



Python Data Handling: A Deeper Dive

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Python Fluency

- Mastery of Python's built-in types, useful libraries, and data handling idioms are a fundamental part of Python literacy
- You shouldn't even have to think twice about it in day-to-day coding
- This course is about reinforcing your skills
- Going beyond an introductory tutorial

Beyond Frameworks

- You might be inclined to turn to libraries and frameworks to solve common data problems
- "Look up the command"
- But, Python provides useful building blocks
- You can quickly code a lot of things yourself if you know how to put them together

Materials and Setup

- Supporting code and data for this course:

<http://www.dabeaz.com/datadeepdive>

- Python 3.6+ is assumed
- Any operating system is fine
- Slides are merely a guide. Presentation will rely heavily on live-demos, examples.

Part I: Data Structure Shootout

Problem

Some data ...

```
name,shares,price  
"AA",100,32.20  
"IBM",50,91.10  
"CAT",150,83.44  
"MSFT",200,51.23  
"GE",95,40.37  
"MSFT",50,65.10  
"IBM",100,70.44  
...
```

???

How do you "best" represent records/
structures in Python?

Tuples

- A collection of values packed together

```
s = ('GOOG', 100, 490.1)
```

- Can use like an array

```
name = s[0]  
cost = s[1] * s[2]
```

- Unpacking into separate variables

```
name, shares, price = s
```

- Immutable

```
s[1] = 75      # TypeError. No item assignment
```

Dictionaries

- An unordered set of values indexed by "keys"

```
s = {  
    'name'      : 'GOOG',  
    'shares'    : 100,  
    'price'     : 490.1  
}
```

- Use the key name to access

```
name = s['name']  
cost = s['shares'] * s['price']
```

- Modifications are allowed

```
s['shares'] = 75  
s['date'] = '7/25/2015'  
del s['name']
```


User-Defined Classes

- A simple data structure class

```
class Stock(object):  
    def __init__(self, name, shares, price):  
        self.name = name  
        self.shares = shares  
        self.price = price
```

- This gives you the nice object syntax...

```
>>> s = Stock('GOOG', 100, 490.1)  
>>> s.name  
'GOOG'  
>>> s.shares * s.price  
49010.0  
>>>
```

Classes and Slots

- For data structures, consider adding `__slots__`

```
class Stock(object):  
    __slots__ = ('name', 'shares', 'price')  
    def __init__(self, name, shares, price):  
        self.name = name  
        self.shares = shares  
        self.price = price
```

- Slots is a performance optimization that is specifically aimed at data structures
- Less memory and faster attribute access

Named Tuples

- `namedtuple(clsname, fieldnames)`

```
from collections import namedtuple
```

```
Stock = namedtuple('Stock',  
                  ['name', 'shares', 'price'])
```

- It creates a class that you use to make instances

```
>>> s = Stock('GOOG', 100, 490.1)  
>>> s.name  
'GOOG'  
>>> s.shares * s.price  
49010.0  
>>>
```

- Instances look like tuples

Challenge

The file "ctabus.csv" is a CSV file containing ridership data from the Chicago Transit Authority bus system.

```
route,date,daytype,rides  
3,01/01/2001,U,7354  
4,01/01/2001,U,9288  
6,01/01/2001,U,6048  
8,01/01/2001,U,6309
```

15.7MB,
736000+ rows

What's the most efficient way to read it into a Python list so that you can work with it?

Part 2: Collections

Collecting Things

- Programs often have to work many objects
- And build relationships between objects
- There are some basic building blocks
 - Lists, tuples, sets, dicts
 - collections module
- Better to think about nature of the problem

Keeping Things in Order

- Use lists when the order of data matters
- Example: A list of tuples

```
portfolio = [  
    ('GOOG', 100, 490.1),  
    ('IBM', 50, 91.1),  
    ('CAT', 150, 83.44)  
]
```

```
portfolio[0] → ('GOOG', 100, 490.1)  
portfolio[1] → ('IBM', 50, 91.1)
```

- Lists can be sorted and rearranged

Keeping Distinct Items

- Use a set for keeping unique/distinct objects

```
a = { 'IBM', 'AA', 'AAPL' }
```

- Converting to a set will eliminate duplicates

```
names = [ 'IBM', 'YHOO', 'IBM', 'CAT', 'MSFT', 'CAT', 'IBM' ]  
unique_names = set(names)
```

- Sets are useful for membership tests

```
members = set()  
  
members.add(item)      # Add an item  
members.remove(item)   # Remove an item  
  
if item in members:    # Test for membership  
    ...
```


Building an Index/Mapping

- Use a dictionary (maps keys -> values)

```
prices = {  
    'GOOG' : 513.25,  
    'CAT'   : 87.22,  
    'IBM'   : 93.37,  
    'MSFT'  : 44.12  
    ...  
}
```

- Usage

```
p = prices['IBM']           # Value lookup  
prices['HPE'] = 37.42       # Assignment  
if name in prices:          # Membership test  
    ...
```

Composite Keys

- Use tuples for keys

```
prices = {  
    ('GOOG', '2017-02-01'): 517.20,  
    ('GOOG', '2017-02-02'): 518.23,  
    ('GOOG', '2017-02-03'): 518.71,  
    ...  
    ('IBM', '2017-02-01'): 92.50,  
    ('IBM', '2017-02-02'): 92.72,  
    ('IBM', '2017-02-03'): 91.92,  
    ...  
}
```

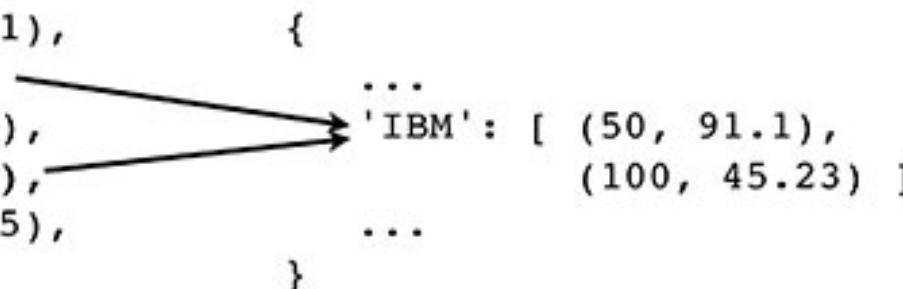
- Usage:

```
p = prices['IBM', '2017-02-01']  
prices['IBM', '2017-02-04'] = 92.3
```

One-to-Many Mapping

- Problem: Map keys to multiple values

```
portfolio = [  
    ('GOOG', 100, 490.1),  
    ('IBM', 50, 91.1),  
    ('CAT', 150, 83.44),  
    ('IBM', 100, 45.23),  
    ('GOOG', 75, 572.45),  
    ('AA', 50, 23.15)  
]
```



The diagram illustrates the transformation of the 'IBM' entries from the portfolio list into a dictionary structure. Two arrows originate from the 'IBM' entries in the list: one from `('IBM', 50, 91.1)` and another from `('IBM', 100, 45.23)`. These arrows point to the right, where a dictionary structure is shown. The dictionary has a key `'IBM':` followed by a list of tuples `[(50, 91.1), (100, 45.23)]`. Ellipses (`...`) are used to indicate that the dictionary contains other keys and values, and that the list for 'IBM' contains more than two elements.

- Strategy: Store multiple values in a container
- Make the value a list, set, dict, etc.

One-to-Many Mapping

- Common solution: `defaultdict(initializer)`

```
from collections import defaultdict
holdings = defaultdict(list)
for name, shares, price in portfolio:
    holdings[name].append((shares, price))
```

```
>>> holdings['IBM']
[ (50, 91.1), (100, 45.23) ]
>>>
```

- `defaultdict` automatically creates initial element

```
>>> d = defaultdict(list)
>>> d['x']
[]
>>> d
defaultdict(<class 'list'>, {'x': []})
>>>
```

Counting Things

- Example: Tabulate total shares of each stock

```
portfolio = [  
    ('GOOG', 100, 490.1),  
    ('IBM', 50, 91.1),  
    ('CAT', 150, 83.44),  
    ('IBM', 100, 45.23),  
    ('GOOG', 75, 572.45),  
    ('AA', 50, 23.15)  
]
```

```
{  
    ...  
    'IBM': 150  
    ...  
}
```

- Solution: Use a Counter

```
from collections import Counter  
total_shares = Counter()  
for name, shares, price in portfolio:  
    total_shares[name] += shares
```

```
>>> total_shares['IBM']  
150  
>>>
```

Challenge

Answer a few questions about the Chicago bus data...

1. How many bus routes exist?
2. How many people rode route 22 on 9-Apr-2007?
3. What are 10 most popular routes?
4. What are 10 most popular routes in 2016?
5. What 10 routes had greatest increase 2001-2016?

Part 3: Python Object Model

Everything is an Object

- Everything you use in Python is an "object"

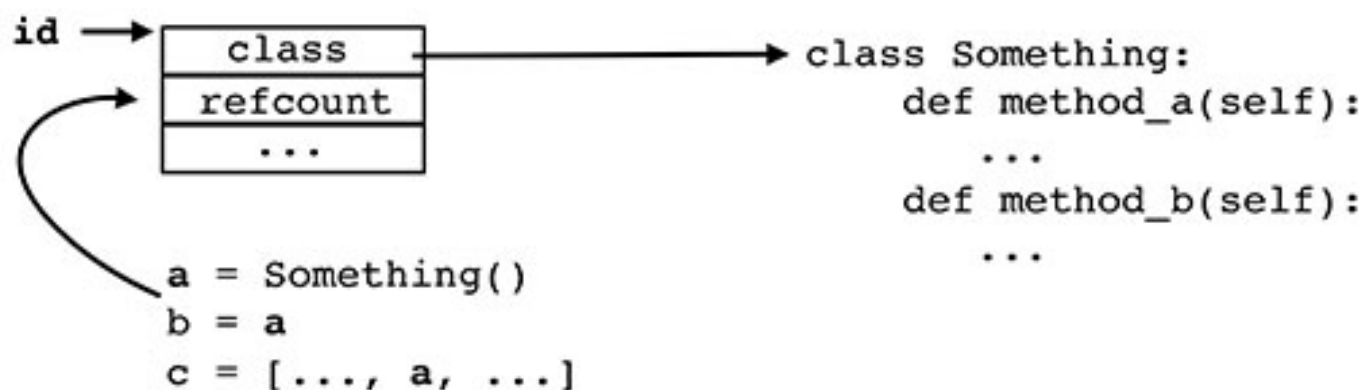
```
a = None
b = 42
c = 4.2
d = "forty two"
e = [1,2,3]
f = ('ACME', 50, 91.5)

def g(x):          # Even functions are objects
    return 2*x
```

- Programs are based on manipulating objects

Under the Covers

- All objects have an id, class and a reference count



- The id is the memory address
- The class is the "type"
- Reference count used for garbage collection

Under the Covers

- You can investigate...

```
>>> a = "hello world"
>>> id(a)
4562360496
>>> type(a)
<class 'str'>
>>> import sys
>>> sys.getrefcount(a)
2
>>>
```

- Normally, you don't think about it too much

Understanding Assignment

- Many operations in Python are related to "assigning" or "storing" values

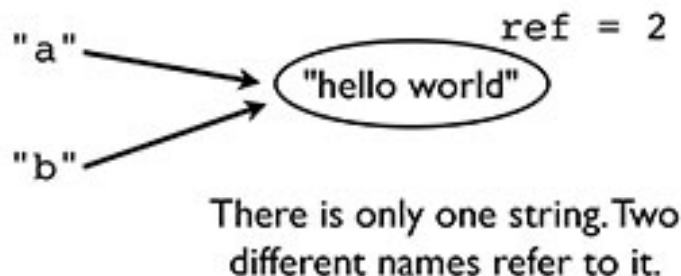
```
a = value           # Assignment to a variable
s[n] = value        # Assignment to an list
s.append(value)     # Appending to a list
d['key'] = value    # Adding to a dictionary
```

- A caution : assignment operations never make a copy of the value being assigned
- All assignments store the memory address only (object id). Increase the refcount.

Assignment Example

- Consider this code fragment:

```
>>> a = "hello world"
>>> b = a
>>> id(a)
4562360496
>>> id(b)
4562360496
>>>
```



- This happens for all objects (ints, floats, etc.)
- You don't notice because of immutability

Mutability Caution

- Consider this version:

```
>>> a = [1,2,3]
>>> b = a
>>> b
[1, 2, 3]
>>> b.append(999)
>>> b
[1, 2, 3, 999]
>>> a
[1, 2, 3, 999]
>>>
```



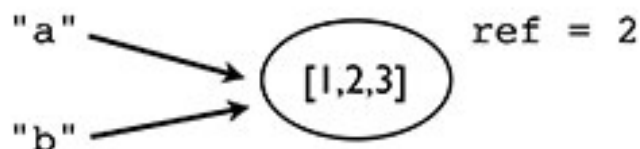
There is only one list object, but there are two references to it

- Both values change!

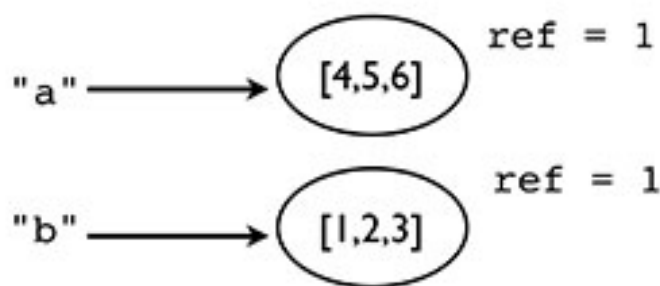
Reassigning Values

- Assignment never overwrites an existing object

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



```
a = [4, 5, 6]
```



- Variables are names for objects
- Assignment moves the name elsewhere

Shallow Copies

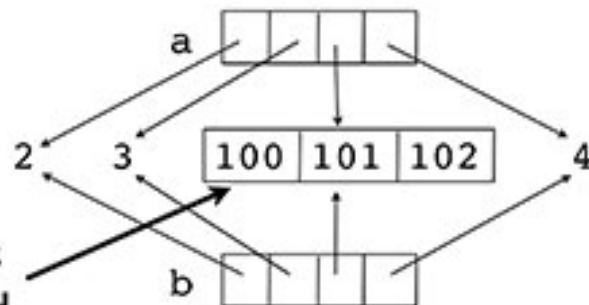
- Containers have methods for copying

```
>>> a = [2,3,[100,101],4]
>>> b = list(a)           # Make a copy
>>> a is b
False
```

- However, items are copied by reference

```
>>> a[2].append(102)
>>> b[2]
[100,101,102]
>>>
```

This inner list is
still being shared



- Known as a "shallow copy"

Deep Copying

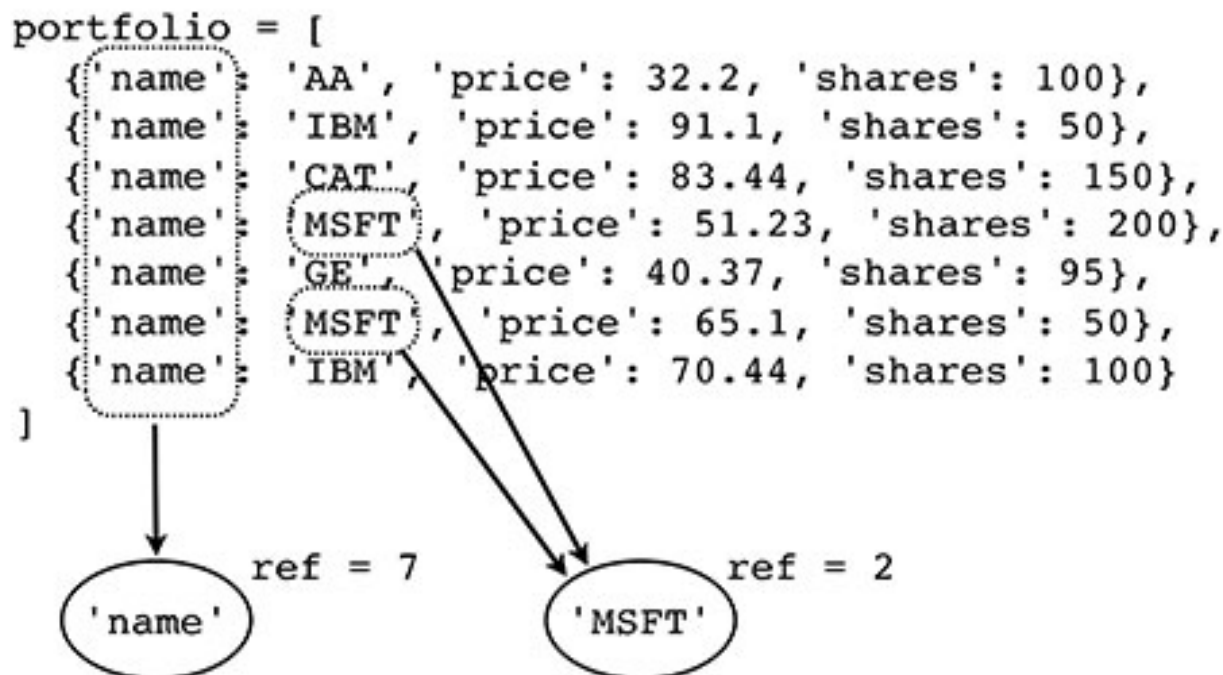
- Sometimes you need to make a copy of an object and all objects contained within it
- Use the copy module

```
>>> a = [2,3,[100,101],4]
>>> import copy
>>> b = copy.deepcopy(a)
>>> a[2].append(102)
>>> b[2]
[100,101]
>>>
```

- This is the only safe way to copy something

Exploiting Immutability

- Immutable values can be safely shared



- Sharing can save significant memory

Challenge

Come up with some clever "hack" to save a lot of memory reading that CTA bus data (hint: look at the data with a hint of string caching)

Builtin Representation

- None (a singleton)

type	(16 bytes)
refcount	

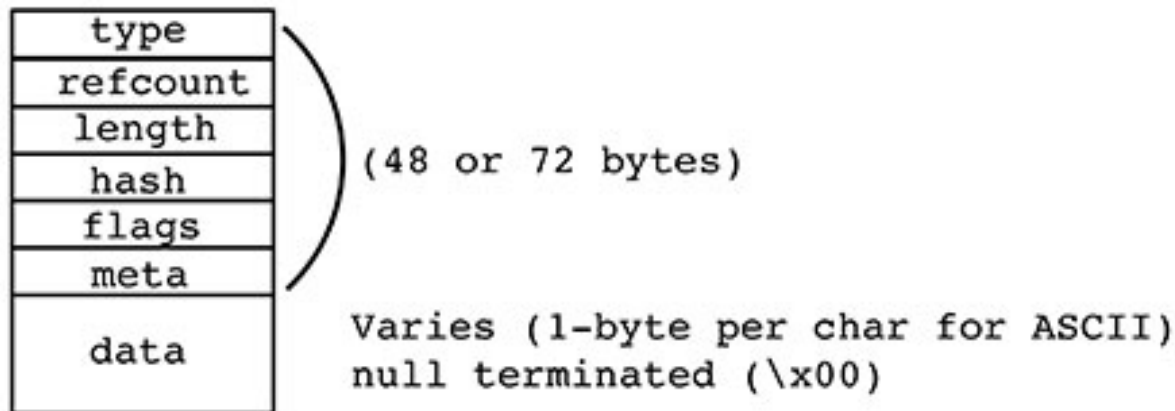
- float (64-bit double precision)

type	(24 bytes)
refcount	
value	

- int (arbitrary precision)

type	(28-??? bytes)
refcount	
size	
digits	
...	digits stored in
digits	30-bit chunks

String Representation

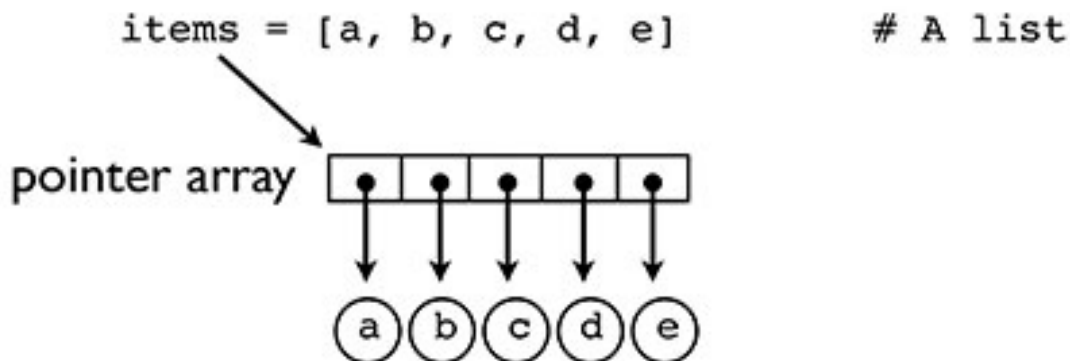


- Strings adapt to Unicode (size may vary)

```
>>> a = 'n'
>>> b = 'ñ'
>>> sys.getsizeof(a)
50
>>> sys.getsizeof(b)
74
>>>
```

Container Representation

- Container objects only hold references (object ids) to their stored values



- All operations involving the container internals only manipulate the ids (not the objects)

Tuple Representation

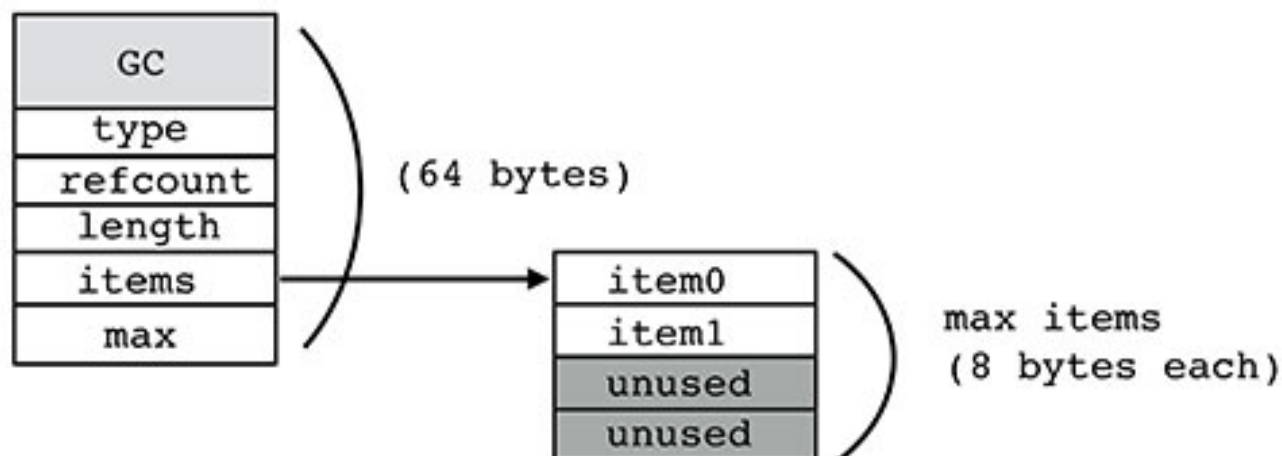


- Examples:

```
>>> a = ()
>>> sys.getsizeof(a)
48
>>> b = (1,2,3)
>>> sys.getsizeof(b)
72
>>>
```

Note: size does not include the items themselves. It's just for the tuple part.

List Representation

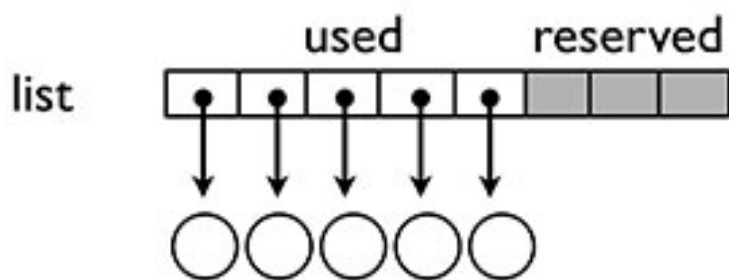


- Lists are resizable (storage space will grow)

```
>>> a = [1,2,3,4]
>>> sys.getsizeof(a)
96
>>> a.append(5)
>>> sys.getsizeof(a)
128
>>>
```

Over-allocation

- All mutable containers (lists, dicts, sets) tend to over-allocate memory so that there are always some free slots available



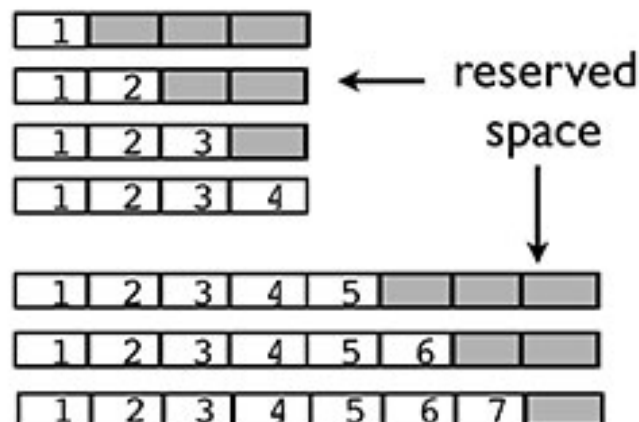
- This is a performance optimization
- Goal is to make appends, insertions fast

Example : List Memory

- Example of list memory allocation

```
items = []  
items.append(1)  
items.append(2)  
items.append(3)  
items.append(4)
```

```
items.append(5)  
items.append(6)  
items.append(7)
```



- Extra space means that most `append()` operations are very fast (space is already available, no memory allocation required)

Set/Dict Hashing

- Sets and dictionaries are based on hashing
- Keys are used to determine an integer "hashing value" (`__hash__()` method)

```
a = 'Python'  
b = 'Guido'  
c = 'Dave'
```

```
>>> a.__hash__()  
-539294296  
>>> b.__hash__()  
1034194775  
>>> c.__hash__()  
2135385778
```

- Value used internally (implementation detail)

Key Restrictions

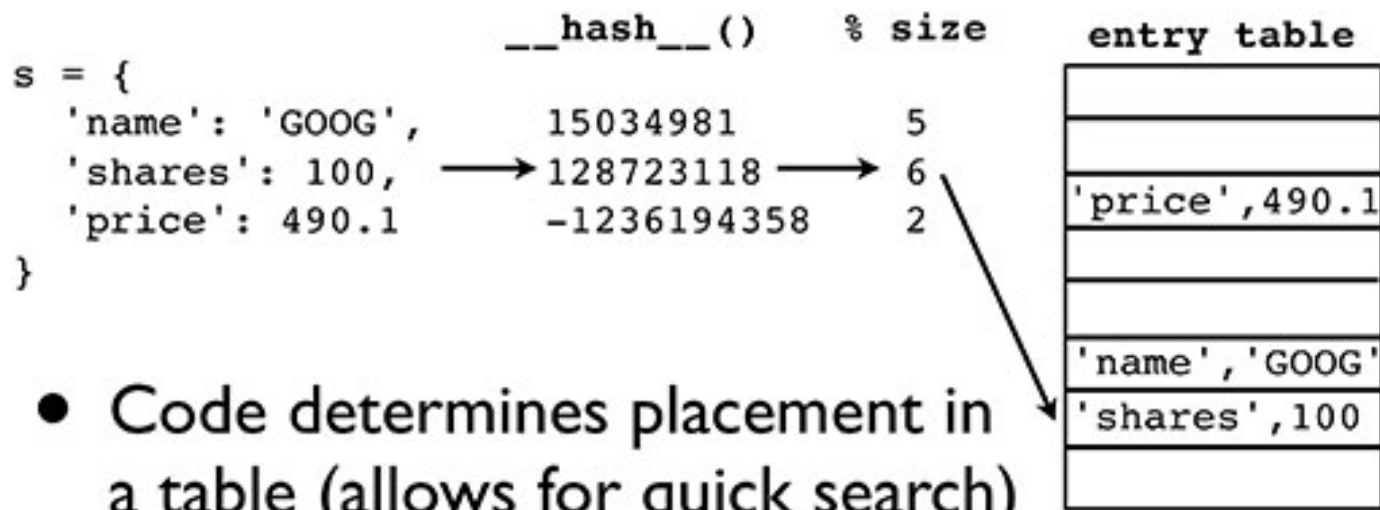
- Sets/dict keys restricted to “hashable” objects

```
>>> a = {'IBM', 'AA', 'AAPL'}  
>>> b = {[1,2],[3,4]}  
Traceback (most recent call last):  
  File "<stdin>", line 1, in <module>  
TypeError: unhashable type: 'list'  
>>>
```

- This usually means you can only use strings, numbers, or tuples (no lists, dicts, sets, etc.)

Item Placement

- Hashing in a nutshell....



- Code determines placement in a table (allows for quick search)
- But there's an issue with collisions...

Collision Resolution

- Hash index is perturbed until an open slot found

```
key='name'  
h = key.__hash__() -> 15034981  
i = h % size -> 5
```

- Recurrence

```
i, h = perturb(i, h, size)  
  
i = 7, 6, 1, 4, 5, 2, 3, 0, ...
```

entry table

	0
	1
	2
	3
	4
OCCUPIED	5
	6
	7

- Every slot is tried eventually
- Works better if many open slots available

Set/Dict Representation

- You always start with space for 8 items

```
>>> a = { }
>>> sys.getsizeof(a)
240
>>> a = { 'a':1, 'b':2, 'c':3, 'd':4 }
>>> sys.getsizeof(a)
240
>>>
```

```
>>> b = set()
>>> sys.getsizeof(b)
224
>>> b = { 1, 2, 3, 4}
>>> sys.getsizeof(b)
224
>>>
```

- But there's a catch... you can't use all of it

Set/Dict Overallocation

- Sets/dicts never fill up completely
- Increase their size if more than 2/3 full

```
>>> a = { 'a':1, 'b':2, 'c':3, 'd':4 }
>>> sys.getsizeof(a)
240
>>> a['e'] = 5
>>> sys.getsizeof(a)
240
>>> a['f'] = 6
>>> sys.getsizeof(a)
368
>>>
```

- A possible surprise if building data structures

Demo

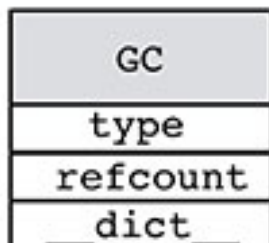
In which Dave demonstrates the unusual fate that befalls a program that places more than 5 entries in a dictionary...

Instance Representation

- Instances normally use dictionaries

```
class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y
```

```
>>> p = Point(2,3)
>>> p.__class__
<class '__main__.Point'>
>>> p.__dict__
{ 'x': 2, 'y': 3 }
>>>
```



(56 bytes)

- There are some optimizations

Key Sharing Dicts

- Instances use a compact key-sharing dict

```
0 - 5 items (112 bytes)
6 - 10 items (152 bytes)
```

- Insight: All instances created will have exactly the same set of keys
- The keys can be shared across dicts
- So, a bit more efficient than a normal dict

Instances w/slots

- Slots eliminate the instance dictionary

```
class Point:
    __slots__ = ('x', 'y')
    def __init__(self, x, y):
        self.x = x
        self.y = y
```

type	
refcount	
-	
x	slot 0
y	slot 1

```
>>> p = Point(2,3)
>>> p.__class__
<class '__main__.Point'>
>>> p.__dict__
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'Point' object has no attribute '__dict__'
>>>
```

Demo

- Tuples vs. slots
- Dicts vs. classes

Part 4: Thinking in Functions

Algebra Refresher

- Functions (from math)

$$f(x) = 3x + 2$$

- Essential Features
 - To evaluate, substitute the "x"
 - For each input, there is one output
 - Output is always the same for the same input
- Often a powerful way to think about coding

Functions

- Functions are building blocks

- Example: Compute $\sum_{n=1}^{100} \frac{1}{n^2}$

```
def square(x):  
    return x * x  
  
def recip(x):  
    return 1/x  
  
def sum_invsquare(start, stop):  
    total = 0  
    for n in range(start, stop+1):  
        total += recip(square(n))  
    return total  
  
result = sum_invsquare(1, 100)
```

Higher-Order Functions

- Functions can accept other functions as input

```
def sum_terms(start, stop, term):  
    total = 0  
    for n in range(start, stop+1):  
        total += term(n)  
    return total  
  
def invsquare(x):  
    return 1.0/(x * x)  
  
total = sum_terms(1, 100, invsquare)
```

- Functions are data just like numbers, strings, etc.

Higher-Order Functions

- Functions can create new functions

```
def compose(f, g):  
    def h(x):  
        return f(g(x))  
    return h
```

```
def recip(x):  
    return 1/x
```

```
def square(x):  
    return x * x
```

```
total = sum_terms(1, 100, compose(recip, square))
```

- Higher-order functions allow generalization and abstraction centered around functions

List Processing

- Applying a function to elements of a list

```
def square(x):  
    return x * x  
  
data = [1, 2, 3, 4, 5, 6, 7]  
  
squared_data = []  
for x in data:  
    squared_data.append(square(x))
```

- This is an extremely common task
- Transforming/filtering list data

List Comprehensions

- Creates a list by mapping an operation to each element of an iterable

```
>>> a = [1, 2, 3, 4, 5]
>>> b = [2*x for x in a]
>>> b
[2, 4, 6, 8, 10]
>>>
```

- Another example:

```
>>> names = ['IBM', 'YHOO', 'CAT']
>>> a = [name.lower() for name in names]
>>> a
['ibm', 'yhoo', 'cat']
>>>
```

List Comprehensions

- A list comprehension can also filter

```
>>> a = [1, -5, 4, 2, -2, 10]
>>> b = [2*x for x in a if x > 0]
>>> b
[2, 8, 4, 20]
>>>
```

- Another example: lines containing a substring

```
>>> f = open('stockreport.csv', 'r')
>>> goog = [line for line in f if 'GOOG' in line]
>>>
```

List Comprehensions

- General syntax

```
[expression for name in sequence if condition]
```

- What it means

```
result = []  
for name in sequence:  
    if condition:  
        result.append(expression)
```

- Can be used anywhere a sequence is expected

```
>>> a = [1, 2, 3, 4]  
>>> sum([x*x for x in a])  
30  
>>>
```

List Comp: Examples

- List comprehensions are hugely useful
- Collecting the values of a specific field

```
stocknames = [s['name'] for s in portfolio]
```

- Performing database-like queries

```
a = [s for s in portfolio if s['price'] > 100  
                                and s['shares'] > 50 ]
```

- Quick mathematics over sequences

```
cost = sum([s['shares']*s['price'] for s in portfolio])
```

Historical Digression

- List comprehensions come from math

```
a = [x**2 for x in s if x > 0]    # Python
```

- Mathematical notation (set theory)

$$a = \{ x^2 \mid x \in s, x > 0 \}$$

- But most Python programmers would probably just view this as a "cool shortcut"

Set/Dict Comprehensions

- List comprehension

```
>>> [ s['name'] for s in portfolio ]  
[ 'AA', 'IBM', 'CAT', 'MSFT', 'GE', 'MSFT', 'IBM ' ]  
>>>
```

- Set comprehension (eliminate duplicates)

```
>>> { s['name'] for s in portfolio }  
{ 'GE', 'IBM', 'CAT', 'AA', 'MSFT' }  
>>>
```

- Dict comprehension (makes a key:value mapping)

```
>>> { s['name']: 0 for s in portfolio }  
{ 'GE': 0, 'IBM': 0, 'CAT': 0, 'AA': 0, 'MSFT': 0 }  
>>>
```


Reductions

- `sum(s)`, `min(s)`, `max(s)`

```
>>> s = [1, 2, 3, 4]
>>> sum(s)
10
>>> min(s)
1
>>> max(s)
4
>>>
```

- Boolean tests: `any(s)`, `all(s)`

```
>>> s = [False, True, True, False]
>>> any(s)
True
>>> all(s)
False
>>>
```

Map-Reduce

- Many problems fit into a "map-reduce" model

```
data = [ ... ]  
      ↓  
mapping = [ op(x) for x in data if predicate(x) ]  
          ↓  
result = reduce(mapping)
```

- Conceptually simple
- Benefits for distributing work/performance

Challenge

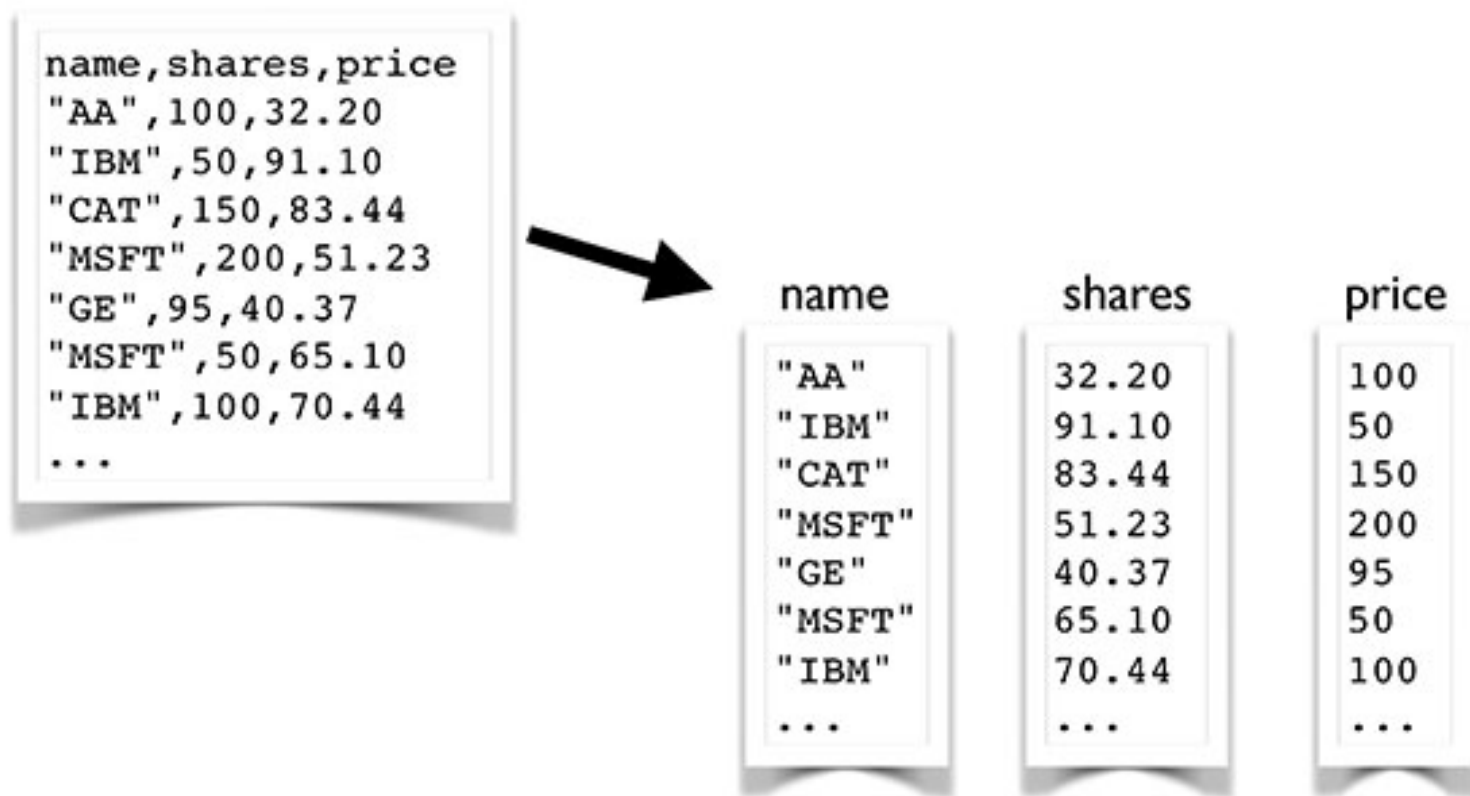
1. Rewrite the bus data code using list comprehensions and a functional programming style.
2. Find out on what day the route 22 bus had the highest ridership.

Part 5: Thinking in Columns

Story so Far

- Main focus has been "object oriented"
- Each row is an "object" or "record"
- Different representations (tuple, dict, etc.)
- But, that's not the only viewpoint

Columns not Rows



Think spreadsheets...

An Experiment

- List of tuples

```
rows = [  
    ('AA', 100, 32.2),  
    ('IBM', 50, 91.1),  
    ('CAT', 150, 83.44),  
    ('MSFT', 200, 51.23),  
    ...  
]
```

- A tuple of lists

```
columns = (  
    ['AA', 'IBM', 'CAT', 'MSFT', ...],  
    [100, 50, 150, 200, ...],  
    [32.2, 91.1, 83.44, 51.23, ...]  
)
```

- What are storage requirements?

An Experiment

- List of tuples

```
rows = [  
    ('AA', 100, 32.2),  
    ('IBM', 50, 91.1),  
    ('CAT', 150, 83.44),  
    ('MSFT', 200, 51.23),  
    ...  
]
```

Per-record overhead:
72 bytes (tuples)

- A tuple of lists

```
columns = (  
    ['AA', 'IBM', 'CAT', 'MSFT', ...],  
    [100, 50, 150, 200, ...],  
    [32.2, 91.1, 83.44, 51.23, ...]  
)
```

Per-record overhead:
24 bytes (list items)

- What are storage requirements?

Challenge

Read the bus data into separate lists representing columns. Does it make a difference? Can you still work with the data?

Arrays

- numpy library provides support for arrays
- A collection of uniformly typed objects

```
>>> import numpy
>>> a = numpy.array([1,2,3,4], dtype=numpy.int64)
>>> a
array([1, 2, 3, 4])
>>>
```

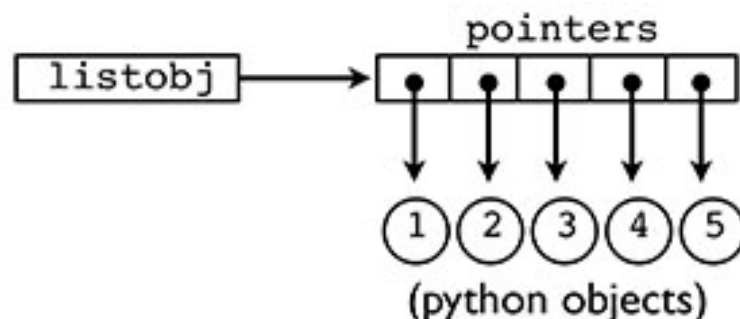
- Differs from a list (heterogenous items)

```
>>> b = [1,2,3,4]
>>> b[2] = 'hello'
>>> b
[1, 2, 'hello', 4]
>>> a[2] = 'hello'           # ValueError exception
```

Arrays vs. Lists

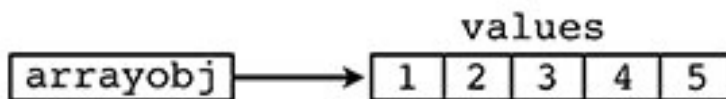
- List

```
a = [1, 2, 3, 4, 5]
```



- Array

```
a = numpy.array([1,2,3,4,5])
```



- Storage is same as arrays in C/C++/Fortran

Digression

- numpy is a large library (100s of functions)
- This is not meant to be a numpy tutorial
- But, let's discuss the "big picture"

Vectorized Operations

- arrays prefer operations on the entire array

```
>>> a
array([1, 2, 3, 4])
>>> a + 10
array([11, 12, 13, 14])
>>> numpy.sqrt(a)
array([ 1.,  1.41421356,  1.73205081,  2.])
>>>
```

- Operations are implemented in C (very fast)

Vectorized Conditionals

- Relations produce boolean arrays

```
>>> a
array([1, 2, 3, 4])
>>> a < 3
array([ True,  True, False, False], dtype=bool)
```

- Boolean arrays can filter

```
>>> a[a<3]
array([1, 2])
>>>
```

- Variant: `where(cond, x, y)`

```
>>> numpy.where(a < 3, -1, 1)
array([-1, -1, 1, 1])
>>>
```

Array Slicing

- Array slices produce overlays

```
>>> a
array([1, 2, 3, 4])
>>> b = a[0:2]
>>> b
array([1, 2])
>>>
```

- Try changing the data

```
>>> b[0] = 10
>>> b
array([10, 2])
>>> a
array([10, 2, 3, 4])
>>>
```

- This is very different than Python lists (copies)

Pandas Dataframes

- Dataframe is a collection of named arrays

```
>>> data = pandas.read_csv('portfolio.csv')
>>> data
```

	name	shares	price
0	AA	100	32.20
1	IBM	50	91.10
2	CAT	150	83.44
3	MSFT	200	51.23

- Think columns

```
>>> data['shares']
```

0	100
1	50
2	150
3	200

```
Name: shares, dtype: int64
>>>
```


Pandas Examples

- Creating a new column

```
>>> data['cost'] = data['shares']*data['price']
>>> data
```

	name	shares	price	cost
0	AA	100	32.20	3220.00
1	IBM	50	91.10	4555.00
2	CAT	150	83.44	12516.00
3	MSFT	200	51.23	10246.00

```
>>>
```

- Filtering

```
>>> data[data['shares'] < 100]
```

	name	shares	price	cost
1	IBM	50	91.10	4555.00

```
>>>
```

Commentary

- Most "standard" Python code is focused on manipulating objects and records
- Most "scientific" Python code is array focused
- There is a conceptual barrier
- Ideally, you want to understand both worlds

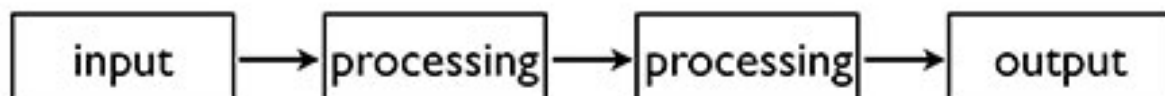
Challenge

Read the bus data using Pandas. Compare with earlier approaches.

Part 6: Thinking in Streams

Stream Processing

- Many problems in data analysis can be broken down into workflows



- Processing stages might transform/filter the data in some way

Iteration

- Iteration defined: Looping over items

```
a = [2,4,10,37,62]
# Iterate over a
for x in a:
    ...
```

- Most programs do a huge amount of iteration
- One way to view iteration is as a "stream" of elements--the for loop consumes it

Iteration

- Many parts of Python produce streams

```
zip(a, b)
map(func, s)
filter(func, s)
enumerate(s)
```

- Example:

```
>>> a = [1,2,3]
>>> b = ['a','b','c']
>>> c = zip(a,b)
>>> c
<zip object at 0x108e5f4c8>
>>> for x, y in c:
...     print(f'{x} -> {y}')
...
1 -> a
2 -> b
3 -> c
```

Generator Functions

- Generators implement customized iteration

```
def countdown(n):  
    print('Counting down from', n)  
    while n > 0:  
        yield n  
        n -= 1
```

```
>>> for i in countdown(5):  
...     print('T-minus', i)  
...  
Counting down from 5  
T-minus 5  
T-minus 4  
T-minus 3  
T-minus 2  
T-minus 1  
>>>
```


Producers & Consumers


- Generators are closely related to various forms of "producer-consumer" programming

producer

```
def follow(f):  
    ...  
    while True:  
        ...  
        yield line  
        ...
```

consumer

```
for line in follow(f):  
    ...
```

An arrow originates from the `yield line` statement in the producer's `while` loop and points to the `line` variable in the consumer's `for` loop, illustrating the flow of data from the producer to the consumer.

- yield produces values
- for consume values

Generator Pipelines



```
def producer():  
    ...  
    yield item  
    ...
```

- Producer is typically a generator (although it could also be a list or some other sequence)
- `yield` feeds data into the pipeline

Generator Pipelines

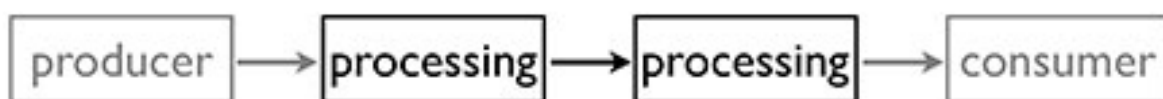


```
def producer():  
    ...  
    yield item  
    ...
```

```
def consumer(s):  
    for item in s:  
        ...
```

- Consumer is just a simple for-loop
- It gets items and does something with them

Generator Pipelines



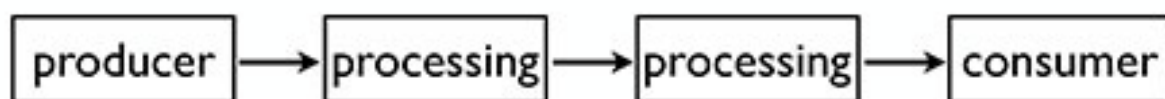
```
def producer():  
    ...  
    yield item  
    ...
```

```
def processing(s):  
    for item in s:  
        ...  
        yield newitem  
    ...
```

```
def consumer(s):  
    for item in s:  
        ...
```

- Intermediate processing stages simultaneously consume and produce items
- They might modify the data stream
- They can also filter (discarding items)

Generator Pipelines



```
def producer():  
    ...  
    yield item  
    ...  
def processing(s):  
    for item in s:  
        ...  
        yield newitem  
        ...  
def consumer(s):  
    for item in s:  
        ...
```

- Pipeline setup (in your program)

```
a = producer()  
b = processing(a)  
c = consumer(b)
```

- You will notice that data incrementally flows through the different functions

Example

- Example: Compute $\sum_{n=1}^{100} \frac{1}{n^2}$

```
def square(nums):  
    for x in nums:  
        yield x*x  
  
def recip(nums):  
    for x in nums:  
        yield 1/x  
  
terms = range(1, 101)  
result = sum(recip(square(terms)))
```

Generator Expressions

- A variant of a list comprehension that produces the results incrementally
- Just slightly different syntax (parentheses)

```
nums = [1,2,3,4]  
squares = (x*x for x in nums)
```

- To get the results, you use a for-loop

```
for n in squares:  
    ...
```

Example

- Example: Compute $\sum_{n=1}^{100} \frac{1}{n^2}$

```
terms = range(1, 101)
squares = (x*x for x in terms)
recip = (1/x for x in squares)
result = sum(recip)
```

- Thinking in streams often leads to very succinct code (step-by-step)
- Can offer a significant memory savings

Challenge

Rewrite bus data handling code to use generators and streams. Compare efficiency to earlier approach.

The End

- Thanks for participating!
- Next step: Looking for commonality with tools and libraries (you will start to see common programming patterns emerge everywhere)
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