

ILP 2022 – W4S2

Testing, asserting and debugging

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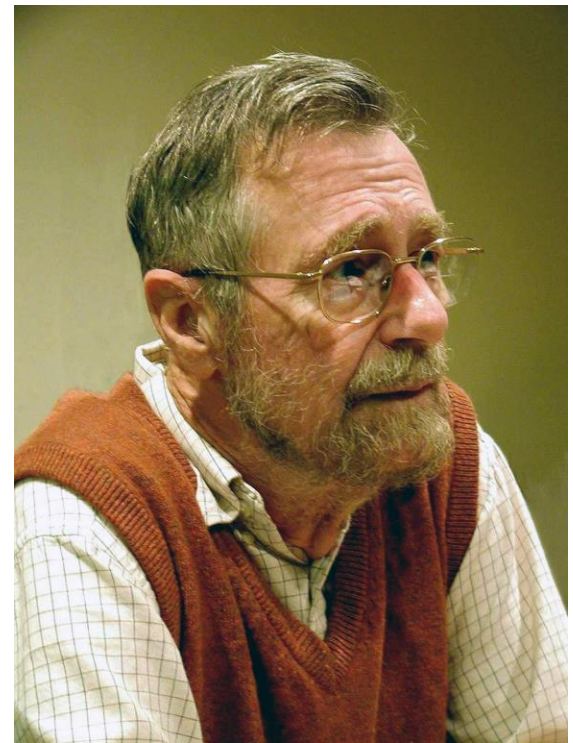
Outline (Week4, Session2 – W4S2)

- Testing
- Unit testing
- Assertion testing
- Integration testing
- Debugging and practice

Testing: a definition?

“Program testing can be used to show the presence of bugs, but never to show their absence!”

– Edsger W. Dijkstra

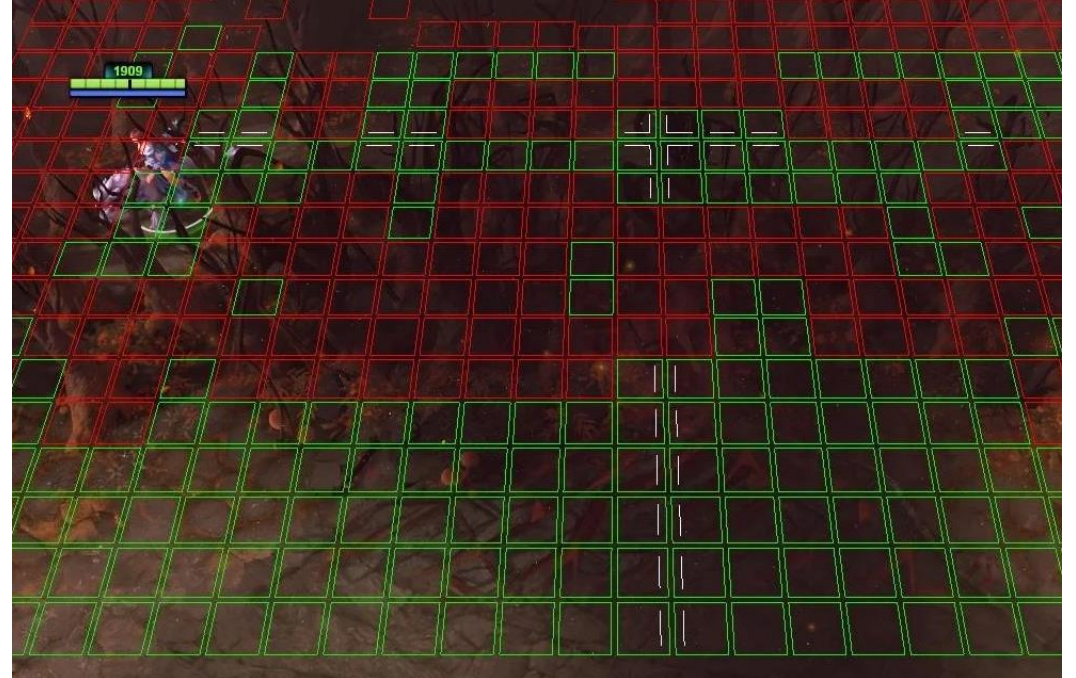
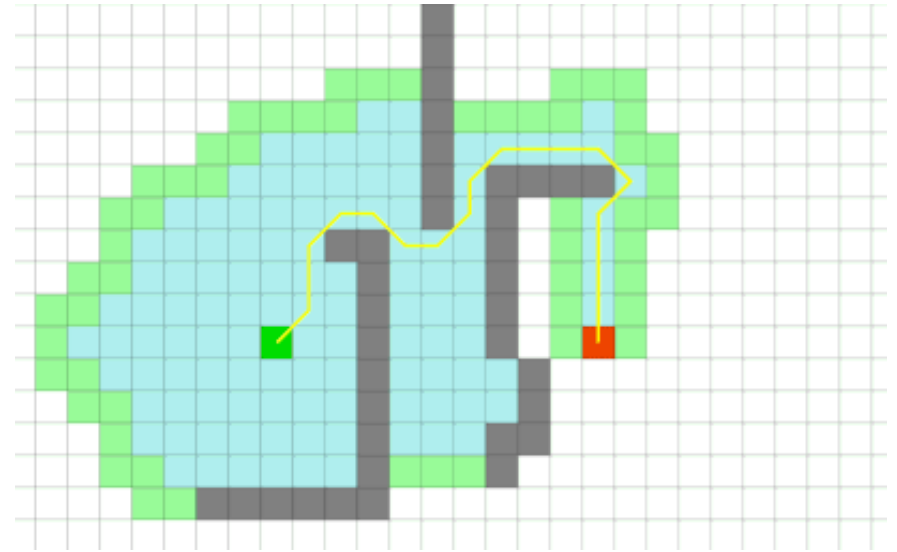


Testing: a definition?

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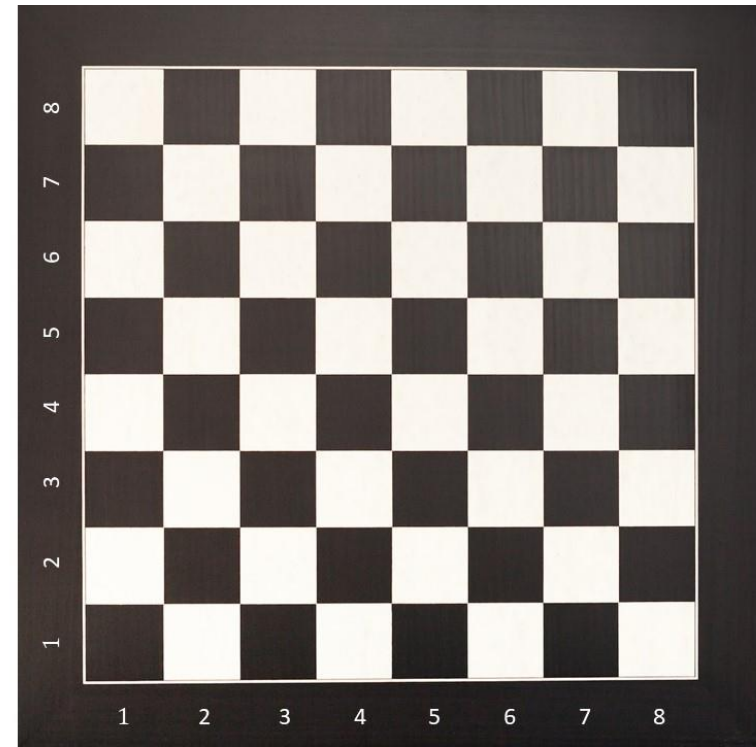
– Edsger W. Dijkstra

FYI: Dijkstra is famous for his algorithm, used for path-finding in many applications (GPS, video games, etc.)



Testing: a definition?

- Program testing is the process of executing a program, with the objective of finding errors.
- Program testing cannot show the absence of errors. It can only show if errors are present.
- It is possible to identify and write the tests before the program.
→ Test driven development.



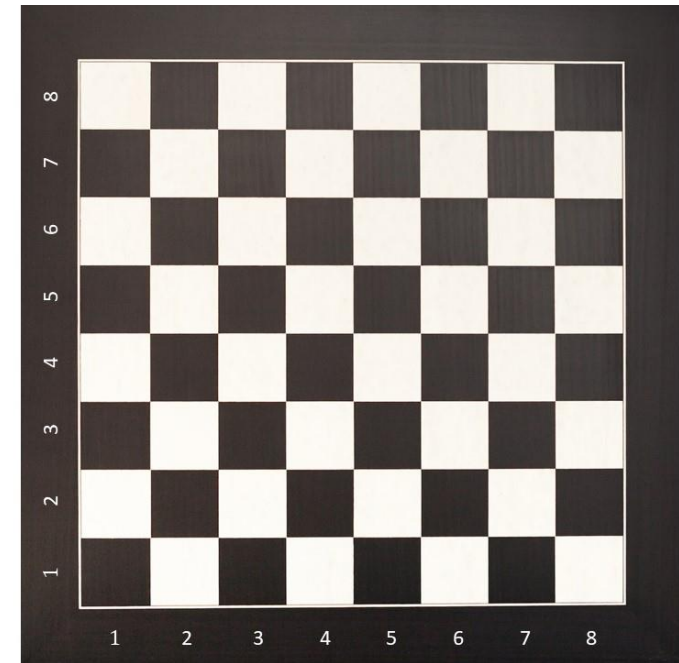
Expected results

A few test cases for you to try:

- The square at coordinates (4,5) is white.
- The square at coordinates (2,2) is black.
- The square at coordinates (4,6) is black.
- The square at coordinates (3,5) is black.

Limits of testing

- **Issue #1:** Program testing cannot show the absence of errors. It can only show if errors are present.
- **Issue #2:** In the ideal world, all possible paths through a programs should be tested.
- But it is often impossible.
 - E.g., I can test all squares of an 8x8 grid, because there is a finite number of them.
 - But I cannot test all possible integers, lists of integers, etc.



Expected solutions

If your function has been correctly designed, the following test cases should work.

```
1  ### Some test cases
2  # This should return True
3  print(is_triangle_rectangular(a = 3, b = 4, c = 5))
4
5  # This should return False
6  print(is_triangle_rectangular(a = 4, b = 4, c = 6))
7
8  # This should return False
9  print(is_triangle_rectangular(a = 3, b = 5, c = 4))
10
11 # This should return True
12 print(is_triangle_rectangular(a = 0, b = 0, c = 0))
```

Unit testing

- **Unit testing:** test cases, whose objective is to verify that a **single** function is able to operate as expected.
- Often a good idea to start simple, and progressively look for more complex/special cases.


```
1 def function(my_list):
2     # Remove max and min from list
3     min_val = min(my_list)
4     max_val = max(my_list)
5     while(min_val in my_list):
6         my_list.remove(min_val)
7     while(max_val in my_list):
8         my_list.remove(max_val)
9     return my_list
```

```
1 # Test case 1: a normal, good looking list,
2 # with a single max value and a single min value
3 my_list = [1,2,3,4,5]
4 print(function(my_list))
```

[2, 3, 4]


```
1  # Test case 2: a normal, good looking list,  
2  # with multiple occurrences of the max and min values  
3  my_list = [1,1,2,3,4,5,5,5]  
4  print(function(my_list))
```

[2, 3, 4]

```
1  # Test case 3: a list with only min and max values  
2  my_list = [1,1,5,5,5]  
3  print(function(my_list))
```

[]

```
1  # Test case 4: a list with only min and max values,  
2  # and the min/max values are identical  
3  my_list = [5,5,5]  
4  print(function(my_list))
```

[]

```
1 # Test case 5: an empty list
2 my_list = []
3 print(function(my_list))
```

ValueError

Traceback (most recent call last)

<ipython-input-9-a5d51a1c5688> in <module>

```
1 # Test case 5: an empty list
2 my_list = []
----> 3 print(function(my_list))
```

<ipython-input-3-02cd6a8e44a3> in function(my_list)

```
1 def function(my_list):
2     # Remove max and min from list
----> 3     min_val = min(my_list)
4     max_val = max(my_list)
5     while(min_val in my_list):
```

ValueError: min() arg is an empty sequence

Unit testing

- **Unit testing:** test cases, whose objective is to verify that a **single** function is able to operate as expected.
- Often a good idea to start simple, and progressively look for more complex/special cases.
- Whenever a test case is identified as not working, **amend** the function to cover for this special case if needed.

```
1 def function_v2(my_list):
2
3     # Warning: Need to cover for empty list case
4     if len(my_list) == 0:
5         return []
6     else:
7         # Remove max and min from list
8         min_val = min(my_list)
9         max_val = max(my_list)
10        while min_val in my_list:
11            my_list.remove(min_val)
12        while max_val in my_list:
13            my_list.remove(max_val)
14        return my_list
```

```
1 # Test case 5: an empty list
2 my_list = []
3 print(function_v2(my_list))
```

[]

Unit testing

- **Unit testing:** test cases, whose objective is to verify that a **single** function is able to operate as expected.
- Often a good idea to start simple, and progressively look for more complex/special cases.
- Whenever a test case is identified as not working, **amend** the function to cover for this special case if needed.
- Unit testing is a **cat-and-mouse game!**

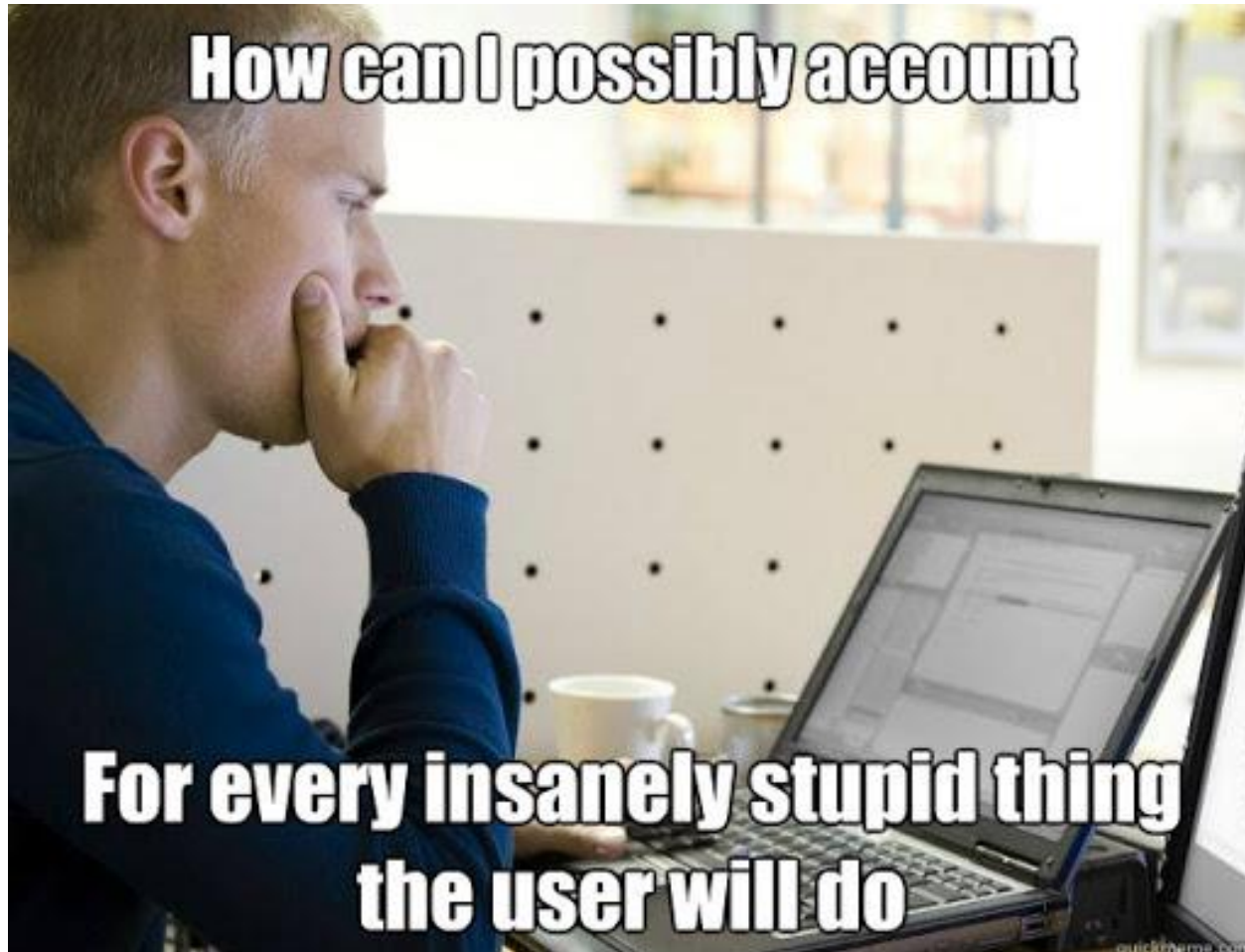
Unit testing is essential...

- But ultimately, it is never enough.
- It is a never ending task, as it will never be able to cover for all possible ways to break our function.

```
1  # Test case 6: a non-empty list  
2  # with non-numerical values  
3  my_list = ["Hello", "What", "is", "up?"]  
4  # Function works without errors,  
5  # but is it really the expected behavior?  
6  print(function_v2(my_list))
```

```
['What', 'is']
```

Finding the right balance?



Assertion testing

- **In some (stupid) cases, the function should simply refuse to operate.**
- Instead, it should check that the function is indeed being used in its “normal” setting.
- And raise error messages to inform the user that he/she is misusing the function, if so.
- That is called **assertion testing**.

Assertions

```
1 from numpy import cos
2 # Works as expected
3 print(cos(0))
4 # The cosine function was not
5 # designed to operate on text!
6 print(cos("Hello"))
```

1.0

TypeError

Traceback (most recent call last)

<ipython-input-1-9b7a6eeabc31> in <module>

4 # The cosine function was not

5 # designed to operate on text!

----> 6 print(cos("Hello"))

TypeError: ufunc 'cos' not supported for the input types, and the inputs could not be safely coerced to any supported types according to the casting rule ''safe''

The **assert** Keyword

- The **assert** keyword is used for assertion testing.
- It is the most basic error control structure; whose objective is to verify that a function/program is being used in its intended purpose/configuration.

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- The **assert** keyword is used for assertion testing.
- It is the most basic error control structure; whose objective is to verify that a function/program is being used in its intended purpose/configuration.
- It receives a Boolean and a message in string format.
- If the Boolean is **True**, **nothing happens**.
- If **False**, the program **crashes on purpose** and the **message is displayed as an error**.

The **assert** Keyword

```
1 bool1 = True
2 message = "Nothing will be displayed."
3 assert bool1, message
```

```
1 bool1 = False
2 message = "Assertion test failed, interrupted program, error message here."
3 assert bool1, message
```

AssertionError

Traceback (most recent call last)

<ipython-input-4-2370335b2e43> in <module>

1 bool1 = False

2 message = "Assertion test failed, interrupted program, error message here."

----> 3 assert bool1, message

AssertionError: Assertion test failed, interrupted program, error message here.

The **assert** Keyword

- The **assert** keyword is used for assertion testing.
- It is the most basic error control structure; whose objective is to verify that a function/program is being used in its intended purpose/configuration.
- Typically used to check
 - That a user entered digits only, when prompted with input(),
 - Mathematical functions are used with numerical types variables,
 - Etc.

Asserting on types

- Another interesting function is the **isinstance()** one, which is used for **type checking**.
- It receives two arguments.
- The first one is a variable,
- The second a type (int, float, str, list, etc.)
- It returns **True**, if the variable is of said type and **False** otherwise.

```
1 x = 10
2 # Returns True, because x is an int type
3 print(isinstance(x, int))
4 # Returns False, because x is an int type
5 print(isinstance(x, str))
```

True

False

An application example: our sqrt function

```
1 def my_sqrt(x):  
2     return x**0.5
```

```
1 # Test case 1: stricly positive number, perfect square  
2 x = 4  
3 print(my_sqrt(x))
```

2.0

```
1 # Test case 2: stricly positive number, not a perfect square  
2 x = 3  
3 print(my_sqrt(x))
```

1.7320508075688772

```
1 # Test case 3: zero  
2 x = 0  
3 print(my_sqrt(x))
```

0.0

An application example: our sqrt function

```
1  # Test case 4: strictly negative number
2  x = -10
3  print(my_sqrt(x))
```

```
(1.9363366072701937e-16+3.1622776601683795j)
```

An application example: our sqrt function

```
1  # Test case 4: strictly negative number
2  x = -10
3  print(my_sqrt(x))
```

(1.9363366072701937e-16+3.1622776601683795j)

```
1  def my_sqrt_v2(x):
2      error_message = "Warning: square roots with neg. values not supported."
3      assert x >= 0, error_message
4      return x**0.5
```

An application example: our sqrt function

```
1 # Test case 4: strictly negative number
2 x = -10
3 print(my_sqrt_v2(x))
```

```
-----
AssertionError                                Traceback (most recent call last)
<ipython-input-18-7af65051bf94> in <module>
      1 # Test case 4: strictly negative number
      2 x = -10
----> 3 print(my_sqrt_v2(x))

<ipython-input-17-b087dc1361f2> in my_sqrt_v2(x)
      1 def my_sqrt_v2(x):
      2     error_message = "Warning: square roots with neg. values not supported."
----> 3     assert x >= 0, error_message
      4     return x**0.5
```

AssertionError: Warning: square roots with neg. values not supported.

An application example: our sqrt function

```
1 # Test case 5: passing a non-numerical variable
2 x = "Hello"
3 print(my_sqrt_v2(x))
```

```
-----
TypeError                                Traceback (most recent call last)
<ipython-input-19-da2de9f8d1ba> in <module>
      1 # Test case 5: passing a non-numerical variable
      2 x = "Hello"
----> 3 print(my_sqrt_v2(x))

<ipython-input-17-b087dc1361f2> in my_sqrt_v2(x)
      1 def my_sqrt_v2(x):
      2     error_message = "Warning: square roots with neg. values not supported."
----> 3     assert x >= 0, error_message
      4     return x**0.5
```

TypeError: '>=' not supported between instances of 'str' and 'int'

```
1 def my_sqrt_v3(x):
2     error_message = "Warning: x must be a strictly positive number."
3     assert isinstance(x, int) or isinstance(x, float), error_message
4     assert x >= 0, error_message
5     return x**0.5
```

```
1 # Test case 5: passing a non-numerical variable
2 x = "Hello"
3 print(my_sqrt_v3(x))
```

```
-----
AssertionError                                Traceback (most recent call last)
<ipython-input-24-1686192c086b> in <module>
      1 # Test case 5: passing a non-numerical variable
      2 x = "Hello"
----> 3 print(my_sqrt_v3(x))

<ipython-input-23-66afafabbe16> in my_sqrt_v3(x)
      1 def my_sqrt_v3(x):
      2     error_message = "Warning: x must be a strictly positive number."
----> 3     assert isinstance(x, int) or isinstance(x, float), error_message
      4     assert x >= 0, error_message
      5     return x**0.5
```

AssertionError: Warning: x must be a strictly positive number.

What makes a good function?

We can define a good function as

1. A function that is able to operate on any of its “normal” test cases (strictly positive numbers for sqrt)
2. A function that is able to cover for special cases (empty lists, division by zero, etc.)
3. A function that raises explicative errors, if it is misused by the user (wrong variable type, not implemented feature, etc.)

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 3. A function that raises explicative errors, if it is misused by the user (wrong variable type, not implemented feature, etc.)
 4. (A function that produces results as fast as possible)
- Start small, progressively build up the function with more features!

From unit testing to integration testing

- It is considered good practice to perform unit tests on **ALL** the functions you design, to control that they operate as expected.

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- **Integration testing:** testing that several subfunctions are able to operate correctly when assembled together in a larger program.

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- **Especially important when “patching” a function:** slightly modifying a single function should not make the rest of the program (game, app, etc.) malfunction!

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- It is considered good practice to perform unit tests on ALL the functions you design, to control that they operate as expected.
- It is also essential to perform integration testing.
- **Integration testing:** testing that several functions are able to operate correctly when assembled together in a larger program.
- **Especially important when “patching” a function:** slightly modifying a single function should not make the rest of the program (game, app, etc.) malfunction!

MORE ON THIS TO BE COVERED IN ADVANCED CLASSES IN SUTD!

Error messages

- Error messages are exceptions, which were caught by the Python compiler program, when it attempted to execute your code.
- Typically, assertions, which did not pass, so that the program could execute normally.

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- Error messages are exceptions, which were caught by the Python compiler program, when it attempted to execute your code.
- Typically, assertions, which did not pass, so that the program could execute normally.
- They usually consist of an **approximate location of where the error occurred**,
- And a **standardized error message**, attempting to explain the type of error encountered.

Error messages

```
1 # Add 1 to all numbers in list_numbers
2 list_numbers = ["0", "1", "2", "3"]
3 add_1_list = []
4 for number in list_numbers:
5     val = number + 1
6     add_1_list.append(val)
7 print(add_1_list)
```

TypeError Traceback (most recent call last)

<ipython-input-8-31df80fbb176> in <module>

```
3 add_1_list = []
4 for number in list_numbers:
----> 5     val = number + 1
6     add_1_list.append(val)
7 print(add_1_list)
```

TypeError: can only concatenate str (not "int") to str

Error messages

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TypeError

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TypeError

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<ipython-input-8-31df80fbb176> in <module>

3 add_1_list = []

4 for number in list_numbers:

----> 5 val = number + 1

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7 print(add_1_list)

TypeError: can only concatenate str (not "int") to str

Typical error types

- **Learn more:** <https://www.tutorialsteacher.com/python/error-types-in-python>

Exception	Description
AssertionError	Raised when the assert statement fails.
AttributeError	Raised on the attribute assignment or reference fails.
EOFError	Raised when the input() function hits the end-of-file condition.
FloatingPointError	Raised when a floating point operation fails.
GeneratorExit	Raised when a generator's close() method is called.
ImportError	Raised when the imported module is not found.
IndexError	Raised when the index of a sequence is out of range.
KeyError	Raised when a key is not found in a dictionary.
KeyboardInterrupt	Raised when the user hits the interrupt key (Ctrl+c or delete).
MemoryError	Raised when an operation runs out of memory.

Debugging

- **Debugging** is the **art/process** of detecting and removing of existing and potential errors (also called as 'bugs') in a code that can cause it to behave unexpectedly or crash.

To **debug** a program, the developer (you) has to

1. start with a problem,
2. isolate the source of the problem,
3. and then propose a fix for it.

Debugging: 1&2. isolating a problem

- Python will try its best to provide a location of where the error occurred in its error message.
- Unfortunately, it is not always good info.
- It is often a good idea to try and pinpoint the location of the error, with some prints, to control which parts of the program work fine and which do not.

Debugging: 1&2. isolating a problem

```
1  # Add 1 to all numbers in list_numbers
2  list_numbers = ["0", "1", "2", "3"]
3  add_1_list = []
4  for number in list_numbers:
5      print("Ok")
6      val = number + 1
7      print("Not ok")
8      add_1_list.append(val)
9  print(add_1_list)
```

Ok

```
TypeError                                Traceback (most recent call last)
<ipython-input-9-c336059098f9> in <module>
      4  for number in list_numbers:
      5      print("Ok")
----> 6      val = number + 1
      7      print("Not ok")
      8      add_1_list.append(val)
```

TypeError: can only concatenate str (not "int") to str

Debugging: 1&2. isolating a problem

```
1  # Add 1 to all numbers in list_numbers
2  list_numbers = ["0", "1", "2", "3"]
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9  print(add_1_list)
```

Ok

TypeError Traceback (most recent call last)

`<ipython-input-9-c336059098f9>` in `<module>`

```
4  for number in list_numbers:
5      print("Ok")
----> 6      val = number + 1
7      print("Not ok")
8      add_1_list.append(val)
```

TypeError: can only concatenate str (not "int") to str

Debugging: 3. Fixing the problem

- The error message indicates that Python was not able to sum a number (int), with a block of text (string).

TypeError: can only concatenate str (not "int") to str

- Why did this occur?
- And how do I fix it?

Debugging: 3. Fixing the problem

```
1 # Add 1 to all numbers in list_numbers
2 list_numbers = ["0", "1", "2", "3"]
3 add_1_list = []
4 for number in list_numbers:
5     print("Ok")
6     val = number + 1
7     print("Not ok")
8     add_1_list.append(val)
9 print(add_1_list)
```

Contains strings of
digits, not number
type!

Ok

TypeError

Traceback (most recent call last)

<ipython-input-9-c336059098f9> in <module>

```
4 for number in list_numbers:
5     print("Ok")
----> 6     val = number + 1
7     print("Not ok")
8     add_1_list.append(val)
```

TypeError: can only concatenate str (not "int") to str

Debugging: 3. Fixing the problem

- **Proposed fix:** convert to **int/float** before summing, convert back to **str** at the end.

```
1  # Add 1 to all numbers in list_numbers
2  list_numbers = ["0", "1", "2", "3"]
3  add_1_list = []
4  for number in list_numbers:
5      val = int(number) + 1
6      add_1_list.append(str(val))
7  print(add_1_list)
```

```
['1', '2', '3', '4']
```



Let us practice some debugging!

Open the “Debugging practice” notebook for some
typical examples of bugs and debugging!

Conclusion

- Testing
- Unit testing
- Assertion testing
- Integration testing
- Debugging and practice

Also

I have uploaded some of the activities from last year's summer school, in case you would like to practice before the midterm exam!

Don't overdo it though!