Generators
Class outline:

- Generators
Generators
Generators

A generator function uses `yield` instead of `return`:

```python
def evens():
    num = 0
    while num < 10:
        yield num
        num += 2
```

A generator is a type of iterator that yields results from a generator function.

Just call the generator function to get back a generator:

```python
evengen = evens()
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
next(evengen)
```
Generators

A **generator function** uses `yield` instead of `return`:

```python
def evens():
    num = 0
    while num < 10:
        yield num
        num += 2
```

A **generator** is a type of iterator that yields results from a generator function.

Just call the generator function to get back a generator:

```python
evengen = evens()
next(evengen)  # 0
next(evengen)  # 2
next(evengen)  # 4
next(evengen)  # 6
next(evengen)  # 8
next(evengen)  # ❌ StopIteration exception
How generators work

```python
def evens():
    num = 0
    while num < 2:
        yield num
        num += 2

gen = evens()
next(gen)
next(gen)
```

- When the function is called, Python immediately returns an iterator without entering the function.
- When `next()` is called on the iterator, it executes the body of the generator from the last stopping point up to the next `yield` statement.
- If it finds a `yield` statement, it pauses on the next statement and returns the value of the yielded expression.
- If it doesn't reach a yield statement, it stops at the end of the function and raises a `StopIteration` exception.

View in PythonTutor
Looping over generators

We can use for loops on generators, since generators are just special types of iterators.

```python
def evens(start, end):
    num = start + (start % 2)
    while num < end:
        yield num
        num += 2

for num in evens(12, 60):
    print(num)
```
Looping over generators

We can use for loops on generators, since generators are just special types of iterators.

```python
def evens(start, end):
    num = start + (start % 2)
    while num < end:
        yield num
        num += 2

for num in evens(12, 60):
    print(num)
```

Looks a lot like...

```python
evens = [num for num in range(12, 60) if num % 2 == 0]
# Or   = filter(lambda x: x % 2 == 0, range(12, 60))
for num in evens:
    print(num)
```
Why use generators?

Generators are lazy: they only generate the next item when needed.

Why generate the whole sequence...

```python
def find_matches(filename, match):
    matched = []
    for line in open(filename):
        if line.find(match) > -1:
            matched.append(line)
    return matched

matched_lines = find_matches('frankenstein.txt', '!
matched_lines[0]
matched_lines[1]
```

...if you only want some elements?

```python
def find_matches(filename, match):
    for line in open(filename):
        if line.find(match) > -1:
            yield line

line_iter = find_matches('frankenstein.txt', '!
next(line_iter)
next(line_iter)
```

A large list can cause your program to run out of memory!
Exercise: Countdown

def countdown(n):
    
    """
    Generate a countdown of numbers from N down to 'blast off!'.
    >>> c = countdown(3)
    >>> next(c)
    3
    >>> next(c)
    2
    >>> next(c)
    1
    >>> next(c)
    'blast off!'
    """
Exercise: Countdown (solution)

```python
def countdown(n):
    
    """
    Generate a countdown of numbers from N down to 'blast off!'.
    >>> c = countdown(3)
    >>> next(c)
    3
    >>> next(c)
    2
    >>> next(c)
    1
    >>> next(c)
    'blast off!'
    """
    while n > 0:
        yield n
        n -= 1
    yield "blast off!"
```
Virahanka-Fibonacci generator

Let's transform this function...

def virfib(n):
    """Compute the nth Virahanka-Fibonacci number, for N >= 1.
    >>> virfib(6)
    8
    """
    prev = 0  # First Fibonacci number
    curr = 1  # Second Fibonacci number
    k = 1
    while k < n:
        (prev, curr) = (curr, prev + curr)
        k += 1
    return curr

def generate_virfib():
    """Generate the next Virahanka-Fibonacci number.
    >>> g = generate_virfib()
    >>> next(g)
    0
    >>> next(g)
    1
    >>> next(g)
    1
    >>> next(g)
    2
    >>> next(g)
    3
    """
def generate_virfib:
    """Generate the next Virahanka-Fibonacci number.
    >>> g = generate_virfib()
    >>> next(g)
    0
    >>> next(g)
    1
    >>> next(g)
    1
    >>> next(g)
    2
    >>> next(g)
    3
    """
    prev = 0  # First Fibonacci number
    curr = 1   # Second Fibonacci number
    while True:
        yield prev
        (prev, curr) = (curr, prev + curr)
Yield from
Yielding from iterables

A `yield from` statement can be used to yield the values from an iterable one at a time.

Instead of...

```python
def a_then_b(a, b):
    for item in a:
        yield item
    for item in b:
        yield item

list(a_then_b(["Apples", "Aardvarks"], ["Bananas", "BEARS"]))
```

We can write...

```python
def a_then_b(a, b):
    yield from a
    yield from b

list(a_then_b(["Apples", "Aardvarks"], ["Bananas", "BEARS"]))
```
Yielding from generators

A `yield from` can also yield the results of another generator function (which could be itself).

```python
def countdown(k):
    if k > 0:
        yield k
    yield from countdown(k - 1)
```
Visualizing countdown

<table>
<thead>
<tr>
<th>Calls</th>
<th>Executed code</th>
<th>Bindings</th>
<th>Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;&gt;&gt; c = countdown(3) def countdown(k):</td>
<td>k = 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Visualizing countdown

<table>
<thead>
<tr>
<th>Calls</th>
<th>Executed code</th>
<th>Bindings</th>
<th>Yields</th>
</tr>
</thead>
</table>
| >>> c = countdown(3) | def countdown(k):
|              |     if k > 0:
|              |         yield k                                   | k = 3    | 3      |
## Visualizing `countdown`

<table>
<thead>
<tr>
<th>Calls</th>
<th>Executed code</th>
<th>Bindings</th>
<th>Yields</th>
</tr>
</thead>
</table>
| `c = countdown(3)` | def countdown(k):
                 |          | k = 3  |
| `next(c)`   | if k > 0:
                 |          | 3      |
|             |    yield k
| `next(c)`   | yield from countdown(k - 1)
|             | def countdown(k):
                 |          | k = 2  |
|             | if k > 0:
                 |          | 2      |
|             |    yield k |
## Visualizing countdown

<table>
<thead>
<tr>
<th>Calls</th>
<th>Executed code</th>
<th>Bindings</th>
<th>Yields</th>
</tr>
</thead>
</table>
| >>> c = countdown(3)   | def countdown(k):
                      |          | k = 3  |
| >>> next(c)            |    if k > 0:
                      |          |        |
|                        |        yield k                                          |          | 3      |
|                        | yield from countdown(k - 1)                            |          |        |
| >>> next(c)            | def countdown(k):
                      |          | k = 2  |
|                        |    if k > 0:
                      |          |        |
|                        |        yield k                                          |          | 2      |
|                        | yield from countdown(k - 1)                            |          |        |
| >>> next(c)            | def countdown(k):
                      |          | k = 1  |
|                        |    if k > 0:
                      |          |        |
|                        |        yield k                                          |          | 1      |
# Visualizing countdown

<table>
<thead>
<tr>
<th>Calls</th>
<th>Executed code</th>
<th>Bindings</th>
<th>Yields</th>
</tr>
</thead>
</table>
| >>> c = countdown(3) | def countdown(k):
  if k > 0:
    yield k
    yield from countdown(k - 1) | k = 3 | 3 |
| >>> next(c) | | |
| >>> next(c) | def countdown(k):
  if k > 0:
    yield k
    yield from countdown(k - 1) | k = 2 | 2 |
| >>> next(c) | | |
| >>> next(c) | def countdown(k):
  if k > 0:
    yield k
    yield from countdown(k - 1) | k = 1 | 1 |
| >>> next(c) | | |
| >>> next(c) | def countdown(k):
  if k > 0:
    yield k
    yield from countdown(k - 1) | k = 0 | StopIteration |
Generator functions with returns
Generator function with a return

When a generator function executes a return statement, it exits and cannot yield more values.

```python
def f(x):
    yield x
    yield x + 1
    return
    yield x + 3
```

```python
list(f(2))
```
Generator function with a return

When a generator function executes a return statement, it exits and cannot yield more values.

def f(x):
    yield x
    yield x + 1
    return
    yield x + 3

list(f(2))  # [2, 3]
Generator functions with return values

Python allows you to specify a value to be returned, but this value is not yielded.

def g(x):
    yield x
    yield x + 1
    return x + 2
    yield x + 3

list(g(2))
Generator functions with return values

Python allows you to specify a value to be returned, but this value is not yielded.

def g(x):
    yield x
    yield x + 1
    return x + 2
    yield x + 3

list(g(2))  # [2, 3]
Generator functions with return values

Python allows you to specify a value to be returned, but this value is not yielded.

```python
def g(x):
    yield x
    yield x + 1
    return x + 2
    yield x + 3

list(g(2))  # [2, 3]
```

It is possible to access that return value, with this one weird trick. But you won't ever need this in 61A!

```python
def h(x):
    y = yield from g(x)
    yield y

list(h(2))
```
Generator functions with return values

Python allows you to specify a value to be returned, but this value is not yielded.

```python
def g(x):
    yield x
    yield x + 1
    return x + 2
    yield x + 3

list(g(2))  # [2, 3]
```

It is possible to access that return value, with this one weird trick. But you won't ever need this in 61A!

```python
def h(x):
    y = yield from g(x)
    yield y

list(h(2))  # [2, 3, 4]
```
Partitions example
(Review) Counting partitions

The number of partitions of a positive integer $n$, using parts up to size $m$, is the number of ways in which $n$ can be expressed as the sum of positive integer parts up to $m$ in increasing order.

```python
count_partitions(6, 4)
```

2 + 4 = 6
1 + 1 + 4 = 6
3 + 3 = 6
1 + 2 + 3 = 6
1 + 1 + 1 + 3 = 6
2 + 2 + 2 = 6
1 + 1 + 2 + 2 = 6
1 + 1 + 1 + 1 + 2 = 6
1 + 1 + 1 + 1 + 1 + 1 = 6

```python
def count_partitions(n, m):
    """
    >>> count_partitions(6, 4)
```
if n < 0 or m == 0:
    return 0
else:
    exact_match = 0
    if n == m:
        exact_match = 1
    with_m = count_partitions(n-m, m)
    without_m = count_partitions(n, m-1)
    return exact_match + with_m + without_m
Converting to a generator

Each call to the generator should yield a partition.

def partitions(n, m):
    """List partitions.

    >>> for p in partitions(6, 4): print(p)
    4 + 2
    4 + 1 + 1
    3 + 3
    3 + 2 + 1
    3 + 1 + 1 + 1
    2 + 2 + 2
    2 + 2 + 1 + 1
    2 + 1 + 1 + 1 + 1
    1 + 1 + 1 + 1 + 1 + 1
    """
def partitions(n, m):
    """List partitions.

    >>> for p in partitions(6, 4): print(p)
    4 + 2
    4 + 1 + 1
    3 + 3
    3 + 2 + 1
    3 + 1 + 1 + 1
    2 + 2 + 2
    2 + 2 + 1 + 1
    2 + 1 + 1 + 1 + 1
    1 + 1 + 1 + 1 + 1 + 1
    ""
    if n < 0 or m == 0:
        return
    else:
        if n == m:
            yield str(m)
            for p in partitions(n-m, m):
                yield str(m) + " + " + p
            yield from partitions(n, m - 1)
Python Project of The Day!
Mathematical Animation Engine

Manim: An open-source Python animation engine for explanatory math videos, first created by Grant Sanderson for 3Blue1Brown videos.

Check out the examples gallery, ooooh!