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An Introduction to PS-algol Programming

Persistent Programming
Research Report 31

Alan Dearle.

An Introduction to PS-algol Programming
Second Edition
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INTRODUCTION

PS-algol is the third member of a family of languages to be designed using a methodology based on the three semantic principles attributed to Strachey, outlined in Appendix1. The first, although we did not recognise it at the time, was a language invented by David Turner called algol-s and was used by him and Ron Morrison as the basis of a Senior Honours project at St Andrews University. David Turner subsequently took up an appointment at the University of Kent at Canterbury and the second language, S-algol was developed by Ron Morrison and Pete Bailey using the main ideas of algol-s. The third language is PS-algol and it incorporates the main concepts of both algol-s and S-algol as well as the concept of persistence developed at the University of Edinburgh.

The Data Curator project began in November 1979 founded by Malcolm Atkinson at the University of Edinburgh. Malcolm was joined by Ken Chisholm and Paul Cockshott and work began on the theoretical basis of persistence, its integration into a programming language and a support system for persistent data. After some dissatisfaction with attempts to integrate persistence with Algol 68 and Pascal contact was made with Ron Morrison and Pete Bailey in St Andrews.

In 1983, Ken Chisholm left the project and Malcolm Atkinson spent a year (August 1983-July 1984) at the University of Pennsylvania, USA. On his return he took up the second Chair of Computing Science at the University of Glasgow. Ron Morrison spent July 1983 to December 1983 at the Australian National University, Canberra and on his return was joined by Alfred Brown and Alan Dearle in St Andrews.

In 1983 ICL began collaboration with us on Persistent Programming at both Universities funding some of the work and setting up an absorber project to build compilers for PS-algol on the ICL machines - initially the ICL 2900 series. Late in 1984 the combined team were notified that they had been awarded funding for the PISA project, which was aimed at, among other things, further developing PS-algol.

In 1985 Paul Cockshott left the project but the group expanded with Ray Carrick and Richard Connor joining St. Andrews and Richard Cooper, John Livingstone and Douglas McFarlane joining the project at Glasgow. At this time also, Ron Morrison was appointed to the Chair of Software Engineering at the University of St. Andrews.

Work is currently continuing in a wide variety of areas, including: type systems, an interactive persistent enviroment, developing a stable store mechanism, a study of concurrancy issues, database applications, program development tools and architectures to support a persistent information space.

Present Team Members

University of Glasgow	University of St. Andrews	ICL
Malcolm Atkinson	Ron Morrison	Graham Pratten
Richard Cooper	Pete Bailey	Nick Capon
Jack Campin	Alfred Brown	John Robinson
John Livingstone	Ray Carrick	Malcolm Jones
Douglas McFarlane	Richard Connor	John Scott
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Associates

Peter Buneman
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Ken Chisholm
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Larry Krablin

1 SIMPLE PROGRAMS USING THE WRITE CLAUSE

Writing correct programs is a lot simpler if you use a good programming language. To show you how easy it can be in PS-algol we will write our first complete program straight away.

write *"This is a PS-algol program."*

The effect of this program is to print out the line of text

```
This is a PS-algol program.
```

Although it must be admitted that this is not very exciting, there are a lot of things about PS-algol programming that we can learn from it. First of all the word **write** is a command to the computer to print out the value of the expression (or, as we shall see shortly, perhaps the values of a list of expressions) that follows it. In this case the expression to be printed is

"This is a PS-algol program."

This particular expression is an example of a **string literal**. A string is one of the types of data we can use and manipulate in a PS-algol program. A string literal is a particularly simple sort of expression being just an ordered collection of characters including spaces and punctuation marks and indeed almost any other character you can type from your keyboard. A string literal must always be written in quotes as shown above. This is to enable the compiler to distinguish it from other types of literal which we do not wish to regard as strings.

Thus, for example, 156 is an integer literal but "156" is a string literal. The reason for making this distinction will become clear later. If you want to include a quotation mark " inside a string this causes a slight problem, since it will be mistaken for the end of the string. We overcome this difficulty by writing an apostrophe followed by a quotation mark '" side by side if we want the quotation mark inside the string. The apostrophe is a special symbol as we shall see later. If you want to use an apostrophe itself in a string you must type '', that is, two apostrophes, side by side.

The PS-algol compiler always evaluates expressions following the **write** command before printing them. The resulting value of a string literal is particularly simple being just the string itself. The quotation marks are stripped off by the compiler when the program is read into the computer. This explains why the output from the program is

```
This is a PS-algol program.
```

rather than

```
"This is a PS-algol program."
```

One final point about our first program. The word **write** has been printed in **bold** type. This is to emphasise that it is a special word that has a known meaning in PS-algol. Such a word is called a *reserved word* and is one of a whole list of reserved words that you will learn in the rest of this book. **We will always print reserved words in bold type,** *program text in italic and* `output from programs in a fixed spaced font` since this makes the program easier to read. When you write programs it is good practice to <u>underline</u> reserved words in your written copy. However when you type programs into the computer you don't need any of this formatting, it's simply to help in this book.

For our second example we will take

```
write 3 * 2 + 5 - 7
```

The spaces are optional and the computer will respond by printing

```
4
```

The reason for this is that the expression following the write command is an integer expression and this is evaluated before printing the result. The asterisk '*' indicates multiplication and is used to avoid confusion between the usual multiplication sign and the letter x. This is common practice in computing and is a consequence of poor printing facilities on early computers which had no multiplication sign. Note that if we had written

```
write "3 * 2 + 5 - 7"
```

the computer would have responded by printing

```
3 * 2 + 5 - 7
```

since we would be asking it to print a string literal.

We mentioned before that we could follow the write command with a list of expressions. To form such a list we simply write down the expressions separated by commas. It should now be obvious that the program

```
write 3 + 4 - 9 , 3 * 2 + 5
```

will produce the output

```
-2      11
```

since the list contains the two expressions *3 + 4 - 9* and *3 * 2 + 5* both of which are evaluated separately before printing.

It is not necessary for each of the expressions in a list to be of the same type. It is good programming practice to make your results as readable as possible. Thus we could write the program

```
write "3 + 2 * 6 = " , 3 + 2 * 6
```

giving the output

```
3 + 2 * 6 = 15
```

since the first expression is a string literal and the second an integer expression. You may have started wondering if the answer to the above example is 15 or 30 depending on the order in which you do the arithmetic. For the moment we will say that the order is the same as you would do it in ordinary arithmetic but we will come back to this point in a later chapter. In the meantime if you are in any doubt you can use brackets to make the meaning clear. Thus

```
( 3 * 2 ) + ( 4 * 4 )
```

has the same value as

```
3 * 2 + 4 * 4
```

but not the same as

```
3 * ( 2 + 4 ) * 4
```


As another example of mixing expressions consider the program

```
write "The square of 27 is" , 27 * 27, " and its cube is ", 27 * 27 * 27, "."
```

You should now understand why the result printed is

```
The square of 27 is 729 and its cube is 19683.
```

We do not have to stick to integers in doing arithmetic. If we write

```
write ( 7.8 * 9.2 + 3.6 ) / 1.2
```

we will obtain the result

```
62.8
```

We have used here the division sign which, in computing, is the oblique stroke /. The numbers used, all of which have a decimal point in them, are called real numbers to distinguish them from the integers which do not have a decimal point but only an implied one after their rightmost digit. Thus

```
187
```

is an integer according to the definition but

```
187.0 and 187.
```

are both real numbers. A real number must always start with a digit. Thus the fraction $^1/_2$ must be written as 0.5 and not just .5.

You are allowed to mix integers and real numbers in an expression but if you do the answer will always be given as a real number. Thus

```
write 5 * 27 / 1.2
```

will give the result

```
112.5
```

and

```
write 6 * 27 / 1.2
```

will give the result

```
135.0
```

When we spoke about integer arithmetic earlier on, we deliberately avoided using the division operator because it is not always obvious what the result should be. If we divide 4 by 2 then the answer is 2 but if we divide 5 by 2 then the exact answer is 2.5 if we are working in real arithmetic, or 2 with remainder 1 if we are working in integers. Computers are stupid things and we have to make clear distinctions in cases like this to be quite clear what we mean. To be fair to computers, some human beings have the same problem!

We make the situation unambiguous by insisting that the division operation, when we use /, will always have a real result.

Thus	7 / 2	will have the result	3.5
and	6 / 2	will have the result	3.0

both answers being real numbers.

Recognising that sometimes we do want to do integer arithmetic with integer answers we introduce two new operators **div** and **rem** which work as follows

	9 **div** 4	gives the integer result	2	which is the integer result of dividing 9 by 4
and	9 **rem** 4	gives the integer result	1	that is, the remainder on division of 9 by 4.

These new operators can be used in integer expressions in exactly the same way as the other arithmetic operators. Note that both **div** and **rem** are reserved words.

The following example uses **div** and **rem** to convert a given number of days to the corresponding number of weeks and days.

write *278, " days is ", 278* **div** *7, " weeks and ", 278* **rem** *7, " days."*

will output

```
278 days is 39 weeks and 5 days.
```

To finish off this chapter we will give one more example of a **write** clause using a string literal. The program

write
" Mary had a little lamb,
Its fleece as black as soot,
And everywhere that Mary went,
Its sooty foot it put."

will produce the output

```
Mary had a little lamb,
Its fleece as black as soot,
And everywhere that Mary went,
Its sooty foot it put.
```

The poem is spaced out in lines like this because when the program is typed at a computer terminal, a key giving a new line has to be pressed and an internal character corresponding to this new line is stored away with the string itself. Note also that in order to place the output nearer to the centre of the page, the opening quote was put over at the left margin. This took up one character itself so, to give the same number of spaces before each line in the actual output, we put the opening M one space further across in the first line. We could have avoided this particular difficulty by typing the initial quote followed by a new line immediately but this would have left an extra blank line before the first line of the poem.

In all the previous examples the output generated by different expressions in a list continued on the same line. To give the user fuller control over the layout of output on the printed page we introduce a new print line convention. In addition to being able to get new lines as in the above example you can also get a new line by typing 'n, that is, the apostrophe character followed by an n, as part of any string literal in the write clause.

To illustrate this point consider the program

write *3 + 2, 5 * 7*

with output

```
5          35
```


If we had written it as

write *3 + 2 , "'n", 5 * 7*

the output would have been

```
5
35
```

At this stage in learning to program this probably seems a clumsy way to control output but we will see later that it is part of a powerful and flexible system.

Exercises 1

1.1 Write a program to print your name and address as you would write it on an envelope.

1.2 Write a program to convert 584 ounces into pounds and ounces. Your output should not just be two numbers but a statement that the given number of ounces is equal to so many pounds and so many ounces.

1.3 In this chapter you have learned three reserved words. What is meant by a reserved word and what are the three reserved words you have learned ?

1.4 The expressions you have learned so far are of type string, integer and real. What are the types of the following expressions and what are their values?

(i) 3 + 2 * 6
(ii) "3 + 2 * 6"
(iii) 5.4 * 6.4 + 2.3 * 3.7
(iv) 8 div 3 + 15 rem 6
(v) 6 + 8 / 2
(vi) (-9) div 2

1.5 Write a program to print on two lines the statements

```
The square of 24 is 576
The square of 31 is 961
```

Your program should only use the word **write** once and should calculate the two squares itself.

1.1 write " *Professor A.J.Cole,*
'"Inisheer'",
Barnyards,
Kilconquhar,
FIFE."

Note the apostrophe, quote symbols around the name of the house appear in the output as single quotes. Why has the name of the professor not been written above the address? How could you overcome this easily? (See "Mary had a little lamb").

1.2 write *584, " ounces is equal to ", 584 div 16, "pounds and ",*
584 rem 16," ounces"

Note that although that we have run over to a new line in writing the program, the output will all appear on the same line since there are no new line symbols inside the string literals and we have not used the 'n symbol. The output will be

```
584 ounces is equal to 36 pounds and 8 ounces
```

1.3 A reserved word is a word which has a special meaning in the PS-algol language. Reserved words must only be used in a program when they have the intended meaning unless they happen to be part of a string literal when their fixed meaning is ignored. The three reserved words we have met so far are **write**, **div** and **rem**.

1.4 (i) type integer, value 15
(ii) type string, value "3 + 2 * 6"
(iii) type real, value 43.07
(iv) type integer, value 5. Note that 8 **div** 3 has value 2 and 15 **rem** 6 has value 3.

(v) type real, value 10.0. Note that 8/2 is of type real since the operation is real division. It makes no difference that 2 happens to divide 8 exactly.

(vi) type integer, value -4. This one is a bit unfair since we did not talk about integer division with negative numbers. The rule is as follows. Forget about the signs and apply **div** as if both numbers were positive. Then if exactly one of the two numbers is negative make the answer negative. Note that x **rem** y is always x - y * (x div y).

1.5 write *"The square of 24 is ", 24 * 24, "'nThe square of 31 is ", 31 * 31*

Note that the new line symbol 'n appears inside the quotes.

2 INITIALISATION AND ASSIGNMENT CLAUSES

In Chapter 1, whenever we used a number or a string we had to write it explicitly in the program. This meant that whenever we wanted to repeat the calculation with different numbers or strings we had to rewrite the whole program. The main reason for using a computer is to save time and effort and one way of doing this is to write programs which will work for many different sets of data. For example, in the program which worked out the square and cube of 27, the program would be more useful if, instead of just working with the number 27, it could be modified to 'read' an integer and then calculate its square and cube. Thus the same program could be used to calculate the squares and cubes of many different integers. The following PS-algol program will do this for us.

```
write "Please enter an integer: "
let X = readi()
write "The square of ", X," is ", X * X, " and its cube is ", X * X * X
```

The clauses in this program need some explanation but first we will give a general idea of how it works. The program first 'reads' an integer which is supplied by the user and makes this the value of the object called X. You can think of X as being the name of a pigeon-hole inside the machine and the user writes an integer, say 30, on a piece of paper and pops it in the pigeon-hole. X is then the name of the pigeon- hole and 30 is the value of X. The effect of evaluating the very simple expression X in the write clause list is to find its value which is 30. Similarly X * X works out 30 * 30 and gives the answer 900 and X * X * X gives 27000. The effect of the whole program given 30 as data is to print

```
The square of 30 is 900 and its cube is 27000
```

The clause

let *X = readi()*

is an example of an **initialising declaration** and introduces four very important ideas.

(i) The reserved word **let** is used to indicate that the name of a new object is to follow, in this case the name is X. Every time we want to use a new name for an object in our program we do it in this way. Some primitive programming languages allow you to use names without specifically declaring them in this way, but although this may be easy to start with, it can cause a lot of trouble later.

(ii) The *readi()* part of the clause causes the computer to 'get' an integer from somewhere. For the moment we will suppose that 'get' means that the computer waits for the user, that is you, to type in an integer from the terminal when the program is running. There are many other ways in which the computer can 'get' an integer but we will leave these for the present. If, by the way, you do not type an integer here but perhaps type a string, PS-algol will tell you that you have made a mistake in the data and stop running your program.

(iii) The = part of the clause does two things. It puts a copy of the integer you have just supplied into the pigeon-hole named X and tells the system that this is a constant and must not be changed in your program during execution. PS-algol will keep an eye on it and if you try to alter the value of X in the rest of your program it will print you an error message at compilation time. Although this may seem tedious to the beginner it is of great help in avoiding errors when you come to write more complex programs.

(iv) The fact that we have written *readi* ensures that the number to be read is an integer. It also tells PS-algol that X is to hold an integer and this information is also remembered by the compiler and can be used to detect subsequent errors in your program.

You should now go back and read the above program again and make sure that you understand what it does. In addition to the *readi* clause we also have *readr* and *reads* clauses which as you may guess read a real number and a string respectively. Thus

let *Y = reads()*

will read a string and assign it to Y which will now have the type string attached to it and similarly for readr. Data supplied by the user at execution time must satisfy the same syntactic conditions as literals included as parts of programs as discussed in Chapter 1. In particular, string literals must be enclosed in quotes, integers do not have a decimal point and reals may be either in the format described in Chapter 1 or may be given as integers which will be converted into real numbers internally. Successive reals or integers must be separated either by spaces or by appearing on a new line. The condition that string literals must be enclosed in quotes may seem a nuisance to the beginner but the reason for it is to keep to a minimum the conditions to be imposed on the way in which string literals can be written. We will discuss later how to remove this condition when you have learnt more about programming and when you know more about the sort of data that may be supplied to a particular program.

Initialising declarations do not necessarily have a read command on their right hand side. Any expression can be written. So

```
let N = 1
```

makes the object of name N an integer constant with value 1 and

```
let P = 3.0 * 6.5 + 4.3
```

makes P a real constant with value 23.8. Note that PS-algol is clever enough to deduce the type of an expression without you having to tell it.

Expressions can involve previously declared objects as well as literals. You can declare these yourself or as in the following example use one such as *pi* which is predeclared by PS-algol itself.

```
write "Enter the radius: "
let radius = readr()
let area = pi * radius * radius
let circumference = 2.0 * pi * radius
write "The area of a circle of radius ", radius, " is ", area,
        " 'nand its circumference is ", circumference, ".'n"
```

If the value 2.6 is given to radius then the result will be

```
The area of a circle with radius 2.6 is 21.2372
and its circumference is 16.3363.
```

You can use as many letters as you like for the name of an object. You may also use digits and the full stop character provided that you always start the name with a letter. Thus

average

K9

father.christmas

are all valid object names. On the other hand

14B

is not since it does not start with a letter and

santa claus

is not since it has a space in the middle. (*santa.claus* is of course valid). It is good programming practice to give names to objects which indicate their use since it makes the program easier to read and understand.

This is why you are allowed to use the full stop and you can use names like

lower.limit

or

pupil.name

All the above declarations introduce names which are to be used and make them constant. We also need to use variables whose value can change during the execution of a program. This is possible using a slightly different declarative clause. For example

```
let count := 0
```

declares the variable with name *count* to be an integer with initial value 0. The combination of characters := is used in place of = to indicate that count is a variable whose value can be changed later. Once the variable's name has been declared in a let clause, subsequent clauses which change its value are written without the let. For example

```
count := count + 1
```

This clause may be read as 'count becomes count plus one' and the meaning is always, 'evaluate the right hand side and assign the new value to the variable named on the left'. The clause above thus adds one to the current value of the variable count. PS-algol will check for you that the type of the expression on the right is the same as that of the identifier on the left and will give an error message if it is not. To the beginner this may seem an added and unnecessary complication but the reason is again to enable PS-algol to help you avoid obscure errors in more complicated programs you may write later on. The one exception to this rule is that integer expressions may be assigned to real variables in which case their values are automatically changed to real for you. We will now give some examples of the use of these ideas. The first example is to print the value of an expression which uses a complicated factor several times.

```
let Q = 1.73 + 4.2 * 0.73
write 5.69 / ( 2 * Q ) + 4.16 / ( ( 3 * Q - 7.77 ) / ( 4 * Q ) )
```

Note that PS-algol sorts out the mixture of reals and integers and prints the answer as a real. Next we print out the square and the cube of a number by a method different from that above.

```
write "Enter a number: "
let X = readr()
let Y := X * X
write "The square of ", X," is ", Y
Y := Y * X
write " and its cube is ", Y, " 'n"
```

In this case X is a real constant with a value that is read in, say 3.86. Y is declared to be a variable of type real with its first value being X squared. The first write clause produces the output

```
The square of 3.86 is 14.8996
```

Y is then given a new value which is the old value times X. That is, the new value of Y is X cubed and the second write clause prints

```
and its cube is 57.512456
```

on the same line as the first since we have not used a new line symbol in either clause. This is rather a clumsy way of solving the problem since the program

```
write "Enter a number: "
let X = readr()
write "The square of ", X," is ", X * X, " and its cube is ", X * X * X
```

would do the same thing. However, the example shows that X is a constant and Y is a variable in the program.

It is useful to put comments into a program, to help explain to the reader what is being done, but which are not really part of the program itself. In PS-algol this is very easy. We use the exclamation mark symbol ! to indicate that anything following it on the same line is a comment and should be ignored by the PS-algol compiler. It is good practice to put a comment at the start of each program giving your name and what the program is intended to do. For example, we could write a program to convert money in sterling to francs and lire reading in the sum of money we wish to convert and the exchange rates from British to French and Italian currency as follows.

```
! Joe Bloggs. Conversion from sterling to francs and lire
! Data is a value in pounds and pence written as one decimal
! e.g. 28.18, and the current conversion rates for francs and lire

write "Enter the amount in sterling: "
let sterling.value = readr()
write "Enter the franc and lire rates please: "
let franc.rate = readr () ; let lire.rate = readr()
write sterling.value, pounds convert to ", sterling.value * franc.rate,
                        " francs and ", sterling.value * lire.rate, " lire'n"
```

We have slipped in a new idea here. We have put two clauses on one line and separated them by a semi-colon. You can separate clauses in this way anywhere you like in your program if you feel that it makes it easier to understand.

If you are a beginner this is probably the most difficult chapter to understand in the book. If you have had any difficulty go back and read it again. If you still do not fully understand it do not despair. Read it again after the next few chapters.

Exercises 2

2.1 Write down initialising declarations for the following

(i) An integer variable P with value 6.
(ii) A real constant Q with value 3.68 * R + 2.2.
(iii) A string constant with value "Yes".

2.2 What is the type of the name T in each of the following clauses. Indicate also whether it is constant or variable.

(i) let *T = 59 div 13*
(ii) let *T := reads()*
(iii) *T := 5 + 7 / 3*
(iv) let *T = "1.4"*

2.3 Write a program to convert a temperature in degrees fahrenheit to degrees centigrade. Your program should read the number of degrees fahrenheit as a real number. Include comments to say what you are doing and use meaningful names.

2.4 Write a program to work out the value of pi squared using the value of pi given by PS-algol. Also work out the number 22/7 and write out its value and its difference from the value of pi given. Do the same thing for pi squared and 22/7 squared putting your answer on a new line. You should include comments on what you are doing and also include string literals in your write clause to make the whole output understandable without reading your program.

2.5 A simplified tax system computes the tax due on the income for a given person by first computing the taxable income by subtracting the personal allowance and child allowance for each child from the income. The tax due is then equal to the current tax rate times the taxable income. The nett income is equal to the income minus the tax due. Assuming that the child allowance is $500 per child and the tax rate is 28% write a program to read in, for one individual, the salary, personal allowance and number of children and to print out the income, taxable income, tax due and net income. Both your program and your output should be self-explanatory.

Solutions to Exercises 2

2.1 (i) **let** *P := 6*
(ii) **let** *Q = 3.68 * R + 2.2*
(iii) **let** *S = "Yes"*

2.2 (i) integer constant
(ii) string variable
(iii) real variable. Remember that a / b is real
(iv) string constant

2.3

```
! Jack Cole. Convert from fahrenheit to centigrade.

let fahrenheit = readr()
write fahrenheit, " degrees fahrenheit converts to ",
        ( fahrenheit - 32 ) * 5 / 9," degrees centigrade'n"
```

2.4

```
! Jack Cole. Comparison of pi with 22 / 7
! and the comparison of the corresponding squares.

let pi.approx = 22 / 7
write "The value of pi is ", pi,
      "'nand the value of 22 / 7 is ", pi.approx,
      "'n and their difference is ", pi - pi.approx,
      "'n The value of pi squared is ", pi * pi,
      "'n and the value of 22 / 7 squared is ", pi.approx * pi.approx,
      "'n and their difference is ",
      pi * pi - pi.approx * pi.approx, "'n"
```

Note that it might have been better to introduce two new constants by

```
let pi.sq = pi * pi
let pi.approx.sq = pi.approx * pi.approx
```

and to have used these values directly in the write clause. Try rewriting the program using this idea.

2.5

```
! Jack Cole. Program to compute tax etc.

let child.allowance = 500       !More readable than writing
let tax.rate = 0.28             !500 and 0.28 in the program.

let income = readr()
let allowance = readr()
let no.of.children = readi()

let taxable.income = income - allowance - no.of.children * child.allowance
let tax.due = taxable.income * tax.rate

write "Income",income,
      "'nTaxable income",taxable.income,
      "'nTax due",tax.due,
      "'nNett income",income - tax.due,"'n"
```

Note that you have not yet learnt how to test for a negative taxable income. We will show you how to do this in Chapter 4 so we will assume for the moment that the data supplied is compatible with the method of solution! You will also learn how to control the layout of real numbers in a write clause in Chapter 8.

3 THE FOR AND WHILE CLAUSES

The programs we have written so far have been simple lists of clauses with each clause being executed once only. Computers are particularly good at doing repetitive tasks and we write programs to make use of this fact. Since many problems can be solved in this way, we introduce some special clauses to help in making the computer repeat sequences of clauses.

Most programming languages have a **for** clause and PS-algol is no exception. The following program works out factorial n. Factorial n is defined as n * (n-1) * ..... * 2 * 1 for a given n.

```
!J.Cole. Factorial program

write "Enter number: "
let n = readi() ; let factorial := 1
for i = 2 to n do
   factorial := i * factorial

write "factorial ", n, " is ", factorial, " 'n"
```

There are three new reserved words used here, namely **for**, **to** and **do**. The **for** clause does several things. Firstly it declares a new integer *i*. This integer *i* is initially set to 2 and the clause following **do** is executed provided that *n* = 2. The effect of the clause following **do** is to multiply 1 by 2 and put the result in *factorial*. The computation then goes back to the start of the **for** clause and adds 1 to *i* making its new value 3, tests this against *n* and if *i* <= *n* repeats execution of the clause following **do** making the new value of factorial equal to 6. It continues in this way until, for the first time, the new value of *i* exceeds the value of *n*. At this point it skips over the clause following **do** and continues with the **write** clause. Notice we have put the clause

```
factorial := i * factorial
```

a little across the page. PS-algol ignores spaces so we can write our programs like this to make them more readable. The way we have written out the program emphasises the fact that this clause is the one 'controlled' by the **for** clause. You should get into the habit of laying out your programs so that they are readable. Keep an eye on how it is done in this book and try to copy the ideas.

There are several points to note about the **for** clause. The name *i* used above can be replaced by any other name we wish to use. To be consistent with our earlier notation for assignment we have used = rather than := in the **for** clause. At first sight this appears to be a contradiction since *i* takes successive values 2, 3, ... and in this sense is not a constant. However the logical interpretation is that each time the computation returns to the **for** part of the clause it defines a new constant *i* with the incremented value. The important thing is that *i* is a constant in the clause controlled by the **for** clause (ie. *factorial := i * factorial)* and cannot be changed by programmed assignment. This is good programming practice since even experienced programmers find logical difficulty in using **for** clauses in languages which allow internal assignment to the control variable. If you really want to program this way you can do it by using the **while** clause to be described later in this chapter but the effect will be entirely your own responsibility. Note that *i* only exists while the **for** clause is being executed. If we tried to print *i* instead of *n* in the **write** clause we would be told by the compiler that it no longer existed.

The numbers 2 and *n* used in the above **for** clause are simple examples of integer expressions. You can use any integer expressions you please in **for** clauses. The value of *i* is set initially to the value of the first expression and the limit for *i* is set to the second.

The above form of the **for** loop always counts in 1's. If we wished to count in 2's say, we could modify the clause to

```
for i = 1 to n by 2 do
```

The new reserved word **by** tells PS-algol that the count is to be done in steps of 2 (in this case). More generally we can put any integer expression in place of 2.

It would be very restrictive to allow only one clause as written above to be controlled by the **for** clause. If we want to execute several clauses we can do this by taking a sequence of clauses and surrounding them with braces { and }, or by the reserved words **begin** and **end**. For small sequences of clauses it is probably clearer to use braces. The sequence of clauses is a very important concept in PS-algol and although the sequence contains several clauses inside itself, it is regarded as a single clause. We regard a complete PS-algol program as a sequence of clauses in this sense.

The following example illustrates the use of a sequence controlled by a **for** clause.

```
! J.Cole.  Program to print a shopping list and total cost.

write "Shopping list 'n"          !This gives a heading to the output
let total := 0.0                  !This initialises the total cost to zero
let no.of.items = readi()         !This gets the total number of items
for I = 1 to no.of.items do
begin
        let quantity = readi()
        let name = reads()
        let cost.per.item = readr()
        let line.total = quantity * cost.per.item
        total := total + line.total
        write quantity, name, " at ", cost.per.item, line.total, " 'n"
end                               !Notice the program layout
write "Total cost of bill is ", total, " 'n"
```

The meaning of this program should be obvious. Note that the only variable in the program is *total*. Although *quantity*, *name* and *cost.per.item* all change their value, they remain constant during any one particular execution of the sequence of clauses. Because the word **let** is inside the sequence for each of the items, they are redefined as new constants each time the sequence is repeated. On the other hand, *total* is declared outside the sequence since we want to set it to zero initially, accumulate its value and then eventually print it out after all the items have been read in and added to the list.

A suitable data set for this program could be

```
6
2       " lbs of sugar    "     0.16
1       " lb of butter    "     0.60
6       " oranges         "     0.10
3       " bottle coke     "     0.27
1       " tin pears       "     0.48
6       "boxes matches "        0.03
```

Note that the items may be separated by either a new line or at least one space. By writing out the data as we have done, we ensure that the strings all have the same length by padding them out with spaces, so we will get a nice neat layout for our bill. We will describe more elegant ways of doing this later on.

We could have used braces here instead of the words **begin** and **end** but it is clearer not to. It is probably better to save the braces for use when all the clauses in the sequence can be put on the same line.

To avoid confusion in the future we need to introduce briefly a new idea, namely that of the scope of an object. As we have seen in the above example we can declare new objects by initialisation clauses anywhere we like in the program. However, if we define a new object in a particular sequence of clauses that object only remains in existence at execution time from the point of its declaration to the end of the sequence. This is called the scope of the object. The moment we leave the sequence, that is, execute another clause outwith the sequence, then all the objects declared inside the sequence are no longer in scope. If after leaving the sequence we enter it again a new 'instance' of the object is created and this has no recollection of previous instances.

Declaring *total* in the program above as a variable in the outer sequence allows us to accumulate a running total each time we enter the inner sequence. None of the other information in the inner sequence is required in the long term so it can be safely declared there and does not remain in existence to cause possible trouble

later. Note also that although, for example, *quantity* may well be given a different value each time we enter the sequence in which it is declared, that value remains constant during the current execution of the sequence. It can and should be declared using '=' rather than ':='. It would not be wrong to use ':=' but it is better programming practice to recognise which objects are constant and which are variables and to declare them accordingly.

This discussion of scope should help to clarify the argument for regarding the control identifier in a **for** loop as a constant rather than a variable.

One final point about scope. If we declare an object in an inner sequence with the same name as one in an outer sequence then the existence of the outer object is temporarily suspended and a new object with the same name is created. On leaving the inner sequence this new object is discarded and the old one reinstated along with its suspended value. This facility is not of much use to the beginner but is very useful when programs are being written jointly by several people, so that someone writing an inner sequence does not have to be told and have to check the name of every object in the outer sequence so as to avoid using these names twice with different meanings.

The **while** clause gives us an alternative way of constructing a repetitive part of a program. We begin by rewriting the first example using the **while** clause.

```
! J.Cole.  Alternative factorial program.

let n = readi() ; let factorial := 1 ; let I := 2
while I <= n do { factorial := I * factorial ; I := I + 1 }
write "factorial ", n, " is ", factorial, " 'n"
```

The way in which the **while** clause works is that the condition which follows the word **while** is evaluated. The answer could be true or false. If it is true then the clause following **do** is evaluated and then the condition is evaluated again. So long as the condition remains true this process is repeated but as soon as the condition becomes false the program jumps over the clause following **do** and continues with the next part of the program. Try following through the action of this program with n being given a value 5 say.

We have talked about the condition following the word **while**. It would have been more accurate to have referred to this as a **boolean expression**. A boolean expression is an expression which evaluates to one of two values true or false. The particular example that we have given namely *I <= n* is either true or false at any particular instant in time. We will see later on that we can write quite complicated boolean expressions and any such one will do to control a **while** loop.

Notice that one of the clauses in curly brackets changes one of the variables in the condition. If this were not the case the boolean value of the condition would never change and the looping operation would go on for ever.

This particular example makes the programming slightly more difficult than the previous one using the **for** clause. However, there are many cases in which we cannot replace the **while** clause by an equivalent **for** loop. To show the full power of the **while** loop we really need some more examples but we will illustrate the point with the shopping list program above. One very artificial thing that we did in the example was to count the number of items in our list and give that number as the first piece of data. This was necessary so that we could set up the count for the **for** loop. We will eliminate the need to count the number of data items, making the computer do it for us, by adding one extra row to our shopping list data with a value that cannot possibly occur. For example we will never want to include a line for zero articles, so we set up the data as follows

```
2       "lbs of sugar    "      0.16
1       "lb of butter    "      0.60
6       "oranges         "      0.10
3       "bottle coke     "      0.27
1       "tin pears       "      0.48
6       "boxes matches "        0.03
0
```

and we write our program using the **while** clause.

```
write "Shopping list 'n"
let total := 0.0 ; let quantity := readi()
while quantity ~= 0 do
begin
        let name = reads() ; let cost.per.item = readr()
        let line.total = quantity * cost.per.item
        total := total + line.total
        write quantity, name, " at ", cost.per.item, line.total, " 'n"
        quantity := readi()          !This is where we change the condition
end
write "Total cost of bill is ", total, " 'n"
```

Notice that the program starts by reading the integer 2 at the start of the first line. The test is to see if 2 is not equal to 0 and this is true. We proceed to read the other two items on the line and continue with the calculations as before. Finally, the last clause reads the first integer on the next line and then goes back to test the condition

quantity ~= 0

again. The symbol ~= is "not equal to". So this clause is "quantity is not equal to 0" (he not symbol may also be used before any boolean as can be seen in the next example). It continues to repeat this operation until it finally reads 0 and at this stage the condition 0 ~= 0 is false and for the first time we jump out of the loop and finish off the program. Notice also that by being cunning and putting the second two read clauses inside the sequence at the beginning we only have to put a single 0 on the last line and not a whole line of redundant data.

An even better way to terminate the input of data for this problem requires another programming concept, namely that of the file. In most computer systems it is possible to record collections of information in files and to refer to these files by their names. In particular your terminal is regarded as a file and you supply the information for the file from the keyboard. Other files in the system have a predefined fixed amount of information in them and are always terminated by an end of file (eoi). On your terminal there will be some combination of keys (e.g. control z) which signifies that no more information is to be supplied from that source. You will need to consult your operating system manuals to find the particular eoi symbols for your terminal. Once you have terminated input in this way you need special techniques, which we will not discuss here, to continue input again. However, in our example, we do not need to put in any more data after the end of our shopping list so, instead of a single 0 as above we can terminate our input with eoi. We can now use ~eoi as the boolean expression controlling our **while** loop. The ~ symbol means boolean negation. That is, if eoi is false then ~eoi is true and therefore ~eoi will not terminate the execution of the loop until input ceases with eoi. This also avoids the clumsiness of having to declare *quantity* outside the loop and then to alter its value at the end of the clause controlled by the **while** loop. Furthermore, *quantity* becomes a constant rather than a variable. The complete program is now

```
write "Shopping list'n"
let total := 0.0
while ~eoi do
begin
        let quantity = readi() ; let name = reads() ; let cost.per.item = readr()
        let line.total = quantity * cost.per.item
        total := total + line.total
        write quantity, name, " at ", cost.per.item, line.total, " 'n"
end
write "Total cost of bill is ", total, " 'n"
```

The **while** clause as described above has its test for execution before any of the code in the controlled clause. This means that whenever the test fails, including possibly the first time that the test is made, the controlled clause is skipped over. Thus the controlled text can be executed zero or many times. It is useful to have another construct which tests after the execution of the controlled clause, thus ensuring that the controlled clause is executed at least once.

The repeat construct enables us to do this. For example

```
repeat
        x := 0.5 * ( x + a/x )
while rabs( x - a/x ) > 0.000001
```

This piece of program assumes that x has been initialised to some suitable starting value and then applies the Newton iterative square root calculating formula until the condition is satisfied. The calculation for a new x is carried out at least once. A function *rabs* has been used here. It calculates the absolute value of the real number which is its argument. A corresponding function *abs* calculates the absolute value of its integer argument. We will see later that functions are a very important and powerful programming mechanism that we will make good use of. It is tedious to have to write out very small or very large constants in full. To alleviate this problem we use the notation 1.0e-6 to indicate that 1.0 is to be multiplied by 10 raised to the power -6. We could have written the constant 0.000001 in this way.

As another example, consider the following program segment to calculate factorial n where n is assumed to have been assigned an integer value > 1

```
let factorial := 1 ; let i := 2
repeat
begin
        factorial := factorial * i
        i := i + 1
end
while i <= n
```

A third variation on the position of the test condition in this construction would be for it to appear in the middle of the controlled clause rather than at the beginning or end. This can be done with a combination of the **repeat** and **while** constructs. As an example, consider the problem of reading a large number of positive real numbers in order to find their how many there are, their sum and the sum of their squares. Very often we don't know how many numbers there are and there is no point in counting them if we have a computer to do it for us. In some cases where information is being gathered as the computation proceeds we may not even know how many pieces of data there are going to be. In our case we have assumed that all the data is positive so we will arbitrarily terminate our data with a zero which is not to be counted as a real data item. You can almost always choose some impractical value as a terminator for the data in practical problems as we did in the second attempt at the shopping list example.

A program sequence to carry out the above calculation would be

```
let number := 0 ; let sum := 0.0
let sum.sq := 0.0 ; let item := 0.0
repeat item := readr()
while item > 0 do
begin
        number := number + 1
        sum := sum + item
        sum.sq := sum.sq + item * item
end
```

Here the test takes place after each new item has been read and so long as the test has the value true, the segment following it is evaluated followed by a new evaluation of the segment immediately following the word **repeat**. Note that the initialisation of the variables *number*, *sum* and *sum.sq* must take place before the word **repeat**. The reason for initialising item to 0.0 before the repeat rather than by writing

```
let item := readr()
```

is more subtle. Briefly, the reason is that the clause between **repeat** and **while** is syntactically separate from that following **do**. The declaration of a variable in the first clause would not be in the scope of the second clause and would lead to a syntax error being indicated.

Exercises 3

3.1 Determine the values written out by the following programs.

(i) **for** *I = 3* **to** *7* **do write** *I*
(ii) **for** *J = 1* **to** *9* **by** *2* **do write** *J*
(iii) **for** *K = 0* **to** *15* **by** *3* **do write** *K*
(iv) **for** *L = 1* **to** *8* **by** *2* **do write** *L*
(v) **let** *K = 3* ; **let** *M = 5*
for *J = K* **to** *M * K* **by** *M* **rem** *K* **do write** *J*
(vi) **for** *I = 10* **to** *3* **by** *-3* **do write** *I*

3.2 Write a program to output a heading saying `'number square cube'` and then use a **for** loop to output a table of squares and cubes of integers between 1 and 20. The fifth line, for example, should read

```
5 25 125
```

3.3 It is permissible to write a **for** clause inside a **for** clause. Work carefully through the following program step by step to see what it does.

```
for I = 1 to 5 do
begin
        write "'n", I
        let K := I * I
        for J = 1 to 3 do { write K ; K := K * I }
end
```

3.4 Rewrite your answer to question 3.2 using a **while** loop instead of a **for** loop.

3.5 Write a program to read in three real numbers a, b and c where a is less than b and print out a table of squares and cubes starting from a and going in steps of c as far as you can without getting greater than b. Thus, for example, if a = 3.10, b = 4.20 and c = 0.35 your output should look like

```
number      square          cube
 3.10       9.6100       29.791000
 3.45       11.9025      41.063625
 3.80       14.4400      54.872000
 4.15       17.2225      71.473375
```

3.6 Write a program to read in the names of football teams together with the number of wins, losses and draws and print out the same information together with the total number of points giving 2 for a win, 0 for a loss and 1 for a draw. Thus a typical line of information could be

```
"East Fife"  14 0 5
```

and the corresponding output would be

```
East Fife  14 0 5 33
```

The data should end with a team name of "****".
You are not expected to sort them into order (yet!).

3.7 Determine the values printed by each of the following program segments

(i)
```
let i := 1
while i < 10 do
begin
        i := i + i
        write i, "'n"
end
```


(ii)
```
let i := 1
repeat
begin
        i := i + i
        write i, "'n"
end
while i < 10
```

(iii)
```
let i := 1
repeat write i, "'n"
while i < 10 do i := i + i
```

Solutions to Exercises 3

3.1 (i) 3 4 5 6 7
(ii) 1 3 5 7 9
(iii) 0 3 6 9 12 15
(iv) 1 3 5 7 Note that the output stops here because the next number will exceed 8.
(v) 3 5 7 9 11 13 15
(vi) 10 7 4

3.2
```
write "number  square  cube 'n"
for I = 1 to 20 do write I, I * I, I * I * I, " 'n"
```

3.3 This program writes a table of an integer, its square, cube and fourth power from 1 to 5. That is

1	1	1	1
2	4	8	16
3	9	27	81
4	16	64	256
5	25	125	625

Convince yourself by working through step by step that this is what the program does. It also works out the fifth power but does not write this out.

3.4
```
write "number  square  cube'n"
let I := 1          !This initialises the count
while I <= 20 do { write I, I * I, I * I * I, " 'n" ;  I := I + 1  }
```

3.5 This example is more difficult to do with a for loop since you can only count in integer steps in a for loop. Using a while loop we could write the program as follows

```
! J.Cole.  Solution to exercise 3.5
let a := readr() ; let b = readr() ; let c = readr()
while a <= b do
begin
        write a, a * a, a * a * a, " 'n"
        a := a + c
end
```

Note that we have made *a* a variable but *b* and *c* are constants. It would not be wrong to make *b* and *c* variables too but it is good programming practice to declare things which are really constants like *b* and *c* by '=' rather than ':='.

3.6
```
let name := reads
while name ~= "****" do
begin
        let wins = readi() ; let losses = readi() ; let draws = readi()
        write name, wins, losses, draws, 2 * wins + draws, " 'n"
        name := reads()
end
```

An alternative solution which only uses one reads command rather than two is
```
let name := ""      !This is a string with no characters in it
repeat name := reads()
while name ~= "****" do
begin
        let wins = readi() ; let losses = readi() ; let draws = readi()
        write name, wins, losses, draws,  2 * wins + draws, " 'n"
end
```

Why do we still need the declaration of name before the repeat command? If you don't understand why, read the last part of Chapter 3 again.

3.7 The printed output will be

(i)	(ii)	(iii)
2	2	1
4	4	2
8	8	8
16	16	8
		16

4 IF CLAUSES

In the previous chapter we showed how sequences of clauses could be repeated a number of times. In this chapter we will look at the possibility of choosing whether a piece of program is to be executed at all, or alternatively a way in which one of two pieces of program can be chosen to be executed and the other one ignored.

In the middle of a program we often want to test some condition and if it has been met, to do something special and then carry on with the main flow of the program. For example, we might want to output a lot of numbers in the form of a table with say six numbers to a line. As we output each number we can add one to a column count and when it reaches six we can output a new line symbol. To do this we need to declare and set to zero a column count earlier in our program by a clause

```
let column.count := 0
```

The program may be in a repetitive loop in which it is calculating new values of x say and when it outputs each new x it tests first to see how many have been output already by using the following piece of program.

```
write x
column.count := column.count + 1
if column.count = 6 do
begin
        write " 'n"
        column.count := 0
end
```

Thus if the value of *column.count* is 6, then since we started with the value 0, six numbers have already been written out and so a new line symbol is output and the count reset to 0. To make this quite clear let us write a whole program to print the first 42 Fibonacci numbers. The Fibonacci numbers are formed by starting with the first two both equal to 1 and always forming the next one by adding the previous two together. Thus the first few Fibonacci numbers are

1 1 2 3 5 8 13 21 34 ....

A program to do this is as follows

```
write "Table of Fibonacci numbers 'n'n"
let a := 1 ; let b := 1
write a, b                  !This prints out the two starting values
let total.no := 2           !This tells us we have printed 2 numbers
let column.count := 2       !Two columns already printed
while total.no < 42 do
begin
        let new.fib = a + b
        write new.fib
        column.count := column.count + 1
        if column.count = 6 do { write " 'n" ; column.count := 0 }
        total.no := total.no + 1
        a := b ; b := new.fib    !Get ready for next Fibonacci number
end
```

This gives us a nice table of 7 rows and 6 columns. The numbers in a column will all be above each other since PS-algol always uses 10 spaces for each integer printed unless you tell it to do something else. We will tell you how to control output yourself in a later chapter.

As in the case of the **while** clause the expression following the word **if** must be a boolean expression and will evaluate to either **true** or **false**. If it evaluates to true then the clause following **do** is executed. If it is false then the clause following **do** is skipped over.

The other type of **if** clause involves the choice of one of two alternatives. Suppose, for example, that we

were reading a list of numbers successively into a variable *x* and we wanted to accumulate separately the sums of the negative and positive values and also the single sum of all their squares. A piece of program to do this is

```
if x > 0 then pos.sum := pos.sum + x
else neg.sum := neg.sum + x
sum.sq := sum.sq + x * x
```

The meaning should be obvious given that the piece of program immediately following **then** is executed if the boolean expression after **if** has the value **true** and the piece of program immediately following **else** is evaluated if this value is **false**. The final clause is executed in both cases. Note the program layout to emphasise this fact. As in Chapter 3, if we want to execute several clauses after **then** or **else** we make them into a single clause by either putting the words **begin** and **end** around them or by enclosing them in braces. We illustrate this point with a full program to carry out the above calculation but also counting the numbers in each case and printing out the averages of the three sums.

```
!J.Cole.  Averages program.

let pos.sum := 0.0 ;  let num.pos := 0
let neg.sum := 0.0 ;  let num.neg := 0
let sum.sq := 0.0 ;  let x := readr()

while x ~= 0 do       !We suppose none of the numbers are 0
begin
        if x > 0 then { pos.sum := pos.sum + x ; num.pos := num.pos + 1 }
        else { neg.sum := neg.sum + x ; num.neg := num.neg + 1 }
        sum.sq := sum.sq + x * x
        x := readr()
end

!We will assume here that neither num.pos nor num.neg is still zero

write   "The mean of the positive numbers is ",  pos.sum / num.pos,  " 'n",
        "The mean of the negative numbers is ",  neg.sum / num.neg,"'n",
        "The mean of the squares is ",  sum.sq / ( num.pos + num.neg ),  " 'n"
```

As in the previous example we have assumed that none of the numbers is zero and used this fact to control the **while** loop using zero to terminate the input. If we wanted to include zero as a possibility, included with the positive numbers say, we could have chosen the boolean expression after **if** to be $x >= 0$ and chosen some large number which could not possibly occur in the list to use in the **while** loop test. For example, if all the numbers are less than 10,000 we could have used

```
while x < 10000.0 do
```

and terminated the list with 10000.0 or any greater number. We could also have used an *eoi* technique.

When we first introduced the **if .. then .. else** clause we were careful to talk about the 'piece of program' following the **then** part or the **else** part. We did this deliberately because this clause can also be an expression. For example

```
if a < b then 0.25 else 1.0
```

We could use this as part of an assignment clause as follows

```
cost := ( if a < b then 0.25 else 1.0 ) * basic.cost
```

We have put the whole **if** clause in parentheses because otherwise it would be ambiguous. We would not know if * *basic.cost* was just multiplying the *1.0* or both the *0.25* and the *1.0*. To avoid such ambiguity you should get into the habit of enclosing any such part of an expression in parentheses.

Notice there is no similar case for the **if .. do** because this would leave the expression unfinished if the

condition were false. We use the word **do** because it implies that we are going to carry out some complete action such as an assignment rather than evaluating an expression which is only part of something else.

The following complete program to compute the greatest common divisor of two positive integers uses the standard mathematical technique for solving this problem.

```
write "Enter the two numbers: "
let a := readi() ; let b := readi()
write "The g.c.d. of ", a, " and ", b, " is"

while a * b ~= 0 do !stop if either is zero
        if a > b then a := a rem b
        else b := b rem a

write if a = 0 then b else a, " 'n"
```

Statements involving **if** ... **do** and **if** ... **then** ... **else** clauses are often made more complicated than necessary. For example the statement

```
if ch = "?" then query := true else query := false
```

can be simplified to

```
query := ch = "?"
```

We are assuming here that the variable *query* is of type boolean. A fuller discussion of objects of type boolean is given in Chapter 8. Similarly, the program segment

```
if x < 0 then sign := true
else
if x > 0 then sign := false
else write "Value is zero 'n"
```

could be simplified to

```
if x = 0 then write "Value is zero 'n" else sign := x < 0
```

To complete this chapter we write a rather silly program to teach the user a single fact. We will give a more realistic example of programmed learning when we have learned a little more about programming!

```
!J.Bloggs. ( I am ashamed to put my name to this )
!Programmed learning. First example.

write "hello'n"
let ans := ""
while ans ~= "China" do
begin
        write "Which country has the most people ? "
        ans := reads()
        if ans ~= "China" do write " 'nNo, the answer is China 'n"
end
write " 'ncorrect 'n"
```

The above program would go on for ever if it was not given the correct answer to the question. We could modify it by putting in a count so that the program stopped after say three tries.


```
!J.Bloggs. Slightly better program

write "hello'n"
let ans := "" ; let count := 0
while ans ~= "China" and count ~= 3 do
begin
        write "Which country has the most people ? "
        ans := reads() ; count := count + 1
        if ans ~= "China" do
        write " 'nNo, the answer is China 'n"
end
if ans = "China" then write "'ncorrect 'n"
else write "'nHave you thought of joining the foreign office as a career? 'n"
```

The boolean expression following the word **while** is more complicated than earlier examples but it still evaluates to either true or false. The boolean operator **and** tells us that the answer is true if both the surrounding boolean expressions are true. If we had used the word **or** instead of **and** then either (or both) the surrounding expressions would have to be true to yield the result true. As shown in the following diagram:

a	*b*	~*a*	*a* **and** *b*	*a* **or** *b*
true	**true**	**false**	**true**	**true**
true	**false**	**false**	**false**	**true**
false	**true**	**true**	**false**	**true**
false	**false**	**true**	**false**	**false**

At the end we tested for the answer being "China" and not for *n=3* since this is what we really needed to give the required output. We know that if the answer is not "China" then n must be 3 anyway to have left the previous loop. Notice also how easy it is to modify the code to bring in new ideas and be sure that your program is still correct.

Exercises 4

4.1 Write a program to read in 3 real numbers a,b and c and check if it is possible for a triangle with sides equal in length to *a*,*b* and *c* to be drawn. The easiest way to do this is to calculate the semi-perimeter

$$S = (a + b + c) / 2$$

and then to check if S - a, S - b and S - c are all positive. If so the triangle can be drawn. The resulting output should be readable as usual!

Supply two sets of data to check that the program is working correctly.

4.2 Write a program to read in a football result such as

"Colinsburgh United" 6 "St Andrews" 0

and to print out the same line together with one of the three comments

Home Win Away Win Draw

4.3 Write a program to read in two words (strings) and write them out in alphabetical order. Note that if *a* and *b* are strings then *a* < *b* has the value true if *a* precedes *b* i n a dictionary and false otherwise. It does not matter about the lengths of the strings being different. For this reason *"dog" < "doggerel"* has the value true.

4.4 You are captain of the starship Enterprise and you are approaching a primitive society which still measures distance in miles, yards and feet. Your range finder can read in feet to the nearest integer number of feet. Write a program to convert from feet to miles, yards and feet (1 mile = 1,760 yards, 1 yard = 3 feet) and print out the answer, leaving out a term if its value is zero. Thus your output should be able to distinguish between

5287 feet = 1 mile, 2 yards, 1 foot
5286 feet = 1 mile, 2 yards
5281 feet = 1 mile, 1 foot
5279 feet = 1759 yards, 2 feet and so on.

The tricky problem here is to leave out the commas as well!

4.5 Revision example

(i) Explain why the clause

let *new.fib = a + b*

rather than **let** *new.fib := a + b*

is used in the Fibonacci number program. Would the last clause be wrong in this context?

(ii) Which clause in the Fibonacci program causes a possible change in the **while** clause boolean condition test ?

Solutions to Exercises 4

4.1
```
let a = readr() ; let b = readr() ; let c = readr()
let S = 0.5 * ( a + b + c )
write  "A figure with sides ", a, b, c,
       if S - a > 0 and S - b > 0 and S - c > 0 then " is "
       else " isn"t ",
       " a triangle'n"
```

You may be surprised by this solution but note that in a **write** clause list the expressions are evaluated before printing and this gives us just what we want. Test data

4 6 7 3 5 9

4.2 !J.Cole. Football result.

```
let home.team = reads() ; let home.score = readi()
let away.team = reads() ; let away.score = readi()
write  home.team, home.score, away.team, away.score, " 'n",
       if home.score > away.score then "Home Win" else
              if home.score < away.score then "Away Win" else "Draw"
```

4.3 !J.Cole. Word sort
```
let a = reads() ; let b = reads()
if a < b then write a, b
else write b, a
```

4.4 !J.Cole. Feet to miles conversion program.
```
let dist = readi() ; let feet = dist rem 3
let yards = ( dist div 3 ) rem 1760 ; let miles = dist div ( 3 * 1760 )
write "The distance is "
let comma := false     !This introduces a boolean variable called comma.
                       !This is the first time we have come across this
                       !idea. We will use it to test if we need to
                       !output a comma between terms.
if miles ~= 0 do
begin
       write miles, if miles = 1 then " mile " else " miles "
       comma := true
end
if yards ~= 0 do
begin
       write if comma then "," else "", yards,
              if yards = 1 then " yard " else " yards "
       comma := true
end
if feet = 0 do
write if comma then "," else "", feet,
       if feet = 1 then "foot " else "feet "
```

This is quite tricky but useful to be able to do. We only want to put commas between items if we have already written something. We set *comma* to the value **false** to start with and set it to **true** as soon as we have written something. It has to be set to **true** in both the first two **if** clauses because one or both may not be executed. When we **write** **if** comma ..... the boolean expression is very simple being just the boolean variable with the name *comma* which has the value true or false. The bad grammar that you often see in computer output is usually due either to an inflexible programming language, to bad programming or to both.

4.5 (i) The clause is inside a sequence controlled by the **while** clause and is not given a new value inside this sequence. It would not be wrong to write := but it is better practice to indicate that objects are constant when they really are.

(ii) The clause *total.no = total.no + 1*

5 STRINGS

We have already met string literals and we are now going to extend the idea of strings to allow us to manipulate text in our programs.

```
let s = "Scotland"
```

declares a string constant, *s*, with the value *"Scotland"*. We can join two strings together by using the concatenation operator '++'. For example

```
let s1 = "Scotland" ; let s2 = "Ireland"
let s3 = s1 ++ " and " ++ s2
write s3
```

will result in

```
Scotland and Ireland
```

s3 is the result of concatenating *s1*, the string literal *" and "* and *s2*. String *s1* is of length 8 since it has 8 characters and *s2* is of length 7. *" and "* is of length 5 since it includes two spaces to make the final output correct. Spaces are simply characters and it is the programmer's responsibility to include these where necessary inside a string. There is a *length* function in PS-algol which allows you to find out the length of any string. In the above program

```
write length( s1 ), length( s2 ), length( s3 )
```

would give the answers

```
8    7    20
```

As well as being able to join strings together we can also extract part of a string in order to create another. For example

```
s1( 5/4 )
```

creates a new string which has the same characters as *s1* starting at character 5 and copying 4 of them. Therefore

```
let s4 = s1( 5/4 )
```

gives *s4* the value "land". There is one rule that may appear odd to the beginner. That is, you cannot change part of a string to something else. If you wish to change the value of a string variable you must create a new string with the correct value and assign it to the variable. For example

```
let s := "Scotland"
let s1 := "Eng" ++ s( 5/4 )
```

s1 now has the value *"England"* and

```
s1 := "Eskimo" ++ s1( 4/4 )
```

alters it to "Eskimoland". So also, of course, would

```
"Eskimo" ++ s(5/4).
```

In both cases the integer literals used in the substring selection can be replaced by integer expressions.

There would have been no need to introduce a new variable *s1* if we had had no further need for the string literal *"Scotland"*. It would be quite valid to write

```
s := "Eng" ++ s( 5/4 )
```

This of course could only be done because *s* is a variable and not a constant.

We can now assign values to string variables and alter them. It is often useful to compare strings as we have already seen in previous sections. Thus in exercise 4.3 we had

```
let a = reads() ; let b = reads()
if a < b then write a, b
else write b, a
```

This program reads in two strings and writes them out in dictionary order. Strings may have more than just alphabetic characters in them. In fact they can have any character in the ASCII code (see Appendix II). The ordering of the characters is defined by the ASCII code. However, for the present it is sufficient to know that

```
"a" < "z",
"1" < "9",
"A" < "Z",
"Z" < "a"
and "9" < "A"
```

and otherwise that the ordering is as in a dictionary.

If the two strings are not of the same length, the characters in them are compared one by one and if the strings are still equal after the comparison the shorter one is considered to be less than the longer. Thus

```
"Morris" < "Morrison"
```

One final point is that it is sometimes useful to use the empty string. This is represented by "". It has length 0 and is less than any other string in dictionary order.

To illustrate the use of strings we will now write a program to read in a string which consists of digits. The string may or may not contain leading zeros. The output from the program will be the string of digits without the leading zeros.

```
!Strip leading zeros program.

let s = reads() ; let count := 1 ; let more.zeros := true
while count <= length( s ) and more.zeros do
        if s( count/1 ) = "0" then count := count + 1
        else more.zeros := false

if count > length( s ) then write "The resultant string is empty"
else write s( count/length( s ) - count + 1 )
```

There are several things to notice about this program. The integer variable *count* indicates the position in the string of the character that is under consideration. The boolean variable *more.zeros* becomes false as soon as a non-zero leading character is found. The **while** loop terminates if *count* gets larger than the string length or as soon as we find a character other than "0" in the string. In this case *count* will contain the position of the first non-zero character in the given string. The loop inspects each character in turn. Finally, we check for the situations that may occur after the loop has terminated and print out a suitable message or the required string.

You may already be getting tired of having to put quotes around strings in your data. The reason for doing

this is to give the beginner as much flexibility as possible in the characters that can be used internally in strings including new line symbols. The more sophisticated user can build up his own string reading routines using the *read* command as described in Chapter 11.

In addition to the length function there are other functions associated with properties of strings. Firstly the *code* and *decode* functions are associated with the internal and external representation of characters. Characters are represented inside the computer by an ASCII code which is an integer between 0 and 127. The function *code(n)* takes an integer *n* as its argument and produces a string of length 1 representing the character *n rem 128* as its result. Similarly, the function *decode(s)* takes a string *s* as its argument and returns the integer value of the ASCII code for the first character of *s* as its result.

The function *letter(s)* takes a string *s* as its argument and produces as its result a boolean value true if the string is of length 1 and is a letter of the alphabet, either upper or lower case and false otherwise. Similarly the function *digit(s)* takes a string s as its argument and produces the value true if that string is of length 1 and is a digit and false otherwise. A piece of code to test to see if a given string *n* is a digit and if so, to put the corresponding integer value of that digit in an integer variable *i* could be

```
if digit( n ) do i := decode( n ) - decode( "0" )
```

For this we need to know that the ASCII codes for digits are consecutive. Check that the right hand side of this assignment clause is correct by looking at the ASCII codes for digits.

Exercises 5

5.1 What is the length of each of the following strings?

(i) `"Ronald"`
(ii) `"Jack Cole"`
(iii) `""`
(iv) `"'"`
(v) `"Writing is done'n"`

5.2 Write a program to read in a string. The string may or may not start with any number of a's or A's (or a combination of both). Write out the string without the leading a's or A's and follow this immediately with the leading part of the string that is a's or A's.

5.3 Write a program to read in the following strings
(i) somebody's name --- name1
(ii) some social function e.g. "wedding", "birthday party" etc.
(iii) a date
(iv) a second name --- name2

and print out a letter saying

Dear <name1>,
Thank you for your kind invitation to your <function> on <date>,
which I am very pleased to accept.
Yours sincerely,
<name2>

where the objects in angled brackets are replaced by the data with which you have been supplied. Do not expect the user to put in blanks around his data.

5.4 Write a program to read a string *s* and to find its reverse (i.e. the characters written backwards)
(i) as the value of a new string *s1* leaving *s* unaltered
(ii) as the new value of *s* without using any other string variables. Your program should still work if *s* is the empty string.

5.1 (i) 6
(ii) 9
(iii) 0
(iv) 1
(v) 16

Remember that '" and 'n represent one character only in a string literal.

5.2

```
!Program to strip leading a's or A's.

let s = reads() ; let count := 1 ;
let more.a.or.A := true
while count <= length( s ) and more.a.or.A do
if s( count/1 ) = "a" or s( count/1 ) = "A" then count := count + 1
else more.a.or.A := false
if s = "" then write "This string is empty"
else write if count - 1 = length( s ) then s( count/length( s ) - count + 1 )

else "", s( 1/count - 1 )
```

5.3

```
!Program to accept invitations.
let name1 = reads() ; let function = reads()
let date = reads() ; let name2 = reads()
write "Dear ", name1, ",'n"
for i = 1 to length( name1 ) + 6 do write " "
write "Thank you for your invitation to your ", function, "on'n ",
      date, ", which I am very pleased to accept.'n"
for i = 1 to 30 do write " "
write "Yours sincerely,'n"
for i = 1 to 30 do write " "
write name2, "'n"
```

If we really wanted to write a good program here we would check to see if the number of characters supplied in <function> and <date> fitted in to the line. Try modifying the program to do this assuming you do not want more than 65 characters on a line (the maximum width of a line is usually 80 for a terminal and 132 for a printer page).

5.4 (i)

```
let s = reads() ; let s1 := ""
for i = 1 to length( s ) do s1 := s( i/1 ) ++ s1
write "Original string is 'n", s, "'n Reversed string is 'n", s1, "'n"
```

Work through the program to verify why it works both with empty and non-empty string.

(ii)

```
let s := reads()
write "Original string is 'n", s
let len = length( s )   !Saves computing length( s ) many times
for i = 1 to len - 1 do  s := s( 1/i - 1 ) ++ s( len/1 ) ++ s( i/len - i )
write "'nThe reverse string is'n", s, "'n"
```

Note the order of concatenation and also the fact that when $i = 1$, the second term $s(1/i-1)$ becomes $s(1/0)$ which is the empty string.

6 VECTORS

In many calculations we want to record linear lists or tables of objects to use in the calculation. For example, if we have been carrying out an experiment a number of times we may want to hold all the results of the experiment together and perhaps sort them into order to see which is the biggest and which is the smallest and so on. In PS-algol we can use a data structure called a **vector** to do this. There are two basic ways in which we can declare a vector for subsequent use. There are several things, however, that we have to do in both cases. Firstly we have to say how many objects the vector is going to contain and what type these objects are. Secondly we need to be able to refer to each of the objects in the vector by some name. The usual way of doing this is to give the whole vector a name, say X, and then refer to the separate objects by using a subscript on X. Because most computer terminals do not have an easy way of printing subscripts we use the notation $X(i)$ to mean X with subscript i. We need to know the range of the subscripts for X. That is, where they start and finish. Quite often the starting value for a subscript is 0 or 1 but it is very restrictive to insist on either of these. The simplest way to declare a vector is to write, for example

```
let X = vector 1::8 of 0
```

This declares X to be a vector of 8 integers with subscripts going from 1 to 8 and with each integer element being set initially to 0. PS-algol deduces the type of the elements in the vector from the initialising value given after the reserved word **of**. Thus if we had written

```
let Y = vector 0::20 of 0.0
```

this would declare a vector of real numbers with 21 elements starting with subscript 0, and

```
let Z = vector 1::100 of " "
```

would declare a vector of strings all being initialised to a single space. We point out straight away that if we subsequently give new values to the elements of Z they can be of any length. They are not restricted to their initial length or to be all of the same length.

You may be wondering why we have used '=' and not ':='. The point is rather subtle and we will not make too much of it in this introduction. Suffice to say, there are two ways in which a vector can be made constant. Either the whole vector is a constant in the sense that we cannot assign another complete vector to that name, or else the elements of the vector are constant and cannot individually be changed. The notation '=' and ':=' are used to distinguish between constant and variable complete vectors. Do not worry about this too much if you do not really understand it - you really need to know some more about programming and to read the later chapters of this book. If you stick to using '=' in declaring vectors for most of the examples in this book you will not get into difficulties. We also discuss the point further a little later on in this chapter.

Having declared a vector we can assign values to individual elements by clauses like

```
X( i ) := 3
```

where i is a previously declared integer with a value between 1 and 8 (look back at the declaration of X). PS-algol checks for you at run-time that the value of the subscript i is indeed in the correct range and that the value being assigned to the element is of the correct type.

Suppose that we wanted to read in 10 real numbers and print out the smallest and the biggest. We could do this without using a vector but we will use one to illustrate the ideas.

```
let x = vector 1::10 of 0.0
for i = 1 to 10 do x( i ) := readr()
let smallest := x( 1 ) ; let largest := x( 1 )
!The above line starts things off with x( 1 ) for both values

for i = 2 to 10 do
begin
        if x( i ) < smallest do smallest := x( i )
        if x( i ) > largest do largest := x( i )
end
write "The smallest number is ", smallest,
                "  and the largest is ", largest
```

We will now write a more ambitious program to read in a list of real numbers and sort them into order. We will do this by writing one for loop inside another one with the inner loop range getting smaller and smaller. At each stage in the inner loop we will put the smallest object to the bottom of the part of the vector under consideration.

```
let n = readi()    !This gives the number of objects
let x = vector 1::n of 0.0
for i = 1 to n do x( i ) := readr()     !sort code starts here
for i = 1 to n - 1 do
begin
        let smallest := x( i ) ; let k := i
        for j = i + 1 to n do
        if x( j ) < smallest do { smallest := x( j ) ; k := j }
        if k ~= i do { x( k ) := x( i ) ; x( i ) := smallest }
end
write "The sorted list of ", n, " numbers is'n'n"
for i = 1 to n do write x( i ), "'n"
```

You should try working through this program step by step with say n = 5 doing exactly what PS-algol does.

If you start off with the numbers

1.3 6.6 1.1 2.8 3.7

the order at the end of each loop will be

1.1 6.6 1.3 2.8 3.7
1.1 1.3 6.6 2.8 3.7
1.1 1.3 2.8 6.6 3.7
1.1 1.3 2.8 3.7 6.6

Notice that we have declared the vector x with subscripts going from 1 to n. Under the appropriate circumstances either of the limits of a vector can be written more generally as any integer expression.

Quite often we want to use **two-dimensional vectors**, that is tables with both rows and columns. We can declare such a vector by writing a list of subscript limits as follows.

```
let p = vector 1::10, 1::8 of 0
```

We like to look at this as a vector of vectors rather than as a two-dimensional array for a reason we will explain shortly. In this case it is a vector with 10 elements, each element of which is a vector of integers with 8 elements.

There are two ways in which we can refer to particular elements in such a vector of vectors. The usual shorthand method is to write p(i,j) to represent the i,jth element but it is also permissible to write p(i)(j). This form is clumsier and will not usually be used when referring to individual elements. We note however that p(i) does have a meaning, namely the whole vector in the ith position in p. This is quite a sophisticated but powerful idea whose use we will illustrate shortly.

Let us consider first an example to read in a table of real numbers with n rows and m columns and to form a new vector containing the row sums. We can do this easily as follows

```
let p = vector 1::n,1::m of 0.0
for i = 1 to n do
        for j = 1 to m do p( i,j ) := readr()   !Reads in values by rows

let p.rowsum = vector 1::n of 0.0
for i = 1 to n do
        for j = 1 to m do p.rowsum( i ) := p.rowsum( i ) + p( i,j )
```

A slightly more elegant program would be

```
let p = vector 1::n,1::m of 0.0
let p.rowsums = vector 1::n of 0.0
for i = 1 to n do
        for j = 1 to m do
        begin
                p( i,j ) := readr()
                p.rowsums( i ) := p.rowsums( i ) + p( i,j )
        end
```

A common problem is to sort the rows of a table of values into order depending on the values in some particular column. Suppose we want to do this with the above vector of vectors p and for the rth column where 1 < r < m. We can do this with a simple modification to the sort loop of the program given above.

```
let n = readi() ; let m = readi()
let p = vector 1::n ,1::m of 0.0
for i = 1 to n do
for j = 1 to m do p( i,j ) := readr()
let r = readi()          !column for sort key
for i = 1 to m - 1 do
begin
        let smallest := p( i ) ; let k := i
        for j = i + 1 to m do
                if p( j,r ) < smallest( r ) do { smallest := p( j ) ; k := j }
        if k = i do { p( k ) := p( i ) ; p( i ) := smallest }
end
```

Note that smallest is the name of a vector which is initially the ith row of p. The comparison of elements

```
p( j,r ) < smallest( r )
```

has correct subscripts since p is a vector of vectors and smallest is a vector. Finally, whenever a change of row is required, this is done by changing the row pointers rather than the individual elements. Note however that it is not possible to change columns in this way. One should therefore think carefully about choosing the order in which vectors of vectors are defined.

In each of the above examples we have initialised the vector elements all to the same value. Although we have used 0 for integers we can use any integer expression for initialisation and similarly for vectors with elements of other types. Quite often we want to initialise vector elements to a collection of different values. We could do this by reading data into them, but if we always need the same values for a particular program it would be better to do it as part of the program.

In PS-algol we do it by a clause of the following sort.

```
let t = @1 of int[ 1,2,3,4,5,6 ]
```

This needs some explanation. The notation *@1* is an indication of where the subscripting is to start. This we call the **lower bound**. The value 1 can be replaced by any integer expression. The words **of int** say that the elements in the vector are all to be of type integer and furthermore are variables. If we want

them to be constants we would write **of cint** instead. The actual values are given as an expression list enclosed in square brackets. We do not need to give the **upper bound** of the vector since PS-algol will count the elements for us.

If we want to initialise a vector of reals like

```
let X = @0 of real[ 0.0, 1.0, -3.7, 2.0 ]
```

we do not need to put in the decimal point in the integers since PS-algol will convert them for us as we have seen earlier. We could thus write

```
let X = @0 of real[ 0, 1, -3.7, 2 ]
```

As another example we will write

```
let days = @1 of cstring[ "Sun", "Mon", 'Tues", "Wed", "Thurs", "Fri", "Sat" ]
```

Note that the strings need not all be of the same length.

The flexibility of the vector notation allows the data structures to be of any complexity that we wish. We could for example write

```
let triangular.array = @1 of * cint[    @1 of cint[ 1 ],
                                        @1 of cint[ 1,1 ],
                                        @1 of cint[ 1,2,1 ],
                                        @1 of cint[ 1,3,3,1 ],
                                        @1 of cint[ 1,4,6,4,1 ]   ]
```

to give a representation of the Pascal triangle

```
1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
```

The type ***cint** used above indicates that each object in the vector *triangular.array* is itself a vector of objects of type **cint**. We discuss this further below.

To illustrate these ideas we will give an example which, given the day of the week on which a given month starts and a date within the month, will work out which day of the week it falls on. We have to think of a way of solving the problem before we can program it. First of all we must find if the day given for the start of the month is the 1st, 2nd..... 7th day of the week. Call this *i*. Then we find the remainder on division by 7 of the actual day given. Call this *date*. If *date = 0* then the actual day is the same as *i*, if *date = 1* then the day is i + 1 and so on. The actual day requested is therefore always

```
( date + i ) rem 7
```

A program to do this is

```
!Program to find the day of the week.

let days = @0 of cstring[   "Sunday", "Monday", "Tuesday", "Wednesday",
                            "Thursday", "Friday", "Saturday"   ]
let first.day = reads()
let i := 0
while first.day ~= days( i ) do i := i + 1
let date = readi()
write "Day ", date, " of the month falls on a ", days( ( i + date ) rem 7 )
```

In introducing the concept of a vector we have not mentioned the data type of this sort of object. The elements of a vector can be of type integer, real, boolean, string or indeed vector or any other data type in

the language. The **data type of a vector** is denoted by an '*'. Thus a vector with integer elements is of type *int if the elements are variable and *cint if the elements are constant. A vector declared by using ':=' is itself variable and may have other vectors assigned to it whereas if it is declared by '=' it is constant. Thus if we had written

```
let X := @1 of int[ 1,2,3 ]
let Y := @1 of int[ 6,7,8,9 ]
```

we can write later on in our program

```
X := Y
```

and *X* will now have the same value as *Y* i.e the same vector. Note that in this case, the elements of the original *X* are now lost for ever.

If we had used

```
let X = @1 of int[ 1,2,3 ]
```

then the subsequent

```
X := Y
```

would be invalid since *X* is a constant.

Since vectors may be assigned, it is often necessary to interrogate the vector to find its bounds. The functions *upb* and *lwb* are provided in PS-algol for this purpose. Thus if q is a vector defined by

```
let q = @1 of int[ 2, 4, 6, 8, 10, 12 ]
```

then *upb(q)* has value *6* and *lwb(q)* has value *1*.

Similarly, if *s* is a vector of vectors defined by

```
let s = vector 0::6,1::10 of ""
```

then *upb(s)* has value *6*, *lwb(s)* has value *0* but *upb(s(3))* has value *10* and *lwb(s(3))* has value *1*.

There is no reason why vectors of vectors of vectors and so on should not be defined. PS-algol allows you to do this by an obvious extension to the notation. Thus, for example, one can define

```
let t = vector 1::8, 1::6, 1::3 of 0
```

and so on.

Exercises 6

6.1 Why in the example to sort numbers have we declared vector x with an '=' but use ':=' to assign a value to x(i) ?

6.2 A bubble sort works in the following way. Given a vector of size n, the first scan of the bubble sort works from 1 to n - 1 looking at successive pairs of numbers. If the first is less than or equal to the second they are left unaltered. Otherwise they are swapped. At the end of this scan the largest will be at the top. Repeat the process with n-1 elements, excluding the top one which is in the correct place, until all the elements are sorted. Write a program to do this. Warning. If you need to swap the elements of a vector it is not correct to write

```
x( i ) := x( j ) ; x( j ) := x( i )
```

because the first assignment destroys the old value of *x(i)*. You will need to write

```
let temp = x( i ) ; x( i ) := x( j ) ; x( j ) := temp
```

6.3 Bubble sort can be stopped as soon as you do not have to change anything in one complete scan. Modify your program above to set a boolean variable to false if any change is made in the order and test it to see if you need to continue. You will need to use a while clause rather than a for clause for this program. Note that bubblesort is one of the most inefficient methods of sorting.

6.4 Write a program to output all the verses of "On the twelfth day of Christmas". If you can do this without looking at the solution you are well on the way to becoming a programmer! (Unless you just write out the song word for word).

6.5 Write a program to read in a list of words, each one as a string, and sort them into dictionary order.

6.6 Suppose x is a vector of vectors defined as

```
let x = @1 of * cint[     @1 of int[ 1,1 ],
                          @4 of int[ 1,2,1 ],
                          @1 of int[ 1,2,3,2,1 ],
                          @1 of int[ 1,2,1 ],
                          @-2 of int[ 1,1 ]    ]
```

Determine the value of upb and lwb for each of the following

```
x
x( 2 )
x( 3 )
x( 5 )
```


Solutions to Exercises 6

6.1 The '=' sign implies that the vector as a complete object cannot be assigned to. Its individual elements can be assigned to and this is why we can use ':='.

6.2

```
!J.Cole. Bubble sort program.

let n = readi()
let x = vector 1::n of 0.0
for i = 1 to n do x( i ) := readr()

!bubble sort starts here

for i = 1 to n - 1 do
        for j = 1 to n - i do
                if x( j ) > x( j + 1 ) do
                begin
                        let temp = x( j )
                        x( j ) := x( j + 1 )
                        x( j + 1 ) := temp
                end

!now write out the answers

write "The sorted numbers are 'n'n"
for i = 1 to n do
write x( i ), "'n"
```

If you did not succeed in solving this yourself try working through the solution step by step with a vector of say 4 elements.

6.3 We change the piece of program between the two comments as follows

```
!bubble sort starts here

let i := 1 ; let more := true
while i <= n and more do
begin
        more := false
        for j = 1 to n - i do
        begin
                if x( j ) > x( j + 1 ) do
                begin
                        let temp = x( j )
                        x( j ) := x( j + 1 )
                        x( j + 1 ) := temp
                        more := true
                end
        end
        i := i + 1
end

!now write out the answers
```

6.4

```
!the first day of Christmas, five verses only.  Extra verses need only
!a change of data.

let phrase1 = "'nOn the"
let phrase2 = " day of Christmas'nmy true love sent to me'n"
let number = @1 of cstring[ "firsi","second","third","fourth","fifth" ]
let gift = @1 of cstring[      " a partridge in a pear tree'n", " two turtle doves'n",

                               " three french hens'n", " four calling birds'n",

                               " five gold rings'n" ]

!calculation starts here

write " The five days of Christmas'n'n"

                    !The first verse is a special case because the word 'and' is not used.

write phrase1, number( 1 ), phrase2, gift( 1 )

!remainder of verse production starts here

let next.verse := " and" ++ gift( 1 )

for i = 2 to 5 do
begin
        next.verse := gift( i ) ++ next.verse
        write phrase1, number( i ), phrase2, next.verse
end
```

6.5 The solution is exactly the same as either of the two sort examples given earlier but you need to change the clauses including readr() to reads() and also the vector declaration to a vector of strings.

6.6

```
upb( x ) = 5    lwb( x ) = 1
upb( x( 2 ) ) = 6   lwb( x( 2 ) ) = 4
upb( x( 3 ) ) = 5   lwb( x( 3 ) ) = 1
upb( x( 5 ) ) = -1  lwb( x( 5 ) ) = -2
```


7 THE CASE CLAUSE

Programs are often complicated to read because of the amount of testing and branching inside them. The **if ... then .... else** clause is a very useful one but even this can be unreadable when similar clauses are nested in the two different parts of the clause itself. The case clause in PS-algol is a very powerful one and we introduce it as usual with an example.

```
case party of
"lab"     : no.lab := no.lab + 1
"cons"    : no.cons := no.cons + 1
"lib"     : no.lib := no.lib + 1
"snp"     : no.snp := no.snp + 1
"comm"    : no.comm := no.comm + 1
"sdp"     : no.sdp := no.sdp + 1
default   : no.rest := no.rest + 1
```

We are assuming here that *party* is the name of a string which is used to hold the political affiliation of a person and the effect is to add one to the corresponding total of members of that party. In the general case the name *party* can be replaced by any expression of any type and the string literals before the colons can be replaced by expressions of that same type or even lists of expressions of that type separated by commas. The effect is that the expression following the word **case** is evaluated and its value is then compared, one by one, with the values of the expressions, or members of the list of expressions, preceding the colon. As soon as a match is found further comparison stops and the clause (or, when relevant, the expression) following the colon is executed. The program then skips over the rest of the case clause to the next part of the program. Thus, whereas the **if** clause allows the selection of one of two alternatives to be executed, the case clause allows one of many. If no match is found then the **default** option is obeyed automatically. A **default** option must always be written. This is good programming practice to make sure that you have not overlooked a case but in the rare case in which you do not need it you should include either

```
default : {}
```

or

```
default : { write "No case matches.Value ## returned'n" ; ## }
!Note that ## must be replaced by a value of the correct type !e.g. 0 or "" etc.
```

An example of a case when all the options are expressions is

```
no.of.legs :=  case animal of
                    "cat", "dog", "horse", "cow" : 4
                    "man"     : 2
                    "ant"     : 6
                    "triffid" : 3
                    default   : 0
```

Some programming languages have a variant on the **case** clause which branches depending on the value of an integer expression only. Usually the programming has been contorted to obtain the appropriate integer before the **case** clause is executed but in our case we do not usually need to think of this. In the rare case in which we do need to use a test for integer values we can write

```
case integer of
1 : ...
2 : ...


9 : ...
default : ...
```

There is no significance in this example finishing with 9. There is no restriction on the number of choices.

In the rest of this chapter we give a number of examples of the use and power of the PS-algol case clause.

A common example in introductory books on programming is the solution of a quadratic equation. If a proper solution is given it is often quite complicated but the following should be immediately understandable. We use here the square root function *sqrt* which is supported automatically by PS-algol.

```
write "Input three real coefficients "
let a = readr() ; let b = readr() ; let c = readr()
if a = 0.0 then write "This is not a quadratic since a = 0'n"
else
begin
        let discrim = b * b - 4.0 * a * c ; let den = 2.0 * a
        case true of
        discrim < -1e-6 : write "Imaginary Roots are ",-b / den,
                                " + or - i * ",sqrt( -discrim )/den,"'n"
        discrim > 1e-6 :  begin
                                let r1 = ( -b + sqrt( discrim ) )/den
                                write "Real Roots are ",r1,
                                        " and ",c/( a * r1 ),"'n"
                          end
        default : write "Single Root is ",-b/den,"'n"
end
```

The apparent complication of the *discrim* > *1e-6* case is nothing to do with the programming but with the computation to produce an accurate result in all cases. If you do not believe this try solving the equation

$$0.08\,x^2 + 21.4\,x + 0.14 = 0$$

and substituting the answers back in the left hand side to see how near to 0 you get. If you just calculate

-b + or - sqrt(b * b - 4 * a * c)

you will get bad results for one root.

The use of **true** as the expression following case is a particularly useful one. We test each of the following conditions to find the first one which is also true for our particular equation.

In the next example we are going to write a program which will read in a French regular verb, find its root and ending and print out the first person singular conjugation of the verb. Our program is not intelligent enough to find out if the verb given is not a regular verb unless its ending is wrong. So if, for example you give it "etre" it will work out the present tense as if it were regular.

```
write "Type a French regular verb "
let verb = reads()
let pronoun =   case verb( 1/1 ) of
                "a","e","h","i","o","u" :    "j'"
                default :  "je "

let ending =    case verb( length( verb ) - 1/2 ) of
                "er"    : "e"
                "ir"    : "is"
                "re"    : "s"
                default : "x"
if ending = "x" then write verb, " is not a French regular verb'n"
else write "The first person present tense of ", verb,
                        " is ", pronoun,  verb( 1/length( verb ) - 2 ),
                                        ending,"'n"
```

Note that the setting of *pronoun* is determined by testing for a vowel and the **default** is for the remaining consonants.

Suppose now that we have the results of a survey on a pop record with the survey information being for each participant :

age sex opinion

where *age* is an integer, *sex* is "m" or "f" and *opinion* is "yes" or "no". Suppose we have a lot of such data terminated by a single entry of *age* = *0* and we wish to find the following totals.

(i) number of females < 20 who like the record
(ii) number of females >= 20 who like the record
(iii) number of females < 20 who dislike the record
(iv) number of females >= 20 who dislike the record
(v) number of males < 20 who like the record
(vi) number of males >= 20 who like the record
(vii) number of males < 20 who dislike the record
(viii) number of males >= 20 who dislike the record

We will write the part of the program which accumulates the totals and leave the writing out of the results to you.

```
let sums = vector 1::8 of 0
let age := readi()
while age ~= 0 do
begin
        let sex = reads() ; let opinion = reads()
        let index =     case true of
                        sex = "f" and age <  20 and opinion = "yes" : 1
                        sex = "f" and age <= 20 and opinion = "yes" : 2
                        sex = "f" and age <  20 and opinion = "no"  : 3
                        sex = "f" and age >= 20 and opinion = "no"  : 4
                        sex = "m" and age <  20 and opinion = "yes" : 5
                        sex = "m" and age >= 20 and opinion = "yes" : 6
                        sex = "m" and age <  20 and opinion = "no"  : 7
                        sex = "m" and age >= 20 and opinion = "no"  : 8
                        default : { write "Invalid data ", age, sex, opinion,
                                                "'nType corrected data 'n" ; 0 }

        if index ~= 0 do sums( index ) := sums( index ) + 1
        age := readi()
end
```

Note how the **default** option picks up invalid data. Although this program is readable it is still not a good program because it has a great deal of almost repetitive writing in it. You could simplify the program by writing instead of the **case** clause

```
let I =  ( if sex = "f" then 1 else 5 ) +
         ( if age < 20 then 0 else 1 ) +
         ( if opinion = "yes" then 0 else 2 )

sums( I ) := sums( I ) + 1
```

but it is not nearly so obvious what you are doing and if you make a mistake it is more difficult to pick up. Furthermore, you still have to check each data line for possible errors.

A better, and still readable solution is to replace the **case** clause by the following piece of program.

```
let i =  case sex of
         "f" :   case opinion of
                 "yes"  : if age < 20 then 1 else 2
                 "no"   : if age < 20 then 3 else 4
                 default : 0
         "m":    case opinion of
                 "yes"  : if age < 20 then 5 else 6
```

```
        "no"   : if age < 20 then 7 else 8
        default : 0
    default : 0

    if i = 0 then write "Error in data ", age, sex, opinion,"'n"
    else sums( i ) := sums( i ) + 1
```

We have again used a value of $i = 0$ to detect errors in the string responses. We could have been more explicit using 0 for an error in *opinion* and -1 for an error in *sex* say.

Exercises 7

7.1 Write a program which will read in three real numbers and check whether a triangle with sides of these lengths exists and if so whether it is scalene, isosceles or equilateral. Think carefully before you start writing your program to decide the tests you need to find the result. If you cannot do this look at the hint at the bottom of these exercises before the solutions and then write the program.

7.2 Write a case clause which sets a name *colour* to a colour shown for the following objects.

"grass"	"green"
"fire engine"	"red"
"leaf"	"green"
"daffodil"	"yellow"
"carrot"	"orange"
"pillar box"	"red"
"emerald"	"green"
anything else	"black"

7.3 Write a program to calculate sums for different combinations for any particular survey data you like to choose. (For example, a survey of school dinners!)

Hint for solution of 7.1. If you test in a case clause in the following order, each test is simple.

1. test if it is a triangle.
2. test if it is equilateral. That is a = b and b = c.
3. test if it is scalene. That is a ~= b and b ~= c and c ~= a.
4. default it must be isosceles.

Solutions to Exercises 7

7.1

```
!J.Cole.  Test triangles.
write "Input three real numbers as sides of a triangle "
let a = readr() ; let b = readr() ; let c = readr()
let s = 0.5 * ( a + b + c )
write "The figure with sides 'n", a, b, c,

case true of
s < a  or s < b  or s < c    : " is not a triangle'n"
a = b  and b = c    : " is an equilateral triangle'n"
a ~= b  and b ~= c  and c ~= a    : " is a scalene triangle'n"
default  : " is an isosceles triangle'n"
```

7.2

```
colour :=  case object of
           "grass", "leaf", "emerald"   : "green"
           "fire engine",
           "pillar box" : "red"
           "daffodil"   : "yellow"
           "carrot"     : "orange"
           default  : "black"
```

7.3 This depends on your choice of survey data but the program will be very similar to the example about a pop record in the above chapter but with different expressions in the case clause.

8 SOME IMPORTANT ODDS AND ENDS

We now clear up some points we left unfinished in the preceding chapters and also introduce a few new ideas. Since there are a lot of different topics covered we will use section headings in this chapter.

8.1 Write facilities

We will discuss briefly the way in which you can control your output rather more precisely than hitherto. We have already introduced the special character 'n as part of a string literal. 'n is the new line symbol. There are four other special symbols of this type.

'o allows overprinting of the current line. That is, it causes the printing to go back to the start of the line you have just completed. The use of this is to enable underlining to be done easily or to overprint characters if you are building up pictures.

'b causes the printer to backspace one place. This gives the same facility as 'o but for just one character. Clearly you can backspace as many characters as you like in a loop.

't is for typewriters or terminals with a tabulate facility. If you do not know what this means forget it!

'p makes the printer skip to a new page.

Note that some of these will give strange results when used on videos where overprinting does not work correctly. (eg. the Mac)

We have assumed that our output for integers and reals is always of the same size. As a default option PS-algol gives you 10 places for an integer and 12 for each real plus two extra spaces after each number printed. There are three ways in which you can control this part of the output.

1. You can reset the default options by setting any of a number of system predefined variables to new values. These variables are

   (a) i.w which controls the integer width. Thus i.w := 6 would set integer width output to 6 until you change it again. i.w is already known to the system, as are the others in this section, and you do not have to redeclare it with a let clause.

   (b) r.w is the same as i.w except that it is for the width of reals.

   (c) s.w sets the spaces left after printing integers or reals. The default value is 2.

2. You can specify the output size for any particular expression by writing ':' followed by an integer expression in a write clause. Thus

   write i : 6, 0.5 * x : 10, j : n, "z" : 8

   would give 6 spaces for *i*, 10 spaces for *0.5 * x*, n spaces for *j* where n is some integer calculated in your program and 7 spaces followed by a z. All output is right justified, which explains why "z" : 8 is output as 7 spaces followed by z. You may not realise the full power of this at the moment but it is a very powerful output control facility. If, using either of the above methods, a number or string will not fit into the space allocated then it is expanded to fit into the smallest possible space.

3. There are two system functions called *eformat* and *fformat* which give you another means of controlling output of real numbers. We do not want to go into detail here for beginners but for the more experienced programmers we will say that *eformat* and *fformat* take three parameters which are the real number and the number of places before and after the decimal point respectively. Thus in a write clause you could include

   write fformat(x,3,2)

   to give the value of x an output format with 3 places before the decimal point, the decimal point itself and 2 places after it. If the numbers cannot be printed correctly in the form you have specified PS-algol will ignore the specification and print them in the usual manner.

8.2 Operator priorities

Standard arithmetic notation is ambiguous. It is not obvious whether the value of

3 + 2 * 5

is 13 or 25. We are taught at school that multiplication has priority over addition so the 'correct' answer is 13 but this is only a convention. We will however keep to this convention ourselves and note that multiplication and division have equal highest priority and addition and subtraction have lower but also equal priority. If ambiguity still remains then we work from left to right.

Thus *6 - 4 - 1* has value 1. Note that **div** and **rem** have equal priority to / and *.

The boolean negation ~ has the next highest priority followed by the relational operators for comparing two objects, namely

= ~= < > <= >=

all of which have equal priority followed by the boolean connectives **and** and **or** both on their own. The complete order of priorities is

/ * **div** **rem** ++

\+ -

~

= ~= < > <= >=

and

or

|

8.3 Simple data types

We have introduced four simple data types so far. These are integer, real, string and boolean and when we spoke about initialising vectors we introduced the corresponding reserved words **int, cint, real, creal, string** and **cstring** for variable and constant integer, real and string elements respectively. We have used the boolean literals true and false and there are two corresponding reserved words to indicate the type boolean, namely **bool** and **cbool**. This apparently curious choice is traditional in computing. **bool** is an abbreviation for boolean which is derived from the name of George Boole, a mathematician, who developed a branch of mathematics which became known as boolean algebra. For example, we use **bool** and **cbool** to declare boolean vectors as follows

let *B* = @1 **of bool** *[* true,true,false,false *]*
or
let *BB* = @ *-3* **of cbool** *[x* **or** *y, x* **and** *y, ~y]*

We can also write

let *D* = **vector** *1::8* **of true**
or
let *E* = **vector** *0::6* **of false**

An example of the use of a vector of booleans is given later in Chapter 12.

8.4 Abort

The reserved word **abort** simply stops the program.

8.5 Functions

We have already mentioned the **length** and sqrt functions. They are used by giving the name of an object or an expression in brackets after the function name.

Thus *sqrt(5 + 4)* has the value 3.0 and *length("abc" ++ "def")* has the value 6.

There are a number of other functions which are commonly used and they are listed in Appendix IV. Do not worry about the formality of the declarations. You will understand them after reading the chapter on procedures. As an example if you want to use sin(x) and cos(x) in your program you can write for example

```
y := a * cos( x ) + b * sin( x )
```

Note that the argument is enclosed in brackets. The comment after each definition in Appendix IV tells you the type for the argument where appropriate.

8.6 Standard Identifiers

A number of standard identifiers exist in the language. They are

r.w	variable initially 12
s.w	variable initially 2
i.w	variable initially 10
s.i	variable set to the standard input
s.o	variable set to the standard output
maxint	constant, the maximum integer
epsilon	constant, the largest real e such that 1 + e = 1
pi	constant, pi
maxreal	constant, the largest real

Note that the minimum integer value is -maxint - 1 and the minimum real value is -maxreal.

8.7 Semi-Colons

As a lexical rule in PS-algol, a semi-colon may be omitted whenever it is used as a separator and coincides with a newline. This, of course, allows many of the annoying semi-colons in a program to be left out. However, to help the compiler deduce where the semi-colons should be, it is a rule that a line may not begin with an binary operator. e.g.

```
a *
b
```

is valid but

```
a
* b
```

is not

This rule also applies to the invisible operator between a vector and its index list. e.g.

```
let b = a( 1,2 )
```

is valid but

```
let b = a
( 1,2 )
```

will be misinterpreted since vectors can be assigned.

8.8 Comments

Comments may be placed in a program by using the symbol '!'. Anything between the ! and the end of the line is regarded by the compiler as a comment. e.g.

```
a + b     ! add a and b
```

8.9 Directives

There are certain compiler directives used to annotate the listing of the program provided by the compiler that the user may wish to invoke. The symbol '%' is used to denote a directive. They are

%list	print the program listing.
%nolist	do not print the program listing.
%title,< string literal >	take a new page and use the string as a heading for this and subsequent pages.
%lines,< integer literal >	Inform the compiler of the number of lines on each page of output paper.
%ul	underline the reserved words in the listing.
%noul	turn off the reserved word underlining.

Exercises 8

8.1 In chapter 3 we wrote a program to print a shopping list. Rewrite the output part so that you do not have to worry about keeping the name of the article strings to the same length when preparing the data.

8.2 Determine the value of the following expressions. To compare your answers to the solution, put in appropriate brackets first to show how the priorities operate.

(i) *3 * 2 + 4 * 8 - 6 * 2*
(ii) *8* **div** *4* **div** *2*
(iii) *3.0 + 6.1 / 2.0 + 1.3*
(iv) **true and ~false or false**

8.3 We have seen how we can print a given string in a field of a given width using : n. This right justifies the string inserting the number of blanks required to the left. Thus if *name* is less than 20 characters long

```
name : 20
```

in a **write** list, right justifies the name in a field of length 20. Write output list elements to write 'name' left justified in a field of length 20.

8.4 Modify the program in section 5.3 to put your address at the top right hand side of your page which is 75 characters wide. Again do not expect the user to put in leading blanks. You should expect them to supply something like

```
"20, Castle Drive,"
"St Andrews,"
"Fife"
```

8.1 write *quantity, name : 14, " at ", cost.per.item, line.total, "'n"*

8.2 (i) *((3 * 2) + (4 * 8)) - (6 * 2) = 26*
(ii) *((8* div *4)* div *2) = 1*
(iii) *((3.0 + (6.1 / 2.0)) + 1.3) = 7.35*
(iv) ((true and (~false)) or false)
= ((true and true) or false)
= true or true
= true

8.3 name, "" : 20 - length(name)
We need two write list entries here. *name* is printed as itself followed by *20 - length(name)* blanks.

8.4
```
!Program to accept invitations.
let name1 = reads ; let function = reads
let date = reads ; let name2 = reads

while ~eoi do
begin
        let address = reads
        write address : 55 + length( address ) +
                        ( 20 - length( address ) ) div 2
end

write "Dear ",name1, ",'n"
write "" : length( name1 ) + 6
write "Thank you for your invitation to your ", function, "on'n ",
            date, ", which I am very pleased to accept.'n"
write "Yours sincerely,'n" : 47
write  name2 : 30 + length( name2 )
```

Note that *55 + length(address) + (20 - length(address))* div *2*
simplifies to *65 + length(address)* div *2*

9 PROCEDURES

The programs we are now writing are more complicated than before because the actual problems themselves are also becoming more complicated. One of the aims of a good programming language is to keep the programs readable so that a lot of program documentation is unnecessary. To help us keep programs more readable we introduce the idea of a **procedure**. The idea is that we can write a section of program and give a name to it and then 'call' this piece of program or procedure from somewhere else in the main program, or indeed from another procedure.

This idea leads us to think about writing programs in a different way. Instead of trying to carry everything in our heads and then write the program as a long linear list of instructions, we start off by thinking of the solution in general terms and then gradually refine the general solution to a complete solution of the problem. Such a method is called a **top down solution**. We illustrate this idea with a few simple examples.

In example 6.2 we wrote a bubble sort program. In the middle of this we wrote a piece of code

```
if x( j ) > x( j + 1 ) do
begin
        let temp = x( j )
        x( j ) := x( j + 1 )
        x( j + 1 ) : = temp
end
```

which swapped the values of x(j) and x(j + 1) if x(j) > x(j + 1). This particular piece of program is not very difficult to read but we will write a procedure to make it even clearer. When we were writing our program we could have written

```
if x( j ) > x( j + 1 ) do swap.xs
```

and finished writing our program, delaying writing the detailed code for the *swap* operation until later. We could then have written a procedure with name *swap.xs* as follows.

```
let swap.xs = proc()
begin
        let temp = x( j )
        x( j ) := x( j + 1 )
        x( j + 1 ) := temp
end
```

The sequence of clauses, or **procedure body** as it is correctly called in this case, is exactly the same as in the previous program but the advantage is that the main program is more immediately understandable and we delayed thinking about how to write the code until later. The effect of the procedure call *swap.xs* in the **if** clause is simply to transfer control to the body of the procedure and when this has finished executing to return control back to the main program.

The name *swap.xs* was chosen to make it clear to the reader what has to be done in the procedure body. The rule for inventing such names is the same as for any other name in PS-algol, namely it must start with a letter and be made up of letters, digits and dots only. We will shortly see how to pass information to the procedure body. In the above case the information has come from the main program itself and the declarations of the objects used in the procedure body apart from *temp* have already been made in the main program. *temp* is purely a local name.

There are two other points to remember about writing procedures. First of all, although we actually wrote our procedure after the main program we still have to insert it in the program before we make the call itself. This is because the PS-algol compiler is a fast one which does all its compilation in a single scan. In order to set up the program links between the call and the procedure it needs to know about the procedure before the call is made. It can come anywhere in your program before the call but after the declaration of the main body objects that it uses. PS-algol recognises the word **proc** in the heading of the procedure declaration and knows that it does not have to execute any code at that moment.

The other point which we have briefly mentioned in the last paragraph, is that in order to compile the code into machine instructions PS-algol needs to know about the names which have an existence outside the procedure. In the *swap.xs* procedure there were names *x* and *j* which were used. This implies a knowledge of *x* and *j*. We would therefore have to put our procedure *swap.xs* declaration immediately after the piece of code

```
for j = i + 1 to n do
begin
```

This is not very nice, could be very confusing and may easily lead to errors which would prevent your program compiling if you were to put this declaration in the wrong place. If we stop to think a little more carefully about the procedure we can see that it is a special case of a more general procedure to swap 2 vector elements, say *z(i)* and *z(j)* or on another occasion *t(m)* and *t(n)*. This leads us to the idea of a procedure with parameters. We use the notation

```
let swap = proc( * real T ; cint i, k )
begin
        let temp = T( i )
        T( i ) := T( k )
        T( k ) := temp
end
```

In the brackets after the procedure name *swap* we have declared the use of a real vector *T* and two integer constants *i* and *k*. We call these the **formal parameters** of the procedure. The word 'parameters' just means that they are names special to the procedure and they are called formal because they are just used to show how the computation has to be carried out in the procedure body. The notation *real is used to indicate that *T* is a vector of reals. In our main program we still call the procedure by writing its name but we now have to say what the actual parameters are. In our case the call would be

```
if x( j ) > x( j + 1 ) do swap( x, j, j + 1 )
```

The effect of this call is to execute the code as defined in the procedure declaration but with the formal parameters *T, i* and *k* given the values of *x, j* and *j + 1* respectively. Note that the constant *temp* is local to the procedure and has no existence outside the procedure body. The procedure is now independent of the actual parameters until it is called and so its declaration can be placed anywhere we like in the program so long as it precedes the call.

If somewhere else in our program we wanted to swap two other actual real vector elements, say p(s) and p(t) we could write

```
swap( p, s, t )
```

and the same procedure would swap their values.

One further point about the use of *real *T*. We declare our formal parameter as a vector in this way because we do not want to tie ourselves down to a fixed length of vector. Although we have introduced the idea of formal parameters which are declared along with their type in the procedure heading this does not prevent us from using parameterless procedures, like our first definition of *swap.xs* if it is convenient to do so.

Suppose now, instead of just writing a program to read in n numbers and sort them into order we wanted to sort some numbers as part of a much larger program. It would be convenient to write a procedure called *sort* say, to do this. Such a procedure could then be used in several different programs and would also help in making the main program more readable.

We need to think first about the parameters that we require. The numbers we wish to sort will always be in a vector so the vector name will be one parameter. We sometimes want only part of the vector so it would be useful to give the sort limits as two integers *i* and *j* say. Since we will need this procedure later on we will make the vector of type **int** and in a similar manner to the above we do this by using the formal parameter ***int** *q* meaning a vector of integers called q. (If we wanted a vector of vectors we would write ****int** *q* and so on.) Our full declaration of the procedure could now be


```
let swap = proc( * int x ; int i,j )
begin
        let temp = x( i )
        x( i ) := x( j )
        x( j ) := temp
end

let sort = proc( * int q ; int i,j )
begin
        for s = i to j - 1 do
                for t = s + 1 to j do
                if q( s ) > q( t ) do swap( q,s,t )
end
```

Note that the declaration of procedure *swap* must precede the declaration of procedure *sort* since *sort* uses *swap* internally. An actual call of the procedure *sort* could be

```
sort( x,1,n )
```

which would sort the vector of integers called *x* from *x(1)* to *x(n)* into order. In the main program we would have declared an integer vector *x* with subscripts including the range 1 to n.

So long as it makes sense we can use expressions in place of simple object names in the actual parameter list. In the above example it does not make sense to replace the actual vector parameter by an expression. It does, however, make sense to replace *i* and *j* by expressions. We could for example write

```
sort( y, i, i + 10 )
```

and this would sort the eleven integers from y(i) to y(i + 10) into order.

The two procedures we have used above both consisted of complete pieces of code which could have been written in a sequence directly in the main program. We chose not to do this largely to make our programs more readable but also to save repeating code if we made more than one call of the procedure in the program.

Sometimes we would like to evaluate an expression and return its value as the result of a procedure call. For example we may have to evaluate a number of quadratic expressions in a program and it would be convenient to write a procedure to do this for us. We need to be clear about the type of answer we are going to produce and in PS-algol we need to declare this along with the formal parameters. For example the quadratic producing procedure could be

```
let quadratic = proc( real a, b, c, x -> real ) ; a * x * x + b * x + c
```

Here we have simply written the expression we want to evaluate as the procedure body and have indicated in the procedure heading by -> **real** that the result is going to be real.

From the computational point of view it would have been slightly better to have written the actual calculation as

```
( a * x + b ) * x + c
```

This happens to save one multiplication operation but is also more accurate in awkward cases where for example x is nearly equal to zero. It also suggests a way in which we can write a procedure to evaluate a polynomial for an arbitrary value of n. The following procedure will do this for us with *a* being a vector of coefficients of the polynomial.

```
let polynomial = proc( * real a ; real x ; int n -> real )
begin
        let p := a( n )
        for i = n - 1 to 0 by -1 do p := p * x + a( i )
        p
end
```

This is a slightly more complicated example in which we have to execute a sequence before producing the answer. When we have to do this, we need to make it clear just what the required answer is and this accounts for *p* being on the last line before the word **end**. If it is necessary, *p* can be replaced by an expression which evaluates to the required answer. Thus our quadratic example is really a special case of this when there is no extra calculation to be done before computing the answer. Before you read on you should convince yourself that this procedure does calculate a polynomial as required. Try taking n = 3 and work through the for clause step by step.

To conclude this chapter we give a few more simple examples of procedure declarations and calls.

In chapter 4 we wrote a program to compute Fibonacci numbers and included a piece of the main program to write these out, six to a line. We will write a procedure to do the output but will make it more flexible for more general use. We have to think carefully first of all about the parameters and the global names that we need. The piece of code that we are going to convert to a procedure is

```
write new.fib
column.count := column.count +1
if column.count = 6 do { write "'n" ; column.count := 0 }
```

To make this more general we will replace the literal *6* by a name say *no.in.line* and make this a parameter of the procedure. It would also be more flexible if we could control the integer output width as described in chapter 8 so we will include a second integer parameter called *width* to do this. The integer variable *column.count* presents a difficulty. The value that it holds is not local to the procedure since it needs to be passed in from the main program and the updated value remembered by the main program for the next time that the procedure is called. This leads us to think rather carefully about the properties of the parameters of the procedure. In PS-algol we say that all parameters are 'called by value'. This means that the values of the parameters at call time are passed into the procedure body and any assignments to the formal parameters inside the procedure body are purely local to the procedure. That is, the values of the corresponding actual parameters in the main program are not altered by such assignments. Declarations of parameters are thus equivalent to the declarations of local names with initial values assigned by the procedure call. Methods of handling parameters are the subject of much discussion by language designers and we do not wish to elaborate on our choice here. We will simply say that we believe that this method of parameter passing leads to fewer program run time errors, than apparently more flexible systems do. We can easily overcome the problem of the global value of *column.count* by declaring it in our main program before we declare the procedure. It thus becomes available for use in the subsequent procedures since the procedure declaration is in the scope of the name. We can rewrite the program as follows

```
write "Table of Fibonacci numbers'n'n"
let a := 1 ; let b := 1 ; let field.width = 10
write a:field.width, b:field.width
let total.no := 2 ; let column.count := 2


let output.no = proc( int number, no.in.line, width )
begin
        write number : width
        column.count := column.count + 1
        if column.count = no.in.line do
        begin
                write "'n"
                column.count := 0
        end
end

while total.no < 42 do
begin
        let new.fib = a + b
        output.no( new.fib, 6, field.width )
        a := b ; b := new.fib
        total.no := total.no + 1
end
```


We often want to leave several blank lines before output lines and it is useful to have a procedure to do this for us. The first example we give is for the case when we want the procedure to issue its own **write** command. Such a procedure could be

```
let lines = proc( int n ) for i = 1 to n do write "'n"
```

A subsequent call *lines(3)* will output three new lines in the output stream.

We may also want a procedure to output a string of new line symbols 'n to include as part of a **write** clause list in the main program or another procedure. Such a procedure could be

```
let new.lines = proc( int n -> string )
begin
        let s := ""
        for i = 1 to n do s := s ++ "'n"
        s
end
```

and it could be used in a **write** clause as, for example

```
write "Title of output", newlines( 3 )
for i = 1 to m do write a( i ), b( i ), c( i ), new.lines( 1 )
```

to produce a title followed by two blank lines and then the table of values, 3 on a line for m lines.

The observant reader may have noticed that despite our statement that parameters are called by value and that if we change the value of a parameter inside a procedure, its global value is unaltered, nevertheless in the procedure the actual values of the elements of the vector have been changed to sort them into the correct order. This is a difficult point to make clear and one which appears to be an exception to the rule. Formally, if *x* is a vector parameter of a procedure, we can assign a new vector to *x* inside the procedure without changing its value externally. In the sorting example we are not changing the whole vector but rather elements of the vector.

Another useful idea which is common to most algol-like languages is that of **recursive** and **mutually recursive** procedures. In Chapter 12 we will discuss the way in which recursive procedures can be used to obtain elegant and readable solutions to some difficult problems but here we will just introduce the ideas with a simple example.

Suppose that we want to read an integer n typed by a user as data for a program and to refuse to accept it until a value between 1 and 10 say is typed. With the knowledge we have so far we could write a piece of program

```
let not.done := true
write "Enter an integer between 1 and 10 "
while not.done do
begin
        n := readi()
        if n < 1 or n > 10 then
                write "Integer must be between 1 and 10. Try again"
        else not.done := false
end
```

Another solution would be to write a procedure called *get.integer* as follows:

```
let get.integer := proc( -> int) ; nullproc

get.integer := proc( -> int )
begin
        let n = readi()
        if n < 1 or n > 10 then
        begin
                write "The integer must be between 1 and 10. Try again"
                get.integer ()
        end
        else n
end
```

Note that
(i) both branches of the **if** ... **then** ... else ... clause produce an integer answer which is the result produced by the procedure.
(ii) a name can only be used **after** its declaration and so to use *get.integer* inside the procedure body we need to first have a dummy declaration and then redeclare it.
(iii) **nullproc** can be used as a dummy procedure body for any type of procedure.
(iv) even when a procedure has no parameters it still requires brackets when called, as in *get.integer()*

The procedure could now be used in the main program by writing

```
write "Enter an integer between 1 and 10"
n := get.integer()
```

You might try generalising this example by adding two integer parameters *lower.bound* and *upper.bound* to the procedure definition so that the same procedure can be used from different parts of the program with different integer bounds on the data. Don't forget to change the message to take account of this.

The idea of mutual recursion involves two or more procedures which call each other. It is difficult to give meaningful elementary examples of this idea but perhaps the following will suffice. Suppose we wish to program a computer game in which there are two types of move called *move.a* and *move.b* but in the code for *move.a* it is possible to call *move.b* and vice versa. For the sake of the illustration suppose both *move.a* and *move.b* use board co-ordinates *x,y* and a status indicator called *status*. Then the procedures could be

```
let move.a = proc( int x, y, status )
begin
        . . . . . .
        if status = 1 do move.b( p,q,1 )
        . . . . . .
end


let move.b = proc( int x, y, status )
begin
        . . . . . .
        if status > 3 do move.a( j, k, status )
        . . . . . .
end
```

A technical problem with this piece of code is that the procedure *move.a* calls *move.b* before it has been declared and vice versa if we change the order of the two procedures.

We overcome this problem by using a dummy declaration for *b* as for the recursive procedure above. This means that the name *b* can be used within the declaration of *a* and then we can rewrite *b*. This looks like :


```
let b := proc( int x, y, status ); nullproc

let move.a := proc( int x, y, status )
begin
        . . . . . .
        if status = 1 do move.b( p,q,1 )
        . . . . . .
end

move.b := proc( int x, y, status )
begin
        . . . . . .
        if status > 3 do move.a( j, k, status )
        . . . . . .
end
```

This means that when *a* is called b has its new value and so the procedures work together in the desired way.

Another point to note about procedures is that they are values like any other ie they can be assigned, passed into procedures, put in vectors, returned from procedures etc. This gives a very powerful generality. As a small example, suppose we wished to have a *get.integer* procedure which read integers between two values, as given earlier in this chapter, but we wanted to be able to generate any number of these procedures then we could write:

```
let new.get.integer = proc( int lower, upper -> proc( -> int ) )
        proc( -> int)
        begin
                write "Enter an integer between", lower, "and", upper, ": "
                let n := readi()
                while n < lower or n > upper do
                begin
                        write "The number should be between", lower, "and", upper, "Try Again:"
                        n := readi()
                end
                n
        end
```

This is a procedure which, when it is called, is given two integers (the upper and lower bounds of the numbers to be read in) and returns a procedure to get an integer between those two values. This culd be used as follows:

```
let int.between.1.and.10 = new.get.integer( 1, 10 )
let i := int.between.1.and.10()
let int.between.5.and.17 = new.get.integer( 5, 17 )
i := int.between.5.and.17()
```

Exercises 9

9.1 Write a procedure without parameters to calculate the distance between two points (x1,x2), (y1,y2). Remember that the square of the distance is

$$(x1 - y1)^2 + (x2 - y2)^2$$

9.2 Modify the procedure in 9.1 to be a procedure with parameters x1, y1, x2, y2.

9.3 Use the procedure in 9.2 to write a program to find the pair of points in a list of points

(x(i), y(i)) (i = 1,2, ... n)

whose distance from each other is maximum for the list.

9.4 Write a procedure which given two integers as actual parameters returns the value of the larger as the result.

9.5 Write a procedure which given a string as a parameter returns the value true if the first character is a vowel and false otherwise.

9.6 Write a procedure to

(i) discard any leading spaces or new line characters in the input stream.

(ii) accumulate the string of characters from this point until the next new line character and return this string as its result. You may use the function *peek* which allows you to look ahead to the next character without actually reading it.

Note that this procedure can be used to read a response from a terminal as a string without enclosing that string in quotation marks.

Solutions to Exercises 9

9.1

```
let dist = proc( -> real )
sqrt( ( x1 - x2 ) * ( x1 - x2 ) + ( y1 - y2 ) * ( y1 - y2 ) )
```

9.2

```
let dist = proc( real x1, x2, y1, y2 -> real )
sqrt( ( x1 - x2 ) * ( x1 - x2 ) + ( y1 - y2 ) * ( y1 - y2 ) )
```

9.3

```
let n = readi()
let x = vector 1::n of 0.0
let y = vector 1::n of 0.0
for i = 1 to n do
begin
        x( i ) := readr()
        y( i ) := readr()
end

! The vectors x and y are now initialised
! Let i,j be the subscripts of the required points
! initially we set both to 1 and distance to 0.0
! Note that we can work with the distance squared and take
!the square root at the end.

let i := 1 ; let j := 1 ; let dist := 0.0

! We write a procedure dsq to work out the
! square of the distance between the
! two points ( a,b ), ( c,d )
! It is unnecessary to find the square root at this point.

let dsq = proc( real a, b, c, d -> real )
( a - c ) * ( a - c ) + ( b - d ) * ( b - d )


for p = 1 to n - 1 do
        for q = p + 1 to n do
        begin
                let d = dsq( x( p ), y( p ), x( q ), y( q ) )
                if d > dist do
                begin
                        dist := d
                        i := p
                        j := q
                end
        end

write "The greatest distance is between points ", i, " and ", j,
                "'nwith values ", x( i ), y( i ), x( j ), y( j ),
                " and the distance equals ", sqrt( dist )
```

9.4

```
let bigger = proc( int i, j -> int )
if i >= j then i else j
```

9.5

```
let vowel = proc( string s -> bool )
s ~= "" and ( case s( 1/1 ) of
                        "a","e","i","o","u" : true
                        default : false )
```

9.6

```
let read.the.line = proc( -> string )
begin
        let s := ""

        repeat s := read()
        while s = " " or s = "'n"

        while peek() ~= "'n"  do s := s ++ read()
        s
end
```

The function read allows you to read the next character in the input stream without the character being enclosed in string quotes.

10 STRUCTURES

It is often useful to collect together several pieces of information and give a name to this collection. We are not referring here to a vector which we have already discussed but rather to something like information about a person. We may wish to read information about a person's name, home town, age and sex say and hold this as one unit of data. We can do this by declaring a structure as follows

```
structure person( string name, home.town ; int age ; string sex )
```

This defines the form of the structure and gives names to the items which make up the structure and also a name, that is *person*, to this type of structure. We can now set up an instance of such a structure by, for example

```
let joe := person( reads(), reads(), readi(), reads() )
```

This sets up a structure of the given type and allows us to refer to joe's name by writing *joe(name)* and so on. As usual, the read commands can be replaced by any relevant expressions that you wish. To set up a complete file of people, say members of class A4 in a given school, we could use a vector of structures as follows.

```
structure person( string name, home.town ; int age ; string sex )
let no.in.class = readi()
let A4 = vector 1::no.in.class of nil

!The above clauses set up a vector of pointers. (see next paragraph)

for i = 1 to no.in.class do
A4( i ) := person( reads(), reads(), readi(), reads() )

!We could now write a program to sort them into any order.
```

We now have a vector with elements containing this information. Although in this example each structure is of the same class, it is not a requirement. The piece of program above includes the declaration of a vector of **nil**. This is a vector of pointers, or more correctly of type ***pntr** in PS-algol. The pointers are used to point at structures. Initially they are set to **nil** which is a predefined name of type **pntr** in PS-algol, and later in the **for** loop they are made to point at different instances of *person*. If we wanted now to work out the average age of the class we could do it as follows.

```
let total.age := 0
for i = 1 to no.in.class do total.age := total.age + A4( i )( age )
let average.age = total.age / no.in.class
```

As with vectors an alternative notation to

```
A4( i )( age )
```

is

```
A4( i,age )
```

which is probably more readable but that is a matter of opinion.

We can also use pntrs in, for example, a new structure definition. Suppose we wished to set up a parental family tree structure. We could do this by defining a structure

```
structure child( string name ; pntr father, mother )
```

and we could set these pointers to the appropriate people when we read in the data. If we want to make this structure into a real family tree going both ways then we need to handle pointers to children as well. We can do this by ensuring that the children entry in the structure is of a variable length. That is, a vector of pointers to children. We use the notation ***pntr** *children* to denote a vector of pointers with the name

children.

The complete definition could then be

```
structure human( string name ; pntr father, mother ; * pntr children )
```

If we want to refer to the i^{th} child of a vector of human structures with the name *Jack* we would write

```
Jack( children )( i )
```
or
```
Jack( children, i )
```

In the following example we are going to help Albert the domino player to play a hand of seven dominoes. Albert plays according to very strict rules. Whenever he has to play he chooses the domino by the following rules.

(a) look at the total number of spots on the domino and play the one with the highest total

(b) if rule (a) fails, Albert always prefers to play a double e.g 2|2 is played before 3|1

(c) finally if rule (b) fails, Albert will then play the domino with the biggest single field e.g. 1/5 is played before 2/4

First of all we have to decide how to represent the information we need for the calculation. Each domino has two fields and because of rule (c) we require to know the larger. Also rule (a) will require the sum of the two fields. Therefore the domino can be represented by the structure

```
structure domino( cint larger, smaller, sum )
```

We make the fields constant integers since once we have created them they will never be altered. There are seven dominoes in a hand and we can represent this by a vector of pointers to structures, each element eventually pointing at a domino structure. Initially we declare the vector of pointers by

```
let dom = vector 1::7 of nil
```

We will now write the program to put the hand into order

```
input.dominoes()
sort.dominoes()
output.hand()
```

The main program consists of three procedure calls which will now be refined until we have a complete program. Let us write the procedure *input.dominoes*

```
let input.dominoes = proc()
    for i = 1 to 7 do
    begin
        let x = readi() ; let y = readi()
        dom( i ) := if x < y then domino( y, x, x + y )
                            else domino( x, y, x + y )
    end
```

Seven pairs of integers are read in and the seven vector elements are made to point at structures representing each domino. We are now going to sort the vector so that the first element will contain the best domino to be played and so on. Notice that the values in the structures are not being altered, only the vector elements which point to them. For the sorting we can use bubblesort


```
let sort.dominoes = proc()
    for i = 1 to 6 do
        for j = i + 1 to 7 do
        if ~greater( dom( i ), dom( j ) ) do swap( dom, i, j )
```

This is essentially the same solution as exercise 6.2. However we have abstracted the solution for clarity and we must now write procedures *swap* and *greater*.
swap can be written by

```
let swap = proc( * pntr t ; int i, j )
begin
    let temp = t( i )
    t( i ) := t( j )
    t( j ) := temp
end
```

which is familiar. Procedure *greater* decides which is the more desirable of the two dominoes according to the rules. The result of this procedure is either true or false and is therefore boolean.

```
let greater = proc( pntr t, t1 -> bool )
    t( sum ) > t1( sum ) or t( sum ) = t1( sum ) and
    ( t( larger ) = t( smaller ) or t1( larger ) ~= t1( smaller ) and
    t( larger ) > t1( larger ) )
```

You should satisfy yourself that this largish boolean expression represents the 3 rules for playing dominoes. All we have to do now is to output the hand.

```
let output.hand = proc()
begin
    write "Albert's hand in preferred order is :- "
    for i = 1 to 7 do
    write dom( i,larger ), " / ", dom( i,smaller ), "'n"
end
```

Careful attention should be paid to the method of solution to this problem. First, the data structures to represent the information required were decided upon. Procedures were then used successively to refine the solution until a program was obtained and finally we put it all together to give the required result. The procedures must be put in the proper order so that none is referred to before it is declared. This gives us the full program.

```
structure domino( cint larger, smaller, sum )
let dom = vector 1::7 of nil


let input.dominoes = proc()
for i = 1 to 7 do
begin
    let x = readi() ; let y = readi()
    dom( i ) := if x < y then domino( y, x, x + y )
                else domino( x, y, x + y )
end


let greater = proc( pntr t, t1 -> bool )
    t( sum ) > t1( sum ) or t( sum ) = t1( sum ) and
    ( t( larger ) = t( smaller ) or t1( larger ) ~= t1( smaller ) and
    t( larger ) > t1( larger ) )
```

```
let swap = proc( * pntr t ; int i, j )
begin
        let temp = t( i )
        t( i ) := t( j )
        t( j ) := temp
end


let sort.dominoes = proc()
for i = 1 to 6 do
for j = i + 1 to 7 do
if ~greater( dom( i ), dom( j ) ) do swap( dom, i, j )


let output.hand = proc()
begin
        write "Albert's hand in preferred order is :- "
        for i = 1 to 7 do
        write dom( i, larger ), " / ", dom( i, smaller ), "'n"
end

!Main Program

input.dominoes()
sort.dominoes()
output.hand()
```

A **pntr** may point to a structure of any class. In the same way that it is useful to interrogate a vector to find its bounds it is also useful to test a pointer for the class of the structure it is currently pointing at. Two relational operators **is** and **isnt** are provided for this purpose. For example if we have

```
structure golfer( cint no.of.rounds, no.of.clubs )
structure cricketer( cstring name ; cint no.of.runs )
```

and

```
let first = golfer( 4, 14 )
let second = cricketer( "Peter", 1192 )
```

then

```
first is golfer
```

yields the value true and

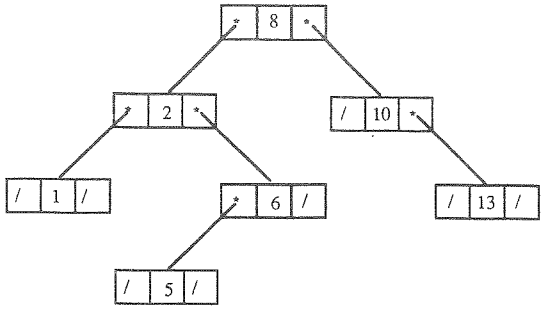
```
second isnt cricketer
```

yields the value false. The full power of **is** and **isnt** is realised when writing general purpose procedures to process a large number of structure classes.

Sorting

Structures can also be used for sorting. So far we have only used bubblesort or variations of it in our programs. Bubblesort is however very inefficient. If there are n elements to be sorted then the number of sorting operations is proportional to n^2. We can do much better than this.

We have already seen how a family tree can be modelled using structures. That is one kind of tree. Another special kind of tree which is useful in sorting is a **binary tree**. Each node in a binary tree has a left and a right subtree which may be empty. When used for sorting the tree is ordered such that for any node the elements in the left subtree are all less than the elements of the current node and the elements in the right are greater or equal. The following is a sorted binary tree



The fields with an '*' in them contain pointers to the next structure. Those with '/' all point to **nil**. The top of the tree is called the head or the root. In constructing an ordered binary tree the head initially points to **nil**. We will now write a program to read in strings and sort them as they are read, using a binary tree for the sorting.

The structure to hold the data is

```
structure tree.node( cstring tree.string ; pntr left, right )
```

This defines the structure to hold a string and a left and right subtree which will be used for the nodes of the tree. The main program is

```
let head := nil
while ~eoi() do
head := enter( head, tree.node( reads(), nil, nil ) )
write "The sorted strings are :-'n"
print.tree()
```

This initialises the head of the tree to **nil** and then goes round a loop adding entries to the tree using procedure *enter*. The enter procedure which we still have to write, takes as parameters the head of the tree and the new node and returns the new head of the tree.

If the tree is empty then the new head of the tree is the new node. If the tree is not empty then the new string value is compared with the string in the head node. If the new node is less than the head node we place the new node on the left subtree and otherwise on the right subtree. The following code will do this.

```
let enter := proc( cpntr head, new -> pntr ) ; nullproc

enter := proc( cpntr head, new -> pntr )
        if head = nil then new else
        if new( tree.string ) < head( tree.string ) then
        begin
                head( left ) := enter( head( left ), new )
                head
        end
        else
        begin
                head( right ) := enter( head( right ), new )
                head
        end
```

The subtlety of the solution is that it uses recursion to take advantage of the recursive nature of the tree definition. At any node, the left and right subtree are either empty or are themselves trees. The procedure

enter may therefore be used to add new nodes to these subtrees.

Having set up the ordered tree we now have to extract the values in the correct order. To do this we perform a left to right scan of the tree. This is called a symmetric order traversal of the tree. That is, at any node in the tree we print the values in the left hand subtree then the current value followed by the values in the right hand subtree. This is again recursive.

```
let print.tree := proc( cpntr head ) ; nullproc

print.tree := proc( cpntr head )
if head ~= nil do
begin
        print.tree( head( left ) )
        write head( tree.string ), "'n"
        print.tree( head( right ) )
end
```

For those in the know, this procedure is the same as the solution to the Towers of Hanoi problem (see Chapter 12) except that it uses data structures. The reader should satisfy himself that the program is complete.

The advantage of this type of sorting is that it is fast. For n elements the number of sorting operations is roughly proportional to nlog(n) which is much less that n^2 for large values of n.

The combination of first class procedures and structures can be used to implement abstract data types. This can be done by hiding the internal structure of the object within the scope of a generator function which returns a set of functions to operate on the abstract type. For example a complex number package might be written as:

```
structure complex.pack( proc( real,real -> pntr ) new .complex;
                        proc( pntr,pntr -> pntr) add.complex;
                        proc( pntr ) print.complex )

let complex.package = proc( -> pntr )
begin
    structure complex( real rpart, ipart )

    let n = proc( real i, r -> pntr ); complex( i,r )

    let a = proc( pntr c1, c2 -> pntr ); complex( c1( rpart ) + c2( rpart ), c1( ipart ) + c2( ipart ) )

    let p = proc( pntr c ); write c( rpart ), " + ", c( ipart ), "i"

    complex.pack( n, a, p )
end
```

This allows complex numbers to be manipulated without knowledge of their representation, as in the following program fragment.

```
let cpack = complex.package()
let new = cpack( new.complex )
let add = cpack( add.complex )
let print = cpack( print.complex )

let c1 = new( 3, 4 )
let c2 = new( 2, 7 )
print( add( c1, c2 ) )
```


Exercises 10

10.1 A linked list is a list of structures that are linked together through one of their fields. For example, a linked list of integers may be constructed out of the structure

```
structure int.list( int number ; pntr link )
```

by the program segment

```
let list := nil
for i = 1 to 3 do list := int.list( i, list )
```

This will result in the list pointed at by list. Given an integer and a list write procedures to perform the following

(i) add a **structure** containing the integer to the start of the list.
(ii) add a **structure** containing the integer to the **end** of the list.
(iii) assuming the list is ordered from high to low, add a **structure** containing the integer in such a way as to preserve the ordering.

10.2 Write a procedure to reverse a list of the above type.

10.3 Define a structure to hold information about oil wells. The structure fields should include the name of the well, its map reference, the number of men on the well, output per day in barrels and nearest neighbouring oil well.

Solutions to Exercises 10

10.1 (i)

```
let add.start = proc( int i ; pntr list -> pntr )
int.list( i, list )
```

(ii)

```
let add.end = proc( int i ; pntr list -> pntr )
if list = nil then int.list( i, nil )
else
begin
        let temp := list
        while temp( link ) ~= nil do temp := temp( link )
        temp( link ) := int.list( i, nil )
        list
end
```

(iii)

```
let add.order = proc( int i ; pntr list -> pntr )
if list = nil or list( number ) <= i then int.list( i,list )
else
begin
        let temp := list
        while temp( link ) ~= nil and temp( link,number ) > i do
        temp := temp( link )
        temp( link ) := int.list( i, temp( link ) )
        list
end
```

10.2

```
let reverse.list = proc( pntr list -> pntr )
begin
        let temp := nil
        while list ~= nil do
        begin
                temp := int.list( list( number ), temp )
                list := list( link )
        end
        temp
end
```

10.3

```
structure oil.well( string well.name,
                    int ref.east, ref.north, no.men, barrels
                    pntr nearest.well )
```


11 FILE INPUT AND OUTPUT

So far we have said very little about files. This is because we did not wish to confuse the issue of PS-algol as a programming language with the particular environment in which PS-algol resides. For PS-algol to be an effective programming tool it must provide the ability to communicate with the outside world to receive data and produce results. The outside world in this case is the operating system of the host computer. The four main implementations of PS-algol are for the operating systems VAX/VMS, UNIX, CP/M and the Apple Macintosh.

The implementations of PS-algol differ in some respects. This chapter describes the Macintosh implementation. It is good programming practice to isolate the sections of your program that are dependent on the operating system's facilities as this will make it easier to transport your programs from system to system.

PS-algol communicates with the outside world via files. To create an object of type file we must 'open' or 'create' the file in the file system. You 'create' a file to bring a new file into existence and 'open' a file if it already exists.

The functions to do this are defined by

```
let create = proc( cstring name ; cint flag -> file )

let open = proc( cstring name ; cint access.mode -> file )
```

These functions take a number of parameters that are as yet unexplained and produce an object of type file which we call a **file descriptor**. The file descriptor can now be used anywhere an object of type file is legal and in particular in read and output clauses. For example

```
let input.file = open( "Ronsfile", 0 )
```

would allow us to write clauses like

```
let c = readi( input.file )
```

in which case the integer will be read from the file called *Ronsfile* instead of the keyboard. The interpretation of the parameters in the create and open functions are as follows

filename : any string.
flag : put as 0 and forget what it means.
access.mode : 0 for read only, 1 for write only and 2 for read and write.

If an attempt to open or create a file fails, the file literal value of nullfile is returned. This value may be used as follows.

```
let s = "a.bad.file"
let the.file = open( s, 0 )  !try to open a read only file
if the.file = nullfile do ! was the open a success
begin
        write "The file ", s, " cannot be opened'n"
        abort
end
```

Once you have finished with a file it should be closed. *close* closes a file and allows no further access to it during the program unless it is re-opened. All files should be explicitly closed by use of this procedure.

The procedure is defined by

```
let close = proc( cfile descriptor )
```

and in the above example we could write

```
close( input.file )
```

to close the file.

Every PS-algol program has two rather special files defined for it called the standard input *s.i* and the standard output *s.o*. These names are predefined for you and are variables of type **file**. The standard input and output files are set up as the computer terminal but they may be reassigned to other files if required. The files are special in that they are taken as the default in **read** and **write** clauses. e.g.

```
let s = reads()
```

is shorthand for

```
let s = reads( s.i )
```

and the same is true for all the other read clauses as well as eoi(). Normally a file acts as a continuous stream of ASCII characters. The action of reading from a file has the effect of forming the characters at the current position in the file into a literal of the type of object specified in the read clause and moving the current position in the file on to the character following the literal just read. If the literal cannot be formed correctly then an error message will be issued. Also when reading reals or integers certain punctuation that precedes the literal will be ignored in the file. Punctuation consists of newlines, spaces and tabs. A summary of all the input functions is given below

read	read the next character in the file.
readi	ignore preceding punctuation and read an integer literal.
readr	ignore punctuation and read a real literal.
readb	ignore punctuation and read a boolean literal.
reads	ignore punctuation and read a string literal.
peek	look at the next character without reading it.
read.a.line	read from the current position up to a newline symbol. Give the result as a string without the newline symbol.
eoi	test for end of file.

Of these functions *read, reads, peek* and *read.a.line* are of type string, *readi* of type int, *readr* of type real and *readb* and *eoi* of type bool. When we wish to read from another file we simply change *s.i* to another file descriptor by assigning to it or by replacing it in the read clause. For example

```
let total = readi( input.file )
```

will read an integer from the file with descriptor *input.file* and use it to initialise the constant *total*.

Output to files is slightly different. The clause

```
write "hello'n"
```

is a short form of

```
output s.o, "hello'n"
```

Like **write**, **output** may also take a list of items to be written out. When we wish to write to another file we simply change *s.o* to a new file descriptor in the output clause.

11.1 Write a program to open a file and read all the text writing out only the first 15 characters of each line.

11.2 Write a program that will copy a file changing all lower case letters to upper case.

11.3 Write a procedure that will read a PS-algol name. Since a name must start with a letter the procedure should take that letter as an input parameter. The procedure then reads letters, digits and dots to form the name. Take care not to read more characters than is necessary.

Solutions to Exercises 11

11.1

```
let F = "Input"
let input = open( F, 0 )
if input = nullfile then write "Cannot open file ",F,"'n"
else
begin
        while ~eoi( input ) do
        begin
                let s = read.a.line( input )
                if length( s ) >= 15 then write s( 1/15 )
                else write s
                write "'n"
        end
        close( input )
end
```

11.2

```
let In.name = "Input" ;  let Out.name = "Output"
let in = open( In.name, 0 )
if in = nullfile then write "Cannot open file ", In.name, "'n"
else
begin
        let out = create( Out.name, 0 )
        if out = nullfile then write "Cannot create file ", Out.name, "'n"
        else
        begin
                let case.diff = decode( "a" ) - decode( "A" )
                while ~eoi( in ) do
                begin
                        let s := read( in )
                        output out, if s >= "a" and s <= "z" then
                                                code( decode( s ) - case.diff )
                                                else s
                end
                close( out )
        end
        close( in )
end
```

11.3

```
let read.an.identifier = proc( cstring s -> string )
begin
        let result := s ;  let s1 := peek()
        while letter( s1 ) or digit( s1 ) or s1 = "." do
        begin
                result := result ++ read()
                s1 := peek()
        end
        result
end
```


12 SOME COMPLETE PROGRAMMING EXAMPLES

In this chapter we will discuss some complete programming examples starting with a discussion of the problem to be solved, the broad principles of the computer solution and finally the development of the program.

Consider the problem of producing a table of primes up to some given integer n. The method used will be that of the traditional Sieve of Eratosthenes which notionally sets up a vector of all the integers between 1 and n and then deletes all the composite numbers which are multiples of 2, 3, 5 and so on, leaving only the primes. At each stage in the process we find the next prime by scanning through the vector from the last prime found looking for the next undeleted entry. It is only necessary to carry out the process up to the largest integer not greater than the square root of n since any number between this and n cannot possibly be exactly divided by any number greater than or equal to root n without the dividend being less than root n itself.

The obvious solution of setting up a vector of integers from 1 to n can be improved upon when we reflect that it is never necessary to inspect the values stored in the vector. We always know that the initial value in the ith element is i. The solution is simplified by declaring a boolean vector p of values true and setting them to false as composite numbers are 'scored out'. We also note that when we consider a prime i, we do not want to erase i itself but only composite numbers with factor i. The first such number will be $2 * i$ followed by every ith element from that point. The basic loop for eliminating multiples of i from a given prime i onwards is therefore

```
for j = 2 * i to n by i do p( j ) := false
```

The fact that composite numbers may be set to false several times does not matter.

We need only enclose this in a loop which counts from 2 to the integer part of the square root of n and to execute the inner loop whenever p(i) corresponds to a prime, that is, has value true. The required double loop is

```
for i = 2 to truncate( sqrt( n ) ) do
        if p( i ) do
        for j = 2 * i to n by i do p( j ) := false
```

where truncate is a function which returns the integer part of a real number. You should convince yourself that this piece of program works correctly by tracing its execution through with a small value of n, say n = 15.

The rest of the program simply reads in the value of n, declares the vector p and writes out the results neatly. This leads us to the complete solution

```
! Sieve of Eratosthenes

write "Input highest number :- "
let n = readi()
let p = vector 2::n of true

for i = 2 to truncate( sqrt( n ) ) do
        if p( i ) do
        for j = 2 * i to n by i do p( j ) := false

write "The primes less than ", n : 4, " are :-'n"
let format.control := 0

for i = 2 to n do
        if p( i ) do
        begin
                write i : 5 ; format.control := format.control + 1
                if format.control = 8 do
                { write "'n" ; format.control := 0 }
        end
```

The above problem was so simple that we did not need to use any procedures in its solution.

Consider next the problem of writing a general purpose procedure for evaluating the integral of an arbitrary function f(x) between limits a and b. Since we do not know the explicit function to be integrated and do not want to have to pass its values either singly or as a vector from the calling program we must use the idea of a procedure as a parameter of another procedure. Such a parameter will be declared along with the other parameters in the procedure declaration. This requires some specification of the 'shape', or more formally the type, of this parameter. Note that f(x) is a function with one real parameter x and on evaluation produces a real result. We use the notation

```
proc( real -> real )f
```

as the required formal parameter declaration in the procedure heading. This is included amongst the parameters in exactly the same way as other formal parameters such as **int** i, **real** u and so on. The notation

```
proc( real -> real )
```

thus corresponds exactly to a type declaration such as **int** or **real** and is indeed the 'type' of this parameter. Note that we only name the object of this type and do not name the constituents of its type declaration. This is because we only need to declare the types themselves and at this stage are not concerned with their actual existence. We can now write down our declaration of the procedure heading as

```
let integral = proc(  proc( real -> real )f ;
                      real a, b ; cint no.of.steps -> real  )
```

Since we do not wish to discuss the intricacies of sophisticated numerical techniques we will use the trapezoidal rule to perform the integration but this can easily be replaced by other numerical integration methods.

The required formula to approximate the integral of function f between a and b is

$$0.5 * h * (f(a) + 2 * (f(a+h) + \ldots + f(a + (no.of.steps-1) * h)) + f(b))$$

where h = (b-a)/no.of.steps.

To simplify the computation slightly we rearrange this as

$$h * (0.5 * f(a) + f(a+h) + \ldots + f(a+(no.of.steps-1) * h) + 0.5 * f(b))$$

We can now write the complete procedure as

```
let integral = proc(  proc( real -> real )f ;
                      real a, b ; cint no.of.steps -> real  )
begin
    let h = ( b - a ) / no.of.steps
    let sum := 0.5 * ( f( a ) + f( b ) )
    for i = 1 to no.of.steps - 1 do
    begin
        a := a + h
        sum := sum + f( a )
    end
    h * sum
end
```

A call of this procedure to integrate sin(x) between 0 and pi using 10 steps, and to put the result in y, may be written

```
y := integral( sin, 0, pi, 10 )
```


Notice that we just write sin and not sin(x) since we are passing the sin function and not a value of sin(x) as a parameter.

The function sin can be replaced by any other function in the program such as

```
let quadratic = proc( real x -> real ) ; ( 3 * x + 4 ) * x - 1
```

with a corresponding call

```
integral( quadratic, 1, 4, 30 )
```

We can now use this single variable integral to evaluate a double integral of a function g(x,y) where x goes from a to b and y goes from c to d.

In order to do this we will write a procedure with name *double.integral* which will integrate f(x,y) in the y-direction for each value of x and then integrate this new function with respect to x. We cannot use the integral procedure twice over directly since g is a function of two variables whereas f is a function of one variable. We overcome this by defining a new function G which is f with the x value held constant. A procedure to do this could be

```
let double.integral = proc( ( real,real -> real ) g ;
                            creal a, b, c, d ; cint x.steps, y.steps -> real )
begin
    let x.coord := a

    let G = proc( real y -> real ) ; g( x.coord,y )

    let hx = ( b - a ) / x.steps
    let double.sum := 0.5 * integral( G, c, d, y.steps )

    for i = 1 to x.steps - 1 do
    begin
        x.coord := x.coord + hx
        double.sum := double.sum + integral( G, c, d, y.steps )
    end

    x.coord := b
    hx * ( double.sum + 0.5 * integral( G, c, d, y.steps ) )
end
```

This uses the procedure *integral* as defined above.

A typical call of this procedure using a previously defined function h(x,y) could be

```
double.integral( h, 0, 1, 0, 2, 20, 40 )
```

A more sophisticated example for the evaluation of a double integral is given in the examples at the end of this chapter.

Consider next the well known problem of the Towers of Hanoi. A fuller discussion of this problem is given in Cole (1981) and in Rouse Ball (1896) so we will restrict ourselves to the following brief description.

Three pegs labelled a, b, c exist and on one of them, say a, are placed n disks in descending order of size with the largest at the bottom and the smallest at the top. The other two pegs are initially empty. The problem is to move the disks to another peg, say b, but only moving the disks one at a time and at no time placing a larger disk on top of a smaller one.

This is a good example of a problem in which one needs to think carefully before writing a word of code. If we only have one disk then the problem is trivial. We simply move that disk from a to b and are

finished. Indeed if we have no disks at all the solution is even simpler. We do nothing and the problems is solved! If n > 0 then some thought leads us to the idea that if we can find a way to move, according to the rules, the top n-1 disks to peg c leaving the largest on peg a, then we may move this larger disk from a to b and never move it again. We now have almost exactly the same problem as before, but have to move the disks from peg c to peg b with the vital difference that we have only to move n-1 disks instead of n. Such a solution, expressing a computational step in terms of itself, is said to be recursive. It leads to a solution because of the special cases n=1 and n=0.

The three steps required in the above solution are

(i) move n-1 disks from a to c
(ii) move 1 disk from a to b
(iii) move n-1 disks from c to b

This transforms immediately into the recursive procedure

```
let hanoi := proc( cint n ; cstring a, b, c ) ; nullproc

hanoi := proc( cint n ; cstring a, b, c )
        if n > 0 do
        begin
                hanoi( n-1, a, c, b )
                move( a, b )
                hanoi( n-1, c, b, a )
        end
```

where n is the number of disks and the strings a, b and c are the names of the pegs. The procedure *move* is simply a clause to write out the move of a single disk

```
let move = proc( cstring a, b ) ; write a, "->", b, "'n"
```

The complete program with a typical call is now as follows:

```
!Towers of Hanoi

let move = proc( cstring a, b )
write a, "->", b, "'n"

let hanoi := proc( cint n; cstring a,b,c ) ; nullproc

hanoi := proc( cint n ; cstring a, b, c )
if n > 0 do
begin
        hanoi( n-1, a, c, b )
        move( a, b )
        hanoi( n-1, c, b, a )
end

hanoi( 9, "a", "b", "c" )
```

Try working this through but with n = 3 or 4 to understand exactly how it works.

Many problems yield elegantly and efficiently to recursive methods. Two such methods are the sorting algorithms known as treesort which you saw in Chapter 10 and quicksort which we discuss here. The bubblesort method discussed earlier is of order n^2 in the sense that the time taken in general to produce a solution increases as the square of the number of elements n. The reason for this is that in finding the biggest element in one scan we accumulate no further information about the remaining elements. The quicksort algorithm is aimed at gaining information at every stage about the relative size of elements and using this information to reduce the computation time to the order of nlog(n).

The technique is to choose a starting element arbitrarily and then by scanning inwards from both ends of the vector simultaneously, to split it into two parts, the one on the left having values less than or equal to

the chosen element. The one on the right has values greater than or equal to it. We can then apply the algorithm to the two parts quite independently of each other. The reason for this technique being in general much faster than bubblesort is that the number of elements in each part is usually nearer to 0.5n than to n-1. One can of course produce pathological examples where this does not happen but in practice this seldom occurs. Methods of speeding up the algorithm still further will be discussed in the examples at the end of this chapter.

Procedure *quicksort* will have as parameters a vector of values x to be sorted and two integer variables lbd and ubd which delimit initially the part of x currently being sorted. These are not equal in general to *lwb(x)* and *upb(x)*.

We will arbitrarily choose the value, *split.val* for the splitting comparisons to be the value of the element with index *(lb + ub)* **div** 2. An improvement on this choice will be given as an exercise. As an example consider the values

3 9 4 6 7 8 5 2

in a vector with indices from 1 to 8. The split point chosen will be in position 4 and this has value 6. The aim now is to split the vector into two parts with the left hand part having elements with values less than or equal to *split.val* and the right hand part having elements greater than or equal to *split.val*. This is done by scanning in from the left and right and looking for elements which are out of place in this scheme. If such a pair is found then they are swapped and the process continues until the left and right hand scans meet. In general this will not be at the previously chosen split point but this does not matter since the element there has not been moved.

```
while lb < ub do
begin
        while lb < ub and x( lb ) < split.val do lb := lb + 1
        while lb < ub and x( ub ) > split.val do ub := ub - 1
        if lb < ub do
        begin
                swap( x, lb, ub )
                lb := lb + 1
                if lb < ub do ub := ub - 1
        end
end
```

In the above example the first pair of values to be swapped is 9 and 2 and then 7 and 5. The scans finally meet at the element with value 8. The order of the elements will now be

3 2 4 6 5 8 7 9

with the final split point being at position 6. We now split the vector into two parts with the value in the position where the scan meets being included with the right or left part depending on whether or not it is greater or less than the old split value itself. Sometimes the split value will be by chance in the position where the two pointers meet and in this case it does not need to be included in either subvector. We must always ensure that *lb* and *ub* do not go outside the range from lbd to ubd. The piece of program to do this is written below immediately after the completion of the splitting code. Finally we make recursive calls of *quicksort* on the resulting pair of subvectors only finishing when a subvector is of length 1. The first split for the above example will be into the subvectors

3 2 4 6 5
and 8 7 9

The complete program including the *swap* procedure is therefore

```
let swap = proc( * int x ; cint i, j )
begin
        let temp = x( i )
        x( i ) := x( j )
        x( j ) := temp
end

let quicksort := proc( * int x ; cint lbd, ubd ) ; nullproc

quicksort := proc( * int x ; cint lbd, ubd )
begin
        let lb := lbd ; let ub := ubd
        let split.val = x( ( lb + ub ) div 2 )

        while lb < ub do
        begin
                while lb < ub and x( lb ) < split.val do lb := lb + 1
                while lb < ub and x( ub ) > split.val do ub := ub - 1

                if lb < ub do
                begin
                        swap( x, lb, ub )
                        lb := lb + 1
                        ub := ub - 1
                end
        end

        ub := lb

        ! ub may have passed lb

        let val = x( lb )

        !To reduce indexing time

        case true of
        val > split.val : lb := lb - 1
        val < split.val : ub := ub + 1
        default :  begin
                        ub := ub + 1
                        lb := lb - 1
                   end

        if lbd < lb  do quicksort( x, lbd, lb )
        if ub < ubd  do quicksort( x, ub, ubd )
end
```

Exercises 12

12.1 Write down formal parameters to be used in a procedure heading corresponding to the following procedures.

(i) let *f* = proc(real *x* ; int *i* -> real)
(ii) let *g* = proc(** real *x, y* ; int -> * real)
(iii) let *h* = proc(real *x, y* ; proc(real,int -> real) *f* -> string)
(iv) let *p* = proc(bool *b* -> bool)

12.2 Primes frequently occur in pairs p, p+2 and less frequently in triples q, q+2, q+6. For example, 11, 13 and 29, 31 are examples of prime pairs and 5, 7, 11 and 17, 19, 23 are examples of prime triples. Write a program to list

(i) all prime pairs from 3 up to some integer n
(ii) all prime triples from 3 up to some integer n
(iii) all prime pairs and triples from 3 up to some integer n but excluding those prime pairs which are part of a triple.

12.3 Write a piece of program to integrate the function x * ln(x) from x=1 to 2 using
(i) 10 steps
(ii) 20 steps.

Compare your answers with the exact integral of this function.

12.4 Determine the effect of the following program

```
let integral = proc( proc( real -> real ) F ; creal a, b -> real )
( b - a ) * F( ( a + b ) / 2.0 )

let G = proc( real z -> real )
begin
        let ep( creal y -> real ) ; exp( z * y )
        integral( ep, 3.0, 4.0 )
end

write fformat( integral( G, 1.0, 2.0 ), 4, 2 ), "\n"
```

12.5 The procedure quicksort can be improved in the following two ways.

(i) by making a special case when the number of terms to be sorted is 2.
(ii) by choosing the split value to be the middle value of x(lb), x(lb + ub) div 2, x(ub).

Modify the quicksort program to incorporate these two improvements.

12.1 **(i) proc(real, int -> real) *p***
(ii) proc(** real, ** real, int -> * real) *q*
(iii) proc(real, real, proc(real,int -> real) -> string) *s*
(iv) proc(bool -> bool) *t*

12.2 Use the Sieve of Eratosthenes program replacing the write clause by the following :

```
write "Table of prime pairs'n'n"
let i := 3

while i <= n - 2 do
begin
        if p( i ) and p( i + 2 ) do write i : 6, i + 2 : 6, "'n"
        i := i + 2
end

write "Table of prime triples'n'n"
let j := 3

while j <= n - 6 do
        if p( j ) and p( j + 2 ) and p( j + 6 ) then
        begin
                write j : 6, j + 2 : 6, j + 6 : 6, "'n"
                j := j + 6
        end
        else j := j + 2

write "Table of triples and pairs not in triples'n'n"
let k := 3

while k <= n - 6 do
        if p( k ) and p( k + 2 ) and p( k + 6 ) then
        begin
                write k : 6, k + 2 : 6, k + 6 : 6, "'n"
                k := k + 6
        end
        else
        begin
                if p( k ) and p( k + 2 ) do
                write k : 6, k + 2 : 6, "'n"
                k := k + 2
        end
        if k <= n - 2 and p( k ) and p( k + 2 ) do
        write k : 6, k + 2 : 6,"'n"
```

12.3 We need to write a procedure corresponding to the required function and also a call of the *integral* procedure. The following will do

```
let f = proc( real x -> real ) ; x * ln( x )

write "The integral with 10 steps is " , integral( f, 1, 2, 10 ) , "'n",
      "The integral with 20 steps is ", integral( f , 1 , 2 , 20 )
```

12.4 The procedure *integral* in this example computes a simple integral with one variable in one step using the mid-point rule. The type of the procedure *G* is **proc(real -> real)** and is therefore a valid parameter of the procedure *integral*. The call


```
integral( G, 1, 2 )
```

gives the integral of G from 1 to 2. That is, the integral from 1 to 2 of the integral from 3 to 4 of the function exp(x*y).

12.5 (i) This requires only a trivial modification to swap the two elements if necessary. The first four lines of executable code after procedure *swap* below will do this.

(ii) The difficulty here is to distinguish efficiently between the six cases

```
a <= b < c
c <= a <= b
a <= c <= b
b <= a <= c
c <= b <= a
b <= c <= a
```

and to take appropriate action. The case required can be determined by using an if and case clauses as below. The action within each case is to rearrange, if necessary, the values in *x(lbd)* , *x(ubd)* and *x(split.pt)*. The procedure can terminate if there are only three values to be sorted. This case is covered by changing the test at the start of the main final loop to

```
if ubd > lbd + 2
```

If this test succeeds sorting can continue with both upper and lower bounds moved inwards by one place. The new quicksort procedure is as follows.

```
let quicksort := proc( * int x ; cint lbd, ubd ) ; nullproc

quicksort := proc( * int x ; cint lbd, ubd )
begin
        let swap = proc( * int v; cint i, j )
        begin
                let temp = v( i )
                v( i ) := v( j )
                v( j ) := temp
        end

        let a = x( lbd )
        let c = x( ubd )

        if ubd = lbd + 1 then
                if a > c do
                begin
                        x( lbd ) := c
                        x( ubd ) := a
                end
                else
                begin
                        let split.pt = ( lbd + ubd ) div 2
                        let b = x( split.pt )
                        let split.val = if a <= b then
                                        case true of
                                        b <= c : b
                                        c <= a : begin
                                                        x( split.pt ) := a
                                                        x( lbd ) := c
                                                        x( ubd ) := b; a
                                                end
                                        default: { x( split.pt ) := c ; x( ubd ) := b ; c}
```

```
                else
                case true of
                a <= c : { x( split.pt ) := a ; x( lbd ) := b ; a }

                c <= b : { x( lbd ) := c ; x( ubd ) := a ; b }
                default: begin
                                x( lbd ) := b
                                x( split.pt ) := a
                                x( ubd ) := a; c
                         end

        if ubd > lbd + 2  do
        begin
                let lb := lbd + 1 ;  let ub := ubd - 1

                while lb < ub  do
                begin
                        while lb < ub  and x( lb ) <= split.val  do l
                        b := lb + 1
                        while lb < ub  and x( ub ) >= split.val  do
                        ub := ub - 1

                        if lb < ub  do
                        begin
                                swap( x, lb, ub )
                                lb := lb + 1
                                ub := ub - 1
                        end

                end
                ub := lb

                ! ub may have passed lb

                let val = x( lb )   !To reduce indexing time

                case true of
                val > split.val : lb := lb - 1
                val < split.val : ub := ub + 1
                default:        begin
                                        ub := ub + 1
                                        lb := lb - 1
                                end

                if lbd < lb  do quicksort( x, lbd, lb )
                if ub < ubd  do quicksort( x, ub, ubd )
        end
    end
end
```


The PS-algol graphics facilities provide a method of manipulating images for bitmapped displays integrated with a line drawing system. Line drawings have the data type picture and bitmaps the type image.

An image is a rectangular grid of pixels of some colour. Images may be created and manipulated using the raster operations provided in the language which are generally available on most bitmap screens.

The picture drawing facilities of PS-algol are a particular implementation of the Outline system[10] which allows the user to produce line drawings in an infinite two dimensional real space. Pictures may be mapped on to an image. Once it has been mapped on to an image it may be manipulated as an image or drawn as an image.

Thus the system provides high level features for manipulating images in a finite two dimensional integer space and line drawings in an infinite two dimensional real space.

Images

In general an image is a 3 dimensional object made up of a rectangular grid of pixels. A pixel has a depth to reflect the number of planes in the image and the image has an X and Y dimension to reflect its size. In its most degenerate form a pixel is one spot which is either on or off. Thus

```
let a = on
```

creates a pixel *a* with a depth of 1. To form a pixel of depth 4 say we could write

```
let b = on & off & off & on
```

which creates *b* this time with a depth of 4. The expression on the right hand side of the above declaration is called a pixel sequence or simply a pixel.

To form an image with an X and Y dimension different from 1 we could write

```
let c = image 5 by 10 of on
```

which creates *c* with 5 pixels in the X direction and 10 in the Y direction all initially on. The origin of all images is 0,0 and in this case the depth is 1.

Full 3 dimensional images may be formed by, for example

```
let d = image 64 by 32 of on & off & on & on
```

but in order to introduce the concept of and operations on images gently we will restrict ourselves for the present to images with a pixel depth of 1 which is the case on the MAC. Everything that we say will be true for images of greater depth as we will see later. Thus

```
let a = image 5 by 10 of on
```

creates such an image.

Images are first class data objects and may be assigned, passed as parameters or returned as results. e.g

```
let b := a
```

will assign the image *a* to the new one *b*. In order to map the operations usual on bitmapped screens, the assignment does not make a new copy of *a* but merely copies the pointer to it. Thus the image acts like a vector or pointer on assignment.

There are 8 raster operations which may be used

ror
rand
xor
copy
nand
nor
not
xnor

thus

xor *b* **onto** *a*

performs a raster operation of *b* onto *a* using exclusive or. Notice that *a* is altered 'in situ'. Both images have origin 0,0 and automatic clipping at the extremities of the destination image is performed. All the other operations follow the same pattern.

The limit operation allows the user to set up windows in images. e.g

let *c* = **limit** *a* **to** *1* **by** *5* **at** *3, 2*

sets *c* to be that part of *a* which starts at 3, 2 and has size 1 by 5. *c* has an origin of 0,0 in itself and is therefore a window on *a*.

Rastering sections of images on to sections of other images can be performed by for example

xor limit *a* **to** *1* **by** *4* **at** *6, 5* **onto**
limit *b* **to** *3* **by** *4* **at** *9, 10*

Automatic clipping on the edges of the limited region is performed. If the starting point of the limited region is omitted 0,0 is used and if the size of the region is omitted then it is taken as the maximum possible. That is from the starting point to the edges of the host image. Limited regions of limited regions may also be defined.

The standard identifier *screen* is an image representing the output screen. Performing a raster operation onto the image screen alters what may be seen by the user. e.g.

let *a* = **image** *100* **by** *100* **of on**
xor *a* **onto limit** *screen* **at** *25, 50*

will create an image 100 pixels by 100 pixels and raster it onto the screen at position 25, 50. This will be visible to the user.

The standard identifier *cursor* is an image representing the cursor. The cursor may be altered in the same manner as any image. e.g.

copy *b* **onto** *cursor*

To cater for hardware with more than one colour plane, the pixels can also have depth. For example

let *a* = **image** *64* **by** *32* **of on & off & on & off**

is a 64 by 32 image with a depth of 4 (i.e. 4 planes). The planes of the pixel are numbered from 0 and so *a* above has planes 0,1,2 and 3.

In systems that support multiple planes the standard identifiers screen and cursor will have a depth greater than 1. All the operations that we have already seen on images (raster, limit and assignment) work more generally with depth. Thus the raster operations perform the raster function plane by plane in one to one correspondence between source and destination. Automatic depth clipping at the destination is performed and if the source is too small to fill all the destination's planes then these planes will remain unaltered. The

limit and assignment operations also work with the depth of the image.

The depth of the image may be restricted by the depth selection operation. For example

let *b* = *a(1/2)*

yields *b* which is an alias for that part of *a* which has the two depth planes 1 and 2. *b* has depth origin 0 and dimensions 64 by 32.

The numbers 1 and 2 above can, of course be replaced by any integer expressions and *a* any image expression. Thus

let *c* = **limit** *a* **to** *32* **by** *16* **at** *8, 8 (2/1)*

yields *c* which is plane 2 of *a* of size 32 by 16 starting at point 8,8 in *a* . *c* has origin 0,0 and depth 1.

Pixels themselves may be indexed. Thus

let *a* = **on & off**

gives *a(0)* as **on** and *a(1)* as **off**. This expression is an r-value only and may not be used on the right hand side of an assignment.

It should be noted that *a(1)* above is of type **pixel** which is not the same as

image *1* **by** *1* **of** off

which is of type **image**.

The standard function *Pixel* will yield pixels from an image. For example, if *a* is defined as follows

let *a* = **image** *9* **by** *9* **of on**

Then *Pixel(a,1,1)* yields **on**.

In programs, the type image is written as **#pixel** and it should be noted that objects of type **#pixel** are assignment incompatible with objects of type **#cpixel** (cf vectors). An object of type **#cpixel** may be formed by the standard function *constant.image*. Thus

let *b* = *constant.image(a)*

causes *b* to be of type c**#cpixel**. In order to ensure that constant pixels are never overwritten a copy of *a* is made.

An image of type **#cpixel** may be used as the source of a raster operation but not the destination. Furthermore a limit operation on an image of type **#cpixel** produces another of the same type.

Image Standard Functions

The image associated with the cursor may be made invisible by

cursor.off()

To return the cursor to normal mode, i.e. it is visible and moves with the mouse we use

cursor.on()

The cursor image is a 16 * 16 grid on the MAC. The tip of the cursor may be changed. The cursor tip is the pixel which decides which pixel in the image screen the cursor is pointing at. The function to change the cursor tip returns the old cursor tip in a point structure which is defined as follows,

```
structure point( cint x.point, y.point )
```

For example

```
let a = cursor.tip( point(4,5) )
write a( x.point ), a( y.point ), "'n"
```

The program will write out 0 16 which is the default cursor tip on the MAC. The standard functions *X.dim* and *Y.dim* give the x and y dimensions of an image. e.g.

```
let a = image 1 by 4 of on
write X.dim( a ), Y.dim( a )
```

yields

```
1                4
```

A straight line may be drawn using the standard function *line*. This function executes a procedure, which is supplied as a parameter, at intervals along a line between two points. How often the function is executed is determined by two parameters which are also supplied to the procedure. For example, to draw a diagonal line on the screen,

```
let copy.fn = proc( # pixel i )
copy image 1 by 1 of on onto i

line( screen, 1, 1, X.dim( screen ), Y.dim( screen ), 1, 1, copy.fn )
```

A seed fill standard function is provided that will start at the pixel indicated in an image and recursively change all the surrounding pixels to the colour specified. The seed fill stops when it meets a pixel of the given colour or the edge of the image. It may be called by e.g.

```
fill( screen, on, 99, 11 )
```

The system also provides a mechanism for pop up menus. The standard function has the form

```
proc menu( c#pixel title ; *c#pixel entries ;
           cbool vertical ; c*proc( c#pixel,int )actions
                                -> proc( cint X, Y -> bool ) )
```

The programmer supplies a menu title which is an image and a vector of images which are the entries in the menu. The standard function returns a function which when applied will cause the menu to appear on the screen with the bottom left hand corner at the point X,Y. The boolean returned from this procedure indicates whether the user selected one of the options or not (the user is at liberty to select outside the menu which has no effect). The menu will be arranged vertically if the parameter *vertical* is true otherwise it will be arranged horizontally. When the menu appears the user may use the mouse to select an entry by placing the cursor over the entries (which change to reverse video when passed over) and pressing a mouse button. The procedure in the *actions* vector in the same position as the selected image will then be called. The menu will stay on the screen whilst this procedure is being executed. This procedure is passed the menu image which was pointed at and the position in the menu (from the top starting at 1).

There is a standard function that allows the user to detect the position of the mouse relative to the screen image. The function is called *locator* and has form,

```
proc locator( -> pntr )
```

when called it will return a structure which is defined by

```
structure mouse( cint X.pos, Y.pos ; cbool selected ; c*cbool the.buttons )
```

This structure is pre-defined by the system and so doesn't need to be included ina program which uses it.The boolean selected indicates whether the screen is currently selected for input or not. The vector of booleans indicate, if true, which button is depressed. The order of these buttons depends on operating system dependent features outside the control of the system. With the Apple Macintosh there is only one button

which is numbered 1 (eg. if mouse.str(the.buttons)(1)). *X.pos* and *Y.pos* indicate the screen co-ordinates.

Pictures

The picture drawing facilities of PS-algol are a particular implementation of the Outline system [11] which allows the user to produce line drawings in two dimensions. The system provides an infinite two dimensional real space. Altering the relationship between different parts of the picture is performed by mathematical transformations which means that pictures are usually built up of a number of sub-pictures.

Line Drawing Facilities

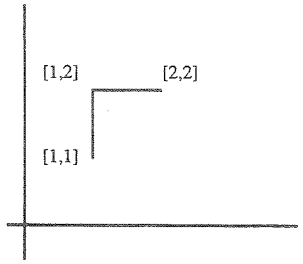
In a line drawing system the simplest picture is a point. The expression

```
[ 0.1,2.0 ]
```

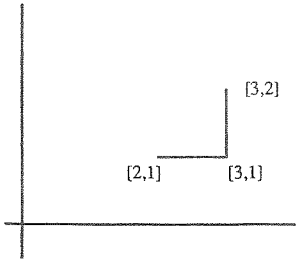
defines the point 0.1, 2.0. It may be given a name by a declaration e.g.

```
let point = [ 0.1,2.0 ]
```

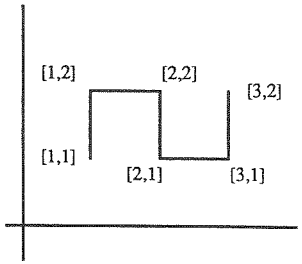
Points in pictures are implicitly ordered. A binary operation on pictures operates between the last point of the first picture and the first point of the second. The resulting picture has as its first point, the first point of the first picture, and as its last, the last point of the second. Pictures may be joined together (using the join operator '^') by a straight line from the last point of the first picture to the first point of the second. For example,




```
let a = [1,1] ^ [1,2] ^ [2,2]
```

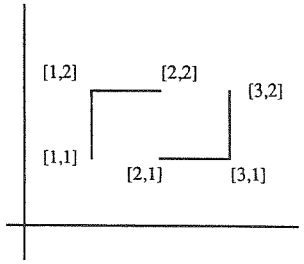



```
let b = [3,2] ^ [3,1] ^ [2,1]
```

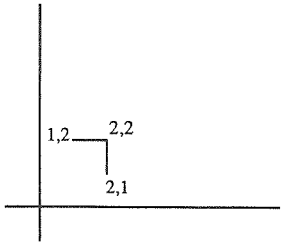


let *c = a ^ b*

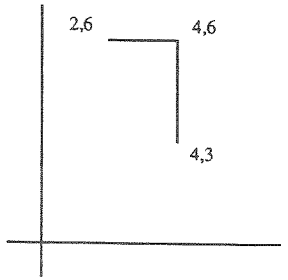
Two pictures may be combined without connection by using the combine operator '&'. The effect of using combine (&) in the example above would be :-



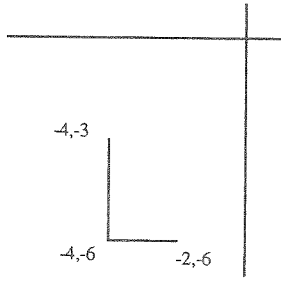
scale is used to enlarge or reduce the size of a picture. The x and y co-ordinates of every point in the operand picture are multiplied by their corresponding scaling factors. To reflect a picture about a line, a negative scale factor should be used. (eg. to reflect in the y-axis a negative x factor should be given). If calls of scale are nested the result will be accumulative.
For example



zap

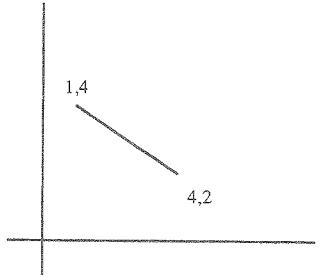


scale *zap* by *2, 3*

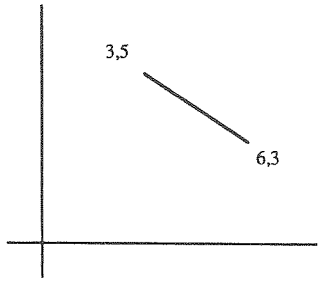


scale *zap* by *-1, -1*

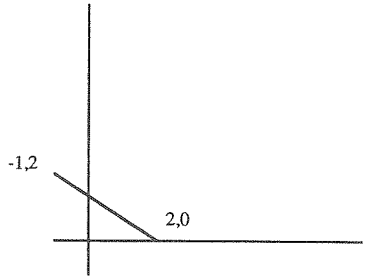
shift adds the shift factor to all the points in the picture. This has the effect of shifting the origin to the specified co-ordinate.
For example



picture



shift *picture* **by** *a,b*



shift *picture* **by** *-c,-d*

The command

shift shift *picture* **by** *a, b* **by** *-a, -b*

would leave the picture unaltered.

The use of **rotate** results in the picture being rotated about the imaginary 'z-axis'. The angle of rotation is specified in degrees, positive in the clockwise direction and the picture will be rotated about the origin. To rotate a picture about a point other than the origin, the following steps should be executed:-

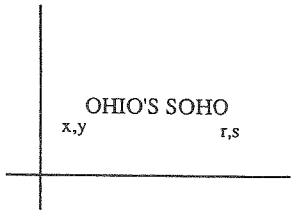
(1) the origin should be moved to the point (x,y) by using a call,
shift *picture* **by** *x, y*

(2) the desired rotation can then be performed,
rotate *picture* **by** *no.of.degrees*

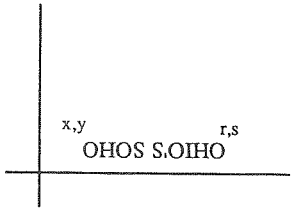
(3) the origin then has to be moved back,
shift *picture* **by** *-x, -y*

The reserved word **text** allows the inclusion of text-strings in pictures. The string may be of any length and may include any ASCII character with the rule that unprintable characters are replaced by a space. Two co-ordinates representing the start and end points of the string are supplied, the characters will then be scaled to fit between these points.

The ordering of the points is important. The string will always be written from the **from** co-ordinate to the to co-ordinate. To produce inverted text the second co-ordinate should precede of the first. If the space allowed for the text is too small then the characters may not be recognizable. If this happens either lengthen the space the string is to occupy or shorten the message. **text** is a picture expression and the picture produced can therefore undergo any of the other picture transformations. For example



text *"OHIO'S SOHO"* **from** *x, y* **to** *r, s*



text *"OHIO'S SOHO"* **from** *r, s* **to** *x, y*

A picture may be coloured by a pixel. Thus

colour *a* **in on**

will colour the line drawing in the colour corresponding to the pixel on in the colour map.

Picture Drawing Facilities

We may map a picture on to an image. e.g

draw(an.image, a.pic, 0.0, 3.2, 1.5, 3.9)

will draw the section of the picture *a.pic* bounded by the box specified by the points (0.0, 3.2) and (1.5, 3.9) on the image *an.image*. Automatic clipping of the line drawing is performed to make it fit the bounding box.

The picture may be drawn directly on to the screen or any part of it. Once the line drawing has been mapped on to an image the image may be manipulated by any of the image operations.

Here is an example of a Sierpinski space filling curve which demonsrates the outline facilities.

```
let draw.sierpinski = proc( cint complexity )
begin
        let rotate.and.draw = proc( cpic s ; cint width )
                draw( screen,s^
                        rotate s by -90^
                        rotate s by -180^
                        rotate s by -270^
                        [ width - 1,-width + 2 ],-width,width,-width,width )

        let sierpinski := proc( cpic s ; cint order,width ) ; nullproc
        sierpinski := proc( cpic s ; cint order,width )
                if order = complexity then rotate.and.draw( s,width )
                else sierpinski( (                      shift s by width,-width^
```

```
                shift rotate s by -90 by width,-width ^
                shift rotate s by 90 by width,width ^
                shift s by width,width ),order + 1,width * 2 )

    sierpinski( [ 1,0 ],0,2 )
end

write "n enter degree of complexity, integer range 1 -> 8 :-"
let complexity = readi()
xor screen onto screen
draw.sierpinski( complexity )
```


The persistence of data is the length of time that the data exists. In PS-algol any data item is allowed the full range of persistence (ie. from temporary results in evaluating expressions to data which may outlive the program). It is necessary for the programmer to identify which data is to persist and in which database it should persist. This section describes the mechanisms for the storage and retrieval of persistent data.

The mechanisms are available via a set of standard procedures which are described below. The actual transfer of data is automatic, data being brought into the program's active heap when the program attempts to access it, and that data which may still be accessible being migrated back at times which are left to the discretion of the implementor or on the insistence of the programmer.

The procedures are divided into two groups, the group concerned with identifying the relationship between data and database, and the implementation of transactions, and the group concerned with providing a new data structure, tables.

Database procedures

All data which persists longer than a program execution is held in the database. There being one database per PS-algol system which is opened as follows:

```
let open.database = proc( -> pntr )
```

opening the database returns a pointer to a table (see below).

Whatever operations are performed on the database, no changes are recorded unless and until the program executes a call of *commit*

```
let commit = proc( -> pntr )
```

This procedure commits the changes made so far to the database opened by the program. Either all or none of the changes will be recorded, so the programmer can use this as a device for ensuring that databases are consistent. It is only after a commit that the changes made can be observed by other programs. Note that only the changes prior to the last commit of a program, if any, are recorded in the database. In this case of an error, an error.record will be returned. If the commit is successful the result is the nil pointer.

Tables

Tables are a system supported data structure in PS-algol. They are commonly used and needed for building databases, but may also be used for more temporary structures. A table stores an updatable mapping from keys to values. The keys may be integers or strings, and the values are pointers to instances of any structures. The implementor will probably have used B-trees or some adaptive hashing technique such as hashed trees to implement these maps

```
let table = proc( -> pntr )
```

This procedure creates a new empty table and returns a pointer as a token for it, which is an instance of the structure class Table. (Note that this structure class name has an upper case tee while the procedure name is all lower case.)

```
let s.enter = proc( string key ; pntr table, value )
let i.enter = proc( int key; pntr table, value )
```

These two procedures may be used to modify the entries in the table given as the parameter table. A table may contain entries whose keys are integers and entries whose keys are strings, a key of one type never matches a key of the other. A new association is recorded in the table between the key and the value, this supersedes any previous association for that key that was held in the table. If the value is nil the effect is to remove any existing entry for the given key from the table.

```
let s.lookup = proc( string key ; pntr table -> pntr )

let i.lookup = proc( int key ; pntr table -> pntr )
```

This procedure returns the value associated with the given key from the given table. If there is no entry for that key then the result is nil.

```
let s.scan = proc( pntr table ; proc( string,pntr -> bool ) user -> int )

let i.scan = proc( pntr table ; proc( int,pntr -> bool ) user -> int )
```

These two routines apply the function provided as *user* to the entries in the stored table given as the first parameter. The function is applied to every element with a string key by *s.scan* and to every element with an integer key by *i.scan*. The function is repeatedly called with the key as its first parameter and the associated value as the second parameter. The function is called with keys in ascending numerical order by *i.scan* and with keys in ascending lexical order of ASCII strings by *s.scan*. Repetition continues until either all the entries for the specified type of key have been parameters to *user* or until *user* returns false. The result of the scan function is the number of times user was called.

Error handling

Certain errors may be detected during the execution of the procedures described in the previous sections. As far as possible these are reported to the calling program so that it may recover, or at least inform the user in appropriate terms.

For example *commit* , if an error is detected, will return an instance of the class error.record which is defined by

```
structure error.record( string error.context, error.fault, error.explain )
```

error.context is the name of the procedure called by the user in which the error was detected, *error.fault* is a short constant string defining the error suitable for testing and *error.explain* is a readable explanation of the fault which a simple program might print.

Procedure libraries

Programs can be constructed so as to use procedures which have been separately compiled by using procedures stored in the database. This may be done by storing in the database a table of procedure names associated with structures containing the procedures either singly or in logically related groups. The effect of modules is obtained by storing procedures in this way. Different views of the same module can be presented and selected by parameterising the module generating procedure with a description, e.g. the class name of the result structure, of the view required.

Tutorial examples of persistent programs

The availability of persistent data allows a system to be built by constructing a number of programs which use the same database. Two examples of such systems, necessarily unrealistic in their simplicity, are given here.

The first is also intended to illustrate the use of tables, by showing four programs to maintain a telephone and address list. Tables were envisaged as a way of packaging index construction. For example singly and multiply indexed relations can be constructed using them. But they have also proved popular as a dynamic data structure constructor.


```
structure person( string name, phone.no ; pntr addr, other )
structure address( string no, street, town ; pntr next.addr )

let db = open.database()
if db is error.record do
begin
        write "Cannot open database - ", db( error.fault ), "'n"
        abort
end


write "Name          ?"        let this.name   = read.a.line()
write "Phone number  ?"        let this.phone  = read.a.line()
write "House number  ?"        let this.house  = read.a.line()
write "Street        ?"        let this.street = read.a.line()
write "Town          ?"        let this.town   = read.a.line()

! construct the address record
let this.addr = address( this.house, this.street, this.town, nil )
! construct a person record
let this.person = person( this.name, this.phone, this.addr, nil )
let addr.list := s.lookup( "addr.list.by.name", db )

! if this is nil this is the first ever entry
if addr.list = nil do
begin
        addr.list := table()
        s.enter( "addr.list.by.name", db, addr.list )
end

s.enter( this.name, addr.list, this.person )
let committed = commit()
if committed = nil then write "Data recorded'n"
else "Data not recorded because - ", committed( error.fault ), "'n"
```

A program to add one person to the address list

Note that the structures used are small and contain a spare pointer field. The first property is an advantage as only structures accessed will be brought into memory. Thus if a phone number is required but the address isn't, the structure containing addresses will not be brought on to the active heap. This applies to pointer, picture, image, procedure, vector and string fields, only if they are actually used by a program will they be brought into active memory. Similarly, in most implementations, only the branches of a tree actually traversed will be transferred. The spare pointer is intended to accommodate data structure growth. It is common to find that extra information is required, and this pointer may lead to the first increment of such additional information. This is not an ideal solution to the requirement for data structure description to evolve after the database has been populated, but is a practical compromise used in PS-algol at present.

```
let db = open.database()
if db is error.record do
begin
        write "Cannot open database - ", db( error.fault ), "'n"
        abort
end
structure person( string name, phone.no ; pntr addr, other )
let addr.list = s.lookup( "addr.list.by.name", db )
if addr.list = nil do { write "'n no address list yet" ; abort }
write "Name?" ; let this.name = read.a.line()
let this.person = s.lookup( this.name, addr.list )
if this.person = nil then write this.name, " not known'n"
else write "Phone number of ", this.name, " is ", this.person( phone.no )
```

A program to look up the phone number of one person

The structure declaration in this program is incrementally matched with that in the program that saved data as follows. Whenever an item of data is recorded in the database, if the description of that data has not yet been recorded, it too is recorded. Whenever data is brought back into active memory, its transfer is initiated by the program attempting to operate on that data. The transfer is only allowed if the type of data brought in matches the type of data expected. In this case this would occur at the start of evaluating *this.person(phone.no)* and would result in a comparison between the data corresponding to the first line of this program and the first line of the previous program. The structure descriptions have to match in name and in the names, types and sequence of their fields. As the address structure is not used by this program it is not necessary or appropriate to declare it. Declaring only the structures used gives a subschema facility.

The next program is included to illustrate the use of scan procedures and to show how simple it is to construct a program to produce some unanticipated derived data by some arbitrary computation over the data structures.

```
let db = open.database()
if db is error.record do
begin
        write "Cannot open database - ", db( error.fault ), "'n"
        abort
end

structure person( string name, phone.no ; pntr addr, other )

let addr.list = s.lookup( "addr.list.by.name", db )
let max.length := 0                    ! initial values
let longest.number := ""

let phone = proc( string nam ; pntr val -> bool )
begin                                  ! used once per entry in list
        let number = val( phone.no ) ; let len = length( number )
        if len > max.length do
        begin
                max.length := len
                longest.number := number
        end
        true
end

let count = s.scan( addr.list, phone )
if count = 0 then write "Nobody in list yet 'n"
else write "Longest number is: ", longest.number, "'n"
```

A program to find the longest telephone number in the address list

The above program applies procedure *phone* to every entry in the address list.

The next program illustrates the construction of a secondary index by constructing an index on phone number. If it were to be maintained a new version of the first program would need to be installed

```
let db = open.database()
if db is error.record do
begin
        write "Cannot open database - ", db( error.fault ), "'n"
        abort
end

structure person( string name, phone.no ; pntr addr, other )

let addr.list = s.lookup( "addr.list.by.name", db )
let phone.number.table = table()    ! new empty table

let put.it.in = proc( string n ; pntr val -> bool )
{ s.enter( val( phone.no ), phone.number.table, val ) ; true }

let count = s.scan( addr.list, put.it.in )

s.enter( "addr.list.by.phone.number", db, phone.number.table )

let committed = commit()
if committed = nil then write "Data recorded'n"
else "Data not recorded because - ", committed( error.fault ), "'n"
```

A program to construct a new index onto the address list

As another illustration a program is presented which stores a procedure in a procedure library which will produce a procedure capable of producing artificial unique identifiers of the general form

<fixed-prefix> <sequence number> <fixed-suffix>

Such identifiers are commonly used for part numbers, etc.

```
structure uid.proc( string uid.doc ;
                proc( string,string -> proc( -> string ) ) uid )

let a.uid = proc( string prefix, suffix -> proc( -> string ) )
begin
        let seq.no := 0
        proc( -> string )
        { seq.no := seq.no + 1 ; prefix ++ iformat( seq.no ) ++ suffix }
end

let a.uid.pack = uid.proc(
"the procedure uid takes two strings, p and q, it yields a
procedure which itself yields identifiers of the form
<p><int><q> such that successive calls have successive
values for the <int> part starting at ""1"" ", a.uid )

let lib = open.database()
if lib is error.record do
begin
        write "Cannot open database - ", lib( error.fault ), "'n"
        abort
end

s.enter( "uid.proc", lib, a.uid.pack )

let committed = commit()
if committed = nil then write "procedure uid.proc put in libraryn"
else "procedure uid.proc not put in library because - ", committed( error.fault ), "'n"
```

A program to leave a utility procedure in a library

The above program also illustrates the conventional arrangements for managing procedure libraries. The next program places two instances of the procedure yielded by the procedure uid into a database which will be used to hold part descriptions and will therefore need to issue part numbers.

It is hoped that this tutorial will have shown the reader how systems may be constructed from relatively small programs operating on one or more databases. In the address list example one would imagine programs to record new addresses, multiple addresses, to print address lists and directories etc. In the second one can easily visualise many programs contributing to the library and many programs requiring the allocation of unique identifiers in the same sequence.

We postulate that because structure is not lost, because the database to program interface is not messy, and because transfers and validation are incremental, present programmers' inhibitions about breaking a task into separate parts will gradually be overcome. When this has happened systems for quite conventional tasks - such as assemblers - will be constructed from a set of rather simple programs. It remains to be seen

whether users can develop satisfactory conventions for their programs and data so that many programs are re-usable in different systems.

Note: the system described above is the implementation for the Apple Macintosh which has only one database. For other systems, with more than one database, the open database procedure is of the form-

open.database(databasename, password -> pntr)

eg let plib = open.database("proc library", "permission")

There are then associated procedures to manipulate databases as follows -

```
let create.database = proc( cstring db.name, pass -> pntr )
! create a db with name db.name and password pass. If successful, return a pointer
! to a table else return an error.record.

let change.passwd = proc( cstring db.name, oldpass, newpass )
! change the password from oldpass to newpass. If successful return nil else an error.record.

let change.owner = proc( cstring db.name ; cint newowner -> pntr )
! change the ownership number to newowner. This can only be done by the PS-algol system.
! If successful return nil else an error.record.

let list.database.dir = proc( -> pntr )
! every database is listed on standard output and if succesful nil is
! returned else an error.record.

let rename.database = proc( cstring oldname, newname, pass -> pntr )
! database oldname is renamed newname if it's password is pass and there
! isn't already a datbase called newname. If successful nil is returned elae
! an error.record.

let remove.database = proc( cstring db.name, pass -> pntr )
! the database db.name has its name deleted from the list of databases if its password
! is pass. If successful nil is return else an error.record. The database can then be
! deleted during disk garbage collection if no other database has references to it.

let restore.database = proc( cstring db.name -> pntr )
! the database db.name is restored to a consistent state from its before look file
! and any locks on it are released, if successful nil is returned else an error.record,
! this procedure ignores locks held on the database.
```


APPENDIX 1

Language Design Methodology

PS-algol is a member of a family of languages in the algol tradition that are constrained by a design methodology. This design methodology is based on the belief that most programming languages are too big and intellectually unmanageable. In addition it is believed that these problems arise in part from the languages being too restrictive. The number of rules to define a language increases when a general rule has additional rules attached to constrain its use in certain cases. Ironically these additional rules usually make the language less powerful as well as more complex.

The design methodology is based on three semantic principles which can be attributed to Strachey. These are

(a) The principle of data type completeness
(b) The principle of abstraction
(c) The principle of correspondence

The principle of data type completeness states that all data types must have the same civil rights in the language and that the rules for using data types must be complete with no gaps. This does not mean that all operators in the language need be defined on all data types but rather that general rules have no exceptions. Examples of lack of completeness can be seen in algol W where arrays are not allowed as fields of records and in Pascal where only some data types are allowed as members of sets. Adhering to the principle of data type completeness leads to simpler languages since it avoids the complexity of special cases.

Abstraction is a process of extracting the general structure to allow the inessential details to be ignored. It is a facility well known to mathematicians and programmers since it is usually the only tool they have to handle complexity. The principle of abstraction when applied to language design is invoked by identifying the semantically meaningful syntactic categories in the language and allowing abstractions over them. The most familiar form of abstraction is the function which is an abstraction over expressions.

Finally, the principle of correspondence states that the rules for introducing and using names should be the same everywhere in a program. In particular there should be a one to one correspondence between introducing names in declarations and introducing names as parameters.

Armed with the above rules the language may be designed as follows

Data Types

Decide which data types, both simple and compound, are required by the language and define the operations on these data types. The flavour of the language will be determined by the data objects it can manipulate. The principle of data type completeness is invoked to ensure that all data objects have the same civil rights. Ignoring the principle means introducing rules to handle exceptions thus making the language more complex.

The Store

Introduce the store, if any, and the manner in which it may be used. First of all the relationship between the store and the data types should be defined. This includes the implementation of pointers, data locations and protection on these locations. For example, constants may be regarded as storage locations which may not be updated.

The introduction of the store also forces consideration of the language control structures.

Abstraction

Tennent has suggested that the method of applying the principle of abstraction is to identify the semantically meaningful syntactic categories and invent abstractions for each. This he does for Pascal and proposes some extensions to complete the abstractions. However, he points out that it is not always an easy matter to identify these categories in the first place.
Most languages have at least the following

Syntactic category	Abstraction
expression	function
statement	procedure
declaration	module

The problem is to identify the useful abstractions. For example, for those of us in love with the algol scope rules, the module is a peculiar abstraction especially since the same power can be derived from function producing functions.

Declaration and Parameters

Invent the declarations and the parametric objects together. There must be a one to one correspondence between the two. This does not mean that they necessarily have the same syntax but that for every type of declaration there is an equivalent parametric type. Parameter passing modes are also included in this correspondence. For example, the declarative equivalent of call by value is an initialising declaration. If functions, record classes etc can be declared then they can be passed as parameters. Finally, if the language has a facility to define new data types and give them a name then the type can be passed as a parameter.

Input and Output

The I/O models for most high level languages tend to reflect the environment in which they were designed. Some attempts have been made to design and implement comprehensive I/O systems. Unfortunately where it has not been tied to particular hardware it has never been very successful. Nowhere else in the design of a programming language does the hardware intervene as much as it does in the I/O system. When a new I/O device becomes available the language must be able to make use of it. Of course, this situation is hopeless and perhaps the wisest approach to I/O is to allow the implementor to deal with it for a particular environment, as the Algol 60 designers proposed.

Iterate

Re-evaluate the language and correct or justify any idiosyncrasies in the design. Hopefully the design process will converge.

Concrete Syntax

The final stage of language design is to propose a concrete syntax. Ideally different groups of workers could have a different syntax. However, there are many users who do not wish to design their own syntax and so the language must provide at least one possibility.

It seems very obvious to say that the syntax should be simple and easy to learn. That may be so but there is no doubt that some of the success of the language depends on the cosmetics. Also, a carefully chosen syntax can ease the problem of compilation.

How often the rules can be broken is for the designer's own conscience. However, every time the rules are broken the language becomes more complex. The rules were introduced to help design simpler and more intellectually manageable languages and should only be ignored with great care.

APPENDIX II

ASCII codes

0 nul	1 soh	2 stx	3 etx	4 eot	5 enq	6 ack	7 bel
8 bs	9 ht	10 nl	11 vt	12 ff	13 cr	14 so	15 si
16 dle	17 dc1	18 dc2	19 dc3	20 dc4	21 nak	22 syn	23 etb
24 can	25 em	26 sub	27 esc	28 fs	29 gs	30 rs	31 us
32 sp	33 !	34 "	35 #	36 $	37 %	38 &	39 '
40 (	41)	42 *	43 +	44 ,	45 -	46 .	47 /
48 0	49 1	50 2	51 3	52 4	53 5	54 6	55 7
56 8	57 9	58 :	59 ;	60 <	61 =	62 >	63 ?
64 @	65 A	66 B	67 C	68 D	69 E	70 F	71 G
72 H	73 I	74 J	75 K	76 L	77 M	78 N	79 O
80 P	81 Q	82 R	83 S	84 T	85 U	86 V	87 W
88 X	89 Y	90 Z	91 [	92 \	93]	94 ^	95 _
96 `	97 a	98 b	99 c	100 d	101 e	102 f	103 g
104 h	105 i	106 j	107 k	108 l	109 m	110 n	111 o
112 p	113 q	114 r	115 s	116 t	117 u	118 v	119 w
120 x	121 y	122 z	123 {	124 |	125 }	126 ~	127 del

APPENDIX III

List of reserved words

if	do	is	or	to	of	by
let	end	int	and	for	rem	div
upb	lwb	eoi	nil	then	else	pntr
bool	real	cint	case	isnt	peek	read
file	true	begin	while	cfile	write	creal
cbool	cpntr	readi	readr	readb	reads	abort
false	vector	string	output	repeat	forward	default
cstring	out.byte	nullfile	structure	proc	read.name	read.byte
read.a.line						

APPENDIX 4
Public Standard Functions

The following standard functions comprise only those intended for the general user.

A complete list of additional standard functions for system use is available in the PS-Algol abstract machine manual.

```
let sqrt = proc( real x -> real )
! the positive square root of x where x >= 0

let exp = proc( real x -> real )
! e to the power x

let ln = proc( real x -> real )
! the logarithm of x to the base e where x > 0

let sin = proc( real x -> real )
! sine of x( radians )

let cos = proc( real x -> real )
! cosine of x( radians )

let atan = proc( real x -> real )
! arctangent of x ( radians ) where - pi / 2 < atan( x ) <  pi / 2

let code = proc( int n -> string )
! string of length 1 where s( 1|1 ) = character with
! numeric code abs( n rem 128 )

let decode = proc( string s -> int )
! numeric code for s( 1|1 )

let truncate = proc( real x -> int )
! the integer i such that |i| <= |x| < |i| + 1 where i * x >= 0

let line.number = proc( -> int )
! the program line number

let rabs = proc( real x -> real )
! the absolute value of real number x

let abs = proc( int n -> int )
! the absolute value of integer n

let length = proc( string s -> int )
! the number of characters in the string s

let eformat = proc( real n ; int w,d -> string )
! the string representing n with w digits
! before the decimal point and d digits after
! with an exponent

let fformat = proc( real n ; int w,d -> string )
! the string representing n with w digits
! before the decimal point and d digits after

let gformat = proc( real n -> string )
! the string representing n in eformat or
```

```
! fformat whichever is suitable

let letter = proc( string s -> bool )
! length( s ) = 1 and
! s >= "A" and s <= "Z" or
! s >= "a" and s <= "z"

let digit = proc( string s -> bool )
! length( s ) = 1 and
! s >= "0" and s <= "9"

let iformat = proc( int n -> string )
! integer n as a string of characters

let options = proc( -> *cstring )
! the command line options are given as a vector of strings

let find.substr = proc( string target, substring -> int )
! return the starting position of string 'substring'
! in 'target', zero otherwise.

let interrupt = proc( -> bool )
! return whether an interrupt ( normally control C ) has been
! received since the last call of this procedure or the start
! of the program.

let date = proc( -> string )
! gives the date and time in a format determined by the implementation

let time = proc( -> int )
! returns the CPU time used since logging in as the number of 60Hz
! clock ticks.


let random = proc( cint seed -> int )
! random number generator as desrcibed in CACM vol 11,9 p642

let trace = proc()
! print a snapshot of the current procedure calls.

let environment = proc( -> *cstring )
! the environment vector for the process is returned as a
! vector of strings, ( this is only available in UNIX ).

let i.lookup := proc( int i ; pntr t -> pntr )
! this looks up pointer value in the table t corresponding to integer
! key i

let s.lookup := proc( string s ; pntr t -> pntr )
! this looks up pointer value in the table t corresponding to string key s

let i.enter := proc( int i ; pntr t,v )
! the pointer value v is entered into table t using integer key i

let s.enter := proc( string s ; pntr t,v )
! the pointer value v is entered into table t using string key s

let table := proc( -> pntr )
! a new table is created and a pointer to it returned

let i.scan := proc( pntr t ; proc( int, pntr -> bool ) u -> int )
! every value in table t with an integer key is passed to procedure
```



```
! u until the procedure u returns
! false or all integer keys have been encountered, the result is the
! number of times procedure u is applied

let s.scan := proc( pntr t ; proc( string,pntr -> bool ) u -> int )
! every value in table t with a string key is passed to procedure
! u until the procedure u returns
! false or all string keys have been encountered, the result is the
! number of times procedure u is applied

let create.database = proc( cstring db.name, pass -> pntr )
! create a db with name db.name and password pass. If successful, return a pointer
! to a table else return an error.record.

let open.database = proc( -> pntr)
! for the Apple Macintosh,
! open the system database and if successful return a pointer
! to a table else an error.record. Note there is only one database.

let open.database = proc( cstring db.name, pass - > pntr )
! for systems with more than one database.
! opens the database db.name if its password is pass. If successful a pointer
! to a table is returned else an error.record.

let change.passwd = proc( cstring db.name, oldpass, newpass )
! change the password from oldpass to newpass. If successful return nil else an error.record.

let change.owner = proc( cstring db.name ; cint newowner -> pntr )
! change the ownership number to newowner. This can only be done by the PS-algol system.
! If successful return nil else an error.record.

let list.database.dir = proc( -> pntr )
! every database is listed on standard output and if succesful nil is
! returned else an error.record.

let rename.database = proc( cstring oldname, newname, pass -> pntr )
! database oldname is renamed newname if it's password is pass and there
! isn't already a datbase called newname. If successful nil is returned elae
! an error.record.

let remove.database = proc( cstring db.name, pass -> pntr )
! the database db.name has its name deleted from the list of databases if its password
! is pass. If successful nil is return else an error.record. The database can then be
! deleted during disk garbage collection if no other database has references to it.

let restore.database = proc( cstring db.name -> pntr )
! the database db.name is restored to a consistent state from its before look file
! and any locks on it are released, if successful nil is returned else an error.record,
! this procedure ignores locks held on the database.


let commit = proc( -> pntr )
! all changes made to objects in the persistent store are made permanent,
! any objects reachable from changed objects are added to the persistent
! store, if successful nil is returned otherwise an error record.

let line = proc( c#pixel i ; cint x1,y1,x2,y2,dx,dy ;
          proc( c#pixel) style )
! draw a line at dx,dy intervals on the image i from x1,y1 to x2,y2
! the line style is governed by procedure 'style'
! which is executed every dx,dy and is passed the limit of image i
```

```
let draw = proc( c#pixel i ; cpic p ; creal x1,x2,y1,y2 )
! draw the picture p on the image i.
! the picture is bounded by x1,x2,y1,y2 in its coordinate space.

let X.dim = proc( c#pixel i -> int )
! return the x dimension of i

let Y.dim = proc( c#pixel i -> int )
! return the y dimension of i

let locator = proc( pntr )
! returns a structure containing information about the status of the mouse.
! the structure returned is a mouse.strc

let cursor.tip = proc( cpntr the.tip -> pntr )
! make the effective tip of the cursor 'the.tip' return old tip
! both pointers are pointers to point.strc( cint point.x,point.y )

let cursor.on = proc()
! make the cursor track the mouse ( the default state ).

let cursor.off = proc()
! make the cursor invisible.

let Pixel = proc( c#pixel i ; cint xpos,ypos -> pixel )
! return the pixel at xpos,ypos in i.

let constant.image = proc( c#pixel i -> #cpixel )
! return a copy of image i with constant pixels.

let variable.image = proc( c#cpixel i -> #pixel )
! return a copy of image i with variable pixels.

let fill = proc( c#pixel i ; cpixel col ; cint xpos,ypos )
! seed fill image i from position xpos,ypos with the pixel col.

let menu = proc( c#pixel title ; c*c#pixel entries ;
          cbool vertical ; c*cproc( c#pixel,cint ) actions
          -> proc( cint,cint -> bool ) )
! Return a procedure that when called will cause a menu to appear
! with its bottom left hand corner at position xpos,ypos relative
! to 'screen'
! 'vertical' indicates the menu orientation
! The menu has a 'title' and a vector of icons called 'entries'
! Associated with each entry in the menu is a procedure which
! will be called when the entry is selected.
! This procedure is passed the associated image and the entry number
! The boolean returned indicates if the user made a selection


let depth = proc( c#pixel i -> int )
! return the number of planes in image i

let colour.map = proc( cpixel p ; cint i )
! when pixel p is displayed the integer i will be
! sent to the display hardware

let colour.of = proc( cpixel p -> int )
! return the integer sent to the hardware when pixel p is displayed

let string.to.tile = proc( cstring the.string,font -> #pixel )
! returns an image which contains 'the.string' in the 'font'
```


Standard Identifiers

A number of standard identifiers exist in the language. They are

r.w	variable initially 14
s.w	variable initially 2
i.w	variable initially 12
maxint	constant, the maximum integer
epsilon	constant, the largest real e such that 1 + e = 1
pi	constant, pi
maxreal	constant, the largest real
screen	constant, image representing the screen
cursor	constant, image representing the cursor

Note that the minimum integer value is -maxint - 1 and the minimum real value is -maxreal.

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