Programming Patterns in Python

Terence Parr
MSDS program
University of San Francisco

Don Knuth on "geekhood"

The main characteristic is an ability to understand many levels of abstraction simultaneously, and to shift effortlessly between in-the-large and in-the-small. A geek knows that, to achieve a certain high-level goal, you need to add one to a certain counter at a certain time.

How programmers design programs

- Experienced programmers draw from a collection of generic high-level / large-scale mental templates as starting points
- There are mental templates for desktop GUI apps, machine learning classifiers, web servers, etc....
- A template provides an overall structure for the program, like lawyers tweaking a contract from previous client for new one
- Engineers building a new suspension bridge do not proceed as if such a thing has never been built before
- Gaining experience as a programmer means recognizing and remembering patterns in your code, both high and low level

Example: data science program template

1. Acquire data, which means finding a suitable file or collecting data from the web and storing it in a file or database
2. Load data from disk or database and organize into a suitable data structure in memory
3. Normalize, filter, clean, or otherwise prepare data
4. Process the data, which can mean training a machine learning model, transforming the data, computing summary statistics, or optimizing a cost function
5. Emit results, which can be anything from simply printing an answer to saving data to the disk to generating a fancy visualization

Basic problem-solving strategy

- **Start with the end result and work your way backwards**
- Ask what the prerequisites are for each step
- The processing step or steps preceding step *i* compute the data or values needed by step *i*
- E.g., median: to pick middle value, previous step must sort data
- Data science problems are often solved with an "iterative refinement of data" approach to arrive at the final result

Low-level programming patterns

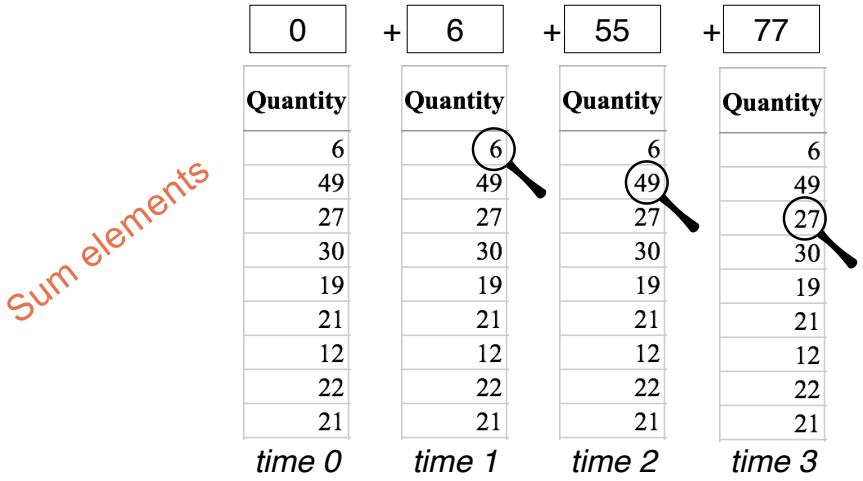
- High-level templates help us organize and plan our program
- Low-level patterns are puzzle pieces that we combine to fill in details and solve parts of the overall template
- These patterns have Python implementations but we design programs by selecting and applying patterns/operations, not specific code sequences
- When designing a program, I never say:
  "*Oh! I need a for-loop with an if-statement right here*"; instead, I say "*Oh! I need to filter for positive numbers here*"

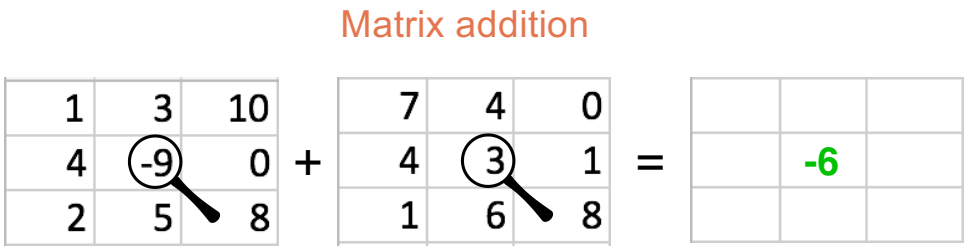
Sample programming patterns

- You're no doubt familiar with simple patterns such as:
  - *sum the numbers in a list*
  - *count the elements in a list*
- But there are many many more, such as:
  - *find all values in a list satisfying a condition*
  - *apply an operation to each element of a list to get new list*
  - *split a list of strings into 2 or more lists*
  - *merge two sorted lists*
  - *delete records in a dataframe that satisfy a condition*
- Think and plan at this level or higher, not the code level

Visualize behavior then identify pattern

- Think visually about how you would physically manipulate lists of data or extract information from data
- Manually moving some data around on paper or in spreadsheet helps me to understand the operation to perform





A parade of patterns

UNIVERSITY OF SAN FRANCISCO

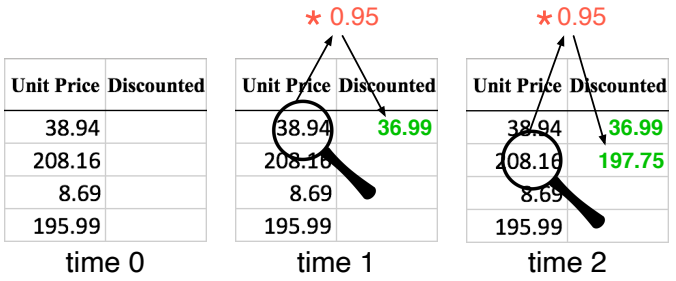
Accumulate

- Traverse a sequence of elements and *accumulate* a value
- In Excel, this is like using **sum(...)** in a cell
- Can use any other arithmetic operator, such as *
- Called *reduce*, as in *map*/*reduce* of distributed computing world

```
Quantity = [6, 49, 27, 30, 19, 21, 12, 22, 21]
sum = 0
for q in Quantity:
    sum += q          # same as: sum = sum + q
print(sum)
```

Experiment in pythontutor

Map



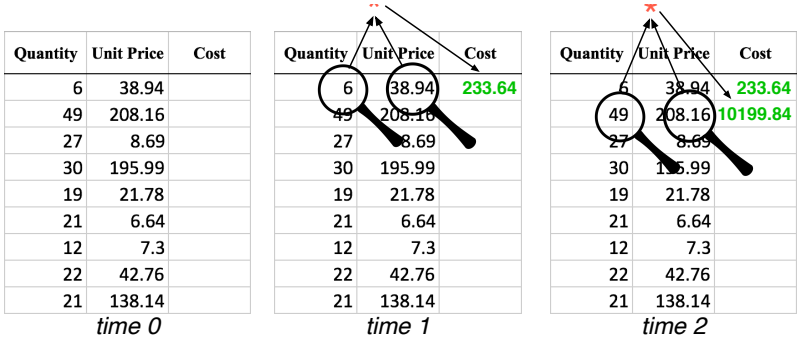
- A very common operation *maps* one sequence to another, applying an operator or function to each element
- It's like using a spreadsheet to create a new column containing a product's unit price discounted by 5%

```
UnitPrice = [38.94, 208.16, 8.69, 195.99]

discounted = [] # empty list
for price in UnitPrice:
    discounted.append(price * 0.95)

# list comprehension shines here!!
discounted = [p*0.95 for p in UnitPrice]
```

Be able to reverse this, going from code to pattern!

Experiment in pythontutor

Combine



Quantity	Unit Price	Cost
6	38.94	
49	208.16	
27	8.69	
30	195.99	
19	21.78	
21	6.64	
12	7.3	
22	42.76	
21	138.14	

time 0

Quantity	Unit Price	Cost
6	38.94	233.64
49	208.16	
27	8.69	
30	195.99	
19	21.78	
21	6.64	
12	7.3	
22	42.76	
21	138.14	

time 1

Quantity	Unit Price	Cost
6	38.94	233.64
49	208.16	10199.84
27	8.69	
30	195.99	
19	21.78	
21	6.64	
12	7.3	
22	42.76	
21	138.14	

time 2

- Traverse two or more lists at once placing the result in a third list
- Multiply the i^{th} element from different sequences and placing the result in the i^{th} position of the output sequence

```
Quantity = [6, 49, 27, 30]
UnitPrice = [38.94, 208.16, 8.69, 195.99]

cost = []
for i in range(len(Quantity)):
    cost.append( Quantity[i] * UnitPrice[i] )

Cost = [Quantity[i] * UnitPrice[i] for i in range(len(Quantity))]
```

Experiment in pythontutor

Split

- The opposite of combining is splitting where we split a stream into two or more new streams
- Example: split list of full names into their first and last names

```
names = ['Terence Parr', 'Diane Woodbridge', 'Yannet Interian']
for name in names:
    print(name.split())

first = []
last = []
for name in names:
    f,l = name.split()
    first.append(f)
    last.append(l)
```

E	F
Customer Name	
Muhammed MacIntyre	
Barry French	
Barry French	
Clay Rozendal	
Carlos Soltero	
Carlos Soltero	

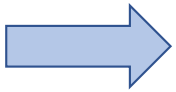
E	F
First Name	**Last Name**
Muhammed	MacIntyre
Barry	French
Barry	French
Clay	Rozendal
Carlos	Soltero
Carlos	Soltero

[Experiment in pythontutor]

Slice a list (or string)

- Some operations yield subsets of the data, such as slice, which extracts a subset of a list (that fits in memory)
- Syntax is **A[begin:end]** where **begin** is inclusive and **end** is not

```
names=['Xue', 'Mary', 'Bob']
print(names[0:1])
print(names[0:2])
print(names[0:3])
print(names[2:3])
print(names[1:])
print(names[-1])
print(names[-2:])
```



```
['Xue']
['Xue', 'Mary']
['Xue', 'Mary', 'Bob']
['Bob’]
['Mary', 'Bob']
Bob
['Mary', 'Bob']
```

Experiment in pythontutor

Filter

- The filter operation is similar to the map operation in that a computation is applied to each element of the input stream
- Filter tests each element for a specific condition and, if true, adds that element to the new sequence

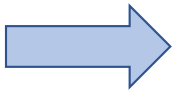
```
shipping = [35, 68.02, 2.99, 3.99, 5.94, 4.95, 7.72, 6.22]
shipping2 = []
for x in shipping:
    if x < 10:
        shipping2.append(x)
print(shipping2) # prints [2.99, 3.99, 5.94, 4.95, 7.72, 6.22]

shipping2 = [x for x in shipping if x < 10] # much easier
```

Experiment in pythontutor

Filtering rows of data

- We can also filter on one column but keep the data within each row together; e.g., filter for Oscar winners

```
oscars = [
    [1984, "A Soldier's Story", 0],
    [1984, 'Places in the Heart', 0],
    [1984, 'The Killing Fields', 0],
    [1984, 'A Passage to India', 0],
    [1984, 'Amadeus', 1],
    [1985, "Prizzi's Honor", 0],
    [1985, 'Kiss of the Spider Woman', 0],
    [1985, 'Witness', 0],
    [1985, 'The Color Purple', 0],
    [1985, 'Out of Africa', 1]
]
print([movie for movie in oscars if movie[2]==1])
```



```
[[1984, 'Amadeus', 1], [1985, 'Out of Africa', 1]]
```

Experiment in pythontutor

Search

- The filter operation finds all elements in a sequence that satisfy a specific condition, but often we'd like to know which element satisfies the condition first (or last)
- Search returns the first (or last) position in the sequence rather than the value at that position

```
first=['Xue', 'Mary', 'Robert']     # our given input
target = 'Mary'                     # searching for Mary
index = -1
for i in range(len(first)):         # i is in range [0..n-1] or [0..n)
    if first[i]==target:
        index = i
        break
print(index)
```

Experiment in pythontutor

Grid/matrix processing

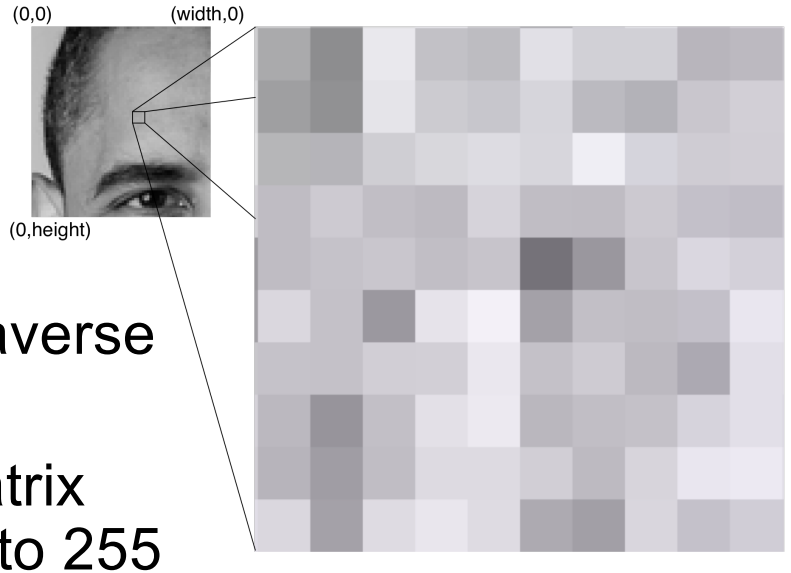
1	3	10
4	-9	0
2	5	8

- Any time you need to process each cell in a two dimensional structure such as an image or matrix, think "nested loop"
- Single loop does 1D, nested loop does 2D, triple loop does 3D...

```
nrows = 3
ncols = 3
# column j value varies more quickly than the row i value
for i in range(nrows):
    for j in range(ncols):
        print( i, j )

# row i value varies more quickly than j
for j in range(ncols):
    for i in range(nrows):
        print( i, j )
```

Experiment in pythontutor

Image processing



- The images project requires that you traverse the x,y coordinates of images
- An image is nothing more than a 2D matrix whose entries are grayscale pixels in 0 to 255
- A pixel value of 0 is black and 255 is white

```
# walk top-down: row-by-row of pixels
for y in range(height):
    for x in range(width):
        print( x, y )
```

Applying patterns

Now that we can read basic Python and have seen some pattern implementations, let's use those patterns to solve some simple problems

Exercise

- Given a list of prices, cut the price of each in half

```
prices = [38.94, 208.16, 8.69, 195.99]
```

- First, must decide if we are altering in place or creating a new; let's create a new list in general for these exercises
- Which pattern should we apply? Map...what does code look like?

```
prices = [p/2 for p in prices]
```

Experiment in pythontutor

Exercise

- Given a list of names, get a list of string lengths called **namelens**; function **len(x)** yields length of lists, strings, etc...

```
names = ['Xue', 'Mary', 'Robert']
```

- Draw out what the transformation looks like

```
['Xue', 'Mary', 'Robert'] ☞ [3, 4, 6]
```

- Which pattern should we apply? Map...what does code look like?

```
namelens = [len(name) for name in names]
```

Experiment in pythontutor

Exercise

- Given a list of prices, get a list of prices greater than $100

```
prices = [38.94, 208.16, 8.69, 195.99]
```

- Which pattern should we apply? Filter...what does code look like?

```
prices = [p for p in prices if p>100]
```

Experiment in pythontutor

Exercise

- Given a list of prices, double any price less than $10

```
prices = [38.94, 208.16, 8.69, 195.99]
```

- Which patterns should we apply? Filter & Map

```
prices = [p for p in prices if p<10]
prices = [p/2 for p in prices]

prices = [p/2 for p in prices if p<10] # Or together
```

Experiment in pythontutor

Exercise (part 1)

- Given a list of movie titles, how many are 3-words long?

```
titles = ["A Soldier's Story", 'Places in the Heart', 'The Killing Fields',
          'A Passage to India', 'Amadeus', "Prizzi's Honor",
          'Kiss of the Spider Woman', 'Witness', 'The Color Purple',
          'Out of Africa']
```

- Which patterns should we apply and how? Hmm…hard to say
- What does the problem-solving process look like?

Think how we can gradually morph the data from titles to result, but start with the desired result and work backwards

Exercise (part 2)

```
["A Soldier's Story", 'Places in the Heart',
 'The Killing Fields', 'A Passage to India',
 'Amadeus', "Prizzi's Honor", 'Kiss of the Spider Woman',
 'Witness', 'The Color Purple', 'Out of Africa']
```

- Work backwards:
  - If we have the list of title lengths, we can filter for length 3 and count

```
[3, 4, 3, 4, 1, 2, 5, 1, 3, 3]  ☞  [3, 3, 3, 3] ☞  4
```

  - To get list of title lengths, map **len()** to list of words of each title

```
[['A', "Soldier's", 'Story'],            ☞  [3, 4, ...]
 ['Places', 'in', 'the', 'Heart'], ...]
```

  - To get the list of words for each title, apply **split()** to each title (map)

```
["A Soldier's Story",
 'Places in the Heart',      ☞   [['A', "Soldier's", 'Story'],
 ...]                             ['Places', 'in', 'the', 'Heart'],
                                  ...]
```

Exercise (part 3)

```
["A Soldier's Story", 'Places in the Heart',
 'The Killing Fields', 'A Passage to India',
 'Amadeus', "Prizzi's Honor", 'Kiss of the Spider Woman',
 'Witness', 'The Color Purple', 'Out of Africa']
```

- Now, reverse it to get the correct sequence:

Map `["A Soldier's Story", 'Places in the Heart', ...]` ☞ `[['A', "Soldier's", 'Story'], ['Places', 'in', 'the', 'Heart'], ...]`

Map `[['A', "Soldier's", 'Story'], ['Places', 'in', 'the', 'Heart'], ...]` ☞ `[3, 4, ...]`

Filter `[3, 4, 3, 4, 1, 2, 5, 1, 3, 3]` ☞ `[3, 3, 3, 3]` ☞ `4`

Exercise (part 4)

```
titles = ["A Soldier's Story", 'Places in the Heart', 'The Killing Fields',
          'A Passage to India', 'Amadeus', "Prizzi's Honor",
          'Kiss of the Spider Woman', 'Witness', 'The Color Purple',
          'Out of Africa']

tsplit = [t.split() for t in titles] # Map
tlen = [len(t) for t in tsplit]      # Map
t3 = [n for n in tlen if n==3]       # Filter
n = len(t3)                          # Prints 4

t3 = [t for t in titles if len(t.split())==3] # Map/Filter
n = len(t3)
```

Experiment in pythontutor

Exercise: What does it compute? What pattern is this?

```
words = ['abigail','advice','antic','antismoking']
text = ""
for w in words:
    text = text + " " + w
text
```

```
' abigail advice antic antismoking'
```

Exercise: what pattern is this?

```
[w.upper() for w in words]
```

```
['ABIGAIL', 'ADVICE', 'ANTIC', 'ANTISMOKING']
```

Map a list of words to another list of words by applying upper()

Exercise: what pattern is this?

```
scores = [87, 47, 39, 36, 6, 57, 82, 45, 90, 89]
p = -1
for i in range(len(scores)):
    if scores[i]==36:
        p = i
```

This sets p to 3 because that is the index of the value 36 in the list An IF inside of a loop should make you think of “filtering”

Exercise: what pattern is this?

```
A=[[48, 53, 65, 67, 26],
   [ 4, 74, 12, 56, 97],
   [67, 50, 80, 45,  0],
   [60, 28, 80, 28, 61],
   [21,  1, 37, 58, 45]]

s = 0
n = 5
for i in range(n):
    for j in range(n):
        s += A[i][j]
```

A nested loop often means finding all combinations of the two loop indexes.

Here, I see a list of list or matrix index, so my brain thinks about image or matrix processing.

This computes the sum of all matrix elements. We are accumulating a value.

Exercise: what pattern is this?

```
s = 0
n = 5
for i in range(n):
    for j in range(n):
        if i == j:
            s += matrix[i][j]
s
```

Now I have a conditional inside of the nested loop, which just means that I'm filtering as well as accumulating.

This computes the trace of the matrix, the sum of the diagonal elements.

$$tr(A) = \sum_{i=1}^{n} a_{ii}$$

Exercise: what pattern is this?

```
names = ['Olivia', 'Emma', 'Ava', 'Charlotte', 'Sophia', 'Amelia',
         'Isabella', 'Mia', 'Evelyn', 'Harper']
scores = [87, 47, 39, 36, 6, 57, 82, 45, 90, 89]
v = 0
results = []
for n,s in zip(names,scores):
    v += s
    results.append(f"{n}: {s}")
```

This both accumulates the sum of the scores and combines the names and scores to get a new list in results

```
['Olivia: 87',
 'Emma: 47',
 'Ava: 39',
 'Charlotte: 36',
 'Sophia: 6',
 'Amelia: 57',
 'Isabella: 82',
 'Mia: 45',
 'Evelyn: 90',
 'Harper: 89']
```