2024

TdP

Python data structures and collections

A wide choice of containers for your data

Fulvio Corno
Giuseppe Averta
Carlo Masone
Francesca Pistilli

https://realpython.com/python-collections-module/
https://realpython.com/python-data-structures/
https://docs.python.org/3/library/collections.html
https://docs.python.org/3/library/datatypes.html

Data structures

- The Python language offers very powerful built-in data structures
  - `list` and `tuple`
  - `set`
  - `dict`
- They can be used to store and search information, and each is specialized to support some use cases
- Additional data structures are available in the standard library, to cover other use cases

Overview

Dictionaries, Maps, Hash Tables	Array Data Structures	Records, Structs, Data Transfer Objects	Sets, Multisets	Stacks (LIFO)	Queues (FIFO)	Priority Queues
• `dict` • `OrderedDict` • `defaultdict` • `ChainMap` • `MappingProxyType`	• `list` • `tuple` • `array` • `str` • `bytes` • `bytearray`	• `dict` • `tuple` • `class` • `dataclass` • `namedtuple`, `NamedTuple` • `Struct`	• `set` • `frozenset` • `Counter`	• `list` • `deque` • `LifoDeque`	• `list` • `deque` • `Queue`	• `list` • `heapq` • `PriorityQueue`

Some types are extremely versatile (list, dict)

Some types are “improvements” of basic types

Some types are very specialized (e.g. for parallel computation)

Remember…

Schema sinottico delle principali operazioni sui contenitori					
Operation	`str`	`list`	`tuple`	`set`	`dict`
Create	`"abc" 'abc'`	`[a, b, c]`	`(a, b, c)`	`{a, b, c}`	`{a:x, b:y, c:z}`
Create empty	`"" ''`	`[] list()`	`() tuple()`	`set()`	`{} dict()`
Access `i`-th item	`s[i]`	`l[i]`	`u[i]`		`d[k]` `d.get(k,default)`
Modify `i`-th item		`l[i]=x`			`d[k]=x`
Add one item (modify value)		`l.append(x)`		`t.add(x)`	`d[k]=x`
Add one item at position (modify value)		`l.insert(i,x)`			
Add one item (return new value)	`s+'x'`	`l+[x]`	`u+(x,)`		
Join two containers (modify value)		`l.extend(l1)`		`t.update(t1)`	
Join two containers (return new value)	`s+s1`	`l+l1`	`u+u1`	`t.union(t1) t|t1`	
Does it contain a value?	`x in s`	`x in l`	`x in u`	`x in s`	`k in d` (search keys) `x in d.values()` (search values)
Where is a value? (returns index)	`s.find(x)` `s.index(x)`	`l.index(x)`	`u.index(x)`		
Delete an item, by index		`l.pop(i) l.pop()`			`d.pop(k)`
Delete an item, by value		`l.remove(x)`		`t.remove(x)` `t.discard(x)`	
Sort (modify value)		`l.sort()`			
Sort (return new **list**)	`sorted(s)`	`sorted(l)`	`sorted(u)`	`sorted(t)`	`sorted(d)` (keys) `sorted(d.items())`

https://polito-informatica.github.io/Materiale/CheatSheet/Python_Cheat_Sheet-3.2.pdf

Dictionaries

- Map a “key” to a “value”
  - Key: unique value of a hashable type
  - Value: any object
- `dict`
  - Very efficient, constant time for insertion, search, deletion
  - Retains insertion order of elements
  - Has built-in syntax `{ key: val }` for creation

`d[key] = value`	Set a new value for a key
`d[key]`	Retrieve value from the key. May raise `KeyError`
`d.clear()`	Clears a dictionary.
`d.get(key, default)`	Returns the value for a key if it exists in the dictionary. Otherwise, returns a default value
`d.items()`	Returns a list of key-value pairs in a dictionary.
`d.keys()`	Returns a list of keys in a dictionary.
`d.values()`	Returns a list of values in a dictionary.
`d.pop(key, default)`	Removes a key from a dictionary, if it is present, and returns its value. Otherwise, returns a default value
`d.popitem()`	Removes the last key-value pair from a dictionary.
`d.update(obj)`	Merges a dictionary with another dictionary

“Hashable”?

- A hashable object
  - Has a hash value that never changes during its lifetime (defines `__hash__`)
  - It can be compared to other objects (defines `__eq__`)
- Hashable objects that compare as equal must have the same hash value
  - $a == b \Rightarrow hash(a) == hash(b)$
- Note: instances of user-defined classes are hashable by default. They all compare unequal (except with themselves), and their hash value is derived from their id(). You can redefine this behavior

Hash functions

- A hash function is a function that maps any object into an integer number (over 64 bit)
- It is needed to quickly discover if two objects are
  - Surely different
  - Very likely equal
- Used in the hash() function and internally in set, frozenset and dict.

https://docs.python.org/3/reference/datamodel.html#object.__hash__

Other dictionaries

- `collections.defaultdict`
  - A class that automatically provides a default value for non-existent keys
  - Requires a “factory” function to build the default values: list, str, int, … or custom
  - `d = collections.defaultdict(int)`
- `types.MappingProxyType`
  - Creates a “read-only” dictionary, without copying it
  - `readonly_d = types.MappingProxyType(normal_d)`
  - All modifications will generate an exception
    - `TypeError: 'mappingproxy' object does not support item assignment`

Main Array types

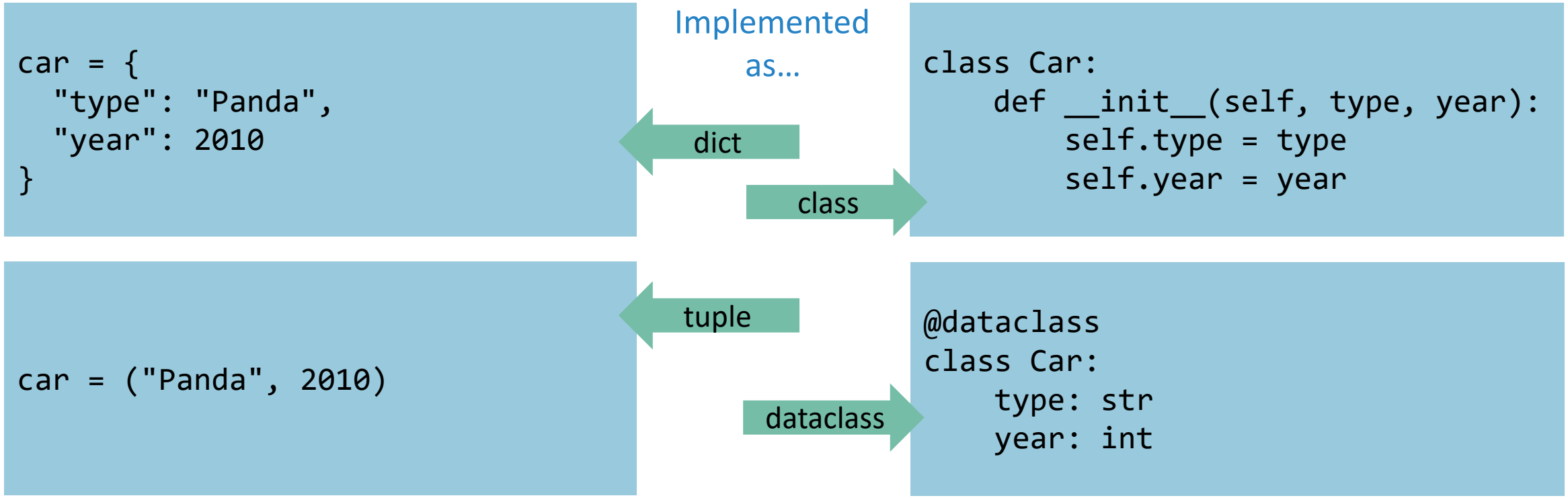
- `list`
  - The most versatile one, mutable ordered sequence of objects of any value
  - Indexed by number (0…len()-1)
- `tuple`
  - An immutable version of a list: elements cannot be added, removed nor replaced
    - But… elements can be mutated, if they are mutable
  - Hashable, if its elements are hashable
- `str`
  - An array of Unicode Characters
  - Immutable

Specialized Array types

- `array.array`
  - Implemented in C as an array of elements of the same basic type (byte, int, float)
  - The type is declared at the time of creation
    - `arr = array.array("f", (1.0, 1.5, 2.0, 2.5))`
  - Uses less memory than normal lists, but less versatile
- `bytes`: Immutable Arrays of Single Bytes
- `bytearray`: Mutable Arrays of Single Bytes

Records

- A record is a collection of data of different types, and different meanings, grouped together to represent a single high-level information



Specialized record types

- `collections.namedtuple`
  - A tuple whose indices are not integers, but attributes (like objects)

```
Car = collections.namedtuple("Car", ("name", "year"))
c1 = Car("Panda", 2010)
c1.name  # ‘Panda’
```

  - Attribute values are immutable
- `typing.NamedTuple`
  - Uses a syntax similar to dataclasses

```
class Car(typing.NamedTuple):
    name: str
    year: int
```

Sets

- `set`
  - Mutable container of hashable objects.
  - Duplicates are not allowed.
  - Simple syntax: `{ 1, 2, 3 }`
  - Supports set-theory operations
- `frozenset`
  - An immutable version of a set: once created, its elements cannot be changed
  - Since it's hashable, it may be used as a key in a dictionary (or as an element in a set)

Multisets and `collections.Counter`

- The Counter class is useful for computing and storing frequencies of items (i.e. counts of elements that may appear more than once in a set)

```
cnt = collections.Counter([1, 2, 3, 3, 4, 5, 1, 8, 3, 5, 2, 2, 3, 8])
Counter({3: 4, 2: 3, 1: 2, 5: 2, 8: 2, 4: 1})
```

- Great for statistics, frequency counting, histogram, duplicate detection, ranking, …
- Internally stored as a defaultdict, with keys at the set elements, and values as the occurrence counts, with default value = 0

https://docs.python.org/3/library/collections.html#counter-objects

Creating `Counter` objects

- `c = Counter()` `# a new, empty counter`
- `c = Counter('gallahad')` `# a new counter from an iterable`
- `c = Counter(['eggs', 'ham'])` `# a new counter from an iterable`
- `c = Counter({'red': 4, 'blue': 2})` `# a new counter from a mapping`
- `c = Counter(cats=4, dogs=8)` `# a new counter from keyword args`

- Manually increasing counts:

```
for word in ['red', 'blue', 'red', 'green', 'blue', 'blue']:
    cnt[word] += 1
```

equivalent to

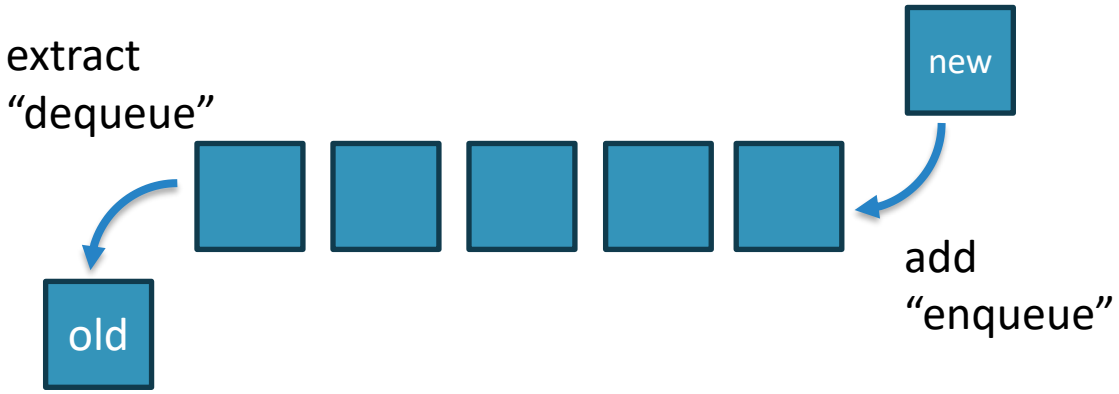
```
cnt = Counter(['red', 'blue', 'red', 'green', 'blue', 'blue'])
```

What can I do with a `Counter`?

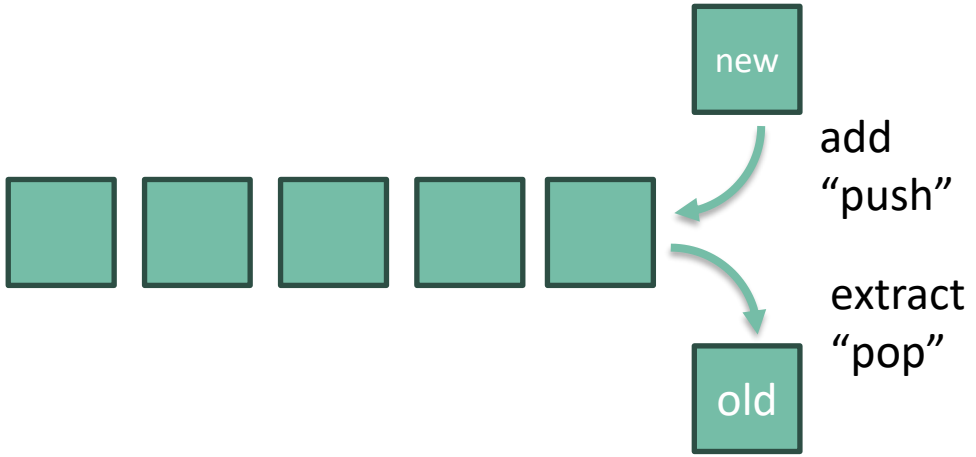
```
• c.most_common(n)                  # the ‘n’ (default: all) most common items
• c.total()                         # total of all counts
• list(c)                           # list unique elements

• set(c)                            # convert to a set
• dict(c)                           # convert to a regular dictionary
• c.items()                         # convert to a list of (elem, cnt) pairs
• c.elements()                      # return a list [elem, …] with repetitions
• Counter(dict(list_of_pairs))      # convert from a list of (elem, cnt) pairs
• c.most_common()[:-n-1:-1]         # n least common elements
• +c                                # remove zero and negative counts
• c.clear()                         # reset all counts
```

Queues and Stacks



FIFO Queue – First-In First-Out



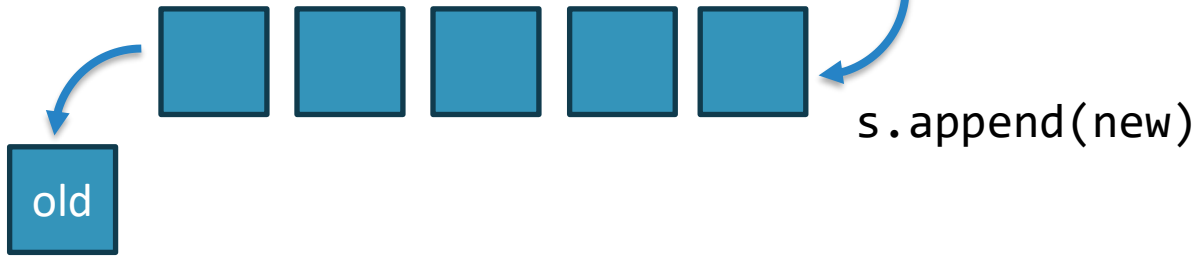
LIFO Stack – Larst-In First-Out

List implementations

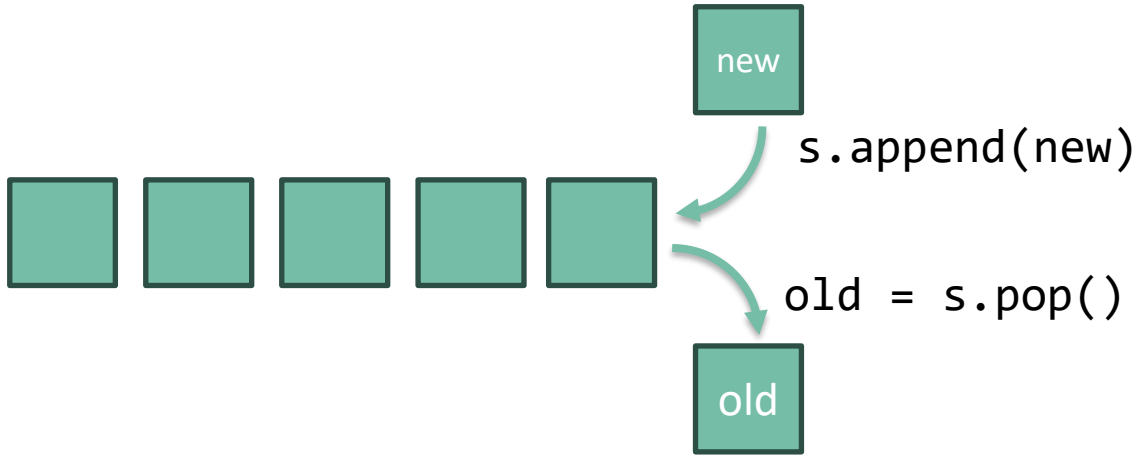
```
s = list()
```

⚠ slow!

```
old = s.pop(0)
```



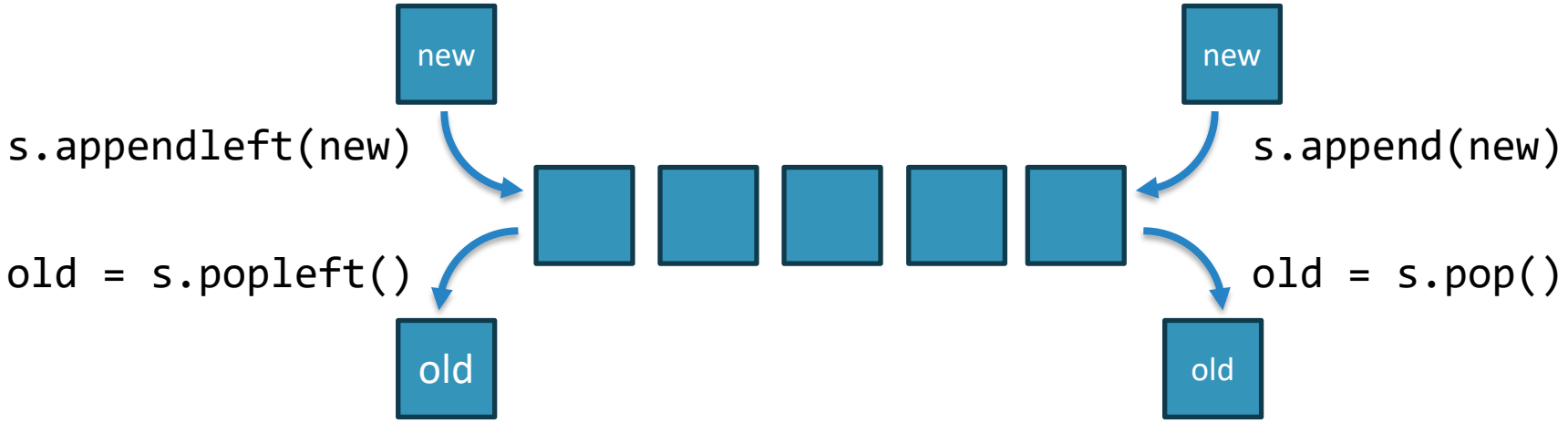
FIFO Queue – First-In First-Out



LIFO Stack – Larst-In First-Out

deque: double-ended queue

```
s = collections.deque()
```



All operations have the same efficiency

https://docs.python.org/3/library/collections.html#deque-objects

Using a **deque**

As a FIFO Queue

- `append` and `popleft`
  - Most popular choice
- `appendleft` and `pop`
  - Also possible, same efficiency

As a LIFO Stack

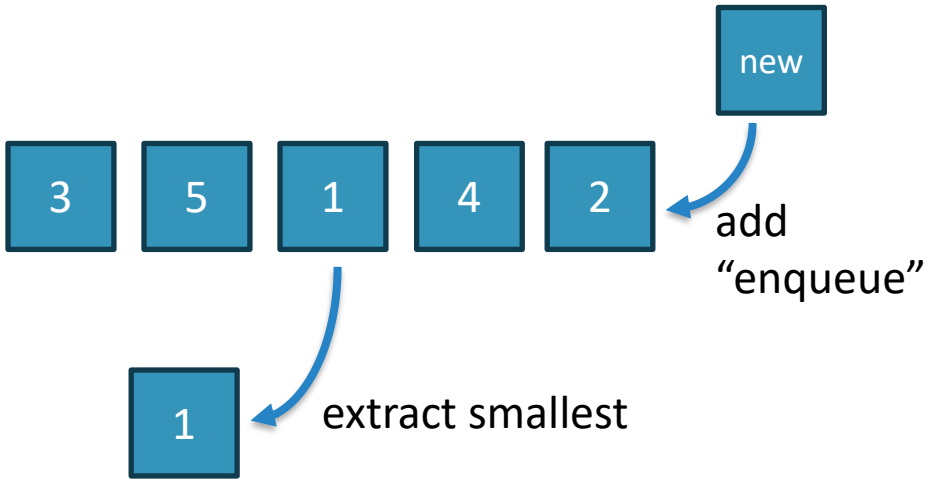
- `append` and `pop`
  - Most popular choice
  - Might use a list, instead
- `appendleft` and `popleft`
  - Also possible, same efficiency

Other **deque** methods

`d = deque()`	New empty deque
`d = deque(iterable)`	Deque from list
`d = deque(maxlen=N)`	Hosts max N elements, discards older ones if more are added
`d.extend(iterable)`	Adds list of elements at end
`d.extendleft(iterable)`	Adds list of elements at beginning
`d.rotate(n)`	Rotate elements by n steps
`d[i]`	Access element (slower than lists)
`d.index(x), d.insert(i, x), d.remove(x), d.reverse()`	Same as lists

https://docs.python.org/3/library/collections.html#deque-objects

Priority Queues



- Elements are added in any order
- Elements are removed according to their “priority”
- Priority is determined by the sorting order of the elements
- Often, we create a tuple:
  - `(priority, value)`

Priority queues in Python

heapq – uses plain lists

- `h = []`
- `h = heapify(iterable)`
- `heapq.heappush(h, x)`
- `x = heapq.heappop(h)`

`queue.PriorityQueue`

- `q = queue.PriorityQueue()`
- `q.qsize()`
- `q.empty()`
- `q.full()`
- `q.put(x)`
- `x = q.get_nowait()`

Items x must be comparable (implement __lt__)

License

- These slides are distributed under a Creative Commons license “**Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0)**”
- **You are free to:**
  - **Share** — copy and redistribute the material in any medium or format
  - **Adapt** — remix, transform, and build upon the material
  - The licensor cannot revoke these freedoms as long as you follow the license terms.
- **Under the following terms:**
  - **Attribution** — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
  - **NonCommercial** — You may not use the material for commercial purposes.
  - **ShareAlike** — If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original.
  - **No additional restrictions** — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.
- https://creativecommons.org/licenses/by-nc-sa/4.0/