Lecture 25: Coroutines

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Announcements

Roadmap

- Introduction
- Functions
- Data
- Mutability
- Objects
- Interpretation
- Paradigms
- Applications

- This week (Paradigms), the goals are:
  - To study examples of paradigms that are very different from what we have seen so far
  - To expand our definition of what counts as programming

Event-Driven Programming

- Almost all programs we have seen so far involve the program running in isolation until completion
- But many practical applications involve *communication* between different programs or with a user
  - For example, many web applications have to wait for user input, such as mouse clicks or text input
  - We have seen one example of this: interactive interpreters wait for the user to type in code before it can execute that code and produce a result
- This style of programming is called *event-driven*, because different *events*, such as user input, trigger different parts of our program to execute

Generators and Generator Functions

Revisiting lazy evaluation

Generator Functions

- A generator function is a function that yields values instead of returning them
- A normal function returns once, a generator function can yield multiple times
- When a generator function is called, it returns a generator that iterates over **yield** statements

```
def range_gen(start, end):
    while start < end:
        yield start
        start += 1
```

```
>>> for i in range_gen(0, 5):
...     print(i)
...
0
1
2
3
4
```

Generators (demo)

- A generator is an iterator, created by a generator function
- Generators act as *implicit*, or *lazy*, sequences
  - Values are not computed when the sequence is created, but when they are asked for
  - This is the same as built-in Python `range` objects, Python iterators, and Scheme streams
  - We can use implicit sequences to create infinite sequences!

```
def naturals():
    curr = 0
    while True:
        yield curr
        curr += 1
```

```
>>> n = naturals()
>>> n
<generator object naturals at ...>
>>> next(n)
0
>>> next(n)
1
```

Generators vs Iterators (demo)

- Generator functions are often simpler and more intuitive to write than iterator classes, because:
  - We only have to write a function instead of a class
  - Yielding pauses execution of the function and automatically saves state for resuming, as opposed to returning
- Recall the iterable interface from lab: `__iter__` and `__next__`
  - `__iter__` returns an iterator, which has a `__next__` method
  - `__next__` returns the next element in our sequence
- A generator function returns a generator, which is an iterator, and the generator returns the next element by calling `__next__` on it
- So, what if we just make our `__iter__` method a generator function? This satisfies all our requirements!

Coroutines

Generalizing generators

Coroutines (demo)

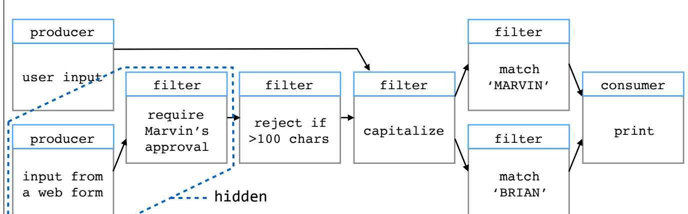
- Generator functions can also consume values using the **`yield`** expression (different from the **`yield`** statement!)
  - Generators that both produce and consume values are called *coroutines*, though they are still generator objects
- We can control coroutines by using the `send` and `close` methods
  - `send`, like `__next__`, resumes the coroutine, but also passes a value to it
    - Calling `__next__` is equivalent to calling `send` with `None`
  - `close` stops the coroutine and raises a **`GeneratorExit`** exception within the coroutine

Sequence Processing (demo)

- Implicit sequences are extremely useful in programming applications that deal with continuous streams of data, e.g., news feeds, sensor measurements, or mathematical sequences
- When working with data streams, a helpful and efficient technique is to set up a *pipeline* for sequence processing
- One way to set up a pipeline is to have each stage of the pipeline be a coroutine!
  - Functions at the beginning of the pipeline, that only send values, are called *producers*
  - Coroutines in the middle, that both send and receive values, are called *filters*
  - Coroutines at the end of the pipeline, that only receive values, are called *consumers*
- The data coming through the stream is sent through this pipeline to produce the final result

Sequence Processing (demo)

- Setting up a pipeline using coroutines allows us to easily change how we process the data by inserting, removing, and modifying different pieces of our program



Event-Driven Programming

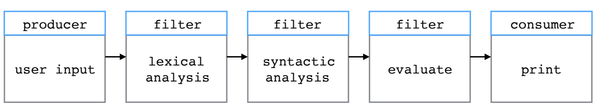
With and without coroutines

Event-Driven Programming

- The paradigm of event-driven programming allows different events, such as user input, to trigger different parts of our program to execute
- Lazy evaluation, such as implicit sequences, is similar to this paradigm in that the “event” of asking for an element from the sequence triggers the computation
  - However, this is not what is usually meant by “event”
- Processing continuous data streams is an example of this paradigm, where incoming data is the event
- Interactive interpreters is another example, where user input is the event
- In event-driven programming, an *event loop* waits for events, and handles them by dispatching them to a *callback function*

Interactive Interpreters (demo)

- The read-eval-print loop is an example of an event loop



- So, we can implement it using coroutines!
- This doesn’t provide an advantage in this case, because the REPL is already fairly simple and elegant
  - But it is still an interesting exercise
- Let’s take a look at the Calculator interpreter

Summary

- Coroutines naturally enforce *modularity* in our code, i.e., splitting complex functionality up into smaller pieces that are easier to write, maintain, and understand
  - Modularity also allows us to easily change our program, simply by swapping in and out different pieces
  - Coroutines are especially useful in building modular pipelines, where data is processed in stages
- Both generators and coroutines maintain their own state, and this is highly useful for particular applications
- Though coroutines by themselves are not a paradigm, they are useful for the paradigm of event-driven programming
  - However, it is important to understand when using coroutines may just be unnecessarily complicated

Summary

- Event-driven programming is a heavily used paradigm in applications such as user interfaces and web development
- In event-driven programming, an event loop handles particular events, such as user input, and uses callback functions to process these events
- One option for implementing callback functions, which often works well, is to use coroutines
  - If the event-driven application has callback functionality that:
    - Is complex and easily made modular,
    - Naturally fits into a processing pipeline, or
    - Involves state that changes over time,
  - Then coroutines are probably the way to go