Composition

Announcements

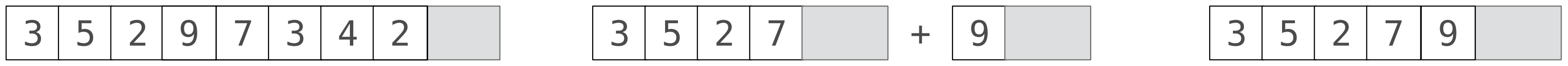
List Efficiency

List Efficiency

Appending, assigning, and list comprehensions are fast:

3 5 2 9 4 2 6
2 4 6 8

Inserting (beginning/middle), slicing, and adding lists are slow:



Example: building long lists of perfect squares (numbers that are an integer times itself)

```
def using_list_comprehension(n):
    return [k * k for k in range(n)]

def using_append(n):
    s = []
    for k in range(n):
        s.append(k * k)
    return s

def using_assign(n):
    s = [0 for k in range(n)]
    for k in range(n):
        s[k] = k * k
    return s
```

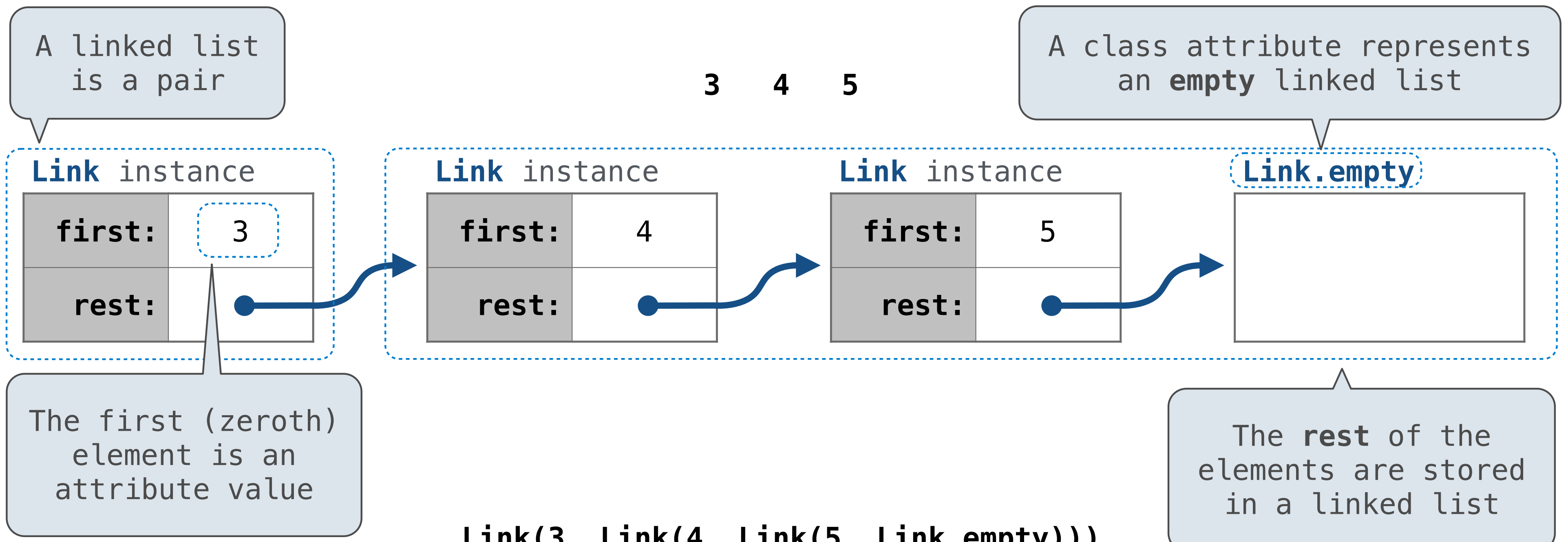
```
def using_insert(n):
    s = []
    for k in range(n):
        s.insert(0, k * k)
    return s

def using_add(n):
    s = []
    for k in range(n):
        s = s + [k*k]
    return s
```

```
When n = 100,000
using_list_comprehension: 1.58 ms
using_append:             1.76 ms
using_assign:             2.58 ms
using_insert:          1,470    ms
using_add:             9,210    ms
```

Linked Lists

Linked List Structure

A linked list is either empty **or** a first value and the rest of the linked list

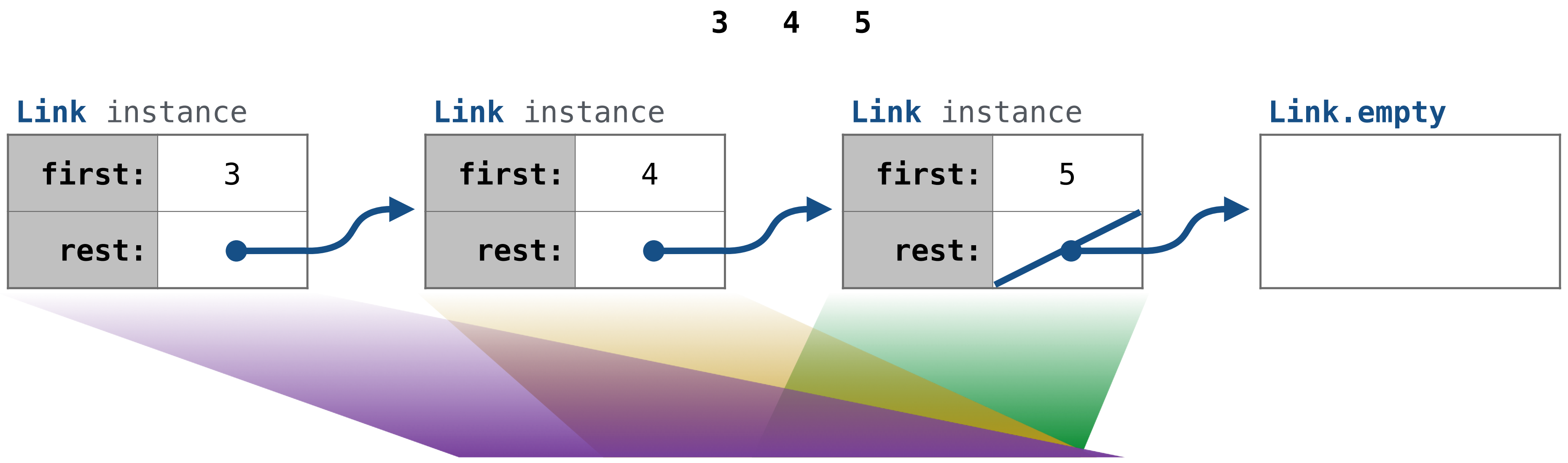


A linked list is a pair
3 4 5
A class attribute represents an **empty** linked list
Link instance
first: 3
rest:
Link instance
first: 4
rest:
Link instance
first: 5
rest:
Link.empty
The first (zeroth) element is an attribute value
The **rest** of the elements are stored in a linked list

Link(3, Link(4, Link(5, Link.empty)))

Linked List Structure

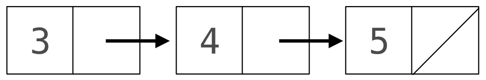
A linked list is either empty **or** a first value and the rest of the linked list



The repr: `Link(3, Link(4, Link(5, Link.empty)))`

The str: `(3 4 5)` *but old midterms will have* `<3 4 5>` *instead*

The fast way to draw it:



Linked List Class

Linked list class: attributes are passed to `__init__`

```
class Link:

    empty = ()

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

A False value that looks right when printed

Returns whether rest is a Link

help(isinstance): Return whether an object is an instance of a class or of a subclass thereof.

Link(3, Link(4, Link(5   )))

(Demo)

Discussion Questions

```
What will be displayed by...

>>> v = Link(1, Link(Link(2, Link(3)), Link(4)))

>>> print(v)

(1 (2 3) 4)

What expression starting with v. evaluates to 3?

v.rest.first.rest.first
```

pollev.com/cs61a

pollev.com/cs61a

Repeated Inserts

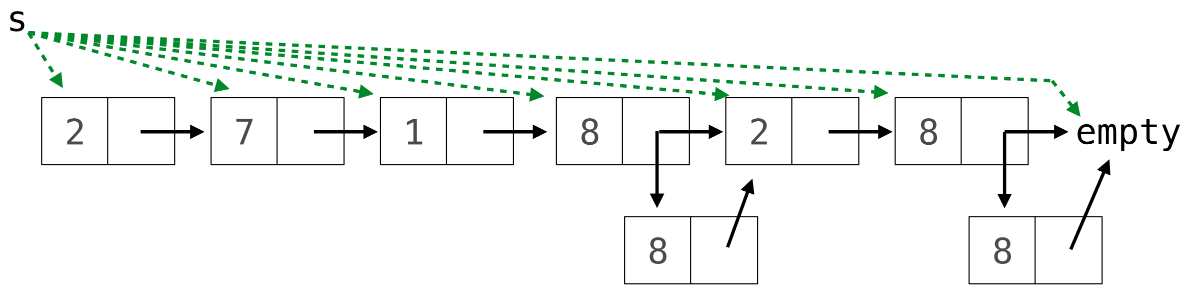
Double a List

```
def double(s, v):
    """Insert another v after each v in list s.

    >>> s = [2, 7, 1, 8, 2, 8]
    >>> double(s, 8)
    >>> s
    [2, 7, 1, 8, 8, 2, 8, 8]
    """
    i = 0

    while i < len(s):

        if s[i] == v:

            s.insert(i+1, v)

            i += 2

        else:

            i += 1
```

Double a Linked List

```
def double_link(s, v):
    """Insert another v after each v in linked list s.

    >>> t = Link(2, Link(7, Link(1, Link(8, Link(2, Link(8))))))
    >>> double_link(t, 8)
    >>> print(t)
    (2 7 1 8 8 2 8 8)
    """

    while s is not Link.empty:

        if s.first == v:

            s.rest = Link(v, s.rest)

            s = s.rest.rest

        else:

            s = s.rest
```

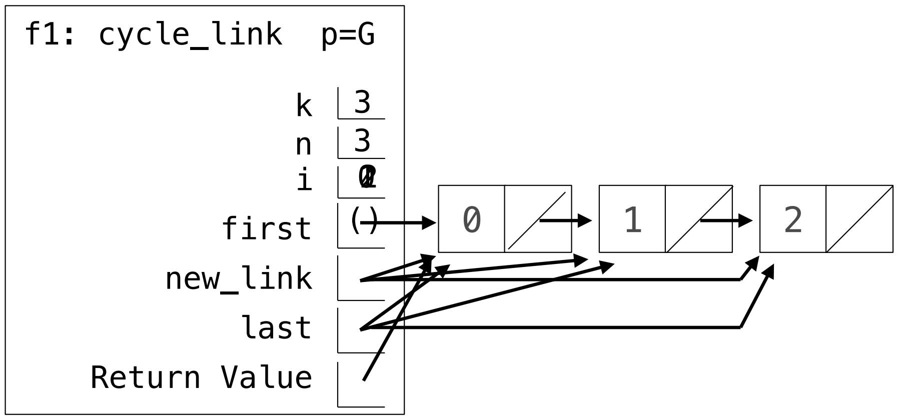
pollev.com/cs61a



Speed Comparison: Double a Cycle

```
def cycle(k, n):
    """Build an n-element list that cycles among range(k).

    >>> cycle(3, 10)
    [0, 1, 2, 0, 1, 2, 0, 1, 2, 0]
    """
    s = []
    for i in range(n):
        s.append(i % k)
    return s

def cycle_link(k, n):
    """Build an n-element linked list that cycles among range(k).

    >>> print(cycle_link(3, 10))
    (0 1 2 0 1 2 0 1 2 0)
    """
    first = Link.empty
    for i in range(n):
        new_link = Link(i % k)
        if first is Link.empty:
            first, last = new_link, new_link
        else:
            last.rest = new_link
            last = new_link
    return first
```

```
double(     cycle(     5, 100000), 3): 299ms
double_link(cycle_link(5, 100000), 3):  14ms
```

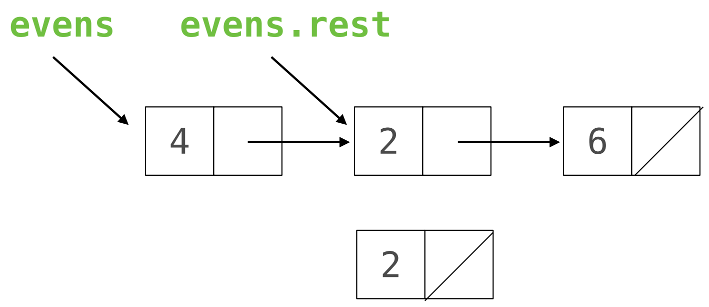


Linked List Practice

Slicing a Linked List

Normal slice notation (such as s[1:3]) doesn't work if s is a linked list.

```
def slice_link(s, i, j):
    """Return a linked list containing elements from i:j.

    >>> evens = Link(4, Link(2, Link(6)))
    >>> slice_link(evens, 1, 100)
    Link(2, Link(6))
    >>> slice_link(evens, 1, 2)
    Link(2)
    >>> slice_link(evens, 0, 2)
    Link(4, Link(2))
    >>> slice_link(evens, 1, 1) is Link.empty
    True
    """
    assert i >= 0 and j >= 0
    if _j == 0_ or s is Link.empty:
        return Link.empty
    elif _i == 0_:
        return Link(s.first, _slice_link(s.rest, i, j-1)_)
    else:
        return slice_link(s.rest, i-1 , j-1 )
```



slice_link(evens, 1, 2) returns

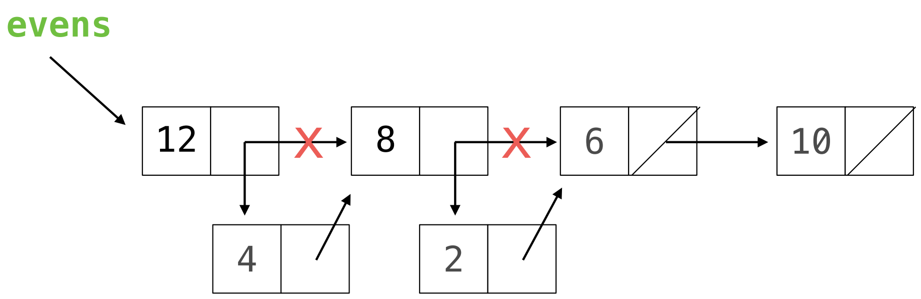
slice_link(evens.rest, 0, 1) links 2 to

slice_link(evens.rest.rest, 0, 0) returns Link.empty

pollev.com/cs61a

Inserting into a Linked List

```
def insert_link(s, x, i):
    """Insert x into linked list s at index i.

    >>> evens = Link(4, Link(2, Link(6)))
    >>> insert_link(evens, 8, 1)
    >>> insert_link(evens, 10, 4)
    >>> insert_link(evens, 12, 0)
    >>> insert_link(evens, 14, 10)
    Index out of range
    >>> print(evens)
    (12 4 8 2 6 10)
    """
    if s is Link.empty:
        print('Index out of range')
    elif i == 0:
        second = Link(s.first, s.rest)
        s.first = x
        s.rest = second
    elif i == 1 and s.rest is Link.empty:
        s.rest = Link(x)
    else:
        insert_link(s.rest, x, i-1)
```

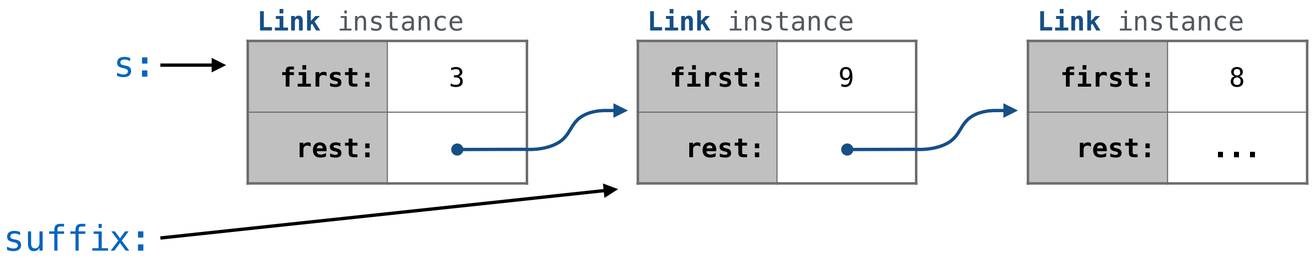


Spring 2023 Midterm 2 Question 3(b)

Definition. A *prefix sum* of a sequence of numbers is the sum of the first n elements for some positive length n.

Implement tens, which takes a non-empty linked list of numbers s represented as a Link instance. It prints all of the prefix sums of s that are multiples of 10 in increasing order of the length of the prefix.

```
def tens(s):
    """Print all prefix sums of Link s that are multiples of ten.
    >>> tens(Link(3, Link(9, Link(8, Link(10, Link(0, Link(14, Link(6))))))))
    20
    30
    30
    50
    """
    def f(suffix, total):
        if total % 10 == 0:
            print(total)
        if suffix is not Link.empty:
            f(suffix.rest, total + suffix.first)
    f(s.rest, s.first)
```


Link instance
Link instance
Link instance
s:
first: 3
rest:
first: 9
rest:
first: 8
rest: ...
suffix: