

Lecture #2: Functions, Expressions

Administrative

- Reader with discussion and other materials available at Vick Copy (Euclid and Hearst).
- Sign yourself up on Piazza. See course web page:
`http://inst.cs.berkeley.edu/~cs61a`
- Be sure to get an account form next week in lab, and provide registration data.

Announcement: We're trying to hire a new lecturer. There will be two candidates coming Jan. 27-28 (Josh Hug) and Feb. 3-4 (John DeNero), and you can help evaluate them! For both days:

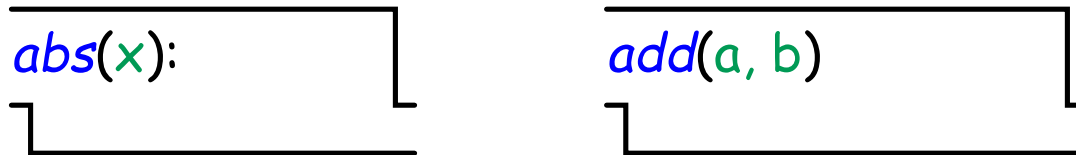
- Mon 01:00pm-02:00pm "Big ideas" talk (in Woz)
- Tue 11:45am-12:45pm Undergrad student lunch on northside (meet in 777 Soda)
- Tue 01:00pm-02:00pm Demo Class talk (in 380 Soda for Josh, Woz for John)
- UG Tue 02:00pm-02:45pm Open Session after demo class (same rooms)

Recap

- From last lecture: *Values* are data we want to manipulate and in particular,
- *Functions* are values that perform computations on values.
- *Expressions* denote computations that produce values.
- Today, we'll look at them in some detail at how functions operate on data values and how expressions denote these operations.
- As usual, although our concrete examples all involve Python, the actual concepts apply almost universally to programming languages.

Functions

- Something like *abs* denotes or evaluates to a function.
- To depict the denoted function values, we sometimes use this notation:



- Idea: The opening on the left takes in values and one on the right to delivers results.
- The (green) *formal parameter names*—such as *x*, *a*, *b*—show the number of parameters (inputs) to the function.
- The list of formal parameter names gives us the function's *signature*—in Python, this is the number of arguments.
- For our purposes, the blue name is simply a helpful comment to suggest what the function does.
- (Python actually maintains this *intrinsic name* and the parameter names internally, but this is not a universal feature of programming languages, and, as you'll see, can be confusing.)

Functions: Lambda

- I'm often going to use a more venerable notation for function values:

$\lambda x: \ll |x| \gg$

$\lambda a, b: \ll \text{the sum of } a \text{ and } b \gg$

- Formal parameters go to the left of the colon.
- The part to the right of the colon is an expression that indicates what value is produced.
- I'll use $\ll \dots \gg$ expressions to indicate non-Python descriptions of values or computations.
- In Python, you can *denote* simple function values like this:

```
lambda a, b : << the sum of a and b >>
```

which evaluates to

$\lambda a, b: \ll \text{the sum of } a \text{ and } b \gg$

- (Well, OK: the $\ll \dots \gg$ isn't really Python, but I'll use it as a placeholder for some computation I'm not prepared to write.)

Calling Functions (I)

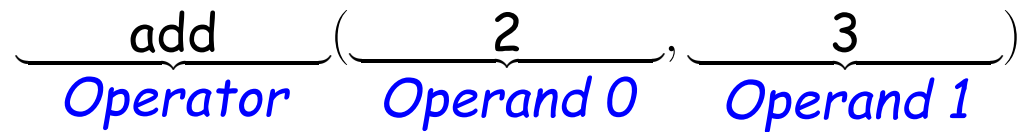
- The fundamental operation on function values is to *call* or *invoke* them, which means giving them one value for each formal parameter and having them produce the result of their computation on these values:

-5 ▷ `abs(number):` ▷ 5

(29, 13) ▷ `add(left, right)` ▷ 42

Call Expressions

- A call expression denotes the operation of calling a function.
- Consider `add(2, 3)`:



- The operator and the operands are all themselves expressions (recursion again).
- To evaluate this call expression:
 - Evaluate the operator (let's call the value C). It must evaluate to a function.
 - Evaluate the operands (or *actual parameters* in the order they appear (let's call these values P_0 and P_1))
 - Call C with parameters P_0 and P_1 .

Calling a Function (I): Substitution

- Once we have the values for the operator and operands, we must still actually evaluate the call.
- A simple way to understand this (which will work for simple expressions) is to think of the process as *substitution*.
- Once you have a value:

$\lambda a, b: \ll \text{sum of } a \text{ and } b \gg$

- and values for the operands (let's say 2 and 3),
- *substitute* the operand values for the formal parameters, replacing the whole call with

$\ll \text{sum of } 2 \text{ and } 3 \gg$

- which in turn evaluates to 5.

Side Trip: Values versus Denotations

- Expressions such as **2** in a programming language are called *literals*.
- To evaluate them, we replace them with whatever values they are supposed to stand for.
- This is confusing:
 - Q: What is the value of the literal 2?
 - A: 2.
- ...and then you get into long, technical explanations about how the second "2" is really in a different language than the first, and actually is just another notation for some mystical Platonic "2" that is floating off somewhere.
- I'll just try to be practical and distinguish values from literals by surrounding values in a boxes: the value of 2 is **2**.
- One way to see the distinction between literals and values: the literals 0x10 and 16 are obviously different, but both denote the same value: **16**.

Example: From Expression to Value

Let's evaluate the expression `mul(add(2, mul(0x4, 0x6)), add(0x3, 005))`.

In the following sequence, values are shown in boxes.

Everything outside a box is an expression.

- $\text{mul}(\underbrace{\text{add}(2, \text{mul}(0x4, 0x6))}_{\text{expression}}, \underbrace{\text{add}(0x3, 005)}_{\text{expression}})$
- $\lambda a, b: \ll a \times b \gg (\text{add}(2, \text{mul}(0x4, 0x6)), \text{add}(0x3, 005))$
- $\lambda a, b: \ll a \times b \gg (\lambda a, b: \ll a + b \gg ([2], \lambda a, b: \ll a \times b \gg ([4], [6])), \text{add}(0x3, 005))$
- $\lambda a, b: \ll a \times b \gg (\lambda a, b: \ll a + b \gg ([2], \ll 4 \times 6 \gg, \text{add}(0x3, 005)))$
- $\lambda a, b: \ll a \times b \gg (\lambda a, b: \ll a + b \gg ([2], [24]), \text{add}(0x3, 005))$
- $\lambda a, b: \ll a \times b \gg (\ll 2 + 24 \gg, \text{add}(0x3, 005))$
- $\lambda a, b: \ll a \times b \gg ([26], \text{add}(0x3, 005))$
- $\lambda a, b: \ll a \times b \gg ([26], \lambda a, b: \ll a + b \gg ([3], [5]))$
- ... $\lambda a, b: \ll a \times b \gg ([26], [8])$
- ... **208**.

Puzzle I

Evaluate

`(lambda a: lambda b: a + b)(1)(3)`

- First, must understand how it's grouped:

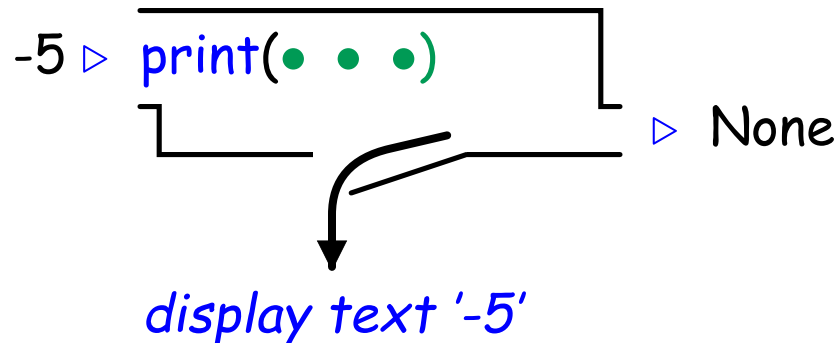
`((lambda a: lambda b: a + b)(1))``(3)`

Puzzle I (contd.)

- $(\text{lambda } a: \text{lambda } b: a + b)(1)(3)$
- $\boxed{\lambda a: \text{lambda } b: a + b}(\boxed{1})(3)$
- $(\text{lambda } b: \boxed{1} + b)(3)$
- $\boxed{\lambda b: \boxed{1} + b}(\boxed{3})$
- $\boxed{1} + \boxed{3}$
- 4

Impure Functions

- The functions so far have been *pure*: their output depends only on their input parameters' values, and they do nothing in response to a call but compute a value.
- Functions may do additional things when called besides returning a value.
- We call such things *side effects*.
- Example: the built-in *print* function:



- Displaying text is *print*'s side effect. Its value, in fact, is generally useless (always the null value).
- For this lecture (at least), I'll use λ ! ("lambda bang") to denote function values with side effects.

Example: Print

What about an expression with side effects?

1. `print(print(1), print(2))`

2. `λ! x: << print x >> (λ! x: << print x >> (1), print(2))`

3. `λ! x: << print x >> (None, print(2))`
and print '1'.

4. `λ! x: << print x >> (None, λ! x: << print x >> (2))`

5. `λ! x: << print x >> (None, None)`
and print '2'.

6. `None`
and print 'None None'.