INF1100 Lectures, Chapter 2: Lists and Loops

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Making a table; problem

- Suppose we want to 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; simple 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 very good at performing repetitive tasks!
- For this purpose we use *loops*

The while loop

- 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
  ```
- 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

- 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`
- Examples:

```
>>> 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

- So far, one variable has referred to one number (or string)
- 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 (part 1)

- A list consists of elements, which are Python objects
- We initialize the list by separating elements with comma and enclosing the collection in square brackets:

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

- Elements are accessed via an index, e.g. `L1[3]` (index=3)
- List indices are always numbered as 0, 1, 2, and so forth up to the number of elements minus one

```
>>> 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 (part 2)

- Some interactive examples on list operations:

```
>>> 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 (part 3)

- More examples in an interactive Python shell:

```
>>> 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
>>> texfile
'book.tex'
>>> logfile
'book.log'
>>> pdf
'book.pdf'
```

For loops

- We can visit each element in a list and process the element with some statements in a *for* loop
- Example:

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

- The statement(s) in the loop must be indented!
- We can simulate the loop by hand
- First pass: `C` is 0
- Second pass: `C` is 10 ...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

- The table of Celsius and Fahreheit 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
```

- The `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
```

- Example: while version of the for loop on the previous slide

```
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
```

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` 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 the same as `range(0, stop, 1)`

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

How to change elements in a list

- 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
- We have to index a list element to change its value:

```
>>> v[1] = 4    # assign 4 to 2nd element (index 1) in v
>>> v
[-1, 4, 10]
```

- To add 2 to all values we need a for loop over indices:

```
>>> for i in range(len(v)):
...     v[i] = v[i] + 2
...
>>> v
[1, 6, 12]
```

List comprehensions

- 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]
```

- We will use list comprehensions a lot, to save space, so there will be many more examples

Traversing multiple lists simultaneously

- What if we want to have a for loop over elements in `Cdegrees` *and* `Fdegrees`?
- We can have a loop over list indices:

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

- Alternative construct (regarded as 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
```

- What if the lists have unequal lengths? The loop stops when the end of the shortest list is reached

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]` is the `Cdegrees` list
- `table1[1]` is the `Fdegrees` list
- `table1[1][2]` is the 3rd element in `Fdegrees`

Table of coloumns 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` gives

```
[[-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
```

Illustration of table of columns

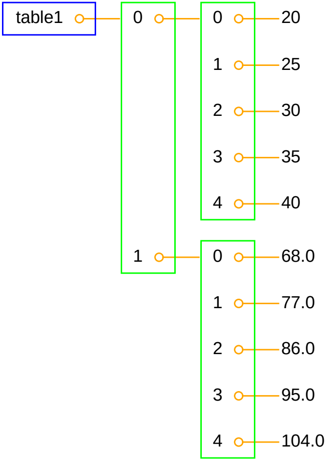
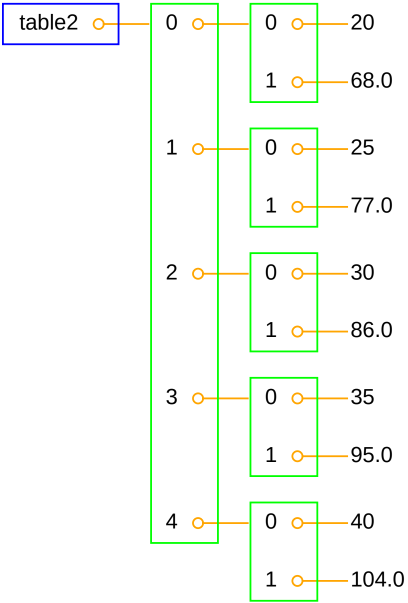


Illustration of table of rows



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]
```

- 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, i.e., we want to run over rows in `table2` starting with the one where `C` is 10 and ending in the row before the row where `C` is 35
- Output:

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

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, i.e., we want to run over rows in `table2` starting with the one where `C` is 10 and ending in the row before the row where `C` is 35
- Output:

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

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, i.e., we want to run over rows in `table2` starting with the one where `C` is 10 and ending in the row before the row where `C` is 35
- Output:

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

More general nested lists

- We have seen one example on a nested list: a table with *n* rows, each row with a `[C, F]` list of two elements
- Traversal of this list (`table2`):

```
for C, F in table2:
    # work with C and F (columns in the current row)
```

- What if we have a more general list with *m* rows, *n* columns, and maybe not the same number of columns in each row?

Example: table with variable no of columns (1)

- We want to record the history of scores in a game
- Each player has played the game a certain number of times
- `scores[i][j]` is a nested list holding the score of game no. `j` for player no. `i`
- Some sample code:

```
scores = []
# score of player no. 0:
scores.append([12, 16, 11, 12])
# score of player no. 1:
scores.append([9])
# score of player no. 2:
scores.append([6, 9, 11, 14, 17, 15, 14, 20])
```

- Desired printing of `scores`:

```
12  16  11  12
 9
 6   9  11  14  17  15  14  20
```

- (Think of many players, each with many games)

Example: table with variable no of columns (2)

We use two loops: one over rows and one over columns

Loops over two list indices (integers):

```
for r in range(len(scores)):
    for c in range(len(scores[r])):
        score = scores[r][c]
        print '%4d' % score,
    print
```

Or: outer loop over rows, inner loop over columns:

```
for row in scores:
    for column in row:
        score = column   # better name...
        print '%4d' % score,
    print
```

Iteration of 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
```

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

Summary of loops, lists and tuples

- 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

`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[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(4.4)`	remove an element (with value `4.4`)
`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`
`a.sort()`	sort list `a` (changes `a`)
`as = sorted(a)`	sort list `a` (return new list)
`a.reverse()`	reverse list `a` (changes `a`)
`b[3][0][2]`	nested list indexing
`isinstance(a, list)`	is `True` if `a` is a list

A summarizing example for Chapter 2; problem

- texttsrc/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, ...],
...
]
```

- 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',
# 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' %

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' %
```

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, d
```

Using a debugger to trace the execution

- A *debugger* is a program that can be used to inspect and understand programs
- A session in IPython will illustrate what this is about:

```
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 (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 index, find "math", click on the link and you get to a description of the module
- Alternative: `pydoc math` in the terminal window (briefer)
- Note: 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