Module 01: Introduction to Programming in Python

Topics:
• Course Introduction
• Introduction to Python basics

Readings: ThinkP 1,2,3

Practice: Self study exercises
Finding course information

- https://www.student.cs.uwaterloo.ca/~cs116/

Announcements will be on Piazza. Assignments on course web page and submitted through MarkUs.
Important Administrative Details

• Announcements
• Weekly Tutorials
• (almost) Weekly Assignments
  – No extensions
  – Remark Policy: 2 weeks
  – Submit code early and often
  – Check your basic tests emails
  – Will drop lowest assignment grade (some restrictions)
• Academic Integrity Policy
• AccessAbility Services
Major Themes from CS115

- Design
- Common Patterns
- Verification
- Communication

CS115 was not a course *just* about Racket!
Major Themes for CS116

• Design
• Common Patterns
• Verification
• Communication
• *Algorithms*

CS116 is not *just* a course about Python!
Introducing Python ...

• We will learn to do the things we did in Racket
• We will learn to do new things we didn’t do in Racket
• Why change?
  – A different programming paradigm
    • Racket is a functional programming language
    • Python is an imperative programming language
  – Design recipe still applies
What can Python programs do?

• Everything we did with Racket programs
• Lots of things we didn't cover in Racket
Functional vs Imperative languages in problem solving

• Much is the same: determine needed data types, variables, and helper functions.
• With a functional language like Racket:
  – Calculations are nested to show precedence
  – Calculated value is returned
• With an imperative language like Python:
  – Steps are separated, and ordered (similar to \texttt{local} in Racket)
  – Data values change as the program executes
  – Calculated values may (or may not) be returned by a function
Running a Python Program

• Uses an interpreter like Racket (unlike most imperative languages)
  – Translates one statement at a time
  – Stops when one error is found
• Most imperative languages use a compiler
  – Translates entire program into machine code
  – Finds all errors in entire program
• Generally, harder to debug with a compiler but code typically runs faster.
What does a Python program look like?

• A series of statements
  – Assignment statements
  – Control statements
  – Function calls

• May include function definitions
  – Made up of statements

• May include new type definitions
Some Python Basics

• Written using regular mathematical notation
  \[ 3 + 4 \]
  \[ 5 \times (3 + 4) - 1 \]

• Two numeric types (integers and floating point numbers) instead of one

• Strings, Booleans, lists

• No character or symbol type used in CS116.
Assignment Statements

\[ v = \text{expr} \]

- Similar to Racket's `define`
- `=` is the assignment operator ("becomes" or "is")
- `v` is any variable name
- `expr` is any Python expression
- How it works:
  1. Evaluate `expr`
  2. "Assign" that value to `v`
- Assignment statements do not return a value. They only have an effect.
A very simple Python program

\[
x = 2 \times (4 + 12) \\
y = x + 8 \\
z = y \times y \\
q = 2.5 + 4.2 \\
w = "hi" \\
u = w + w
\]

What are the values of \(x, y, z, q, w, u\)?
Racket vs Python: Numeric types

• Numeric calculations in Racket were exact, unless involving irrational numbers
  – no real difference between 3 and 3.0
• Integers in Python are stored exactly
• Other numbers are approximated by floating point values → Representation error
• Two different numeric types:
  – 3 is of type Int, but 3.0 is of type Float
## Racket vs Python: Numeric types

<table>
<thead>
<tr>
<th>Value</th>
<th>Racket Representation</th>
<th>Type</th>
<th>Python Representation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>natural</td>
<td>exact</td>
<td>Nat</td>
<td>exact</td>
<td>Nat</td>
</tr>
<tr>
<td>integer</td>
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</tr>
<tr>
<td>rational</td>
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<td>Num</td>
<td>inexact</td>
<td>Float</td>
</tr>
<tr>
<td>irrational</td>
<td>inexact</td>
<td>Num</td>
<td>inexact</td>
<td>Float</td>
</tr>
</tbody>
</table>

Recall, in Racket:
- **check-expect** for testing exact values
- **check-within** for testing inexact values

Use these type names in Python contracts
Basic Mathematical Operations

• Addition (+), Subtraction (-), Multiplication (*):
  – If combining two \texttt{Int} values, the result is an \texttt{Int}
  – If combining two \texttt{Float} values, or a \texttt{Float} and an \texttt{Int}, the result is a \texttt{Float}
Basic Mathematical Operations

• Division: \( x \div y \)
  – The result is a Float for any numerical values \( x \) and \( y \) (even if both are Int)

• Integer division: \( x \div\!\!\!// y \)
  – The result is the integer part of the division
  – If \( x \) and \( y \) are both Int, the result is an Int
  – If either \( x \) or \( y \) is a Float, the result is a Float
  – Returns quotient when \( x \) and \( y \) are Nat
Other Mathematical Operations

- Remainder: \( x \ % \ y \)
  - \( x \) and \( y \) should both be \( \text{Nat} \)
  - returns the \( \text{Nat} \) remainder when \( x \) divided by \( y \)

- Exponents: \( x \ ** \ y \)
  - (anyof Int Float) (anyof Int Float) -> (anyof Int Float)
  - returns \( x \) raised to the power of \( y \)
More useful things to know

• Python precedence operations are standard math precedence rules (BEDMAS)
• Use `##` or `#` for comments (from beginning or middle of line)
• Do not use dash in variable names
  – Use underscore instead
Calling functions in Python

\textbf{fn\_name (arg1, arg2, ..., arg\textit{N})}

- built-in function or a user-defined \texttt{fn\_name}
- must have correct number of arguments
- separate arguments by single comma
- examples:
  \begin{align*}
  \text{abs}(-3.8) & \Rightarrow 3.8 \\
  \text{len}("Hello There") & \Rightarrow 11 \\
  \text{max}(3,5.2,9) & \Rightarrow 9 \\
  \text{min}("ABC", "AA") & \Rightarrow "AA"
  \end{align*}
The `math` Module

- A Python module is a way to group together information, including a set of functions
- The `math` module includes constants and functions for basic mathematical calculations
- To use functions from `math`
  - Import the `math` module into your program
  - Use `math.fn` or `math.const` to reference the function or constant you want
Type in the interactions window

```python
import math
math.sqrt(25)
math.log(32, 2)
math.log(32.0, 10)
math.floor(math.log(32.0, math.e))
math.factorial(10)
math.cos(math.pi)
sqrt(100.3)
```

Error!! Must use `math.sqrt(100.3)`
More **math** functions

```python
>>> import math
>>> dir(math)
[...,'acos','asinh','atan','ceil','cos','cosh','degrees','e','exp','factorial','floor','log','log10','pi','pow','radians','sin','sqrt','tan','trunc',...]
>>> help(math.floor)
Help on built-in function floor in module math:

floor(...)

    floor(x)
    Return the floor of x as an integer.
    This is the largest integral value <= x.
```
Creating new functions in Python

def fname (p1, p2, ..., pN):
    statement1
    ...
    statement

- Indent each statement the same amount
- For a function to return a value, include
  
  \texttt{return answer}

  where \texttt{answer} is the value the function returns
- If there is no \texttt{return} statement or a \texttt{return} statement without an expression for \texttt{answer}, the function will return \texttt{None} (which is the default with a Python function).
Example: Write a Python function that consumes 3 different integers and returns the middle value.

```python
def middle(a, b, c):
    largest = max(a, b, c)
    smallest = min(a, b, c)
    mid = (a+b+c) - largest - smallest
    return mid
```
Review: Design Recipe for Functions

When writing functions in Racket, we included:

- Purpose statement
- Contract
- Examples
- Function body
- Test cases

We'll continue with these steps for Python programs, but there will be some changes.
Python's docstring

• Python provides a convenient way to associate documentation with a function.
• A string included after the function header becomes the help documentation for that function.
• As this will require more than one line, we will use special string delimiters: three single quotes before and after our design recipe steps.
Basic docstring usage

**Definitions window**

```python
def middle(a, b, c):
    ''' returns middle value of a, b, c
    '''
    lr = max(a, b, c)
    sm = min(a, b, c)
    mid = (a+b+c) - lr - sm
    return mid
```

**Interactions window**

```python
>>> help(middle)
Help on function middle in module __main__:
middle(a, b, c)
    returns middle value of a, b, c
```
Design Recipe: Some things remain basically the same

Some steps are the same in Python as in Racket:

• Purpose statement:
  – Explicitly indicate what the function does, including how the parameters are used
  – New style: Use "returns" rather than "produces"

• Contract
  – Types of consumed and returned values
  – Include any needed requirements on parameters
  – Most type names are the same as in Racket, except for Num; Use Nat, Int, Float as appropriate
Design Recipe: Some things have to change

Examples ...

• We cannot write our examples as tests as we did in Racket, so a different approach is needed here.

• Our new approach (inside our docstring)

\[ \text{fn}(\text{arg}_1, \text{arg}_2, ...) \Rightarrow \text{expected} \]

• For example:

\[ \text{middle}(4,2,8) \Rightarrow 4 \]
\[ \text{middle}(3,2,1) \Rightarrow 2 \]
def middle(a, b, c):
    ''' returns the middle (median) value of a, b, c

    middle: Int Int Int -> Int
    requires: a, b, c are all different

    Examples:
    middle(4, 2, 8) => 4
    middle(3, 2, 1) => 2
    '''

    largest = max(a, b, c)
    smallest = min(a, b, c)
    mid = (a + b + c) - largest - smallest
    return mid
More on design recipe

• We will soon see that testing is similar, but different

• While templates will not be a focus in CS116, you may still find them helpful, and we will try to point out common code patterns when it might be helpful.
Why we use the Design Recipe

Program design still involves creativity, but the design recipe can be very helpful:

• It provides a place to start.
• Contracts and purpose can reduce simple syntax errors.
• Good design and template choices can
  – reduce logical errors
  – provide better solutions
What goes in the body of a Python function?

- Assignment statements
  - May introduce new, local variables
- Calls to other functions
  - Built-in functions
  - User-defined functions
- `return` statement
  - Will be last code executed when present

We will learn more Python statements as we progress.
Using local variables in Python

In middle,

• largest, smallest, mid

are local variables.

They do not exist outside of middle.
More on local variables and functions

• A variable initialized inside a function only exists in that function
• If your function calls a helper function, the helper function cannot access the caller’s variables
• Helper functions can be defined locally, but we will learn about that later
• Need only provide contract and purpose for helper functions
Example: Write a Python function to compute the area of a circle with nonnegative radius $r$

```python
import math

def area_circle(radius):
    ''' returns the area of a circle with the given radius
    
    area_circle: Float -> Float
    requires: radius >=0
    
    Examples:
    area_circle(0.0) => 0.0
    area_circle(1.0) => 3.14159265
    '''
    return math.pi * radius * radius
```
Picky, picky, picky …

Indentation in Python

A small change in indentation will lead to error

```python
def tens_digit(n):
    '''returns the tens digit in n
    tens_digit: Nat -> Nat
    Examples:
    tens_digit(1234) => 3
    tens_digit(4) => 0
    '''
    div10 = n // 10
    tens = div10 % 10
    return tens
```

WARNING!!
This example contains indentation errors!
Design Recipe: Testing in Python

• Our Python functions must still be tested
• Choosing test cases will be similar to before
  – Black box tests
    • Based on problem description
  – White box test
    • Based on actual implementation
• The mechanics of testing in Python will be different as Python does not have built-in check-expect or check-within
CS116 "check" Module

• Download the file: `check.py` from the CS116 web pages. Put a copy in the same folder as your `.py` files for each assignment.

• Add the following line to each assignment file:

```python
import check
```

• You do NOT need to submit `check.py` when you submit your assignment files.

• A message is displayed for each test.
## Question 1, Test 1: description

`check.expect("Q1T1", expr, value_expected)`

- This function performs the test:
  Does `expr` exactly equal `value_expected`?
- Use for checking exact values (integer or strings).
Testing `middle`

```python
check.expect(
    "middle is first value",
    middle(3,10,1),3)
check.expect(
    "middle is second value",
    middle(2,5,9), 5)
```

*Note: Since your examples are written as comments, you should include these same situations in your test cases.*
Testing functions that return \texttt{Float} values

• Recall that Python has two numeric types: \texttt{Int} and \texttt{Float}.

• \texttt{Float} values may not be stored exactly, and additional errors may be introduced in floating point calculations.
  – Answers may not be exact

• Do not use \texttt{check.expect} for testing functions that return a \texttt{Float}. Always use \texttt{check.within} instead.
# Question 2, Test 2: description

```python
check.within(
    "Q2T2",
    expr,
    value_expected,
    tolerance)
```

- This function performs the test:
  ```python
  abs(expr - value_expected) <= tolerance
  ```
- Use for checking inexact values (floating point numbers only).

Label the test
- Actual result from function
- Expected result
- Maximum allowed error
Testing `area_circle`

(area_circle) returns a floating point

→ Don’t test for exact equality

```python
check.within("zero radius",
    "area_circle(0.0), 0.0, 0.00001"
)

check.within("positive radius",
    area_circle(1.0), 3.14159, 0.00001)
```

Note: 0.00001 is typically a good threshold for our tests.
def total_digits(secret):
    ones = secret % 10
    tens = secret // 10
    sum = ones + tens
    return

>>> d = total_digits(74)
What is the value of d?
How would you write the contract of total_digits?
And even further

def total_digits(secret):
    ones = secret % 10
    tens = secret // 10
    sum = ones + tens

def calculation(secret):
    s = total_digits(secret)
    return secret - s

c = calculation(74)
Warning: Continuing a Python statement over multiple lines

• Python expects each line of code to be an entire statement
  – Can be a problem with line length and readability due to indentation

• If a statement is not done, use a \ (backslash) character to show it continues on next line
  – \ is not needed if you have an open bracket on the unfinished line
More on Basic Types in Python

- Remember that the differences between integers and floating point numbers can complicate calculations
- Python has many built-in conversion functions from one basic type to another
How to get the type we want:
More Casting and Conversion Functions

• **float: Int ➔ Float**
  – `float(1) ➔ 1.0`, `float(10) ➔ 10.0`

• **float: Str ➔ Float**
  – `float("34.1") ➔ 34.1`,
  – `float("2.7.2") ➔ Error`
  – `float("23") ➔ 23.0`

• **float: Float ➔ Float**
  – `float(23.4) ➔ 23.4`
More Casting Functions

• `int`: (anyof Float Str Int) \(\rightarrow\) Int
  - `int(4.7) \Rightarrow 4`, `int(3.0/4) \Rightarrow 0`,
  - `int(-12.4) \Rightarrow -12`
  - This is a truncation operation (not rounding)
  - `int("23") \Rightarrow 23`
  - `int("2.3") \Rightarrow Error`

• `str`: (anyof Int Float Str) \(\rightarrow\) Str
  - `str(3) \Rightarrow "3"`, `str(42.9) \Rightarrow "42.9"`
Goals of Module 1

• Become comfortable in Python
  – Basic types and mathematical operations
  – Calling functions
  – Defining functions
  – Using `return` correctly
  – Design recipe in Python