DM536
Introduction to Programming

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LIST PROCESSING

Lists as Sequences

- lists are sequences of values
- lists can be constructed using "[" and "]"
- Example: [42, 23]

  ["Hello", "World", "!"]

  ["strings and", int, "mix", 2]

  []
- lists can be nested, i.e., a list can contain other lists
- Example: [[1, 2, 3], [4, 5, 6], [7, 8, 9]]
- lists are normal values, i.e., they can be printed, assigned etc.
- Example: x = [1, 2, 3]

  print x, [x, x], [[x, x], x]

Mutable Lists

- lists can be accessed using indices
- lists are mutable, i.e., they can be changed destructively
- Example:

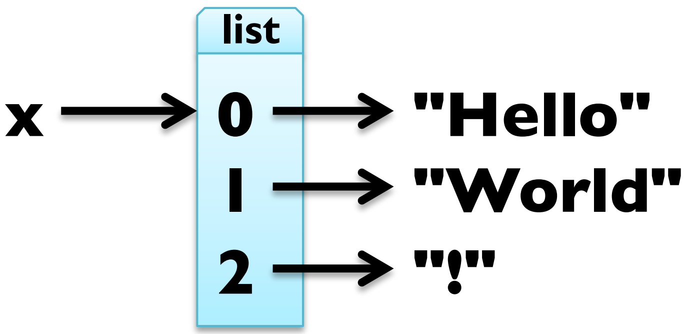
```
x = [1, 2, 3]
print x[1]
x[1] = 4
print x, x[1]
```

- len(object) and negative values work like for strings
- Example:

```
x[2] == x[-1]
x[1] == x[len(x)-2]
```

Stack Diagrams with Lists

- lists can be viewed as mappings from indices to elements
- Example 1: x = ["Hello", "World", "!"]



- Example 2: x = [[23, 42, -3.0], "Bye!"]

Traversing Lists

- for loop consecutively assigns variable to elements of list
- Example: print squares of numbers from 1 to 10

```
for x in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]:
    print x**2
```

- arithmetic sequences can be generated using range function:
  - range([start,] stop[, step])
- Example:

```
range(4) == [0, 1, 2, 3]
range(1, 11) == [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
range(9, 1, -2) == [9, 7, 5, 3]
range(1,10, 2) == [1, 3, 5, 7, 9]
```

Traversing Lists

- for loop consecutively assigns variable to elements of list
- general form

```
for element in my_list:
    print element
```

- iteration through list with indices:

```
for index in range(len(my_list)):
    element = my_list[index]
    print element
```

- Example: in-situ update of list

```
x = [8388608, 439804651104, 0.125]
for i in range(len(x)):
    x[i] = math.log(x[i], 2)
```

List Operations

- like for strings, "+" concatenates two lists
- Example:

```
[1, 2, 3] + [4, 5, 6] == range(1, 7)
[[23, 42] + [-3.0]] + ["Bye!"] == [[23, 42, -3.0], "Bye!"]
```

- like for strings, "* n" with integer n produces n copies
- Example:

```
len(["I", "love", "penguins!"] * 100) == 300
(range(1, 3) + range(3, 1, -1)) * 2 == [1, 2, 3, 2, 1, 2, 3, 2]
```

List Slices

- slices work just like for strings
- Example:

```
x = ["Hello", 2, "u", 2, "!"]
x[2:4] == ["u", 2]
x[2:] == x[-3:len(x)]
y = x[:]          # make a copy (lists are mutable!)
```

- BUT: we can also assign to slices!
- Example:

```
x[1:4] = ["to", "you", "too"]
x == ["Hello", "to", "you", "too", "!"]
x[1:3] = ["to me"]
x == ["Hello", "to me", "too", "!"]
x[2:3] = []
x == ["Hello", "to me", "!"]
```

List Methods

- appending elements to the end of the list (destructive)
- Example:
```
x = [5, 3, 1]
y = [2, 4, 6]
for e in y:     x.append(e)
```
- Note: `x += [e]` would create new list in each step!
- also available as method: `x.extend(y)`

- sorting elements in ascending order (destructive)
- Example:
```
x.sort()
x == range(1, 7)
```

- careful with destructive updates: `x = x.sort()`

Higher-Order Functions (map)

- Example 1: new list with squares of all elements of a list

```
def square_all(x):
    res = []
    for e in x:    res.append(e**2)
    return res
```

- Example 2: new list with all elements increased by one

```
def increment_all(x):
    res = []
    for e in x:    res.append(e+1)
    return res
```

Higher-Order Functions (map)

- these *map* operations have an identical structure:

```
res = []
for e in x:   res.append(e**2)
return res
```

```
res = []
for e in x:   res.append(e+1)
return res
```

- Python has generic function map(function, sequence)
- Implementation idea:

```
def map(function, sequence):
    res = []
    for e in sequence:
        res.append(function(e))
    return res
```

Higher-Order Functions (map)

- these *map* operations have an identical structure:

```
res = []
for e in x:   res.append(e**2)
return res
```

```
res = []
for e in x:   res.append(e+1)
return res
```

- Python has generic function map(function, sequence)
- Example:

```
def square(x):          return x**2
def increment(x):       return x+1
def square_all(x):
    return map(square, x)
def increment_all(x):
    return map(increment, x)
```

Higher-Order Functions (filter)

- Example 1: new list with elements greater than 42

```
def filter_greater42(x):
    res = []
    for e in x:
        if e > 42:    res.append(e)
    return res
```

- Example 2: new list with elements whose length is smaller 3

```
def filter_len_smaller3(x):
    res = []
    for e in x:
        if len(e) < 3:   res.append(e)
    return res
```

Higher-Order Functions (filter)

- these *filter* operations have an identical structure:

```
res = []
for e in x:
    if e > 42:   res.append(e)
return res
```

```
res = []
for e in x:
    if len(e) < 3:   res.append(e)
return res
```

- Python has generic function filter(function, iterable)
- Implementation idea:

```
def filter(function, iterable):
    res = []
    for e in iterable:
        if function(e):      res.append(e)
    return res
```

Higher-Order Functions (filter)

- these *filter* operations have an identical structure:

```
res = []
for e in x:
    if e > 42:   res.append(e)
return res
```

```
res = []
for e in x:
    if len(e) < 3:   res.append(e)
return res
```

- Python has generic function filter(function, iterable)
- Example:

```
def greater42(x):              return x > 42
def len_smaller3(x):           return len(x) < 3
def filter_greater42(x):       return filter(greater42,  x)
def filter_len_smaller3(x):    return filter(len_smaller3, x)
```

Higher-Order Functions (reduce)

- Example 1: computing factorial using range

```
def mul_all(x):
    prod = 1
    for e in x:   prod *= e          # prod = prod * e
    return prod
def factorial(n):
    return mul_all(range(1,n+1))
```

- Example 2: summing all elements in a list

```
def add_all(x):
    sum = 0
    for e in x:   sum += e           # sum = sum + e
    return sum
```

Higher-Order Functions (reduce)

- these *reduce* operations have an identical structure:

```
prod = 1                        sum = 0
for e in x:   prod *= e         for e in x:     sum += e
return prod                     return sum
```

- Python has generic function reduce(function, sequence, initial)
- Implementation idea:

```
def reduce(function, sequence, initial):
    result = initial
    for e in sequence:
        result = function(result, e)
    return result
```

Higher-Order Functions (reduce)

- these *reduce* operations have an identical structure:

```
prod = 1                              sum = 0
for e in x:    prod *= e              for e in x:    sum += e
return prod                           return sum
```

- Python has generic function reduce(function, sequence, initial)
- Example:

```
def add(x,y):    return x+y
def mul(x,y):    return x*y
def add_all(x):
    return reduce(add, x, 0)
def mul_all(x):
    return reduce(mul, x, 1)
```

Deleting Elements

- there are three different ways to delete elements from list
- if you know index and want the element, use pop(index)
- Example: my_list = [23, 42, -3.0, 4711]
  my_list.pop(1) == 42
  my_list == [23, -3.0, 4711]
- if you do not know index, but the element, use remove(value)
- Example: my_list.remove(-3.0)
  my_list == [23, 4711]
- if you know the index, you can use the del statement
- Example: del my_list[0]
  my_list == [4711]

Deleting Elements

- there are three different ways to delete elements from list

- as we have seen, you can also use slices to delete elements
- Example:

```
my_list = [23, 42, -3.0, 4711]
my_list[2:] = []
my_list == [23, 42]
```

- alternatively, you can use del together with slices
- Example:

```
my_list = my_list * 3
del my_list[:3]
my_list == [42, 23, 42]
```

Lists vs Strings

- string = sequence of letters
- list = sequence of values

- convert a string into a list using the built-in list() function
- Example: list("Hej hop") == ["H", "e", "j", " ", "h", "o", "p"]

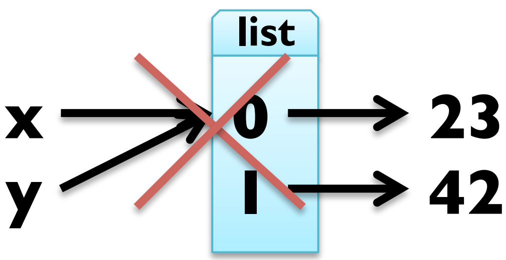
- split up a string into a list using the split(sep) method
- Example: "Slartibartfast".split("a") == ["Sl", "rtib", "rtf", "st"]

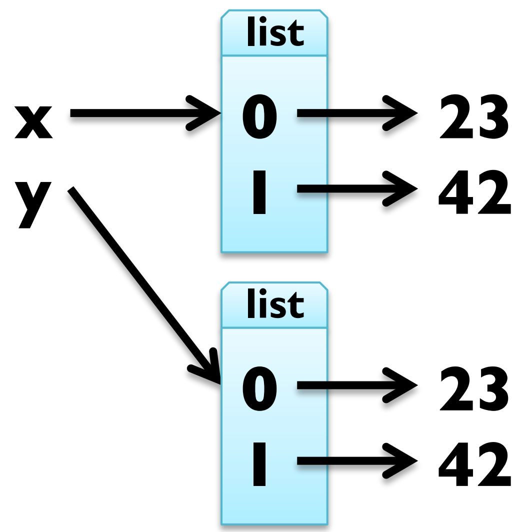
- reverse operation is the join(sequence) method
- Example: " and ".join(["A", "B", "C"]) == "A and B and C"
  "".join(["H", "e", "j", " ", "h", "o", "p"]) = "Hej Hop"

Objects and Values

- two possible stack diagrams for a = "mango"; b = "mango"

- we can check identity of objects using the is operator
- Example: a is b == True
- two possible stack diagrams for x = [23, 42]; y = [23, 42]

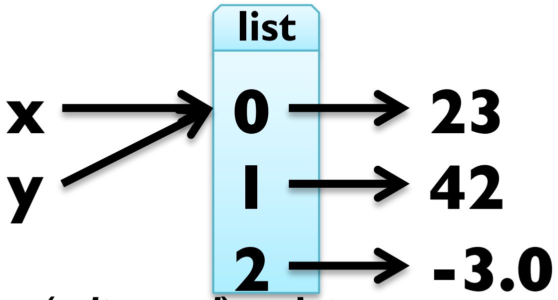




- Example: x is y == False

Aliasing

- when assigning y = x, both variables refer to same object
- Example: x = [23, 42, -3.0]
  y = x
  x is y == True



- here, there are two *references* to one (*aliased*) object

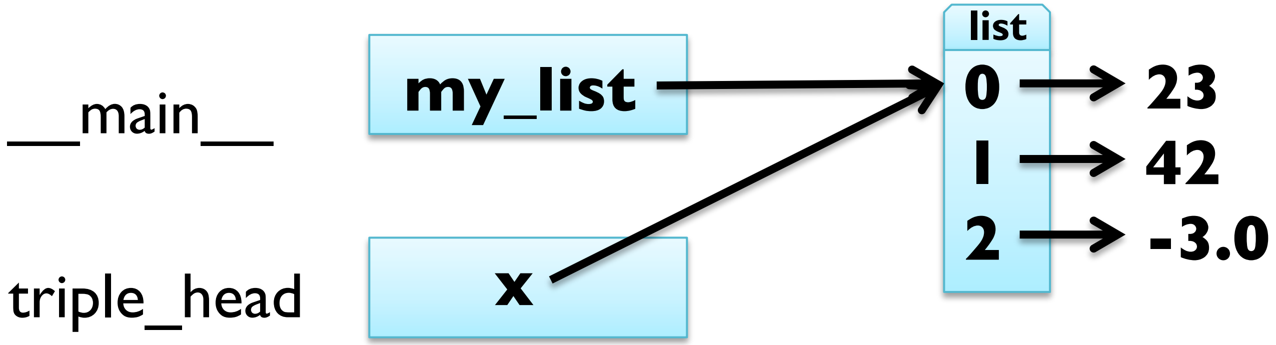
- fine for immutable objects (like strings)
- problematic for mutable objects (like lists)
- Example: y[2] = 4711
  x == [23, 42, 4711]

- HINT: when unsure, always copy list using y = x[:]

List Arguments

- lists passed as arguments to functions can be changed
- Example: tripling the first element

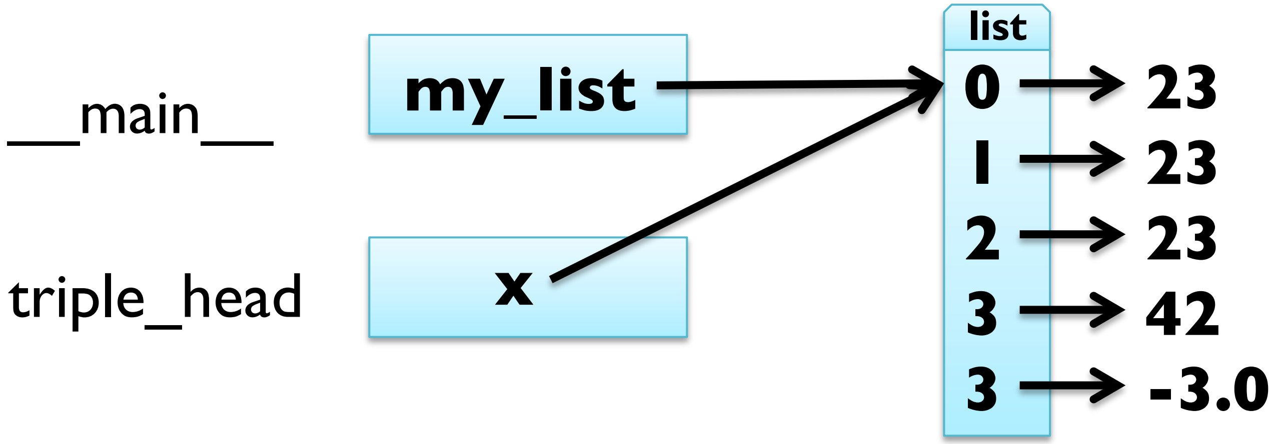
```
def triple_head(x):
    x[:1] = [x[0]]*3
my_list = [23, 42, -3.0]
triple_head(my_list)
```



List Arguments

- lists passed as arguments to functions can be changed
- Example: tripling the first element

```
def triple_head(x):
    x[:1] = [x[0]]*3
my_list = [23, 42, -3.0]
triple_head(x)
my_list == [23, 23, 23, 42, -3.0]
```



List Arguments

- lists passed as arguments to functions can be changed
- some operations change object
  - assignment using indices
  - append(object) method
  - extend(iterable) method
  - sort() method
  - del statement
- some operations return a new object
  - access using slices
  - strip() method
  - "+" on strings and lists
  - "* n" on strings and lists

Debugging Lists

- working with mutable objects like lists requires attention!

1. many list methods return None and modify destructively
   - word = word.strip() makes sense
   - t = t.sort() does NOT!
2. there are many ways to do something – stick with one!
   - t.append(x) or t = t + [x]
   - use either pop, remove, del or slice assignment for deletion
3. make copies when you are unsure!
   - Example:

```
...
sorted_list = my_list[:]
sorted_list.sort()
...
```

DICTIONARIES

Generalized Mappings

- list = mapping from integer indices to values
- dictionary = mapping from (almost) any type to values
- indices are called *keys* and pairs of keys and values *items*

- empty dictionaries created using curly braces "{}"
- Example: `en2da = {}`

- keys are assigned to values using same syntax as for sequences
- Example:

```
en2da["queen"] = "dronning"
print en2da
```

- curly braces "{" and "}" can be used to create dictionary
- Example: `en2da = {"queen" :  "dronning", "king" : "konge"}`

Dictionary Operations

- printing order can be different: print en2da
- access using indices: en2da["king"] == "konge"
- KeyError when key not mapped: print en2da["prince"]
- length is number of items: len(en2da) == 2
- in operator tests if key mapped: "king" in en2da == True
  "prince" in en2da == False
- keys() metod gives list of keys:
  en2da.keys() == ["king", "queen"]
- values() method gives list of values:
  en2da.values() == ["konge", "dronning"]
- useful e.g. for test if value is used:
  "prins" in en2da.values() == False

Dictionaries as Sets

- dictionaries can be used as sets
- **Idea:** assign None to all elements of the set
- Example: representing the set of primes smaller than 20

  primes = {2: None, 3: None, 5: None, 7: None, 11: None, 13: None, 17: None, 19: None}
- then in operator can be used to see if value is in set
- Example:

  15 in primes == False

  17 in primes == True
- for lists, needs steps proportional to number of elements
- for dictionary, needs (almost) constant number of steps

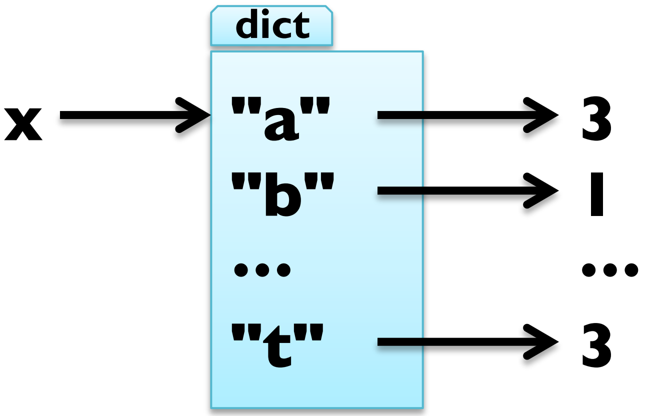
Counting Letter Frequency

- **Goal:** count frequency of letters in a string (*histogram*)
- many possible implementations, e.g.:
  - create 26(+3?) counter variables for each letterl; use chained conditionals (if … elif … elif …) to increment
  - create a list of length 26(+3?); increment the element at index n-1 if the n-th letter is encountered
  - create a dictionary with letters as keys and integers as values; increment using index access
- all these implementations work (differently)
- big differences in *runtime* and *ease of implementation*
- choice of data structure is a *design decision*

Counting with Dictionaries

- fast and counts all characters – no need to fix before!

```
def histogram(word):
    d = {}
    for char in word:
        if char not in d:
            d[char] = 1
        else:
            d[char] += 1
    return d
```



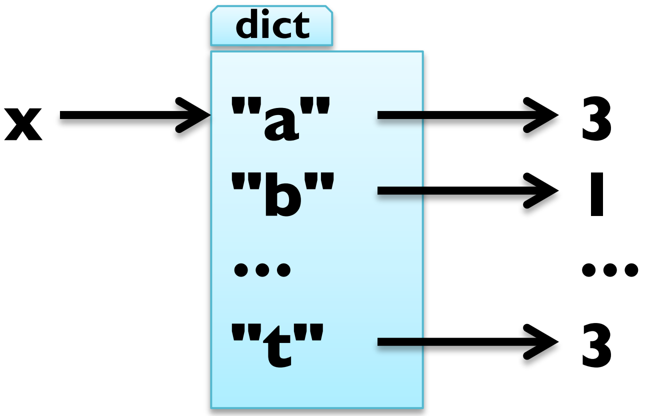
- Example: h = histogram("slartibartfast")

  h == {"a":3, "b":1, "f":1, "i":1, "l":1, "s":2, "r":2, "t":3}

Counting with Dictionaries

- fast and counts all characters – no need to fix before!

```
def histogram(word):
    d = {}
    for char in word:
        if char not in d:
            d[char] = 1
        else:
            d[char] += 1
    return d
```



- access using the get(k, d) method:

```
h.get("t", 0) == 3
h.get("z", 0) == 0
```

Traversing Dictionaries

- using a for loop, you can traverse all keys of a dictionary
- Example:

```
for key in en2da:
    print key, en2da[key]
```

- you can also traverse all values of a dictionary
- Example:

```
for value in en2da.values():
    print value
```

- finally, you can traverse all items of a dictionary
- Example:

```
for item in en2da.items():
    print item[0], item[1]        # key, value
```

Reverse Lookup

- given dict. d and key k, finding value v with v == d[k] easy
- this is called a dictionary *lookup*
- given dict. d and value v, finding key k with v == d[k] hard
- there might be more than one key mapping to v (cf. example)
- Possible implementation 1:

```
def reverse_lookup(d, v):
    result = []
    for key in d:
        if d[key] == v:
            result.append(key)
    return result
```

- returns empty list, when no key maps to value v

Reverse Lookup

- given dict. d and key k, finding value v with v == d[k] easy
- this is called a dictionary *lookup*
- given dict. d and value v, finding key k with v == d[k] hard
- there might be more than one key mapping to v (cf. example)
- Possible implementation 2:

```
def reverse_lookup(d, v):
    for k in d:
        if d[k] == v:
            return k
    raise ValueError
```

- gives error when no key maps to value v

Reverse Lookup

- given dict. d and key k, finding value v with v == d[k] easy
- this is called a dictionary *lookup*
- given dict. d and value v, finding key k with v == d[k] hard
- there might be more than one key mapping to v (cf. example)
- Possible implementation 2:

```
def reverse_lookup(d, v):
    for key in d:
        if d[k] == v:
            return k
    raise ValueError, "value not found in dictionary"
```

- gives error when no key maps to value v

Dictionaries and Lists

- lists cannot be keys, as they are mutable
- list can be values stored in dictionaries
- Example: inverting a dictionary

```
def invert_dict(d):
    inv = {}
    for key in d:
        val = d[key]
        if val not in inv:
            inv[val] = [key]
        else:
            inv[val].append(key)
    return inv
```

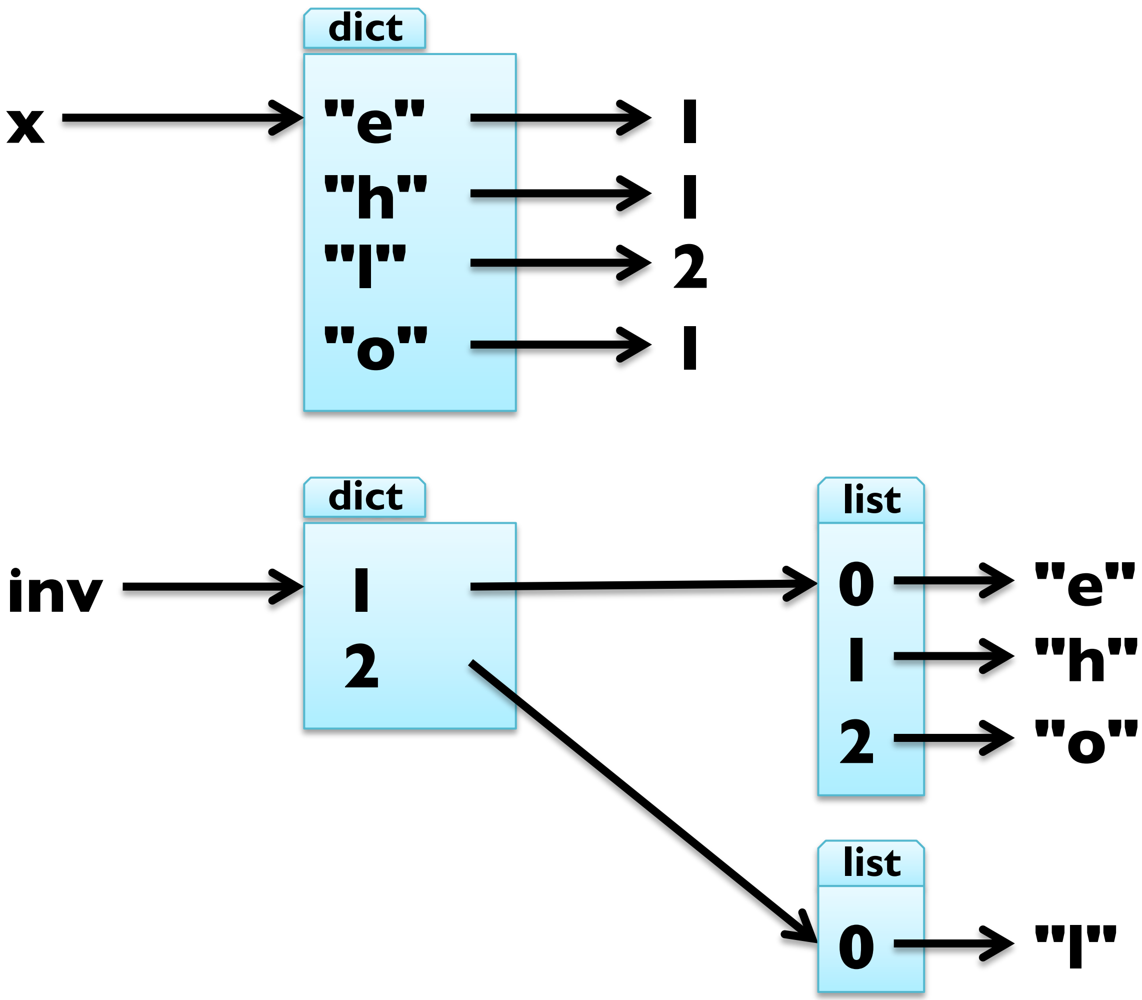
Dictionaries and Lists

- lists cannot be keys, as they are mutable
- list can be values
- Example: inverting a dictionary

```
def invert_dict(d):
    inv = {}
    for key in d:
        val = d[key]
        if val not in inv:
            inv[val] = []
        inv[val].append(key)
    return inv
```

- Example: `print invert_dict(histogram("hello"))`

Dictionaries and Lists



- Example: print invert_dict(histogram("hello"))

Memoizing

- Fibonacci numbers lead to exponentially many calls:

```
def fib(n):
    if n in [0,1]: return n
    return fib(n-1) + fib(n-2)
```

- keeping previously computed values (*memos*) helps:

```
known = {0:0, 1:1}
def fib_fast(n):
    if n in known:
        return known[n]
    res = fib_fast(n-1) + fib_fast(n-2)
    known[n] = res
    return res
```

Global Variables

- known is created outside fib_fast and belongs to __main__
- such variables are called *global*
- many uses for global variables (besides memoization)
- Example 1: flag for controlling output

```
debug = True
def pythagoras(a,b):
    if debug:       print "pythagoras with a =d", a, " and b = d", b
    result = math.sqrt(a**2 + b**2)
    if debug:       print "result of pythagoras:", result
    return result
```

Global Variables

- known is created outside fib_fast and belongs to __main__
- such variables are called *global*
- many uses for global variables (besides memoization)
- Example 2: track number of calls

```
num_calls = 0
def pythagoras(a,b):
    global num_calls
    num_calls += 1
    return math.sqrt(a**2 + b**2)
```

- gives UnboundLocalError as num_calls is local to pythagoras
- declare num_calls to be global using a global statement

Long Integers

- Python uses 32 or 64 bit for int
- this limits the numbers that can be represented:
  - 32 bit: from -2**31 to 2**31–1
  - 64 bit: from -2**63 to 2**63–1

- for larger numbers, Python automatically uses long integers
- Example:

  fib(93) == 12200160415121876738L

- long integers work just like int, only with "L" as suffix
- Example: 2**64 + 2**64 == 2**65

  fib(100)**fib(20) # has 139016 digits :-o

Debugging Larger Datasets

- debugging larger data sets, simple printing can be too much

1. scale down the input – start with the first n lines; a good value for n is a small value that still exhibits the problem
2. scale down the output – just print a part of the output; when using strings and lists, slices are very handy
3. check summaries and types – check that type and len(…) of objects is correct by printing them instead of the object
4. write self-checks – include some *sanity checks*, i.e., test Boolean conditions that should definitely hold
5. pretty print output – even larger sets can be easier to interpret when printed in a more human-readable form

TUPLES

Tuples as Immutable Sequences

- tuple = immutable sequence of values
- like lists, tuples are indexed by integers

- tuples can be enclosed in parentheses "(" and ")"
- Example:

```
t1 = "D", "o", "u", "g", "l", "a", "s"
t2 = (65, 100, 97, 109, 115)
t3 = 42,          # or (42,) - but not (42)
```

- tuples can be created from sequences using tuple(iterable)
- Example:

```
t1 == tuple("Douglas")
tuple(["You", 2]) == ("You", 2)
```

Tuples as Immutable Sequences

- tuple = immutable sequence of values
- like lists, tuples are indexed by integers

- tuples can be accessed using indices and slices
- Example:
  ```
  t = "D", "o", "u", "g", "l", "a", "s"
  t[3] == "g"
  t[1:3] == ("o", "u")
  ```

- tuples cannot be changed, but they can be concatenated
- Example:
  ```
  u = ("d",) + t[1:]
  ```

Tuple Assignment

- remember, how to exchange two values:
  - Solution 1 (new variable): `z = y; y = x; x = z`
  - Solution 2 (parallel assign.): `x, y = y, x`
- now, we see that this is a tuple assignment
- assignment to a tuple is assignment to each tuple element
- works not only with other tuple, but with any sequence
- Example:

```
x, y, z = [23, 42, -3.0]
name = "Peter Schneider-Kamp"
first, last = name.split()
```