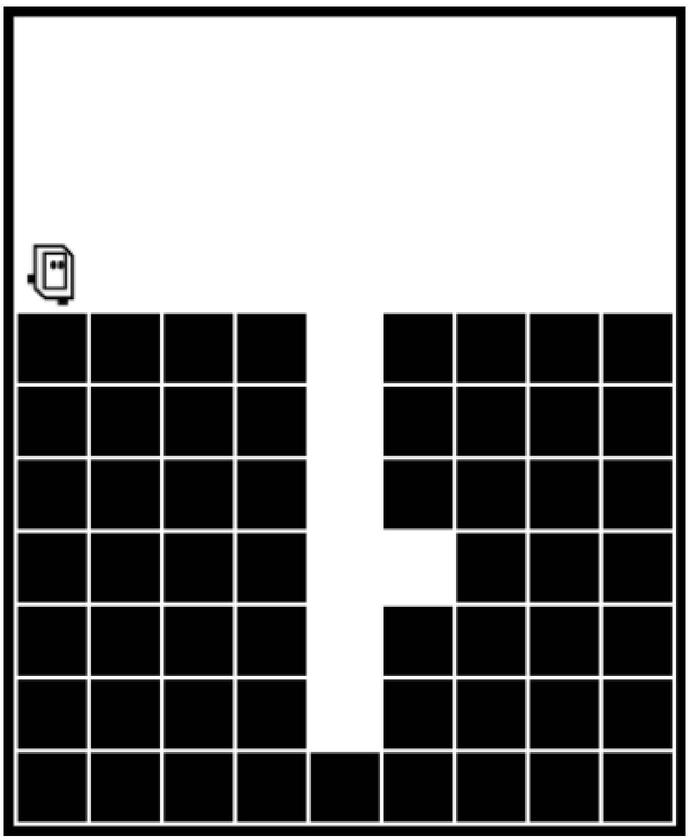
Today: function-call, decomposition bottom-up, top-down, delegation power, style-1

go-niche Example Problem

Here's a problem we'll use to talk about making a drawing.

Problem: Bit moves forward until hole appears below. Then bit goes down the hole until a little niche appears on bits left side. Move bit into the niche.

> go-niche



Strategy...

I'll walk though how I use a drawing to work out the code. This is how you can work the homework problems too, especially if whatever you typed in first is not working and you cannot figure out why.

No - Do It In Your Head

I think a lot of Stanford students feel like - I've gotten pretty far doing stuff in my head! But this work can be very detailed. Kind of "fiddly". The amount of detail is going to grow, so doing it in your head will not always work.

No - Keep Watching The Animation

Don't watch the animation, clicking Run again and again. The animation is not generally well suited to debugging. With Bit, you can debug with the steps slider, dragging it to show a key moment when things go wrong.

Yes - Make A Drawing - "Detail Oriented"

The drawing is frozen, not moving. It can be fairly simple. Use the drawing to take your time with the details, work out the right test is for line 6 or whatever.

The phrase "detail oriented" is kind of running joke for code. People may be detail oriented, but with computer it's taken to the next level. This means we need to slow things down, work the details carefully.

Yes - Helps With Blank Screen

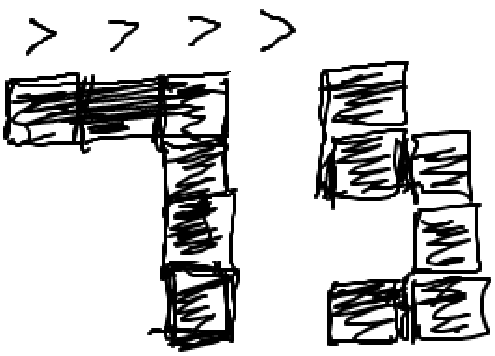
Suppose you are staring at a blank screen and you don't know what line of code to type first. Making a little sketch of the input kind of gets your brain started to picking off parts of the problem.

Aside: Drawing - Office Hours

Inevitably if you are stuck and come to office hours to get help (which is why we are here!). You will notice that the staffer will often end up making a little drawing to work out the details (or ask you to make the drawing).

go-niche Drawing

Here's the sort of drawing we might make to think about the start of this code. What is the while test to advance bit to the hole? This is the sort of drawing you could make to solve the homework problems.

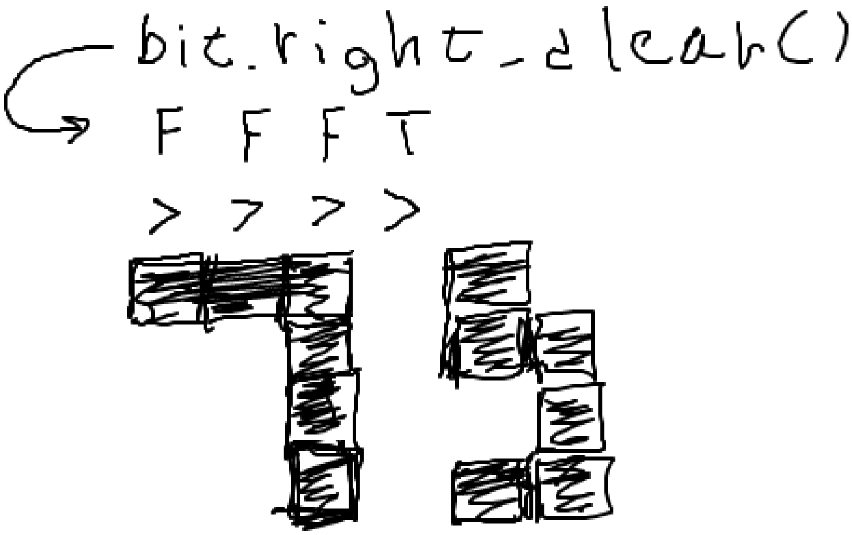


First Guess - `bit.right_clear()`

What is the while-test to find the first hole? I think `bit.right_clear()` is a good first guess. We clearly want something to do with bit's right, and that's the one function we have there.

Draw In the T/F Details

Put the boolean `True/False` values that function will return for each of bit's spots...



Recall: a black block is not clear. Therefore in the above drawing we have `False` when there's a block to bit's right and `True` otherwise.

Opposite Day!

That pattern of `False/True` there is not right. In fact, it's the exact opposite of what we want. We want `True` when bit should move and then a `False` at the last spot where bit should stop.

That's actually easy to fix. The `not` operator, to the left of a boolean value, inverts `True/False`. The correct test is `while not bit.right_clear()` - giving `T T T F` in the drawing, which advances bit to the hole perfectly.

We can click over to the problem and try that first loop. The rest of the problem you will need solve on your own.

> go-niche

The Point - Drawing and Intention

This is not such an easy problem. Use a drawing to freeze the problem, work out the interplay between the details and the code. Then you are putting in the lines of code with intention, knowing what each does. Not putting in random lines and hitting Run in the hopes that maybe it will work.

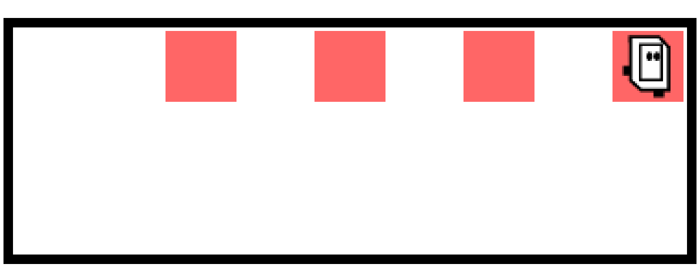
Check Front, then Move

Bit code cannot just do a `move()` any old time. The move needs to be preceded by a `front_clear()` check - in effect this is how bit looks where it is going. This is the issue with this next problem.

Tricky Case: Double Move

> double-move (while + two moves in loop)

The goal here is that bit paints the 2nd, 4th, etc. moved-to squares red, leaving the others blank. This can be solved with two moves and one paint inside the loop, but it's a little tricky.



The code below is a good first try, but it generates a move error for certain world widths. Why? The first move in the loop is safe, but the second will make an error if the world is even width. Run with Case-1 and Case-2 to see this.

```
def double_move(filename):
    bit = Bit(filename)
    while bit.front_clear():
        bit.move()
        bit.move()
        bit.paint('red')
```

Usually you run your code one case at a time, using the Run All option as a final check that all the cases work. In this case, Run All reveals that some cases have a problem with the above code.

Aside: Do Not Run-All To Debug Code

To figure out what is wrong with your code and fix, run a single case so the lines hilight as it runs. Use Run-All to find a case with a problem, but don't debug with it.

Double Move Solution

The problem is the second move - it is not guarded by a front_clear() check, so depending on the world width, it will try move through a wall. The first move in the loop does not have this problem - think about the while-test just before it.

So we don't know if the second move is safe or not. The solution is to put it in an if-statement that checks if the front is clear, only doing the move if front_clear is true:

```
def double_move(filename):
    bit = Bit(filename)
    while bit.front_clear():
        bit.move()  # This move is fine
        if bit.front_clear():
            bit.move()  # This move needs a check
            bit.paint('red')
```

More Practice: Falling Water

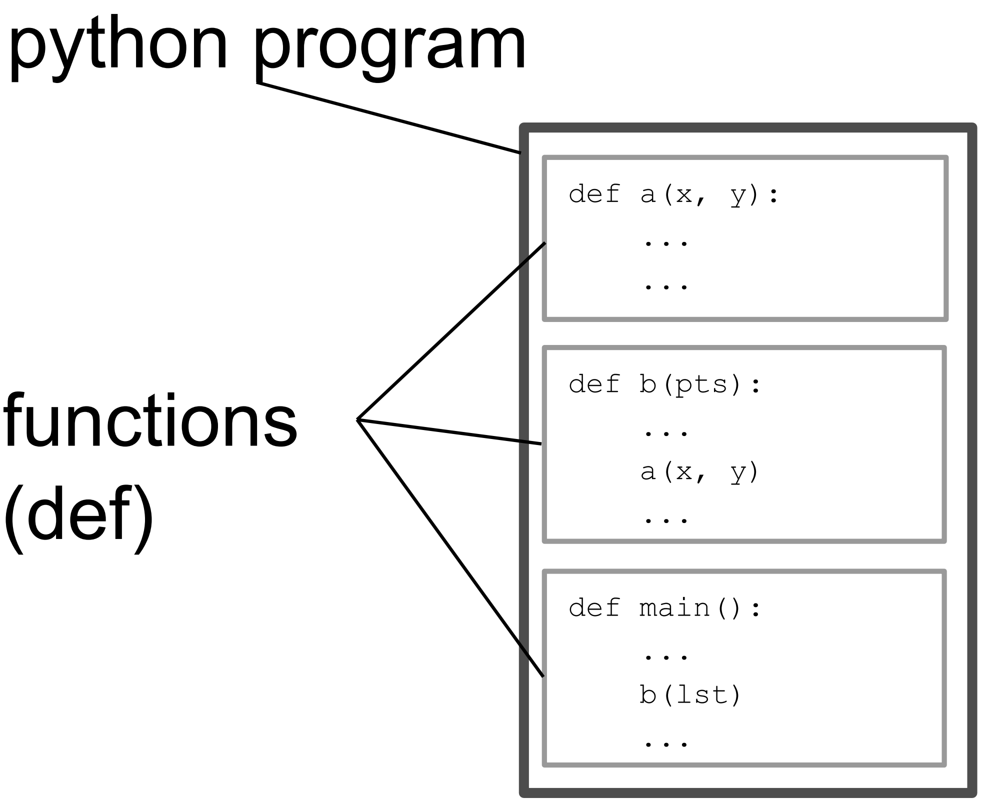
The Falling Water problem in the puzzle section also demonstrates this issue for practice.

Decomposition - Program and Functions

- "Decomposition" - touching on this topic today, more later
- Divide a program into functions, each of manageable size
- "Call" the right function when that situation appears
- This will feel a bit **magical** when it clicks
- Examples below will explore this strategy

Program Made of Functions

Our big picture - program made up of functions



Decomposition Strategy - Divide and Conquer

"Divide and Conquer" - a classic strategy, works very well with computer code

- Confronted with a giant code problem
  Looks impossible

- Divide into more manageable sub-problems
  aka "helper" functions
- Work on the smaller, helper functions, not so bad
- Mesh the functions together to solve the whole thing
- I cannot overstate how key this strategy is to computer systems
  It's how all projects work
- Today: decompose out a helper function

Web Browser - 21 Million Lines Of Code

- Think about the code of a web browser
- PNG images, urls, HTML, inline video, network packets, SSL encryption, DOM tree, ...
- The Firefox web browser is built from 21 million lines of code
- That is an inconceivable amount of code

Decompose Browser into Functions

- Writing all the browser code is too much
- But you can imagine a function that solves one part of the browser
  `render_png_image()`
  `check_ssl_keys()`
- This is how code projects of any size are built
- Decompose into smaller functions
- Work on each function separately

Call/Run a Function - 2 Ways

To "call" a function means to go run its code, and there are two ways it is done in Python. Which way a function is called is set by its author when the function is defined.

1. Call by noun.verb

For "object oriented" code, which is how bit is built, the function call is the noun.verb form, e.g. `bit.left()`. Here "left" is the name of the function. Your code calls bit functions with this form now, and in future weeks we'll use many functions with the same noun.verb syntax...

```
bit.left()          # turn bit


s.lower()           # compute lowercase of s


lst.append(123)     # append to list
```

`def` - Function Name and Code

Look at a `def` again to see what it does. Here's what `def` for a bit problem might look like...

```
def go_west(bit):
    bit.left()
    bit.paint('blue')
    ...
```

The def establishes that this function name, **`go_west`**, refers to these indented lines of code. the def does not run the code. It establishes that this name refers to this code. If another part of the program wants to refer to this function, it uses the name **`go_west`**.

2. Call Function By Name

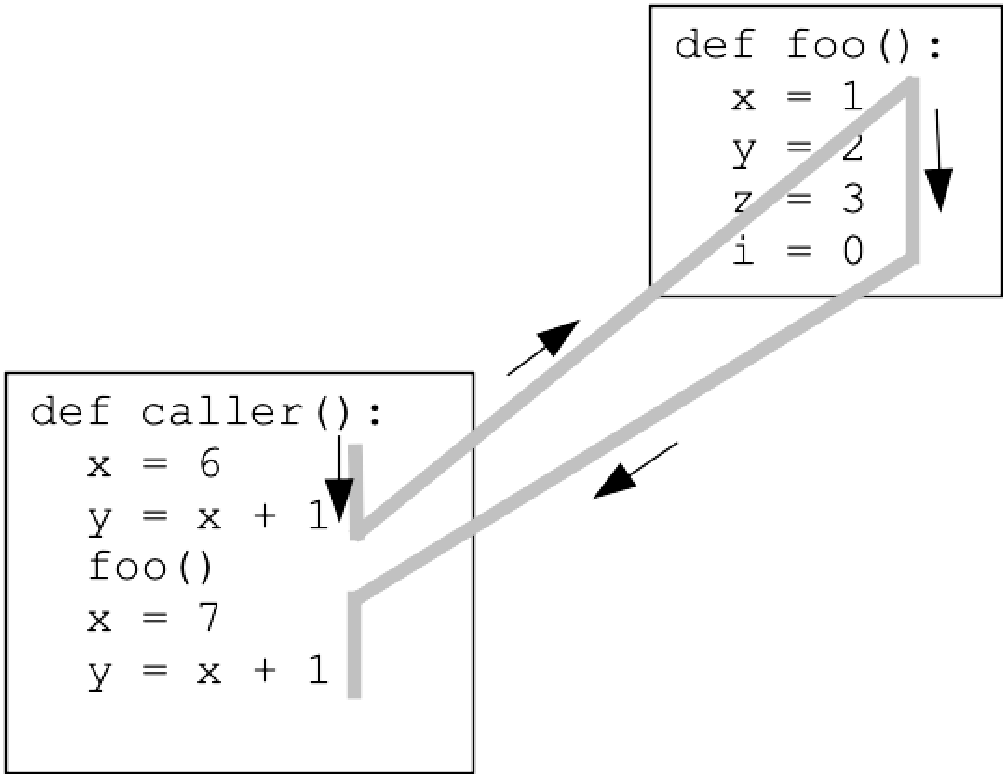
The second type of function call in Python is deceptively simple. You just type the function's name with parenthesis after it. Here is what a line of code calling the above **`go_west`** function looks like:

```
    ...
    go_west(bit)
    ...
```

The word "bit" goes in the parenthesis for now. We will explain that in detail later.

Function Call Picture

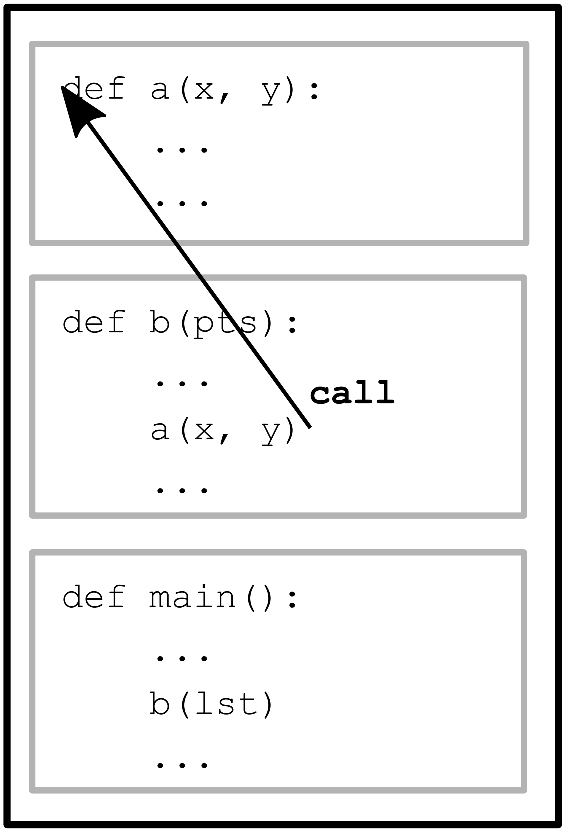
Calling a function prompts the computer to go run the code in that function, and then comes back to where it was. Say for example the computer is running in a "caller" function, and within there is a call to a `foo()` function - the computer goes to run the `foo()` code, then returns and continues in the caller function where it left off.



The computer is only running one function at a time.

Foreshadow Picture - Functions Calling Functions

High level - we have a program made of functions, each marked by a `def` and a name. Functions inside of the program will call each other, using their names. Python does not care what order the defs are in the program. Usually we put the simpler functions at the top, and the more complex ones below.



Helper Function

A "helper function" is function that solves a smaller, sub-problem. We build the helper function first, then later functions can call it to solve that sub-problem.

Decomposition - Bottom Up

For our first examples, we'll work on the helper function first, then the function that calls it. This is the "bottom up" order. There's also a top-down example we'll do at the end where you write the helper last. These are both fine techniques.

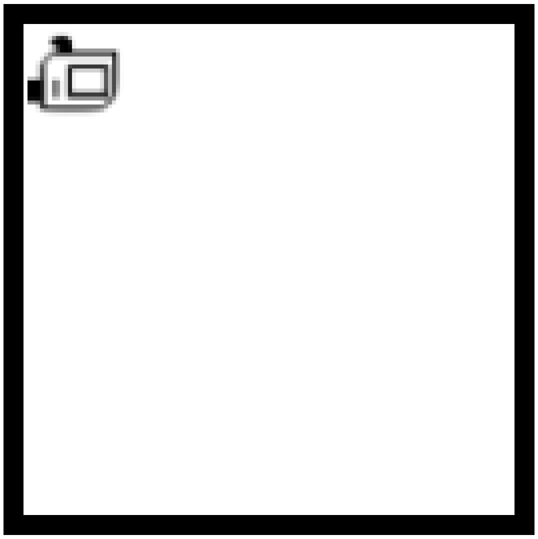
Decomposition Example 1 - Fill Example

This example demonstrates bit code combined with divide-and-conquer decomposition. We'll write a helper function to solve a sub-part of the problem.

> Fill Example

The whole program does this: bit starts at the upper left facing down. We want to fill the whole world with blue, like this

Program Before:



Program After:

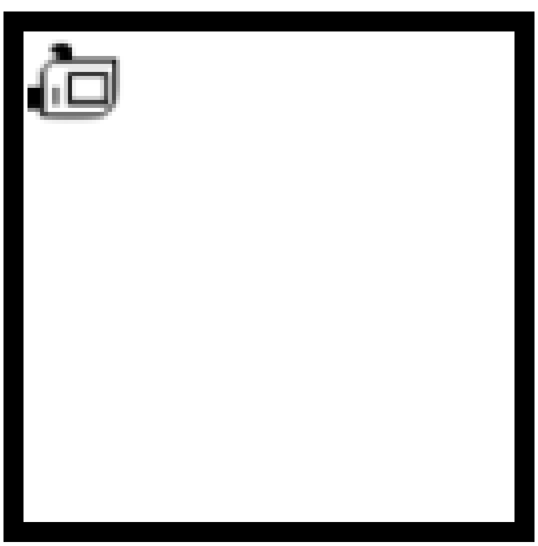
alt: world filled blue, bit at lower left

Step 1. - Helper Function `fill_row_blue()`

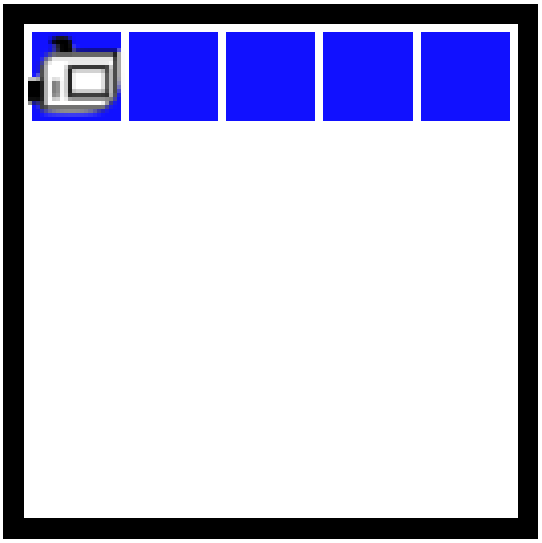
First we'll decompose out a fill_row_blue() function that just does 1 row.

This is a "helper" function - solves a smaller sub-problem.

`fill_row_blue()` Before (pre)



`fill_row_blue` After (post):



We could have you write the code for this one, but we're providing it today to get to the next part.

Run the `fill_row_blue()` helper a few times (Case-1) to see what it does.

Function Pre/Post Conditions

- We want to divide the whole program into functions
  Divide And Conquer!
- Careful about each functions boundaries, so they fit together
- Think about their pre/post conditions
- **Pre** - precondition of function
  Required before it runs
- **Post** - postcondition after it runs
  Promised after it runs
- Pre/Post make the "contract" of function - what it does
  What it gets to assume when it is called
  What it promises to provide

Pre/Post - Why Do I Care?

- We are building a program of multiple functions
  This practice is a huge productivity booster
- Need to make sure the functions mesh together

- Can we just call a function any old time?
- No - need to meet its pre conditions
- Suppose we want to call `a()` and then call `b()` - what's required?
- First check `a()` pre, make sure those conditions are true
- Then check the `a()` post matches the `b()` pre
  May need to do a little adjustment, e.g. `bit.left()`, before calling `b()`

fill_row_blue() Pre/Post

- Pre: bit is at left edge facing down
- Post: the horizontal row is all blue, bit is back at the exact start location and direction
- Convention: it's not required, but a post condition where bit returns to its original location is simple and easy to keep in mind, so we often do it that way.

Now comes the magic step for today - calling the helper function.

Challenge: Write `fill_world_blue()`

- Now write the fill_world_blue() function to solve the whole world
- Make a drawing to guide thinking
- Mindful of pre/post of helper

Aside: Milestone Strategy

To build a big program, don't write the whole thing and then try running it. Have a partially functional "milestone", get that working and debugged. Then work on a next milestone, and eventually the whole thing is done. We'll do this on every project, and it's the quickest way to get systems working.

2 Row Milestone

As an experiment write code to just solve the first 2 rows, without a loop. This is a test "milestone", working out that some things work, but without solving the whole thing.

1. How can I get the 1st row filled?

This can be done with 1 line of code. Think function-call.

2. How can I get the 2nd line filled?

Where is bit and with what facing after solving one row? How can you know what the bit state will be?

3. Loop Solve n-1 Rows

Put in a while loop, solve all the rows except the top one.

4. Solve The Whole Thing

Put in one call to solve the top row, then a loop solves all the lower rows.

`fill_world_blue()` Solution

```
def fill_world_blue(filename):
    bit = Bit(filename)   # provided
    fill_row_blue(bit)
    while bit.front_clear():
        bit.move()
        fill_row_blue(bit)
```

Helper Functions - A Great Deal!

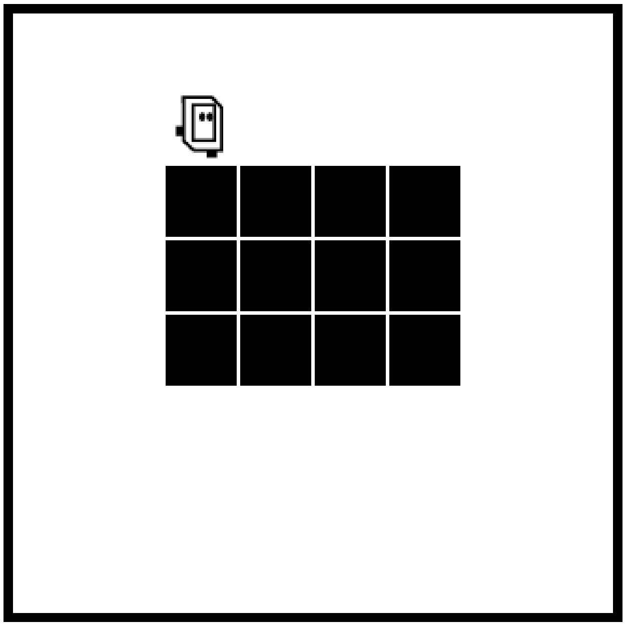
- Create a helper function for a sub-problem
- Later, just call it to solve that
- Like you're the boss - do what I say!
- Think about its pre/post conditions when calling

Decomposition Example 2 - Cover

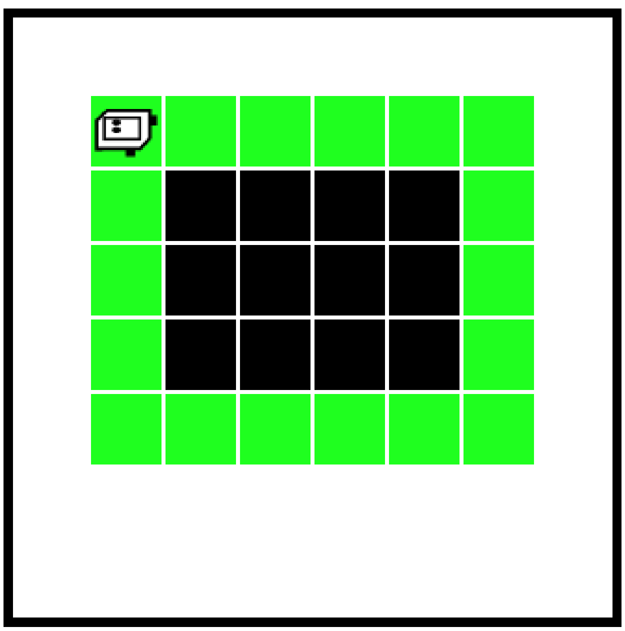
> [Cover Example]

Bit starts next to a block of solid squares (these are not "clear" for moving). Bit goes around the 4 sides clockwise, painting everything green.

`cover_square()` Before (pre):



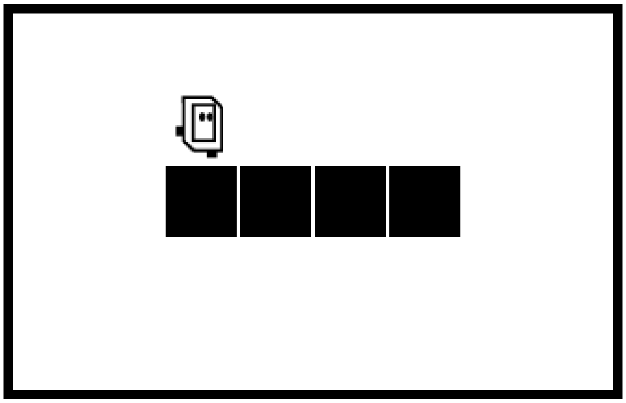
`cover_square()` After (post):



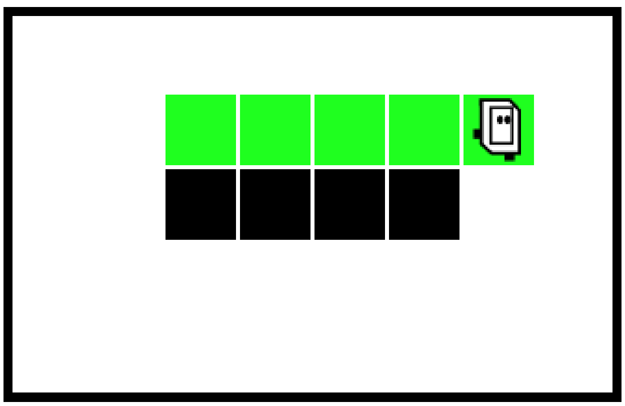
Cover Helper - `cover_side()`

Code for this is provided.

`cover_side()` Before: on top of first square, facing direction to go



`cover_side()` After - move until clear to the right, painting every square green



1. Run cover_side()

cover_side(bit) specification: Move bit forward until the right side is clear. Color every square green.

Run this code with case-1, to see what it does. (code provided)

2. Challenge: write code for `cover_square()`

cover_square(bit) specification: Bit begins atop the upper left corner, facing right. Paint all 4 sides green. End one square to the left of the original position, facing up.

Add code to paint the top and right sides. Key ideas:

- Call previously defined function to do work
- Must figure on helper function pre/post to mesh the calls properly
- Trap: think about code inside cover_side()

- Correct: think only of its pre/post
- "Like A Boss" - just call the function, it jumps to your command!
- What happens if just turn right, and call the helper? What's the problem?
- Start with top and right sides to get the idea
- Then add the other 2 sides
- The partial bit-output works as a sort of drawing to work out the needed pre/post

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Top-Down Decomposition Strategy

- Thus far, we write the helper first - aka "bottom - up"
- Top-Down Decomposition recipe:
- We have problem X to solve
- Thinking up the code for solve_x() function
- Q: what would be useful helper function here?
- Q: something I could call to solve a sub-part of the problem?
- These functions do not exist yet, we are trying to think them up
- What should be the pre and post conditions of the helper?
- e.g. say we think up a function called helper()
- 1. Outline the code for solve_x(), calling helper()
- 2. Now go implement the code for helper() too
- 3. Ideally, test helper() independently .. not doing that here

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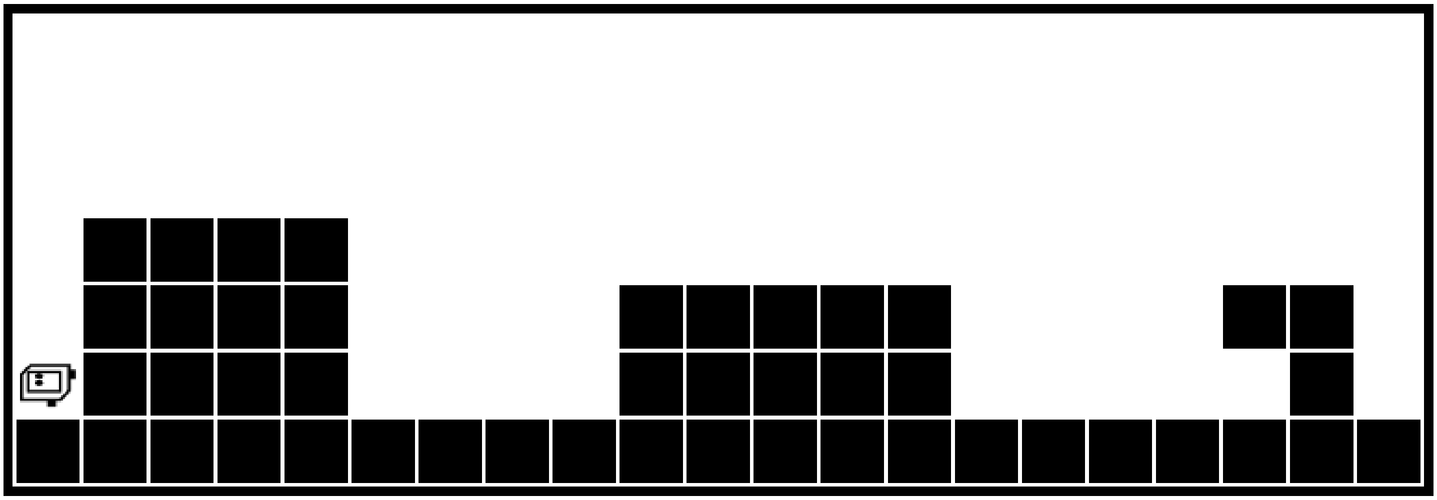
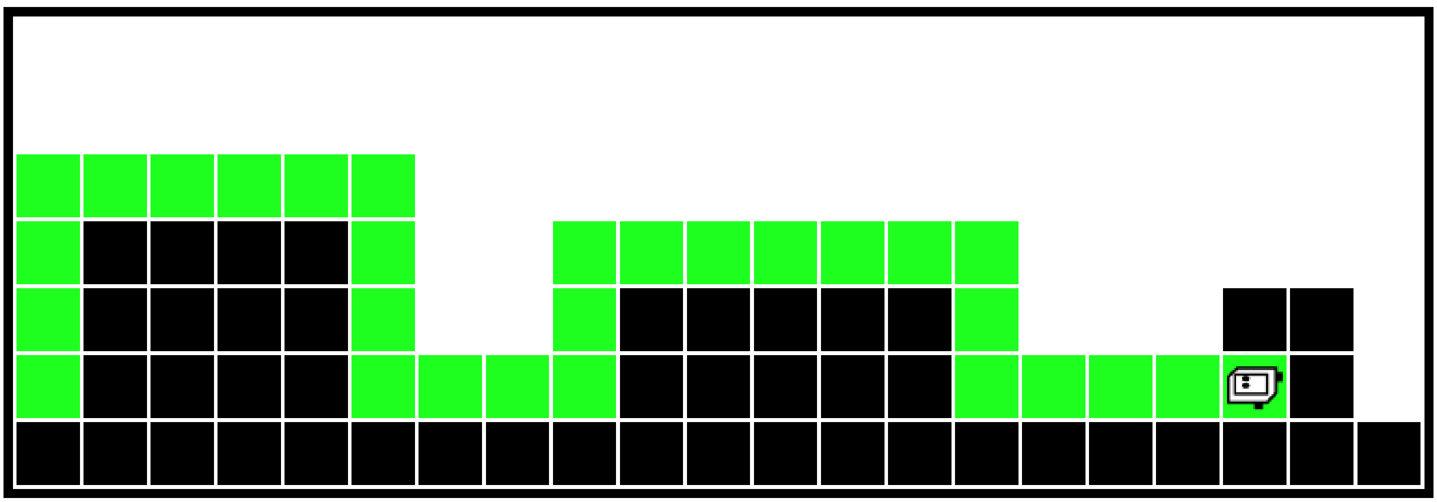
Decomposition Example 3 - Hurdles

> Hurdles

Before



After



Top-Down Decomposition - Hurdles

- Do this as a top-down decomposition example
- Start with the top level function that solves the whole thing
  e.g. **solve_hurdles()** code below
- What helper function would be helpful?
- Write solve_1_hurdle() first
- Then write helpers for that
- Keep pre/post in mind as we go

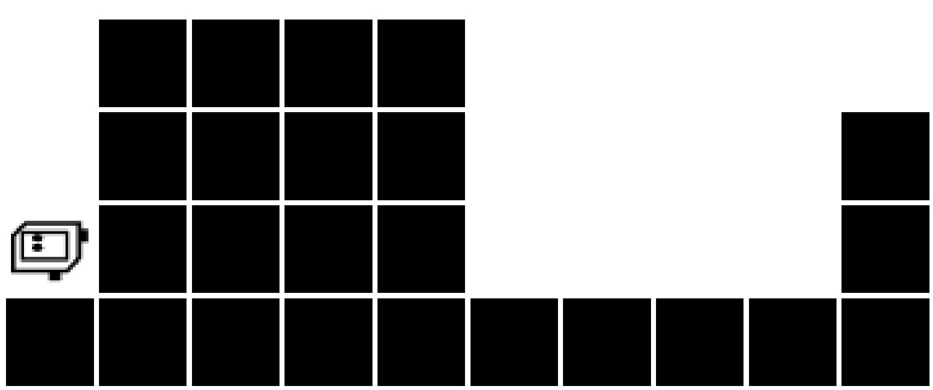
solve_hurdles()

- solve_hurdles() function - the "top level" function
  solves the whole thing
- Its helper could be solve_1_hurdle()
  pre: facing up start of hurdle
  post: facing up start of next hurdle

```
def solve_hurdles(filename):
    """
    Solve the sequence of hurdles.
    Start facing north at the first hurdle.
    Finish facing north at the end.
    (provided)
    """
    while bit.front_clear():
        solve_1_hurdle(bit)
```

solve_1_hurdle()

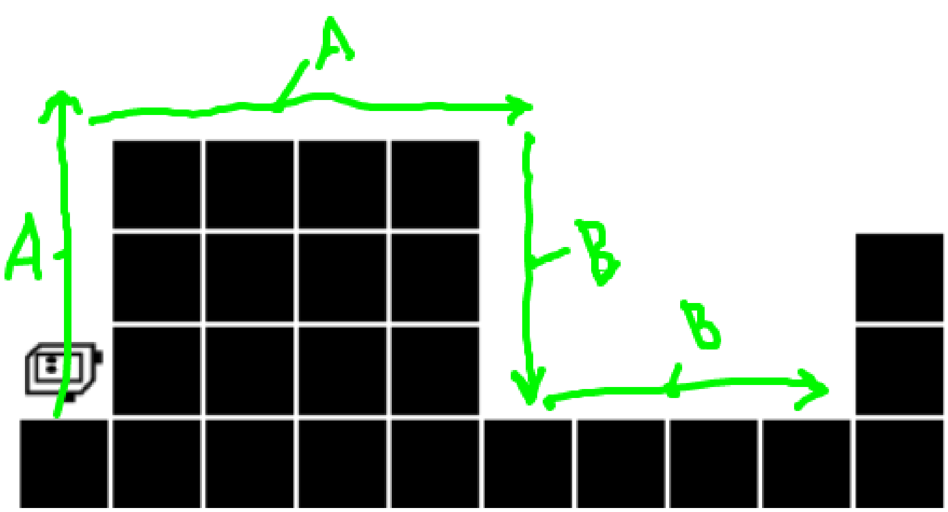
Want a helper function to solve one hurdle. If we had this, `solve_hurdles()` would be easy. Just doing one hurdle is not so intimidating. Divide and conquer!



What helper functions would be useful here? Make observation about the 4 moves that make up a hurdle.

- Now focus on writing solve_1_hurdle()
- What are its pre/post conditions?
- What helpers would be useful in here?
- There are 4 moves, 2 moves of one type (A), 2 moves of a second type (B)
- Write a helper function for each move type
- helper A: `go_wall_right()` - go while wall to right
- helper B: `go_until_blocked()` - go until wall in front
- Running a hurdle looks somewhat like A, A, B, B
  With some turn/moves in between
- Note the pre/post of the helpers to mesh together
- Write solve_1_hurdle() code calling them
- Then need to go write the helpers
- Divide and conquer theme: isolate a sub problem, write code for just that part

Here is a sketch, working out that there are two sub-problem types



Imagine that the helpers `go_wall_right()` (A) and `go_until_blocked()` will exist. See if you can write code for `solve_1_hurdle()`, which is the most interesting function. You cannot run it until the helpers exist (next section).

`solve_1_hurdle()` Solution

```
def solve_1_hurdle(bit):
    """
    Solve one hurdle, painting all squares green.
    Start facing up at the hurdle's left edge.
    End facing up at the start of the next hurdle.
    """
    go_wall_right(bit)
    bit.right()
    bit.move()
    go_wall_right(bit)
    bit.right()
    go_until_blocked(bit)
    bit.left()
    go_until_blocked(bit)
    bit.left()
```

Write The A/B Helpers

Now write the helpers for the A/B sub-problems. Here we see the importance of the pre/post to mesh the functions together. (For lecture demo, may just use prepared versions of these.)

```
def go_wall_right(bit):
    """
    Move bit forward so long as there
    is a wall to the right. Paint
    all squares green. Leave bit with the
    original facing.
    """
    bit.paint('green')
    while not bit.right_clear():
        bit.move()
        bit.paint('green')


def go_until_blocked(bit):
    """
    Move bit forward until blocked.
    Painting all squares green.
```

```
    Leave bit with the original facing.
    """
    bit.paint('green')
    while bit.front_clear():
        bit.move()
        bit.paint('green')
```

Single Hurdle Test

With the helpers written, set solve_hurdles() to the code below, testing one hurdle but not the loop:

```
def solve_hurdles(filename):
    """
    Solve the sequence of hurdles.
    Start facing up at the left edge of a hurdle.
    Finish facing up at the end.
    (provided)
    """
    bit = Bit(filename)
    solve_1_hurdle(bit)
    # Un-comment the loop when the helpers
    # are done
    # while bit.front_clear():
    #    solve_1_hurdle(bit)
```

Final Test

When it can solve one hurdle, change it to the loop form to solve the whole thing:

```
    bit = Bit(filename)
    while bit.front_clear():
        solve_1_hurdle(bit)
```

Try running it on a few worlds. Switch to a small font so you can see all the code at once, watch the run jump around. Go, Bit go!

Power Move: Helpers and Delegation

Think about writing that line where you call a helper

```
...
go_until_blocked(bit)
...
```

- Knowledge is Power, so they say
- Calling a helper function is like delegation
- Call it, do not think about its internal detail
- Just rely on the pre/post
- Say I call a wash_dishes() function
- I want the post condition: dishes are cleaned and not broken
- Do I care if the hand drying is counter clockwise?
- Do I care if they stand here or there?
- Do I care which lights are on?
- In CS these are called the "details" of the computation
- We care about the post condition
- **Not knowing** the details is power
- Work the pre/post, keep your mind clear of the details

Decomposition Practice

You can try the above lecture examples yourself. Use the "Reset Code" button to set it back to the start state.

There's also more problems on the experimental server for practice, Holes and Beloved:

> Holes

> Beloved

Some other points to clean up, if we have time.

Helpers At Top - Convention

There is a convention to put the smallest, helper functions first in a file. The larger functions that call them down below. This is just a habit; Python code will work with the functions in any order. Placing the helpers first does have a kind of logic — looking at solve_1_hurdle(), the functions it uses are defined above it, not after.

solve_1_hurdle() Helpers + Triple Quote

At the top of each function is a description of what the function does within triple-quote marks - we'll start writing these from now on. This is a Python convention known as "Pydoc" for each function. The description is essentially a summary of the pre/post in words, see the """ section in here:

```
def go_wall_right(bit):
    """
    Move bit forward so long as there
    is a wall to the right. Paint
    all squares green. Leave bit with the
    original facing.
    """
    bit.paint('green')
    while not bit.right_clear():
        bit.move()
        bit.paint('green')
```

Run vs. Helper Tests

Previously we had separate testing for each helper which is ideal, and we will do that again in CS106A. In this case, we just run the whole thing and see if it works without the benefit of helper tests.

Coding Style 1.0 - Tactics

CS106A doe not just teach coding. It has always taught how to write *clean* code with good style. Your section leader will talk with you about the correctness of code, but also pointers for good style.

All the code we show you will follow PEP8, so just picking up the style tactic that way is the easiest.

See our Python Guide Style section. We'll pick out a few things today (for hw1), re-visit it for the rest later.

- Today:
- indent 4 spaces after the colon (:), for def/while/if etc.
  See all our examples
- 1 space between each pair of elements:
  e.g. `1 + 2 * 3`
  e.g. `if x == 'red':`
- No space inside parenthesis, no space to left of comma
  e.g. `foo(1, 1 + 2 * 3, 3)`

- We prefer single quote mark for strings like `'red'`
- The word `pass` in Python means is a placeholder that does nothing
  Often `pass` in the code marks the place where you add code
  Remove the `pass` when you put your code in, it's just a placeholder
- 2 blank lines between defs