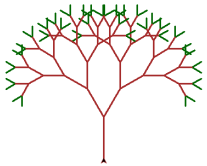
Recursion with Turtles



CS111 Computer Programming

Department of Computer Science
Wellesley College

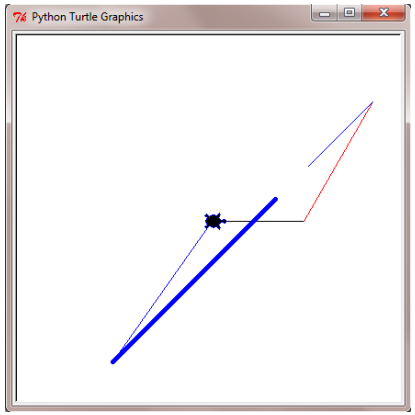
Turtle Graphics

Python has a built-in module named turtle. See the Python turtle module API for details.

Use `from turtle import *` to use these commands:

`fd(dist)`	turtle moves forward by *dist*
`bk(dist)`	turtle moves backward by *dist*
`lt(angle)`	turtle turns left *angle* degrees
`rt(angle)`	turtle turns right *angle* degrees
`pu()`	(pen up) turtle raises pen in belly
`pd()`	(pen down) turtle lower pen in belly
`pensize(width)`	sets the thickness of turtle's pen to *width*
`pencolor(color)`	sets the color of turtle's pen to *color*
`shape(shp)`	sets the turtle's shape to *shp*
`home()`	turtle returns to (0,0) (center of screen)
`clear()`	delete turtle drawings; no change to turtle's state
`reset()`	delete turtle drawings; reset turtle's state
`setup(width,height)`	create a turtle window of given *width* and *height*

A Simple Example with Turtles



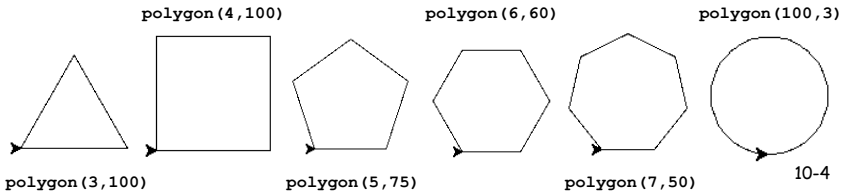

```
from turtle import *

setup(400,400)
fd(100)
lt(60)
shape('turtle')
pencolor('red')
fd(150)
rt(15)
pencolor('blue')
bk(100)
pu()
bk(50)
pd()
pensize(5)
bk(250)
pensize(1)
home()
```


Looping Turtles

Loops can be used in conjunction with turtles to make interesting designs.

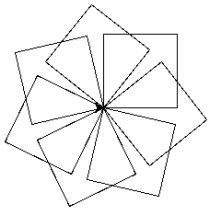
```
# Draws a polygon with the specified number
# of sides, each with the specified length
def polygon(numSides, sideLength):
```



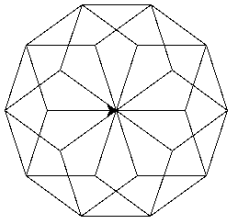
Looping Turtles

```
# Draws "flowers" with numPetals arranged around
# a center point. Each petal is a polygon with
# petalSides sides of length petalLen.
def polyFlow(numPetals, petalSides, petalLen):
```

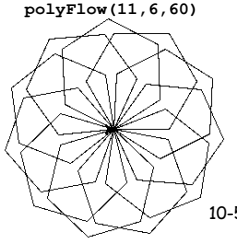
polyFlow(7,4,80)



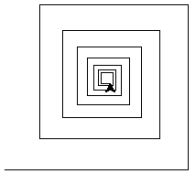
polyFlow(10,5,75)



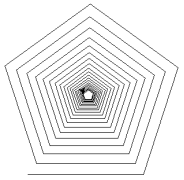
polyFlow(11,6,60)



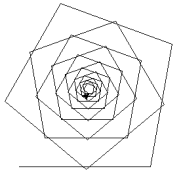
Spiraling Turtles: A Recursion Example



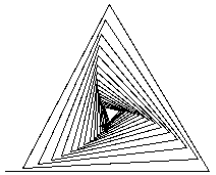
spiral(200,90,0.9,10)



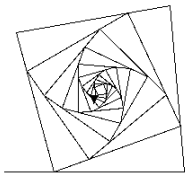
spiral(200,72,0.97,10)



spiral(200,80,0.95,10)



spiral(200,121,0.95,15)

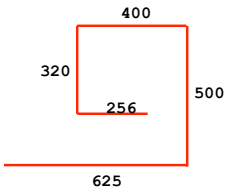


spiral(200,95,0.93,10)

`spiral(sideLen, angle, scaleFactor, minLength)`

- **sideLen** is the length of the current side
- **angle** is the amount the turtle turns left to draw the next side
- **scaleFactor** is the multiplicative factor by which to scale the next side (it is between 0.0 and 1.0)
- **minLength** is the smallest side length that the turtle will draw

`spiral(625, 90, 0.8, 250)`



Spiraling Turtles: A Recursion Example

```
def spiral(sideLen, angle, scaleFactor, minLength):
```

```
spiral(625, 90, 0.8, 250)
```


```
spiral(625, 90, 0.8, 250)
```

```
spiral(625, 90, 0.8, 250)
if sideLen >= minLength:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```



```
spiral(625, 90, 0.8, 250)
```

```
spiral(625, 90, 0.8, 250)
if True:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```



```
spiral(625, 90, 0.8, 250)
```

625

```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

spiral(625, 90, 0.8, 250)


```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)


```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

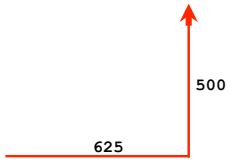
```
spiral(500, 90, 0.8, 250)
if sideLen >= minLength:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)


```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

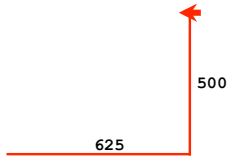

spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

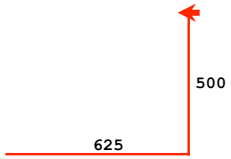
spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)

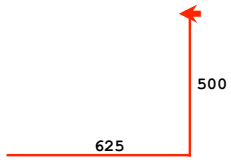



```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if sideLen >= minLength:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)

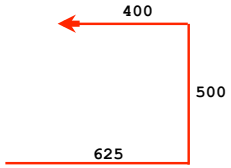



```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)

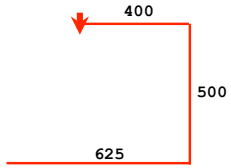



```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

spiral(625, 90, 0.8, 250)

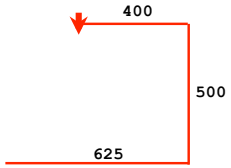



```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)



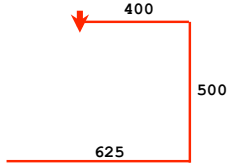

```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if sideLen >= minLength:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)



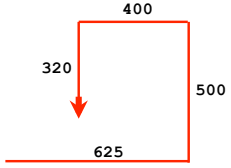

```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)



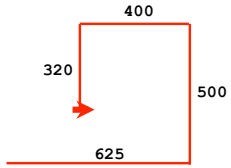

```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

spiral(625, 90, 0.8, 250)



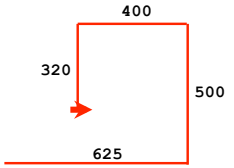

```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

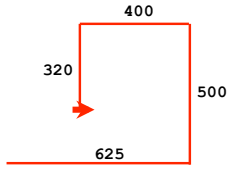
```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(256, 90, 0.8, 250)
if sideLen >= minLength:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```


spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(256, 90, 0.8, 250)
if True:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```


spiral(625, 90, 0.8, 250)


```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

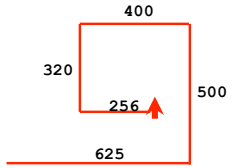
```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(256, 90, 0.8, 250)
if True:
  fd(256)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```

spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

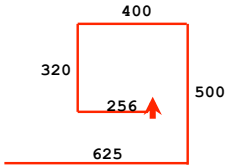
```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```

```
spiral(256, 90, 0.8, 250)
if True:
  fd(256)
  lt(90)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

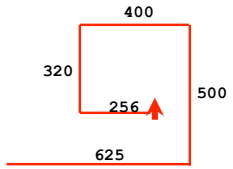
```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```

```
spiral(256, 90, 0.8, 250)
if True:
  fd(256)
  lt(90)
  spiral(204.8, 90,
         0.8, 250)
```

```
spiral(204.8, 90, 0.8, 250)
if sideLen >= minLength:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```


spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

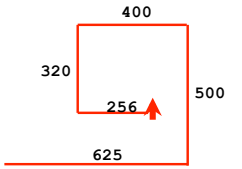
```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```

```
spiral(204.8, 90, 0.8, 250)
if False:
  fd(sideLen)
  lt(angle)
  spiral(sideLen*scaleFactor, angle,
         scaleFactor, minLength)
```

```
spiral(256, 90, 0.8, 250)
if True:
  fd(256)
  lt(90)
  spiral(204.8, 90,
         0.8, 250)
```


spiral(625, 90, 0.8, 250)




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

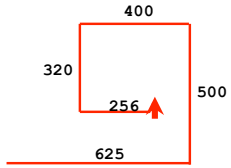
```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```

```
spiral(256, 90, 0.8, 250)
if True:
  fd(256)
  lt(90)
  spiral(204.8, 90,
         0.8, 250)
```

`spiral(625, 90, 0.8, 250)`



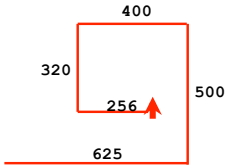

```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

```
spiral(320, 90, 0.8, 250)
if True:
  fd(320)
  lt(90)
  spiral(256, 90,
         0.8, 250)
```


`spiral(625, 90, 0.8, 250)`

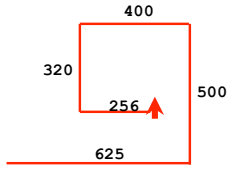



```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```

```
spiral(400, 90, 0.8, 250)
if True:
  fd(400)
  lt(90)
  spiral(320, 90,
         0.8, 250)
```

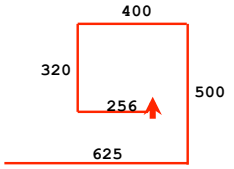

`spiral(625, 90, 0.8, 250)`




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

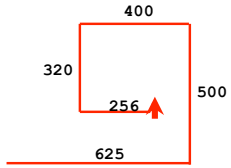
```
spiral(500, 90, 0.8, 250)
if True:
  fd(500)
  lt(90)
  spiral(400, 90,
         0.8, 250)
```


`spiral(625, 90, 0.8, 250)`




```
spiral(625, 90, 0.8, 250)
if True:
  fd(625)
  lt(90)
  spiral(500, 90,
         0.8, 250)
```

```
spiral(625, 90, 0.8, 250)
```

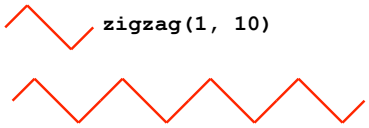


Invariant Spiraling

A function is invariant relative to an object's state if the state of the object is the same before and after the function is invoked.

```
# Draws a spiral. The state of the turtle (position,
# color, heading, etc.) after drawing the spiral is the
# same as before drawing the spiral.
def spiralBack(sideLen, angle, scaleFactor, minLength):
```

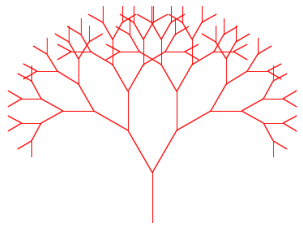

Zigzags



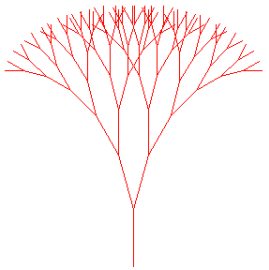

```
# Draws the specified number of zigzags with the specified
# length.
def zigzag(num, length):
        if num>0:
                lt(45)
                fd(length)
                rt(90)
                fd(2*length)
                lt(90)
                fd(length)
                rt(45)
                zigzag(num-1, length)
```

Exercise: modify zigzag to make the turtle's state invariant.

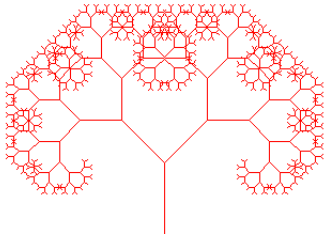
Trees



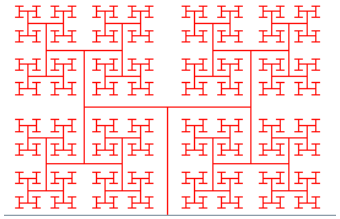
tree(7, 75, 30, 0.8)



tree(7, 75, 15, 0.8)

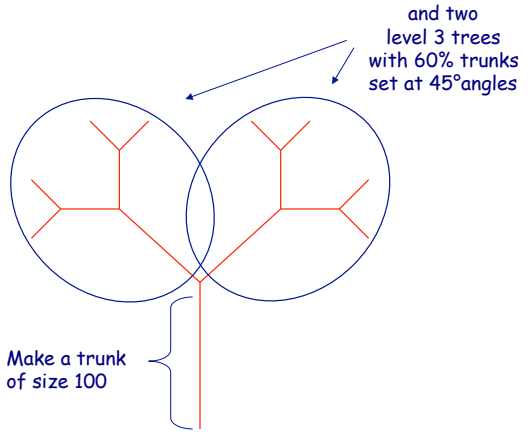


tree(10, 80, 45, 0.7)

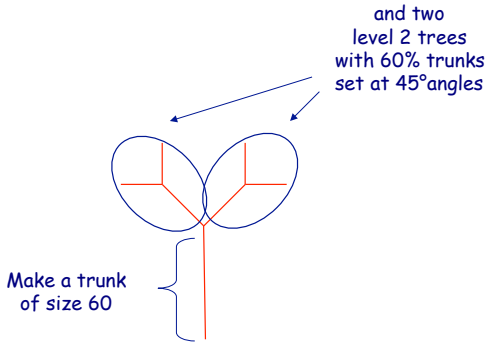


tree(10, 100, 90, 0.68)

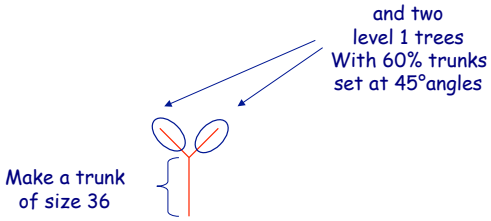
How to make a 4 level tree: `tree(4, 100, 45, 0.6)`



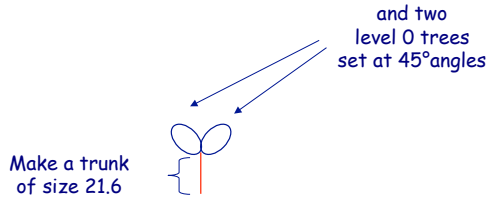
How to make a 3 level tree: `tree(3, 60, 45, 0.6)`



How to make a 2 level tree: `tree(2, 36, 45, 0.6)`



How to make a 1 level tree: `tree(1, 21.6, 45, 0.6)`



How to make a 1 level tree: `tree(0, 12.96, 45, 0.6)`

Do nothing!

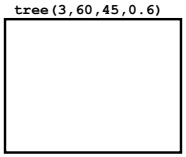
`tree(levels, trunkLen, angle, shrinkFactor)`

- **`levels`** is the number of branches on any path from the root to a leaf
- **`trunkLen`** is the length of the base trunk of the tree
- **`angle`** is the angle from the trunk for each subtree
- **`shrinkFactor`** is the shrinking factor for each subtree

Trees

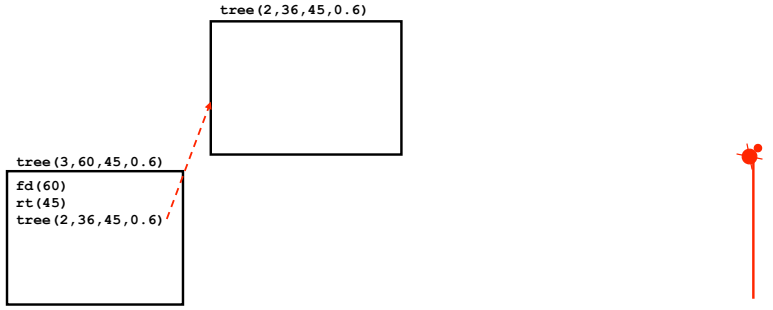
```
def tree(levels, trunkLen, angle, shrinkFactor):
```


Tracing the invocation of `tree(3, 60, 45, 0.6)`

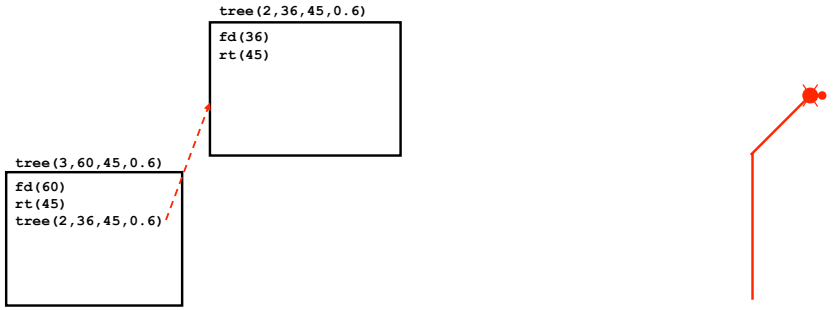


Draw trunk and turn to draw level 2 tree

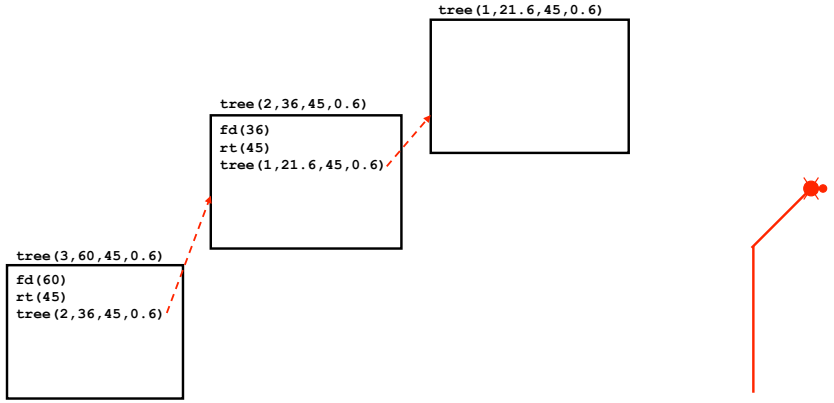
Begin recursive invocation to draw level 2 tree



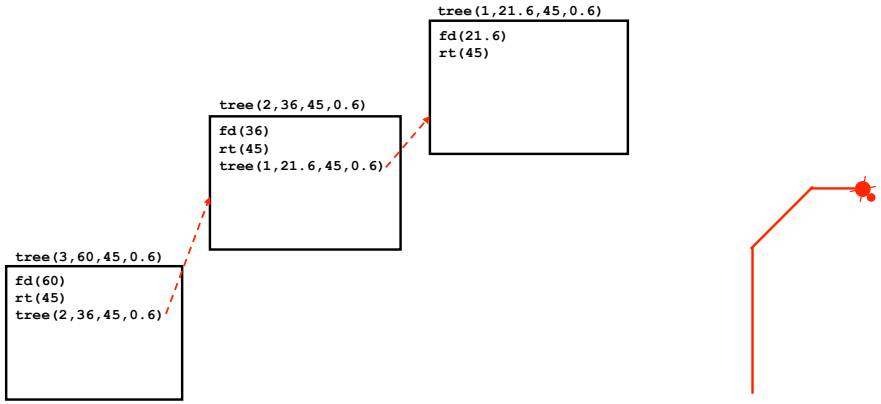
Draw trunk and turn to draw level 1 tree



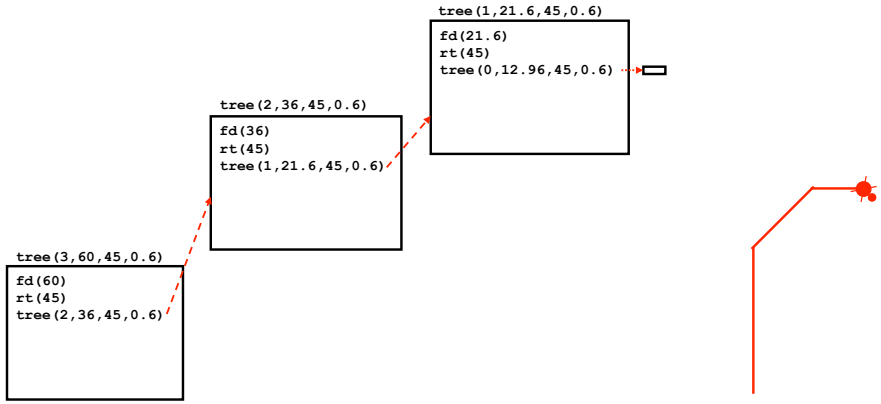
Begin recursive invocation to draw level 1 tree



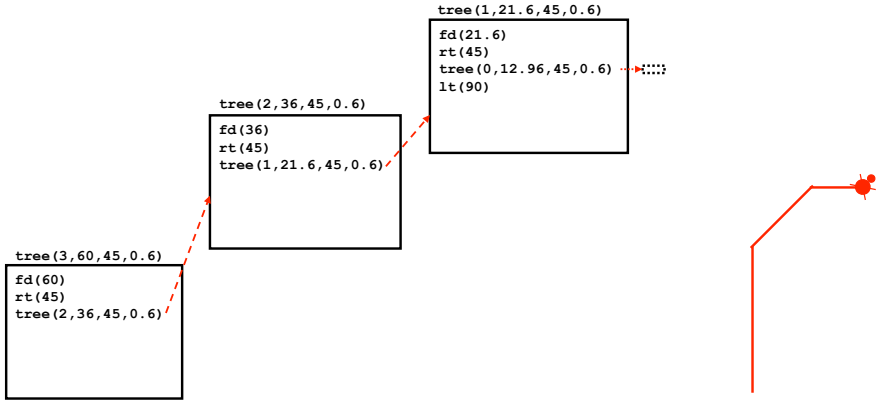
Draw trunk and turn to draw level 0 tree



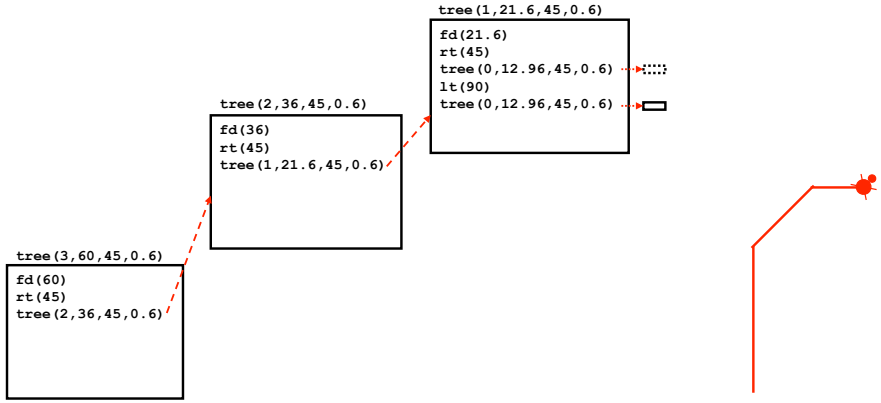
Begin recursive invocation to draw level 0 tree



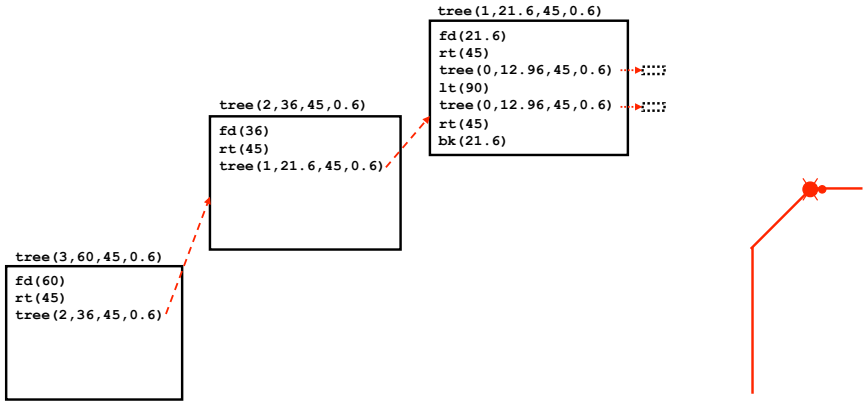
Complete level 0 tree and turn to draw another level 0 tree



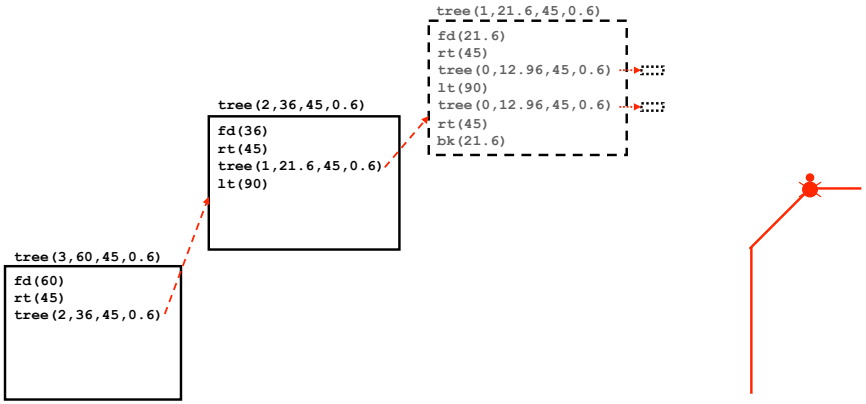
Begin recursive invocation to draw level 0 tree



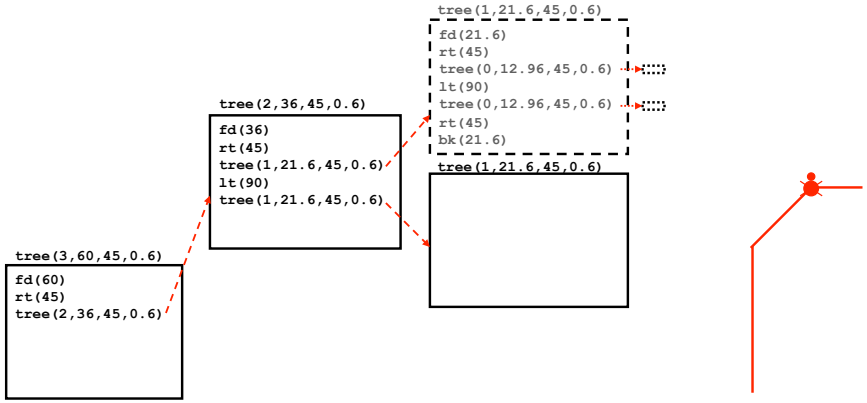
Complete level 0 tree and return to starting position of level 1 tree



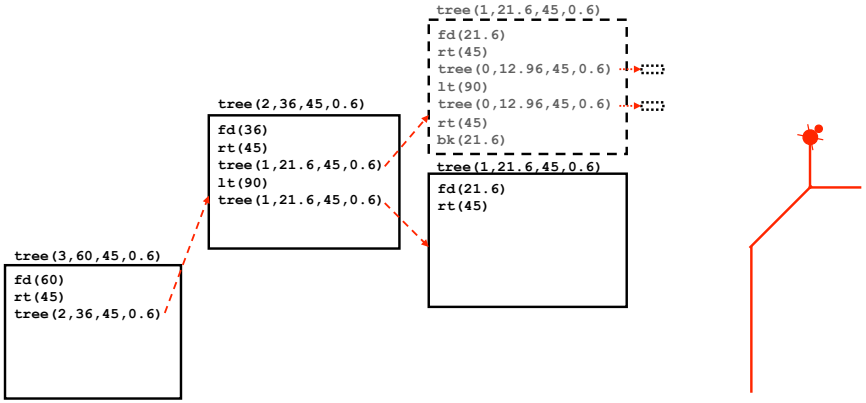
Complete level 1 tree and turn to draw another level 1 tree



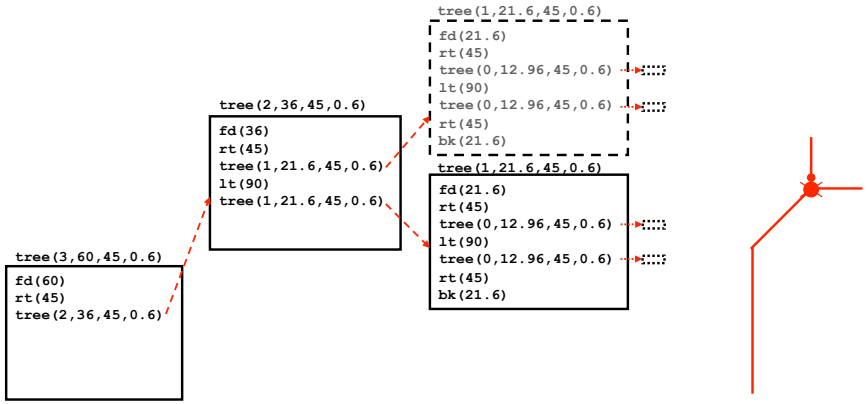
Begin recursive invocation to draw level 1 tree



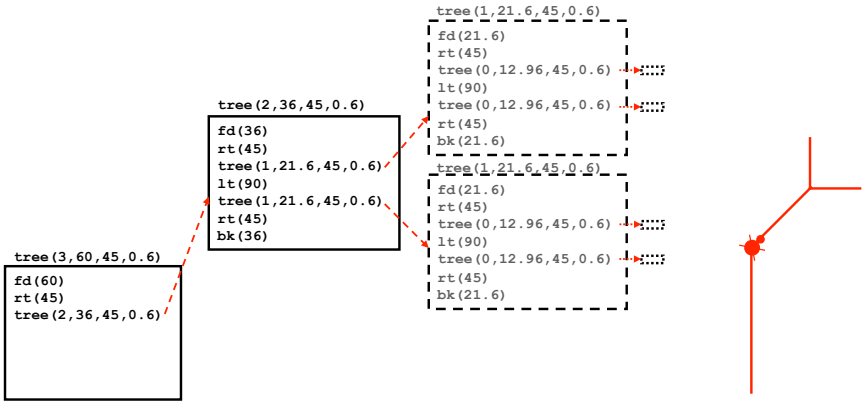
Draw trunk and turn to draw level 0 tree



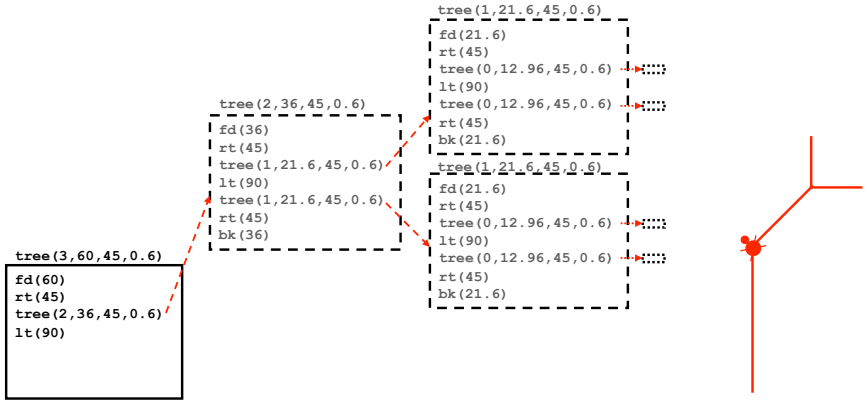
Complete two level 0 trees and return to starting position of level 1 tree



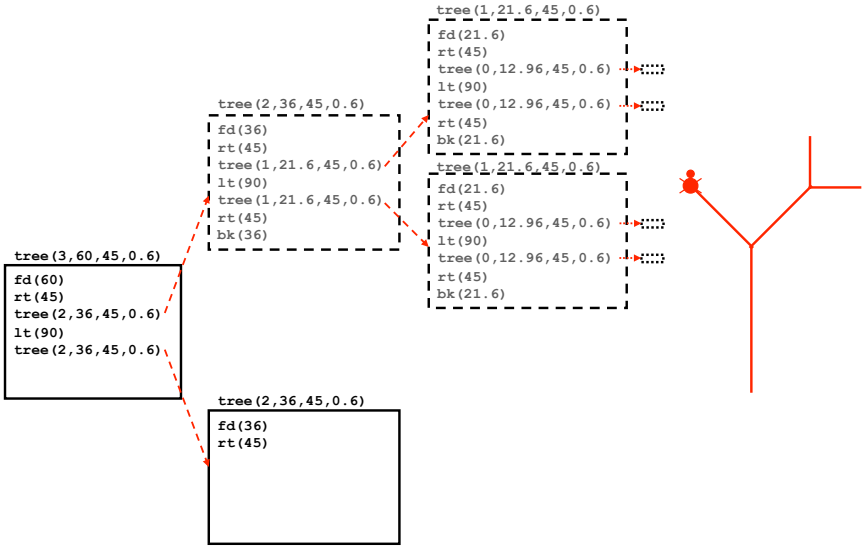
Complete level 1 tree and return to starting position of level 2 tree



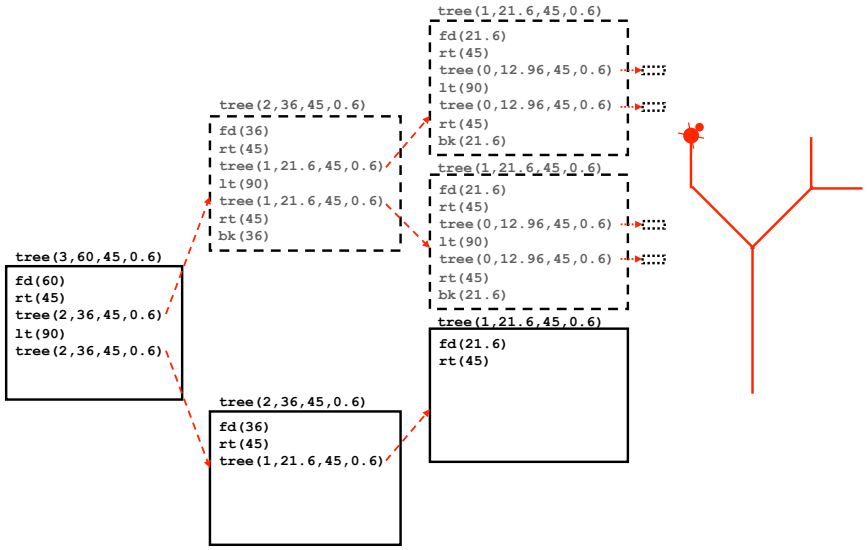
Complete level 2 tree and turn to draw another level 2 tree



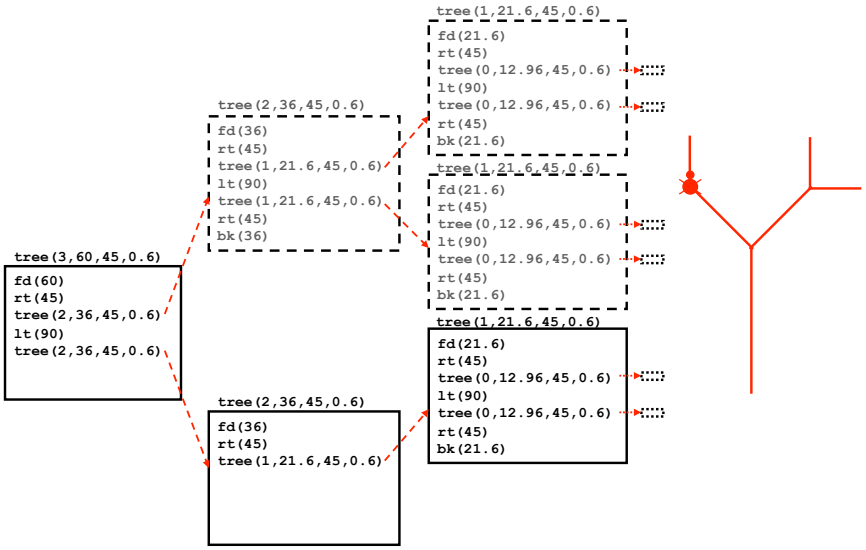
Draw trunk and turn to draw level 1 tree



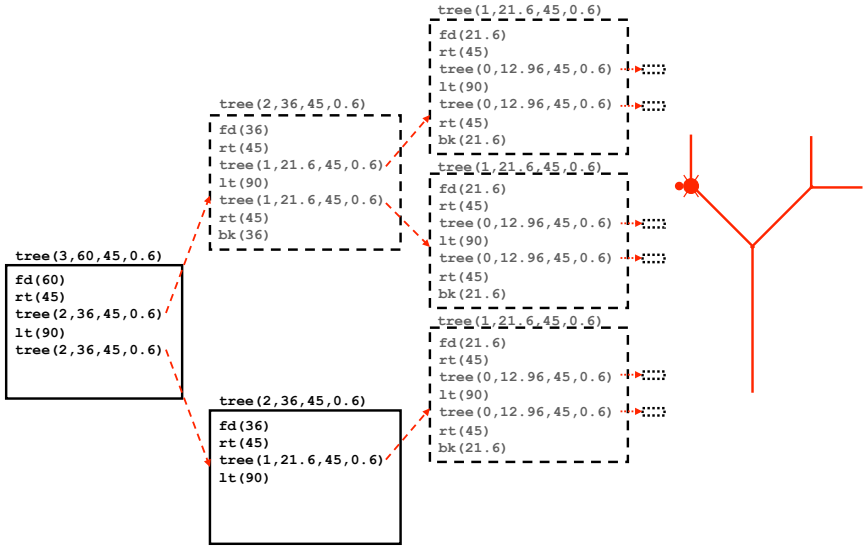
Draw trunk and turn to draw level 0 tree



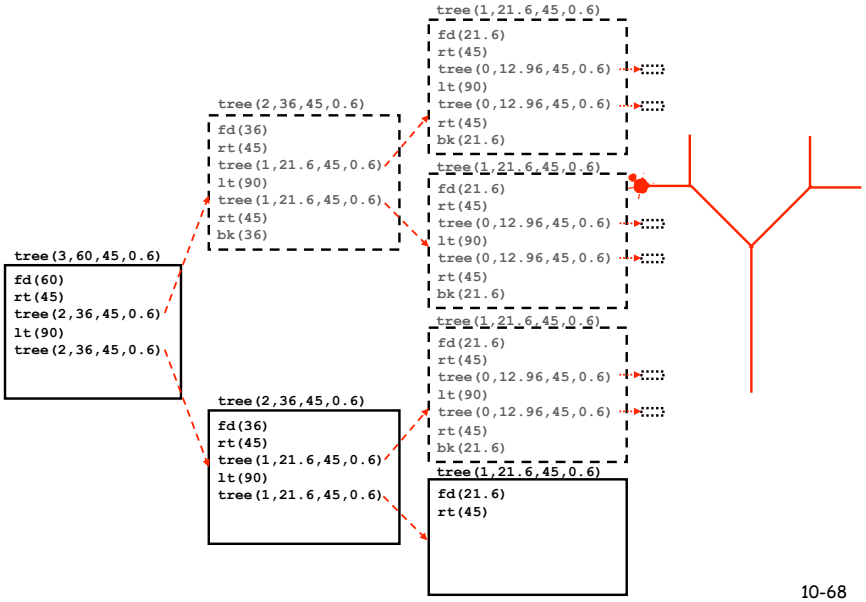
Complete two level 0 trees and return to starting position of level 1 tree



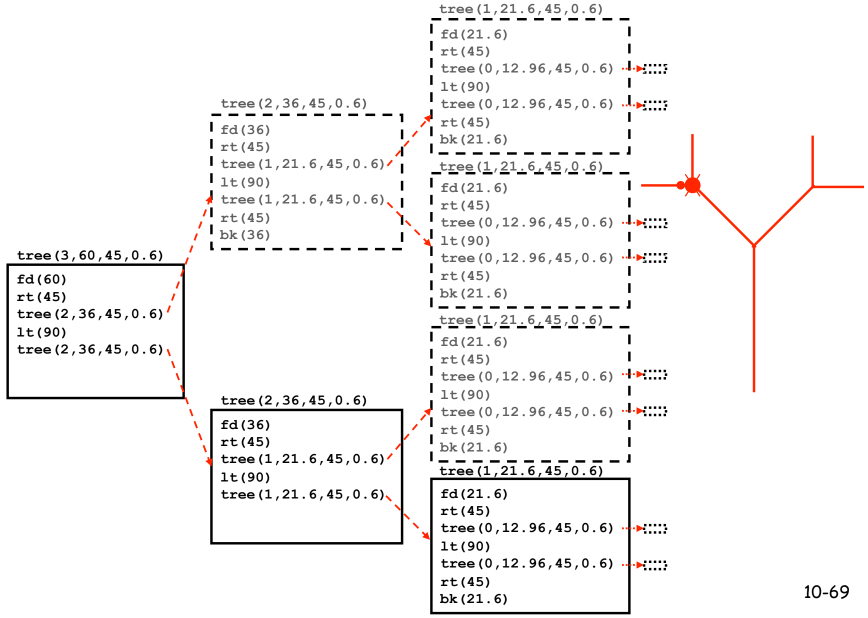
Complete level 1 tree and turn to draw another level 1 tree



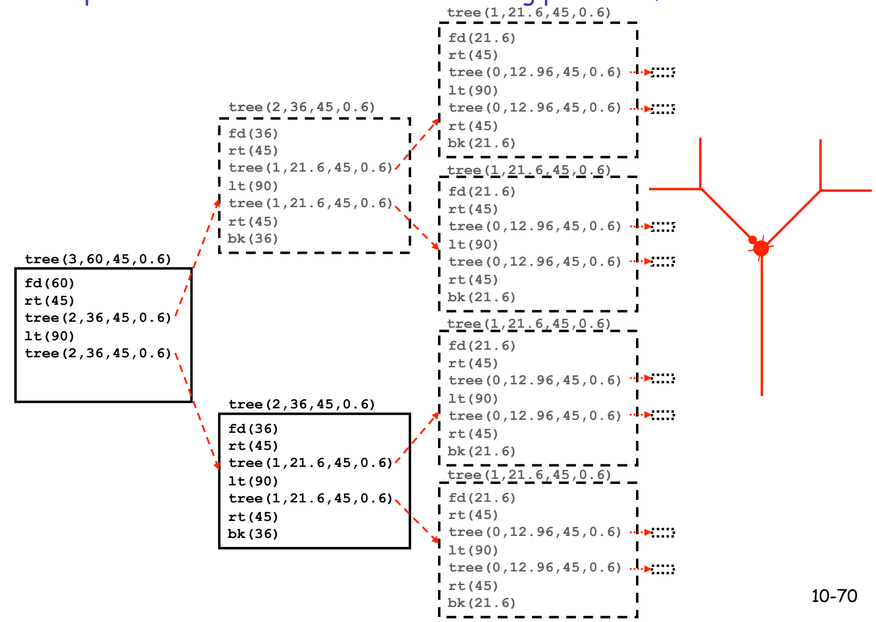
Draw trunk and turn to draw level 0 tree



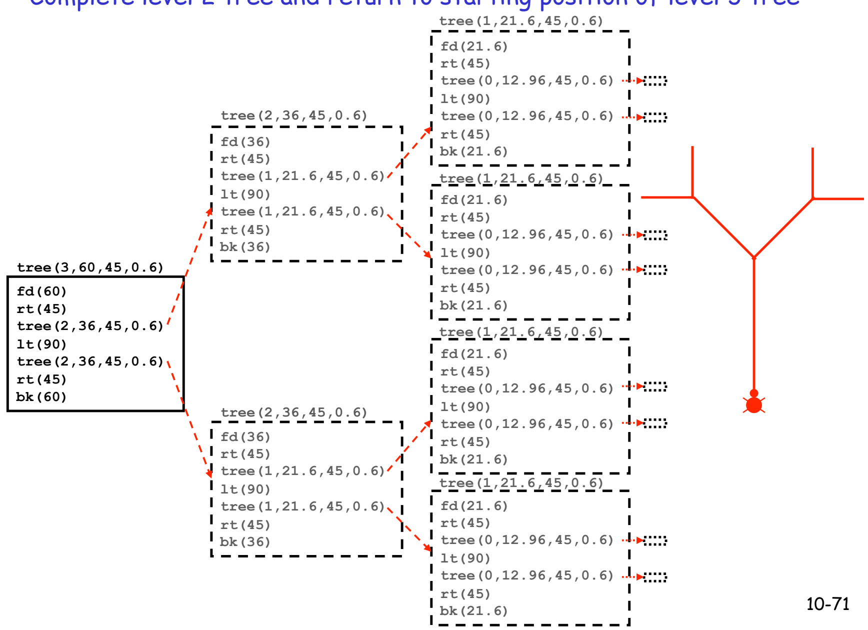
Complete two level 0 trees and return to starting position of level 1 tree



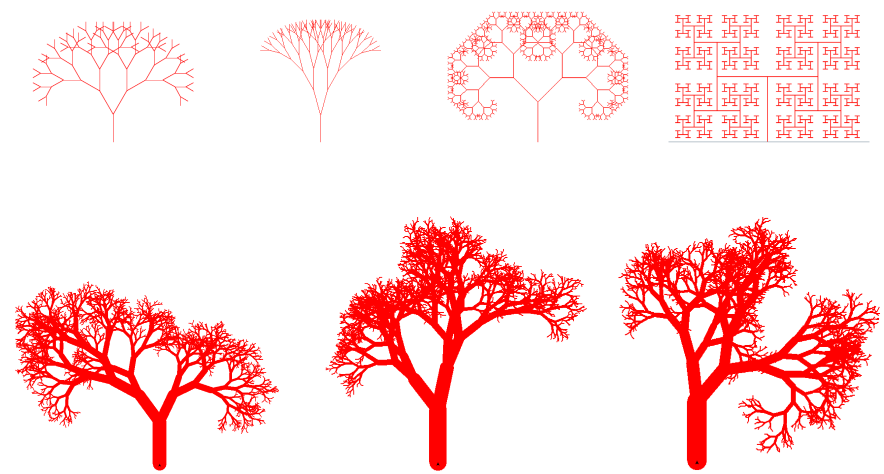
Complete level 1 tree and return to starting position of level 2 tree



Complete level 2 tree and return to starting position of level 3 tree



The squirrels aren't fooled



Random Trees

```
def treeRandom(length, minLength, thickness, minThickness,
               minAngle, maxAngle, minShrink, maxShrink):
    if (length < minLength) or (thickness < minThickness): # Base case
        pass # Do nothing
    else:
        angle1 = random.uniform(minAngle, maxAngle)
        angle2 = random.uniform(minAngle, maxAngle)
        shrink1 = random.uniform(minShrink, maxShrink)
        shrink2 = random.uniform(minShrink, maxShrink)
        pensize(thickness)
        fd(length)
        rt(angle1)
        treeRandom(length*shrink1, minLength, thickness*shrink1,
                   minThickness, minAngle, maxAngle, minShrink, maxShrink)
        lt(angle1 + angle2)
        treeRandom(length*shrink2, minLength, thickness*shrink2,
                   minThickness, minAngle, maxAngle, minShrink, maxShrink)
        rt(angle2)
        pensize(thickness)
        bk(length)
```


Turtle Ancestry

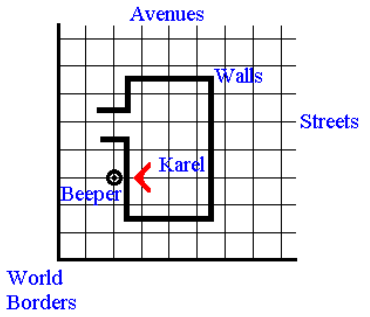
- "Floor turtles" used to teach children problem solving in late 1960s. Controlled by LOGO programming language created by Wally Feurzeig (BBN), Daniel Bobrow (BBN), and Seymour Papert (MIT).

- Logo-based turtles introduced around 1971 by Papert's MIT Logo Laboratory.

- Turtles play a key role in "constructionist learning" philosophy espoused by Papert in *Mindstorms* (1980).

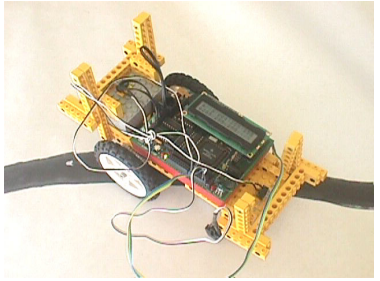
Turtle Ancestry (cont'd)

- Richard Pattis's Karel the Robot (1981) teaches problem-solving using Pascal robots that manipulate beepers in a grid world.
- *Turtle Geometry* book by Andrea diSessa and Hal Abelson (1986).
- LEGO/Logo project at MIT (Mitchel Resnick and Steve Ocko, 1988); evolves into Handyboards (Fred Martin and Brian Silverman), Crickets (Robbie Berg @ Wellesley), and LEGO Mindstorms
- StarLogo – programming with thousands of turtles in Resnick's *Turtles, Termites, and Traffic Jams* (1997).

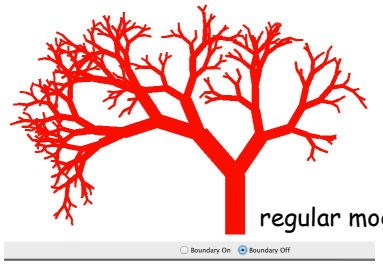


Turtles, Buggles, & Friends At Wellesley

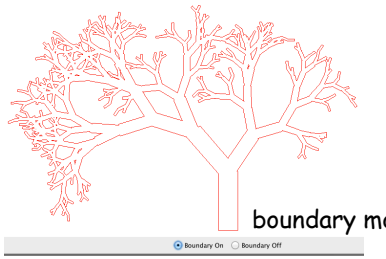
- In mid-1980s, Eric Roberts teaches programming using software-based turtles.
- In 1996, Robbie Berg and Lyn Turbak start teaching Robotic Design Studio with Sciborgs.
- In 1996, Randy Shull and Takis Metaxas use turtles to teach problem solving in CS110.
- In 1997, BuggleWorld introduced by Lyn Turbak when CS111 switches from Pascal to Java. Turtles are also used in the course
- In 2006, Robbie Berg and others introduce PICO Crickets: http://www.picocricket.com
- In 2011, Lyn Turbak and the TinkerBlocks group introduce TurtleBlocks, a blocks-based turtle language whose designs can be turned into physical artifacts with laser and vinyl cutters.



Laser Cutting a Tree



regular mode



boundary mode

laser cutting