Lecture #6: Recursion

Philosophy of Functions (I)

Syntactic specification (signature)

Precondition

```
def sqrt(x):
    """Assuming X >= 0,
    returns approximation to square root of X."""
```

Postcondition

Semantic specification

- Specifies a *contract* between caller and function implementor.
- **Syntactic specification** gives syntax for calling (number of arguments).
- **Semantic specification** tells what it does:
  - **Preconditions** are requirements on the caller.
  - **Postconditions** are promises from the function's implementor.

Philosophy of Functions (II)

- Ideally, the specification (syntactic and semantic) should suffice to use the function (i.e., without seeing the body).
- There is a *separation of concerns* here:
  - The caller (client) is concerned with providing values of x, a, b, and c and using the result, but *not* how the result is computed.
  - The implementor is concerned with how the result is computed, but not where x, a, b, and c come from or how the value is used.
  - From the client's point of view, `sqrt` is an *abstraction* from the set of possible ways to compute this result.
  - We call this particular kind *functional abstraction.*
- Programming is largely about choosing abstractions that lead to clear, fast, and maintainable programs.

Philosophy of Functions (III)

- Each function should have exactly one, logically coherent and well defined job.
  - Intellectual manageability.
  - Ease of testing.
- Functions should be properly documented, either by having names (and parameter names) that are unambiguously understandable, or by having comments (docstrings in Python) that accurately describe them.
  - Should be able to understand code that calls a function without reading the body of the function.
- Don't Repeat Yourself (*DRY*).
  - Simplifies revisions.
  - Isolates problems.

Philosophy of Functions (IV)

- Corollary of DRY: Make functions general
  - copy-paste leads to maintenance headaches
- Taking two (nearly) repeated sections of program code and turning them into calls to a common function is an example of *refactoring*.
- Keep names of functions and parameters meaningful:

Instead of	**Use**
boolean	turn_is_over
d	dice
helper	take_turn

(Bowling example From Kernighan&Plauger):

y	score
L	ball
f	frame

Simple Linear Recursions (Review)

- We've been dealing with recursive function (those that call themselves, directly or indirectly) for a while now.
- From Lecture #3:

```
def sum_squares(N):
    """The sum of K**2 for K from 1 to N (inclusive)."""
    if N < 1:
        return 0
    else:
        return N**2 + sum_squares(N - 1)
```

- This is a simple *linear recursion*, with one recursive call per function instantiation.
- Can imagine a call as an expansion:

```
sum_squares(3) => 3**2 + sum_squares(2)
               => 3**2 + 2**2 + sum_squares(1)
               => 3**2 + 2**2 + 1**2 + sum_squares(0)
               => 3**2 + 2**2 + 1**2 + 0 => 14
```

- Each call in this expansion corresponds to an environment frame, linked to the global frame, as shown here.

Tail Recursion

- We've also seen a special kind of linear recursion that is strongly linked to iteration:

```
def sum_squares(N):
    """The sum of K**2
    for 1 <= K <= N."""
    accum = 0
    k = 1
    while k <= N:
        accum += k**2
        k += 1
    return accum
```

```
def sum_squares(N):
    """The sum of K**2
    for 1 <= K <= N."""
    def part_sum(k, accum):
        if k <= N:
            return part_sum(k+1, accum + k**2)
        else:
            return accum
    part_sum(1, 0)
```

- The right version is a *tail-recursive function*: the recursive call is either the returned value or very last action performed.
- The environment frames correspond to the iterations of the loop on the left, as shown here.

Recursive Thinking

- So far in this lecture, I've shown recursive functions by tracing or repeated expansion of their bodies.
- But when you call a function from the Python library, you don't look at its implementation, just its documentation ("the contract").
- *Recursive thinking* is the extension of this same discipline to functions *as you are defining them.*
- When implementing `sum_squares`, we reason as follows:
  - **Base case:** We know the answer is 0 if there is nothing to sum ($N < 1$).
  - Otherwise, we observe that the answer is N^2 plus the sum of the positive integers from 1 to $N - 1$.
  - But there is a function (`sum_squares`) that can compute $1 + \ldots + N - 1$ (its comment says so).
  - So when $N \geq 1$, we should return $N^2 + \texttt{sum\_squares}(N - 1)$.
- This "recursive leap of faith" works as long as we can guarantee we'll hit the base case.

Recursive Thinking in Mathematics

- To prevent an infinite recursion, must use this technique only when
  - The recursive cases are "smaller" than the input case, and
  - There is a minimum "size" to the data, and
  - All chains of progressively smaller cases reach a minimum in a finite number of steps.
- We say that such "smaller than" relations are *well founded*.
- We have

  Theorem (Noetherian Induction): Suppose $\prec$ is a well-founded relation and P is some property (predicate) such that whenever $P(y)$ is true for all $y \prec x$, then $P(x)$ is also true. Then $P(x)$ is true for all x.

  (After Emmy Noether 1882–1935, Göttingen and Bryn Mawr).
- More general than the "line of dominos" induction you may have encountered: If true for a base case b, and if true for k when true for $k-1$, then true for all $k > b$.

A Problem

```
def find_first(start, pred):
    """Find the smallest k >= START such that PRED(START)."""
    ?
```