

Functions as First-Class Citizens


- Functions as first-class citizens means that we can pass functions around in a program as values, not much different than an integer or real value!
- When functional languages first appeared in the late 1970's and the 1980's this was a radical concept
- Today almost all modern languages support this, e.g.
 - Python, JavaScript, Rust, Go

Functions as First-Class Citizens

```
-- first-class functions

-- define our increment function
function inc with i do
    return i+1.
end

let foo = inc.  -- foo now holds a function value
let x = foo 1.  -- execute the function in foo with value 1
assert(x == 2).
```



Functions as First-Class Citizens

```
-- first-class functions

-- define our increment function
function inc with i do
  return i+1.
end


-- define our decrement function
function dec with i do
  return i-1.
end

-- c expects a function and a value
function c with (f:%function, v:%integer) do
  return f v.
end

-- we can modify c's behavior depending what kind of
-- function we pass it.

let x = c (inc,1).
assert(x == 2).

let y = c (dec,1).
assert(y == 0).
```



Python

- Python supports functions as first-class citizens

```
[lutz$ python3
Python 3.8.2 (default, Jun  8 2021, 11:59:35)
[Clang 12.0.5 (clang-1205.0.22.11)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
[>>> def inc(i):
...     return i+1
...
[>>> foo = inc
[>>> foo(1)
2
>>> █
```

Python

```
# first-class functions

# define our increment function
def inc(i):
    return i+1

# define our decrement function
def dec(i):
    return i-1

# c expects a function and a value
def c(f,v):
    return f(v)

# we can modify c's behavior depending what kind of
# function we pass it.

x = c (inc,1)
assert(x == 2)

y = c (dec,1)
assert(y == 0)
```

Higher-Order Programming


- Higher-order programming refers to the fact that we take advantage of functions as first-class citizens in our algorithms.

The Lambda Function

- The most well-known feature of higher-order programming is the *lambda* function.
- A lambda function is a function definition without a name.
- In functional-style programming this is often used for functions that are so trivial that they don't warrant a full function definition


Asteroid:

```
load system "io".  
  
let y = (lambda with x do return x+1) 1.  
println y. -- print out the value 2
```



Python:

```
>>> y = (lambda x : x+1) (1)  
>>> print(y)  
2  
>>>
```



The Lambda Function

- Lambda functions are values!

Asteroid:

```
load system "io".  
  
let p = (lambda with x do return x+1).  
let y = p 1.  
println y. -- print out the value 2
```

Python:

```
>>> p = (lambda x : x+1)  
>>> y = p (1)  
>>> print(y)  
2  
>>> █
```

- The true power of lambda functions only becomes apparent when combined with other higher-order programming features

The Map Function

- The map function allows you to replace iteration over a list with mapping a function onto the list.
- The map function is a higher-order function since it expects a function as a parameter.

The Map Function

● Asteroid

```
-- compute a list whose elements are incremented  
-- by one compared to the input list
```

```
let a = [1,2,3].  
let b = [].
```

```
-- iterate over the list  
for e in a do  
  b @append(e+1).  
end
```

```
assert(b == [2,3,4]).
```

```
-- compute a list whose elements are incremented  
-- by one compared to the input list
```

```
let a = [1,2,3].  
let b = [].
```

```
-- using map
```

```
let b = a @map(lambda with i do return i+1).
```



```
assert(b == [2,3,4]).
```

The Map Function

● Python

```
# compute a list whose elements are incremented  
# by one compared to the input list
```

```
a = [1,2,3]  
b = []
```

```
# iterate over the list
```

```
for e in a:  
    b.append(e+1)
```

```
assert(b == [2,3,4])
```

```
# compute a list whose elements are incremented  
# by one compared to the input list
```

```
a = [1,2,3]  
b = []
```

```
# using map
```

```
b = map((lambda x : x+1), a) 
```

```
assert(list(b) == [2,3,4])
```

The Map Function

- One way to think about map is that it applies the given function to each element of the list.

```
function map
```

```
-- Apply f to each element of the list l
```

```
with (f:%function,l:%list) do
```

```
  let r = [].
```

```
  for i in l do
```

```
    r @append(f i).
```

```
  end
```

```
  return r.
```

```
end
```

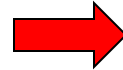
Function Application



The Map Function

- One way to think about map is that it applies the given function to each element of the list.

```
[1,2,3] @map(lambda with i do return i+1)
```



```
[  
  (lambda with i do return i+1) 1,  
  (lambda with i do return i+1) 2,  
  (lambda with i do return i+1) 3  
]
```

The Map Function

- The lists themselves can consist of structured objects – the supplied function must be able to handle the elements of the list as arguments.
- The return value of the function being mapped can be different from its input values.

```
-- applying map to a list of tuples
```

```
let [3,7,11] = [(1,2),(3,4),(5,6)] @map(lambda with (x,y) do return x+y).
```

The Reduce Function


- The reduce function computes a single value from an input list

```
let 6 = [1,2,3] @reduce(lambda with (acc,v) do return acc+v).
```

```
let 10 = [1,2,3] @reduce((lambda with (acc,v) do return acc+v), 4).
```

The Reduce Function

- The reduce function maps a two-argument function onto a list.
 - First arg acts as accumulator
 - Second arg steps through the elements



```
def reduce(function, iterable, initializer=None):  
    it = iter(iterable)  
    if initializer is None:  
        value = next(it)  
    else:  
        value = initializer  
    for element in it:  
        value = function(value, element) ←  
    return value
```

Source: <https://realpython.com/python-reduce-function/>

The Reduce Function

- Interesting way to implement the factorial operation

Asteroid

```
-- factorial implementation using reduce

let x = 3.
let fact = [1 to x] @reduce(lambda with (acc,j) do return acc*j).
assert(fact == 6).
```

Python

```
from functools import reduce

x = 3

def mul(acc,j):
    return acc*j

fact = reduce(mul, [i for i in range(1,x+1)])

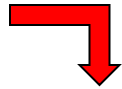
assert(fact == 6)
```

Function Currying

- Function currying is a technique that transforms any multi-argument function into a cascade of single-argument functions.
- The advantage is, this approach allows for partially evaluated functions!

Function Currying

```
function add with (a,b) do  
  return a+b.  
end
```



```
function addc with a do  
  return (lambda with b do return a+b).  
end
```

```
let sum = add(1,2).  
let sumc = addc 1 2.  
  
assert(sum == 3).  
assert(sumc == 3).
```




Arguments to a curried function
are given as a sequence of values!

Function Currying

- Partially evaluated functions!

```
function addc with a do  
  return (lambda with b do return a+b).  
end
```

```
-- partially evaluated functions!  
let partial = addc 1.  
let final = partial 2.   
  
assert(final == 3).
```

Function Currying

-- demonstration of currying with 3 args

```
function sum with (a,b,c) do  
  return a+b+c.  
end
```

```
function sumc with a do  
  return lambda with b do  
    return lambda with c do  
      return a+b+c  
    end  
  end  
end
```

```
assert( sum(1,2,3) == 6 ).  
assert( sumc 1 2 3 == 6 ).
```

Function Currying

- This also works in Python

```
>>> def addc(a):  
...     return lambda b : a+b  
...  
>>> p = addc(1)  
>>> p  
<function addc.<locals>.<lambda> at 0x102b4baf0>  
>>> q = p(2)  
>>> q  
3  
>>> █
```

```
>>> def sumc(a):  
...     return lambda b : lambda c : a+b+c  
...  
>>> sumc(1)(2)(3)  
6  
>>> █
```

Function Currying

- Why is this interesting?
 - Unique approach to library design – if the library consists of curried functions then the library can be easily extended by partially evaluating those functions
- The libraries for Haskell and ML take this approach

Function Currying

- An example in Python, we assume that we have a library with curried functions...

```
>>> def addc(a):  
...     return lambda b : a+b  
...  
>>> def mulc(a):  
...     return lambda b : a*b  
...  
>>> inc = addc(1)  
>>> double = mulc(2)  
>>>  
>>> inc(1)  
2  
>>> double(4)  
8  
>>> █
```

Curried library functions

Extending the library with
partially evaluated curried
functions!

Assignment

- Assignment #5 – See BrightSpace