Chapter 1

Handling exceptions

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All applications have to deal with exceptional situations. Arithmetic errors may occur (such as division by zero), unexpected situations may arise (file not found), or resources may be exhausted (network down, disk full, etc.). The old-fashioned solution is to have operations that fail return a special *error code*; this means that client code must check the return value of each operation, and take special action to handle errors. This leads to brittle code.

With the help of a series of examples, we shall explore all of these possibilities, and we shall also take a deep look into the internal mechanics of exceptions and exception handlers.

1.1 Introduction

Modern programming languages, including Smalltalk offer a dedicated exception-handling mechanism that greatly simplifies the way in which exceptional situations are signaled and handled. Before the development of the ANSI Smalltalk standard in 1996, several exception handling mechanisms existed, largely incompatible with each other. Pharo's exception handling follows the ANSI standard, with some embellishments; we present it in this chapter from a user perspective.

The basic idea behind exception handling is that client code does not clutter the main logic flow with checks for error codes, but specifies instead an *exception handler* to "catch" exceptions. When something goes wrong, instead of returning an error code, the method that detects the exceptional situation interrupts the main flow of execution by *signaling* an exception. This does two things: it captures essential information about the context in which the exception occurred, and transfers control to the exception handler, written by the client, which decides what to do about it. The "essential information about the context" is saved in an Exception object; various classes of Exception are specified to cover the varied exceptional situations that may arise.

Pharo's exception-handling mechanism is particularly expressive and flexible, covering a wide range of possibilities. Exception handlers can be used to *ensure* that certain actions take place even if something goes wrong, or to take action only if something goes wrong. Like everything in Smalltalk, exceptions are objects, and respond to a variety of messages. When an exception is caught by a handler, there are many possible responses: the handler can specify an alternative action to perform; it can ask the exception object to *resume* the interrupted operation; it can *retry* the operation; it can *pass* the exception to another handler; or it can *reraise* a completely different exception.

1.2 Ensuring execution

The ensure: message can be sent to a block to make sure that, even if the block fails (*e.g.*, raises an exception) the argument block will still be executed:

```
anyBlock ensure: ensuredBlock    "ensuredBlock will run even if anyBlock fails"
```

Consider the following example, which creates an image file from a screenshot taken by the user:

```
| writer |
writer := GIFReadWriter on: (FileStream newFileNamed: 'Pharo.gif').
[ writer nextPutImage: (Form fromUser) ]
   ensure: [ writer close ]
```

This code ensures that the writer file handle will be closed, even if an error occurs in Form fromUser or while writing to the file.

Here is how it works in more detail. The nextPutImage: method of the class GIFReadWriter converts a form (*i.e.*, an instance of the class Form, representing a bitmap image) into a GIF image. This method writes into a stream which has been opened on a file. The nextPutImage: method does not close the stream it is writing to, therefore we should be sure to close the stream even if a problem arises while writing. This is achieved by sending the message ensure: to the block that does the writing. In case nextPutImage: fails, control will flow into the block passed to ensure:. If it does *not* fail, the ensured block will still be executed. So, in either case, we can be sure that writer is closed.

Here is another use of ensure:, in class Cursor:

```
Cursor»showWhile: aBlock
  "While evaluating the argument, aBlock,
  make the receiver be the cursor shape."
  | oldcursor |
  oldcursor := Sensor currentCursor.
  self show.
  ^aBlock ensure: [ oldcursor show ]
```

The argument [oldcursor show] is evaluated whether or not aBlock signals an exception. Note that the result of ensure: is the value of the receiver, not that of the argument.

```
[ 1 ] ensure: [ 0 ]    ⟶    1    "not 0"
```

1.3 Handling non-local returns

The message ifCurtailed: is typically used for "cleaning" actions. It is similar to ensure:, but instead of ensuring that its argument block is evaluated even if the receiver terminates abnormally, ifCurtailed: does so *only* if the receiver fails or returns.

In the following example, the receiver of ifCurtailed: performs an early return, so the following statement is never reached. In Smalltalk, this is referred to as a *non-local return*. Nevertheless the argument block will be executed.

```
[^ 10] ifCurtailed: [Transcript show: 'We see this'].
Transcript show: 'But not this'.
```

In the following example, we can see clearly that the argument to ifCurtailed: is evaluated only when the receiver terminates abnormally.

```
[Error signal] ifCurtailed: [Transcript show: 'Abandoned'; cr].
Transcript show: 'Proceeded'; cr.
```

Open a transcript and evaluate the code above in a workspace. When the pre-debugger windows opens, first try selecting Proceed *and then* Abandon. *Note that the argument to* ifCurtailed: *is evaluated only when the receiver terminates abnormally. What happens when you select* Debug*?*

Here are some examples of ifCurtailed: usage: the text of the Transcript show: describes the situation:

```
[^ 10] ifCurtailed: [Transcript show: 'This is displayed'; cr]

[10] ifCurtailed: [Transcript show: 'This is not displayed'; cr]

[1 / 0] ifCurtailed: [Transcript show: 'This is displayed after selecting Abandon in the
      debugger'; cr]
```

Although in Pharo ifCurtailed: and ensure: are implemented using a a marker primitive (described at the end of the chapter), in principle ifCurtailed: could be implemented using ensure: as follows:

```
ifCurtailed: curtailBlock
   | result curtailed |
   curtailed := true.
   [   result := self value.
      curtailed := false ] ensure: [ curtailed ifTrue: [ curtailBlock value ] ].
   ^ result
```

In a similar fashion, ensure: could be implemented using ifCurtailed: as follows:

```
ensure: ensureBlock
   | result |
   result := self ifCurtailed: ensureBlock.
   "If we reach this point, then the receiver has not been curtailed,
   so ensureBlock still needs to be evaluated"
   ensureBlock value.
   ^ result
```

Both ensure: and ifCurtailed: are very useful for making sure that important "cleanup" code is executed, but are not by themselves sufficient for handling all exceptional situations. Now let's look at a more general mechanism for handling exceptions.

1.4 Exception handlers

The general mechanism is provided by the message on:do:. It looks like this:

```
aBlock on: exceptionClass do: handlerAction
```

aBlock is the code that detects an abnormal situation and signals an exception; it is called the *protected block*. *handlerAction* is the block that is evaluated if an exception is signaled; it is called the *exception handler*. exceptionClass defines the class of exceptions that handlerAction will be asked to handle.

The message on:do: returns the value of the receiver (the protected block) and when an error occurs it returns the value of the handlerAction block as illustrated by the following expressions:

```
[1+2] on: ZeroDivide do: [:exception | 33]
  ⟶   3

[1/0] on: ZeroDivide do: [:exception | 33]
  ⟶   33

[1+2. 1+ 'kjhjkhjk'] on: ZeroDivide do: [:exception | 33]
  ⟶   raise another Error
```

The beauty of this mechanism lies in the fact that the protected block can be written in a straightforward way, *without regard to any possible errors*. A single exception handler is responsible for taking care of anything that may go wrong.

Consider the following example, where we want to copy the contents of one file to another. Although several file-related things could go wrong, with exception handling we simply write a straight-line method, and define a single exception handler for the whole transaction:

```
| source destination fromStream toStream |
source := 'log.txt'.
destination := 'log−backup.txt'.
[ fromStream := FileStream oldFileNamed: (FileSystem workingDirectory / source).
   [ toStream := FileStream newFileNamed: (FileSystem workingDirectory / destination).
      [ toStream nextPutAll: fromStream contents ]
         ensure: [ toStream close ] ]
      ensure: [ fromStream close ] ]
   on: FileStreamException
   do: [ :ex | UIManager default inform: 'Copy failed −− ', ex description ].
```

If any exception concerning FileStreams is raised, the handler block (the block after do:) is executed with the exception object as its argument. Our handler code alerts the user that the copy has failed, and delegates to the exception object ex the task of providing details about the error. Note the two nested uses of ensure: to make sure that the two file streams are closed, whether or not an exception occurs.

It is important to understand that the block that is the receiver of the message on:do: defines the scope of the exception handler. This handler will be used only if the receiver (*i.e.*, the protected block) has not completed. Once completed, the exception handler will not be used. Moreover, a handler is associated exclusively with the kind of exception specified as the first argument to on:do:. Thus, in the previous example, only a FileStreamException (or a more specific variant thereof) can be handled.

A Buggy Solution. Study the following code and see why it is wrong.

```
| source destination fromStream toStream |
source := 'log.txt'.
destination := 'log−backup.txt'.
   [ fromStream := FileStream oldFileNamed: (FileSystem workingDirectory / source).
   toStream := FileStream newFileNamed: (FileSystem workingDirectory / destination).
   toStream nextPutAll: fromStream contents ]
      on: FileStreamException
      do: [ :ex | UIManager default inform: 'Copy failed −− ', ex description ].
   fromStream ifNotNil: [fromStream close].
   toStream ifNotNil: [toStream close].
```

If any other exception than FileStreamException happens the files are not properly closed.

1.5 Error codes — don't do this!

Without exceptions, one (bad) way to handle a method that may fail to produce an expected result is to introduce explicit error codes as possible return values. In fact, in languages like C, code is littered with checks for such error codes, which often obscure the main application logic. Error codes are also fragile in the face of evolution: if new error codes are added, then all clients must be adapted to take the new codes into account. By using exceptions instead of error codes, the programmer is freed from the task of explicitly checking each return value, and the program logic stays uncluttered. Moreover, because exceptions are classes, as new exceptional situations are discovered, they can be subclassed; old clients will still work, although they may provide less-specific exception handling than newer clients.

If Smalltalk did not provide exception-handling support, then the tiny example we saw in the previous section would be written something like this, using error codes:

```
"Pseudo−code −− luckily Smalltalk does not work like this. Without the
benefit of exception handling we must check error codes for each operation."
source := 'log.txt'.
destination := 'log−backup.txt'.
success := 1. "define two constants, our error codes"
failure := 0.
fromStream := FileStream oldFileNamed: (FileSystem workingDirectory / source).
fromStream ifNil: [
   UIManager default inform: 'Copy failed −− could not open', source.
   ^ failure "terminate this block with error code" ].
toStream := FileStream newFileNamed: (FileSystem workingDirectory / destination).
toStream ifNil: [
   fromStream close.
```

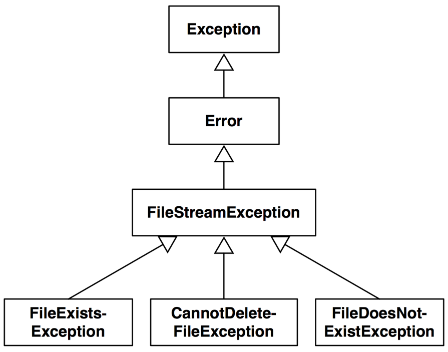


Figure 1.1: A small part of the Pharo exception hierarchy.

```
    UIManager default inform: 'Copy failed -- could not open', destination.
    ^ failure ].
contents := fromStream contents.
contents ifNil: [
    fromStream close.
    toStream close.
    UIManager default inform: 'Copy failed -- source file has no contents'.
    ^ failure ].
result := toStream nextPutAll: contents.
result ifFalse: [
    fromStream close.
    toStream close.
    UIManager default inform: 'Copy failed -- could not write to ', destination.
    ^ failure ].
fromStream close.
toStream close.
^ success.
```

What a mess! Without exception handling, we must explicitly check the result of each operation before proceeding to the next. Not only must we check error codes at each point that something might go wrong, but we must also be prepared to cleanup any operations performed up to that point and abort the rest of the code.

1.6 Specifying which exceptions will be handled

In Smalltalk, exceptions are, of course, objects. In Pharo, an exception is an instance of an exception class which is part of a hierarchy of exception classes. For example, because the exceptions FileDoesNotExistException, FileExistsException and CannotDeleteFileException are special kinds of FileStreamException, they are represented as subclasses of FileStreamException, as shown in Figure 1.1. This notion of "specialization" lets us associate an exception handler with a more or less general exceptional situation. So, we can write different expressions depending on the level of granularity we want:

```
[ ... ] on: Error do: [ ... ]  or
[ ... ] on: FileStreamException do: [ ... ] or
[ ... ] on: FileDoesNotExistException do: [ ... ]
```

The class FileStreamException adds information to class Exception to characterize the specific abnormal situation it describes. Specifically, FileStreamException defines the fileName instance variable, which contains the name of the file that signaled the exception. The root of the exception class hierarchy is Exception, which is a direct subclass of Object.

Two key messages are involved in exception handling: on:do:, which, as we have already seen, is sent to blocks to set an exception handler, and signal, which is sent to subclasses of Exception to signal that an exception has occurred.

Catching sets of exceptions

So far we have always used on:do: to catch just a single class of exception. The handler will only be invoked if the exception signaled is a sub-instance of the specified exception class. However, we can imagine situations where we might like to catch multiple classes of exceptions. This is easy to do, just specify a list of classes separated by commas as shown in the following example.

```
result := [ Warning signal . 1/0 ]
   on: Warning, ZeroDivide
   do: [:ex | ex resume: 1 ].
result    ⟶    1
```

If you are wondering how this works, just have a look at the implementation of Exception class»,

```
Exception class», anotherException
   "Create an exception set."
   ^ExceptionSet new add: self; add: anotherException; yourself
```

The rest of the magic occurs in the class ExceptionSet, which has a surprisingly trivial implementation.

```
Object subclass: #ExceptionSet
   instanceVariableNames: 'exceptions'
   classVariableNames: ''
```

```
    poolDictionaries: ''
    category: 'Exceptions-Kernel'

ExceptionSet»initialize
    super initialize.
    exceptions := OrderedCollection new

ExceptionSet», anException
    self add: anException.
    ^self

ExceptionSet»add: anException
    exceptions add: anException

ExceptionSet»handles: anException
    exceptions do: [:ex | (ex handles: anException) ifTrue: [^true]].
    ^false
```

The message handles: is also defines on a single exception and returns whether the receiver handles the exception.

1.7 Signaling an exception

To signal an exception[1], you only need to create an instance of the exception class, and to send it the message signal, or signal: with a textual description. The class Exception class provides a convenience method signal, which creates and signals an exception. So, here are two equivalent ways to signal a ZeroDivide exception:

```
    ZeroDivide new signal.
    ZeroDivide signal.    "class-side convenience method does the same as above"
```

You may wonder why it is necessary to create an instance of an exception in order to signal it, rather than having the exception class itself take on this responsibility. Creating an instance is important because it encapsulates information about the context in which the exception was signaled. We can therefore have many exception instances, each describing the context of a different exception.

When an exception is signaled, the exception handling mechanism searches in the execution stack for an exception handler associated with the class of the signaled exception. When a handler is encountered (*i.e.*, the message on:do: is on the stack), the implementation checks that the exceptionClass

[1]Synonyms are to "raise" or to "throw" an exception. Since the vital message is called signal, we use that terminology exclusively in this chapter.

is a superclass of the signaled exception, and then executes the handlerAction with the exception as its sole argument. We will see shortly some of the ways in which the handler can use the exception object.

When signaling an exception, it is possible to provide information specific to the situation just encountered, as illustrated in the code below. For example, if the file to be opened does not exist, the name of the non-existent file can be recorded in the exception object:

```
StandardFileStream class»oldFileNamed: fileName
   "Open an existing file with the given name for reading and writing. If the name has no
      directory part, then default directory will be assumed. If the file does not exist, an
      exception will be signaled. If the file exists, its prior contents may be modified or
      replaced, but the file will not be truncated on close."
   | fullName |
   fullName := self fullName: fileName.
   ^(self isAFileNamed: fullName)
      ifTrue: [self new open: fullName forWrite: true]
      ifFalse: ["File does not exist..."
         (FileDoesNotExistException new fileName: fullName) signal]
```

The exception handler may make use of this information to recover from the abnormal situation. The argument ex in an exception handler [:ex | ...] will be an instance of FileDoesNotExistException or of one of its subclasses. Here the exception is queried for the filename of the missing file by sending it the message fileName.

```
| result |
result := [(StandardFileStream oldFileNamed: 'error42.log') contentsOfEntireFile]
   on: FileDoesNotExistException
   do: [:ex | ex fileName , ' not available'].
Transcript show: result; cr
```

Every exception has a default description that is used by the development tools to report exceptional situations in a clear and comprehensible manner. To make the description available, all exception objects respond to the message description. Moreover, the default description can be changed by sending the message messageText: *aDescription*, or by signaling the exception using signal: *aDescription*.

Another example of signaling occurs in the doesNotUnderstand: mechanism, a pillar of the reflective capabilities of Smalltalk. Whenever an object is sent a message that it does not understand, the VM will (eventually) send it the message doesNotUnderstand: with an argument representing the offending message. The default implementation of doesNotUnderstand:, defined in class Object, simply signals a MessageNotUnderstood exception, causing a debugger to be opened at that point in the execution.

The doesNotUnderstand: method illustrates the way in which exception-specific information, such as the receiver and the message that is not understood, can be stored in the exception, and thus made available to the debugger.

```
Object»doesNotUnderstand: aMessage
  "Handle the fact that there was an attempt to send the given message to the receiver
    but the receiver does not understand this message (typically sent from the machine
     when a message is sent to the receiver and no method is defined for that selector).
    "
  MessageNotUnderstood new
    message: aMessage;
    receiver: self;
    signal.
  ^ aMessage sentTo: self.
```

That completes our description of how exceptions are used. The remainder of this chapter discusses how exceptions are implemented, and adds some details that are relevant only if you define your own exceptions.

1.8 Finding handlers

We will now take a look at how exception handlers are found and fetched from the execution stack when an exception is signaled. However, before we do this, we need to understand how the control flow of a program is internally represented in the virtual machine.

At each point in the execution of a program, the execution stack of the program is represented as a list of activation contexts. Each activation context represents a method invocation and contains all the information needed for its execution, namely its receiver, its arguments, and its local variables. It also contains a reference to the context that triggered its creation, *i.e.*, the activation context associated with the method execution that sent the message that created this context. In Pharo, the class MethodContext (whose superclass is ContextPart) models this information. The references between activation contexts link them into a chain: this chain of activation contexts *is* Smalltalk's execution stack.

Suppose that we attempt to open a FileStream on a non-existent file from a doIt. A FileDoesNotExistException will be signaled, and the execution stack will contain MethodContexts for doIt, oldFileNamed:, and signal, as shown in Figure 1.2.

Since everything is an object in Smalltalk, we would expect method contexts to be objects. However, some Smalltalk implementations use the native C execution stack of the virtual machine to avoid creating objects all the time. The current Pharo virtual machine does actually use full Smalltalk objects all

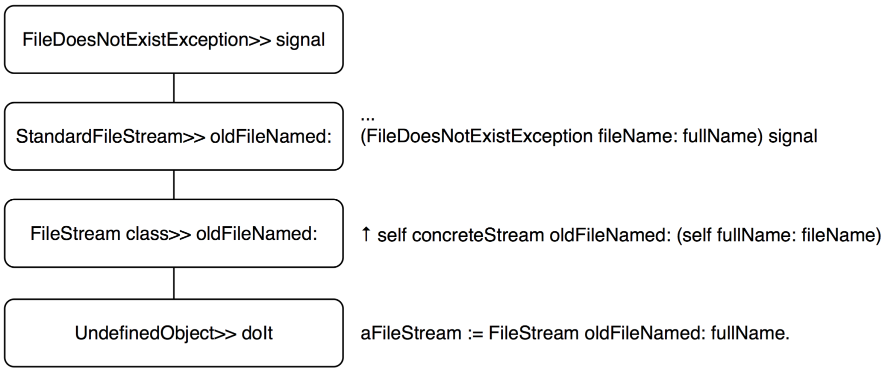

FileDoesNotExistException>> signal
StandardFileStream>> oldFileNamed:
...
(FileDoesNotExistException fileName: fullName) signal
FileStream class>> oldFileNamed:
↑ self concreteStream oldFileNamed: (self fullName: fileName)
UndefinedObject>> doIt
aFileStream := FileStream oldFileNamed: fullName.

Figure 1.2: A Pharo execution stack.

the time; for speed, it recycles old method context objects rather than creating a new one for each message-send.

When we send *aBlock* on: *ExceptionClass* do: *actionHandler*, we intend to associate an exception handler (*actionHandler*) with a given class of exceptions (*ExceptionClass*) for the activation context of the protected block *aBlock*. This information is used to identify and execute *actionHandler* whenever an exception of an appropriate class is signaled; *actionHandler* can be found by traversing the stack starting from the top (the most recent message-send) and working down to the context that sent the on:do: message.

If there is no exception handler on the stack, the message defaultAction will be sent either by ContextPart»handleSignal: or by UndefinedObject»handleSignal:. The latter is associated with the bottom of the stack, and is defined as follows:

```
UndefinedObject»handleSignal: exception
   "When no more handler (on:do:) context is left in the sender chain, this gets called.
      Return from signal with default action."
   ^ exception resumeUnchecked: exception defaultAction
```

The message handleSignal: is sent by Exception»signal.

When an exception E is signaled, the system identifies and fetches the corresponding exception handler by searching down the stack as follows:

1. Look in the current activation context for a handler, and test if that handler canHandleSignal: E.

2. If no handler is found and the stack is not empty, go down the stack and return to step 1.

3. If no handler is found and the stack is empty, then send defaultAction to

E. The default implementation in the Error class leads to the opening of a debugger.

4. If the handler is found, send to it value: E.

Nested Exceptions. Exception handlers are outside of their own scope. This means that if an exception is signaled from within an exception handler — what we call a nested exception — a *separate* handler must be set to catch the nested exception.

Here is an example where one on:do: message is the receiver of another one; the second will catch errors signaled by the handler of the first (remember that the result of on:do: is either the protected block value or the handler action block value):

```
result := [[ Error signal: 'error 1' ]
   on: Exception
   do: [ Error signal: 'error 2' ]]
      on: Exception
      do: [:ex | ex description ].
result    ⟶    'Error: error 2'
```

Without the second handler, the nested exception will not be caught, and the debugger will be invoked.

An alternative would be to specify the second handler within the first one:

```
result := [ Error signal: 'error 1' ]
   on: Exception
   do: [[ Error signal: 'error 2' ]
      on: Exception
      do: [:ex | ex description ]].
result    ⟶    'Error: error 2'
```

This is subtle point so try it and study it.

1.9 Handling exceptions

When an exception is signaled, the handler has several choices about how to handle it. In particular, it may:

(i) *abandon* the execution of the protected block, by simply specifying an alternative result – it is part of the protocol but not used since it is similar to return;

(ii) *return* an alternative result for the protected block, by sending return: *aValue* to the exception object;

(iii) *retry* the protected block, by sending retry, or try a different block by sending retryUsing:;

(iv) *resume* the protected block at the failure point, by sending resume or resume:;

(v) *pass* the caught exception to the enclosing handler, by sending pass; or

(vi) *resignal* a different exception, by sending resignalAs: to the exception.

We will briefly look at the first three possibilities, and then we will take a closer look at the remaining ones.

Abandon the protected block

The first possibility is to abandon the execution of the protected block, as follows:

```
answer := [ |result|
   result := 6 * 7.
   Error signal.
   result  "This part is never evaluated" ]
      on: Error
      do: [ :ex | 3 + 4 ].
answer    ⟶    7
```

The handler takes over from the point where the error is signaled, and any code following in the original block is not evaluated.

Return a value with return:

A block returns the value of the last statement in the block, regardless of whether the block is protected or not. However, there are some situations where the result needs to be returned by the handler block. The message return: *aValue* sent to an exception has the effect of returning *aValue* as the value of the protected block:

```
result := [Error signal]
   on: Error
   do: [ :ex | ex return: 3 + 4 ].
result    ⟶    7
```

The ANSI standard is not clear regarding the difference between using do: [:ex | 100] and do: [:ex | ex return: 100] to return a value. We suggest that you use return: since it is more intention-revealing, even if these two expressions are equivalent in Pharo.

A variant of return: is the message return, which returns nil.

Note that, in any case, control will *not* return to the protected block, but will be passed on up to the enclosing context.

```
6 * ([Error signal] on: Error do: [ :ex | ex return: 3 + 4 ])    ⟶    42
```

Retry a computation with retry and retryUsing:

Sometimes we may want to change the circumstances that led to the exception and retry the protected block. This is done by sending retry or retryUsing: to the exception object. It is important to be sure that the conditions that caused the exception have been changed before retrying the protected block, or else an infinite loop will result:

```
[Error signal] on: Error do: [:ex | ex retry]    "will loop endlessly"
```

Here is a better example. The protected block is re-evaluated within a modified environment where theMeaningOfLife is properly initialized:

```
result := [ theMeaningOfLife * 7 ]    "error −− theMeaningOfLife is nil"
   on: Error
   do: [:ex | theMeaningOfLife := 6. ex retry ].
result    ⟶    42
```

The message retryUsing: aNewBlock enables the protected block to be replaced by aNewBlock. This new block is executed and is protected with the same handler as the original block.

```
x := 0.
result := [ x/x ]    "fails for x=0"
   on: Error
   do: [:ex |
      x := x + 1.
      ex retryUsing: [1/((x−1)*(x−2))]    "fails for x=1 and x=2"
   ].
result    ⟶    (1/2)    "succeeds when x=3"
```

The following code loops endlessly:

```
[1 / 0] on: ArithmeticError do: [:ex | ex retryUsing: [ 1 / 0 ]]
```

whereas this will signal an Error:

```
[1 / 0] on: ArithmeticError do: [:ex | ex retryUsing: [ Error signal ]]
```

As another example, recall the file handling code we saw earlier, in which we printed a message to the Transcript when a file is not found. Instead, we could prompt for the file as follows:

```
[(StandardFileStream oldFileNamed: 'error42.log') contentsOfEntireFile]
   on: FileDoesNotExistException
   do: [:ex | ex retryUsing: [FileList modalFileSelector contentsOfEntireFile] ]
```

Resuming execution

A method that signals an exception that isResumable can be resumed at the place immediately following the signal. An exception handler may therefore perform some action, and then resume the execution flow. This behavior is achieved by sending resume: to the exception in the handler. The argument is the value to be used in place of the expression that signaled the exception. In the following example we signal and catch MyResumableTestError, which is defined in the Tests-Exceptions category:

```
result := [ | log |
   log := OrderedCollection new.
   log addLast: 1.
   log addLast: MyResumableTestError signal.
   log addLast: 2.
   log addLast: MyResumableTestError signal.
   log addLast: 3.
   log ]
      on: MyResumableTestError
      do: [ :ex |  ex resume: 0 ].
result    ⟶    an OrderedCollection(1 0 2 0 3)
```

Here we can clearly see that the value of MyResumableTestError signal is the value of the argument to the resume: message.

The message resume is equivalent to resume: nil.

The usefulness of resuming an exception is illustrated by the following functionality which loads. When installing packages, warnings may be signaled. Warnings should not be considered fatal errors, so we should simply ignore the warning and continue installing. The class PackageInstaller does not exist but here is a sketch of a possible implementation.

```
PackageInstaller»installQuietly: packageNameCollection
    ....
    [ self install ] on: Warning do: [ :ex | ex resume ].
```

Another situation where resumption is useful is when you want to ask the user what to do. For example, suppose that we were to define a class ResumableLoader with the following method:

```
ResumableLoader»readOptionsFrom: aStream
   | option |
   [aStream atEnd]
      whileFalse: [option := self parseOption: aStream.
         "nil if invalid"
         option isNil
            ifTrue: [InvalidOption signal]
            ifFalse: [self addOption: option]].
```

If an invalid option is encountered, we signal an InvalidOption exception. The context that sends readOptionsFrom: can set up a suitable handler:

```
ResumableLoader»readConfiguration
   | stream |
   stream := self optionStream.
   [self readOptionsFrom: stream]
      on: InvalidOption
      do: [:ex | (UIManager default confirm: 'Invalid option line. Continue loading?')
            ifTrue: [ex resume]
            ifFalse: [ex return]].
   stream close
```

Note that to be sure to close the stream, the stream close should guarded by an ensure: invocation.

Depending on user input, the handler in readConfiguration might return nil, or it might resume the exception, causing the signal message send in readOptionsFrom: to return and the parsing of the options stream to continue.

Note that InvalidOption must be resumable; it suffices to define it as a subclass of Exception.

You can have a look at the senders of resume: to see how it can be used.

Passing exceptions on

To illustrate the remaining possibilities for handling exceptions such as passing an exception, we will look at how to implement a generalization of the perform: method. If we send perform: *aSymbol* to an object, this will cause the message named *aSymbol* to be sent to that object:

```
5 perform: #factorial    ⟶    120    "same as: 5 factorial"
```

Several variants of this method exist. For example:

```
1 perform: #+ withArguments: #(2)    ⟶    3    "same as: 1 + 2"
```

These perform:-like methods are very useful for accessing an interface dynamically, since the messages to be sent can be determined at run-time. One message that is missing is one that sends a cascade of unary messages to a given receiver. A simple and naive implementation is:

```
Object»performAll: selectorCollection
   selectorCollection do: [:each | self perform: each]    "aborts on first error"
```

This method could be used as follows:

```
Morph new performAll: #( #activate #beTransparent #beUnsticky)
```

However, there is a complication. There might be a selector in the collection that the object does not understand (such as #activate). We would like to ignore such selectors and continue sending the remaining messages. The following implementation seems to be reasonable:

```
Object»performAll: selectorCollection
   selectorCollection do: [:each |
      [self perform: each]
         on: MessageNotUnderstood
         do: [:ex | ex return]]    "also ignores internal errors"
```

On closer examination we notice another problem. This handler will not only catch and ignore messages not understood by the original receiver, but also any messages sent but not understood in methods for messages that *are* understood! This will hide programming errors in those methods, which is not our intent. To address this, we need our handler to analyze the exception to see if it was indeed caused by the attempt to perform the current selector. Here is the correct implementation.

Method 1.1: *Object»performAll:*

```
Object»performAll: selectorCollection
   selectorCollection do: [:each |
      [self perform: each]
         on: MessageNotUnderstood
         do: [:ex | (ex receiver == self and: [ex message selector == each])
            ifTrue: [ex return]
            ifFalse: [ex pass]]]    "pass internal errors on"
```

This has the effect of passing on MessageNotUnderstood errors to the surrounding context when they are not part of the list of messages we are performing. The pass message will pass the exception to the next applicable handler in the execution stack.

If there is no next handler on the stack, the defaultAction message is sent to the exception instance. The pass action does not modify the sender chain in any way — but the handler that control is passed to may do so. Like the other messages discussed in this section, pass is special — it never returns to the sender.

The goal of this section has been to demonstrate the power of exceptions. It should be clear that while you can do almost anything with exceptions, the code that results is not always easy to understand. There is often a simpler way to get the same effect without exceptions; see method 1.2 on page 37 for a better way to implement performAll:.

Resending exceptions

Now suppose that in our performAll: example we no longer want to ignore selectors not understood by the receiver, but instead we want to consider an occurrence of such a selector as an error. However, we want it to be signaled as an application-specific exception, let's say InvalidAction, rather than the generic MessageNotUnderstood. In other words, we want the ability to "resignal" a signaled exception as a different one.

It might seem that the solution would simply be to signal the new exception in the handler block. The handler block in our implementation of performAll: would be:

```
[:ex | (ex receiver == self and: [ex message selector == each])
   ifTrue: [InvalidAction signal]    "signals from the wrong context"
   ifFalse: [ex pass]]
```

A closer look reveals a subtle problem with this solution, however. Our original intent was to replace the occurrence of MessageNotUnderstood with InvalidAction. This replacement should have the same effect as if InvalidAction were signaled at the same place in the program as the original MessageNotUnderstood exception. Our solution signals InvalidAction in a different location. The difference in locations may well lead to a difference in the applicable handlers.

To solve this problem, resignaling an exception is a special action handled by the system. For this purpose, the system provides the message resignalAs:. The correct implementation of a handler block in our performAll: example would be:

```
[:ex |  (ex receiver == self and: [ex message selector == each])
   ifTrue: [ex resignalAs: InvalidAction]    "resignals from original context"
   ifFalse: [ex pass]]
```

1.10 Comparing outer with pass

The ANSI protocol also specifies the outer behavior. The method outer is very similar to pass. Sending outer to an exception also evaluates the enclosing handler action. The only difference is that if the outer handler resumes the exception, then control will be returned to the point where outer was sent, not the original point where the exception was signaled:

```
passResume := [[ Warning signal . 1 ]    "resume to here"
   on: Warning
   do: [ :ex | ex pass . 2 ]]
      on: Warning
      do: [ :ex | ex resume ].
passResume    ⟶    1    "resumes to original signal point"
```

```
outerResume := [[ Warning signal . 1 ]
   on: Warning
   do: [ :ex | ex outer . 2 ]]    "resume to here"
      on: Warning
      do: [ :ex | ex resume ].
outerResume    ⟶    2    "resumes to where outer was sent"
```

1.11 Exceptions and ensure:/ifCurtailed: interaction

Now that we saw how exceptions work, we present the interplay between exceptions and the ensure: and ifCurtailed: semantics. Exception handlers are executed then ensure: or ifCurtailed: blocks are executed. ensure: argument is always executed while ifCurtailed: argument is only executed when its receiver execution led to a stack got unwind.

The following example shows such behavior. It prints: should show first error followed by then should show curtailed and returns 4.

```
[[ 1/0 ]
   ifCurtailed: [ Transcript show: 'then should show curtailed'; cr. 6 ]]
   on: Error do: [ :e |
      Transcript show: 'should show first error'; cr.
      e return: 4 ].
```

First the [1/0] raises a division by zero error. This error is handled by the exception handler. It prints the first message. Then it returns the value 4 and since the receiver raised an error, the argument of the ifCurtailed: message is evaluated: it prints the second message. Note that ifCurtailed: does not change the return value expressed by the error handler or the ifCurtailed: argument.

The following expression shows that when the stack is not unwound the expression value is simply returned and none of the handlers is executed. 1 is returned.

```
[[ 1 ]
      ifCurtailed: [ Transcript show: 'curtailed'; cr. 6 "does not display it" ]]
   on: Error do: [ :e |
      Transcript show: 'error'; cr.  "does not display it"
      e return: 4 ].
```

ifCurtailed: is a watchdog that reacts to stack abnormal behavior. For example, if we add a return statement in the receiver of the previous expression, the argument of the ifCurtailed: message is raised. Indeed the return statement is invalid since it is not defined in a method.

```
[[ ^ 1 ]
        ifCurtailed: [ Transcript show: 'only shows curtailed'; cr. ]]
    on: Error do: [ :e |
        Transcript show: 'error 2'; cr. "does not display it"
        e return: 4 ].
```

The following example shows that ensure: is executed systematically, even when no error is raised. Here the message should show ensure is displayed and 1 is returned as a value.

```
[[ 1 ]
        ensure: [ Transcript show: 'should show ensure'; cr. 6 ]]
    on: Error do: [ :e |
        Transcript show: 'error'; cr. "does not display it"
        e return: 4 ].
```

The following expression shows that as previously when an error occurs the handler associated with the error is executed before the ensure: argument. Here the expression prints should show error first, then then should show ensure and it returns 4.

```
[[ 1/0 ]
        ensure: [ Transcript show: 'then should show ensure'; cr. 6 ]]
    on: Error do: [ :e |
        Transcript show: 'should show error first'; cr.
        e return: 4 ].
```

Finally the last expression shows that errors are executed one by one from the closest to the farthest from the error, then the ensure: argument. Here error1, then error2, and then then should show ensure are displayed.

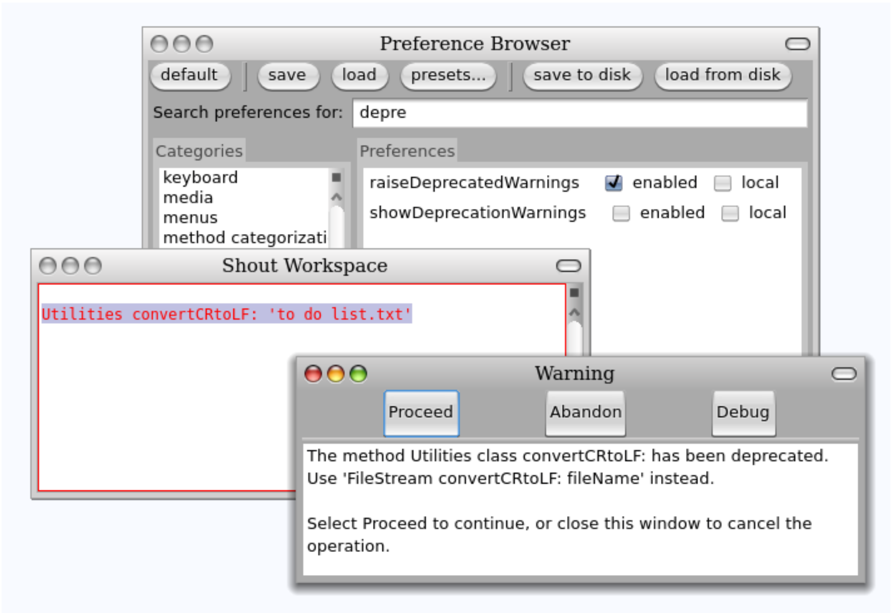
```
[[[ 1/0 ] ensure: [ Transcript show: 'then should show ensure'; cr. 6 ]]
    on: Error do: [ :e|
            Transcript show: 'error 1'; cr.
            e pass ]] on: Error do: [ :e |
                Transcript show: 'error 2'; cr. e return: 4 ].
```

1.12 Example: Deprecation

Deprecation offers a case study of a mechanism built using resumable exceptions. Deprecation is a software re-engineering pattern that allows us to mark a method as being “deprecated”, meaning that it may disappear in a future release and should not be used by new code. In Pharo, a method can be marked as deprecated as follows:

```
Utilities class»convertCRtoLF: fileName
   "Convert the given file to LF line endings. Put the result in a file with the extention '.lf'"

   self deprecated: 'Use ''FileStream convertCRtoLF: fileName'' instead.'
      on: '10 July 2009' in: #Pharo1.0 .
   FileStream convertCRtoLF: fileName
```

When the message convertCRtoLF: is sent, if the setting raiseWarning is true, then a pop-up window is displayed with a notification and the programmer may resume the application execution; this is shown in Figure 1.3 (Settings are explained in details in Chapter **??**). Of course, since this method is deprecated you will not find it in current Pharo distributions. Look for another sender of deprecated:on:in:.



Search preferences for: depre

raiseDeprecatedWarnings ✓ enabled ☐ local
showDeprecationWarnings ☐ enabled ☐ local

```
Utilities convertCRtoLF: 'to do list.txt'
```

The method Utilities class convertCRtoLF: has been deprecated.
Use 'FileStream convertCRtoLF: fileName' instead.

Select Proceed to continue, or close this window to cancel the operation.

Figure 1.3: Sending a deprecated message.

Deprecation is implemented in Pharo in just a few steps. First, we define Deprecation as a subclass of Warning. It should have some instance variables to contain information about the deprecation: in Pharo these are methodReference, explanationString, deprecationDate and versionString; we therefore need to define an instance-side initialization method for these variables, and a class-side instance creation method that sends the corresponding message.

When we define a new exception class, we should consider overriding isResumable, description, and defaultAction. In this case the inherited implementations of the first two methods are fine:

- isResumable is inherited from Exception, and answers true;
- description is inherited from Exception, and answers an adequate textual description.

However, it is necessary to override the implementation of defaultAction, because we want that to depend on some settings. Here is Pharo's implementation:

```
Deprecation»defaultAction
   Log ifNotNil: [:log| log add: self].
   self showWarning  ifTrue:
      [Transcript nextPutAll: self messageText; cr; flush].
   self raiseWarning ifTrue:
      [super defaultAction]
```

The first preference simply causes a warning message to be written on the Transcript. The second preference asks for an exception to be signaled, which is accomplished by super-sending defaultAction.

We also need to implement some convenience methods in Object, like this one:

```
Object»deprecated: anExplanationString on: date in: version
   (Deprecation
      method: thisContext sender method
      explanation: anExplanationString
      on: date
      in: version) signal
```

1.13 Example: Halt implementation

As we discussed in the Debugger chapter of *Pharo By Example*, the usual way of setting a breakpoint within a Smalltalk method is to insert the message-send self halt into the code. The method halt, implemented in Object, uses exceptions to open a debugger at the location of the breakpoint; it is defined as follows:

```
Object»halt
   "This is the typical message to use for inserting breakpoints during
   debugging. It behaves like halt:, but does not call on halt: in order to
   avoid putting this message on the stack. Halt is especially useful when
   the breakpoint message is an arbitrary one."
   Halt signal
```

Halt is a direct subclass of Exception. A Halt exception is *resumable*, which means that it is possible to continue execution after a Halt is signaled.

Halt overrides the defaultAction method, which specifies the action to perform if the exception is not caught (*i.e.*, there is no exception handler for Halt anywhere on the execution stack):

```
Halt»defaultAction
   "No one has handled this error, but now give them a chance to decide
   how to debug it.  If no one handles this then open debugger
   (see UnhandedError−defaultAction)"
   UnhandledError signalForException: self
```

This code signals a new exception, UnhandledError, that conveys the idea that no handler is present. The defaultAction of UnhandledError is to open a debugger:

```
UnhandledError»defaultAction
   "The current computation is terminated. The cause of the error should be logged or
      reported to the user. If the program is operating in an interactive debugging
      environment the computation should be suspended and the debugger activated."
   ^ UIManager default unhandledErrorDefaultAction: self exception
```

```
MorphicUIManager»unhandledErrorDefaultAction: anException
   ^ Smalltalk tools debugError: anException.
```

A few messages later, the debugger opens:

```
Process»debug: context title: title full: bool
   ^ Smalltalk tools debugger
               openOn: self
               context: context
               label: title
               contents: nil
               fullView: bool.
```

1.14 Exceptions implementation

Up to now, we have presented the use of exceptions without really explaining deeply how there are implemented at the Virtual Machine level. Note that since you do not need to know how exceptions are implemented to use them, you can simply skip this section in a first reading. Now if you are curious and really want to know how this is implemented at the Virtual Machine level, this section is for you. The mechanism is quite simple, making it worth to know how it operates. Let's have a look at how exceptions are implemented at the Virtual Machine level and use stack execution elements to store their information.

Storing Handlers. First we need to understand how the exception class and its associated handler are stored and how this information is found at run-time. Let's look at the definition of the central method on:do: defined on the class BlockClosure.

```
BlockClosure»on: exception do: handlerAction
   "Evaluate the receiver in the scope of an exception handler."
   | handlerActive |
   <primitive: 199>
   handlerActive := true.
   ^self value
```

This code tells us two things: First, this method is implemented as a primitive, which means that a primitive operation of the virtual machine is executed when this method is invoked. VM primitives don't normally return: successful execution of a primitive terminates the method that contains the <primitive: *n*> instruction, answering the result of the primitive. So, the Smalltalk code that follows the primitive serves two purposes: it documents what the primitive does, and is available to be executed if the primitive fails. Here we see that on:do: simply sets the temporary variable handlerActive to true, and then evaluates the receiver (which is, of course, a block).

This is surprisingly simple, but somewhat puzzling. Where are the arguments of the on:do: method stored? To get the answer, let's look at the definition of the class MethodContext, whose instances make up the execution stack:

```
ContextPart variableSubclass: #MethodContext
   instanceVariableNames: 'method closureOrNil receiver'
   classVariableNames: ''
   poolDictionaries: ''
   category: 'Kernel−Methods'
```

There is no instance variable here to store the exception class or the handler, nor is there any place in the superclass to store them. However, note that MethodContext is defined as a variableSubclass. This means that in addition to the named instance variables, objects of this class have some indexed slots. In fact, every MethodContext has an indexed slot for each argument of the method whose invocation it represents. There are also additional indexed slots for the temporary variables of the method.

In the case that interest us, the arguments of the on:do: message are stored in the indexed variables of the stack execution instance. To verify this, evaluate the following piece of code:

```
| exception handler |
   [ thisContext  explore.
   self halt.
   exception := thisContext  sender at: 1.
   handler := thisContext sender at: 2.
   1 / 0]
      on: Error
      do: [:ex | 666].
   ^ {exception. handler} explore
```

In the protected block, we query the stack element that represents the protected block execution using thisContext sender. This execution was triggered by the on:do: message execution. The last line explores a 2-element array that contains the exception class and the exception handler.

If you get some strange results using halt and inspect inside the protected block, pay attention that contexts are recycled by the Virtual Machine. Opening an explorer on thisContext will show you that the context sender is effectively the execution of the method on:do:.

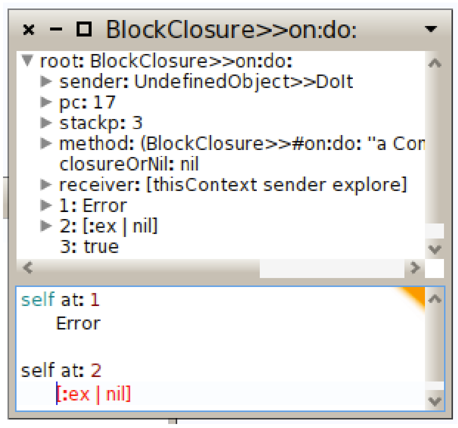
Note that you can also execute the following code you obtain an explorer and that you can see that the exception class and the handler are stored in the first and second variable instance variables of the method context object (a method context represents an execution stack element).

```
[thisContext sender explore] on: Error do: [:ex|].
```

So we saw that on:do: execution stores the exception class and its handler on the method context (execution stack frame). Note that this is not specific to on:do: but any message execution stores argument on the stack frame.

Finding Handlers. Now that we know where the information is stored, let's have a look at how it is found at runtime.

We might think that the primitive 199 is complex to write. But it is trivial, because primitive 199 *always* fails! Because the primitive always fails, the



```
root: BlockClosure>>on:do:
  sender: UndefinedObject>>DoIt
  pc: 17
  stackp: 3
  method: (BlockClosure>>#on:do: "a Con
  closureOrNil: nil
  receiver: [thisContext sender explore]
  1: Error
  2: [:ex | nil]
  3: true
```

```
self at: 1
    Error

self at: 2
    [:ex | nil]
```

Figure 1.4: Explore a method context to find the exception class and the handler.

Smalltalk body of on:do: is always executed. However, the presence of the <primitive: 199> annotation marks the executing context in a unique way.

The source code of the primitive is found in Interpreter» primitiveMarkHandlerMethod in the *VMMaker* SqueakSource package:

```
primitiveMarkHandlerMethod
    "Primitive. Mark the method for exception handling. The primitive must fail after
    marking the context so that the regular code is run."

    self inline: false.
   ^self primitiveFail
```

So now we know that when the method on:do: is executed, the MethodContext that makes up the stack frame is tagged and the handler and exception class are stored there.

Now, if an exception is signaled further up the stack, the method signal can search the stack to find the appropriate handler. This is what the following code is doing:

```
Exception»signal
   "Ask ContextHandlers in the sender chain to handle this signal.
   The default is to execute and return my defaultAction."

   signalContext := thisContext contextTag.
   ^ thisContext nextHandlerContext handleSignal: self
```

```
ContextPart»nextHandlerContext
```

```
	^ self sender findNextHandlerContextStarting
```

The method findNextHandlerContextStarting is implemented as a primitive (number 197); its body describes what it does. It looks to see if the stack frame is a context created by the execution of the method on:do: (it just looks to see if the primitive number is 199). If this is the case it answers with that context.

```
ContextPart»findNextHandlerContextStarting
	"Return the next handler marked context, returning nil if there
	is none. Search starts with self and proceeds up to nil."
	| ctx |
	<primitive: 197>
	ctx := self.
	[  ctx isHandlerContext ifTrue: [^ctx].
	   (ctx := ctx sender) == nil ] whileFalse.
	^nil
```

```
MethodContext»isHandlerContext
	"is this context for method that is marked?"
	^method primitive = 199
```

Since the method context supplied by findNextHandlerContextStarting contains all the exception-handling information, it can be examined to see if the exception class is suitable for handling the current exception. If so, the associated handler can be executed; if not, the look-up can continue further. This is all implemented in the handleSignal: method.

```
ContextPart»handleSignal: exception
	"Sent to handler (on:do:) contexts only.  If my exception class (first arg) handles
	    exception then execute my handle block (second arg), otherwise forward this
	    message to the next handler context.  If none left, execute exception's defaultAction
	     (see nil>>handleSignal:)."

	| val |
	(((self tempAt: 1) handles: exception) and: [self tempAt: 3]) ifFalse: [
	    ^ self nextHandlerContext handleSignal: exception].

	exception privHandlerContext: self contextTag.
	self tempAt: 3 put: false.  "disable self while executing handle block"
	val := [(self tempAt: 2) valueWithPossibleArgs: {exception}]
	    ensure: [self tempAt: 3 put: true].
	self return: val.  "return from self if not otherwise directed in handle block"
```

Notice how this method uses tempAt: 1 to access the exception class, and ask if it handles the exception. What about tempAt: 3? That is the temporary variable handlerActive of the on:do: method. Checking that handlerActive is true and then setting it to false ensures that a handler will not be asked to handle an exception that it signals itself. The return: message sent as the final action of handleSignal is responsible for "unwinding" the execution stack by removing the stack frames above self.

So, to summarize, the signal method, with minimal assistance from the virtual machine, finds the context that correspond to an on:do: message with an appropriate exception class. Because the execution stack is made up of Context objects that may be manipulated just like any other object, the stack can be shortened at any time. This is a superb example of flexibility of Smalltalk.

1.15 Ensure:'s implementation

Now we propose to have a look at the implementation of the method ensure:.

First we need to understand how the unwind block is stored and how this information is found at run-time. Let's look at the definition of the central method ensure: defined on the class BlockClosure.

```
ensure: aBlock
   "Evaluate a termination block after evaluating the receiver, regardless of
    whether the receiver's evaluation completes.  N.B.  This method is *not*
    implemented as a primitive.  Primitive 198 always fails.  The VM uses prim
    198 in a context's method as the mark for an ensure:/ifCurtailed: activation."

   | complete returnValue |
   <primitive: 198>
   returnValue := self valueNoContextSwitch.
   complete ifNil: [
      complete := true.
      aBlock value ].
   ^ returnValue
```

The <primitive: *198*> works the same way of the <primitive: *199*> we saw in the previous section. It always fails, however, its presence marks the executing context in a unique way. Moreover, the unwind block is stored the same way as the exception class and its associated handler. More explicitely, it is stored in the context (stack frame) of ensure: method execution, that can be accessed from the block through thisContext sender tempAt: 1.

In the case where the block doesn't fail and doesn't have a non-local return, the ensure: message implementation is very easy to understand. It evaluates the block, stores the result in the returnValue variable, evaluates the argument block and lastly returns the result of the block previously stored. The complete variable is just here to prevent to execute twice the argument block.

Ensuring a failing block. The ensure: message will execute the argument block even if the block fails. In the following example, the ensureWithOnDo message returns 2 and executes 1. In the subsequent section we will carefully look at where and what the block is actually returning and in which order are the blocks executed.

```
Bexp>>ensureWithOnDo
   ^[ [ Error signal ] ensure: [ 1 ].
     ^3 ] on: Error do: [ 2 ]
```

Let's have a quick example before looking at the implementation. We define 4 blocks and 1 method that ensure a failing Block.

```
Bexp>>mainBlock
   ^[ self traceCr: 'mainBlock start'.
    self failingBlock ensure: self ensureBlock.
    self traceCr: 'mainBlock end' ]

Bexp>>failingBlock
   ^[ self traceCr: 'failingBlock start'.
    Error signal.
    self traceCr: 'failingBlock end' ]

Bexp>>ensureBlock
   ^[ self traceCr: 'ensureBlock value'.
    #EnsureBlockValue ]

Bexp>>exceptionHandlerBlock
   ^[ self traceCr: 'exceptionHandlerBlock value'.
     #ExceptionHandlerBlockValue ]

Bexp>>start
   | res |
   self traceCr: 'start start'.
   res := self mainBlock on: Error do: self exceptionHandlerBlock.
   self traceCr: 'start end'.
   self traceCr: 'The result is : ', res, '.'.
   ^ res
```

Executing Bexp new start prints the following (we added indentation to stress the calling flow).

```
start start
   mainBlock start
      failingBlock start
         exceptionHandlerBlock value
         ensureBlock value
start  end
The result is: ExceptionHandlerBlockValue.
```

There are three important things to see. First, the failing block and the main block are not fully executed because of the signal message. Secondly, the exception block is executed before the ensure block. Lastly, the start method will return the result of the exception handler block.

To understand how this works, we have to look at the end of the exception implementation. We finish the previous explanation on the handleSignal method.

```
ContextPart»handleSignal: exception
   "Sent to handler (on:do:) contexts only.  If my exception class (first arg) handles
      exception then execute my handle block (second arg), otherwise forward this
      message to the next handler context.  If none left, execute exception's defaultAction
       (see nil>>handleSignal:)."

   | val |
   (((self tempAt: 1) handles: exception) and: [self tempAt: 3]) ifFalse: [
      ^ self nextHandlerContext handleSignal: exception].

   exception privHandlerContext: self contextTag.
   self tempAt: 3 put: false.  "disable self while executing handle block"
   val := [(self tempAt: 2) valueWithPossibleArgs: {exception}]
      ensure: [self tempAt: 3 put: true].
   self return: val.  "return from self if not otherwise directed in handle block"
```

In our example, Pharo will execute the failing block, then will look for the next handler context, marked with <primitive: *199*>. As a regular exception, Pharo finds the exception handler context, and runs the exceptionHandlerBlock. The method handleSignal finishes with the return: method. Let's have a look into it.

```
ContextPart>>return: value
   "Unwind thisContext to self and return value to self's sender.  Execute any unwind
      blocks while unwinding.  ASSUMES self is a sender of thisContext"

   sender ifNil: [self cannotReturn: value to: sender].
   sender resume: value
```

The return: message will check if the context has a sender, and, if not, send a CannotReturn Exception. Then the sender of this context will call the resume: message.

```
ContextPart>>resume: value
   "Unwind thisContext to self and resume with value as result of last send.  Execute
      unwind blocks when unwinding.  ASSUMES self is a sender of thisContext"

   | ctxt unwindBlock |
   self isDead ifTrue: [self cannotReturn: value to: self].
   ctxt := thisContext.
```

```
	[   ctxt := ctxt findNextUnwindContextUpTo: self.
	    ctxt isNil
	] whileFalse: [
	    (ctxt tempAt: 2) ifNil:[
	        ctxt tempAt: 2 put: true.
	        unwindBlock := ctxt tempAt: 1.
	        thisContext terminateTo: ctxt.
	        unwindBlock value].
	].
	thisContext terminateTo: self.
	^ value
```

This is the method where the argument block of ensure: is executed. This method looks for all the unwind contexts between the context of the method resume: and self, which is the sender of the on:do: context (in our case the context of start). When the method finds an unwound context, the unwound block is executed. Lastly, it triggers the terminateTo: message.

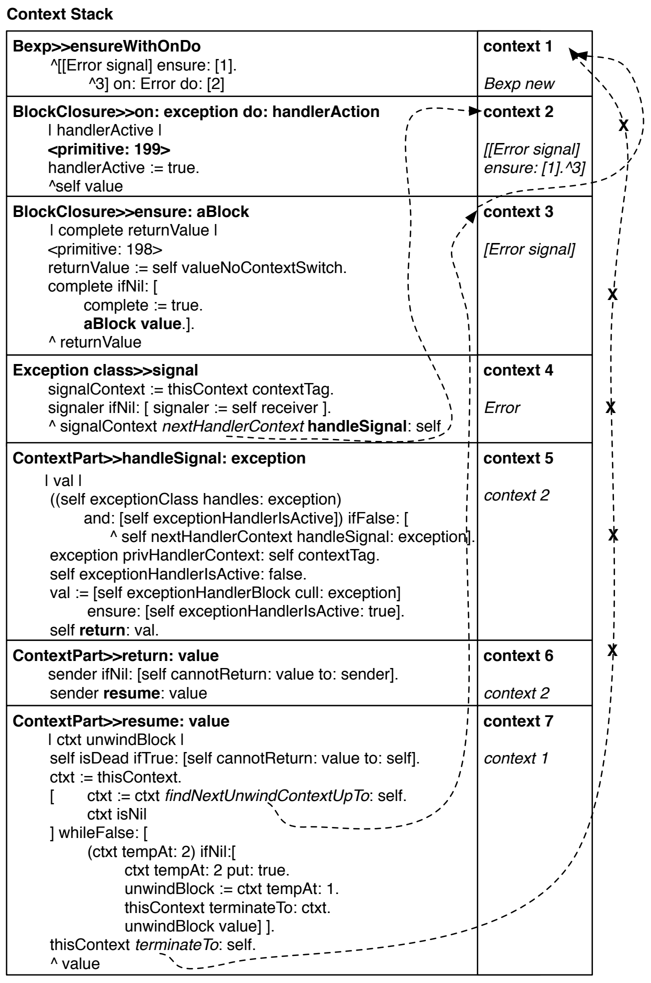
```
ContextPart>>terminateTo: previousContext
    "Terminate all the Contexts between me and previousContext, if previousContext is on
        my Context stack. Make previousContext my sender."

    | currentContext sendingContext |
    <primitive: 196>
    (self hasSender: previousContext) ifTrue: [
        currentContext := sender.
        [currentContext == previousContext] whileFalse: [
            sendingContext := currentContext sender.
            currentContext terminate.
            currentContext := sendingContext]].
    sender := previousContext
```

Basically, this method terminates all the contexts between thisContext and self, which is the sender of the on:do: context (in our case the context of start). Moreover, the sender of thisContext will become self, which is the sender of the on:do: context (in our case the context of start). It is implemented as a primitive, but the code below explains how it works.

Let's summarize what happens with Figure 1.5 which represents the execution of the method ensureWithOnDo defined previously.

Ensuring a non local return. There is also an implementation of ensure: for the non local return. Basically there is the same kind of lookup for unwound contexts as in the resume: message that is triggered when we return the value in resume:through:

```
ContextPart>>resume: value through: firstUnwindCtxt
    "Unwind thisContext to self and resume with value as result of last send.
```



Context Stack

```
Bexp>>ensureWithOnDo                                              context 1
    ^[[Error signal] ensure: [1].
        ^3] on: Error do: [2]                                     Bexp new

BlockClosure>>on: exception do: handlerAction                     context 2
    | handlerActive |
    <primitive: 199>                                              [[Error signal]
    handlerActive := true.                                        ensure: [1].^3]
    ^self value

BlockClosure>>ensure: aBlock                                      context 3
    | complete returnValue |
    <primitive: 198>                                              [Error signal]
    returnValue := self valueNoContextSwitch.
    complete ifNil: [
        complete := true.
        aBlock value.].
    ^ returnValue

Exception class>>signal                                           context 4
    signalContext := thisContext contextTag.
    signaler ifNil: [ signaler := self receiver ].                Error
    ^ signalContext nextHandlerContext handleSignal: self

ContextPart>>handleSignal: exception                              context 5
    | val |
    ((self exceptionClass handles: exception)                     context 2
        and: [self exceptionHandlerIsActive]) ifFalse: [
            ^ self nextHandlerContext handleSignal: exception].
    exception privHandlerContext: self contextTag.
    self exceptionHandlerIsActive: false.
    val := [self exceptionHandlerBlock cull: exception]
        ensure: [self exceptionHandlerIsActive: true].
    self return: val.

ContextPart>>return: value                                        context 6
    sender ifNil: [self cannotReturn: value to: sender].
    sender resume: value                                          context 2

ContextPart>>resume: value                                        context 7
    | ctxt unwindBlock |
    self isDead ifTrue: [self cannotReturn: value to: self].      context 1
    ctxt := thisContext.
    [   ctxt := ctxt findNextUnwindContextUpTo: self.
        ctxt isNil
    ] whileFalse: [
        (ctxt tempAt: 2) ifNil:[
            ctxt tempAt: 2 put: true.
            unwindBlock := ctxt tempAt: 1.
            thisContext terminateTo: ctxt.
            unwindBlock value] ].
    thisContext terminateTo: self.
    ^ value
```

Figure 1.5: Context stack

```
Execute any unwind blocks while unwinding. ASSUMES self is a sender of
  thisContext."

| ctxt unwindBlock |
```

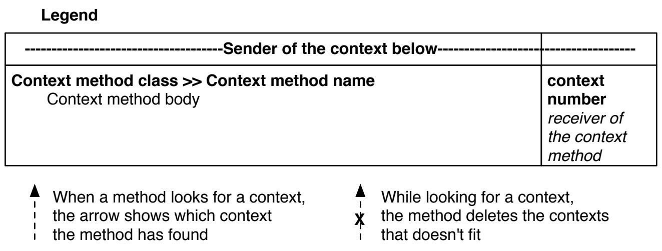

Legend
Sender of the context below
Context method class >> Context method name
Context method body
context number
receiver of the context method
When a method looks for a context, the arrow shows which context the method has found
While looking for a context, the method deletes the contexts that doesn't fit

Figure 1.6: Legend of the figure.

```
self isDead ifTrue: [self cannotReturn: value to: self].
ctxt := firstUnwindCtxt.
[ctxt isNil] whileFalse:
   [(ctxt tempAt: 2) ifNil:
      [ctxt tempAt: 2 put: true.
       unwindBlock := ctxt tempAt: 1.
       thisContext terminateTo: ctxt.
       unwindBlock value].
   ctxt := ctxt findNextUnwindContextUpTo: self].
thisContext terminateTo: self.
^value
```

1.16 Specific exceptions

The class Exception in Pharo has ten direct subclasses, as shown in Figure 1.7. The first thing that we notice from this figure is that the Exception hierarchy is a bit of a mess; you can expect to see some of the details change as Pharo is improved.

The second thing that we notice is that there are two large sub-hierarchies: Error and Notification. Errors tell us that the program has fallen into some kind of abnormal situation. In contrast, Notifications tell us that an event has occurred, but without the assumption that it is abnormal. So, if a Notification is not handled, the program will continue to execute. An important subclass of Notification is Warning; warnings are used to notify other parts of the system, or the user, of abnormal but non-lethal behavior.

The property of being resumable is largely orthogonal to the location of an exception in the hierarchy. In general, Errors are not resumable, but 10 of its subclasses *are* resumable. For example, MessageNotUnderstood is a subclass of Error, but it is resumable. TestFailures are not resumable, but, as you would expect, ResumableTestFailures are.

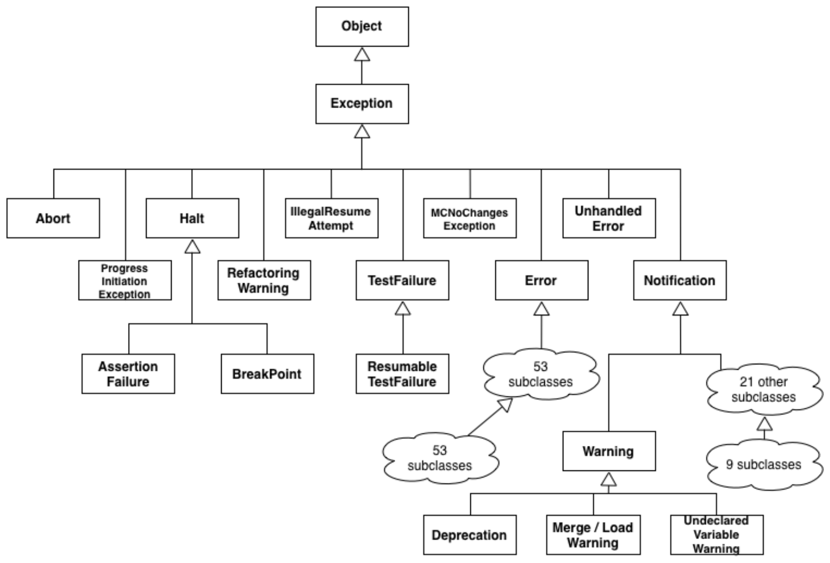


Figure 1.7: A part of Pharo exception hierarchy.

Resumability is controlled by the private Exception method isResumable. For example:

```
Exception new isResumable   ⟶   true
Error new isResumable   ⟶   false
Notification new isResumable   ⟶   true
Halt new isResumable   ⟶   true
MessageNotUnderstood new isResumable   ⟶   true
```

As it turns out, roughly 2/3 of all exceptions are resumable:

```
Exception allSubclasses size   ⟶   160
(Exception allSubclasses select: [:each | each new isResumable]) size   ⟶   79
```

If you declare a new subclass of exceptions, you should look in its protocol for the isResumable method, and override it as appropriate to the semantics of your exception.

In some situations, it will never makes sense to resume an exception. In such a case you should signal a non-resumable subclass — either an existing one or one of your own creation. In other situations, it will always be OK to resume an exception, without the handler having to do anything. In fact, this gives us another way of characterizing a notification: a Notification is a resumable Exception that can be safely resumed without first modifying the state of the system. More often, it will be safe to resume an exception only if the state of the system is first modified in some way. So, if you signal a resumable exception, you should be very clear about what you expect an exception handler to do before it resumes the exception.

When defining a new exception. It is a difficult problem to decide when it is worth to define a new exception instead of reusing an existing one. Here are some heuristics: first, you should evaluate if you can have an adequate solution to the exceptional situation. Second if you need a specific default behavior when the exceptional situation is not handled. Finally if you need to store more information to handle the exception case.

1.17 When not to use exceptions

Just because Pharo has exception handling, you should not conclude that it is always appropriate to use it. Recall that in the introduction to this chapter, we said that exception handling is for *exceptional* situations. So, the first rule for using exceptions is *not* to use them for situations that *can reasonably be expected to occur* in a normal execution.

Of course, if you are writing a library, what is normal depends on the context in which your library is used. To make this concrete, let's look at Dictionary as an example: *aDictionary* at: *aKey* will signal an Error if *aKey* is not present. But you should not write a handler for this error! If the logic of your application is such that there is some possibility that the key will not be in the dictionary, then you should instead use at: *aKey* ifAbsent: [*remedial action*]. In fact, Dictionary»at: is implemented using Dictionary»at:ifAbsent:. *aCollection* detect: *aPredicateBlock* is similar: if there is any possibility that the predicate might not be satisfied, you should use *aCollection* detect: *aPredicateBlock* ifNone: [*remedial action*].

When you write methods that signal exceptions, you should consider whether you should also provide an alternative method that takes a remedial block as an additional argument, and evaluates it if the normal action cannot be completed. Although this technique can be used in any programming language that support closures, because Smalltalk uses closures for *all* its control structures, it is a particularly natural one to use in Smalltalk.

Another way of avoiding exception handling is to test the precondition of the exception before sending the message that may signal it. For example, in method 1.1, we sent a message to an object using perform:, and handled the MessageNotUnderstood error that might ensue. A much simpler alternative is to check to see if the message is understood before executing the perform:

Method 1.2: *Object»performAll: revisited*

```
performAll: selectorCollection
  selectorCollection
    do: [:each | (self respondsTo: each)
        ifTrue: [self perform: each]]
```

The primary objection to method 1.2 is efficiency. The implementation of respondsTo: s has to lookup s in the target's method dictionary to find out if s will be understood. If the answer is yes, then perform: will look it up again. Moreover, the first lookup is implemented in Smalltalk, not in the virtual machine. If this code is in a performance-critical loop, this might be an issue. However, if the collection of messages comes from a user interaction, the speed of performAll: will not be a problem.

1.18 Chapter Summary

In this chapter we saw how to use exceptions to signal and handle abnormal situations arising in our code.

- Don't use exceptions as a control-flow mechanism. Reserve them for notifications and for *abnormal* situations. Consider providing methods that take blocks as arguments as an alternative to signaling exceptions.
- Use *protectedBlock* ensure: *actionBlock* to ensure that *actionBlock* will be performed even if *protectedBlock* terminates abnormally.
- Use *protectedBlock* ifCurtailed: *actionBlock* to ensure that *actionBlock* will be performed *only* if *protectedBlock* terminates abnormally.
- Exceptions are objects. Exception classes form a hierarchy with the class Exception at the root of the hierarchy.
- Use *protectedBlock* on: *ExceptionClass* do: *handlerBlock* to catch exceptions that are instances of *ExceptionClass* (or any of its subclasses). The *handlerBlock* should take an exception instance as its sole argument.
- Exceptions are signaled by sending one of the messages signal or signal:. signal: takes a descriptive string as its argument. The description of an exception can be obtained by sending it the message description.
- You can set a breakpoint in your code by inserting the message-send self halt. This signals a resumable Halt exception, which, by default, will open a debugger at the point where the breakpoint occurs.

- When an exception is signaled, the runtime system will search up the execution stack, looking for a handler for that specific class of exception. If none is found, the defaultAction for that exception will be performed (*i.e.*, in most cases the debugger will be opened).
- An exception handler may terminate the protected block by sending return: to the signaled exception; the value of the protected block will be the argument supplied to return:.
- An exception handler may retry a protected block by sending retry to the signaled exception. The handler remains in effect.
- An exception handler may specify a new block to try by sending retryUsing: to the signaled exception, with the new block as its argument. Here, too, the handler remains in effect.
- Notifications are subclass of Exception with the property that they can be safely resumed without the handler having to take any specific action.

Acknowledgments. We thank Paolo Bonzini for the Smalltalk implementations of ensure: and ifCurtailed:.