Module 01: Introduction to Programming in Python

Topics:
• Course Introduction
• Introduction to Python basics

Readings: ThinkP 1,2,3
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
• Academic Integrity Policy
• AccessAbility Services
Grading

• Assignments 20%
• Participation 5%
  (clicker questions with tutorial bonus)
• Midterm 30%
• Final 45%

Note: You must pass the weighted average of the midterm and final in order to pass the course.
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
  – Data values change as the program executes
  – Calculated values may (or may not) be returned
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
\[ v = \text{expr} \]

- `=` is the assignment operator ("becomes")
- `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

\[ \begin{align*}
x &= 2 \times (4 + 12) \\
y &= x + 8 \\
z &= y \times y \\
w &= "hi" \\
u &= w + w
\end{align*} \]

What are the values of \( x, y, z, w, u \)?
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>Racket Type</th>
<th>Python Representation</th>
<th>Python 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>
<td>exact</td>
<td>Int</td>
<td>exact</td>
<td>Int</td>
</tr>
<tr>
<td>rational</td>
<td>exact</td>
<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.
More about
Racket vs Python: Numeric types

• Approximations are made at intermediate steps of calculations \( \rightarrow \) Round-off error
• **Do not** compare two floating point numbers for exact equality (*more later ...*)
• **Do not** rely on floating point values being exact!
• Use `Int`, `Float`, or `(any of Int Float)` in contracts, adding requirements as needed
Basic Mathematical Operations

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

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

• Integer division: \( x \div y \)
  – The result is the integer part of the division
  – If \( x \) and \( y \) are both \texttt{Int}, the result is an \texttt{Int}
  – If either \( x \) or \( y \) is a \texttt{Float}, the result is an \texttt{Float}, with the decimal part being \( .0 \)
  – Usually used with \( x \) and \( y \) as \texttt{Int}
Other Mathematical Operations

• Remainder: \( x \ % \ y \)
  – \( x \) and \( y \) should both be \textbf{Nat}
  – returns the \textbf{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

\[ \text{fn\_name (arg1, arg2, \ldots, argN)} \]
- built-in function or a user-defined \text{fn\_name}
- must have correct number of arguments
- separate arguments by single comma
- examples:
  - \text{abs(-3.8)} => 3.8
  - \text{len("Hello There")} => 11
  - \text{type(5)} => <type 'int'>
  - \text{max(3,5,9)} => 9
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
    statement2
    ...
    statementK

Notes:
• Indent each statement the same amount
• For function to return a value, include
  return answer
  where answer is the value the function returns
• If no return statement, the function returns None
Example: Write a Python function that consumes 3 different integers and returns the middle value.

```python
# middle(a,b,c) returns the middle value of a,b,c
# middle: Int Int Int -> Int
# requires: a,b,c are all different
# Examples:
# ...
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.
Design Recipe (continued)

Some steps are the same in Python as in Racket:

• Purpose statement:
  – Explicitly indicate what the function does, including how the parameters are used

• 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
Some steps are a bit different: Examples ...

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

• Our new approach:

  # fn(arg1, arg2, ...) => expected

• For example:

  # middle(4,2,8) => 4
  # middle(3,2,1) => 2
Design Recipe (continued)

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

• While templates are not required in CS116, you may still find them helpful, and we will try to point out common code patterns.
Design Recipe (summary)

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

# 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

def area_circle(radius):
    return math.pi * radius * radius
```
Picky, picky, picky ...

Indentation in Python

A small change in indentation will lead to error

# tens_digit(n) returns the tens digit of n
# tens_digit: Nat -> Nat
# Examples:
# tens_digit(1234) => 3
# tens_digit(4) => 0

def tens_digit(n):
    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.
check.expect

## Question 1, Test 1: description

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

• This function performs the test:
  Does \texttt{expr} exactly equal \texttt{value\_expected}?
• Use for checking exact values (integer or strings).

Label the test
Actual result - usually a function call
Expected result; Calculate it yourself
check.within

## Question 2, Test 2: description
check.within(
    "Q2T2",
    expr,
    value_expected,
    tolerance)

• This function performs the test:
  \[ \text{abs}(\text{expr} - \text{value}_{\text{expected}}) \leq \text{tolerance} \]
• Use for checking inexact values (floating point numbers only).

Label the test
Actual result
Expected result
"Close enough" value
Testing middle

## Test 1: middle is first value
```python
check.expect(
    "Q1T1", middle(3, 10, 1), 3)
```

## Test 2: middle is second value
```python
check.expect(
    "Q1T2", middle(2, 5, 9), 5)
```

*Note: You should now include your examples with your tests.*
Testing `area_circle`

`area_circle` returns a floating point
→ Don’t test for exact equality

## Q2, Test 1: zero radius
```
check.within("Q2T1", area_circle(0.0), 0.0, 0.00001)
```

## Q2, Test 2: positive radius (1.0)
```
check.within("Q2T2", area_circle(1.0), 3.14159, 0.00001)
```
Investigating \texttt{return} further

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

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

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

Assume
10 ≤ secret ≤ 99

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

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

• Don't finish a line in the middle of a statement!

• Python expects each line of code to be an entire statement
  – Can be a problem e.g. due to indentation

• If a statement is not done, use a \ (backslash) character to show it continues on next line
  – 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 $\rightarrow$ Float**
  - `float(1) => 1.0, float(10) => 10.0`

- **float: Str $\rightarrow$ Float**
  - `float("34.1") => 34.1,`
  - `float("2.7.2") => Error`
  - `float("23") => 23.0`

- **float: Float $\rightarrow$ Float**
  - `float(23.4) => 23.4`
More Casting Functions

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

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

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