Lecture 11 — Decisions Part 2

Overview — Logic and Decision Making, part 2

- Program structure
- Debugging and “hardening” a simple function
- A bit of design and a bit of a random walk
- More on logic - the key to getting programs right
    - Boolean logic
    - Nested if statements
    - Assigning boolean variables

Part 1: Program Structure

Programming requires four basic skills:

1. Develop a solution.
    - Start with small steps, solve them, and then add complexity
2. Structure your code.
    - Move repeated code into functions
    - Make your code easy to read and modify. Use meaningful variable names and break complex operations into smaller parts.
    - Place values in variables so they are easy to change.
    - Include comments for important functions, but do not clutter your code with unnecessary comments. A classic example of a completely unnecessary comment is

    ```
    x += 1   # increment x
    ```

    - Document assumptions about what is passed to a function.
    - If your function is meant to return a value, make sure it always does.
3. Test your code.
    - Find all possible cases that your program should handle, including typos in the input. As programs get larger, this is increasingly hard.

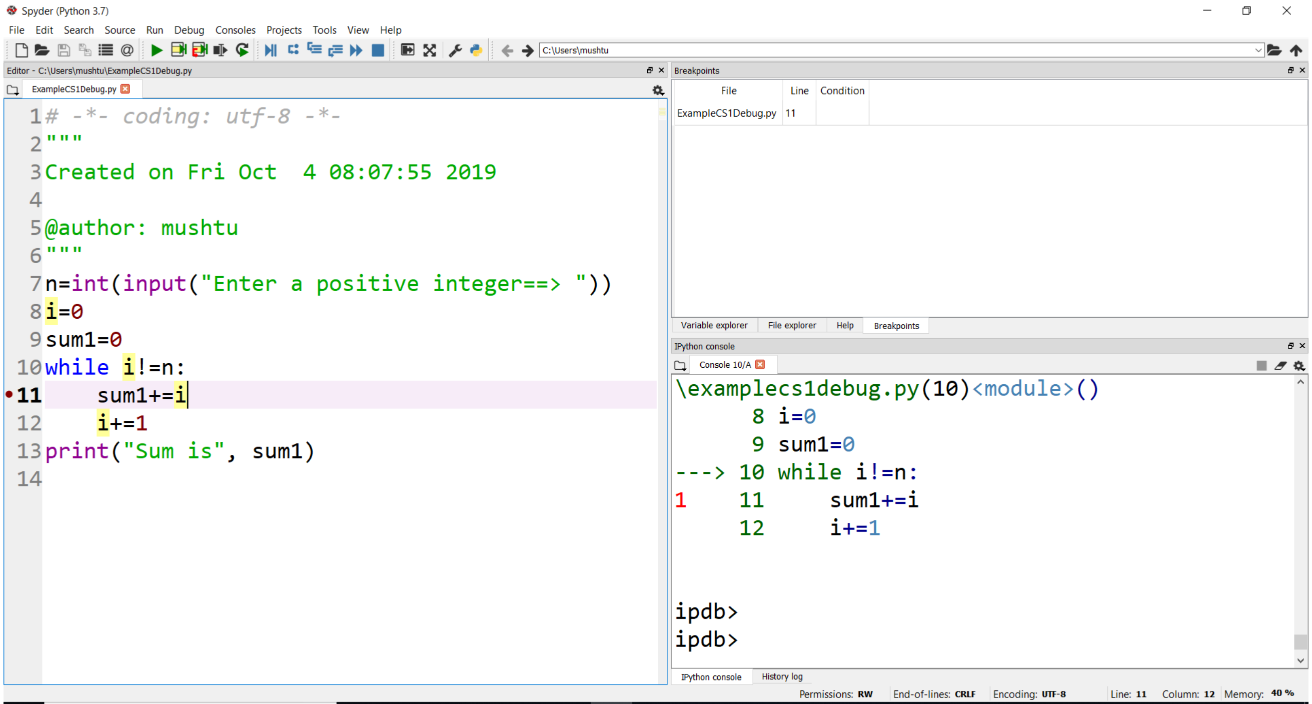
    - If you cannot check for all inputs, then you must then check your code for meaningful inputs: regular (expected inputs) and edge cases (inputs that can break your code).
4. Debug your code.
    - Never assume an untested part of your code is bug free. "If it ain't tested, it's broken."
    - Learn syntax well so that you can spot and fix syntax errors fast.
    - Semantic errors are much harder to find and fix. You need strategies to isolate where the error is.
    - Print output before and after crucial steps.
    - Look at where your program crashed.
    - Fix the first error first, not the biggest error. The first error may be the cause of bigger errors later in your code.
    - Use a debugger.
    - Simplify the problem: remove (by commenting out) parts of your code until you no longer have an error. Look at the last code removed for a source of at least part of your errors.
    - Test parts of your code separately and once you are convinced they are bug free, concentrate on other parts.

Help with debugging

- Consider the following code to add the first `n` integers:

```
n = int(input("Enter a positive integer ==> "))
total = 0
i = 0
while i != n:
    total += i
    i += 1
print('Sum is', total)
```

- Does it work? For all inputs? Might it run forever? (We'll ignore the fact that a `for` loop would be better here.)
- How might we find such an error?
    - Careful reading of the code
    - Insert print statements
    - Use the Spyder IDE debugger.
- We will practice with the Spyder IDE debugger in class, using it to understand the behavior of the program. We will explain the following picture



and note the use of

- The symbols on the top of the display, and
- The ipdb at the bottom of the display.

- Debugging becomes crucial in tracking logic errors as well.

Program organization

- Envision your code as having two main parts: the main body and the functions that help the main code.
- Make sure your functions accomplish one well-defined task. This makes them both easy to test and useful in many places.
- As we will see in an example below, in Python it is good practice to separate the functions and the main body with the following addition to the program structure:

```
if __name__ == "__main__"
    # Put the main body of the program below this line
```

- This will have no apparent effect when a program is run. However, if a program is imported as a module into another program (like the utility code we have been giving you), any code within the above `if` block is skipped!
- This allows programs to work both as modules and stand alone code.
- When the primary purpose of your code is to provide functionality as a module, it is best to use the code in the main body to test the module functions.

Part 2: Extended Example of a Random Walk

- Many numerical simulations, including many video games, involve random events.
- Python includes a module to generate numbers at random. For example,

```
import random

# Print three numbers randomly generated between 0 and 1.
print(random.random())
print(random.random())
print(random.random())

# Print a random integer in the range 0..5
print(random.randint(0,5))
print(random.randint(0,5))
print(random.randint(0,5))
```

- We'd like to use this to simulate a "random walk":
  - Hypothetically, a person takes a step forward or backward, completely at random (equally likely to go either way). This can be repeated over and over again until some stopping point is reached.
  - Suppose the person is on a platform with N steps and the person starts in the middle, this random forward/backward stepping process is repeated until they fall off (reach step 0 or step $N+1$)
    - "forward" is represented by an increasing step, while "backward" is represented by a decreasing step
  - How many steps does it take to fall off?
- Many variations on this problem appear in physical simulations.
- We can simulate a step in several ways:
  1. If `random.random()` returns a value less than 0.5 step backward; otherwise step forward.
  2. If `random.randint(0,1)` returns 1 then step forward; otherwise, step backward.
  3. Eliminate the `if` entirely and just increment by whatever `random.choice([-1,1])` returns (it will return either -1 (step backward) or 1 (step forward)).
- So, in summary, we want to start a random walk at position $N/2$ and repeatedly take a step forward or backward based on the output of the random number generator until the walker falls off.
- We will solve this problem together during lecture. We we start by enumerating some of the needed steps and then solving them individually before putting together the whole program.
  - Once we see the result we can think of several ways to change things and explore new questions and ideas. Remember, a program is never done!

Part 3: Review of Boolean Logic

- Invented / discovered by George Boole in the 1840's to reduce classical logic to an algebra
    - This was a crucial mathematical step on the road to computation and computers
- Values (in Python) are `True` and `False`
- Operators
    - Comparisons: `<, >, <=, >=, == !=`
    - Logic: `and`, `or`, `not`

Truth Tables

- Aside: recall the syntax: `and, or, not` are lower case!
- If we have two boolean expressions, which we will refer to as `ex1` and `ex2`, and if we combine their "truth" values using `and` we have the following "truth table" to describe the result

`ex1`	`ex2`	`ex1 and ex2`
`False`	`False`	`False`
`False`	`True`	`False`
`True`	`False`	`False`
`True`	`True`	`True`

- If we combine the two expressions using `or`, we have

`ex1`	`ex2`	`ex1 or ex2`
`False`	`False`	`False`
`False`	`True`	`True`
`True`	`False`	`True`
`True`	`True`	`True`

- Finally, using `not` we have

`ex1`	`not ex1`
`False`	`True`

`ex1`	`not ex1`
`True`	`False`

DeMorgan's Laws Relating and, or, not

- Using `ex1` and `ex2` once again to represent boolean expressions, we have

```
not (ex1 and ex2) == (not ex1) or (not ex2)
```

- And,

```
not (ex1 or ex2) == (not ex1) and (not ex2)
```

- Also, distribution laws

```
ex1 and (ex2 or ex3) == (ex1 and ex2) or (ex1 and ex3)
ex1 or (ex2 and ex3) == (ex1 or ex2) and (ex1 or ex3)
```

- We can prove these using truth tables.

Why Do We Care?

- When we've written logical expressions into our programs, it no longer matters what we intended; it matters what the logic actually does.
- For complicated boolean expressions, we may need to almost prove that they are correct

Part 4: Additional Techniques in Logic and Decision Making

We will examine:

- Short-ciruiting
- Nested conditionals
- Storing the result of boolean expressions in variables

and then apply them to several problems

Short-Circuited Boolean Expressions

- Python only evaluates expressions as far as needed to make a decision.
- Therefore, in a boolean expression of the form

  ```
  ex1 and ex2
  ```

  `ex2` will not be evaluated if `ex1` evaluates to `False`. Think about why.
- Also, in a boolean expression of the form

  ```
  ex1 or ex2
  ```

  `ex2` will not be evaluated if `ex1` evalues to `True`.
- This "short-circuiting" is common across many programming languages.

Nested If Statements

- We can place `if` statements inside of other `if` statements.
- To illustrate, consider the following where `ex1`, `ex2`, `ex3` and `ex4` are all boolean expressions, and `blockA`, `blockB`, `blockD` and `blockE` are sections of code.

  ```
  if ex1:
      if ex2:
          blockA
      elif ex3:
          blockB
  elif ex4:
      blockD
  else:
      blockE
  ```

- We will examine this example in class and answer the following questions:
  - Under what conditions is each block executed?
  - Is it possible that no blocks are executed?
  - What is the equivalent non-nested if-elif-else structure?

Storing the Result of a Boolean Expression

- Sometimes we store the result of boolean expressions in a variable for later use:

```
f = float(input("Enter a Fahrenheit temperature: "))
is_below_freezing = f < 32.0
if is_below_freezing:
    print("Brrr.  It is cold")
```

- We use this to
    - Make code clearer
    - Avoid repeated evaluation of the same expression, especially if the expression requires a lot of computation.

Examples for Lecture

We will work on the following examples during class, as time permits.

1. In the following code, for what values of `x` and `y` does the code print 1, for what values does the code print 2, and for what values does the code print nothing at all?

    ```
    if x>5 and y<10:
        if x<5 or y>2:
            if y>3 or z<3:
                print 1
        else:
            print 2
    ```

    The moral of the story is that you should be careful to ensure that your logic and if structures **cover the entire range of possibilities**!

2. Doctors sometimes assess a patient's risk of heart disease in terms of a combination of the BMI (body mass index) and age using the following table:

	Age ≤ 45	**Age** > 45
BMI < 22.0	Low	Medium
BMI ≥ 22.0	Medium	High

    Assuming the values for a patient are stored in variables `age` and `bmi`, we can write the following code

    ```
    slim = bmi < 22.0
    young = age <= 45
    ```

We will work out two different ways of printing *Low*, *Medium* or *High* according to the table based on the values of the boolean variables `slim` and `young`.

3. Challenge example: Suppose two rectangles are determined by their corner points - `(x0,y0)` and `(x1,y1)` for one rectangle and `(u0,v0)` and `(u1,v1)` for the other. Write a function that takes these four tuples as arguments and returns `True` when the two rectangles intersect and `False` otherwise.

Summary of Discussion of If Statements and Logic

- Logic is a crucial component of every program.
- Basic rules of logic, including DeMorgan's laws, help us to write and understand boolean expressions.
- It sometimes requires careful, precise thinking, even at the level of a proof, to ensure logical expressions and if statement structures are correct.
    - Many bugs in supposedly-working programs are caused by conditions that the programmers did not fully consider.
- If statements can be structured in many ways, sometimes nested several levels deep.
    - Nesting deeply can lead to confusing code, however.
    - Warning specifically for Python: you can easily change the meaning of your program by accidentally changing indentation. It is very hard to debug these changes.
- Using variables to store boolean values can make code easier to understand and avoids repeated tests.
- Make sure your logic and resulting expressions cover the universe of possibilities!