Programming Languages and Techniques (CIS1200)

Lecture 29

Iterators, Exceptions

Chapters 25 and 27

Announcements

- HW07: PennPals
  - Programming with Java Collections
  - Due Tuesday!

Iterating over collections

iterators, while, for, for-each loops

Iterator and Iterable

```
interface Iterator<E> {
   public boolean hasNext();
   public E next();
   public void delete();   // optional
}
```

```
interface Iterable<E> {
   public Iterator<E> iterator();
}
```

```
interface Collection<E> extends Iterable<E> …
```

Challenge: given a List<Book> object how would you add each book’s data to a catalogue using an iterator?

While Loops

syntax:

```
// repeat body until condition becomes false
while (condition) {
   body
}
```

statement

boolean *guard* expression

example:

```
List<Book> shelf = …  // create a list of Books

// iterate through the elements on the shelf
Iterator<Book> iter = shelf.iterator();
while (iter.hasNext()) {
   Book book = iter.next();
   catalogue.addInfo(book);
   numBooks = numBooks+1;
}
```

For Loops

syntax:

```
for (init-stmt; condition; next-stmt) {
   body
}
```

equivalent while loop:

```
init-stmt;
while (condition) {
   body
   next-stmt;
}
```

```
List<Book> shelf = …  // create a list of Books

// iterate through the elements on the shelf
for (Iterator<Book> iter = shelf.iterator();
         iter.hasNext();) {
     Book book = iter.next();
     catalogue.addInfo(book);
     numBooks = numBooks+1;
}
```

For-each Loops

syntax:

```
// repeat body for each element in collection
for (type var : coll) {
   body
}
```

element type E

Array of E or instance of Iterable<E>

example:

```
List<Book> shelf = …  // create a list of books

// iterate through the elements on a shelf
for (Book book : shelf) {
    catalogue.addInfo(book);
    numBooks = numBooks+1;
}
```

For-each Loops (cont'd)

Another example:

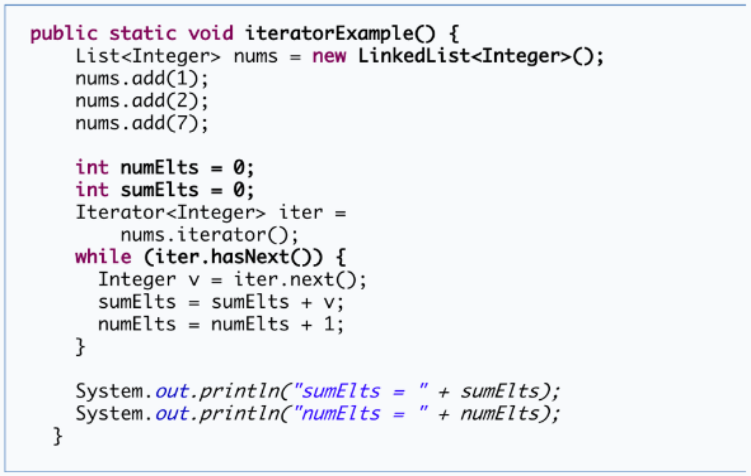
```
int[] arr = …  // create an array of ints

// count the non-null elements of an array
for (int elt : arr) {
    if (elt != 0) cnt = cnt+1;
}
```

For-each can be used to iterate over arrays or any class that implements the `Iterable<E>` interface (notably `Collection<E>` and its subinterfaces).

29: What is printed by iteratorExample()?

0



```
public static void iteratorExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int numElts = 0;
    int sumElts = 0;
    Iterator<Integer> iter =
        nums.iterator();
    while (iter.hasNext()) {
      Integer v = iter.next();
      sumElts = sumElts + v;
      numElts = numElts + 1;
    }

    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

sumElts = 0 numElts = 0 0%

sumElts = 3 numElts = 2 0%

sumElts = 10 numElts = 3 0%

NullPointerException 0%

something else 0%

Iterator example

```
public static void iteratorExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int numElts = 0;
    int sumElts = 0;
    Iterator<Integer> iter =
        nums.iterator();
    while (iter.hasNext()) {
      Integer v = iter.next();
      sumElts = sumElts + v;
      numElts = numElts + 1;
    }

    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

What is printed by iteratorExample()?

1. sumElts = 0 numElts = 0
2. sumElts = 3 numElts = 2
3. sumElts = 10 numElts = 3
4. NullPointerException
5. Something else

Answer: 3

For-each version

```
public static void forEachExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int numElts = 0;
    int sumElts = 0;
    for (Integer v : nums) {
      sumElts = sumElts + v;
      numElts = numElts + 1;
    }

    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

Another Iterator example

```
public static void nextNextExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int sumElts = 0;
    int numElts = 0;
    Iterator<Integer> iter =
        nums.iterator();
    while (iter.hasNext()) {
      Integer v = iter.next();
      sumElts = sumElts + v;
      v = iter.next();
      numElts = numElts + v;
    }
    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

What is printed by nextNextExample()?

1. sumElts = 0 numElts = 0
2. sumElts = 3 numElts = 2
3. sumElts = 8 numElts = 2
4. NullPointerException
5. Something else

Answer: 5   NoSuchElementException

29: What is printed by nextNextExample()?

0

```
public static void nextNextExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int sumElts = 0;
    int numElts = 0;
    Iterator<Integer> iter =
        nums.iterator();
    while (iter.hasNext()) {
      Integer v = iter.next();
      sumElts = sumElts + v;
      v = iter.next();
      numElts = numElts + v;
    }
    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

sumElts = 0 numElts = 0 — 0%

sumElts = 3 numElts = 2 — 0%

sumElts = 8 numElts = 2 — 0%

NullPointerException — 0%

something else — 0%

Enumerations

Enumerations (a.k.a. Enum Types)

- Java supports *enumerated* type constructors
  - Intended to represent constant data values
  - see: CommandParser.java

```
private enum CommandType {
    CREATE, INVITE, JOIN, KICK, LEAVE, MESG, NICK
}
```

- Intuitively similar to a simple usage of OCaml datatypes
  - …but each language provides extra bells and whistles that the other does not

Enumerations (a.k.a. Enum Types)

```
public enum ErrorCode {

    INVALID_NAME(401),
    NO_SUCH_CHANNEL(402),
    NO_SUCH_USER(403),
    USER_NOT_IN_CHANNEL(404),
    USER_NOT_OWNER(406),
    …

    private final int value;

    ServerError(int value) {
        this.value = value;
    }

    public int getCode() {
        return value;
    }
}
```

Elements of the enum can be declared along with "parameters"

When the object representing each element is created, the associated parameters are passed to the constructor method.

Intuitively similar to OCaml datatypes
…but each language provides extra bells and whistles that the other does not

ErrorCode.java in HW 7

Enums are Classes

- Enums are a convenient way of defining a class along with some standard static methods
  - `valueOf` : converts a `String` to an Enum

    ```
    ErrorCode e = ErrorCode.valueOf("INVALID_NAME");
    ```

  - `values`: returns an `Array` of all the enumerated constants

-
  ```
  ErrorCode[] values = ErrorCode.values();
  ```
- Implicitly extend class java.lang.Enum
- See Java manual for more

Using Enums: Switch

```
public static void print (ErrorCode e) {
    switch (e) {
        case INVALID_NAME: System.out.println("Invalid name");
          break;
        case NO_SUCH_CHANNEL: System.out.println("No such channel");
          break;
        case NO_SUCH_USER: System.out.println("No such user");
          break;
        default: System.out.println("Unknown error code: " + e);
    }
}
```

- Multi-way branch, similar to OCaml's match
  - Works for: primitive data 'int', 'byte', 'char', *etc.*, plus enum types and String
  - Not as powerful as OCaml pattern matching, yet! (New pattern matching features coming to future version of Java)
- The **`default`** keyword specifies a "catch all" (wildcard) case

Alternative Option – switch Expressions

- No need for **break** statements to prevent fall through

```
public static String stringify (ErrorCode e) {
    return switch (e) {
        case INVALID_NAME -> "Invalid name";
        case NO_SUCH_CHANNEL -> "No such channel";
        case NO_SUCH_USER -> "No such user";
        default -> "Unknown error code: " + e;
    };
}
```

- Read more here - https://docs.oracle.com/en/java/javase/14/language/switch-expressions.html

Some Advice on Debugging

Use the Scientific Method

1. Make an observation / ask a question
   - One of my test cases fails!
   - Which assertion? What exception? What is the stack trace?
2. Formulate a hypothesis
   - Could I have passed null as bar to foo.munge(bar)?
3. Conduct an experiment
   - Modify the program to try to confirm / refute the hypothesis.
   - *Don't* make random changes!
   - You should try to predict the effects of your experiment
   - Re-run test cases
4. Analyze the results
   - Did the modified code behave as expected?
5. Draw conclusions / Report results
   - Create a new test case (if appropriate)

Observing Behavior

- Understand exceptions and the stack trace
  - They give you a lot of information

- If you are using Eclipse, it is worth taking a little time to learn how to use the debugger!
  - See Piazza for a Quick Start tutorial

- Simple print statements are also very effective!
  - Confirm or disprove hypothesis
  - e.g.: The code reached "HERE!" (or not)

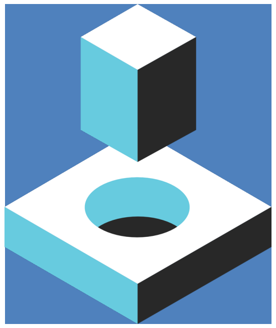
Exceptions

Dealing with the unexpected

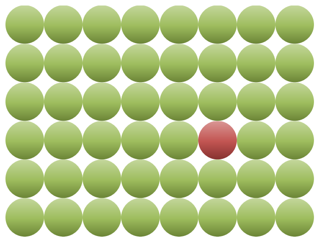
Why do methods “fail”?

- Some methods expect their arguments to satisfy conditions
  - Input to `max` must be a nonempty list, Item must be non-null, more elements must be available when calling `next`, …
- Interfaces may be imprecise
  - Some Iterators don't support the "remove" operation
- External components of a system might fail
  - Try to open a file or resource that doesn't exist
- Resources might be exhausted
  - Program uses all of the computer's memory or disk space

- These are all *exceptional circumstances…*
  - How do we deal with them?

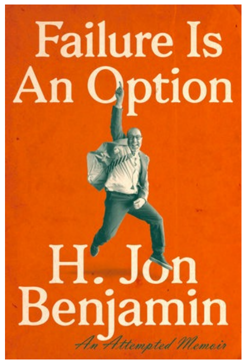


Error 404
Page Not Found!



Ways to handle failure

- Return an error value (or default value)
  - e.g. Math.sqrt returns NaN ("not a number") if given input < 0
  - e.g. Many Java libraries return `null`
  - e.g. file reading method returns -1 if no more input available
  - *Caller is supposed to check return value, but it's easy to forget* ☹
  - *Use with caution – easy to introduce nasty bugs!* ☹
- Use an informative result
  - e.g. in OCaml we used options to signal potential failure
  - *Passes responsibility to caller, who must do the proper check to extract value*
- Use *exceptions*
  - Available both in OCaml and Java
  - Any caller (not just the immediate one) can handle the exception
  - If an exception is not caught, the program terminates



Exceptions

- An exception is an *object* representing an abnormal condition
  - Its internal state describes what went wrong
  - e.g.: NullPointerException,
    IllegalArgumentException,
    IOException
  - Can define your own exception classes
- *Throwing* an exception is an *emergency exit* from the current context
  - The exception propagates up the invocation stack until it either reaches the top of the stack, in which case the program aborts with the error, or the exception is *caught*
- *Catching* an exception lets callers take appropriate actions to handle the abnormal circumstances
  - Java uses try / catch blocks to handle exceptions.

Example from Pennstagram HW

```
private void load(String filename) {
        ImageIcon icon;

        try {
            if ((new File(filename)).exists())
                icon = new ImageIcon(filename);
            else {
                java.net.URL u = new java.net.URL(filename);
                icon = new ImageIcon(u);
            }
        } catch (Exception e) {
            throw new RuntimeException(e);
        }
        …
}
```

30: What happens if we do (new C()).foo(). ? The program does...

✓ 0

Program stops without printing anything

0%

Program prints “here in bar”, then stops

0%

Program prints “here in bar”, then “here in foo”, then stops

0%

Something else

0%

Simplified Example

```
class C {
  public void foo() {
    this.bar();
    System.out.println("here in foo");
  }
  public void bar() {
    this.baz();
    System.out.println("here in bar");
  }
  public void baz() {
    throw new RuntimeException();
  }
}
```

What happens if we do `(new C()).foo()` ?

1. Program stops without printing anything
2. Program prints “here in bar”, then stops
3. Program prints “here in bar”, then “here in foo”, then stops
4. Something else

Answer: 4* (*well… depends on whether you count stderr as "printing")

Abstract Stack Machine

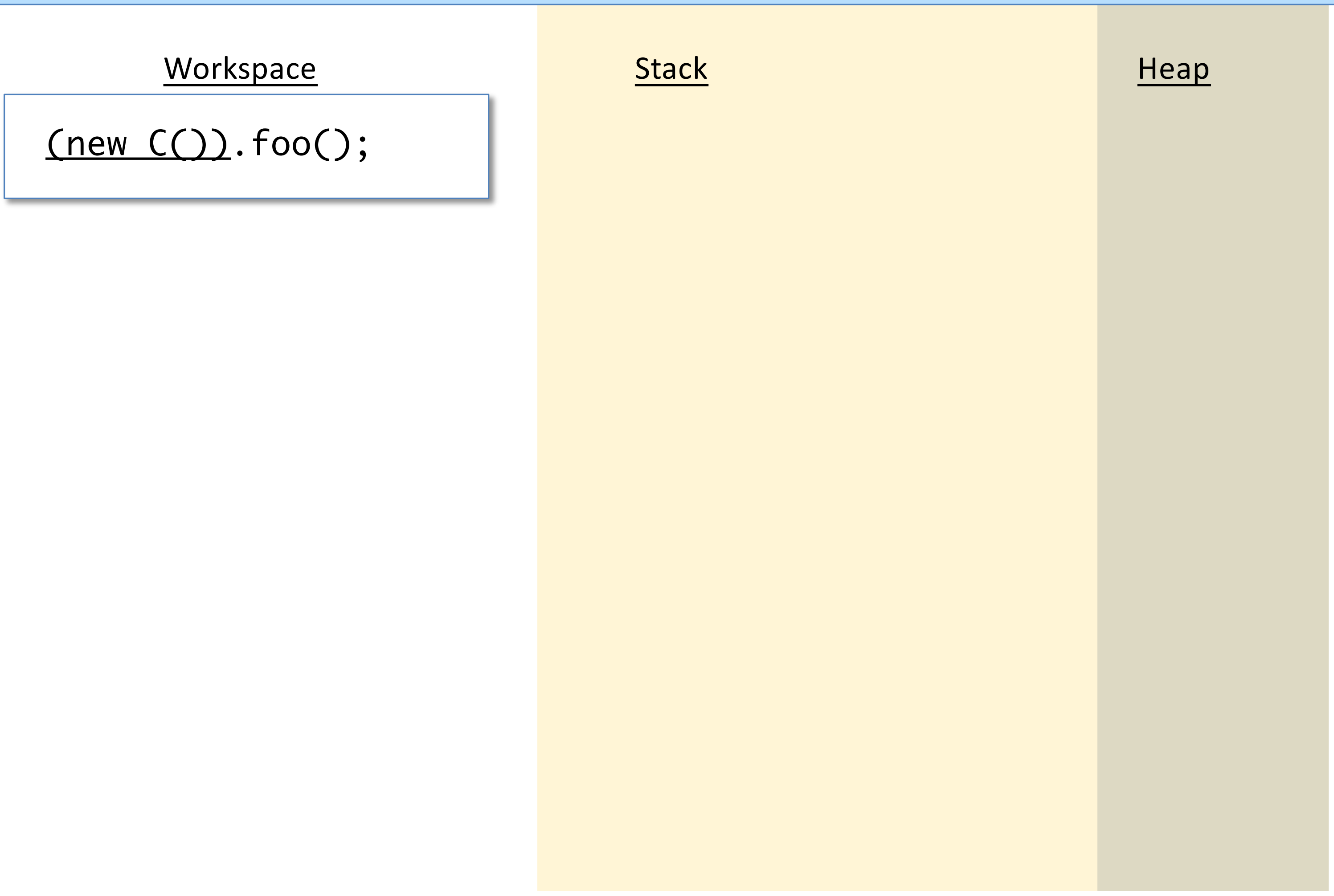
Workspace

```
(new C()).foo();
```

Stack

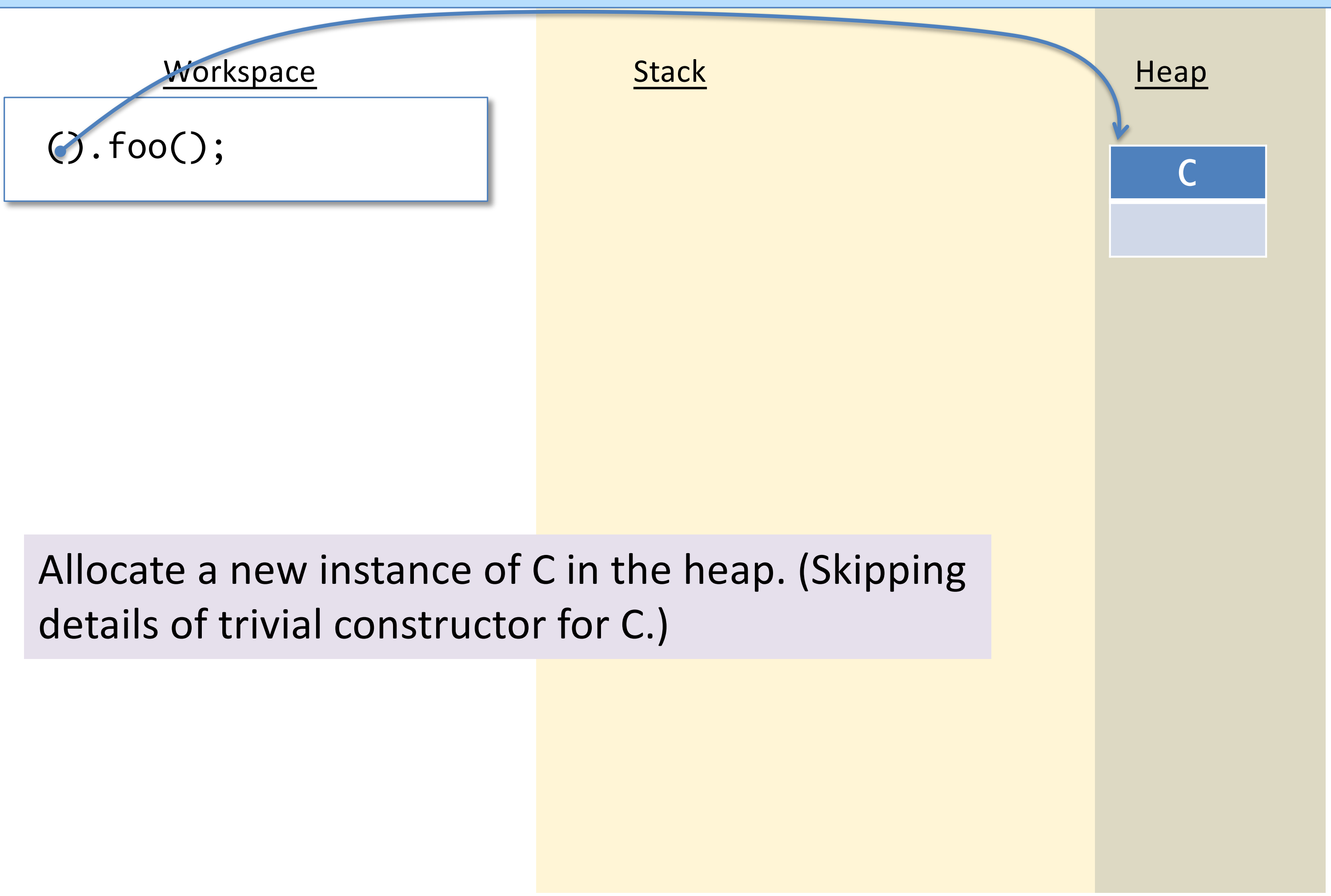
Heap

Abstract Stack Machine



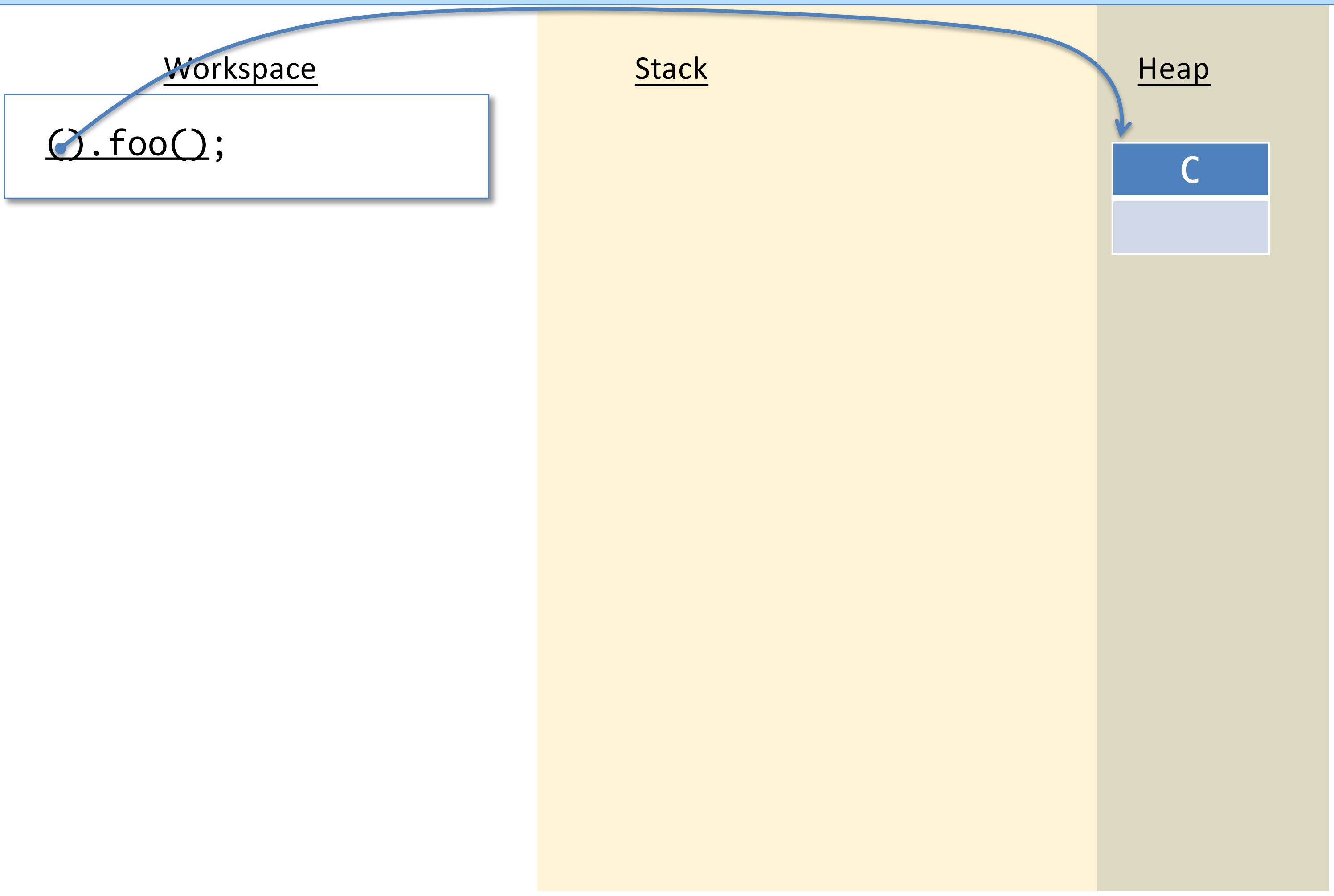
```
(new C()).foo();
```

Abstract Stack Machine

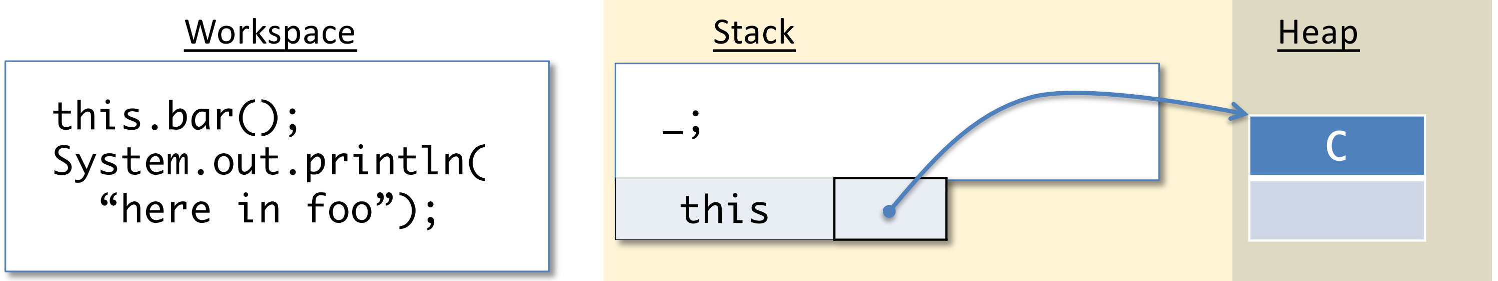


Allocate a new instance of C in the heap. (Skipping details of trivial constructor for C.)

Abstract Stack Machine



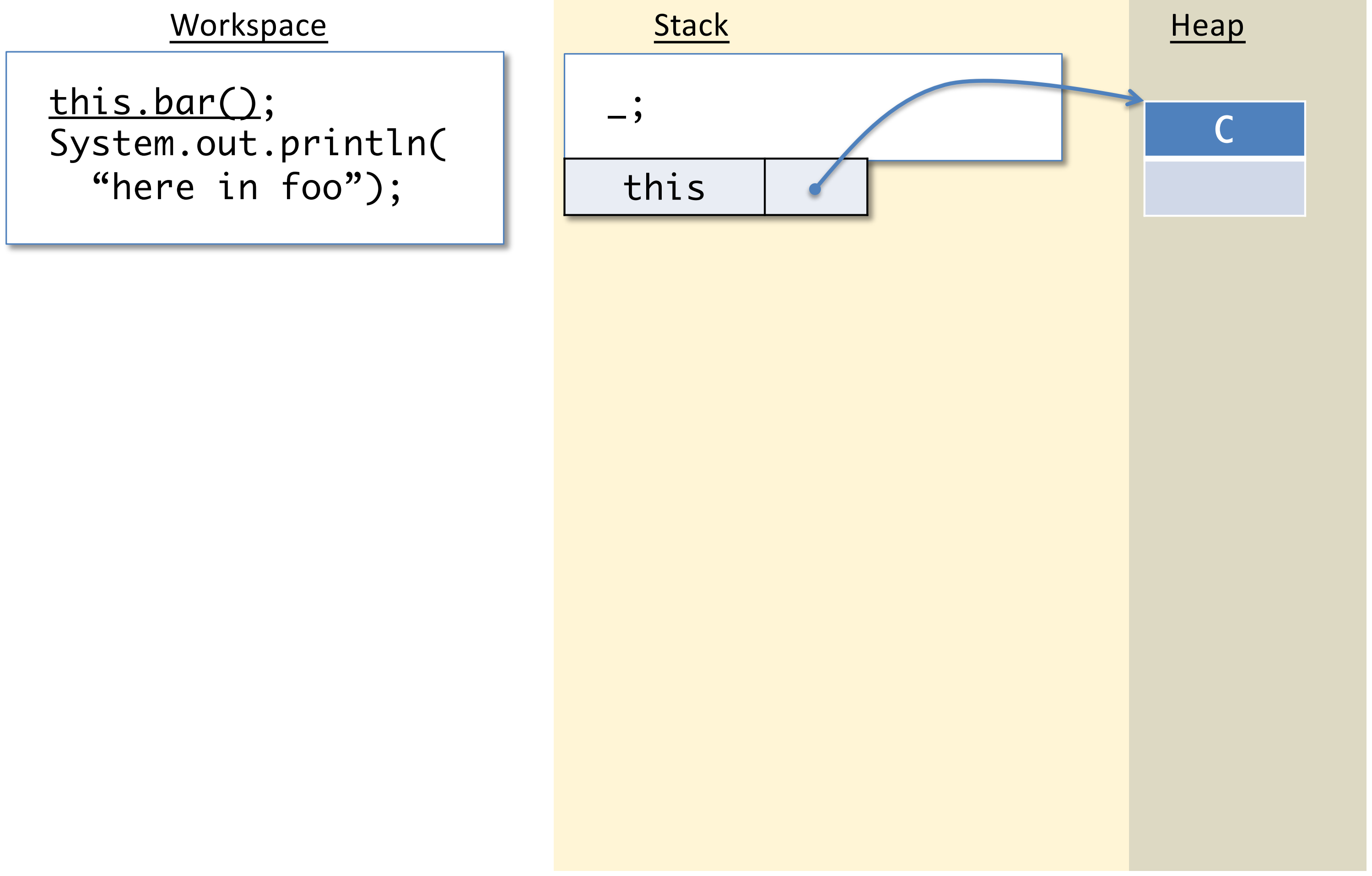
Abstract Stack Machine



```
this.bar();
System.out.println(
  “here in foo”);
```

Save a copy of the current workspace in the stack, leaving a “hole”, written _, where we return to. Push the `this` pointer, followed by arguments (in this case none) onto the stack. Use the dynamic class to look up the method body from the class table.

Abstract Stack Machine



```
this.bar();
System.out.println(
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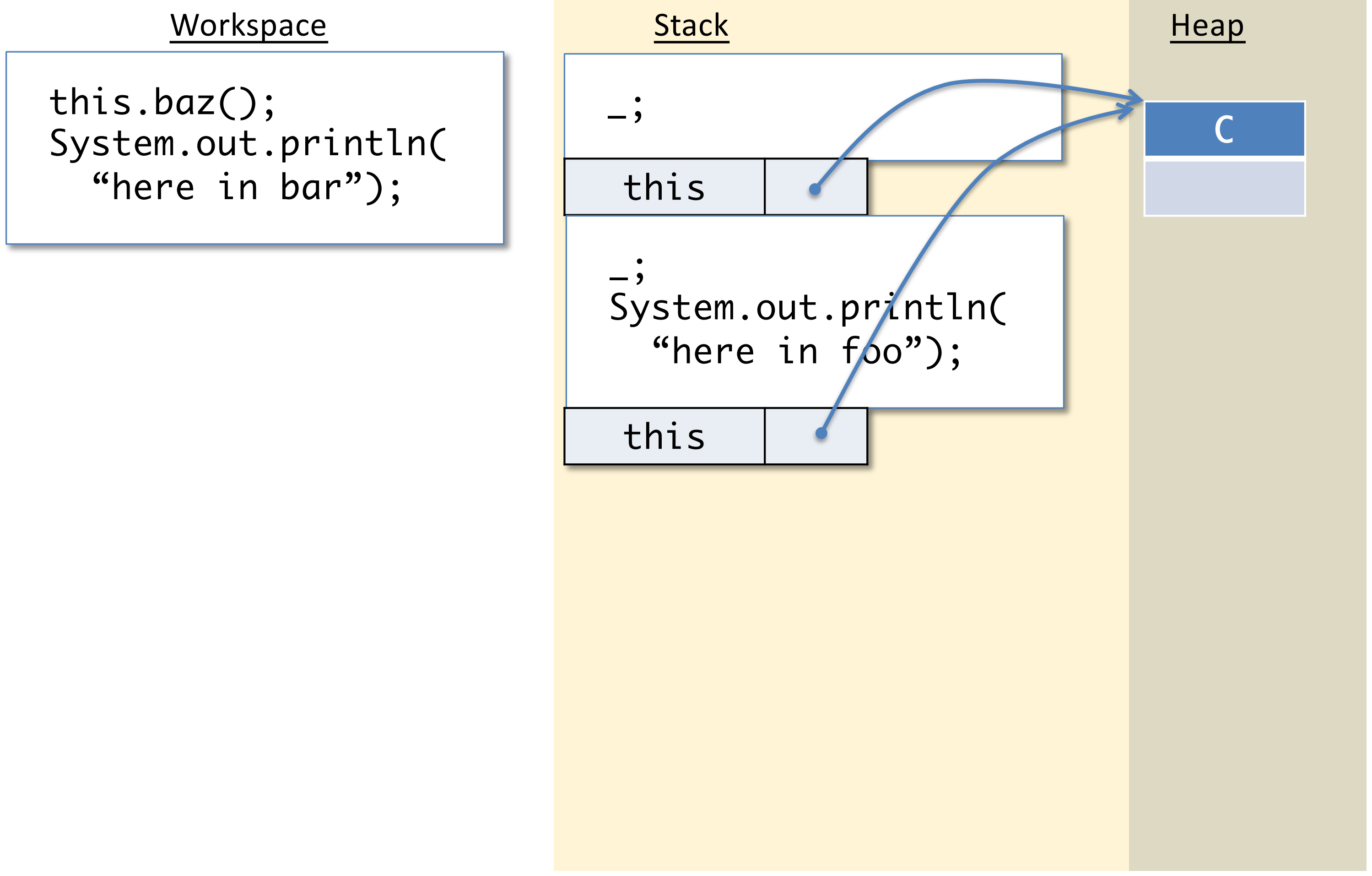
Abstract Stack Machine

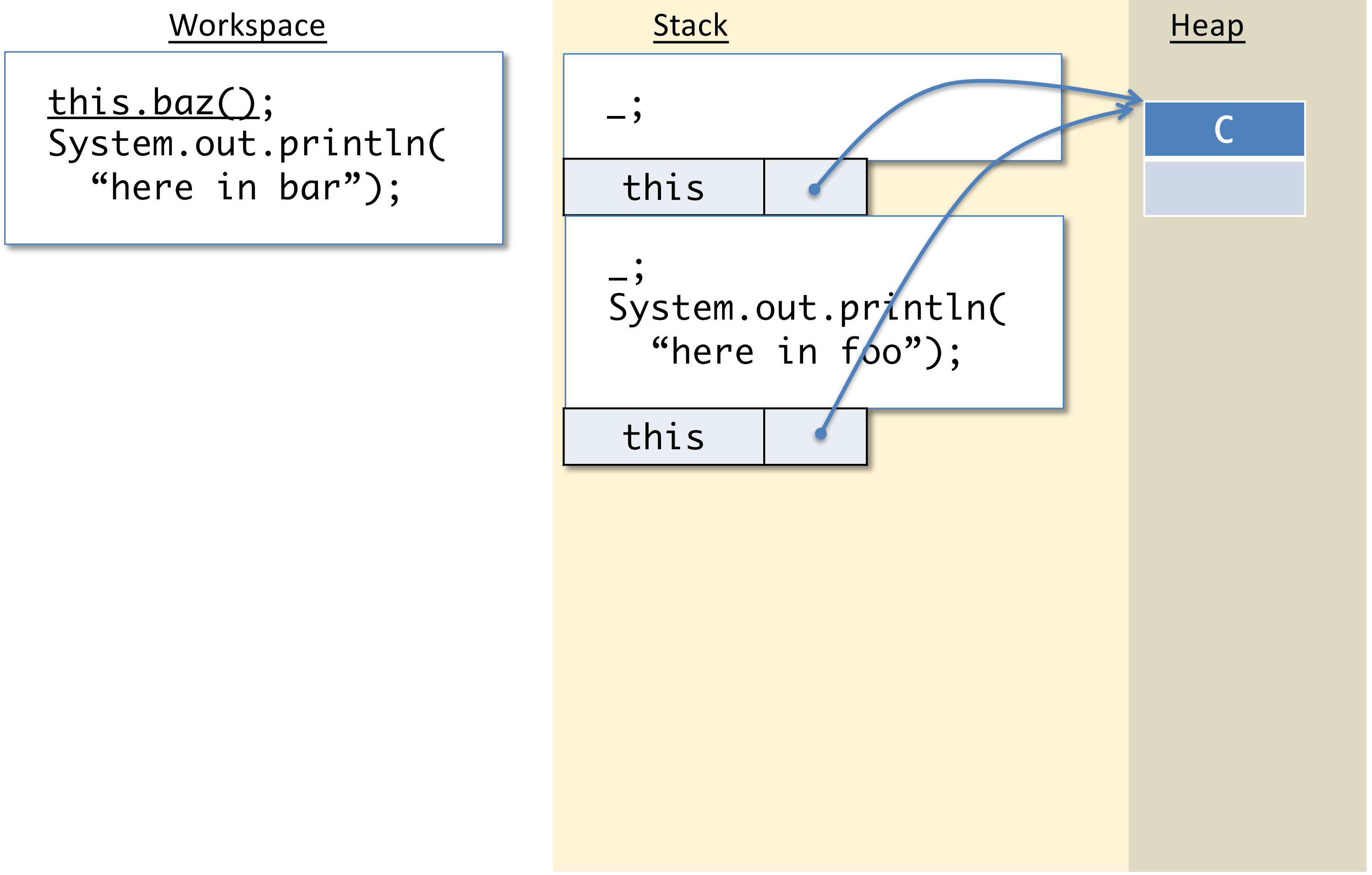


```
this.baz();
System.out.println(
  “here in bar”);
```

```
_;
```

```
_;
System.out.println(
  “here in foo”);
```

Abstract Stack Machine



Workspace

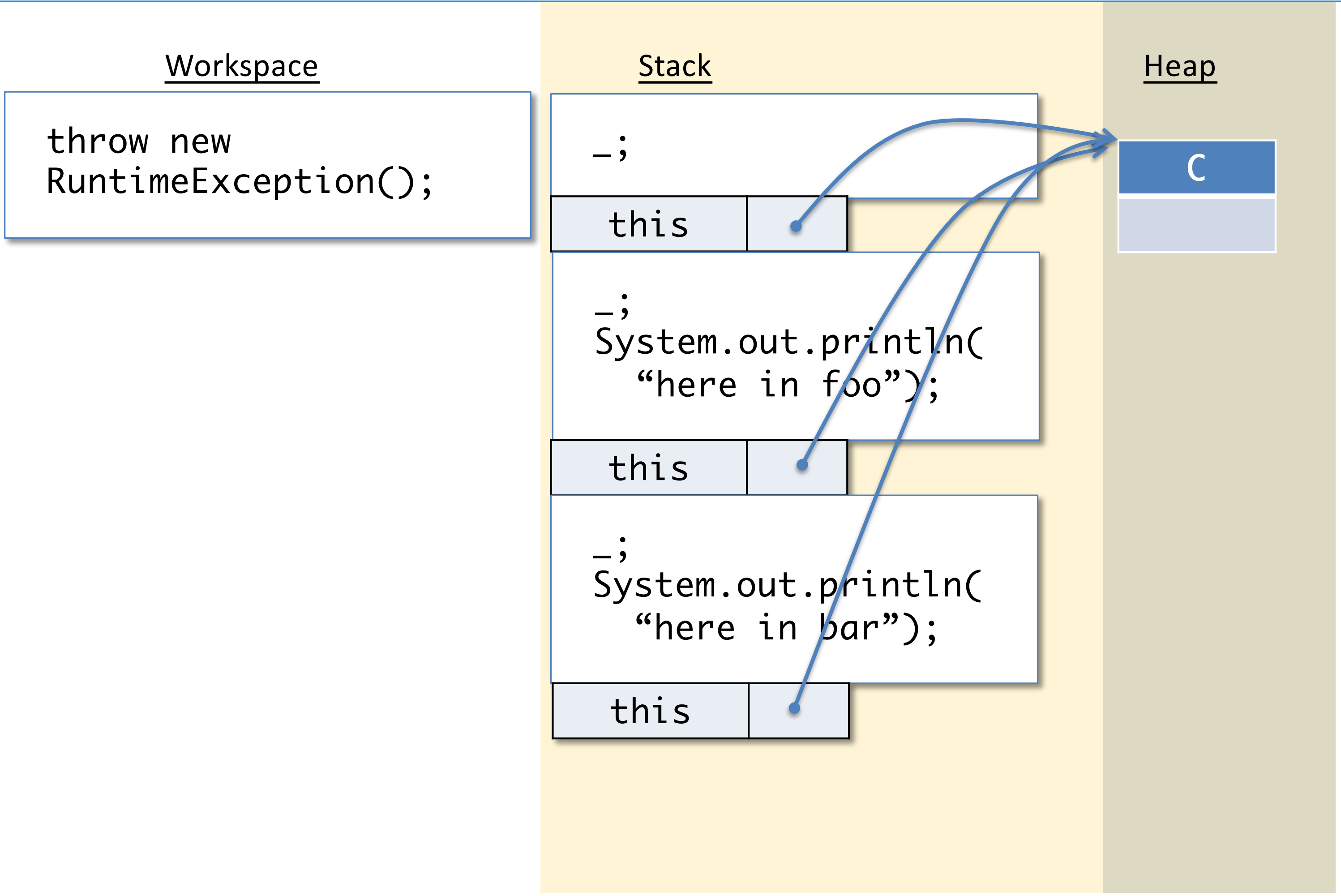
```
this.baz();
System.out.println(
  “here in bar”);
```

Stack

```
_;
```

```
_;
System.out.println(
  “here in foo”);
```

Abstract Stack Machine



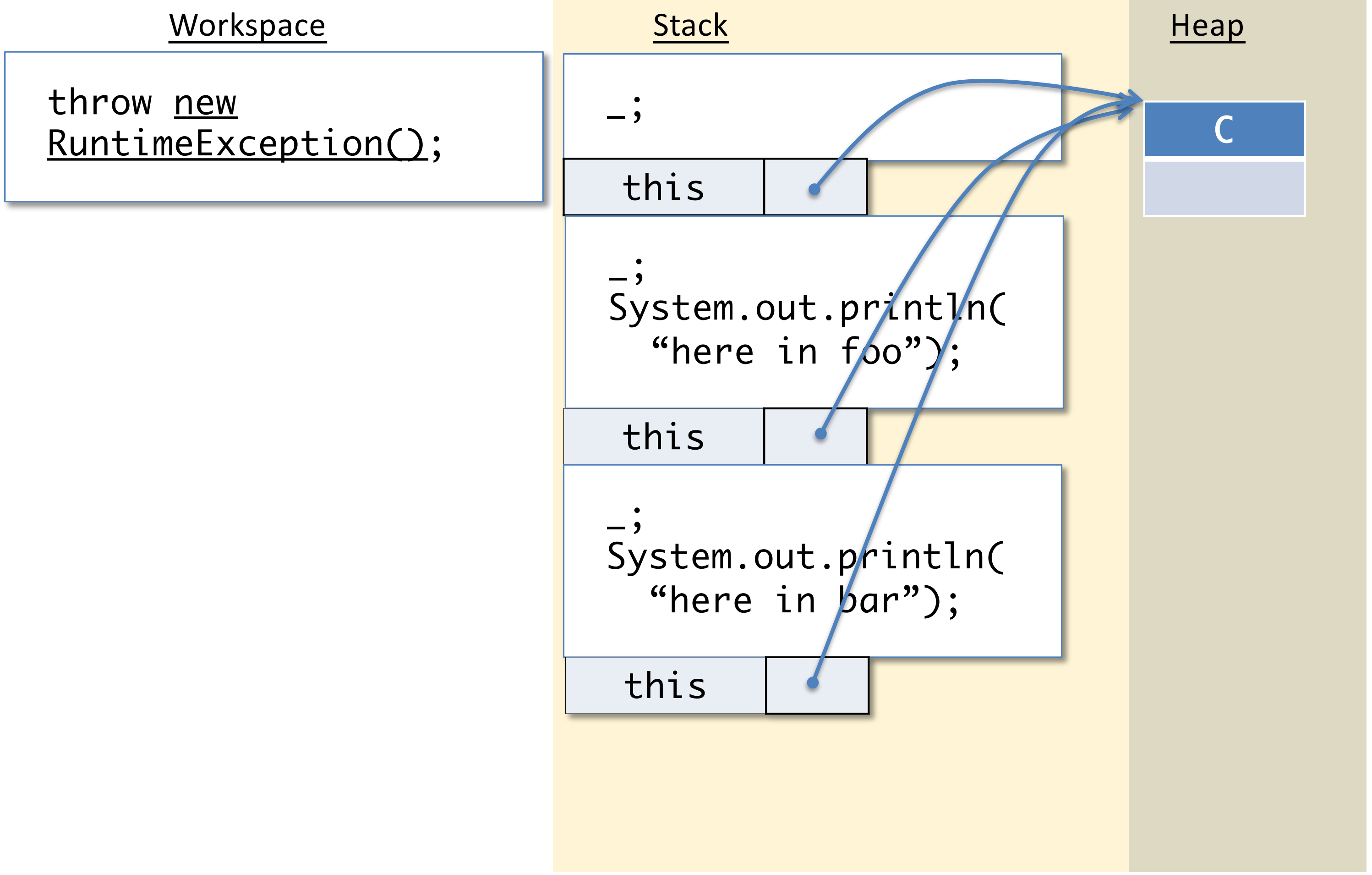
```
throw new
RuntimeException();
```

```
_;
```

```
_;
System.out.println(
  “here in foo”);
```

```
_;
System.out.println(
  “here in bar”);
```

Abstract Stack Machine



```
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```

```
_;
```

```
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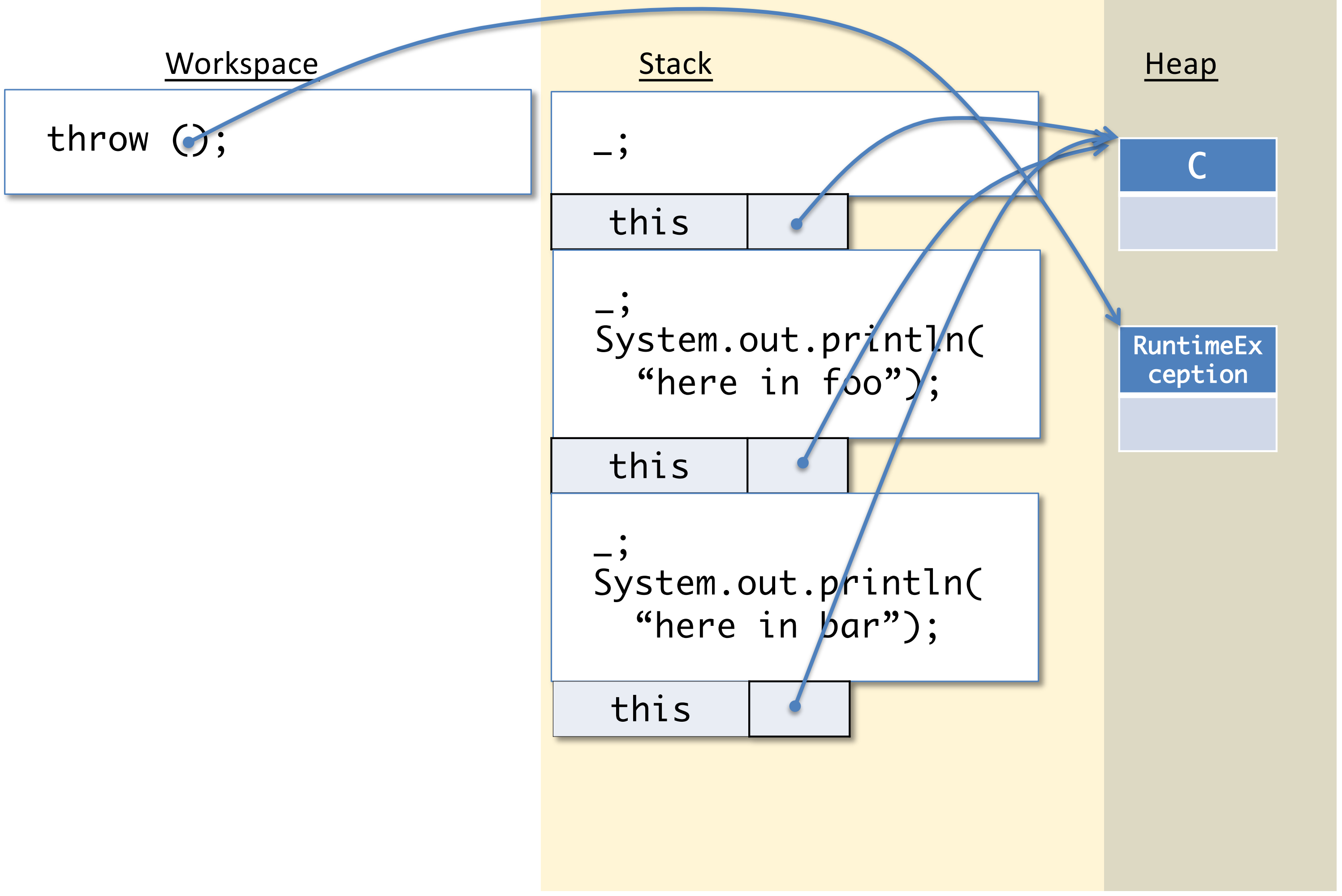
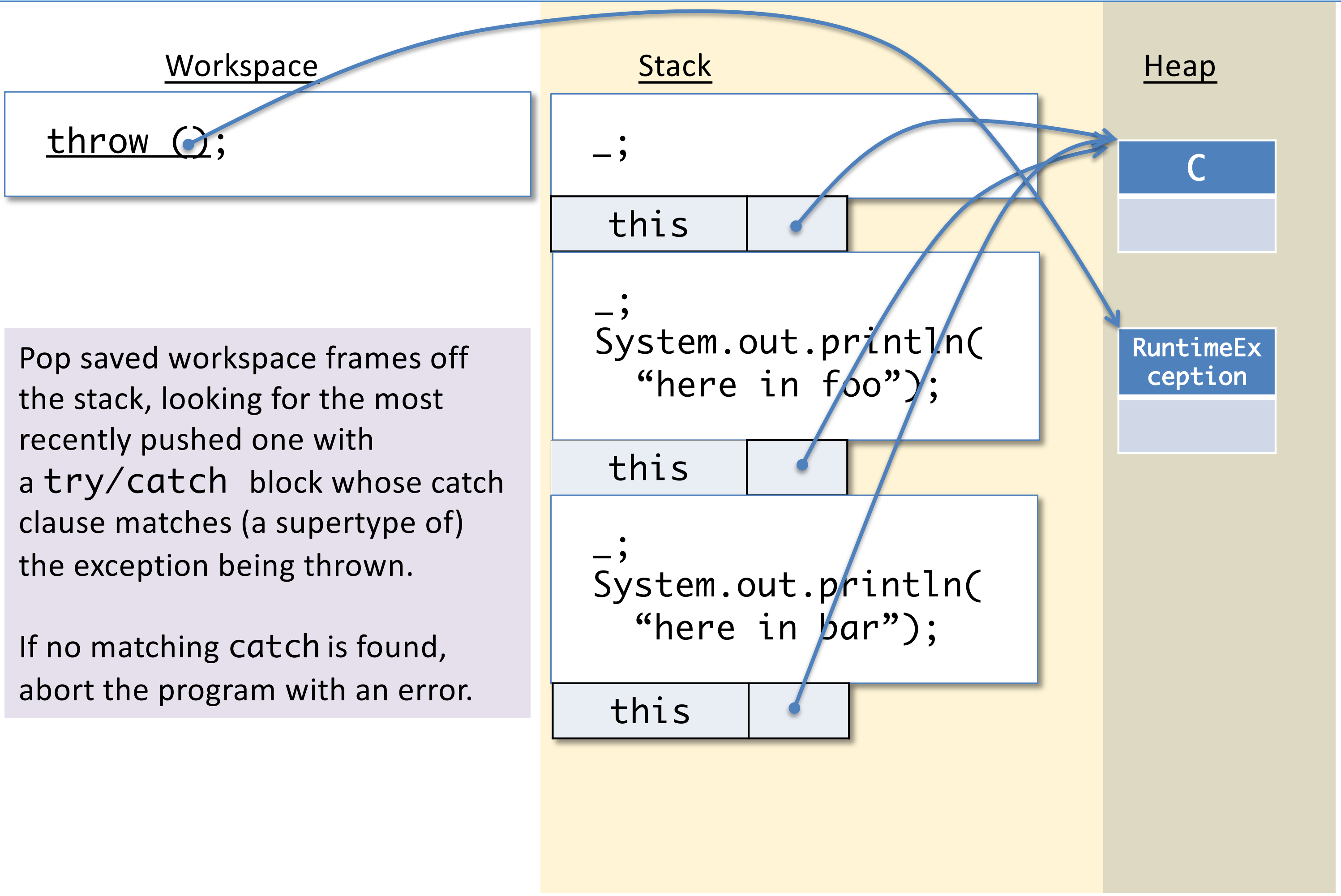
```

```
_;
System.out.println(
  “here in bar”);
```

Abstract Stack Machine



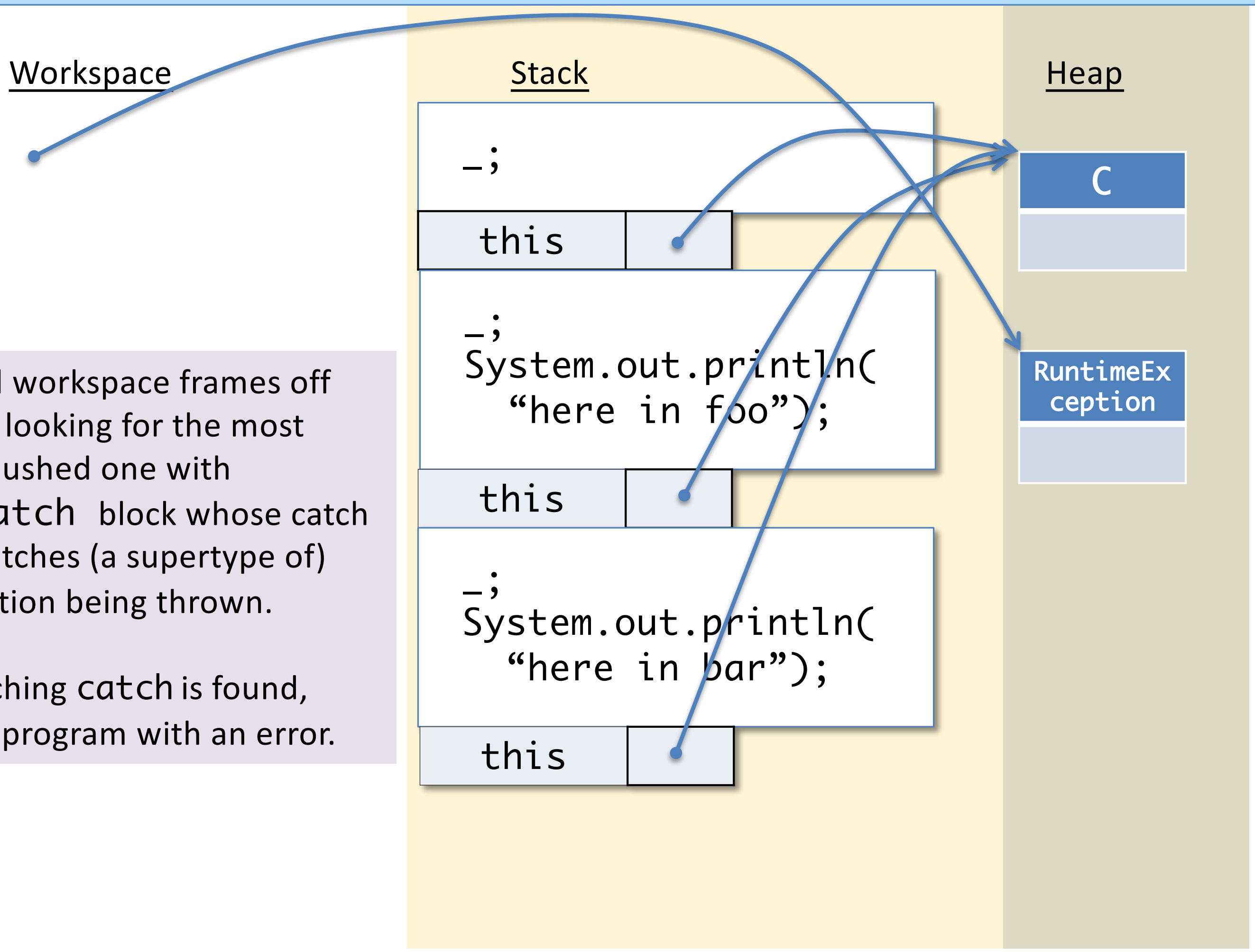
Abstract Stack Machine



Pop saved workspace frames off the stack, looking for the most recently pushed one with a `try/catch` block whose catch clause matches (a supertype of) the exception being thrown.

If no matching `catch` is found, abort the program with an error.

Abstract Stack Machine



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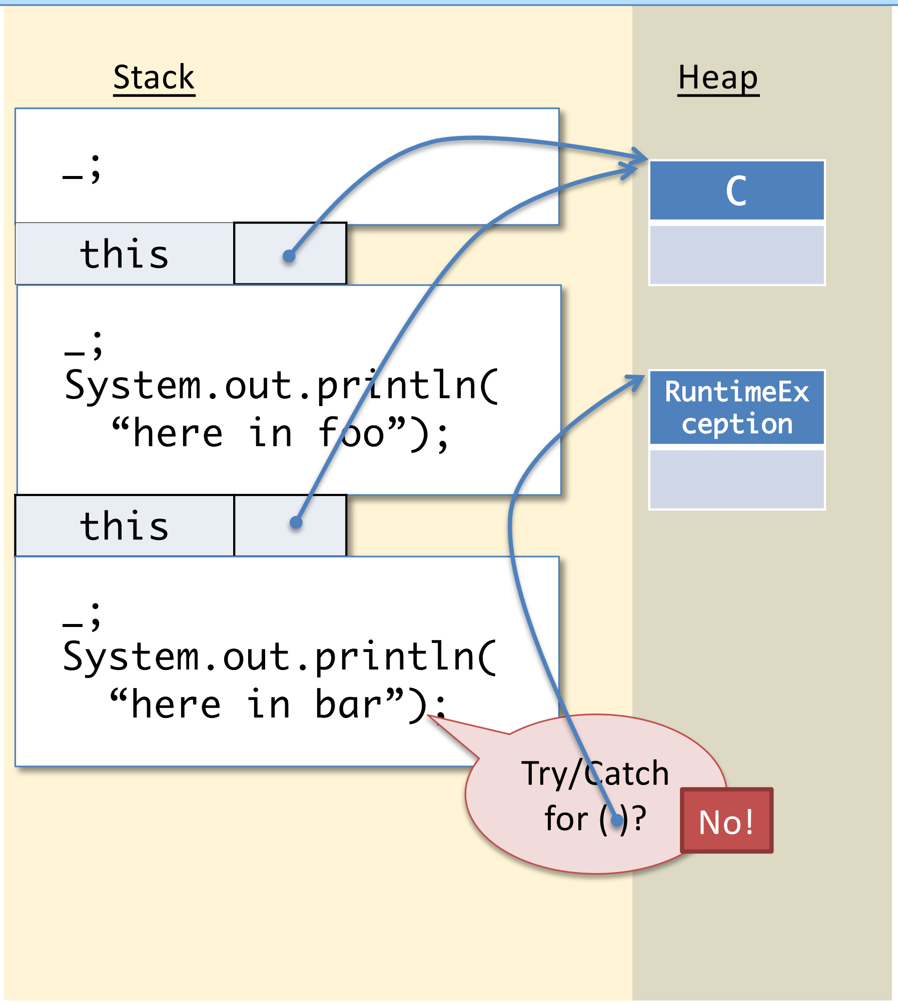

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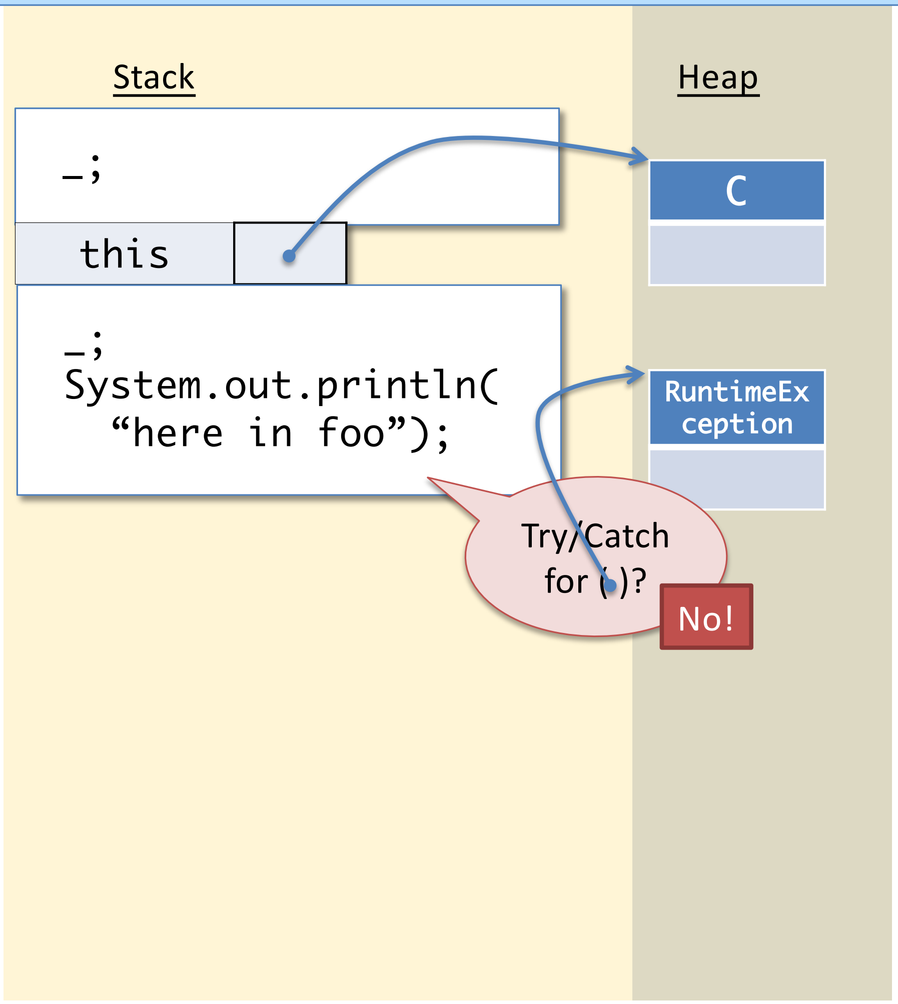
Abstract Stack Machine

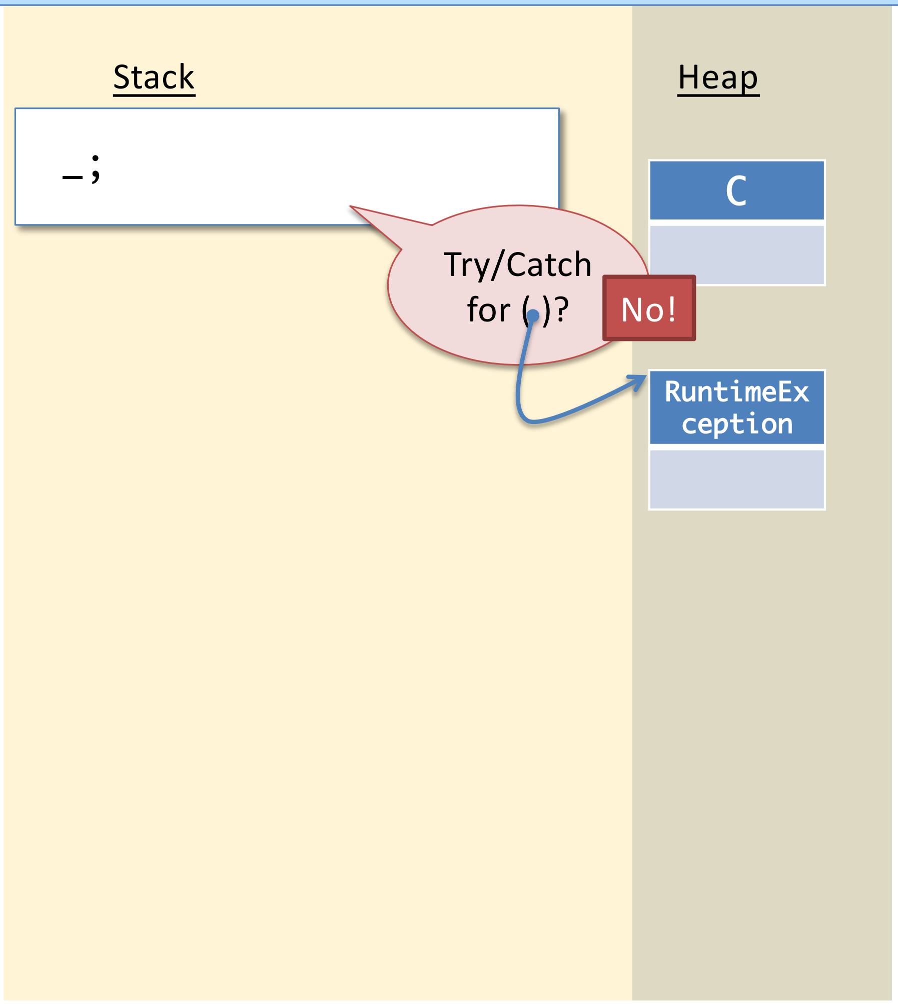


Discard the current workspace.

Then, pop saved workspace frames off the stack, looking for the most recently pushed one that contains a `try/catch` block whose catch clause declares a supertype of the exception being thrown.

If no matching catch is found, abort the program with an error.

Abstract Stack Machine



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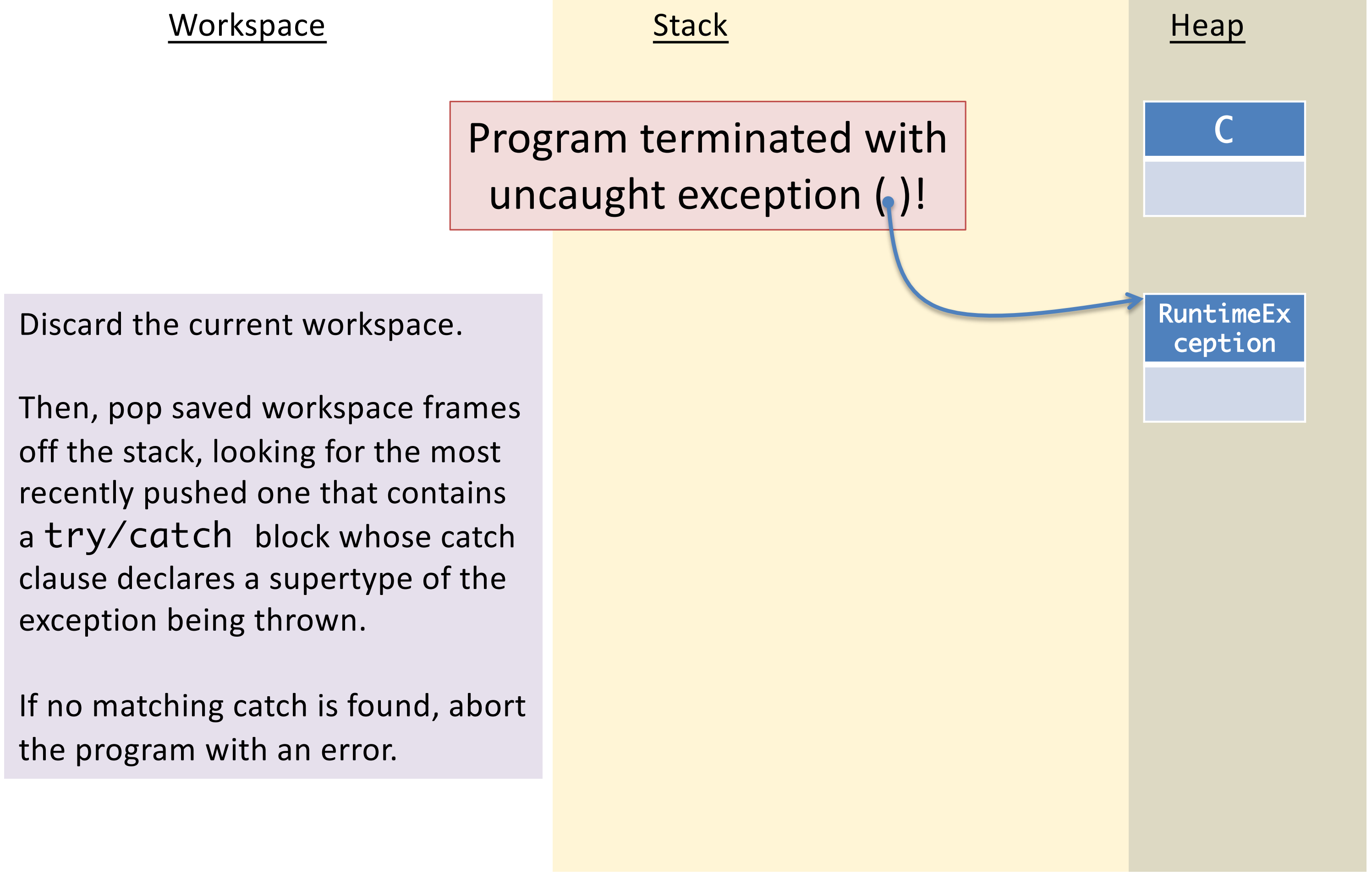
Abstract Stack Machine



Discard the current workspace.

Then, pop saved workspace frames off the stack, looking for the most recently pushed one that contains a `try/catch` block whose catch clause declares a supertype of the exception being thrown.

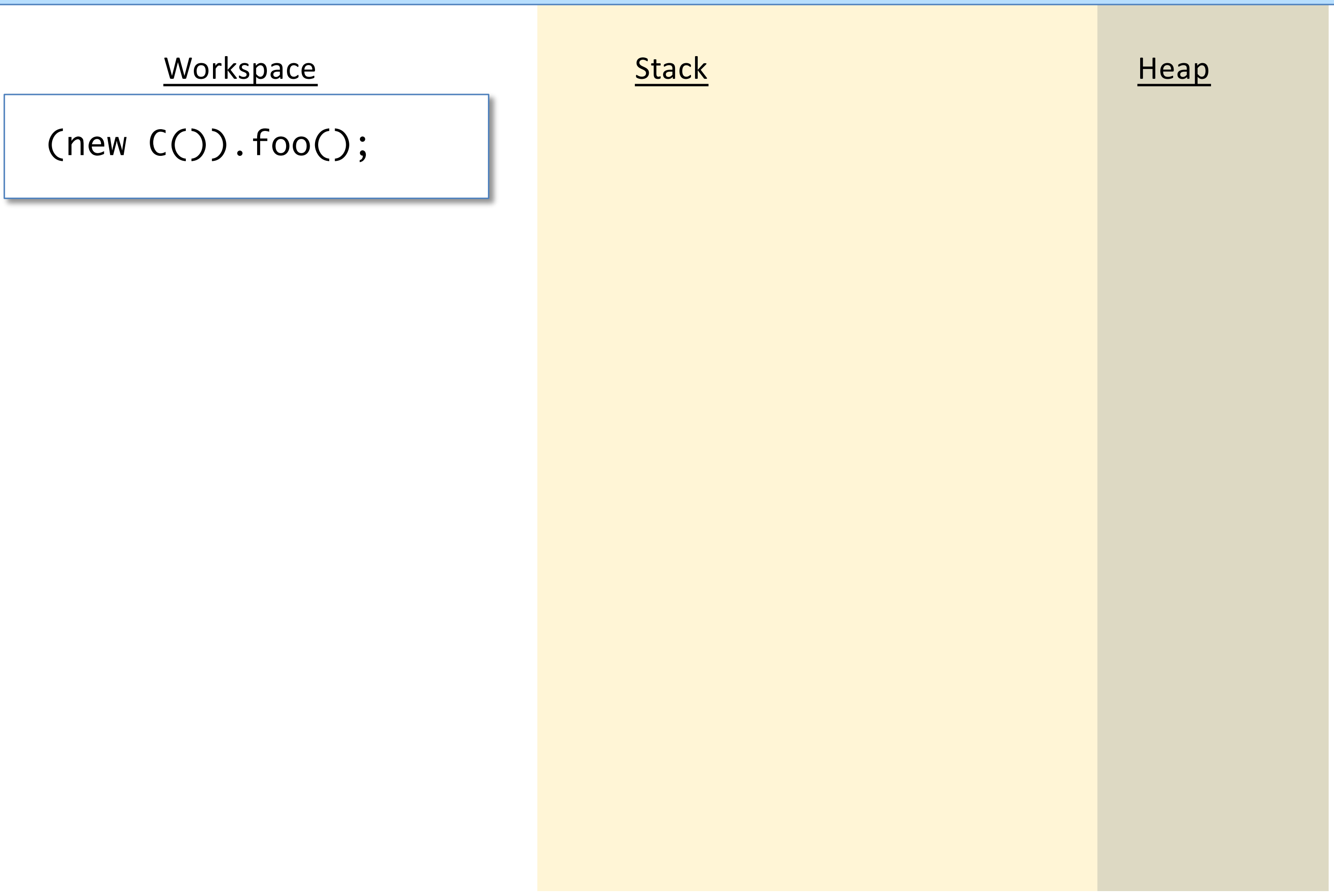
If no matching catch is found, abort the program with an error.

Catching the Exception

```
class C {
  public void foo() {
    this.bar();
    System.out.println("here in foo");
  }
  public void bar() {
    try {
      this.baz();
    } catch (Exception e) { System.out.println("caught"); }
    System.out.println("here in bar");
  }
  public void baz() {
    throw new RuntimeException();
  }
}
```

Now what happens if we do `(new C()).foo();`?

Abstract Stack Machine



```
(new C()).foo();
```

Abstract Stack Machine

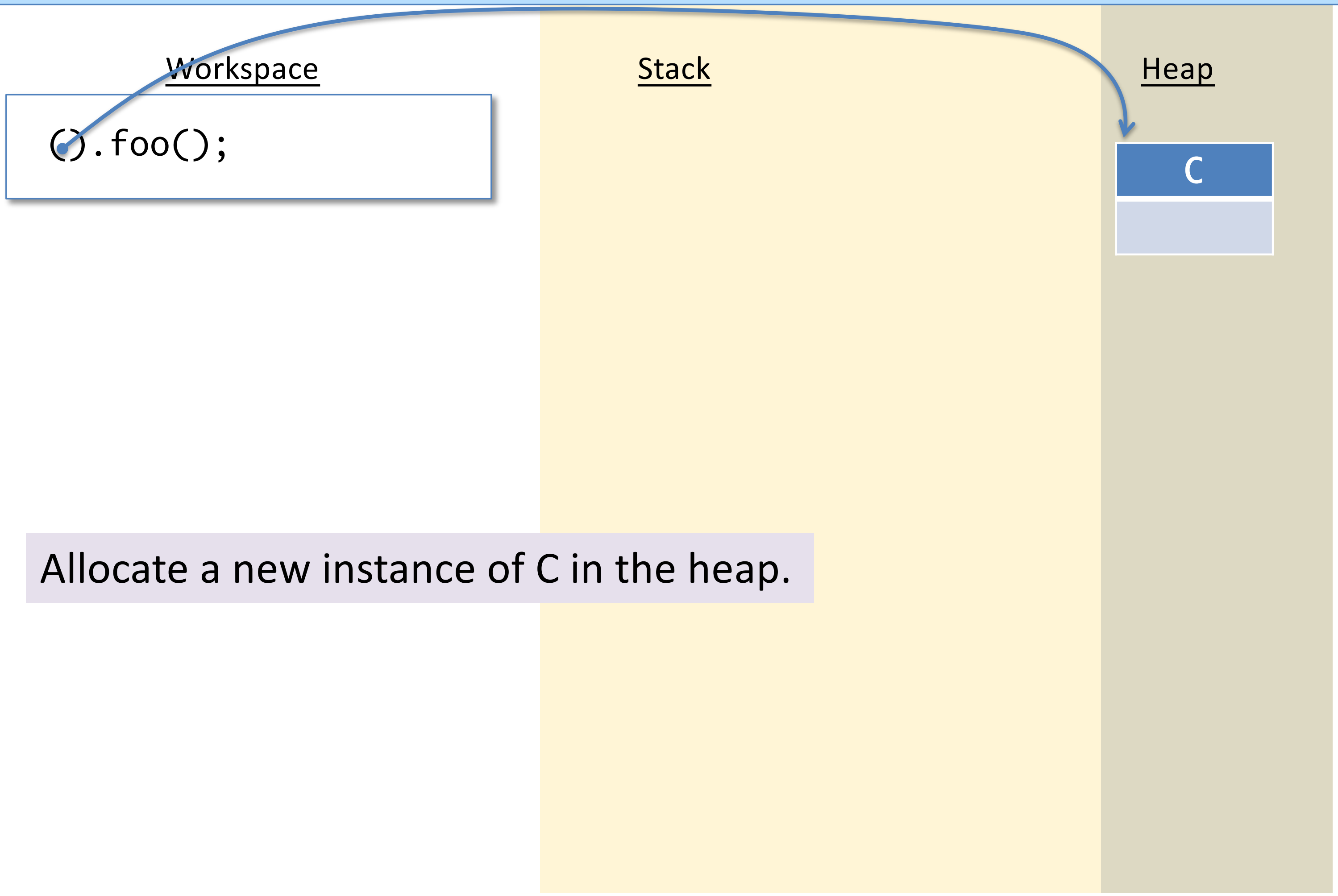
Workspace

```
(new C()).foo();
```

Stack

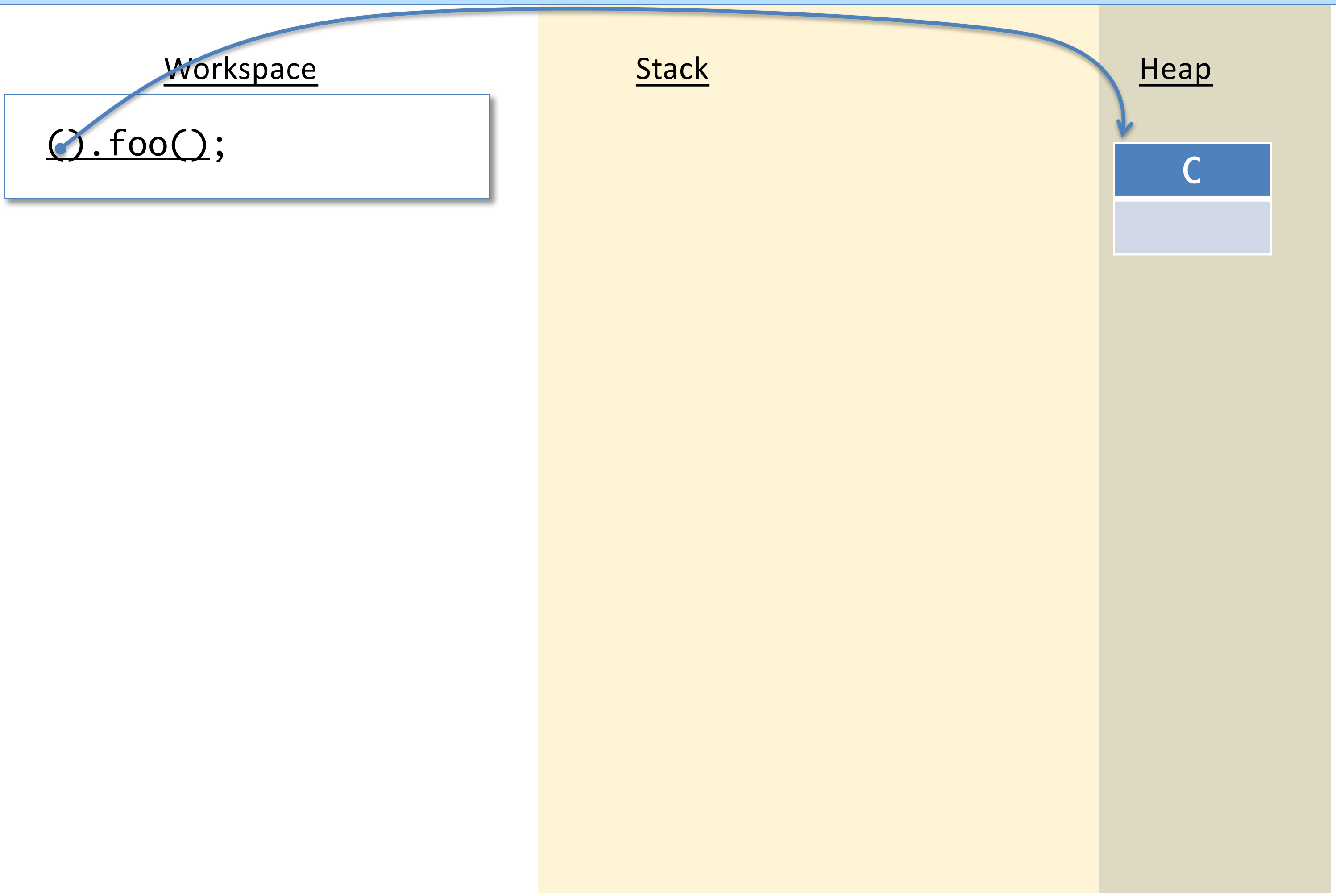
Heap

Abstract Stack Machine



Allocate a new instance of C in the heap.

Abstract Stack Machine



Abstract Stack Machine

Workspace

```
this.bar();
System.out.println(
  “here in foo”);
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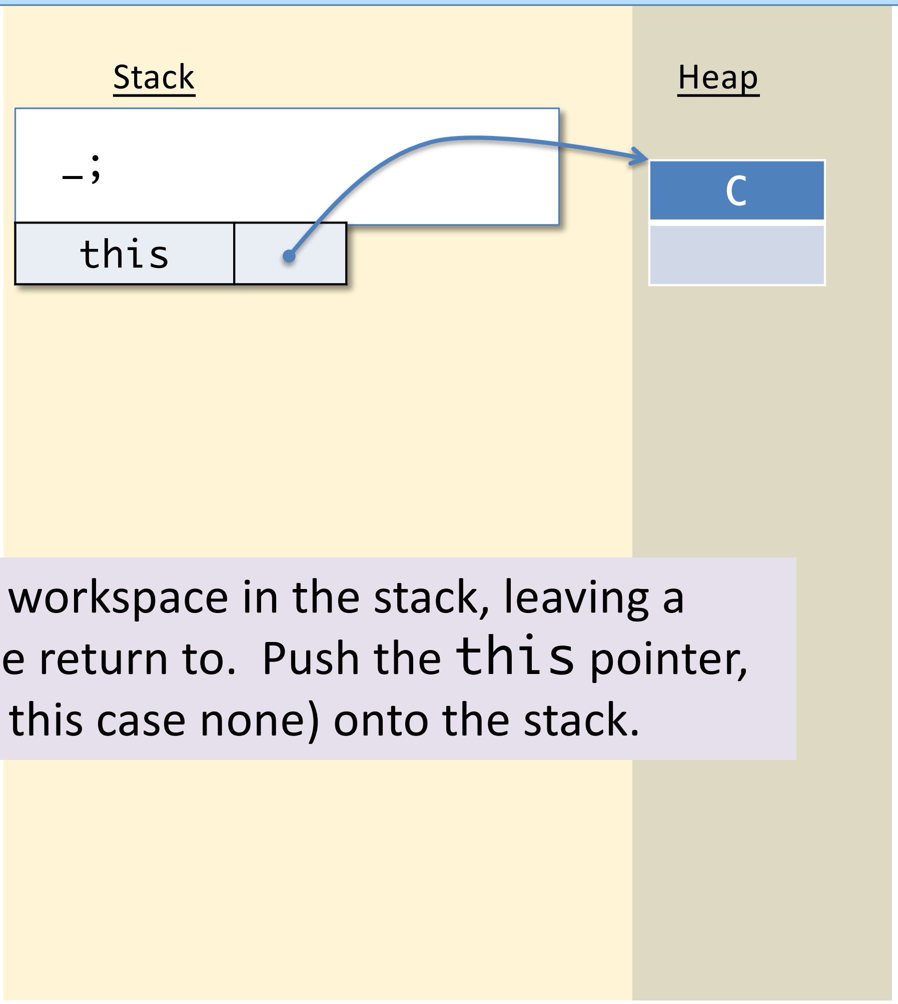

Save a copy of the current workspace in the stack, leaving a “hole”, written _, where we return to. Push the `this` pointer, followed by arguments (in this case none) onto the stack.

Abstract Stack Machine

Workspace

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System.out.println(
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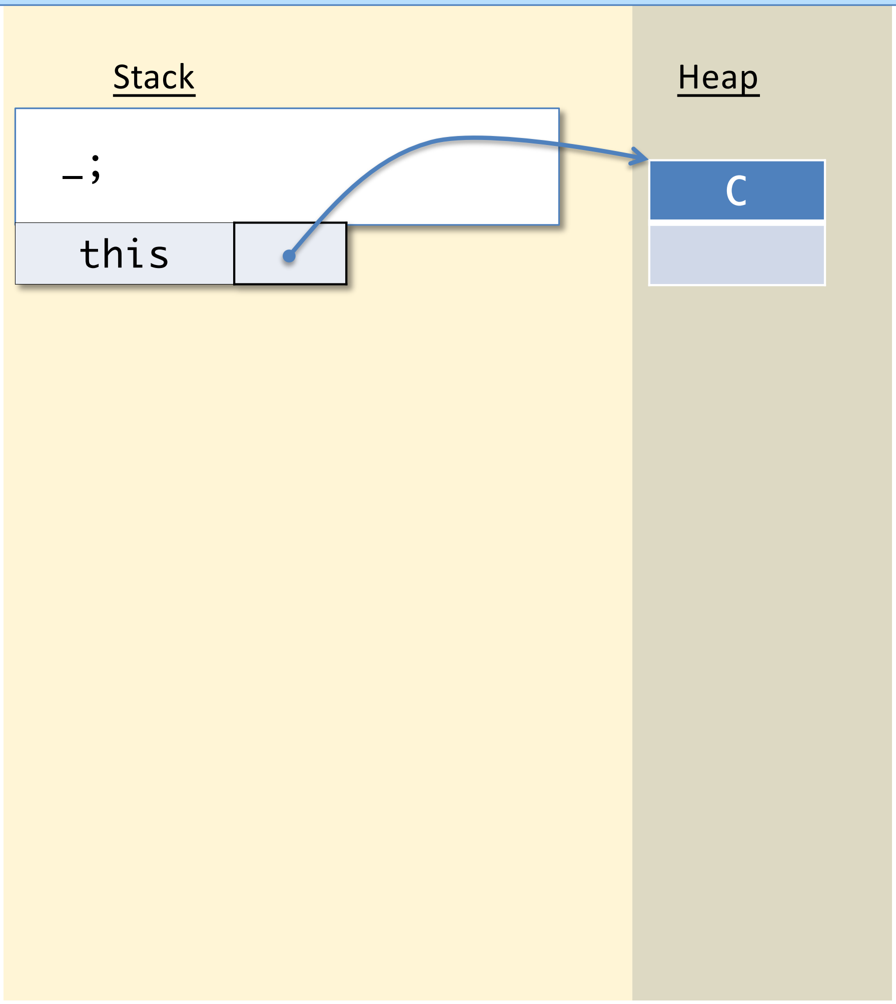
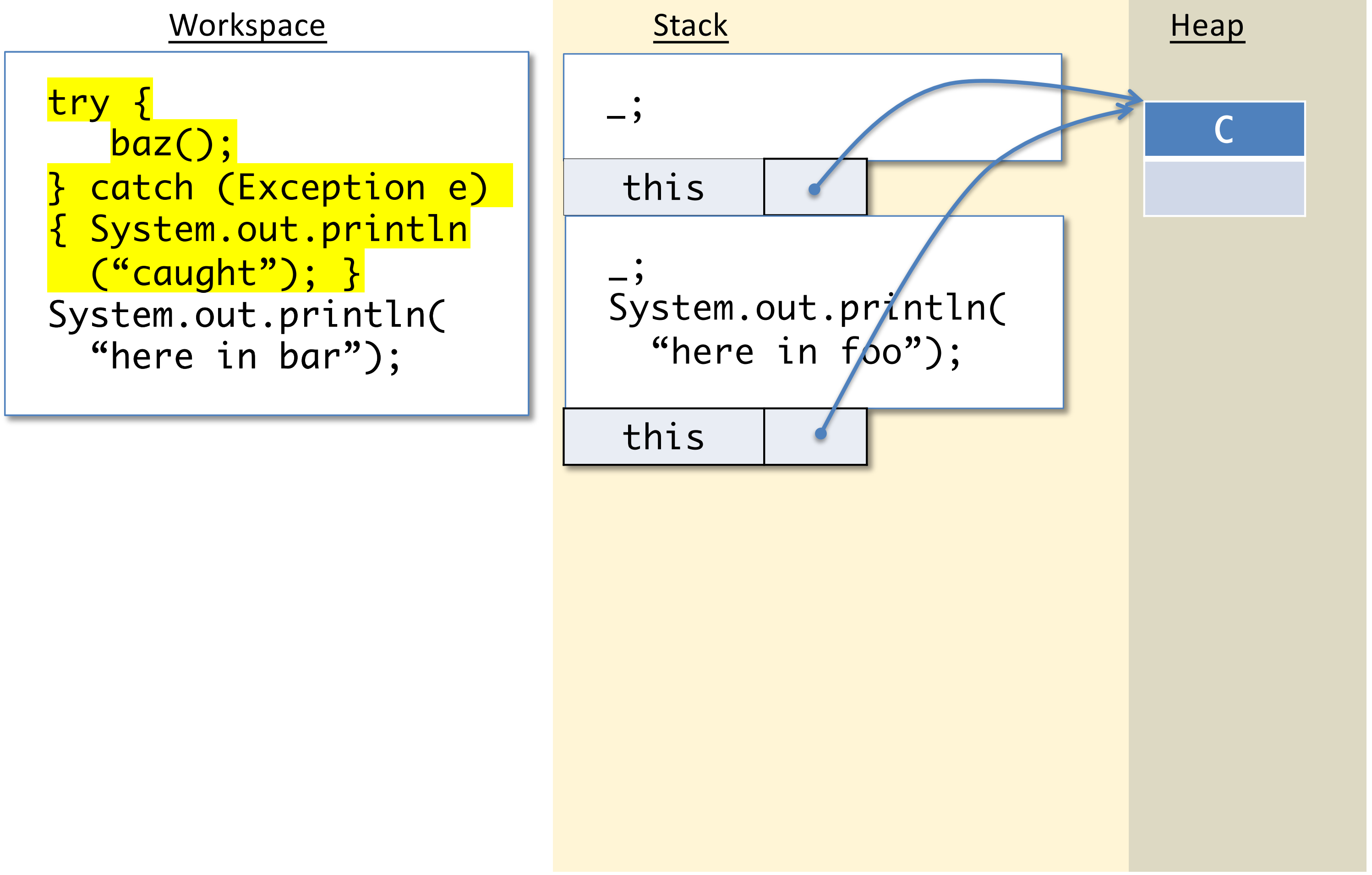


Abstract Stack Machine



```
try {
   baz();
} catch (Exception e)
{ System.out.println
  ("caught"); }
System.out.println(
  "here in bar");
```

```
_;
```

```
_;
System.out.println(
  "here in foo");
```

Abstract Stack Machine

Workspace

```
try {
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} catch (Exception e)
{ System.out.println
  ("caught"); }
System.out.println(
  "here in bar");
```
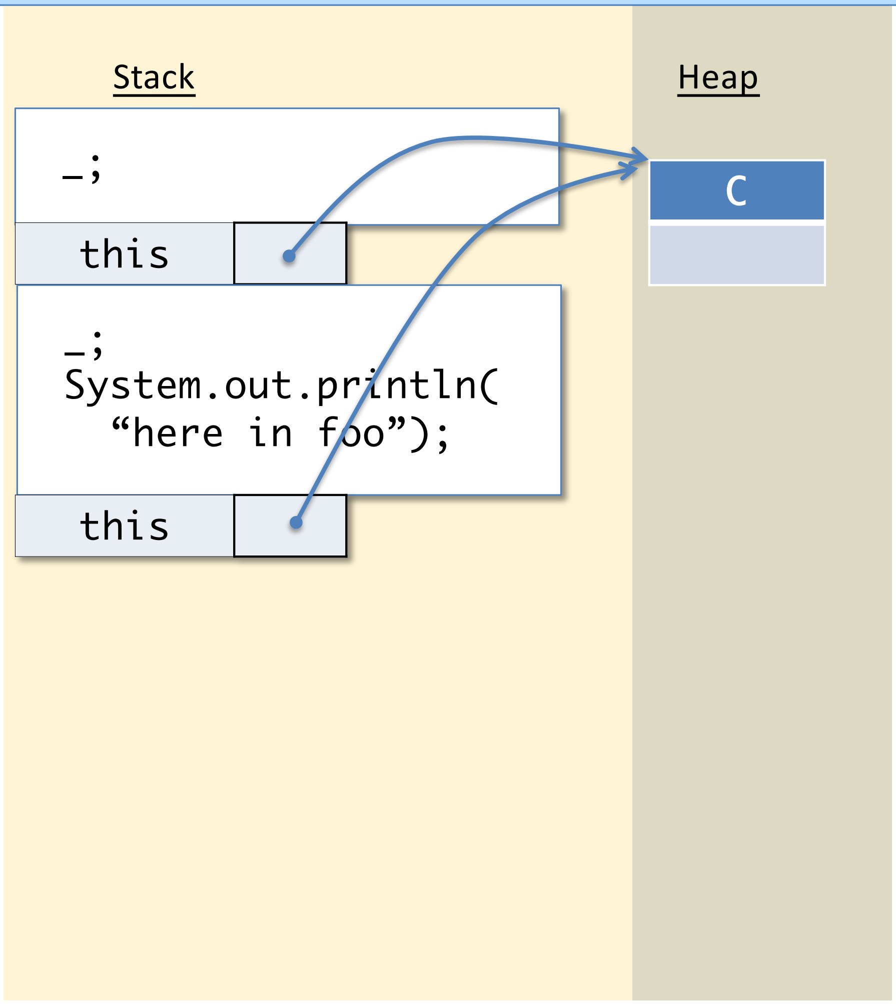



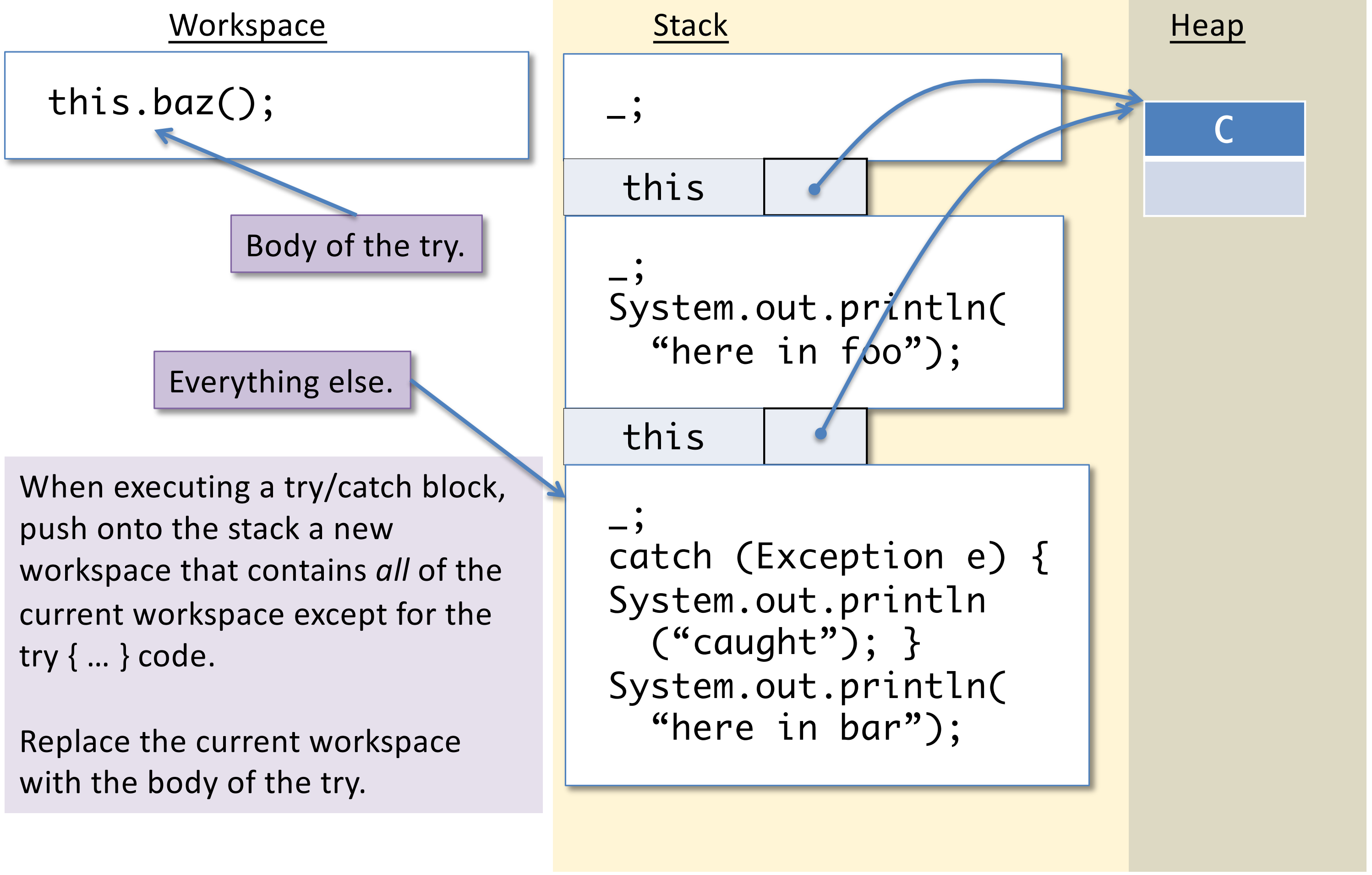
```
_;
```

```
_;
System.out.println(
  "here in foo");
```

When executing a try/catch block, push onto the stack a new workspace that contains *all* of the current workspace except for the try { … } code.

Replace the current workspace with the body of the try.

Abstract Stack Machine



```
this.baz();
```

```
_;
```

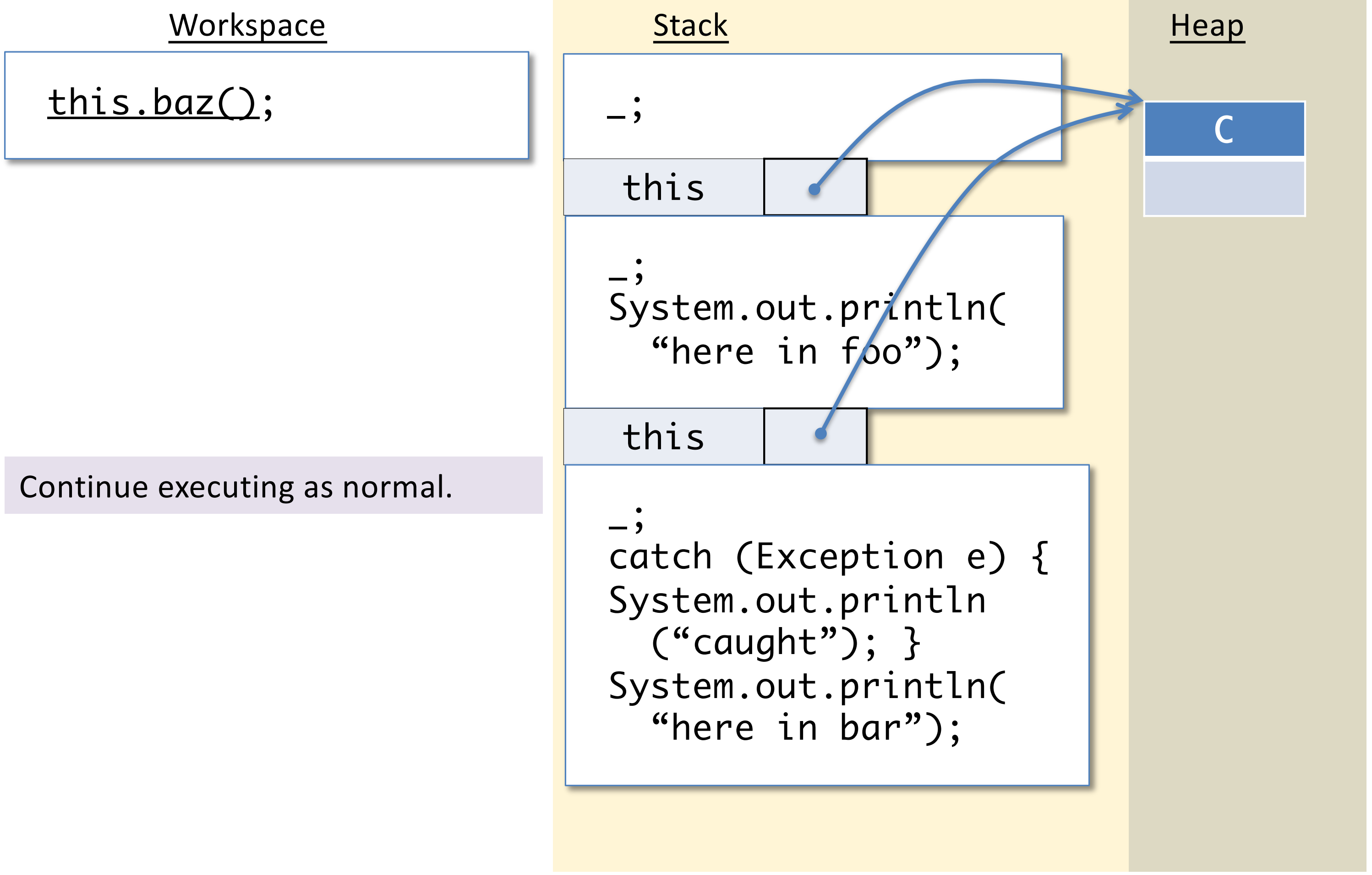
```
_;
System.out.println(
  “here in foo”);
```

```
_;
catch (Exception e) {
System.out.println
  (“caught”); }
System.out.println(
  “here in bar”);
```

When executing a try/catch block, push onto the stack a new workspace that contains *all* of the current workspace except for the try { … } code.

Replace the current workspace with the body of the try.

Abstract Stack Machine



```
this.baz();
```

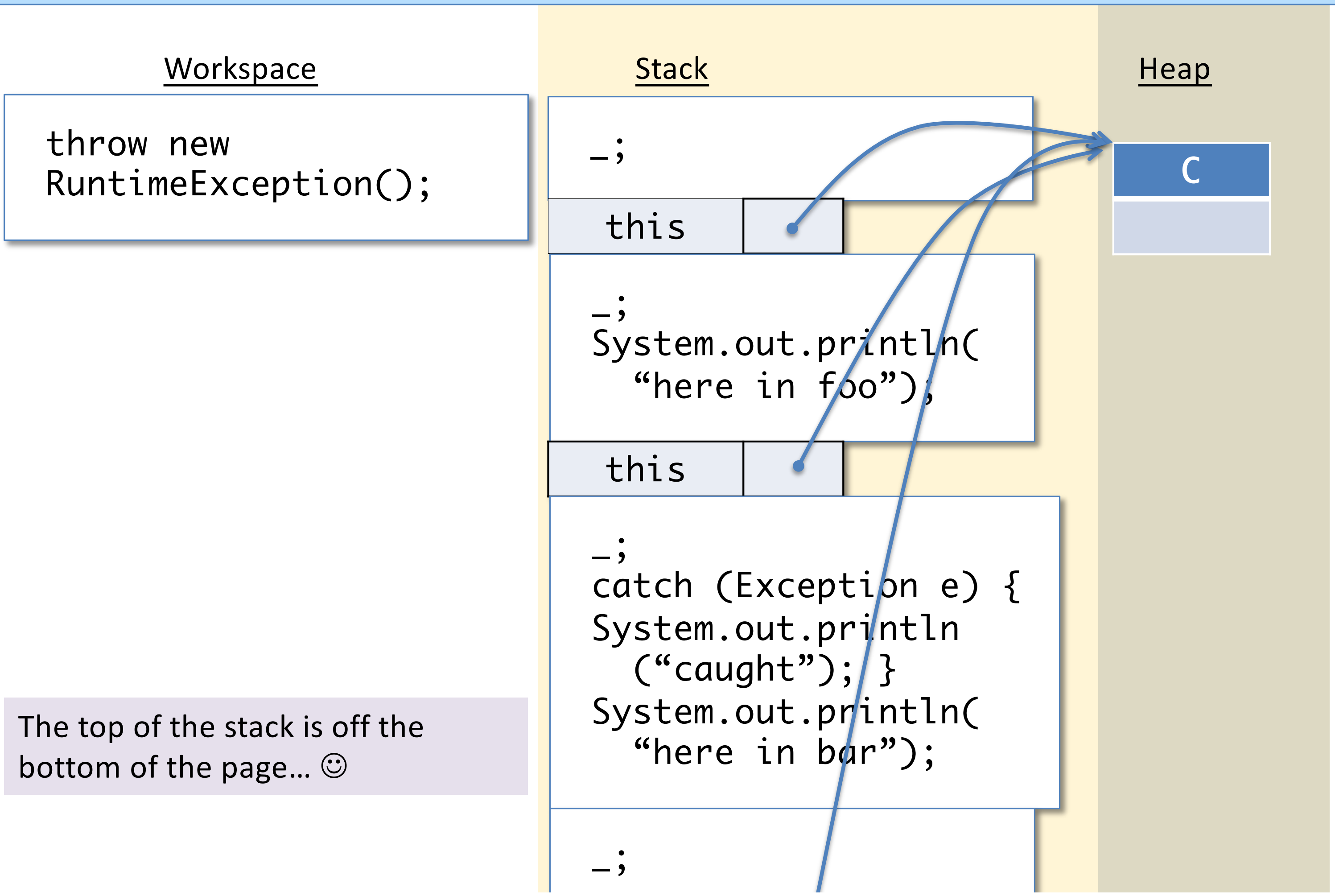
```
_;
```

```
_;
System.out.println(
  “here in foo”);
```

```
_;
catch (Exception e) {
System.out.println
  (“caught”); }
System.out.println(
  “here in bar”);
```

Continue executing as normal.

Abstract Stack Machine



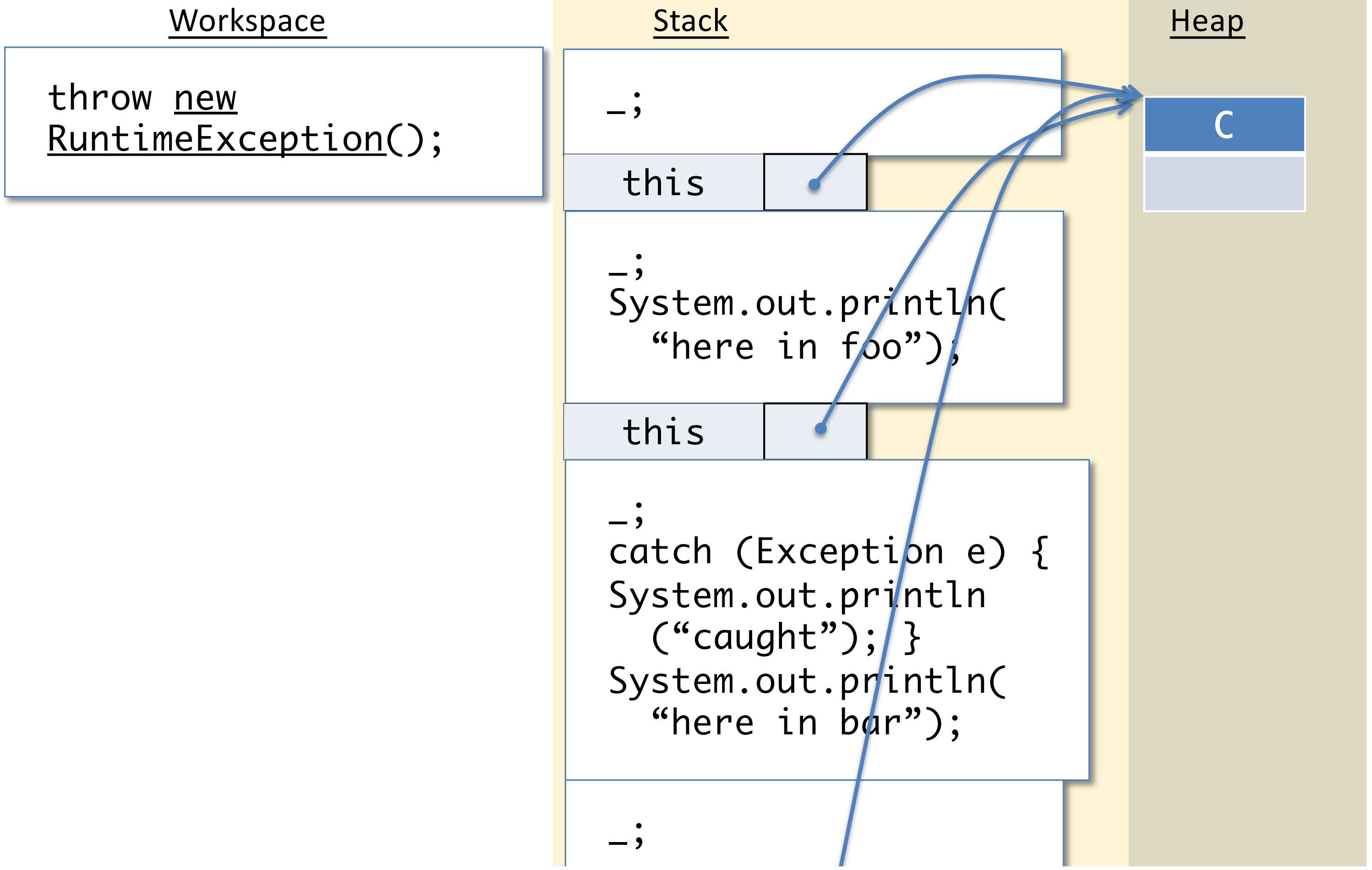
```
throw new
RuntimeException();
```

```
_;
System.out.println(
  “here in foo”);
```

```
_;
catch (Exception e) {
System.out.println
  (“caught”); }
System.out.println(
  “here in bar”);
```

The top of the stack is off the bottom of the page… ☺

Abstract Stack Machine



```
throw new
RuntimeException();
```

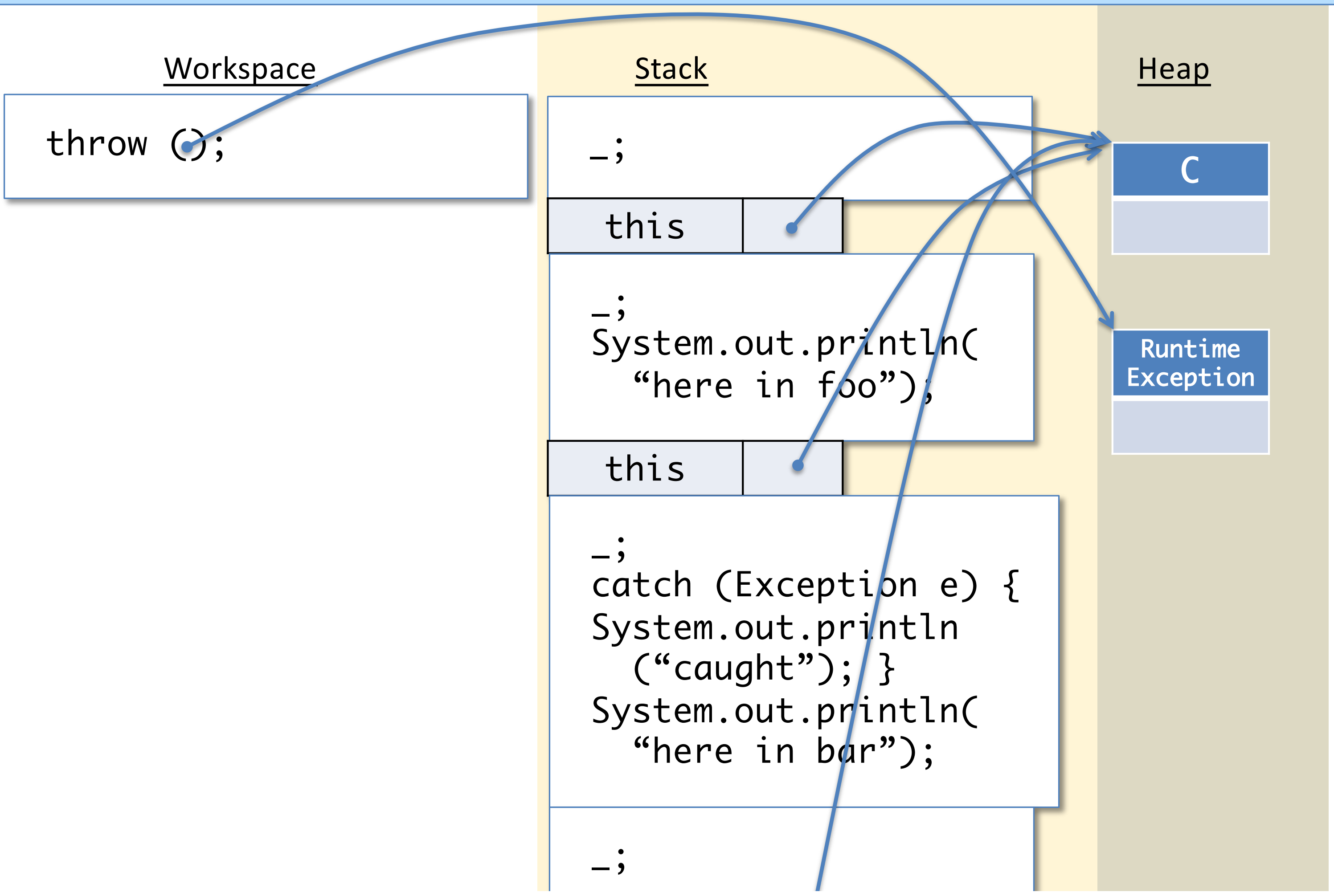
```
_;
```

```
_;
System.out.println(
  "here in foo");
```

```
_;
catch (Exception e) {
System.out.println
  ("caught"); }
System.out.println(
  "here in bar");
```

```
_;
```

Abstract Stack Machine



Workspace

```
throw ();
```

Stack

```
_;
```

this

```
_;
System.out.println(
  “here in foo”);
```

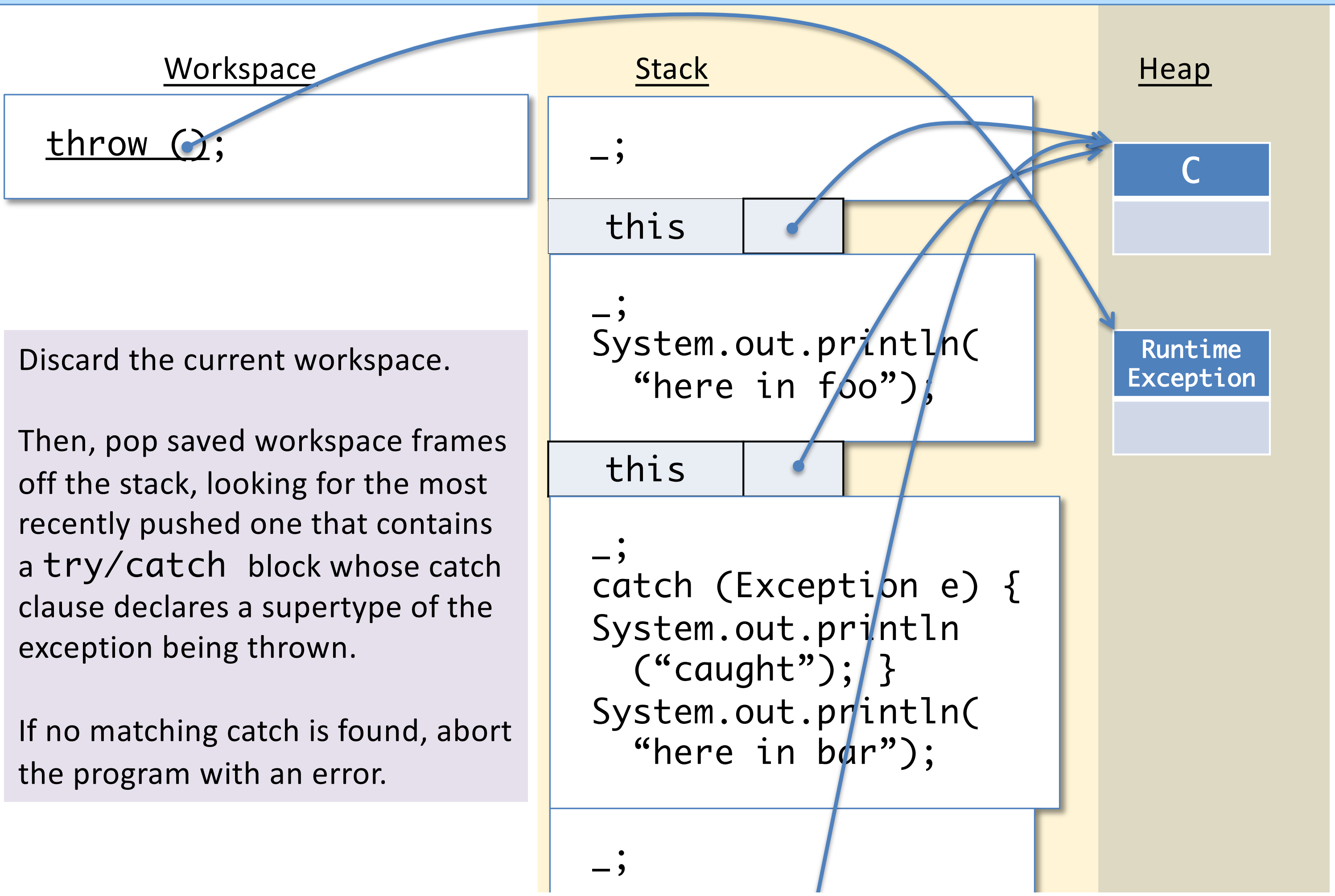
this

```
_;
catch (Exception e) {
System.out.println
  (“caught”); }
System.out.println(
  “here in bar”);
```

```
_;
```

Heap

Abstract Stack Machine

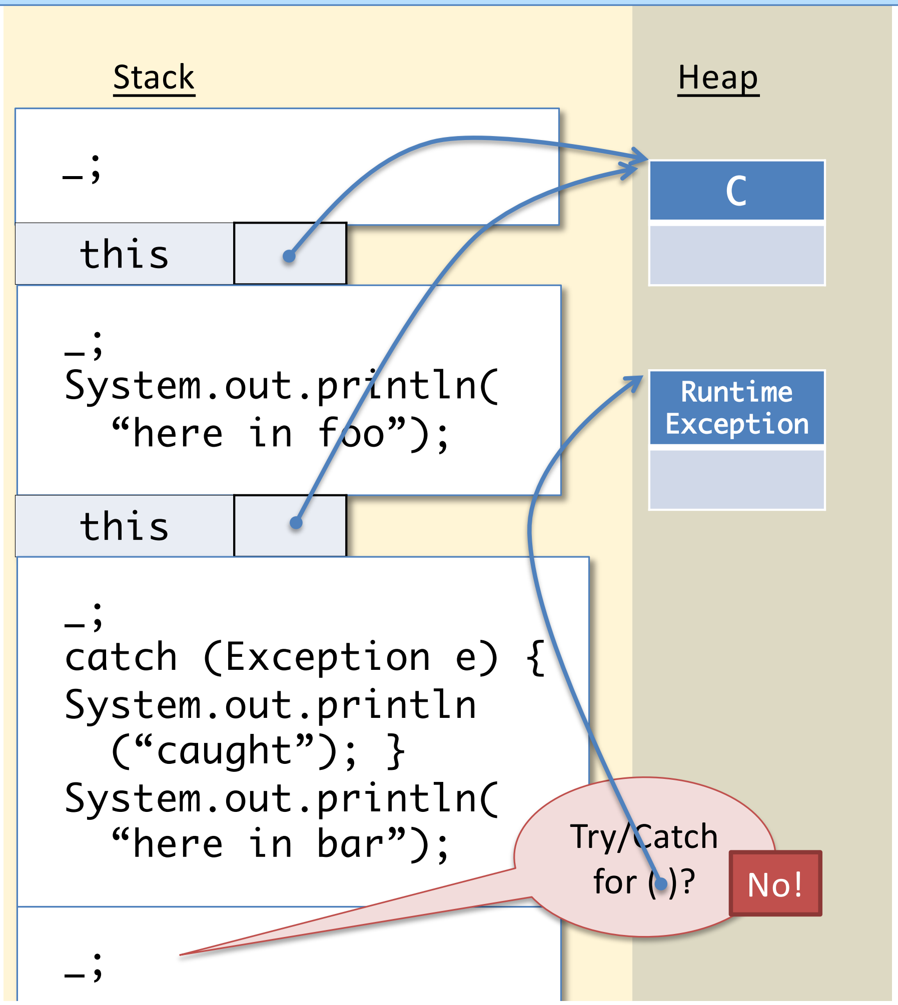


Discard the current workspace.

Then, pop saved workspace frames off the stack, looking for the most recently pushed one that contains a `try/catch` block whose catch clause declares a supertype of the exception being thrown.

If no matching catch is found, abort the program with an error.

Abstract Stack Machine



Discard the current workspace.

Then, pop saved workspace frames off the stack, looking for the most recently pushed one that contains a `try/catch` block whose catch clause declares a supertype of the exception being thrown.

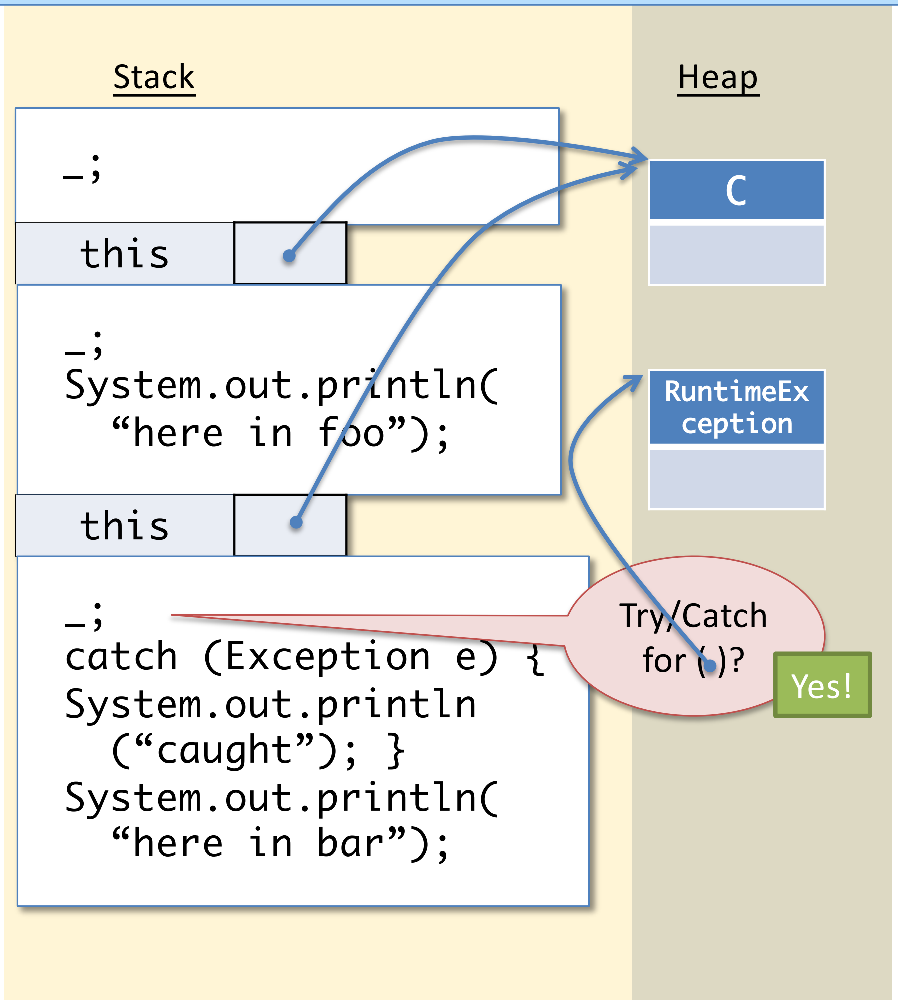
If no matching catch is found, abort the program with an error.

Abstract Stack Machine

Workspace

When a matching catch block is found, add a new binding to the stack for the exception variable declared in the catch. Then replace the workspace with catch body and the rest of the saved workspace.

Continue executing as usual.



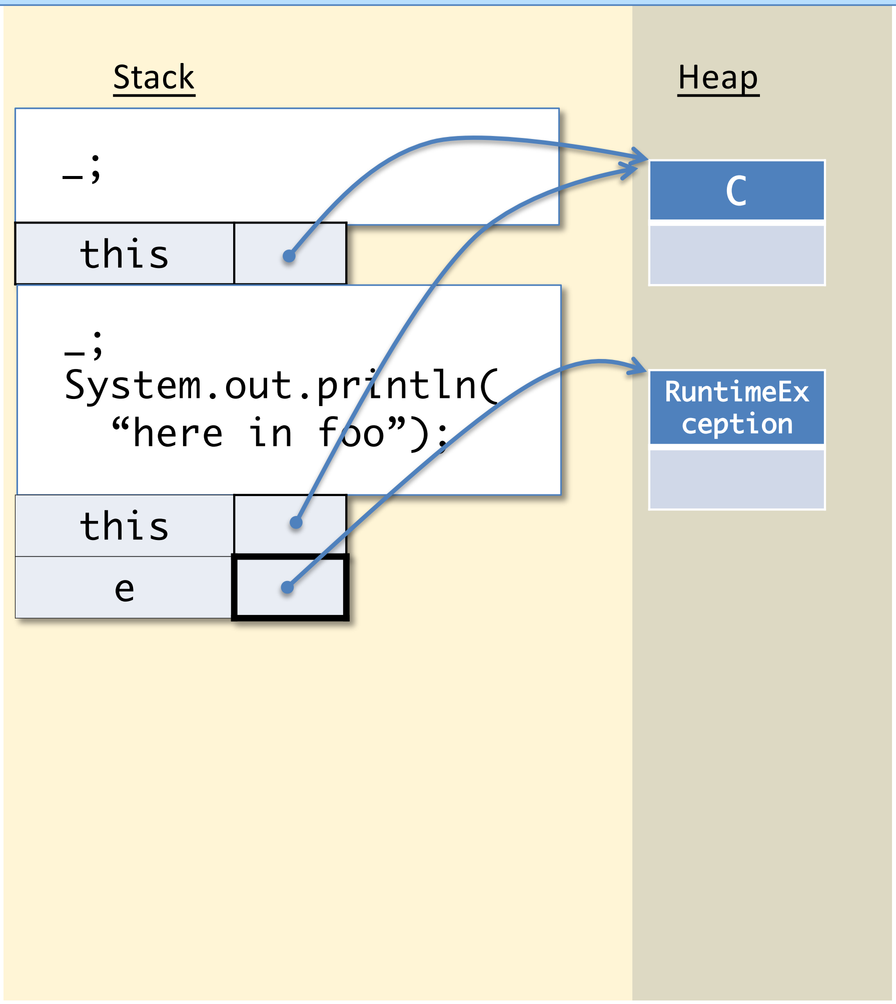
Abstract Stack Machine

Workspace

```
{ System.out.println
  (“caught”); }
System.out.println(
  “here in bar”);
```

When a matching catch block is found, add a new binding to the stack for the exception variable declared in the catch. Then replace the workspace with catch body and the rest of the saved workspace.

Continue executing as usual.



```
_;
```

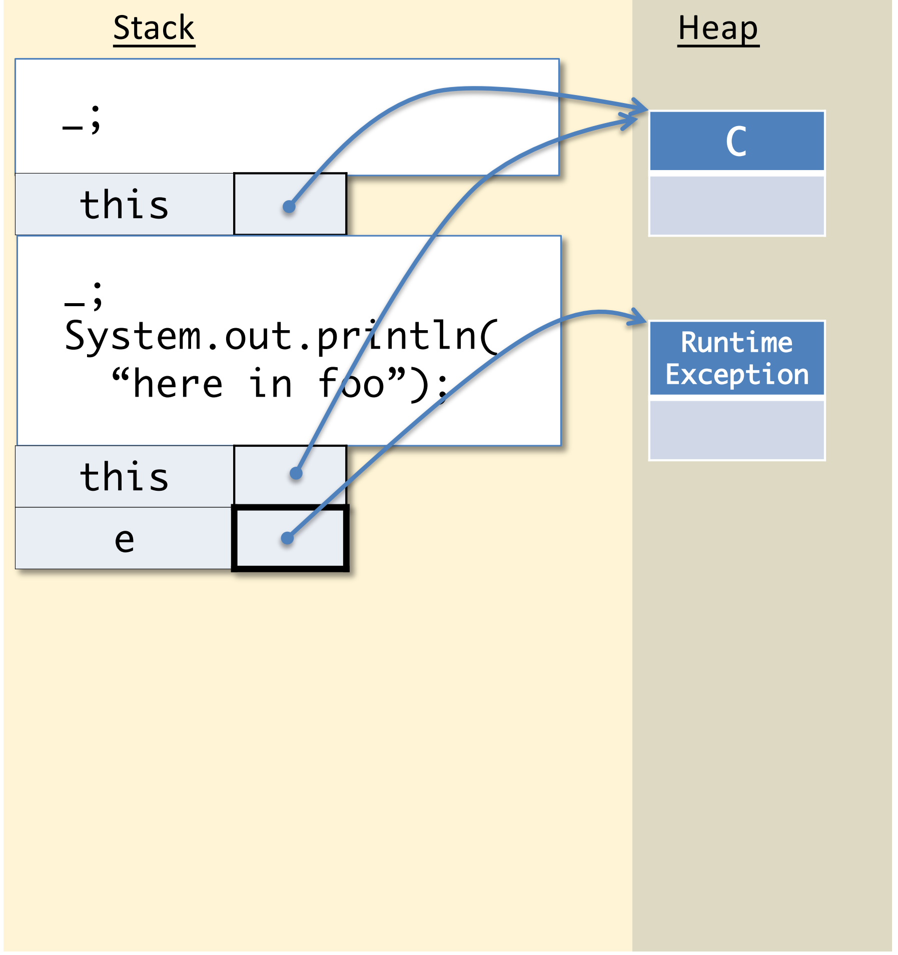
```
_;
System.out.println(
  “here in foo”);
```

Abstract Stack Machine

Workspace

```
{ System.out.println
  ("caught"); }
System.out.println(
  "here in bar");
```

Continue executing as usual.



Abstract Stack Machine

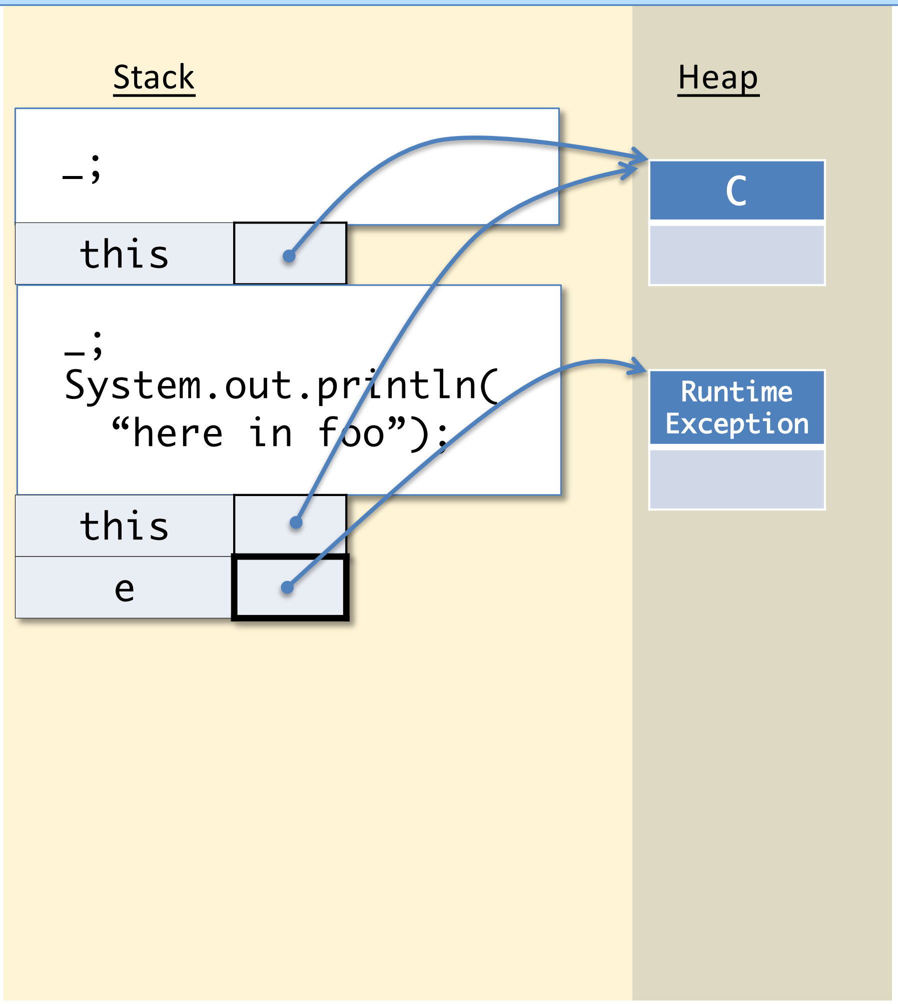
Workspace

```
{ ; }
System.out.println(
  “here in bar”);
```

Continue executing as usual.

Console

```
caught
```



Abstract Stack Machine

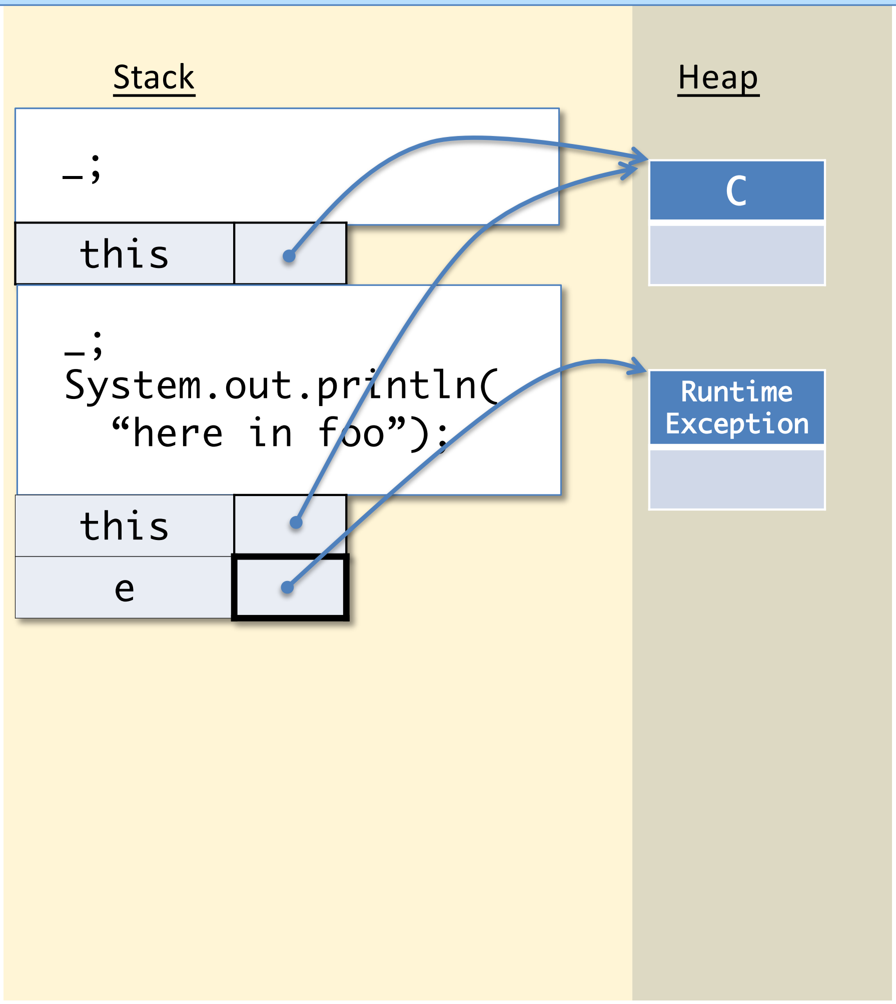
Workspace

```
~~{ ; }~~
System.out.println(
  “here in bar”);
```

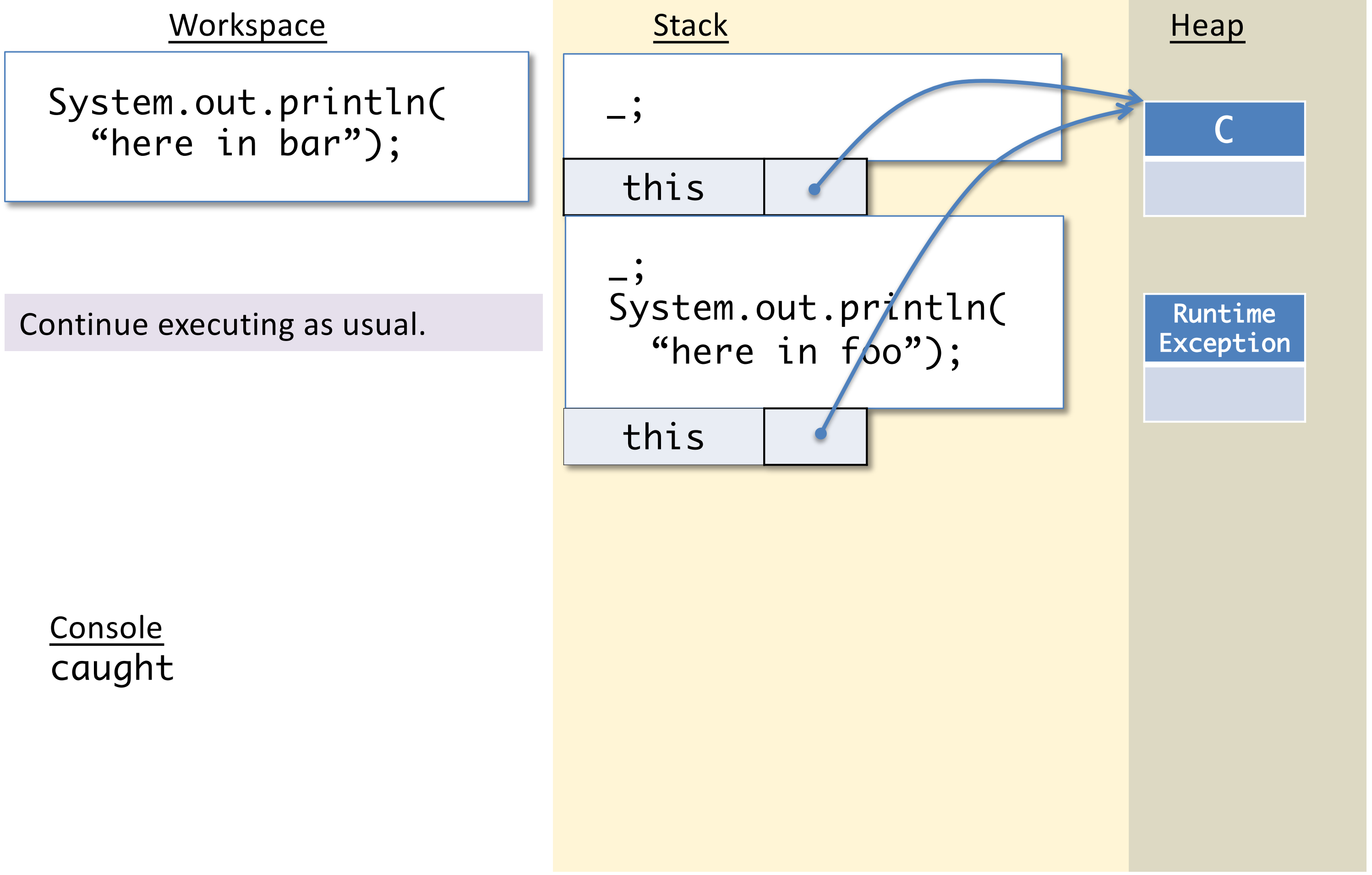
We’re sweeping a few details about lexical scoping of variables under the rug – the scope of e is just the body of the catch, so when that is done, e must be popped from the stack too.

Console

```
caught
```



Abstract Stack Machine



```
System.out.println(
  “here in bar”);
```

```
_;
System.out.println(
  “here in foo”);
```

Continue executing as usual.

Abstract Stack Machine

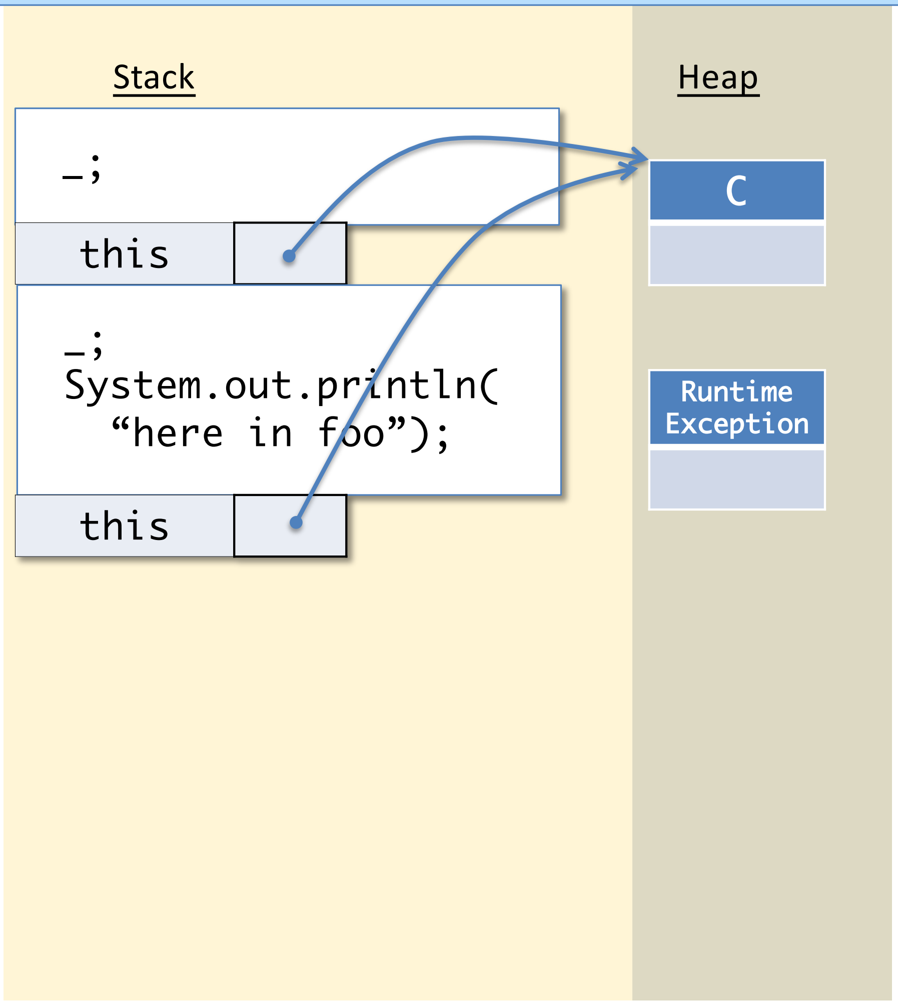
Workspace

```
System.out.println(
   "here in bar");
```

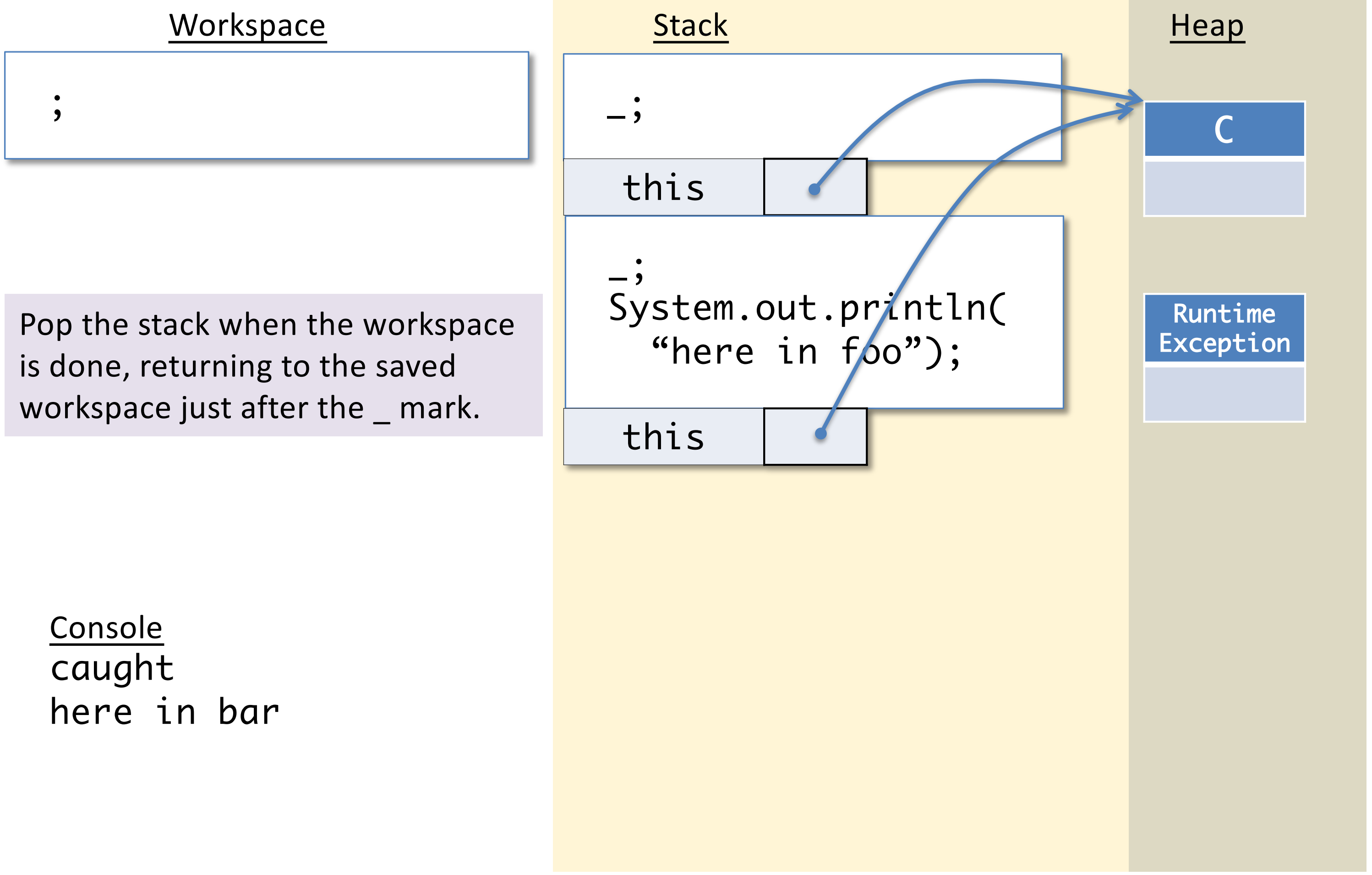
Continue executing as usual.

Console

```
caught
```



Abstract Stack Machine



Pop the stack when the workspace is done, returning to the saved workspace just after the _ mark.

Console

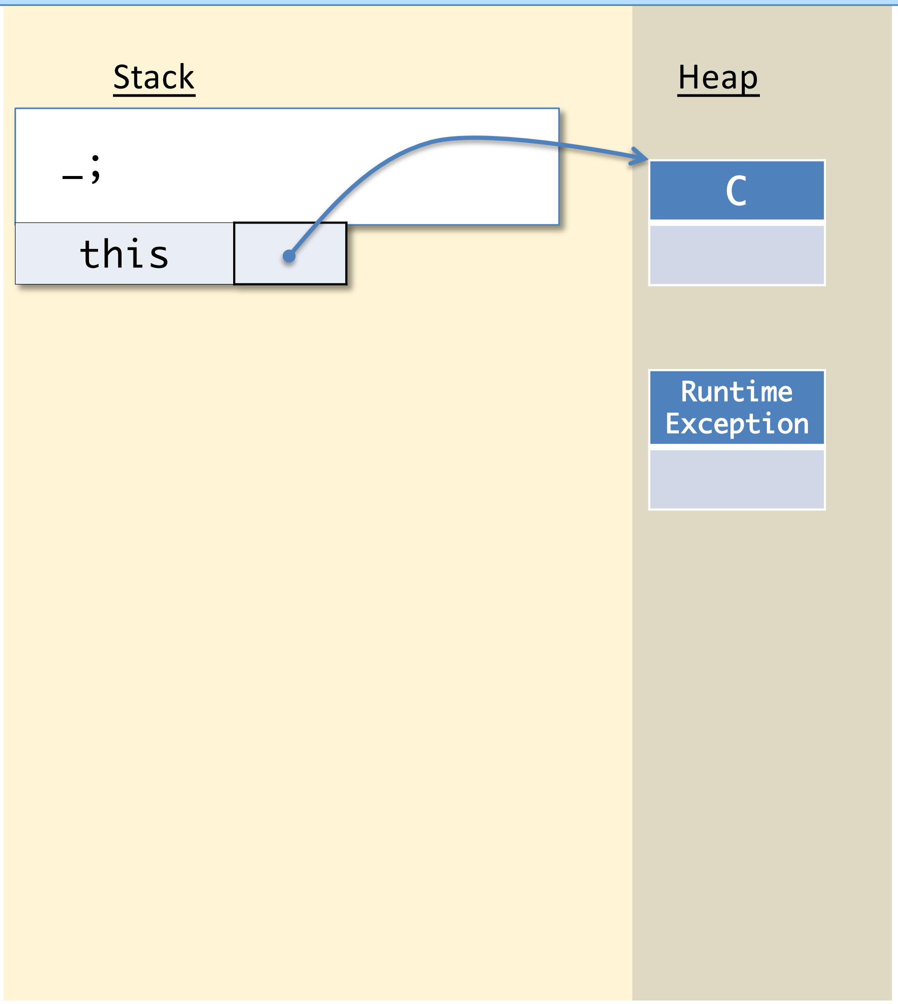
```
caught
here in bar
```

Abstract Stack Machine

Workspace

```
System.out.println(
  “here in foo”);
```

Continue executing as usual.



Console

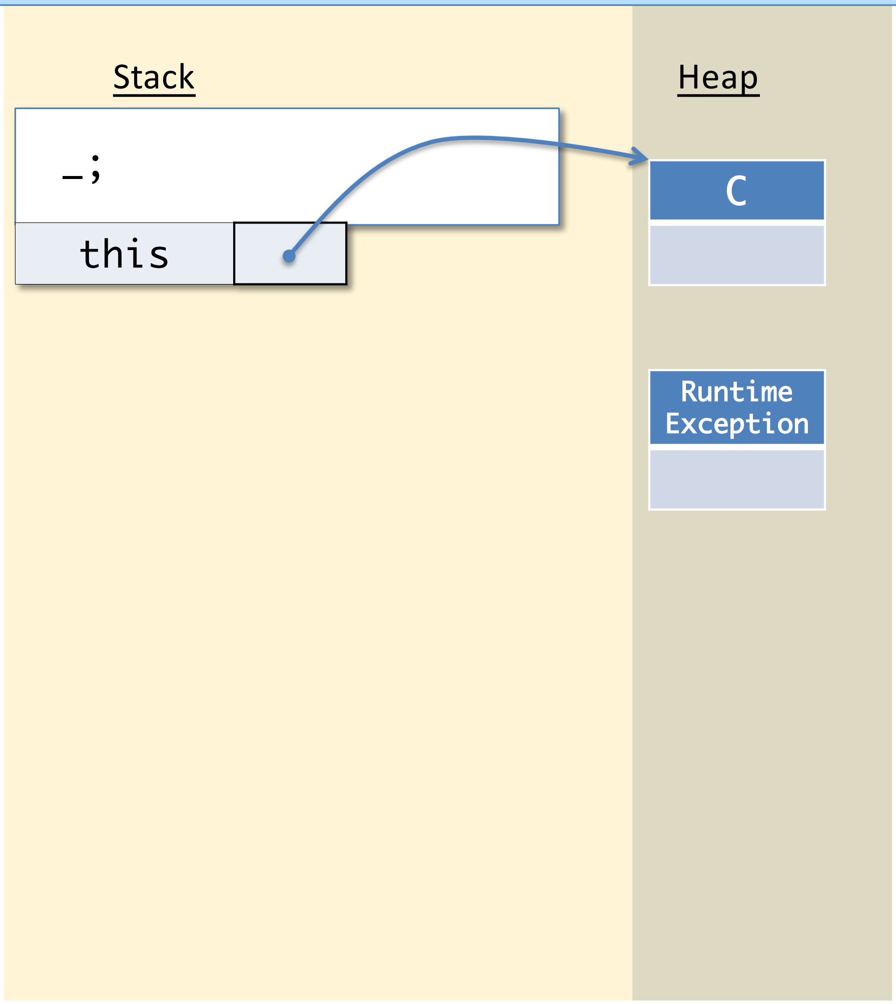
```
caught
here in bar
```

Abstract Stack Machine

Workspace

```
System.out.println(
  "here in foo");
```

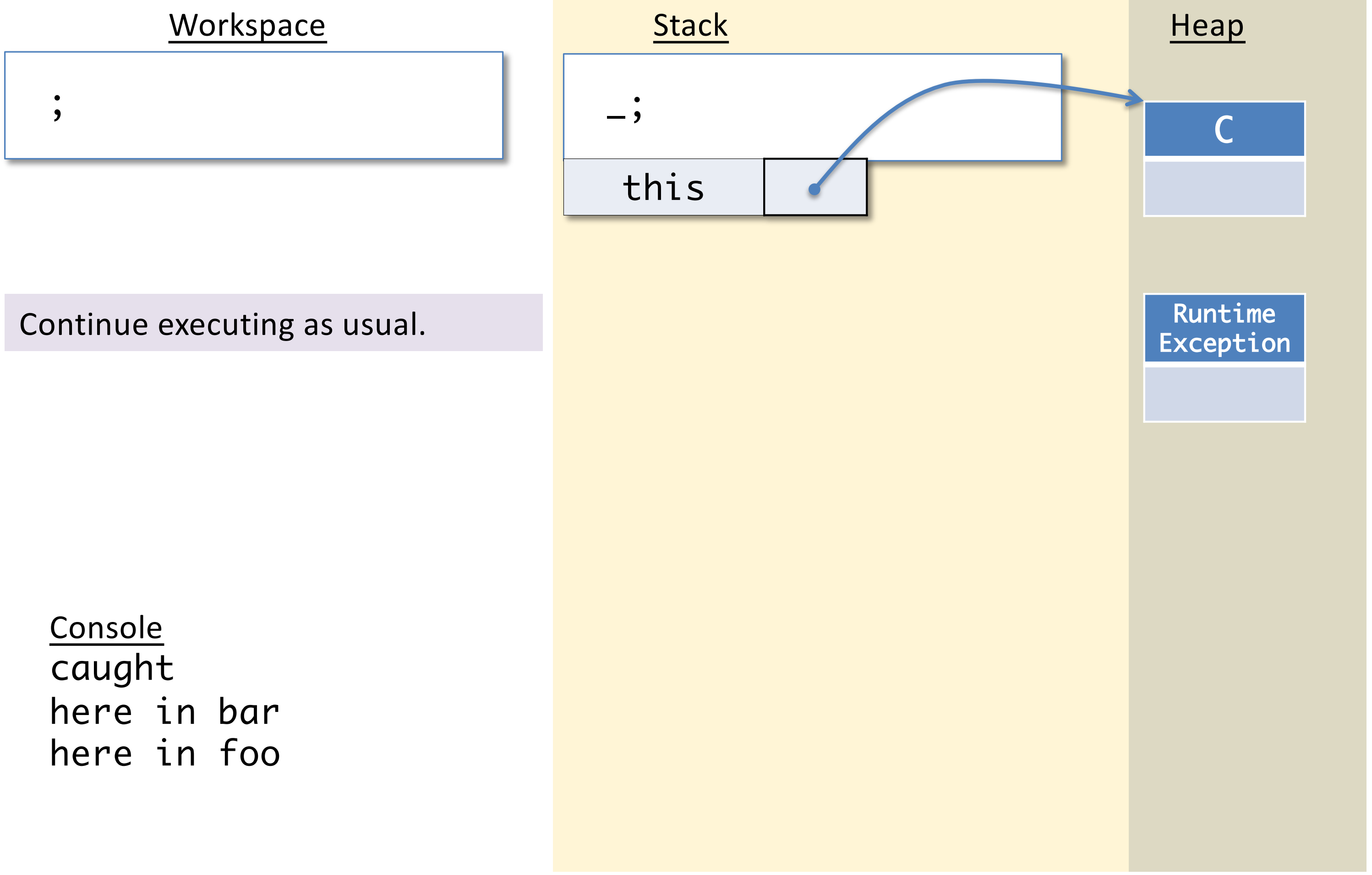
Continue executing as usual.



Console

```
caught
here in bar
```

Abstract Stack Machine

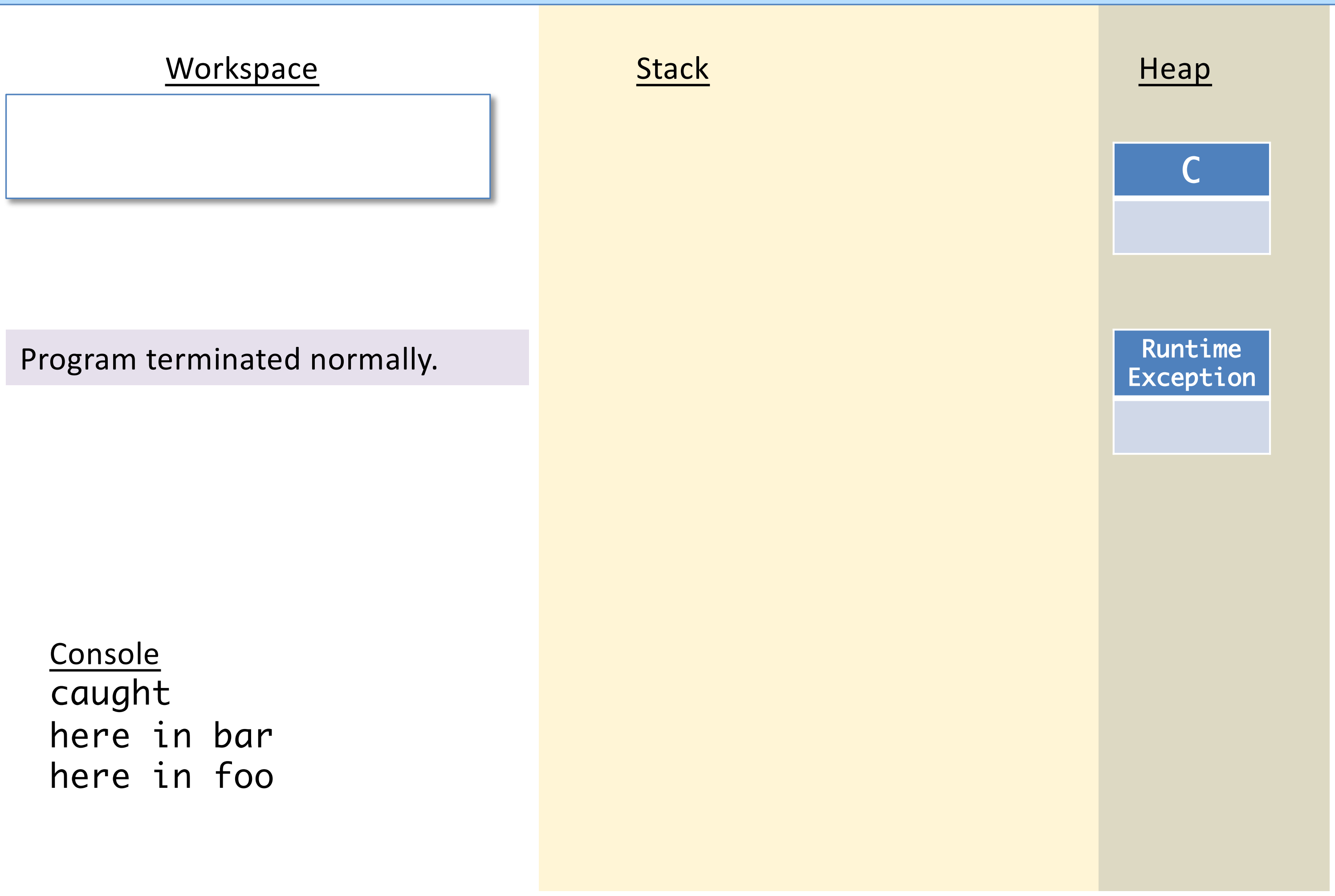


Continue executing as usual.

Console

```
caught
here in bar
here in foo
```

Abstract Stack Machine



Program terminated normally.

Console

```
caught
here in bar
here in foo
```

When No Exception is Thrown

If no exception is thrown while executing the body of a try {…} block, evaluation *skips* the corresponding catch block.

- i.e. if you ever reach a workspace where “catch” is the statement to run, just skip it:

Workspace

```
catch
(RuntimeException e)
{ System.out.Println
  (“caught”); }
System.out.println(
  “here in bar”);
```

$\Rightarrow$

Workspace

```
System.out.println(
  “here in bar”);
```

Catching Exceptions

There can be more than one "catch" clause associated with a given "try"

- Matched in order, according to the *dynamic* class of the exception thrown
- Helps refine error handling

```
try {
      …    // do something with the IO library
} catch (FileNotFoundException e) {
      …    // handle an absent file
} catch (IOException e) {
      …    // handle other kinds of IO errors.
}
```

- Good style: be as specific as possible about the exceptions you're handling.
  - Avoid `catch (Exception e) {…}` it's usually too generic!