O is for …

• Open Source
  • Copyright meets the Creative Commons
• Object Oriented
  • Using classes and more in programming
• Occam's Razor
  • Not just compsci. Simple is good
Cynthia Rudin

- Duke CompSci Professor
  - Univ Buffalo, BS Mathematical Physics, BA Music Theory
  - Princeton, PhD.
- Works in interpretable machine learning, which is crucial for responsible and trustworthy AI
- Winner of Squirrel AI Award for AI for the Benefit of Humanity – 1 million
  - Detecting crime series
  - Con Edison NYC – underground electrical distribution network

She uses AI’s power to help society.
Announcements

• APT-4 due tonight
• APT-5 out, due March 24
• Assign 4 due Thursday, March 17

• No Lab Friday

• Have a great Spring Break!
PFTD

• Images
• Classes and Objects
• Tuples sprinkled about
Images

What is Photoshop?
Image Processing

- Convert image into format for manipulating the image
  - Visualization, Sharpening, Restoration, Recognition, Measurement, more
- Resizing, Red-eye Removal, more
- CrashCourse: Navigating Digital Info
Image Library

• PIL: Python Image Library -> Pillow
  • To install run the command below in a terminal
    • Terminal in PyCharm, not “Python Console”
    • `pip install Pillow`
      – If that doesn’t work try:
      – `Python3 -m pip install Pillow`

• Library has extensive API, far more than we need
  • Concepts often apply to every image library
  • Realized in Python-specific code/functions
Color Models

• Cameras, Displays, Phones, JumboTron: RGB
  • Additive Color Model: Red, Green, Blue
  • https://en.wikipedia.org/wiki/RGB_color_model

• Contrast Printers and Print which use CMYK
  • Subtractive: Cyan, Magenta, Yellow, Key/Black
An image is made up of Pixels

- A pixel is a square of color
Images and Pixels

- **Image is a collection of pixels**
  - Organized in rows: # rows is image height
  - Each row has the same length: image width

- **Pixels addressed by (x, y) coordinates**
  - Upper-left (0,0), Lower-right (width-1,height-1)
  - Typically is a single (x, y) entity: tuple

- **Remember: Tuple is immutable, indexed sequence**
  (a, b, c)
Each pixel has a location in Image

Pixel at $x \ y \ (1, \ 0)$

Pixel at $x \ y \ (4, \ 2)$

Pixel at $x \ y \ (2, \ 3)$
Each pixel has an RGB color

- Duke has three Duke blues
- Duke Athletics RGB: (0, 48, 145)
- Two for academics

**BLUE (DUKE ATHLETICS)**
- PANTONE: PMS 287 C
- HEX COLOR: #003087;
- RGB: (0, 48, 135)
- CMYK: (100, 75, 2, 18)
- BUY MATCHING PAINT

**DUKE ROYAL BLUE**
- HEX COLOR: #00539B
- RGB: (0, 83, 155)
- CMYK: (100, 53, 2, 16)

**DUKE NAVY BLUE**
- HEX COLOR: #012169;
- RGB: (1, 33, 105)
- CMYK: (100, 85, 5, 22)
SimpleDisplay.py

• Access to PIL and Image module
  • What type is img?
  • https://pillow.readthedocs.io/en/latest/

```python
from PIL import Image

if __name__ == '__main__':
    img = Image.open("images/bluedevil.png")
    #img = Image.open("images/eastereggs.jpg")
    img.show()
    print("width %d height %d" % (img.width, img.height))
```
String formatting with % operator

- Use formatted string with % in string to show where to put values
  - Followed by % and tuple of values
  - %d is for an int
  - %f is for a float
  - %.xf is to specify x digits past the decimal
  - %s is for a string or something that could be shown as a string
String Formatting Examples

name = "Xiao"
age = 19
print("%s is %d years old" % (name, age))
alist = [6, 7.8643, 2]
print("%f is a list %s" % (alist[1], alist))
print("fav in %s is %.2f" % (alist, alist[1]))

OUTPUT:
WOTO-1 Images
What is a class in Python?

- Class ≈ module ≈ library (for this CS101)
- Class – Also blueprint/Factory for creating objects
  - We've used int, float, str
  - `<class 'int'>, <class 'list'>`
  - Everything is a class in Python3

- Objects are created from a class
  - x = [5, 6, 7]
  - b = “Moe”
  - c = “Charlotte”
Types

```python
print(type(6))
print(type([1,1]))
print(type('blue'))
print(type((6,[7])))

img = Image.open("images/bluedevil.png")
print(type(img))

img = Image.open("images/eastereggs.jpg")
print(type(img))
```
What is a class in Python?

• Use . dot notation to access object's innards
  • word = "Hello"
    • word is an object from the String class
  • word.lower()
    • .lower() is a function, but don’t call it that!
    • Function that goes with a class is called method
    • .lower() is a method from the String class
  • img.width is an attribute aka field/property
    • Note there are no ()’s, like a variable
Image Library Basics

• Library can create/open images in different formats, e.g., .png, .jpg, .gif, ...

• Images have properties: width, height, type, color-model, and more (variables associated with class)
  • Functions and fields access these properties, e.g., `im.width`, `im.format`, and more

• Pixels are formed as triples (255,255,255), (r,g,b)
  • In Python these are tuples: immutable sequence
Types

```python
img = Image.open("images/bluedevil.png")
print(type(img.format))

img = Image.open("images/eastereggs.jpg")
print(type(img.format))
```
Demo: Convert Color to Gray

Process each pixel
Convert to gray
```python
if __name__ == '__main__':
    img = Image.open("images/eastereggs.jpg")
    start = time.process_time()
    gray_img = grayByPixel(img, True)
    #gray_img = grayByData(img, True)
    end = time.process_time()
    img.show()
    gray_img.show()
    print("Time = %1.3f" % (end - start))
```
grayByPixel Function

def grayByPixel(img, debug=False):
    width = img.width
    height = img.height
    new_img = img.copy()
    if debug:
        print("creating %d x %d image" % (width, height))
    for x in range(width):
        for y in range(height):
            (r, g, b) = img.getpixel((x, y))
            grays = getGray(r, g, b)
            new_img.putpixel((x, y), grays)
    return new_img
getGray function

```python
def getGray(r, g, b):
    gray = int(0.21*r + 0.71*g + 0.07*b)
    return (gray, gray, gray, gray)
```
WOTO-3 GrayScale
def grayByPixel(img, debug=False):
    width = img.width
    height = img.height
    new_img = img.copy()
    if debug:
        print("creating %d x %d image" % (width, height))
    for x in range(width):
        for y in range(height):
            (r, g, b) = img.getpixel((x, y))
            grays = getGray(r, g, b)
            new_img.putpixel((x, y), grays)

How does this code make a grey image?

New stuff here, what and where?
Revisiting nested Loops

• What is printed here? y varies first
  • Value of x as inner loop iterates?

```python
>>> for x in range(5):
    ...
    for y in range(3):
        ...
        print(x, y)
...
```

Why is the first column have the number repeated like that?
What if the print became:
print(y, x)?
Make Gray cont.

```python
def grayByPixel(img, debug=False):
    width = img.width
    height = img.height
    new_img = img.copy()
    if debug:
        print("creating %d x %d image" % (width, height))
    for x in range(width):
        for y in range(height):
            (r, g, b) = img.getpixel((x, y))
            grays = getGray(r, g, b)
            new_img.putpixel((x, y), grays)
```

If stop code halfway, what half of image is gray?

How many parameters does putpixel have?

Nested Loops
Accessing Individual Pixels is Inefficient

- Accessing each one one-at-a-time is inefficient
  - Python can do better "under the hood"

- PIL provides a function `img.getdata()`
  - Returns list-like object for accessing all pixels
  - Similar to how file is a sequence of characters
  - Symmetry: `img.putdata(sequence)`
Processing all Pixels at Once

• Treat `img.getdata()` as list, it's not quite a list
  • Iterable: object use in “for ... in ...” loop

```python
def grayByData(img, debug=False):
    pixels = [getGray(r, g, b) for (r, g, b) in img.getdata()]
    new_img = Image.new("RGB", img.size)
    new_img.putdata(pixels)
```

Think: An image is 2D and `putdata(seq)` takes a 1D sequence. How did we get an image?

Hint: What type are the elements in the list comprehension?

Hint: What do we know about the length of that sequence and the sequence `putdata(...)` needs?
def grayByData(img, debug=False):
    pixels = [getGray(r, g, b) for (r, g, b) in img.getdata()]
    new_img = Image.new("RGB", img.size)
    new_img.putdata(pixels)
    if debug:
        print("created %dx%d gray image" % (img.width, img.height))
    return new_img
Summary of Image functions

- Many, many more

<table>
<thead>
<tr>
<th>Image function/method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>im.show()</td>
<td>Display image on screen</td>
</tr>
<tr>
<td>im.save(&quot;foo.jpg&quot;)</td>
<td>Save image with filename</td>
</tr>
<tr>
<td>im.copy()</td>
<td>Return copy of im</td>
</tr>
<tr>
<td>im.getdata()</td>
<td>Return iterable pixel sequence</td>
</tr>
<tr>
<td>im.load()</td>
<td>Return Pixel collection indexed by tuple (x,y)</td>
</tr>
</tbody>
</table>
WOTO-4 More on Images