Ch.2: Loops and lists

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Make a table of Celsius and Fahrenheit degrees

```
-20  -4.0
-15   5.0
-10  14.0
 -5  23.0
  0  32.0
  5  41.0
 10  50.0
 15  59.0
 20  68.0
 25  77.0
 30  86.0
 35  95.0
 40 104.0
```

How can a program write out such a table?

Making a table: the simple naive solution

We know how to make one line in the table:

```
C = -20
F = 9.0/5*C + 32
print C, F
```

We can just repeat these statements:

```
C = -20;  F = 9.0/5*C + 32;  print C, F
C = -15;  F = 9.0/5*C + 32;  print C, F
...
C =  35;  F = 9.0/5*C + 32;  print C, F
C =  40;  F = 9.0/5*C + 32;  print C, F
```

- Very boring to write, easy to introduce a misprint
- When programming becomes boring, there is usually a construct that automates the writing!
- The computer is extremely good at performing repetitive tasks
- For this purpose we use *loops*

The while loop makes it possible to repeat almost similar tasks

A while loop executes repeatedly a set of statements as long as a boolean condition is true

```
while condition:
    <statement 1>
    <statement 2>
    ...
<first statement after loop>
```

- All statements in the loop must be indented!
- The loop ends when an unindented statement is encountered

The while loop for making a table

```
print '------------------' # table heading
C = -20                    # start value for C
dC = 5                     # increment of C in loop
while C <= 40:             # loop heading with condition
    F = (9.0/5)*C + 32     # 1st statement inside loop
    print C, F             # 2nd statement inside loop
    C = C + dC             # last statement inside loop
print '------------------' # end of table line
```

The program flow in a while loop

```
C = -20
dC = 5
while C <= 40:
    F = (9.0/5)*C + 32
    print C, F
    C = C + dC
```

(Visualize execution)

Let us simulate the while loop by hand:

- First `C` is -20, $-20 \leq 40$ is true, therefore we execute the loop statements
- Compute `F`, print, and update `C` to -15
- We jump up to the `while` line, evaluate $C \leq 40$, which is true, hence a new round in the loop
- We continue this way until `C` is updated to 45
- Now the loop condition $45 \leq 40$ is false, and the program jumps to the first line after the loop - the loop is over

Boolean expressions are true or false

An expression with value true or false is called a boolean expression. Examples: $C = 40$, $C \neq 40$, $C \geq 40$, $C > 40$, $C < 40$.

```
C == 40  # note the double ==, C = 40 is an assignment!
C != 40
C >= 40
C >  40
C <  40
```

We can test boolean expressions in a Python shell:

```
>>> C = 41
>>> C != 40
True
>>> C < 40
False
>>> C == 41
True
```

Combining boolean expressions

Several conditions can be combined with and/or:

```
while condition1 and condition2:
    ...

while condition1 or condition2:
    ...
```

Rule 1: `C1 and C2` is `True` if both `C1` and `C2` are `True`
Rule 2: `C1 or C2` is `True` if one of `C1` or `C2` is `True`

```
>>> x = 0;  y = 1.2
>>> x >= 0 and y < 1
False
>>> x >= 0 or y < 1
True
>>> x > 0 or y > 1
True
>>> x > 0 or not y > 1
False
>>> -1 < x <= 0   #  -1 < x and x <= 0
True
>>> not (x > 0 or y > 0)
False
```

Lists are objects for storing a sequence of things (objects)

So far, one variable has referred to one number (or string), but sometimes we naturally have a collection of numbers, say degrees $-20, -15, -10, -5, 0, \ldots, 40$

Simple solution: one variable for each value

```
C1 = -20
C2 = -15
C3 = -10
...
C13 = 40
```

Stupid and boring solution if we have many values!

Better: a set of values can be collected in a list

```
C = [-20, -15, -10, -5, 0, 5, 10, 15, 20, 25, 30, 35, 40]
```

Now there is one variable, `C`, holding all the values

List operations: initialization and indexing

Initialize with square brackets and comma between the Python objects:

```
L1 = [-91, 'a string', 7.2, 0]
```

Elements are accessed via an index: `L1[3]` (index=3).

List indices start at `0`: `0`, `1`, `2`, ... `len(L1)-1`.

```
>>> mylist = [4, 6, -3.5]
>>> print mylist[0]
4
>>> print mylist[1]
6
>>> print mylist[2]
-3.5
>>> len(mylist)  # length of list
3
```

List operations: append, extend, insert, delete

```
>>> C = [-10, -5, 0, 5, 10, 15, 20, 25, 30]
>>> C.append(35)   # add new element 35 at the end
>>> C
[-10, -5, 0, 5, 10, 15, 20, 25, 30, 35]
>>> C = C + [40, 45]     # extend C at the end
>>> C
[-10, -5, 0, 5, 10, 15, 20, 25, 30, 35, 40, 45]
>>> C.insert(0, -15)     # insert -15 as index 0
>>> C
[-15, -10, -5, 0, 5, 10, 15, 20, 25, 30, 35, 40, 45]
>>> del C[2]             # delete 3rd element
>>> C
[-15, -10, 0, 5, 10, 15, 20, 25, 30, 35, 40, 45]
>>> del C[2]             # delete what is now 3rd element
>>> C
[-15, -10, 5, 10, 15, 20, 25, 30, 35, 40, 45]
>>> len(C)               # length of list
11
```

List operations: search for elements, negative indices

```
>>> C.index(10)   # index of the first element with value 10
3
>>> 10 in C       # is 10 an element in C?
True
>>> C[-1]         # the last list element
45
>>> C[-2]         # the next last list element
40
>>> somelist = ['book.tex', 'book.log', 'book.pdf']
>>> texfile, logfile, pdf = somelist  # assign directly to variables
>>> texfile
'book.tex'
>>> logfile
'book.log'
>>> pdf
'book.pdf'
```

Loop over elements in a list with a for loop

Use a *for* loop to loop over a list and process each element:

```
degrees = [0, 10, 20, 40, 100]
for C in degrees:
    print 'Celsius degrees:', C
    F = 9/5.*C + 32
    print 'Fahrenheit:', F
print 'The degrees list has', len(degrees), 'elements'
```

(Visualize execution)

As with *while* loops, the statements in the loop must be indented!

Simulate a for loop by hand

```
degrees = [0, 10, 20, 40, 100]
for C in degrees:
    print C
print 'The degrees list has', len(degrees), 'elements'
```

Simulation by hand:

- First pass: `C` is 0
- Second pass: `C` is 10 ...and so on...
- Third pass: `C` is 20 ...and so on...
- Fifth pass: `C` is 100, now the loop is over and the program flow jumps to the first statement with the same indentation as the `for C in degrees` line

Making a table with a for loop

```
Cdegrees = [-20, -15, -10, -5, 0, 5, 10, 15,
             20, 25, 30, 35, 40]
for C in Cdegrees:
    F = (9.0/5)*C + 32
    print C, F
```

Note: `print C, F` gives ugly output. Use printf syntax to nicely format the two columns:

```
print '%5d %5.1f' % (C, F)
```

Output:

```
-20  -4.0
-15   5.0
-10  14.0
 -5  23.0
```

```
  0  32.0
  ......
 35  95.0
 40 104.0
```

A for loop can always be translated to a while loop

The for loop

```
for element in somelist:
    # process element
```

can always be transformed to a corresponding while loop

```
index = 0
while index < len(somelist):
    element = somelist[index]
    # process element
    index += 1
```

But not all while loops can be expressed as for loops!

While loop version of the for loop for making a table

```
Cdegrees = [-20, -15, -10, -5, 0, 5, 10,
            15, 20, 25, 30, 35, 40]
index = 0
while index < len(Cdegrees):
    C = Cdegrees[index]
    F = (9.0/5)*C + 32
    print '%5d %5.1f' % (C, F)
    index += 1
```

Implement a mathematical sum via a loop

$$S = \sum_{i=1}^{N} i^2$$

```
N = 14

S = 0
for i in range(1, N+1):
    S += i**2
```

Or (less common):

```
S = 0
i = 1
while i <= N:
    S += i**2
    i += 1
```

Mathematical sums appear often so remember the implementation!

Storing the table columns as lists

Let us put all the Fahrenheit values in a list as well:

```
Cdegrees = [-20, -15, -10, -5, 0, 5, 10,
            15, 20, 25, 30, 35, 40]
Fdegrees = []            # start with empty list
for C in Cdegrees:
    F = (9.0/5)*C + 32
    Fdegrees.append(F)   # add new element to Fdegrees
print Fdegrees
```

(Visualize execution)

`print Fdegrees` results in

```
[-4.0, 5.0, 14.0, 23.0, 32.0, 41.0, 50.0, 59.0,
 68.0, 77.0, 86.0, 95.0, 104.0]
```

For loop with list indices

For loops usually loop over list values (elements):

```
for element in somelist:
    # process variable element
```

We can alternatively loop over list indices:

```
for i in range(0, len(somelist), 1):
    element = somelist[i]
    # process element or somelist[i] directly
```

`range(start, stop, inc)` generates a list of integers `start`, `start+inc`, `start+2*inc`, and so on up to, *but not including*, `stop`. `range(stop)` is short for `range(0, stop, 1)`.

```
>>> range(3)          # = range(0, 3, 1)
[0, 1, 2]
>>> range(2, 8, 3)
[2, 5]
```

How can we change the elements in a list?

```
>>> v = [-1, 1, 10]
>>> for e in v:
...     e = e + 2
...
>>> v
[-1, 1, 10]   # unaltered!!
```

```
v = [-1, 1, 10]
for e in v:
    e = e + 2
```

(Visualize execution)

Changing a list element requires assignment to an indexed element

What is the problem?

Inside the loop, `e` is an ordinary (`int`) variable, first time `e` becomes 1, next time `e` becomes 3, and then 12 - but the list `v` is unaltered

Solution: must *index a list element* to change its value:

```
>>> v[1] = 4    # assign 4 to 2nd element (index 1) in v
>>> v
[-1, 4, 10]
>>>
>>> for i in range(len(v)):
...     v[i] = v[i] + 2
...
>>> v
[1, 6, 12]
```

List comprehensions: compact creation of lists

```
n = 16
Cdegrees = [];  Fdegrees = []  # empty lists

for i in range(n):
```

```
    Cdegrees.append(-5 + i*0.5)
    Fdegrees.append((9.0/5)*Cdegrees[i] + 32)
```

Python has a compact construct, called *list comprehension*, for generating lists from a for loop:

```
Cdegrees = [-5 + i*0.5 for i in range(n)]
Fdegrees = [(9.0/5)*C + 32 for C in Cdegrees]
```

General form of a list comprehension:

```
somelist = [expression for element in somelist]
```

where `expression` involves `element`

Interactive demonstration of list comprehensions

```
n = 4
Cdegrees = [-5 + i*2 for i in range(n)]
Fdegrees = [(9.0/5)*C + 32 for C in Cdegrees]
```

(Visualize execution)

Traversing multiple lists simultaneously with zip

Can we one loop running over two lists? Solution 1: loop over indices

```
for i in range(len(Cdegrees)):
    print Cdegrees[i], Fdegrees[i]
```

Solution 2: use the `zip` construct (more "Pythonic"):

```
for C, F in zip(Cdegrees, Fdegrees):
    print C, F
```

Example with three lists:

```
>>> l1 = [3, 6, 1];  l2 = [1.5, 1, 0];  l3 = [9.1, 3, 2]
>>> for e1, e2, e3 in zip(l1, l2, l3):
...     print e1, e2, e3
...
3 1.5 9.1
6 1 3
1 0 2
```

Nested lists: list of lists

- A list can contain *any* object, also another list
- Instead of storing a table as two separate lists (one for each column), we can stick the two lists together in a new list:

```
Cdegrees = range(-20, 41, 5)
Fdegrees = [(9.0/5)*C + 32 for C in Cdegrees]

table1 = [Cdegrees, Fdegrees]  # list of two lists

print table1[0]     # the Cdegrees list
print table1[1]     # the Fdegrees list
print table1[1][2]  # the 3rd element in Fdegrees
```

Table of columns vs table of rows

- The previous `table = [Cdegrees,Fdegrees]` is a table of (two) columns
- Let us make a table of rows instead, each row is a `[C,F]` pair:

```
table2 = []
for C, F in zip(Cdegrees, Fdegrees):
    row = [C, F]
    table2.append(row)

# more compact with list comprehension:
table2 = [[C, F] for C, F in zip(Cdegrees, Fdegrees)]
```

```
print table2
```

```
[[-20, -4.0], [-15, 5.0], ......., [40, 104.0]]
```

Iteration over a nested list:

```
for C, F in table2:
    # work with C and F from a row in table2

# or
for row in table2:
    C, F = row
    ...
```

Illustration of table of columns

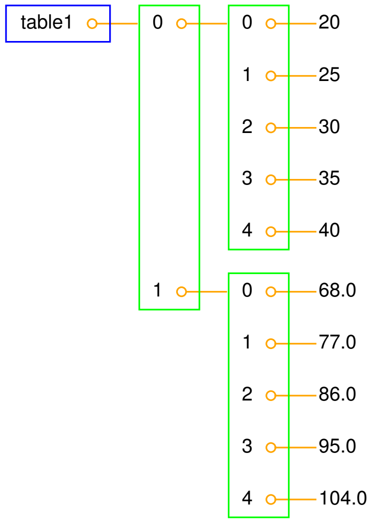
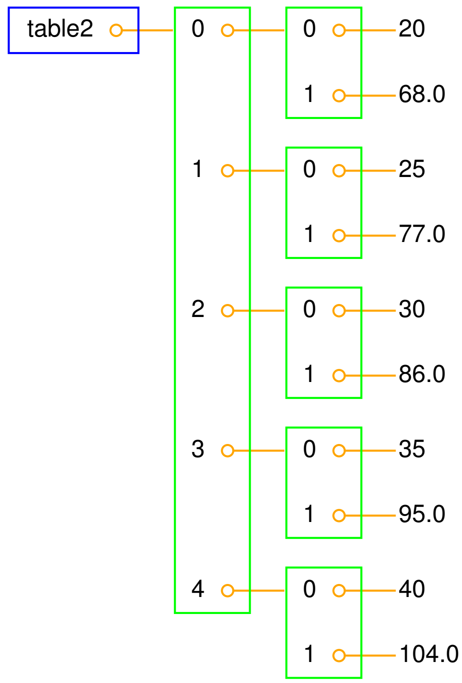


Illustration of table of rows



Extracting sublists (or slices)

We can easily grab parts of a list:

```
>>> A = [2, 3.5, 8, 10]
>>> A[2:]   # from index 2 to end of list
[8, 10]

>>> A[1:3]  # from index 1 up to, but not incl., index 3
[3.5, 8]

>>> A[:3]   # from start up to, but not incl., index 3
[2, 3.5, 8]

>>> A[1:-1] # from index 1 to next last element
[3.5, 8]

>>> A[:]    # the whole list
[2, 3.5, 8, 10]
```

Note: sublists (slices) are *copies* of the original list!

What does this code snippet do?

```
for C, F in table2[Cdegrees.index(10):Cdegrees.index(35)]:
    print '%5.0f %5.1f' % (C, F)
```

- This is a for loop over a sublist of `table2`
- Sublist indices: `Cdegrees.index(10)`, `Cdegrees.index(35)`, i.e., the indices corresponding to elements 10 and 35

Output:

```
10  50.0
15  59.0
20  68.0
25  77.0
30  86.0
```

Iteration over general nested lists

List with many indices: `somelist[i1][i2][i3]...`

```
for i1 in range(len(somelist)):
    for i2 in range(len(somelist[i1])):
        for i3 in range(len(somelist[i1][i2])):
            for i4 in range(len(somelist[i1][i2][i3])):
                value = somelist[i1][i2][i3][i4]
                # work with value
```

```
for sublist1 in somelist:
    for sublist2 in sublist1:
        for sublist3 in sublist2:
            for sublist4 in sublist3:
                value = sublist4
                # work with value
```

Iteration over a specific nested list

```
L = [[9, 7], [-1, 5, 6]]
for row in L:
    for column in row:
        print column
```

(Visualize execution)

Simulate this program by hand!

Question. How can we index element with value 5?

Tuples are constant lists

Tuples are constant lists that cannot be changed:

```
>>> t = (2, 4, 6, 'temp.pdf')    # define a tuple
>>> t =  2, 4, 6, 'temp.pdf'     # can skip parenthesis
>>> t[1] = -1
...
TypeError: object does not support item assignment

>>> t.append(0)
...
AttributeError: 'tuple' object has no attribute 'append'

>>> del t[1]
...
TypeError: object doesn't support item deletion
```

Tuples can do much of what lists can do:

```
>>> t = t + (-1.0, -2.0)           # add two tuples
>>> t
(2, 4, 6, 'temp.pdf', -1.0, -2.0)
>>> t[1]                           # indexing
4
>>> t[2:]                          # subtuple/slice
(6, 'temp.pdf', -1.0, -2.0)
>>> 6 in t                         # membership
True
```

Why tuples when lists have more functionality?

- Tuples are constant and thus protected against accidental changes
- Tuples are faster than lists

- Tuples are widely used in Python software
  (so you need to know about them!)

- Tuples (but not lists) can be used as keys is dictionaries
  (more about dictionaries later)

Key topics from this chapter

- While loops
- Boolean expressions
- For loops
- Lists
- Nested lists
- Tuples

Summary of loops, lists and tuples

While loops and for loops:

```
while condition:
    <block of statements>

for element in somelist:
    <block of statements>
```

Lists and tuples:

```
mylist  = ['a string', 2.5, 6, 'another string']
mytuple = ('a string', 2.5, 6, 'another string')
mylist[1]  = -10
mylist.append('a third string')
mytuple[1] = -10  # illegal: cannot change a tuple
```

List functionality

Construction	Meaning
`a = []`	initialize an empty list
`a = [1, 4.4, 'run.py']`	initialize a list
`a.append(elem)`	add `elem` object to the end
`a + [1,3]`	add two lists
`a.insert(i, e)`	insert element `e` before index `i`
`a[3]`	index a list element
`a[-1]`	get last list element
`a[1:3]`	slice: copy data to sublist (here: index 1, 2)
`del a[3]`	delete an element (index `3`)
`a.remove(e)`	remove an element with value `e`
`a.index('run.py')`	find index corresponding to an element's value
`'run.py' in a`	test if a value is contained in the list
`a.count(v)`	count how many elements that have the value `v`
`len(a)`	number of elements in list `a`
`min(a)`	the smallest element in `a`
`max(a)`	the largest element in `a`
`sum(a)`	add all elements in `a`
`sorted(a)`	return sorted version of list `a`
`reversed(a)`	return reversed sorted version of list `a`
`b[3][0][2]`	nested list indexing
`isinstance(a, list)`	is `True` if `a` is a list
`type(a) is list`	is `True` if `a` is a list

A summarizing example; problem

`src/misc/Oxford_sun_hours.txt`: data of the no of sun hours in Oxford, UK, for every month since Jan, 1929:

```
[
[43.8, 60.5, 190.2, ...],
[49.9, 54.3, 109.7, ...],
[63.7, 72.0, 142.3, ...],
...
]
```

Tasks:

- Compute the average number of sun hours for each month during the total data period (1929–2009),
- Which month has the best weather according to the means found in the preceding task?
- For each decade, 1930-1939, 1949-1949, ..., 2000-2009, compute the average number of sun hours per day in January and December

A summarizing example; program (task 1)

```
data = [
[43.8, 60.5, 190.2, ...],
[49.9, 54.3, 109.7, ...],
[63.7, 72.0, 142.3, ...],
...
]
monthly_mean = [0]*12
for month in range(1, 13):
    m = month - 1   # corresponding list index (starts at 0)
    s = 0           # sum
    n = 2009 - 1929 + 1  # no of years
    for year in range(1929, 2010):
        y = year - 1929  # corresponding list index (starts at 0)
        s += data[y][m]
    monthly_mean[m] = s/n
month_names = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun',
               'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']
# nice printout:
for name, value in zip(month_names, monthly_mean):
    print '%s: %.1f' % (name, value)
```

A summarizing example; program (task 2)

```
max_value = max(monthly_mean)
month = month_names[monthly_mean.index(max_value)]
print '%s has best weather with %.1f sun hours on average' % \
      (month, max_value)

max_value = -1E+20
for i in range(len(monthly_mean)):
    value = monthly_mean[i]
    if value > max_value:
        max_value = value
        max_i = i  # store index too
print '%s has best weather with %.1f sun hours on average' % \
      (month_names[max_i], max_value)
```

A summarizing example; program (task 3)

```
decade_mean = []
for decade_start in range(1930, 2010, 10):
    Jan_index = 0; Dec_index = 11  # indices
```

```
    s = 0
    for year in range(decade_start, decade_start+10):
        y = year - 1929  # list index
        print data[y-1][Dec_index] + data[y][Jan_index]
        s += data[y-1][Dec_index] + data[y][Jan_index]
    decade_mean.append(s/(20.*30))
for i in range(len(decade_mean)):
    print 'Decade %d-%d: %.1f' % \
          (1930+i*10, 1939+i*10, decade_mean[i])
```

Complete code: `src/looplist/sun_data.py`

Using a debugger to trace the execution

A *debugger* is a program that can be used to inspect and understand programs. Example:

```
In [1]: run -d some_program.py
ipdb> continue  # or just c (go to first statement)
1---> 1 g = 9.81;  v0 = 5
      2 dt = 0.05
      3
ipdb> step  # or just s (execute next statement)
ipdb> print g
Out[1]: 9.8100000000000005
ipdb> list  # or just l (list parts of the program)
1     1 g = 9.81;  v0 = 5
----> 2 dt = 0.05
      3
      4 def y(t):
      5     return v0*t - 0.5*g*t**2
      6
ipdb> break 15   # stop program at line 15
ipdb> c          # continue to next break point
```

How to find Python info

- The book contains only fragments of the Python language
  (intended for real beginners!)
- These slides are even briefer, so you will need to look up more Python information
- Primary reference: The official Python documentation at `docs.python.org`

- Very useful: The Python Library Reference, especially the index
- Example: what can I find in the `math` module?
  - Go to the Python Library Reference, click index
  - Go to M
  - find *math (module)*, click on the link
- Alternative: run `pydoc math` in the terminal window (briefer description)

Warning about reading programming documentation

Warning. For a newbie it is difficult to read manuals (intended for experts!) - you will need a lot of training; just browse, don't read everything, try to dig out the key info.

It's much like googling in general: only a fraction of the information is relevant for you.