

15-494/694: Cognitive Robotics

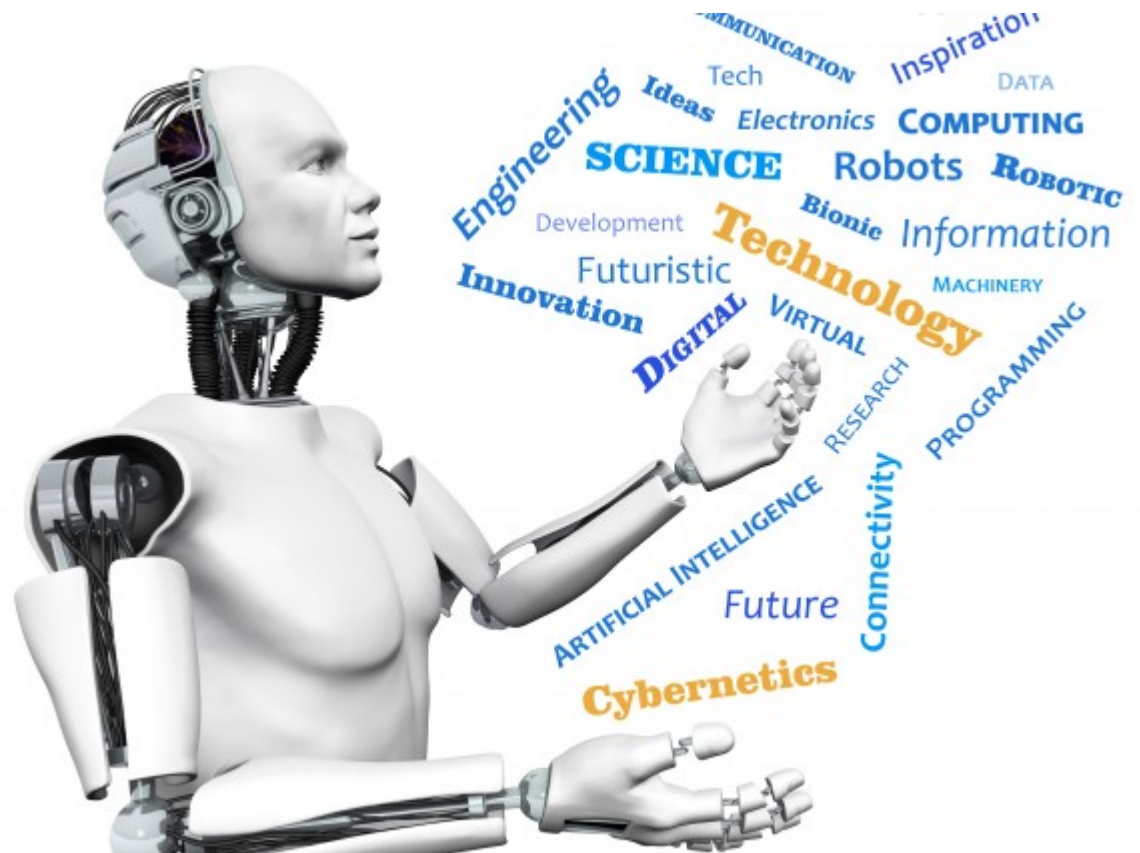
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Lecture 2:

Cozmo Software
Architecture

and

Python Control Structure



Cozmo Software Architecture

- A robot is a complex collection of interacting hardware/software systems.
- Example: navigation isn't just motion.
 - Need vision to find landmarks.
 - Head + body motion to point the camera.
- Layers of control:
 - Low level: control one actuator
 - Middle level: coordinate multiple actuators (e.g., head and wheels) for one task.
 - High level: goal-directed behaviors.

Control Levels in Cozmo (1)

- **Actions:** basic operations that focus on one effector but can optionally include some gratuitous animations.
 - drive_forward
 - turn_in_place
 - set_head_angle
 - move_lift
 - say_text



Control Levels in Cozmo (2)

- **Animations:** short behavior sequences that involve a combination of body motions, facial expressions, and sound effects.
- Designed by former Pixar animators.
- In SDK version 1.4.10 there are 997 animations, organized into groups.
- See `robot.conn.anim_names` for the list.
- Use the Cozmo Animation Explorer tool to try them out.

997 Animations

The screenshot displays the COZMO Animation Explorer interface. At the top left, the logo reads "COZMO Animation Explorer". At the top right, it says "created by GrinningHermit" next to a small robot icon. Below the header are three tabs: "Animations", "Triggers", and "Behaviors". The "Animations" tab is active, showing a search bar and a scrollable list of animation names. To the right of the list is an "Info" panel with instructions and a grid of animation buttons.

COZMO Animation Explorer

created by GrinningHermit

Animations Triggers Behaviors

return to pose after animation

Search

ANIMATION_TEST
ID_pokedA
ID_pokedB
ID_reactTppl_Surprise
ID_test_shiver
anim_bored_01
anim_bored_02
anim_bored_event_01
anim_bored_event_02
anim_bored_event_03
anim_bored_event_04
anim_bored_getout_01
anim_bored_getout_02
anim_cozmosays_app_getin
anim_cozmosays_app_getout_01
anim_cozmosays_app_getout_02
anim_cozmosays_badword_01
anim_cozmosays_badword_01_head_angle_-20
anim_cozmosays_badword_01_head_angle_20

Info

A list of animations. Pick an animation from the list and click the play button to animate Cozmo.

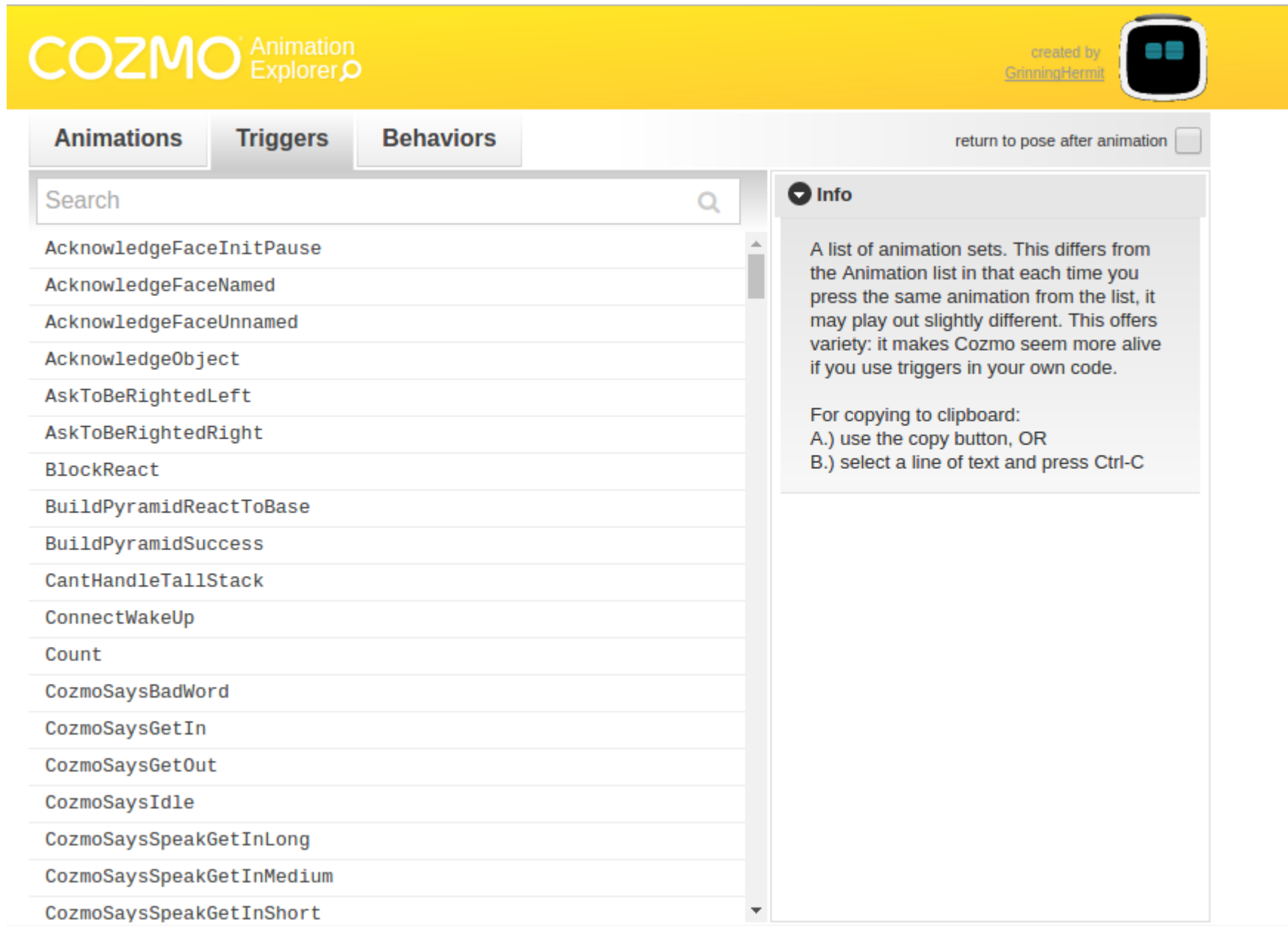
For copying to clipboard:
A.) use the copy button, OR
B.) select a line of text and press Ctrl-C

bored cozmosays driving explorer
freeplay gotosleep greeting hiking
keepalive keepaway launch loco
lookingplaceforfaces meetcozmo
memorymatch neutral pause
petdetection pounce pyramid qa
reacttoblock reacttocliff reacttoface
rtc rtpkeepaway rtpmemorymatch
sdk sparking speedtap triple
upgrade workout

Control Levels in Cozmo (2.5)

- **Animation Triggers:** Families of animations that are variants on a theme.
- Playing a trigger will select one animation at random from the family.
- In version 1.4.10 of the SDK there are 603 triggers.
- `dir(cozmo.anim.Triggers)`
- Both animations and triggers have well-defined completion points.

603 Animation Triggers



The screenshot shows the COZMO Animation Explorer interface. At the top, there is a yellow header with the COZMO logo and the text "Animation Explorer". To the right of the header, it says "created by GrinningHermit" next to a small robot icon. Below the header, there are three tabs: "Animations", "Triggers", and "Behaviors". The "Triggers" tab is currently selected. In the top right corner of the interface, there is a checkbox labeled "return to pose after animation".

On the left side, there is a search bar with the text "Search" and a magnifying glass icon. Below the search bar is a list of animation triggers:

- AcknowledgeFaceInitPause
- AcknowledgeFaceNamed
- AcknowledgeFaceUnnamed
- AcknowledgeObject
- AskToBeRightedLeft
- AskToBeRightedRight
- BlockReact
- BuildPyramidReactToBase
- BuildPyramidSuccess
- CantHandleTallStack
- ConnectWakeUp
- Count
- CozmoSaysBadWord
- CozmoSaysGetIn
- CozmoSaysGetOut
- CozmoSaysIdle
- CozmoSaysSpeakGetInLong
- CozmoSaysSpeakGetInMedium
- CozmoSaysSpeakGetInShort

On the right side, there is an "Info" panel with a dropdown arrow. The text in the info panel reads:

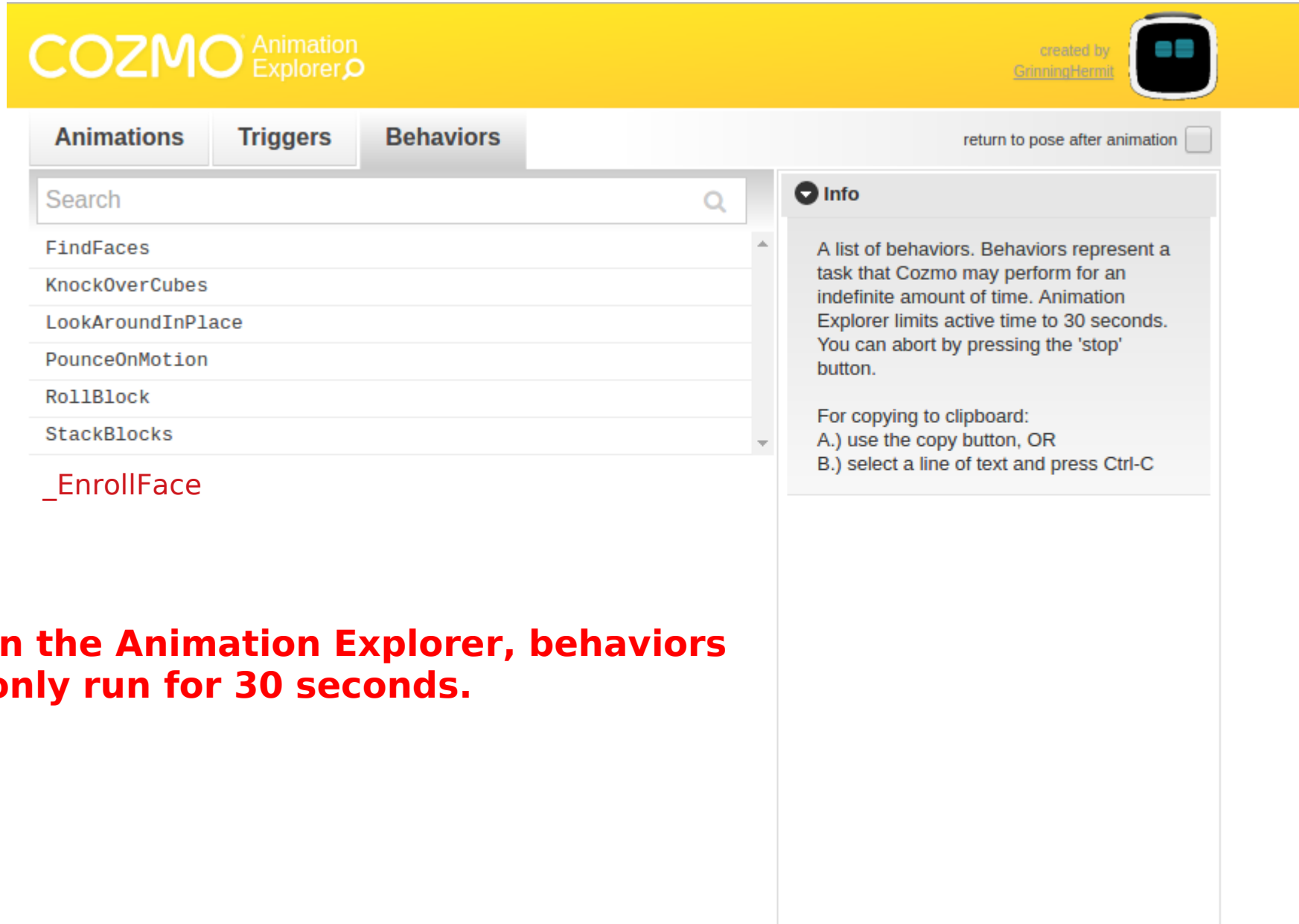
A list of animation sets. This differs from the Animation list in that each time you press the same animation from the list, it may play out slightly different. This offers variety: it makes Cozmo seem more alive if you use triggers in your own code.

For copying to clipboard:
A.) use the copy button, OR
B.) select a line of text and press Ctrl-C

Control Levels in Cozmo (3)

- Behaviors: Complex operations that try to accomplish a goal.
- Only seven were defined:
 - Vision: FindFaces, LookAroundInPlace, _EnrollFace
 - Manipulation: KnockOverCubes, RollBlock, StackBlocks
 - Human interaction: PounceOnMotion
- Behaviors use multiple animations.
- Behaviors never complete; they must be explicitly stopped.

Only 7 Behaviors



The screenshot shows the COZMO Animation Explorer interface. At the top, there is a yellow header with the COZMO logo and the text "Animation Explorer" on the left, and "created by GrinningHermit" with a small robot icon on the right. Below the header, there are three tabs: "Animations", "Triggers", and "Behaviors". The "Behaviors" tab is selected. To the right of the tabs, there is a checkbox labeled "return to pose after animation". Below the tabs, there is a search bar with the word "Search" and a magnifying glass icon. Below the search bar, there is a list of behaviors: "FindFaces", "KnockOverCubes", "LookAroundInPlace", "PounceOnMotion", "RollBlock", and "StackBlocks". Below this list, there is a red text label "_EnrollFace". To the right of the search bar, there is an "Info" section with a downward arrow icon. The "Info" section contains the following text: "A list of behaviors. Behaviors represent a task that Cozmo may perform for an indefinite amount of time. Animation Explorer limits active time to 30 seconds. You can abort by pressing the 'stop' button." Below this text, there is a section titled "For copying to clipboard:" with two options: "A.) use the copy button, OR" and "B.) select a line of text and press Ctrl-C".

In the Animation Explorer, behaviors only run for 30 seconds.

Python Control Concepts

- The Cozmo SDK is written in industrial strength Python 3.7.
- To understand the SDK, you must be familiar with:
 - Iterators
 - Generators
 - Coroutines
 - Asyncio: futures, tasks, handles, event loops

Iterators

```
>>> nums = [1,2,3,4]
```

```
>>> for x in nums: print('x=%s' % x)
```

```
x=1
```

```
x=2
```

```
x=3
```

```
x=4
```

```
>>> [x*x for x in nums] ← list comprehension
```

```
[1, 4, 9, 16]
```

What Makes an Object Iterable?

Defines an `__iter__()` method that returns an iterator.

```
>>> nums.__iter__
```

```
<method-wrapper '__iter__' of list  
object at 0x7ffa366baf48>
```

```
>>> nums.__iter__()
```

```
<list_iterator object at 0x7ffa34aa3c88>
```

What Is an Iterator?

References a sequence and defines a `__next__()` method that returns the next item or raises `StopIteration` if there are no more items.

```
>>> a = nums.__iter__()
```

```
>>> a.__next__()
```

1

```
>>> a.__next__()
```

2

StopIteration

```
>>> a.__next__()
```

```
3
```

```
>>> a.__next__()
```

```
4
```

```
>>> a.__next__()
```

```
Traceback: ... StopIteration
```

How a For Loop Works

```
for x in nums: print('x=%s' % x)
```

```
it = nums.__iter__()  
try:  
    while True:  
        x = it.__next__()  
        print('x=%s' % x)  
except StopIteration:  
    pass
```

Lots of Things Are Iterable

```
>>> '__iter__' in dir([1,2,3])           list  
True
```

```
>>> '__iter__' in dir(range(3,5))       range  
True
```

```
>>> '__iter__' in dir({1,2,3})         set  
True
```

```
>>> '__iter__' in dir({'foo' : 3})     dictionary  
True
```


Make Your Own Iterable Thing

Needs an `__iter__` method.

```
class MyIterable():  
  
    def __init__(self, vals):  
        self.vals = vals  
  
    def __iter__(self):  
        return MyIterator(self.vals) ←
```

Make Your Own Iterator

Needs a `__next__` method.

```
class MyIterator():
    def __init__(self, vals):
        self.vals = vals
        self.index = 0

    def __next__(self): ←
        if self.index == len(self.vals):
            raise StopIteration
        else:
            self.index += 1
            return self.vals[self.index-1]
```

Testing MyIterable

```
>>> a = MyIterable([1, 2, 3, 4])
>>> for x in a: print('x=%s' % x)
x=1
x=2
x=3
x=4

>>> [x**3 for x in a]
[1, 8, 27, 64]
```

Generators

- Generators are *coroutines* that suspend their state using the **yield** keyword.
- Generators are represented by **generator** objects instead of functions.
- Generators can be used either as *producers* (similar to iterators) or as *consumers*.

Generator As Producer

```
def myproducer(vals):  
    print('myproducer called')  
    index = 0  
    while index < len(vals):  
        print('yielding')  
        yield vals[index] ←  
        index += 1  
    raise StopIteration
```

Because “yield” appears in myproducer, calling myproducer doesn't actually run the function; it returns a generator object.

Generator As Producer

```
>>> g = myproducer(['foo', 'bar'])  
<generator object myproducer at ...>
```

```
>>> next(g)  
myproducer called ←  
yielding  
'foo'
```

```
>>> next(g)  
yielding  
'bar'
```

Generator Expressions

Like a list comprehension, but uses parentheses instead of brackets: lazy.

```
>>> g = (x**2 for x in [1,2,3,4,5])  
<generator object <genexpr> at ...>
```

```
>>> next(g)  
1
```

```
>>> g.__next__()  
4
```

list() exhausts a generator

```
>>> g  
<generator object <genexpr> at ...>
```

```
>>> list(g)  
[9, 16, 25]
```


Generator As Consumer

```
def myconsumer():  
    print('myconsumer called')  
    try:  
        while True:  
            x = yield ←  
            print('%s squared is %s' %  
                  (x, x**2))  
    except GeneratorExit:  
        print('Generator closed.')
```

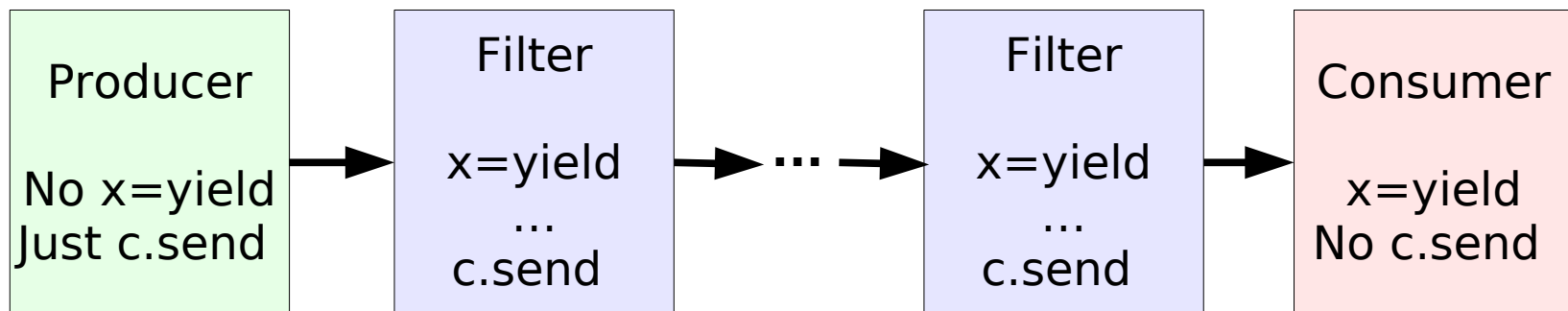
A statement 'x=yield' marks a *consumer* generator, which must be primed.

Generator As Consumer

```
>>> c = myconsumer()  
<generator object myconsumer at ...>  
>>> c.send(None)  
myconsumer called ←  
>>> for x in range(1,5): c.send(x)  
1 squared is 1  
2 squared is 4  
...  
>>> c.close()  
Generator closed.
```

Generator Pipeline

Generators can be chained together for complex processing tasks.



That's all we're going to say about generators. What about coroutines?

Python Will Drive You Crazy

- Python changes every year.
- This has been going on for a long time.
- The terminology changes as well.
- Result: Python can be confusing.
- Reading tutorials written several years ago will drive you crazy.
- Coroutines are a prime example.

Newbie: *“How do coroutines work?”*

Expert: *“Well, in Python 2.7 it did this, but then in Python 3.3 it did that, and now in Python 3.5 it does this other thing, but in Python 3.7 it's going to ...”*

Newbie: *“Kill me now.”*



History of Python Coroutines

- You don't want to know.
- Stuff to forget about:
 - @coroutine decorator
 - @asyncio.coroutine decorator
 - “generators are coroutines” – no longer

Coroutines Since Python 3.5

- In computer science, coroutines are procedures that repeatedly cede control to their caller and get it back again.
- In CS terms, Python generators are coroutines. They use “yield”.
- In Python 3.5 and up, “coroutine” has a more specific meaning, and generators are not coroutines.

Coroutines Since Python 3.5

- The `asyncio` module provides a kind of scheduler called an *event loop*.
- Coroutines are asynchronously executing procedures, ceding control to each other or the event loop that manages them.
- Coroutines in Python 3.5 are defined with **`async def`** instead of the usual **`def`**.
- They use the **`await`** keyword to cede control until the thing they're awaiting has **`returned`**. They cannot use **`yield`**.

Coroutine Example

```
import asyncio
```

```
async def mycor():  
    for i in range(1,5):  
        print('i=', i, end=' ' )  
        x = await yourcor(i) ←  
        print(' x=', x)
```

```
async def yourcor(i):  
    await asyncio.sleep(1) ←  
    return i**2
```

Testing the Coroutine Example

```
>>> c = mycor()
```

```
<coroutine object mycor at ...>
```

```
>>> loop = asyncio.get_event_loop()
```

```
<_UnixSelectorEventLoop ...>
```

```
>>> loop.run_until_complete(c)
```

```
i=1 x=1
```

```
i=2 x=4
```

```
i=3 x=9
```

```
i=4 x=16
```

Tasks and Futures

- A **Future** is an object representing an asynchronous computation that may not yet have completed.
- You can attach handlers to futures that will be notified when the future completes.
- A **Task** is a kind of Future that is managed by an event loop.

Adding Tasks To the Queue

```
>>> t = loop.create_task(yourcor(5))  
<Task pending coro=yourcor() ...>
```

```
>>> loop.run_until_complete(t)  
25
```

Scheduling Non-Coroutines

```
def goof(i):  
    print('i=', i)
```

```
>>> loop.call_soon(goof, 150)
```

```
<Handle goof(150) at ...>
```

```
>>> loop.call_later(3, goof, 250)
```

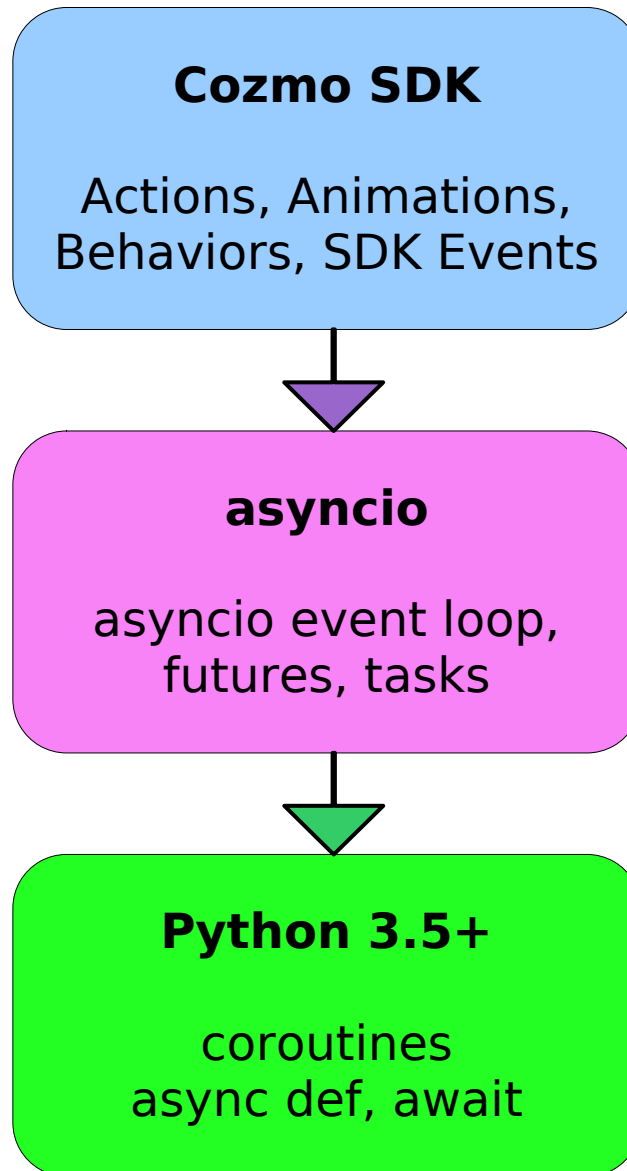
```
<TimerHandle when=...>
```

```
>>> loop.run_forever()
```

```
i=150
```

```
i=250
```

The Big Picture



SDK and the Event Loop

- The Cozmo SDK includes an asyncio event loop which is accessible at `robot.loop`.
- The Cozmo SDK provides its own classes for representing actions, animations, etc. as tasks managed by this event loop.
- The SDK (not asyncio) method `wait_for_completed()` waits until the event loop has completed the task.

Cozmo SDK Actions Are Tasks

```
#!/usr/bin/python3

import asyncio
import cozmo

async def mytalker(robot):
    action = robot.say_text('hello')
    print('act =', action)
    coro = action.wait_for_completed()
    print('coro =', coro)

cozmo.run_program(mytalker)
```


Cozmo Actions Are Tasks

```
$ ./mytalker.py
```

```
... [set up connection to robot ... ]
```

```
act = <SayText state=action_running ...>  
coro = <coroutine object  
      Action.wait_for_completed ...>
```

The SDK's Event Dispatcher

- The SDK defines a collection of robot events (e.g., an object has become visible, or a cube is tapped).
- The SDK includes its own event dispatcher, and a way to set up listeners for SDK events.
- Don't confuse this with the asyncio event loop. Despite the name “event loop”, asyncio doesn't have events. The SDK does.

Threads

- The Cozmo Python SDK is single-threaded.
- The REPL runs in a separate thread.
- But cozmo-tools uses multiple threads for visualization tools such as the world map viewer.
- Not thread-safe, but close enough.

Does This Look Like Fun? No???

- Explicitly managing coroutines, tasks, etc. looks like it could be a real pain.
- Is there a better way?



- State machines. See next lecture.