# Lists and Recursion

*Prolog Development Center*
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List processing – handling sequences of elements – is a powerful technique in Prolog. In this tutorial, we explain what lists are and how to declare them, and then give several examples that show how you might use list processing in your own applications. We also define two well known Prolog predicates – member and append – while looking at list processing from both a recursive and a procedural standpoint.

After that, we introduce findall, a Visual Prolog standard predicate that enables you to find and collect all solutions to a single goal. We round out this tutorial with a discussion of compound lists – combinations of different types of elements – and an example of parsing by difference lists.

## What Is a List?

In Prolog, *a list* is an object that contains an arbitrary number of other objects within it. Lists correspond roughly to arrays in other languages, but, unlike an array, a list does not require you to declare how big it will be before you use it.

A list that contains the numbers 1, 2, and 3 is written as

```
[ 1, 2, 3 ]
```

The order of the elements in this list matters:

- Number "1" is the first element,
- "2" - the second,
- "3" - the third.

List [ 1, 2, 3 ] is different from the list [ 1, 3, 2 ].

Each item contained in the list is known as an *element*. To form a list data structure, you separate the elements of a list with commas and then enclose them in square brackets. Here are some examples:

```
["dog", "cat", "canary"]
["valerie ann", "jennifer caitlin", "benjamin thomas"]
```

The same element can be present in the list several times, for example:

```
[ 1, 2, 1, 3, 1 ]
```

### Declaring Lists

To declare the domain for a list of integers, you use the domains declaration, like this:

```
domains
   integer_list = integer*.
```

The asterisk means "list of"; that is, integer* means "list of integers."

Note that the word *"list"* has no special meaning in Visual Prolog. You could equally well have called your list domain *zanzibar*. It is the asterisk, not the name that signifies a list domain.

The elements in a list can be anything, including other lists. However, all elements in a list must belong to the same domain, and in addition to the declaration of the list domain, there must be a **domains** declaration for the elements:

```
domains
   element_list = elements*.
   elements = ....
```

Here *elements* must be equated to a single domain type (for example, integer, real, or symbol) or to a set of alternatives marked with different functors. Visual Prolog does not allow you to mix standard types in a list. For example, the following declarations would not properly indicate a list made up of integers, reals, and symbols:

```
element_list = elements*.
elements =
   integer;
   real;
   symbol.
      /* Incorrect */
```

The way to declare a list made up of integers, reals, and symbols is to define a single domain comprising all three types, with functors to show which type a particular element belongs to. For example:

```
element_list = elements*.
elements =
   i(integer);
   r(real);
   s(symbol).
      /* the functors are i, r, and s */
```

(For more information about this, refer to "Compound Lists" later in this tutorial.)

#### Heads and Tails

A list is really a recursive compound object. It consists of two parts: the head, of a list, which is the first element, and the tail, which is a list comprising all the subsequent elements.

***The tail of a list is always a list;  the head of a list is an element.***

For example,

```
the head of [a, b, c] is a
the tail of [a, b, c] is [b, c]
```

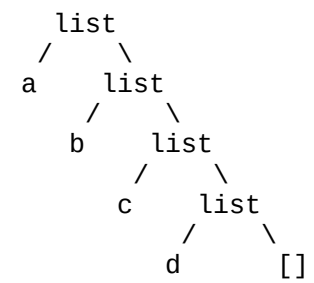
What happens when you get down to a one-element list? The answer is that:

```
the head of [c] is c
the tail of [c] is []
```

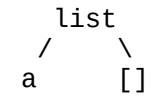
***If you take the first element from the tail of a list enough times, you will eventually get down to an empty list ([ ]).***

***The empty list cannot be broken into head and tail.***

This means that, conceptually, lists have a tree structure just like other compound objects. The tree structure of [a, b, c, d] is:




Further, a one-element list such as [a] is not the same as the element that it contains, because [a] is really the compound data structure shown here:




## List Processing

Prolog provides a way to make a head and a tail of a list explicit. Instead of separating elements with commas, you can separate the head and tail with a vertical bar (|). For instance,

> [a, b, c] is equivalent to [a|[b, c]]

and, continuing the process,

> [a|[b,c]] is equivalent to [a|[b|[c]]]
>
> which is equivalent to [a|[b|[c|[]]]]

You can even use both kinds of separators in the same list, provided the vertical bar is the last separator. So, if you really want to, you can write [a, b, c, d] as [a, b|[c, d]]. Table 1 gives more examples.

***Table 1: Heads and Tails of Lists***

| List | Head | Tail |
|---|---|---|
| ['a', 'b', 'c'] | 'a' | ['b', 'c'] |
| [ 'a' ] | 'a' | [] /* an empty list */ |
| [ ] | undefined | undefined |
| [[1, 2, 3], [2, 3, 4], []] | [1, 2, 3] | [[2, 3, 4], []] |

Table 2 gives several examples of list unification.

***Table 2: Unification of Lists***

| List 1 | List 2 | Variable Binding |
|---|---|---|
| [X, Y, Z] | [egbert, eats, icecream] | X=egbert, Y=eats, Z=icecream] |
| [7] | [X \| Y] | X=7, Y=[] |

| | | |
|---|---|---|
| [1, 2, 3, 4] | [X, Y \| Z] | X=1, Y=2, Z=[3,4] |
| [1, 2] | [3 \| X] | fail |

## Using Lists

Because a list is really a recursive compound data structure, you need recursive algorithms to process it. The most basic way to process a list is to work through it, doing something to each element until you reach the end.

An algorithm of this kind usually needs two clauses. One of them says what to do with an ordinary list (one that can be divided into a head and a tail). The other says what to do with an empty list.

### Writing Lists

For example, if you just want to print out the elements of the list, here is what you do:

```
class my
domains
   list = integer*.
      /* or whatever type you wish to use */
predicates
   write_a_list : (list).
end class
implement my
clauses
   write_a_list([]).
      /* If the list is empty, do nothing more. */
   write_a_list([H|T]):-
      /* Match the head to H and the tail to T, then... */
      stdio::write(H),stdio::nl,
      write_a_list(T).
end implement
goal
   console::init(),
   my::write_a_list([1, 2, 3]).
```

Here are the two write_a_list clauses described in natural language:

1. To write an empty list, do nothing.
2. Otherwise, to write a list, write its head (which is a single element), then write its tail (a list).

The first time through, the goal is:

```
my::write_a_list([1, 2, 3]).
```

This matches the second clause, with H=1 and T=[2, 3]; this writes 1 and then calls write_a_list recursively with the tail of the list:

```
my::write_a_list([2, 3]).
      /* This is write_a_list(T). */
```

This recursive call matches the second clause, this time with H=2 and T=[3], so it writes 2 and again calls write_a_list recursively:

```
my::write_a_list([3]).
```

Now, which clause will this goal match? Recall that, even though the list [3] has only one element; it does have a head and tail; the head is 3 and the tail is []. So, again the goal matches the second clause, with H=3 and T=[]. Hence, 3 is written and write_a_list is called recursively like this:

```
my::write_a_list([]).
```

Now you see why this program needs the first clause. The second clause will not match this goal because [] cannot be divided into head and tail. So, if the first clause were not there, the goal would fail. As it is, the first clause matches and the goal succeeds without doing anything further.

**Counting List Elements**

Now consider how you might find out how many elements are in a list. What is the length of a list, anyway? Here is a simple logical definition:

The length of [] is 0.
The length of any other list is 1 plus the length of its tail.

Can you implement this? In Prolog it is very easy. It takes just two clauses:

```
class my
domains
   list = integer*.
      /* or whatever type you wish to use */
predicates
   length_of : (list, integer) procedure(i,o).
end class
implement my
clauses
   length_of([], 0).
   length_of([_|T], L):-
      length_of(T, TailLength),
      L = TailLength + 1.
end implement
goal
   console::init(),
   my::length_of([1, 2, 3], L),
   stdio::write(L).
```

Take a look at the second clause first. Crucially, [_|T] will match any nonempty list, binding T to the tail of the list. The value of the head is unimportant; as long as it exists, it can be counted it as one element.

So the goal:

```
my::length_of([1, 2, 3], L)
```

will match the second clause, with T=[2, 3]. The next step is to compute the length of T. When this is done (never mind how), TailLength will get the value 2, and the computer can then add 1 to it and bind L to 3.

So how is the middle step executed? That step was to find the length of [2, 3] by satisfying the goal

```
my::length_of([2, 3], TailLength)
```

In other words, length_of calls itself recursively. This goal matches the second clause,

binding

- [3] in the goal to T in the clause and
- TailLength in the goal to L in the clause.

Recall that TailLength in the goal will not interfere with TailLengt*h* in the clause, because ***each recursive invocation of a clause has its own set of variables***.

So now the problem is to find the length of [3], which will be 1, and then add 1 to that to get the length of [2, 3], which will be 2. So far, so good.

Likewise, length_of will call itself recursively again to get the length of [3]. The tail of [3] is [], so T is bound to [], and the problem is to get the length of [], then add 1 to it, giving the length of [3].

This time it's easy. The goal:

```
my::length_of([], TailLength)
```

matches the *first* clause, binding TailLength to 0. So now the computer can add 1 to that, giving the length of [3], and return to the calling clause. This, in turn, will add 1 again, giving the length of [2, 3], and return to the clause that called it; this original clause will add 1 again, giving the length of [1, 2, 3].

Confused yet? We hope not. In the following brief illustration we'll summarize the calls. We've used subscripts to indicate that similarly named variables in different clauses – or different invocations of the same clause – are distinct.

```
my::length_of([1, 2, 3], L1).
my::length_of([2, 3], L2).
my::length_of([3], L3).
my::length_of([], 0).
L3 =  0+1 = 1.
L2 = L3+1 = 2.
L1 = L2+1 = 3.
```

**Tail Recursion**

You probably noticed that length_of is not, and can't be, tail-recursive, because the recursive call is not the last step in its clause. Can you create a tail-recursive list-length predicate? Yes, but it will take some effort.

The problem with length_of is that you can't compute the length of a list until you've already computed the length of the tail. It turns out there's a way around this. You'll need a list-length predicate with three arguments.

- One is the list, which the computer will whittle away on each call until it eventually becomes empty, just as before.
- Another is a free argument that will ultimately contain the result (the length).
- The third is a counter that starts out as 0 and increments on each call.

When the list is finally empty, you'll unify the counter with the (up to then) unbound result.

```
class my
domains
   list = integer*.
      /* or whatever type you wish to use */
predicates
```

```
    length_of : (list, integer, integer)
      procedure(i,o,i).
end class
implement my
clauses
    length_of([], Result, Result).
    length_of([_|T], Result, Counter):-
      NewCounter = Counter + 1,
      length_of(T, Result, NewCounter).
end implement
goal
    console::init(),
    my::length_of([1, 2, 3], L, 0),
      /* start with Counter = 0 */
    stdio::write(" L = ", L).
```

This version of the length_of predicate is more complicated, and in many ways less logical, than the previous one. We've presented it merely to show you that, by devious means, ***you can often find a tail-recursive algorithm for a problem that seems to demand a different type of recursion***.

#### Another Example – Modifying the List

Sometimes you want to take a list and create another list from it. You do this by working through the list element by element, replacing each element with a computed value. For example, here is a program that takes a list of numbers and adds 1 to each of them:

```
class my
domains
    list = integer*.
predicates
    add1 : (list, list) procedure(i,o).
end class
implement my
clauses
    add1([], []).
      /* boundary condition */
    add1([Head|Tail],[Head1|Tail1]):-
      /* separate the head */
      /* from the rest of the list */
    Head1 = Head+1,
      /* add 1 to the first element */
    add1(Tail, Tail1).
      /* call element with the rest of the list */
end implement
goal
    console::init(),
    my::add1([1,2,3,4], NewList),
    stdio::write(NewList)).
```

To paraphrase this in natural language:

> To add 1 to all the elements of the empty list,
>  just produce another empty list.
>
> To add 1 to all the elements of any other list,
>  add 1 to the head and make it the head of the result, and then
>  add 1 to each element of the tail and make that the tail of the result.

Load the program, and run the goal with the specified goal

```
add1([1,2,3,4], NewList).
```

The goal will return

```
NewList=[2,3,4,5]
1 Solution
```

#### *Tail Recursion Again*

Is add1 tail-recursive? If you're accustomed to using Lisp or Pascal, you might think it isn't, because you think of it as performing the following operations:

1. Split the list into *Head* and *Tail*.
2. Add 1 to *Head*, giving *Head1*.
3. Recursively add 1 to all the elements of *Tail*, giving *Tail1*.
4. Combine *Head1* and *Tail1*, giving the resulting list.

This isn't tail-recursive, because the recursive call is not the last step.

But – and this is important – ***that is not how Prolog does it***. In Visual Prolog, add1 is tail-recursive, because its steps are really the following:

1. Bind the head and tail of the original list to *Head* and *Tail*.
2. Bind the head and tail of the result to *Head1* and *Tail1*. (*Head1* and *Tail1* do not have values yet.)
3. Add 1 to *Head*, giving *Head1*.
4. Recursively add 1 to all the elements of *Tail*, giving *Tail1*.

When this is done, *Head1* and *Tail1* are *already* the head and tail of the result; there is no separate operation of combining them. So the recursive call really is the last step.

#### *More on Modifying Lists*

Of course, you don't actually need to put in a replacement for every element. Here's a program that scans a list of numbers and copies it, leaving out the negative numbers:

```
class my
domains
   list = integer*.
predicates
   discard_negatives : (list, list) procedure(i,o).
end class
implement my
clauses
   discard_negatives([], []).
   discard_negatives([H|T], ProcessedTail):-
      H < 0,
      !,    /* If H is negative, just skip it */
      discard_negatives(T, ProcessedTail).
   discard_negatives([H|T], [H|ProcessedTail]):-
      discard_negatives(T, ProcessedTail).
end implement
goal
   console::init(),
   my::discard_negatives ([2, -45, 3, 468], X),
   stdio::write(X).
```

For example, the goal

```
my::discard_negatives([2, -45, 3, 468], X)
```

gives

```
X=[2, 3, 468].
```

And here's a predicate that copies the elements of a list, making each element occur twice:

```
doubletalk([], []).
doubletalk([H|T], [H, H|DoubledTail]) :-
   doubletalk(T, DoubledTail).
```

**List Membership**

Suppose you have a list with the names *John*, *Leonard*, *Eric*, and *Frank* and would like to use Visual Prolog to investigate if a given name is in this list. In other words, you must express the relation "membership" between two arguments: a name and a list of names. This corresponds to the predicate

```
member(name, namelist).
   /* "name" is a member of "namelist" */
```

In the **e01.pro** program, the first clause investigates the head of the list. If the head of the list is equal to the name you're searching for, then you can conclude that Name is a member of the list. Since the tail of the list is of no interest, it is indicated by the anonymous variable. Thanks to this first clause, the goal

```
my::member("john", ["john", "leonard", "eric", "frank"])
```

is satisfied.

```
      /* Program e01.pro */
class my
domains
  namelist = name*.
  name = symbol.
predicates
  member : (name, namelist) determ.
end class
implement my
clauses
  member(Name, [Name|_]) :-
    !.
  member(Name, [_|Tail]):-
    member(Name,Tail).
end implement
goal
  console::init(),
  my::member("john",
     ["john", "leonard", "eric", "frank"]),
  !,
  stdio::write("Success")
  ;
  stdio::write("No solution").
```

If the head of the list is not equal to Name, you need to investigate whether Name can be found in the tail of the list.

In English:

Name is a member of the list if Name is the first element of the list, or
Name is a member of the list if Name is a member of the tail.

The second clause of member relates to this relationship. In Visual Prolog:

```
my::member(Name, [_|Tail]) :-
   member(Name, Tail).
```

### Appending One List to Another: Declarative and Procedural Programming

As given, the member predicate of the **e01.pro** program works in two ways. Consider its clauses once again:

```
member(Name, [Name|_]).
member(Name, [_|Tail]) :-
   member(Name, Tail).
```

You can look at these clauses from two different points of view: declarative and procedural.

1. From a declarative viewpoint, the clauses say:

   Name is a member of a list if the head is equal to Name;
   if not, Name is a member of the list if it is a member of the tail.

2. From a procedural viewpoint, the two clauses could be interpreted as saying:

   To find a member of a list, find its head;
   otherwise, find a member of its tail.

These two points of view correspond to the goals

```
member(2, [1, 2, 3, 4]).
```

and

```
member(X, [1, 2, 3, 4]).
```

In effect, the first goal asks Visual Prolog to check whether something is true; the second asks Visual Prolog to find all members of the list [1,2,3,4]. Don't be confused by this. The member predicate is the same in both cases, but its behavior may be viewed from different angles.

#### Recursion from a Procedural Viewpoint

The beauty of Prolog is that, often, when you construct the clauses for a predicate from one point of view, they'll work from the other. To see this duality, in this next example you'll construct a predicate to append one list to another. You'll define the predicate append with three arguments:

```
append(List1, List2, List3).
```

This combines List1 and List2 to form List3. Once again you are using recursion (this time from a procedural point of view).

If List1 is empty, the result of appending *List1* and List2 will be the same as List2. In Prolog:

```
append([], List2, List2).
```

If List1 is not empty, you can combine List1 and List2 to form *List3* by making the head of List1 the head of List3. (In the following code, the variable H is used as the head of both List1 and List3.) The tail of List3 is L3, which is composed of the rest of List1 (namely, L1) and all of List2. In Prolog:

```
append([H|L1], List2, [H|L3]) :-
  append(L1, List2, L3).
```

The append predicate operates as follows: While List1 is not empty, the recursive rule transfers one element at a time to List3. When List1 is empty, the first clause ensures that List2 hooks onto the back of List3.

**One Predicate Can Have Different Uses**

Looking at append from a declarative point of view, you have defined a relation between three lists. This relation also holds if List1 and List3 are known but List2 isn't. However, it also holds true if only List3 is known. For example, to find which two lists could be appended to form a known list, you could use a goal of the form

```
append(L1, L2, [1, 2, 4]).
```

With this goal, Visual Prolog will find these solutions:

```
1L1=[], L2=[1,2,4]
L1=[1], L2=[2,4]
L1=[1,2], L2=[4]
L1=[1,2,4], L2=[]
4 Solutions
```

You can also use append to find which list you could append to [3,4] to form the list [1,2,3,4]. Try giving the goal

```
append(L1, [3,4], [1,2,3,4]).
```

Visual Prolog finds the solution

```
L1=[1,2].
```

This append predicate has defined a relation between an *input set* and an *output set* in such a way that the relation applies both ways. Given that relation, you can ask

Which output corresponds to this given input?

or

Which input corresponds to this given output?

The status of the arguments to a given predicate when you call that predicate is referred to as a *flow pattern*. An argument that is bound or instantiated at the time of the call is an input argument, signified by (i); a free argument is an output argument, signified by (o).

The append predicate has the ability to handle any flow pattern you provide. However, not all predicates have the capability of being called with different flow patterns. When a Prolog clause is able to handle multiple flow patterns, it is known as an invertible clause. When

writing your own Visual Prolog clauses, keep in mind that an invertible clause has this extra advantage and that creating invertible clauses adds power to the predicates you write.

## Finding All the Solutions at Once

Backtracking and recursion are two ways to perform repetitive processes. Recursion won out because, unlike backtracking, it can pass information (through arguments) from one recursive call to the next. Because of this, a recursive procedure can keep track of partial results or counters as it goes along.

But there's one thing backtracking can do that recursion can't do – namely, find all the alternative solutions to a goal. So you may find yourself in a quandary: You need all the solutions to a goal, but you need them all at once, as part of a single compound data structure. What do you do?

Fortunately, Visual Prolog provides a way out of this impasse. The built-in predicate findall takes a goal as one of its arguments and collects all of the solutions to that goal into a single list. findall takes three arguments:

- The first argument, VarName, specifies which argument in the specified predicate is to be collected into a list.
- The second, mypredicate, indicates the predicate from which the values will be collected.
- The third argument, ListParam, is a variable that holds the list of values collected through backtracking. Note that there must be a user-defined domain to which the values of ListParam belong.

The **e02.pro** program uses findall to print the average age of a group of people.

```
        /* Program e02.pro */
class my
domains
   name = string.
   address = string.
   age = integer.
   list = age*.
predicates
   person : (name, address, age)
      multi(o,o,o).
   sumlist : (list, age, integer)
      procedure(i,o,o).
end class
implement my
clauses
   sumlist([],0,0).
   sumlist([H|T], Sum, N):-
      sumlist(T, S1, N1),
      Sum=H+S1, N=1+N1.
   person("Sherlock Holmes",
      "22B Baker Street", 42).
   person("Pete Spiers",
      "Apt. 22, 21st Street", 36).
   person("Mary Darrow",
      "Suite 2, Omega Home", 51).
end implement
goal
   console::init(),
   findall(Age, my::person(_, _, Age), L),
   my::sumlist(L, Sum, N),
   Ave = Sum/N,
   stdio::write("Average=", Ave, ". ").
```

The findall clause in this program creates a list L, which is a collection of all the ages obtained from the predicate person. If you wanted to collect a list of all the people who are 42 years old, you could give the following subgoal:

```
findall(Who, my::person(Who, _, 42), List)
```

Before trying this, please note that it requires the program to contain a domain declaration for the resulting list:

```
slist = string*.
```

## Compound Lists

A list of integers can be simply declared as

```
integer_list = integer*.
```

The same is true for a list of real numbers, a list of symbols, or a list of strings.

However, it is often valuable to store a combination of different types of elements within a list, such as:

```
[2, 3, 5.12, ["food", "goo"], "new"].
    /* Not correct Visual Prolog*/
```

*Compound lists* are lists that contain more than one type of element. You need special declarations to handle lists of multiple-type elements, because ***Visual Prolog requires that all elements in a list belong to the same domain***. The way to create a list in Prolog that stores these different types of elements is to use functors, because ***a domain can contain more than one data type as arguments to functors***.

The following is an example of a domain declaration for a list that can contain an integer, a character, a string, or a list of any of these:

```
domains
    /* the functors are l, i, c, and s */
  llist = l(list); i(integer); c(char); s(string).
  list = llist*.
```

The list

```
[ 2, 9, ["food", "goo"], "new" ]
    /* Not correct Visual Prolog */
```

would be written in Visual Prolog as:

```
[i(2), i(9), l([s("food"), s("goo")]), s("new")]
    /* Correct Visual Prolog */
```

The following example of append shows how to use this domain declaration in a typical list-manipulation program.

```
class my
domains
  llist = l(list); i(integer); c(char); s(string).
```

```
    list = llist*.
predicates
    append : (list,list,list) procedure (i,i,o).
end class
implement my
clauses
    append([], L, L).
    append([X|L1], L2, [X|L3]):-
        append(L1, L2, L3).
end implement
goal
    console::init(),
    my::append([my::s("likes"),
        my::l([my::s("bill"), my::s("mary")])],
        [my::s("bill"), my::s("sue")], Ans),
    stdio::write("FIRST LIST: ", Ans,"\n\n"),
    my::append([my::l([my::s("This"),
        my::s("is"),my::s("a"),my::s("list")]),
        my::s("bee")], [my::c('c')], Ans2),
    stdio::write("SECOND LIST: ", Ans2, "\n\n").
```

### Parsing by Difference Lists

The **ch07e10.pro** program demonstrates parsing by *difference lists*. The process of parsing by difference lists works by reducing the problem; in this example we transform a string of input into a Prolog structure that can be used or evaluated later.

The parser in this example is for a very primitive computer language. Although this example is very advanced for this point in the tutorial, we decided to put it here because parsing is one of the areas where Visual Prolog is very powerful. If you do not feel ready for this topic, you can skip this example and continue reading the tutorial without any loss of continuity.

```
#include @"pfc\exception\exception.ph"
#include @"pfc\string\string.ph"
#include @"pfc\console\console.ph"
class my_t
domains
    toklist = string*.
predicates
    tokl : (string, toklist) procedure (i,o).
end class
implement my_t
clauses
    tokl(Str, [H|T]) :-
        string::fronttoken(Str, H, Str1), !,
        tokl(Str1, T).
    tokl(_, []).
end implement
/* * * * * * * * * * * * * * * * * * *
* This second part of the program
* is the parser *
* * * * * * * * * * * * * * * * * * */
class my_p
domains
    program = program(statement_list).
    statement_list = statement*.
/* * * * * * * * * * * * * * * * *
* Definition of what constitutes
* a statement *
* * * * * * * * * * * * * * * * */
    statement =
        if_Then_Else(exp, statement, statement);
        if_Then(exp, statement);
        while(exp, statement);
        assign(id, exp).
/* * * * * * * * * * * * * * *
```

```
* Definition of expression *
* * * * * * * *  * * * * * */
   exp = plus(exp, exp);
      minus(exp, exp);
      var(id);
      int(integer).
  id = string.
predicates
   s_program : (my_t::toklist, program)
      procedure (i,o).
   s_statement : (my_t::toklist, my_t::toklist,
      statement) determ (i,o,o).
   s_statement_list : (my_t::toklist, my_t::toklist,
      statement_list) determ (i,o,o).
   s_exp : (my_t::toklist, my_t::toklist, exp)
      determ (i,o,o).
   s_exp1 : (my_t::toklist, my_t::toklist,
      exp, exp) determ (i,o,i,o).
   s_exp2 : (my_t::toklist, my_t::toklist,
      exp) determ (i,o,o).
end class
implement my_p
clauses
   s_program(List1, program(StatementList)):-
      s_statement_list(List1, _, StatementList),
      !.
   s_program(_, program([])).

clauses
   s_statement_list([], [], []) :- !.
   s_statement_list(
      List1, List4, [Statement|Program]) :-
      s_statement(List1, List2, Statement),
      List2=[";"|List3],
      s_statement_list(List3, List4, Program).
   s_statement(["if"|List1], List7,
      if_then_else(Exp,
      Statement1, Statement2)):-
      s_exp(List1, List2, Exp),
      List2=["then"|List3],
      s_statement(List3, List4, Statement1),
      List4=["else"|List5],!,
      s_statement(List5, List6, Statement2),
      List6=["fi"|List7].
   s_statement(["if"|List1], List5,
      if_then(Exp, Statement)) :- !,
      s_exp(List1, List2, Exp),
      List2=["then"|List3],
      s_statement(List3, List4, Statement),
      List4=["fi"|List5].
   s_statement(["do"|List1], List4,
      while(Exp, Statement)) :- !,
      s_statement(List1, List2, Statement),
      List2=["while"|List3],
      s_exp(List3, List4, Exp).
   s_statement([ID|List1], List3,
      assign(Id,Exp)) :-
      string::isname(ID),
      List1=["="|List2],
      s_exp(List2, List3, Exp).
   s_exp(List1, List3, Exp):-
      s_exp2(List1, List2, Exp1),
      s_exp1(List2, List3, Exp1, Exp).
   s_exp1(["+"|List1], List3, Exp1, Exp) :- !,
      s_exp2(List1, List2, Exp2),
      s_exp1(List2, List3, plus(Exp1, Exp2), Exp).
   s_exp1(["-"|List1], List3, Exp1, Exp) :- !,
      s_exp2(List1, List2, Exp2),
      s_exp1(List2, List3, minus(Exp1, Exp2), Exp).
```

```
    s_exp1(List, List, Exp, Exp).
    s_exp2([Int|Rest], Rest, int(I)) :-
        trap(I = toTerm(Int),Error,
            exception::clear_fail(Error)),
        !.
    s_exp2([Id|Rest], Rest, var(Id)) :-
        string::isname(Id).
end implement
goal
    console::init(),
    my_t::tokl(
        "b=2; if b then a=1 else a=2 fi; do a=a-1 while a;",
        Ans),
    stdio::write(Ans),
    my_p::s_program(Ans, Res),
    stdio::write(Res).
```

Load and run this program, then enter the following goal:

```
goal
    my_t::tokl(
        "b=2; if b then a=1 else a=2 fi; do a=a-1 while a;",
        Ans),
    my_p::s_program(Ans, Res).
```

Visual Prolog will return the program structure:

```
Ans=["b","=","2",";","if","b","then","a","=","1",
    "else","a","=","2","fi",";","do","a","=","a",
    "-","1","while","a",";"
    ],
Res=program([assign("b",int(2)),
    if_then_else(var("b"),assign("a",int(1)), assign("a",int(2))),
    while(var("a"),assign("a",minus(var("a"),int(1))))
    ])
1 Solution
```

The transformation in this example is divided into two stages: scanning and parsing. The tokl predicate is the scanner; it accepts a string and converts it into a list of tokens. All the predicates with names beginning in s_ are parser predicates. In this example the input text is a Pascal-like program made up of Pascal-like statements. This programming language only understands certain statements: IF THEN ELSE, IF THEN, DO WHILE, and ASSIGNMENT. Statements are made up of expressions and other statements. Expressions are addition, subtraction, variables, and integers.

Here's how this example works:

1. The first scanner clause, s_program, takes a list of tokens and tests if it can be transformed into a list of statements.
2. The predicate s_statement_list takes this same list of tokens and tests if the tokens can be divided up into individual statements, each ending with a semicolon.
3. The predicate s_statement tests if the first tokens of the token list make up a legal statement. If so, the statement is returned in a structure and the remaining tokens are returned back to s_statement_list.
    a. The four clauses of the s_statement correspond to the four types of statements the parser understands. If the first s_statement clause is unable to transform the list of tokens into an IF THEN ELSE statement, the clause fails and backtracks to the next s_statement clause, which tries to transform the list of tokens into an IF THEN statement. If that clause fails, the next one tries to transform the list of tokens into a DO WHILE statement.
    b. If the first three s_statement clauses fail, the last clause for that predicate tests

if the statement does assignment. This clause tests for assignment by testing if the first term is a symbol, the second term is "=", and the next terms make up a simple math expression.

4. The s_exp, s_exp1, and s_exp2 predicates work the same way, by testing if the first terms are expressions and – if so – returning the remainder of the terms and an expression structure back to s_statement.

## Summary

These are the important points covered in this tutorial:

1. *Lists* are objects that can contain an arbitrary number of elements; you declare them by adding an asterisk at the end of a previously defined domain.
2. A list is a recursive compound object that consists of a head and a tail. The head is the first element and the tail is the rest of the list (without the first element). The tail of a list is always a list; the head of a list is an element. A list can contain zero or more elements; the empty list is written [].
3. The elements in a list can be anything, including other lists; all elements in a list must belong to the same domain. The domain declaration for the elements must be of this form:

```
domains
  element_list = elements*.
  elements = ....
```

   where elements = one of the standard domains (integer, real, etc.) or a set of alternatives marked with different functors (int(integer); rl(real); smb(symbol); etc.). You can only mix types in a list in Visual Prolog by enclosing them in compound objects/functors.
4. You can use separators (commas, [, and |) to make the head and tail of a list explicit; for example, the list

```
[a, b, c, d]
```

   can be written as:

```
[a|[b, c, d]] or
[a, b|[c, d]] or
[a, b, c|[d]] or
[a|[b|[c, d]]] or
[a|[b|[c|[d]]]] or even
[a|[b|[c|[d|[]]]]]
```

5. List processing consists of recursively removing the head of the list (and usually doing something with it) until the list is an empty list.
6. The classic Prolog list-handling predicates member and append enable you to check if an element is in a list and check if one list is in another (or append one list to another), respectively.
7. A predicate's *flow pattern* is the status of its arguments when you call it; they can be *input parameters* (i) – which are bound or instantiated – or *output parameters* (o), which are free.
8. Visual Prolog provides a built-in predicate, findall, which takes a goal as one of its arguments and collects all of the solutions to that goal into a single list.
9. Because Visual Prolog requires that all elements in a list belong to the same domain, you use functors to create a list that stores different types of elements.
10. The process of *parsing by difference lists* works by reducing the problem; the example in this tutorial transforms a string of input into a Prolog structure that can be used or

evaluated later.