Python Programming for Data Science

Week 40, Friday

- Computational Complexity
- Exceptions

Computational Complexity

How long does it take to find a recipy in a cookbook?

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How can we answer a question like this?

Exercise: Finding a recipy in a cookbook

Let's say our cookbook contains 100 recipes.

How many recipes would we (on average) need to look at before finding the one we are looking for?

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Exercise: Finding a recipy in a cookbook — solution

How many recipes would we (on average) need to look at before finding the one we are looking for?

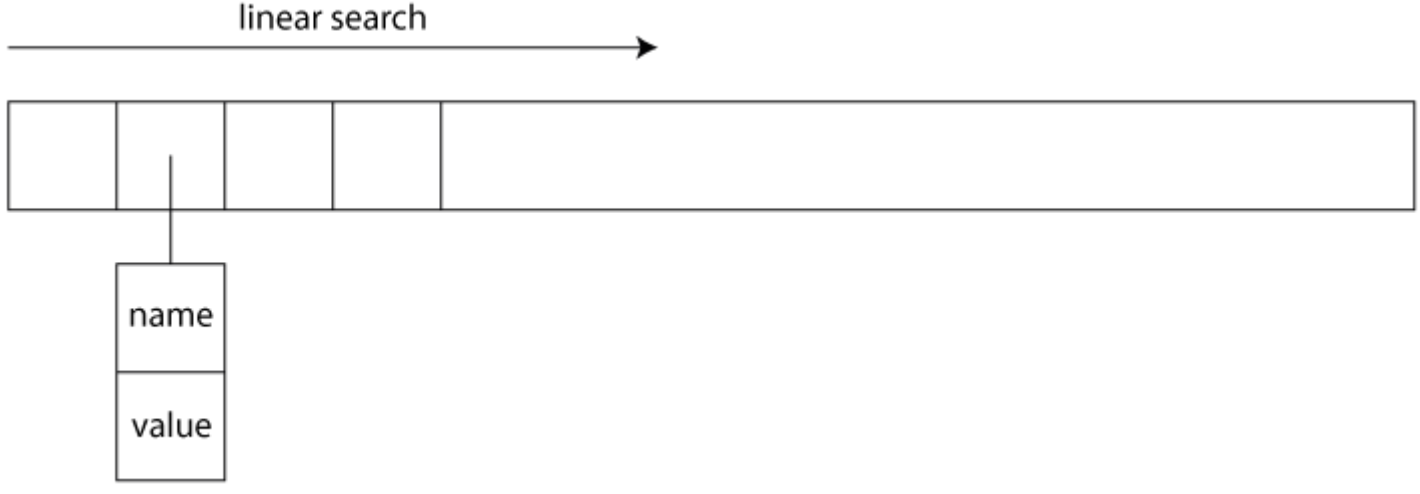
Algorithm: We look at the recipes from the beginning to the end, and stop when we find it. On average, we will have to look at $100/2$ recipes.

Exercise 1

Data: 25.000 genes and their DNA sequences. How do we represent this?

1. Could we use a list? How many genes would we need to look at to find a particular gene?
2. Would it help if we sorted the elements in the list?
3. How many genes would we need to look at to find a particular gene if we used a dictionary?

Exercise 1.1 - solution: Linear search



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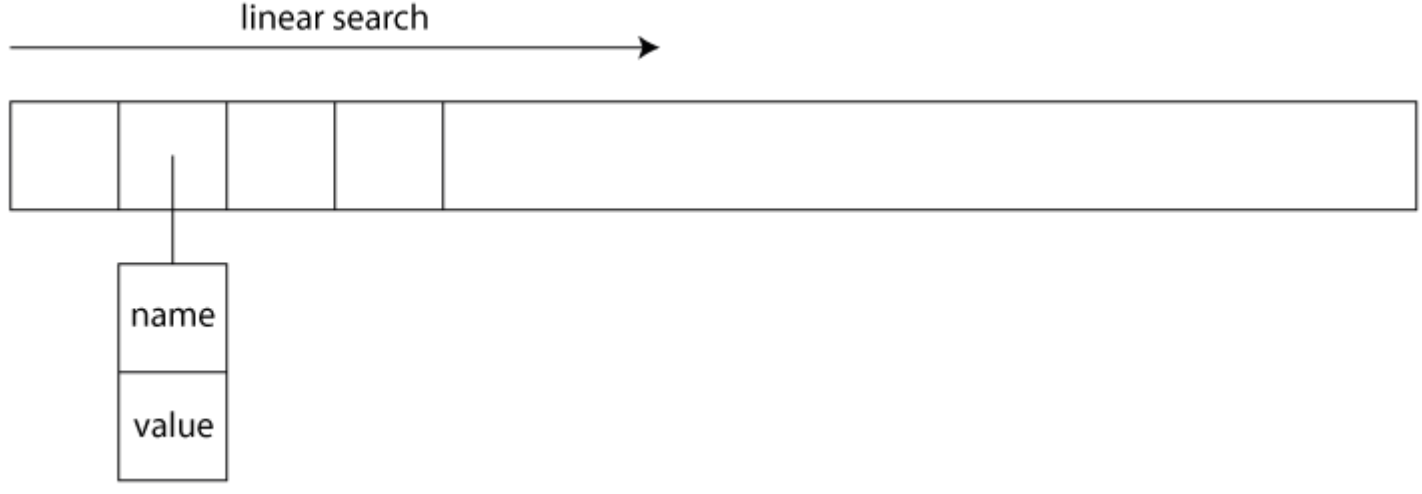

Q: How many elements will we (on average) have to look at before finding our element?

A: On average, we will have to look at 25.000/2 elements before we find the element we want

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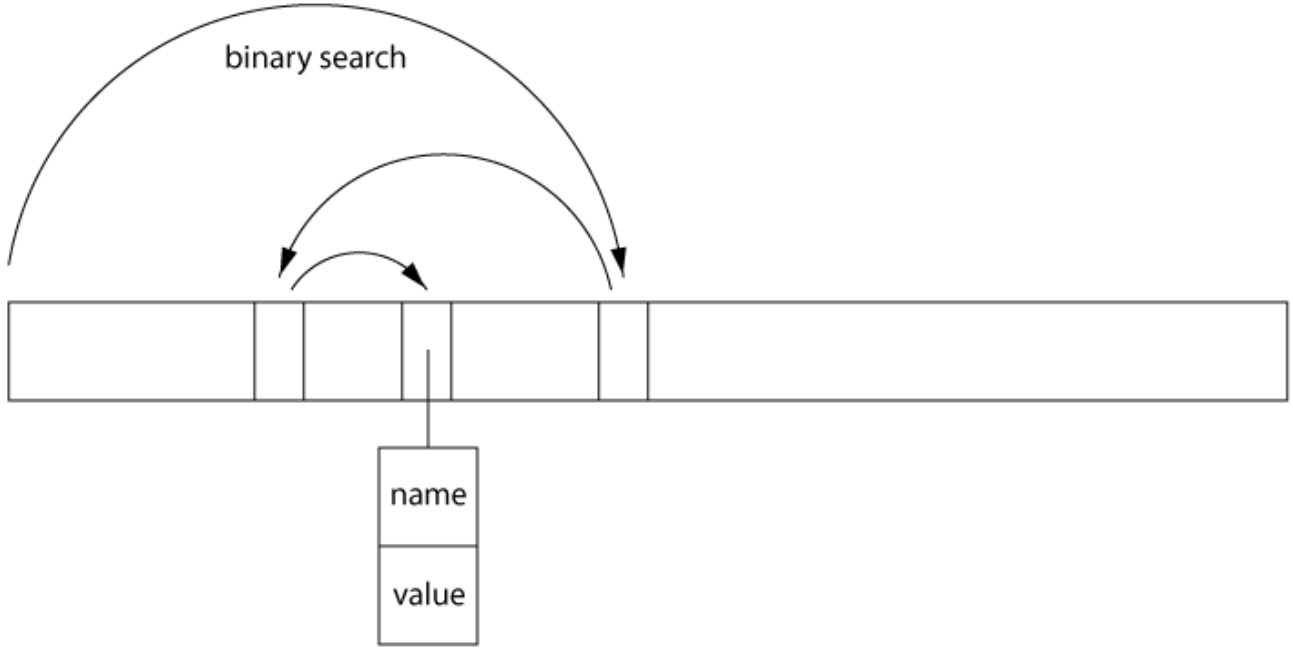
Yes.

Exercise 1.2 - solution: Binary search



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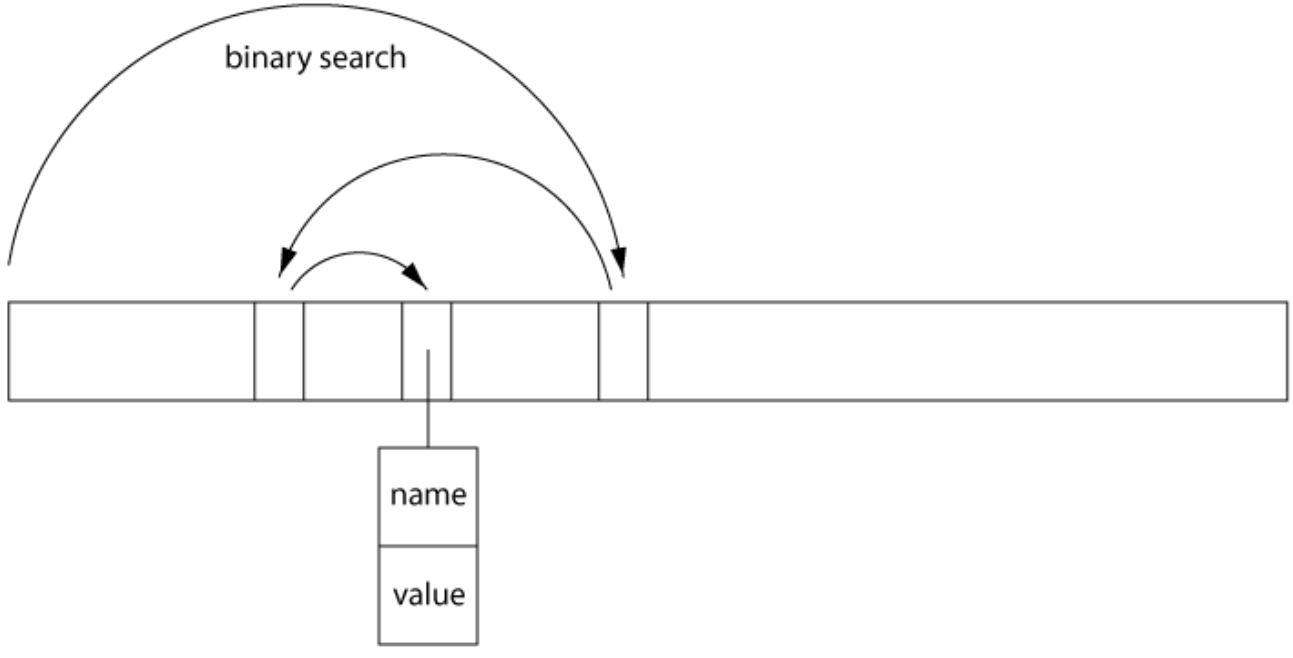

Using binary search, we exclude half of the list each time.

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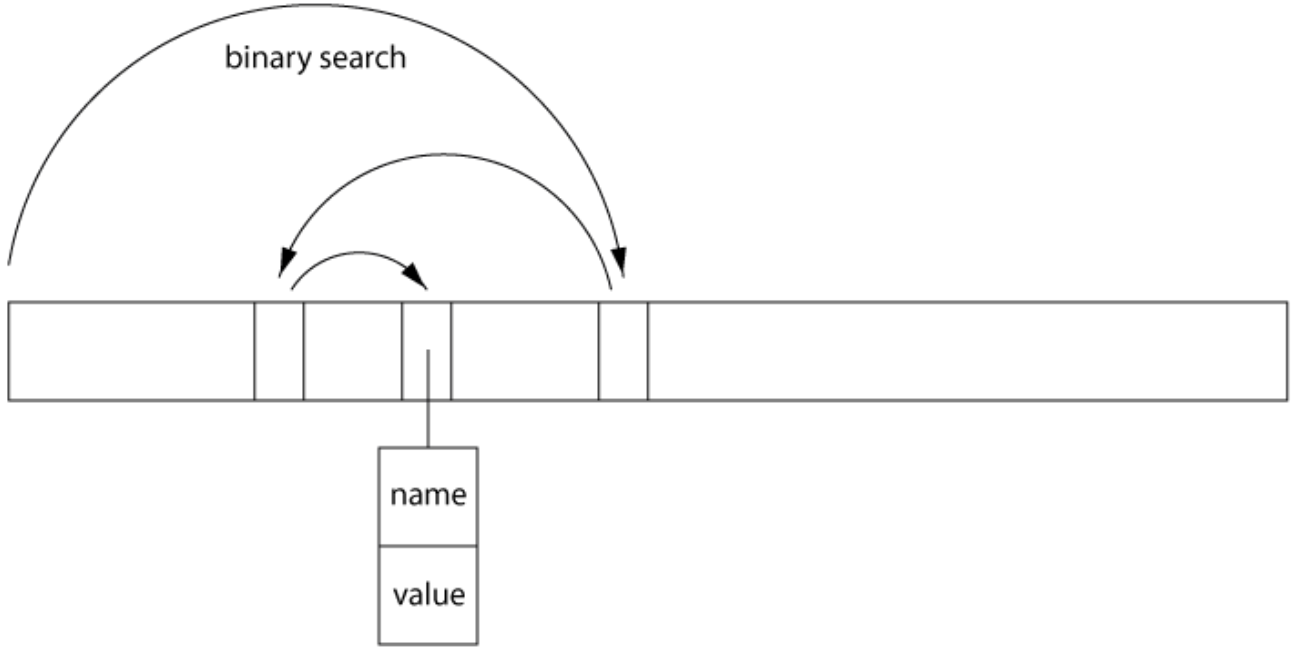

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This means we have to check roughly $\log_2(25000) \approx 15$ elements before we find the element we want.

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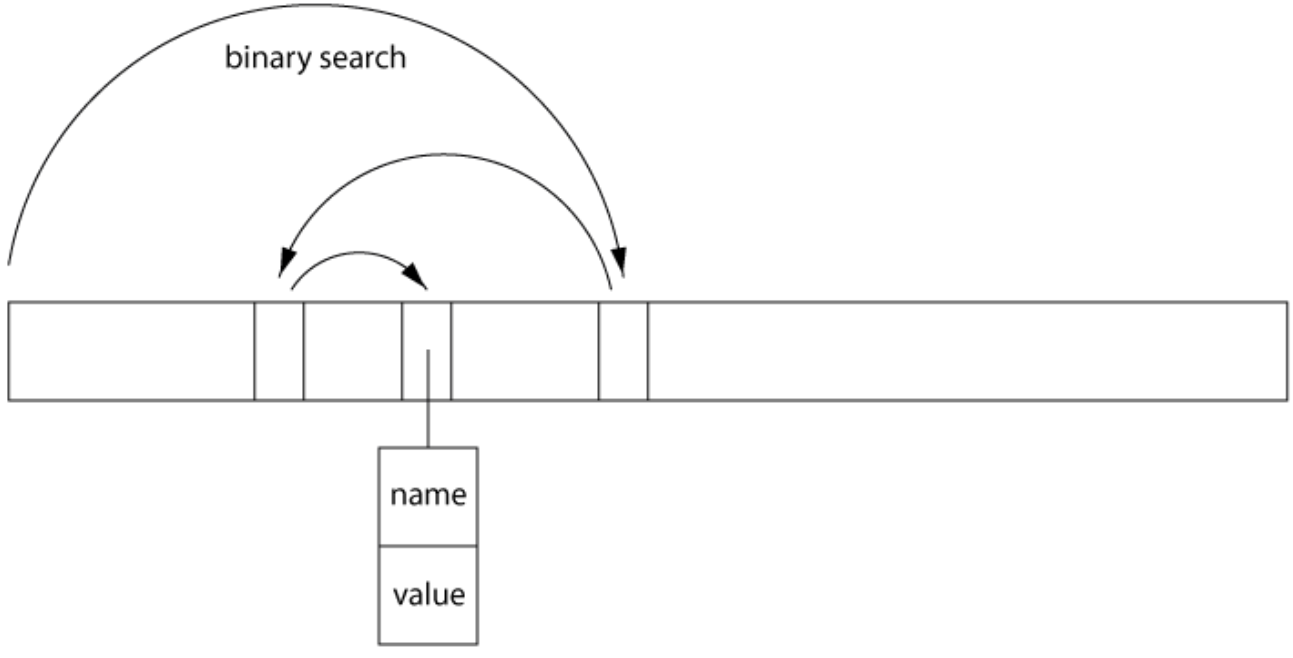
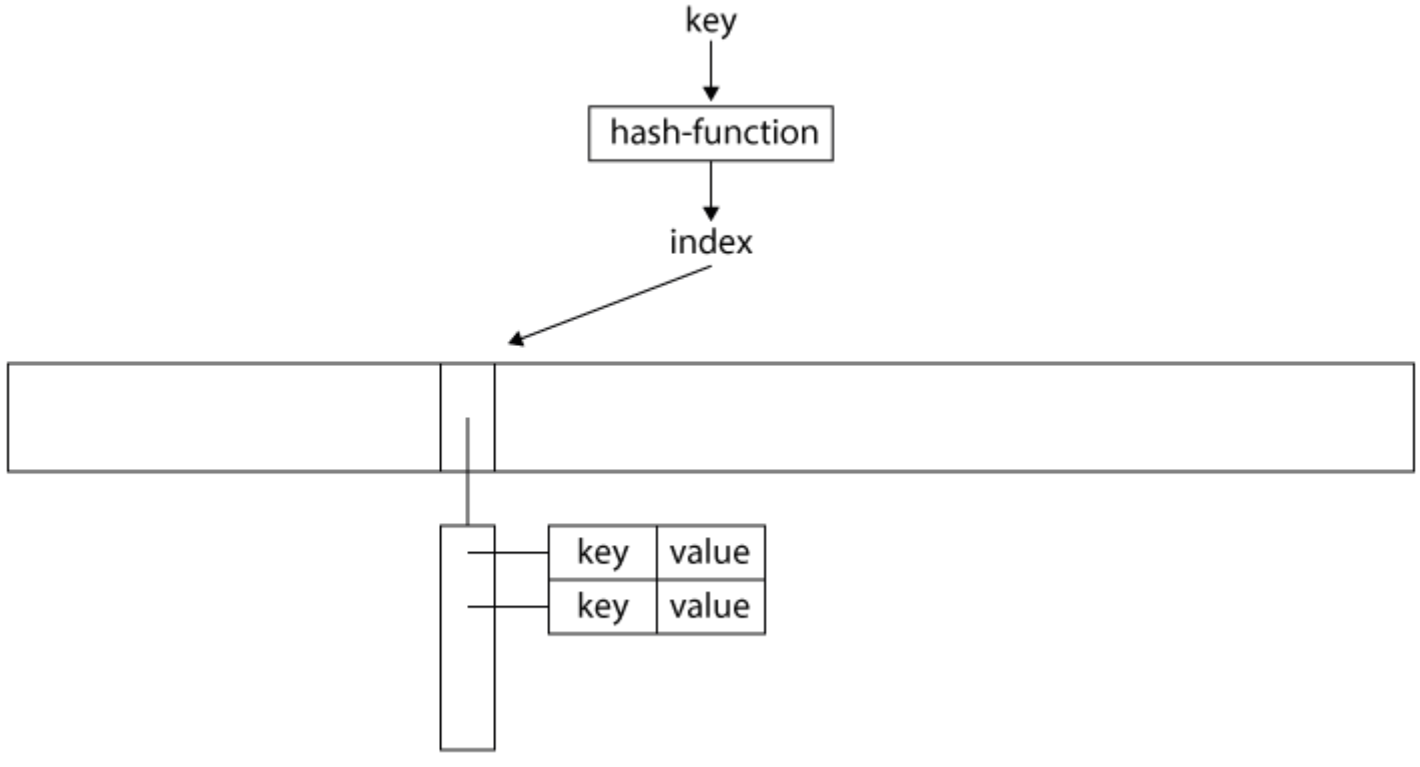


Using binary search, we exclude half of the list each time.

This means we have to check roughly $\log_2(25000) \approx 15$ elements before we find the element we want.

(note: sorting also takes time: $(\sim 25000 * \log_2(25000))$.

Exercise 1.3 - solution: Dictionary



A dictionary will automatically create a function that maps key values to indices in a list. This means it can do lookups in very few operations.

Structuring data

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Structuring data

- In data science, you are often in a situation where you need to represent a large amount of data in your program.
- We have seen several examples of situations where we read in data and store it in some data structure, for instance a list of lists or a dictionary of lists.
- The speed by which a given task can be solved is often very dependent on how you represent the data.

Quantifying "the speed"

Different algorithms can be faster or slower

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Different algorithms can be faster or slower

We want to express the efficiency of an algorithm independent on the specific choice of cookbook, and independently of whether we run on a slow or a fast computer.

"How long" can therefore not really be measured in minutes or seconds.

Instead, we can express it in terms of the *input size*, n — in our case the number of recipes in the cookbook.

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To quantify how "fast" an algorithm is, computer scientists introduced the concept of *computational complexity*:

- a conservative (worst case) estimate of the number of steps necessary to complete the algorithm
- expressed in terms of the size of the input n
- formally described using the big-O notation (e.g. $O(n)$)

Big-O notation

Mathematical notation that describes the asymptotic behaviour of a function.

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Think of the time complexity of a program as a function $f(n)$ of the input size n.

- As the input size grows, the execution time typically grows
- We don't know *exactly* how it grows
- The O formalism is designed to give an upper bound.

Big-O notation - for the mathematically inclined

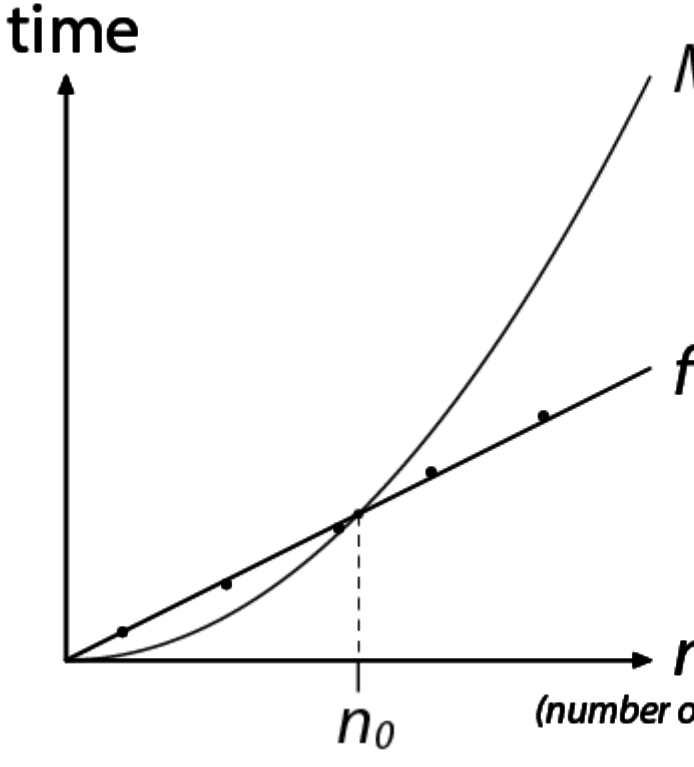
We say that

$$f(n) \in O(g(n))$$

if there exists values n_0 and M, such that

$$|f(n)| < M \cdot |g(n)|$$

for all $n > n_0$



Big-O notation - Examples

$n^2 + n + 3$	$\in$
$3n^8 + 4n + 7n^{10}$	$\in$
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Complexity - Exercise 2

1. What is the complexity of:

```
print(l)                          # l is a list of length n
```

2. What is the time complexity of the following code?

```
for i in range(len(l)):           # l is a list of length n
    for j in range(len(l)):
        if l[i] > l[j]:
            l[i], l[j] = l[j], l[i]
print(l)
```

3. What is the time complexity of the following code? And what does it do?

```
for i in range(len(l)):           # l is a list of length n
    for j in range(i,len(l)):
        if l[i] > l[j]:
            l[i], l[j] = l[j], l[i]
print(l)
```

Complexity - Exercise 2 - Solution (1)

```
l = [4,6,2,5,7,8,9]
print(l)
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Complexity - Exercise 2 - Solution (1)

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l = [4,6,2,5,7,8,9]
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```

Even though it is just a single command, print will have to look at all elements in the list in order to print them. The complexity is therefore $O(n)$.

Complexity - Exercise 2 - Solution (2)

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```

Complexity: $O(n^2 + n) = O(n^2)$

Complexity - Exercise 2 - Solution (3)

```
l = [4,6,2,5,7,8,9]
for i in range(len(l)):
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for i in range(len(l)):
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print(l)
```

Complexity: $O(n(n+1)/2+n) = O(n^2)$

This algorithm is called *bubble sort*. It sorts the lists.

The built in sort method in python lists is faster. It has complexity $O(n \cdot \log(n))$

Complexity - Exercise 3

1. What is the complexity of looking up an element in a list using []?
2. What is the complexity of removing an element in a Python list (using pop())?
3. What is the complexity of the strip() method in the string class?
4. What is the complexity of your handin4_test.py?

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4. What is the complexity of your handin4_test.py? $O(n)$, where n is the number of lines in the file.

Exceptions

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We have already seen exceptions in action many times. Every time you have written a program that crashed this has been due to an exception.

Exceptions - example

exceptions.py

```
a = ?
```

output

```
  File "/home/lpp/lpp2016/exceptions.py", line 1
    a = ?
        ^
SyntaxError: invalid syntax
```

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The program crashes because we assign ? to the variable a.

This does not make sense, so Python complains.

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The program crashes because we assign ? to the variable a.

This does not make sense, so Python complains.

Python automatically raises built-in exception when it discovers an error, and terminates the program (default behavior).

Exceptions - more examples

exceptions.py

```
d = {'Mon':'Monday', 'Tue':'Tuesday'}
print(d[Wed])
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 2, in
    print(d[Wed])
NameError: name 'Wed' is not defined
```

Q: What's wrong here? What is Python trying to tell us?

Exceptions - more examples

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NameError: name 'Wed' is not defined
```

Q: What's wrong here? What is Python trying to tell us?

A: Python thinks Wed is a variable, which is not defined

Exceptions - more examples (1)

exceptions.py

```
print(d['Wed'])       # Specify Wed as a string
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 2, in
    print(d['Wed'])
KeyError: 'Wed'
```

Exceptions - more examples (1)

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KeyError: 'Wed'
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Q: What's wrong this time? What is Python trying to tell us?

A: The key 'Wed' is not present in our dictionary.

Catching exceptions

Rather than letting the program crash, you can define how to respond to an exception

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This is done using *try-catch* statements

errors.py

```
d = {'Mon':'Monday', 'Tue':'Tuesday'}
try:
    d['Wed']      # you can have as many lines as you want in here
except:
    # print keys to screen when error occurs.
    print("Key not found in dictionary. Available keys:", d.keys())
```

output

```
Key not found in dictionary. Available keys:  ['Mon', 'Tue']
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output

```
Key not found in dictionary. Available keys:  ['Mon', 'Tue']
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Now that the exception has been caught, it will no longer crash your program.

Catching specific exceptions

Rather than catching *any* type of exception, you can specify that you only want to catch exceptions of a certain type.

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try:
    d['Wed']
except KeyError:  # <- Only catch KeyError exceptions
    # print keys to screen when error occurs.
    print("Key not found in dictionary. Available keys: ", d.keys())
```

output

```
Key not found in dictionary. Available keys:  ['Mon', 'Tue']
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Catching specific exceptions (continued)

If we catch the wrong exception type, we will get the original behavior:

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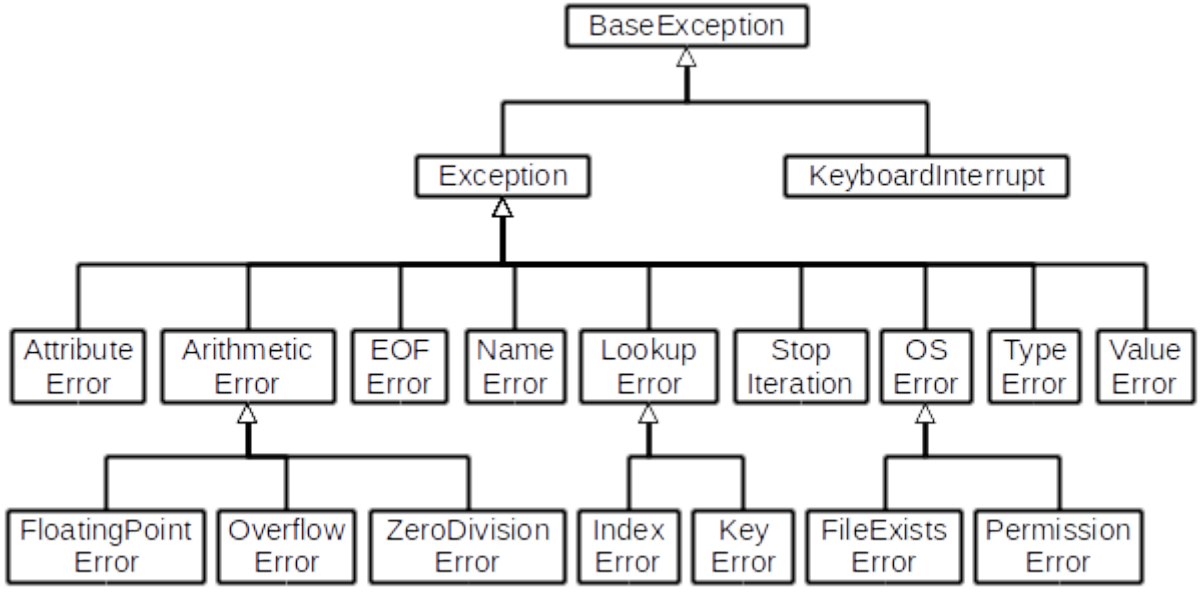
```
d = {'Mon':'Monday', 'Tue':'Tuesday'}
try:
    d['Wed']
except NameError:  # <- Only catch NameError exceptions
    # print keys to screen when error occurs.
    print("Key not found in dictionary. Available keys: ", d.keys())
```

output

```
Traceback (most recent call last):
  File "/home/lpp/Documents/lpp2015/errors.py", line 2, in <module>
    d['Wed']
KeyError: 'Wed'        # <- NOTE: our bug produces a KeyError
```

Exceptions – Class hierarchy

Pythons built-in exceptions are structured in a class hierarchy.



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The exception type that you specify ***and all derived classes from this class*** will be caught

errors.py

```
d = {'Mon':'Monday', 'Tue':'Tuesday'}
try:
    d['Wed']
except Exception:  # Exception covers both NameError and KeyError
    print("Key not found in dictionary. Available keys: ", d.keys())
```

Catching exceptions – accessing details

You can access the exception object itself to gain extra information regarding the error.

This this done using the *as* keyword

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This this done using the *as* keyword

errors.py

```
d = {'Mon':'Monday', 'Tue':'Tuesday'}
try:
    d['Wed']
except Exception as error:    # Save error object
    # error contains information about key that failed
    print("Information about error: " + str(error))
```

output

```
Information about error: 'Wed'
```

Exercise

Write the most specific try/except statement for each of the following situations:

1.

```
print(I_love_python)
```

2.

```
l=[1,2,3,4]
print(l[4])
```

3.

```
print(1/0)
```

Exercise - solution 1

1.

exceptions.py

```
print(I_love_python)
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 1, in
    print(I_love_python)
NameError: name 'I_love_python' is not defined
```

Exercise - solution 1

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output

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Traceback (most recent call last):
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We note that our mistake raises a NameError. Solution:

Exercise - solution 1

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We note that our mistake raises a NameError. Solution:

```
try:
    print(I_love_python)
except NameError as error:
    print("Something is wrong here: %s" % error)
```

Exercise - solution 2

2.

exceptions.py

```
l=[1,2,3,4]
print(l[4])
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 2, in
    print(l[4])
IndexError: list index out of range
```

Exercise - solution 2

2.

exceptions.py

```
l=[1,2,3,4]
print(l[4])
```

output

```
Traceback (most recent call last):
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We note that our mistake raises an IndexError. Solution:

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IndexError: list index out of range
```

We note that our mistake raises an IndexError. Solution:

```
l=[1,2,3,4]
try:
    print(l[4])
except IndexError as error:
    print("Something is wrong here: %s" % error)
```

Exercise - solution 3

3.

exceptions.py

```
print(1/0)
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 1, in
    print(1/0)
ZeroDivisionError: integer division or modulo by zero
```

Exercise - solution 3

3.

exceptions.py

```
print(1/0)
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 1, in
    print(1/0)
ZeroDivisionError: integer division or modulo by zero
```

We note that our mistake raises a ZeroDivisionError.

Solution:

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ZeroDivisionError: integer division or modulo by zero
```

We note that our mistake raises a ZeroDivisionError.

Solution:

```
try:
    print(1/0)
except ZeroDivisionError as error:
    print("Something is wrong here: %s" % error)
```

Raising exceptions

You can also raise the built-in exceptions yourself:

exceptions.py

```
raise KeyError
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py", line 1, in
    raise KeyError
KeyError
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KeyError
```

The raise statement can be used at any place in your code to interrupt the program

Exceptions – the assert statement

It is common to insert sanity checks in a program, testing that a particular condition is always true

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if not condition:
    raise exception
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assert condition    # raises an AssertionError if condition is not True
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if not condition:
    raise exception
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There is a statement called assert that does this automatically

```
assert condition    # raises an AssertionError if condition is not True
```

Example:

exceptions.py

```
x = 2
assert x>0 and x<10
assert x<0 and x>10
```

output

```
Traceback (most recent call last):
  File "/home/lpp/lpp2016/exceptions.py",
    assert x<0 and x>10
AssertionError
```

Exercise

Write a function that takes a single number as argument

1. The function should check that this number is an even number (0,2,4,6,...) and raise an exception otherwise.
2. Call the function with an uneven number:
    - Without catching the exception
    - Catching the exception and printing a warning.

Exercise - solution

errors.py

```
def my_function(value):
    '''Function without any functionality. But assumes that value is even.
    assert value%2 == 0    # Raise exception if value is not even

# Call with uneven number
my_function(1)
```

output

```
Traceback (most recent call last):
  File "/home/lpp/Documents/lpp2016/errors.py", line 22, in <module>
    my_function(1)
  File "/home/lpp/Documents/lpp2016/errors.py", line 13, in my_function
    assert value%2 == 0
AssertionError
```

errors.py

```
# Call with uneven number - catch AssertionError
try:
    my_function(1)
except AssertionError:
    print("Assertion failed in function")
```

output

```
Assertion failed in function
```

Defining your own exceptions

Rather than using the built-in exception types, you can define your own exceptions, to cover specific problems relevant to your program

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Rather than using the built-in exception types, you can define your own exceptions, to cover specific problems relevant to your program

This is done by creating a class that inherits from Exception

```
class MyException(Exception):    # Defining a very simple exception class
    pass

raise MyException                # Raising an exception of this type
```

```
Traceback (most recent call last):
  File "/home/lpp/Documents/lpp2014/errors.py", line 8, in <module>
    raise MyException
__main__.MyException
```

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    raise MyException
__main__.MyException
```

For more information, see the python docs.

try...except...finally

Consider this code

```
try:
    data_file = open("/usr/share/dict/british-english")

    words = {}
    for i, line in enumerate(data_file):
        words[line.strip()] = i

    print(words['bokeh'])

    data_file.close()
except KeyError as error:
    print("Word %s not found" % str(error))
```

Q: What's wrong here?

try...except...finally

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except KeyError as error:
    print("Word %s not found" % str(error))
```

Q: What's wrong here? A: We don't close the file when an exception occurs

try...except...finally(2)

You can fix the previous example by adding a finally clause to your try-except statement

```
try:
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except KeyError as error:
    print("Word %s not found" % str(error))
finally:
    data_file.close()
```

This code will be executed no matter whether an exception was raised or not

The `with` statement

This pattern is very common

```
thing = initialize_thing()    # (e.g. open a file)
try:
    # do something with thing
finally:
    finalize_thing()          # (e.g. close a file)
```

The `with` statement

This pattern is very common

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For this reason, the following shortcut was introduced

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with initialize_thing() as thing:
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with initialize_thing() as thing:
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Example from before:

```
with open("/usr/share/dict/british-english") as data_file:
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The `with` statement (2)

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Note how the file is now automatically closed when the file exists the with statement

The `with` statement (2)

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This only works for classes that have implemented the following two methods:

- __enter__: Initializes object
- __exit__: Finalizes object

The file class is one such example