Programming Languages and Techniques (CIS120)

Lecture 28

March 25, 2013

Exceptions

Announcements

- HW 08 due tonight at midnight
- Weirich OH: 1:30 – 3PM today

- Midterm 2 is this Friday
  - Towne 100 last names A—K
  - Cohen G17 last names L—Z
- Review session: Wednesday 6:30-9:30pm
  - Wu & Chen (Levine 101)
  - Lab this week is review (bring questions!)

Exceptions

Dealing with the unexpected

Why do methods “fail”?

- Some methods make requirements of their arguments
  - Input to max is a nonempty list, Item is non-null, no more elements for next
- Interfaces may be imprecise
  - Some Iterators don't support the "remove" operation
- External components might fail
  - Try to open a file that doesn't exist
- Resources might be exhausted
  - Program uses all of the computer's disk space

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

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 must check return value*
  - *Use with caution – easy to introduce hard to find bugs*
- Use an informative result
  - e.g. in OCaml we used options to signal potential failure
  - e.g. in Java, create a special class like option
  - *Passes responsibility to caller, but caller must do the proper check*
- Use exceptions
  - Available both in OCaml and Java
  - Any caller can handle the situation
  - If exceptions are uncaught, the program terminates

Exceptions

- An exception is an *object* representing abnormal conditions.
  - 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 method.
  - The exception propagates up the invocation stack until it either reaches the top and 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

Example from HW 7

```
void loadImage (String fileName) {
  try {
      Picture p = new Picture(fileName);     // could fail

      // ... code to display the new picture in the window
      // executes only if the picture is successfully created.

   } catch (IOException ex) {

      // Use the GUI to send an error message to the user
      // using a dialog window
      JOptionPane.showMessageDialog(
          frame,                  // parent of dialog window
                                  // error message to display
          "Cannot load file\n" + ex.getMessage(),
          "Alert",                        // title of dialog
          JOptionPane.ERROR_MESSAGE    // type of dialog
         );
  }
```

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 Exception();
    }
}
```

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

Abstract Stack Machine

Workspace

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

Stack

Heap

Abstract Stack Machine

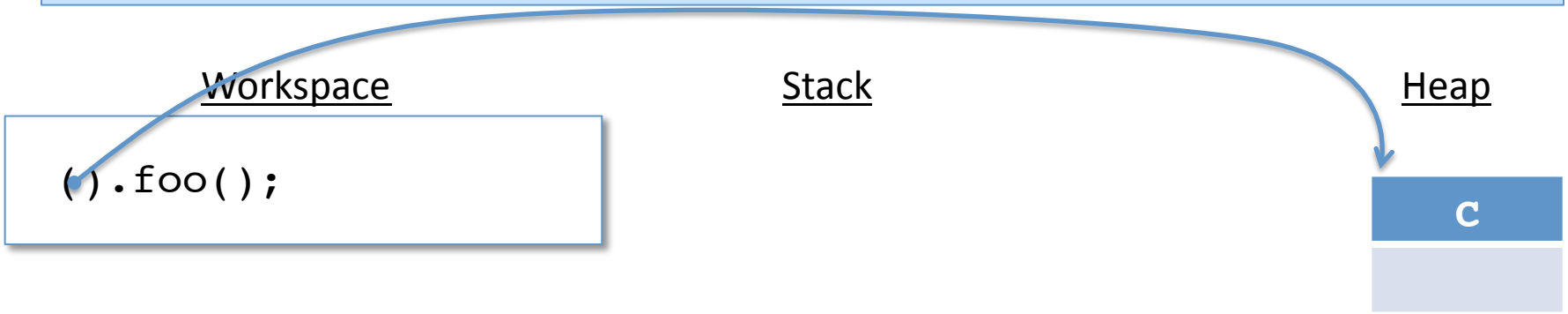
Workspace

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

Stack

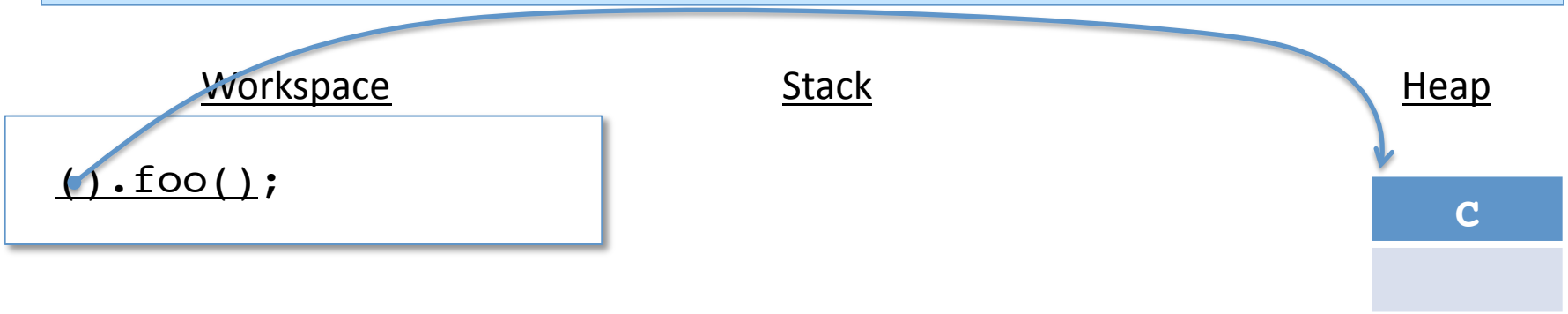
Heap

Abstract Stack Machine

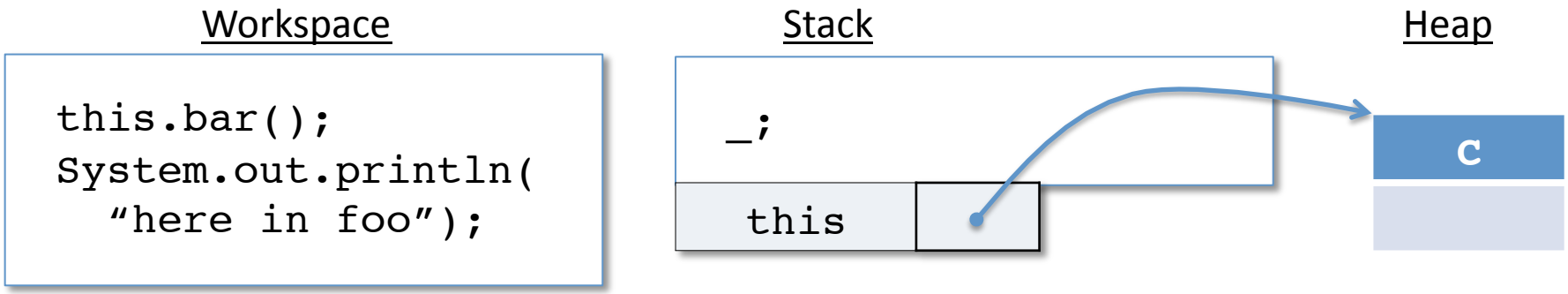


Allocate a new instance of C in the heap. (Skipping details of trivial Constructor.)

Abstract Stack Machine



Abstract Stack Machine

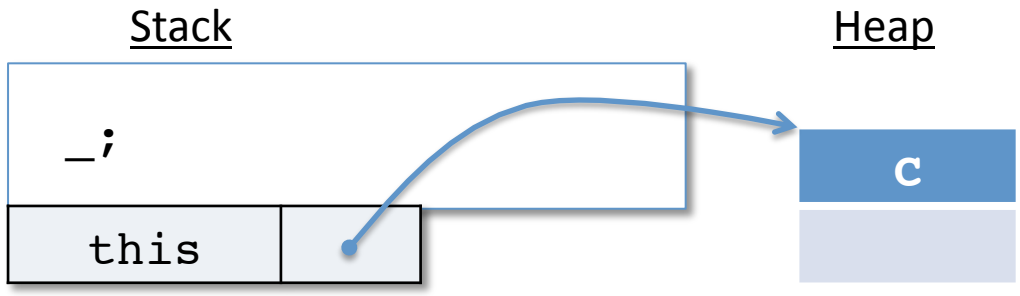


Save a copy of the current workspace in the stack, leaving a "hole", written _, where we return to. Push the `this` pointer, followed by arguments (in this case none) onto the stack. Use the dynamic class to lookup the method body from the class table.

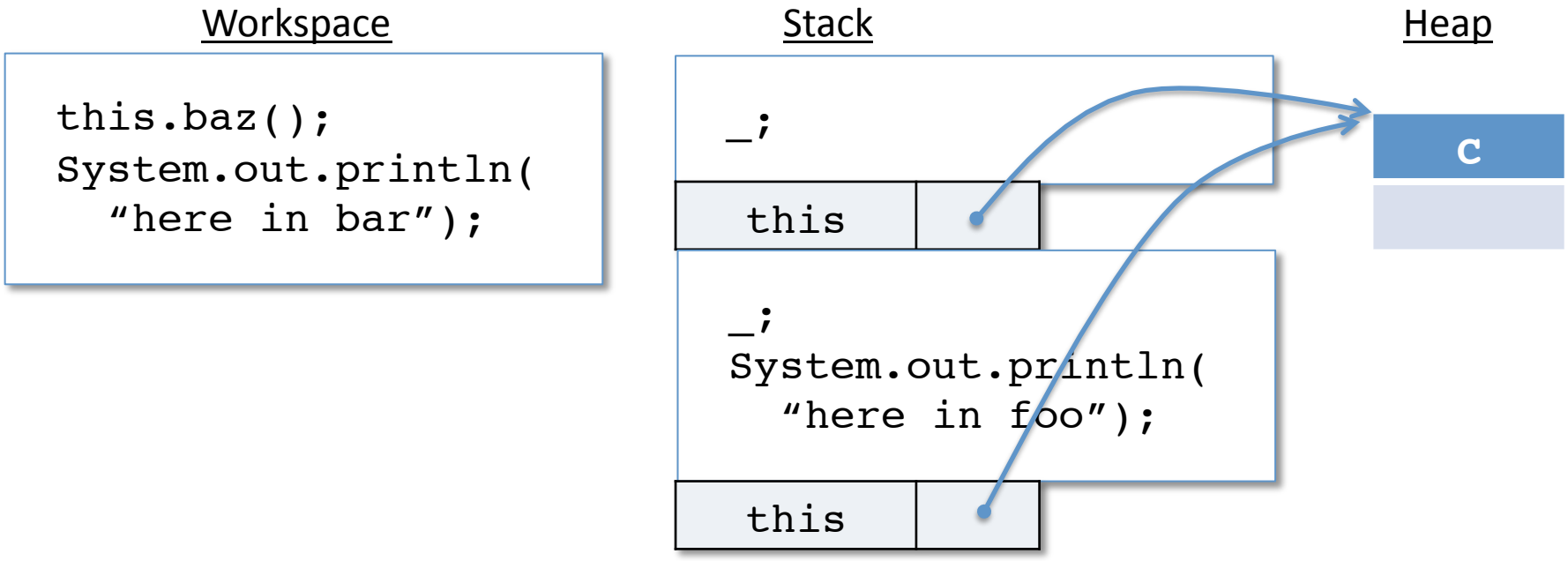
Abstract Stack Machine

Workspace

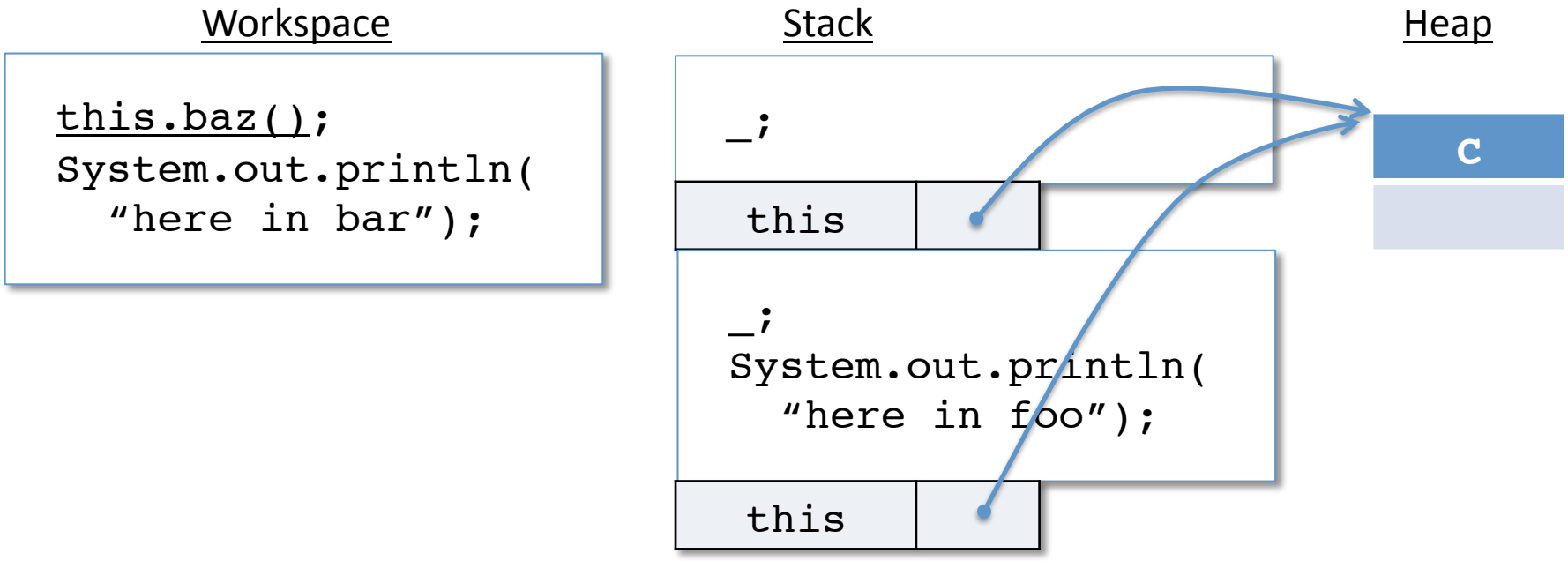
```
this.bar();
System.out.println(
  "here in foo");
```



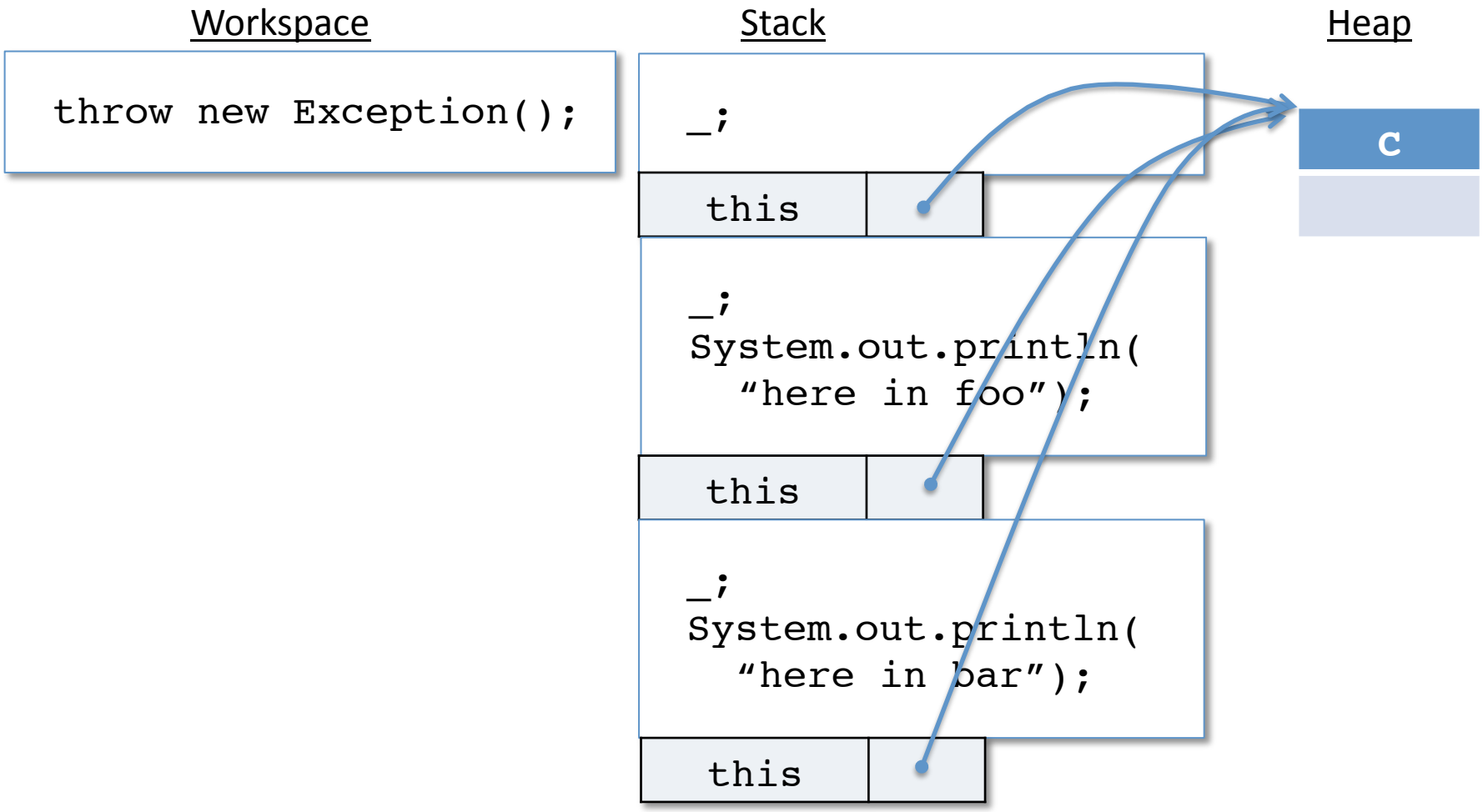
Abstract Stack Machine



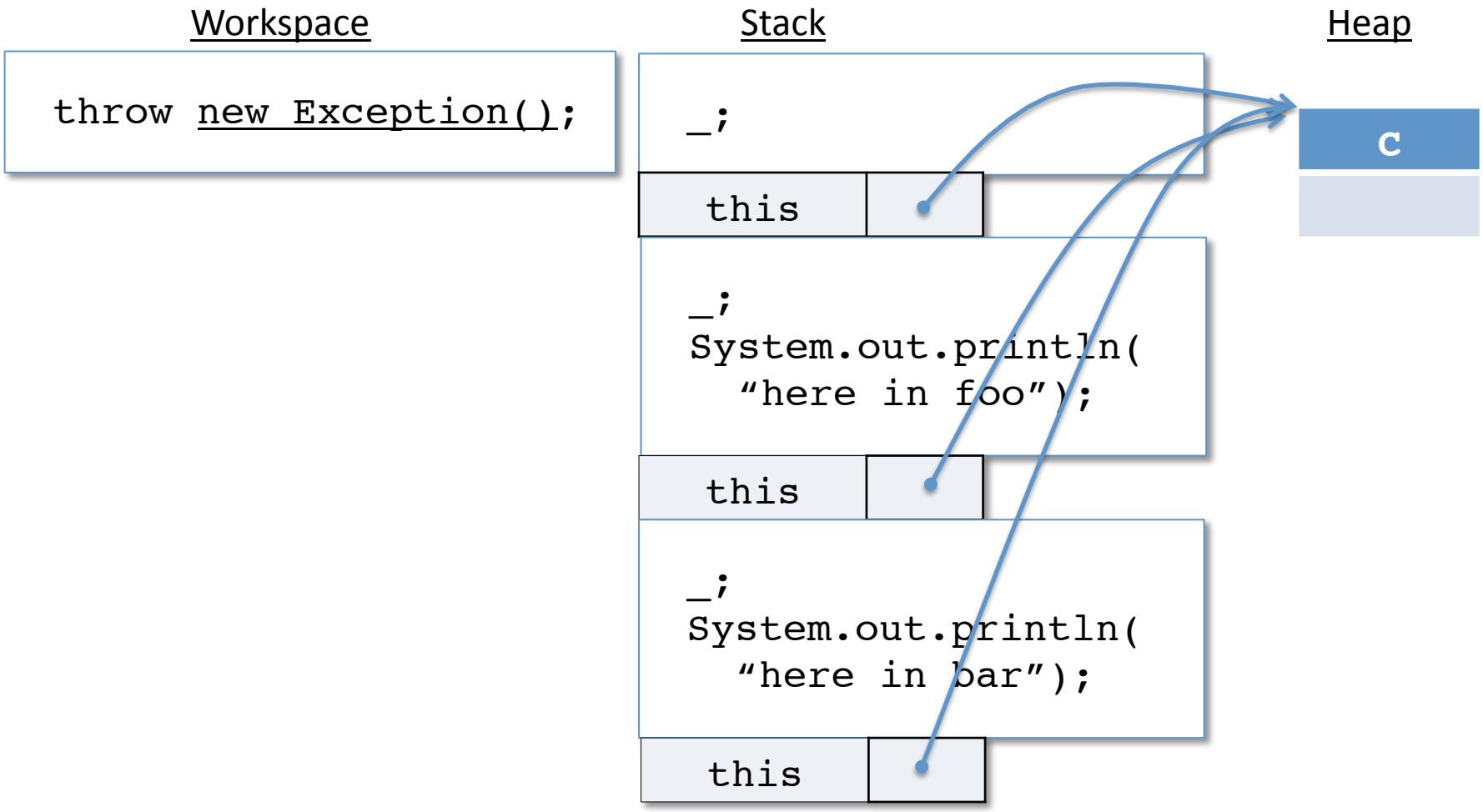
Abstract Stack Machine



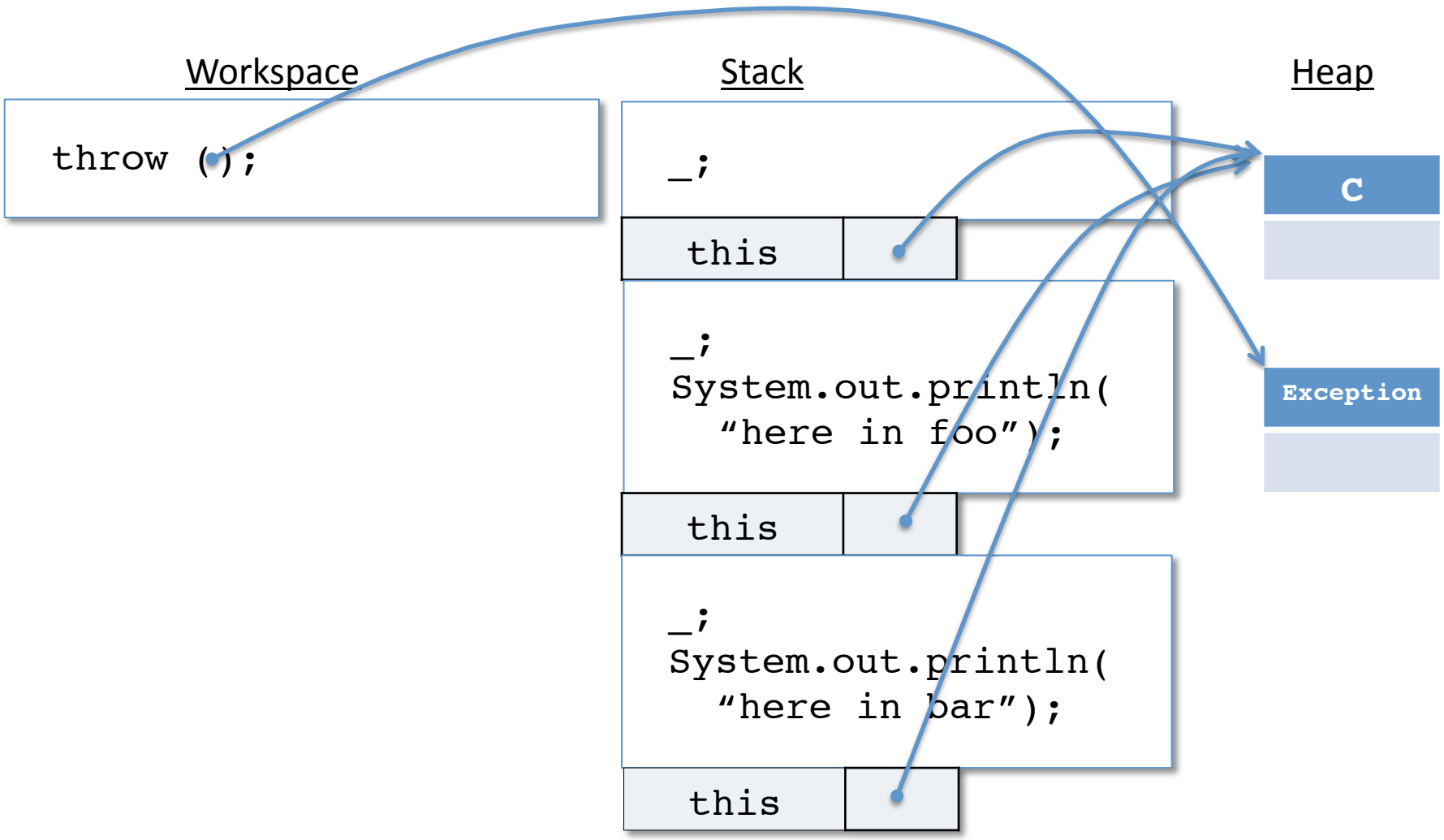
Abstract Stack Machine



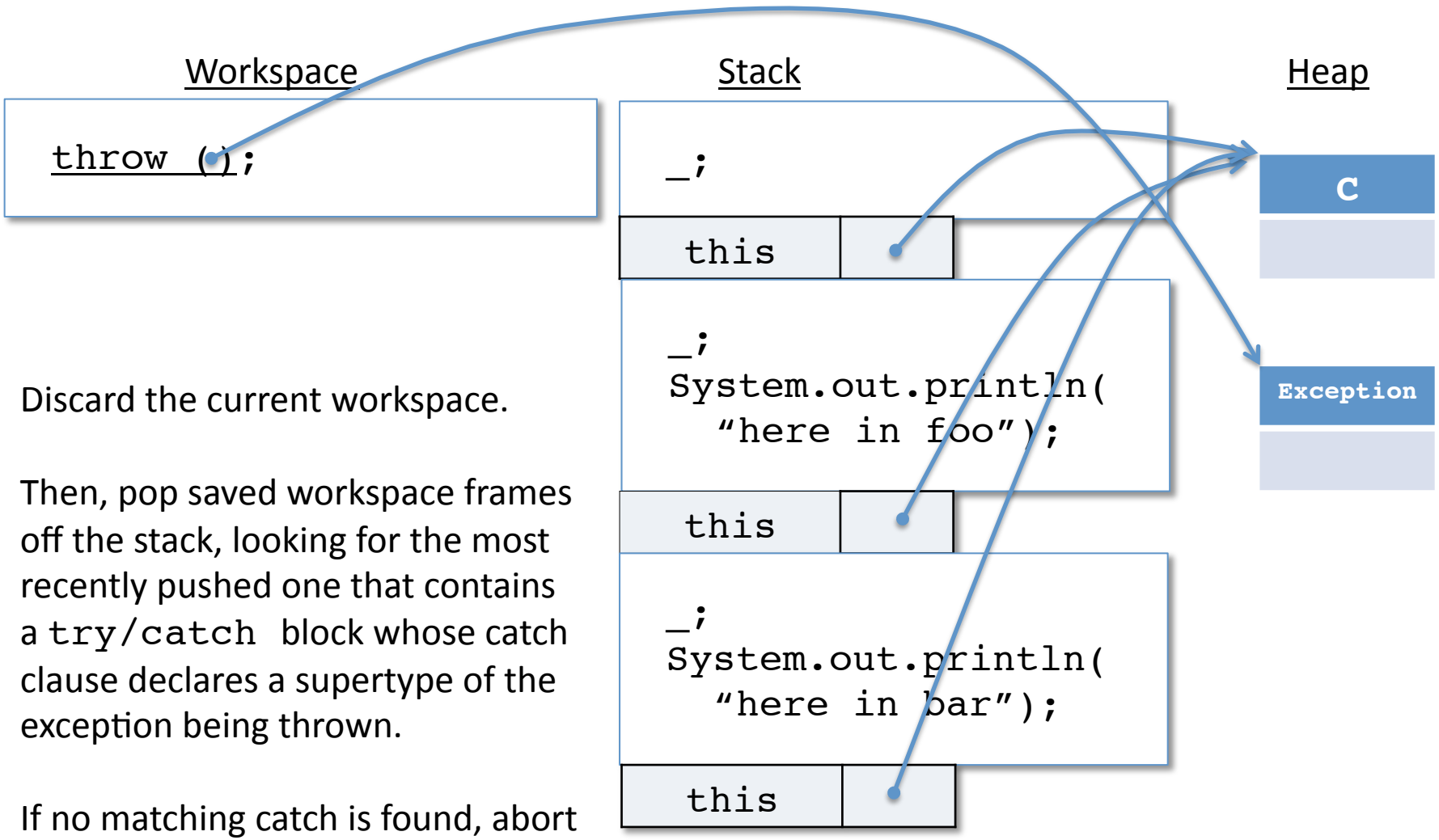
Abstract Stack Machine



Abstract Stack Machine



Abstract Stack Machine

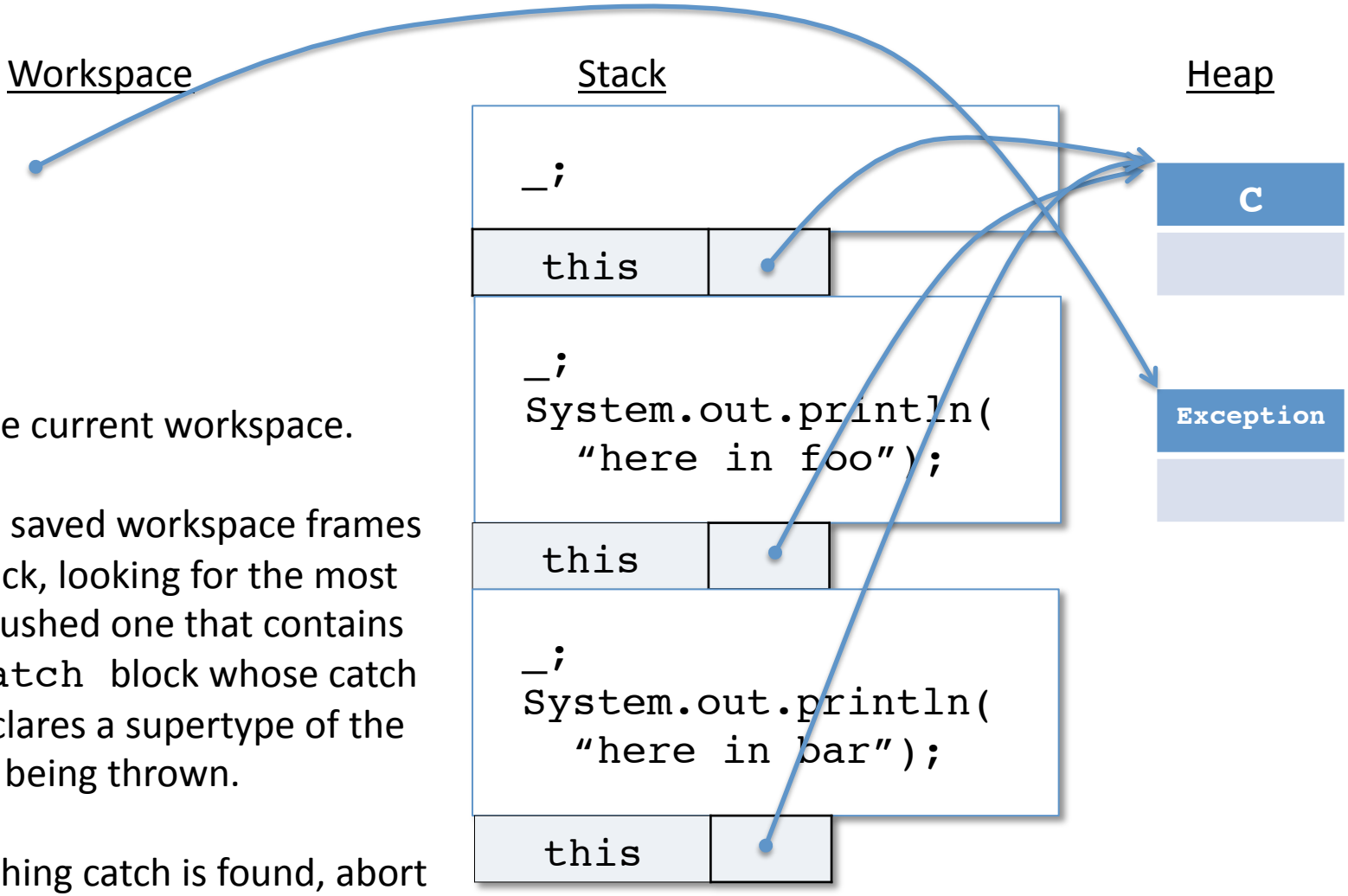


Discard the current workspace.

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.

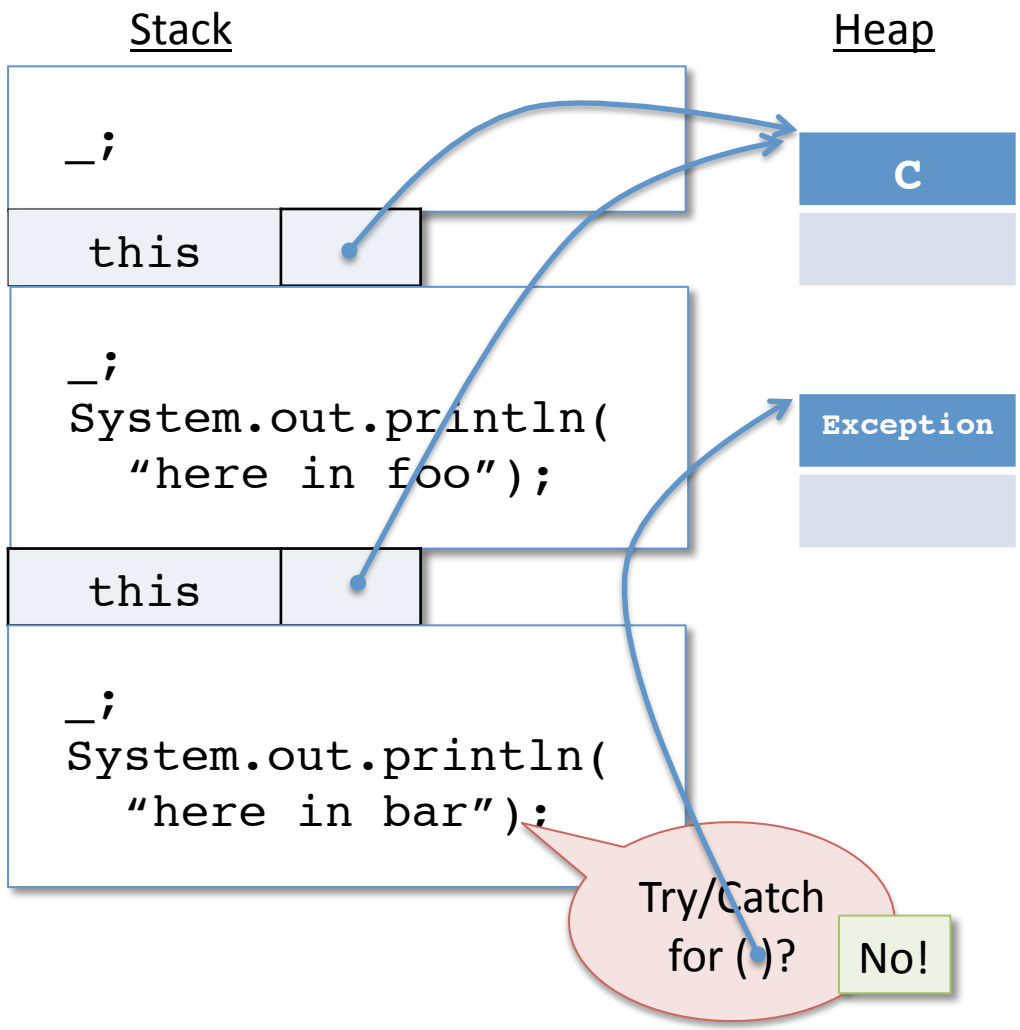
Abstract Stack Machine

Workspace

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.

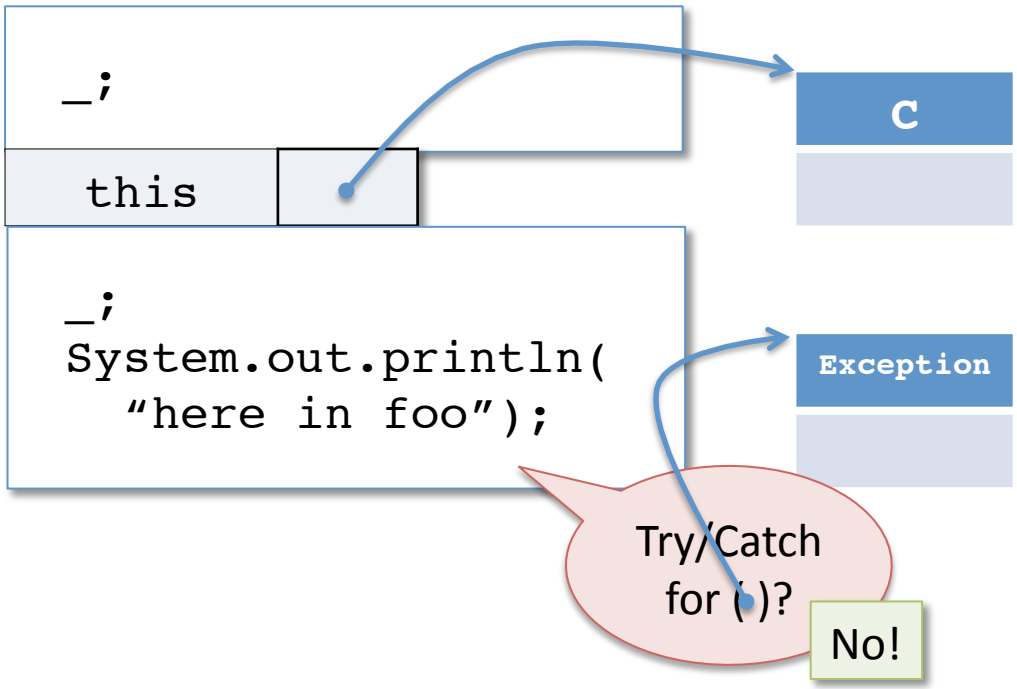


Abstract Stack Machine

Workspace

Stack

Heap

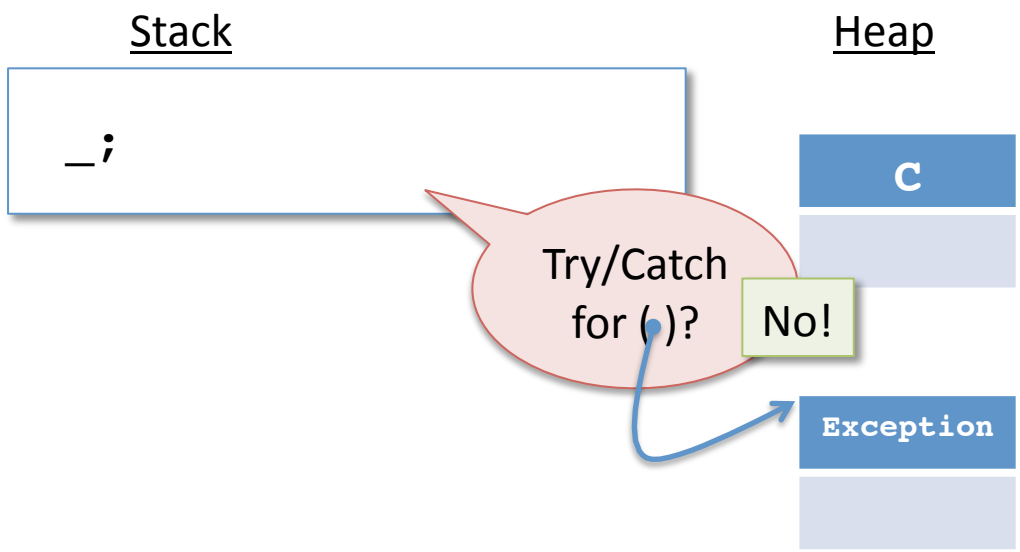


Discard the current workspace.

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 | Stack | Heap

Program terminated with uncaught exception ( )!

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 Exception();
    }
}
```

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

Abstract Stack Machine

Workspace

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

Stack

Heap

Abstract Stack Machine

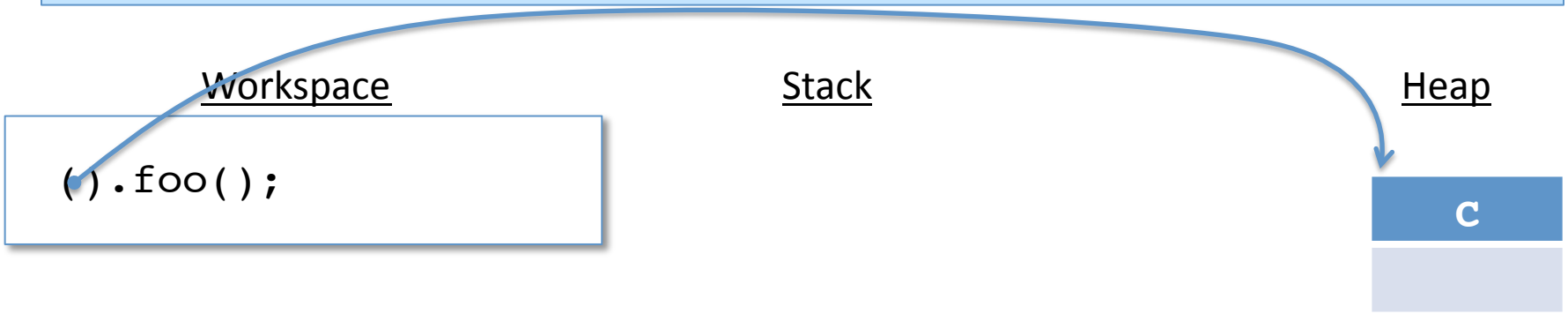
Workspace

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

Stack

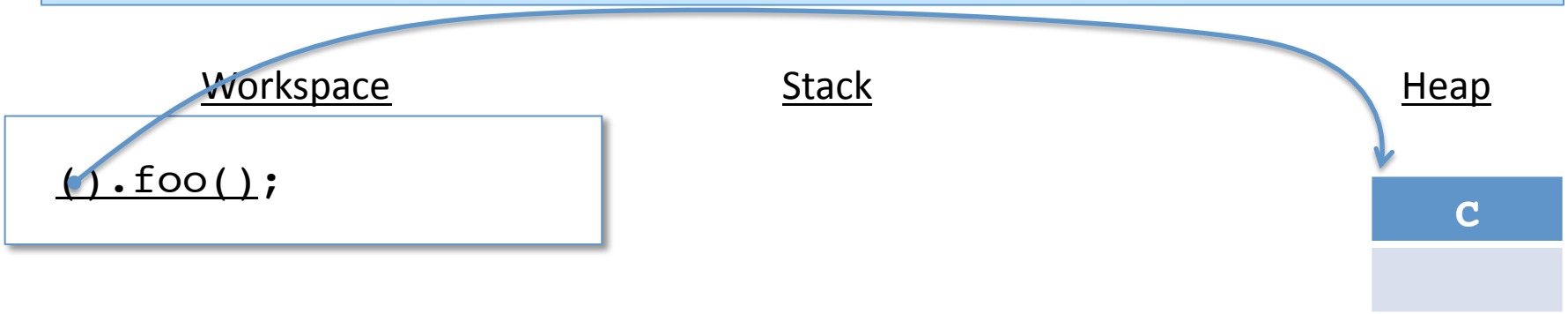
Heap

Abstract Stack Machine

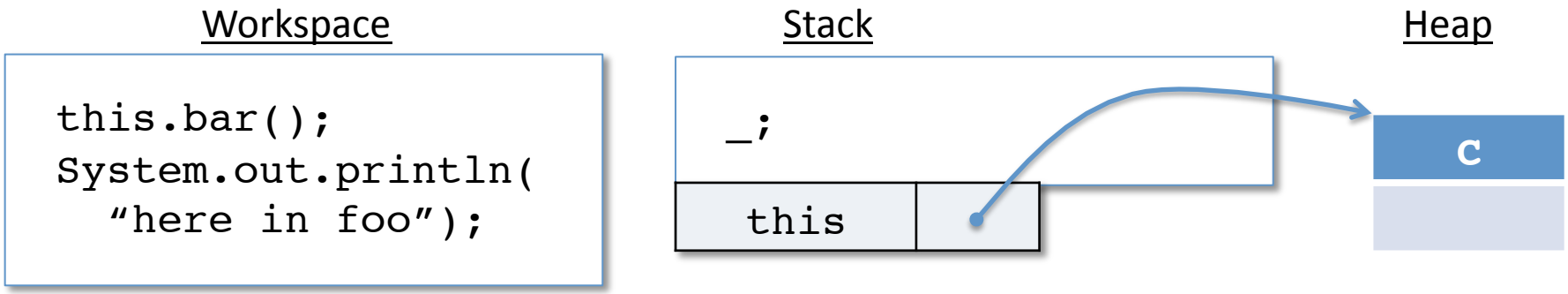


Allocate a new instance of C in the heap.

Abstract Stack Machine



Abstract Stack Machine



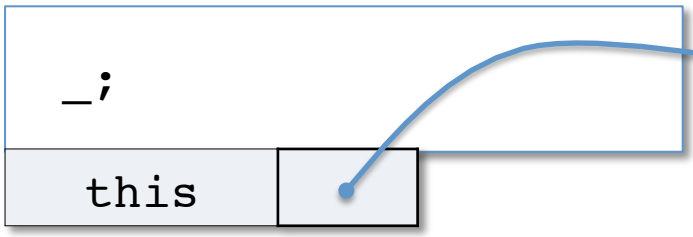
Save a copy of the current workspace in the stack, leaving a "hole", written _, where we return to. Push the `this` pointer, followed by arguments (in this case none) onto the stack.

Abstract Stack Machine

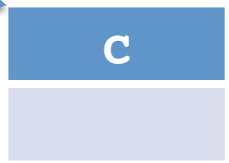
Workspace

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

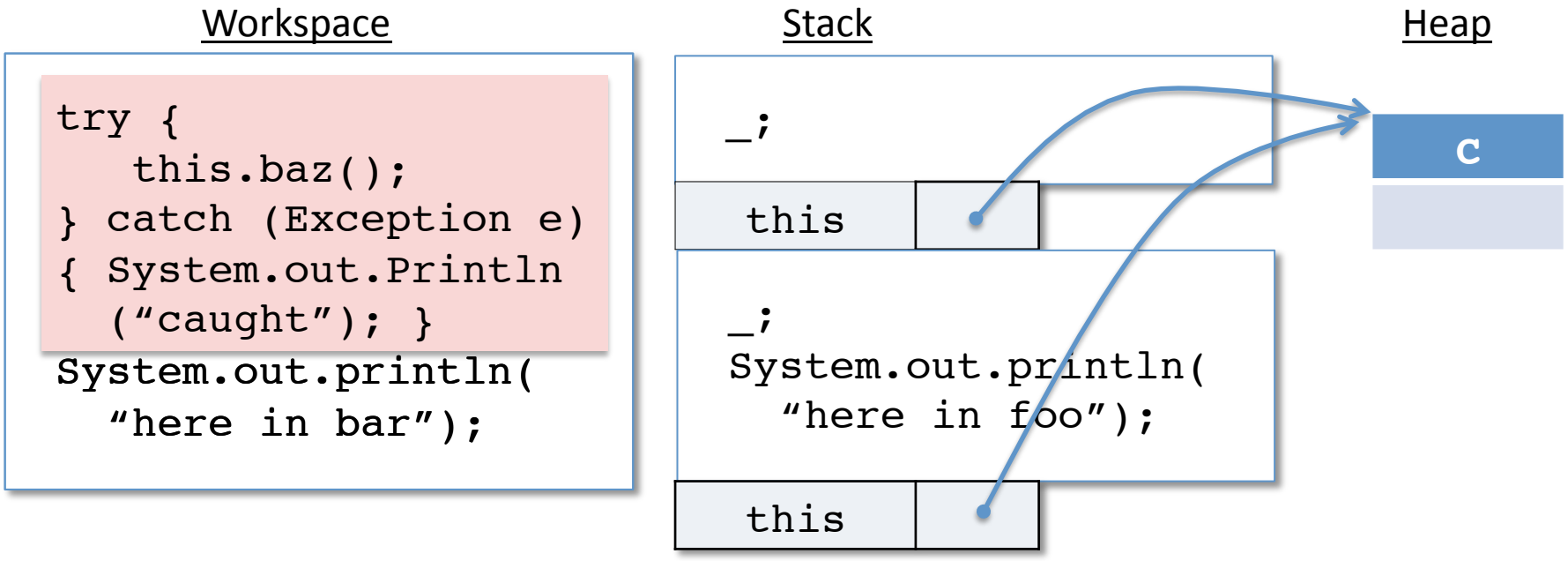
Stack



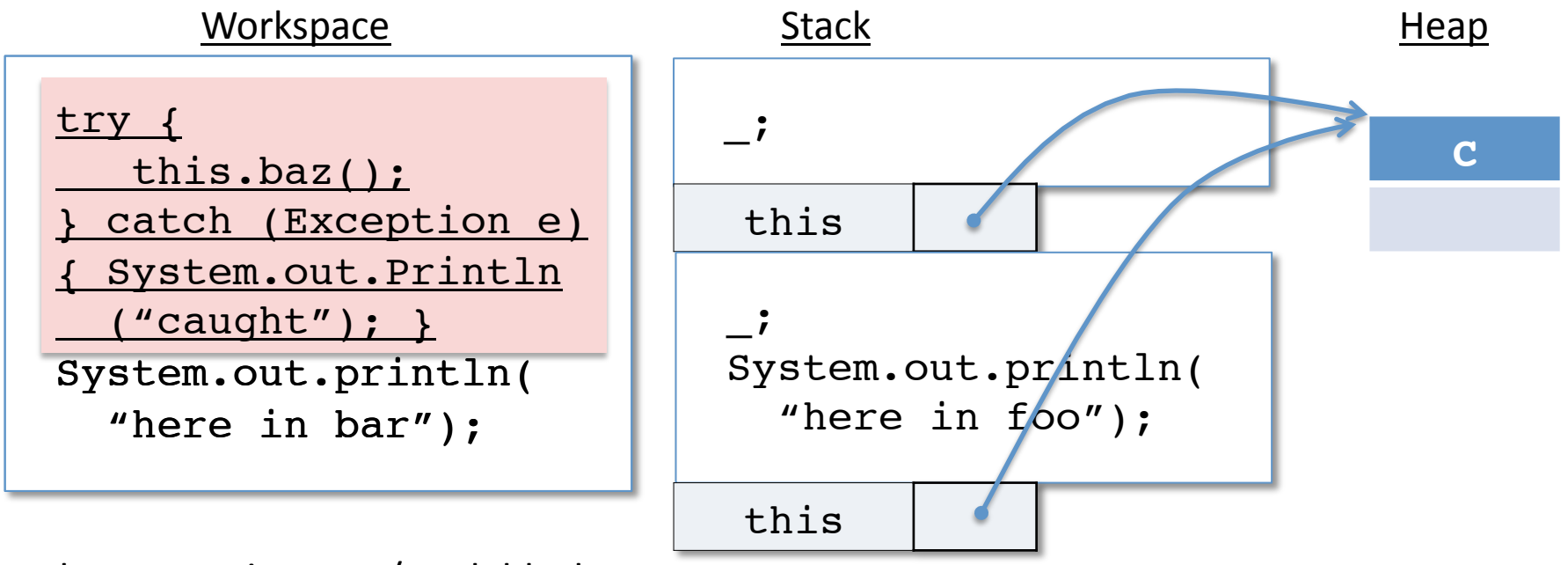
Heap



Abstract Stack Machine



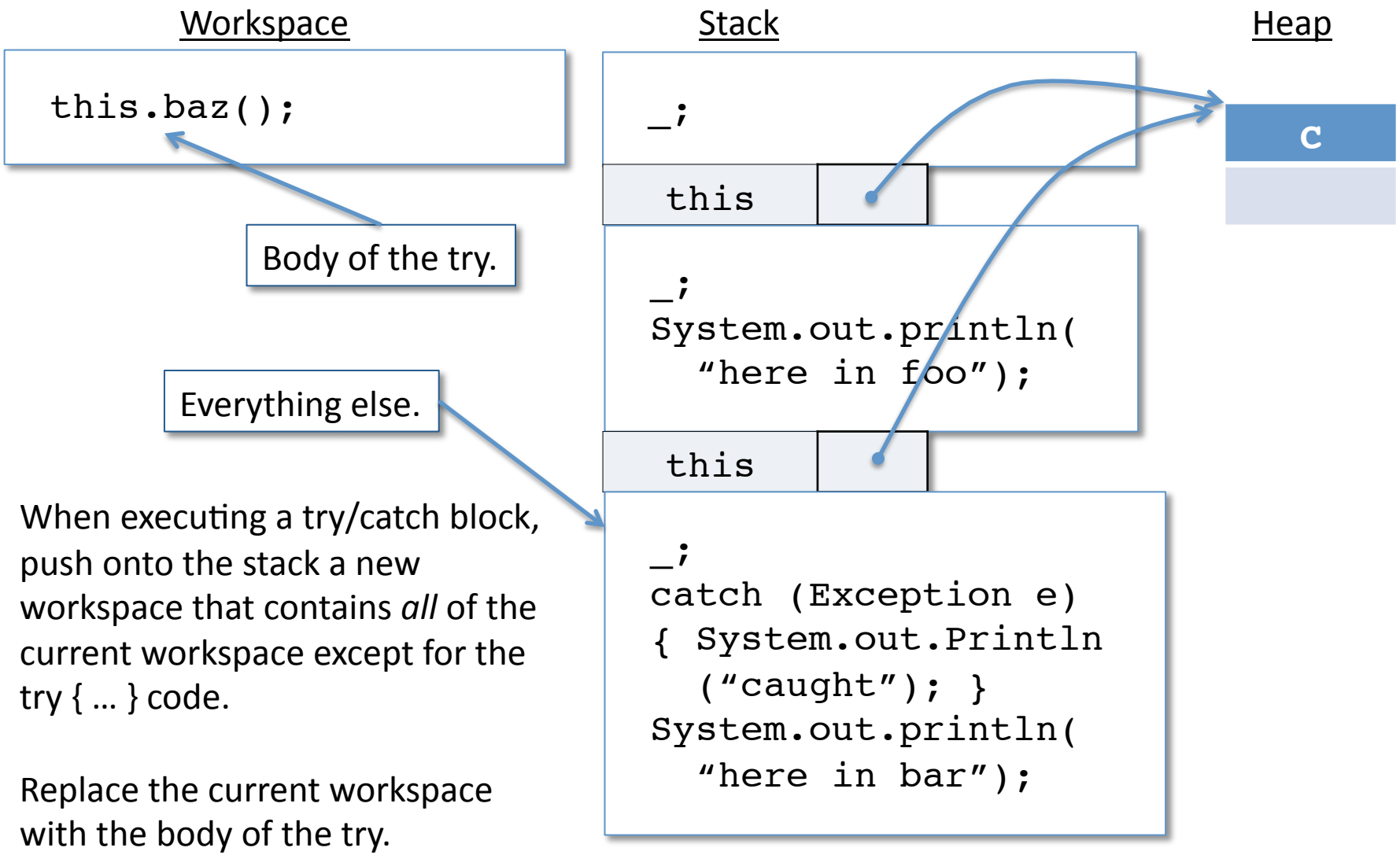
Abstract Stack Machine



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.

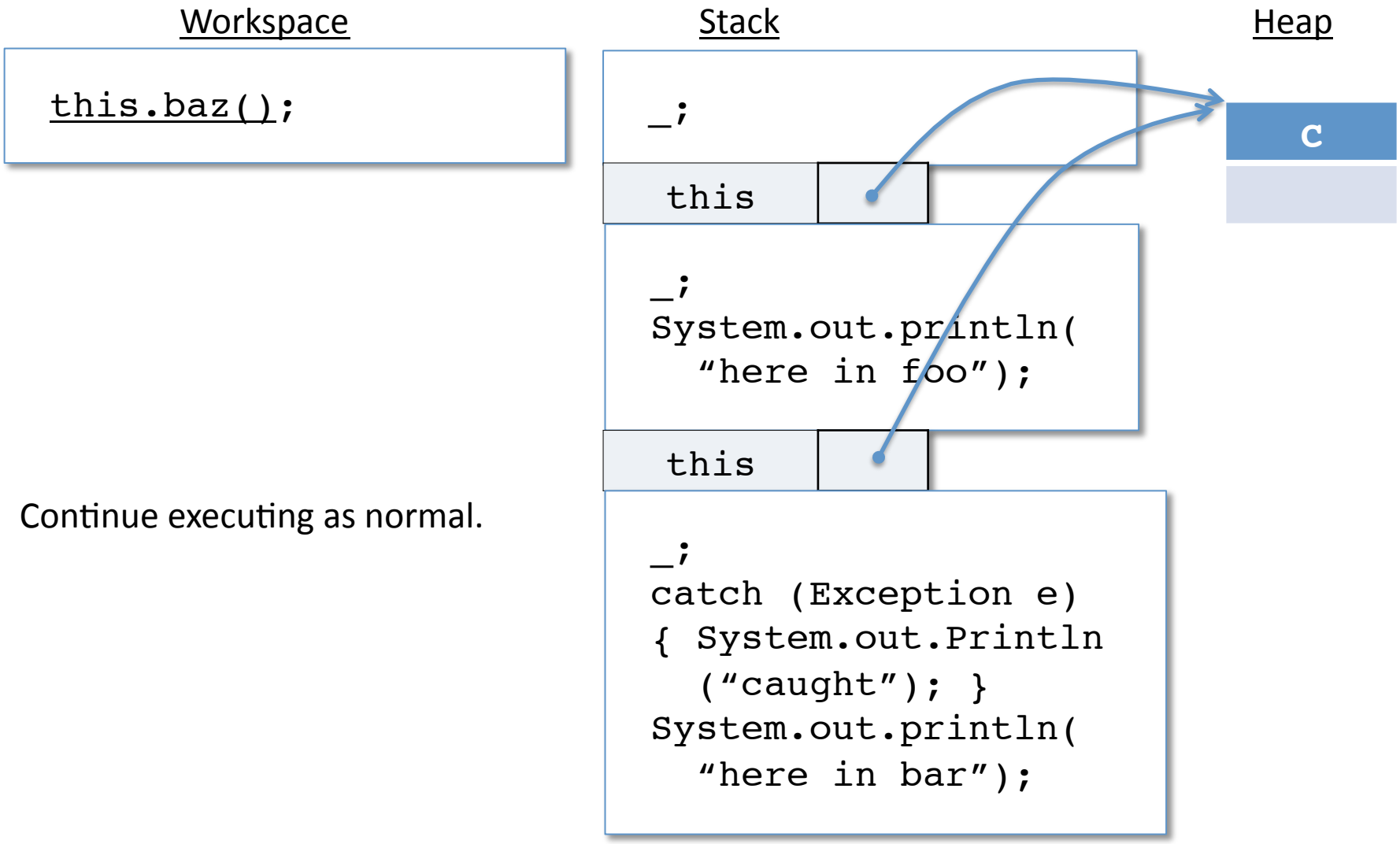
Abstract Stack Machine



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.

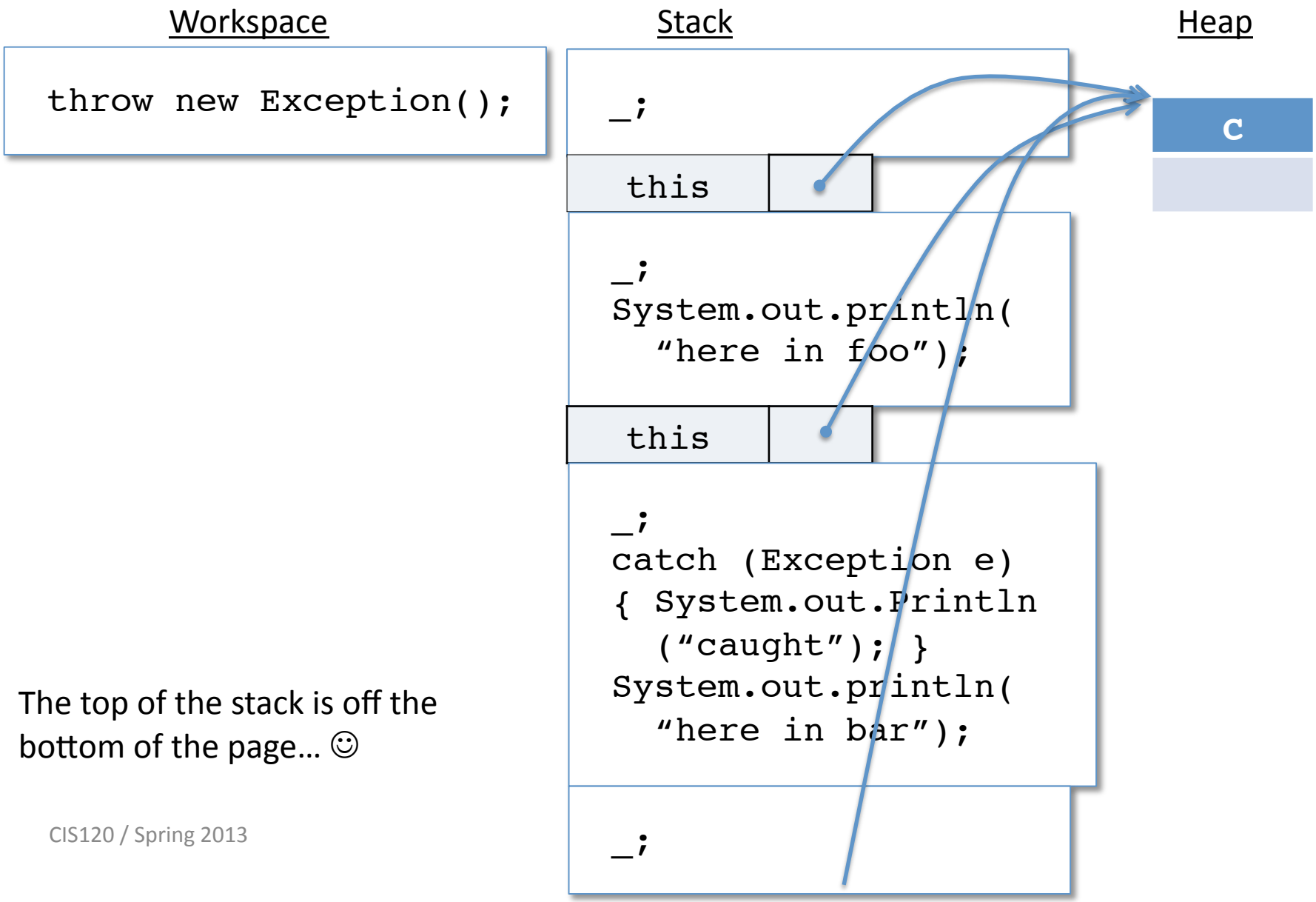
Replace the current workspace with the body of the try.

Abstract Stack Machine



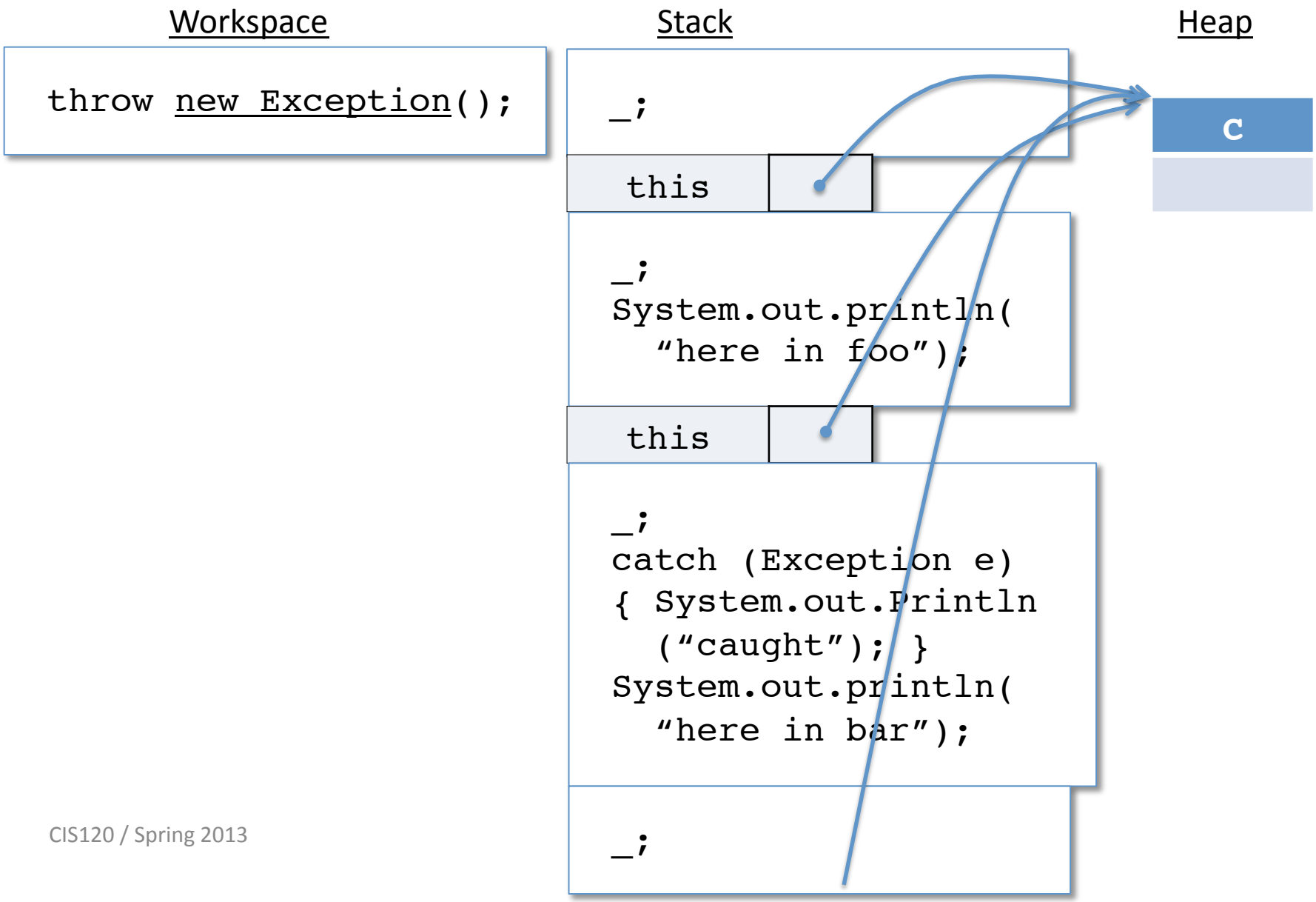
Continue executing as normal.

Abstract Stack Machine

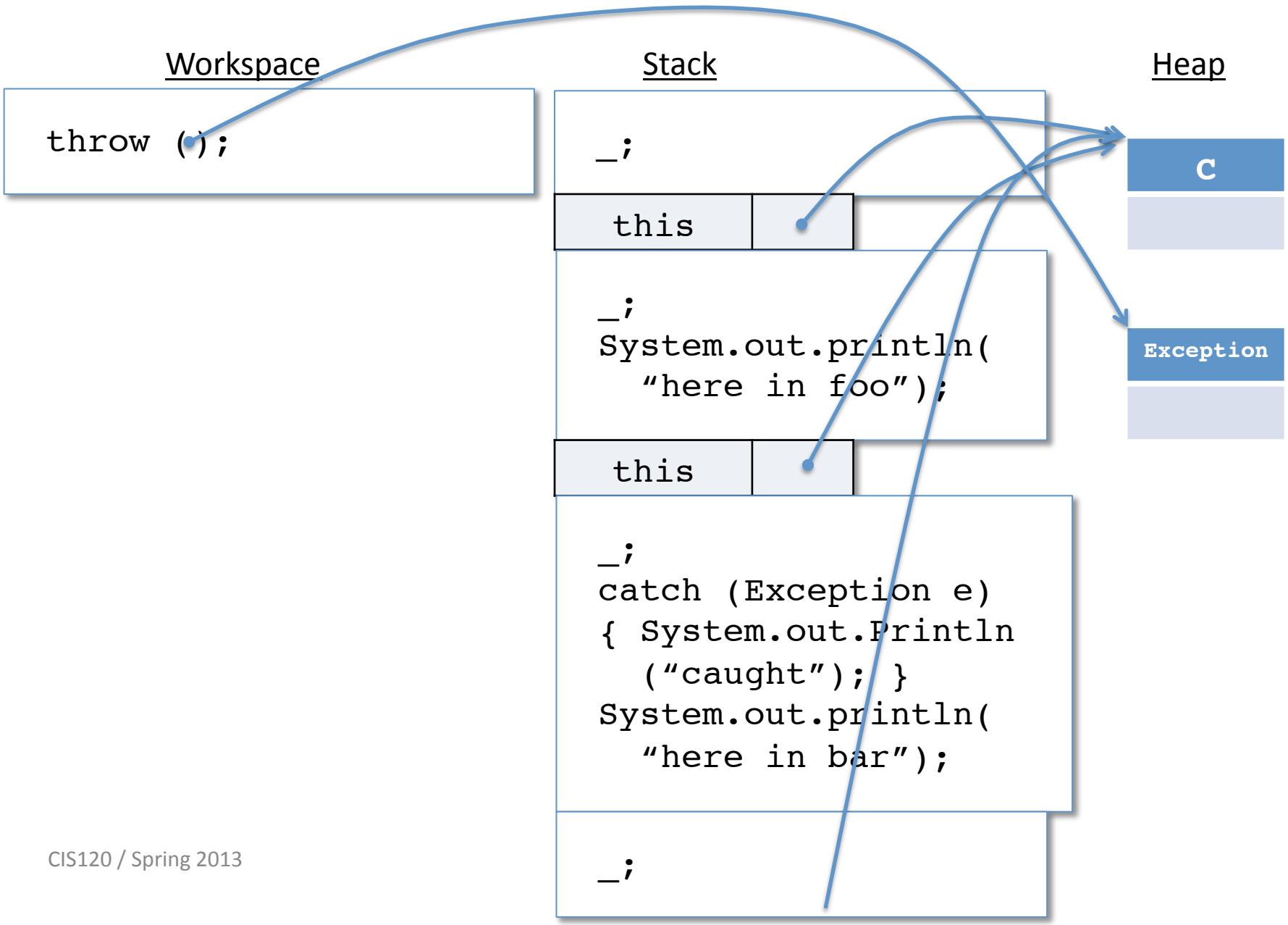


The top of the stack is off the bottom of the page… ☺

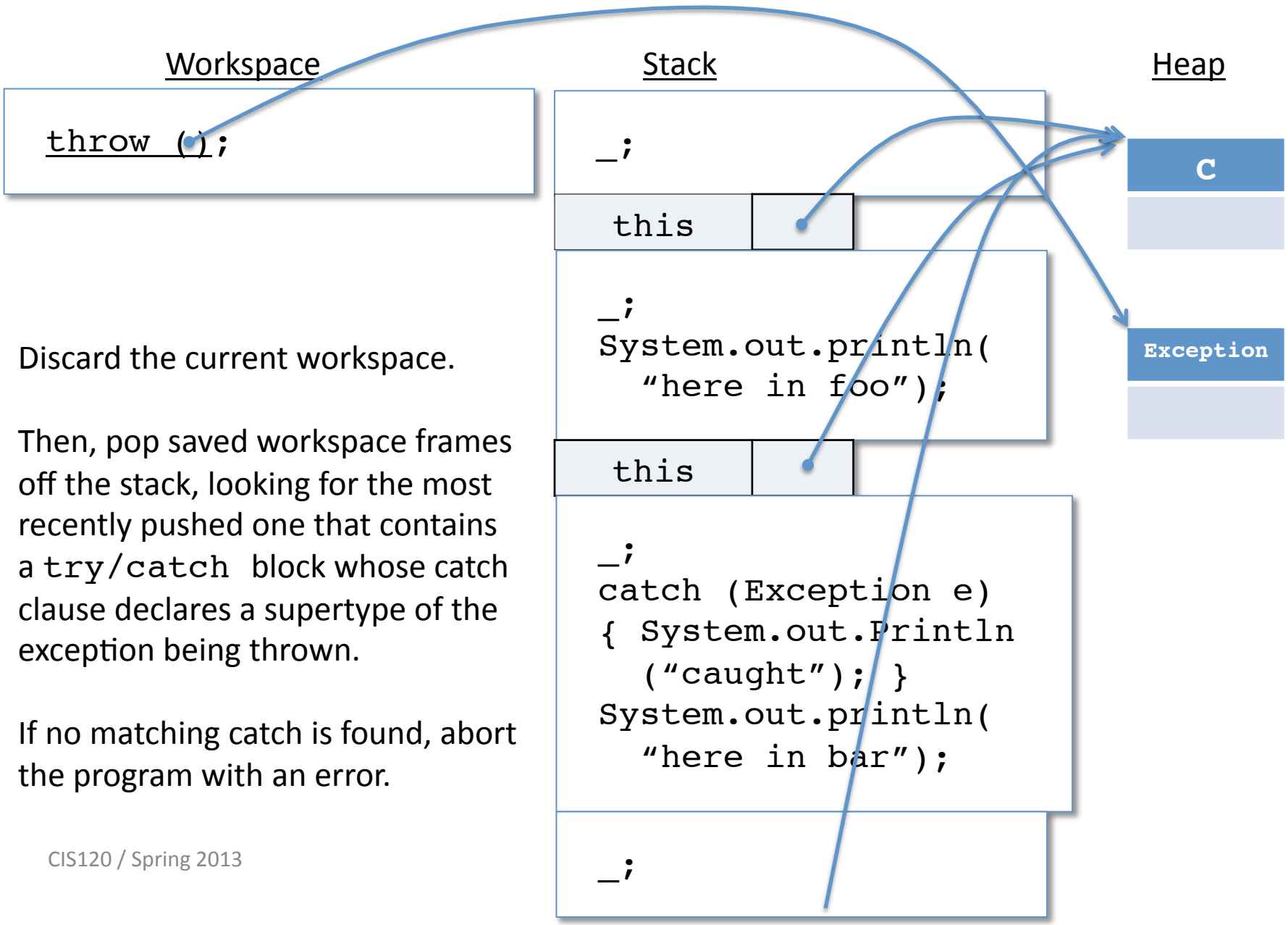
Abstract Stack Machine



Abstract Stack Machine



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.

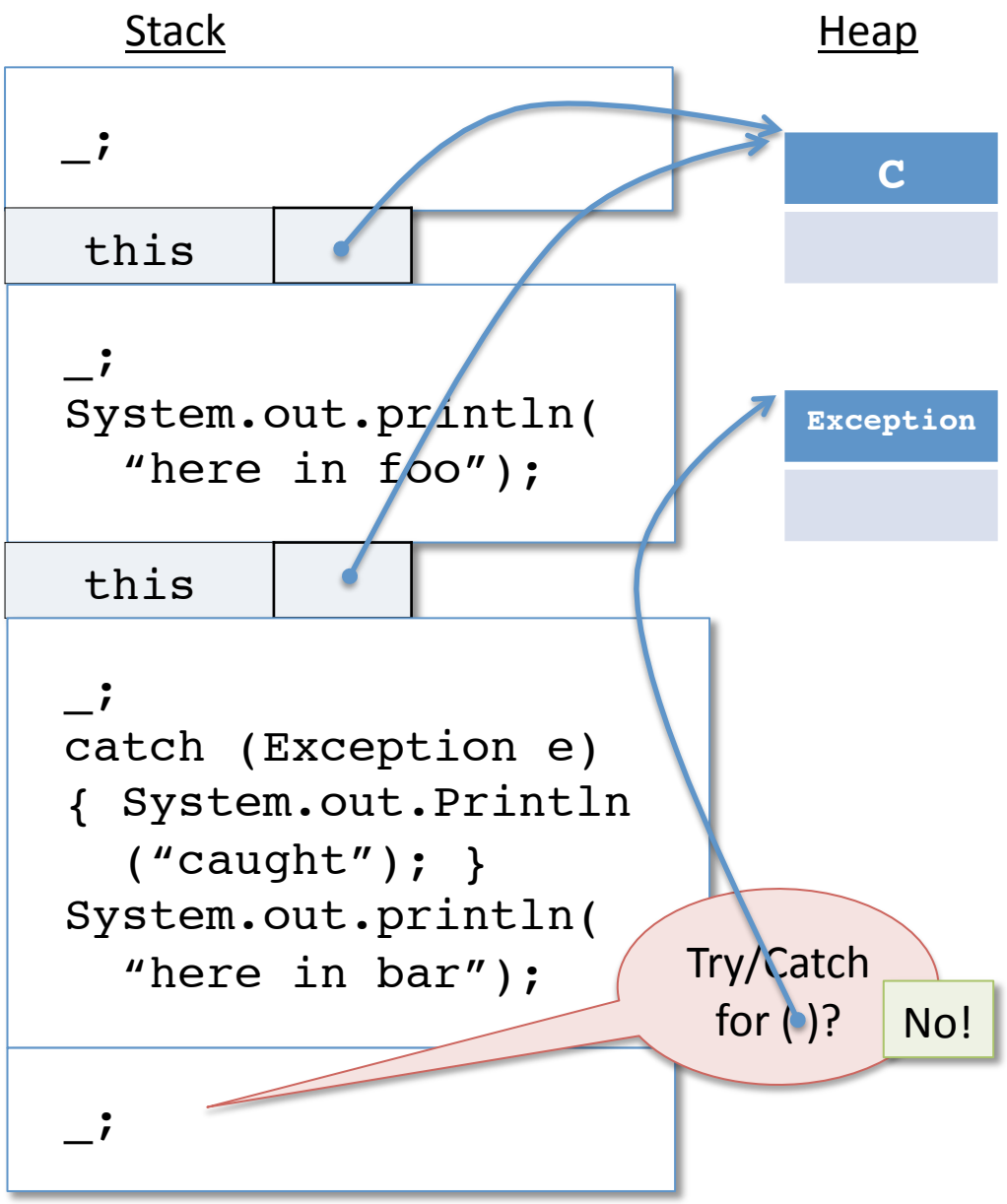
Abstract Stack Machine

Workspace

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.

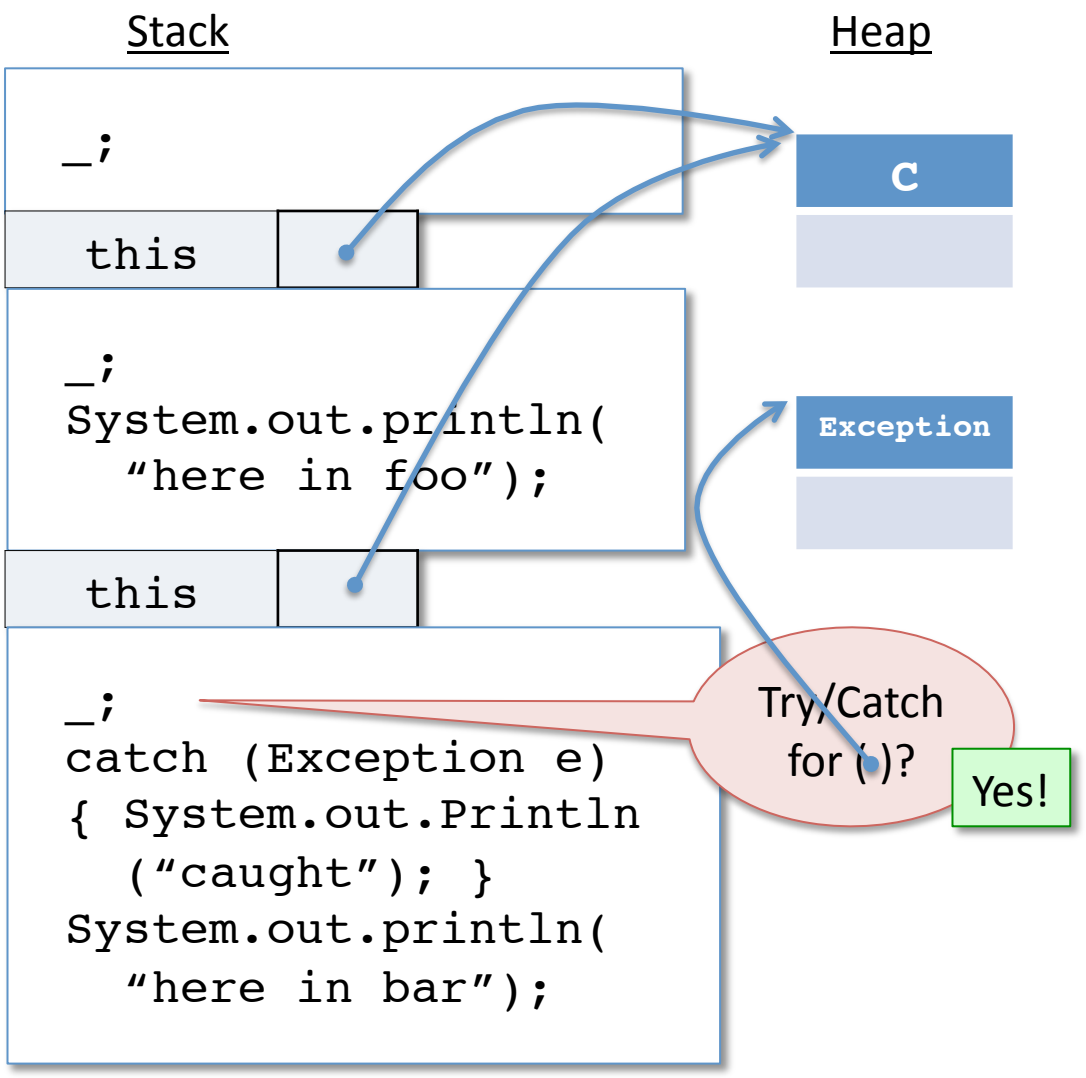
If no matching catch is found, abort the program with an error.



Abstract Stack Machine

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.

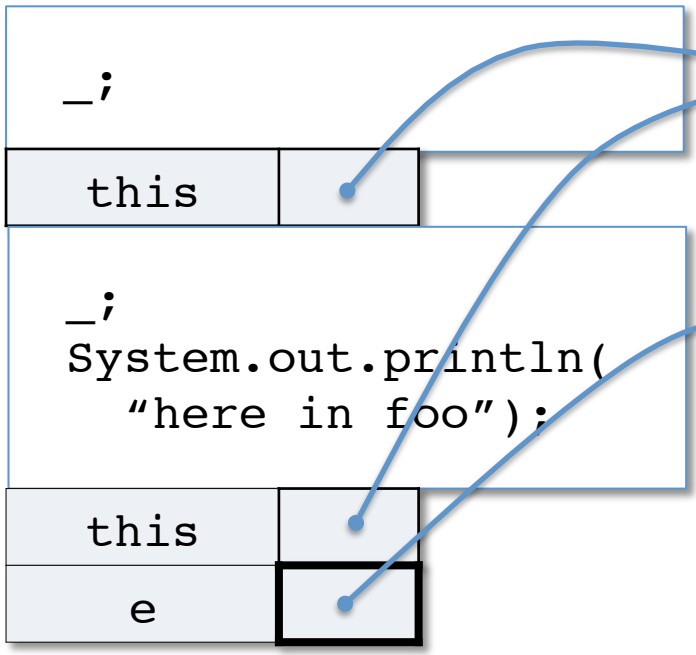


Abstract Stack Machine

Workspace

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

Stack



Heap

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.

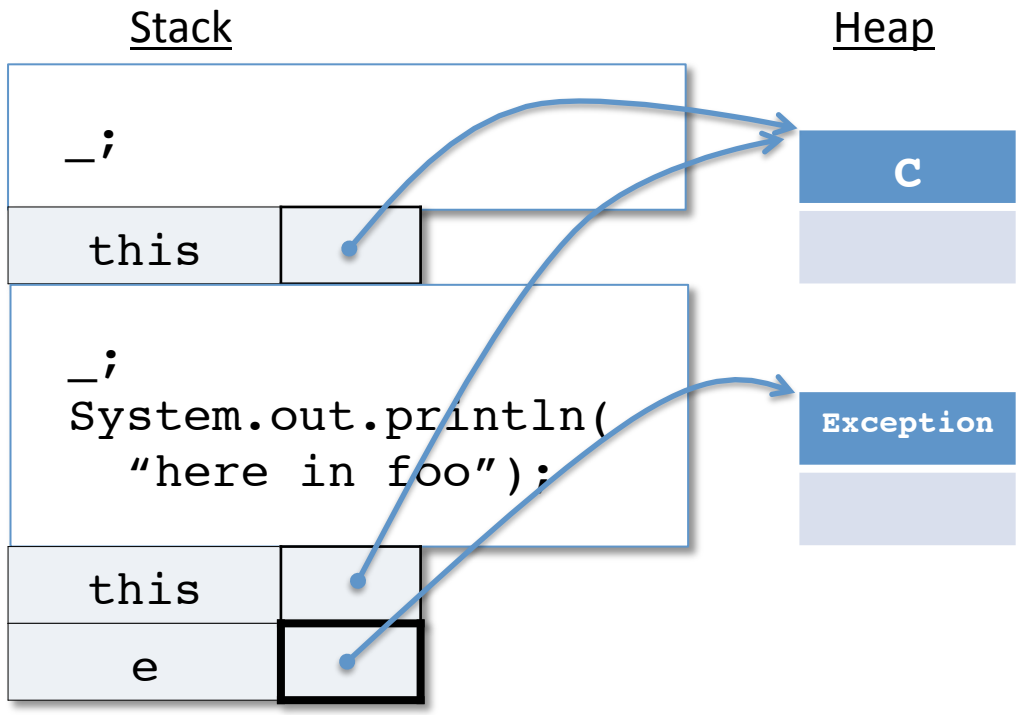
Continue executing as usual.

Abstract Stack Machine

Workspace

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

Continue executing as usual.

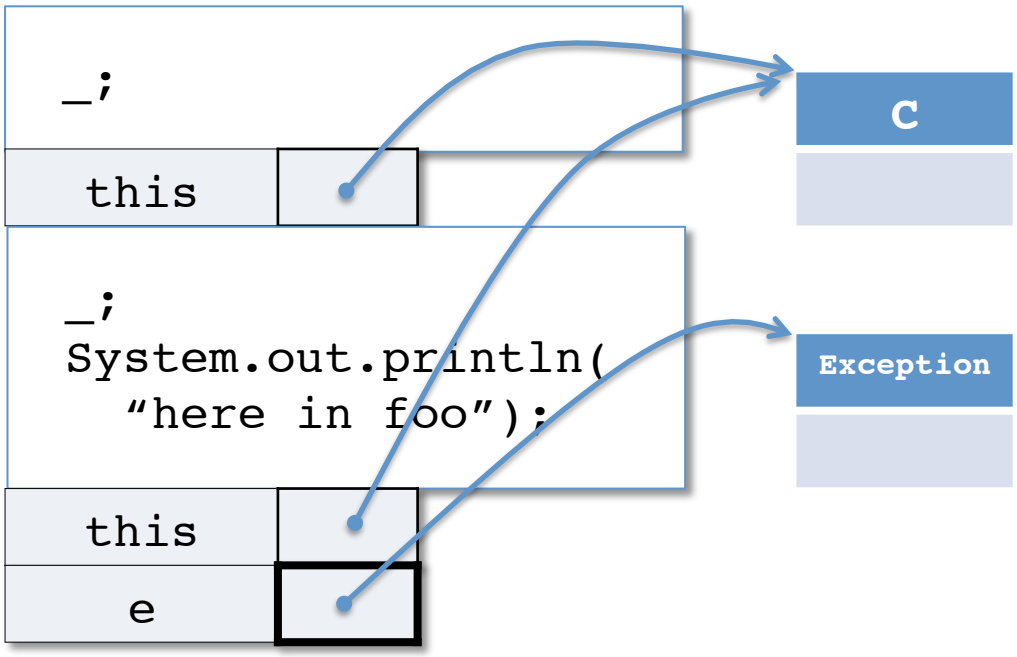


Abstract Stack Machine

Workspace

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

Stack



Heap

Continue executing as usual.

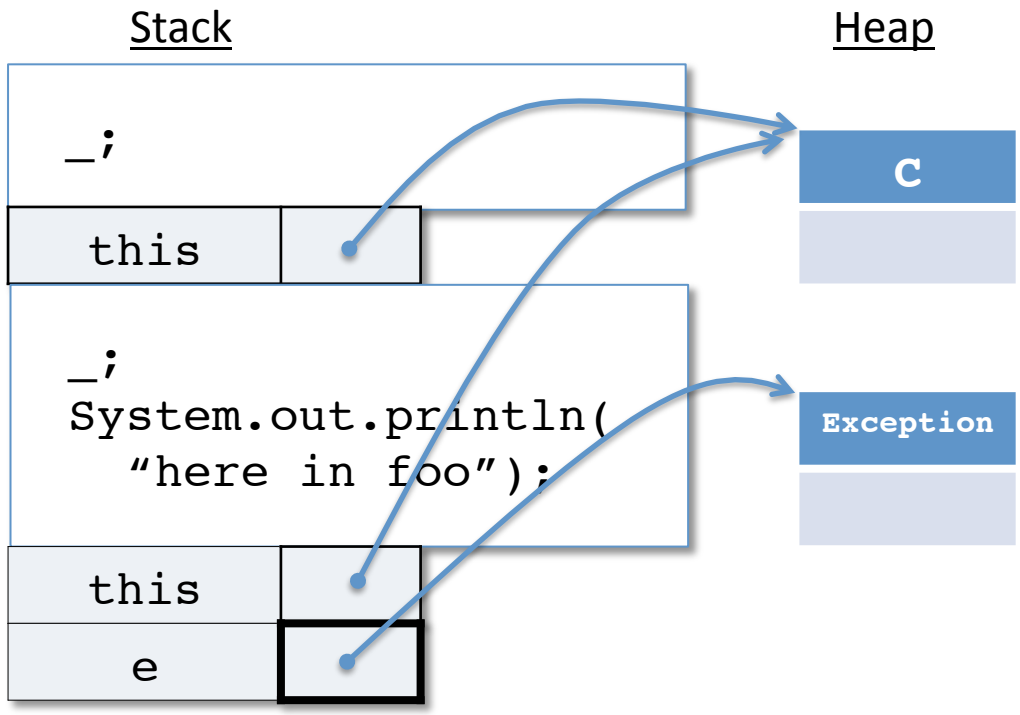
Console

```
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.

Console

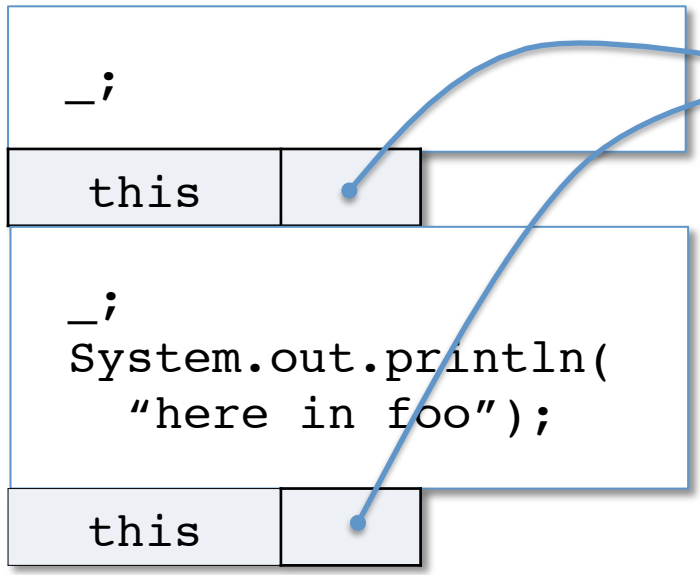
```
caught
```

Abstract Stack Machine

Workspace

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

Stack



Heap

Continue executing as usual.

Console

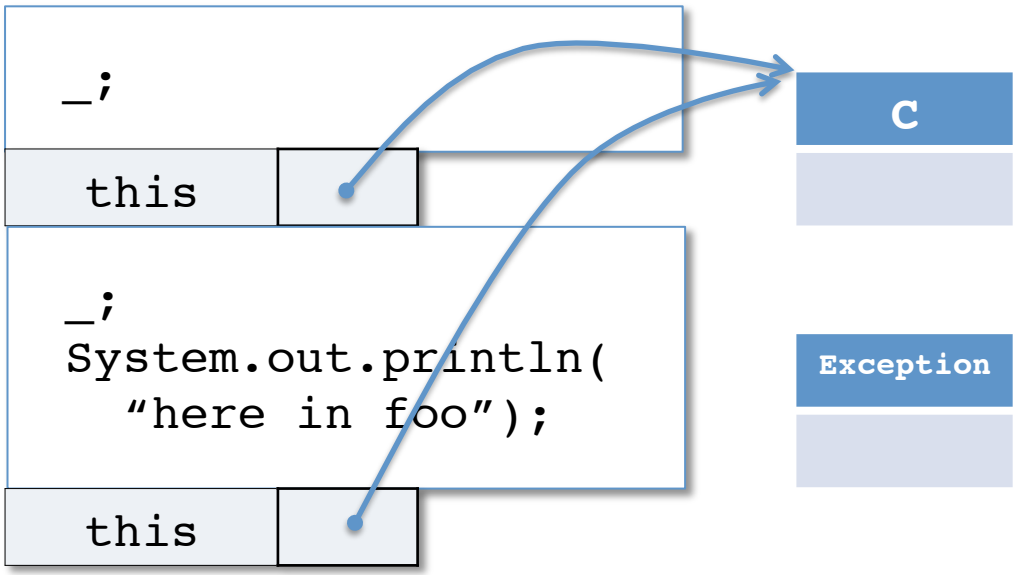
```
caught
```

Abstract Stack Machine

Workspace

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

Stack



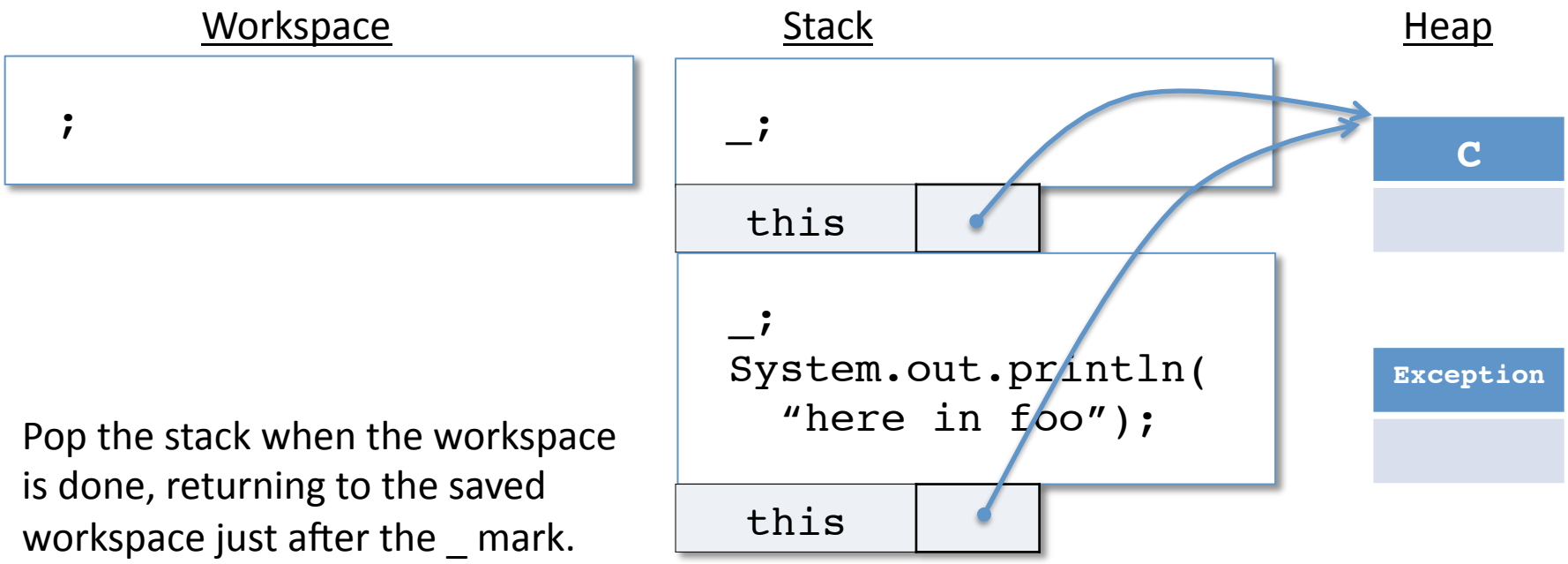
Heap

Continue executing as usual.

Console

```
caught
```

Abstract Stack Machine

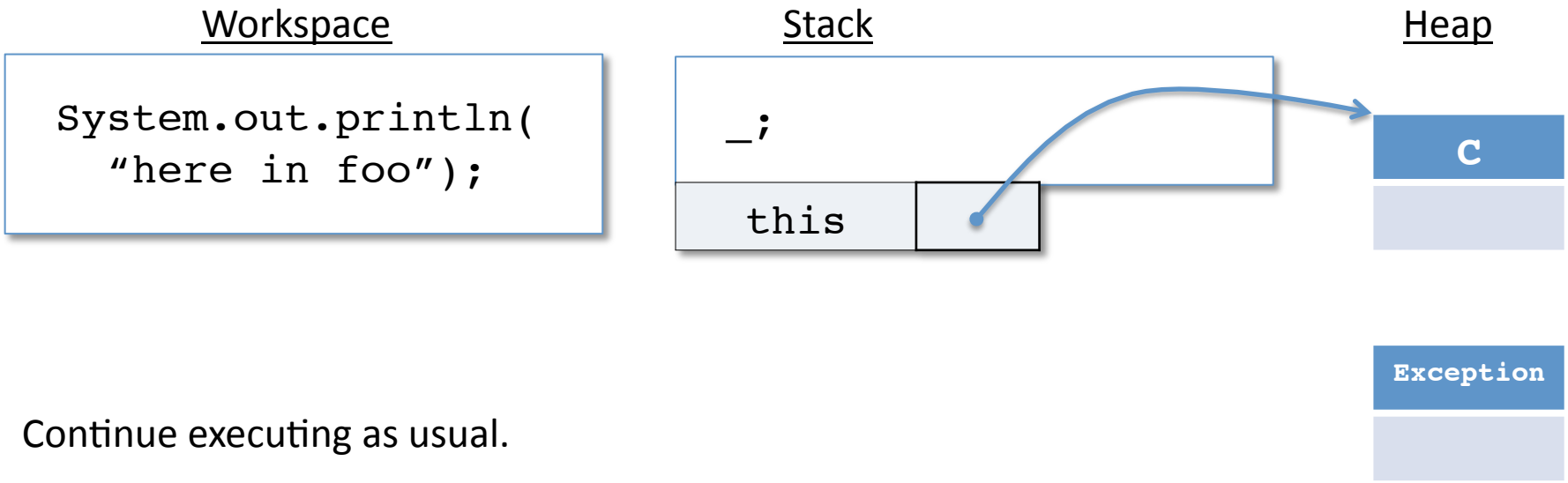


Pop the stack when the workspace is done, returning to the saved workspace just after the _ mark.

Console

```
caught
here in bar
```

Abstract Stack Machine

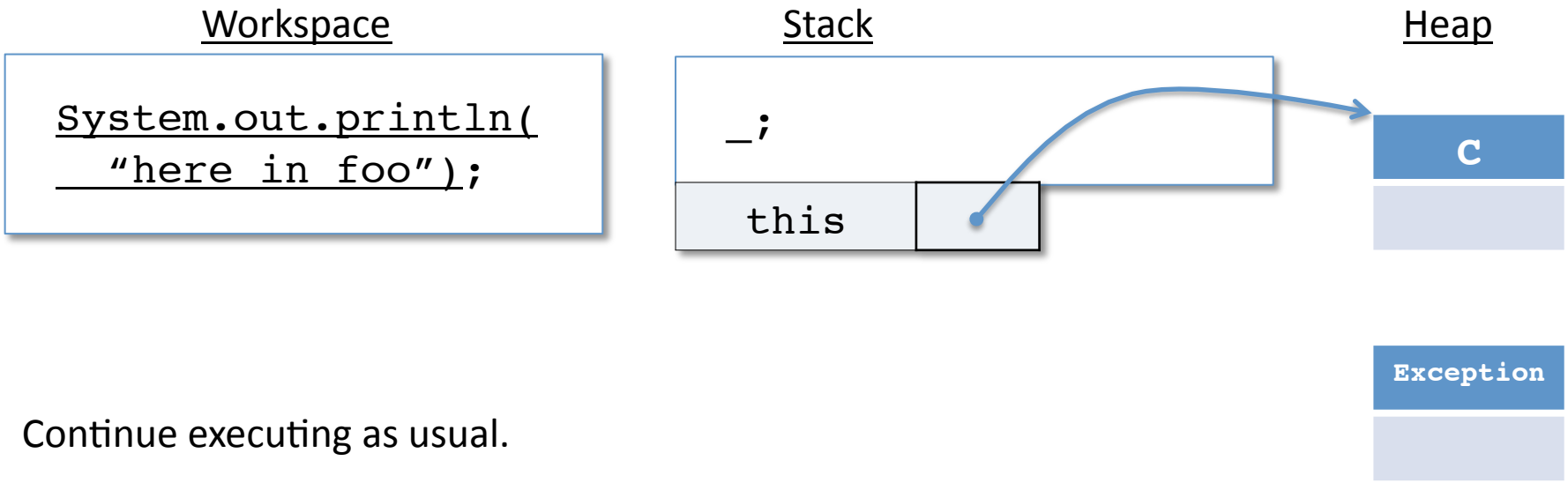


Continue executing as usual.

Console

```
caught
here in bar
```

Abstract Stack Machine

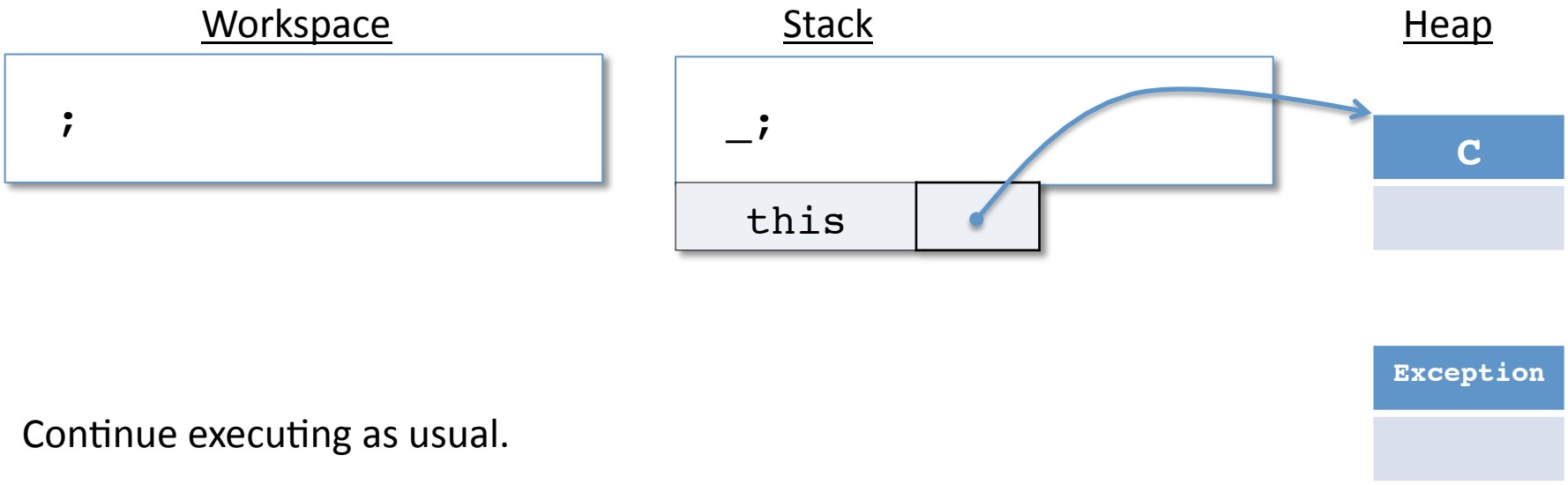


Continue executing as usual.

Console

```
caught
here in bar
```

Abstract Stack Machine



Continue executing as usual.

Console

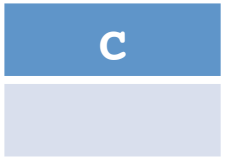
```
caught
here in bar
here in foo
```

Abstract Stack Machine

Workspace

Stack

Heap



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

Workspace

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

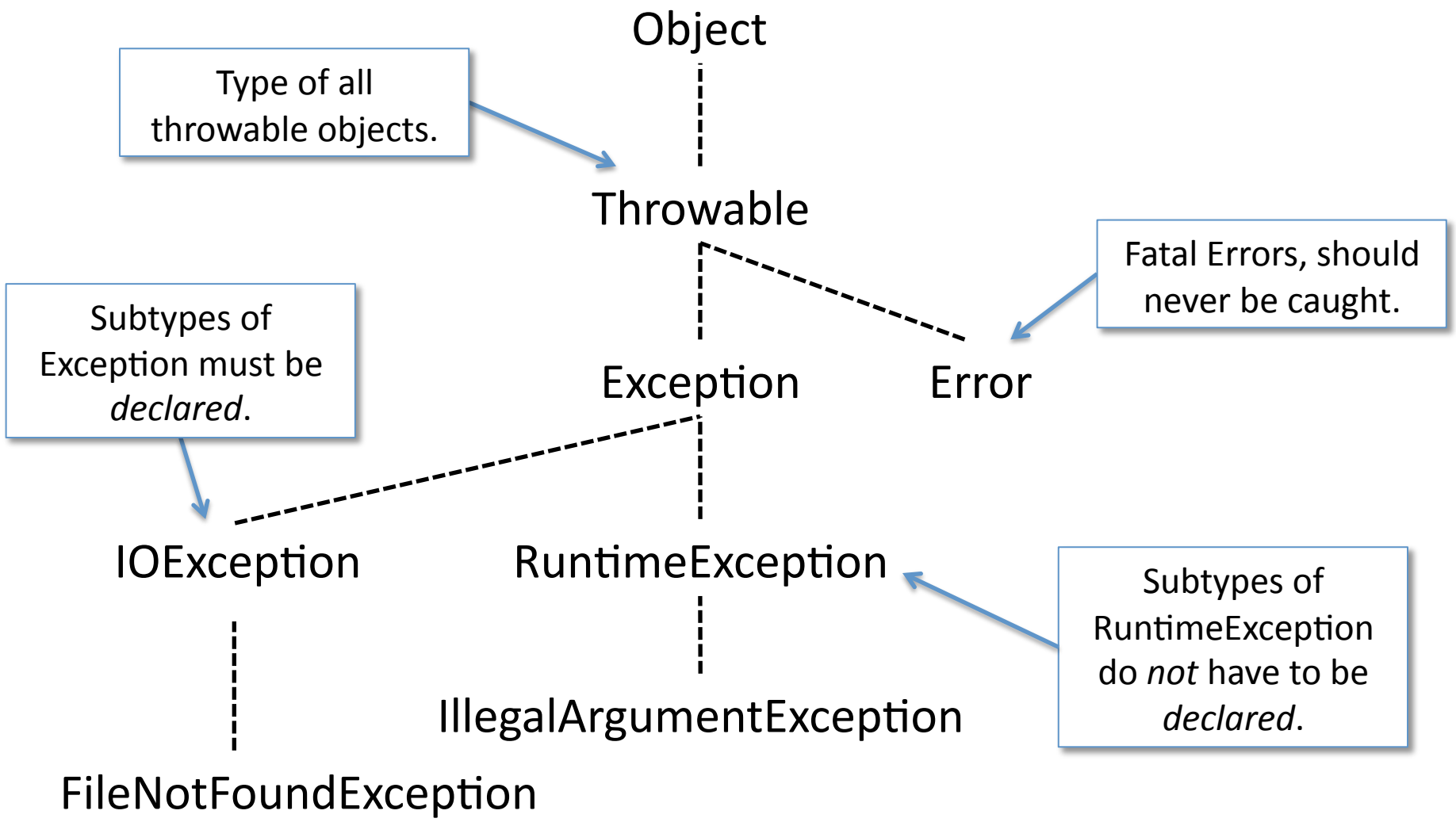
Catching Exceptions

- There can be more than one "catch" clause associated with each "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!

Exception Class Hierarchy



Checked (Declared) Exceptions

- Exceptions that are subtypes of Exception but not RuntimeException are called *checked* or *declared*.
- A method that might throw a checked exception must declare it using a "throws" clause in the method type.
- The method might raise a checked exception, either by:
  - directly throwing such an exception

```
public void maybeDoIt (String file) throws AnException {
    if (…) throw new AnException();  // directly throw
    …
```

  - or, calling another method that might itself throw a checked exception

```
public void doSomeIO (String file) throws IOException {
    Reader r = new FileReader(file);  // might throw
    …
```

Unchecked (Undeclared) Exceptions

- Subclasses of RuntimeException *do not* need to be declared via "throws"
  - even if the method does not explicitly handle them.
- Many "pervasive" types of errors cause RuntimeExceptions
  - NullPointerException
  - IndexOutOfBoundsException
  - IllegalArgumentException

```
public void mightFail (String file) {
    if (file.equals("dictionary.txt") {
        // file could be null!
    …
```

- The original intent was that such exceptions represent disastrous conditions from which it was impossible to sensibly recover…

Declared vs. Undeclared?

- Tradeoffs in the software design process:
- Declared = better documentation
  - forces callers to acknowledge that the exception exists
- Undeclared = fewer static guarantees
  - but, much easier to refactor code
- In practice: test-driven development encourages "fail early/fail often" model of code design and lots of code refactoring, so "undeclared" exceptions are prevalent.

- A good compromise?
  - Declared exceptions for libraries, where the documentation and usage enforcement are critical
  - Undeclared for client-exceptions to facilitate more flexible code

Good Style for Exceptions

- In Java, exceptions should be used to capture *exceptional* circumstances
  - Try/catch/throw incur performance costs and complicate reasoning about the program, don't use them when better solutions exist
- Re-use existing exception types when they are meaningful to the situation
  - e.g. use NoSuchElementException when implementing a container
- Define your own subclasses of Exception when doing so can convey useful information to possible callers that can handle the exception.
- It is often sensible to catch one exception and re-throw a different (more meaningful) kind of exception.
  - e.g. when implementing WordScanner, we caught IOException and threw NoSuchElementException in the next() method.
- Catch exceptions as near to the source of failure as makes sense
  - i.e. where you have the information to deal with the exception
- Catch exceptions with as much precision as you can
  - i.e. Don't do: try {…} catch (Exception e) {…}
    instead do: try {…} catch (IOException e) {…}

Finally

- A "finally" clause of a try/catch/finally statement *always* gets run, regardless of whether there is no exception, a propagated exception, a caught exception, or even if the method returns from inside the try.
- "Finally" is most often used for releasing resources that might have been held/created by the "try" block:

```
public void doSomeIO (String file) {
  FileReader r = null;
  try {
    r = new FileReader(file);
    … // do some IO
  } catch (FileNotFoundException e) {
    … // handle the absent file
  } catch (IOException e) {
    … // handle other IO problems
  } finally {
    if (r != null) {    // don't forget null check!
      try { r.close(); } catch (IOException e) {…}
    }
  }
}
```