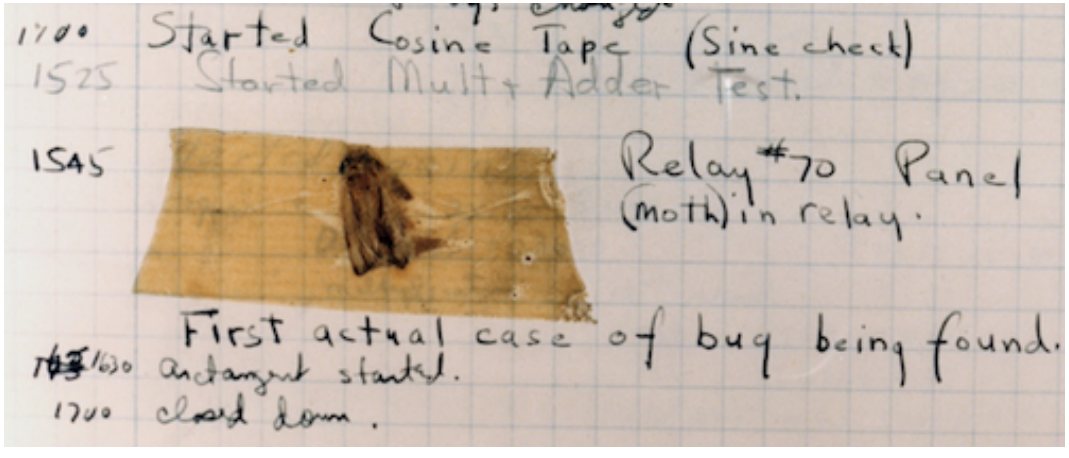
Australian National University

COMP1730/COMP6730
Programming for Scientists

Debugging and Testing

What is a “bug”?

In 1946, when [Grace] Hopper was released from active duty, she joined the Harvard Faculty at the Computation Laboratory where she continued her work on the Mark II and Mark III. Operators traced an error in the Mark II to **a moth trapped in a relay, coining the term bug**. This bug was carefully removed and taped to the **log book**:



Stemming from the first bug, today we call **errors or glitches** in a program a bug.

Source: `https://en.wikipedia.org/wiki/Software_bug`

The debugging process

1. Detection – realising that you have a bug, e.g., by extensive testing.
2. Isolation – narrowing down where and when it manifests.
3. Comprehension – understanding what you did wrong.
4. Correction; and
5. Prevention – making sure that by correcting the error, you do not introduce another.
6. Go back to step *1*.

Kinds of bugs/errors

1. Syntax errors
   - Easy to detect.
2. Runtime errors
   - Easy to detect (when they occur).
   - Possibly hard to understand (the cause).
3. Semantic (logic) errors
   - Difficult to detect and understand.

1. Syntax errors

* IDE/interpreter will tell you where they are.

```
  File "test.py", line 2
    if spam = 42:
            ^
SyntaxError: invalid syntax
```

```
if spam == 42:
    print("yes")

  print("spam is:", spam)
```

```
  File "../python/test.py", line 5
    print("spam is:", spam)
                          ^
IndentationError: unindent does not match any outer indentation level
```

2. Runtime errors

* Code is syntactically valid, but you're asking the python interpreter to do something impossible.
  - E.g., apply operation to values of wrong type, call a function that is not defined, etc.
  - Causes an *exception*, which interrupts the program and prints an error message.
  - Learn to read (and understand) python's error messages!

```
>>> pets = ['cat', 'dog', 'mouse']
>>> 'I have ' + len(pets) + ' pets'

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

>>> print(pets[3])

IndexError: list index out of range

>> print(pests[0])

NameError: name 'pests' is not defined

>>> print(pets(0))

TypeError: 'list' object is not callable
```

3. Semantic/logic errors

* The code is syntactically valid and runs without error, but *it does the wrong thing* (perhaps only sometimes).
* To detect this type of bug, you must have a good understanding of what the code is *supposed* to do.
* Logic errors are usually the hardest to detect and to correct, particularly if they only occur under certain conditions.

Isolating and understanding a fault

* Work back from where it is detected (e.g., the line number in an error message).
* Find the simplest input that triggers the error.
* Use `print` (or debugger) to see intermediate values of variables and expressions.
* Test functions used by the failing program separately to rule them out as the source of the error.
  - If the bug only occurs in certain cases, these need to be covered by the test set.

Some common errors

* python is not English.

```
if n is not int:
    ...
if n is (not int):
    ...
```

* Statement in/not in suite.

```
while i <= n:
    s = s + i**2
    i = i + 1
    return s
```

* Precision *and* range of floating point numbers.

* Loop condition not modified in loop.

```
def sum_to_n(n):
    k = 0
    total = 0
    while k <= n:
        total = total + k
    return total
```

* Off-by-one.

```
def smallest_power_of_2(n):
    """Return the smallest power of 2 that is >= n"""
    k = 1            # start at 0 or 1 ?
    p = 2
    while p <= n:    # < or <= ?
        p = p * 2
        k = k + 1
    return k         # k or k - 1 ?
```

Defensive programming

Everyone knows that debugging is twice as hard as writing a program in the first place. So if you're as clever as you can be when you write it, how will you ever debug it?

Brian Kernighan

* Write code that is easy to read and well documented.
  - If it's hard to understand, it's harder to debug.
* Make your assumptions explicit, and *fail fast* when they are violated.

Assertions

```
assert test_expression
assert test_expression, "error message"
```

* The `assert` statement causes a runtime error if *`test_expression`* evaluates to `False`.
* Violated assumption/restriction results in an immediate error, in the place where it occurred.
* Don't use assertions for conditions that will result in a runtime error anyway (typically, type errors).

```python
# Bad practice (delayed error)

def sum_of_squares(n):
    if n < 0:
        return "error: n is negative"
    return (n * (n + 1) * (2 * n + 1)) // 6

m = ...
k = ...
a = sum_of_squares(m)
b = sum_of_squares(m - k)
c = sum_of_squares(k)
if a - b != c:
    print(a, b, c)
```

```
# Good practice (immediate error)

def sum_of_squares(n):
    assert n >= 0, str(n) + " is negative"
    return (n * (n + 1) * (2 * n + 1)) // 6

m = ...
k = ...
a = sum_of_squares(m)
b = sum_of_squares(m - k)
c = sum_of_squares(k)
if a - b != c:
    print(a, b, c)
```

Testing

Unit testing

* Different kinds of testing (load, integration, user experience, etc) have different purposes.
* Testing for errors (bugs) in a component of the program – typically a function – is called *unit testing*.
  - Specify the assumptions.
  - Identify test cases (arguments), particularly “edge cases”.
  - Verify behaviour or return value in each case.
* The purpose of unit testing is to *detect bugs*.

Good test cases

* Satisfy the assumptions.
* Simple (enough that correctness of the value can be determined "by hand").
* Cover the space of inputs *and* outputs.
* Cover branches in the code.
* What are edge cases?
  - Integers: zero, positive, negative.
  - `float`: zero, very small (1e-308) or big (1e308).
  - Sequences: empty string, empty list, length one.
  - Any value that requires special treatment in the code.

Debugging problem: Here is a function that returns the sum of even digits of a positive integer (see week 4 lab, exercise 5):

```
def sum_even_digits(number):
    dsum = 0 # digit sum
    if number < 10:
        if number % 2 == 0:
            dsum = number

    while number >= 10:
        # extract the last digit
        digit = number % 10
        if digit in [0,2,4,6,8]:
            dsum = dsum + digit

        # divide by 10 (rounded down) to remove the last digit
        number = number // 10

    return dsum
```

But this function is wrong. How can you debug it?

Added after lecture

```
  ## test cases added during live lecture
assert sum_even_digits(0) == 0
assert sum_even_digits(1) == 0
assert sum_even_digits(2) == 2
assert sum_even_digits(10) == 0
assert sum_even_digits(5317) == 0
assert sum_even_digits(2624) == 14
```

Bug found when running the last test case, where the left-most digit is not considered. Lecturer tempted to change the condition *number* $>=$ 10 to *number* $>=$ 1 which solved that last test case, but it's still the wrong fix.

How can you fix it?