COMP10001 Foundations of Computing
Recursion

Semester 2, 2016
Chris Leckie

September 12, 2016

Lecture Agenda

- Last lecture:
  - MST
- This lecture:
  - Recursion
- Next lecture:
  - Guest lecture: Dr Vanessa Teague on security

A Recursive Mindset I

- Imagine there was no iteration
  - No `for` or `while` loops
  - No list comprehensions
  - No builtins like `min`, `sum`, `len`
- Count the number of damaged houses from the recent Katmandu Earthquake. You have data in a list of True and False for a grid of houses.

```
data = [True, False, False, True, ...]

def count(lst):
    '''Return the number of True's in a list.'''
```

A Recursive Mindset II

- The tool we have at our disposal are function `def` and `return`
- How can we break the problem into an instance of the same problem, but on a smaller input?
- ???
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A Recursive Mindset II

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- How can we break the problem into an instance of the same problem, but on a smaller input?
- `count(lst) = int(lst[0]) + count(lst[1:])`
- `count([]) = 0`

Class Exercise

- Write a function to sum all elements in a list without using iteration.
- Hint: think recursively. How can you break down the problem of adding up n elements in a list into one of adding up one element and $n-1$ elements?

The Elements of Recursion

- “Recursive” function definitions are often use to solve problems in a “divide-and-conquer” manner, breaking the problem down into smaller sub-problems and solving them in the same way as the big problem
- They are generally made up of two parts:
  - recursive function call(s) on smaller inputs
  - a (reachable) base case to ensure the calculation halts
- Recursion is closely related to “mathematical induction”

Class Exercise

- Write a function to compute $n!$ without using iteration.
- Hint: think recursively. How can you compute $n!$ based on $(n-1)!$? What is the base case?

But why?

- Defining answers recursively (in terms of instances of the same problem on a smaller input) is common in maths
- Simple to translate to Python

$$F(n) = \begin{cases} F(n-1) + F(n-2) & \text{, if } n > 2 \\ 1 & \text{, otherwise} \end{cases}$$

$$Q(n) = \begin{cases} Q(n - Q(n-1)) + Q(n - Q(n-2)) & , n > 2 \\ 1 & , n \leq 2 \end{cases}$$

But why? II

- Cast your mind back to Lecture 3a, second last slide...
    - Assuming an unlimited number of coins of each of the following denominations:

      $$(1, 2, 5, 10, 20)$$

      calculate the number of distinct coin combinations which make up a given amount N (in cents).
- We answered this with 5 nested for loops

Coins I

```python
'''Count the number of combinations of
   (1,2,5,10,20) that sum to N
'''
answer = 0
for a in range(N+1):
  for b in range(N//2+1):
    for c in range(N//5+1):
      for d in range(N//10+1):
        for e in range(N//20+1):
           if a+2*b+5*c+10*d+20*e == N:
             answer += 1
```

An iterative solution. But what if there were 6 denominations, or 7, or 8, or *k*?

Coins I

- Think recursively. How many ways can we put in the first coin, and then work out all the combinations for the rest.

`answer(N, (1,2,5,10,20) )`

Put in zero 1's, then need `answer(N, (2,5,10,20) )`

Put in one 1, then need `answer(N-1, (2,5,10,20) )`

Put in two 1's, then need `answer(N-2, (2,5,10,20) )`

Put in three 1's, then need `answer(N-3, (2,5,10,20) )`

...

```
answer(N, coins) = sum answer(N-i*coins[0], coins[1:])
                   for i in 0,1,2,...N//coins[0]
```

Coins II

```
answer(N, coins) = sum answer(N-i*coins[0], coins[1:])
                   for i in 0,1,2,...N//coins[0]
```

What's the base case?

```
    answer(N, single_coin) =
```

How many ways can you make up N with only one coin denomination?

Coins III

```python
def answer(N, coins):
    if len(coins) == 1:
        if N % coins[0] == 0:
            return 1
        else:
            return 0

    c = coins[0]
    count = 0
    for i in range(0, N//c+1):
        count += answer(N-i*c, coins[1:])

    return(count)
```

The problem is difficult with iteration.

The Powerset Problem

Given a set, S, compute the powerset $\mathcal{P}(S)$ of that set (a set of all subsets, including $\{\}$).

Think recursively: construct the powerset of $n-1$ items, and add first item to each of them.

```
def power_set(lst): # lists easier than sets
    if lst == []:
        return [[]]
    rest = power_set(lst[1:])
    result = []
    for item in rest:
        result.append(item)
        result.append([lst[0]] + item)
    return result
```

`index` - Linear Search

- Input: sorted `list` of numbers
- Output: the index of a given number `x`, or `None` if it's not in the list
- Thinking recursively:

$$index(x, lst) = \begin{cases} None & \text{if lst is empty} \\ 0 & \text{if lst[0]} == \text{x} \\ 1 + index(x, lst[1:]) & \text{otherwise} \end{cases}$$

`index` - Binary Search

- Input: sorted `list` of numbers
- Output: the index of a given number `x`, or `None` if it's not in the list
- Thinking recursively and cleverly (`n=len(lst)`):

$$index(x, lst) = \begin{cases} None & \text{if lst is empty} \\ n/2 & \text{if lst[n/2] is x} \\ index(x, lst[:n/2]) & \text{if x < lst[n/2]} \\ n/2 + index(x, lst[n/2:]) & \text{otherwise} \end{cases}$$

0	1	2	3	4	5	6	7
1	3	10	12	15	45	86	91

Binary Search: Recursive Solution

```
def bsearch(val,nlist):
    return bs_rec(val,nlist,0,len(nlist)-1)

def bs_rec(val,nlist,start,end):
    if start > end:
        return None
    mid = start+(end-start)//2
    if nlist[mid] == val:
        return mid
    elif nlist[mid] < val:
        return bs_rec(val,nlist,mid+1,end)
    else:
        return bs_rec(val,nlist,start,mid-1)
```

Binary Search: Iterative Solution

... but again, there's an equally elegant iterative solution:

```
def bs_it(val,nlist):
    start = 0
    end = len(nlist) - 1
    while start < end:
        mid = start+(end-start)//2
        if nlist[mid] == val:
            return mid
        elif nlist[mid] < val:
            start = mid + 1
        else:
            end = mid - 1
    return None
```

So When *Should* You Use Recursion?

Recursion comes to its fore when an iterative solution would involve a level of iterative nesting proportionate to the size of the input, e.g.:

- the powerset problem: given a list of items, return the list of unique groupings of those items (each in the form of a list)
- the change problem: given a list of different currency denominations (e.g. `[5,10,20,50,100,200]`), calculate the number of distinct ways of forming a given amount of money from those denominations

Making Head and Tail of Recursion

- Recursion occurs in two basic forms:
  1. **head recursion:** recurse first, then perform some local calculation

```
def counter_head(n):
    if n < 0:
        return
    counter_head(n-1)
    print n
```

  2. **tail recursion:** perform some local calculation, then recurse

```
def counter_tail(n):
    if n < 0:
        return
    print n
    counter_tail(n-1)
```

Recursion: A Final Word

- Recursion is very powerful, and should always be used with caution:
    - function calls are expensive, meaning deep recursion comes at a price
    - always make sure to catch the base case, and avoid infinite recursion!
    - there is often a more efficient iterative solution to the problem, although there may not be a general iterative solution (esp. in cases where the obvious solution involves arbitrary levels of nested iteration)
    - recursion is elegant, but elegance $\neq$ more readable or efficient

Lecture Summary

- What is recursion? What two parts make up a recursive function?
- What is the difference between head and tail recursion?
- What is binary search, and how does it work?
- In what cases is recursion particularly effective?
- Why should recursion be used with caution?