Today: variables, digital images, RGB color, for loop

Takes a Few Hours

The HW problems are not that easy. Can take hours. It's not just you!

But we hope, once you have it working, you understand it, then could do it more easily. Like if your homework were deleted, you could do it again pretty readily.

106A Debug Steps, 1 and 2

- 1. Error message
  Read the error message, look at line number
- 2. Wrong Output - (Office Hours)
  Look at the output
  Look at the code that produced it
  What line did the wrong output?
  Draw the world at that moment

Variables - First 3 Rules

See the Python Guide Variables chapter for more details.

A Python variable has a name and stores a value. We'll start with three rules of variables.

1. Creating a Variable

A variable is created in the code by a single equal sign = like this which creates a variable named **x**:

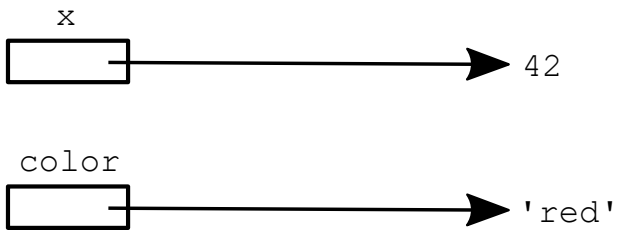
```
x = 42
```

The variable **x** is set at the moment the line runs.

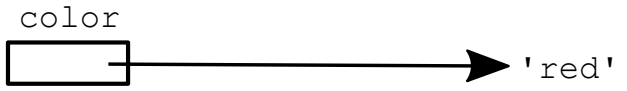
Suppose there is also a line that sets a variable named **color**:

```
color = 'red'
```

Each variable is stored in the computer's memory. Think of the variable as a little box, labeled with the variable's name and containing a pointer to the value stored:



2. Reading A Variable



Suppose code sets a variable **color** to `'red'`. On subsequent lines, appearances of the word `color` will retrieve the stored color. So for example, these lines paint two squares red:

```
color = 'red'
bit.paint(color)
bit.move()
bit.paint(color)
```

The variable, `color`, is set on the first line, and then two later lines use it by its name. The variable name does not have quote marks around it, just appearing as a bare word in the code.

3. Changing Variable – "Now point to"

If a variable already exists, using **=** to change the variable simply changes the variable to refer to the new value. The old value is forgotten. Later references to the variable will use the new value.

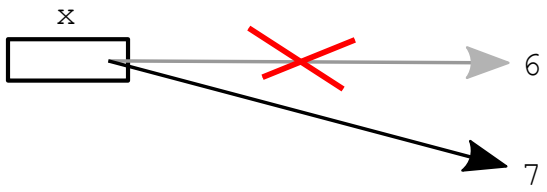
In Mathematical proofs, the equal sign sets up a permanent equality. Not so in code! In code, the = sets the variable to something, but it can be changed to something else with the next =.

So in this example, the first paint is red, but the second is blue

```
color = 'red'
bit.paint(color)

color = 'blue'
bit.paint(color)
```

Or here is an example with numbers




```
x = 6
# for lines here,
# x is 6
...
x = 7
# for lines here,
# now x is 7
...
```

In summary, the **=** is like the phrase: "Now point to"

Optional - All Blue Variable

We're not doing this one in class, but you can try it on your own to see a variable in action.

> all-blue

Go back to our all-blue Bit loop. Change the code to use a `color` variable as below. The variable `color` is set to hold the value `'blue'`, and the later lines just paint whatever color is in the `color` variable. This version paints the whole row blue.

```
def all_blue(filename):
    bit = Bit(filename)
    color = 'blue'
    bit.paint(color)
```

```
while bit.front_clear():
    bit.move()
    bit.paint(color)
bit.right()
```

Look at the lines `bit.paint(color)` lines - they refer to the variable by its name, following the arrow to retrieve `'blue'` or whatever was stored there.

Q: How would you change this code to paint the whole row red?

A: Change line 3 to `color = 'red'` - the later lines just use whatever is in the color variable, so now they will paint red with no other change.

Python Math Expression + Evaluation

Recall that "expression" is a phrase of code that Python "evaluates" to get a value.

You would think that computer programs have a lot of math at their core. It's true! Python can evaluate mathematical expressions, like a calculator can. Python follows the order of operations, so multiplication and division (* /) are evaluated before addition and subtraction (+ -). Other than that, the math is done from left to right. The math here looks a lot like regular mathematics, so we're not going to spend a lot of time explaining it.

So is the resulting value when Python evaluates this expression?

```
1 + 2 * 3
```

The answer is 7, since Python does the multiplication before the addition.

This works with variables too.

```
x = 6
1 + 2 * x * 3
```

The expression evaluates to 37, doing the multiplications from left to right, then the addition.

Interpreter >>> on Experimental Servier

The Python "interpreter" is a program on your laptop which makes Python work on your laptop. More details later on that. However, there is a way you can type code right at the interpreter to see what it does.

Try the >>> interpreter on the experimental server - there's a button for this at the bottom of each problem page on the experimental server. You type a little expression at the ">>>" prompt and hit the enter key. Python evaluates it, prints the resulting value on the next line. We'll use this more as we get into more Python features.

So the ">>>" is the Python interpreter. You type Python code to it directly, see what it does. Not a good way to get work done, but an excellent way to try little phrases of code to see what they do.

Variable Expression Demo

We can use the interpreter to try out the claims about variables and math expressions.

1. Variable Set / Get

```
>>> x = 11
>>> x
11
```

2. Expression

```
>>> 4 + 2 * 5 + 1
15
```

3. Variable + Expression

```
>>> x = 6
>>> 1 + 2 * x    # evaluates to what?
```

The answer is 13. The appearance of **x** in the expression is just an example of a variable - Python retrieves whatever value was set to that variable, in this case 6.

4. Change Variable

```
>>> x = 6
>>> x
6
>>> 1 + 2 * x
```

```
13
>>> x = 7          # change x
>>> 1 + 2 * x
15
```

Changing a variable changes it to point to a new value. After that, uses of the variable use the new value.

Images - Numbers - Code

- Layers of understanding
- 1. See An image - anyone can do that!
- 2. Understand structure of numbers, red/green/blue etc. making an image
- 3. Write code to change the numbers, changing the image .. CS106A!
- We'll look at all of these today

Digital Images - Pixels

- Originally the internet was made of text
- But perhaps images is where it really shines
- Digital images are made of small square "pixels"
  "picture element" - "pixel"
- Pixel = small, square, shows a single color
- The color of a pixel is very often encoded as RGB
- Demo: pebbles.jpg in Mac Preview
  Preview feature: new-from-clipboard to open copied image
  It can zoom in far to see the pixels

See pebbles-zoomed.png

RGB Color Scheme

- The red-green-blue scheme, RGB
- We have three lights: **red**, **green**, and **blue**
- Each color is controlled by a number in the range 0..255
- (Why 255? I'll explain later)
- Each number represents the brightness of the red/green/blue light
- 0 = light is off
- 255 = light at maximum
- Can mix these 3 lights to make any color!
- Define any color by 3 numbers, 0..255
- Live RGB explorer: rgb-explorer
- Note: the RGB light-mixing scheme
  different from paint-mixing scheme

Live RGB LED Demo - IRL!

- Three super-bright LEDs
- red/green/blue

- A "MaxM" unit https://thingm.com/products/blinkm-maxm
- When I type "255 255 0" to this hardware
  Turn red/green to max, blue off
  Can set any combination on these three lights
- We can demo red / green / blue light mixing .. IRL!

Aside: Color Perception - Yikes!

- Red + green makes yellow
- That's close enough for our purposes
- But here's more to it for the curious...
- In reality, yellow is a different color than red or green
  Think of the rainbow
  red, green, yellow - three different colors on the rainbow
  light color = photon frequency
- In reality, your brain **sees** red + green light, interprets it as yellow
- It looks to us as if the red + green made yellow in the air, but that's just perception
- It's actually a bunch of red photons + a bunch of green photons
  Your brain interprets this as yellow

Image Structure in the Computer

- Image is made of pixels
- Pixels are in an x,y coordinate scheme
- Origin (0, 0) at the upper left
  Origin at the upper left feels a little weird at first
  Super common system on computers
  We'll use it all quarter
- x numbers - x=0 is left edge
  x values grow going to the right
- y numbers - y=0 is the top row
  y values grow going down

- Each pixel:
  Small
  Square
  Shows one color
- Pixel's color is encoded as 3 RGB numbers

Image Made of Pixels

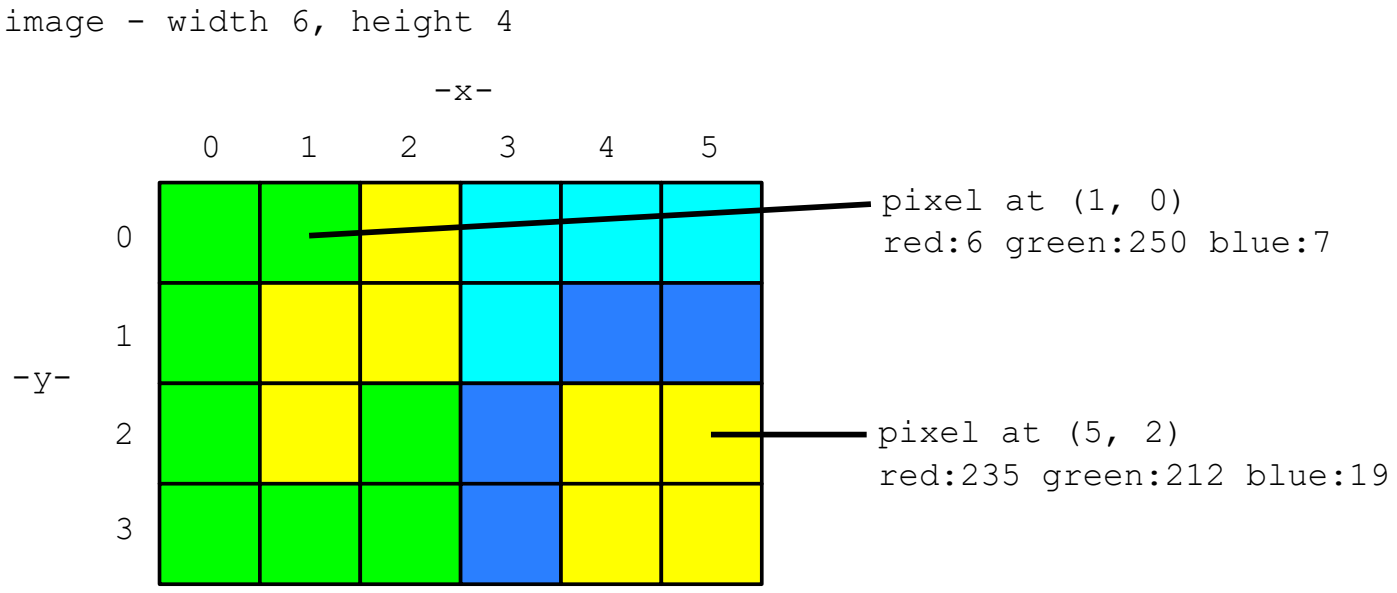
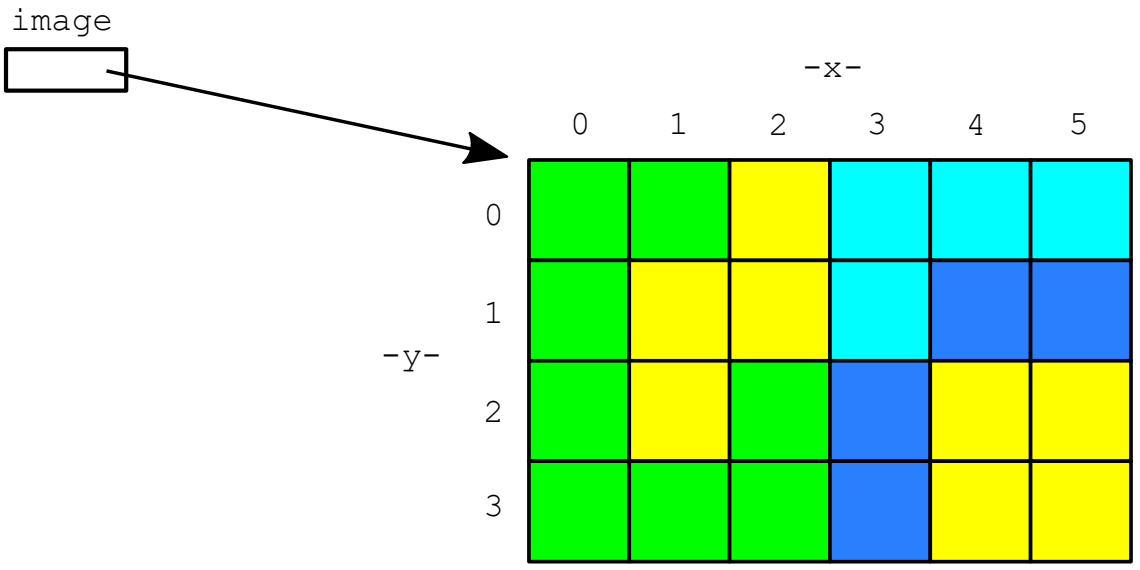


Image Loading Code

This line loads an image into Python memory, and sets a variable named `image` to point to it, ready for Python to work on it.

```
# Load an image from the filesystem
# into memory in variable named "image".
# Now the image can be manipulated by code.

image = SimpleImage('flowers.jpg')
```



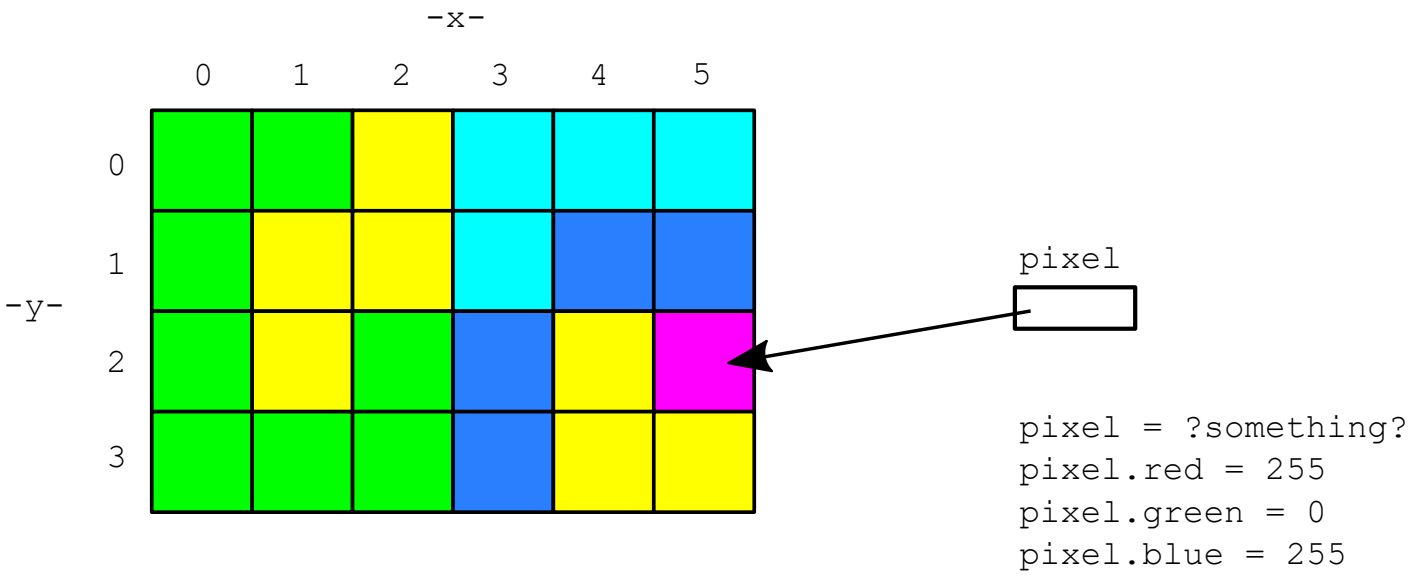
Have an Image, How To Change it?

Say we have loaded an `image` variable as shown above. Now we want to write code to change the image in some way.

For example, let's say we want to set the blue and green values in each pixel of the image to 0. This will leave just the red values. This is called the "red channel" of the image - an image made of just its red lights.

Change Pixel Color: `pixel.red = 255`

Suppose we have a variable `pixel` that refers to one pixel inside an image. (We'll show how to obtain such a `pixel` variable in the next step.)

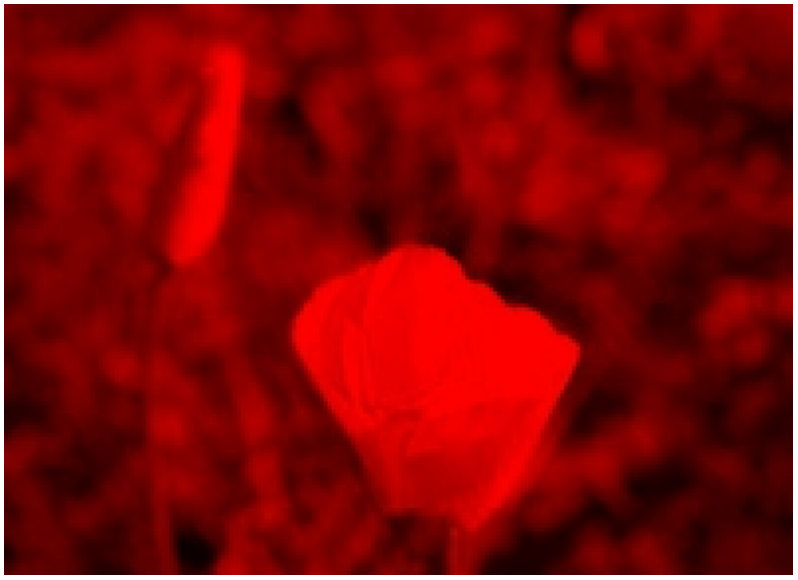


Then the syntax `pixel.red` or `pixel.blue` or `pixel.green` refers to the red or blue or green value 0..255 inside the pixel.

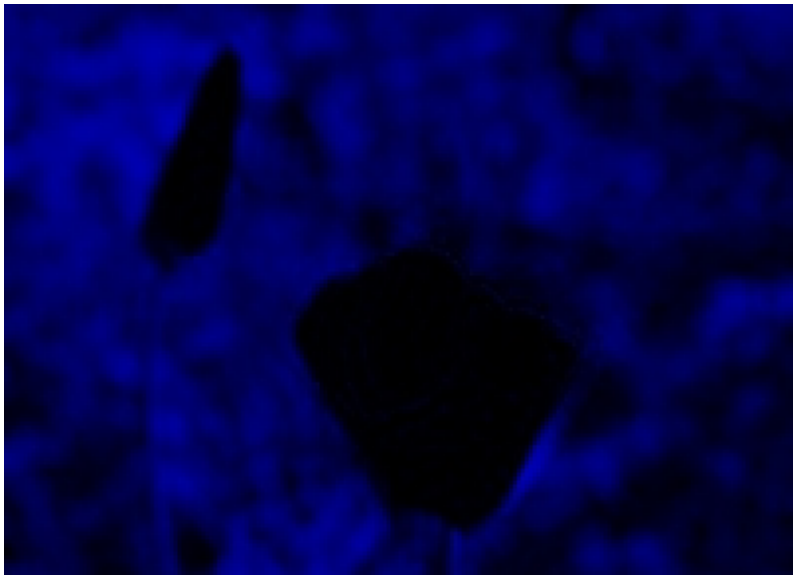
The example code uses = to set the red and blue values of the pixel to 255 and the green value to 0. This changes the pixel to be magenta.

Background: Color Channels

If we take an image, and turn off all the green and blue light but leave the red lights on. This makes the "red channel" image:



Similarly, we can make the green and blue channels:



We'll use these in a minute as an example.

For Loop Introduction

The for-loop is probably the single most useful loop we'll see. Say you have a collection of 1000 urls. The for-loop lets you write a few lines of code, and then run those lines once for each url or whatever is in the collection. This is sometimes called a "for each" loop, since it runs the code once for each element. Being able to run some code once for each element in a collection is very handy, and this is exactly what the for loop gives us.

For Loop Syntax

```
for variable in collection:
    # use variable in here
```

for loop Example - Red Channel

The "red channel" of an image is just the red lights, with blue and green all turned off. Here is the code to make the red channel of an image using a for loop.

```
def red_channel(filename):
    image = SimpleImage(filename)
    for pixel in image:
        pixel.green = 0
```

```
        pixel.blue = 0
    return image
```

Here is a link - you can try running it first, then we'll see how it works

> Image1 Red

Image For Loop Operation

The most important element in the for loop is the **variable** which comes after the `for`. The for-loop takes control of the variable, setting it to point to the next element for each run of the loop body.

For the red-channel example, the loop sets the `pixel` to point to the first pixel in the image and runs the loop body. Then it sets `pixel` to point to the second pixel and runs the loop again. And so on, running the body once for each pixel in the image. If the image has 50,000 pixels, the loop body runs 50,000 times, once for each pixel in the image.

```
for pixel in image:
    # "pixel" points to the next pixel
    # each iteration of the loop
    pixel.green = 0
    pixel.blue = 0
```

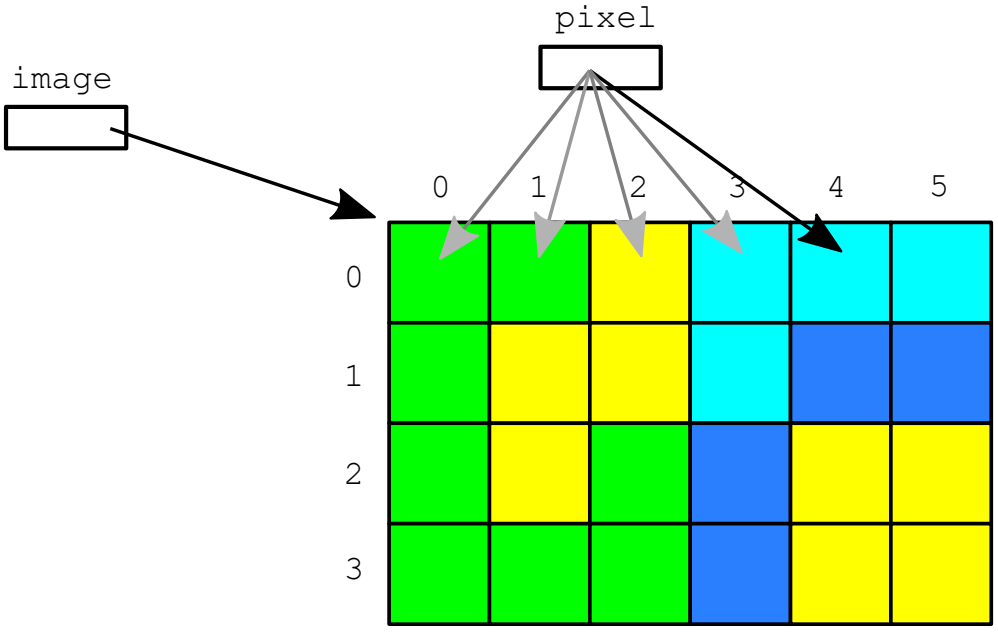


Image For Loop Observations

- Filename is like `'flowers.jpg'`
- `image = SimpleImage(filename)`
  loads image data into memory
- `image` is a variable, points to image data
- `for pixel in image:`
  Loop runs lines once for each pixel in image
  Loop sets `pixel` to point to each pixel in turn
- `return image`
  `return xxx` returns a value back to our caller, more later
- Q: how many times does first line run? How many times do the lines in the loop?
- A: once, once for each pixel
- Demo red_channel()
- So if there are 50,000 pixels, the loop body is run 50,000 times
- Experiment: green channel, make every pixel black
- See how for loop runs over the image
- See how `pixel.red` accesses red/green/blue numbers in the image

Side trip about math

Update Variable: `x = x + 1`

What does this do:

```
x = 6
x = x + 1
```

- Update the value of a variable
- Variable is on both left and right of =
- This changes the variable in a relative way
- Code rule:

- 1. first "evaluate" right side expression, after the =
- 2. assign that value back into the variable
- So x is 7 at the end
- Terminology
  RHS is right hand side `x + 1`
  LHS is left hand side `x =`
  Basically, evaluate the RHS first, then do the LHS assignment

```
x = 6
x = x + 1
```

Example - Make Image Darker

> Image1 Darker

- Try making values smaller, image gets darker
  e.g. red 200, change to red 100 .. literally darker
- `pixel.red = pixel.red * 0.5`
- Relative change of red/green/blue on each pixel
- See below about "shorthand", re-write with *=
- (equivalently `pixel = pixel.red / 2`)

```
for pixel in image:
    pixel.red = pixel.red * 0.5
    pixel.green = pixel.green * 0.5
    pixel.blue = pixel.blue * 0.5
    # or shorthand form:
    # pixel.red *= 0.5
```

Relative Variable Shorthand: += -= *=

Say we have this

```
x = x + 1
```

That can be written in shorthand like this:

```
x += 1
```

If we have this

```
x = x * 2
```

Shorthand form:

```
x *= 2  # double x
```

For these image problems, that looks like

```
pixel.red = pixel.red * 0.5  # long form
pixel.red *= 0.5             # shorthand for
above
```

- Works for all operators, such as `+= -= *= /=`
- Handy because relative math on a variable is very common
- This just make the code more compact, not changing the underlying math

```
>>> x = 10
>>> x += 3
```

```
>>> x
13
>>> x *= 2
>>> x
26
```

Image1 Puzzles

The image1 section is all image problems solved with a for loop to do some operation on every pixel in the image.

> Copper Puzzle

Loop over the image, write code to change pixels, recovering the hidden image. Nick solves part, then students try to type code for the rest.

> 5-10-20 Banana Puzzle

5-10-20 puzzle: The red, green, and blue values are too small by a factor of 5 10 20. But we do not know which factor goes with which color. Figure it out by experimenting with code to modify the image with various factors (i.e. guessing and running it).

> The image1 section has problems like this. The the Iron Puzzle.

Start working on the coordinate numbers .. use this for next lecture examples.

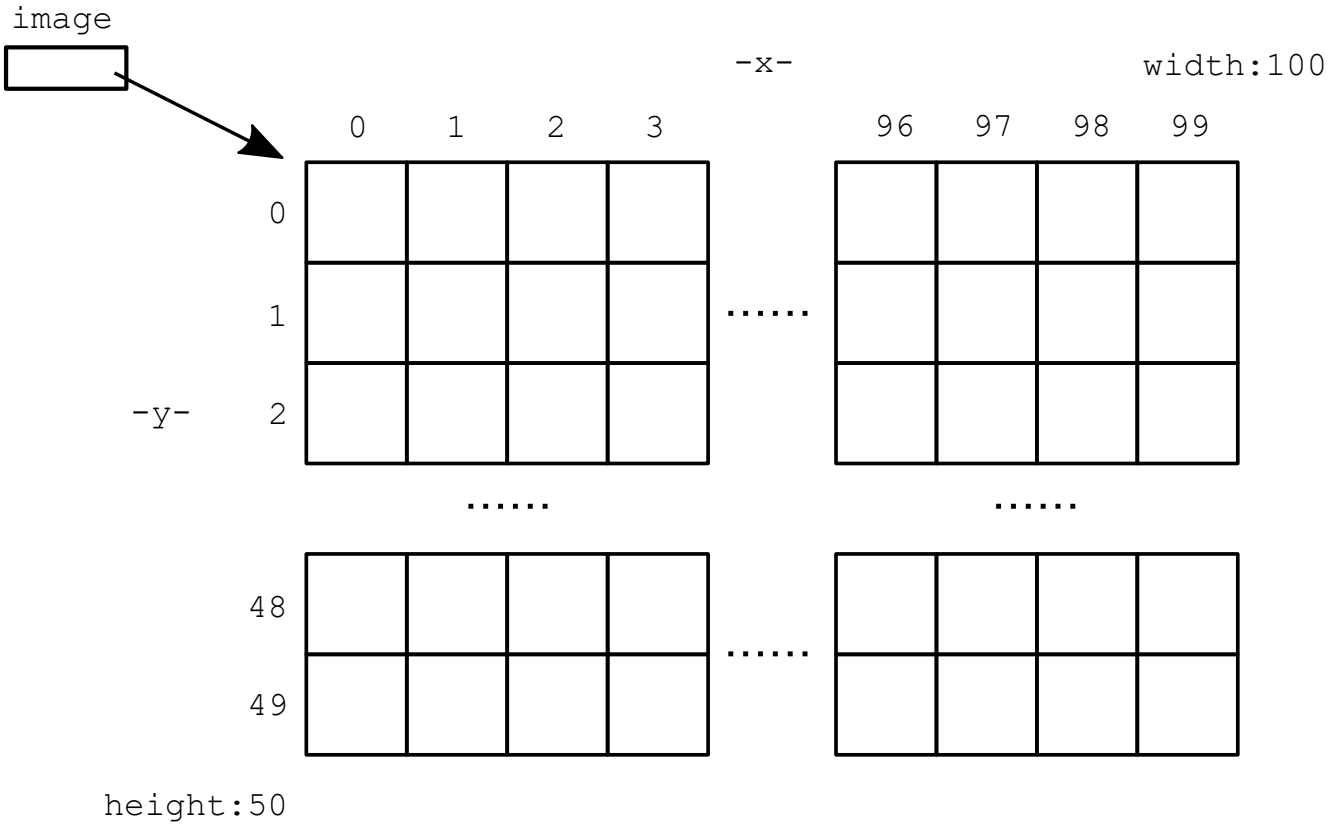
Image Coordinate System

Previously loaded image into memory like this. Look at the x/y coordinate scheme of the pixels.

```
image = SimpleImage(filename)
```

- `image.width`, `image.height` - int number of pixels
  e.g. image.width is 200, image.height is 100
  (like pixel.red - these are Python "properties")
- Origin x=0 y=0 is at upper left
- x grows right
- y grows down

- This coordinate scheme is like typesetting lines of text
- **Zero based indexing**
  First element is index 0
- Q: Say width is 100, what is the rightmost pixel's x value
- A: it's not 100! it's 99
  Super common mistake in zero-based world
- width 100, height 50 drawing, (x, y) pixels:
  (0, 0) pixel at upper left
  (99,0) at upper right
  (99, 49) at lower right
- These x,y values are all fundamentally **int** numbers
  There's no pixel at x=2.5
  Using a float value to address an x,y will fail with an error
  Talk about float values later



Goal: Loop Over All the x values for an image

Say we have an image 100 pixels wide.

Want to loop over the x coordinates: 0, 1, 2, ...98, 99

First we'll look at the Python `range(n)` function

Step 1: range() function

`range(n)` Function

- 1-parameter range(n) function
- `range(10)` represents the series:
  0, 1, 2, ... 8, 9
- Start at 0, go up to but not including the n parameter
- **UBNI** - up to but not including
- `range(10)` = 0, 1, 2, .. 9
- `range(5)` = 0, 1, 2, 3, 4
- `range(2)` = 0, 1
- `range(1)` = 0
- `range(0)` = (no numbers)
- `range(n)` = 0, 1, ... n-1
- `range(n)` works in a foreach loop
- Perfect for zero-based indexing

image + range() = ♥

- Say image width is 100
- So x values are: 0, 1, 2, ...98, 99
- `range(100)` will make exactly all the x coordinates
- aka `range(image_width)` -> 0, 1, 2, 3 .... image_with-1

Hack/Demo: Try In Interpreter

> interpreter >>>

Demo (or you can try it). The print(xx) function in this context just prints out what is passed to it within the parenthesis. Normally we indent by 4 spaces, but it's ok to just indent by 2 spaces in this temporary, on-the-fly context.

```
>>> for x in range(10):
      print('in loop:', x)
in loop: 0
in loop: 1
in loop: 2
in loop: 3
in loop: 4
in loop: 5
in loop: 6
in loop: 7
in loop: 8
in loop: 9
```

1. We see that the for loop works with `range()`, running the body once for each number.

2. Try different numbers as the parameter passed in to range(). (Use up-arrow in the interpreter to recall previously typed lines - a great time saver.