Ch.2: Lists and loops

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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
```

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: 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
```

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
```

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: 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 varisble
>>> 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'
```

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

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'
```

(Visualize execution)
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

Table of Celsius and Fahrenheit degrees:

```
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
```

Translation of a for loop to a while loop

The for loop

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

can always be transformed to a while loop

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

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

Mathematical sums appear often so remember the implementation (usually via `for` loop)

Storing the table columns as lists

Let us put all the Fahrenheit values also in a list:

```
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 F` now prints the list

```
[-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]
```

Changing a list element requires assignment to an indexed element

Say we want to add 2 to all numbers in a list:

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

Explanation: 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

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

Example: compute two lists in a for loop

```
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`

Traversing multiple lists simultaneously with zip

What if we want to a for loop over elements in `Cdegrees` *and* `Fdegrees`?

Solution 1: loop over indices

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

Solution 2: `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

table1[0]     # the Cdegrees list
table1[1]     # the Fdegrees list
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

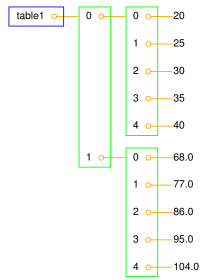
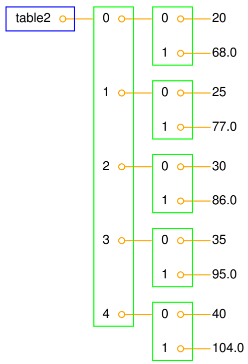


Illustration of table of rows



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]...`

Loops over list indices:

```
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
```

Loops over sublists:

```
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 lists that cannot be changed

Tuples are "constant lists":

```
>>> 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 ¡linebreak¿ (so you need to know about tuples!)
- Tuples (but not lists) can be used as keys is dictionaries ¡linebreak¿ (more about dictionaries later)

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: ind*
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 elem*
'run.py' in a	*test if a value is contained in the lis*
a.count(v)	*count how many elements that have*
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*

A summarizing example for Chapter 2; 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)', r'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 for Chapter 2; the 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 for Chapter 2; the 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 for Chapter 2; the 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])
```

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 more Python information

- The book contains only fragments of the Python language ¡linebreak¿ (intended for real beginners!)
- These slides are even briefer
- Therefore 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 and you get to a description of the module
- Alternative: run `pydoc math` in the terminal window (briefer)

Warning.