CS 115 Lecture 11

The debugger; while loops

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Debugging

We've seen how to write test cases to help you find bugs in your program. What to do when you find that something is wrong?

- Find the line that's wrong, and fix it.
  - Which line is wrong?
  - We know the symptoms, not the disease.
  - So our job that of a doctor...
  - Find out what's making the patient sick!
- Sometimes just reading and tracing the program is enough.
  - And once upon a time that was the only option.
  - But doctors can run tests, ask questions, ...
  - If we could interact with the program while it's running...

    ...then we might be able to see the bug as it happens.

The debugger

The **debugger** is a tool for controlling and inspecting a program as it runs.

- Part of most IDEs (WingIDE and IDLE included).
- It *doesn't* find the bugs for you.
- Instead, it:
  - "Slows down" the program by letting you run it one line at a time.
  - Shows you variables and their values.
  - Shows what functions are currently running ("call stack").

Breakpoints

When using the debugger, you usually start by setting a **breakpoint**.

- This tells the debugger to pause the program just before it executes that line.
- In WingIDE, click next to the line number.
  - A red dot appears to show there is a breakpoint there.
  - Click again to turn them off.
  - Note: breakpoints are **not** saved with the program!
- In IDLE, right click the code and "Set breakpoint".
  - The line will be highlighted in yellow.
- To run under the debugger, click the "Debug" icon in Wing.
  - In IDLE, select **Debug** → **Debugger** then run the program normally.
  - It will run the program full-speed until it reaches the breakpoint.
  - Then it pauses the program and gives you control.
  - If you run the program without "Debug", breakpoints are ignored!
- With branches and loops, you might need several breakpoints to make sure execution reaches one of them.

Single-stepping

Single stepping means running the next line of the program. In most IDEs there are three ways to single-step.

- Step Over ("Over" in IDLE)
  - Execute the current line, pausing again when it finishes.
  - If the line calls a function, will execute the whole function.
- Step Into ("Step" in IDLE)
  - Execute the current line, pausing at the next line executed.
  - If the line calls a function, will pause at the beginning of that function.
- Step Out ("Out" in IDLE)
  - Execute the rest of this function, pausing after it returns.
  - Stepped into a function you didn't want to see? Use this to get back.
- More about the differences when we cover functions.
- These only work when your program is paused by the debugger.
  - So only in debug mode.
  - And you need a breakpoint first!

Debugging variables

The **watch window** shows you the variables that exist before executing the current line.

- In WingIDE, called "Stack Data".
- In IDLE, called "Locals".
- Shows variables that are **in scope**:
  - Already defined in this function.
  - Not destroyed yet.
- Also shows their values and types.
- Watch this window when single-stepping.
  - That will show you what variables are changing and how.
  - Make sure they change as you expect!

Debugging example

Let's see an example of the debugger in action.

- `triangular-bug.py`

While loops

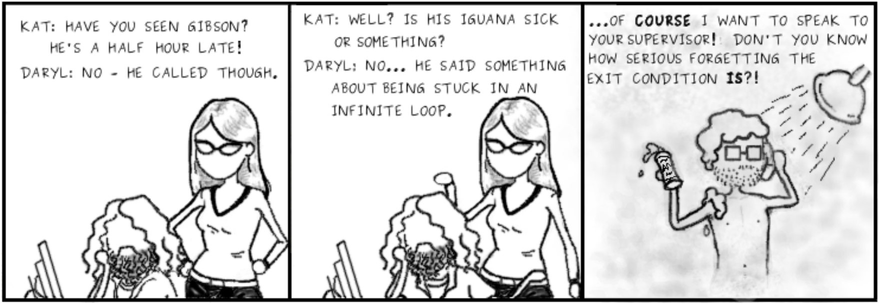


Image: `skunklogic.com`, 2011

How do we fix this?

1. Lather
2. Rinse
3. Repeat if necessary

Bounded and unbounded iteration

The for loops we've been using are **bounded** or **definite** loops.

- The interpreter decides in advance how many times it will run.
- That doesn't change once the loop starts.

  ```
  for i in range(5):
      i = 1
      print(i)
  ```

  Even though we're changing *i*, the loop still runs five times!
- That's kind of nice because it means no infinite loops.
- But. . .

Unbounded iteration

- In 1928 (long before computers existed!), German mathematician Wilhelm Ackermann proved that bounded iteration is not sufficient to define all mathematical functions.
  - In mathematician-speak he called it "primitive recursion".
  - Wikipedia "Ackermann function" if you're curious.
- A simpler example: asking the user to input a positive number.
  - If they give a negative number or zero, we'll repeat the question.
  - How many times do we need to repeat?
  - No way to know in advance.
- So we need some way to make a loop that can run an unlimited number of times.
  - An **unbounded** or **indefinite** loop.
  - Indefinite, not infinite!
    - Most loops should still stop eventually—we just can't predict when.
    - "Repeat if necessary." — We just need to say when it's necessary.

While loop syntax and semantics

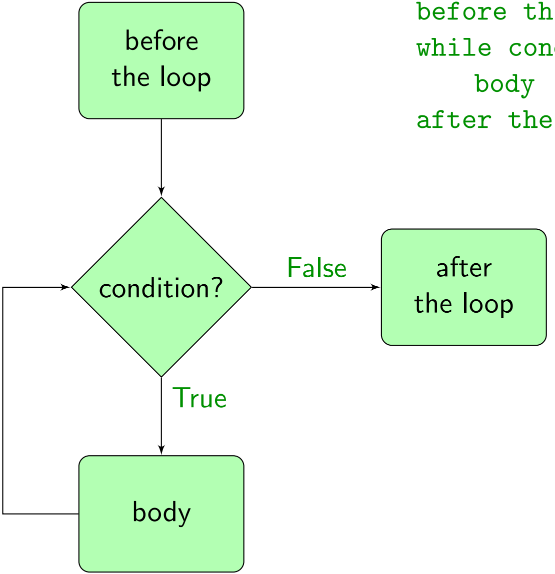
- Syntax:

```
while condition:
    body
```

  - The condition is a boolean expression, just like `if`.
  - The body is... an indented block of code.
    - ★ (How many times have you heard that?)
- Semantics:
  1. Check the loop condition.
  2. If false, end the loop.
  3. If true, run the body and repeat.

  - If the condition was false to begin with, the body never runs!
- Structured programming guarantees:
  - One entrance: always starts by checking the condition.
  - One exit: ends only when the condition is false.
  - Only checks the condition again after running the entire body.

Flowchart for `while`




```
before the loop
while condition:
    body
after the loop
```

Common errors

- What happens if the condition is a tautology (always true)?
  - The loop never ends!
  - An **infinite loop** is usually an error.
  - If you really do want to run forever:

    ```
    while True:
        ...
    ```
- Conversely, what if the condition is a falsehood?
  - Then the body will never run at all.
  - What do we call code that never runs?
    - Dead code!

Sentinel logic

One common use for a while loop is to process data.

- We want to keep getting more data until we see a special value.
  - Read from a file until you see a blank line.
  - Ask for a number until they enter 0.
  - Get commands from the user until they type "quit".
  - Read and log temperatures until one is out of range.
  - This special value (or values) is called a **sentinel**.
    - Just a fancy word for "guard".
- Sounds like a job for a while loop!
  - But a while loop checks at the very beginning.
  - But we can't check until we have the first input!

Loops with sentinel logic

The solution: the sentinel loop pattern.
Get the input in two places:

- Just before the loop.
- As the last step of the loop body.

1. Get the first input
2. While the input is not a sentinel:
    2.1. Do something with the input.
    2.2. Get the next input.

```
num = int(input("Enter a number, 0 to exit: "))
while num != 0:
    print("Its reciprocal is", 1 / num)
    num = int(input("Enter another number, 0 to exit: "))
```

Input validation

Sentinel logic can also be used for input validation.

- That is, asking the user until we get a "good" value.
- We just need a slight twist:
  - We repeat the loop if the input is *bad*.
  - So our "sentinel" is *any good input*.
  - What goes in the loop body?
    - An error message.
    - Then get the next input.

Example: `positive.py`

Loop example: numeric input

Remember our programs with `int(input(...))`. What happened when the user provided non-numeric input?

- It crashed. . . what part crashed, exactly?
  - The type cast!
  - So can we validate the input before doing the type cast?
- Python gives us a way to check if a string contains only digits.
  - `mystr.isdigit()` — What does the dot syntax mean?
    - Calling a method: Strings are objects!
  - `isdigit` returns true if:
    - The string contains no non-digit characters; *and*
    - It has at least one digit (so the method is badly named).
  - Only works for non-negative integers! "." and "-" are not digits!
    - There are other special cases, too (Arabic digits, . . .)
    - In a later class, we'll see how to do this properly with exceptions.
- `numeric.py`

Loop example: Collatz conjecture

Consider the following arithmetic procedure on an integer.

- If the integer is even, divide it by 2.
- Otherwise, multiply by 3 and add 1.
- What will happen if we repeat this process?
- $1 \to 4 \to 2 \to 1 \to \cdots$
- $3 \to 10 \to 5 \to 16 \to 8 \to 4 \to 2 \to 1 \cdots$
- Will we always get back to one?
  - Lothar Collatz (1937) conjectured that we always get back to 1.
  - But nobody knows for sure!
  - Computers have tested all numbers less than 5.764×10^{18}
  - So far they all get back to 1 eventually, but there's no proof that bigger numbers always will.
- Let's write a program to test it!
  - `collatz.py`

Flags and while loops

Sometime we only discover inside the loop that we want to leave.

- For example, "Do you want to play again?"
- Python lets us `break` out of the loop...
  - ...but that violates the structured programming constraints.
  - So we won't use it in CS 115.
- Instead, we can set a **flag**.
  - A boolean variable (we saw these with `if`).
  - Use the flag as the condition of the `while`.
  - Initialize the flag before the loop:
  - When we discover that we're done, change the flag.

While loop with a flag

```
done = False
while not done:
    play a round
    answer = play_again()
    if not answer:
        done = True
```

Why don't we use sentinel logic?

- Sentinel logic would ask before the loop...
- But we want to play one round before we ask!

While loops with a counter

While loops can be combined with a counter to simulate a for loop over a range.

- Initialize the counter (to the start).
- While the counter is less than the stop:
  - Do stuff.
  - Add the step to the counter.

```
i = 0
while i < 4:
    print(i, "squared is", i**2)
    i += 1
```

- Why would you ever write it this way?
  - Maybe the step size changes.
  - Maybe there are multiple stopping conditions.

Another loop example: any

Remember our "any" for loop pattern:

```
anyodd = False
for num in 2, 1, 4, 16, 12, 0, 3:
    if num % 2 == 1:
        anyodd = True
```

- What if we don't have all the numbers in advance?
  - Then we can't use a `for` loop.
- Also, notice it keeps going even when we're sure the answer is True.
  - (because `anyodd` can never become False again)
- As soon as we see an odd number, we can stop, because the answer must be True!
- We can solve both problems with a while loop.

While loop example: any

Let's solve the first problem and make it accept any number of inputs.
We need a sentinel value: let's use 0.

```
anyodd = False
num = int(input("Enter an integer, 0 to quit."))
while num != 0:
    if num % 2 == 1:
        anyodd = True
    num = int(input("Enter an integer, 0 to quit."))

if anyodd:
    print("At least one number was odd.")
else:
    print("No odd numbers found.")          anyodd.py
```

It still asks for more numbers after an odd one. Let's fix that.

While loop with multiple exits

- Stop the loop if `anyodd` is true.
  - (It can never become false again).
- But we still want to stop the loop if the input is zero
  - Stop if the loop if `anyodd` is true **or** if the input is 0.
  - Continue the loop if anyodd is false **and** the input is not zero.
    - ⋆ **de Morgan's law**: "not (A or B)" = "(not A) and (not B)"

While loop example: any

```
anyodd = False
num = int(input("Enter an integer, 0 to quit."))
while not anyodd and num != 0:
    if num % 2 == 1:
        anyodd = True
    else:  # don't ask if we're just going to quit
        num = int(input("Enter an integer, 0 to quit."))
if anyodd:
    print("At least one number was odd.")
else:
    print("No odd numbers found.")
```

anyodd-2.py

Common errors with flags

- Accidentally using `or` instead of `and`.
  - The loop will run too long.
  - If the condition is a tautology, infinite loop.
- Accidentally using `and` instead of `or`.
  - The loop won't run long enough.
  - If the condition is a falsehood, doesn't run at all.
- Not initializing the flag.
  - Run-time error.
- Always setting the flag.
  - Let's see an example of that.

Broken loop: unconditional flag

```
anyodd = False
num = int(input("Enter an integer, 0 to quit."))
while num != 0:
    if num % 2 == 1:
        anyodd = True
    else:
        anyodd = False
    num = int(input("Enter an integer, 0 to quit."))

if anyodd:
    print("At least one number was odd.")
else:
    print("No odd numbers found.")
```

- This version sets the flag every time through the loop.
- So the flag won't actually mean "are any numbers odd?".
- Instead, this version only cares about the *last* number.
  - Seeing an even number shouldn't change our answer at all!

Sentinel logic: recap

To recap sentinel logic:

- Repeating a loop until you see a special value.
- Get input both **before** the loop,
  and **at the end** of the body.
- "Enter a number, or 0 to quit."
  - Keep asking until we see the **sentinel** 0.
  - While the number is not zero...
  - Inside the loop, process the (nonzero) number.
- In reverse: input validation.
  - Keep asking until we get what we want.
  - Now a *good* value makes us leave the loop.
  - While the number is not positive...
  - Inside the loop, print an error message.
  - Process a valid input after the loop is over.