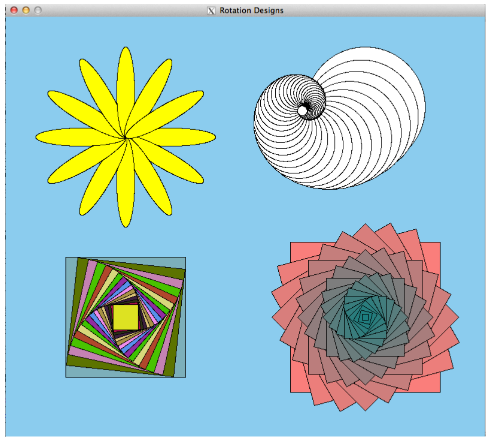
Iteration: Sequences and `for` Loops



CS111 Computer Programming

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Overview pt. 1

- **Primitive** types in Python: int, float, Boolean, NoneType.
  - Values of such types cannot be decomposed in smaller parts.
  - This is why in the memory diagram model for variables we depict these values **within the variable box**. They cannot be decomposed in smaller units.
- **Composite** types in Python: str, list, range, tuple, dict.
  - Values of such types can be decomposed further.
  - This is why in the memory diagram model for variables we depict these values **outside of the variable box**.

Overview pt. 2

- Strings, lists, ranges, and tuples are known as **sequences** in Python, because they are **ordered**.
- To represent the order in a sequence we use **indices**. Python has an indexing operator **[ ]** (square brackets) that allows us to **access** an element at a certain position in the ordered sequence. Indices always start at the value 0.

Recall:

a = ‘Boston’

a[0] has the value ’B’, a[3] has the value ‘t’, a[-1] has the value ‘n’, a[5] also has the value ‘n’, and so on.

Overview pt. 3

- Most of the time, we will access sequence items through a **for loop**.
- This lecture discusses sequences and for loops together.
- We present two types of for loops: **value loops** and **index loops**.

Motivation Example: How many vowels in a word?

- You're given words like `'Boston'`, `'Wellesley'`, `'abracadabra'`, `'bureaucracies'`, etc.
- Tasks:
  - count the number of vowels in a word.
  - count the number of times a certain character appears in a word

```
def countVowels(word):
    # body here

            ?
```

```
def countChar(char, word):
    # body here

            ?
```

Slides 4 to 12 explain what we need to know/learn to solve these problems.

Review: Accessing characters in a string through indices

Concepts in this slide: Indices and their properties.

```
In [1]: word = 'Boston'
In [2]: word[0]
Out[2]: 'B'
In [3]: word[1]
Out[3]: 'o'
In [4]: word[2]
Out[4]: 's'
In [5]: word[3]
Out[5]: 't'
In [5]: word[4]
Out[5]: 'o'
In [5]: word[5]
Out[5]: 'n'
```

Notice

- 0, 1, 2, etc. are the **indices** (plural of **index**).
- Indices start at 0.
- Indices go from 0 to `len(word)-1`.
- We read **`word[0]`** as word sub 0.
- **`[]`** is known as the indexing operator.

To think: How will indices be useful for solving our "counting vowels" problem?

Old friend: `isVowel()`!

```
def isVowel(char):
    c = char.lower()
    return (c == 'a' or c == 'e' or c == 'i'
            or c == 'o' or c == 'u')

def isVowel(char):
    return (len(char) == 1
            and char.lower() in 'aeiou')
```

To think: How will the function **`isVowel`** be useful for solving our "counting vowels" problem?

Possible solution: which side is correct?

Concepts in this slide: Difference between independent vs. chained conditionals. New operator**: +=**

```
word = 'Boston'
vowelCount = 0
if isVowel(word[0]):
    vowelCount += 1
if isVowel(word[1]):
    vowelCount += 1
if isVowel(word[2]):
    vowelCount += 1
if isVowel(word[3]):
    vowelCount += 1
if isVowel(word[4]):
    vowelCount += 1
if isVowel(word[5]):
    vowelCount += 1
print(vowelCount)
```

```
word = 'Boston'
vowelCount = 0
if isVowel(word[0]):
    vowelCount += 1
elif isVowel(word[1]):
    vowelCount += 1
elif isVowel(word[2]):
    vowelCount += 1
elif isVowel(word[3]):
    vowelCount += 1
elif isVowel(word[4]):
    vowelCount += 1
elif isVowel(word[5]):
    vowelCount += 1
print(vowelCount)
```

Does our solution work for all words?

it's your turn

- Do you think the right-side solution from the previous slide will work for all words: `'Wellesley'`, `'Needham'`, `'Lynn'`, etc.?
- What happens if we use an index that's greater than or equal to the length of the word?

```
In [1]: word = 'Lynn'
In [2]: word[4]
IndexError: string index out of range
```

How to generate the correct indices of the string?

Approach 1: Using a **while** loop to visit all string indices

```
word = 'Boston'
index = 0
while index < len(word):
    print('word[' + str(index) + '] => ' + word[index])
    index += 1
```

```
word[0] => B
word[1] => o
word[2] => s
word[3] => t
word[4] => o
word[5] => n
```

while loops to the rescue!

Concepts in this slide:
An example of a `while` loop over a string that accumulates a value

```
word = 'Boston'
vowelCount = 0
if isVowel(word[0]):
    vowelCount += 1
if isVowel(word[1]):
    vowelCount += 1
if isVowel(word[2]):
    vowelCount += 1
if isVowel(word[3]):
    vowelCount += 1
if isVowel(word[4]):
    vowelCount += 1
if isVowel(word[5]):
    vowelCount += 1
print(vowelCount)
```

```
word = 'Boston'
vowelCount = 0
index = 0
while index < len(word):
    if isVowel(word[index]):
        vowelCount += 1
    index += 1
print(vowelCount)
```

Concepts in this slide:
New execution kind: iteration done through loops.

Approach 2: Iterating over sequence elements with `for` loops

One of the most common ways to manipulate a sequence is to perform some action for each element in the sequence. This is called **looping** or **iterating** over the elements of a sequence. In Python, we use a **`for`** loop to iterate.

```
for var in sequence:
    # Body of the loop
    statements using var
```

Generic form of a **`for`** loop

A **`for`** executes the statements in the body of the loop for each element in the sequence. In each execution of the body, the **iteration variable** ***`var`*** holds the current element.

Value `for` loop for vowel counting

```
word = 'Boston'

vowelCount = 0

for char in word:
    if isVowel(char):
        vowelCount += 1

print(vowelCount)
```

What does this code print?

Guess before going to the next slide!

To notice:

- There are three variables in the code: **`word`**, **`vowelCount`**, **`char`**.
- The variables **`char`** and **`vowelCount`** can change values from one iteration to the next.
- **`char`** takes as values the elements of the string sequence.
- There's no need for an explicit `index` variable!
  This is the main advantage of a **`for`** loop over a **`while`** loop

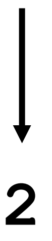
`for` loop model example for vowel counting

```
word = 'Boston'

vowelCount = 0

for char in word:
    if isVowel(char):
        vowelCount += 1

print(vowelCount)
```



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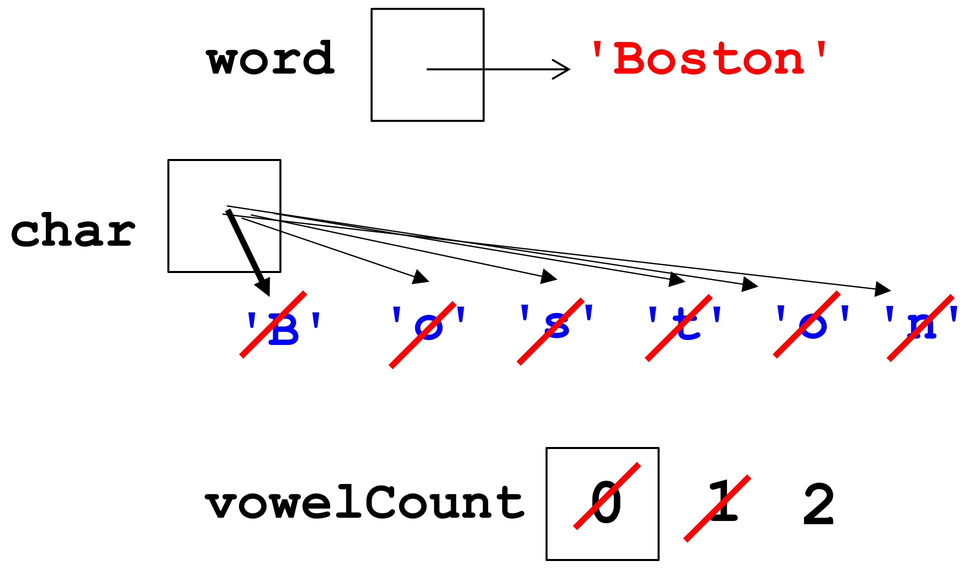


New ordered, composite data type: Lists

While strings are sequences of characters, a **list** is a sequence of elements that are **any type of value**.

Lists are written as values that are separated by commas and wrapped in a pair of square brackets.

Examples:

`[17, 8, 12, 5]` is a list of four integers.

`['Boston', 'Paris’, 'Seoul’]` is a list of three strings.

New ordered, composite data type: Lists

The type of a list value is `list`.

E.g. `type([17, 8])` is `list`.

There's also a built-in function `list` that converts a string to a list of characters.

Example:

`list('cat')` evaluates to `['c', 'a', 't’]`

for loops can iterate over lists of values

```
phrase = ["an", "autumn", "day"] # phrase is a list
for word in phrase:
    print(word + '!')
```

```
What does this code print?
```

```
def sumList(nums):
    '''Returns the sum of the elements in nums'''
    sumSoFar = 0
    for num in nums:
        sumSoFar += num
    return sumSoFar
```

```
What does sumList([17,8,12,5]) return?
```

for loops can iterate over lists of values

```
phrase = ["an", "autumn", "day"] # phrase is a list
for word in phrase:
    print(word + '!')
```

```
an!
autumn!
day!
```

```
def sumList(nums):
    '''Returns the sum of the elements in nums'''
    sumSoFar = 0
    for num in nums:
        sumSoFar += num
    return sumSoFar
```

```
In [1]: sumList([17,8,12,5])
Out [1]: 42
```

`for` loops are disguised `while` loops!

Digging Deeper

```
def sumListFor(nums):
    '''Returns the sum of the elements in nums'''
    sumSoFar = 0
    for n in nums:
        sumSoFar += n # or sumSoFar = sumSoFar + n
    return sumSoFar


# If Python did not have a for loop, the above for loop
# could be automatically translated to the while loop below
def sumListWhile(nums):
    '''Returns the sum of the elements in nums'''
    sumSoFar = 0
    index = 0
    while index < len(nums):
        n = nums[index]
        sumSoFar += n # or sumSoFar = sumSoFar + n
        index += 1    # or index = index + 1
    return sumSoFar
```

Creating a sequence of numbers with `range`

Concepts in this slide:
Built-in function `range` and new type list.

When the **`range`** function is given two integer arguments, it returns a range object of all integers starting at the first and up to, *but not including*, the second.

However, when we give the interpreter `range(0, 10)`, for example, the output is not very helpful.

```
In [1]: range(0, 10)
Out[1]: range(0, 10)

In [2]: type(range(0, 10))
Out[2]: range
```

Creating a sequence of numbers with **range**

Concepts in this slide:
Built-in function **range** and new type list.

To see all the numbers that are included in **range**, we pass that to the **list** function which returns to us a list of the numbers.

```
In [3]: list(range(3, 7))
Out[3]: [3, 4, 5, 6]

In [4]: list(range(3, 2))
Out[4]: []

In [5]: list(range(3, 3))
Out[5]: []

In [6]: list(range(3))# missing 1st argument defaults to 0
Out[6]: [0, 1, 2]
```

Properties of the `range` function

An optional third argument to **`range`** controls the step size between elements (which defaults to 1).

```
In [1]: list(range(1, 10, 2))
Out[1]: [1, 3, 5, 7, 9]

In [2]: list(range(3, 70, 10))
Out[2]: [3, 13, 23, 33, 43, 53, 63]

In [3]: list(range(9, 0, -1))
Out[3]: [9, 8, 7, 6, 5, 4, 3, 2, 1]

In [4]: list(range(9, 0, -2))
Out[4]: [9, 7, 5, 3, 1]

In [5]: list(range(63, 0, -10))
Out[5]: [63, 53, 43, 33, 23, 13, 3]
```

To notice:

- With the help of the third argument of **`range`**, we can create different sequences of integers.
- Step can be positive or negative.
- When step is negative, the start value has to be larger than the end value.

Strings, lists, and ranges are all sequences

Digging Deeper

```
In [1]: word =
'Boston'
In [2]: word[2]
Out[2]: 's'
In [3]: len(word)
Out[3]: 6
In [4]: word + 'Globe'
Out[4]: 'Boston Globe'
In [5]: 'o' in word
Out[5]: True
In [6]: 'b' in word
Out[6]: False
```

```
In [1]: digits =
[1, 2, 3, 4]
In [2]: digits[2]
Out[2]: 3
In [3]: len(digits)
Out[3]: 4
In [4]: digits + [4]
Out[4]: [1, 2, 3, 4, 4]
In [5]: 1 in digits
Out[5]: True
In [6]: 5 in digits
Out[5]: False
```

```
In [1]: digRange =
range(1, 5)
In [2]: digRange[2]
Out[2]: 3
In [3]: len(digRange)
Out[3]: 4
In [5]: 1 in digRange
Out[5]: True
In [6]: 5 in digRange
Out[5]: False
```

A sequence is an "abstract" type, which serves as template for "concrete" types such as string or list. Note that concatenation is not supported for range objects. Doing `range(3) + range(2)` will result in a TypeError.

Concepts in this slide: The combination of `range` and `len` to generate indices for a sequence.

Solving the indexing problem

```
word = 'Boston'
vowelCount = 0
if isVowel(word[0]):
     vowelCount += 1
if isVowel(word[1]):
     vowelCount += 1
if isVowel(word[2]):
     vowelCount += 1
if isVowel(word[3]):
     vowelCount += 1
if isVowel(word[4]):
     vowelCount += 1
if isVowel(word[5]):
     vowelCount += 1
print vowelCount
```

```
In [1]: word = 'Boston'
In [2]: list(range(len(word)))
Out[2]: [0, 1, 2, 3, 4, 5]

In [3]: word = 'Wellesley'
In [4]: list(range(len(word)))
Out[4]: [0,1,2,3,4,5,6,7,8]

In [5]: word = 'Lynn'
In [6]: list(range(len(word)))
Out[6]: [0, 1, 2, 3]
```

`range` solves our indexing problem, by generating the correct list of indices.

Concepts in this slide: An example of a `for` loop with a conditional.

Approach 3 of vowel counting: Index `for` loop

```
word = 'Boston'
vowelCount = 0
if isVowel(word[0]):
    vowelCount += 1
if isVowel(word[1]):
    vowelCount += 1
if isVowel(word[2]):
    vowelCount += 1
if isVowel(word[3]):
    vowelCount += 1
if isVowel(word[4]):
    vowelCount += 1
if isVowel(word[5]):
    vowelCount += 1
print vowelCount
```

```
word = 'Boston'
vowelCount = 0
for i in range(len(word)):
    if isVowel(word[i]):
        vowelCount += 1
print(vowelCount)
```

Important: we have been using `list` to display the numbers held in `range` but we do not need it to iterate! Note how we do not write `list(range(len(word)))`

for loop model example with range

Concepts in this slide: Modeling how code in a loop is executed.

```
word = 'Wellesley'

vowelCount = 0
```

$$\overbrace{\texttt{range(}\underbrace{\texttt{len(word)}}_{8}\texttt{)}}^{\texttt{[0,1,2,3,4,5,6,7]}}$$

```
for i in range(len(word)):
    if isVowel(word[i]):
 vowelCount += 1


print(vowelCount)
```

word $\boxed{} \rightarrow$ 'Wellesley'

i $\boxed{\cancel{0}}$ $\cancel{1}$ $\cancel{2}$ $\cancel{3}$ $\cancel{4}$ $\cancel{5}$ $\cancel{6}$ $\cancel{7}$

vowelCount $\boxed{\cancel{0}}$ $\cancel{1}$ $\cancel{2}$ 3

To notice:

- There are three variables in the code: **`i`**, **`word`**, **`vowelCount`**.
- The variables **`i`** and **`vowelCount`**. change values from one iteration to the next.
- Because **`vowelCount`**. is within a conditional, it's only updated when the condition is true.

Concepts in this slide: Two different ways of looping over a sequence.

Value loops vs index loops

- We can loop directly over the elements in a list.

Value Loop

```
phrase = ["an", "autumn", "day"]
for word in phrase:
      print(word + '!')
```

- The **range** function provides a sequence of indices that we can loop over to access the elements from a sequence. The code below produces the **same output** as the code above.

Index Loop

```
phrase = ["an", "autumn", "day"]
for i in range(len(phrase)):
      print(phrase[i] + '!')
```

Unless there is a need for the index (see next slide), **we will prefer value loops** over index loops.

When is it better to use `range` instead of directly looping?

Digging Deeper

- Let's modify the previous example to print both the index and the item for each item in the list.

```
for i in range(len(phrase)):
      print(i, phrase[i], '!')
```

```
0 an!
1 autumn!
2 day!
```

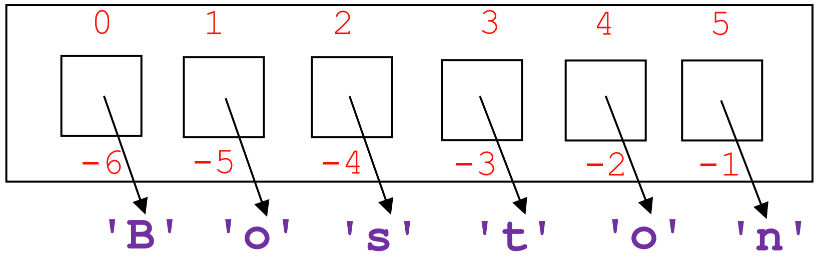
- Tracking the order of elements would **not** be possible if we directly looped over the list.

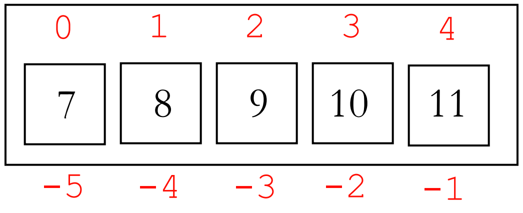
How do indices work?

Digging Deeper

```
word = 'Boston'
```

```
digits = range(7, 12)
```





Indices in Python are both positive and negative.
Everything outside these values will cause an IndexError.

```
In [7]: word[::-1]
Out[7]: 'notsoB'
```

This means: start at 0 until the end of sequence with step -1. And it works because of the negative indices.

Important Note: The model for the word Boston above is not accurate since it's storing strings within the variable boxes. It was done for space reasons.

Digging Deeper

Operations in Sequences

Operation	Result
`x in seq`	True if an item of seq is equal to x
`x not in seq`	False if an item of seq is equal to x
`seq1 + seq2`	The concatenation of seq1 and seq2*
`seq*n, n*seq`	n copies of seq concatenated
`seq[i]`	i'th item of seq, where origin is 0
`seq[i:j]`	slice of seq from i to j
`seq[i:j:k]`	slice of seq from i to j with step k
`len(seq)`	length of seq
`min(seq)`	smallest item of seq
`max(seq)`	largest item of seq

*Recall that concatenation is not supported for range objects.

Digging Deeper

The Slicing operator [:]

```
In [1]: word =
'Boston'
In [2]: word[2]
Out[2]: 's'
In [3]: word[2:5]
Out[3]: 'sto'
In [4]: word[:3]
Out[4]: ‘Bos'
In [5]: word[3:10]
Out[5]: 'ton'
In [6]: word[3:]
Out[6]: 'ton'
In [7]: word[0:6:2]
Out[7]: ‘Bso'
In [8]: word[::-1]
Out[8]: 'notsoB'
```

```
In [1]: digits =
[1, 2, 3, 4]
In [2]: digits[2]
Out[2]: 3
In [3]: digits[1:4]
Out[3]: [2, 3, 4]
In [4]: digits[:3]
Out[4]: [1, 2, 3]
In [5]: digits[3:10]
Out[5]: [4]
In [6]: digits[3:]
Out[6]: [4]
In [7]: digits[0:5:2]
Out[7]: [1, 3]
In [8]: digits[::-1]
Out[8]: [4, 3, 2, 1]
```

```
In [1]: digRange =
range(1, 5)
In [2]: digRange[2]
Out[2]: 3
In [3]: digRange[1:4]
Out[3]: range(2, 5)
In [4]: digRange[:3]
Out[4]: range(1, 4)
In [5]: digRange[3:10]
Out[5]: range(4, 5)
In [6]: digRange[3:]
Out[6]: range(4, 5)
In [7]: digRange[0:5:2]
Out[7]: range(1, 5, 2)
In [8]: digRange[::-1]
Out[8]: range(4, 0, -1)
```

Summary

1. Strings, lists, and ranges are examples of sequences, **ordered** items that are stored together. Because they are ordered, we can use indices to access each of them individually and sequentially.
2. How does a **`for`** loop differ from a **`while`** loop? How are they similar?
3. The indexing operator `[]` takes index values from 0 to len(sequence)-1. However, negative indices are possible too in Python.
4. If we can access each element of a sequence (string, list, range) one by one, then we can perform particular operations with them.
5. To access each element we need a **loop**, an execution mechanism that repeats a set of statements until a stopping condition is fulfilled.
6. When we loop over a sequence, the stopping mechanism is the arrival at the last element and not having anywhere to go further.
7. We use the built-in function **`range`** to generate indices for sequences.
8. Python makes it easy for us to iterate over a sequence's elements even without the use of indices. In fact we can write: **`for item in sequence:`** and that will access each item of the sequence. (A value loop!)
9. In addition to accessing one element at a time with `[]`, we can use `[:]` (slicing) to get a substring, sublist, or subrange.