Data Abstraction

Announcements

- Lab 3 due on Wednesday 7/05
- Lab 4 due on Thursday 7/06
- Hog Project due Thursday 7/06
  - Turn in by Wednesday 7/05 for 1 EC point
  - Project Party **TODAY (4-6:30)** and Thursday (3-5:30)
- Grades for assignments have been released
  - Carefully look through this Ed post
  - Regrade request post will be made soon
  - If you had an approved extension and it didn't go through request a regrade
- Homework Recovery starts this week!
- Midterm 7/13 7-9 pm
  - Exam alterations and accommodations, please fill out the form

Office Hours and Hog Checkpoint

So important it gets its own slide

As of right now, only 320 out of 473 students have submitted the Hog Checkpoint

This is 1 point and contributes to your grade

Missing it is not the end of the world, but you should be aiming to get this in on time, and we expect you to get it turned in by the final deadline

Utilize the resources we offer!

Utilize resources amongst other students (Within what academic conduct allows)

You should be able to submit assignments on time in this course with the resources and support we provide

Cats is released immediately after Hog is due, don’t put it off, start early!

Data Abstraction

Data Abstraction

- Compound values combine other values together
  - A date: a year, a month, and a day
  - A geographic position: latitude and longitude
- Data abstraction lets us manipulate compound values as units
- Isolate two parts of any program that uses data:
  - How data are represented (as parts)
  - How data are manipulated (as units)
- Data abstraction: A methodology by which functions enforce an abstraction barrier between ***representation*** and ***use***

All Programmers

Great Programmers

Rational Numbers

$$\frac{\texttt{numerator}}{\texttt{denominator}}$$

Exact representation of fractions

A pair of integers

As soon as division occurs, the exact representation may be lost! (Demo)

Assume we can compose and decompose rational numbers:

Constructor

- rational(n, d) returns a rational number x

Selectors

- numer(x) returns the numerator of x
- denom(x) returns the denominator of x

Rational Number Arithmetic

$$\frac{3}{2} * \frac{3}{5} = \frac{9}{10}$$

$$\frac{3}{2} + \frac{3}{5} = \frac{21}{10}$$

$$\frac{nx}{dx} * \frac{ny}{dy} = \frac{nx*ny}{dx*dy}$$

$$\frac{nx}{dx} + \frac{ny}{dy} = \frac{nx*dy + ny*dx}{dx*dy}$$

General Form

Rational Number Arithmetic Implementation

```python
def mul_rational(x, y):
    return rational(numer(x) * numer(y),
                    denom(x) * denom(y))
```

Constructor

Selectors

$$\frac{nx}{dx} * \frac{ny}{dy} = \frac{nx*ny}{dx*dy}$$

```python
def add_rational(x, y):
    nx, dx = numer(x), denom(x)
    ny, dy = numer(y), denom(y)
    return rational(nx * dy + ny * dx, dx * dy)
```

$$\frac{nx}{dx} + \frac{ny}{dy} = \frac{nx*dy + ny*dx}{dx*dy}$$

```python
def print_rational(x):
    print(numer(x), '/', denom(x))

def rationals_are_equal(x, y):
    return numer(x) * denom(y) == numer(y) * denom(x)
```

Example

- rational(n, d) returns a rational number x
- numer(x) returns the numerator of x
- denom(x) returns the denominator of x

These functions implement an abstract representation for rational numbers

Representing Rational Numbers

Representing Rational Numbers

```python
def rational(n, d):
    """Construct a rational number that represents N/D."""
    return [n, d]
```

Construct a list

```python
def numer(x):
    """Return the numerator of rational number X."""
    return x[0]

def denom(x):
    """Return the denominator of rational number X."""
    return x[1]
```

Select item from a list

(Demo)

Reducing to Lowest Terms

Example:

$$\frac{3}{2} * \frac{5}{3} = \boxed{\frac{5}{2}} \qquad \frac{2}{5} + \frac{1}{10} = \boxed{\frac{1}{2}}$$

$$\frac{15}{6} * \frac{1/3}{1/3} = \frac{5}{2} \qquad \frac{25}{50} * \frac{1/25}{1/25} = \frac{1}{2}$$

```
from math import gcd
```

Greatest common divisor

```
def rational(n, d):
    """Construct a rational that represents n/d in lowest terms."""
    g = gcd(n, d)
    return [n//g, d//g]
```

(Demo)

Abstraction Barriers

Abstraction Barriers

Parts of the program that...	Treat rationals as...	Using...
Use rational numbers to perform computation	whole data values	add_rational, mul_rational rationals_are_equal, print_rational
Create rationals or implement rational operations	numerators and denominators	rational, numer, denom
Implement selectors and constructor for rationals	two-element lists	list literals and element selection

Implementation of lists

Violating Abstraction Barriers

Does not use constructors

Twice!

```
add_rational( [1, 2], [1, 4] )
```

```
def divide_rational(x, y):
    return [ x[0] * y[1], x[1] * y[0] ]
```

No selectors!

And no constructor!

Data Representations

What are Data?

- We need to guarantee that constructor and selector functions work together to specify the right behavior
- Behavior condition: If we construct rational number x from numerator n and denominator d, then numer(x)/denom(x) must equal n/d
- Data abstraction uses selectors and constructors to define behavior
- If behavior conditions are met, then the representation is valid

You can recognize an abstract data representation by its behavior

(Demo)

Rationals Implemented as Functions

```
def rational(n, d):
    def select(name):
        if name == 'n':
            return n
        elif name == 'd':
            return d
    return select
```

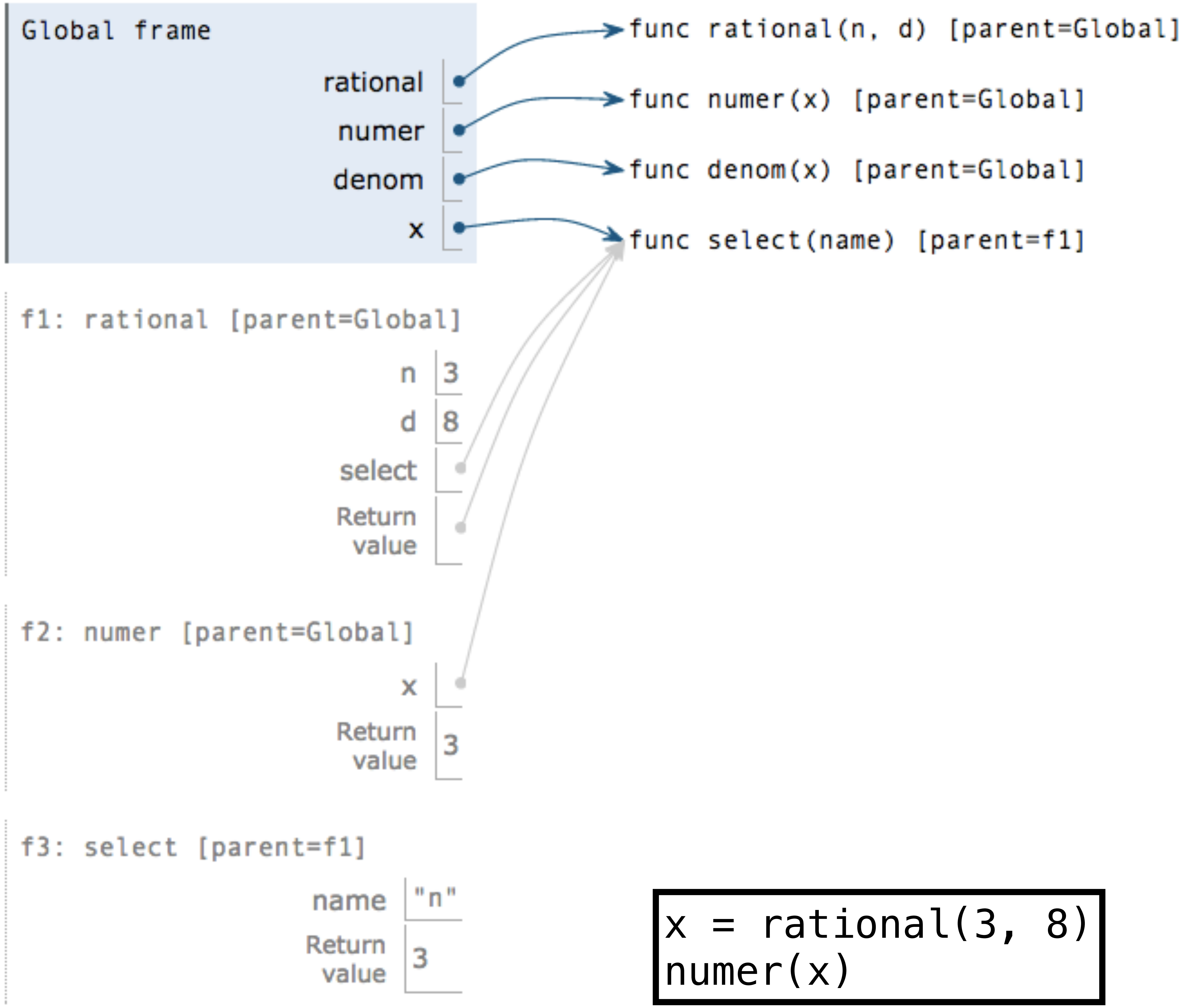
This function represents a rational number

Constructor is a higher-order function

```
def numer(x):
    return x('n')

def denom(x):
    return x('d')
```

Selector calls x




```
x = rational(3, 8)
numer(x)
```

pythontutor.com/composingprograms.html#code=def%20rational%28n,%20d%29%3A%0A%20%20%20%20def%20select%28name%29%3A%0A%20%20%20%20%20%20%20%20if%20name%20%3D%3D%20'n'%3A%0A%20%20%20%20%20%20%20%20%20%20%20%20return%20n%0A%20%20%20%20%20%20%20%20elif%20name%20%3D%3D%20'd'%3A%0A%20%20%20%20%20%20%20%20%20%20%20%20return%20d%0A%20%20%20%20return%20select%0A%20%20%20%20%20%20%0Adef%20numer%28x%29%3A%0A%20%20%20%20return%20x%28'n'%29%0A%0Adef%20denom%28x%29%3A%0A%20%20%20%20return%20x%28'd'%29%0A%20%20%20%20%20%0Ax%20%3D%20rational%283,%208%29%0Anumer%28x%29&mode=display&origin=composingprograms.js&cumulative=true&py=3&rawInputLstJSON=[]&curInstr=0

Mutability

Objects

(Demo)

Objects

- Objects represent information
- They consist of data and behavior, bundled together to create abstractions
- Objects can represent things, but also properties, interactions, & processes
- A type of object is called a class; **classes** are first-class values in Python
- Object-oriented programming:
  - A metaphor for organizing large programs
  - Special syntax that can improve the composition of programs
- In Python, every value is an object
  - All **objects** have **attributes**
  - A lot of data manipulation happens through object **methods**
  - Functions do one thing; objects do many related things

Example: Strings

(Demo)

Representing Strings: the ASCII Standard

American Standard Code for Information Interchange

"Bell" (\a)

"Line feed" (\n)

ASCII Code Chart

8 rows: 3 bits

		0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0 0 0	0	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
0 0 1	1	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EM	SUB	ESC	FS	GS	RS	US
0 1 0	2		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
0 1 1	3	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
1 0 0	4	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1 0 1	5	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
1 1 0	6	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
1 1 1	7	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	DEL

16 columns: 4 bits

- Layout was chosen to support sorting by character code
- Rows indexed 2-5 are a useful 6-bit (64 element) subset
- Control characters were designed for transmission

(Demo)

Representing Strings: the Unicode Standard

- 137,994 characters in Unicode 12.1
- 150 scripts (organized)
- Enumeration of character properties, such as case
- Supports bidirectional display order
- A canonical name for every character

http://ian-albert.com/unicode_chart/unichart-chinese.jpg

LATIN CAPITAL LETTER A

DIE FACE-6 '⚅'

EIGHTH NOTE '♪'

(Demo)

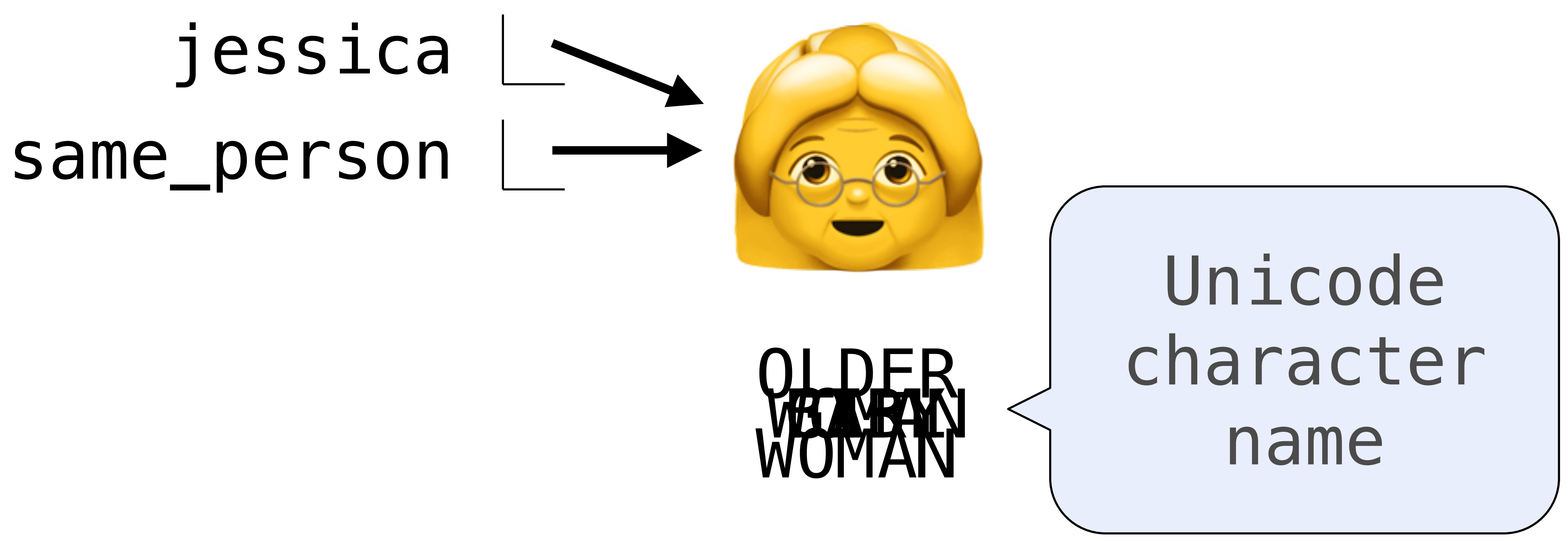
Mutation Operations

Some Objects Can Change

[Demo]

First example in the course of an object changing state

The same object can change in value throughout the course of computation



All names that refer to the same object are affected by a mutation

Only objects of *mutable* types can change: lists & dictionaries

{Demo}

Mutation Can Happen Within a Function Call

A function can change the value of any object in its scope

```
>>> four = [1, 2, 3, 4]
>>> len(four)
4
>>> mystery(four)
>>> len(four)
2
```

```
def mystery(s):
    s.pop()
    s.pop()
```

or

```
def mystery(s):
    s[2:] = []
```

```
>>> four = [1, 2, 3, 4]
>>> len(four)
4
>>> another_mystery() # No arguments!
>>> len(four)
2
```

```
def another_mystery():
    four.pop()
    four.pop()
```

https://pythontutor.com/cp/composingprograms.html#code=def%20mystery%28s%29%3A%0A%20%20%20%20s.pop%28%29%0A%20%20%20%20s.pop%28%29%0A%0Afour%20%3D%20%5B1,%202,%203,%204%5D%0Amystery%28four%29%0Aprint%28four%29&cumulative=true&curInstr=0&mode=display&origin=composingprograms.js&py=3&rawInputLstJSON=%5B%5D

Tuples

(Demo)

Tuples are Immutable Sequences

Immutable values are protected from mutation

```
>>> turtle = (1, 2, 3)
>>> ooze()
>>> turtle
(1, 2, 3)
```

```
>>> turtle = [1, 2, 3]
>>> ooze()
>>> turtle
['Anything could be inside!']
```

The value of an expression can change because of changes in names or objects

Name change:

```
>>> x = 2
>>> x + x
4
>>> x = 3
>>> x + x
6
```

Object mutation:

```
>>> x = [1, 2]
>>> x + x
[1, 2, 1, 2]
>>> x.append(3)
>>> x + x
[1, 2, 3, 1, 2, 3]
```

An immutable sequence may still change if it *contains* a mutable value as an element

```
>>> s = ([1, 2], 3)
>>> s[0] = 4
ERROR
```

```
>>> s = ([1, 2], 3)
>>> s[0][0] = 4
>>> s
([4, 2], 3)
```

Mutation

Sameness and Change

- As long as we never modify objects, a compound object is just the totality of its pieces
- A rational number is just its numerator and denominator
- This view is no longer valid in the presence of change
- A compound data object has an "identity" in addition to the pieces of which it is composed
- A list is still "the same" list even if we change its contents
- Conversely, we could have two lists that happen to have the same contents, but are different

```
>>> a = [10]
>>> b = a
>>> a == b
True
>>> a.append(20)
>>> a
[10, 20]
>>> b
[10, 20]
>>> a == b
True
```

```
>>> a = [10]
>>> b = [10]
>>> a == b
True
>>> b.append(20)
>>> a
[10]
>>> b
[10, 20]
>>> a == b
False
```

Identity Operators

Identity

`<exp0> is <exp1>`

evaluates to True if both <exp0> and <exp1> evaluate to the same object

Equality

`<exp0> == <exp1>`

evaluates to True if both <exp0> and <exp1> evaluate to equal values

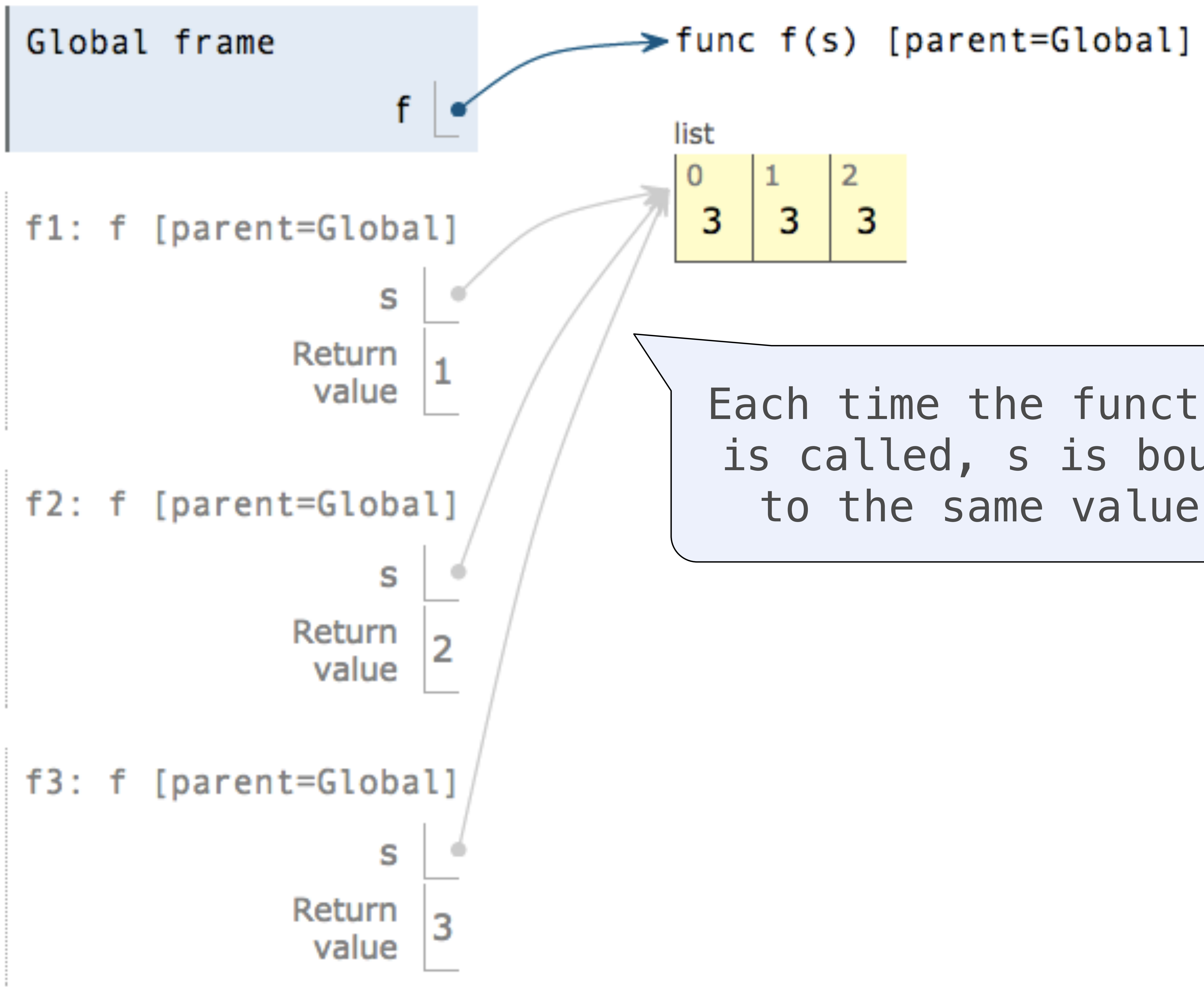
Identical objects are always equal values

(Demo)

Mutable Default Arguments are Dangerous

A default argument value is part of a function value, not generated by a call

```
>>> def f(s=[]):
...     s.append(3)
...     return len(s)
...
>>> f()
1
>>> f()
2
>>> f()
3
```



Each time the function is called, s is bound to the same value!

pythontutor.com/composingprograms.html#code=def%20f%28s%3D[]%29%3A%0A%20%20%20%20s.append%283%29%0A%20%20%20%20return%20len%28s%29%0A%20%20%20%20%0Af%28%29%0Af%28%29%0Af%28%29&mode=display&origin=composingprograms.js&cumulative=true&py=3&rawInputLstJSON=[]&curInstr=0

Summary

Mutable Functions

A Function with Behavior That Varies Over Time

Let's model a bank account that has a balance of $100

```
>>> withdraw = make_withdraw_list(100)
```

In a (mutable) list referenced in the parent frame of the function

```
>>> withdraw(25)
75
```

Argument: amount to withdraw

Return value: remaining balance

```
>>> withdraw(25)
50
```

Second withdrawal of the same amount

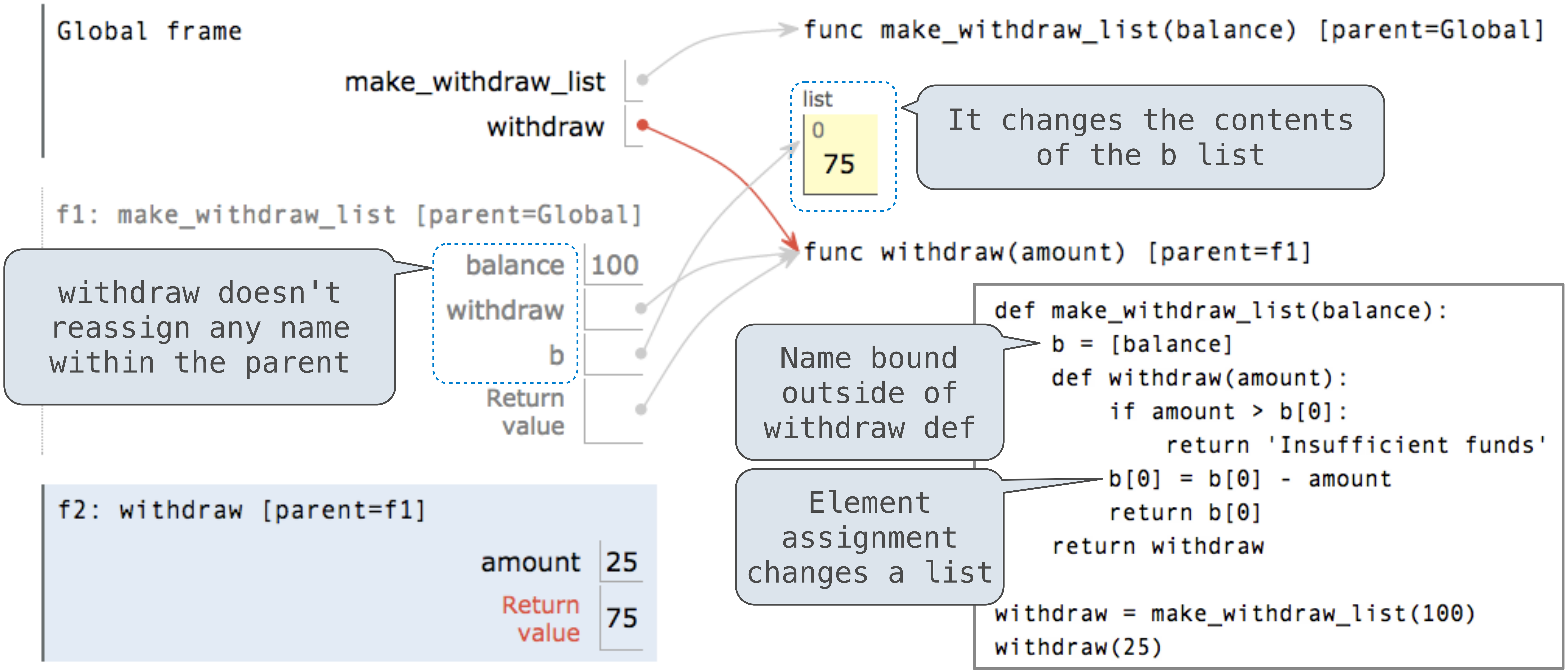
Different return value!

```
>>> withdraw(60)
'Insufficient funds'
```

```
>>> withdraw(15)
35
```

Where's this balance stored?

Mutable Values & Persistent Local State




```
def make_withdraw_list(balance):
    b = [balance]
    def withdraw(amount):
        if amount > b[0]:
            return 'Insufficient funds'
        b[0] = b[0] - amount
        return b[0]
    return withdraw

withdraw = make_withdraw_list(100)
withdraw(25)
```