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

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**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.

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**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

- Contrast Printers and Print which use CMYK
  - Subtractive: Cyan, Magenta, Yellow, Key/Black

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
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, 145)
CMYK: (100, 75, 2, 18)
BUT MATCHING PAINT
```

SimpleDisplay.py

- Access to PIL and Image module
  - What type is `img`?

```
from PIL import Image

if __name__ == '__main__':
    img = Image.open("images/bluedevil.png")
    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

```
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:
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])))
```

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

```python
img = Image.open("images/eastereggs.jpg")
print(type(img))
```

Use . dot notation to access object's innards

- `word = "Hello"
  - `word` is an object from the String class
    - `word.lower()`
  - 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))
```

```python
img = Image.open("images/eastereggs.jpg")
print(type(img.format))
```

Demo: Convert Color to Gray

```
Process each pixel
Convert to gray
```
main

```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

```python
def grayByPixel(img, debug=False):
    width = img.width
    height = img.height
    new_img = img.copy()
    if debug:
        print("creating %dx%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)
```

WOTO-3 GrayScale

### Make Gray: Notice the Tuples!

```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)
```

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.

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

### 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)`

Tuple

Nested Loops

How many parameters does putpixel have?

Tuple

Tuple

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?

GrayByData

```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)
        if debug:
            print("created %d x %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><code>im.show()</code></td>
<td>Display image on screen</td>
</tr>
<tr>
<td><code>im.save(&quot;foo.jpg&quot;)</code></td>
<td>Save image with filename</td>
</tr>
<tr>
<td><code>im.copy()</code></td>
<td>Return copy of im</td>
</tr>
<tr>
<td><code>im.getdata()</code></td>
<td>Return iterable pixel sequence</td>
</tr>
<tr>
<td><code>im.load()</code></td>
<td>Return Pixel collection indexed by tuple (x,y)</td>
</tr>
</tbody>
</table>