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
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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

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```

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Iteration 1:

```
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```

Iteration 2:

```
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sum += n
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```

Iteration 2:

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sum += n
print(sum, n)
```

```
n = sequence[2]
sum += n
print(sum, n)
```

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Iteration 2:
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Iteration 3:
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Iteration 2:
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sum += n
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Iteration 3:
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n = sequence[2]
sum += n
print(sum, n)
```

```
n = sequence[3]
sum += n
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Iteration 3:
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Iteration 1:
```
n = sequence[0]
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print(sum, n)
```
→ 6 6

Iteration 2:
```
n = sequence[1]
sum += n
print(sum, n)
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Iteration 3:
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n = sequence[2]
sum += n
print(sum, n)
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Iteration 4:
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Is equivalent to:

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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)
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Iteration 4:
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n = sequence[3]
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Iteration 3:
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n = sequence[2]
sum += n
print(sum, n)      → 14 5
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Iteration 4:
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n = sequence[3]
sum += n
print(sum, n)      → 21 7
```

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average = sum / 4
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- ✓ Any sequence is a valid one to index the loop

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for i in [(1,3), ('a', 2), (True, 'hello', 5)]:
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- ✓ `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

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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

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→ -1, 1, 3, 5, 7, 9

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→ 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`

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percent = []
for n in numbers:
    if n == 0 or n < 0:
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    frac = n / 100
    percent.append(frac)
    print("New percentage:", frac)
print("Non zero:", len(percent))
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jump to the end of the loop code block

→ new iteration starts: `n` gets its next value

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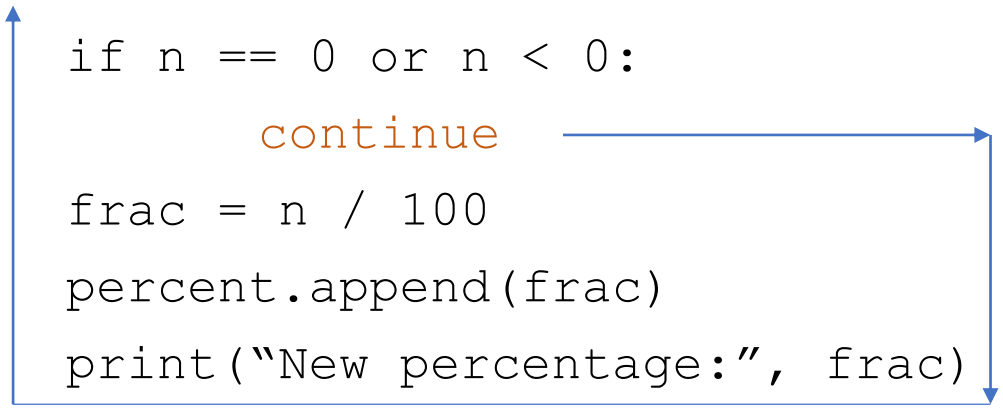

Iteration 1

`n = 30`

Executed instructions:

`if, append, print`

`percent: [0.3]`

jump to the end of the loop code block

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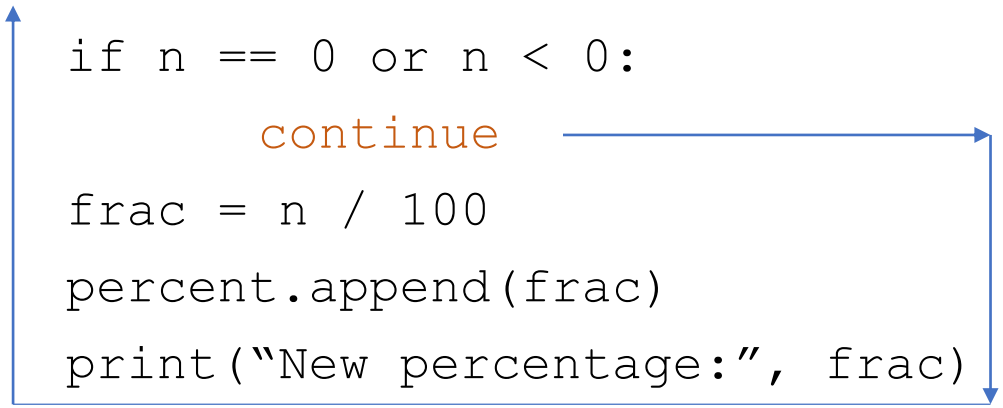

Iteration 1

`n = 30`

Executed instructions:

`if, append, print`

`percent: [0.3]`

Iteration 2

`n = 40`

Executed instructions:

`if, append, print`

`percent: [0.3,0.4]`

jump to the end of the loop code block

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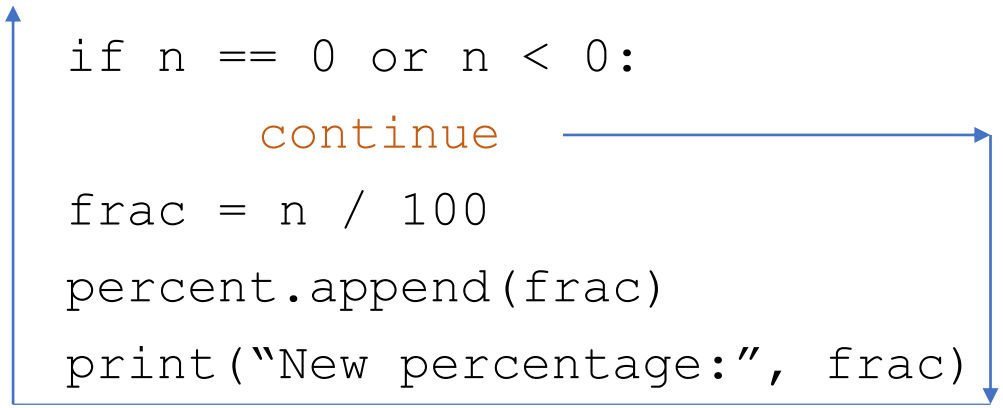

Iteration 1

`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]`

jump to the end of the loop code block

→ new iteration starts: `n` gets its next value

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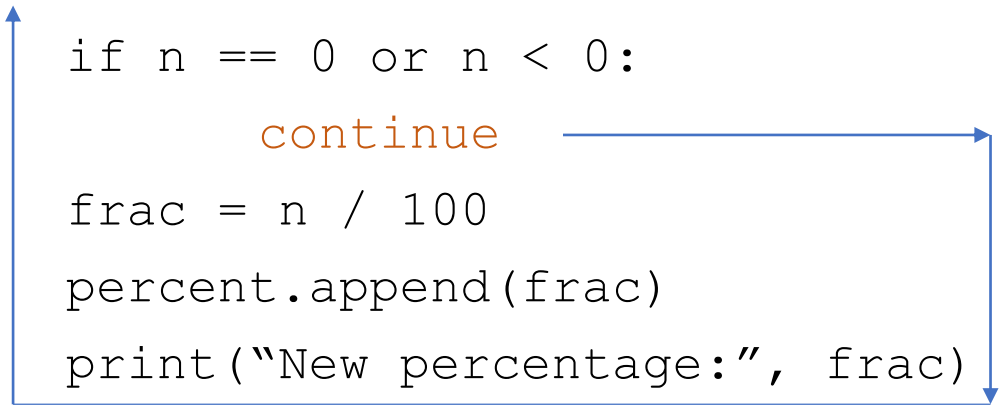

Iteration 1

`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`

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            break
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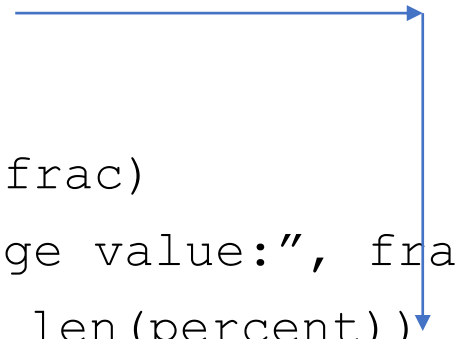

jump out of the loop

→ next program instruction is executed

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print("Non zero:", len(percent))
```
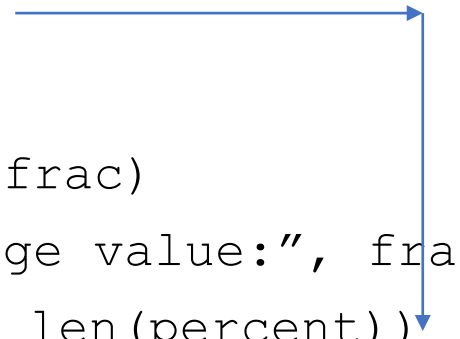



Iteration 1

`n = 30`

Executed instructions:

`if, append, print`

`percent: [0.3]`

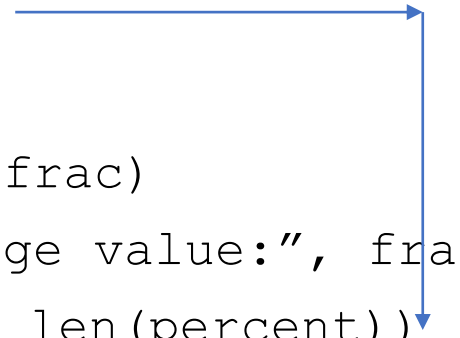
jump out of the loop

→ next program instruction is executed

`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]`

jump out of the loop

→ next program instruction is executed

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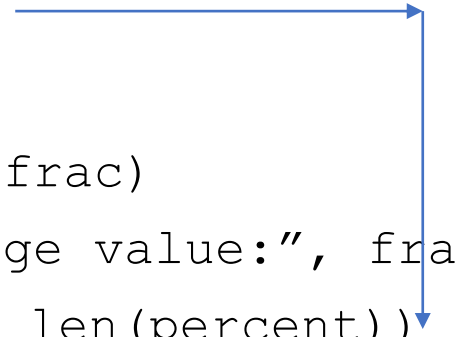
    percent.append(frac)
    print("Percentage value:", frac)
print("Non zero:", len(percent))
```



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]`

jump out of the loop

→ next program instruction is executed

`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`

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    percent.append(frac)
    print("Percentage value:", frac)
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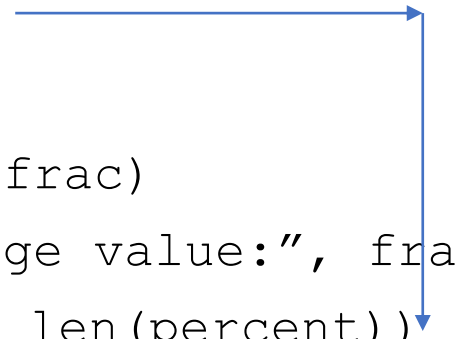

Iteration 1

`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

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```
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))
```

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Iteration 1

`n = 30`

Sequence to go:

`[40,'*',20]`

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    n /= 100
    frac = n
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print('Total percent:', len(percent))
```

Iteration 1

`n = 30`

Sequence to go:

`[40,'*',20]`

Iteration 2

`n = 40`

Sequence to go:

`['*',20]`

Modifying loop index variable and sequence during iteration?

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```

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]`

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- Also the sequence, if modifiable (i.e., not a `range`()), can be changed (*you shouldn't*) during the iterations

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            numbers += [1,2,3]
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    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]`

…

Modifying loop index variable and sequence during iteration?

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- Also the sequence, if modifiable (i.e., not a `range`()), can be changed (*you shouldn't*) during the iterations

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            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:

`[]`

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percent = []
for n in numbers:
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            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

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

Two level nesting, each level is independently defined

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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

- ✓ Typical operation on databases

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]  ]
```

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         ['Ferrari', 'blue', 2015, 85000]  ]

colors = [ 'white', 'red', 'blue']
```

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cars = [ ['Toyota', 'white', 2012, 15000],
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colors = [ 'white', 'red', 'blue']
cars_of_specific_color = []
```

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Nested loops

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cars = [ ['Toyota', 'white', 2012, 15000],
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         ['BMW', 'blue', 2018, 50000],
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         ['Ferrari', 'red', 2016, 100000],
         ['Ferrari', 'blue', 2015, 85000]  ]

colors = [ 'white', 'red', 'blue']
cars_of_specific_color = []
for c in cars:
```

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Nested loops

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colors = [ 'white', 'red', 'blue']
cars_of_specific_color = []
for c in cars:
    for col in colors:
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         ['Ferrari', 'blue', 2015, 85000]  ]

colors = [ 'white', 'red', 'blue']
cars_of_specific_color = []
for c in cars:
    for col in colors:
        if c[1] == col:
```

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Nested loops

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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)
```

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Nested loops

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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**

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

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print(max(list1))
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→ what will be printed here?

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        ]
print(max(list1))
rgb_max = -1
iteration_count = 0
```

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for s1 in list1:
```

→ what will be printed here?

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for s1 in list1:
    for s2 in s1:
```

→ what will be printed here?

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        ]
print(max(list1))
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]
```

→ what will be printed here?

Nested loops: accessing data in lists of lists

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iteration_count = 0
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    for s2 in s1:
        for s3 in s2:
            if s3[0] > rgb_max:
                rgb_max = s3[0]
            iteration_count += 1
```

→ what will be printed here?

Nested loops: accessing data in lists of lists

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iteration_count = 0
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    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)
```

→ what will be printed here?

Nested loops: accessing data in lists of lists

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```

→ what will be printed here?

***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

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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

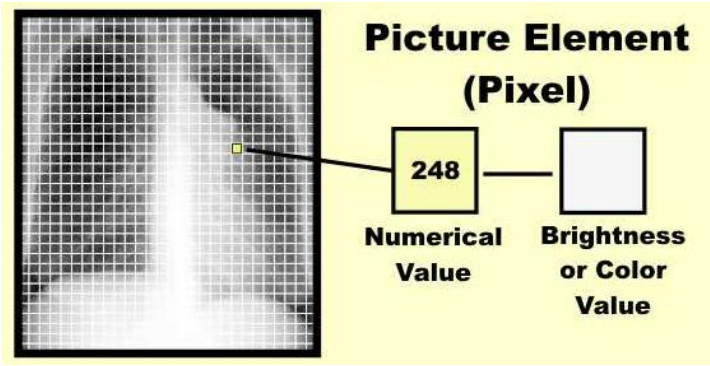
Nested loops: creating and accessing matrix data structures

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

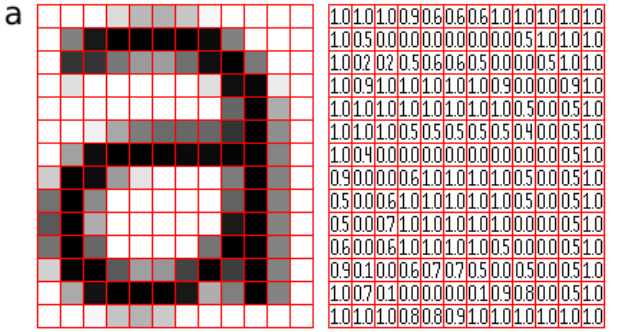
Nested loops: creating and accessing matrix data structures

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

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



a



Nested loops: creating and accessing matrix data structures

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

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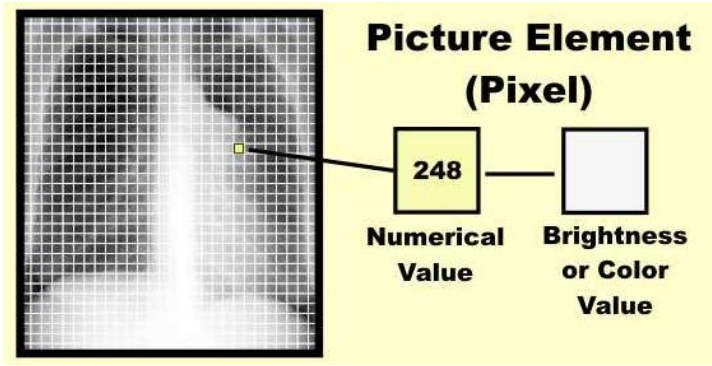
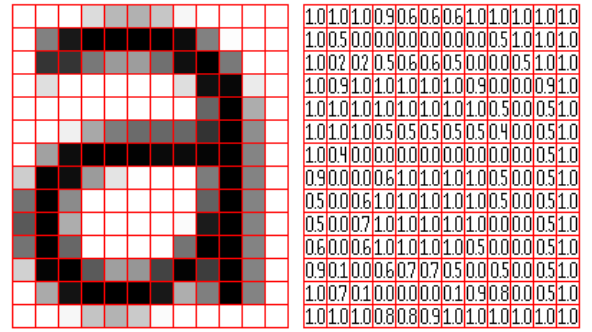


Grayscale image: each pixel is encoded in one byte, such that it can take values in the integer range between 0 and 255

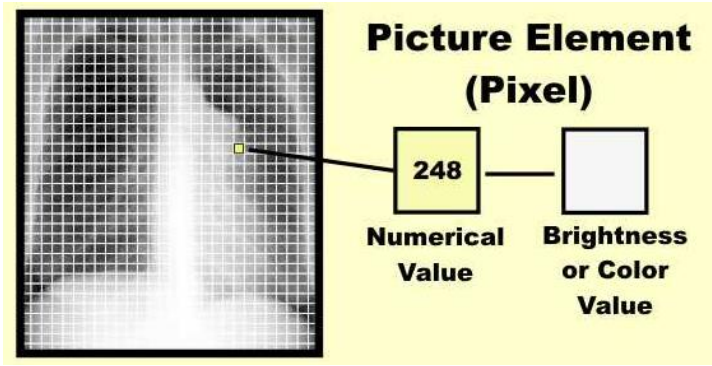
a



Nested loops: creating and accessing matrix data structures

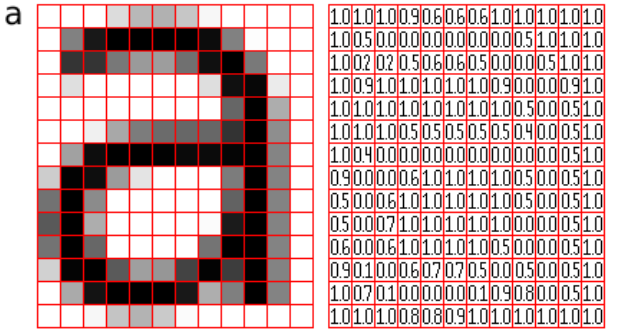
- Exemplary use of matrices in computing: digital image processing!

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

a



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

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

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rows, cols = 10, 8
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    for c in range(cols):
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for r in range(rows):
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WRONG!

Nested loops: creating and accessing matrix data structures

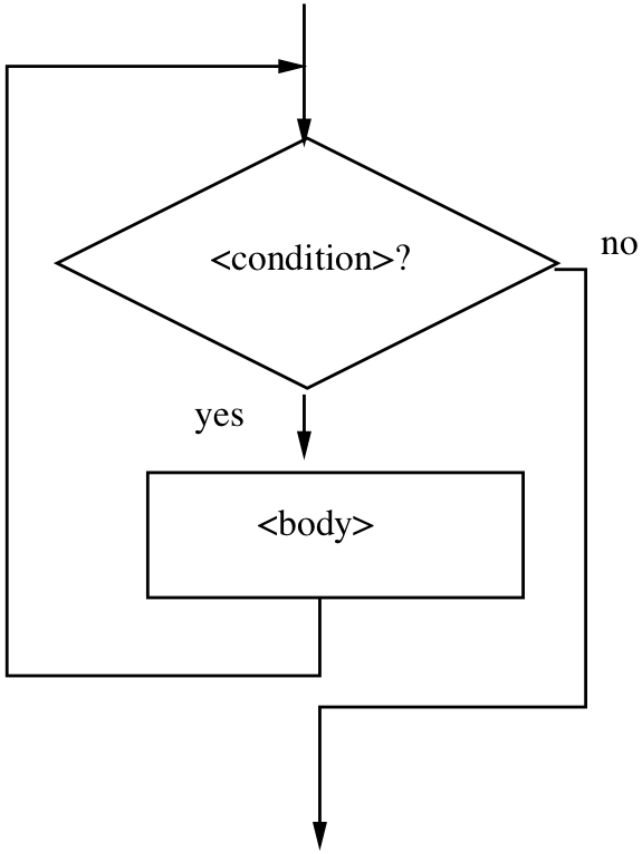
- Finding the **max (min) in a list of lists,** using indexes and `range()`

```
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 until a certain condition is true**



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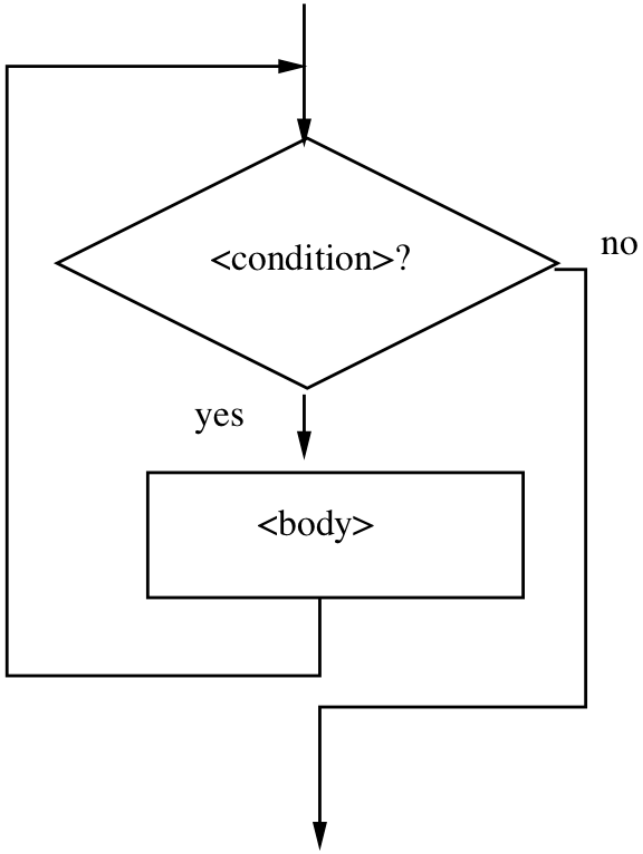


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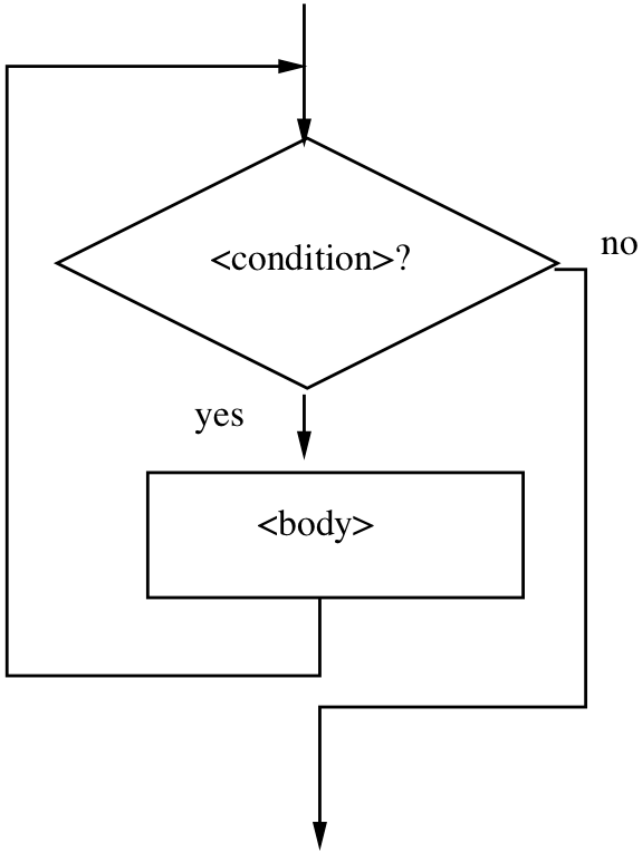


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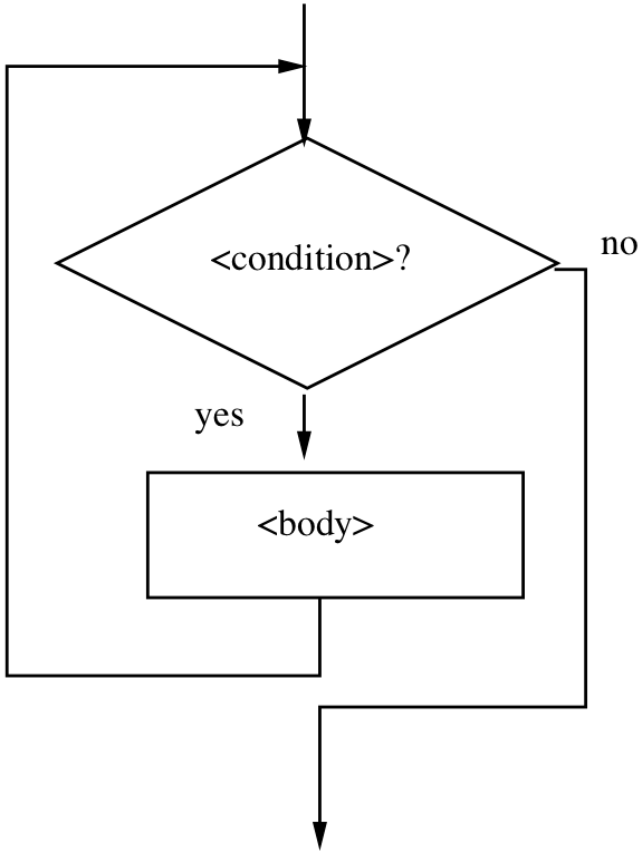


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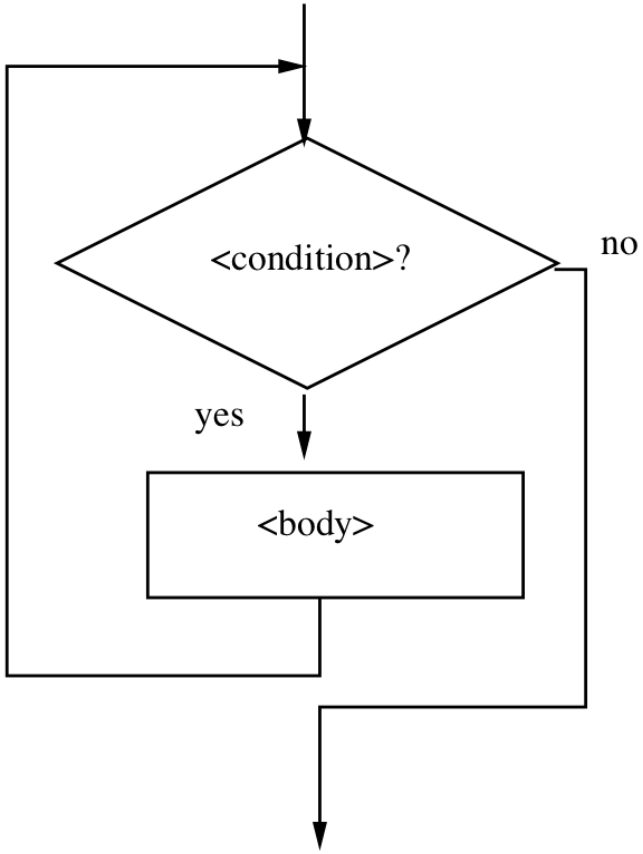


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- ✓ More flexible and general than for loops, since we are not restricted to iterate over a sequence, but code can be less compact and more prone to errors …

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get the first data item
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val = 1
while val > 0.45:
    print("Value:", val)
    val *= 0.9
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    print("Value:", val)
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```
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)
```

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  - ➢ Not clear how many inputs, hard to safely implement with a for loop

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print("\nThe average of the numbers is", sum / count)
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- 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

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