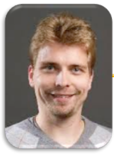

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Computational Structures in Data Science

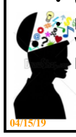
Lecture #11: Iterators and Generators

Tax day, 2019

http://inst.eecs.berkeley.edu/~cs88

Computational Concepts Toolbox

- Data type: values, literals, operations,
- Expressions, Call expression
- Variables
- Assignment Statement, Tuple assignment
- Sequences: tuple, list
- Dictionaries
- Function Definition Statement
- Conditional Statement
- Iteration: list comp, for, while
- Lambda function expr.
- Higher Order Functions
  - Functions as Values
  - Functions with functions as argument
  - Assignment of function values
- Higher order function patterns
  - Map, Filter, Reduce
- Function factories – create and return functions
- Recursion
- Abstract Data Types
- Mutation
- Class & Inheritance
- Exceptions
- Iterators & Generators



Today:

- Review Exceptions
- Sequences vs Iterables
- Using iterators without generating all the data
- Generator concept
  - Generating an iterator from iteration with `yield`
- Magic methods
  - `next`
  - `Iter`
- Iterators – the iter protocol
- Getitem protocol
- Is an object iterable?
- Lazy evaluation with iterators

Key concepts to take forward

- Classes embody and allow enforcement of ADT methodology
- Class definition
- Class namespace
- Methods
- Instance attributes (fields)
- Class attributes
- Inheritance
- Superclass reference

Summary of last week

- Approach creation of a class as a design problem
  - Meaningful behavior => methods [& attributes]
  - ADT methodology
  - What's private and hidden? vs What's public?
- Design for inheritance
  - Clean general case as foundation for specialized subclasses
- Use it to streamline development
- Anticipate exceptional cases and unforeseen problems
  - try … catch
  - raise / assert

Mind Refresher 1

An object is…

A) an instance of a class
B) a python thing
C) inherited from a class
D) All of the above

Solution:
A) An object is an instance of a class

Mind Refresher 2

A setter method…

A) constructs an object
B) changes the internal state of an object or class
C) is required by Python to access variables
D) All of the above

Solution:
B) Changes the internal state of an object or class by allowing access to a private variable.

Exception (read 3.3)

- Mechanism in a programming language to declare and respond to "exceptional conditions"
  - enable non-local cntinuations of control
- Often used to handle error conditions
  - Unhandled exceptions will cause python to halt and print a stack trace
  - You already saw a non-error exception – end of iterator
- Exceptions can be handled by the program instead
  - `assert, try, except, raise` statements
- Exceptions are objects!
  - They have classes with constructors

Handling Errors – `try` / `except`

- Wrap your code in `try` – `except` statements

```
try:
    <try suite>
except <exception class> as <name>:
    <except suite>
... # continue here if <try suite> succeeds w/o exception
```

- Execution rule
  - <try suite> is executed first
  - If during this an exception is raised and not handled otherwise
  - And if the exception inherits from <exception class>
  - Then <except suite> is executed with <name> bound to the exception
- Control jumps to the except suite of the most recent `try` that handles the exception

Types of exceptions

- `TypeError` -- A function was passed the wrong number/type of argument
- `NameError` -- A name wasn't found
- `KeyError` -- A key wasn't found in a dictionary
- `RuntimeError` -- Catch-all for troubles during interpretation
- . . .

Demo

```python
def safe_apply_fun(f,x):
    try:
        return f(x)          # normal execution, return the result
    except Exception as e:   # exceptions are objects of class deri
        return e             # value returned on exception
```

```python
def divides(x, y):
    assert x != 0, "Bad argument to divides - denominator should be non-zero"
    if (type(x) != int or type(y) != int):
        raise TypeError("divides only takes integers")
    return y%x == 0
```


Exceptions are Classes

```python
class NoiseyException(Exception):
    def __init__(self, stuff):
        print("Bad stuff happened", stuff)
```

```python
try:
    return fun(x)
except:
    raise NoiseyException((fun, x))
```

Mind Refresher 3

Exceptions…

A) allow to handle errors non-locally
B) are objects
C) cannot happen within a catch block
D) B, C
E) A, B

Solution:
B, C) Exceptions are objects and they can occur any time.

Iterable - an object you can iterate over

- *iterable*: An object capable of yielding its members one at a time.
- *iterator*: An object representing a stream of data.
- We have worked with many iterables as if they were sequences

Functions that return iterables

- map
- range
- zip

- These objects are not sequences.
- If we want to see all of the elements at once, we need to explicitly call list() or tuple() on them

Generators: turning iteration into an iterable

- *Generator* functions use iteration (for loops, while loops) and the yield keyword
- Generator functions have no return statement, but they don't return None
- They implicitly return a generator object
- Generator objects are just iterators

```
def squares(n):
    for i in range(n):
        yield (i*i)
```


Nest iteration

```
def all_pairs(x):
    for item1 in x:
        for item2 in x:
            yield(item1, item2)
```


Next element in generator iterable

- Iterables work because they have some "magic methods" on them. We saw magic methods when we learned about classes,
- e.g., __init__, __repr__ and __str__.
- The first one we see for iterables is __next__

- `iter( )` – transforms a sequence into an iterator

Iterators – iter protocol

- In order to be *iterable*, a class must implement the **iter protocol**
- The iterator objects themselves are required to support the following two methods, which together form the iterator protocol:
  - __iter__() : Return the iterator object itself. This is required to allow both containers and iterators to be used with the for and in statements.
  - This method returns an iterator object, Iterator can be self
  - __next__() : Return the next item from the container. If there are no further items, raise the StopIteration exception.
- Classes get to define how they are iterated over by defining these methods

Getitem protocol

- Another way an object can behave like a sequence is *indexing*: Using square brackets "[ ]" to access specific items in an object.
- Defined by special method: **__getitem__**(self, i)
  - Method returns the item at a given index

```
class myrange2:
    def __init__(self, n):
        self.n = n

    def __getitem__(self, i):
        if i >= 0 and i < self.n:
            return i
        else:
            raise IndexError

    def __len__(self):
        return self.n
```


Determining if an object is iterable

- **`from collections.abc import Iterable`**
- **`isinstance([1,2,3], Iterable)`**

- This is more general than checking for any list of particular type, e.g., list, tuple, string...

Solutions for the Wandering Mind

N bits can represent 2^N configurations.

1) How many functions can be created that map from N bits to 1 bit (binary functions)? **#functions=2^{2^N}**

2) How many functions can be created that map from N bits to M bits? **#functions=M^{2^N}**

3) How many functions can be created that map from N k-bit length integers to M bits? **#functions=$M^{2^{kN}}$**

4) If we were representing the functions 1, 2, and 3 in tables: a) How many different tables would we need?
2^{2^N}, M^{2^N}, $M^{2^{kN}}$ tables, respectively.

b) How big is each table?
$(N+1)*2^N$ table cells.

=> It's easier to abstract the tables using functions, abstract data types, and object orientation!

Questions for the Wandering Mind

1) Adding two n-bit integers, how many bits can the result have?

2) Multiplying two n bit integers, how many bits can the result have?

Assume:

a) Exceptions don't exist
b) We only reserve 8bit for an integer variable (0-255)

Questions:

1) What would be the result of an addition 255+255?
2) What would be the result of a multiplication 255*255?
3) Assume l additions of 8bit integers into the same 8bit variable. Can you formulate the maximum error that can occur as a function of l?