Lecture 27

Generators

Announcements for This Lecture

Prelim 2

- **Thurs, Dec 5 at 7:30**
  - See webpage for rooms
  - Review **Wed Dec. at 5pm**
  - **Review in Phillips 101**
- **Material up to Nov. 12**
  - Recursion + Loops + Classes
  - No short answer!
- **Make-Ups are Notified**
  - Contact Amy (ahf42)

Other Announcements

- **A7** due **Mon, Dec. 9 (11th)**
  - Extensions are possible
  - Work on it during Thur/Fri
- **Final, Dec 14^{th} 2-4:30 pm**
  - Study guide is posted Thurs
  - Also will post conflict form
- **Submit a course evaluation**
  - Will get an e-mail for this
  - Part of the "participation grade" (e.g. polling grade)

Recall: The Range Iterable

range(x)

- Creates an *iterable*
  - Can be used in a for-loop
  - Makes ints (0, 1, ... x-1)
- But it is not a tuple!
  - A **black-box** for numbers
  - Entirely used in for-loop
  - Contents of folder hidden

Example

```
>>> range(3)
range(0,3)
>>> for x in range(3)
...     print(x)
0
1
2
```

Recall: The Range Iterable

range(x)	Example

- Creates an *iterable*
  - Can be u
  - Makes i
- But it is n
  - A **black-**
  - Entirely used in for-loop
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```
>>> range(3)

e(3)



1
2
```

Iterable: Anything that can be used in a for-loop

Iterators: Iterables Outside of For-Loops

- Iterators can *manually* extract elements
  - Get each element with the `next()` function
  - Keep going until you reach the end
  - Ends with a `StopIteration` (Why?)
- Can create iterators with `iter()` function

```
>>> a = iter([1,5,3])
>>> next(a)
1
>>> next(a)
5
```

Must be a **iterable**

Iterators Can Be Used in For-Loops

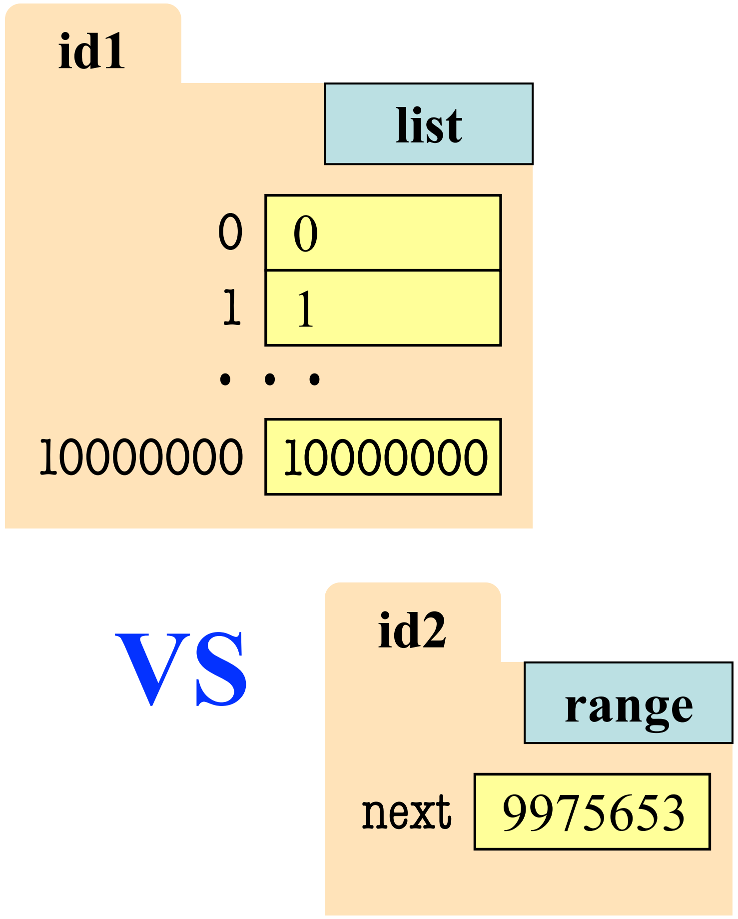
```
>>> a = iter([1,2])
>>> for x in a:
....     print(x)
....
1
2
>>> for x in a:
....     print(x)
....
>>>
```

Technically, iterators are also iterable

But they are one-use only!

Motivation for Iterables

- Large lists are a problem
  - Use a lot of space in heap
  - **Ex:** `list(range(10000000))`
- But do we need all this?
  - for-loop gets just one elt.
  - Only need the *next* value
- This is how `range` works
  - Stores the next value
  - *Generates* this on demand
  - More space efficient



Iterators are Classes

```
class range2iter(object):
    """Iterator class for squares of a range"""
    # Attribute _limit: end of range
    # Attribute _pos: current spot of iterator
    ...
    def __next__(self):
        """Returns the next element"""
        if self._pos >= self._limit:
            raise StopIteration()
        else:
            value = self._pos*self._pos
            self._pos += 1
            return value
```

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Defines the next() fcn

Iterators are Classes

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```

How far to go

How far we are

Raise error when gone too far

Iterators are Classes

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        else:
            value = self._pos*self._pos
            self._pos += 1
            return value
```

Update “loop” **after** doing computation

Essentially a loop variable

Iterables are Also Classes

```
class range2(object):
    """Iterable class for squares of a range"""

    def __init__(self,n):
        """Initializes a squares iterable"""
        self._limit = n

    def __iter__(self):
        """Returns a new iterator"""
        return range2iter(self._limit)
```

Defines the iter() function

Returns an iterator

Iterables are Also Classes

```
class range2(object):
    """Iterable class for squares of a range"""

    def __init__(self,n):
        """Initializes a squares iter
        self._limit = n

    def __iter__(self):
        """Returns a new iterator"""
        return range2iter(self._limit)
```

Iterables are objects that generate **iterators** on demand

Iterators are Hard to Write!

- Has the same problem as GUI applications
  - We have a hidden loop
  - All loop variables are now attributes
  - Similar to inter-frame/intra-frame reasoning
- Would be easier if loop were **not** hidden
  - **Idea:** Write this as a function definition
  - Function makes loop/loop variables visible
- But iterators "return" multiple values
  - So how would this work?

The Wrong Way

```
def range2iter(n):
    """
    Iterator for the squares of numbers 0 to n-1

    Precondition: n is an int >= 0
    """
    for x in range(n):
        return x*x
```

Stops at the first value

The **yield** Statement

- **Format**: yield <*expression*>
  - Used to produce a value
  - But it **does not stop** the "function"
  - Useful for making iterators
- **But**: These are not normal functions
  - Presence of a yield makes a **generator**
  - Function that returns an iterator

The Generator approach

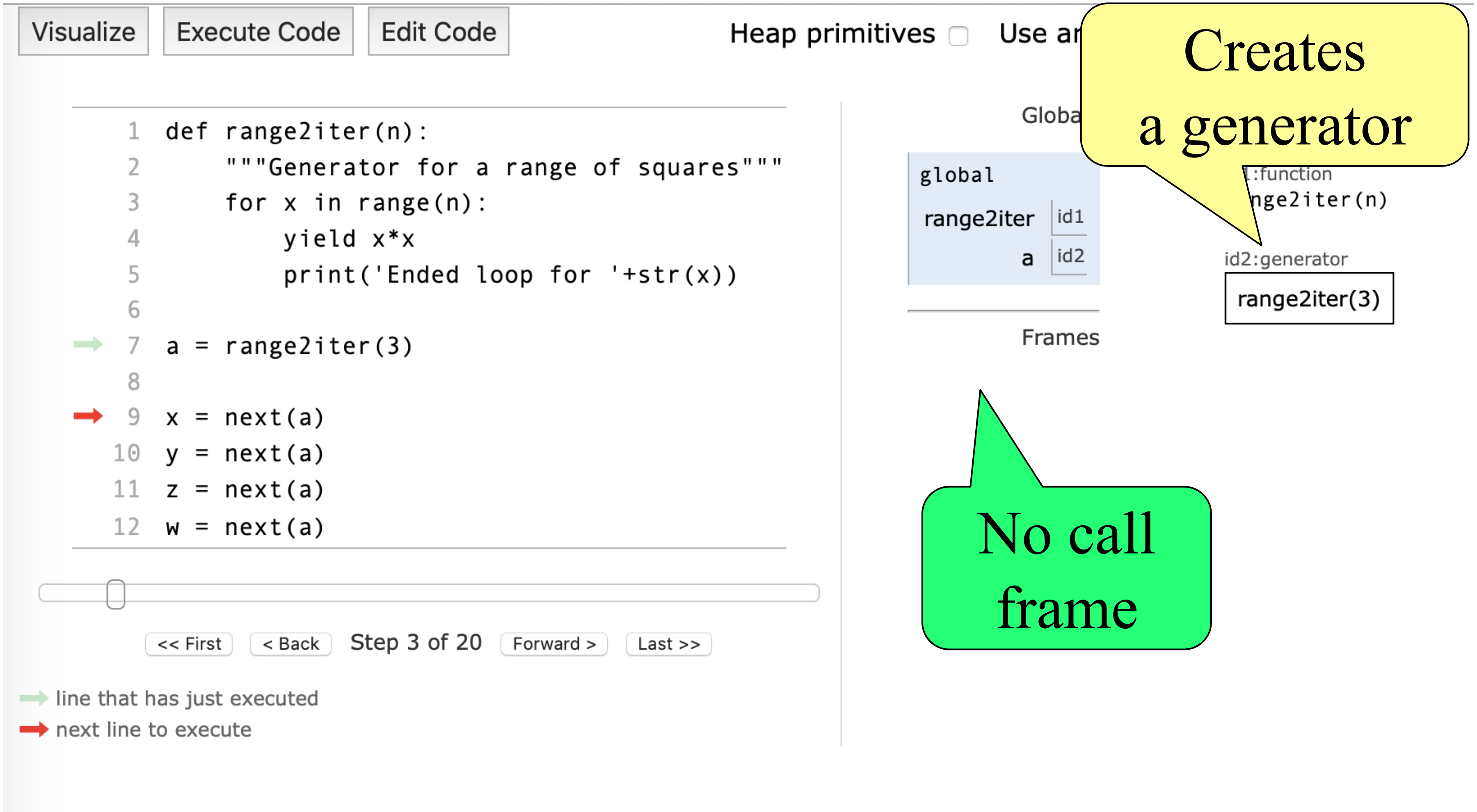
```
def range2iter(n):
    """
    Generator for the squares
    of numbers 0 to n-1

    Precon: n is an int >= 0
    """
    for x in range(n):
        yield x*x
```

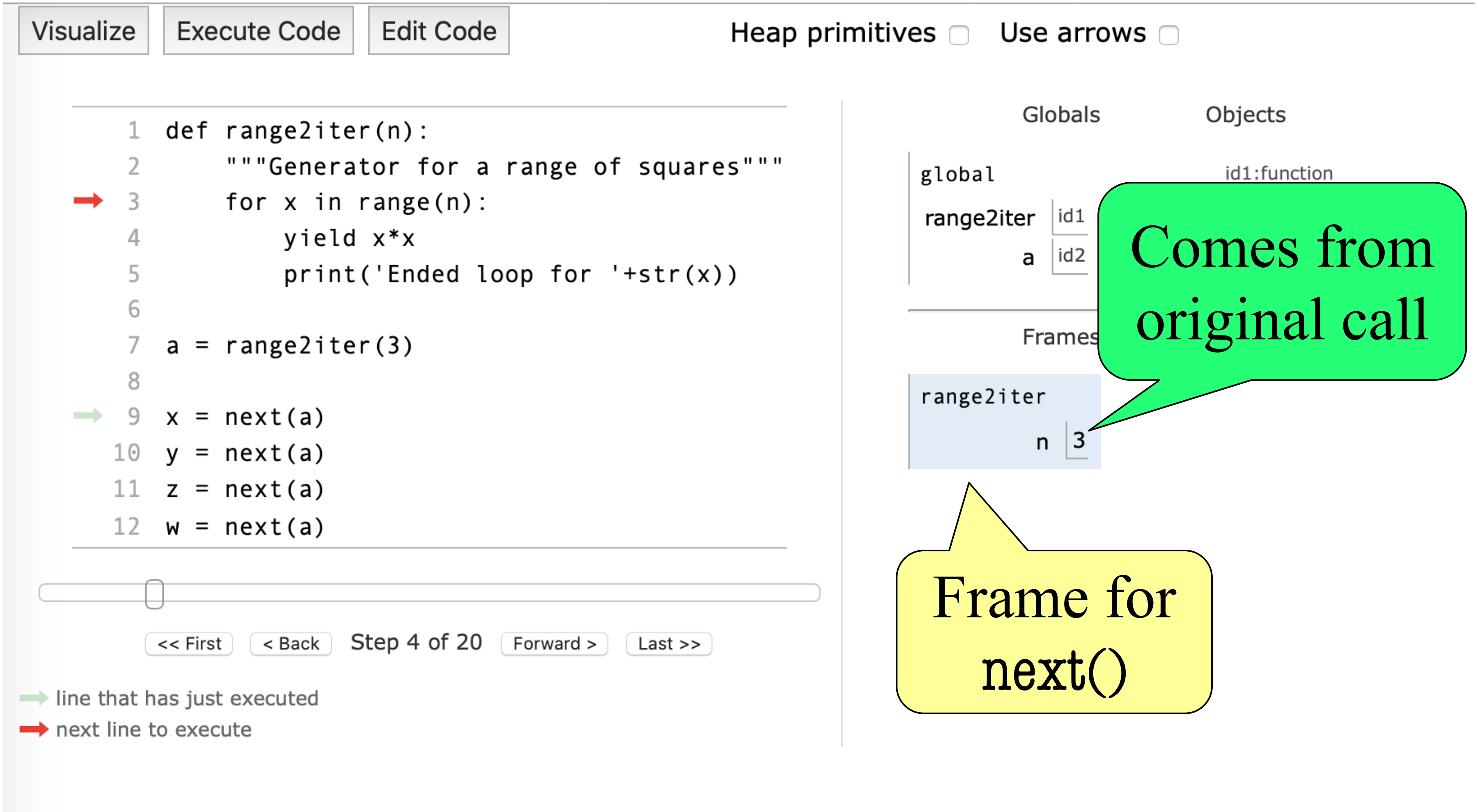
```
>>> a = range2iter(3)
>>> a
<generator
>>> next(a)
0
>>> next(a)
1
>>> next(a)
4
```

Essentially a constructor

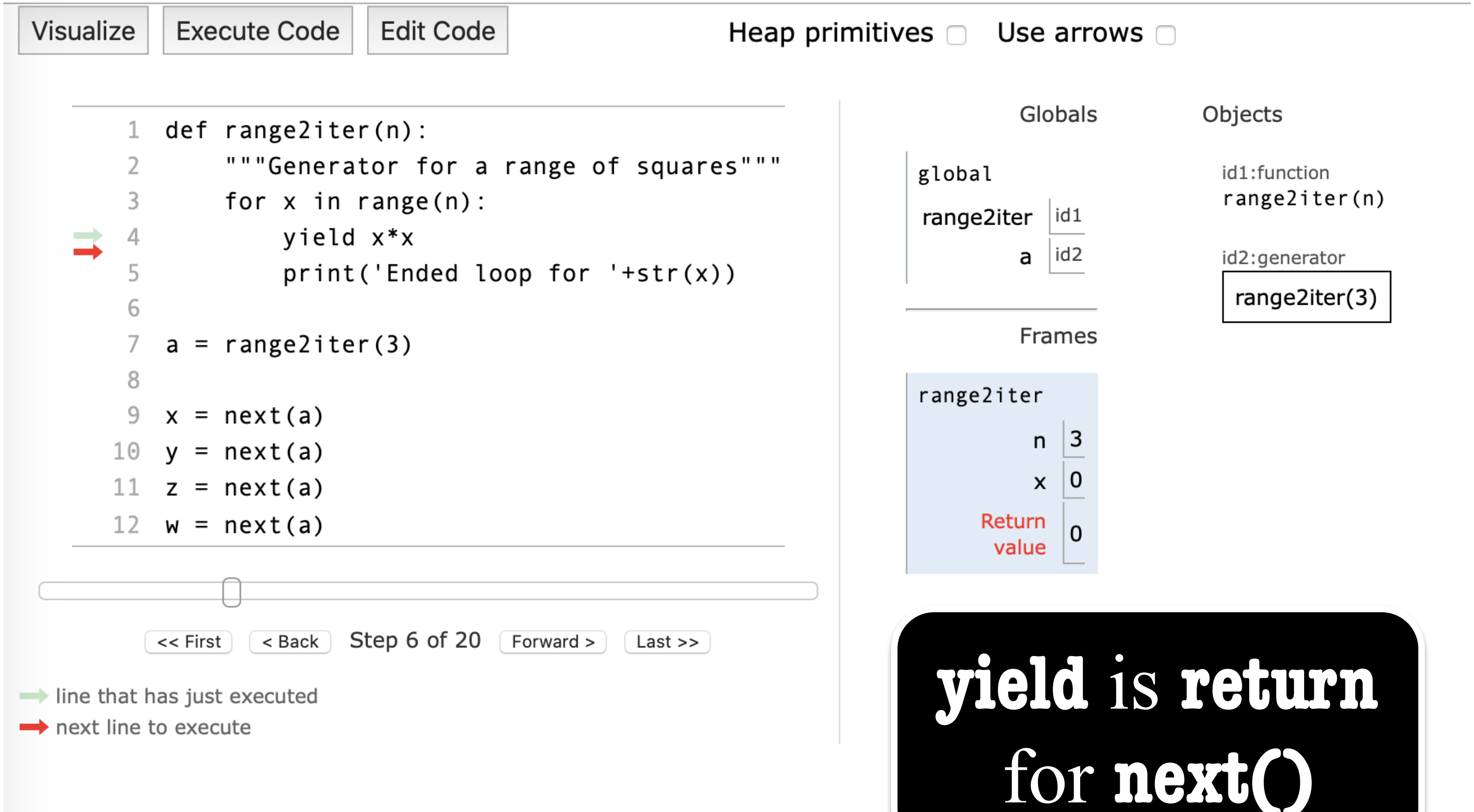
What Happens on a Function Call?



next() Initiates a Function Call

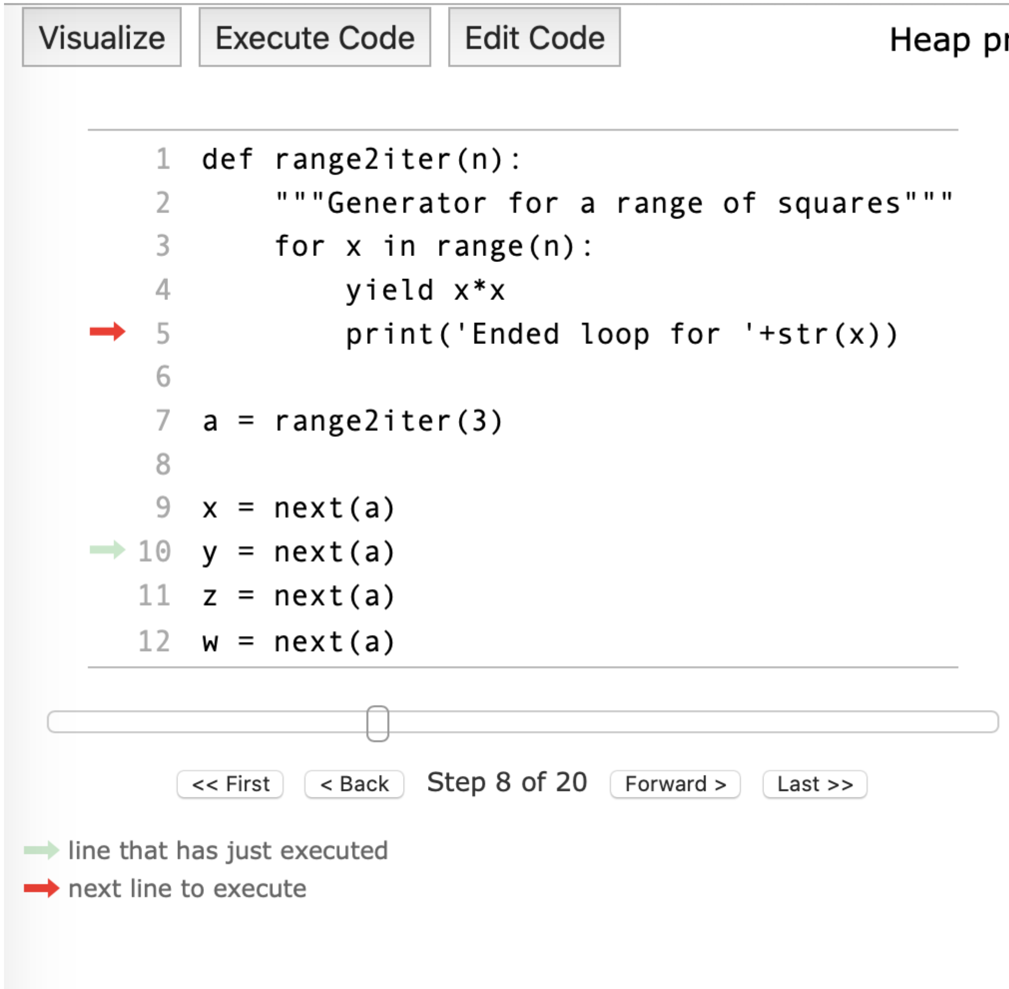


Call Finishes at the **yield**



yield is **return** for **next()**

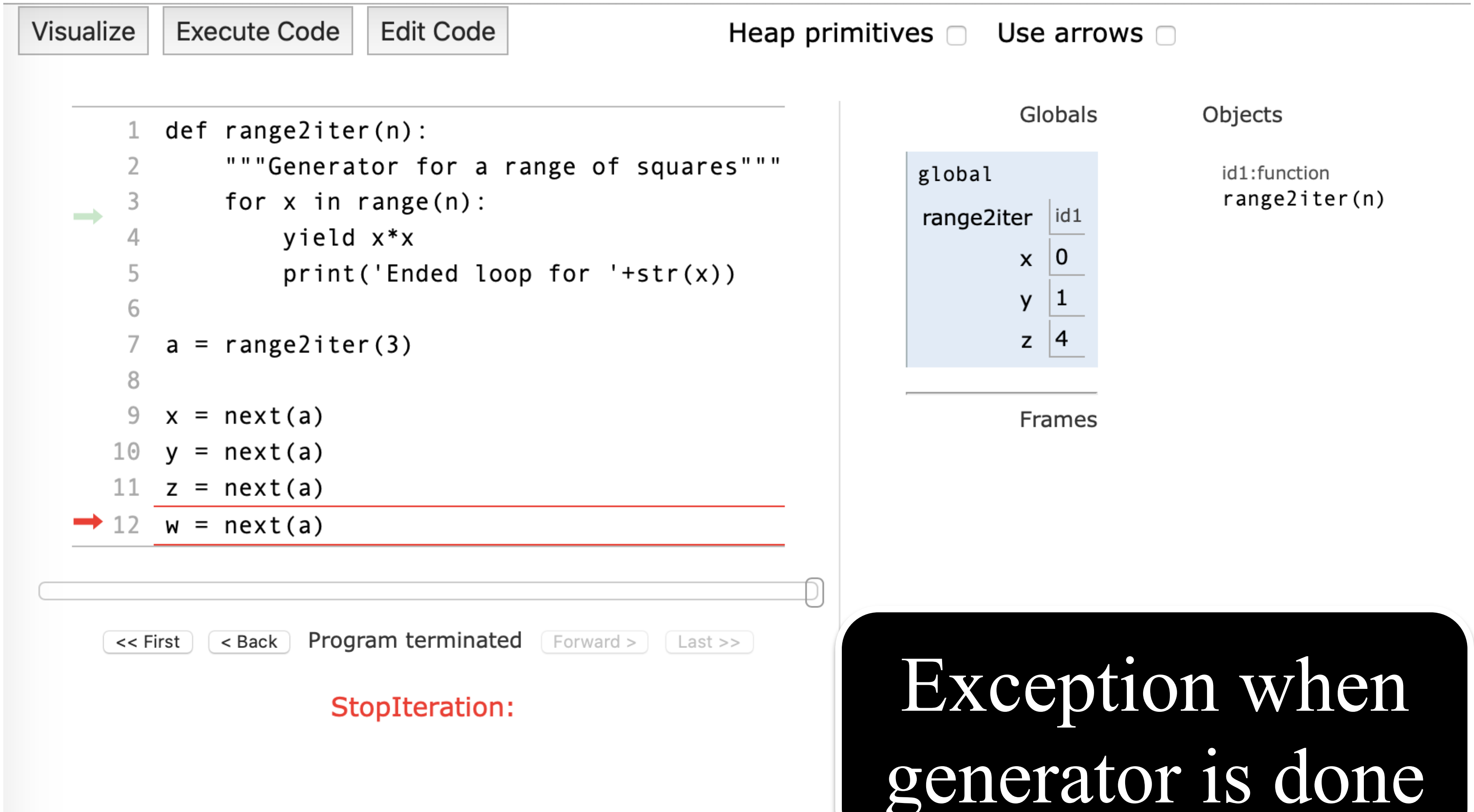
Later Calls Resume After the **yield**



From last time

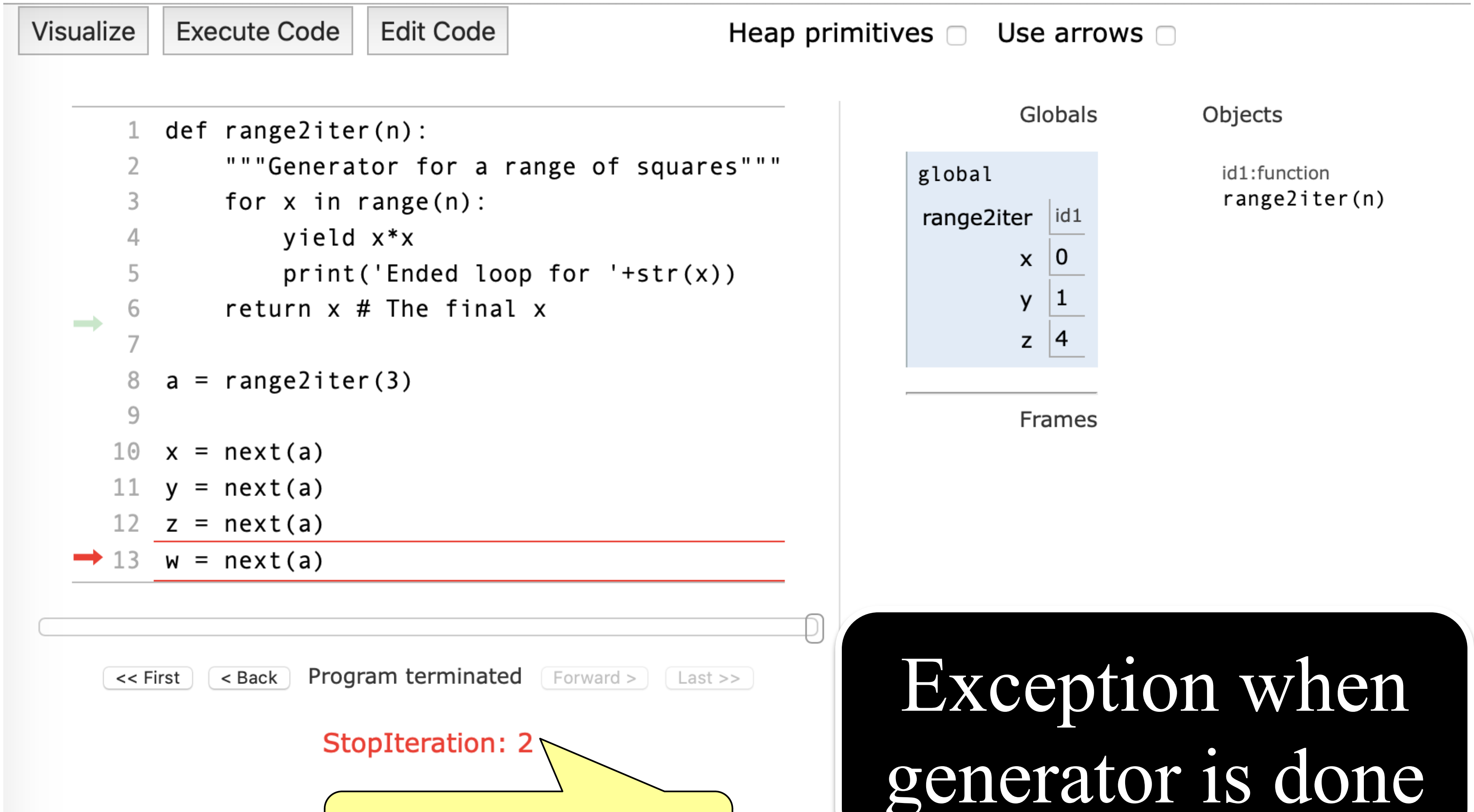
Next call returns to where it left off

Exception is Made Automatically



Exception when generator is done

Return Statements Make Exceptions



Return Value

Exception when generator is done

Activity: Call Frame Time

Function Defintions

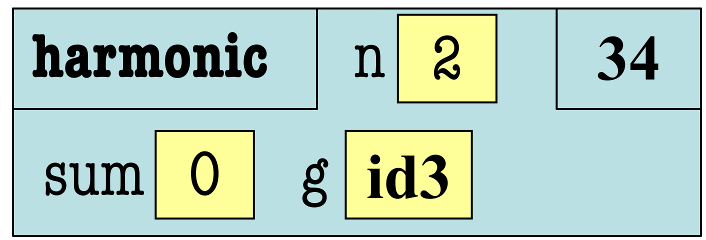
```
    def rnginv(n):        #Inverse range
19      for x in range(1,n):
20          yield 1/x

    def harmonic(n):    #Harmonic sum
32      sum = 0
33      g = rnginv(n)
34      for x in g:
35          sum = sum+x
36      return x
```

Function Call

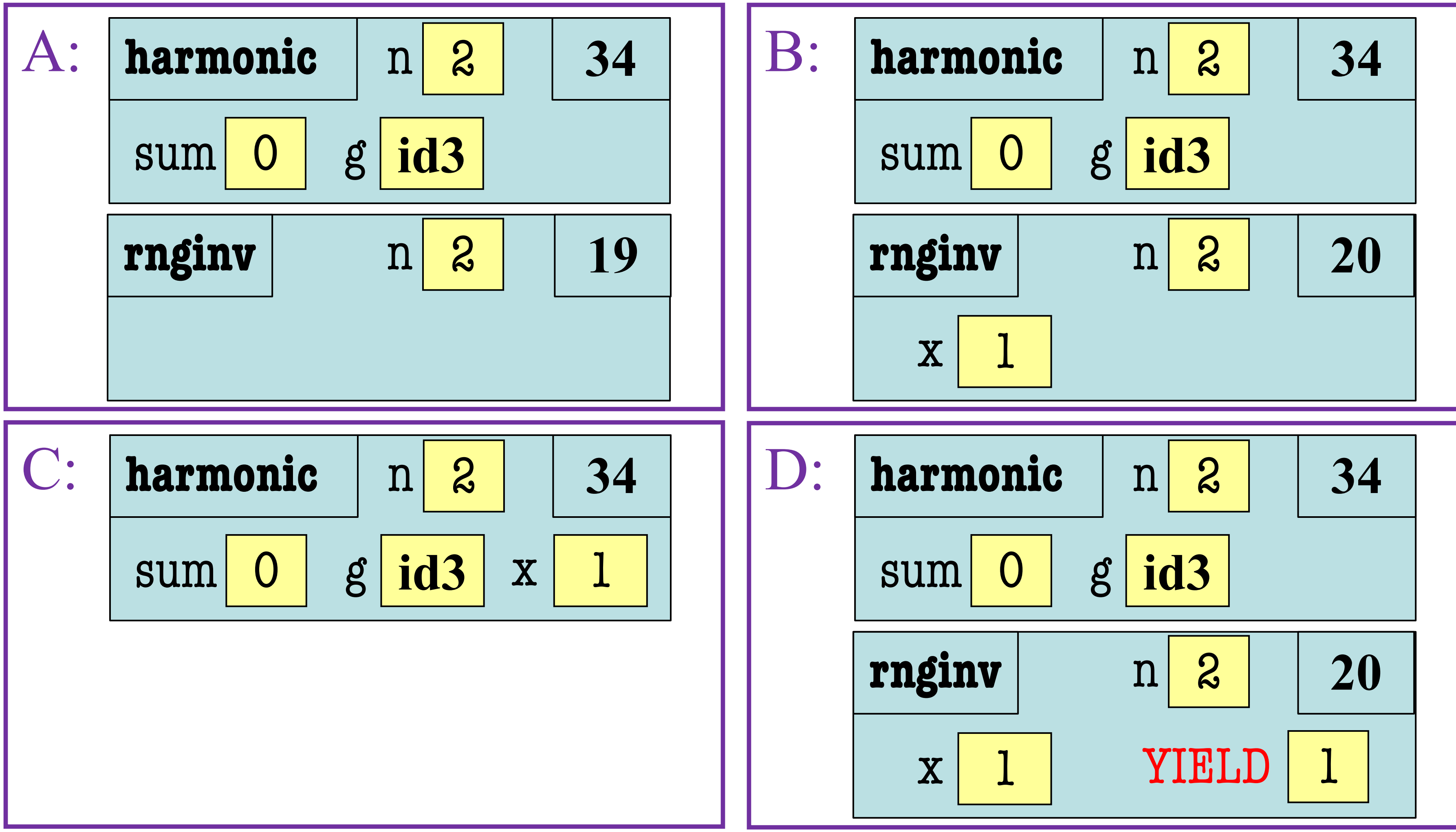
```
>>> x = harmonic(2)
```

Assume we are here:



Ignoring the heap,
what is the **next step**?

Which One is Closest to Your Answer?



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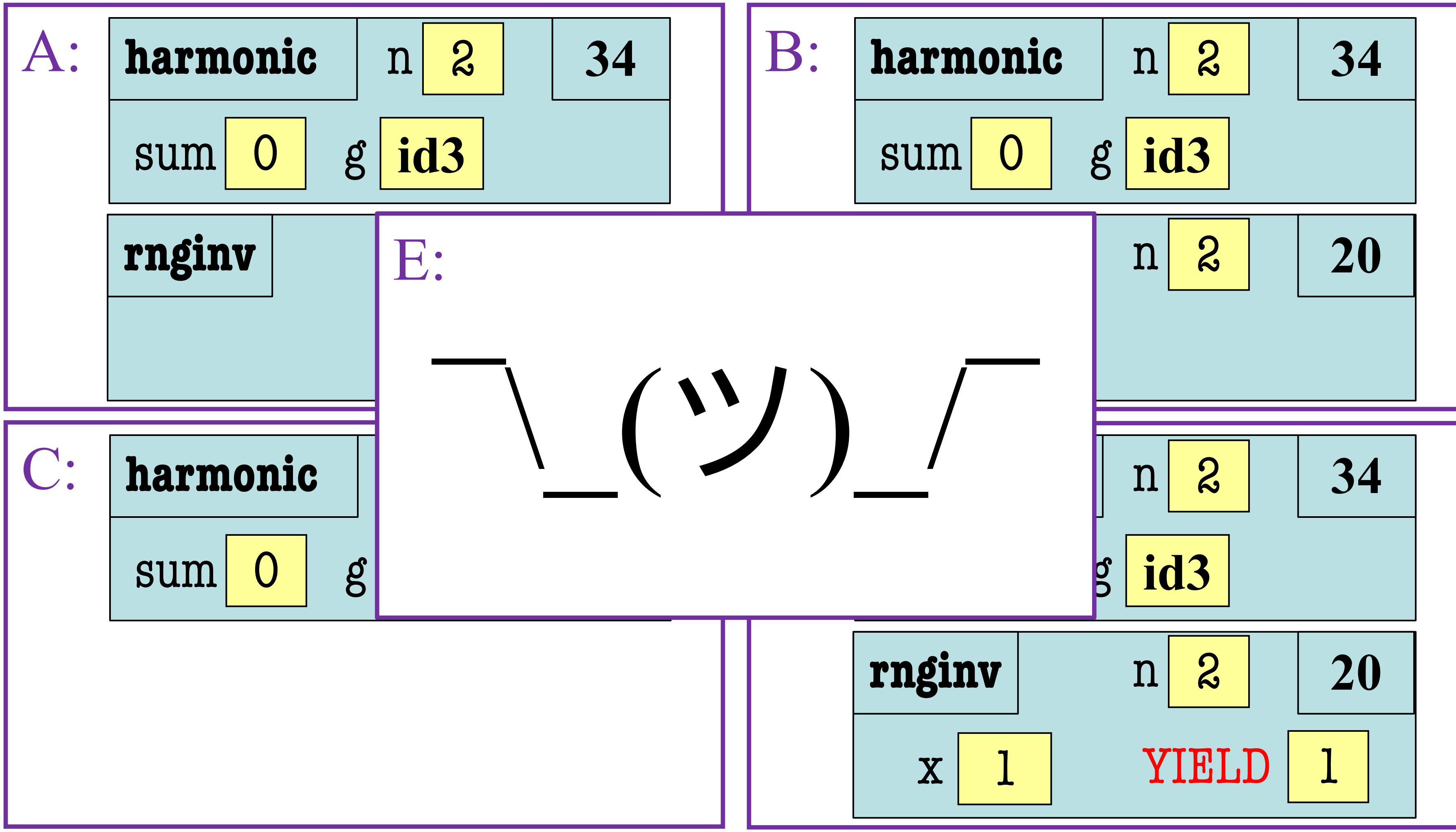

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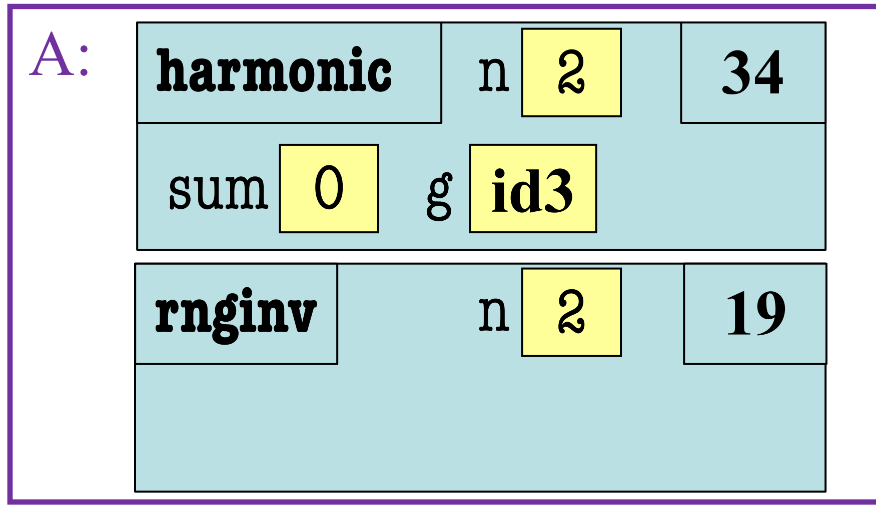
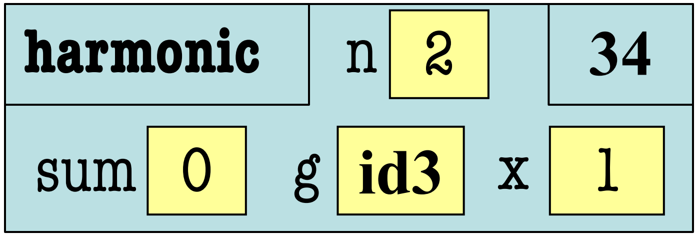


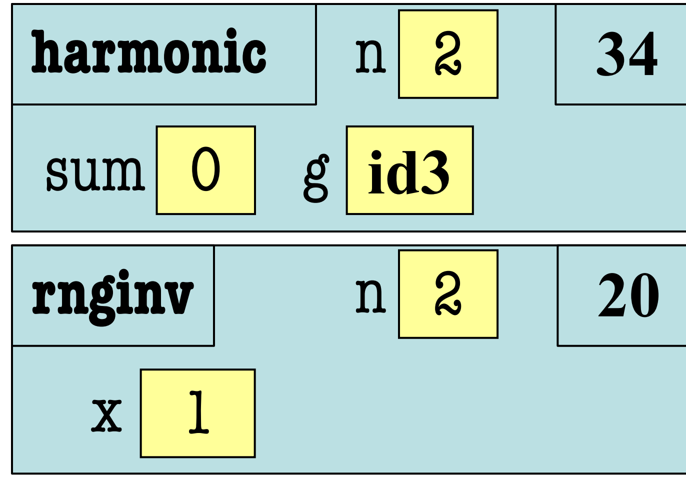
What is the **next step**?

Which One is Closest to Your Answer?

A:



B:



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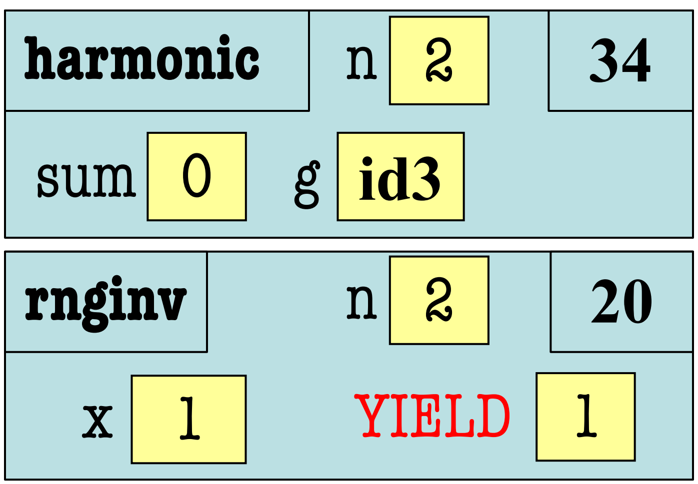
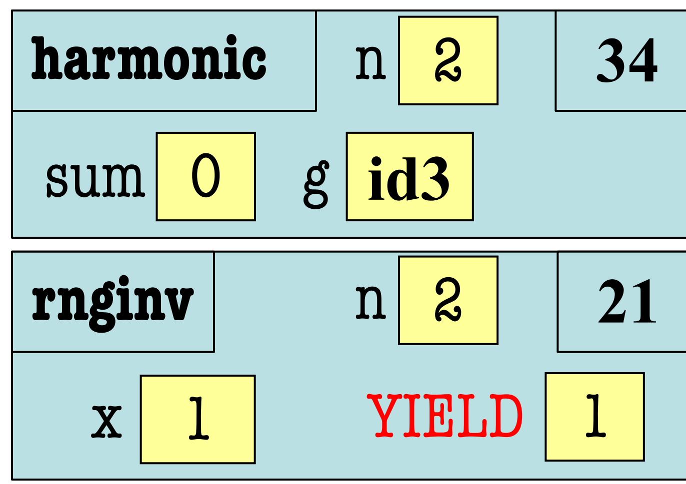


D:



Activity: Call Frame Time

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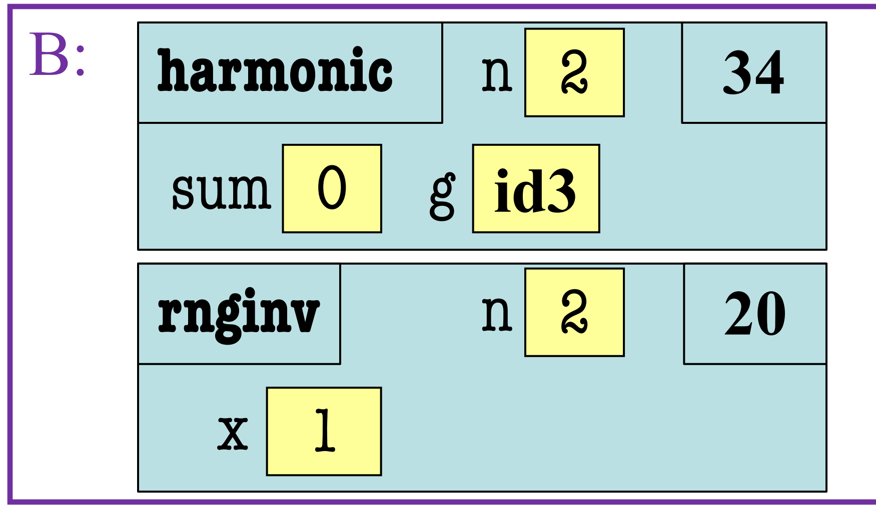

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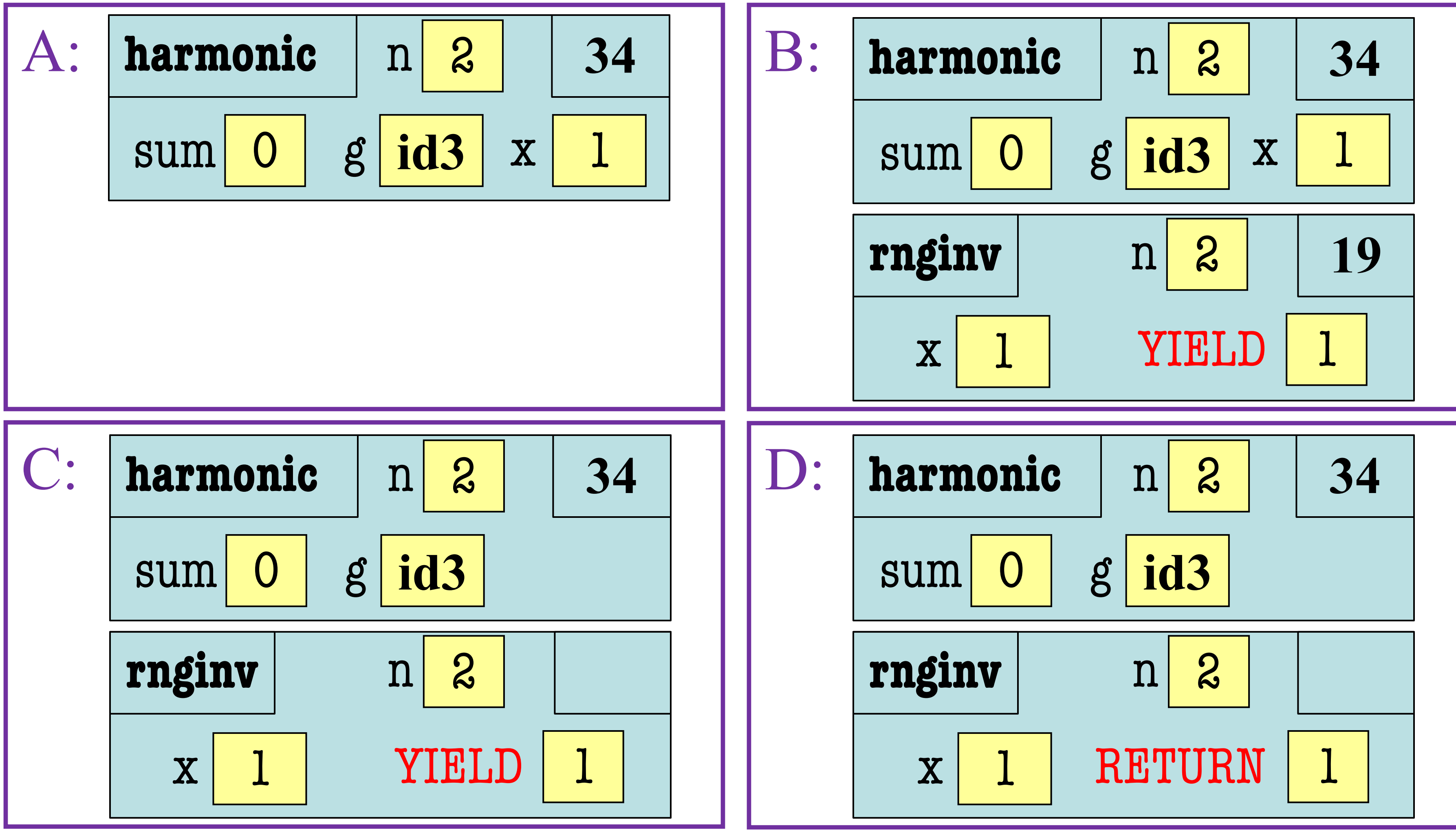

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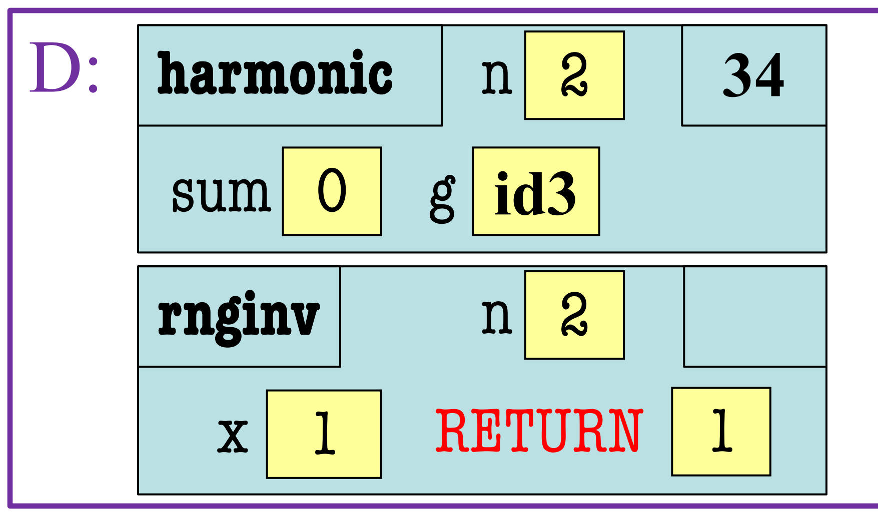

Generators Are Easy

- They replace the **accumulator pattern**
  - Function input is an iterable (string, list, tuple)
  - Function output typically a transformed copy
  - **Old way:** Accumulate a new list or tuple
  - **New way:** Yield one element at a time
- New way makes an **iterator** (not **iterable**)
  - So can only be used once!
  - But easily turned into a list or tuple

Accumulators: The Old Way

```
def add_one(lst):
    """Returns copy with 1 added to every element

    Precond: lst is a list of all numbers"""
    copy = []  # accumulator
    for x in lst:
        x = x +1
        copy.append(x)
    return copy
```

Generators: The New Way

```
def add_one(input)
    """Generates 1 added to each element of input

    Precond: input is a iterable of all numbers"""

    for x in input :
        yield x +1
```

Much Simpler!

yield eliminates the accumlator

Accumulators: The Old Way

```
def evens(lst):
    """Returns a copy with even elements only

    Precond: lst is a list of all numbers"""
    copy = []  # accumulator
    for x in lst:
        if x % 2 == 0:
            copy.append(x)
    return copy
```

Generators: The New Way

```python
def evens(input):
    """Generates only the even elements of input

    Precond: input is a iterable of all numbers"""


    for x in input:
        if x % 2 == 0:
            yield x
```

Accumulators: The Old Way

```
def average(lst):
    """Returns a running average of lst (elt n is average of lst[0:n])

    Ex: average([1, 3, 5, 7]) returns [1.0, 2.0, 3.0, 4.0]

    Precond: lst is a list of all numbers"""
    result = []                  # actual accumulator
    sum = 0; count = 0    # accumulator "helpers"
    for x in lst:
        sum = sum+x; count = count+1
        result.append(sum/count)
    return result
```

Accumulators: The Old Way

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    Ex: average([1, 3, 5, 7]) returns [1.0, 2.0, 3.0, 4.0]

    Precond: lst is a list of all numbers"""
    result = []              #
    sum = 0; count = 0       #
    for x in lst:
        sum = sum+x; count = count+1
        result.append(sum/count)
    return result
```

Allows multiple assignments per line

Generators: The New Way

```
def average(input):
    """Generates a running average of input

    Ex: input 1, 3, 5, 7 yields 1.0, 2.0, 3.0, 4.0

    Precond: input is a iterable of all numbers"""
    sum = 0       # accumulator “helper”
    count = 0     # accumulator “helper”
    for x in lst:
        sum = sum+x
        count = count+1
        yield sum/count
```

Chaining Generators

- Generators can be chained together
  - Take an iterator/iterable as input
  - Produce an iterator as output
  - Output of one generator = input of another
- Powerful programming technique

Simple Chaining


```
>>> a = [1, 2, 3, 4]                          # Start w/ any iterable
>>> b = add_one(average(evens(a)))            # Apply right to left
>>> c = list(b)                               # Convert to list/tuple
>>> c
[3.0, 4.0]
```

Simple Chaining

Natural way to process data streams

```
>>> a = [1, 2                                  any iterable
>>> b = add_                                   ht to left
>>> c = list(b)                                # Convert to list/tuple
>>> c
[3.0, 4.0]
```

Why Do We Care?

- Stream programming is an advanced topic
  - Involves chaining together many generators
  - Will see this again if go on to 3110
- But we have an application in **A7!**
  - Remember that GUIs are like iterator classes
  - Game app runs with an "invisible" loop
  - All **loop variables** implemented as **attributes**
  - Generators are a way to **simplify** all this

Why Do We Care?

- Stream programming is an advanced topic
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- But we have an application in **A7**!
  - Remember that GUIs are like iterator classes
  - Game
  - All **loc** **utes**
  - Generators are a way to **simplify** all this

Unfortunately out of scope