CS61A Lecture 9
Immutable Data Structures

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Computer Science in the News

Google unveils Glass at Google I/O, June 27

- Prototypes available to developers at the beginning of next year for around $1500 and to general public in 2014.
- Skydivers wore Glasses and jumped off a plane: their views were transmitted live to an audience at the Moscone Center. (Video: http://www.youtube.com/watch?v=D7TB8b2t3QE)
- Glasses are meant to interact with people's senses, without blocking them.
- Display on the Glasses' computer appears as a small rectangle on a rim above the right eye.

http://www.pddnet.com/news-googles-futuristic-glasses-move-closer-to-reality-062812/

Today

- Review: Tuples.
- Review: Data abstraction.
- New sequences and data structures:
  Ranges, Pairs, Immutable recursive lists.

Sequences

A ***sequence*** is an ordered collection of data values.

There are many kinds of sequences, and all share certain properties.

Length: A sequence has a *finite length*.

Element selection: A sequence has an element for any non-negative integer less than its length.

Review: Tuples

A ***tuple*** is a built-in type that represents a sequence.

```
>>> triplet = (1, 2, 3)
>>> len(triplet)
3
>>> triplet[0]
1
>>> from operator import getitem
>>> getitem(triplet, 0)
1
```

Tuples have length.

Elements can be selected.

Review: Tuples

A tuple is an example of a ***data structure***.

A data structure is a type of data that exists primarily to hold other pieces of data in a specific way.

Review: Working with Tuples

Write the higher order function `map`, which takes a function `fn` and a tuple of values `vals`, and returns a tuple of results of applying `fn` to each value in `vals`.

```
>>> map(square, (1, 2, 3, 4, 5))
(1, 4, 9, 16, 25)
>>> map(lambda x: x+1, (1, 2, 3, 4, 5))
(2, 3, 4, 5, 6)
```

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Review: Working with Tuples

Write the higher order function `map`, which takes a function `fn` and a tuple of values `vals`, and returns a tuple of results of applying `fn` to each value in `vals`.

```
def map(fn, vals):
    results = ()
    for val in vals:
        results = results + (fn(val),)
    return results
```

Start with an empty tuple.

Iterate over the elements of the tuple.

Add the new element to the growing tuple.

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Review: Working with Tuples

Write the higher order function `filter`, which takes a predicate function `pred` and a tuple of values `vals`, and returns a tuple of values that satisfy the predicate.

```
>>> filter(lambda x: x%2==0, (1, 2, 3, 4, 5))
(2, 4)
>>> filter(isprime, (2, 3, 4, 5, 6))
(3, 5)
```

Predicate functions return `True` or `False`.

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Ranges

A ***range*** is another built-in type that represents a sequence. It represents a range of integers.

```
>>> range(0, 10)
range(0, 10)
>>> tuple(range(0, 10))
(0, 1, 2, 3, 4, 5, 6, 7, 8, 9)
>>> tuple(range(4))
(0, 1, 2, 3)
>>> tuple(range(0, 4, 2))
(0, 2)
>>> len(range(0, 10))
10
>>> range(1, 10)[3]
4
```

```
>>> sum = 0
>>> for val in range(5):
...     sum += val
>>> sum
10
>>> for _ in range(3):
...     print("Go Bears!")
Go Bears!
Go Bears!
Go Bears!
```

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Announcements

- Homework 4 is due **July 3**.
- Homework 5 is released, due **July 6**.
- Project 2 is released, due **July 13**.
- No class on Wednesday, **July 4**.
- Project 1 contest is on!
  - *How to submit*: Submit a file with your `final_strategy` to `proj1-contest`.
  - *Deadline*: Friday, **July 6** at **11:59pm**.
  - *Prize*: One of 3 copies of *Feynman* and 1 extra credit point.
  - *Metric*: We will simulate your strategy against everyone else's, and tally your win rate. Draws count as losses.

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Announcements: Midterm 1

- Midterm 1 is on **July 9**.
  - *Where*? 2050 VLSB.
  - *When*? 7PM to 9PM.
  - *How much*? Material covered until July 4.
- Closed book and closed electronic devices.
- One 8.5” x 11” ‘cheat sheet’ allowed.
- Group portion is 15 minutes long.
- Post-midterm potluck on Wednesday, **July 11**.

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Review: Data Abstraction

We want to think about data in terms of its ***meaning***, not its ***representation***.

Programs should operate on ***abstract data***.

We use functions to create a ***division*** between manipulation and representation.

Functions can be ***constructors*** or ***selectors***.

Example: Student Records

We would like to work with *student records*.

Constructor

`make_student(name, id, grades)` creates a new record.
`name(student)` returns the name of `student`.
`calid(student)` returns the ID of `student`.
`grades(student)` returns a tuple of grades of `student`.

Selectors

Example: Student Records

Write a function `names_start_with` that takes in a tuple of student records, `records`, and a `letter`, and returns a tuple of the IDs of the students whose name starts with `letter`.

Example: Student Records

Write a function `names_start_with` that takes in a tuple of student records, `records`, and a `letter`, and returns a tuple of the IDs of the students whose name starts with `letter`.

```
def names_start_with(records, letter):
    results = ()
    for record in records:
        if name(record).startswith(letter):
            results = results + (calid(record),)
    return results
```

Did not even have to implement the functions for the student record abstract data type (ADT).

Example: Student Records

Can use anything to construct the student record, as long as the selectors are consistent.

```
def make_student(name, id, grades):
    return (name, id, grades)
def name(student):
    return student[0]
def calid(student):
    return student[1]
def grades(student):
    return student[2]
```

Respect the Data Abstraction!

Louis Reasoner wrote the following code to count the number of As for a given student. However, he has a data abstraction violation. Correct his code so that it respects the data abstraction.

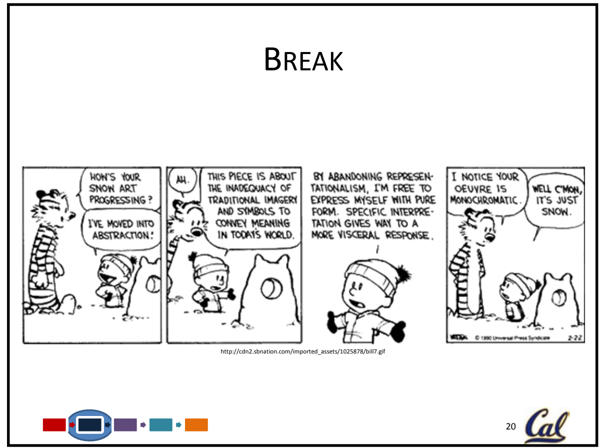
```
def count_as(student):
    number_of_as = 0
    for grade in student[2]:
        if grade == “A”:
            number_of_as = number_of_as + 1
    return number_of_as
```

Respect the Data Abstraction!

Louis Reasoner wrote the following code to count the number of As for a given student. However, he has a data abstraction violation. Correct his code so that it respects the data abstraction.

```
def count_as(student):
    number_of_as = 0
    for grade in grades(student):
        if grade == "A":
            number_of_as = number_of_as + 1
    return number_of_as
```


Break



http://cdn2.sbnation.com/imported_assets/1025878/bill7.gif

Immutability

Numbers, Booleans, strings, tuples, and ranges are examples of ***immutable*** data structures.

Immutability

To "modify" an immutable data structure, we would need to make a *brand new* object with the new values.

```
def map(fn, vals):
    results = ()
    for val in vals:
        results = results + (fn(val),)
    return results
```

Makes a new tuple!

Data Structure: Pairs

A ***pair*** is an ADT that can hold two elements.

It can be implemented using tuples.

(But it can be implemented in other ways, including using functions.)

Constructor

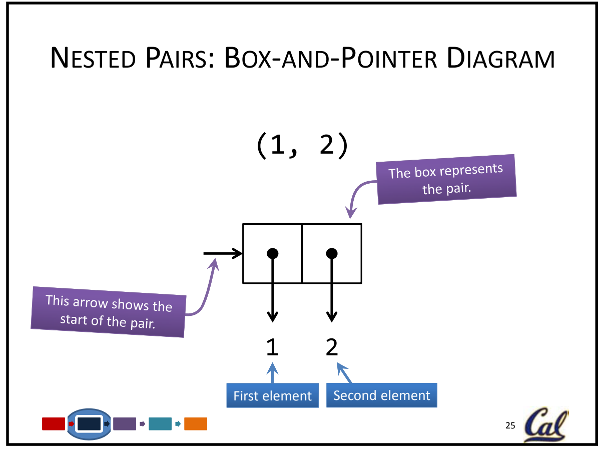
`make_pair(x, y)` creates a new pair.
`first(x)` returns the first element of the pair.
`second(x)` returns the second element of the pair.

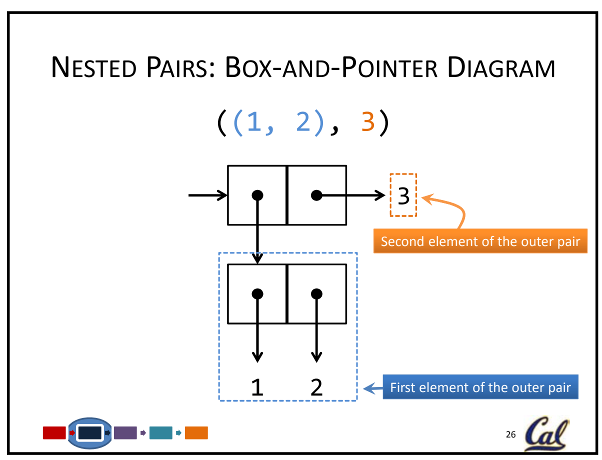
Nested Pairs

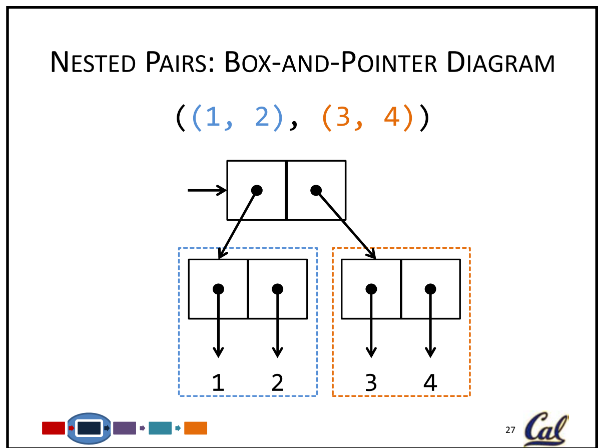
For simplicity, we will represent pairs as two-element tuples.

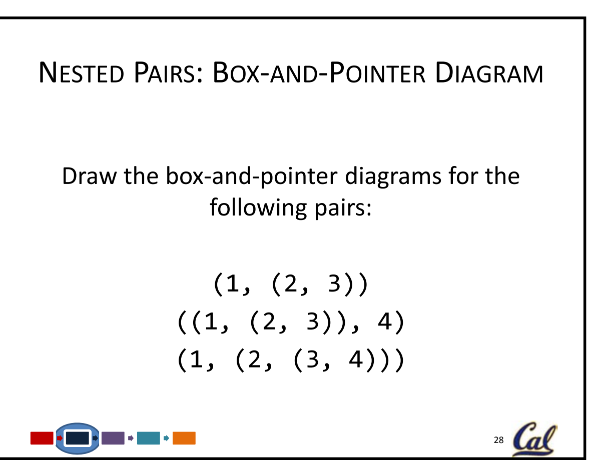
Pairs can contain other pairs as elements.

```
(1, 2)
((1, 2), 3)
((1, 2), (3, 4))
((1, (2, 3)), 4)
```


NESTED PAIRS: BOX-AND-POINTER DIAGRAM
(1, 2)
The box represents the pair.
This arrow shows the start of the pair.
1
2
First element
Second element
25


NESTED PAIRS: BOX-AND-POINTER DIAGRAM
((1, 2), 3)
3
Second element of the outer pair
1
2
First element of the outer pair
26


NESTED PAIRS: BOX-AND-POINTER DIAGRAM
((1, 2), (3, 4))
1
2
3
4
27


NESTED PAIRS: BOX-AND-POINTER DIAGRAM
Draw the box-and-pointer diagrams for the following pairs:
(1, (2, 3))
((1, (2, 3)), 4)
(1, (2, (3, 4)))
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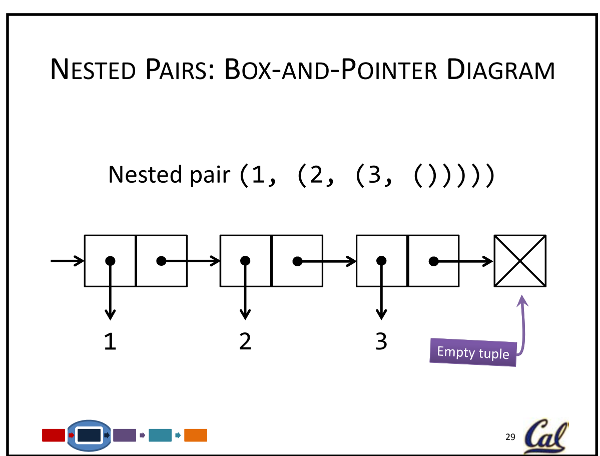
NESTED PAIRS: BOX-AND-POINTER DIAGRAM
Nested pair (1, (2, (3, ()))))
1
2
3
Empty tuple
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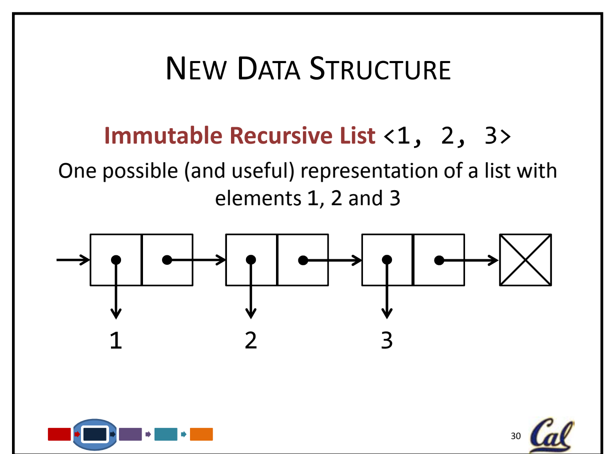
NEW DATA STRUCTURE
Immutable Recursive List <1, 2, 3>
One possible (and useful) representation of a list with elements 1, 2 and 3
1
2
3
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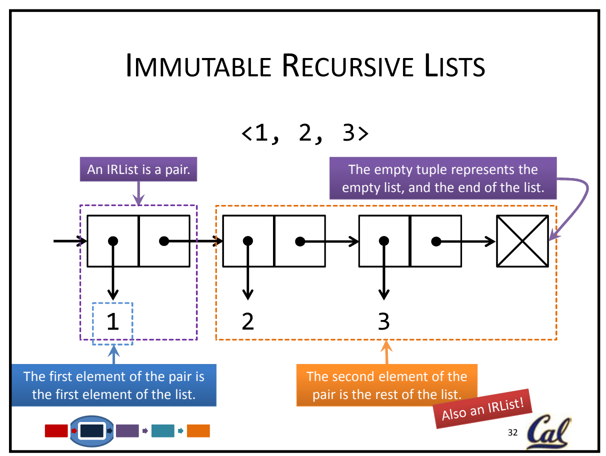
Immutable Recursive Lists

An ***immutable recursive list*** (or an ***IRList***) is a *pair* such that:

- The first element of the pair is the *first* element of the list.
- The second element of the pair is the *rest* of the list – another immutable recursive list. The rest of the list could be empty.

Immutable Recursive Lists



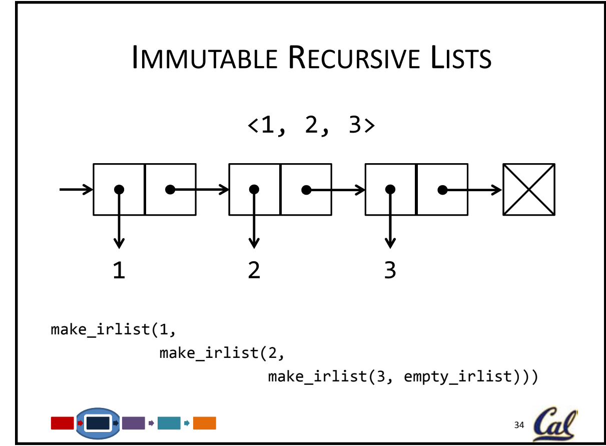
Immutable Recursive Lists

```
empty_irlist = ()

def make_irlist(first, rest=empty_irlist):
    return (first, rest)

def irlist_first(irlist):
    return irlist[0]
def irlist_rest(irlist):
    return irlist[1]
```

Constructor

Selectors

Immutable Recursive Lists



Immutable Recursive Lists

Why are they useful?

- They are defined *recursively*. Functions that operate on IRLists are usually best and easily defined *recursively*.
- They are the basis for *linked lists*, a versatile data structure in computer science.

http://charmainesmusepallet.files.wordpress.com/2011/06/group-of-10-on-the-beach-conga-line-71523.jpg

Immutable Recursive Lists

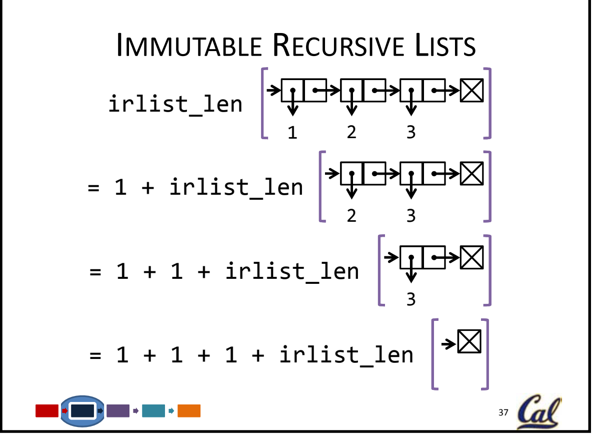
Write the function `irlist_len` that takes an IRList `irlist` and returns its length.

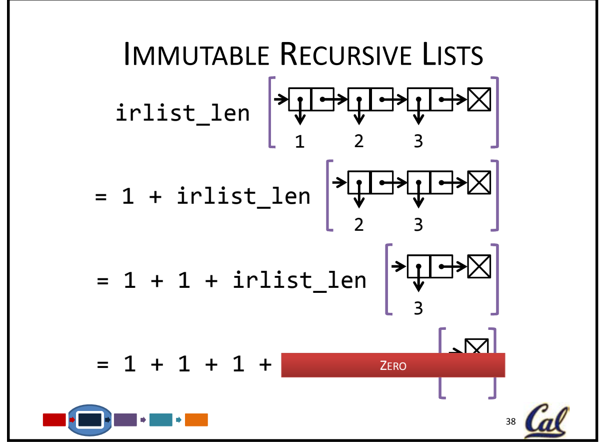
```
def irlist_len(irlist):
    if irlist == empty_irlist:
        return 0
    return 1 + irlist_len(irlist_rest(irlist))
```

Base case: Simplest IRList is the empty IRList.

Add 1 to the result of …

… calling `irlist_len` recursively on the rest of the IRList, which is *also* an IRList.





Immutable Recursive Lists

Write the function `irlist_select` that returns the element at position `index` of the `irlist`.
(Assume the inputs are valid.)

```
def irlist_select(irlist, index):
    if index == 0:
        return ________________________
    return irlist_select(_____________,
                         _____________)
```


Immutable Recursive Lists

Write the function `irlist_select` that returns the element at position `index` of the `irlist`.
(Assume the inputs are valid.)

```
def irlist_select(irlist, index):
    if index == 0:
        return irlist_first(irlist)
    return irlist_select(irlist_rest(irlist),
                         index - 1)
```


Immutable Recursive Lists

Write the function `irlist_map` that takes a function `fn` and an `irlist`, and returns an IRList of the results of applying `fn` to the elements of `irlist`.

```
def irlist_map(fn, irlist):
    if irlist == empty_irlist:
        return ______________________________
    return make_irlist(______________________,
                       ______________________)
```

IRLists are immutable!

Immutable Recursive Lists

Write the function `irlist_map` that takes a function `fn` and an `irlist`, and returns an IRList of the results of applying `fn` to the elements of `irlist`.

```
def irlist_map(fn, irlist):
    if irlist == empty_irlist:
        return empty_irlist
    return make_irlist(fn(irlist_first(irlist)),
                       irlist_map(fn,
                                  irlist_rest(irlist)))
```

IRLists are immutable!

CONCLUSION

- Data abstraction allows us to separate the meaning of abstract data from its implementation.
- A sequence is an ordered collection of data with certain properties.
- There are many useful ADTs in computer science, some of which are *immutable*.
- One example of a useful ADT is the immutable recursive list, built from pairs.
- ***Preview***: Immutable dictionaries.

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