# CS 61A Spring 2022 — Linked Lists, Iterators, Generators

Discussion 7: March 9, 2022 Solutions

##Walkthrough Videos

Feel free to try these problems on the worksheet in discussion or on your own, and then come back to reference these walkthrough videos as you study.

To see these videos, you should be logged into your berkeley.edu email.

# Linked Lists

There are many different implementations of sequences in Python. Today, we'll explore the linked list implementation.

A linked list is either an empty linked list, or a Link object containing a `first` value and the `rest` of the linked list.

To check if a linked list is an empty linked list, compare it against the class attribute `Link.empty`:

```
if link is Link.empty:
    print('This linked list is empty!')
else:
    print('This linked list is not empty!')
```

You can find an implementation of the `Link` class below:

```
class Link:
    """A linked list."""
    empty = ()

    def __init__(self, first, rest=empty):
        assert rest is Link.empty or isinstance(rest, Link)
        self.first = first
        self.rest = rest

    def __repr__(self):
        if self.rest:
            rest_repr = ', ' + repr(self.rest)
        else:
            rest_repr = ''
        return 'Link(' + repr(self.first) + rest_repr + ')'

    def __str__(self):
        string = '<'
        while self.rest is not Link.empty:
            string += str(self.first) + ' '
            self = self.rest
        return string + str(self.first) + '>'
```

### Q1: WWPD: Linked Lists

What would Python display?

> Note: If you get stuck, try drawing out the box-and-pointer diagram for the linked list or running examples in 61A Code.

```
>>> link = Link(1, Link(2, Link(3)))
>>> link.first
```

1

```
>>> link.rest.first
```

2

```
>>> link.rest.rest.rest is Link.empty
```

True

```
>>> link.rest = link.rest.rest
>>> link.rest.first
```

3

```
>>> link = Link(1)
>>> link.rest = link
>>> link.rest.rest.rest.rest.first
```

1

```
>>> link = Link(2, Link(3, Link(4)))
>>> link2 = Link(1, link)
>>> link2.first
```

1

```
>>> link2.rest.first
```

2

### Q2: Remove All

Implement a function `remove_all` that takes a `Link`, and a `value`, and remove any linked list node containing that value. You can assume the list already has at least one node containing `value` and the first element is never removed. Notice that you are not returning anything, so you should mutate the list.

**Note:** Can you create a recursive and iterative solution for `remove_all`?

```
def remove_all(link, value):
    """Remove all the nodes containing value in link. Assume that
    the
    first element is never removed.

    >>> l1 = Link(0, Link(2, Link(2, Link(3, Link(1, Link(2, Link(3)
    ))))))
    >>> print(l1)
    <0 2 2 3 1 2 3>
    >>> remove_all(l1, 2)
    >>> print(l1)
    <0 3 1 3>
    >>> remove_all(l1, 3)
    >>> print(l1)
    <0 1>
    >>> remove_all(l1, 3)
    >>> print(l1)
    <0 1>
    """
    if link is Link.empty or link.rest is Link.empty:
        return
    if link.rest.first == value:
        link.rest = link.rest.rest
        remove_all(link, value)
    else:
        remove_all(link.rest, value)
```

```
def remove_all(link, value):
    # Alternate recursive solution
    if link is not Link.empty and link.rest is not Link.empty:
        remove_all(link.rest, value)
        if link.rest.first == value:
            link.rest = link.rest.rest

    # Iterative solution
    ptr = link
    while ptr is not Link.empty and ptr.rest is not Link.empty:
        if ptr.rest.first == value:
            ptr.rest = ptr.rest.rest
        else:
            ptr = ptr.rest
```

# Iterators

An iterable is an object where we can go through its elements one at a time. Specifically, we define an **iterable** as any object where calling the built-in `iter` function on it returns an *iterator*. An **iterator** is another type of object which can iterate over an iterable by keeping track of which element is next in the iterable.

For example, a sequence of numbers is an iterable, since `iter` gives us an iterator over the given sequence:

```
>>> lst = [1, 2, 3]
>>> lst_iter = iter(lst)
>>> lst_iter
<list_iterator object ...>
```

With an iterator, we can call `next` on it to get the next element in the iterator. If calling `next` on an iterator raises a `StopIteration` exception, this signals to us that the iterator has no more elements to go through. This will be explored in the example below.

Calling `iter` on an iterable multiple times returns a new iterator each time with distinct states (otherwise, you'd never be able to iterate through a iterable more than once). You can also call `iter` on the iterator itself, which will just return the same iterator without changing its state. However, note that you cannot call `next` directly on an iterable.

For example, we can see what happens when we use `iter` and `next` with a list:

```
>>> lst = [1, 2, 3]
>>> next(lst)             # Calling next on an iterable
TypeError: 'list' object is not an iterator
>>> list_iter = iter(lst) # Creates an iterator for the list
>>> next(list_iter)       # Calling next on an iterator
1
>>> next(iter(list_iter)) # Calling iter on an iterator returns
    itself
2
>>> for e in list_iter:   # Exhausts remainder of list_iter
...     print(e)
3
>>> next(list_iter)       # No elements left!
StopIteration
>>> lst                   # Original iterable is unaffected
[1, 2, 3]
```

**Q3: WWPD: Iterators**

What would Python display?

```
>>> s = [[1, 2, 3, 4]]
>>> i = iter(s)
>>> j = iter(next(i))
>>> next(j)
```

1

```
>>> s.append(5)
>>> next(i)
```

5

```
>>> next(j)
```

2

```
>>> list(j)
```

[3, 4]

```
>>> next(i)
```

StopIteration

# Generators

We can define custom iterators by writing a *generator function*, which returns a special type of iterator called a **generator**.

A generator function has at least one `yield` statement and returns a ***generator object*** when we call it, without evaluating the body of the generator function itself.

When we first call `next` on the returned generator, then we will begin evaluating the body of the generator function until an element is yielded or the function otherwise stops (such as if we `return`). The generator remembers where we stopped, and will continue evaluating from that stopping point on the next time we call `next`.

As with other iterators, if there are no more elements to be generated, then calling `next` on the generator will give us a `StopIteration`.

For example, here's a generator function:

```
def countdown(n):
    print("Beginning countdown!")
    while n >= 0:
        yield n
        n -= 1
    print("Blastoff!")
```

To create a new generator object, we can call the generator function. Each returned generator object from a function call will separately keep track of where it is in terms of evaluating the body of the function. Notice that calling `iter` on a generator object doesn't create a new bookmark, but simply returns the existing generator object!

```
>>> c1, c2 = countdown(2), countdown(2)
>>> c1 is iter(c1)  # a generator is an iterator
True
>>> c1 is c2
False
>>> next(c1)
Beginning countdown!
2
>>> next(c2)
Beginning countdown!
2
```

In a generator function, we can also have a `yield from` statement, which will **yield** each element **from** an iterator or iterable.

```
>>> def gen_list(lst):
...     yield from lst
...
>>> g = gen_list([1, 2])
>>> next(g)
1
>>> next(g)
2
>>> next(g)
StopIteration
```

### Q4: Filter-Iter

Implement a generator function called `filter_iter(iterable, f)` that only yields elements of `iterable` for which `f` returns True.

```
def filter_iter(iterable, f):
    """
    >>> is_even = lambda x: x % 2 == 0
    >>> list(filter_iter(range(5), is_even)) # a list of the values
    yielded from the call to filter_iter
    [0, 2, 4]
    >>> all_odd = (2*y-1 for y in range(5))
    >>> list(filter_iter(all_odd, is_even))
    []
    >>> naturals = (n for n in range(1, 100))
    >>> s = filter_iter(naturals, is_even)
    >>> next(s)
    2
    >>> next(s)
    4
    """
    for elem in iterable:
        if f(elem):
            yield elem

# Alternate solution
def filter_iter(iterable, f):
    yield from [elem for elem in iterable if f(elem)]
```

### Q5: Infinite Hailstone

Write a generator function that outputs the hailstone sequence starting at number `n`. After reaching the end of the hailstone sequence, the generator should yield the value 1 infinitely.

Here's a quick reminder of how the hailstone sequence is defined:

1. Pick a positive integer `n` as the start.
2. If `n` is even, divide it by 2.
3. If `n` is odd, multiply it by 3 and add 1.
4. Continue this process until `n` is 1.

Write this generator function recursively. If you're stuck, you can first try writing it iteratively and then seeing how you can turn that implementation into a recursive one.

**Hint:** Since `hailstone` returns a generator, you can `yield from` a call to `hailstone`!

```
def hailstone(n):
    """Yields the elements of the hailstone sequence starting at n.
       At the end of the sequence, yield 1 infinitely.

    >>> hail_gen = hailstone(10)
    >>> [next(hail_gen) for _ in range(10)]
    [10, 5, 16, 8, 4, 2, 1, 1, 1, 1]
    >>> next(hail_gen)
    1
    """
    yield n
    if n == 1:
        yield from hailstone(n)
    elif n % 2 == 0:
        yield from hailstone(n // 2)
    else:
        yield from hailstone(n * 3 + 1)
```

```
# Iterative solution
def hailstone(n):
    while n > 1:
        yield n
        if n % 2 == 0:
            n //= 2
        else:
            n = n * 3 + 1

    while True:
        yield n
```

### Q6: Primes Generator

Write a function `primes_gen` that takes a single argument `n` and yields all prime numbers less than or equal to `n` in decreasing order. Assume `n >= 1`. You may use the `is_prime` function included below, which we implemented in Discussion 3.

Optional Challenge: Now rewrite the generator so that it also prints the primes in *ascending order*.

```
def is_prime(n):
    """Returns True if n is a prime number and False otherwise.
    >>> is_prime(2)
    True
    >>> is_prime(16)
    False
    >>> is_prime(521)
    True
    """
    def helper(i):
        if i > (n ** 0.5): # Could replace with i == n
            return True
        elif n % i == 0:
            return False
        return helper(i + 1)
    return helper(2)

def primes_gen(n):
    """Generates primes in decreasing order.
    >>> pg = primes_gen(7)
    >>> list(pg)
    [7, 5, 3, 2]
    """
    if n == 1:
        return
    if is_prime(n):
        yield n
    yield from primes_gen(n-1)
```