15-110 Principles of Computing – S19

Lecture 9:
Iteration 2

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Loops so far: definite loops, `for` construct

✓ Repeat a set of actions a **defined number of times** (at *most*)

```
for variable in sequence:
    actions
```

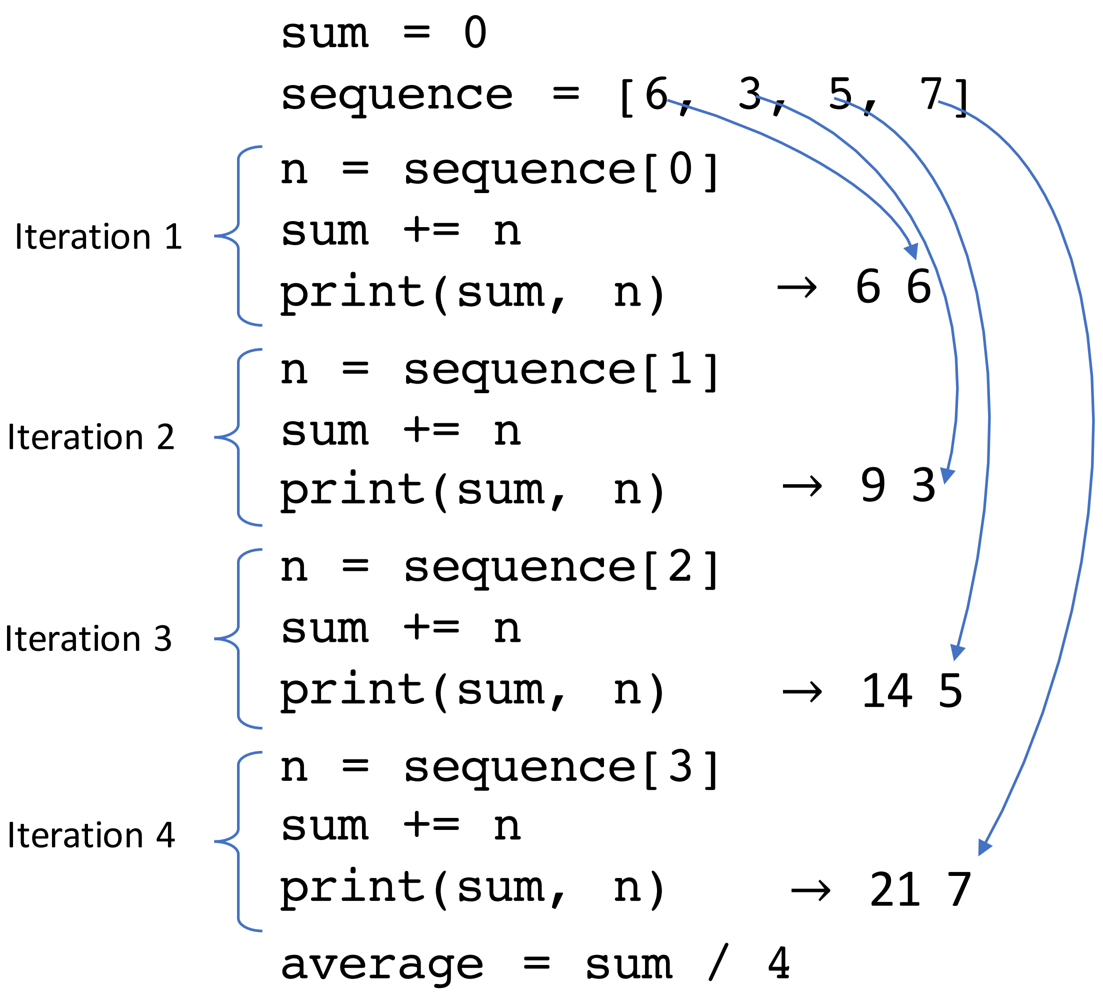
sequence: tuple, list

`len(sequence)` **iterations** (at most)

variable: *loop index*: each time the variable is set to the value of the next item in the sequence

```
sum = 0
for n in [6, 3, 5, 7]:
    sum += n
    print(sum, n)
average = sum / 4
```

Is equivalent to:



```
sum = 0
sequence = [6, 3, 5, 7]
```

Iteration 1
```
n = sequence[0]
sum += n
print(sum, n)      → 6 6
```

Iteration 2
```
n = sequence[1]
sum += n
print(sum, n)      → 9 3
```

Iteration 3
```
n = sequence[2]
sum += n
print(sum, n)      → 14 5
```

Iteration 4
```
n = sequence[3]
sum += n
print(sum, n)      → 21 7
```

```
average = sum / 4
```

Loops so far: definite loops, `for` construct

✓ Any sequence is a valid one to index the loop

```
for i in [(1,3), ('a', 2), (True, 'hello', 5)]:
    print('This is a loop iteration')
```

```
sum = 0
for i in [(1,3), ('a', 2), (True, 5, 'hello')]:
  sum += i[1]
  print('Loop variable:', i, 'Sum:', sum)
```

✓ `range(start, end, step)` function for generating sequences that are ranges of integer numbers

```
for i in range(-1,10,2):
    print(i)
```

→ -1, 1, 3, 5, 7, 9

```
for i in range(2,9):
    print(i)
```

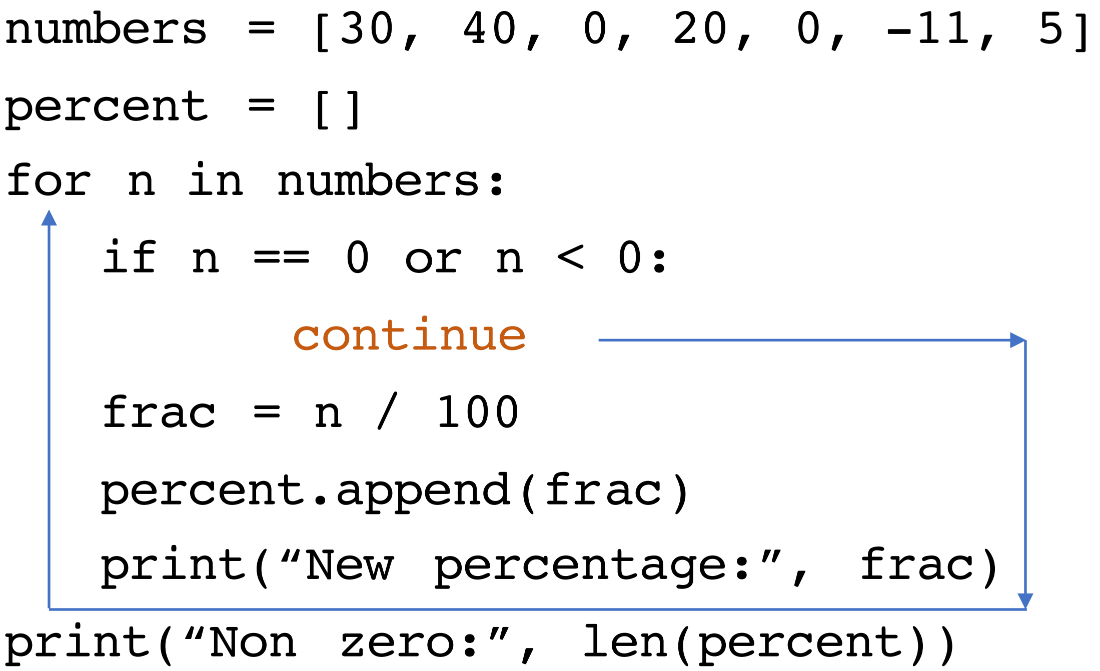
→ 2, 3, 4, 5, 6, 7, 8

```
for i in range(10):
    print(i)
```

→ 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

`continue`: jump to the end of the loop, skip to next iteration

- It might happen that **a part of the block of code in the for body need to be skipped for certain data items based on conditional tests**, moving straight to ne next iteration → `continue`



```
numbers = [30, 40, 0, 20, 0, -11, 5]
percent = []
for n in numbers:
    if n == 0 or n < 0:
        continue
    frac = n / 100
    percent.append(frac)
    print(“New percentage:”, frac)
print(“Non zero:”, len(percent))
```

Iteration 1
`n = 30`

Executed instructions:
`if, append, print`

`percent: [0.3]`

Iteration 2
`n = 40`

Executed instructions:
`if, append, print`

`percent: [0.3,0.4]`

Iteration 3
`n = 0`

Executed instructions:
`if, continue`

`percent: [0.3,0.4]`

Iteration 4
`n = 20`

Executed instructions:
`if, append, print`

`percent: [0.3,0.4,0.2]`

jump to the end of the loop code block

→ new iteration starts: n gets its next value

`break:` jump out of the loop (that *at most*)

- It might happen that *according to a conditional test*, the **loop must be interrupted** without performing any further instructions, moving the program counter to the first instruction after the loop → `break`

```
numbers = [30, 40, 0, 20, 0, -11, 5]
percent = []
for n in numbers:
    if n == 0 or n < 0:
            print(“Value not allowed!”)
            break
    frac = n / 100
    percent.append(frac)
    print(“Percentage value:”, frac)
print(“Non zero:”, len(percent))
```

Iteration 1

`n = 30`

Executed instructions:

`if, append, print`

`percent: [0.3]`

Iteration 2

`n = 40`

Executed instructions:

`if, append, print`

`percent: [0.3,0.4]`

Iteration 3

`n = 0`

Executed instructions:

`if, print, break`

`percent: [0.3,0.4]`

Out of the loop

Executed instructions:

`print`

`percent: [0.3,0.4], n = 0`

jump out of the loop

→ next program instruction is executed

Modifying loop index variable and sequence during iteration?

- The loop index variable is just a variable, therefore it can (*you shouldn’t*) be modified inside a loop
- Also the sequence, if modifiable (i.e., not a `range()`), can be changed (*you shouldn’t*) during the iterations

```
numbers = [30, 40, '*', 20]
percent = []
for n in numbers:
    if n == '*' :
          numbers += [1,2,3]
          continue
    n /= 100
    frac = n
    percent.append(frac)
print('Total percent:', len(percent))
```

Iteration 1
`n = 30`

Sequence to go:

`[40,’*’,20]`

Iteration 2
`n = 40`

Sequence to go:

`[’*’,20]`

Iteration 3
`n = ‘*’`

Sequence to go:

`[20,1,2,3]`

…

Iteration 7
`n = 3`

Sequence to go:

`[]`

What happens with: `numbers[:] = []` ?

Nested loops

- **Loops can be nested** in arbitrary levels, that can be directly related or not to each other

```
for s1 in seq1:
    for s2 in seq2:
        #do something with (s1, s2)
```

Two level nesting, each level is independently defined

```
for s1 in seq1:
    for s2 in s1:
        for s3 in s2:
            #do something with s3
```

Three level nesting, in this example each level is derived from the previous one

Nested loops

```
cars = [ ['Toyota', 'white', 2012, 15000],
         ['Toyota', 'black', 2011, 12000],
         ['Nissan', 'black', 2011, 10000],
         ['Toyota', 'black', 2015, 25000],
         ['BMW', 'blue', 2018, 50000],
         ['Toyota', 'white', 2018, 60000],
         ['Ferrari', 'red', 2016, 100000],
         ['Ferrari', 'blue', 2015, 85000]   ]

colors = [ 'white', 'red', 'blue']
cars_of_specific_color = []
for c in cars:
    for col in colors:
        if c[1] == col:
            cars_of_specific_color.append(c)
print('Found', len(cars_of_specific_color), 'cars of the desired colors:')
for c in cars_of_specific_color:
    print(c)
```

✓ Typical operation on databases

Nested loops: accessing data in lists of lists

- Finding the **max (min) in a list of lists**

```
list1 = [ [ [ [110, 'r'], [22, 'g'], [3, 'b']  ]  ],
          [ [ [45, 'r'], [105, 'g'], [26, 'b'] ] ],
          [ [ [76, 'r'], [88, 'g'], [190, 'b'] ] ]
        ]
print(max(list1))
```

→ what will be printed here?

```
rgb_max = -1
iteration_count = 0
for s1 in list1:
    for s2 in s1:
        for s3 in s2:
            if s3[0] > rgb_max:
                rgb_max = s3[0]
            iteration_count += 1
print('max rgb:', rgb_max, _iteration_count)
```

***Complexity* of the computing:**

- Doing one `if` comparison + assignment = : how many times?

  length(list level 1) * length(list level 2) * length(list level 3)

Nested loops: creating and accessing matrix data structures

- **Matrix:** in linear algebra it is a *rectangular* array of numbers organized in m rows and n columns, where the rows are horizontal and the columns are vertical
- Each row and each column can be read as a *vector*, of dimension n and m respectively

$$M = \begin{bmatrix} 3 & 109 & 88 \\ 17 & 4 & 12 \end{bmatrix}$$

2 x 3 matrix

$$M = \begin{bmatrix} 0.4 & 100 \\ -3 & 247 \\ 0 & 25 \end{bmatrix}$$

3 x 2 matrix

$$M = \begin{bmatrix} 1 & 4 & 88 \\ 25.4 & -100 & 7 \\ 2 & 99 & 4.5 \end{bmatrix}$$

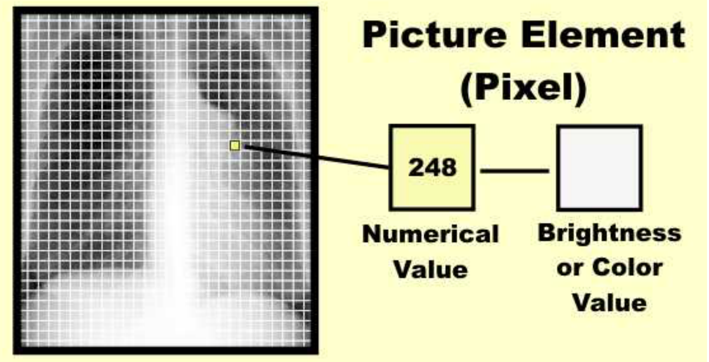
3 x 3 matrix

- Given a matrix A, the notation m_{ij} or M_{ij} is commonly used to refer to the element in row i and column j
- In python, a matrix data structure can be implemented using lists/tuples, and it can be *convenient* to use something like `m[i][j]` to access the elements

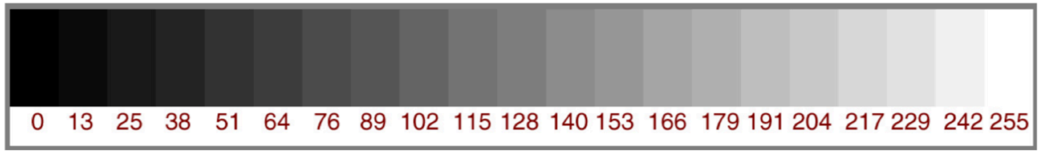
Nested loops: creating and accessing matrix data structures

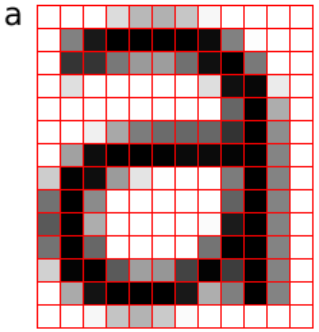
- Exemplary use of matrices in computing: digital image processing!

A digital image is basically represented as an $m \times n$ **matrix of pixel values**



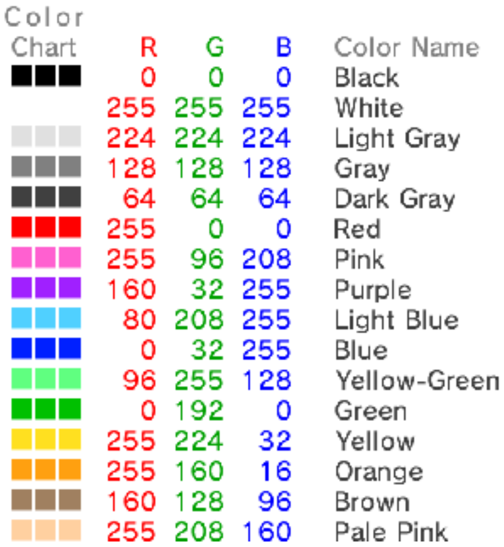
Grayscale image: each pixel is encoded in one byte, such that it can take values in the integer range between 0 and 255





1.0	1.0	1.0	0.9	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0
1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.0	1.0
1.0	0.2	0.2	0.5	0.6	0.6	0.5	0.0	0.0	0.5	1.0	1.0
1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.0	0.0	0.9	1.0
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.4	0.0	0.5	1.0
1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0
0.9	0.0	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
0.5	0.0	0.6	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
0.5	0.0	0.7	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.5	1.0
0.6	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.0	0.5	1.0
0.9	0.1	0.0	0.6	0.7	0.7	0.5	0.0	0.5	0.0	0.5	1.0
1.0	0.7	0.1	0.0	0.0	0.0	0.1	0.9	0.8	0.0	0.5	1.0
1.0	1.0	1.0	0.8	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0

RGB image: color images where each pixel has a triple of values (r,g,b), each encoded in one byte, that altogether encode the color



Color Chart	R	G	B	Color Name
■■■	0	0	0	Black
	255	255	255	White
■■■	224	224	224	Light Gray
■■■	128	128	128	Gray
■■■	64	64	64	Dark Gray
■■■	255	0	0	Red
■■■	255	96	208	Pink
■■■	160	32	255	Purple
■■■	80	208	255	Light Blue
■■■	0	32	255	Blue
■■■	96	255	128	Yellow-Green
■■■	0	192	0	Green
■■■	255	224	32	Yellow
■■■	255	160	16	Orange
■■■	160	128	96	Brown
■■■	255	208	160	Pale Pink

Nested loops: creating and accessing matrix data structures

- **Create an image matrix** using lists (we will see different ways of doing this same task), `range( )` is useful!

```
rows, cols = 10, 8
img = [[]]*rows
print(img)
for r in range(rows):
    for c in range(cols):
        img[r] = [0]*cols
```

- So far it’s I=initialized with all zero, let’s give some more meaningful values to the entries:

```
for r in range(rows):
    for c in range(cols):
        img[r][c] = (r * c) % 255
    print(img[r])
```

- **Data smoothing / filtering**

WRONG!

```
for r in range(rows):
    for c in range(1, cols-1):
        img[r][c] = int((2 * img[r][c-1] + img[r][c] + 2 * img[r][c+1]) / 3)
    print(img[r])
```

Nested loops: creating and accessing matrix data structures

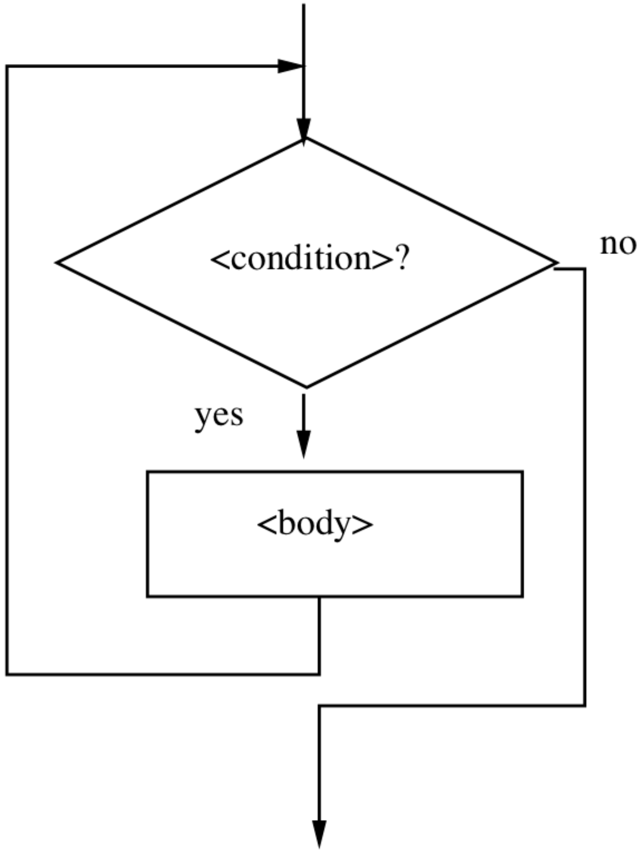
- Finding the **max (min) in a list of lists,** using indexes and `range()`

```
list1 = [ [ [ [110, 'r'], [22, 'g'], [3, 'b']  ]  ],
          [ [ [45, 'r'], [105, 'g'], [26, 'b'] ] ],
          [ [ [76, 'r'], [88, 'g'], [190, 'b'] ] ] ]

print(max(list1))
rgb_max = -1
for i1 in range(len(list1)):
    for i2 in range(len(list1[i1])) :
        for i3 in range(len(list1[i1][i2])):
            item = list1[i1][i2][i3]
            if item[0] > rgb_max:
                rgb_max = item[0]
print("max rgb:", rgb_max, count)
```

Indefinite (or conditional) iterations: `while` loops

- ✓ Repeat a set of actions an **unspecified number of times: keep doing <u>until a certain condition is true</u>**



```
while condition_is_true:
    actions
```

```
i = 0
while i <= 10:
    print("Loop counter:", i)
    i += 1
```

vs.

```
for i in range(10):
    print("Loop counter:", i)
```

- ✓ More flexible and general than for loops, since we are not restricted to iterate over a sequence, but code can be less compact and more prone to errors …

Typical use of `while` loops

✓ **Sentinel loops:** keep processing data until a special value (a sentinel) that signals the end of the processing is reached

```
i = 0
while i <= 10:
    print("Loop counter:", i)
    i += 1
```

General computing pattern:

```
get the first data item
while item is not the sentinel:
    process the item
    get the next data item
```

- This type of while loops can be also implemented as `for` loops as long as we have a sound estimate of the <u>maximum number of iterations that would be required</u> (in the “worst” case), and then use `break` to exit the loop

```
val = 1
while val > 0.45:
    print(”Value:", val)
    val *= 0.9
```

```
max_iterations = 1000000
val = 1
for n in range(max_iterations):
    print('Value:’, val)
    val *= 0.9
    if val <= 0.45:
        break
```

Example, computing the square root

```
x = 9
g = 8.5
while abs(g * g – x) > 0.1:
    print('g', g)
    g = (g + x/g)/2
print('Square root of', x, 'is', g)
```

Typical use of `while` loops

- ✓ **Input loops:** keep processing data until more data is available from some input device (e.g., interactive user, file, sensor)
  - ➢ Not clear how many inputs, hard to safely implement with a for loop

Making an average sum *interactively using user inputs*:

```
sum = 0.0
count = 0
moredata = "yes"
while moredata[0] == "y":
    x = eval(input("Enter a number >> "))
    sum = sum + x
    count = count + 1
    moredata = input("Do you have more numbers (yes or no)? ")
print("\nThe average of the numbers is", sum / count)
```

Never ending iterations with `while` loops

- ✓ If the condition is always true, the loop will never end, in principle

```
i = 0
while i <= 10:
    print(”Hello!”)
```

Watch out when you define while loops!

- ✓ If we want to keep **looping forever** (until the computer is shutdown …)

```
while True:
    print(”Hello!”)
```

- Can we generate a never ending `for` loop?
  - No! We can keep extending the sequence, but eventually we reach either a memory or a number representation limit

Nested `while` loops

- ✓ Similar possibilities / (and more) issues as when using `for` loops

```
i = 1
while i <= 10:
    j = 0
    while j < 5:
        j += i * (i/10)
        print(i,j)
    i += 1
```

Watch out how you define, initialize, and modify sentinel variables!