10.1.3 An abstract syntax tree

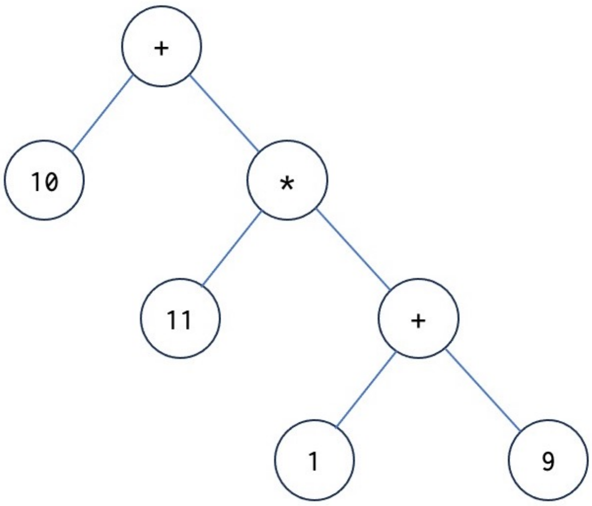
Description

In this section, we will show how to represent an expression by means of an abstract syntax tree. An *abstract syntax tree* (*AST*) or just *syntax tree* is a data structure that may represent the structure of a text described by a grammar.

The “*tree*” in AST refers to the fact that an AST is an example of a common data structure called a tree. A tree represents a hierarchical structure with a set of connected *nodes*. A node may have zero or more *children* which are also nodes. A child has exactly one *parent*. Nodes that have no children are called *leaf nodes*. The top node in a tree is called the *root* and have no parent.

A *binary tree* is a common used data structure where each parent has at most two children and the two nodes are often ordered in a *left* node and a *right* node.

For our expression grammar we will use a binary tree and the tree in the figure below shows a representation of the expression `"10 + 11 * (1 + 9)"`.



An AST for “10 + 11 * (1 + 9)”

In the following, we introduce classes to represent a binary AST for our expression grammar as shown in the figure. We start by introducing a general class being the superclass of all nodes of an AST:

```
class Node(label: var char, left: ref Node, right: ref Node):
   eval -> v: var integer:<
      inner(eval)
   print(ind: var integer):
         ...
```

Class `Node` has three parameters, the `label` of the node, and `left` and `right` representing the two children of the `Node`. In addition, a `Node` has an `eval`-method and a `print`-method. We return to these later in this section.

For each nonterminal except `<Primary>`, we have a subclass of `Node`:

```
class ExpNode: Node
   eval::
      v := left.eval + right.eval
class TermNode: Node
   eval::
      v := left.eval * right.eval
class NumberNode: Node
```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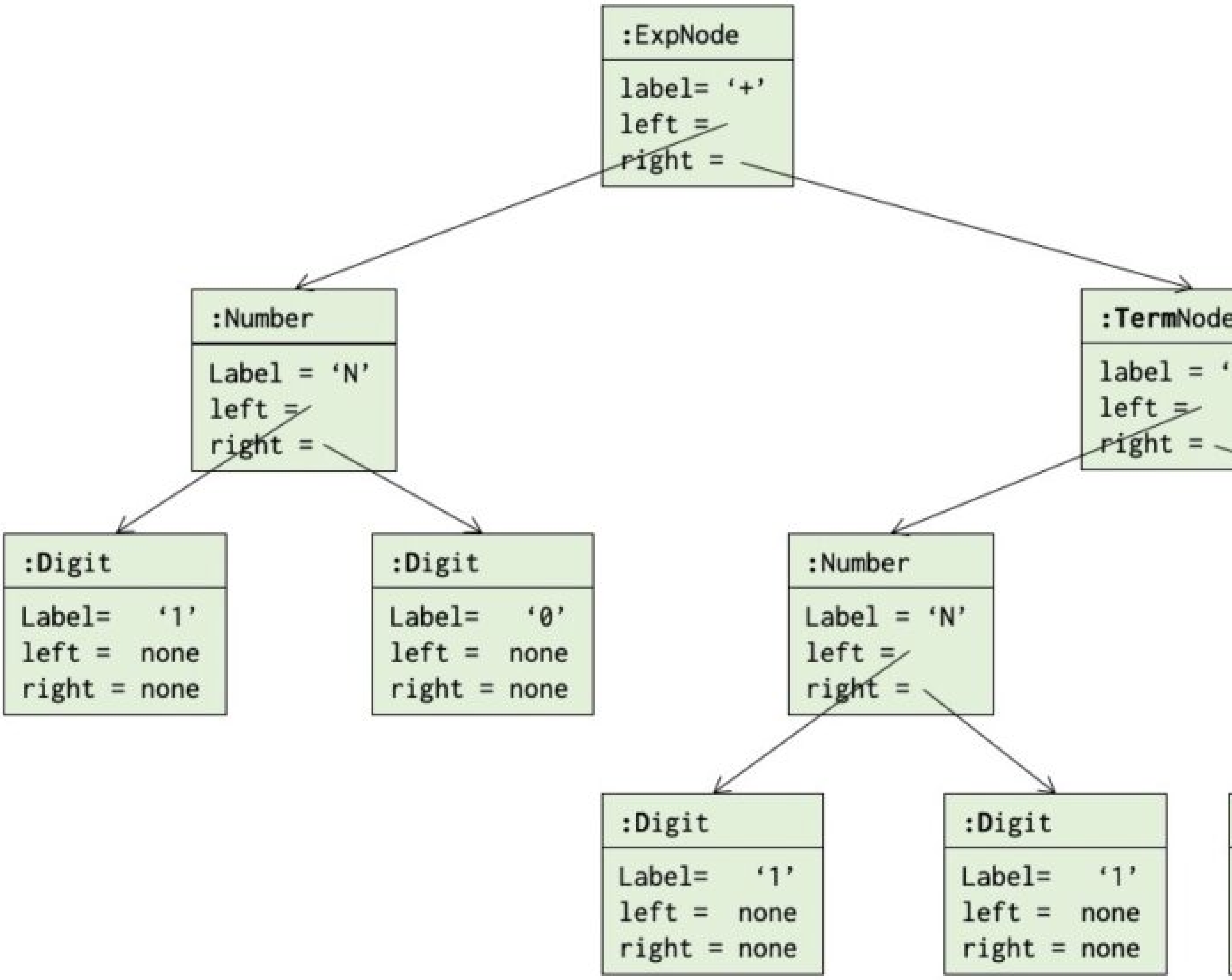
```
   eval::
      if (right == none) :then
         v := left.eval
      :else
         v := (left.eval * 10) + right.eval
class DigitNode: Node
   eval::
       v := label - '0'
```

The next figure shows how the above tree representing "`10 + 11 * (1 + 9)`" may be represented as objects of these classes:



AST-b/An object diagram for “10 + 11 * (1 + 9)”

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The `eval`-method performs a recursive traversal of the tree and evaluates the expression represented by the tree. If `root` is a reference to the root of the tree, `root.eval` will return the value 120.

Building the AST

We now extend the parser to build the AST during parsing. Each method will then return the AST for the string being parsed by the method. Consider `exp`:

```
exp -> N: ref Node:
   N := term
   addOp: do
      if (ch = '+') :then
         rN: ref Node
         nextChar
         rN := term
         N := expNode('+',N,rN)
         restart(addOp)
```

As can be seen the return value of `exp` is a `Node` represented by the reference variable `N`. The method `term` is assumed to return the AST representing the string parsed by `term`.

If no `'+'` character is following the first call of `term` (`ch = '+'`) then `exp` just returns the `Node` returned by term. If a `'+'` character is met, `term` invoked again, and `exp` returns an `ExpNode` with the first argument being a `'+'`, and the second and third argument being the nodes returned by the first an second call of `term`. This is repeated as long as `ch = '+'.`

The revised methods `term` and `primary` may look as follows:

```
term ->  N: ref node:
   N := primary
   multOp: do
      if (ch = '*') :then
         rN: ref Node
         nextChar
         rN := primary
         N := termNode('*',N,rN)
         restart(multOP)
primary -> N: ref Node:
   if (ch = '(') :then
      nextChar
      N := exp
      if (ch = ')') :then
         nextChar
      :else
         syntaxError(1)
   :else
      N := number
```

As can be seen, the structure of `term` similar to `exp` whereas `primary` just returns the `Node` returned by `exp` or `number`.

Next we show the revised versions of `number` and `digit`:

```
number -> N: ref node:
   N := digit
   moreDigits: do
      if (ascii.isDigit(ch)) :then
         rN: ref Node
         rN := digit
         N := NumberNode('N',N,rN)
         restart(moreDigits)
      :else
         N := NumberNode('N',N,none)
digit -> N: ref Node:
   if (ascii.isDigit(ch)) :then
```


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```
      N:= digitNode(ch,none,none)
      nextChar
   :else
       syntaxError(2)
```

These should be straightforward to understand. Note, however, that both may return a `Node` where the left and/or right child is `none`.

Finally we may show the new version of the `parse` method:

```
parse:
   N: ref Node
   inn :=  "10 + 11 * (1 + 9)"
   console.print(("\nParse: " + inn + "\n")
   nextChar
   N := exp
   if (ch <> ascii.null) :then
      syntaxError(3)
   if (not hasSyntaxErrors) :then
      console.print("\nResulting AST:\n")
      console.print(N.print(0))
      console.print("Evaluation of exp is: N.eval))
```

If no syntax errors have happened during the `exp`-call, the resulting AST is printed and the result of evaluating it is also printed.

We have not shown details of a `print`-method and leave this to the reader. The parameter of `print` is supposed to be the level of a given `Node` in an AST where the `root` is at level `0` and the children of the root at level `1`, etc. This should make it easier to print an indented text version of the AST.

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