8: Basic Data Structures

Learning outcomes

- **Distinguish** basic data structures such as arrays, linked lists and associative maps
- **Determine** the complexity of accessing and manipulating data in these data structures
- **Choose** the correct data structure for a given task

Research Journal Peer Review

Basic containers in Python

Memory allocation

- Memory is allocated in **blocks**
- The program specifies the size, in bytes, of the block it wants
- The OS allocates a **contiguous** block of that size
- The program owns that block until it frees it
- Forgetting to free a block is called a **memory leak** (not really possible in Python, but a common bug in C++)
- Blocks can be allocated and deallocated at will, but can **never grow or shrink**

Containers

- Memory management is hard and programmers are lazy
- Containers are an **abstraction**
  - Hide the details of memory allocation, and allow the programmer to write simpler code
- Containers are an **encapsulation**
  - Bundle together the data's representation in memory along with the algorithms for accessing it

Arrays

- An **array** is a contiguous block of memory in which objects are stored, equally spaced, one after the other
- Each array element has an **index**, starting from zero
- Given the address of the 0th element, it is easy to find the ith element:

$$\text{address}_i = \text{address}_0 + (i \times \text{elementSize})$$

- E.g. if the array starts at address 1000 and each element is 4 bytes, the 3rd element is at address $1000 + 4 \times 3 = 1012$
- Accessing an array element is **constant time** $O(1)$

Lists

- An array is a block of memory, so its size is **fixed** once created
- A **list** is a variable size array
- When the list needs to change size, it **creates** a new array, **copies** the contents of the old array, and **deletes** the old array
- Implementation details: `http://www.laurentluce.com/posts/python-list-implementation/`

Time taken to append an element to a list of size *n*
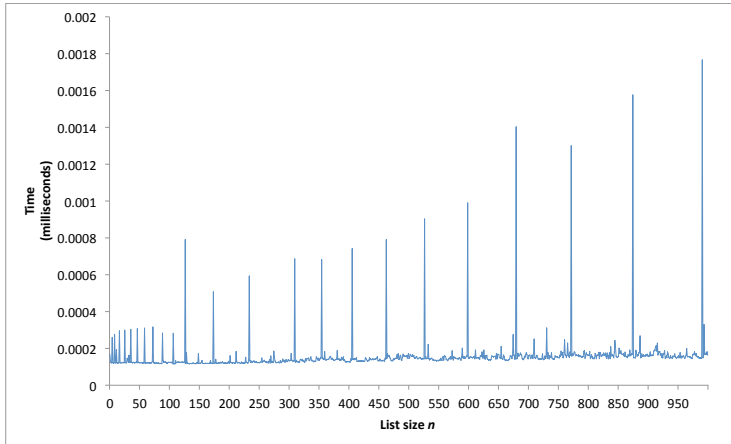
Operations on lists

- **Appending** to a list is **amortised constant time**
  - Usually $O(1)$, but can go up to $O(n)$ if the list needs to change size
- **Inserting** anywhere other than the end is **linear time**
  - Can't just insert new bytes into a memory block — need to move all subsequent list elements to make room
- Similarly, **deleting** anything other than the last element is **linear time**

Tuples

- Tuples are like lists, but are **immutable**
  - Read-only
  - Once created, can't be changed
- Useful for storing sequences of values where adding, inserting, deleting or changing individual values does not make sense
  - E.g. *xy* coordinates, RGB colours, ...
- Create tuples with `()`, just as you create lists with `[]`
  - Exception: a single element tuple is created as `(foo,)` because `(foo)` would be interpreted as a bracketed expression
- Can often omit the parentheses entirely, e.g.

`my_tuple = 1,2,3`

Unpacking

If `foo` is a list or tuple of length 4, the following are equivalent:

```
a, b, c, d = foo
```

```
a = foo[0]
b = foo[1]
c = foo[2]
d = foo[3]
```

- ▸ Unpacking requires the number of elements to match exactly — if `foo` has more than 4 elements, the code on the left will give an error

One weird trick (Java programmers hate it!)

The following are equivalent:

```
a, b = b, a
```

```
temp = a
a = b
b = temp
```

Strings are immutable

- **Strings** are immutable in Python
  - This is not true of all programming languages
- But wait... we change strings all the time, don't we?

```
my_string = "Hello "
my_string += "world"
```

- This isn't changing the string, it's creating a new one and throwing the old one away!
- Hence building a long string by appending can be slow (appending strings is $O(n)$)

Dictionaries

- Dictionaries are **associative maps**
- A dictionary maps **keys** to **values**
  - Keys must be immutable (numbers, strings, tuples etc)
  - Values can be anything (including dictionaries or other containers)
- A dictionary is implemented as a **hash table**

Using dictionaries

Create them using `{}`:

```
age = {"Alice": 23, "Bob": 36, "Charlie": 27}
```

Access values using `[]`:

```
print age["Alice"]   # prints 23
age["Bob"] = 40      # overwriting an existing item
age["Denise"] = 21   # adding a new item
```

Iterating over dictionaries

Iterating over a dictionary gives the **keys**:

```
for x in age:
    print x    # prints Alice, Bob, Charlie
```

Use `iteritems` to get **key,value** pairs:

```
for key, value in age.iteritems():
    print key, "is", age, "years old"
```

Dictionaries are unordered

What does this print?

```
square_root = {}
for i in xrange(30):
    square_root[i*i] = i

for key, value in square_root.iteritems():
    print "The square root of", key, "is", value
```

Dictionaries are **unordered** — never rely on the order of their elements, because the order isn't guaranteed!

Sets

- Sets are like dictionaries without the values
- Sets are **unordered** collections of **unique** elements
- Certain operations on sets scale better on average than the equivalent operations on lists:

Operation	List	Set
Add element	Append: $O(1)$ Insert: $O(n)$	$O(1)$
Delete element	$O(n)$	$O(1)$
Contains element?	$O(n)$	$O(1)$

Pass by reference

References

- Our picture of a variable: a labelled box containing a value
- For "plain old data" (e.g. numbers), this is accurate
- For **objects** (i.e. instances of classes), variables actually hold **references** (a.k.a. **pointers**)
- It is possible (indeed common) to have **multiple references** to the same underlying object

The wrong picture

```
class Thing:
    def __init__(self,
                 a, b):
        self.a = a
        self.b = b

x = Thing(30, 40)
y = Thing(50, 60)
z = y
```

Variable	Value	
x	a	30
	b	40
y	a	50
	b	60
z	a	50
	b	60

The right picture
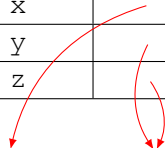
```
class Thing:
    def __init__(self,
                 a, b):
        self.a = a
        self.b = b

x = Thing(30, 40)
y = Thing(50, 60)
z = y
```

Variable	Value
x	
y	
z	

a	30
b	40

a	50
b	60

Values and references

Socrative room code: `FALCOMPED`

```
a = 10
b = a
a = 20
print "a:", a
print "b:", b
```

Values and references

```python
class X:
    def __init__(self, value):
        self.value = value

a = X(10)
b = a
a.value = 20
print "a:", a.value
print "b:", b.value
```

Values and references

```python
class X:
    def __init__(self, value):
        self.value = value

a = X(10)
b = X(10)
a.value = 20
print "a:", a.value
print "b:", b.value
```

Pass by value

In **function parameters**, "plain old data" is passed by **value**

```
def double(x):
    x *= 2

a = 7
double(a)
print a
```

`double` does not actually do anything, as `x` is just a local copy of whatever is passed in!

Pass by reference

However, instances are passed by **reference**

```
class Box:
    def __init__(self, v):
        self.value = v

def double(x):
    x.value *= 2

a = Box(7)
double(a)
print a.value
```

`double` now has an effect, as `x` gets a reference to the `Box` instance

Lists are objects too

```
a = ["Hello"]
b = a
b.append("world")
print a   # ["Hello", "world"]
```

... which means you should be careful when passing lists into functions, because the function might actually change the list!