ILP 2022 – W4S2
Testing, asserting and debugging

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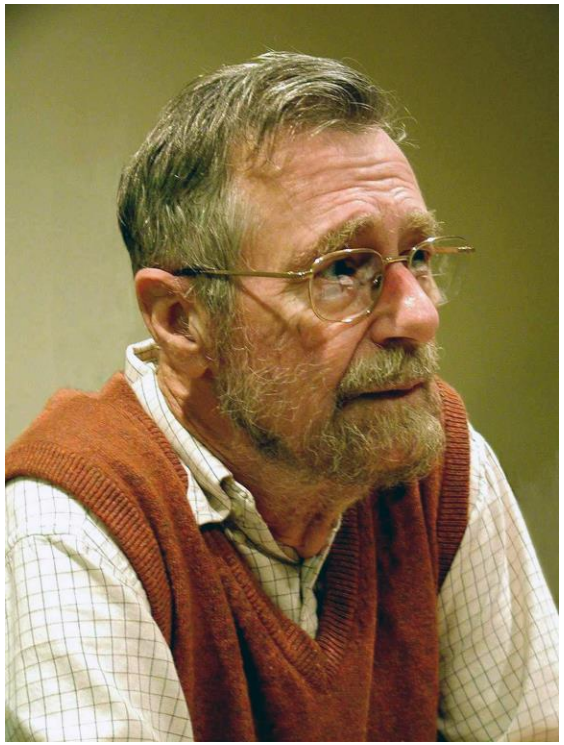
Outline (Week4, Session2 – W4S2)

- 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



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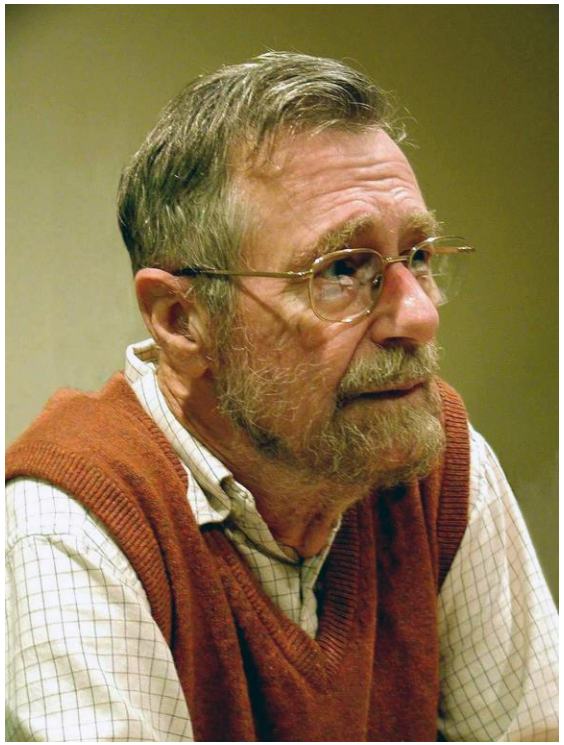
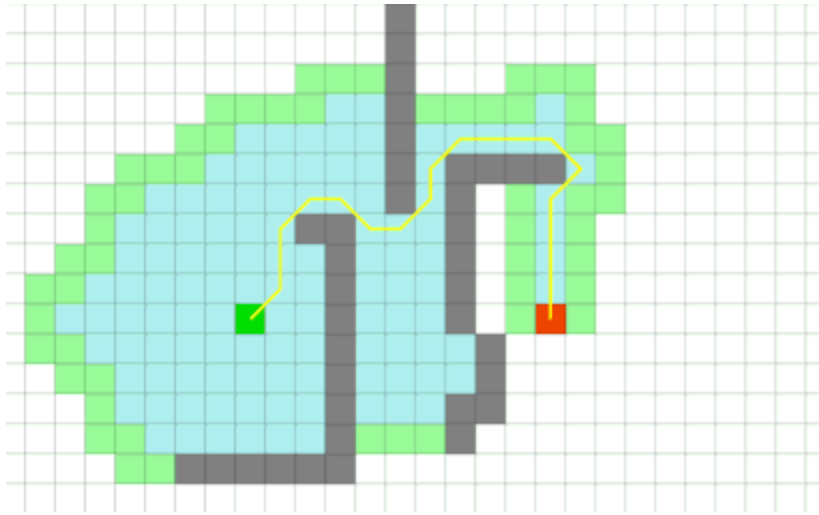
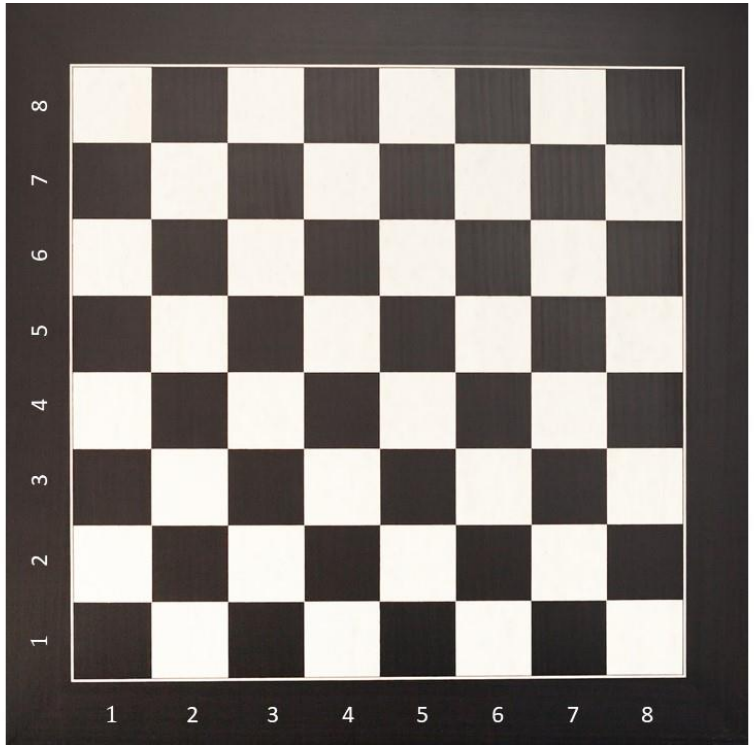


FYI: Dijkstra is famous for his algorithm, used for path-finding in many applications (GPS, video games, etc.)



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.



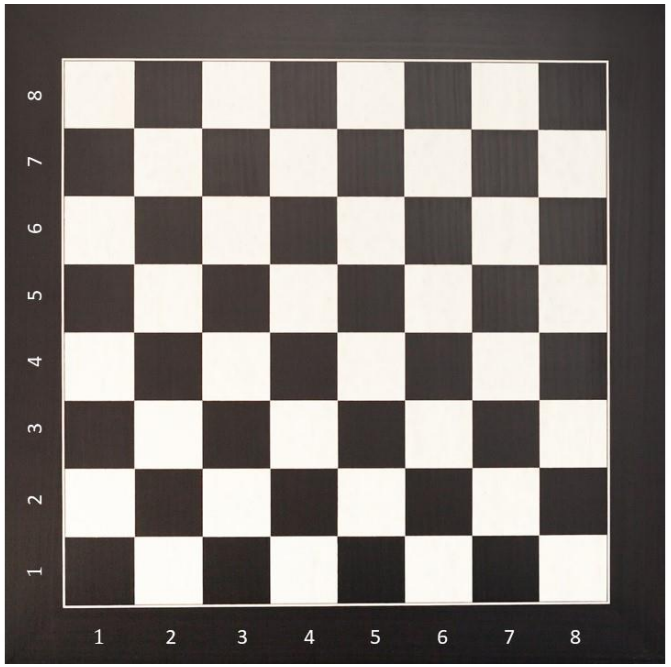
Expected results

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.

```
### Some test cases
# This should return True
print(is_triangle_rectangular(a = 3, b = 4, c = 5))

# This should return False
print(is_triangle_rectangular(a = 4, b = 4, c = 6))

# This should return False
print(is_triangle_rectangular(a = 3, b = 5, c = 4))

# This should return True
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.

```
def function(my_list):
    # Remove max and min from list
    min_val = min(my_list)
    max_val = max(my_list)
    while(min_val in my_list):
        my_list.remove(min_val)
    while(max_val in my_list):
        my_list.remove(max_val)
    return my_list
```

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

```
[2, 3, 4]
```

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

```
[2, 3, 4]
```

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

```
[]
```

```
# Test case 4: a list with only min and max values,
# and the min/max values are identical
my_list = [5,5,5]
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.

```python
def function_v2(my_list):

    # Warning: Need to cover for empty list case
    if(len(my_list) == 0):
        return []
    else:
        # Remove max and min from list
        min_val = min(my_list)
        max_val = max(my_list)
        while(min_val in my_list):
            my_list.remove(min_val)
        while(max_val in my_list):
            my_list.remove(max_val)
        return my_list
```

```python
# Test case 5: an empty list
my_list = []
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!**

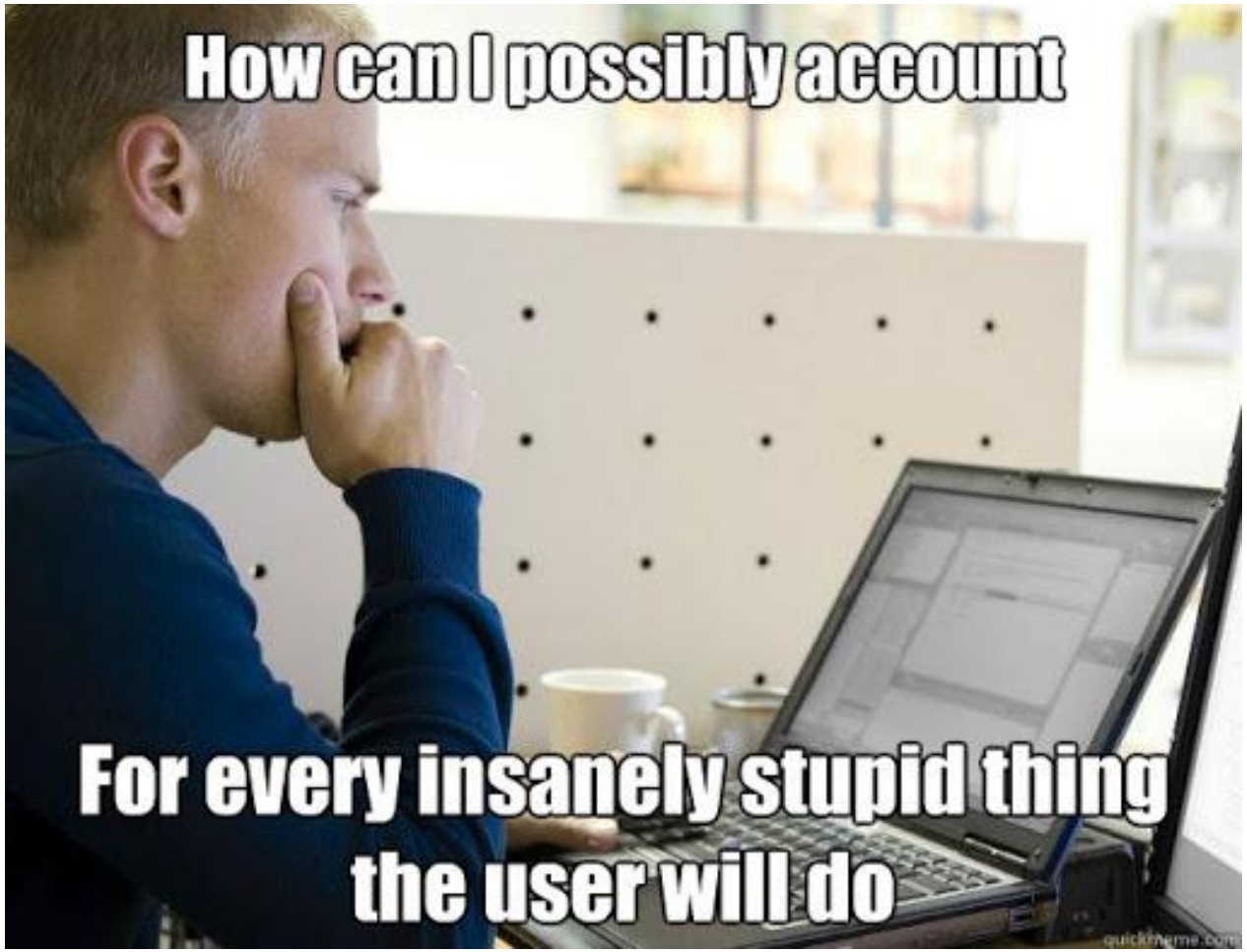
Unit testing is essential…

- 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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- 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+3.162277601683795j)
```

An application example: our sqrt function

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

```
(1.9363366072701937e-16+3.162277601683795j)
```

```
def my_sqrt_v2(x):
    error_message = "Warning: square roots with neg. values not supported."
    assert x >= 0, error_message
    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'
```

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

```python
# Test case 5: passing a non-numerical variable
x = "Hello"
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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→ Start small, progressively build up the function with more features!

From unit testing to integration testing

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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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- It is also essential to perform **integration testing**.
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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!

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.
- 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.

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.

- 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

```
1 # Add 1 to all numbers in list_numbers
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```

```
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```
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TypeError                                 Traceback (most recent call last)
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----> 5     val = number + 1
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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
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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!