

Python data structures and collections

A wide choice of containers for your data

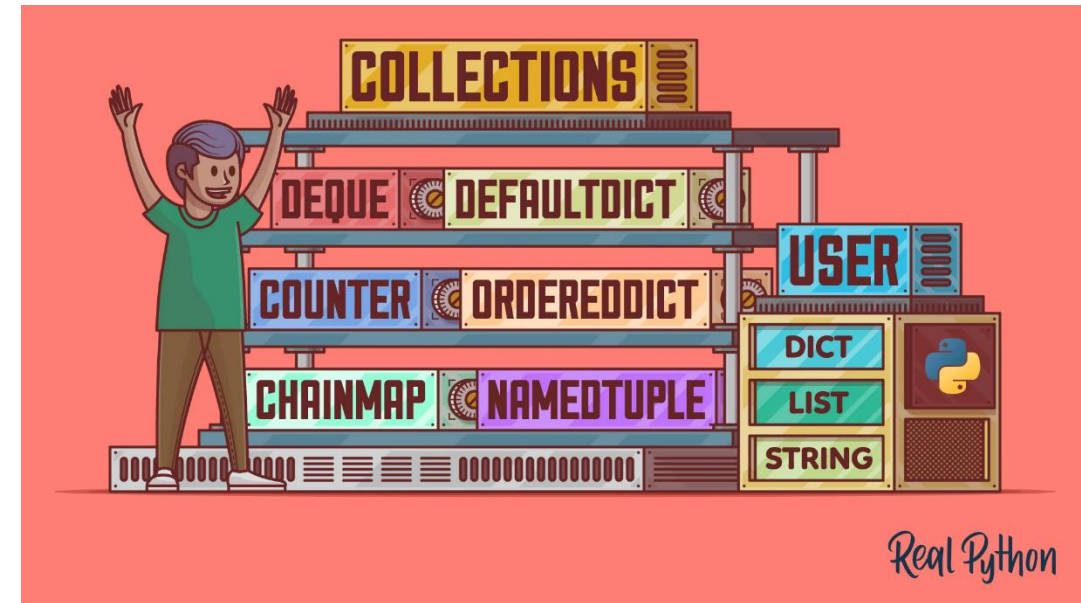
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<https://realpython.com/python-collections-module/>

<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
<ul style="list-style-type: none">• dict• OrderedDict• defaultdict• ChainMap• MappingProxyType	<ul style="list-style-type: none">• list• tuple• array• str• bytes• bytearray	<ul style="list-style-type: none">• dict• tuple• class• dataclass• namedtuple, NamedTuple• Struct	<ul style="list-style-type: none">• set• frozenset• Counter	<ul style="list-style-type: none">• list• deque• LifoDeque	<ul style="list-style-type: none">• list• deque• Queue	<ul style="list-style-type: none">• 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

Comparison and ordering

- Objects can be compared if they define an `__eq__` method
 - Used internally by `==` and `!=` operators
 - Used internally by `find`, `index`, `in`, ...
- Objects can be ordered if they define a `__lt__` method (and optionally, other comparison dunder methods)
 - Must define `__eq__`, in addition
 - Used internally by `<` `<=` `>` `>=` operators
 - Used internally by `sort`, `sorted`

Special case: predefined types

- Some built-in collections already define `__eq__` and `__lt__`, therefore they are comparable and sortable
 - str, list, tuple compare their elements in left-to-right order
 - The contained values must be comparable/sortable, too
- Dictionaries support `__eq__` but not `__lt__`
 - dict object cannot be ordered
- Sets support `__eq__`, but define `__lt__` to mean “subset”
 - Misleading, do not try to order a list of sets

Special case: dataclasses

- By default, a dataclass defines the `__eq__` method
 - To **prevent**, define it as `@dataclass(eq=False)`
- By default, a dataclass does **not** define the `__lt__` method
 - To generate it, define with `@dataclass(order=True)`: will generate `__lt__()`, `__le__()`, `__gt__()`, and `__ge__()`
 - Automatically generated methods compare **all** the fields of the object, **in the order** in which they are declared
 - One or more fields **may be omitted** from comparison and ordering methods, by initializing them with `field(compare=False)`

Example

```
@dataclass(order=True)
class Voto:
    esame: str
    cfu: int
    punteggio: int
    lode: bool
    data: str = field(compare=False)
```


Sorting by other criteria

- If you want to sort a collection using criteria **different** from the `__lt__` method (or if `__lt__` is not defined), use the **key=** argument
- **key=operator.itemgetter('keyname')**
 - sort by dictionary['keyname']
- **key=operator.itemgetter(itemnumber)**
 - Sort by list/tuple[itemnumber]
- **key=operator.attrgetter('attrname')**
 - Sort by object.attrname
- **key = lambda obj: something(obj)**
 - Sort by value of something() function
 - Example: `lambda v: v.voto` is equivalent to `operator.attrgetter('voto')`

Overview

Dictionaries, Maps, Hash Tables

- dict
- OrderedDict
- defaultdict
- ChainMap
- MappingProxyType

Array Data Structures

- list
- tuple
- array
- str
- bytes
- bytearray

Records, Structs, Data Transfer Objects

- dict
- tuple
- class
- dataclass
- namedtuple, NamedTuple
- Struct

Sets, Multisets

- set
- frozenset
- Counter

Stacks (LIFO)

- list
- deque
- LifoDeque

Queues (FIFO)

- list
- deque
- Queue

Priority Queues

- list
- heapq
- PriorityQueue

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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

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

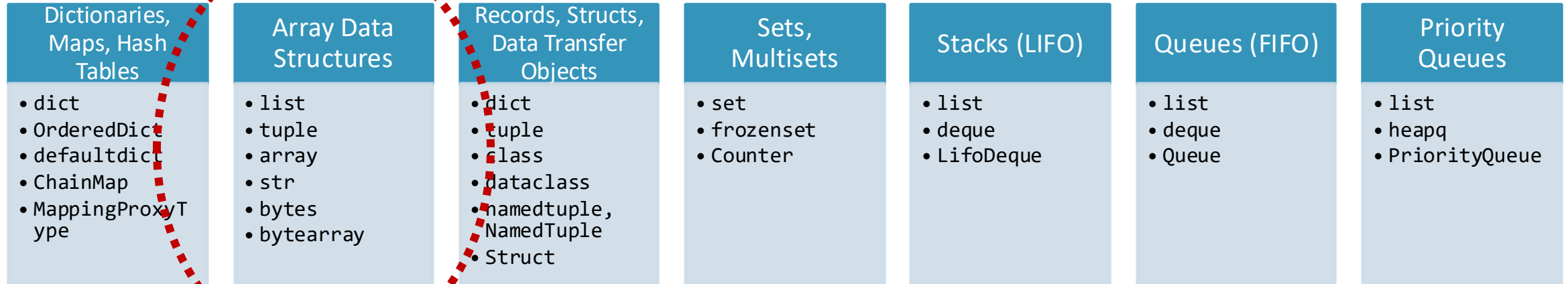
- A hash function is a function that maps any object into an integer number (over 64 bit)
- It is needed to quickly discover if two objects are
 - Surely different
 - Very likely equal
- Used in the `hash()` function and internally in `set`, `frozenset` and `dict`.

<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`

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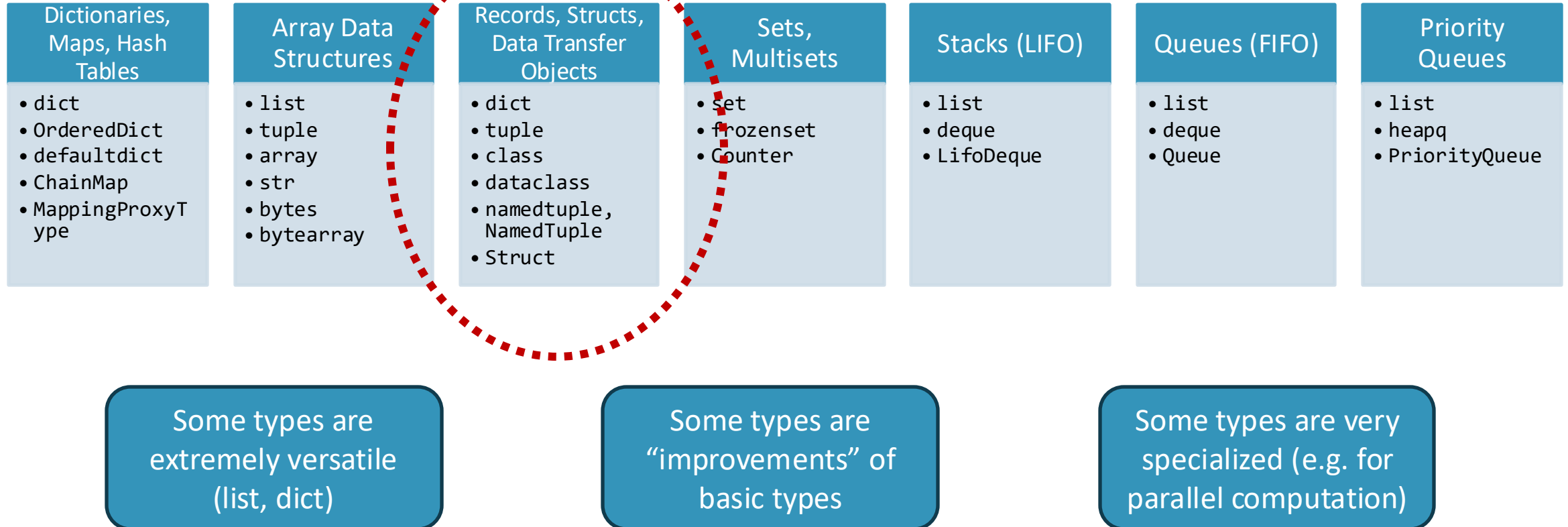
Main Array types

- `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

Overview



Records

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

Implemented
as...

```
car = {  
    "type": "Panda",  
    "year": 2010  
}
```

dict

class

```
class Car:  
    def __init__(self, type, year):  
        self.type = type  
        self.year = year
```

tuple

dataclass

```
car = ("Panda", 2010)
```

```
@dataclass  
class Car:  
    type: str  
    year: int
```

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'
```

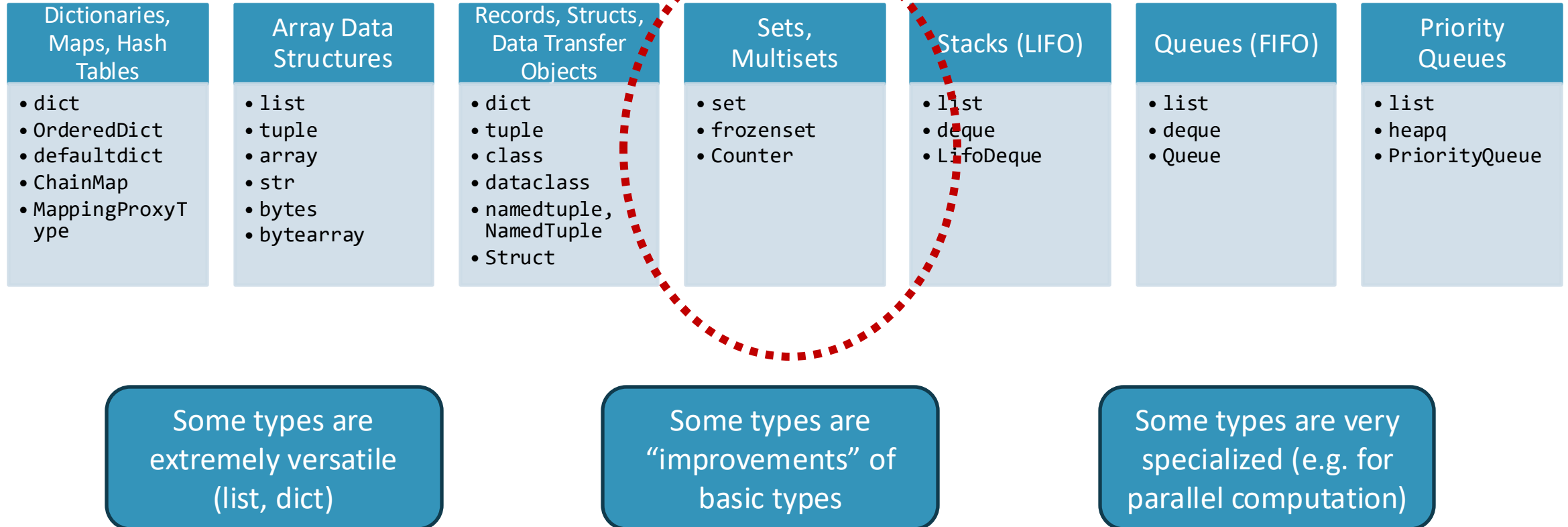
- Attribute values are immutable

- `typing.NamedTuple`

- Uses a syntax similar to dataclasses

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

Overview



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
```

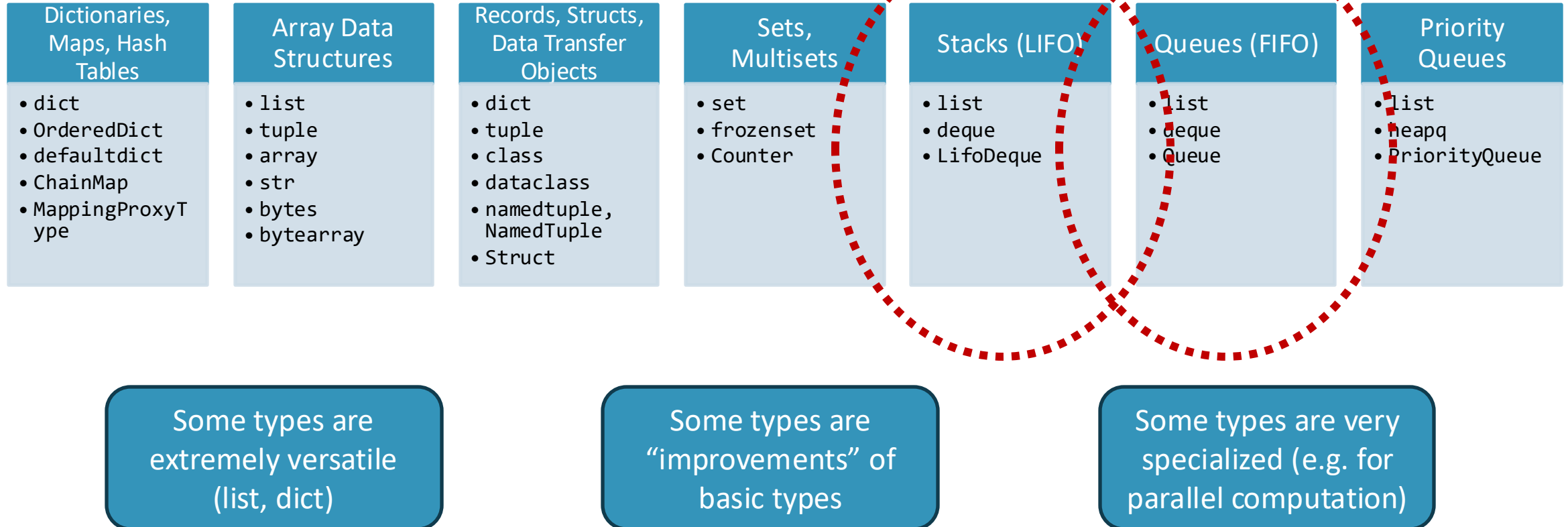
equivalent to

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

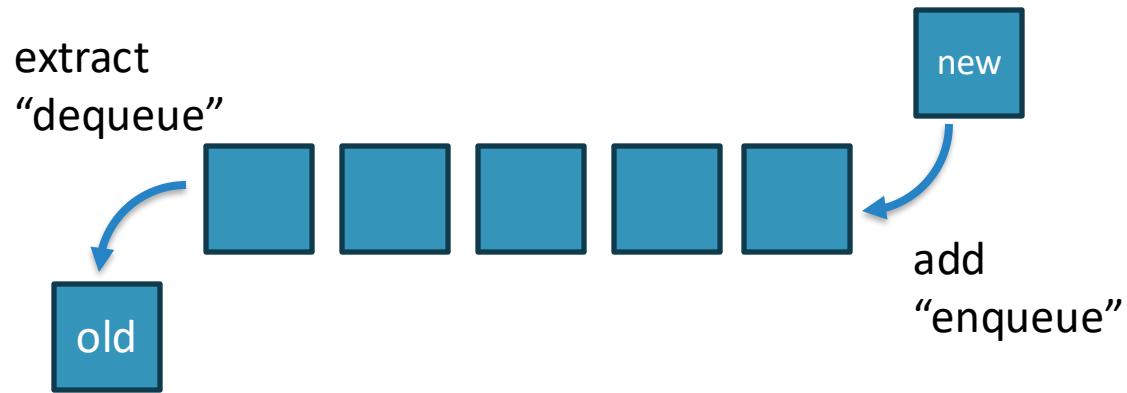

What can I do with a Counter?

- `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

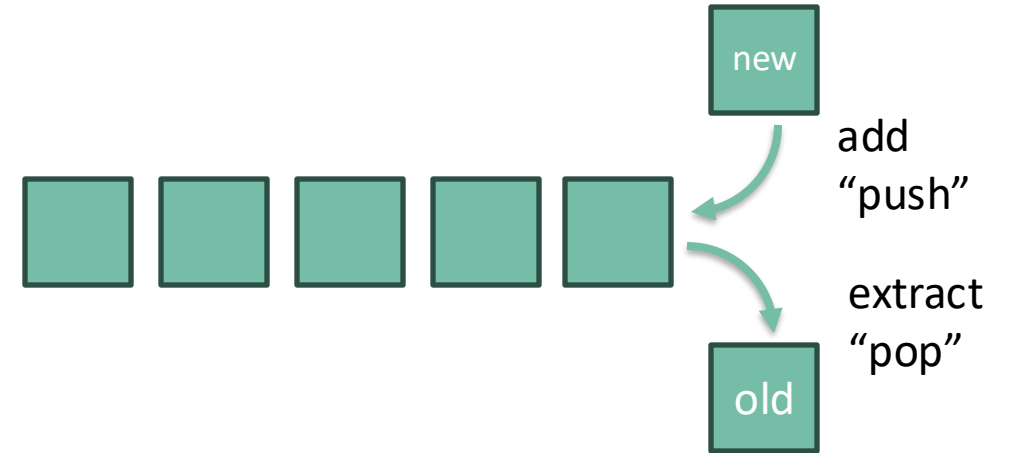
Overview



Queues and Stacks



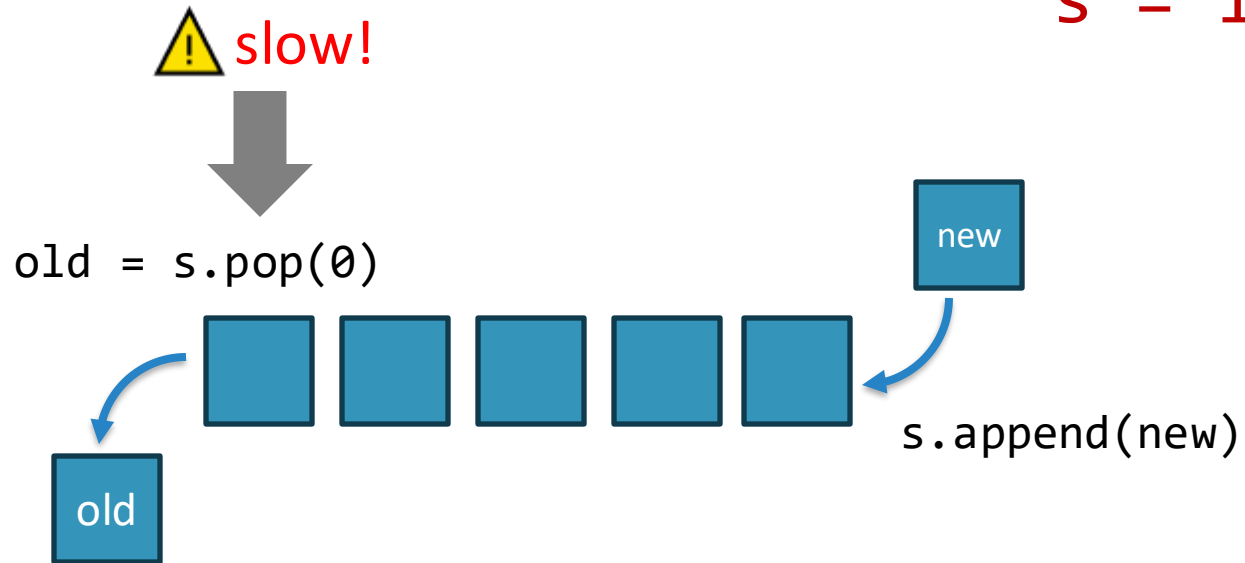
FIFO Queue – First-In First-Out



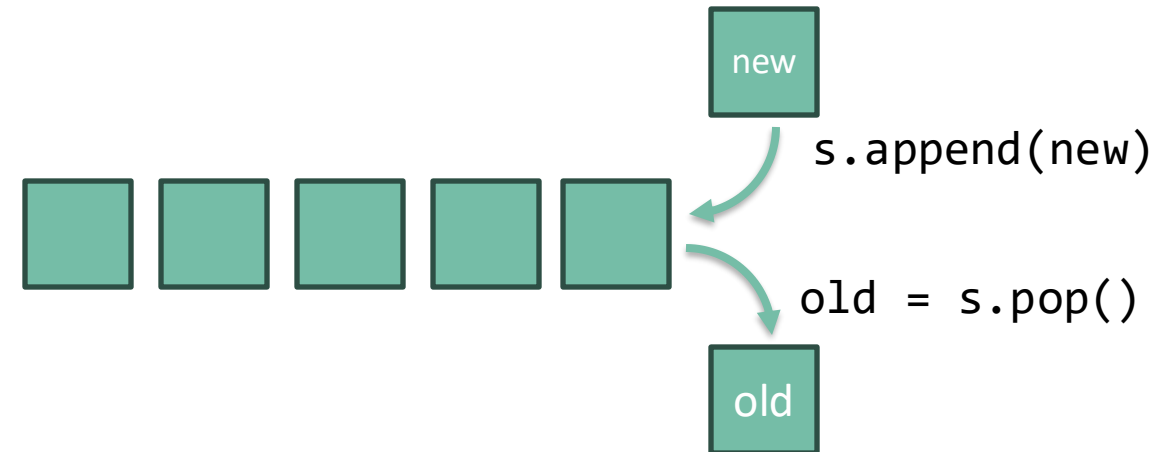
LIFO Stack – Last-In First-Out

List implementations

`s = list()`



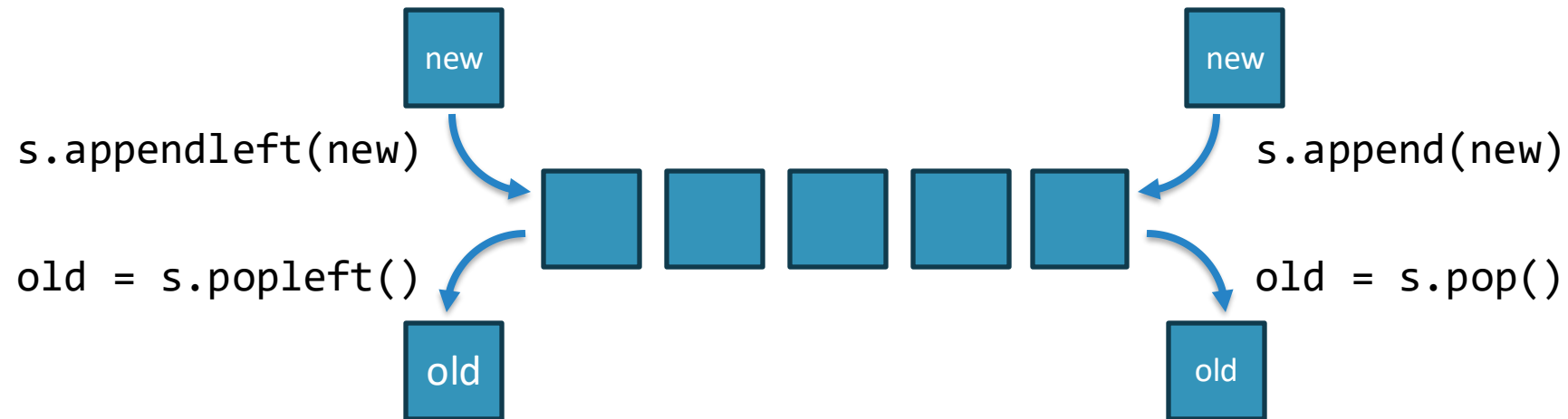
FIFO Queue – First-In First-Out



LIFO Stack – Last-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

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

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

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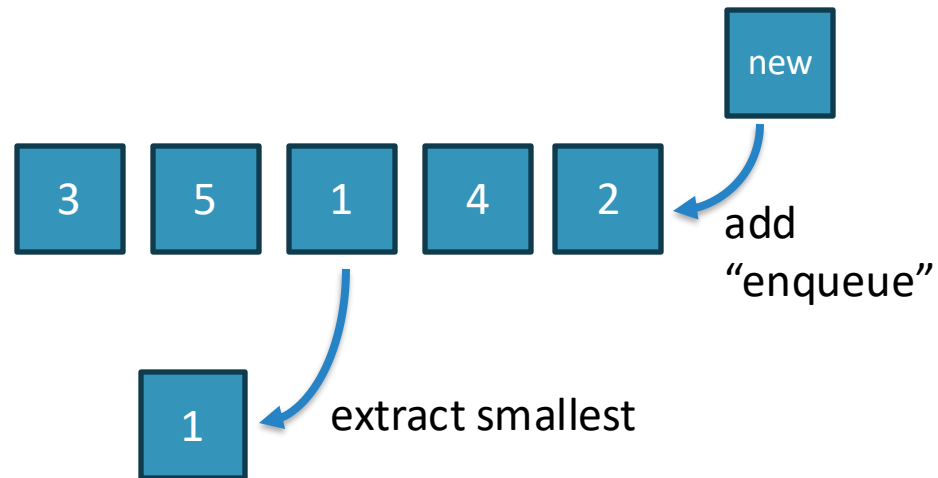
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Priority Queues



- 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)
- Or we rely on the object’s `__lt__` method

Priority queues in Python

Items `x` must be comparable
(implement `__lt__`)

`heapq` – uses plain lists

- `h = []`
- `h = heapify(iterable)`
- `len(h)`
- `len(h)==0`
- `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()`

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