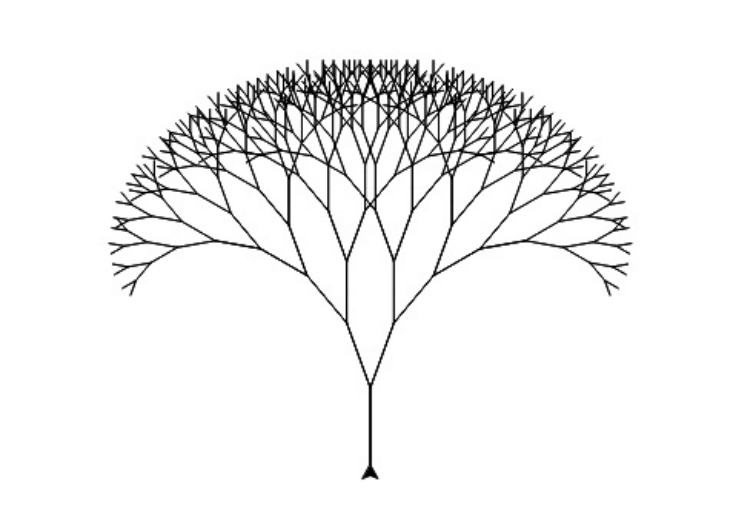
Lab 1

Lab 1 - Recursive Tree



Recursive Tree

Trees can be drawn recursively. Draw a branch. At the end of the branch, draw two smaller branches with one to the left and the other to the right. Repeat until a certain condition is true. This program will walk you through drawing a tree in this way.

Turtle Graphics Review

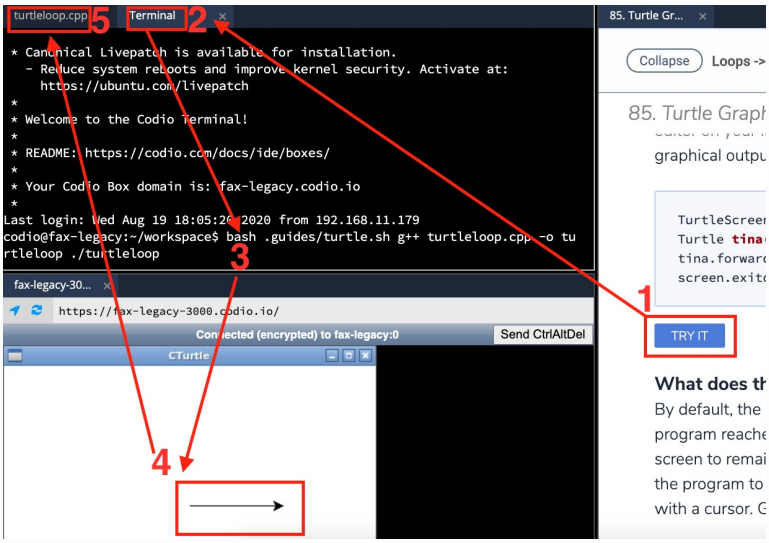
We will be using Turtle Graphics to visualize recursion. Here is some review on what a Turtle object (`tina`) can do in C++:

▼ *Turtle Graphics Review*

- `tina.forward(n)` - Where `n` represents the number of pixels.
- `tina.backward(n)` - Where `n` represents the number of pixels.
- `tina.right(d)` - Where `d` represents the number of degrees.
- `tina.left(d)` - Where `d` represents the number of degrees.
- `tina.pencolor({"COLOR"})` - Where `COLOR` represents the track or line color you want tina to leave behind.
- `tina.width(W)` - Where `W` represents how wide (in pixels) tina's track is.
- `tina.shape("SHAPE")` - Where `SHAPE` represents the shape tina takes.
- `tina.speed(SPEED)` - Where `SPEED` represents how fast tina moves

Command	Parameter	Examples
`tina.pencolor({"COLOR"})`	Where `COLOR` represents the track or line color you want tina to leave behind	red, orange, yellow, green, blue, purple
`tina.width(W)`	Where `W` represents how wide (in pixels) tina's track is	any positive integer (e.g. 1, 10, 123, etc.)
`tina.shape("SHAPE")`	Where `SHAPE` represents the shape tina takes	triangle, indented triangle, square, arrow
`tina.speed(SPEED)`	Where `SPEED` represents how fast tina moves	TS_FASTEST, TS_FAST, TS_NORMAL, TS_SLOW, TS_SLOWEST

And some instructions on how Turtle Graphics work on the Terminal:



.guides/img/TurtleGraphicsFlow

1. `TRY IT` button is clicked by the user.
2. The `Terminal` tab is opened.
3. The terminal runs the command to compile the program and to display the graphical output.
4. The output is displayed as a screen on the bottom left panel. You can click the screen to close the output.
5. Click on the file name tab to go back to the text editor if you want to make changes to the program.

Program Instructions

Let's start by creating a canvas `screen` and a Turtle object `tina` in `main()` to allow the Turtle object to move around on. Feel free to edit the screen size so that it fits comfortably on your monitor. You'll also notice that there is function called `RecursiveTree()`. This function takes three parameters, `branch_length`, `angle`, and `t`.

Note that when passing an object (like a Turtle), you should should pass it as a reference using the `&` symbol (i.e. `Turtle& t`).

This is the code you have so far in the text editor:

```
////////// DO NOT EDIT HEADER! //////////
#include <iostream>                    //
#include "CTurtle.hpp"                 //
#include "CImg.h"                      //
using namespace cturtle;               //
using namespace std;                   //
////////////////////////////////////////

/**
 * @param branch_length An integer
 * @param angle The angle of degree
 * @param t A Turtle object
 * @return A drawing symbolizing a tree branch
 */
void RecursiveTree(int branch_length, int angle, Turtle& t) {

  //add function definitions below



  //add function definitions above

}

int main(int argc, char** argv) {

  //add code below this line



  //add code above this line

  screen.exitonclick();
  return 0;

}
```

The base case for this function is a bit different. In previous examples, if the base case is true a value was returned. The function `RecursiveTree()` does not return a value, it draws on the screen instead. So the base case will be to keep recursing as long as `branch_length` is greater than some value. Define the base case as `branch_length` as being greater than 5.

```
void RecursiveTree(int branch_length, int angle, Turtle& t) {

  //add function definitions below

  if (branch_length > 5) {

  }

  //add function definitions above

}
```

Start drawing the tree by going forward and turning right. Then call `RecursiveTree()` again, but reduce `branch_length` by `15`. The code should run, but the tree will not look like a tree. It looks more like a curve made of a series of line segments decreasing in size.

```
void RecursiveTree(int branch_length, int angle, Turtle& t) {

  //add function definitions below

  if (branch_length > 5) {
    t.forward(branch_length);
    t.right(angle);
    RecursiveTree(branch_length - 15, angle, t);
  }

  //add function definitions above

}
```

In `main()`, let's call the `RecursiveTree()` function and pass in some initial values.

```
int main(int argc, char** argv) {

  //add code below this line

  TurtleScreen screen(400, 300);
  Turtle tina(screen);
  RecursiveTree(45, 20, tina);

  //add code above this line

  screen.exitonclick();
  return 0;

}
```

The next step is to draw the branch that goes off to the left. Since the turtle turned to the right the number of degrees that the parameter `angle` represents, the turtle needs to turn to the left twice the degrees of `angle`. Turning to the left `angle` will put the turtle back at its original heading. The turtle needs to go further to the left. Then draw another branch whose length is reduced by `15`.

```
void RecursiveTree(int branch_length, int angle, Turtle& t) {

  //add function definitions below

  if (branch_length > 5) {
    t.forward(branch_length);
    t.right(angle);
    RecursiveTree(branch_length - 15, angle, t);
    t.left(angle * 2);
    RecursiveTree(branch_length - 15, angle, t);
  }

  //add function definitions above

}
```

The tree is looking better, but there are two more things that need to be done. First, put the turtle back to its original heading by turning right `angle` degrees. Then go backwards the length of the branch. If you tweak some of the arguments when calling the `RecursiveTree()` function, you might notice the tree changing.

```
void RecursiveTree(int branch_length, int angle, Turtle& t) {

  //add function definitions below

  if (branch_length > 5) {
    t.forward(branch_length);
    t.right(angle);
    RecursiveTree(branch_length - 15, angle, t);
    t.left(angle * 2);
    RecursiveTree(branch_length - 15, angle, t);
    t.right(angle);
    t.backward(branch_length);
  }

  //add function definitions above

}
```

challenge

What happens if you:

- Increase the branch length argument when calling `RecursiveTree()` in `main()` for the first time such as `35` or `60`?
- Increase and decrease the angle argument when calling `RecursiveTree()` in `main()` for the first time such as `10` or `40`?
- Change all of the recursive cases in the function from `branch_length - 15` to something smaller like `branch_length - 5`?
- Change the base case to `if (branchLength > 1)` in the function?
- Rotate the `tina` `90` degrees to the left before calling `RecursiveTree()` in `main()` for the first time?

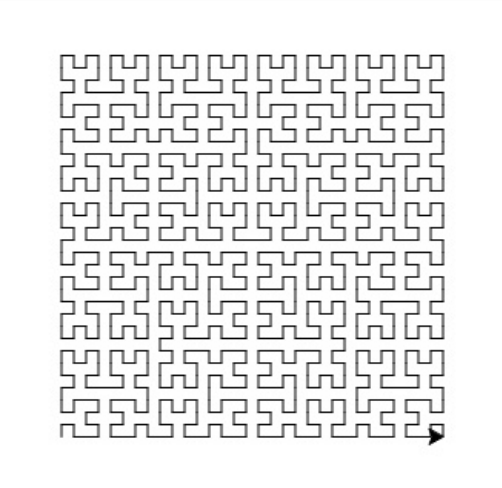
▼ **Code Sample**

```
////////// DO NOT EDIT HEADER! //////////
#include <iostream>                    //
#include "CTurtle.hpp"                 //
#include "CImg.h"                      //
using namespace cturtle;               //
using namespace std;                   //
////////////////////////////////////////

/**
 * @param branch_length An integer
```

```
 * @param angle The angle of degree
 * @param t A Turtle object
 * @return A drawing symbolizing a tree branch
 */
void RecursiveTree(int branch_length, int angle, Turtle& t) {

  //add function definitions below

  if (branch_length > 5) {
    t.forward(branch_length);
    t.right(angle);
    RecursiveTree(branch_length - 5, angle, t);
    t.left(angle * 2);
    RecursiveTree(branch_length - 5, angle, t);
    t.right(angle);
    t.backward(branch_length);
  }

  //add function definitions above

}

int main(int argc, char** argv) {

  //add code below this line

  TurtleScreen screen(400, 300);
  Turtle tina(screen);
  tina.left(90); //rotates Turtle's original position
  tina.speed(TS_FASTEST); //speeds up Turtle's movement
  RecursiveTree(35, 20, tina);

  //add code above this line

  screen.exitonclick();
  return 0;

}
```

Lab 2

Lab 2 - The Hilbert Curve



Hilbert Curve

The Hilbert Curve is a fractal, space-filling curve. Start by creating a Turtle object, and then write the function header for the recursive function `Hilbert`. The parameters for the function are the distance the turtle will travel, the rule to be used, an angle (determines how tight the fractal is), depth (how intricate the fractal is), and the Turtle object.

This is the code you have so far in the text editor:

```
///////// DO NOT EDIT HEADER! /////////
#include <iostream>                    //
#include "CTurtle.hpp"                 //
#include "CImg.h"                      //
using namespace cturtle;               //
using namespace std;                   //
///////////////////////////////////////

/**
 * @param dist, integer
 * @param rule, integer
 * @param angle, integer
 * @param depth, integer
 * @param t, Turtle
 * @return A drawing of the Hilbert Curve
 */
void Hilbert(int dist, int rule, int angle, int depth, Turtle&
        t) {

  //add function definitions below



  //add function definitions above

}

int main(int argc, char** argv) {

  //add code below this line

  TurtleScreen screen(400, 300);
  Turtle tina(screen);

  //add code above this line

  screen.exitonclick();
  return 0;

}
```

The base case for the function is when `depth` is 0. Another way to think about the base case is that if `depth` is greater than 0, keep drawing the fractal. Use `if (depth > 0)` as the base case. Also, there are two rules for the turtle. Ask if `rule` is equal to 1 or if it is equal to 2.

```
void Hilbert(int dist, int rule, int angle, int depth, Turtle&
       t) {

  //add function definitions below

  if (depth > 0) {
    if (rule == 1) {
      //rule1 code
    }
    if (rule == 2) {
      //rule2 code
    }
  }

  //add function definitions above

}
```

The code continues with if `rule` is equal to 1, then the turtle is going to turn left, recursively call the `Hilbert()` function with `rule` set to 2, go forward, turn right, recursively call the `Hilbert()` function with `rule` set to 1, go forward, recursively call the `Hilbert()` function with `rule` set to 1, turn right, and finally move forward. Because the base case is based on `depth`, it must be reduced by 1 each time the `Hilbert()` function is called recursively.

```
if (rule == 1) {
  //rule1 code
  t.left(angle);
  Hilbert(dist, 2, angle, depth - 1, t);
  t.forward(dist);
  t.right(angle);
  Hilbert(dist, 1, angle, depth - 1, t);
  t.forward(dist);
  Hilbert(dist, 1, angle, depth - 1, t);
  t.right(angle);
  t.forward(dist);
  Hilbert(dist, 2, angle, depth - 1, t);
  t.left(angle);
}
```

If `rule` is equal to 2, then the code is almost the inverse of when `rule` is equal to 1. The turtle will still go forward, but left turns become right turns, right turns become left turns, and recursive calls to `Hilbert()` will use 2 instead of 1 for the `rule` parameter (and vice versa).

```
if (rule == 2) {
  //rule2 code
  t.right(angle);
  Hilbert(dist, 1, angle, depth - 1, t);
  t.forward(dist);
  t.left(angle);
  Hilbert(dist, 2, angle, depth - 1, t);
  t.forward(dist);
  Hilbert(dist, 2, angle, depth - 1, t);
  t.left(angle);
  t.forward(dist);
  Hilbert(dist, 1, angle, depth - 1, t);
  t.right(angle);
}
```

Finally, call the `Hilbert()` function in `main()` and run the program to see the fractal.

```
int main(int argc, char** argv) {

  //add code below this line

  TurtleScreen screen(400, 300);
  Turtle tina(screen);
  Hilbert(5, 1, 90, 5, tina);

  //add code above this line

  screen.exitonclick();
  return 0;

}
```

▼ **Speeding up the turtle**

The Hilbert Curve can be slow to draw. You can change the speed of the Turtle `tina` with the following command `tina.speed(TS_FASTEST);` before calling the `Hilbert()` function.

challenge

What happens if you:

- Change the `dist` parameter to `3`?
- Start with the `rule` parameter as `2`?
- Change the `angle` parameter to `85`?
- Change the `depth` parameter to `4`?

Note: You might need to adjust your TurtleScreen's size to capture all of the output.

▼ **Sample Code**

```
///////// DO NOT EDIT HEADER! /////////
#include <iostream>                    //
#include "CTurtle.hpp"                 //
#include "CImg.h"                      //
using namespace cturtle;               //
using namespace std;                   //
///////////////////////////////////////

/**
 * @param dist, integer
 * @param rule, integer
 * @param depth, integer
 * @param t, Turtle
 * @return A drawing of the Hilbert Curve
 */
void Hilbert(int dist, int rule, int angle, int depth, Turtle&
        t) {

  //add function definitions below

  if (depth > 0) {
    if (rule == 1) {
      //rule1 code
      t.left(angle);
      Hilbert(dist, 2, angle, depth - 1, t);
      t.forward(dist);
      t.right(angle);
      Hilbert(dist, 1, angle, depth - 1, t);
      t.forward(dist);
      Hilbert(dist, 1, angle, depth - 1, t);
      t.right(angle);
      t.forward(dist);
```

```
      Hilbert(dist, 2, angle, depth - 1, t);
      t.left(angle);
    }
    if (rule == 2) {
      //rule2 code
      t.right(angle);
      Hilbert(dist, 1, angle, depth - 1, t);
      t.forward(dist);
      t.left(angle);
      Hilbert(dist, 2, angle, depth - 1, t);
      t.forward(dist);
      Hilbert(dist, 2, angle, depth - 1, t);
      t.left(angle);
      t.forward(dist);
      Hilbert(dist, 1, angle, depth - 1, t);
      t.right(angle);
     }
  }

  //add function definitions below

}

int main(int argc, char** argv) {

  //add code below this line

  TurtleScreen screen(400, 300);
  Turtle tina(screen);
  tina.speed(TS_FASTEST);
  Hilbert(8, 1, 90, 4, tina);

  //add code above this line

  screen.exitonclick();
  return 0;

}
```

Lab Challenge

Lab Challenge

Problem
Write a recursive function called `RecursivePower()` that takes **two integers** as parameters. The first parameter is the base number and the second parameter is the exponent. Return the base number parameter to the power of the exponent.

DO NOT edit any existing code or you will not receive credit for your work!

```
#include <iostream>
using namespace std;

//add function definitions below this line



//add function definitions above this line

int main(int argc, char** argv) {
  cout << RecursivePower(stoi(argv[1]), stoi(argv[2])) << endl;
  return 0;
}
```

Expected Output
* If the function call is `RecursivePower(5, 3)`, then the function will return `125`.
* If the function call is `RecursivePower(4, 5)`, then the function will return `1024`.

Compile and test your code with a few different values

▼ **Expected Output**

```
216
```

▼ **Expected Output**

```
1
```