function setup()
{
  createCanvas(400, 400)
}

function draw()
{
  background(220)
}
```

Sketch C3.2 target circle

We are going to create a `target` which will just be a circle, this is what the `vehicles` (cars) will chase around the canvas. The `target` becomes a vector object. From that vector we pull out the `x` and `y` values which we will initialise to `width/2` and `height/2`.

sketch.js

```
let target


function setup()
{
  createCanvas(400, 400)
}


function draw()
{
  background(220)
  target = createVector(width/2, height/2)
  circle(target.x, target.y, 30)
}
```

Notes

You get a static `target` (circle)

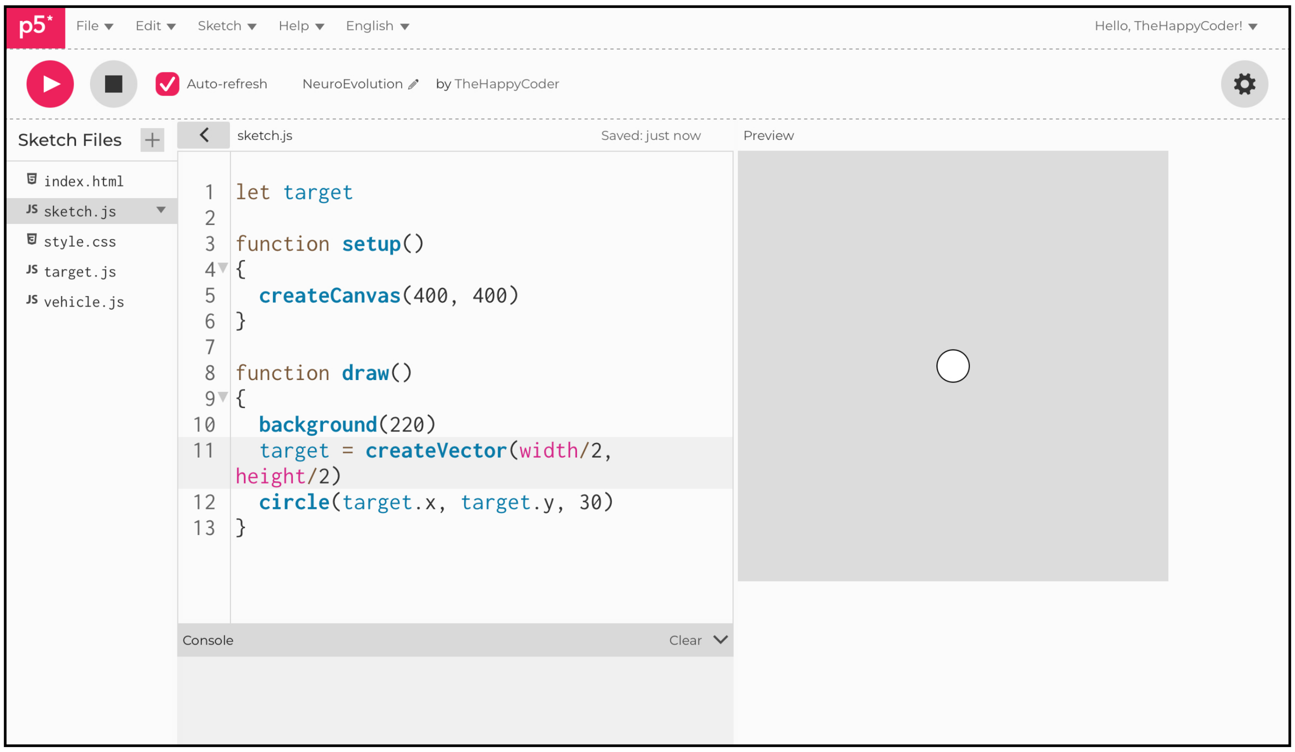
Challenge

Add some colour or even change the shape

Code Explanation

`target = createVector(width/2, height/2)`	The target is a vector, its position is in the centre of the canvas
`circle(target.x, target.y, 30)`	The circle is drawn to the coordinates of the target (target.x and target.y)

Figure C3.2



```
let target

function setup()
{
  createCanvas(400, 400)
}

function draw()
{
  background(220)
  target = createVector(width/2,
height/2)
  circle(target.x, target.y, 30)
}
```

Sketch C3.3 target class

❗ Now we move over to the target.js file.
We don't want a stationary target we want to give it movement and in this instance a random motion called perlin noise. For this we need to create a class called Target.

target.js

```
class Target
{
  constructor()
  {
    this.xoff = 0
    this.yoff = 1000
    this.position = createVector()
  }
}
```

Notes

If you haven't done coding snippets 4 then here is a brief explanation of Perlin Noise, think of it as a continuous random where the next random value is dependant on the previous one. What this means is that there isn't a wild discrepancy from one value to the next, this creates the illusion of a smooth, gentle wandering of the circle.

Imagine a wavy line and the starting point on this wavy line is at 0 (xoff) which will return a value between 0 and +1, if you move along the line to position 1000 (yoff), you get another value between 0 and +1. We then inch along this line and we get a random value just a bit more or a bit less than the previous value. We do this for the x offset and the y offset otherwise we would have the same value for both if they both started at 0 or 1000 for example.

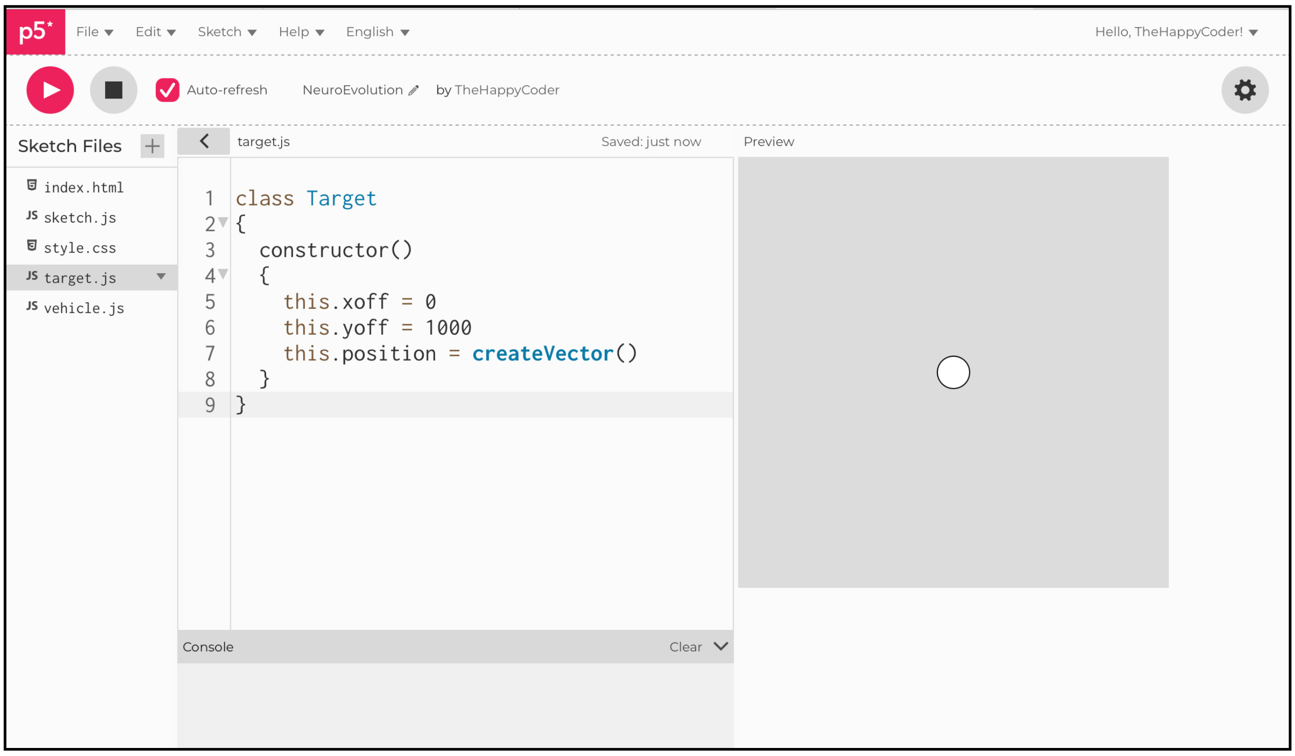
🌻 Challenges

1. Have a different starting position on the perlin noise time line for the x and y components.
2. What do you think would happen if they were the same?

🛠️ Code Explanation

`this.xoff = 0`	The initial x value on the perlin noise time line
`this.yoff = 1000`	The initial y value on the perlin noise time line
`this.position = createVector()`	Create a vector for the position of the target

Figure C3.3



```
class Target
{
  constructor()
  {
    this.xoff = 0
    this.yoff = 1000
    this.position = createVector()
  }
}
```

Sketch C3.4 perlin noise

We are going to use this randomness to move the `target` (circle) around the canvas. So we need to connect the position of the target to the `noise` (perlin) value and then increment along that random wavy line by `0.01` for `x` and `y`. We add our two favourite functions `show()` and `move()`.

target.js

```
class Target
{
  constructor()
  {
    this.xoff = 0
    this.yoff = 1000
    this.position = createVector()
  }

  move()
  {
    this.position.x = noise(this.xoff) * width
    this.position.y = noise(this.yoff) * height
    this.xoff += 0.01
    this.yoff += 0.01
  }

  show()
  {
    circle(this.position.x, this.position.y, 30)
  }
}
```

🗒️ Notes

We multiply by `width` and `height` because the `noise()` function returns values between `0` and `1`, and we want the `target` to move between `0` and `width` and `height` of the canvas.

🌻 Challenge

How would you use the `map()` function?

🛠️ Code Explanation

`this.position.x = noise(this.xoff) * width`	We get our target x position from the perlin noise() function (times the width)
`this.position.y = noise(this.yoff) * height`	We get our target y position from the perlin noise() function (times the height)
`this.xoff += 0.01`	Increment along the noise time line for x
`this.yoff += 0.01`	Increment along the noise time line for y

Sketch C3.5 moving target

❗ Back to sketch.js. Comment out and remove the two lines of code for the circle.
We are going to use the Target class to create a target object and then run the update() and show() functions from that object. Now you now have a target (circle) wandering around the canvas.

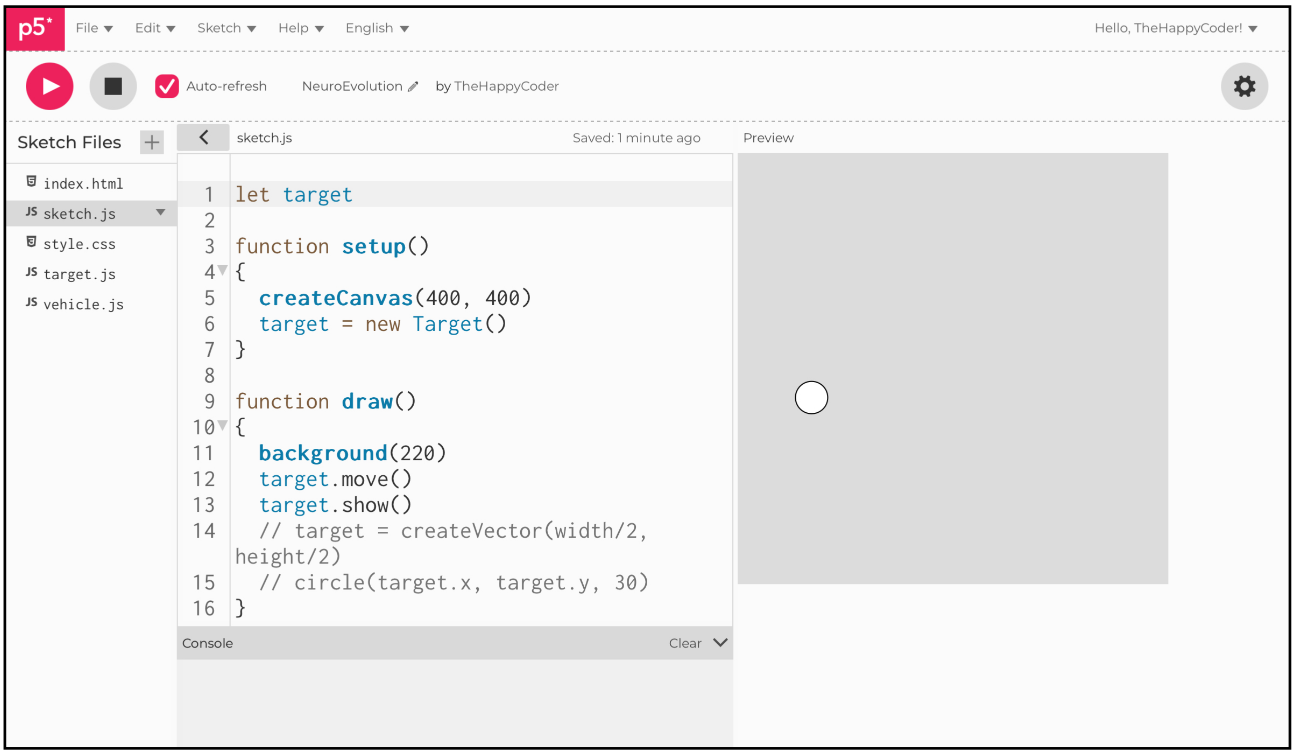
sketch.js

```
let target

function setup()
{
  createCanvas(400, 400)
  target = new Target()
}

function draw()
{
  background(220)
  target.move()
  target.show()
  // target = createVector(width/2, height/2)
  // circle(target.x, target.y, 30)
}
```

Notes

The target should be moving around the canvas in a gentle swooping way

Figure C3.5



```
let target

function setup()
{
  createCanvas(400, 400)
  target = new Target()
}

function draw()
{
  background(220)
  target.move()
  target.show()
  // target = createVector(width/2,
height/2)
  // circle(target.x, target.y, 30)
}
```

Sketch C3.6 a vehicle

❗ hop over to vehicle.js

Now we need a vehicle. We will create a Vehicle class and in its constructor function we will have position, velocity and acceleration. This should be fairly familiar to you by now.

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
  }

  show()
  {
    push()
    translate(this.position.x, this.position.y)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

Notes

When we create a vehicle the constructor() function will receive two arguments, the (x, y) coordinates. Nothing will appear just yet as we haven't actually created a vehicle. We previously called them pos, vel and acc, just nice to be different.

Sketch C3.7 random position

❗ back to sketch.js
Let's create one vehicle for now at some random position.

sketch.js

```
let target
let vehicle

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  vehicle = new Vehicle(random(width), random(height))
}

function draw()
{
  background(220)
  target.move()
  target.show()
  vehicle.show()
}
```

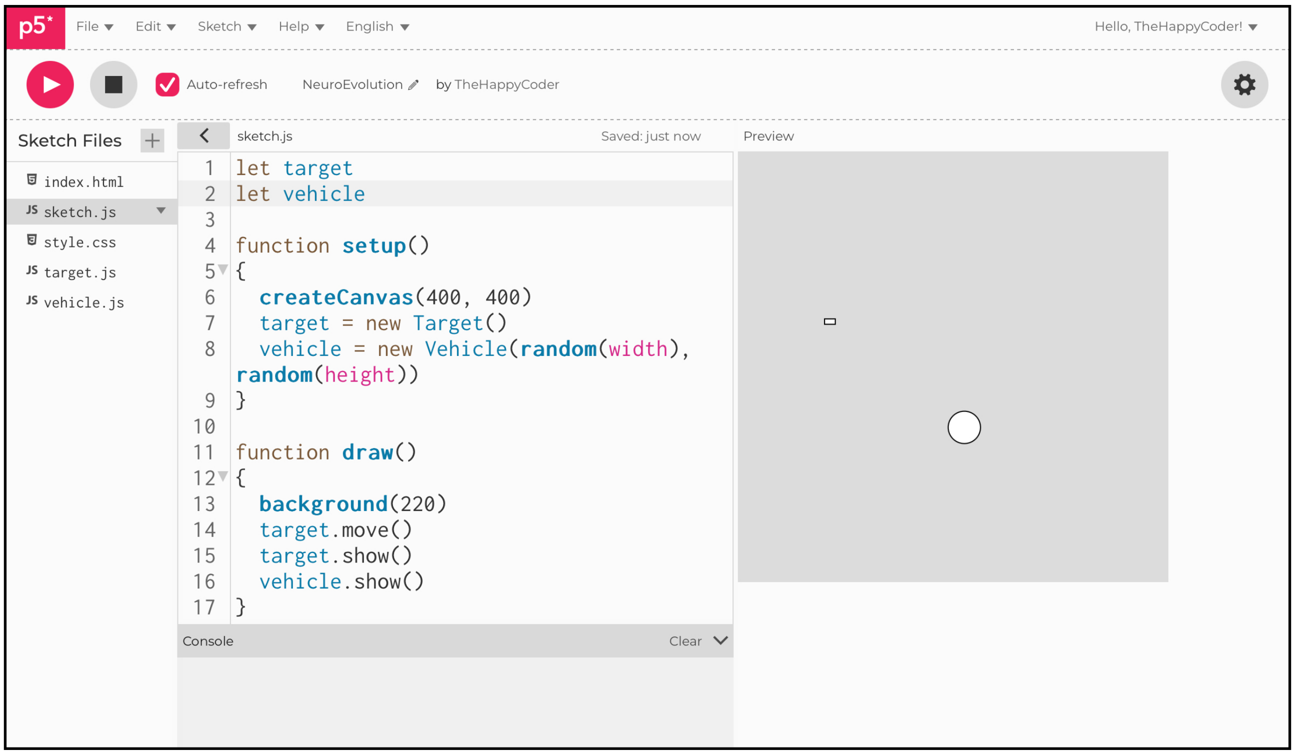
Notes

Every time you run the sketch you will get another random vehicle somewhere on the canvas.

Challenge

Give the vehicle some colour

Figure C3.7



```
let target
let vehicle

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  vehicle = new Vehicle(random(width),
random(height))
}

function draw()
{
  background(220)
  target.move()
  target.show()
  vehicle.show()
}
```

Sketch C3.8 moving towards the target

❗ moving back to vehicle.js

We will now get the vehicle moving using the usual formula of adding the components together for movement.

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.maxSpeed = 4
  }

  move()
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
  }

  show()
  {
    push()
    translate(this.position.x, this.position.y)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

🗒️ Notes

We won't see anything happen yet (except the `target` wandering) because we haven't the `move()` function in `sketch.js`

🛠️ Code Explanation

`this.acceleration.mult(0)`	The acceleration is zeroed so that the vehicle doesn't run away with itself

Sketch C3.9 the seek function

❗ Because we have covered most of this in the coding snippets 4 unit with the seek() function I won't labour this part.
We will want to get it to move towards the target and also to rotate. This was covered briefly in the coding snippets 4 unit using heading() function. Also we do need to have a maximum force. The vehicle will be steered towards the target by a force of some magnitude, we turn the vehicle in that direction. This is where we add the applyForce() function and the seek() function

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.maxSpeed = 4
    this.maxForce = 0.2
  }

  move()
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
  }

  applyForce(force)
  {
    this.acceleration.add(force)
  }

  seek(target)
  {
    let desired = p5.Vector.sub(target, this.position)
    desired.setMag(this.maxSpeed)
    let steer = p5.Vector.sub(desired, this.velocity)
    steer.limit(this.maxForce)
    this.applyForce(steer)
  }

  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x, this.position.y)
    rotate(angle)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

🗒️ Notes

In the show function we find the `angle` from the `heading()` function and then rotate the vehicle according to that `angle`. The `seek()` and `applyForce()` functions are the same as we explored in `coding snippets 4`

🛠️ Code Explanation

`let angle = this.velocity.heading()`	We get the angle from the direction of the velocity vector
`rotate(angle)`	We rotate the vehicle by that angle

Sketch C3.10 seek and ye shall find

❗ return to sketch.js

We create a vector for the position of the target and then seek that vector.

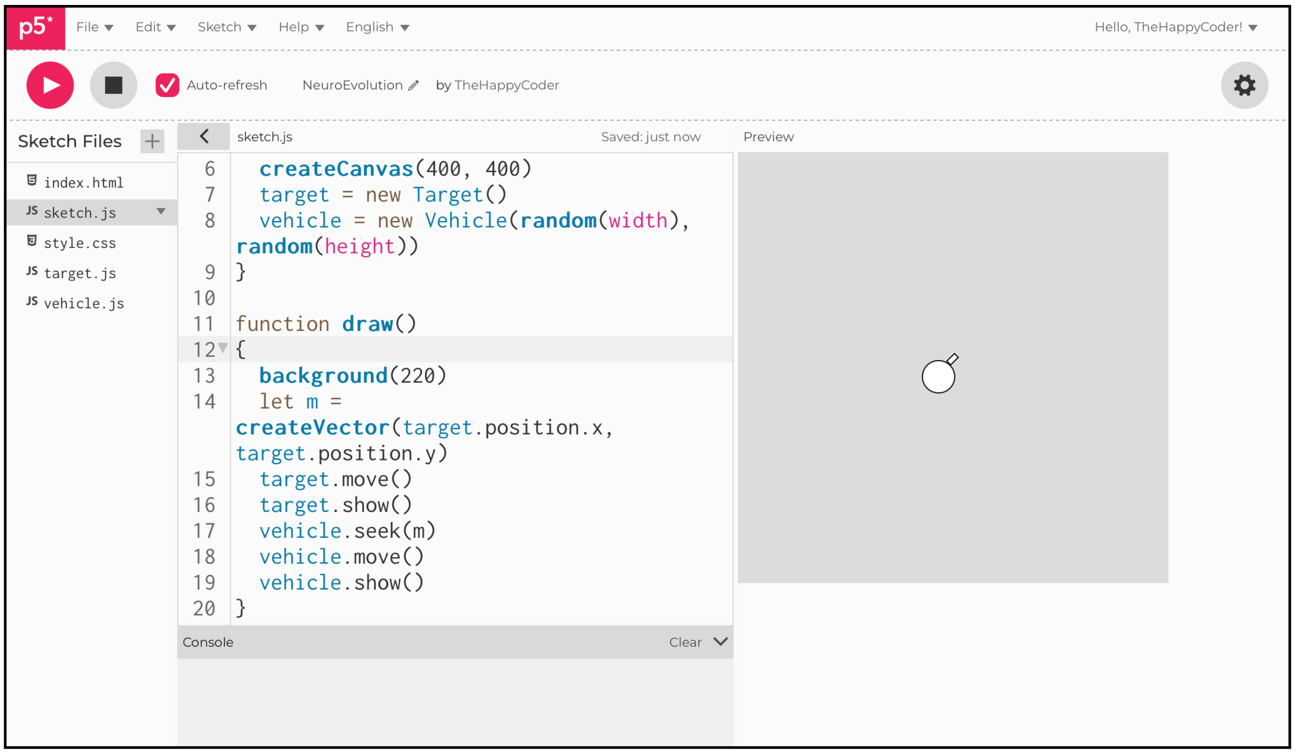
```
sketch.js
```

```
let target
let vehicle

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  vehicle = new Vehicle(random(width), random(height))
}

function draw()
{
  background(220)
  let m = createVector(target.position.x, target.position.y)
  target.move()
  target.show()
  vehicle.seek(m)
  vehicle.move()
  vehicle.show()
}
```

Notes

The vehicle now follows the target, job done! It is quite mesmerising to watch.

Figure C3.10



```
  createCanvas(400, 400)
  target = new Target()
  vehicle = new Vehicle(random(width),
random(height))
}

function draw()
{
  background(220)
  let m =
createVector(target.position.x,
target.position.y)
  target.move()
  target.show()
  vehicle.seek(m)
  vehicle.move()
  vehicle.show()
}
```

Sketch C3.11 more vehicles

We are now going to create 50 of these vehicles. We will replace a number of lines of code to move from the single `vehicle` to an array of `vehicles`.

sketch.js

```
let target
let vehicles = []

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
}

function draw()
{
  background(220)
  let m = createVector(target.position.x, target.position.y)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(m)
    vehicle.move()
    vehicle.show()
  }
}
```

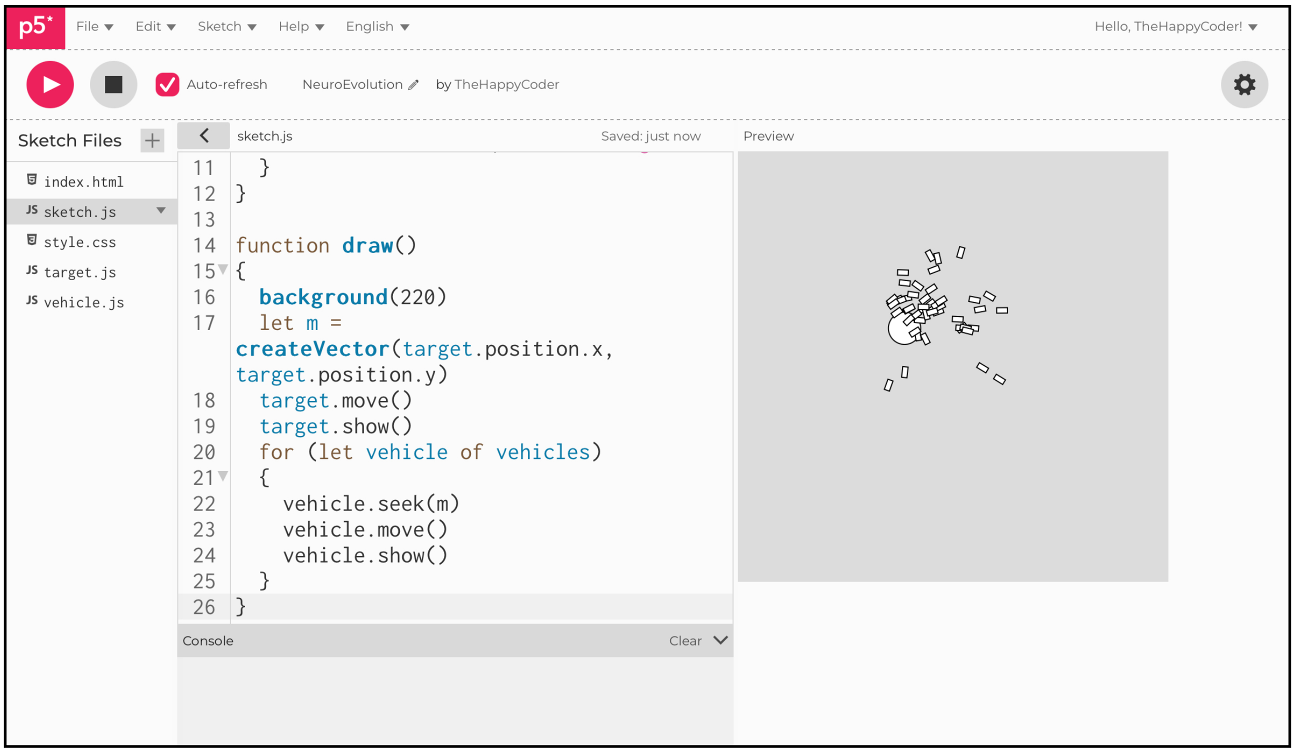
🗒️ Notes

You should have a whole bunch of `vehicles` following the target, as shown in `figure C3.11`. Each `vehicle` will start from a different random position but eventually coalesce into one vehicle.

🌻 Challenge

Try different numbers of vehicles

Figure C3.11



```
  }
}

function draw()
{
  background(220)
  let m = 
createVector(target.position.x, 
target.position.y)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(m)
    vehicle.move()
    vehicle.show()
  }
}
```

A neuroevolution brain

Although much of the neural network stuff we have already covered is used here in this module and unit, there is a subtle difference. We can see it in the lines of code in the next sketch as we add the neural network brain to the vehicles. First of all we give the brain the inputs and outputs:

The five inputs are:

1️⃣ The x component of the vector between the vehicle and the target
2️⃣ The y component of the vector between the vehicle and the target
3️⃣ The distance between the target and the vehicle
4️⃣ The x component of the velocity of the vehicle
5️⃣ The y component of the velocity of the vehicle

The outputs are:

1️⃣ The angle the vehicle must turn to move towards the target
2️⃣ The magnitude of the power to move it to the target

Then we are going to give it the task: `regression`. However here is the big difference we will inform the neural network that this is a neuroevolution network with the `neuroEvolution: true` line of code. Then, finally, we inform the neural network that we are not doing any training with the `noTraining: true` line of code.

Remember that this is a Reinforcement Learning challenge, there is no data for the neural network to learn from, we are simply going to select the best brains (neural networks) that appear to solve the challenge without hard coding the vehicles with the `seek()` function, which really is the simple solution to this challenge.

Sketch C3.12 giving the vehicle a brain

❗ bob over to vehicle.js

In the Vehicle class we give the vehicle a brain. The brain is the neural network which has five inputs and two outputs. There will be 50 brains driving their own vehicles.

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.maxSpeed = 4
    this.maxForce = 0.2
    ml5.setBackend("cpu")
    this.brain = ml5.neuralNetwork({
      inputs: 5,
      outputs: 2,
      task: "regression",
      neuroEvolution: true,
      noTraining: true
    })
  }

  move()
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
  }

  applyForce(force)
  {
    this.acceleration.add(force)
  }

  seek(target)
  {
    let desired = p5.Vector.sub(target, this.position)
    desired.setMag(this.maxSpeed)
    let steer = p5.Vector.sub(desired, this.velocity)
    steer.limit(this.maxForce)
    this.applyForce(steer)
  }

  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x, this.position.y)
    rotate(angle)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

Notes

Notice that this is a regression task, it is also not a normal neural network, this means we can access the `mutate()` and `crossover()` functions later as part of the neuroevolution network we will implement later.

🛠️ Code Explanation

`neuroEvolution: true,`	This is a neuroevolution challenge
`noTraining: true`	We are not doing any training

Sketch C3.13 steering the vehicles

From the inputs we need to know how much to steer the vehicles, for that we need to know their velocity, their position relative to the target and the desired velocity. This is all about magnitude and the direction at the end of the day. We do need to do a bit of normalising so that things don't get out of control, hence dividing things by the width or the maxSpeed.

We are going rewrite the entire seek(target) function in the Vehicle class. Nothing will happen (except an error message) because we have done nothing about the outputs which will determine the force to move the vehicle.

There is a lot to unpack in the seek() function. These are our five inputs for the neural network, hence the refactoring.

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.maxSpeed = 4
    this.maxForce = 0.2
    ml5.setBackend("cpu")
    this.brain = ml5.neuralNetwork({
      inputs: 5,
      outputs: 2,
      task: "regression",
      neuroEvolution: true,
      noTraining: true
    })
  }

  move()
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
  }

  applyForce(force)
  {
    this.acceleration.add(force)
  }

  seek(target)
  {
    let v = p5.Vector.sub(target.position, this.position)
    let distance = v.mag() / width
    v.normalize()
    let inputs = [
      v.x,
      v.y,
      distance,
      this.velocity.x / this.maxSpeed,
      this.velocity.y / this.maxSpeed
    ]
  }

  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x, this.position.y)
    rotate(angle)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

🗒️ Notes

You will get an error if you try to run it now, so don't try. The variable v is a vector of the difference between any one vehicle's position and the target position. We then get the distance from the magnitude of that difference (mag()). We then normalise the vector v before creating the five inputs from all that data.

🛠️ Code Explanation

`v = p5.Vector.sub(target.position, this.position)`	Subtracting two vectors to get a third vector v
`distance = v.mag() / width`	Distance is the magnitude of the vector v, reducing the magnitude by the width
`v.normalize()`	Normalising v
`v.x`	The x component of the vector v
`v.y`	The y component of the vector v
`this.velocity.x / this.maxSpeed`	Reducing the x component of the velocity by the maxSpeed
`this.velocity.y / this.maxSpeed`	Reducing the y component of the velocity by the maxSpeed

Sketch C3.14 the outputs

❗ back to sketch.js

Now for the outputs. We have two outputs, the angle and the magnitude. The predicted values are random. They take in the values from the inputs then generate outputs that are meaningless. Also you will notice that in the brain there is an argument for noTraining, this is because we are not using any data to train the neural network we are just choosing to select the best performing ones. So when you run this they just disappear off into the distance.

❗ We will remove:

`let m = createVector(target.position.x, target.position.y)`

and replace with:

`vehicle.seek(target)`

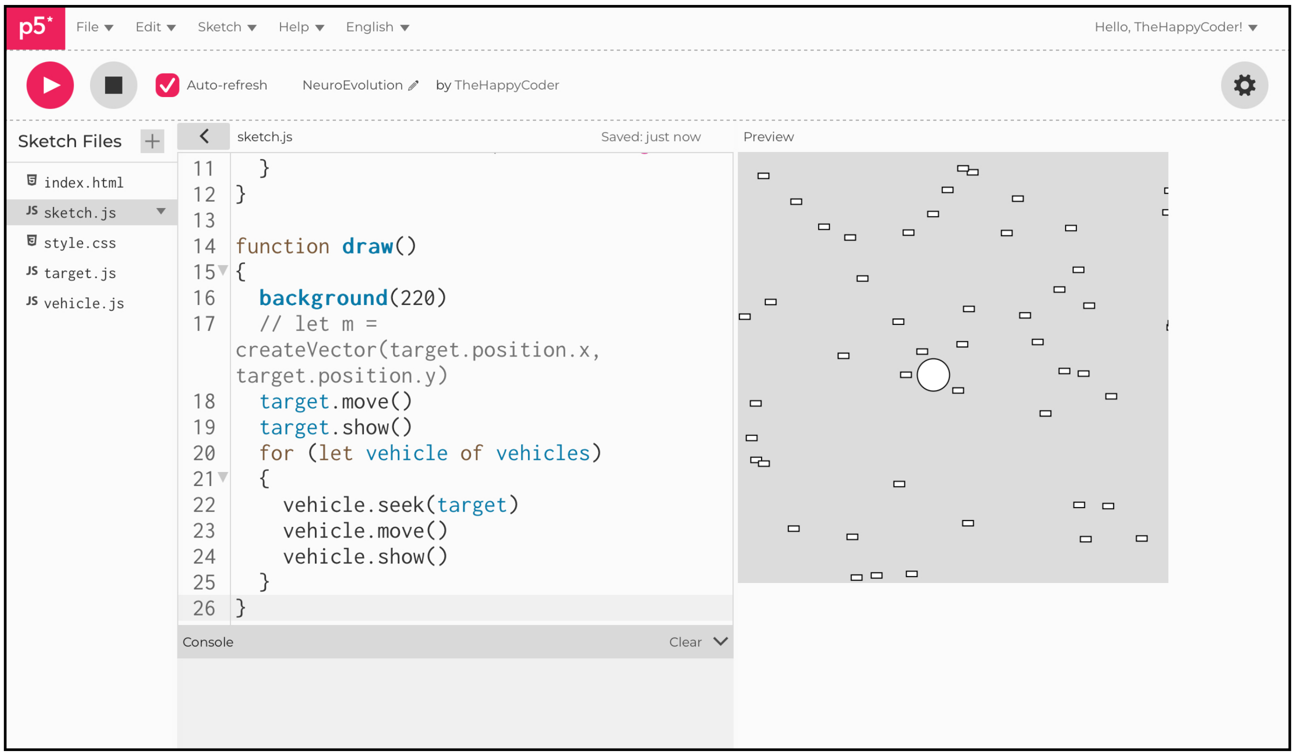
sketch.js

```
let target
let vehicles = []

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
}

function draw()
{
  background(220)
  // let m = createVector(target.position.x, target.position.y)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(target)
    vehicle.move()
    vehicle.show()
  }
}
```

Notes

You will get static vehicles

Figure C3.14



```
  }
}

function draw()
{
  background(220)
  // let m =
createVector(target.position.x,
target.position.y)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(target)
    vehicle.move()
    vehicle.show()
  }
}
```

Sketch C3.15 they move

❗ skip on over to vehicle.js

Now let's get them moving

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.maxSpeed = 4
    this.maxForce = 0.2
    ml5.setBackend("cpu")
    this.brain = ml5.neuralNetwork({
      inputs: 5,
      outputs: 2,
      task: "regression",
      neuroEvolution: true,
      noTraining: true
    })
  }

  move(target)
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
  }
  applyForce(force)
  {
    this.acceleration.add(force)
  }

  seek(target)
  {
    let v = p5.Vector.sub(target.position, this.position)
    let distance = v.mag() / width
    v.normalize()
    let inputs = [
      v.x,
      v.y,
      distance,
      this.velocity.x / this.maxSpeed,
      this.velocity.y / this.maxSpeed
    ]
    let outputs = this.brain.predictSync(inputs)
    let angle = outputs[0].value * TWO_PI
    let magnitude = outputs[1].value
    let force = p5.Vector.fromAngle(angle)
    force.setMag(magnitude)
    this.applyForce(force)
  }

  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x, this.position.y)
    rotate(angle)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

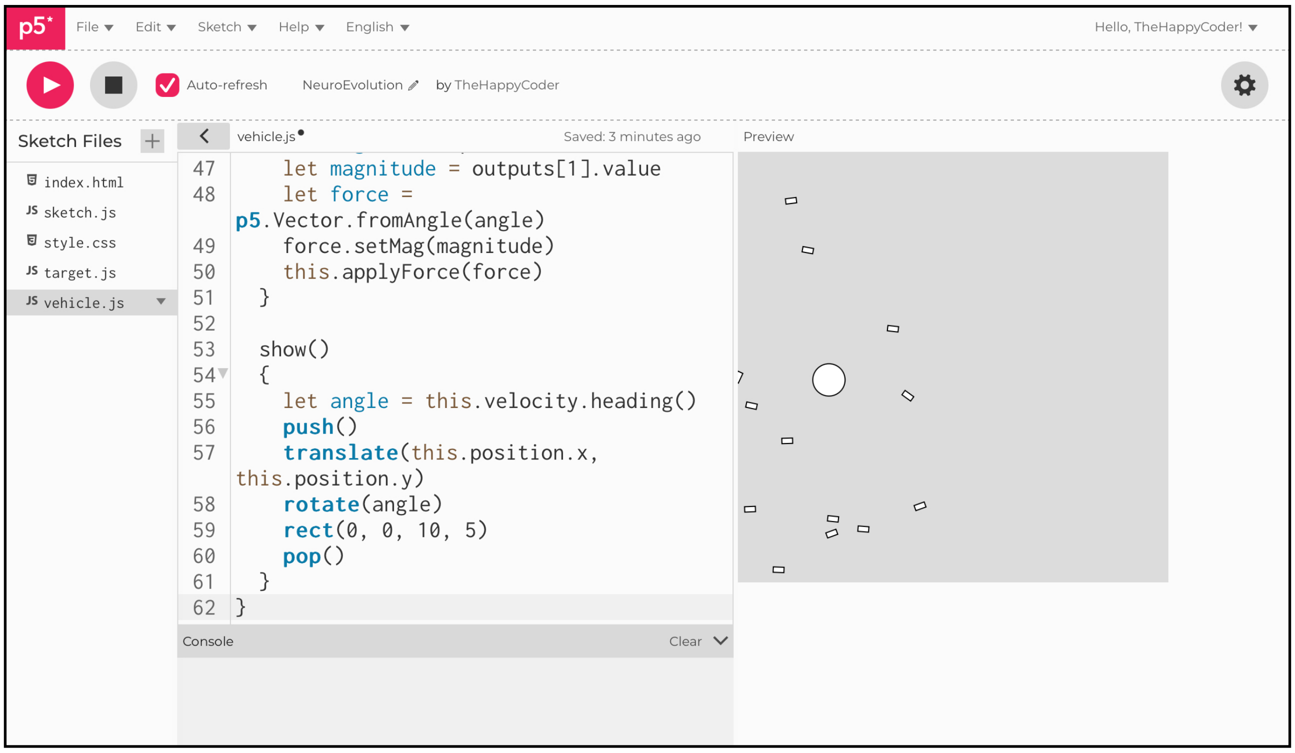
🗒️ Notes

They move but they just wonder off into the sunset! This is because they have no reason to do otherwise.

🛠️ Code Explanation

`outputs = this.brain.predictSync(inputs)`	predictSync() means it waits for the inputs before predicting
`angle = outputs[0].value * TWO_PI`	The outputs index [0] is the angle which we multiply by 2π (to scale the output value
`magnitude = outputs[1].value`	The outputs index [1] is the magnitude
`force = p5.Vector.fromAngle(angle)`	The function fromAngle() creates a vector from an angle in radians

Figure C3.15



```
    let magnitude = outputs[1].value
    let force =
p5.Vector.fromAngle(angle)
    force.setMag(magnitude)
    this.applyForce(force)
  }

  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x,
this.position.y)
    rotate(angle)
    rect(0, 0, 10, 5)
    pop()
  }
}
```

Sketch C3.16 fitness scores

For this to evolve we need to attribute a fitness score to each vehicle. We need to know a number of things, one of the main indicators is how close the vehicle gets to the target so we move an imaginary circle which will help us know when the target and the vehicle overlap. We call the vehicle radius l and for the target we will call this r.

vehicle.js

```
class Vehicle
{
  constructor(x, y)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.l = 5
    this.fitness = 0
    this.maxSpeed = 4
    this.maxForce = 0.2
    ml5.setBackend("cpu")
    this.brain = ml5.neuralNetwork({
      inputs: 5,
      outputs: 2,
      task: "regression",
      neuroEvolution: true,
      noTraining: true
    })
  }

  move()
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
    let d = p5.Vector.dist(this.position, target.position)
    if (d < this.l + target.r)
    {
      this.fitness++
    }
  }

  applyForce(force)
  {
    this.acceleration.add(force)
  }

  seek(target)
  {
    let v = p5.Vector.sub(target.position, this.position)
    let distance = v.mag() / width
    v.normalize()
    let inputs = [
      v.x,
      v.y,
      distance,
      this.velocity.x / this.maxSpeed,
      this.velocity.y / this.maxSpeed
    ]
    let outputs = this.brain.predictSync(inputs)
    let angle = outputs[0].value * TWO_PI
    let magnitude = outputs[1].value
    let force = p5.Vector.fromAngle(angle)
    force.setMag(magnitude)
    this.applyForce(force)
  }


  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x, this.position.y)
    rotate(angle)
    rect(0, 0, this.l*2, this.l)
    pop()
  }
}
```

🗒️ Notes

We haven't actually defined r yet (see next sketch)

🛠️ Code Explanation

`d = p5.Vector.dist(this.position, target.position)`	We calculate the distance between the position of each vehicle and the target
`if (d < this.l + target.r)`	If the distance is less than the l value (5) and the r value (15 in next sketch) combined then...
`this.fitness++`	Increase the fitness score of that particular vehicle

Sketch C3.17 we ned a radius

❗ mosey on over to target.js

We need a variable for the radius r of the circle (target) to measure the fitness.

target.js

```
class Target
{
  constructor()
  {
    this.xoff = 0
    this.yoff = 1000
    this.position = createVector()
    this.r = 15
  }

  move()
  {
    this.position.x = noise(this.xoff) * width
    this.position.y = noise(this.yoff) * height
    this.xoff += 0.01
    this.yoff += 0.01
  }

  show()
  {
    circle(this.position.x, this.position.y, this.r * 2)
  }
}
```

🗒️ Notes

We now have a variable so we can compare the distance between the vehicle and the target

Sketch C3.18 overlap

❗ back we go to sketch.js

So we have added a fitness to each vehicle and those that pass within a distance of r + l (they overlap) their fitness will increase. This is all prep for latter on as we add in more features. Yet we do need to normalise the fitness of the vehicle otherwise you will get huge differences. We do this very simply by adding up all the fitnesses (sum) and dividing an individual vehicle fitness by that total value (sum) of all the fitnesses together, this means that they all add up to 1, which is important later on.

sketch.js

```
let target
let vehicles = []

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
}

function draw()
{
  background(220)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(target)
    vehicle.move()
    vehicle.show()
  }
}
```

```
function normaliseFitness()
{
  let sum = 0
  for (let vehicle of vehicles)
  {
    sum += vehicle.fitness
  }
  for (let vehicle of vehicles)
  {
    vehicle.fitness = vehicle.fitness / sum
  }
}
```

🗒️ Notes

The `vehicle of vehicles` goes through the array of `vehicles`, one by one. We have created this new function but nothing will happen until we call it.

🌻 Challenge

you could change the name to for (thing of vehicles) and so what else would you have to change.

🛠️ Code Explanation

`sum = 0`	The total (sum) starts with zero
`sum += vehicle.fitness`	Go through all the vehicles adding their fitness scores as we go along
`vehicle.fitness = vehicle.fitness / sum`	Change the fitness score of each vehicle by dividing by the total (sum)

Weighted selection

The next step is to select the highest scoring vehicles, the ones with the best fitness. However, this isn't very natural even if it seems very logical. This is an approach you might consider whereby you walk through the population array picking out the highest pairs of values and mating them and removing them for the array before looking for the next highest pair.

Instead we will use what is called weighted selection which still gives every vehicle a chance to be selected but will favour those who have the highest fitness. The way that Dan Shiffman explained it his brilliant book Nature of Code is summarised thus:

Imagine that you are in a relay race, the race starts and you hand over the baton to the next runner and so on until your team reach the end of the race. But, instead of each runner running the same distance on each leg of the relay, the fittest runs a longer leg based on their fitness and the least fit runs a shorter leg, and this is where the analogy breaks down a bit, the winner is the runner that crosses the line first.

This means that it is possible for any runner (depending on the distance of the race) to potentially win, although the fittest runner has a higher probability of winning because it is more likely to be there at the end when they cross the finishing line.

If you read the code below you can see how that works even if it isn't very intuitive. I will include a link to the website that has the book online for you to read.

Sketch C3.19 the relay race

We want to reproduce with the better vehicles based on their fitness. But first we need to decide which ones are the best and select their brain. For this we use a technique called weighted selection. This is a more realistic way of natural selection. The best ones will still have the best chance so it isn't purely random but it does give other lesser vehicles to reproduce as well.

It uses an probability, random(1) which is the length of the race between 0 and 1, it then goes through the array reducing that distance (called start) until it reaches the end (0), whichever vehicle crosses the line at the end is the winner. The clock stops (the array stops, hence index--), then continues again with the array from where we left off, with a new random number (race distance) and see who the winner is on this occasion until we have gone through the whole array of vehicles (population).

Remember that the fitness score of all the vehicles add up to 1.

sketch.js

```
let target
let vehicles = []

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
}

function draw()
{
  background(220)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(target)
    vehicle.move()
    vehicle.show()
  }
}

function normaliseFitness()
{
  let sum = 0
  for (let vehicle of vehicles)
  {
    sum += vehicle.fitness
  }
  for (let vehicle of vehicles)
  {
    vehicle.fitness = vehicle.fitness / sum
  }
}

function weightedSelection()
{
  let index = 0
  let start = random(1)
  while (start > 0)
  {
    start = start - vehicles[index].fitness
    index++
  }
  index--
  return vehicles[index].brain
}
```

🗒️ Notes

This is a bit challenging to get your head around at first. This approach is memory efficient but computationally more challenging, this is only a problem if there is a very large population where another approach might be better.

🌻 Challenge

Can you think of a better way?

🛠️ Code Explanation

`index = 0`	We begin with the first in the array of population, this is our first runner
`start = random(1)`	We create a random number between 0 and 1, this is the length of the race
`while (start > 0)`	We keep going until we reach the end of the race
`start = start - vehicles[index].fitness`	We remove the fitness score for that vehicle (runner) reducing the start random value (race distance)
`index++`	Go to the next vehicle (runner)
`index--`	When finished stop the race
`return vehicles[index].brain`	Get the detail of the best vehicle (runner)

Reproduction

We want a `lifespan` for the current vehicles, say `250` frames, so that just before they die off they reproduce a better version of themselves. They don't all mate, only those who have a reasonably high fitness.

From the `weighted selection` we chose two parents and create a child through crossover, where the child will carrying some of the genes from each parent. This child will have a mutation rate. This is important otherwise the gene pool becomes stagnant. There needs to be some element of randomness. This is often seen in nature. If those mutations are useful they can be incorporated otherwise they die off.

The ml5.js machine learning library has a builtin function for `crossover()` and `mutation()` which is a relatively new addition but ever so helpful if you are developing simulations or games.

The `crossover()` function simply takes some of the weights of one successful parent's neural network with the weights of another successful parent's neural network and in some way combining them producing new neural network with these combined weights. There are various ways that can be done but that is for another discussion, for now let us just make use of it.

Sketch C3.20 the next generation

To create the next generation we need to create a new function and we will call reproduction(). Here we will create the next generation of children which will be the same length of our first generation. This is a holding array called nextVehicles and once we have filled it we will rename it vehicles.

sketch.js

```
let target
let vehicles = []

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
}

function draw()
{
  background(220)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(target)
    vehicle.move()
    vehicle.show()
  }
```

```
}

function normaliseFitness()
{
  let sum = 0
  for (let vehicle of vehicles)
  {
    sum += vehicle.fitness
  }
  for (let vehicle of vehicles)
  {
    vehicle.fitness = vehicle.fitness / sum
  }
}

function weightedSelection()
{
  let index = 0
  let start = random(1)
  while (start > 0)
  {
    start = start - vehicles[index].fitness
    index++
  }
  index--
  return vehicles[index].brain
}

function reproduction()
{
  let nextVehicles = []
  for (let i = 0; i < vehicles.length; i++)
  {
    let parentA = weightedSelection()
    let parentB = weightedSelection()
    let child = parentA.crossover(parentB)
    child.mutate(0.01)
    nextVehicles[i] = new Vehicle(random(width), random(height), 
child)
  }
  vehicles = nextVehicles
}
```

🗒️ Notes

Notice that we have an extra argument for creating the next generation of vehicle, the `child`. We will need to add it to the `constructor()` function in the `Vehicle` class.

🛠️ Code Explanation

`nextVehicles = []`	We create an empty array for the new vehicles.
`parentA = weightedSelection()`	Select the first parent, call the weightedSelection() function
`parentB = weightedSelection()`	Select the second parent, call the weightedSelection() function
`child.mutate(0.01)`	When the child is created apply a tiny mutation rate of 0.01
`nextVehicles[i] = new Vehicle(random(width), random(height), child)`	Create a new vehicle from the child
`vehicles = nextVehicles`	Rename all the new vehicles: vehicles

Sketch C3.21 birth of a child

❗ go over to vehicle.js

You may have noticed that when we create a new Vehicle() we have included a third argument called child. This is effectively the brain, but when we originally created a vehicle we only used two arguments, the x and the y position. So we need to factor that in when creating our second generation and onwards. We need to check if there is a brain in the first place and if we have then we update it with the new one.

We get round this by checking to see if there is already a brain and replacing it, if there isn't a brain we give it one. We alter the constructor() function of the Vehicle Class as appropriate.

❗ we create an if. . .else() statement to check whether the vehicle already has a brain and if not then create one. We have moved the neural network (brain) inside the else() statement hence it is highlighted.

vehicle.js

```
class Vehicle
{
  constructor(x, y, brain)
  {
    this.position = createVector(x, y)
    this.velocity = createVector(0, 0)
    this.acceleration = createVector(0, 0)
    this.l = 5
    this.fitness = 0
    this.maxSpeed = 4
    this.maxForce = 0.2
    if (brain)
    {
      this.brain = brain
    }
    else
    {
      ml5.setBackend("cpu")
      this.brain = ml5.neuralNetwork({
        inputs: 5,
        outputs: 2,
        task: "regression",
        neuroEvolution: true,
        noTraining: true
      })
    }
  }

  move()
  {
    this.velocity.add(this.acceleration)
    this.velocity.limit(this.maxSpeed)
    this.position.add(this.velocity)
    this.acceleration.mult(0)
    let d = p5.Vector.dist(this.position, target.position)
    if (d < this.l + target.r)
    {
      this.fitness++
    }
  }

  applyForce(force)
  {
    this.acceleration.add(force)
  }

  seek(target)
  {
    let v = p5.Vector.sub(target.position, this.position)
    let distance = v.mag() / width
    v.normalize()
    let inputs = [
      v.x,
      v.y,
      distance,
      this.velocity.x / this.maxSpeed,
      this.velocity.y / this.maxSpeed
    ]
    let outputs = this.brain.predictSync(inputs)
    let angle = outputs[0].value * TWO_PI
    let magnitude = outputs[1].value
    let force = p5.Vector.fromAngle(angle)
    force.setMag(magnitude)
    this.applyForce(force)
  }

  show()
  {
    let angle = this.velocity.heading()
    push()
    translate(this.position.x, this.position.y)
    rotate(angle)
    rect(0, 0, this.l*2, this.l)
    pop()
  }
}
```

Notes

If you run it you shouldn't get any errors but neither will you see the next `generation` just yet. We need to have a `lifespan` so that the previous `generation` die out and the next are birthed.

🛠️ Code Explanation

`constructor(x, y, brain)`	Added the brain (child) component argument to the constructor function
`if (brain)`	Check to see if the vehicle already has a brain
`this.brain = brain`	If it does then replace it with the new brain (child)

Sketch C3.22 lifeCounter

❗ return to sketch.js

All we have got left to do is give the vehicle a lifespan and then reproduce. We need to count the number of iterations rather than actual frames (which is another way of doing it), this way we could have a countdown. We are also going to keep track of how many generations and display this later on.

sketch.js

```
let target
let vehicles = []
let lifeSpan = 250
let lifeCounter = 0
let generations = 0

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
}

function draw()
{
  background(220)
  target.move()
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.seek(target)
    vehicle.move()
    vehicle.show()
  }
  lifeCounter++
  if (lifeCounter > lifeSpan)
  {
    normaliseFitness()
    reproduction()
    lifeCounter = 0
    generations++
  }
}

function normaliseFitness()
{
  let sum = 0
  for (let vehicle of vehicles)
  {
    sum += vehicle.fitness
  }
  for (let vehicle of vehicles)
  {
    vehicle.fitness = vehicle.fitness / sum
  }
}

function weightedSelection()
{
  let index = 0
  let start = random(1)
  while (start > 0)
  {
    start = start - vehicles[index].fitness
    index++
  }
  index--
  return vehicles[index].brain
}


function reproduction()
{
  let nextVehicles = []
  for (let i = 0; i < vehicles.length; i++)
  {
    let parentA = weightedSelection()
    let parentB = weightedSelection()
    let child = parentA.crossover(parentB)
    child.mutate(0.01)
    nextVehicles[i] = new Vehicle(random(width), random(height),
child)
  }
  vehicles = nextVehicles
}
```

🗒️ Notes

You should now see the `generations` appearing. They should also start to `follow` the target after a little while (you have to be patient). If you are impatient then look at the next sketch.

🌻 Challenges

1. Add colour or images (instead of rectangles) for the scene
2. How would you go about creating a 3D version (not easy but not impossible)

🛠️ Code Explanation

`lifeSpan = 250`	The life of a vehicle
`lifeCounter = 0`	Keeps track of how many iterations there have been
`generations = 0`	Counts the number of generations
`lifeCounter++`	Counts the number of iterations, adding 1 each time
`if (lifeCounter > lifeSpan)`	Chen is to see if the vehicles have reached the end of their lifespan
`normaliseFitness()`	The fitness is normalised at the end of each generation
`reproduction()`	The reproduction happens at the end of the generation
`lifeCounter = 0`	Reset the counter
`generations++`	Add another generation to the tally

What next?

In a sense you have done it. If you watch long enough you will see the changes take place. The `vehicles` will start to follow the `target` as they evolve through the improved fitness levels of those who are successful. This, however is a slow process and there is a way of speeding it up and also having a bit more information on the number of `generations` you are at.

We can use a `slider` to speed up the process, remember that the computer can do this much faster than we are watching it, this is so we can see it happening in real time as it were.

You can be as creative as you want, I created some bees following a honey pot

Sketch C3.23 adding a slider

Adding a slider, what we are doing is increasing the rate of iterations as another for() loop within draw(). We can also see the number of generations, this helps get an idea how many generations have past. The create slider function has three arguments, the minimum value (1), the maximum value (20) and the increments value (1).

sketch.js

```
let target
let vehicles = []
let lifeSpan = 250
let lifeCounter = 0
let generations = 0
let timeSlider

function setup()
{
  createCanvas(400, 400)
  target = new Target()
  for (let i = 0; i < 50; i++)
  {
    vehicles[i] = new Vehicle(random(width), random(height))
  }
  timeSlider = createSlider(1, 20, 1)
  timeSlider.position(10, 420)
}

function draw()
{
  background(220)
  target.show()
  for (let vehicle of vehicles)
  {
    vehicle.show()
  }

  for (let i = 0; i < timeSlider.value(); i++)
  {
    for (let vehicle of vehicles)
    {
      vehicle.seek(target)
      vehicle.move()
    }
    target.move()
    lifeCounter++
  }

  if (lifeCounter > lifeSpan)
  {
    normaliseFitness()
    reproduction()
    lifeCounter = 0
    generations++
  }
  textSize(40)
  text(generations, 10, 380)
}

function normaliseFitness()
{
  let sum = 0
  for (let vehicle of vehicles)
  {
    sum += vehicle.fitness
  }
  for (let vehicle of vehicles)
  {
    vehicle.fitness = vehicle.fitness / sum
  }
}

function weightedSelection()
{
  let index = 0
  let start = random(1)
  while (start > 0)
  {
    start = start - vehicles[index].fitness
    index++
  }
  index--
  return vehicles[index].brain
}

function reproduction()
{
  let nextVehicles = []
  for (let i = 0; i < vehicles.length; i++)
  {
    let parentA = weightedSelection()
    let parentB = weightedSelection()
    let child = parentA.crossover(parentB)
    child.mutate(0.01)
    nextVehicles[i] = new Vehicle(random(width), random(height),
child)
  }
  vehicles = nextVehicles
}
```

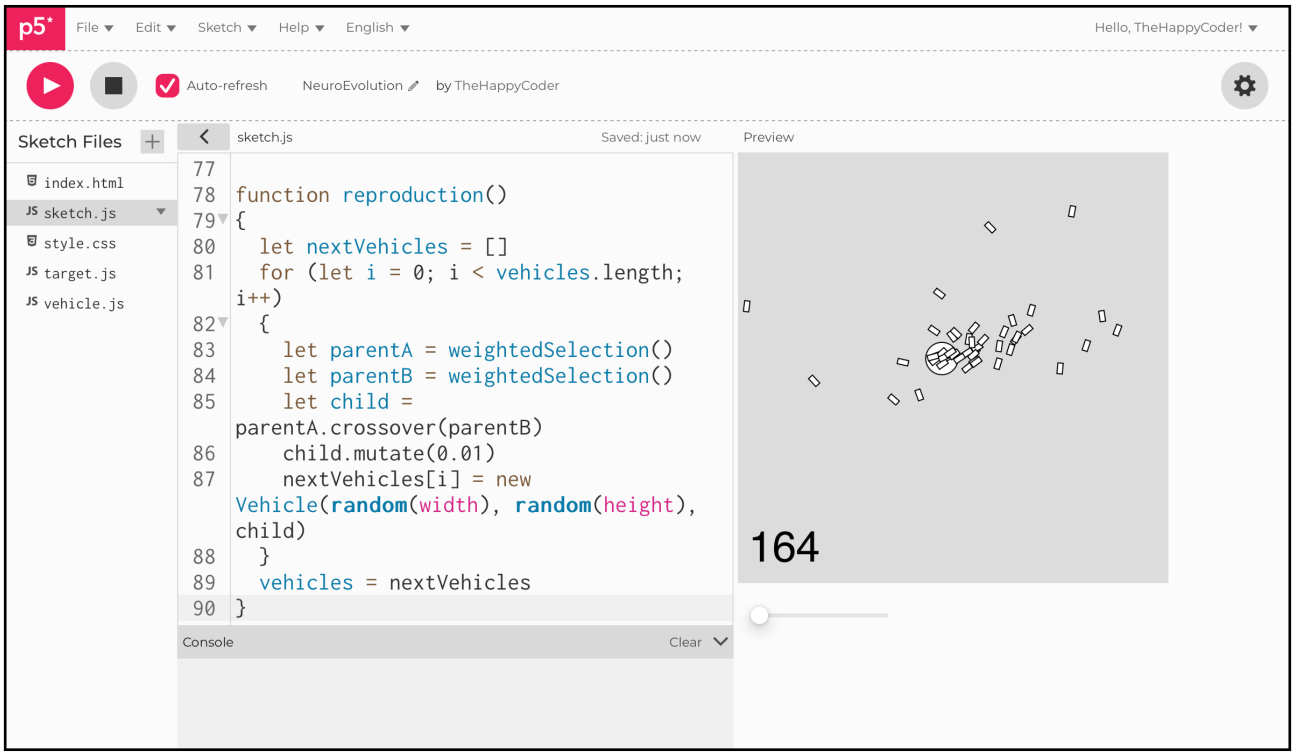
🗒️ Notes

Moving the `slider` along until around `150` iterations shows a huge improvement in their attraction to the target.

🌻 Challenge

Try other values

Figure C3.23



```
function reproduction()
{
  let nextVehicles = []
  for (let i = 0; i < vehicles.length; i++)
  {
    let parentA = weightedSelection()
    let parentB = weightedSelection()
    let child = parentA.crossover(parentB)
    child.mutate(0.01)
    nextVehicles[i] = new Vehicle(random(width), random(height), child)
  }
  vehicles = nextVehicles
}
```