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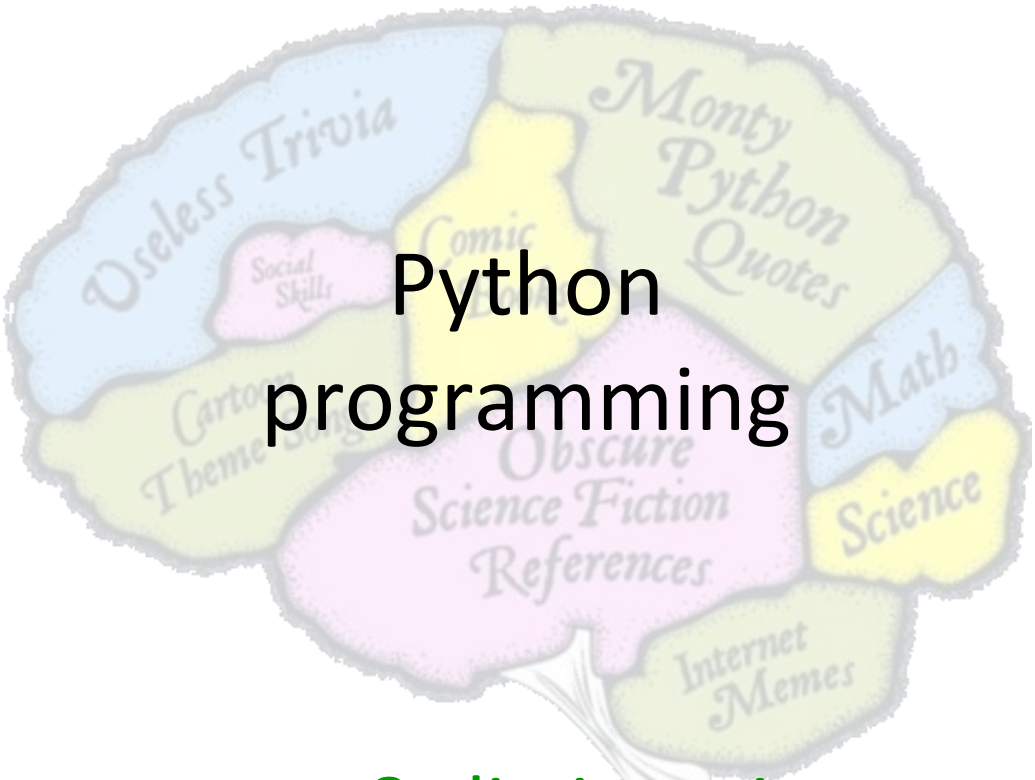

Python programming

sets & dictionaries

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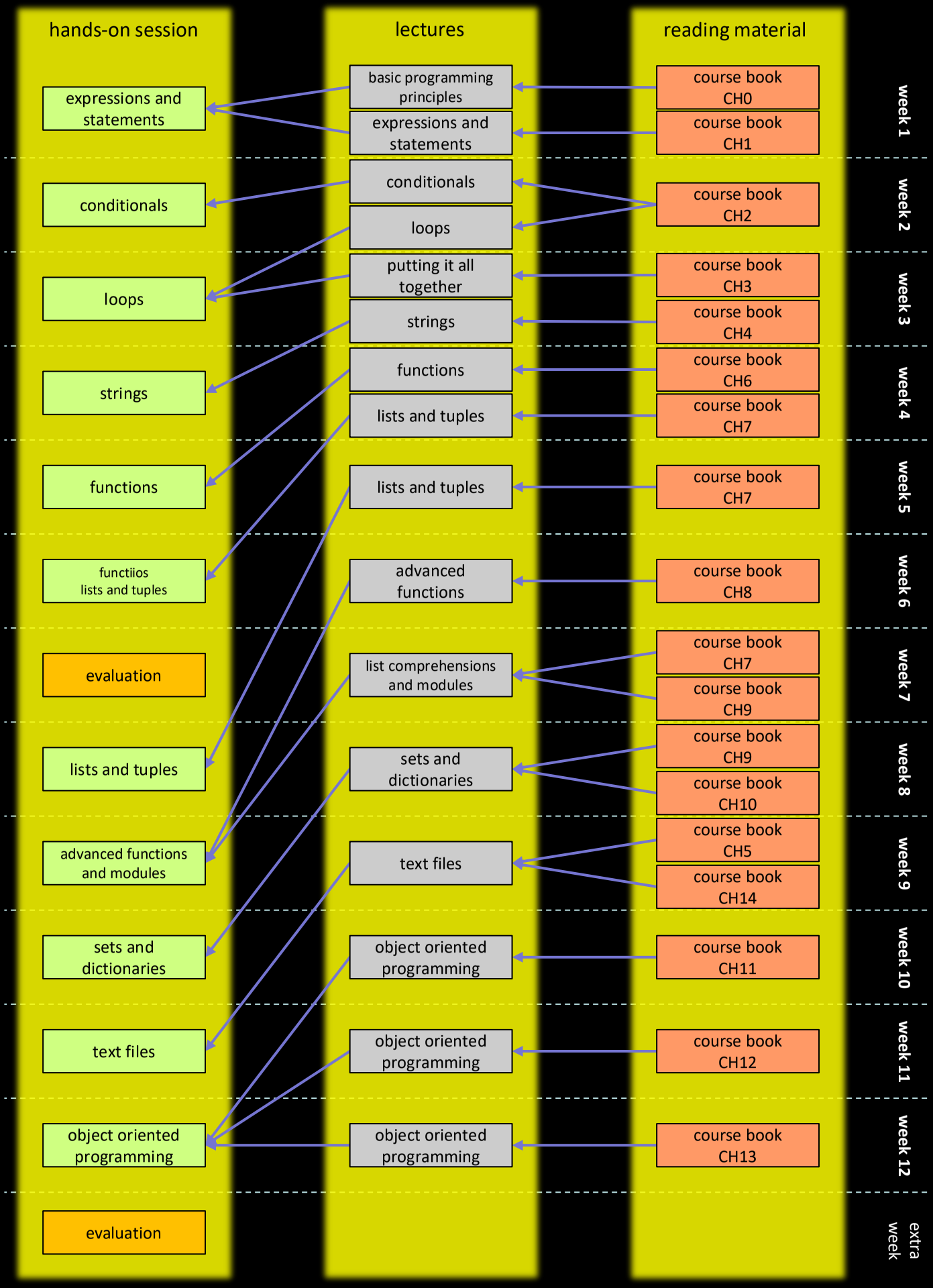
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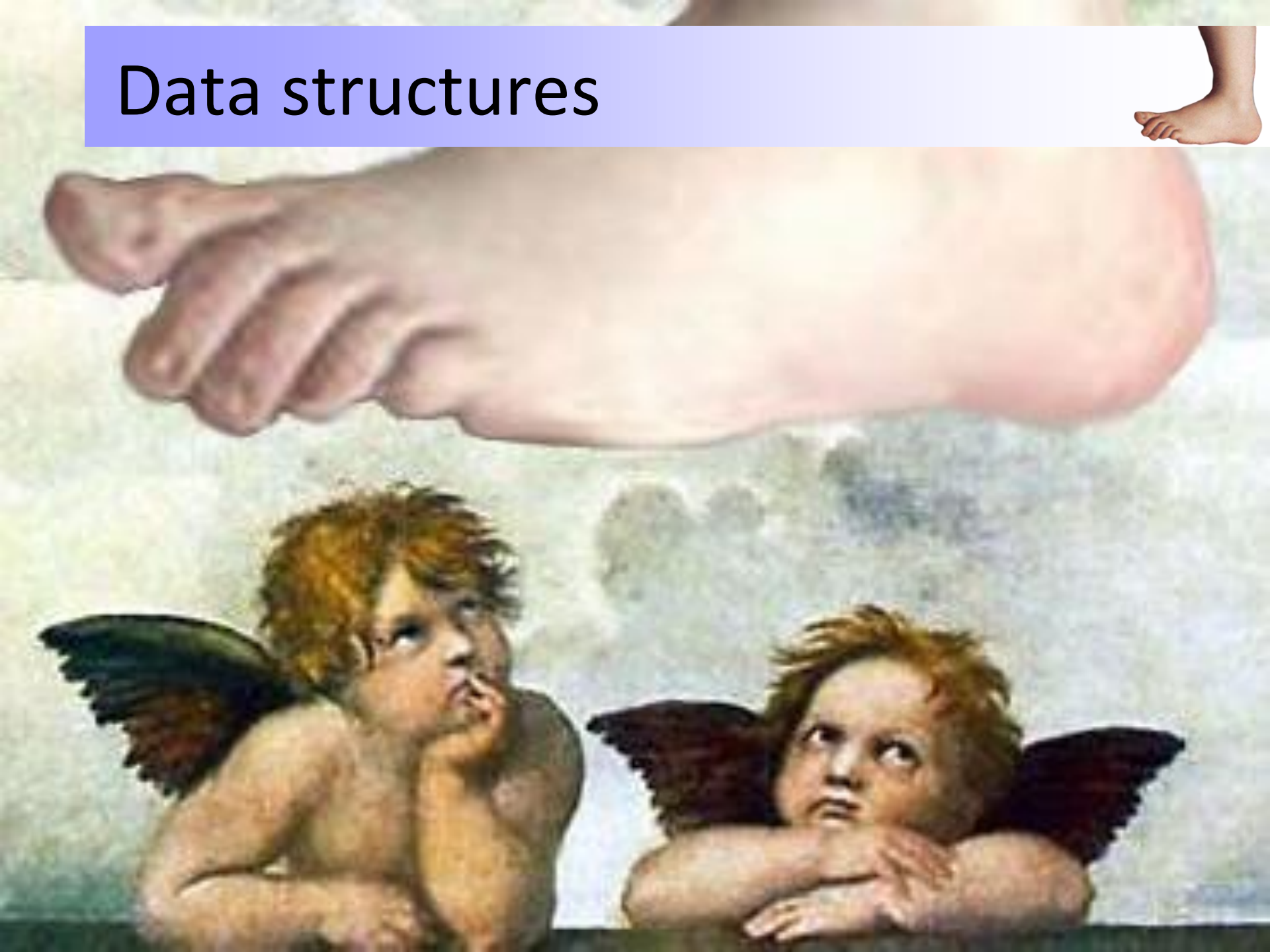
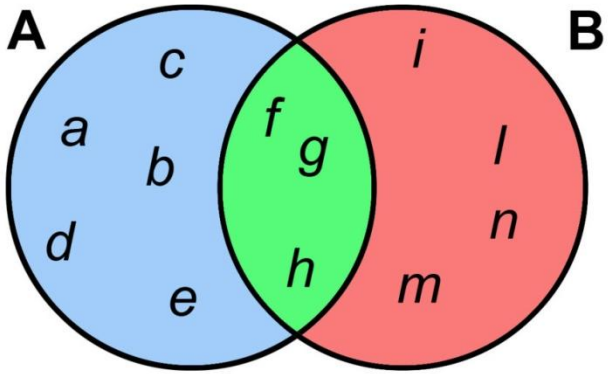
Data structures



Data structures

- the world is *not* only made of lists
  - just because it's the first data structure we have discussed, doesn't make it the right one for every task
  - this lecture introduces two other fundamental data structures
    - they will allow you to create programs that are simpler and more efficient
  - we will also discuss what "efficient" really means
- first new data structure: sets



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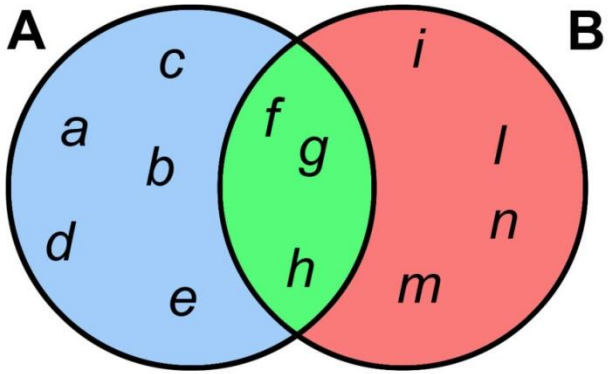
Sets

- **set**: unordered collection of distinct objects
  - unordered: objects are looked up by value, rather than location
  - distinct: any object appears at most once
- fundamental concept in mathematics
  - an afterthought in most programming languages
  - but essential in problem solving



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Sets

- **`set`** data type is built into Python
  - create a new set by calling **`set()`** or **`{e1, e2, …}`**
  - insert and remove objects, test for membership, …
  - **`set(i)`** converts *iterable object* **`i`** into a set

```
>>> vowels = set()
>>> for character in 'aieoeiaoaaeieou':
...     vowels.add(character)
...
>>> vowels
{'a', 'i', 'e', 'u', 'o'}
>>> set('unconsciousness')
{'c', 'e', 'i', 'o', 'n', 's', 'u'}
>>> {x // 2 for x in range(10)}
{0, 1, 2, 3, 4}
```

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Set operations

- like other objects, sets have methods
  - following methods change set *in place* and return value **None**

```
>>> lows = {0, 1, 2, 3, 4}
>>> lows.remove(0)              # remove an element
>>> lows
{1, 2, 3, 4}
>>> lows.add(3)                 # add an element
>>> lows.add(9)
>>> lows
{1, 2, 3, 4, 9}
>>> lows.clear()                # remove all elements
>>> lows
set()
```

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Set operations

- like other objects, sets have methods
  - following methods return new set

```
>>> tens = set(range(10))
>>> lows = {0, 1, 2, 3, 4}
>>> odds = {1, 3, 5, 7, 9}
>>> lows.difference(odds)                # difference
{0, 2, 4}
>>> lows
{0, 1, 2, 3, 4}
>>> odds.difference(lows)                # asymmetric
{9, 5, 7}
>>> lows.symmetric_difference(odds) # symmetric
{0, 2, 4, 5, 7, 9}
```

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Set operations

- like other objects, sets have methods
  - following methods return new set
  - can also be expressed using operators

```
>>> tens = set(range(10))
>>> lows = {0, 1, 2, 3, 4}
>>> odds = {1, 3, 5, 7, 9}
>>> lows - odds                          # difference
{0, 2, 4}
>>> lows
{0, 1, 2, 3, 4}
>>> odds - lows                          # asymmetric
{9, 5, 7}
>>> lows ^ odds                          # symmetric
{0, 2, 4, 5, 7, 9}
```

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Set operations

- like other objects, sets have methods
  - following methods return new set

```
>>> tens = set(range(10))
>>> lows = {0, 1, 2, 3, 4}
>>> odds = {1, 3, 5, 7, 9}
>>> lows.intersection(odds)          # intersection
{1, 3}
>>> lows.union(odds)                 # union
{0, 1, 2, 3, 4, 5, 7, 9}
>>> lows.issubset(tens)              # subset
True
>>> lows.issuperset(odds)           # superset
False
```

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Set operations

- like other objects, sets have methods
  - following methods return new set
  - can also be expressed using operators

```
>>> tens = set(range(10))
>>> lows = {0, 1, 2, 3, 4}
>>> odds = {1, 3, 5, 7, 9}
>>> lows & odds                          # intersection
{1, 3}
>>> lows | odds                          # union
{0, 1, 2, 3, 4, 5, 7, 9}
>>> lows <= tens                         # subset
True
>>> lows >= odds                         # superset
False
```

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Iterating sets

- sets are *iterable objects*

```
>>> monty_python = ['Graham Chapman', 'Eric Idle',
...                 'Terry Gilliam', 'Terry Jones',
...                 'John Cleese', 'Michael Palin']
>>> firstnames = [v for v, f in
...     [name.split() for name in monty_python]]
>>> firstnames
['Graham','Eric','Terry','Terry','John','Michael']
>>> unique_names = set(voornamen)
>>> for name in unique_names:
...     print(name, end=' ')
...
Michael John Graham Eric Terry
```

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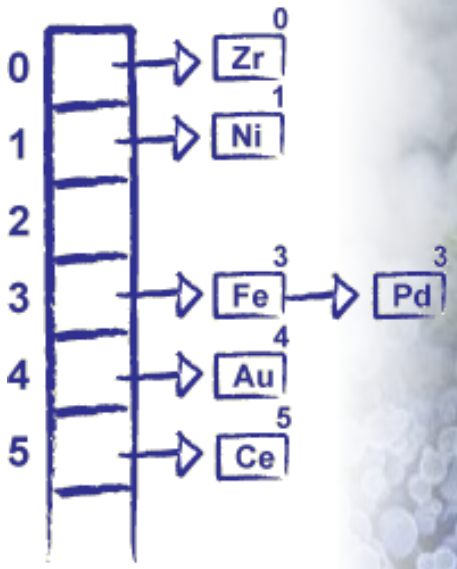
How set values are stored

- implementation goal
  - make lookup as quick as possible
  - without making insertion and removal expensive

- possible solution: *hash table*
  - compute a hash value for every object being inserted
  - store object at that location in list
  - collisions → objects grouped in sublist
  - good hash function → collisions will be rare



  - result: looking up an object takes *constant time*, regardless of how many objects are being stored

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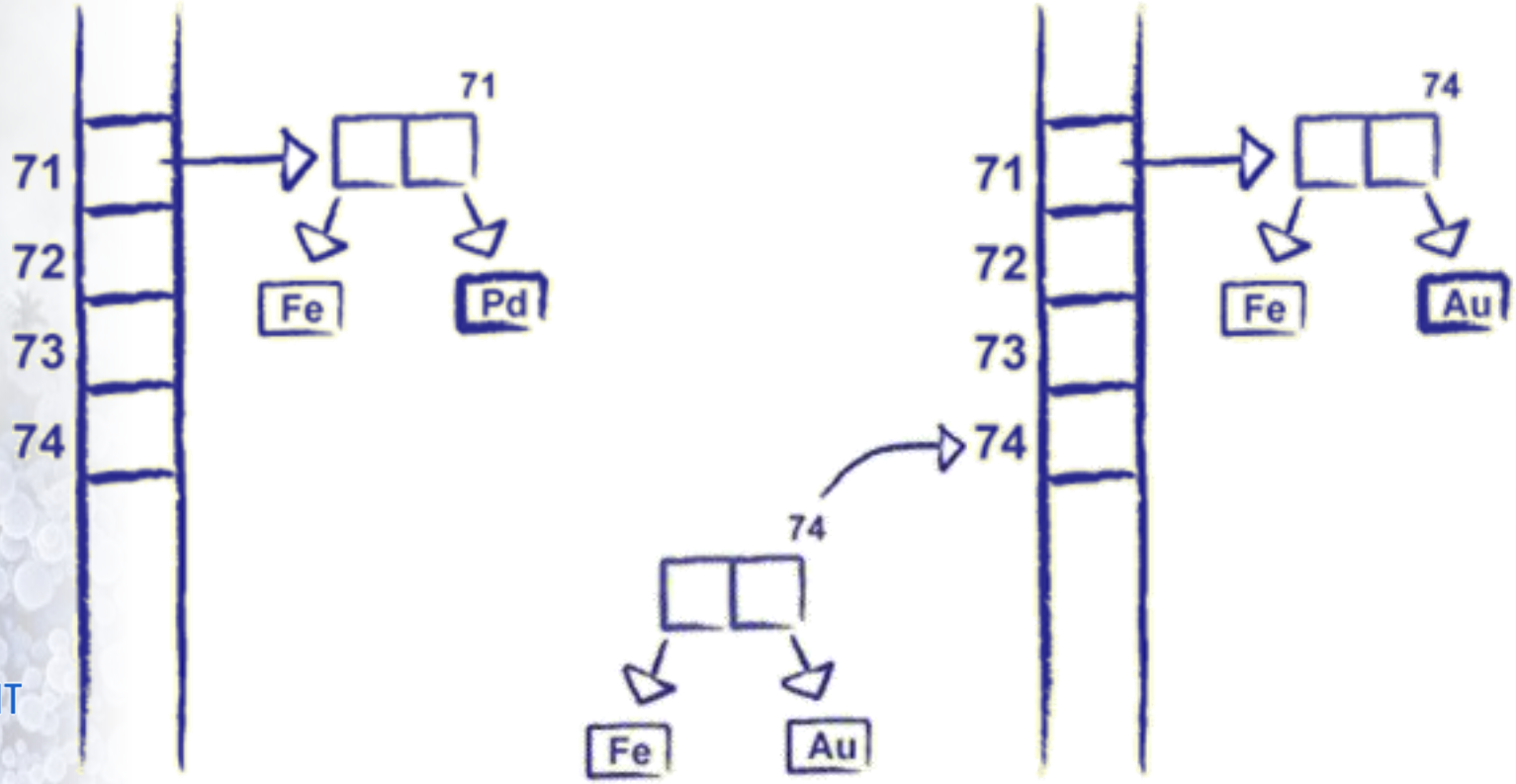
Immutability

- this only works if the hash value of an object never changes after it is inserted
  - otherwise the object will be stored in the wrong place



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Immutability

- this only works if the hash value of an object never changes after it is inserted
  - otherwise the object will be stored in the wrong place
  - Python therefore only allows sets to contain immutable objects
    - booleans, numbers, strings, tuples, …
    - … but **not** lists

```
>>> monty_python = set()
>>> monty_python.add('Graham Chapman')
>>> monty_python
{'Graham Chapman'}
>>> monty_python.add(('Eric', 'Idle'))
>>> monty_python
{'Graham Chapman', ('Eric', 'Idle')}
>>> monty_python.add(['Terry', 'Gilliam'])
TypeError: unhashable type: 'list'
```

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Immutability

- this only works if the hash value of an object never changes after it is inserted
  - otherwise the object will be stored in the wrong place
  - Python therefore only allows sets to contain immutable objects
    - this is one of the reasons tuples were invented
      - allows hashing of multi-part objects

```
>>> monty_python = set()
>>> monty_python.add('Graham Chapman')
>>> monty_python
{'Graham Chapman'}
>>> monty_python.add(('Eric', 'Idle'))
>>> monty_python
{'Graham Chapman', ('Eric', 'Idle')}
>>> monty_python.add(['Terry', 'Gilliam'])
TypeError: unhashable type: 'list'
```

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Frozen sets

- what about sets of sets?
  - sets themselves have to be mutable, so that values can be inserted and removed
- Python also provides "frozen" sets
  - no changes allowed after creation
  - they're almost always initialized from a collection of some kind

```
>>> monty_python = set()
>>> terries = frozenset(['Terry Jones', 'Terry Gilliam'])
>>> monty_python.add(terries)
>>> monty_python
set([frozenset(['Terry Gilliam', 'Terry Jones'])])
>>> terries.add('Michael Palin')
AttributeError: 'frozenset' object has no attribute 'add'
```

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A note on language design

- many languages (but not Python)
  allow mutable elements in sets
  - users are trusted no to modify them after insertion
  - rich source of hard-to-find-bugs
- some languages (but not Python)
  keep track of all sets an object is in
  - "move" them when their values change
  - makes all programs slow for the benefit of a few
- every software system
  contains tradeoffs like this

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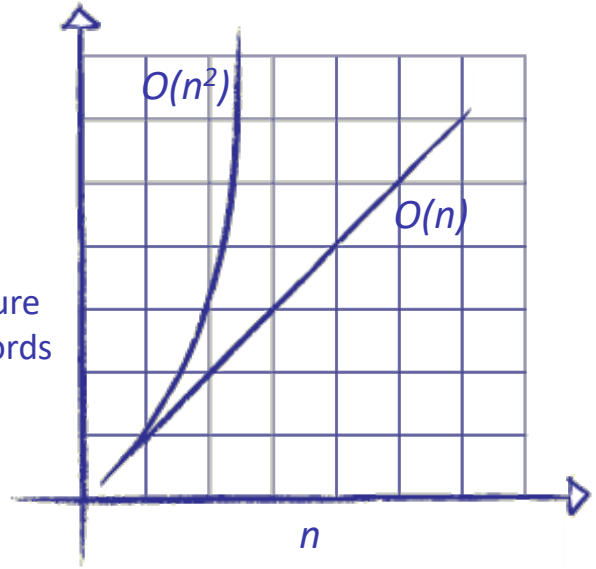
Efficiency

- so is using sets worthwhile?
  - construct data structure with *n* unique words

```
if word in words
```

  - `type(words) == list`
    - each check requires *n*/2 comparisons on average
    - building up those *n* unique words thus requires *n*(*n*+1)/4 comparisons
  - `type(words) == set`
    - build set with *n* unique words only takes *n* comparisons
    - difference is dramatic



build data structure with *n* unique words

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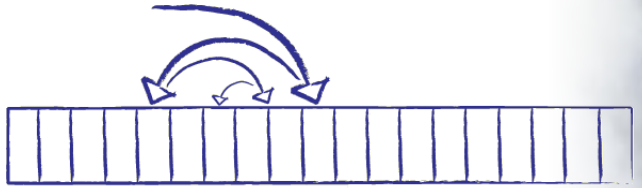
Efficiency

- so is using sets worthwhile?
  - construct data structure with *n* unique words

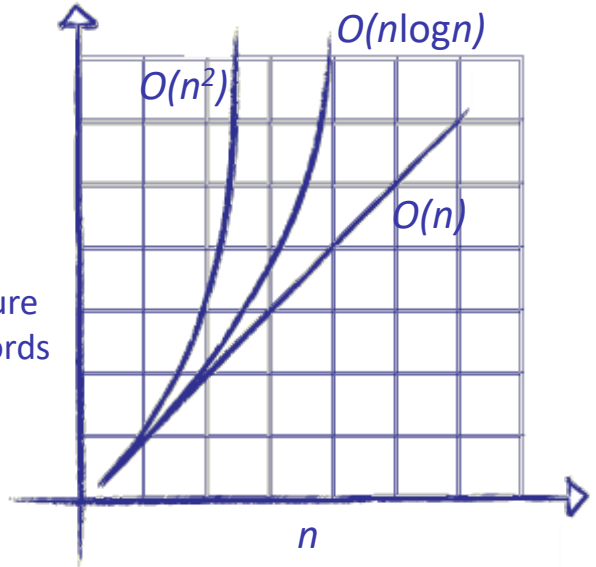
```
if word in words
```



binary search

  - `type(words) == list`
    - can get better performance if we keep list sorted
    - *k* checks is enough to find an object in a list of length 2^k
      - list containing *n* objects can be searched in $\log_2 n$ steps
      - building list of *n* unique words takes $n\log_2 n$ comparisons

build data structure with *n* unique words



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Algorithmic complexity

- algorithmic complexity
  - relationship between problem size and running time
  - usually described in terms of upper bounds
  - if $f(x) < kg(x)$ for large x and some constant k, then $f(x)$ is $O(g(x))$
- for example
  - $O(1)$ something that takes the same time regardless of the data size
  - $O(\log n)$ time grows as the logarithm of the data size
  - $O(n)$ time grows proportional to the number of objects
- storing unique words in a list is $O(n^2)$
  - $n(n+1)/4 = n^2/4 + n/4 \sim n^2$ as n grows large

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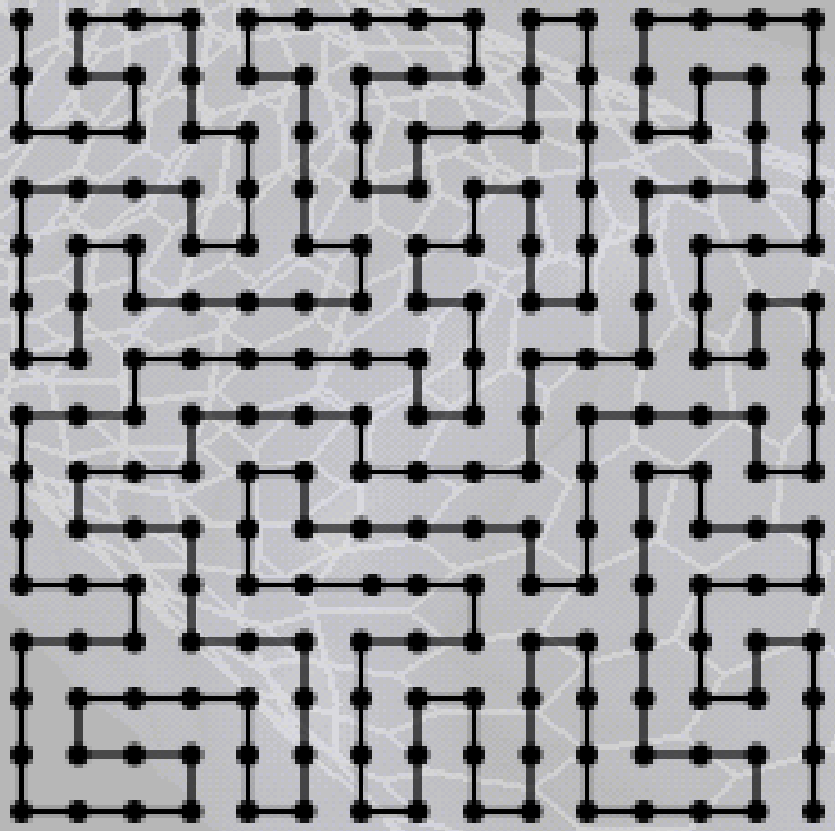
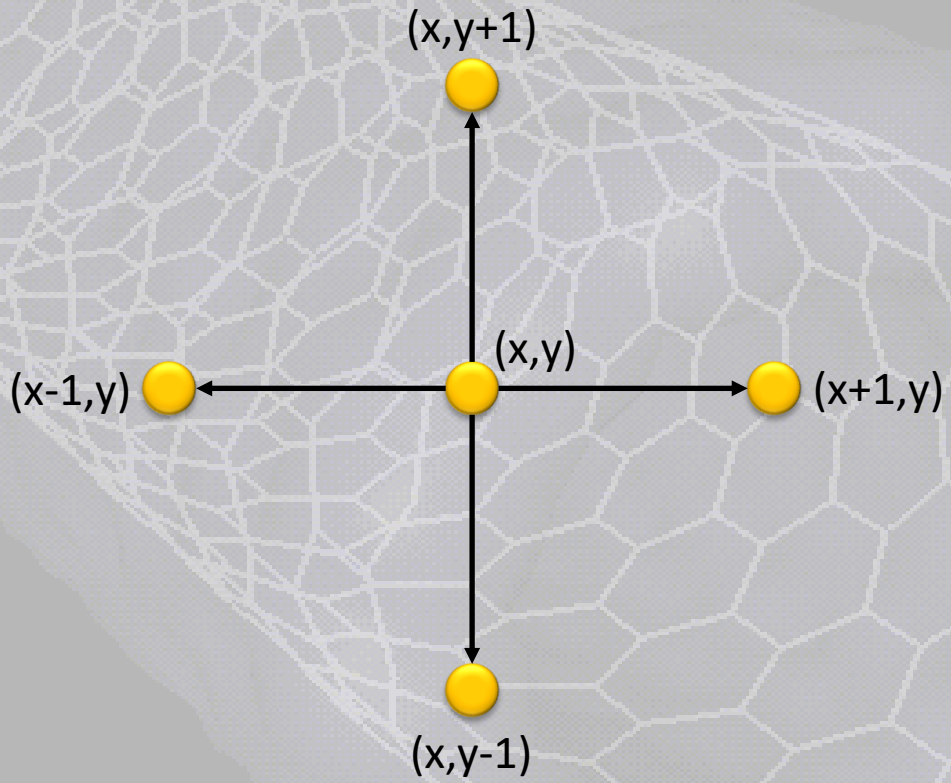
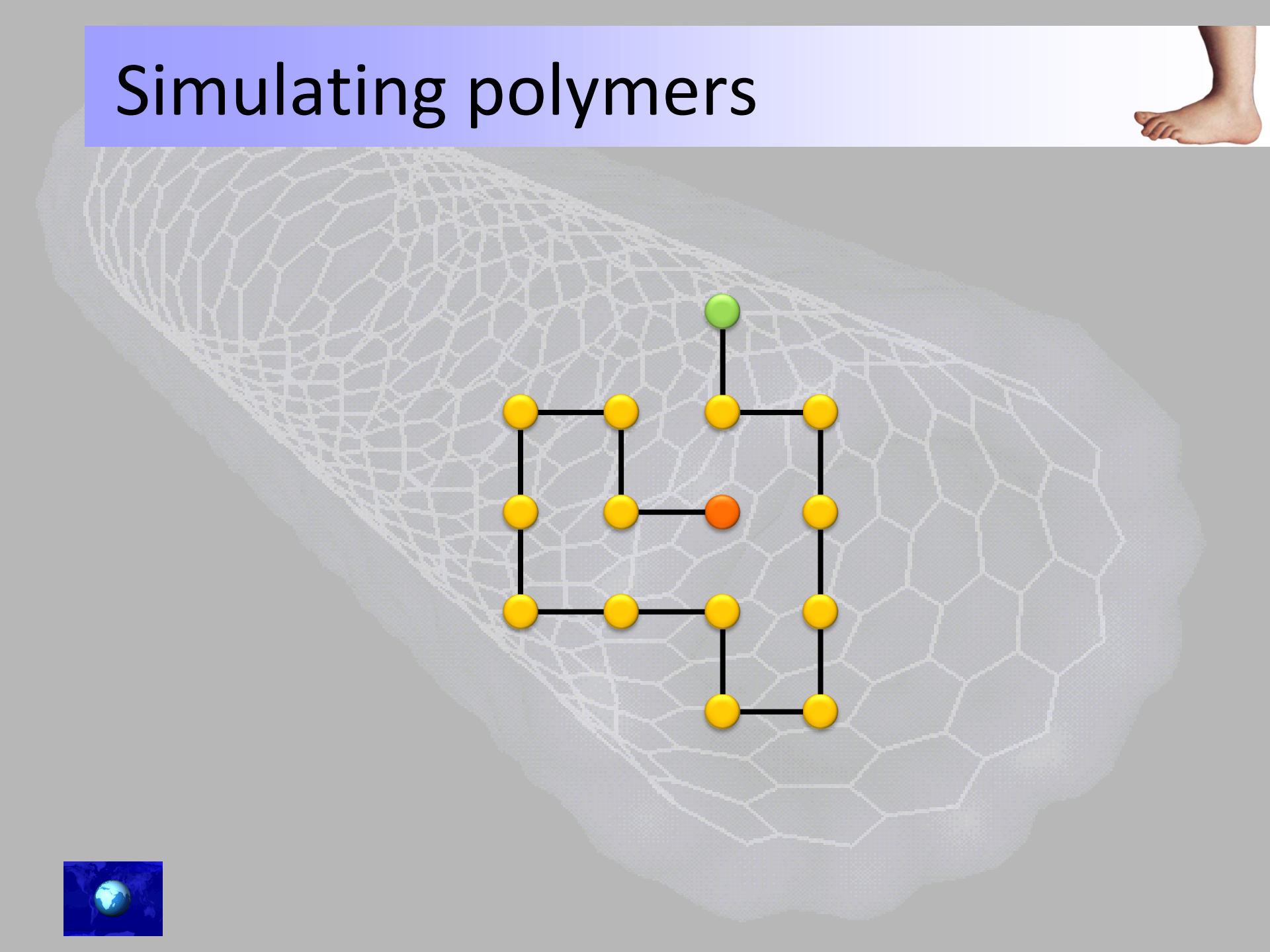
Simulating polymers



Simulating polymers

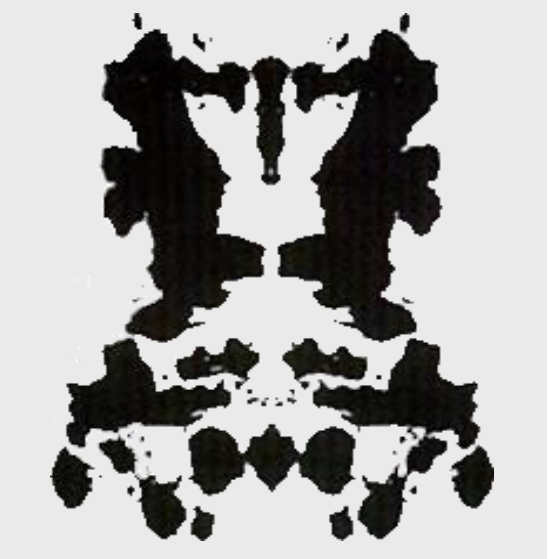


Simulating polymers



Dictionaries

Human associations



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Human associations

APPLE

What are you associating this word with ?

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Did you think about …

delicious

fruit

GREEN

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… or rather about?

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Logos after financial crisis

DOWNJONES

NOKIA
Disconnecting People

PLEASE BUY

2M

Will work for food

DEFAULT

citigroup

LG
Life's tough

CRISISLER

DELL

YAHOO?

BAD YEAR

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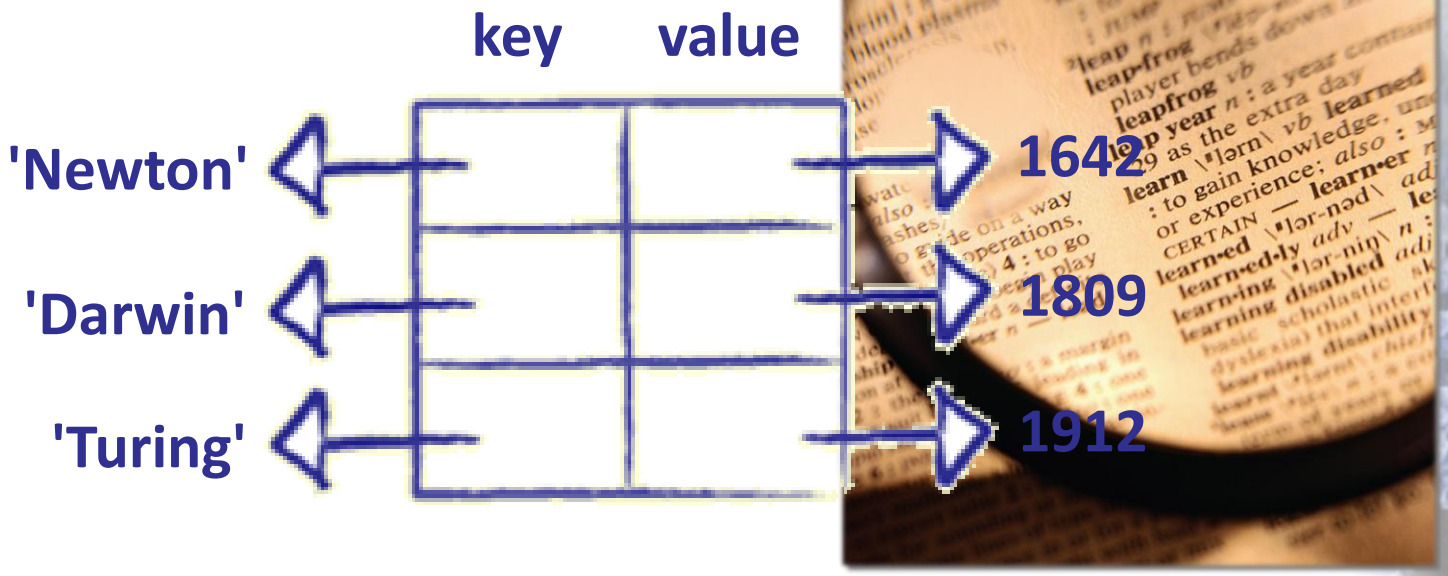
FIASCO SYSTEMS

Fail

Ferrari

Dictionaries

- **motivation**: store extra data with each element of a set
- **dictionary**: unordered mutable collection
  - not a sequence but a *mapping*
  - associates one *value* with each of its *keys*
  - synonyms: map, hash, associative array
  - often visualized as two-column table



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Creating and indexing

- create a dictionary by pytting key/value pairs inside **{** and **}**
  - empty dictionaries are written as **{}**
- look up value associated with a key using **[** and **]**
  - only existing keys can be accessed
  - just as you can't index elements of a list that aren't there

```
>>> birthday = {'Newton':1642, 'Darwin':1809}
>>> f"Darwin's birthday: {birthday['Darwin']}"
Darwin's birthday: 1809
>>> f"Newton's birthday: {birthday['Newton']}"
Newton's birthday: 1642
>>> f"Turing's birthday: {birthday['Turing']}"
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
KeyError: 'Turing'
```

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Updating

- associating an object to a key
  - key does not exist: create a new key/value pair
  - key does exist: overwrite value associated with key
- remove entry: **`del d[`*`key`*`]`**
  - only entries that are actually present can be removed

```
>>> birthday = {}
>>> birthday['Darwin'] = 1809
>>> birthday['Newton'] = 1942      # oops
>>> birthday['Newton'] = 1642
>>> birthday['Turing'] = 1912
>>> birthday
{'Turing': 1912, 'Darwin': 1809, 'Newton': 1642}
>>> del birthday['Turing']
>>> birthday
{'Darwin': 1809, 'Newton': 1642}
>>> del birthday['Faraday']
KeyError: 'Faraday'
```

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Testing membership

- **`k in d`**
  - tests whether a key **`k`** occurs in dictionary **`d`**
  - once again, inconsistent with behaviour of lists, but useful

```
>>> birthday = {'Newton':1642, 'Darwin':1809}
>>> for name in ['Newton', 'Turing']:
...     if name in birthday:
...         print(name, birthday[name])
...     else:
...         print(f'Who is {name} ?')
...
Newton 1642
Who is Turing ?
```

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Loops

- **`for s in d`**
  - iterates the keys of dictionary **`d`** (rather than its values)
  - different from lists, where **`for`** loops over the values, rather than the indices

```
>>> birthday = {
...       'Newton' : 1642,
...       'Darwin' : 1809,
...       'Turing' : 1912
... }
>>> for name in birthday:
...       print(name, birthday[name])
...
Turing 1912
Newton 1642
Darwin 1809
```

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Dictionary methods

- yes, dictionaries are objects too …

```
>>> birthday = {'Newton':1642,'Darwin':1809,'Turing':1912}
```

method	purpose	example	result
`clear`	empty the dictionary	`d.clear()`	returns `None`, but `d` is now empty
`get`	return the value associated with a key, or a default value if the key is not present	`d.get('x', 99)`	returns `d['x']` if `'x' in d`, or `99` if it is not
`keys`	return the dictionary's keys as a list; entries are guaranteed to be unique	`birthday.keys()`	`['Turing', 'Newton', 'Darwin']`
`values`	return the dictionary's values as a list; entries may or may not be unique	`birthday.values()`	`[1912, 1642, 1809]`
`items`	return a list of key/value pairs as an iterable of tuples	`birthday.items()`	`[('Turing', 1912), ('Newton', 1642), ('Darwin', 1809)]`
`update`	copy keys and values from one dictionary into another	`d2 = {}` `d2.update(d)`	

Dictionary methods

```
>>> birthday = {
...     'Newton' : 1642,
...     'Darwin' : 1809,
...     'Turing' : 1912
... }
>>> f'keys: {list(birthday.keys())}')
keys: ['Turing', 'Newton', 'Darwin']
>>> f'values: {list(birthday.values())}')
values: [1912, 1642, 1809]
>>> f'items: {list(birthday.items())}'
items: [('Turing', 1912), ('Newton', 1642), ('Darwin', 1809)]
>>> f'get: {birthday.get('Curie', 1867)}'
get: 1867
>>> temp = {'Curie':1867, 'Hopper':1906, 'Franklin':1920}
>>> birthday.update(temp)
>>> birthday
{'Curie': 1867, 'Darwin': 1809, 'Franklin': 1920,
 'Turing': 1912, 'Newton': 1642, 'Hopper': 1906}
>>> temp.clear()
>>> temp
{}
```

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Cryptograms

C	h		l	d							o	w	
Q	m	v	r	b	w	l	f		x	w	k	d	

f	a	s			r			k					
i	o	p	z	l	w		v	f		z	m	l	

	p		i		g	t			k	e	.		
p	c	w	v	f	x	z	v	y	l	.			

Histogram construction

observations1.py

```
# birds that need to be counted
birds = ['tern', 'goose', 'goose', 'hawk',
         'tern', 'goose', 'tern']

# build a dictionary of frequencies
observations = {}
for bird in birds:
    if bird in observations:
        # already seen, so increment by 1
        observations[bird] += 1
    else:
        # never seen before, so add to dictionary
        observations[bird] = 1

# display dictionary
print(observations)
```

```
{'hawk': 1, 'goose': 3, 'tern': 3}
```

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A slight simplification

observations2.py

```
# birds that need to be counted
birds = ['tern', 'goose', 'goose', 'hawk',
         'tern', 'goose', 'tern']

# build a dictionary of frequencies
observations = {}
for bird in birds:
    # dict.get: fetch bird observations
    # with default value 0
    observations[bird] = observations.get(bird, 0) + 1



# display dictionary
print(observations)
```

```
{'hawk': 1, 'goose': 3, 'tern': 3}
```

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Imposing order

- a dictionary's keys are unordered (~ set elements)
  - remember, sets randomize (hash) their elements for fast lookup
  - so, to print counts in alphabetic order
    - get the list of keys
    - sort that list
    - loop over it

```
# display dictionary in alphabetic order
birds = list(observations.keys())
birds.sort()
for bird in birds:
    print(bird, observations[bird])
```

```
goose 3
hawk 1
tern 3
```

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Imposing order

- a dictionary's keys are unordered (~ set elements)
  - remember, sets randomize (hash) their elements for fast lookup
  - so, to print counts in alphabetic order
    - get the list of keys
    - sort that list
    - loop over it

```
# display dictionary in alphabetic order


for bird in sorted(observations):
    print(bird, observations[bird])
```

```
goose 3
hawk 1
tern 3
```

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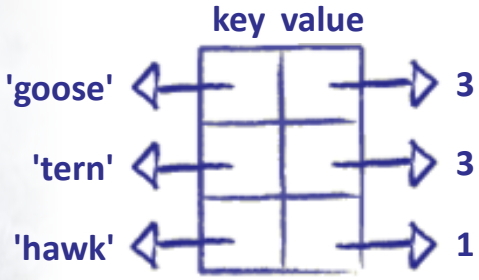
Inverting a dictionary

- but how to print in order of frequency ?
  - need to invert dictionary: swap keys and values



observations

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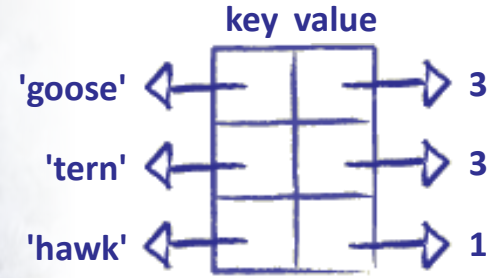
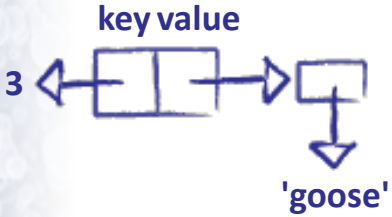
Inverting a dictionary

- but how to print in order of frequency ?
  - need to invert dictionary: swap keys and values
  - there might be collisions, since values aren't necessarily unique
    - what is the inverse of `{'a':1, 'b':1, 'c':1}` ?



observations



inverse

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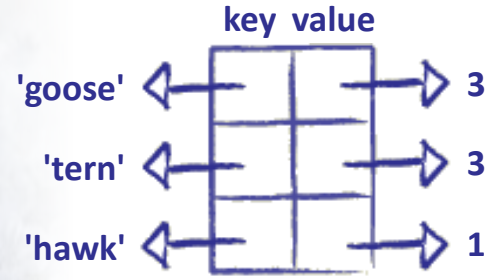
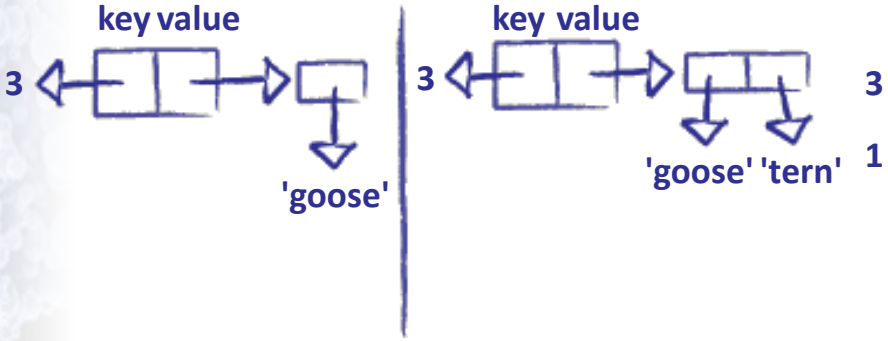
Inverting a dictionary

- but how to print in order of frequency ?
  - need to invert dictionary: swap keys and values
  - there might be collisions, since values aren't necessarily unique
    - what is the inverse of `{'a':1, 'b':1, 'c':1}` ?
  - solution: store a list of values instead of just a single value
    - use **`dict.get(key, [])`** instead of **`dict.get(key, 0)`**



observations

inverse



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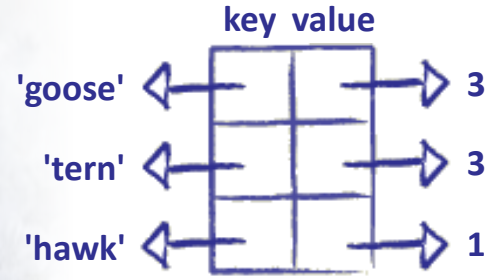
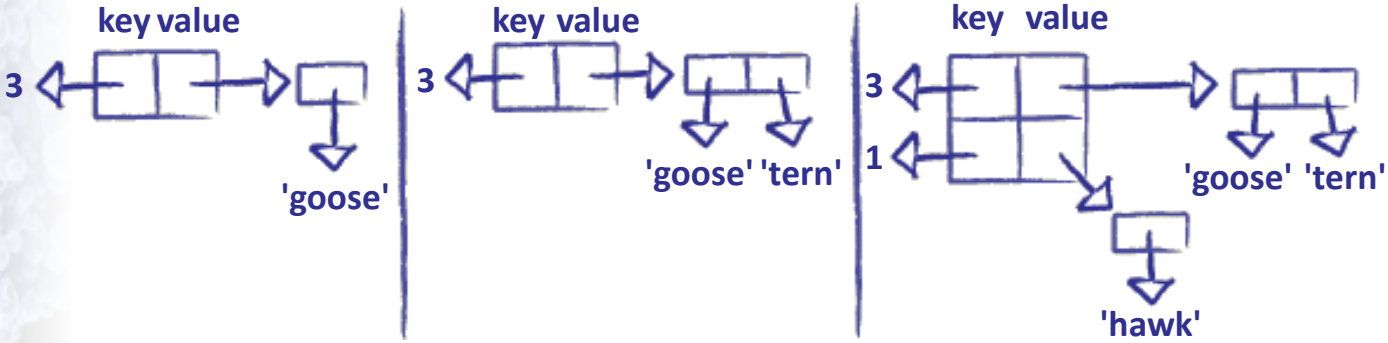
Inverting a dictionary

- but how to print in order of frequency ?
  - need to invert dictionary: swap keys and values
  - there might be collisions, since values aren't necessarily unique
    - what is the inverse of `{'a':1, 'b':1, 'c':1}` ?
  - solution: store a list of values instead of just a single value
    - use `dict.get(key, [])` instead of `dict.get(key, 0)`



observations

inverse



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Inverting a dictionary

- but how to print in order of frequency ?
  - need to invert dictionary: swap keys and values

```
# invert dictionary
inverse = {}
for key, value in observations.items():
    birds = inverse.get(value, [])
    birds.append(key)
    inverse[value] = birds

# display dictionary in sorted order
for count in sorted(inverse):
    print(count, inverse[count])
```

```
1 ['hawk']
3 ['goose', 'tern']
```

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Another way to do it

- but how to print in order of frequency ?
  - need to invert dictionary: swap keys and values

```
# invert dictionary
inverse = {}
for key, value in observations.items():
    if value not in inverse:
        inverse[value] = []
    inverse[value].append(key)

# display dictionary in sorted order
for count in sorted(inverse):
    print(count, inverse[count])
```

```
1 ['hawk']
3 ['goose', 'tern']
```

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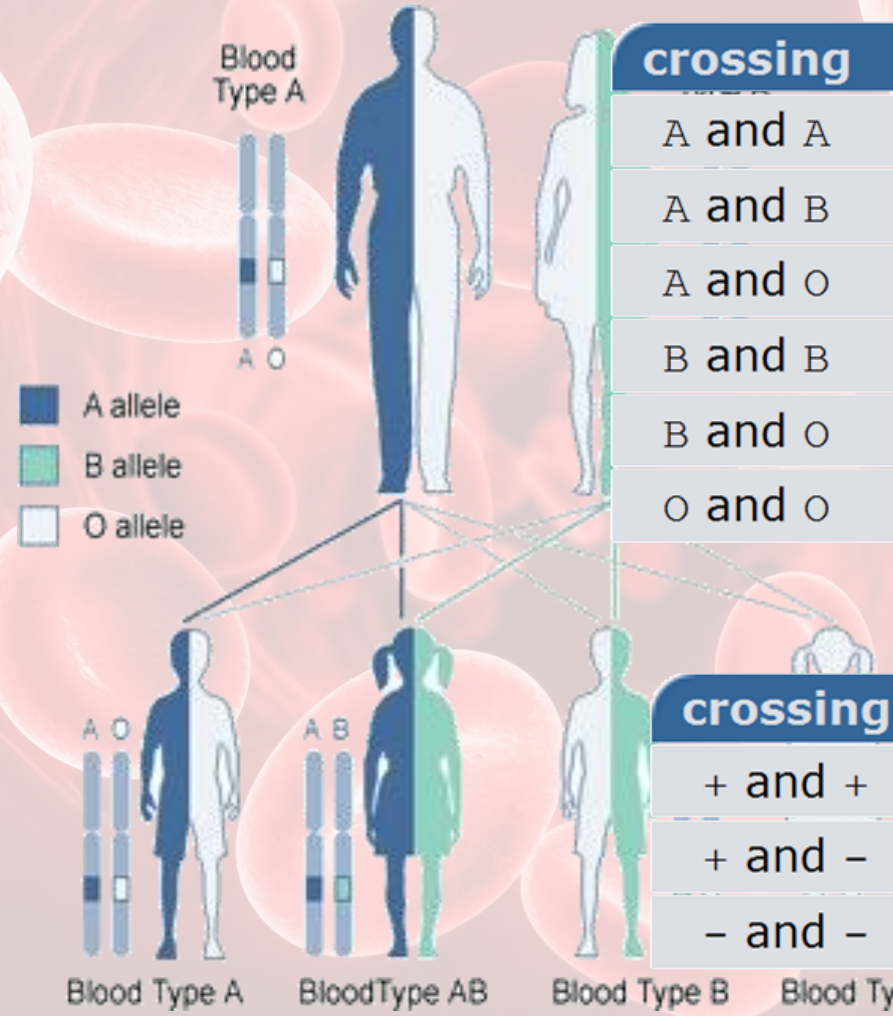
Blood types



crossing	ABO blood group
A and A	A
A and B	AB
A and O	A
B and B	B
B and O	B
O and O	O

crossing	Rhesus factor
+ and +	+
+ and –	+
– and –	–

Formatting strings with dicts

- complex string formatting can be hard to read
  - especially if one value needs to be used several times
  - use keyword arguments with string method **`format`**
    - use **`{key}`** inside format string to identify what has to be substituted at this position

```
birthday = {'Newton':1642, 'Darwin':1809, 'Turing':1912}
opmaak = '{name}: {year}'
for name, year in birthday.items():
    print(opmaak.format(name=name, year=year))
```

```
Turing: 1912
Newton: 1642
Darwin: 1809
```

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Additional keyword arguments

- the ** before **keywords** means
  - put additional keyword arguments in dictionary **keywords**
- supports functions with variable number of arguments

```
client : John Cleese
shopkeeper : Michael Palin
sketch : Cheese Shop Sketch
-- Do you have any Limburger ?
-- I'm sorry, we're all out of Limburger
```

```
def cheeseshop(cheese, **keywords):
    print(f'-- Do you have any {cheese} ?')
    print(f"-- I'm sorry, we're all out of {cheese}")
    print('-' * 40)
    for key in sorted(keywords):
        print(f'{key}: {keywords[key]}')

cheeseshop(
    'Limburger',
    client='John Cleese',
    shopkeeper='Michael Palin',
    skecth='Cheese Shop Sketch'
)
```

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Additional positional arguments

- the * before **arguments** means
  - put additional positional arguments in tuple **arguments**
- there may be only one * per functie

```
def cheeseshop(cheese, *arguments, **keywords):
    print(f"-- Do you have any {cheese}?")
    print("I'm sorry, we're all out of {cheese}")
    for argument in arguments:
        print(argument)
    print('-' * 40)
    for key in sorted(keywords):
        print(f'{key}:{keywords[key]}')
```

```
cheeseshop(
    'Limburger',
    "It's very runny, sir.",
    "It's really very, VERY runny, sir.",
    client='John Cleese',
    shopkeeper='Michael Palin',
    skecth='Cheese Shop Sketch'
)
```

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Homework (next lecture)

- course book
  - read chapter 5 (files and exceptions)
  - read chapter 14 (files and exceptions II)
- classroom exercises (series 09)
  - Alphabetic encoding
  - Cellophane
  - World Cup soccer

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Questions or remarks?

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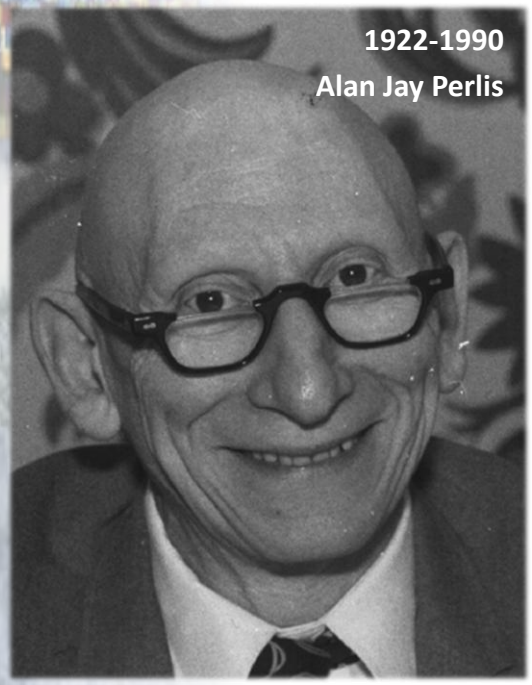
The sky is the limit…



"If a listener nods his head when you're explaining your program, wake him up."

— Alan J. Perlis

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