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# occam 2 Toolset Language and Libraries Reference Manual

SGS-THOMSON MICROELECTRONICS

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# Contents overview

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# Preface

## Host versions

The documentation set which accompanies the occam 2 toolset is designed to cover all host versions of the toolset:

- IMS D7305 – IBM PC compatible running MS–DOS
- IMS D4305 – Sun 4 systems running SunOS.
- IMS D6305 – VAX systems running VMS.

## About this manual

This manual is the *Language and Libraries Reference Manual* to the occam 2 toolset and provides a language reference for the toolset and implementation data.

The larger part of the manual is contained in one chapter which introduces and describes the occam libraries. Each library is described in a separate section. For each library, a summary of the procedures it provides, is followed by a detailed description of each procedure.

Appendices provide:

- a description of the language extensions that are supported by the occam 2 compiler.
- implementation details of the Dx305 occam 2 toolset.
- details of the alias and usage checking rules adopted by the toolset.

## About the toolset documentation set

The documentation set comprises the following volumes:

- *72 TDS 366 01 occam 2 Toolset User Guide*

  Describes the use of the toolset in developing programs for running on the transputer. The manual is divided into two sections; '*Basics*' which describes each of the main stages of the development process and includes a '*Getting started*' tutorial. The '*Advanced Techniques*' section is aimed at more experienced users. The appendices contain a glossary of terms and a bibliography. Several of the chapters are generic to other INMOS toolsets.

- *72 TDS 367 01 occam 2 Toolset Reference Manual*

  Provides reference material for each tool in the toolset including command line options, syntax and error messages. Many of the tools in the toolset are generic to other INMOS toolset products, e.g. the ANSI C and FORTRAN toolsets, and the documentation reflects this – examples may be given in more than one language. The appendices provide details of toolset conventions, transputer types, the assembler, server protocol, ITERM files and bootstrap loaders.

- *72 TDS 368 01 occam 2 Toolset Language and Libraries Reference Manual* (this manual)

- *72 TDS 379 00 Performance Improvement with the INMOS Dx305 occam 2 Toolset*

  This document provides advice about how to maximize the performance of the toolset. It brings together information provided in other toolset documents particularly from the *Language and Libraries Reference Manual.* **Note:** details of how to manipulate the software virtual through-routing mechanism are given in the *User Guide.*

- *72 TDS 377 00 occam 2 Toolset Handbook*

  A separately bound reference manual which lists the command line options for each tool and the library functions. It is provided for quick reference and summarizes information provided in more detail in the *Tools Reference Manual* and the *Language and Libraries Reference Manual.*

- *72 TDS 378 00 occam 2 Toolset Master Index*

  A separately bound master index which covers the *User Guide, Toolset Reference Manual, Language and Libraries Reference Manual* and the *Performance Improvement* document.

## Other documents

Other documents provided with the toolset product include:

- Delivery manual giving installation data, this document is host specific.
- Release notes, common to all host versions of the toolset.
- '*occam 2 Reference Manual*' published by Prentice Hall.
- '*A Tutorial Introduction to occam Programming*' published by BSP Professional Books.

## FORTRAN toolset

At the time of writing the FORTRAN toolset product referred to in this document set is still under development and specific details relating to it are subject to change.

## Documentation conventions

The following typographical conventions are used in this manual:

| | |
|---|---|
| **Bold type** | Used to emphasize new or special terminology. |
| `Teletype` | Used to distinguish command line examples, code fragments, and program listings from normal text. |
| *Italic type* | In command syntax definitions, used to stand for an argument of a particular type. Used within text for emphasis and for book titles. |
| Braces { } | Used to denote optional items in command syntax. |
| Brackets [ ] | Used in command syntax to denote optional items on the command line. |
| Ellipsis . . . | In general terms, used to denote the continuation of a series. For example, in syntax definitions denotes a list of one or more items. |
| \| | In command syntax, separates two mutually exclusive alternatives. |

# Libraries

# 1 The occam libraries

## 1.1 Introduction

A comprehensive set of occam libraries is provided for use with the toolset. They include the *compiler libraries* which the compiler itself uses, and a number of *user libraries* to support common programming tasks. The compiler libraries are automatically referenced whereas user libraries must be declared in a `#USE` directive. Libraries, including the compiler libraries, must be specified to the linker. Table 1.1 lists the occam libraries.

| **Library** | **Description** | **Source provided** |
|---|---|---|
| Compiler libraries | | No |
| `occamx.lib` | Multiple length integer arithmetic<br>Floating point functions<br>32–bit IEEE arithmetic functions<br>64–bit IEEE arithmetic functions<br>2D block move library<br>Bit manipulation<br>CRC functions<br>Supplementary floating point support<br>Dynamic code loading support<br>Transputer-related functions | |
| User libraries | | |
| `snglmath.lib` | Single length mathematical functions | Yes |
| `dblmath.lib` | Double length mathematical functions | Yes |
| `tbmaths.lib` | T400/T414/T425/T426 optimized maths | Yes |
| `hostio.lib` | Host file server library | Yes |
| `streamio.lib` | Stream I/O library | Yes |
| `string.lib` | String handling library | Yes |
| `convert.lib` | String conversion library | Yes |
| `crc.lib` | Block CRC library | Yes |
| `xlink.lib` | Extraordinary link handling library | No |
| `debug.lib` | Debugging support library | No |
| `msdos.lib` | DOS specific hostio library | Yes |

Table 1.1 occam libraries

## 1.2 Using the occam libraries

User libraries must be declared in a `#USE` directive. For example:

```
#USE "hostio.lib"
```

Any use of a library routine must be in scope with the `#USE` directive which references the associated library. The scope of a library, like any occam declaration, depends on its level of indentation within the text.

If the library uses a file of predefined constants (see section 1.2.3) then this must be declared by an `#INCLUDE` directive, before the associated `#USE`. For example:

```
#INCLUDE "hostio.inc"
```

### 1.2.1 Linking libraries

All libraries used by a program or program module must be linked with the main program. This includes the compiler libraries even though they are automatically referenced by the compiler (see section 1.3).

### 1.2.2 Listing library contents

You can use the `ilist` tool to examine the contents of a library and determine which routines are available. The tool displays procedural interfaces for routines in each library module and the code size and workspace requirements for individual modules. It can also be used to determine the transputer types and error modes for which the code was compiled. (See chapter 10 of the *occam 2 Toolset Reference Manual* for details of `ilist`).

### 1.2.3 Library constants

Constants and protocols used by the libraries are defined in six include files:

| File | Description |
|---|---|
| `hostio.inc` | Constants for the host file server interface (*hostio* library) |
| `streamio.inc` | Constants for the stream i/o interface (*streamio* library) |
| `mathvals.inc` | Maths constants |
| `linkaddr.inc` | Addresses of transputer links |
| `ticks.inc` | Rates of the two transputer clocks |
| `msdos.inc` | DOS specific constants |

Table 1.2 Library constants

Include files should always be declared before the related library.

## 1.3 Compiler libraries

Compiler libraries contain multiple length and floating point arithmetic functions, IEEE functions, and special transputer functions such as bit manipulation and 2D block data moves. They are found automatically by the compiler on the path specified by the `ISEARCH` host environment variable and do not need to be referenced by a `#USE` directive. However, they *must* be specified to the linker along with all other libraries that the program uses; this is best done using one of the linker indirect files `occam2.lnk`, `occam8.lnk`, or `occama.lnk`, which specify the correct libraries for the transputer target.

Separate compiler libraries are supplied for different types and families of processors. Processor types supported are:

- T2 family
- T8 family
- 32-bit processors

The compiler selects the correct library for the transputer type specified. All error modes are supported in each library.

| File | Processor types supported |
|---|---|
| `occam2.lib` | T212/T222/T225/M212 |
| `occam8.lib` | T800/T801/T805 |
| `occama.lib` | T400/T414/T425/T426/TA/TB |
| `occamutl.lib` | All |
| `virtual.lib` | All |

`occamutl.lib` contains routines which are called from within some of the other compiler libraries and `virtual.lib` is used to support interactive debugging. These two libraries support all processor types and error modes.

File names of the compiler libraries must not be changed. The compiler assumes these filenames, and generates an error if they are not found. (See section A.4 in the *occam 2 Toolset Reference Manual* for details of the mechanism for locating files.)

The compiler '`E`' option disables all of the compiler libraries except `virtual.lib`, which can be disabled by the '`Y`' option.

The *occam 2 Reference Manual* contains formal descriptions of many of the compiler library routines.

### 1.3.1 Using compiler library routines

Although primarily intended for use by the compiler, some compiler library routines are available to the programmer. These are listed in sections 1.3.2 through 1.3.9.

They can be called directly without referencing them via a `#USE` statement and are disabled by the compiler '`E`' option.

As an example of how they may be used, consider an application which requires compliance with the IEEE standards for **NaNs** ('Not a Number') and **Infs** ('± infinity'). The occam compiler defaults to non-IEEE behavior i.e. **NaNs** and **Infs** are treated as errors, whereas ANSI/IEEE 754-1985 requires there to be error and overflow handling. To obtain IEEE behavior the appropriate compiler library function must be called.

The following code fragments show a simple addition can be implemented by default or using IEEE-compatible functions.

If `A`, `B`, and `C` are `REAL32`s and `b` is a `BOOL`:

```
A := B + C  -- default occam behavior.


A := REAL32OP(B, 0, C)        -- IEEE function, round
                              -- to nearest only. The 0
                              -- indicates a '+'
                              -- operation.

b, A := IEEE32OP(B, 1, 0, C) -- IEEE function with
                              -- rounding option. The
                              -- 1 indicates round to
                              -- nearest. The 0
                              -- indicates a '+'
                              -- operation.
```

### 1.3.2 Maths functions

The following table lists compiler library maths functions available to the programmer. Further details can be found in appendices K, L, and M of the *occam 2 Reference Manual.*

| Result(s) | Function name | Parameter specifiers |
|---|---|---|
| REAL32 | ABS | VAL REAL32 x |
| REAL32 | SQRT | VAL REAL32 x |
| REAL32 | LOGB | VAL REAL32 x |
| INT, REAL32 | FLOATING.UNPACK | VAL REAL32 x |
| REAL32 | MINUSX | VAL REAL32 x |
| REAL32 | MULBY2 | VAL REAL32 x |
| REAL32 | DIVBY2 | VAL REAL32 x |
| REAL32 | FPINT | VAL REAL32 x |

| Result(s) | Function name | Parameter specifiers |
|---|---|---|
| BOOL | ISNAN | VAL REAL32 x |
| BOOL | NOTFINITE | VAL REAL32 x |
| REAL32 | SCALEB | VAL REAL32 x, VAL INT n |
| REAL32 | COPYSIGN | VAL REAL32 x, y |
| REAL32 | NEXTAFTER | VAL REAL32 x, y |
| BOOL | ORDERED | VAL REAL32 x, y |
| BOOL, INT32, REAL32 | ARGUMENT.REDUCE | VAL REAL32 x, y, y.err |
| REAL32 | REAL32OP | VAL REAL32 x, VAL INT op, VAL REAL32 y |
| REAL32 | REAL32REM | VAL REAL32 x, y |
| BOOL,REAL32 | IEEE32OP | VAL REAL32 x, VAL INT rm, op, VAL REAL32 y |
| BOOL,REAL32 | IEEE32REM | VAL REAL32 x, y |
| BOOL | REAL32EQ | VAL REAL32 x, y |
| BOOL | REAL32GT | VAL REAL32 x, y |
| INT | IEEECOMPARE | VAL REAL32 x, y |
| REAL64 | DABS | VAL REAL64 x |
| REAL64 | DSQRT | VAL REAL64 x |
| REAL64 | DLOGB | VAL REAL64 x |
| INT,REAL64 | DFLOATING.UNPACK | VAL REAL64 x |
| REAL64 | DMINUSX | VAL REAL64 x |
| REAL64 | DMULBY2 | VAL REAL64 x |
| REAL64 | DDIVBY2 | VAL REAL64 x |
| REAL64 | DFPINT | VAL REAL64 x |
| BOOL | DISNAN | VAL REAL64 x |
| BOOL | DNOTFINITE | VAL REAL64 x |
| REAL64 | DSCALEB | VAL REAL64 x, VAL INT n |
| REAL64 | DCOPYSIGN | VAL REAL64 x, y |
| REAL64 | DNEXTAFTER | VAL REAL64 x, y |
| BOOL | DORDERED | VAL REAL64 x, y |
| BOOL, INT32, REAL64 | DARGUMENT.REDUCE | VAL REAL64 x, y, y.err |

| Result(s) | Function name | Parameter specifiers |
|---|---|---|
| REAL64 | REAL64OP | VAL REAL64 x, VAL INT op, VAL REAL64 y |
| REAL64 | REAL64REM | VAL REAL64 x, y |
| BOOL, REAL64 | IEEE64OP | VAL REAL64 x, VAL INT rm, op, VAL REAL64 y |
| BOOL, REAL64 | IEEE64REM | VAL REAL64 x, y |
| BOOL | REAL64EQ | VAL REAL64 x, y |
| BOOL | REAL64GT | VAL REAL64 x, y |
| INT | DIEEECOMPARE | VAL REAL64 x, y |
| INT | LONGADD | VAL INT left, right, carry.in |
| INT | LONGSUM | VAL INT left, right, carry.in |
| INT | LONGSUB | VAL INT left, right, borrow.in |
| INT, INT | LONGDIFF | VAL INT left, right, borrow.in |
| INT, INT | LONGPROD | VAL INT left, right, carry.in |
| INT, INT | LONGDIV | VAL INT dividend.hi, dividend.lo, divisor |
| INT, INT | SHIFTLEFT | VAL INT hi.in, lo.in, places |
| INT, INT | SHIFTRIGHT | VAL INT hi.in, lo.in, places |
| INT, INT, INT | NORMALISE | VAL INT hi.in, lo.in |
| INT | ASHIFTLEFT | VAL INT argument, places |
| INT | ASHIFTRIGHT | VAL INT argument, places |
| INT | ROTATELEFT | VAL INT argument, places |
| INT | ROTATERIGHT | VAL INT argument, places |

## Notes

`SHIFTRIGHT` and `SHIFTLEFT` return zeroes when the number of places to shift is negative, or is greater than twice the transputer's word length. In this case they may take a long time to execute.

`ASHIFTRIGHT`, `ASHIFTLEFT`, `ROTATERIGHT` and `ROTATELEFT` are all invalid when the number of places to shift is negative or exceeds the transputer's word length.

### 1.3.3 2D block moves

This section describes compiler library block move routines available to the programmer.

| Procedure | Parameter Specifiers |
|---|---|
| MOVE2D | `VAL [][]BYTE Source, VAL INT sx, sy, [][]BYTE Dest, VAL INT dx, dy, width, length` |
| DRAW2D | `VAL [][]BYTE Source, VAL INT sx, sy, [][]BYTE Dest, VAL INT dx, dy, width, length` |
| CLIP2D | `VAL [][]BYTE Source, VAL INT sx, sy, [][]BYTE Dest, VAL INT dx, dy, width, length` |

MOVE2D

```
PROC MOVE2D (VAL [][]BYTE Source,
             VAL INT sx, sy, [][]BYTE Dest,
             VAL INT dx, dy, width, length)
```

Moves a data block of size `width` by `length` starting at byte `Source[sy][sx]` to the block starting at `Dest[dy][dx]`.

This is equivalent to:

```
SEQ y = 0 FOR length
  [Dest[y+dy] FROM dx FOR width] :=
  [Source[y+sy] FROM sx FOR width]
```

DRAW2D

```
PROC DRAW2D (VAL [][]BYTE Source,
             VAL INT sx, sy, [][]BYTE Dest,
             VAL INT dx, dy, width, length)
```

As MOVE2D but only non-zero bytes are transferred.

This is equivalent to:

```
SEQ line = 0 FOR length
  SEQ point = 0 FOR width
    VAL temp IS Source[line+sy][point+sx] :
    IF
      temp <> (0(BYTE))
        Dest[line+dy][point+dx] := temp
      TRUE
        SKIP
```

`CLIP2D`

```
PROC CLIP2D (VAL [][]BYTE Source,
             VAL INT sx, sy, [][]BYTE Dest,
             VAL INT dx, dy, width, length)
```

As `MOVE2D` but only zero bytes are transferred.

This is equivalent to:

```
SEQ line = 0 FOR length
  SEQ point = 0 FOR width
    VAL temp IS Source[line+sy][point+sx] :
    IF
      temp = (0(BYTE))
        Dest[line+dy][point+dx] := 0(BYTE)
      TRUE
        SKIP
```

### 1.3.4 Bit manipulation functions

This section describes compiler library bit-based routines available to the programmer.

| Result | Function name | Parameter Specifiers |
|---|---|---|
| `INT` | `BITCOUNT` | `VAL INT Word, CountIn` |
| `INT` | `BITREVNBITS` | `VAL INT x, n` |
| `INT` | `BITREVWORD` | `VAL INT x` |

`BITCOUNT`

```
INT FUNCTION BITCOUNT (VAL INT Word, CountIn)
```

Counts the number of bits set to 1 in `Word`, adds it to `CountIn`, and returns the total.

`BITREVNBITS`

```
INT FUNCTION BITREVNBITS (VAL INT x, n)
```

Returns an `INT` containing the n least significant bits of `x` in reverse order. The upper bits are set to zero. The operation is invalid if `n` is negative or greater than the number of bits in a word.

`BITREVWORD`

```
INT FUNCTION BITREVWORD (VAL INT x)
```

Returns an `INT` containing the bit reversal of `x`.

### 1.3.5 CRC functions

This section describes compiler library CRC functions available to the programmer.

| Result | Function name | Parameter Specifiers |
|---|---|---|
| `INT` | `CRCWORD` | `VAL INT data, CRCIn, generator` |
| `INT` | `CRCBYTE` | `VAL INT data, CRCIn, generator` |

A cyclic redundancy check value is the remainder from modulo 2 polynomial division. Consider bit sequences as representing the coefficients of polynomials; for example, the bit sequence 10100100 (where the leading bit is the most significant bit) corresponds to $P(x) = x^7 + x^5 + x^2$. `CRCWORD` and `CRCBYTE` calculate the remainder of the modulo 2 polynomial division:

$$(x^n H(x) + F(x))/G(x)$$

where: $F(x)$ corresponds to `data` (the whole word for `CRCWORD`; only the *most* significant byte for `CRCBYTE`)

$G(x)$ corresponds to `generator`

$H(x)$ corresponds to `CRCIn`

$n$ is the word size in bits of the processor used (i.e. $n$ is 16 or 32).

(`CRCIn` can be viewed as the value that would be pre-loaded into the cyclic shift register that is part of hardware implementations of CRC generators.)

When representing $G(x)$ in the word `generator`, note that there is an understood bit before the msb of `generator`. For example, on a 16-bit processor, with $G(x) = x^{16} + x^{12} + x^5 + 1$, which is #11021, then `generator` must be assigned #1021, because the bit corresponding to $x^{16}$ is understood. Thus, a value of #9603 for `generator`, corresponds to $G(x) = x^{16} + x^{15} + x^{12} + x^{10} + x^9 + x + 1$, for a 16-bit processor.

A similar situation holds on a 32-bit processor, so that:

$$G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

is encoded in `generator` as #04C11DB7.

It is possible to calculate a 16-bit CRC on a 32-bit processor. For example if $G(x) = x^{16} + x^{12} + x^5 + 1$, then `generator` is #10210000, because the most significant 16 bits of the 32-bit integer form a 16-bit generator and for:

`CRCWORD`, the least significant 16 bits of `CRCIn` form the initial CRC value; the most significant 16 bits of `data` form the data; and the calculated CRC is the most significant 16 bits of the result.

CRCBYTE, the most significant 16 bits of CRCIn form the initial CRC value; the next 8 bits of CRCIn (the third most significant byte) form the byte of data; and the calculated CRC is the most significant 16 bits of the result.

CRCWORD

**INT FUNCTION CRCWORD (VAL INT data, CRCIn, generator)**

Takes the whole of the word **data** to correspond to *F*(*x*) in the above formula. This implements the following algorithm:

```
INT MyData, CRCOut, OldCRC :
VALOF
  SEQ
    MyData, CRCOut := data, CRCIn
    SEQ i = 0 FOR BitsPerWord  -- 16 or 32
      SEQ
        OldCRC := CRCOut
        CRCOut, MyData := SHIFTLEFT (CRCOut, MyData, 1)
        IF
          OldCRC < 0 -- MSB of CRC = 1
            CRCOut := CRCOut >< generator
          TRUE
            SKIP
  RESULT CRCOut
```

CRCBYTE

**INT FUNCTION CRCBYTE (VAL INT data, CRCIn, generator)**

Takes the *most* significant byte of **data** to correspond to *F*(*x*) in the above formula. This implements the following algorithm:

```
INT MyData, CRCOut, OldCRC :
VALOF
  SEQ
    MyData, CRCOut := data, CRCIn
    SEQ i = 0 FOR 8
      SEQ
        OldCRC := CRCOut
        CRCOut, MyData := SHIFTLEFT (CRCOut, MyData, 1)
        IF
          OldCRC < 0 -- MSB of CRC = 1
            CRCOut := CRCOut >< generator
          TRUE
            SKIP
  RESULT CRCOut
```

**Note:** The predefines CRCBYTE and CRCWORD can be chained together to help calculate a CRC from a string considered as one long polynomial. A simple chaining would calculate:

$$(x^k H(x) + F(x))/G(x)$$

where $F(x)$ corresponds to the string and $k$ is the number of bits in the string. This is not the same CRC that is calculated by CRCFROMMSB and CRCFROMLSB in `crc.lib`, section 1.9, because these latter routines shift the numerator by $x^n$.

### 1.3.6 Floating point arithmetic support functions

| Result(s) | Function name | Parameter Specifiers |
|---|---|---|
| INT | FRACMUL | VAL INT x, y |
| INT, INT, INT | UNPACKSN | VAL INT x |
| INT | ROUNDSN | VAL INT Yexp, Yfrac, Yguard |

FRACMUL

```
INT FUNCTION FRACMUL  (VAL INT x, y)
```

Performs a fixed point multiplication of x and y, treating each as a binary fraction in the range [-1, 1), and returning their product rounded to the nearest available representation. The value of the fractions represented by the arguments and result can be obtained by multiplying their INT value by $2^{-31}$ (on a 32-bit processor) or $2^{-15}$ (on a 16-bit processor). The result can overflow if both x and y are -1.0.

This routine is compiled inline into a sequence of transputer instructions on 32-bit processors, or as a call to a standard library routine for 16-bit processors.

UNPACKSN

```
INT, INT, INT FUNCTION UNPACKSN (VAL INT x)
```

This returns three parameters; from left to right they are Xfrac, Xexp, and Type. x is regarded as an IEEE single length real number (i.e. a RETYPED REAL32). The function unpacks x into Xexp, the (biased) exponent, and Xfrac the fractional part, with implicit bit restored. It also returns an integer defining the Type of x, ignoring the sign bit:

| Type | Reason |
|---|---|
| 0 | X is zero |
| 1 | X is a normalized or denormalized number |
| 2 | X is Inf |
| 3 | X is NaN |

**Examples:**

```
UNPACKSN (#40490FDB) returns #C90FDB00 ,#00000080, 1
UNPACKSN (#00000001) returns #00000100 ,#00000001, 1
UNPACKSN (#7FC00001) returns #40000100 ,#000000FF, 3
```

This routine is compiled inline into a sequence of transputer instructions on 32-bit processors such as the `IMS T425`, which do not have a floating support unit, but do have special instructions for floating point operations. For other 32-bit processors the function is compiled as a call to a standard library routine. It is invalid on 16-bit processors, since `Xfrac` cannot fit into an `INT`.

ROUNDSN

```
INT FUNCTION ROUNDSN  (VAL INT Yexp, Yfrac, Yguard)
```

This takes a possibly unnormalized fraction, guard word and exponent, and returns the IEEE single length floating point value it represents. It takes care of all the normalization, post-normalization, rounding and packing of the result. The rounding mode used is round to nearest. The exponent should already be biased. This routine is not intended for use with `Yexp` and `Yfrac` representing an infinity or a **NaN**.

**Examples:**

```
ROUNDSN (#00000080, #C90FDB00, #00000000) returns #40490FDB
ROUNDSN (#00000080, #C90FDB80, #00000000) returns #40490FDC
ROUNDSN (#00000080, #C90FDA80, #00000000) returns #40490FDA
ROUNDSN (#00000080, #C90FDA80, #00003000) returns #40490FDB
ROUNDSN (#00000001, #00000100, #00000000) returns #00000001
```

The function normalizes and post-normalizes the number represented by `Yexp`, `Yfrac` and `Yguard` into local variables `Xexp`, `Xfrac`, and `Xguard`. It then packs the (biased) exponent `Xexp` and fraction `Xfrac` into the result, rounding using the extra bits in `Xguard`. The sign bit is set to 0. If overflow occurs, `Inf` is returned.

This routine is compiled inline into a sequence of transputer instructions on 32-bit processors such as the IMS T425, which do not have a floating support unit, but do have special instructions for floating point operations. For other 32-bit processors the function is compiled as a call to a standard library routine. It is invalid on 16-bit processors, since `Xfrac` cannot fit into an `INT`.

### 1.3.7 Dynamic code loading support

This section describes compiler library dynamic loading routines available to the programmer.

#### Procedures

| Procedure | Parameter Specifiers |
|---|---|
| `KERNEL.RUN` | `VAL []BYTE code,`<br>`VAL INT entry.offset,`<br>`[]INT workspace,`<br>`VAL INT no.of.parameters` |
| `LOAD.INPUT.CHANNEL` | `INT here,`<br>`CHAN OF ANY in` |
| `LOAD.INPUT.CHANNEL.VECTOR` | `INT here,`<br>`[]CHAN OF ANY in` |
| `LOAD.OUTPUT.CHANNEL` | `INT here,`<br>`CHAN OF ANY out` |
| `LOAD.OUTPUT.CHANNEL.VECTOR` | `INT here,`<br>`[]CHAN OF ANY out` |
| `LOAD.BYTE.VECTOR` | `INT here,`<br>`VAL []BYTE bytes` |

#### Functions

| Result(s) | Function name | Parameter Specifiers |
|---|---|---|
| `INT` | `WSSIZEOF` | `routinename` |
| `INT` | `VSSIZEOF` | `routinename` |

`KERNEL.RUN`

```
PROC KERNEL.RUN (VAL []BYTE code,
                 VAL INT entry.offset,
                 []INT workspace,
                 VAL INT no.of.parameters)
```

The effect of this procedure is to call the procedure loaded in the `code` buffer, starting execution at the location `code[entry.offset]`.

The `code` to be called must begin at a word-aligned address. To ensure proper alignment either start the array at zero or realign the code on a word boundary before passing it into the procedure.

The `workspace` buffer is used to hold the local data of the called procedure. The required size of this buffer, and the code buffer, must be derived by visually inspecting the executable code file (`.rsc` file) to be loaded using the binary lister tool `ilist`. Alternatively, a routine can be written to read this file and pass the information to `KERNEL.RUN`. The format of the `.rsc` file is described in section 3.6 of the *Tools Reference Manual.*

The parameters passed to the called procedure should be placed at the top of the `workspace` buffer by the calling procedure before the call of `KERNEL.RUN`. The call to `KERNEL.RUN` returns when the called procedure terminates. If the called procedure requires a separate vector space, then another buffer of the required size must be declared, and its address placed as the last parameter at the top of `workspace`. As calls of `KERNEL.RUN` are handled specially by the compiler it is necessary for `no.of.parameters` to be a constant known at compile time and to have a value ≥ 3.

The workspace passed to `KERNEL.RUN` must be at least:

```
[ws.requirement + (no.of.parameters + 2)]INT
```

where `ws.requirement` is the size of workspace required, determined when the called procedure was compiled and stored in the code file, and `no.of.parameters` includes the vector space pointer if it is required.

The parameters must be loaded before the call of `KERNEL.RUN`. The parameter corresponding to the first formal parameter of the procedure should be in the word adjacent to the saved **Iptr** word, and the vector space pointer or the last parameter should be adjacent to the top of workspace where the **Wptr** word will be saved.

`LOAD.INPUT.CHANNEL`

```
LOAD.INPUT.CHANNEL (INT here, CHAN OF ANY in)
```

The variable `here` is assigned the address of the input channel `in`.

The normal protocol checking of channel parameters is suppressed; therefore channels of any protocol may be passed to this routine. The channel parameter is considered by the compiler to have been used for input.

`LOAD.INPUT.CHANNEL.VECTOR`

```
LOAD.INPUT.CHANNEL.VECTOR (INT here,
                           []CHAN OF ANY in)
```

The variable `here` is assigned the address of the base element of the channel array `in` (i.e. the base of the array of pointers).

The normal protocol checking of channel parameters is suppressed; therefore channels of any protocol may be passed to this routine. The channel parameter is considered by the compiler to have been used for input.

`LOAD.OUTPUT.CHANNEL`

```
LOAD.OUTPUT.CHANNEL (INT here, CHAN OF ANY out)
```

The variable `here` is assigned the address of the output channel `out`.

The normal protocol checking of channel parameters is suppressed; therefore channels of any protocol may be passed to this routine. The channel parameter is considered by the compiler to have been used for input.

`LOAD.OUTPUT.CHANNEL.VECTOR`

```
LOAD.OUTPUT.CHANNEL.VECTOR (INT here,
                            []CHAN OF ANY out)
```

The variable `here` is assigned the address of the base element of the channel array `out` (i.e. the base of the array of pointers).

The normal protocol checking of channel parameters is suppressed; therefore channels of any protocol may be passed to this routine. The channel parameter is considered by the compiler to have been used for input.

`LOAD.BYTE.VECTOR`

```
LOAD.BYTE.VECTOR (INT here, VAL []BYTE bytes)
```

The variable `here` is assigned the address of the byte array `bytes`. This can be used in conjunction with `RETYPES` to find the address of any variable.

`WSSIZEOF`

```
INT FUNCTION WSSIZEOF (routinename)
```

This function returns the number of workspace 'slots' (words) required by the procedure or function *routinename*. `INLINE` or predefined routines are not permitted.

`VSSIZEOF`

```
INT FUNCTION VSSIZEOF (routinename)
```

This function returns the number of vectorspace 'slots' (words) required by the procedure or function `routinename`. `INLINE` or predefined routines are not permitted.

### 1.3.8 Transputer-related procedures

This section describes compiler library transputer-specific routines available to the programmer.

| Procedure | Parameter Specifiers |
|---|---|
| `CAUSEERROR` | `()` |
| `RESCHEDULE` | `()` |

`CAUSEERROR`

`CAUSEERROR()`

Inserts instructions into the program to set the transputer error flag. If the program is in STOP or UNIVERSAL mode instructions to stop the current process are also inserted.

The error is then treated in exactly the same way as any other error would be treated in the error mode in which the program is compiled. For example, in HALT mode the whole processor will halt and in STOP mode that process will stop, leaving the transputer error flag set `TRUE`. If run-time error checking has been suppressed (e.g. by a command line option), this stop is suppressed.

The difference between `CAUSEERROR()` and the `STOP` process, is that `CAUSEERROR` guarantees to set the transputer's error flag.

`RESCHEDULE`

`RESCHEDULE()`

This causes the current process to be rescheduled by inserting instructions into the program to cause the current process to be moved to the end of the current priority scheduling queue. This occurs even if the current process is a 'high priority' process.

`RESCHEDULE` effectively forces a 'timeslice', even in high priority.

### 1.3.9 Miscellaneous operations

This section describes miscellaneous compiler library routines available to the programmer.

| Procedure | Parameter Specifiers |
|---|---|
| `ASSERT` | `VAL BOOL test` |

`ASSERT`

```
PROC ASSERT (VAL BOOL test)
```

At compile time the compiler will check the value of `test` and if it is `FALSE` the compiler will give a compile time error; if it is `TRUE`, the compiler does nothing. If `test` cannot be checked at compile-time then the compiler will insert a run-time check to detect its status. This run-time check may be disabled by means of a command line option.

`ASSERT` is a useful routine for debugging purposes. Once a program is working correctly the compiler option '`NA`' can be used to prevent code being generated to check for `ASSERT`s at run-time. If possible `ASSERT`s will still be checked at compile time.

## 1.4 Maths libraries

Elementary maths and trigonometric functions are provided in three libraries, as follows:

| Library | Description |
|---|---|
| `snglmath.lib` | Single length library |
| `dblmath.lib` | Double length library |
| `tbmaths.lib` | TB optimized library |

The single and double length libraries contain the same set of maths functions in single and double length forms. The double length forms all begin with the letter '`D`'. All function names are in upper case.

The TB optimized library is a combined single and double length library containing functions for the T4 series (T400, T414, T425, and T426). The functions have been optimized for speed. The standard single or double length libraries *can* be used on T4 processors but optimum performance will be achieved by using the TB optimized library. The accuracy of the T400/T414/T425/T426 optimized functions is similar to that of the standard single length functions but results returned may not be identical because different algorithms are used. If the optimized library is used in code compiled for any processor except a T400, T414, T425, or T426, the compiler reports an error.

To obtain the best possible speed performance with the occam maths functions use the following strategy:

- For networks consisting of only T4 series transputers, use the **`tbmaths.lib`** library.
- For networks consisting of only T8 series transputers, use the **`snglmath.lib`** and **`dblmath.lib`** libraries.
- For networks consisting of a mix of T4 series and T8 series transputers use:
  - **`tbmaths.lib`** on the T4 series and **`snglmath.lib`** or **`dblmath.lib`** on the T8 series when a consistent level of accuracy is not required;
  - if accuracy must be the same in the T8 and T4 processes then use the **`snglmath.lib`** and **`dblmath.lib`** libraries.

Constants for the maths libraries are provided in the include file **`mathvals.inc`**.

The elementary function library is also described in appendix N of the *occam 2 Reference manual.*

### 1.4.1 Introduction and terminology

This, and the following subsections, contain some notes on the presentation of the elementary function libraries described in section 1.4.2, and the TB version described in section 1.4.3.

These function subroutines have been written to be compatible with the ANSI standard for binary floating-point arithmetic (ANSI-IEEE std 754-1985), as implemented in occam. They are based on the algorithms in:

> Cody, W. J., and Waite, W. M. [1980]. *Software Manual for the Elementary Functions.* Prentice-Hall, New Jersey.

The only exceptions are the pseudo-random number generators, which are based on algorithms in:

> Knuth, D. E. [1981]. *The Art of Computer Programming, 2nd. edition, Volume 2: Seminumerical Algorithms.* Addison-Wesley, Reading, Mass.

**Inputs**

All the functions in the library (except **RAN** and **DRAN**) are called with one or two parameters which are binary floating-point numbers in one of the IEEE standard formats, either 'single-length' (32 bits) or 'double-length' (64 bits). The parameter(s) and the function result are of the same type.

**NaNs and Infs**

The functions will accept any value, as specified by the standard, including special values representing **NaNs** ('Not a Number') and **Infs** ('Infinity'). **NaNs** are copied to the result, whilst **Infs** may or may not be in the domain. The domain is the set of arguments for which the result is a normal (or denormalized) floating-point number.

**Outputs**

**Exceptions**

Arguments outside the domain (apart from **NaNs** which are simply copied through) give rise to *exceptional results*, which may be **NaN**, **+Inf**, or **–Inf**. **Infs** mean that the result is mathematically well-defined but too large to be represented in the floating-point format.

Error conditions are reported by means of three distinct **NaNs**:

**undefined.NaN**

This means that the function is mathematically undefined for this argument, for example the logarithm of a negative number.

**unstable.NaN**

This means that a small change in the argument would cause a large change in the value of the function, so *any* error in the input will render the output meaningless.

**inexact.NaN**

This means that although the mathematical function is well-defined, its value is in range, and it is stable with respect to input errors at this argument, the limitations of word-length (and reasonable cost of the algorithm) make it impossible to compute the correct value.

The implementations will return the following values for these Not-a-Numbers:

| Error | Single length value | Double length value |
|---|---|---|
| `undefined.NaN` | #7F800010 | #7FF00002 00000000 |
| `unstable.NaN` | #7F800008 | #7FF00001 00000000 |
| `inexact.NaN` | #7F800004 | #7FF00000 80000000 |

## Accuracy

### Range Reduction

Since it is impractical to use rational approximations (i.e. quotients of polynomials) which are accurate over large domains, nearly all the subroutines use mathematical identities to relate the function value to one computed from a smaller argument, taken from the 'primary domain', which is small enough for such an approximation to be used. This process is called 'range reduction' and is performed for all arguments except those which already lie in the primary domain.

For most of the functions the quoted error is for arguments in the primary domain, which represents the basic accuracy of the approximation. For some functions the process of range reduction results in a higher accuracy for arguments outside the primary domain, and for others it does the reverse. Refer to the notes on each function for more details.

### Generated Error

If the true value of the function is large the difference between it and the computed value (the 'absolute error') is likely to be large also because of the limited accuracy of floating-point numbers. Conversely if the true value is small, even a small absolute error represents a large proportional change. For this reason the error relative to the true value is usually a better measure of the accuracy of a floating-point function, except when the output range is strictly bounded.

If $f$ is the mathematical function and $F$ the subroutine approximation, then the relative error at the floating-point number $X$ (provided $f(X)$ is not zero) is:

$$RE(X) = \frac{(F(X) - f(X))}{f(X)}$$

Obviously the relative error may become very large near a zero of $f(X)$. If the zero is at an irrational argument (which cannot be represented as a floating-point value), the absolute error is a better measure of the accuracy of the function near the zero.

As it is impractical to find the relative error for every possible argument, statistical measures of the overall error must be used. If the relative error is sampled at a number of points $X_n$ ($n$ = 1 to $N$), then useful statistics are the *maximum relative error* and the *root-mean-square relative error*.

$$MRE = \max_{1 \le n \le N} |RE(X_n)| \cdot$$

$$RMSRE = \sqrt{\sum_{n=1}^{N} (RE(X_n))^2}$$

Corresponding statistics can be formed for the absolute error also, and are called *MAE* and *RMSAE* respectively.

The *MRE* generally occurs near a zero of the function, especially if the true zero is irrational, or near a singularity where the result is large, since the 'granularity' of the floating-point numbers then becomes significant.

A useful unit of relative error is the relative magnitude of the least significant bit in the floating-point fraction, which is called one 'unit in the last place' (ulp), (i.e. the smallest $\varepsilon$ such that $1+\varepsilon \neq 1$). Its magnitude depends on the floating-point format: for single-length it is $2^{-23} = 1.19*10^{-7}$, and for double-length it is $2^{-52} = 2.22*10^{-16}$.

**Propagated Error**

Because of the limited accuracy of floating-point numbers the result of any calculation usually differs from the exact value. In effect, a small error has been added to the exact result, and any subsequent calculations will inevitably involve this error term. Thus it is important to determine how each function responds to errors in its argument. Provided the error is not too large, it is sufficient just to consider the first derivative of the function (written $f'$).

If the relative error in the argument $X$ is $d$ (typically a few ulp), then the absolute error ($E$) and relative error ($e$) in $f(X)$ are:

$$E = |Xf'(X)d| \equiv Ad \cdot$$

$$e = \left| \frac{Xf'(X)d}{f(X)} \right| \equiv Rd$$

This defines the absolute and relative error magnification factors $A$ and $R$. When both are large the function is unstable, i.e. even a small error in the argument, such as would be produced by evaluating a floating-point expression, will cause a large error in the value of the function. The functions return an **unstable.NaN** in such cases which are simple to detect.

The functional forms of both $A$ and $R$ are given in the specification of each function.

**Test Procedures**

For each function, the generated error was checked at a large number of arguments (typically 100 000) drawn at random from the appropriate domain. First the double-length functions were tested against a 'quadruple-length' implementation (constructed for accuracy rather than speed), and then the single-length functions were tested against the double-length versions.

In both cases the higher-precision implementation was used to approximate the mathematical function (called *f* above) in the computation of the error, which was evaluated in the higher precision to avoid rounding errors. Error statistics were produced according to the formulae above.

### Symmetry

The subroutines were designed to reflect the mathematical properties of the functions as much as possible. For all the functions which are even, the sign is removed from the input at the beginning of the computation so that the sign-symmetry of the function is always preserved. For odd functions, either the sign is removed at the start and then the appropriate sign set at the end of the computation, or else the sign is simply propagated through an odd degree polynomial. In many cases other symmetries are used in the range-reduction, with the result that they will be satisfied automatically.

## The Function Specifications

### Names and Parameters

All single length functions except **RAN** return a single result of type **REAL32**, and all except **RAN**, **POWER** and **ATAN2** have one parameter, a **VAL REAL32**.

**POWER** and **ATAN2** have two parameters which are **VAL REAL32**s for the two arguments of each function.

**RAN** returns two results, of types **REAL32** and **INT32**, and has one parameter which is a **VAL INT32**.

In each case the double-length version of *name* is called **D***name*, returns a **REAL64** (except **DRAN**, which returns **REAL64**, **INT64**), and has parameters of type **VAL REAL64** (**VAL INT64** for **DRAN**).

### Terms used in the Specifications

**A and R** Multiplying factors relating the absolute and relative errors in the output to the relative error in the argument.

**Exceptions** Outputs for invalid inputs (i.e. those outside the *domain*), other than **NaN** (**NaNs** are copied directly to the output and are not listed as exceptions). These are all **Infs** or **NaNs**.

**Generated Error** The difference between the true and computed values of the function, when the argument is error-free. This is measured statistically and displayed for one or two ranges of arguments, the first of which is usually the *primary domain* (see below). The second range, if present, is chosen to illustrate the typical behavior of the function.

**Domain** The range of valid inputs, i.e. those for which the output is a normal or denormal floating-point number.

**MAE and RMSAE** The Maximum Absolute Error and Root-Mean-Square absolute error taken over a number of arguments drawn at random from the indicated range.

**MRE and RMSRE** The Maximum Relative Error and Root-Mean-Square relative error taken over a number of arguments drawn at random from the indicated range.

**Range** The range of outputs produced by all arguments in the *Domain*. The given endpoints are not exceeded.

**Primary Domain** The range of arguments for which the result is computed using only a single rational approximation to the function. There is no argument reduction in this range.

**Propagated Error** The absolute and relative error in the function value, given a small relative error in the argument.

**ulp** The unit of relative error is the 'unit in the last place' (ulp). This is the relative magnitude of the least significant bit of the floating-point fraction (i.e. the smallest $\varepsilon$ such that $1+\varepsilon \neq 1$).

N.B. this depends on the floating-point format.

For the standard single-length format it is $2^{-23} = 1.19*10^{-7}$.

For the double-length format it is $2^{-52} = 2.22*10^{-16}$.

This is also used as a measure of absolute error, since such errors can be considered 'relative' to unity.

**Specification of Ranges**

Ranges are given as intervals, using the convention that a square bracket '[' or ']' means that the adjacent endpoint is included in the range, whilst a round bracket '(' or ')' means that it is excluded. Endpoints are given to a few significant figures only.

Where the range depends on the floating-point format, single-length is indicated with an S and double-length with a D.

For functions with two arguments the complete range of both arguments is given. This means that for each number in one range, there is at least one (though sometimes only one) number in the other range such that the pair of arguments is valid. Both ranges are shown, linked by an 'x'.

**Abbreviations**

In the specifications, *XMAX* is the largest representable floating-point number: in single-length it is approximately $3.4*10^{38}$, and in double-length it is approximately $1.8*10^{308}$.

Pi means the closest floating-point representation of the transcendental number $\pi$, ln(2) the closest representation of $\log_e(2)$, and so on.

In describing the algorithms, '*X*' is used generically to designate the argument, and 'result' (or RESULT, in the style of occam functions) to designate the output.

### 1.4.2 Single and double length elementary function libraries

The versions of the libraries described by this section have been written using only floating-point arithmetic and pre-defined functions supported in occam. Thus they can be compiled for any processor with a full implementation of occam, and give identical results.

These two libraries will be efficient on processors with fast floating-point arithmetic and good support for the floating-point predefined functions such as **MULBY2** and **ARGUMENT.REDUCE**. For 32-bit processors without special hardware for floating-point calculations the alternative optimized library described in section 1.4.3 using fixed-point arithmetic will be faster, but will not give identical results.

A special version has been produced for 16-bit transputers, which avoids the use of any double-precision arithmetic in the single precision functions. This is distinguished in the notes by the annotation 'T2 special'; notes relating to the version for T8 and TB are denoted by 'standard'.

Single and double length maths functions are listed below. Descriptions of the functions can be found in succeeding sections.

To use the single length library a program header must include the line

```
#USE "snglmath.lib"
```

To use the double length library a program header must include the line

```
#USE "dblmath.lib"
```

| Result(s) | Function | Parameter specifiers |
|---|---|---|
| REAL32 | ALOG | VAL REAL32 X |
| REAL32 | ALOG10 | VAL REAL32 X |
| REAL32 | EXP | VAL REAL32 X |
| REAL32 | POWER | VAL REAL32 X, VAL REAL32 Y |
| REAL32 | SIN | VAL REAL32 X |
| REAL32 | COS | VAL REAL32 X |
| REAL32 | TAN | VAL REAL32 X |
| REAL32 | ASIN | VAL REAL32 X |
| REAL32 | ACOS | VAL REAL32 X |
| REAL32 | ATAN | VAL REAL32 X |
| REAL32 | ATAN2 | VAL REAL32 X, VAL REAL32 Y |
| REAL32 | SINH | VAL REAL32 X |
| REAL32 | COSH | VAL REAL32 X |
| REAL32 | TANH | VAL REAL32 X |
| REAL32,INT32 | RAN | VAL INT32 X |
| REAL64 | DALOG | VAL REAL64 X |
| REAL64 | DALOG10 | VAL REAL64 X |
| REAL64 | DEXP | VAL REAL64 X |

| Result(s) | Function | Parameter specifiers |
|---|---|---|
| `REAL64` | `DPOWER` | `VAL REAL64 X, VAL REAL64 Y` |
| `REAL64` | `DSIN` | `VAL REAL64 X` |
| `REAL64` | `DCOS` | `VAL REAL64 X` |
| `REAL64` | `DTAN` | `VAL REAL64 X` |
| `REAL64` | `DASIN` | `VAL REAL64 X` |
| `REAL64` | `DACOS` | `VAL REAL64 X` |
| `REAL64` | `DATAN` | `VAL REAL64 X` |
| `REAL64` | `DATAN2` | `VAL REAL64 X, VAL REAL64 Y` |
| `REAL64` | `DSINH` | `VAL REAL64 X` |
| `REAL64` | `DCOSH` | `VAL REAL64 X` |
| `REAL64` | `DTANH` | `VAL REAL64 X` |
| `REAL64,INT64` | `DRAN` | `VAL INT64 X` |

## Function definitions

`ALOG`
`DALOG`

```
REAL32 FUNCTION ALOG (VAL REAL32 X)
REAL64 FUNCTION DALOG (VAL REAL64 X)
```

Compute $\log_e(X)$.

| | |
|---|---|
| **Domain:** | $(0, XMAX]$ |
| **Range:** | $[MinLog, MaxLog]$ $[MinLog, MaxLog]$ (See note 2) |
| **Primary Domain:** | $[\surd 2/2, \surd 2) = [0.7071, 1.4142)$ |

### Exceptions

All arguments outside the domain generate an **undefined.NaN**.

### Propagated Error

$A \equiv 1, \quad R = 1/\log_e(X)$

### Generated Error

| Primary Domain Error: | MRE | RMSRE |
|---|---|---|
| **Single Length(Standard):** | 1.7 ulp | 0.43 ulp |
| **Single Length(T2 special):** | 1.6 ulp | 0.42 ulp |
| **Double Length:** | 1.4 ulp | 0.38 ulp |

### The Algorithm

1 Split $X$ into its exponent $N$ and fraction $F$.

2 Find *LnF*, the natural log of *F*, with a floating-point rational approximation.

3 Compute ln(2) $*$ *N* with extended precision and add it to *LnF* to get the result.

**Notes**

1) The term ln(2) $*$ *N* is much easier to compute (and more accurate) than *LnF*, and it is larger provided *N* is not 0 (i.e. for arguments outside the primary domain). Thus the accuracy of the result improves as the modulus of log(*X*) increases.

2) The minimum value that can be produced, *MinLog*, is the logarithm of the smallest denormalized floating-point number. For single length *MinLog* is –103.28, and for double length it is –744.4. The maximum value *MaxLog* is the logarithm of *XMAX*. For single-length it is 88.72, and for double-length it is 709.78.

3) Since **Inf** is used to represent *all* values greater than *XMAX* its logarithm cannot be defined.

4) This function is well-behaved and does not seriously magnify errors in the argument.

```
ALOG10
DALOG10
```

```
REAL32 FUNCTION ALOG10 (VAL REAL32 X)
REAL64 FUNCTION DALOG10 (VAL REAL64 X)
```

Compute $\log_{10}(X)$.

| | |
|---|---|
| **Domain:** | (0, *XMAX*] |
| **Range:** | [*MinL*10, *MaxL*10] (See note 2) |
| **Primary Domain:** | [$\sqrt{2}/2$, $\sqrt{2}$) = [0.7071, 1.4142) |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A \equiv \log_{10}(e)$, $R = \log_{10}(e)/\log_e(X)$

**Generated Error**

| Primary Domain Error: | **MRE** | **RMSRE** |
|---|---|---|
| **Single Length (Standard):** | 1.70 ulp | 0.45 ulp |

| | | |
|---|---|---|
| **Single Length (T2 special):** | 1.71 ulp | 0.46 ulp |
| **Double Length:** | 1.84 ulp | 0.45 ulp |

**The Algorithm**

1 Set *temp*:= `ALOG(X)`.

2 If *temp* is a **NaN**, copy it to the output, otherwise set result = log($e$) $*$ *temp*

**Notes**

1) See note 1 for `ALOG`.

2) The minimum value that can be produced, $MinL10$, is the base-10 logarithm of the smallest denormalized floating-point number. For single length $MinL10$ is –44.85, and for double length it is –323.3. The maximum value $MaxL10$ is the base-10 logarithm of $XMAX$. For single length $MaxL10$ is 38.53, and for double-length it is 308.26.

3) Since **Inf** is used to represent *all* values greater than $XMAX$ its logarithm cannot be defined.

4) This function is well-behaved and does not seriously magnify errors in the argument.

```
EXP
DEXP
```

```
REAL32 FUNCTION EXP (VAL REAL32 X)
REAL64 FUNCTION DEXP (VAL REAL64 X)
```

Compute $e^X$.

| | |
|---|---|
| **Domain:** | [–**Inf**, $MaxLog$) = [–**Inf**, 88.72)S, [–**Inf**, 709.78)D |
| **Range:** | [0, **Inf**) (See note 4) |
| **Primary Domain:** | [$-Ln2/2$, $Ln2/2$) = [–0.3466, 0.3466) |

**Exceptions**

All arguments outside the domain generate an **Inf**.

**Propagated error**

$A = Xe^X, \quad R = X$

**Generated error**

| Primary Domain Error: | MRE | RMSRE |
|---|---|---|
| **Single Length(Standard):** | 0.99 ulp | 0.25 ulp |

| | | |
|---|---|---|
| **Single Length(T2 special):** | 1.0 ulp | 0.25 ulp |
| **Double Length:** | 1.4 ulp | 0.25 ulp |

**The Algorithm**

1 Set $N$ = integer part of $X$/ln(2).

2 Compute the remainder of $X$ by ln(2), using extended precision arithmetic.

3 Compute the exponential of the remainder with a floating-point rational approximation.

4 Increase the exponent of the result by $N$. If $N$ is sufficiently negative the result must be denormalized.

**Notes**

1) *MaxLog* is $\log_e(XMAX)$.

2) For sufficiently negative arguments (below –87.34 for single-length and below –708.4 for double-length) the output is denormalized, and so the floating-point number contains progressively fewer significant digits, which degrades the accuracy. In such cases the error can theoretically be a factor of two.

3) Although the true exponential function is never zero, for large negative arguments the true result becomes too small to be represented as a floating-point number, and `EXP` underflows to zero. This occurs for arguments below –103.9 for single-length, and below –745.2 for double-length.

4) The propagated error is considerably magnified for large positive arguments, but diminished for large negative arguments.

`POWER`
`DPOWER`

```
REAL32 FUNCTION POWER (VAL REAL32 X, Y)
REAL64 FUNCTION DPOWER (VAL REAL64 X, Y)
```

Compute $X^Y$.

| | |
|---|---|
| **Domain:** | [0, Inf] x [–Inf, Inf] |
| **Range:** | (–Inf, Inf) |
| **Primary Domain:** | See note 3. |

**Exceptions**

If the first argument is outside its domain, **undefined.NaN** is returned. If the true value of $X^Y$ exceeds $XMAX$, **Inf** is returned. In certain other cases other **NaNs** are produced: See note 2.

**Propagated Error**

$A = YX^Y(1 \pm \log_e(X))$, $R = Y(1 \pm \log_e(X))$ (See note 4)

**Generated error**

| Example Range Error: | MRE | RMSRE | (See note 3) |
|---|---|---|---|
| **Single Length(Standard):** | 1.0 ulp | 0.25 ulp | |
| **Single Length(T2 special):** | 63.1 ulp | 13.9 ulp | |
| **Double Length:** | 21.1 ulp | 2.4 ulp | |

**The Algorithm**

Deal with special cases: either argument = 1, 0, +Inf or –Inf (see note 2). Otherwise:

(a) For the standard single precision:

1 Compute $L = \log_e(X)$ in double precision, where $X$ is the first argument.

2 Compute $W = Y \times L$ in double precision, where $Y$ is the second argument.

3 Compute $RESULT = e^W$ in single precision.

(b) For double precision, and the single precision special version:

1 Compute $L = \log_2(X)$ in extended precision, where $X$ is the first argument.

2 Compute $W = Y \times L$ in extended precision, where $Y$ is the second argument.

3 Compute $RESULT = 2^W$ in extended precision.

**Notes**

1) This subroutine implements the mathematical function $x^y$ to a much greater accuracy than can be attained using the ALOG and EXP functions, by performing each step in higher precision. The single-precision version is more efficient than using DALOG and EXP because redundant tests are omitted.

2) Results for special cases are as follows:

| First Input (X) | Second Input (Y) | Result |
|---|---|---|
| $<0$ | ANY | **undefined.NaN** |
| 0 | $\leq 0$ | **undefined.NaN** |
| 0 | $0 < Y \leq XMAX$ | 0 |
| 0 | **Inf** | **unstable.NaN** |
| $0 < X < 1$ | **Inf** | 0 |
| $0 < X < 1$ | **–Inf** | **Inf** |
| 1 | $-XMAX \leq Y \leq XMAX$ | 1 |
| 1 | ± **Inf** | **unstable.NaN** |
| $1 < X \leq XMAX$ | **Inf** | **Inf** |
| $1 < X \leq XMAX$ | **–Inf** | 0 |
| **Inf** | $1 \leq Y \leq$ **Inf** | **Inf** |
| **Inf** | **–Inf** $\leq Y \leq -1$ | 0 |
| **Inf** | $-1 < Y < 1$ | **undefined.NaN** |
| otherwise | 0 | 1 |
| otherwise | 1 | $X$ |

3) Performing all the calculations in extended precision makes the double-precision algorithm very complex in detail, and having two arguments makes a primary domain difficult to specify. As an indication of accuracy, the functions were evaluated at 100 000 points logarithmically distributed over (0.1, 10.0), with the exponent linearly distributed over (–35.0, 35.0) (single-length), and (–300.0, 300.0) (double-length), producing the errors given above. The errors are much smaller if the exponent range is reduced.

4) The error amplification factors are calculated on the assumption that the relative error in $Y$ is $\pm$ that in $X$, otherwise there would be separate factors for both $X$ and $Y$. It can be seen that the propagated error will be greatly amplified whenever $\log_e(X)$ or $Y$ is large.

```
SIN
DSIN
```

```
REAL32 FUNCTION SIN (VAL REAL32 X)
REAL64 FUNCTION DSIN (VAL REAL64 X)
```

Compute sine($X$) (where $X$ is in radians).

| | |
|---|---|
| **Domain:** [$-Smax$, $Smax$] | = [–205887.4, 205887.4]S (Standard), |
| | = [$-4.2*10^6$, $4.2*10^6$]S (T2 special) |
| | = [$-4.29*10^9$, $4.29*10^9$]D |
| **Range:** | [–1.0, 1.0] |
| **Primary Domain:** | [$-Pi/2$, $Pi/2$]= [–1.57, 1.57] |

### Exceptions

All arguments outside the domain generate an **inexact.NaN**, except $\pm$ **Inf**, which generates an **undefined.NaN**.

### Propagated Error

$A = X\cos(X)$, $R = X\cot(X)$

### Generated error (See note 1)

| | Primary Domain | | [0, 2*Pi*] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length(Standard):** | 0.94 ulp | 0.23 ulp | 0.96 ulp | 0.19 ulp |
| **Single Length(T2 special):** | 0.92 ulp | 0.23 ulp | 0.94 ulp | 0.19 ulp |
| **Double Length:** | 0.90 ulp | 0.22 ulp | 0.91 ulp | 0.18 ulp |

### The Algorithm

1 Set $N$ = integer part of $|X|/Pi$.

2 Compute the remainder of $|X|$ by *Pi*, using extended precision arithmetic (double precision in the standard version).

3 Compute the sine of the remainder using a floating-point polynomial.

4 Adjust the sign of the result according to the sign of the argument and the evenness of $N$.

### Notes

1) For arguments outside the primary domain the accuracy of the result depends crucially on step 2. The extra precision of step 2 is lost if $N$ becomes too large, and the cut-off *Smax* is chosen to prevent this. In any case for large arguments the 'granularity' of floating-point numbers becomes a significant factor. For arguments larger than *Smax* a change in the argument of 1 ulp would change more than half of the significant bits of the result, and so the result is considered to be essentially indeterminate.

2) The propagated error has a complex behavior. The propagated relative error becomes large near each zero of the function (outside the primary range), but the propagated absolute error only becomes large for large arguments. In effect, the error is seriously amplified only in an interval about each irrational zero, and the width of this interval increases roughly in proportion to the size of the argument.

3) Since only the remainder of $X$ by *Pi* is used in step 3, the symmetry $sin(x+n\pi) = \pm sin(x)$ is preserved, although there is a complication due to differing precision representations of $\pi$.

4) The output range is not exceeded. Thus the output of `SIN` is always a valid argument for `ASIN`.

COS
DCOS

```
REAL32 FUNCTION COS (VAL REAL32 X)
REAL64 FUNCTION DCOS (VAL REAL64 X)
```

Compute cosine(*X*) (where *X* is in radians).

| | |
|---|---|
| **Domain:** [–*Cmax*, *Cmax*] | = [–205887.4, 205887.4]S (Standard), |
| | = [–12868.0, 12868.0]S (T2 special) |
| | = [$-2.1*10^8$, $2.1*10^8$]D |
| **Range:** | [–1.0, 1.0] |
| **Primary Domain:** | See note 1. |

**Exceptions**

All arguments outside the domain generate an **inexact.NaN**, except **±Inf**, which generates an **undefined.NaN**.

**Propagated Error**

$A = -X \sin(X)$, $R = -X \tan(X)$ (See note 4)

**Generated error**

| | [0, *Pi*/4) | | [0, 2*Pi*] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length(Standard):** | 0.93 ulp | 0.25 ulp | 0.88 ulp | 0.18 ulp |
| **Single Length(T2 special):** | 1.1 ulp | 0.3 ulp | 0.94 ulp | 0.19 ulp |
| **Double Length:** | 1.0 ulp | 0.28 ulp | 0.90 ulp | 0.19 ulp |

**The Algorithm**

1 Set $N$ = integer part of $(|X| + Pi/2)/Pi$ and compute the remainder of $(|X| + Pi/2)$ by *Pi*, using extended precision arithmetic (double precision in the standard version).

2 Compute the sine of the remainder using a floating-point polynomial.

3 Adjust the sign of the result according to the evenness of $N$.

**Notes**

1) Inspection of the algorithm shows that argument reduction always occurs, thus there is no 'primary domain' for COS. So for all arguments the

accuracy of the result depends crucially on step 2. The standard single-precision version performs the argument reduction in double-precision, so there is effectively no loss of accuracy at this step. For the T2 special version and the double-precision version there are effectively $K$ extra bits in the representation of $\pi$($K$=8 for the former and 12 for the latter). If the argument agrees with an odd integer multiple of $\pi/2$ to more than $k$ bits there is a loss of significant bits from the computed remainder equal to the number of extra bits of agreement, and this causes a loss of accuracy in the result.

2) The difference between COS evaluated at successive floating-point numbers is given approximately by the absolute error amplification factor, A. For arguments larger than *Cmax* this difference may be more than half the significant bits of the result, and so the result is considered to be essentially indeterminate and an **inexact.NaN** is returned. The extra precision of step 2 in the double-precision and T2 special versions is lost if $N$ becomes too large, and the cut-off at *Cmax* prevents this also.

3) For small arguments the errors are not evenly distributed. As the argument becomes smaller there is an increasing bias towards negative errors (which is to be expected from the form of the Taylor series). For the single-length version and $X$ in [–0.1, 0.1], 62% of the errors are negative, whilst for $X$ in [–0.01, 0.01], 70% of them are.

4) The propagated error has a complex behavior. The propagated relative error becomes large near each zero of the function, but the propagated absolute error only becomes large for large arguments. In effect, the error is seriously amplified only in an interval about each irrational zero, and the width of this interval increases roughly in proportion to the size of the argument.

5) Since only the remainder of ($|X|$+*Pi*/2) by *Pi* is used in step 3, the symmetry $\cos(x+n\pi) = \pm\cos(x)$ is preserved. Moreover, since the same rational approximation is used as in SIN, the relation $\cos(x) = \sin(x+\pi/2)$ is also preserved. However, in each case there is a complication due to the different precision representations of $\pi$.

6) The output range is not exceeded. Thus the output of COS is always a valid argument for ACOS.

```
TAN
DTAN
```

```
REAL32 FUNCTION TAN (VAL REAL32 X)
REAL64 FUNCTION DTAN (VAL REAL64 X)
```

Compute tan($X$) (where $X$ is in radians).

| | |
|---|---|
| **Domain:** [–*Tmax*, *Tmax*] | = [–102943.7, 102943.7]S(Standard), |
| | = [$-2.1*10^6$, $2.1*10^6$]S(T2 special), |
| | = [$-2.1*10^9$, $2.1*10^9$]D |
| **Range:** | **(–Inf, Inf)** |
| **Primary Domain:** | [–*Pi*/4, *Pi*/4]= [–0.785, 0.785] |

**Exceptions**

All arguments outside the domain generate an **inexact.NaN**, except ± **Inf**, which generate an **undefined.NaN**. Odd integer multiples of $\pi/2$ may produce **unstable.NaN**.

**Propagated Error**

$A = X(1+\tan^2(X))$, $R = X(1+\tan^2(X))/\tan(X)$ (See note 3)

**Generated error**

| Primary Domain Error: | MRE | RMSRE | (See note 3) |
|---|---|---|---|
| **Single Length(Standard):** | 1.44 ulp | 0.39 ulp | |
| **Single Length(T2 special):** | 1.37 ulp | 0.39 ulp | |
| **Double Length:** | 1.27 ulp | 0.35 ulp | |

**The Algorithm**

1 Set $N$ = integer part of $X/(Pi/2)$, and compute the remainder of $X$ by *Pi*/2, using extended precision arithmetic.

2 Compute two floating-point rational functions of the remainder, *XNum* and *XDen*.

3 If $N$ is odd, set *RESULT* = –*XDen*/*XNum*, otherwise set *RESULT* = *XNum*/*XDen*.

**Notes**

1) $R$ is large whenever $X$ is near to an integer multiple of $\pi/2$, and so tan is very sensitive to small errors near its zeros and singularities. Thus for arguments outside the primary domain the accuracy of the result depends crucially on step 2, so this is performed with very high precision, using double precision *Pi*/2 for the standard single-precision function and two double-precision floating-point numbers for the representation of $\pi/2$ for the double-precision function. The T2 special version uses two single-precision floating-point numbers. The extra precision is lost if $N$ becomes too large, and the cut-off *Tmax* is chosen to prevent this.

2) The difference between **TAN** evaluated at successive floating-point numbers is given approximately by the absolute error amplification factor,

$A$. For arguments larger than *Smax* this difference could be more than half the significant bits of the result, and so the result is considered to be essentially indeterminate and an **inexact.NaN** is returned.

3) Tan is quite badly behaved with respect to errors in the argument. Near its zeros outside the primary domain the relative error is greatly magnified, though the absolute error is only proportional to the size of the argument. In effect, the error is seriously amplified in an interval about each irrational zero, whose width increases roughly in proportion to the size of the argument. Near its singularities both absolute and relative errors become large, so any large output from this function is liable to be seriously contaminated with error, and the larger the argument, the smaller the maximum output which can be trusted. If step 3 of the algorithm requires division by zero, an **unstable.NaN** is produced instead.

4) Since only the remainder of $X$ by *Pi*/2 is used in step 3, the symmetry $\tan(x+n\pi) = \tan(x)$ is preserved, although there is a complication due to the differing precision representations of $\pi$. Moreover, by step 3 the symmetry $\tan(x) = 1/\tan(\pi/2 - x)$ is also preserved.

**ASIN**
**DASIN**

```
REAL32 FUNCTION ASIN (VAL REAL32 X)
REAL64 FUNCTION DASIN (VAL REAL64 X)
```

Compute $\text{sine}^{-1}(X)$ (in radians).

| | |
|---|---|
| **Domain:** | [–1.0, 1.0] |
| **Range:** | [–*Pi*/2, *Pi*/2] |
| **Primary Domain:** | [–0.5, 0.5] |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A = X/\sqrt{1-X^2},\ R = X/(\sin^{-1}(X)\sqrt{1-X^2})$

**Generated Error**

| | Primary Domain | | [–1.0, 1.0] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length:** | 0.58 ulp | 0.21 ulp | 1.35 ulp | 0.33 ulp |
| **Double Length:** | 0.59 ulp | 0.21 ulp | 1.26 ulp | 0.27 ulp |

**The Algorithm**

1 If $|X| > 0.5$, set *Xwork*:= `SQRT` ((1 – $|X|$)/2). Compute *Rwork* = arcsine(–2 $*$ *Xwork*) with a floating-point rational approximation, and set the result = *Rwork* + *Pi*/2.

2 Otherwise compute the result directly using the rational approximation.

3 In either case set the sign of the result according to the sign of the argument.

**Notes**

1) The error amplification factors are large only near the ends of the domain. Thus there is a small interval at each end of the domain in which the result is liable to be contaminated with error: however since both domain and range are bounded the *absolute* error in the result cannot be large.

2) By step 1, the identity $\sin^{-1}(x) = \pi/2 - 2\sin^{-1}(\sqrt{(1-x)/2})$ is preserved.

ACOS
DACOS

```
REAL32 FUNCTION ACOS (VAL REAL32 X)
REAL64 FUNCTION DACOS (VAL REAL64 X)
```

Compute $\text{cosine}^{-1}(X)$ (in radians).

| | |
|---|---|
| **Domain:** | [–1.0, 1.0] |
| **Range:** | [0, *Pi*] |
| **Primary Domain:** | [–0.5, 0.5] |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A = -X/\sqrt{1-X^2}$, $R = -X/(\sin^{-1}(X)\sqrt{1-X^2})$

**Generated Error**

| | Primary Domain | | [–1.0, 1.0] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length:** | 1.06 ulp | 0.38 ulp | 2.37 ulp | 0.61 ulp |
| **Double Length:** | 0.96 ulp | 0.32 ulp | 2.25 ulp | 0.53 ulp |

**The Algorithm**

1 If $|X| > 0.5$, set *Xwork*:= `SQRT ((1 – |X|)/2)`. Compute *Rwork* = arcsine(2 ∗ *Xwork*) with a floating-point rational approximation. If the argument was positive, this is the result, otherwise set the result = *Pi* – *Rwork*.

2 Otherwise compute *Rwork* directly using the rational approximation. If the argument was positive, set result = *Pi*/2 – *Rwork*, otherwise result = *Pi*/2 + *Rwork*.

**Notes**

1) The error amplification factors are large only near the ends of the domain. Thus there is a small interval at each end of the domain in which the result is liable to be contaminated with error, although this interval is larger near 1 than near –1, since the function goes to zero with an infinite derivative there. However since both the domain and range are bounded the *absolute* error in the result cannot be large.

2) Since the rational approximation is the same as that in `ASIN`, the relation $\cos^{-1}(x) = \pi/2 - \sin^{-1}(x)$ is preserved.

**ATAN**
**DATAN**

```
REAL32 FUNCTION ATAN (VAL REAL32 X)
REAL64 FUNCTION DATAN (VAL REAL64 X)
```

Compute $\tan^{-1}(X)$ (in radians).

| | |
|---|---|
| **Domain:** | [–Inf, Inf] |
| **Range:** | [–*Pi*/2, *Pi*/2] |
| **Primary Domain:** | $[-z, z]$, $z = 2 - \sqrt{3} = 0.2679$ |

**Exceptions**

None.

**Propagated Error**

$A = X/(1 + X^2), R = X/(\tan^{-1}(X)(1 + X^2))$

**Generated Error**

| Primary Domain Error: | MRE | RMSRE |
|---|---|---|
| **Single Length:** | 0.56 ulp | 0.21 ulp |
| **Double Length:** | 0.52 ulp | 0.21 ulp |

**The Algorithm**

1 If $|X| > 1.0$, set $Xwork = 1/|X|$, otherwise $Xwork = |X|$.

2 If $Xwork > 2-\sqrt{3}$, set $F = (Xwork*\sqrt{3} - 1)/(Xwork + \sqrt{3})$, otherwise $F = Xwork$.

3 Compute *Rwork* = arctan(*F*) with a floating-point rational approximation.

4 If *Xwork* was reduced in (2), set *R* = *Pi*/6 + *Rwork*, otherwise *R* = *Rwork*.

5 If *X* was reduced in (1), set *RESULT* = *Pi*/2 – *R*, otherwise *RESULT* = *R*.

6 Set the sign of the *RESULT* according to the sign of the argument.

**Notes**

1) For $|X| > ATmax$, $|\tan^{-1}(X)|$ is indistinguishable from $\pi/2$ in the floating-point format. For single-length, $ATmax = 1.68*10^7$, and for double-length $ATmax = 9*10^{15}$, approximately.

2) This function is numerically very stable, despite the complicated argument reduction. The worst errors occur just above $2-\sqrt{3}$, but are no more than 3.2 ulp.

3) It is also very well behaved with respect to errors in the argument, i.e. the error amplification factors are always small.

4) The argument reduction scheme ensures that the identities $\tan^{-1}(X) = \pi/2 - \tan^{-1}(1/X)$, and $\tan^{-1}(X) = \pi/6 + \tan^{-1}((\sqrt{3}*X-1)/(\sqrt{3} + X))$ are preserved.

```
ATAN2
DATAN2
```

```
REAL32 FUNCTION ATAN2 (VAL REAL32 X, Y)
REAL64 FUNCTION DATAN2 (VAL REAL64 X, Y)
```

Compute the angular co-ordinate $\tan^{-1}(Y/X)$ (in radians) of a point whose *X* and *Y* co-ordinates are given.

| | |
|---|---|
| **Domain:** | [–Inf, Inf] x [–Inf, Inf] |
| **Range:** | (–*Pi*, *Pi*] |
| **Primary Domain:** | See note 2. |

**Exceptions**

(0, 0) and (±Inf,±Inf) give **undefined.NaN**.

**Propagated Error**

$A = X(1 \pm Y)/(X^2 + Y^2)$, $R = X(1 \pm Y)/(\tan^{-1}(Y/X)(X^2 + Y^2))$ (See note 3)

**Generated Error**

See note 2.

### The Algorithm

1 If $X$, the first argument, is zero, set the result to $\pm \pi /2$, according to the sign of $Y$, the second argument.

2 Otherwise set *Rwork*:= **ATAN** ($Y/X$). Then if $Y < 0$ set *RESULT* = *Rwork* – *Pi*, otherwise set *RESULT* = *Pi* – *Rwork*.

### Notes

1) This two-argument function is designed to perform rectangular-to-polar co-ordinate conversion.

2) See the notes for **ATAN** for the primary domain and estimates of the generated error.

3) The error amplification factors were derived on the assumption that the relative error in $Y$ is $\pm$ that in $X$, otherwise there would be separate factors for $X$ and $Y$. They are small except near the origin, where the polar co-ordinate system is singular.

## SINH
## DSINH

```
REAL32 FUNCTION SINH (VAL REAL32 X)
REAL64 FUNCTION DSINH (VAL REAL64 X)
```

Compute sin$h$($X$).

| | |
|---|---|
| **Domain:** [–*Hmax*, *Hmax*] | = [–89.4, 89.4]S, [–710.5, 710.5]D |
| **Range:** | (–**Inf**, **Inf**) |
| **Primary Domain:** | (–1.0, 1.0) |

### Exceptions

$X < -Hmax$ gives –**Inf**, and $X > Hmax$ gives **Inf**.

### Propagated Error

$A = X\cosh(X)$, $R = X\coth(X)$ (See note 3)

### Generated Error

| | Primary Domain | | [1.0, *XBig*] (See note 2) | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length:** | 0.91 ulp | 0.26 ulp | 1.41 ulp | 0.34 ulp |
| **Double Length:** | 0.67 ulp | 0.22 ulp | 1.31 ulp | 0.33 ulp |

### The Algorithm

1 If $|X| > XBig$, set *Rwork*:= **EXP** ($|X| - \ln(2)$).

2 If *XBig* ≥ $|X|$ ≥ 1.0, set temp:= **EXP** ($|X|$), and set *Rwork* = (*temp* – 1/*temp*)/2.

3 Otherwise compute sinh($|X|$) with a floating-point rational approximation.

4 In all cases, set *RESULT* = $\pm$ *Rwork* according to the sign of *X*.

**Notes**

1) *Hmax* is the point at which sinh(*X*) becomes too large to be represented in the floating-point format.

2) *XBig* is the point at which $e^{-|X|}$ becomes insignificant compared with $e^{|X|}$, (in floating-point). For single-length it is 8.32, and for double-length it is 18.37.

3) This function is quite stable with respect to errors in the argument. Relative error is magnified near zero, but the absolute error is a better measure near the zero of the function and it is diminished there. For large arguments absolute errors are magnified, but since the function is itself large, relative error is a better criterion, and relative errors are not magnified unduly for any argument in the domain, although the output does become less reliable near the ends of the range.

```
COSH
DCOSH
```

```
REAL32 FUNCTION COSH (VAL REAL32 X)
REAL64 FUNCTION DCOSH (VAL REAL64 X)
```

Compute cosh(*X*).

| | |
|---|---|
| **Domain:** [–*Hmax*, *Hmax*] | = [–89.4, 89.4]S, [–710.5, 710.5]D |
| **Range:** | [1.0, Inf) |
| **Primary Domain:** | [–*XBig*, *XBig*]= [–8.32, 8.32]S<br>= [–18.37, 18.37]D |

**Exceptions**

$|X|$ > *Hmax* gives Inf.

**Propagated Error**

$A = X\,\sinh(X)$ , $R = X\,\tanh(X)$ (See note 3)

**Generated Error**

| Primary Domain Error: | MRE | RMS |
|---|---|---|
| **Single Length:** | 1.24 ulp | 0.32 ulp |
| **Double Length:** | 1.24 ulp | 0.33 ulp |

### The Algorithm

1 If $|X| > XBig$, set *result*:= `EXP (|X| - ln(2))`.

2 Otherwise, set *temp*:= `EXP (|X|)`, and set *result* = (*temp* + 1/*temp*)/2.

### Notes

1) *Hmax* is the point at which cosh($X$) becomes too large to be represented in the floating-point format.

2) *XBig* is the point at which $e^{-|X|}$ becomes insignificant compared with $e^{|X|}$ (in floating-point).

3) Errors in the argument are not seriously magnified by this function, although the output does become less reliable near the ends of the range.

**TANH**
**DTANH**

```
REAL32 FUNCTION TANH (VAL REAL32 X)
REAL64 FUNCTION DTANH (VAL REAL64 X)
```

Compute tanh($X$).

| | |
|---|---|
| **Domain:** | [–Inf, Inf] |
| **Range:** | [–1.0, 1.0] |
| **Primary Domain:** | [–Log(3)/2, Log(3)/2] = [–0.549, 0.549] |

### Exceptions

None.

### Propagated Error

$A = X/\cosh^2(X)$, $R = X/\sinh(X)\cosh(X)$

### Generated Error

| Primary Domain Error: | MRE | RMS |
|---|---|---|
| **Single Length:** | 0.53 ulp | 0.2 ulp |
| **Double Length:** | 0.53 ulp | 0.2 ulp |

### The Algorithm

1 If $|X| > \ln(3)/2$, set *temp*:= `EXP (|X|/2)`. Then set *Rwork* = 1 – 2/(1+*temp*).

2 Otherwise compute *Rwork* = tanh($|X|$) with a floating-point rational approximation.

3 In both cases, set *RESULT* = $\pm$ *Rwork* according to the sign of *X*.

**Notes**

1) As a floating-point number, tanh(*X*) becomes indistinguishable from its asymptotic values of $\pm$1.0 for |*X*|> *HTmax*, where *HTmax* is 8.4 for single-length, and 19.06 for double-length. Thus the output of `TANH` is equal to $\pm$1.0 for such *X*.

2) This function is very stable and well-behaved, and errors in the argument are always diminished by it.

RAN
DRAN

```
REAL32,INT32 FUNCTION RAN (VAL INT32 X)
REAL64,INT64 FUNCTION DRAN (VAL INT64 X)
```

These produce a pseudo-random sequence of integers, or a corresponding sequence of floating-point numbers between zero and one. X is the seed integer that initiates the sequence.

| | |
|---|---|
| **Domain:** | Integers (see note 1) |
| **Range:** | [0.0, 1.0] x Integers |

**Exceptions**

None.

**The Algorithm**

1 Produce the next integer in the sequence: $N_{k+1} = (aN_k + 1)_{mod\,M}$

2 Treat $N_{k+1}$ as a fixed-point fraction in [0,1), and convert it to floating point.

3 Output the floating point result and the new integer.

**Notes**

1) This function has two results, the first a real, and the second an integer (both 32 bits for single-length, and 64 bits for double-length). The integer is used as the argument for the next call to `RAN`, i.e. it 'carries' the pseudo-random linear congruential sequence $N_k$, and it should be kept in scope for as long as `RAN` is used. It should be initialized before the first call to `RAN` but not modified thereafter except by the function itself.

2) If the integer parameter is initialized to the same value, the same sequence (both floating-point and integer) will be produced. If a different sequence is required for each run of a program it should be initialized to some 'random' value, such as the output of a timer.

3) The integer parameter can be copied to another variable or used in expressions requiring random integers. The topmost bits are the most random. A random integer in the range $[0,L]$ can conveniently be produced by taking the remainder by $(L+1)$ of the integer parameter shifted right by one bit. If the shift is not done an integer in the range $[-L,L]$ will be produced.

4) The modulus $M$ is $2^{32}$ for single-length and $2^{64}$ for double-length, and the multipliers, $a$, have been chosen so that all $M$ integers will be produced before the sequence repeats. However several different integers can produce the same floating-point value and so a floating-point output may be repeated, although the *sequence* of such will not be repeated until $M$ calls have been made.

5) The floating-point result is uniformly distributed over the output range, and the sequence passes various tests of randomness, such as the 'run test', the 'maximum of 5 test' and the 'spectral test'.

6) The double-length version is slower to execute, but 'more random' than the single-length version. If a highly-random sequence of single-length numbers is required, this could be produced by converting the output of `DRAN` to single-length. Conversely if only a relatively crude sequence of double-length numbers is required, `RAN` could be used for higher speed and its output converted to double-length.

### 1.4.3 IMS T400/T414/T425/T426 elementary function library

To use this library a program header must include the line:

```
#USE "tbmaths.lib"
```

The version of the library described by this section has been written for 32-bit processors without hardware for floating-point arithmetic. Functions from it will give results very close, but not identical to, those produced by the corresponding functions from the single and double length libraries.

This is the version specifically intended to derive maximum performance from the IMS T400, T414, T425, and T426 processors. The single-precision functions make use of the `FMUL` instruction available on 32-bit processors without floating-point hardware. The library is compiled for transputer class `TB`.

The tables and notes at the beginning of section 1.4 apply equally here. However all the functions are contained in one library.

#### Function definitions

**ALOG**
**DALOG**

```
REAL32 FUNCTION ALOG (VAL REAL32 X)
REAL64 FUNCTION DALOG (VAL REAL64 X)
```

These compute: $\log_e(X)$

| | |
|---|---|
| **Domain:** | $(0, XMAX]$ |
| **Range:** | $[MinLog, MaxLog]$ (See note 2) |
| **Primary Domain:** | $[\surd 2/2, \surd 2)$ = [0.7071, 1.4142) |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A \equiv 1$, $R = \log_e(X)$

**Generated Error**

| Primary Domain Error: | **MRE** | **RMSRE** |
|---|---|---|
| **Single Length:** | 1.19 ulp | 0.36 ulp |
| **Double Length:** | 2.4 ulp | 1.0 ulp |

**The Algorithm**

1 Split $X$ into its exponent $N$ and fraction $F$.

2 Find the natural log of $F$ with a fixed-point rational approximation, and convert it into a floating-point number $LnF$.

3 Compute ln(2) $*$ $N$ with extended precision and add it to $LnF$ to get the result.

**Notes**

1) The term ln(2) $*$ $N$ is much easier to compute (and more accurate) than $LnF$, and it is larger provided $N$ is not 0 (i.e. for arguments outside the primary domain). Thus the accuracy of the result improves as the modulus of log($X$) increases.

2) The minimum value that can be produced, $MinLog$, is the logarithm of the smallest denormalized floating-point number. For single length $MinLog$ is –103.28, and for double length it is –744.4. The maximum value $MaxLog$ is the logarithm of $XMAX$. For single-length it is 88.72, and for double-length it is 709.78.

3) Since **Inf** is used to represent *all* values greater than $XMAX$ its logarithm cannot be defined.

4) This function is well-behaved and does not seriously magnify errors in the argument.

```
ALOG10
DALOG10
```

```
REAL32 FUNCTION ALOG10 (VAL REAL32 X)
REAL64 FUNCTION DALOG10 (VAL REAL64 X)
```

These compute: $\log_{10}(X)$

| | |
|---|---|
| **Domain:** | $(0, XMAX]$ |
| **Range:** | $[MinL10, MaxL10]$ (See note 2) |
| **Primary Domain:** | $[\surd 2/2, \surd 2) = [0.7071, 1.4142)$ |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A \equiv \log_{10}(e)$, $R = \log_{10}(e)/\log_e(X)$

**Generated Error**

| Primary Domain Error: | MRE | RMSRE |
|---|---|---|
| **Single Length:** | 1.43 ulp | 0.39 ulp |
| **Double Length:** | 2.64 ulp | 0.96 ulp |

**The Algorithm**

1 Set $temp$:= ALOG(X).

2 If $temp$ is a **NaN**, copy it to the output, otherwise set result = $\log(e) * temp$.

**Notes**

1) See note 1 for ALOG.

2) The minimum value that can be produced, $MinL10$, is the base-10 logarithm of the smallest denormalized floating-point number. For single length $MinL10$ is –44.85, and for double length it is –323.3. The maximum value $MaxL10$ is the base-10 logarithm of $XMAX$. For single length $MaxL10$ is 38.53, and for double-length it is 308.26.

3) Since **Inf** is used to represent *all* values greater than $XMAX$ its logarithm cannot be defined.

4) This function is well-behaved and does not seriously magnify errors in the argument.

```
EXP
DEXP
```

```
REAL32 FUNCTION EXP (VAL REAL32 X)
REAL64 FUNCTION DEXP (VAL REAL64 X)
```

These compute: $e^X$

| | |
|---|---|
| **Domain:** | [–Inf, *MaxLog*) = [–Inf, 88.03)S, [–Inf, 709.78)D |
| **Range:** | [0, Inf) (See note 4) |
| **Primary Domain:** | [–*Ln*2/2, *Ln*2/2) = [–0.3466, 0.3466) |

**Exceptions**

All arguments outside the domain generate an **Inf**.

**Propagated Error**

$A = Xe^X, \quad R = X$

**Generated Error**

| Primary Domain Error: | MRE | RMSRE |
|---|---|---|
| **Single Length:** | 0.51 ulp | 0.21 ulp |
| **Double Length:** | 0.5 ulp | 0.21 ulp |

**The Algorithm**

1 Set $N$ = integer part of $X$/ln(2).

2 Compute the remainder of $X$ by ln(2), using extended precision arithmetic.

3 Convert the remainder to fixed-point, compute its exponential using a fixed-point rational function, and convert the result back to floating point.

4 Increase the exponent of the result by $N$. If $N$ is sufficiently negative the result must be denormalized.

**Notes**

1) *MaxLog* is $\log_e(XMAX)$.

2) The analytical properties of $e^x$ make the relative error of the result proportional to the absolute error of the argument. Thus the accuracy of step 2, which prepares the argument for the rational approximation, is crucial to the performance of the subroutine. It is completely accurate when $N = 0$, i.e. in the primary domain, and becomes less accurate as the magnitude

of $N$ increases. Since $N$ can attain larger negative values than positive ones, `EXP` is least accurate for large, negative arguments.

3) For sufficiently negative arguments (below –87.34 for single-length and below –708.4 for double-length) the output is denormalized, and so the floating-point number contains progressively fewer significant digits, which degrades the accuracy. In such cases the error can theoretically be a factor of two.

4) Although the true exponential function is never zero, for large negative arguments the true result becomes too small to be represented as a floating-point number, and `EXP` underflows to zero. This occurs for arguments below –103.9 for single-length, and below –745.2 for double-length.

5) The propagated error is considerably magnified for large positive arguments, but diminished for large negative arguments.

`POWER`
`DPOWER`

```
REAL32 FUNCTION POWER (VAL REAL32 X, Y)
REAL32 FUNCTION DPOWER (VAL REAL64 X, Y)
```

These compute: $X^Y$

| | |
|---|---|
| **Domain:** | [0, Inf] x [–Inf, Inf] |
| **Range:** | (–Inf, Inf) |
| **Primary Domain:** | See note 3. |

### Exceptions

If the first argument is outside its domain, **undefined.NaN** is returned. If the true value of $X^Y$ exceeds $XMAX$, **Inf** is returned. In certain other cases other **NaNs** are produced: See note 2.

### Propagated Error

$A = YX^Y(1 \pm \log_e(X))$, $R = Y(1 \pm \log_e(X))$ (See note 4)

### Generated Error

| Example Range Error: | **MRE** | **RMSRE** (See note 3) |
|---|---|---|
| **Single Length:** | 1.0 ulp | 0.24 ulp |
| **Double Length:** | 13.2 ulp | 1.73 ulp |

### The Algorithm

Deal with special cases: either argument = 1, 0, +Inf or –Inf (see note 2). Otherwise:

(a) For single precision:

1 Compute $L = \log_2(X)$ in fixed point, where $X$ is the first argument.

2 Compute $W = Y \times L$ in double precision, where $Y$ is the second argument.

3 Compute $2^W$ in fixed point and convert to floating-point result.

(b) For double precision:

1 Compute $L = \log_2(X)$ in extended precision, where $X$ is the first argument.

2 Compute $W = Y \times L$ in extended precision, where $Y$ is the second argument.

3 Compute $RESULT = 2^W$ in extended precision.

**Notes**

1) This subroutine implements the mathematical function $x^y$ to a much greater accuracy than can be attained using the ALOG and EXP functions, by performing each step in higher precision.

2) Results for special cases are as follows:

| First Input (X) | Second Input (Y) | Result |
|---|---|---|
| $<0$ | ANY | undefined.NaN |
| 0 | $\leq 0$ | undefined.NaN |
| 0 | $0 < Y \leq XMAX$ | 0 |
| 0 | Inf | unstable.NaN |
| $0 < X < 1$ | Inf | 0 |
| $0 < X < 1$ | –Inf | Inf |
| 1 | $-XMAX \leq Y \leq XMAX$ | 1 |
| 1 | ± Inf | unstable.NaN |
| $1 < X \leq XMAX$ | Inf | Inf |
| $1 < X \leq XMAX$ | –Inf | 0 |
| Inf | $1 \leq Y \leq$ Inf | Inf |
| Inf | –Inf $\leq Y \leq -1$ | 0 |
| Inf | $-1 < Y < 1$ | undefined.NaN |
| otherwise | 0 | 1 |
| otherwise | 1 | $X$ |

3) Performing all the calculations in extended precision makes the double-precision algorithm very complex in detail, and having two arguments

makes a primary domain difficult to specify. As an indication of accuracy, the functions were evaluated at 100 000 points logarithmically distributed over (0.1, 10.0), with the exponent linearly distributed over (–35.0, 35.0) (single-length), and (–300.0, 300.0) (double-length), producing the errors given above. The errors are much smaller if the exponent range is reduced.

4) The error amplification factors are calculated on the assumption that the relative error in $Y$ is $\pm$ that in $X$, otherwise there would be separate factors for both $X$ and $Y$. It can be seen that the propagated error will be greatly amplified whenever $\log_e(X)$ or $Y$ is large.

**The Algorithm**

1 Compute $L = \log_2(X)$ in fixed point, where $X$ is the first argument.

2 Compute $W = Y \times L$ in double precision, where $Y$ is the second argument.

3 Compute $2^W$ in fixed point and convert to floating-point result.

4 Compute $L = \log_2(X)$ in extended precision, where $X$ is the first argument.

5 Compute $W = Y \times L$ in extended precision, where $Y$ is the second argument.

6 Compute $RESULT = 2^W$ in extended precision.

## SIN
## DSIN

```
REAL32 FUNCTION SIN (VAL REAL32 X)
REAL64 FUNCTION DSIN (VAL REAL64 X)
```

These compute: sine($X$)    (where $X$ is in radians)

| | |
|---|---|
| **Domain:** | [–*Smax*, *Smax*] = [–12868.0, 12868.0]S, |
| | = [$-2.1*10^8$, $2.1*10^8$]D |
| **Range:** | [–1.0, 1.0] |
| **Primary Domain:** | [–*Pi*/2, *Pi*/2] = [–1.57, 1.57] |

**Exceptions**

All arguments outside the domain generate an **inexact.NaN**, except $\pm$ **Inf**, which generates an **undefined.NaN**.

**Propagated Error**

$A = X\cos(X)$,    $R = X\cot(X)$

**Generated Error** (See note 3)

| Range: | Primary Domain | | [0, *2Pi*] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length:** | 0.65 ulp | 0.22 ulp | 0.74 ulp | 0.18 ulp |
| **Double Length:** | 0.56 ulp | 0.21 ulp | 0.64 ulp | 0.16 ulp |

**The Algorithm**

1 Set $N$ = integer part of $\lfloor X\rceil / Pi$.

2 Compute the remainder of $\lfloor X\rceil$ by $Pi$, using extended precision arithmetic.

3 Convert the remainder to fixed-point, compute its sine using a fixed-point rational function, and convert the result back to floating point.

4 Adjust the sign of the result according to the sign of the argument and the evenness of $N$.

**Notes**

1) For arguments outside the primary domain the accuracy of the result depends crucially on step 2. The extended precision corresponds to $K$ extra bits in the representation of $\pi$ ($K$ = 8 for single-length and 12 for double-length). If the argument agrees with an integer multiple of $\pi$ to more than $K$ bits there is a loss of significant bits in the remainder, equal to the number of extra bits of agreement, and this causes a loss of accuracy in the result.

2) The extra precision of step 2 is lost if $N$ becomes too large, and the cut-off *Smax* is chosen to prevent this. In any case for large arguments the 'granularity' of floating-point numbers becomes a significant factor. For arguments larger than *Smax* a change in the argument of 1 ulp would change more than half of the significant bits of the result, and so the result is considered to be essentially indeterminate.

3) The propagated error has a complex behavior. The propagated relative error becomes large near each zero of the function (outside the primary range), but the propagated absolute error only becomes large for large arguments. In effect, the error is seriously amplified only in an interval about each irrational zero, and the width of this interval increases roughly in proportion to the size of the argument.

4) Since only the remainder of $X$ by $Pi$ is used in step 3, the symmetry $\sin(x+n\pi) = \pm\sin(x)$ is preserved, although there is a complication due to differing precision representations of $\pi$.

5) The output range is not exceeded. Thus the output of `SIN` is always a valid argument for `ASIN`.

COS
DCOS

```
REAL32 FUNCTION COS (VAL REAL32 X)
REAL64 FUNCTION DCOS (VAL REAL64 X)
```

These compute: cosine ($X$) (where $X$ is in radians)

| | |
|---|---|
| **Domain:** | [$-Smax$, $Smax$] = [–12868.0, 12868.0]S, = [$-2.1*10^8$, $2.1*10^8$]D |
| **Range:** | [–1.0, 1.0] |
| **Primary Domain:** | See note 1. |

**Exceptions**

All arguments outside the domain generate an **inexact.NaN**, except ±Inf, which generates an **undefined.NaN**.

**Propagated Error**

$A = -X \sin(X)$, $R = -X \tan(X)$ (See note 4)

**Generated Error**

| Range: | [0,*Pi*/4) | | [0, 2*Pi*] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length:** | 1.0 ulp | 0.28 ulp | 0.81 ulp | 0.17 ulp |
| **Double Length:** | 0.93 ulp | 0.26 ulp | 0.76 ulp | 0.18 ulp |

**The Algorithm**

1 Set $N$ = integer part of ($|X|$+$Pi$/2)/$Pi$.

2 Compute the remainder of ($|X|$+$Pi$/2) by $Pi$, using extended precision arithmetic.

3 Compute the remainder to fixed-point, compute its sine using a fixed-point rational function, and convert the result back to floating point.

4 Adjust the sign of the result according to the evenness of $N$.

**Notes**

1) Inspection of the algorithm shows that argument reduction always occurs, thus there is no 'primary domain' for COS. So for all arguments the accuracy of the result depends crucially on step 2. The extended precision corresponds to $K$ extra bits in the representation of $\pi$ ($K$ = 8 for single-length and 12 for double length). If the argument agrees with an odd integer multiple of $\pi/2$ to more than $K$ bits there is a loss of significant bits in the

remainder, equal to the number of extra bits of agreement, and this causes a loss of accuracy in the result.

2) The extra precision of step 2 is lost if *N* becomes too large, and the cut-off *Smax* is chosen to prevent this. In any case for large arguments the 'granularity' of floating-point numbers becomes a significant factor. For arguments larger than *Smax* a change in the argument of 1 ulp would change more than half of the significant bits of the result, and so the result is considered to be essentially indeterminate.

3) For small arguments the errors are not evenly distributed. As the argument becomes smaller there is an increasing bias towards negative errors (which is to be expected from the form of the Taylor series). For the single-length version and *X* in [–0.1, 0.1], 62% of the errors are negative, whilst for *X* in [–0.01, 0.01], 70% of them are.

4) The propagated error has a complex behavior. The propagated relative error becomes large near each zero of the function, but the propagated absolute error only becomes large for large arguments. In effect, the error is seriously amplified only in an interval about each irrational zero, and the width of this interval increases roughly in proportion to the size of the argument.

5) Since only the remainder of (|*X*|+*Pi*/2) by *Pi* is used in step 3, the symmetry cos($x+n\pi$) = $\pm$ cos($x$) is preserved. Moreover, since the same rational approximation is used as in `SIN`, the relation cos($x$) =sin($x+\pi/2$) is also preserved. However, in each case there is a complication due to the different precision representations of $\pi$.

6) The output range is not exceeded. Thus the output of `COS` is always a valid argument for `ACOS`.

`TAN`
`DTAN`

```
REAL32 FUNCTION TAN (VAL REAL32 X)
REAL64 FUNCTION DTAN (VAL REAL64 X)
```

These compute: tan(*X*) (where *X* is in radians)

| | | |
|---|---|---|
| **Domain:** | [–*Tmax*, *Tmax*] | = [–6434.0, 6434.0]S |
| | | = [$-1.05*10^8$, $1.05*10^8$]D |
| **Range:** | (–Inf, Inf) | |
| **Primary Domain:** | [–*Pi*/4, *Pi*/4] | = [–0.785, 0.785] |

**Exceptions**

All arguments outside the domain generate an **inexact.NaN**, except $\pm$ **Inf**, which generate an **undefined.NaN**. Odd integer multiples of $\pi/2$ may produce **unstable.NaN**.

**Propagated Error**

$A = X(1+\tan^2(X))$, $R = X(1+\tan^2(X))/\tan(X)$ (See note 4)

**Generated Error**

| Primary Domain Error: | **MRE** | **RMSRE** |
|---|---|---|
| **Single Length:** | 3.5 ulp | 0.23 ulp |
| **Double Length:** | 0.69 ulp | 0.23 ulp |

**The Algorithm**

1 Set $N$ = integer part of $X/(Pi/2)$.

2 Compute the remainder of $X$ by $Pi/2$, using extended precision arithmetic.

3 Convert the remainder to fixed-point, compute its tangent using a fixed-point rational function, and convert the result back to floating point.

4 If $N$ is odd, take the reciprocal.

5 Set the sign of the result according to the sign of the argument.

**Notes**

1) $R$ is large whenever $X$ is near to an integer multiple of $\pi/2$, and so tan is very sensitive to small errors near its zeros and singularities. Thus for arguments outside the primary domain the accuracy of the result depends crucially on step 2. The extended precision corresponds to $K$ extra bits in the representation of $\pi/2$ ($K = 8$ for single-length and 12 for double-length). If the argument agrees with an integer multiple of $\pi/2$ to more than $K$ bits there is a loss of significant bits in the remainder, approximately equal to the number of extra bits of agreement, and this causes a loss of accuracy in the result.

2) The extra precision of step 2 is lost if $N$ becomes too large, and the cut-off *Tmax* is chosen to prevent this. In any case for large arguments the 'granularity' of floating-point numbers becomes a significant factor. For arguments larger than *Tmax* a change in the argument of 1 ulp would change more than half of the significant bits of the result, and so the result is considered to be essentially indeterminate.

3) Step 3 of the algorithm has been slightly modified in the double-precision version from that given in Cody & Waite to avoid fixed-point underflow in the polynomial evaluation for small arguments.

4) Tan is quite badly behaved with respect to errors in the argument. Near its zeros outside the primary domain the relative error is greatly magnified,

though the absolute error is only proportional to the size of the argument. In effect, the error is seriously amplified in an interval about each irrational zero, whose width increases roughly in proportion to the size of the argument. Near its singularities both absolute and relative errors become large, so any large output from this function is liable to be seriously contaminated with error, and the larger the argument, the smaller the maximum output which can be trusted. If step 4 of the algorithm requires division by zero, an **unstable.NaN** is produced instead.

5) Since only the remainder of *X* by *Pi*/2 is used in step 3, the symmetry $\tan(x + n\pi) = \tan(x)$ is preserved, although there is a complication due to the differing precision representations of $\pi$. Moreover, by step 4 the symmetry $\tan(x) = 1/\tan(\pi/2 - x)$ is also preserved.

ASIN
DASIN

```
REAL32 FUNCTION ASIN (VAL REAL32 X)
REAL64 FUNCTION DASIN (VAL REAL64 X)
```

These compute: $\sin^{-1}(X)$ (in radians)

| | |
|---|---|
| **Domain:** | [–1.0, 1.0] |
| **Range:** | [–*Pi*/2, *Pi*/2] |
| **Primary Domain:** | [–0.5, 0.5] |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A = X/\sqrt{1 - X^2}, \quad R = X/(\sin^{-1}(X)\sqrt{1 - X^2})$

**Generated Error**

| | Primary Domain | | [–1.0, 1.0] | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| **Single Length:** | 0.53 ulp | 0.21 ulp | 1.35 ulp | 0.33 ulp |
| **Double Length:** | 2.8 ulp | 1.4 ulp | 2.34 ulp | 0.64 ulp |

**The Algorithm**

1 If $|X| > 0.5$, set *Xwork*:= SQRT ((1 – |*X*|)/2).
Compute *Rwork* = arcsine(–2 * *Xwork*) with a floating-point rational approximation, and set the result = *Rwork* + *Pi*/2.

2 Otherwise compute the result directly using the rational approximation.

3 In either case set the sign of the result according to the sign of the argument.

**Notes**

1) The error amplification factors are large only near the ends of the domain. Thus there is a small interval at each end of the domain in which the result is liable to be contaminated with error: however since both domain and range are bounded the *absolute* error in the result cannot be large.

2) By step 1, the identity $\sin^{-1}(x) = \pi/2 - 2\sin^{-1}(\surd((1-x)/2))$ is preserved.

ACOS
DACOS

```
REAL32 FUNCTION ACOS (VAL REAL32 X)
REAL64 FUNCTION DACOS (VAL REAL64 X)
```

These compute: cosine$^{-1}(X)$ (in radians)

| | |
|---|---|
| **Domain:** | [–1.0, 1.0] |
| **Range:** | [0, *Pi*] |
| **Primary Domain:** | [–0.5, 0.5] |

**Exceptions**

All arguments outside the domain generate an **undefined.NaN**.

**Propagated Error**

$A = -X/\surd 1 - X^2, \quad R = -X/(\sin^{-1}(X)\ \surd 1 - X^2)$

**Generated Error**

| | Primary Domain | | [–1.0, 1.0] | |
|---|---|---|---|---|
| | MRE | RMSRE | MAE | RMSAE |
| Single Length: | 1.1 ulp | 0.38 ulp | 2.4 ulp | 0.61 ulp |
| Double Length: | 1.3 ulp | 0.34 ulp | 2.9 ulp | 0.78 ulp |

**The Algorithm**

1 If $|X| > 0.5$, set *Xwork*:= SQRT ((1–$|X|$)/2) . Compute *Rwork* = arcsine (2 $*$ *Xwork*) with a floating-point rational approximation. If the argument was positive, this is the result, otherwise set the result = *Pi* – *Rwork*.

2 Otherwise compute *Rwork* directly using the rational approximation. If the argument was positive, set result = *Pi*/2 – *Rwork*, otherwise result = *Pi*/2 + *Rwork*.

### Notes

1) The error amplification factors are large only near the ends of the domain. Thus there is a small interval at each end of the domain in which the result is liable to be contaminated with error, although this interval is larger near 1 than near −1, since the function goes to zero with an infinite derivative there. However since both the domain and range are bounded the *absolute* error in the result cannot be large.

2) Since the rational approximation is the same as that in **ASIN**, the relation $\cos^{-1}(x) = \pi/2 - \sin^{-1}(x)$is preserved.

## ATAN
## DATAN

```
REAL32 FUNCTION ATAN (VAL REAL32 X)
REAL64 FUNCTION DATAN (VAL REAL64 X)
```

These compute: $\tan^{-1}(X)$ (in radians)

| | |
|---|---|
| **Domain:** | [−Inf, Inf] |
| **Range:** | $[-Pi/2, Pi/2]$ |
| **Primary Domain:** | $[-z, z]$, $z = 2 - \sqrt{3} = 0.2679$ |

### Exceptions

None.

### Propagated Error

$A = X/(1 + X^2)$, $R = X/(\tan^{-1}(X)(1 + X^2))$

### Generated Error

| Primary Domain Error: | **MRE** | **RMSRE** |
|---|---|---|
| **Single Length:** | 0.53 ulp | 0.21 ulp |
| **Double Length:** | 1.27 ulp | 0.52 ulp |

### The Algorithm

1 If $|X| > 1.0$, set $Xwork = 1/|X|$, otherwise $Xwork = |X|$.

2 If $Xwork > 2-\sqrt{3}$, set $F = (Xwork*\sqrt{3} - 1)/(Xwork + \sqrt{3})$, otherwise $F = Xwork$.

3 Compute $Rwork = \arctan(F)$ with a floating-point rational approximation.

4 If $Xwork$ was reduced in (2), set $R = Pi/6 + Rwork$, otherwise $R = Rwork$.

5 If $X$ was reduced in (1), set $RESULT = Pi/2 - R$, otherwise $RESULT = R$.

6 Set the sign of the $RESULT$ according to the sign of the argument.

## Notes

1) For $|X| > ATmax$, $|\tan^{-1}(X)|$ is indistinguishable from $\pi/2$ in the floating-point format. For single-length, $ATmax = 1.68*10^7$, and for double-length $ATmax = 9*10^{15}$, approximately.

2) This function is numerically very stable, despite the complicated argument reduction. The worst errors occur just above $2-\surd 3$, but are no more than 1.8 ulp. 3) It is also very well behaved with respect to errors in the argument, i.e. the error amplification factors are always small.

4) The argument reduction scheme ensures that the identities $\tan^{-1}(X) = \pi/2 - \tan^{-1}(1/X)$, and $\tan^{-1}(X) = \pi/6 + \tan^{-1}((\surd 3*X-1)/(\surd 3 + X))$ are preserved.

## ATAN2
## DATAN2

```
REAL32 FUNCTION ATAN2 (VAL REAL32 X, Y)
REAL64 FUNCTION DATAN2 (VAL REAL64 X, Y)
```

These compute the angular co-ordinate $\tan^{-1}(Y/X)$ (in radians) of a point whose $X$ and $Y$ co-ordinates are given.

| | |
|---|---|
| **Domain:** | [–Inf, Inf] x [–Inf, Inf] |
| **Range:** | (–*Pi*, *Pi*] |
| **Primary Domain:** | See note 2. |

### Exceptions

(0, 0) and ($\pm$Inf,$\pm$Inf) give **undefined.NaN**.

### Propagated Error

$A = X(1 \pm Y)/(X^2 + Y^2)$, $R = X(1 \pm Y)/(\tan^{-1}(Y/X)(X^2 + Y^2))$ (See note 3)

### Generated Error

See note 2.

### The Algorithm

1 If $X$, the first argument, is zero, set the result to $\pm\,\pi/2$, according to the sign of $Y$, the second argument.

2 Otherwise set *Rwork*:= **ATAN** (*Y*/*X*) . Then if $Y < 0$ set *RESULT* = *Rwork* – *Pi*, otherwise set *RESULT* = *Pi* – *Rwork*.

**Notes**

1) This two-argument function is designed to perform rectangular-to-polar co-ordinate conversion.

2) See the notes for **ATAN** for the primary domain and estimates of the generated error.

3) The error amplification factors were derived on the assumption that the relative error in *Y* is $\pm$ that in *X*, otherwise there would be separate factors for *X* and *Y*. They are small except near the origin, where the polar co-ordinate system is singular.

SINH
DSINH

```
REAL32 FUNCTION SINH (VAL REAL32 X)
REAL64 FUNCTION DSINH (VAL REAL64 X)
```

These compute: sinh(*X*)

| | |
|---|---|
| **Domain:**[–*Hmax*, *Hmax*] | = [–89.4, 89.4]S, [–710.5, 710.5]D |
| **Range:** | (–Inf, Inf) |
| **Primary Domain:** | (–1.0, 1.0) |

**Exceptions**

$X < -Hmax$ gives –Inf, and $X > Hmax$ gives Inf.

**Propagated Error**

$A = X\cosh(X)$, $R = X\coth(X)$ (See note 3)

**Generated Error**

| | Primary Domain | | [1.0, *XBig*] (See note 2) | |
|---|---|---|---|---|
| | **MRE** | **RMSRE** | **MAE** | **RMSAE** |
| Single Length: | 0.89 ulp | 0.3 ulp | 0.98 ulp | 0.31 ulp |
| Double Length: | 1.3 ulp | 0.51 ulp | 1.0 ulp | 0.3 ulp |

**The Algorithm**

1 If $|X| > XBig$, set *Rwork*:= **EXP** ($|X|$ – ln(2)) .

2 If $XBig \geq |X| \geq 1.0$, set *temp*:= **EXP** ($|X|$) , and set *Rwork* = (*temp* – 1/*temp*)/2.

3 Otherwise compute *Rwork* = sinh(|*X*|) with a fixed-point rational approximation.

4 In all cases, set *RESULT* = $\pm$ *Rwork* according to the sign of *X*.

**Notes**

1) *Hmax* is the point at which sinh(*X*) becomes too large to be represented in the floating-point format.

2) *XBig* is the point at which $e^{-|X|}$ becomes insignificant compared with $e^{|X|}$, (in floating-point). For single-length it is 8.32, and for double-length it is 18.37.

3) This function is quite stable with respect to errors in the argument. Relative error is magnified near zero, but the absolute error is a better measure near the zero of the function and it is diminished there. For large arguments absolute errors are magnified, but since the function is itself large, relative error is a better criterion, and relative errors are not magnified unduly for any argument in the domain, although the output does become less reliable near the ends of the range.

COSH
DCOSH

```
REAL32 FUNCTION COSH (VAL REAL32 X)
REAL64 FUNCTION DCOSH (VAL REAL64 X)
```

These compute: cosh(*X*)

| | |
|---|---|
| **Domain:** [–*Hmax*, *Hmax*] | = [–89.4, 89.4]S, [–710.5, 710.5]D |
| **Range:** [1.0, Inf) | |
| **PrimaryDomain:** [–*XBig*, *XBig*] | = [–8.32, 8.32]S<br>= [–18.37, 18.37]D |

**Exceptions**

|*X*| > *Hmax* gives Inf.

**Propagated Error**

$A = X\,\sinh(X)$ ,  $R = X\,\tanh(X)$  (See note 3)

**Generated Error**

| Primary Domain Error: | **MRE** | **RMS** |
|---|---|---|
| **Single Length:** | 0.99 ulp | 0.3 ulp |
| **Double Length:** | 1.23 ulp | 0.3 ulp |

### The Algorithm

1 If $|X| > XBig$, set *result*:= `EXP (|X| – ln(2))`.

2 Otherwise, set *temp*:= `EXP (|X|)`, and set *result* = (*temp* + 1/*temp*)/2.

### Notes

1) *Hmax* is the point at which cosh($X$) becomes too large to be represented in the floating-point format.

2) *XBig* is the point at which $e^{-|X|}$ becomes insignificant compared with $e^{|X|}$ (in floating-point).

3) Errors in the argument are not seriously magnified by this function, although the output does become less reliable near the ends of the range.

`TANH`
`DTANH`

```
REAL32 FUNCTION TANH (VAL REAL32 X)
REAL64 FUNCTION DTANH (VAL REAL64 X)
```

These compute: tanh($X$)

| | |
|---|---|
| **Domain:** | [–Inf, Inf] |
| **Range:** | [–1.0, 1.0] |
| **Primary Domain:** | [–*Log*(3)/2, *Log*(3)/2] = [–0.549, 0.549] |

### Exceptions

None.

### Propagated Error

$A = X/\cosh^2(X)$, $R = X/\sinh(X)\cosh(X)$

### Generated Error

| Primary Domain Error: | **MRE** | **RMS** |
|---|---|---|
| **Single Length:** | 0.52 ulp | 0.2 ulp |
| **Double Length:** | 4.6 ulp | 2.6 ulp |

### The Algorithm

1 If $|X| > \ln(3)/2$, set *temp*:= `EXP (|X|/2)`. Then set *Rwork* = 1 – 2/(1+*temp*).

2 Otherwise compute *Rwork* = tanh($|X|$) with a floating-point rational approximation.

3 In both cases, set $RESULT = \pm Rwork$ according to the sign of $X$.

**Notes**

1) As a floating-point number, $\tanh(X)$ becomes indistinguishable from its asymptotic values of $\pm 1.0$ for $|X| > HTmax$, where $HTmax$ is 8.4 for single-length, and 19.06 for double-length. Thus the output of `TANH` is equal to $\pm 1.0$ for such $X$.

2) This function is very stable and well-behaved, and errors in the argument are always diminished by it.

**RAN**
**DRAN**

```
REAL32,INT32 FUNCTION RAN (VAL INT32 X)
REAL64,INT64 FUNCTION DRAN (VAL INT64 X)
```

These produce a pseudo-random sequence of integers, and a corresponding sequence of floating-point numbers between zero and one.

| | |
|---|---|
| **Domain:** | Integers (see note 1) |
| **Range:** | [0.0, 1.0] x Integers |

**Exceptions**

None.

**The Algorithm**

1 Produce the next integer in the sequence: $N_{k+1} = (aN_k + 1)_{mod\,M}$

2 Treat $N_{k+1}$ as a fixed-point fraction in [0,1), and convert it to floating point.

3 Output the floating point result and the new integer.

**Notes**

1) This function has two results, the first a real, and the second an integer (both 32 bits for single-length, and 64 bits for double-length). The integer is used as the argument for the next call to `RAN`, i.e. it 'carries' the pseudo-random linear congruential sequence $N_k$, and it should be kept in scope for as long as `RAN` is used. It should be initialized before the first call to `RAN` but not modified thereafter except by the function itself.

2) If the integer parameter is initialized to the same value, the same sequence (both floating-point and integer) will be produced. If a different sequence is required for each run of a program it should be initialized to some 'random' value, such as the output of a timer.

3) The integer parameter can be copied to another variable or used in expressions requiring random integers. The topmost bits are the most random. A random integer in the range [0,$L$] can conveniently be produced by taking the remainder by ($L$+1) of the integer parameter shifted right by one bit. If the shift is not done an integer in the range [–$L$,$L$] will be produced.

4) The modulus $M$ is $2^{32}$ for single-length and $2^{64}$ for double-length, and the multipliers, $a$, have been chosen so that all $M$ integers will be produced before the sequence repeats. However several different integers can produce the same floating-point value and so a floating-point output may be repeated, although the *sequence* of such will not be repeated until $M$ calls have been made.

5) The floating-point result is uniformly distributed over the output range, and the sequence passes various tests of randomness, such as the 'run test', the 'maximum of 5 test' and the 'spectral test'.

6) The double-length version is slower to execute, but 'more random' than the single-length version. If a highly-random sequence of single-length numbers is required, this could be produced by converting the output of DRAN to single-length. Conversely if only a relatively crude sequence of double-length numbers is required, RAN could be used for higher speed and its output converted to double-length.

## 1.5 Host file server library

**Library: `hostio.lib`**

The host file server library contains routines that are used to communicate with the host file server. The routines are independent of the host on which the server is running. Using routines from this library you can guarantee that programs will be portable across all implementations of the toolset.

Constant and protocol definitions for the hostio library, including error and return codes, are provided in the include file `hostio.inc`.

The result value from many of the routines in this library can take the value ≥ `spr.operation.failed` which is a server dependent failure result. It has been left open with the use of ≥ because future server implementations may give more information back via this byte.

### 1.5.1 Errors and the server run time library

The hostio routines use functions provided by the host file server. These are defined in Appendix C in the *Toolset Reference Manual*. The server is implemented in C and uses routines in a C run time library, some of which are implementation dependent.

In particular, the hostio routines do not check the validity of stream identifiers, and the consequences of specifying an incorrect streamid may differ from system to system. For example, some systems may return an error tag, some may return a text message. If you use only those stream ids returned by the hostio routines that open files (`so.open`, `so.open.temp`, and `so.popen.read`), invalid ids are unlikely to occur. It is also possible in rare circumstances for a program to fail altogether with an invalid streamid because of the way the C library is implemented on the system. This error can only occur if direct use of the library to perform the operation would produce the same error.

### 1.5.2 Inputting real numbers

Routines for inputting real numbers only accept numbers in the standard occam format for REAL numbers. Programs that allow other ways of specifying real numbers must convert to the occam format before presenting them to the library procedure.

For details of the occam syntax for real numbers see the *occam 2 Reference Manual*.

### 1.5.3 Procedure descriptions

In the procedure descriptions, `fs` is the channel *from* the host file server, and `ts` is the channel *to* the host file server. The `SP` protocol used by the host file server channels is defined in the include file `hostio.inc`. The hostio routines are divided into six groups: five groups that reflect function and use, and a sixth miscellaneous group. The five specific groups are:

- File access and management
- General host access
- Keyboard input
- Screen output
- File output.

Each group of routines is described in a separate section. Each section begins with a list of the routines in the group with their formal parameters. This is followed by a description of each routine in turn. **Note**: for those routines which write data to a stream (including the screen), if the data is not sent as an entire block then it cannot be guaranteed that the data arrives contiguously at its destination. This is because another process writing to the same destination may interleave its server request(s) with those of these routines.

### 1.5.4 File access

This group includes routines for managing file streams, for opening and closing files, and for reading and writing blocks of data.

| Procedure | Parameter Specifiers |
|---|---|
| `so.open` | `CHAN OF SP fs, ts, VAL []BYTE name, VAL BYTE type, mode, INT32 streamid, BYTE result` |
| `so.open.temp` | `CHAN OF SP fs, ts, VAL BYTE type, [so.temp.filename.length]BYTE filename, INT32 streamid, BYTE result` |
| `so.popen.read` | `CHAN OF SP fs, ts, VAL []BYTE filename, VAL []BYTE path.variable.name, VAL BYTE open.type, INT full.len, []BYTE full.name, INT32 streamid, BYTE result` |
| `so.close` | `CHAN OF SP fs, ts, VAL INT32 streamid, BYTE result` |
| `so.read` | `CHAN OF SP fs, ts, VAL INT32 streamid, INT length, []BYTE data` |
| `so.write` | `CHAN OF SP fs, ts, VAL INT32 streamid, VAL []BYTE data, INT length` |
| `so.gets` | `CHAN OF SP fs, ts, VAL INT32 streamid, INT length, []BYTE data, BYTE result` |
| `so.puts` | `CHAN OF SP fs, ts, VAL INT32 streamid, VAL []BYTE data, BYTE result` |
| `so.flush` | `CHAN OF SP fs, ts, VAL INT32 streamid, BYTE result` |
| `so.seek` | `CHAN OF SP fs, ts, VAL INT32 streamid, VAL INT32 offset, origin, BYTE result` |
| `so.tell` | `CHAN OF SP fs, ts, VAL INT32 streamid, INT32 position, BYTE result` |
| `so.eof` | `CHAN OF SP fs, ts, VAL INT32 streamid, BYTE result` |
| `so.ferror` | `CHAN OF SP fs, ts, VAL INT32 streamid, INT32 error.no, INT length, []BYTE message, BYTE result` |
| `so.remove` | `CHAN OF SP fs, ts, VAL []BYTE name, BYTE result` |
| `so.rename` | `CHAN OF SP fs, ts, VAL []BYTE oldname, newname, BYTE result` |
| `so.test.exists` | `CHAN OF SP fs, ts, VAL []BYTE filename, BOOL exists` |

## Procedure definitions

### so.open

```
PROC so.open  (CHAN OF SP fs, ts,
               VAL []BYTE name,
               VAL BYTE type, mode,
               INT32 streamid, BYTE result)
```

Opens the file given by **name** and returns a stream identifier **streamid** for all future operations on the file until it is closed. If **name** does not include a directory then the file is searched for in the current directory. File type is specified by **type** and the mode of opening by **mode**.

**type** can take the following values:

| | |
|---|---|
| spt.binary | File contains raw bytes only. |
| spt.text | File contains text records separated by newline sequences. |

**mode** can take the following values:

| | |
|---|---|
| spm.input | Open existing file for reading. |
| spm.output | Open new file, or truncate an existing one, for writing. |
| spm.append | Open a new file, or append to an existing one, for writing. |
| spm.existing.update | Open an existing file for update (reading and writing), starting at beginning of the file. |
| spm.new.update | Open new file, or truncate existing one, for update. |
| spm.append.update | Open new file, or append to an existing one, for update. |

**result** can take the following values:

| | |
|---|---|
| spr.ok | The open was successful. |
| spr.bad.name | Null file name supplied. |
| spr.bad.type | Invalid file type. |
| spr.bad.mode | Invalid open mode. |
| spr.bad.packet.size | File name too large (i.e.> **sp.max.openname.size**). |
| ≥ spr.operation.failed | If **result** ≥ **spr.operation.failed** then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

### so.open.temp

```
PROC so.open.temp
        (CHAN OF SP fs, ts,
         VAL BYTE type,
         [so.temp.filename.length]BYTE filename,
         INT32 streamid, BYTE result)
```

Opens a temporary file in `spm.new.update` mode. The first filename tried is `temp`00. If the file already exists the `nn` suffix on the name `temp`*nn* is incremented up to a maximum of 9999 until an unused number is found. If the number exceeds 2 digits the last character of `temp` is overwritten. For example: if the number exceeds 99 the `p` is overwritten, as in `tem999`; if the number exceeds 999, the `m` is overwritten, as in `te9999`. File type can be `spt.binary` or `spt.text`, as with `so.open`. The name of the file actually opened is returned in filename. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The open was successful. |
| `spr.notok` | There are already 10,000 temporary files. |
| `spr.bad.type` | Invalid file type specified. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

### so.popen.read

```
PROC so.popen.read
              (CHAN OF SP fs, ts,
               VAL []BYTE filename,
               VAL []BYTE path.variable.name,
               VAL BYTE open.type,
               INT full.len, []BYTE full.name,
               INT32 streamid, BYTE result)
```

As for `so.open`, but if the file is not found and the filename does not include a directory, the routine uses the directory path string associated with the host environment variable, given in `path.variable.name`, and performs a search in each directory in the path in turn. This corresponds to the searching rules used by the toolset, using the environment variable ISEARCH, see section 3.10.2 in the *occam 2 Toolset User Guide*.

File type can be `spt.binary` or `spt.text`, as with `so.open`. The mode of opening is always `spm.input`.

The name of the file opened is returned in `full.name`, and the length of the file name is returned in `full.len`. If no file is opened, `full.len` and `full.name` are undefined, and the result will not be `spr.ok`.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The open was successful. |
| `spr.bad.name` | Null name supplied. |
| `spr.bad.type` | Invalid file type specified. |
| `spr.bad.packet.size` | File name is too large (i.e. > `sp.max.openname.size`) or `path.variable.name` is too large (i.e.> `sp.max.getenvname.size`). |
| `spr.buffer.overflow` | The environment string referenced by `path.variable.name` is longer than 507 characters. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*). |

`so.close`

```
PROC so.close (CHAN OF SP fs, ts,
               VAL INT32 streamid,
               BYTE result)
```

Closes the stream identified by streamid. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The close was successful. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.read`

```
PROC so.read  (CHAN OF SP fs, ts,
               VAL INT32 streamid,
               INT length, []BYTE data)
```

Reads a block of bytes from the specified stream up to a maximum given by the size of the array `data`. If `length` returned is not the same as the size of `data` then the end of the file has been reached or an error has occurred.

**Note:** `so.read` reads in multiples of the packet size defined by `sp.max.readbuffer.size`. For greatest efficiency, read requests should be made in multiples of this size.

### so.write

```
PROC so.write (CHAN OF SP fs, ts,
               VAL INT32 streamid,
               VAL []BYTE data,
               INT length)
```

Writes a block of data to the specified stream. If `length` is less than the size of `data` then an error has occurred.

**Note:** `so.write` writes in multiples of the packet size defined by `sp.max.writebuffer.size`. For greatest efficiency, write requests should be made in multiples of this size.

### so.gets

```
PROC so.gets (CHAN OF SP fs, ts,
              VAL INT32 streamid,
              INT length, []BYTE data,
              BYTE result)
```

Reads a line from the specified input stream. Characters are read until a newline sequence is found, the end of the file is reached, or `sp.max.readbuffer.size` characters have been read. The characters read are in the first `length` bytes of `data`. The newline sequence is not included in the returned array. If the read fails then either the end of file has been reached or an error has occurred.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The read was successful. |
| `spr.bad.packet.size` | Data is too large (> `sp.max.readbuffer.size`). |
| `spr.buffer.overflow` | The line was larger than the buffer `data` and has been truncated to fit. |
| ≥ `spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

## so.puts

```
PROC so.puts (CHAN OF SP fs, ts,
              VAL INT32 streamid,
              VAL []BYTE data, BYTE result)
```

Writes a line to the specified output stream. A newline sequence is added to the end of the line. The size of **data** must be less than or equal to the hostio constant **sp.max.writebuffer.size**.

The result returned can take any of the following values:

| | |
|---|---|
| **spr.ok** | The write was successful. |
| **spr.bad.packet.size** | **SIZE data** is too large ( > **sp.max.writebuffer.size**). |
| ≥ **spr.operation.failed** | If **result** ≥ **spr.operation.failed** then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

## so.flush

```
PROC so.flush (CHAN OF SP fs, ts,
               VAL INT32 streamid,
               BYTE result)
```

Flushes the specified output stream. All internally buffered data is written to the stream. Write and put operations that are directed to standard output are flushed automatically. The stream remains open.

The result returned can take any of the following values:

| | |
|---|---|
| **spr.ok** | The flush was successful. |
| ≥ **spr.operation.failed** | If **result** ≥ **spr.operation.failed** then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.seek`

```
PROC so.seek (CHAN OF SP fs, ts,
              VAL INT32 streamid,
              VAL INT32 offset, origin,
              BYTE result)
```

Sets the file position for the specified stream. A subsequent read or write will access data at the new position.

For a binary file the new position will be `offset` bytes from the position defined by `origin`. For a text file `offset` must be zero or a value returned by `so.tell`, in which case `origin` must be `spo.start`.

`origin` may take the following values:

| | |
|---|---|
| `spo.start` | The start of the file. |
| `spo.current` | The current position in the file. |
| `spo.end` | The end of the file. |

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.bad.origin` | Invalid origin. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.tell`

```
PROC so.tell (CHAN OF SP fs, ts,
              VAL INT32 streamid,
              INT32 position, BYTE result)
```

Returns the current file position for the specified stream.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.eof`

```
PROC so.eof (CHAN OF SP fs, ts,
             VAL INT32 streamid, BYTE result)
```

Tests whether the specified stream has reached the end of a file. The end of file is reached when a read operation attempts to read past the end of file.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | End of file has been reached. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) This result will also be obtained if `eof` has not been reached. |

`so.ferror`

```
PROC so.ferror (CHAN OF SP fs, ts,
                VAL INT32 streamid,
                INT32 error.no, INT length,
                []BYTE message, BYTE result)
```

Indicates whether an error has occurred on the specified stream. The integer `error.no` is a host defined error number. The returned message is in the first `length` bytes of `message`. `length` will be zero if no message can be provided. If the returned message is longer than 503 bytes then it is truncated to this size.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | An error has occurred on the specified stream. |
| `spr.buffer.overflow` | An error has occurred but the message is too large for `message` and has been truncated to fit. |
| ≥ `spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) This result will also be obtained if no error has occurred on the specified stream. |

`so.remove`

```
PROC so.remove (CHAN OF SP fs, ts,
                VAL []BYTE name, BYTE result)
```

Deletes the specified file.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The delete was successful. |
| `spr.bad.name` | Null name supplied. |
| `spr.bad.packet.size` | `SIZE name` is too large ( > `sp.max.removename.size`). |
| ≥ `spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

**so.rename**

```
PROC so.rename (CHAN OF SP fs, ts,
                VAL []BYTE oldname, newname,
                BYTE result)
```

Renames the specified file.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.bad.name` | Null name supplied. |
| `spr.bad.packet.size` | File names are too large ((`SIZE oldname + SIZE newname`) > `sp.max.renamename.size`). |
| ≥ `spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

**so.test.exists**

```
PROC so.test.exists (CHAN OF SP fs, ts,
                     VAL []BYTE filename,
                     BOOL exists)
```

Tests if the specified file exists. The value of `exists` is `TRUE` if the file exists, otherwise it is `FALSE`.

### 1.5.5 General host access

This group contains routines to access the host computer for system information and services.

| Procedure | Parameter Specifiers |
|---|---|
| `so.commandline` | `CHAN OF SP fs, ts,`<br>`VAL BYTE all, INT length,`<br>`[]BYTE string, BYTE result` |
| `so.parse.command.line` | `CHAN OF SP fs, ts,`<br>`VAL [][]BYTE option.strings,`<br>`VAL []INT`<br>`option.parameters.required,`<br>`[]BOOL option.exists,`<br>`[][2]INT option.parameters,`<br>`INT error.len, []BYTE line` |
| `so.getenv` | `CHAN OF SP fs, ts,`<br>`VAL []BYTE name, INT length,`<br>`[]BYTE value, BYTE result` |
| `so.system` | `CHAN OF SP fs, ts,`<br>`VAL []BYTE command,`<br>`INT32 status, BYTE result` |
| `so.exit` | `CHAN OF SP fs, ts,`<br>`VAL INT32 status` |
| `so.core` | `CHAN OF SP fs, ts`<br>`VAL INT32 offset,`<br>`INT bytes.read,`<br>`[]BYTE data, BYTE result` |
| `so.version` | `CHAN OF SP fs, ts,`<br>`BYTE version, host, os, board` |

#### Procedure definitions

`so.commandline`

```
PROC so.commandline (CHAN OF SP fs, ts,
                     VAL BYTE all, INT length,
                     []BYTE string, BYTE result)
```

Returns the command line passed to the server when it was invoked. If `all` has the value `sp.short.commandline` then all valid server options and their arguments are stripped from the command line, as is the server command name. If `all` is `sp.whole.commandline` then the command line is returned exactly as it was invoked. The returned command line is in the first `length` bytes of `string`. If the command line string is longer than 507 bytes then it is truncated to this size. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.buffer.overflow` | Command line too long for `string` and has been truncated to fit. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.parse.command.line`

```
PROC so.parse.command.line
          (CHAN OF SP fs, ts,
           VAL [][]BYTE option.strings,
           VAL []INT option.parameters.required,
           []BOOL option.exists,
           [][2]INT option.parameters,
           INT error.len, []BYTE line)
```

This procedure reads the server command line and parses it for specified options and associated parameters.

The parameter `option.strings` contains a list of all the possible options and must be in upper case. Options may be any length up to 256 bytes and when entered on the command line may be either upper or lower case. Because all of the strings in `option.strings` must be the same length, trailing spaces should be used to pad.

To read a parameter that has no preceding option (such as a file name) then the first option string should be empty (contain only spaces). For example, consider a program to be supplied with a file name, and any of three options 'A', 'B' and 'C'. The array `option.strings` would look like this:

```
VAL option.strings IS [" ", "A", "B", "C"]:
```

The parameter `option.parameters.required` indicates if the corresponding option (in `option.strings`) requires a parameter. The values it may take are:

| | |
|---|---|
| `spopt.never` | Never takes a parameter. |
| `spopt.maybe` | Optionally takes a parameter. |
| `spopt.always` | Must take a parameter. |

Continuing the above example, if the file name must be supplied and none of the options take parameters, except for 'C', which may or may not have a parameter, then `option.parameters.required` would look like this:

```
  VAL option.parameters.required IS
    [spopt.always, spopt.never,
     spopt.never, spopt.maybe]:
```

If an option was present on the command line the corresponding element of `option.exists` is set to `TRUE`, otherwise it is set to `FALSE`.

If an option was followed by a parameter then the position in the array `line` where the parameter starts and the length of the parameter are given by the first and second elements respectively in the corresponding element in `option.parameters`.

If an error occurs whilst the command line is being parsed then `error.len` will be greater than zero and `line` will contain an error message of the given length. If no error occurs then `line` will contain the command line as supplied by the host file server.

Most of the possible error messages are self-explanatory, however, it is worth noting the meaning of the error '**Command line error: called incorrectly**'.

This error means that either:

- `option.strings` was null, or
- `SIZE option.exists`, `SIZE option.parameters` or `SIZE option.parameters.required` does not equal `SIZE option.strings`.

`so.getenv`

```
PROC so.getenv (CHAN OF SP fs, ts,
                VAL []BYTE name,
                INT length, []BYTE value,
                BYTE result)
```

Returns the string defined for the host environment variable `name`. The returned string is in the first `length` bytes of `value`. If `name` is not defined on the system `result` takes the value ≥ `spr.operation.failed`. If the environment variable's string is longer than 507 bytes then it is truncated to this size.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.bad.name` | The specified name is a null string. |
| `spr.bad.packet.size` | `SIZE name` is too large ( > `sp.max.getenvname.size`). |
| `spr.buffer.overflow` | Environment string too large for value but has been truncated to fit. |
| ≥ `spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

## `so.system`

```
PROC so.system (CHAN OF SP fs, ts,
                VAL []BYTE command,
                INT32 status, BYTE result)
```

Passes the string `command` to the host command processor for execution. If the command string is of zero length `result` takes the value `spr.ok` if there is a host command processor, otherwise an error is returned.

If `command` is non-zero in length then `status` contains the host-specified value of the command, otherwise it is undefined.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | Host command processor exists. |
| `spr.bad.packet.size` | The array `command` is too large (> `sp.max.systemcommand.size`). |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

## `so.exit`

```
PROC so.exit (CHAN OF SP fs, ts,
              VAL INT32 status)
```

Terminates the server, which returns the value of `status` to its caller. If `status` has the special value `sps.success` then the server will terminate with a host specific 'success' result. If `status` has the special value `sps.failure` then the server will terminate with a host specific 'failure' result.

## `so.core`

```
PROC so.core (CHAN OF SP fs, ts,
              VAL INT32 offset, INT bytes.read,
              []BYTE data, BYTE result)
```

Returns the contents of the root transputer's memory as peeked from the transputer when `iserver` is invoked with the analyze ('`SA`') option. The start of the memory segment is given by `offset` which is an offset from the base of memory (and is therefore positive). The number of bytes to be read is given by the size of the `data` vector. The number of bytes actually read into `data` is given by `bytes.read`. An error is returned if `offset` is larger than the total amount of peeked memory.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.bad.packet.size` | The array `data` is too large (> `sp.max.corerequest.size`). |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

This procedure can also be used to determine whether the memory was peeked (whether the server was invoked with the '`SA`' option), by specifying a size of zero for `data` and `offset`. If the result returned is `spr.ok` the memory was peeked.

## so.version

```
PROC so.version (CHAN OF SP fs, ts,
                 BYTE version, host, os, board)
```

Returns version information about the server and the host on which it is running. A value of zero for any of the items indicates that the information is unavailable.

The version of the server is given by `version`. The value should be divided by ten to yield the true version number. For example, a value of 15 means version 1.5.

The host machine type is given by `host`, and can take any of the following values:

| | |
|---|---|
| `sph.unknown` | unknown host type |
| `sph.PC` | IBM PC |
| `sph.S370` | IBM 370 Architecture |
| `sph.NECPC` | NEC PC |
| `sph.VAX` | DEC VAX |
| `sph.SUN3` | Sun Microsystems Sun 3 |
| `sph.BOX.SUN4` | Sun Microsystems Sun 4 |
| `sph.BOX.SUN386` | Sun Microsystems Sun 386i |
| `sph.BOX.APOLLO` | Apollo |
| `sph.BOX.ATARI` | Atari ST or TT |

Values up to 127 are reserved for use by INMOS.

The host operating system is given by `os`, and can take any of the following values:

| | |
|---|---|
| `spo.unknown` | unknown OS type |
| `spo.DOS` | DOS |
| `spo.HELIOS` | HELIOS |
| `spo.VMS` | VMS |
| `spo.SUNOS` | SunOS |
| `spo.CMS` | CMS |
| `spo.TOS` | TOS |

Values up to 127 are reserved for use by INMOS.

The interface board type is given by **`board`**, and can take any of the following values:

| | |
|---|---|
| `spb.unknown` | unknown board type |
| `spb.B004` | IMS B004 |
| `spb.B008` | IMS B008 |
| `spb.B010` | IMS B010 |
| `spb.B011` | IMS B011 |
| `spb.B014` | IMS B014 |
| `spb.B015` | IMS B015 |
| `spb.B016` | IMS B016 |
| `spb.DRX11` | DRX-11 |
| `spb.IBMCAT` | CAT |
| `spb.QT0` | Caplin QT0 |
| `spb.UDPLINK` | UDP link |
| `spb.TCPLINK` | TCP link |
| `spb.ACSILA` | ACSILA |

Values up to 127 are reserved for use by INMOS.

### 1.5.6 Keyboard input

| Procedure | Parameter Specifiers |
|---|---|
| `so.pollkey` | `CHAN OF SP fs, ts,` `BYTE key, result` |
| `so.getkey` | `CHAN OF SP fs, ts,` `BYTE key, result` |
| `so.read.line` | `CHAN OF SP fs, ts,` `INT len, []BYTE line,` `BYTE result` |
| `so.read.echo.line` | `CHAN OF SP fs, ts,` `INT len, []BYTE line,` `BYTE result` |
| `so.ask` | `CHAN OF SP fs, ts,` `VAL []BYTE prompt, replies,` `VAL BOOL display.possible.replies,` `VAL BOOL echo.reply,` `INT reply.number` |
| `so.read.echo.int` | `CHAN OF SP fs, ts, INT n,` `BOOL error` |
| `so.read.echo.int32` | `CHAN OF SP fs, ts, INT32 n,` `BOOL error` |
| `so.read.echo.int64` | `CHAN OF SP fs, ts, INT64 n,` `BOOL error` |
| `so.read.echo.hex.int` | `CHAN OF SP fs, ts, INT n,` `BOOL error` |
| `so.read.echo.hex.int32` | `CHAN OF SP fs, ts, INT32 n,` `BOOL error` |
| `so.read.echo.hex.int64` | `CHAN OF SP fs, ts, INT64 n,` `BOOL error` |
| `so.read.echo.any.int` | `CHAN OF SP fs, ts, INT n,` `BOOL error` |
| `so.read.echo.real32` | `CHAN OF SP fs, ts, REAL32 n,` `BOOL error` |
| `so.read.echo.real64` | `CHAN OF SP fs, ts, REAL64 n,` `BOOL error` |

## Procedure definitions

### so.pollkey

```
PROC so.pollkey (CHAN OF SP fs, ts,
                 BYTE key, result)
```

Reads a single character from the keyboard. If no key is available then it returns immediately with ≥ **spr.operation.failed**. The key is not echoed on the screen.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | A key was available and has been returned in **key**. |
| ≥`spr.operation.failed` | If `result`≥`spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

### so.getkey

```
PROC so.getkey (CHAN OF SP fs, ts,
                BYTE key, result)
```

As `so.pollkey` but waits for a key if none is available.

### so.read.line

```
PROC so.read.line (CHAN OF SP fs, ts, INT len,
                   []BYTE line, BYTE result)
```

Reads a line of text from the keyboard, without echoing it on the screen. The characters read are in the first `len` bytes of `line`. The line is read until 'RETURN' is pressed at the keyboard. The line is truncated if `line` is not large enough. A newline or carriage return is not included in `line`.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The read was successful. |
| ≥`spr.operation.failed` | If `result`≥`spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.read.echo.line`

```
PROC so.read.echo.line (CHAN OF SP fs, ts,
                        INT len, []BYTE line,
                        BYTE result)
```

As `so.read.line`, but user input (except newline or carriage return) is echoed on the screen.

`so.ask`

```
PROC so.ask (CHAN OF SP fs, ts,
             VAL []BYTE prompt, replies,
             VAL BOOL display.possible.replies,
             VAL BOOL echo.reply,
             INT reply.number)
```

Prompts on the screen for a user response on the keyboard. The prompt is specified by the string `prompt`, and the list of permitted relies by the string `replies`. Only single character responses are permitted, and alphabetic characters are *not* case sensitive. For example if the permitted responses are 'Y', 'N' and 'Q' then the `replies` string would contain the characters 'YNQ', and 'y', 'n' and 'q' would also be accepted. `reply.number` indicates which response was typed, numbered from zero. ' ? ' is automatically output at the end of the prompt.

If `display.possible.replies` is `TRUE` the permitted replies are displayed on the screen. If `echo.reply` is `TRUE` the user's response is displayed.

The procedure will not return until a valid response has been typed.

`so.read.echo.int`

```
PROC so.read.echo.int (CHAN OF SP fs, ts, INT n,
                       BOOL error)
```

Reads a decimal integer typed at the keyboard and displays it on the screen. The number must be terminated by 'RETURN'. The boolean `error` is set to `TRUE` if an invalid integer is typed, `FALSE` otherwise.

`so.read.echo.int32`

```
PROC so.read.echo.int32 (CHAN OF SP fs, ts,
                         INT32 n, BOOL error)
```

As `so.read.echo.int` but reads 32-bit numbers.

so.read.echo.int64

```
PROC so.read.echo.int64 (CHAN OF SP fs, ts,
                         INT64 n, BOOL error)
```

As so.read.echo.int but reads 64-bit numbers.

so.read.echo.hex.int

```
PROC so.read.echo.hex.int (CHAN OF SP fs, ts,
                           INT n, BOOL error)
```

As so.read.echo.int but reads a number in hexadecimal format. The number may be in lower or upper case but must be prefixed with either '#', or '$' which directly indicates a hexadecimal number, or '%', which means add MOSTNEG INT to the given hex (using modulo arithmetic). For example, on a 32-bit transputer %70 is interpreted as #80000070, and on a 16-bit transputer as #8070. This is useful when specifying transputer addresses, which are signed and start at MOSTNEG INT.

so.read.echo.hex.int32

```
PROC so.read.echo.hex.int32 (CHAN OF SP fs, ts,
                             INT32 n, BOOL error)
```

As so.read.echo.hex.int but reads 32-bit numbers.

so.read.echo.hex.int64

```
PROC so.read.echo.hex.int64 (CHAN OF SP fs, ts,
                             INT64 n, BOOL error)
```

As so.read.echo.hex.int but reads 64-bit numbers.

so.read.echo.any.int

```
PROC so.read.echo.any.int (CHAN OF SP fs, ts,
                           INT n, BOOL error)
```

As so.read.echo.int but accepts numbers in either decimal or hexadecimal format. Hexadecimal numbers may be lower or upper case but must be prefixed with either '#' or '$' which specifies the number directly, or '%', which means add MOSTNEG INT to the given hex (using modulo arithmetic). For example, on a 32-bit transputer %70 is interpreted as #80000070, and on a 16-bit transputer as #8070. This is useful when specifying transputer addresses, which are signed and start at MOSTNEG INT.

`so.read.echo.real32`

```
PROC so.read.echo.real32 (CHAN OF SP fs, ts,
                          REAL32 n, BOOL error)
```

Reads a real number typed at the keyboard and displays it on the screen. The number must conform to occam syntax and be terminated by 'RETURN'. The boolean variable `error` is set to `TRUE` if an invalid number is typed, `FALSE` otherwise.

`so.read.echo.real64`

```
PROC so.read.echo.real64 (CHAN OF SP fs, ts,
                          REAL64 n, BOOL error)
```

As `so.read.echo.real32` but for 64-bit real numbers.

### 1.5.7 Screen output

| Procedure | Parameter Specifiers |
|---|---|
| `so.write.char` | `CHAN OF SP fs, ts,` `VAL BYTE char` |
| `so.write.nl` | `CHAN OF SP fs, ts,` |
| `so.write.string` | `CHAN OF SP fs, ts,` `VAL []BYTE string` |
| `so.write.string.nl` | `CHAN OF SP fs, ts,` `VAL []BYTE string` |
| `so.write.int` | `CHAN OF SP fs, ts,` `VAL INT n, width` |
| `so.write.int32` | `CHAN OF SP fs, ts,` `VAL INT32 n, VAL INT width` |
| `so.write.int64` | `CHAN OF SP fs, ts,` `VAL INT64 n, VAL INT width` |
| `so.write.hex.int` | `CHAN OF SP fs, ts,` `VAL INT n, width` |
| `so.write.hex.int32` | `CHAN OF SP fs, ts,` `VAL INT32 n, VAL INT width` |
| `so.write.hex.int64` | `CHAN OF SP fs, ts,` `VAL INT64 n, VAL INT width` |
| `so.write.real32` | `CHAN OF SP fs, ts,` `VAL REAL32 r, VAL INT Ip, Dp` |
| `so.write.real.64` | `CHAN OF SP fs, ts,` `VAL REAL64 r, VAL INT Ip, Dp` |

## Procedure definitions

### so.write.char

```
PROC so.write.char (CHAN OF SP fs, ts,
                    VAL BYTE char)
```

Writes the single byte `char` to the screen.

### so.write.nl

```
PROC so.write.nl (CHAN OF SP fs, ts)
```

Writes a newline sequence to the screen.

### so.write.string

```
PROC so.write.string (CHAN OF SP fs, ts,
                      VAL []BYTE string)
```

Writes the string `string` to the screen.

### so.write.string.nl

```
PROC so.write.string.nl (CHAN OF SP fs, ts,
                         VAL []BYTE string)
```

As `so.write.string`, but appends a newline sequence to the end of the string.

### so.write.int

```
PROC so.write.int (CHAN OF SP fs, ts,
                   VAL INT n, width)
```

Writes the value `n` (of type `INT`) to the screen as decimal ASCII digits, padded out with leading spaces and an optional sign to the specified field width, `width`. If the field width is too small for the number it is widened as necessary; a zero value for `width` specifies minimum width. A negative value for `width` is an error.

### so.write.int32

```
PROC so.write.int32 (CHAN OF SP fs, ts,
                     VAL INT32 n, VAL INT width)
```

As `so.write.int` but for 32-bit integers.

### so.write.int64

```
PROC so.write.int64 (CHAN OF SP fs, ts,
                     VAL INT64 n, VAL INT width)
```

As `so.write.int` but for 64-bit integers.

`so.write.hex.int`

```
PROC so.write.hex.int (CHAN OF SP fs, ts,
                       VAL INT n, width)
```

Writes the value `n` (of type `INT`) to the screen as hexadecimal ASCII digits, preceded by the '`#`' character. The number of characters printed is `width + 1`. If `width` is larger than the size of the number then the number is padded with leading '`0`'s or '`F`'s as appropriate. If `width` is smaller than the size of the number, the number is truncated, from the left, to `width` digits. A negative value for `width` is an error.

`so.write.hex.int32`

```
PROC so.write.hex.int64 (CHAN OF SP fs, ts,
                         VAL INT32 n,
                         VAL INT width)
```

As `so.write.hex.int` but for 32-bit integers.

`so.write.hex.int64`

```
PROC so.write.hex.int64 (CHAN OF SP fs, ts,
                         VAL INT64 n,
                         VAL INT width)
```

As `so.write.hex.int` but for 64-bit integers.

`so.write.real32`

```
PROC so.write.real32 (CHAN OF SP fs, ts,
                      VAL REAL32 r,
                      VAL INT Ip, Dp)
```

Writes the value `r` (of type `REAL32`) to the screen as ASCII characters formatted using `Ip` and `Dp` as described under `REAL32TOSTRING` (see section 1.8).

**Note**: Due to fixed size internal buffers, this procedure will be invalid if the string representing the real number is longer than 24 characters. If this is a problem, it is suggested you write your own procedure to perform this function. The procedure should include a buffer set to the required size, a call to `REAL32TOSTRING`, followed by a call to `so.write`.

`so.write.real64`

```
PROC so.write.real64 (CHAN OF SP fs, ts,
                      VAL REAL64 r,
                      VAL INT Ip, Dp)
```

As `so.write.real32` but for 64-bit real numbers. The formatting variables `Ip` and `Dp` are described under `REAL32TOSTRING` (see section 1.8).

**Note** : Due to fixed size internal buffers, this procedure will be invalid if the string representing the real number is longer than 30 characters. If this is a problem, it is suggested you write your own procedure to perform this function. The procedure should include a buffer set to the required size, a call to `REAL64TOSTRING`, followed by a call to `so.write`.

### 1.5.8 File output

These routines write characters and strings to a specified stream, usually a file. The result returned can take the values `spr.ok`, `spr.notok` or, very rarely, ≥ `spr.operation.failed`.

| Procedure | Parameter Specifiers |
|---|---|
| `so.fwrite.char` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid,`<br>`VAL BYTE char, BYTE result` |
| `so.fwrite.nl` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid, BYTE result` |
| `so.fwrite.string` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid,`<br>`VAL []BYTE string, BYTE result` |
| `so.fwrite.string.nl` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid,`<br>`VAL []BYTE string,`<br>`BYTE result` |
| `so.fwrite.int` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid,`<br>`VAL INT n, width, BYTE result` |
| `so.fwrite.int32` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid, n,`<br>`VAL INT width,`<br>`BYTE result` |
| `so.fwrite.int64` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid,`<br>`VAL INT64 n, VAL INT width,`<br>`BYTE result` |
| `so.fwrite.hex.int` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid,`<br>`VAL INT n, width, BYTE result` |
| `so.fwrite.hex.int32` | `CHAN OF SP fs, ts,`<br>`VAL INT32 streamid, n`<br>`VAL INT width, BYTE result` |

| Procedure | Parameter Specifiers |
|---|---|
| `so.fwrite.hex.int64` | `CHAN OF SP fs, ts,` `VAL INT32 streamid,` `VAL INT64 n, VAL INT width,` `BYTE result` |
| `so.fwrite.real32` | `CHAN OF SP fs, ts,` `VAL INT32 streamid,` `VAL REAL32 r, VAL INT Ip, Dp,` `BYTE result` |
| `so.fwrite.real64` | `CHAN OF SP fs, ts,` `VAL INT32 streamid,` `VAL REAL64 r, VAL INT Ip, Dp,` `BYTE result` |

**Procedure definitions**

`so.fwrite.char`

```
PROC so.fwrite.char (CHAN OF SP fs, ts,
                     VAL INT32 streamid,
                     VAL BYTE char,
                     BYTE result)
```

Writes a single character to the specified stream. The result `spr.notok` will be returned if the character is not written.

`so.fwrite.nl`

```
PROC so.fwrite.nl (CHAN OF SP fs, ts,
                   VAL INT32 streamid,
                   BYTE result)
```

Writes a newline sequence to the specified stream.

If `result` takes a value ≥ `spr.operation.failed` then this denotes a server returned failure, details of which are documented in in section C.2 of the *Toolset Reference Manual.*

`so.fwrite.string`

```
PROC so.fwrite.string (CHAN OF SP fs, ts,
                       VAL INT32 streamid,
                       VAL []BYTE string,
                       BYTE result)
```

Writes a string to the specified stream. The result `spr.notok` will be returned if not all the characters are written.

`so.fwrite.string.nl`

```
PROC so.fwrite.string.nl (CHAN OF SP fs, ts,
                          VAL INT32 streamid,
                          VAL []BYTE string,
                          BYTE result)
```

As `so.fwrite.string`, but appends a newline sequence to the end of the string.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.notok` | Not all of the characters were written. |
| ≥`spr.operation.failed` | If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.fwrite.int`

```
PROC so.fwrite.int (CHAN OF SP fs, ts,
                    VAL INT32 streamid,
                    VAL INT n, width,
                    BYTE result)
```

Writes the value `n` (of type `INT`) to the specified stream as decimal ASCII digits, padded out with leading spaces and an optional sign to the specified field width, `width`. If the field width is too small for the number it is widened as necessary; a zero value for `width` specifies minimum width. A negative value for `width` is an error.

The result `spr.notok` will be returned if not all of the digits are written.

`so.fwrite.int32`

```
PROC so.fwrite.int32 (CHAN OF SP fs, ts,
                      VAL INT32 streamid, n,
                      VAL INT width,
                      BYTE result)
```

As `so.fwrite.int` but for 32-bit integers.

`so.fwrite.int64`

```
PROC so.fwrite.int64 (CHAN OF SP fs, ts,
                      VAL INT32 streamid,
                      VAL INT64 n, VAL INT width,
                      BYTE result)
```

As `so.fwrite.int` but for 64-bit integers.

`so.fwrite.hex.int`

```
PROC so.fwrite.hex.int (CHAN OF SP fs, ts,
                        VAL INT32 streamid,
                        VAL INT n, width,
                        BYTE result)
```

Writes the value `n` (of type `INT`) to the specified stream as hexadecimal ASCII digits preceded by the '`#`' character. The number of characters printed is `width + 1`. If `width` is larger than the size of the number then the number is padded with leading '`0`'s or '`F`'s as appropriate. If `width` is smaller than the size of the number, then the number is truncated, from the left, to `width` digits. A negative value for `width` is an error.

The result `spr.notok` will be returned if not all the characters are written.

`so.fwrite.hex.int32`

```
PROC so.fwrite.hex.int32 (CHAN OF SP fs, ts,
                          VAL INT32 streamid, n
                          VAL INT width,
                          BYTE result)
```

As `so.fwrite.hex.int` but for 32-bit integers.

`so.fwrite.hex.int64`

```
PROC so.fwrite.hex.int64 (CHAN OF SP fs, ts,
                          VAL INT32 streamid,
                          VAL INT64 n,
                          VAL INT width,
                          BYTE result)
```

As `so.fwrite.hex.int` but for 64-bit integers.

`so.fwrite.real32`

```
PROC so.fwrite.real32 (CHAN OF SP fs, ts,
                       VAL INT32 streamid,
                       VAL REAL32 r,
                       VAL INT Ip, Dp,
                       BYTE result)
```

Writes the value `r` (of type `REAL32`) to the specified stream as ASCII characters formatted using `Ip` and `Dp` as described under `REAL32TOSTRING` (see section 1.8).

The result `spr.notok` will be returned if not all the characters are written.

**Note**: Due to fixed size internal buffers, this procedure will be invalid if the string representing the real number is longer than 24 characters. If this is a problem, it is suggested you write your own procedure to perform this function. The procedure should include a buffer set to the required size, a call to `REAL32TOSTRING`, followed by a call to `so.write`.

`so.fwrite.real64`

```
PROC so.fwrite.real64 (CHAN OF SP fs, ts,
                       VAL INT32 streamid,
                       VAL REAL64 r,
                       VAL INT Ip, Dp,
                       BYTE result)
```

As `so.fwrite.real32` but for 64-bit real numbers. The formatting variables `Ip` and `Dp` are described under `REAL32TOSTRING` (see section 1.8).

**Note** : Due to fixed size internal buffers, this procedure will be invalid if the string representing the real number is longer than 30 characters. If this is a problem, it is suggested you write your own procedure to perform this function. The procedure should include a buffer set to the required size, a call to `REAL64TOSTRING`, followed by a call to `so.write`.

### 1.5.9 Miscellaneous

This miscellaneous group includes procedures for:

- Time and date processing
- Buffering and multiplexing

**Time processing**

| Procedure | Parameter Specifiers |
|---|---|
| `so.time` | `CHAN OF SP fs, ts,` `INT32 localtime, UTCtime` |
| `so.time.to.date` | `VAL INT32 input.time,` `[so.date.len]INT date` |
| `so.date.to.ascii` | `VAL [so.date.len]INT date,` `VAL BOOL long.years,` `VAL BOOL days.first,` `[so.time.string.len]BYTE string` |
| `so.time.to.ascii` | `VAL INT32 time,` `VAL BOOL long.years,` `VAL BOOL days.first` `[so.time.string.len]BYTE string` |
| `so.today.date` | `CHAN OF SP fs, ts,` `[so.date.len]INT date` |
| `so.today.ascii` | `CHAN OF SP fs, ts,` `VAL BOOL long.years,` `VAL BOOL days.first,` `[so.time.string.len]BYTE string` |

`so.time`

```
PROC so.time (CHAN OF SP fs, ts,
              INT32 localtime, UTCtime)
```

Returns the local time and Coordinated Universal Time. Both times are expressed as the number of seconds that have elapsed since midnight on 1st January, 1970. If UTC time is unavailable then it will have a value of zero. The times are given as unsigned `INT32`s.

`so.time.to.date`

```
PROC so.time.to.date (VAL INT32 input.time,
                      [so.date.len]INT date)
```

Converts time (as supplied by `so.time`) to six integers, stored in the `date` array. The elements of the array are as follows:

| Element of array | Data |
|---|---|
| 0 | Seconds past the minute |
| 1 | Minutes past the hour |
| 2 | The hour (24 hour clock) |
| 3 | The day of the month |
| 4 | The month (1 to 12) |
| 5 | The year (4 digits) |

`so.date.to.ascii`

```
PROC so.date.to.ascii
                (VAL [so.date.len]INT date,
                 VAL BOOL long.years,
                 VAL BOOL days.first,
                 [so.time.string.len]BYTE string)
```

Converts an array of six integers containing the date (as supplied by `so.time.to.date`) into an ASCII string of the form:

*HH:MM:SS DD/MM/YYYY*

If `long.years` is `FALSE` then year is reduced to two characters, and the last two characters of the year field are padded with spaces. If `days.first` is `FALSE` then the ordering of day and month is changed (to the U.S. standard).

`so.time.to.ascii`

```
PROC so.time.to.ascii
                (VAL INT32 time,
                 VAL BOOL long.years,
                 VAL BOOL days.first
                 [so.time.string.len]BYTE string)
```

Converts time (as supplied by `so.time`) into an ASCII string, as described for `so.date.to.ascii`.

`so.today.date`

```
PROC so.today.date (CHAN OF SP fs, ts,
                    [so.date.len]INT date)
```

Gives today's date, in local time, as six integers, stored in the array `date`. The format of the array is the same as for `so.time.to.date`. If the date is unavailable all elements in `date` are set to zero.

`so.today.ascii`

```
PROC so.today.ascii
              (CHAN OF SP fs, ts,
               VAL BOOL long.years, days.first,
               [so.time.string.len]BYTE string)
```

Gives today's date, in local time, as an ASCII string, in the same format as procedure `so.date.to.ascii`. If the date is unavailable `string` is filled with spaces.

### Buffers and multiplexors

This group of procedures are designed to assist with buffering and multiplexing data exchange between the program and host.

| Procedure | Parameter Specifiers |
|---|---|
| `so.buffer` | `CHAN OF SP fs, ts,` `from.user, to.user,` `CHAN OF BOOL stopper` |
| `so.overlapped.buffer` | `CHAN OF SP fs, ts,` `from.user, to.user,` `CHAN OF BOOL stopper` |
| `so.multiplexor` | `CHAN OF SP fs, ts,` `[]CHAN OF SP from.user,` `to.user,` `CHAN OF BOOL stopper` |
| `so.overlapped.multiplexor` | `CHAN OF SP fs, ts,` `[]CHAN OF SP from.user,` `to.user,` `CHAN OF BOOL stopper` `[]INT queue` |
| `so.pri.multiplexor` | `CHAN OF SP fs, ts,` `[]CHAN OF SP from.user,` `to.user,` `CHAN OF BOOL stopper` |
| `so.overlapped.pri.multiplexor` | `CHAN OF SP fs, ts,` `[]CHAN OF SP from.user,` `to.user,` `CHAN OF BOOL stopper` `[]INT queue` |

## Buffering procedures

### so.buffer

```
PROC so.buffer (CHAN OF SP fs, ts,
                            from.user, to.user,
                CHAN OF BOOL stopper)
```

This procedure buffers data between the user and the host. It can be used by processes on a network to pass data to the host across intervening processes. It is terminated by sending either a `TRUE` or `FALSE` value on the channel `stopper`.

### so.overlapped.buffer

```
PROC so.overlapped.buffer (CHAN OF SP fs, ts,
                                      from.user,
                                      to.user,
                           CHAN OF BOOL stopper)
```

Similar to `so.buffer`, but allows many host communications to occur simultaneously through a train of processes. This can improve efficiency if the communications pass through many processes before reaching the server. It is terminated by either a `TRUE` or `FALSE` value on the channel `stopper`.

## Multiplexing procedures

**Note:** when pairs of channels are passed as parameters, they are normally passed as input then output. Hence all `so.` ... routines take the first parameters `fs`, `ts` (i.e. *from server*, *to server*). The multiplexors take the next two parameters as *from user*, *to user* which will normally correspond with *to server*, *from server*.

### so.multiplexor

```
PROC so.multiplexor (CHAN OF SP fs, ts,
                     []CHAN OF SP from.user,
                                  to.user,
                     CHAN OF BOOL stopper)
```

This procedure multiplexes any number of pairs of `SP` protocol channels onto a single pair of `SP` protocol channels, which may go to the file server or another `SP` protocol multiplexor (or buffer). It is terminated by sending either a `TRUE` or `FALSE` value on the channel `stopper`. For n channels, each channel is guaranteed to be able to pass on a message for every n messages that pass through the multiplexor. This is achieved by cycling the selection priority from the lowest index of `from.user`. However, `stopper` always has highest priority.

`so.overlapped.multiplexor`

```
PROC so.overlapped.multiplexor
               (CHAN OF SP fs, ts,
                []CHAN OF SP from.user, to.user,
                CHAN OF BOOL stopper,
                []INT queue)
```

Similar to **so.multiplexor**, but can pipeline server requests. The number of requests than can be pipelined is determined by the size of **queue**, which must provide one word for each request that can be pipelined. If **SIZE queue** is zero then the routine simply waits for input from **stopper**. Pipelining improves efficiency if the server requests have to pass through many processes on the way to and from the server. It is terminated by sending either a **TRUE** or **FALSE** value on the channel stopper.

The multiplexing is done in the same cyclic manner as in **so.multiplexor**. **stopper** has higher priority than any of **from.user**.

`so.pri.multiplexor`

```
PROC so.pri.multiplexor
               (CHAN OF SP fs, ts,
                []CHAN OF SP from.user, to.user,
                CHAN OF BOOL stopper)
```

As **so.multiplexor** but the multiplexing is *not* done in a cyclic manner; rather there is a hierarchy of priorities amongst the channels – **from.user**: **from.user[i]** is of higher priority than **from.user[j]**, **for i < j**. Also **stopper** is of lower priority than any of **from.user**.

`so.overlapped.pri.multiplexor`

```
PROC so.overlapped.pri.multiplexor
               (CHAN OF SP fs, ts,
                []CHAN OF SP from.user, to.user,
                CHAN OF BOOL stopper,
                []INT queue)
```

As **so.overlapped.multiplexor** but the multiplexing is done in the same prioritized manner as in **so.pri.multiplexor**. **stopper** has higher priority than any of **from.user**.

## 1.6 Streamio library

**Library: `streamio.lib`**

The streamio library contains routines for reading and writing to files and to the terminal at a higher level of abstraction than the hostio library. The file `streamio.inc` defines the `KS` and `SS` protocols and constants used by the streamio library routines. The result value from many of the routines in this library can take a value ≥ `spr.operation.failed` which is a server dependent failure result. It has been left open with the use of ≥ because future server implementations may give more failure information back via this byte. Names for result values can be found in the file `hostio.inc`.

The streamio routines can be classified into three main groups:

- Stream processes
- Stream input procedures
- Stream output procedures.

Stream input and output procedures are used to input and output characters in keystream `KS` and screen stream `SS` protocols. `KS` and `SS` protocols must be converted to the server protocol before communicating with the host.

Stream processes convert streams from keyboard or screen protocol to the server protocol `SP` or to related data structures. They are used to transfer data from the stream input and output routines to the host. Stream processes can be run as parallel processes serving stream input and output routines called in sequential code. For example, the following code clears the screen of a terminal supporting ANSI escape sequences:

```
CHAN OF SS scrn :
PAR
  so.scrstream.to.ANSI(fs, ts, scrn)
  SEQ
    ss.goto.xy(scrn, 0, 0)
    ss.clear.eos(scrn)
    ss.write.endstream(scrn)
```

The key stream and screen stream protocols are identical to those used in the IMS D700 Transputer Development System (TDS) and facilitate the porting of programs between the TDS and the toolset.

### 1.6.1 Naming conventions

Procedure names always begin with a prefix derived from the first parameter. Stream processes, where the `SP` channel (listed first) is used in combination with either the `KS` or `SS` protocols, are prefixed with '`so.`'. Stream input routines, which use only the `KS` protocol are prefixed with '`ks.`', and stream output routines, which use only the SS protocol, are prefixed with 'ss.'. The KS-to-SS conversion routine, which actually uses both protocols, is prefixed for convenience with 'ks.'.

### 1.6.2 Stream processes

| Procedure | Parameter Specifiers |
|---|---|
| so.keystream.from.kbd | CHAN OF SP fs, ts,<br>CHAN OF KS keys.out,<br>CHAN OF BOOL stopper,<br>VAL INT ticks.per.poll |
| so.keystream.from.file | CHAN OF SP fs, ts,<br>CHAN OF KS keys.out,<br>VAL []BYTE filename,<br>BYTE result |
| so.keystream.from.stdin | CHAN OF SP fs, ts,<br>CHAN OF KS keys.out,<br>BYTE result |
| ks.keystream.sink | CHAN OF KS keys |
| ks.keystream.to.scrstream | CHAN OF KS keyboard,<br>CHAN OF SS scrn |
| ss.scrstream.sink | CHAN OF SS scrn |
| so.scrstream.to.file | CHAN OF SP fs, ts,<br>CHAN OF SS scrn,<br>VAL []BYTE filename,<br>BYTE result |
| so.scrstream.to.stdout | CHAN OF SP fs, ts,<br>CHAN OF SS scrn,<br>BYTE result |
| ss.scrstream.to.array | CHAN OF SS scrn,<br>[]BYTE buffer |
| ss.scrstream.from.array | CHAN OF SS scrn,<br>VAL []BYTE buffer |
| ss.scrstream.fan.out | CHAN OF SS scrn,<br>screen.out1,<br>screen.out2 |
| ss.scrstream.copy | CHAN OF SS scrn.in, scrn.out |
| so.scrstream.to.ANSI | CHAN OF SP fs, ts,<br>CHAN OF SS scrn |
| so.scrstream.to.TVI920 | CHAN OF SP fs, ts,<br>CHAN OF SS scrn |
| ss.scrstream.multiplexor | []CHAN OF SS screen.in,<br>CHAN OF SS screen.out,<br>CHAN OF INT stopper |

## Procedure definitions

`so.keystream.from.kbd`

```
PROC so.keystream.from.kbd (CHAN OF SP fs, ts,
                            CHAN OF KS keys.out,
                            CHAN OF BOOL stopper,
                            VAL INT ticks.per.poll)
```

Reads characters from the keyboard and outputs them one at a time as integers on the channel `keys.out`. It is terminated by sending either a `TRUE` or `FALSE` on the boolean channel `stopper`. The procedure polls the keyboard at an interval determined by the value of `ticks.per.poll`, in transputer clock cycles, unless keys are available, in which case they are read at full speed. It is an error if `ticks.per.poll` is less than or equal to zero.

After `FALSE` is sent on the channel `stopper` the procedure sends the negative value `ft.terminated` on `keys.out`.

`so.keystream.from.file`

```
PROC so.keystream.from.file (CHAN OF SP fs, ts,
                             CHAN OF KS keys.out,
                             VAL []BYTE filename,
                             BYTE result)
```

Reads lines from the specified text file and outputs them on `keys.out`. Terminates automatically on error or when it has reached the end of the file and all the characters have been output on the `keys.out` channel. A '`*c`' is output to terminate a text line. The negative value `ft.terminated` is sent on the channel `keys.out` to mark the end of the file. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| `spr.bad.packet.size` | Filename too large i.e. `SIZE filename` > `sp.max.openname.size`. |
| `spr.bad.name` | Null file name. |
| ≥`spr.operation.failed` | The open failed or reading the file failed. If `result`≥`spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`so.keystream.from.stdin`

```
PROC so.keystream.from.stdin (CHAN OF SP fs, ts,
                              CHAN OF KS keys.out,
                              BYTE result)
```

As `so.keystream.from.file`, but reads from the standard input stream. The standard input stream is normally assigned to the keyboard, but can be redirected by the host operating system. End of file from keyboard will terminate this routine. The result returned may take any of the following values:

| | |
|---|---|
| `spr.ok` | The operation was successful. |
| ≥`spr.operation.failed` | Reading standard input failed. If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

**`ks.keystream.sink`**

```
PROC ks.keystream.sink (CHAN OF KS keys)
```

Reads word length quantities until `ft.terminated` is received, then terminates.

**`ks.keystream.to.scrstream`**

```
PROC ks.keystream.to.scrstream (CHAN OF KS keyboard,
                                CHAN OF SS scrn)
```

Converts key stream protocol to screen stream protocol. The value `ft.terminated` on `keyboard` terminates the procedure.

**`ss.scrstream.sink`**

```
PROC ss.scrstream.sink (CHAN OF SS scrn)
```

Reads screen stream protocol and ignores it except for the stream terminator from `ss.write.endstream` which terminates the procedure.

**`so.scrstream.to.file`**

```
PROC so.scrstream.to.file (CHAN OF SP fs, ts,
                           CHAN OF SS scrn,
                           VAL []BYTE filename,
                           BYTE result)
```

Creates a new file with the specified name and writes the data sent on channel `scrn` to it. The `scrn` channel uses the screen stream protocol which is used by all the stream output library routines (and is the same as the INMOS TDS screen stream protocol). It terminates on receipt of the stream terminator from `ss.write.endstream`, or on an error condition. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The data sent on `scrn` was successfully written to the file. |
| `spr.bad.packet.size` | Filename too large i.e. `SIZE filename > sp.max.openname.size`. |
| `spr.bad.name` | Null file name. |
| `≥spr.operation.failed` | If `result≥spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

If used in conjunction with `so.scrstream.fan.out` this procedure may be used to file a copy of everything sent to the screen.

`so.scrstream.to.stdout`

```
PROC so.scrstream.to.stdout (CHAN OF SP fs, ts,
                             CHAN OF SS scrn,
                             BYTE result)
```

Performs the same operation as `so.scrstream.to.file`, but writes to the standard output stream. The standard output stream goes to the screen, but can be redirected to a file by the host operating system. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The data sent on `scrn` was successfully written to standard output. |
| `≥spr.operation.failed` | If `result≥spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`ss.scrstream.to.array`

```
PROC ss.scrstream.to.array (CHAN OF SS scrn,
                            []BYTE buffer)
```

Buffers a screen stream whose total size does not exceed the capacity of `buffer`, for debugging purposes or subsequent onward transmission using `so.scrstream.from.array`. The procedure terminates on receipt of the stream terminator from `ss.write.endstream`.

`ss.scrstream.from.array`

```
PROC ss.scrstream.from.array (CHAN OF SS scrn,
                              VAL []BYTE buffer)
```

Regenerates a screen stream buffered in `buffer` by a previous call of `so.scrstream.to.array`. Terminates when all buffered data has been sent.

`ss.scrstream.fan.out`

```
PROC ss.scrstream.fan.out (CHAN OF SS scrn,
                                      screen.out1,
                                      screen.out2)
```

Sends copies of everything received on the input channel `scrn` to two output channels. The procedure terminates on receipt of the stream terminator from `ss.write.endstream` without passing on the terminator.

`ss.scrstream.copy`

```
PROC ss.scrstream.copy (CHAN OF SS scrn.in,
                                   scrn.out)
```

Copies screen stream protocol input on `scrn.in` to `scrn.out`. Terminates on receipt of the end-stream terminator from `ss.write.endstream`, which is not passed on.

`so.scrstream.to.ANSI`

```
PROC so.scrstream.to.ANSI (CHAN OF SP fs, ts,
                           CHAN OF SS scrn)
```

Converts screen stream protocol into a stream of `BYTE`s according to the requirements of ANSI terminal screen protocol. Not all of the screen stream commands are supported.

The following tags are ignored:

```
st.ins.char  st.reset  st.terminatest.help  st.claim
st.key.raw  st.key.cooked  st.release  st.initialise
```

The procedure terminates on receipt of the stream terminator from `ss.write.endstream`.

`so.scrstream.to.TVI920`

```
PROC so.scrstream.to.TVI920 (CHAN OF SP fs, ts,
                             CHAN OF SS scrn)
```

Converts screen stream protocol into a stream of `BYTE`s according to the requirements of TVI 920 (and compatible) terminals. Not all of the screen stream commands are supported. The following tags are ignored:

```
st.reset  st.terminate  st.help  st.initialise

st.key.raw  st.key.cooked  st.release  st.claim
```

The procedure terminates on receipt of the stream terminator from `ss.write.endstream`.

`ss.scrstream.multiplexor`

```
PROC ss.scrstream.multiplexor([]CHAN OF SS screen.in,
                              CHAN OF SS screen.out,
                              CHAN OF INT stopper)
```

This procedure multiplexes up to 256 screen stream channels onto a single screen stream channel. Each change of input channel directs output to the next line of the screen, and each such line is annotated at the left with the array index of the channel used followed by '>'. The tag `st.endstream` is ignored. The procedure is terminated by the receipt of any integer on the channel `stopper`. For *n* channels, each channel is guaranteed to be able to pass on a message for every *n* messages that pass through the multiplexor. This is achieved by cycling from the lowest index of `screen.in`. However, `stopper` always has highest priority.

## 1.6.3 Stream input

These routines read characters and strings from the input stream, in KS protocol.

| Procedure | Parameter Specifiers |
|---|---|
| `ks.read.char` | `CHAN OF KS source, INT char` |
| `ks.read.line` | `CHAN OF KS source, INT len, []BYTE line, INT char` |
| `ks.read.int` | `CHAN OF KS source, INT number, char` |
| `ks.read.int64` | `CHAN OF KS source, INT64 number, INT char` |
| `ks.read.real32` | `CHAN OF KS source, REAL32 number, INT char` |
| `ks.read.real64` | `CHAN OF KS source, REAL64 number, INT char` |

### Procedure definitions

`ks.read.char`

```
PROC ks.read.char (CHAN OF KS source, INT char)
```

Returns in `char` the next word length quantity from `source`.

`ks.read.line`

```
PROC ks.read.line (CHAN OF KS source, INT len,
                   []BYTE line, INT char)
```

Reads text into the array `line` up to but excluding '`*c`', or up to and excluding any error code. Any '`*n`' encountered is thrown away. `len` gives the number of characters in `line`. If there is an error its code is returned as `char`, otherwise the value of `char` will be `INT` '`*c`'. If the array is filled before a '`*c`' is encountered all further characters are ignored.

`ks.read.int`

```
PROC ks.read.int (CHAN OF KS source,
                  INT number, char)
```

Skips input up to a digit, #, + or -, then reads a sequence of digits to the first non-digit, returned as `char`, and converts the digits to an integer in `number`. `char` must be initialized to the first character of the input. If the first significant character is a '#' then a hexadecimal number is input, thereby allowing the user the option of which number base to use. The hexadecimal may be in upper or lower case.

`char` is returned as `ft.number.error` if the number overflows the `INT` range.

`ks.read.int64`

```
PROC ks.read.int64 (CHAN OF KS source,
                    INT64 number, INT char)
```

As `ks.read.int`, but for 64-bit integers.

`ks.read.real32`

```
PROC ks.read.real32 (CHAN OF KS source,
                     REAL32 number, INT char)
```

Skips input up to a digit, + or -, then reads a sequence of digits with optional decimal point and exponent) up to the first invalid character, returned as `char`. Converts the digits to a floating point value in `number`.`char` must be initialized to the first character of the input. If there is an error in the syntax of the real, if it is ± infinity, or if more than 24 characters read then `char` is returned as `ft.number.error`.

`ks.read.real64`

```
PROC ks.read.real64 (CHAN OF KS source,
                     REAL64 number, INT char)
```

As `ks.read.real32`, but for 64-bit real numbers. Allows for reading up to 30 characters.

### 1.6.4 Stream output

These routines write text, numbers and screen control codes to an output stream in `SS` protocol.

| Procedure | Parameter Specifiers |
|---|---|
| `ss.write.char` | `CHAN OF SS scrn, VAL BYTE char` |
| `ss.write.nl` | `CHAN OF SS scrn` |
| `ss.write.string` | `CHAN OF SS scrn, VAL []BYTE str` |
| `ss.write.endstream` | `CHAN OF SS scrn` |
| `ss.write.text.line` | `CHAN OF SS scrn, VAL []BYTE str` |
| `ss.write.int` | `CHAN OF SS scrn,` `VAL INT number, width` |
| `ss.write.int64` | `CHAN OF SS scrn, VAL INT64 number,` `VAL INT width` |
| `ss.write.hex.int` | `CHAN OF SS scrn,` `VAL INT number, width` |
| `ss.write.hex.int64` | `CHAN OF SS scrn, VAL INT64 number,` `VAL INT width` |
| `ss.write.real32` | `CHAN OF SS scrn, VAL REAL32 number,` `VAL INT Ip, Dp` |
| `ss.write.real64` | `CHAN OF SS scrn, VAL REAL64 number,` `VAL INT Ip, Dp` |
| `ss.goto.xy` | `CHAN OF SS scrn, VAL INT x, y` |
| `ss.clear.eol` | `CHAN OF SS scrn` |
| `ss.clear.eos` | `CHAN OF SS scrn` |
| `ss.beep` | `CHAN OF SS scrn` |
| `ss.up` | `CHAN OF SS scrn` |
| `ss.down` | `CHAN OF SS scrn` |
| `ss.left` | `CHAN OF SS scrn` |
| `ss.right` | `CHAN OF SS scrn` |
| `ss.insert.char` | `CHAN OF SS scrn, VAL BYTE ch` |
| `ss.delete.chr` | `CHAN OF SS scrn` |
| `ss.delete.chl` | `CHAN OF SS scrn` |
| `ss.ins.line` | `CHAN OF SS scrn` |
| `ss.del.line` | `CHAN OF SS scrn` |

### Procedure definitions

`ss.write.char`

```
PROC ss.write.char (CHAN OF SS scrn,
                    VAL BYTE char)
```

Sends the ASCII value `char` on `scrn`, in `scrstream` protocol, to the current position in the output line.

`ss.write.nl`

```
PROC ss.write.nl (CHAN OF SS scrn)
```

Sends "`*c*n`" to `scrn`.

`ss.write.string`

```
PROC ss.write.string (CHAN OF SS scrn,
                      VAL []BYTE str)
```

Sends all characters in `str` to `scrn`.

`ss.write.endstream`

```
PROC ss.write.endstream (CHAN OF SS scrn)
```

Sends a special stream terminator value to `scrn`.

`ss.write.text.line`

```
PROC ss.write.text.line (CHAN OF SS scrn,
                         VAL []BYTE str)
```

Sends all of `str` to `scrn` ensuring that, whether or not the last character of `str` is '`*c`', the last two characters sent are "`*c*n`".

`ss.write.int`

```
PROC ss.write.int (CHAN OF SS scrn,
                   VAL INT number, width)
```

Converts `number` into a sequence of ASCII decimal digits padded out with leading spaces and an optional sign to the specified field width, `width`, if necessary. If the number cannot be represented in `width` characters it is widened as necessary; a zero value for `width` will give minimum width. The converted number is sent to `scrn`. A negative value for `width` is an error.

`ss.write.int64`

```
PROC ss.write.int64 (CHAN OF SS scrn,
                     VAL INT64 number,
                     VAL INT width)
```

As `ss.write.int` but for 64-bit integers.

`ss.write.hex.int`

```
PROC ss.write.hex.int (CHAN OF SS scrn,
                       VAL INT number, width)
```

Converts number into a sequence of ASCII hexadecimal digits, using upper case letters, preceded by '#'. The total number of characters sent is always `width + 1`, padding out with '0' or 'F' on the left if necessary. The number is truncated at the left if the field is too narrow, thereby allowing the less significant part of any number to be printed. The converted number is sent to `scrn`. A negative value for `width` is an error.

`ss.write.hex.int64`

```
PROC ss.write.hex.int64 (CHAN OF SS scrn,
                         VAL INT64 number,
                         VAL INT width)
```

As `ss.write.hex.int` but for 64-bit integer values.

`ss.write.real32`

```
PROC ss.write.real32 (CHAN OF SS scrn,
                      VAL REAL32 number,
                      VAL INT Ip, Dp)
```

Converts `number` into an ASCII string formatted using `Ip` and `Dp`, as described for `REAL32TOSTRING` (see section 1.8). The converted number is sent to `scrn`. If the formatted form of `number` is larger than 24 characters then this procedure acts as an invalid process.

`ss.write.real64`

```
PROC ss.write.real64 (CHAN OF SS scrn,
                      VAL REAL64 number,
                      VAL INT Ip, Dp)
```

As for `ss.write.real32` but for 64-bit real values. See section 1.8, `REAL32TOSTRING` for details of the formatting effect of `Ip` and `Dp`. If the formatted form of number is larger than 30 characters then this procedure acts as an invalid process.

`ss.goto.xy`

```
PROC ss.goto.xy (CHAN OF SS scrn, VAL INT x, y)
```

Sends the cursor to screen position (x,y). The origin (0,0) is at the top left corner of the screen.

`ss.clear.eol`

```
PROC ss.clear.eol (CHAN OF SS scrn)
```

Clears screen from the cursor position to the end of the current line.

`ss.clear.eos`

```
PROC ss.clear.eos (CHAN OF SS scrn)
```

Clears screen from the cursor position to the end of the current line and all lines below.

`ss.beep`

```
PROC ss.beep (CHAN OF SS scrn)
```

Sends a bell code to the terminal.

`ss.up`

```
PROC ss.up (CHAN OF SS scrn)
```

Sends a command to the terminal to move the cursor one line up the screen.

`ss.down`

```
PROC ss.down (CHAN OF SS scrn)
```

Sends a command to the terminal to move the cursor one line down the screen.

`ss.left`

```
PROC ss.left (CHAN OF SS scrn)
```

Sends a command to the terminal to move the cursor one place left.

`ss.right`

```
PROC ss.right (CHAN OF SS scrn)
```

Sends a command to the terminal to move the cursor one place right.

`ss.insert.char`

```
PROC ss.insert.char (CHAN OF SS scrn,
                     VAL BYTE ch)
```

Sends a command to the terminal to move the character at the cursor and all those to the right of it one place to the right and inserts `char` at the cursor. The cursor moves one place right.

`ss.delete.chr`

```
PROC ss.delete.chr (CHAN OF SS scrn)
```

Sends a command to the terminal to delete the character at the cursor and move the rest of the line one place to the left. The cursor does not move.

`ss.delete.chl`

```
PROC ss.delete.chl (CHAN OF SS scrn)
```

Sends a command to the terminal to delete the character to the left of the cursor and move the rest of the line one place to the left. The cursor also moves one place left.

`ss.ins.line`

```
PROC ss.ins.line (CHAN OF SS scrn)
```

Sends a command to the terminal to move all lines below the current line down one line on the screen, losing the bottom line. The current line becomes blank.

`ss.del.line`

```
PROC ss.del.line (CHAN OF SS scrn)
```

Sends a command to the terminal to delete the current line and move all lines below it up one line. The bottom line becomes blank.

## 1.7 String handling library

Library: `string.lib`

This library contains functions and procedures for handling strings and scanning lines of text. They assist with the manipulation of character strings such as names, commands, and keyboard responses. The library provides routines for:

- Identifying characters
- Comparing strings
- Searching strings
- Editing strings
- Scanning lines of text

| Result | Function | Parameter specifiers |
|---|---|---|
| BOOL | is.in.range | VAL BYTE char, bottom, top |
| BOOL | is.upper | VAL BYTE char |
| BOOL | is.lower | VAL BYTE char |
| BOOL | is.digit | VAL BYTE char |
| BOOL | is.hex.digit | VAL BYTE char |
| BOOL | is.id.char | VAL BYTE char |
| INT | compare.strings | VAL []BYTE str1, str2 |
| BOOL | eqstr | VAL []BYTE s1, s2 |
| INT | string.pos | VAL []BYTE search, str |
| INT | char.pos | VAL BYTE search<br>VAL []BYTE str |
| INT, BYTE | search.match | VAL []BYTE possibles, str |
| INT, BYTE | search.no.match | VAL []BYTE possibles, str |

| Procedure | Parameter Specifiers |
|---|---|
| `str.shift` | `[]BYTE str,`<br>`VAL INT start, len, shift,`<br>`BOOL not.done` |
| `delete.string` | `INT len, []BYTE str,`<br>`VAL INT start, size,`<br>`BOOL not.done` |
| `insert.string` | `VAL []BYTE new.str,`<br>`INT len, []BYTE str,`<br>`VAL INT start, BOOL not.done` |
| `to.upper.case` | `[]BYTE str` |
| `to.lower.case` | `[]BYTE str` |
| `append.char` | `INT len, []BYTE str,`<br>`VAL BYTE char` |
| `append.text` | `INT len, []BYTE str,`<br>`VAL []BYTE text` |
| `append.int` | `INT len, []BYTE str,`<br>`VAL INT number, width` |
| `append.int64` | `INT len, []BYTE str,`<br>`VAL INT64 number, VAL INT width` |
| `append.hex.int` | `INT len, []BYTE str,`<br>`VAL INT number, width` |
| `append.hex.int64` | `INT len, []BYTE str,`<br>`VAL INT64 number,`<br>`VAL INT width` |
| `append.real32` | `INT len, []BYTE str,`<br>`VAL REAL32 number,`<br>`VAL INT Ip, Dp` |
| `append.real64` | `INT len, []BYTE str,`<br>`VAL REAL64 number,`<br>`VAL INT Ip, Dp` |
| `next.word.from.line` | `VAL []BYTE line,`<br>`INT ptr, len,`<br>`[]BYTE word, BOOL ok` |
| `next.int.from.line` | `VAL []BYTE line,`<br>`INT ptr, number, BOOL ok` |

### 1.7.1 Character identification

`is.in.range`

```
BOOL FUNCTION is.in.range (VAL BYTE char, bottom, top)
```

Returns `TRUE` if the value of `char` is in the range defined by `bottom` and `top` inclusive, otherwise returns `FALSE`.

`is.upper`

```
BOOL FUNCTION is.upper (VAL BYTE char)
```

Returns `TRUE` if `char` is an ASCII upper case letter, otherwise returns `FALSE`.

`is.lower`

```
BOOL FUNCTION is.lower (VAL BYTE char)
```

Returns `TRUE` if `char` is an ASCII lower case letter, otherwise returns `FALSE`.

`is.digit`

```
BOOL FUNCTION is.digit (VAL BYTE char)
```

Returns `TRUE` if `char` is an ASCII decimal digit, otherwise returns `FALSE`.

`is.hex.digit`

```
BOOL FUNCTION is.hex.digit (VAL BYTE char)
```

Returns `TRUE` if `char` is an ASCII hexadecimal digit, otherwise returns `FALSE`. Upper or lower case letters A–F are allowed.

`is.id.char`

```
BOOL FUNCTION is.id.char (VAL BYTE char)
```

Returns `TRUE` if `char` is an ASCII character which can be part of an occam name; otherwise returns `FALSE`.

### 1.7.2 String comparison

These two procedures allow strings to be compared for order or for equality.

`compare.strings`

```
INT FUNCTION compare.strings (VAL []BYTE str1, str2)
```

This general purpose ordering function compares two strings according to the lexicographic ordering standard. (Lexicographic ordering is the ordering used in dictionaries etc., using the ASCII values of the bytes). It returns one of the 5 results 0, 1, −1, 2, or −2, as follows:

| | |
|---|---|
| 0 | The strings are exactly the same in length and content. |
| 1 | `str2` is a leading substring of `str1` |
| −1 | `str1` is a leading substring of `str2` |
| 2 | `str1` is lexicographically later than `str2` |
| −2 | `str2` is lexicographically later than `str1` |

So if s is "abcd":

```
compare.strings ("abc", [s FROM 0 FOR 3])        = 0
compare.strings ("abc", [s FROM 0 FOR 2])        = 1
compare.strings ("abc", s)                       =-1
compare.strings ("bc", s)                        = 2
compare.strings ("a4", s)                        =-2
```

`eqstr`

```
BOOL FUNCTION eqstr (VAL []BYTE s1,s2)
```

This is an optimized test for string equality. It returns `TRUE` if the two strings are the same size and have the same contents, `FALSE` otherwise.

### 1.7.3 String searching

These procedures allow a string to be searched for a match with a single byte or a string of bytes, for a byte which is one of a set of possible bytes, or for a byte which is not one of a set of bytes. Searches insensitive to alphabetic case should use `to.upper.case` or `to.lower.case` on both operands before using these procedures.

`string.pos`

```
INT FUNCTION string.pos (VAL []BYTE search, str)
```

Returns the position in `str` of the first occurrence of a substring which exactly matches `search`. Returns –1 if there is no such match.

`char.pos`

```
INT FUNCTION char.pos (VAL BYTE search,
                       VAL []BYTE str)
```

Returns the position in `str` of the first occurrence of the byte `search`. Returns –1 if there is no such byte.

`search.match`

```
INT, BYTE FUNCTION search.match
                   (VAL []BYTE possibles, str)
```

Searches `str` for any one of the bytes in the array `possibles`. If one is found its index and identity are returned as results. If none is found then –1,255(`BYTE`) are returned.

`search.no.match`

```
INT, BYTE FUNCTION search.no.match
                   (VAL []BYTE possibles, str)
```

Searches `str` for a byte which does not match any one of the bytes in the array `possibles`. If one is found its index and identity are returned as results. If none is found then –1,255(`BYTE`) are returned.

### 1.7.4 String editing

These procedures allow strings to be edited. The string to be edited is stored in an array which may contain unused space. The editing operations supported are: deletion of a number of characters and the closing of the gap created; insertion of a new string starting at any position within a string, which creates a gap of the necessary size.

These two operations are supported by a lower level procedure for shifting a consecutive substring left or right within the array. The lower level procedure does exhaustive tests against overflow.

`str.shift`

```
PROC str.shift ([]BYTE str, VAL INT start,
                len, shift, BOOL not.done)
```

Takes a substring `[str FROM start FOR len]`, and copies it to a position `shift` places to the right. Any implied actions involving bytes outside the string are not performed and cause the error flag `not.done` to be set to `TRUE`. Negative values of `shift` cause leftward moves.

`delete.string`

```
PROC delete.string (INT len, []BYTE str,
                    VAL INT start, size,
                    BOOL not.done)
```

Deletes `size` bytes from the string `str` starting at `str[start]`. There are initially `len` significant characters in `str` and it is decremented appropriately. If `start` is outside the string, or `start` + `size` is greater than `len`, then no action occurs and `not.done` is set to `TRUE`.

`insert.string`

```
PROC insert.string (VAL []BYTE new.str, INT len,
                    []BYTE str, VAL INT start,
                    BOOL not.done)
```

Creates a gap in `str` after `str[start]` and copies the string `new.str` into it. There are initially `len` significant characters in `str` and `len` is incremented by the length of `new.str` inserted. Any overflow of the declared size of `str` results in truncation at the right and setting `not.done` to `TRUE`. This procedure may be used for simple concatenation on the right by setting `start` = `len` or on the left by setting `start` = 0. This method of concatenation differs from that using the **append** procedures in that it can never cause the program to stop.

`to.upper.case`

```
PROC to.upper.case ([]BYTE str)
```

Converts all alphabetic characters in **str** to upper case. All other characters are left unaltered.

`to.lower.case`

```
PROC to.lower.case ([]BYTE str)
```

Converts all alphabetic characters in **str** to lower case. All other characters are left unaltered.

`append.char`

```
PROC append.char (INT len, []BYTE str,
                  VAL BYTE char)
```

Writes a byte **char** into the array **str** at **str[len]**. **len** is incremented by 1. Behaves like **STOP** if the array overflows.

`append.text`

```
PROC append.text (INT len, []BYTE str,
                  VAL []BYTE text)
```

Writes a string **text** into the array **str**, starting at **str[len]** and computing a new value for **len**. Behaves like **STOP** if the array overflows.

`append.int`

```
PROC append.int (INT len, []BYTE str,
                 VAL INT number, width)
```

Converts **number** into a sequence of ASCII decimal digits padded out with leading spaces and an optional sign to the specified field width, **width**, if necessary. If the number cannot be represented in **width** characters it is widened as necessary. A zero value for **width** will give minimum width. The converted number is written into the array **str** starting at **str[len]** and **len** is incremented. Behaves like **STOP** if the array overflows or if **width** < 0.

`append.int64`

```
PROC append.int64 (INT len, []BYTE str,
                   VAL INT64 number,
                   VAL INT width)
```

As **append.int** but for 64-bit integers.

`append.hex.int`

```
PROC append.hex.int (INT len, []BYTE str,
                     VAL INT number, width)
```

Converts `number` into a sequence of ASCII hexadecimal digits, using upper case letters, preceded by '#'. The total number of characters set is always `width`+1, padding out with '0' or 'F' on the left if necessary. The number is truncated at the left if the field is too narrow, thereby allowing the less significant part of any number to be printed. The converted number is written into the array `str` starting at `str[len]` and `len` is incremented. Behaves like `STOP` if the array overflows or if `width` < 0.

`append.hex.int64`

```
PROC append.hex.int64 (INT len, []BYTE str,
                       VAL INT64 number,
                       VAL INT width)
```

As `append.hex.int` but for 64-bit integers.

`append.real32`

```
PROC append.real32 (INT len, []BYTE str,
                    VAL REAL32 number,
                    VAL INT Ip, Dp)
```

Converts `number` into a sequence of ASCII characters formatted using `Ip` and `Dp` as described under `REAL32TOSTRING` (see section 1.8).

The converted number is written into the array `str` starting at `str[len]` and `len` is incremented. Behaves like `STOP` if the array overflows.

`append.real64`

```
PROC append.real64 (INT len, []BYTE str,
                    VAL REAL64 number,
                    VAL INT Ip, Dp)
```

As `append.real32`, but for 64-bit real values. The formatting variables `Ip` and `Dp` are described under `REAL32TOSTRING` (see section 1.8).

### 1.7.5 Line parsing

Depending on the initial value of the variable `ok` these two procedures either read a line serially, returning the next word and next integer respectively, or the procedures act almost like a `SKIP` (see below). The user should initialize the variable `ok` as appropriate.

`next.word.from.line`

```
PROC next.word.from.line (VAL []BYTE line,
                           INT ptr, len,
                           []BYTE word,
                           BOOL ok)
```

If `ok` is passed in as `TRUE`, on entry to the procedure, skips leading spaces and horizontal tabs and reads the next word from the string `line`. The value of `ptr` is the starting point of the search. A word continues until a space or tab or the end of the string `line` is encountered. If the end of the string is reached without finding a word, the boolean `ok` is set to `FALSE`, and `len` is `0`. If a word is found but is too large for `word`, then `ok` is set to `FALSE`, but `len` will be the length of the word that was found; otherwise the found word will be in the first `len` bytes of `word`. The index `ptr` is updated to be that of the space or tab immediately after the found word, or is `SIZE line`. If `ok` is passed in as `FALSE`, `len` is set to `0`, `ptr` and `ok` remain unchanged, and `word` is undefined.

`next.int.from.line`

```
PROC next.int.from.line (VAL []BYTE line,
                         INT ptr, number,
                         BOOL ok)
```

If `ok` is passed in as `TRUE`, on entry to the procedure, skips leading spaces and horizontal tabs and reads the next integer from the string `line`. The value of `ptr` is the starting point of the search. The integer is considered to start with the first non-space, non-tab character found and continues until a space or tab or the end of the string `line` is encountered. If the first sequence of non-space, non-tab characters does not exist, does not form an integer, or forms an integer that overflows the `INT` range then `ok` is set to `FALSE`, and `number` is undefined; otherwise `ok` remains `TRUE`, and `number` is the integer read. A '+' or '–' may be the first character of the integer. The index `ptr` is updated to be that of the space or tab immediately after the found integer, or is `SIZE line`. If `ok` is passed in as `FALSE`, then `ptr` and `ok` remain unchanged, and `number` is undefined.

## 1.8 String conversion library

Library: `convert.lib`

This library contains procedures for converting numeric values to strings and vice versa. String to numeric conversions return two results, the converted value and a boolean error indication. Numeric to string conversions return the converted string and an integer which represents the number of significant characters written into the string.

These routines are also described in appendix O of the *occam 2 Reference Manual*.

| Procedure | Parameter Specifiers |
|---|---|
| `INTTOSTRING` | `INT len, []BYTE string, VAL INT n` |
| `INT16TOSTRING` | `INT len, []BYTE string, VAL INT16 n` |
| `INT32TOSTRING` | `INT len, []BYTE string, VAL INT32 n` |
| `INT64TOSTRING` | `INT len, []BYTE string, VAL INT64 n` |
| `HEXTOSTRING` | `INT len, []BYTE string, VAL INT n` |
| `HEX16TOSTRING` | `INT len, []BYTE string, VAL INT16 n` |
| `HEX32TOSTRING` | `INT len, []BYTE string, VAL INT32 n` |
| `HEX64TOSTRING` | `INT len, []BYTE string, VAL INT64 n` |
| `REAL32TOSTRING` | `INT len, []BYTE string, VAL REAL32 X, VAL INT Ip, Dp` |
| `REAL64TOSTRING` | `INT len, []BYTE string, VAL REAL64 X, VAL INT Ip, Dp` |
| `BOOLTOSTRING` | `INT len, []BYTE string, VAL BOOL b` |
| `STRINGTOINT` | `BOOL Error, INT n, VAL []BYTE string` |
| `STRINGTOINT16` | `BOOL Error, INT16 n, VAL []BYTE string` |
| `STRINGTOINT32` | `BOOL Error, INT32 n, VAL []BYTE string` |
| `STRINGTOINT64` | `BOOL Error, INT64 n, VAL []BYTE string` |
| `STRINGTOHEX` | `BOOL Error, INT n, VAL []BYTE string` |
| `STRINGTOHEX16` | `BOOL Error, INT16 n, VAL []BYTE string` |
| `STRINGTOHEX32` | `BOOL Error, INT32 n, VAL []BYTE string` |
| `STRINGTOHEX64` | `BOOL Error, INT64 n, VAL []BYTE string` |
| `STRINGTOREAL32` | `BOOL Error, REAL32 X, VAL []BYTE string` |
| `STRINGTOREAL64` | `BOOL Error, REAL64 X, VAL []BYTE string` |
| `STRINGTOBOOL` | `BOOL Error, b, VAL []BYTE string` |

### Procedure definitions

INTTOSTRING

```
PROC INTTOSTRING (INT len, []BYTE string,
                  VAL INT n)
```

Converts an integer value to a string. The procedure returns the decimal representation of `n` in `string` and the number of characters in the representation, in `len`. If `string` is not long enough to hold the representation then this routine acts as an invalid process.

Similar procedures are provided for the types `INT16`, `INT32`, and `INT64`.

INT16TOSTRING

```
PROC INT16TOSTRING (INT len, []BYTE string,
                    VAL INT16 n)
```

As `INTTOSTRING` but for 16-bit integers.

INT32TOSTRING

```
PROC INT32TOSTRING (INT len, []BYTE string,
                    VAL INT32 n)
```

As `INTTOSTRING` but for 32-bit integers.

INT64TOSTRING

```
PROC INT64TOSTRING (INT len, []BYTE string,
                    VAL INT64 n)
```

As `INTTOSTRING` but for 64-bit integers.

HEXTOSTRING

```
PROC HEXTOSTRING (INT len, []BYTE string,
                  VAL INT n)
```

The procedure returns the hexadecimal representation of `n` in `string` and the number of characters in the representation, in `len`. All the bits of `n`, (in 4-bit wide word lengths) are output so that leading zeroes or 'F's are included. The number of characters will be the number of bits in an `INT` divided by four. A '#' is not output by the `HEXTOSTRING` procedure. If `string` is not long enough to hold the representation then this routine acts as an invalid process.

Similar procedures are provided for the types `HEX16`, `HEX32` and `HEX64`.

HEX16TOSTRING

```
PROC HEX16TOSTRING (INT len, []BYTE string,
                    VAL INT16 n)
```

As `HEXTOSTRING` but for 16-bit integers.

HEX32TOSTRING

```
PROC HEX32TOSTRING (INT len, []BYTE string,
                    VAL INT32 n)
```

As HEXTOSTRING but for 32-bit integers.

HEX64TOSTRING

```
PROC HEX64TOSTRING (INT len, []BYTE string,
                    VAL INT64 n)
```

As HEXTOSTRING but for 64-bit integers.

REAL32TOSTRING

```
PROC REAL32TOSTRING (INT len, []BYTE string,
                     VAL REAL32 X,
                     VAL INT Ip, Dp)
```

Converts a 32-bit real number (represented in single precision IEEE format) to a string of ASCII characters. len is the number of characters (BYTEs) of string used for the formatted decimal representation of the number. (The following description applies to and notes the differences between this procedure and REAL64TOSTRING).

The string must match the format for occam real literals as defined in the *occam 2 Reference Manual*, p 123, for example, 1.2E+2.

Depending on the value of X and the two formatting variables Ip and Dp the procedure will use either a fixed or exponential format for the output string. These formats are defined as follows:

| | |
|---|---|
| **Fixed :** | First, either a minus sign or space (an explicit plus sign is not used), followed by a fraction in the form <digits>.<digits>. Padding spaces are added to the left of the sign indicator, as necessary. (Ip gives the number of places before the point and Dp the number of places after the point). |
| **Exponential :** | First, either a minus sign or space (again, an explicit plus sign is not used), followed by a fraction in the form <digit>.<digits>, the exponential symbol (E), the sign of the exponent (explicitly plus or minus), then the exponent, which is two digits for a REAL32 and three digits for a REAL64. (Dp gives the number of digits in the fraction (1 before the decimal point and the others after)). |

Possible combinations of Ip and Dp fall into three categories, described below. **Note**: the term 'Free format' means that the procedure may adopt either fixed or exponential format, depending on the actual value of X.

1 If `Ip`=0, `Dp`=0, then free format is adopted. Exponential format is used if the absolute value of `X` is less than $10^{-4}$, but non-zero, or greater than $10^9$ (for `REAL32`), or greater than $10^{17}$ (for `REAL64`); otherwise fixed format is used.

The value of `len` is dependent on the actual value of `X` with trailing zeroes suppressed. The maximum length of the result is 15 or 24, depending on whether it is `REAL32` or `REAL64` respectively.

If `X` is 'Not-a-Number' or infinity then the string will contain one of the following: '`Inf`', '`-Inf`' or '`NaN`', (excluding the quotes).

2 If `Ip`>0, `Dp`>0, fixed format is used, unless the value needs more than `Ip` significant digits before the decimal point, in which case, exponential format is used. If exponential does not fit either, then a signed string '`Ov`' is produced. The length is always `Ip` + `Dp` + 2 when `Ip`>0, `Dp`>0.

If `X` is 'Not-a-Number' or infinity then the string will contain one of the following: '`Inf`', '`-Inf`' or '`NaN`', (excluding the quotes) and padded out by spaces on the right to fill the field width.

3 If `Ip`=0, `Dp`>0, then exponential format is always used. The length of the result is `Dp` + 6 or `Dp` + 7, depending on whether `X` is a `REAL32` or `REAL64`, respectively.

If `Ip`=0, `Dp`=1, then a special result is produced consisting of a sign, a blank, a digit and the exponent. The length is 7 or 8 depending on whether `X` is a `REAL32` or `REAL64`. **Note**: this result does not conform to the occam format for a `REAL`.

If `X` is 'Not-a-Number' or infinity then the string will contain one of the following: '`Inf`', '`-Inf`' or '`NaN`', (excluding the quotes) and padded out by spaces on the right to fill the field width.

All other combinations of `Ip` and `Dp` are errors.

If string is not long enough to hold the requested formatted real number as a string then these routines act as invalid processes.

**REAL64TOSTRING**

```
PROC REAL64TOSTRING (INT len, []BYTE string,
                     VAL REAL64 X,
                     VAL INT Ip, Dp)
```

As `REAL32TOSTRING` but for 64-bit numbers.

BOOLTOSTRING

```
PROC BOOLTOSTRING (INT len, []BYTE string,
                   VAL BOOL b)
```

Converts a boolean value to a string. The procedure returns '`TRUE`' in `string` if `b` is `TRUE` and '`FALSE`' otherwise. `len` contains the number of characters in the string returned. If `string` is not long enough to hold the representation then this routine acts as an invalid process.

STRINGTOINT

```
PROC STRINGTOINT (BOOL Error, INT n,
                  VAL []BYTE string)
```

Converts a string to a decimal integer. The procedure returns in `n` the value represented in `string`. `error` is set to `TRUE` if a non-numeric character is found in `string` or if `string` is empty. `+` or a `-` are allowed in the first character position. `n` will be the value of the portion of `string` up to any illegal characters, with the convention that the value of an empty string is 0. `error` is also set to `TRUE` if the value of `string` overflows the range of `INT`, in this case `n` will contain the low order bits of the binary representation of `string`. `error` is set to `FALSE` in all other cases.

Similar procedures are provided for the types `INT16`, `INT32`, and `INT64`.

STRINGTOINT16

```
PROC STRINGTOINT16 (BOOL Error, INT16 n,
                    VAL []BYTE string)
```

As `STRINGTOINT` but converts to a 16-bit integer.

STRINGTOINT32

```
PROC STRINGTOINT32 (BOOL Error, INT32 n,
                    VAL []BYTE string)
```

As `STRINGTOINT` but converts to a 32-bit integer.

STRINGTOINT64

```
PROC STRINGTOINT64 (BOOL Error, INT64 n,
                    VAL []BYTE string)
```

As `STRINGTOINT` but converts to a 64-bit integer.

STRINGTOHEX

```
PROC STRINGTOHEX (BOOL Error, INT n,
                  VAL []BYTE string)
```

The procedure returns in `n` the value represented by the hexadecimal `string`. No '#' is allowed in the input and hex digits must be in upper case (`A` to `F`) rather than lower case (`a` to `f`). `error` is set to `TRUE` if a non-hexadecimal character is found in `string`, or if `string` is empty. `n` will be the value of the portion of `string` up to any illegal character with the convention that the value of an empty string is `0`. `error` is also set to `TRUE` if the value represented by `string` overflows the range of `INT`. In this case `n` will contain the low order bits of the binary representation of `string`. In all other cases `error` is set to `FALSE`.

Similar procedures are provided for the types `HEX16`, `HEX32`, and `HEX64`.

STRINGTOHEX16

```
PROC STRINGTOHEX16 (BOOL Error, INT16 n,
                    VAL []BYTE string)
```

As `STRINGTOHEX` but converts to a 16-bit integer.

STRINGTOHEX32

```
PROC STRINGTOHEX32 (BOOL Error, INT32 n,
                    VAL []BYTE string)
```

As `STRINGTOHEX` but converts to a 32-bit integer.

STRINGTOHEX64

```
PROC STRINGTOHEX64 (BOOL Error, INT64 n,
                    VAL []BYTE string)
```

As `STRINGTOHEX` but converts to a 64-bit integer.

STRINGTOREAL32

```
PROC STRINGTOREAL32 (BOOL Error, REAL32 X,
                     VAL []BYTE string)
```

Converts a string to a 32-bit real number. This procedure takes a string containing a decimal representation of a real number and converts it into the corresponding real value. If the value represented by `string` overflows the range of the type then an appropriately signed infinity is returned. Errors in the syntax of string are signalled by a 'Not-a-Number' being returned and `error` being set to `TRUE`. The string is scanned from the left as far as possible while the syntax is still valid. If there are any characters after the end of the longest correct string then `error` is set to `TRUE`, otherwise it is `FALSE`. For example if `string` was "12.34*E*+2+1.0" then the value returned would be $12.34 \times 10^2$ with `error` set to `TRUE`·

STRINGTOREAL64

```
PROC STRINGTOREAL64 (BOOL Error, REAL64 X,
                     VAL []BYTE string)
```

As STRINGTOREAL32 but converts to a 64-bit number.

STRINGTOBOOL

```
PROC STRINGTOBOOL (BOOL Error, b,
                   VAL []BYTE string)
```

Converts a string to a boolean value. The procedure returns TRUE in b if the first four characters of string are 'TRUE' and FALSE if the first five characters are 'FALSE'; b is undefined in other cases. TRUE is returned in error if string is not exactly 'TRUE' or 'FALSE'.

## 1.9 Block CRC library

**Library:** `crc.lib`

The block CRC library provides two functions for calculating cyclic redundancy check values from byte strings. Such values can be of use in, for example, the generation of the frame check sequence (FCS) in data communications.

A cyclic redundancy check value is the remainder from modulo 2 polynomial division. Consider bit sequences as representing the coefficients of polynomials; for example, the bit sequence 10100100 (where the leading bit is the most significant bit (msb)) corresponds to $P(x) = x^7 + x^5 + x^2$. The routines in the library calculate the remainder of the modulo 2 polynomial division:

$$(x^{k+n} H(x) + x^n F(x))/G(x)$$

where: $F(x)$ corresponds to `InputString`

$G(x)$ corresponds to `PolynomialGenerator`

$H(x)$ corresponds to `OldCRC`

$k$ is the number of bits in `InputString`

$n$ is the word size in bits of the processor used (i.e. $n$ is 16 or 32).

(`OldCRC` can be viewed as the value that would be pre-loaded into the cyclic shift register that is part of hardware implementations of CRC generators.).

When representing $G(x)$ in the word `PolynomialGenerator`, note that there is an understood bit before the msb of `PolynomialGenerator`. For example, on a 16-bit processor, with $G(x) = x^{16} + x^{12} + x^5 + 1$, which is #11021, then `PolynomialGenerator` must be assigned #1021, because the bit corresponding to $x^{16}$ is understood. Thus, a value of #9603 for `PolynomialGenerator`, corresponds to $G(x) = x^{16} + x^{15} + x^{12} + x^{10} + x^9 + x + 1$, for a 16-bit processor.

A similar situation holds on a 32-bit processor, so that:

$$G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

is encoded in `PolynomialGenerator` as #04C11DB7.

It is possible, however, to calculate a 16-bit CRC on a 32-bit processor. For example, if $G(x) = x^{16} + x^{12} + x^5 + 1$, then `PolynomialGenerator` is #10210000. This is because the most significant 16 bits of the 32-bit integer form a 16-bit generator; the least significant 16 bits of `OldCRC` form the initial CRC value; and the calculated CRC is the most significant 16 bits of the result from `CRCFROMMSB` and the least significant 16 bits of the result from `CRCFROMLSB`.

### 1.9.1 Example of use

Suppose it is required to transmit information between two 32-bit transputers, and the message that is to be transmitted is the byte array `[data FROM 4 FOR` `size.message]`, where there are `size.message` bytes in the message. Both the transmitter and receiver use the same 32-bit generating polynomial and `OldCRC` value. There are two methods for the receiver to check messages:

First `CRCFROMMSB` is given the message as an input string, the result is placed into the first four bytes of `data` and the message is sent. The receiver can either:

> Give the received `data` (which is `(size.message + 4)` bytes long) to `CRCFROMMSB` and expect a result of zero,

or:

> Give the received `[data FROM 4 FOR (size.message)]` to `CRCFROMMSB` and check that the result is equal to the `INT` contained in the received `[data FROM 0 FOR 4]`.

These methods of checking are equivalent. If the check fails then the transmitted data was corrupted and re-transmission can be requested; if the check passes then it is most probable that the data was transmitted without corruption - just how probable depends on many factors, associated with the transmission media.

**Note:** The occam predefines `CRCBYTE` and `CRCWORD` can be chained together to help calculate a CRC from a byte string, and this is indeed the use to which they are put in `CRCFROMMSB` and `CRCFROMLSB`. However, because these latter routines shift the polynomial $F(x)$ corresponding to `InputString` by $x^n$, these routines should not be chained together over segments of a byte string to find its CRC; the whole string must be used in a single call to `CRCFROMMSB` or `CRCFROMLSB`.

### 1.9.2 Function definitions

`CRCFROMMSB`

```
INT FUNCTION CRCFROMMSB (VAL []BYTE InputString,
                         VAL INT PolynomialGenerator,
                         VAL INT OldCRC)
```

This routine is intended for strings in normal transputer format (little-endian). The most significant bit of the given string is taken to be bit-16 or bit-32, depending, that is, on the word size of the processor, of `InputString[(SIZE InputString) - 1]`.

`PolynomialGenerator`, `OldCRC` and the result are all also in normal transputer format (little-endian).

`CRCFROMLSB`

```
INT FUNCTION CRCFROMLSB (VAL []BYTE InputString,
                         VAL INT PolynomialGenerator,
                         VAL INT OldCRC)
```

This routine accommodates strings in big-endian format. The most significant bit of `InputString` is taken to be bit 0 of `InputString[0]`. The generated CRC is given in big-endian format. `PolynomialGenerator` and `OldCRC` are taken to be in little-endian format.

## 1.10 Extraordinary link handling library

**Library: `xlink.lib`**

The extraordinary link handling library contains routines for handling communication failures on a link. Four procedures are provided to allow failures on input and output channels to be handled by timeout or by signalling the failure on another channel. A fifth procedure allows the channel to be reset. Use of these routines is described in section 13.5 of the *User Guide*.

| Procedure | Parameter Specifiers |
|---|---|
| `InputOrFail.t` | `CHAN OF ANY c, []BYTE mess,` `TIMER t, VAL INT time, BOOL aborted` |
| `OutputOrFail.t` | `CHAN OF ANY c, VAL []BYTE mess,` `TIMER t, VAL INT time, BOOL aborted` |
| `InputOrFail.c` | `CHAN OF ANY c, []BYTE mess` `CHAN OF INT kill, BOOL aborted` |
| `OutputOrFail.c` | `CHAN OF ANY c, VAL []BYTE mess,` `CHAN OF INT kill, BOOL aborted` |
| `Reinitialise` | `CHAN OF ANY c` |

**CAUTION:**

Use of the routines in `xlink.lib` during *interactive debugging* will lead to undefined results.

### 1.10.1 Procedure definitions

The first four of these procedures take as parameters a link channel `c` (on which the communication is to take place), a byte vector `mess` (the object of the communication), and the boolean variable `aborted`. The choice of a byte vector for the message allows an object of any type to be passed along the channel providing it is retyped first. `aborted` is set to `TRUE` if the communication times out or is aborted; otherwise it is set to `FALSE`.

**Note:** In rare circumstances `aborted` *may* be set to `TRUE` even though the communication is successful. This happens if the communication terminates successfully in the interval between the timeout/abort and channel renitialization. The likelihood of this event is very small.

`InputOrFail.t`

```
PROC InputOrFail.t (CHAN OF ANY c, []BYTE mess,
                    TIMER t, VAL INT time,
                    BOOL aborted)
```

This procedure is used for communication where failure is determined by a timeout. It takes a timer parameter `t`, and an absolute time `time`. The procedure treats the communication as having failed when the time as measured by the timer `t` is `AFTER` the specified time `time`. If the timeout occurs then the channel `c` is reset and this procedure terminates.

`OutputOrFail.t`

```
PROC OutputOrFail.t (CHAN OF ANY c,
                      VAL []BYTE mess,
                      TIMER t, VAL INT time,
                      BOOL aborted)
```

This procedure is used for communication where failure is determined by a timeout. It takes a timer parameter `t`, and an absolute time `time`. The procedure treats the communication as having failed when the time as measured by the timer `t` is `AFTER` the specified time `time`. If the timeout occurs then the channel `c` is reset and this procedure terminates.

`InputOrFail.c`

```
PROC InputOrFail.c (CHAN OF ANY c, []BYTE mess,
                    CHAN OF INT kill,
                    BOOL aborted)
```

This procedure provides, through an abort control channel, for communication failure on a channel expecting an input. This is useful if failure cannot be detected by a simple timeout. Any integer on the channel `kill` will cause the channel `c` to be reset and this procedure to terminate.

`OutputOrFail.c`

```
PROC OutputOrFail.c (CHAN OF ANY c,
                      VAL []BYTE mess,
                      CHAN OF INT kill,
                      BOOL aborted)
```

This procedure provides, through an abort control channel, for communication failure on a channel attempting to output. This is useful if failure cannot be detected by a simple timeout. Any integer on the channel `kill` will cause the channel `c` to be reset and this procedure to terminate.

`Reinitialise`

```
PROC Reinitialise (CHAN OF ANY c)
```

This procedure may be used to reinitialize the link channel `c` after it is known that all activity on the link has ceased.

`Reinitialise` must only be used to reinitialize a link channel after communication has finished. If the procedure is applied to a link channel which is being used for communication the transputer's error flag will be set and subsequent behavior is undefined.

## 1.11 Debugging support library

**Library: `debug.lib`**

The debugging support library provides four procedures. Two procedures are provided to stop a process, one on a specified condition. The third procedure is used to insert debugging messages and the fourth procedure is a timer process for analyzing deadlocks.

| Procedure | Parameter Specifiers |
|---|---|
| DEBUG.STOP | () |
| DEBUG.ASSERT | VAL BOOL assertion |
| DEBUG.MESSAGE | VAL []BYTE message |
| DEBUG.TIMER | CHAN OF INT stop |

### 1.11.1 Procedure definitions

DEBUG.ASSERT

```
PROC DEBUG.ASSERT (VAL BOOL assertion)
```

If a condition fails this procedure stops a process and notifies the debugger.

If `assertion` evaluates `FALSE`, `DEBUG.ASSERT` stops the process and sends process data to the debugger. If `assertion` evaluates `TRUE` no action is taken.

If the program is not being run within the breakpoint debugger and the assertion fails, then the procedure behaves like `DEBUG.STOP`.

DEBUG.MESSAGE

```
PROC DEBUG.MESSAGE (VAL []BYTE message)
```

This procedure sends a message to the debugger which is displayed along with normal program output. **Note:** that only the first 83 characters of the message are displayed.

If the program is not being run within the breakpoint debugger the procedure has no effect.

DEBUG.STOP

```
PROC DEBUG.STOP ()
```

This procedure stops the process and sends process data to the debugger.

If the program is not being run within the breakpoint debugger then the procedure stops the process or processor, depending on the error mode that the processor is in.

DEBUG.TIMER

```
PROC DEBUG.TIMER (CHAN OF INT stop)
```

A timer process for use when analyzing deadlocks in occam programs. The procedure remains on the timer queue until receipt of any integer value on the channel `stop`, whereupon it will terminate. For an example of this form of usage see section 9.14.6 in the *User Guide*.

## 1.12 DOS specific hostio library

**Library:** `msdos.lib`

The MSDOS host file server library allows programs to use some facilities specific to the IBM PC. A set of constants for the library are provided in the include file `msdos.inc`.

**Caution:** Programs that use this DOS specific library will not be portable to versions of the toolset on other hosts.

| Procedure | Parameter Specifiers |
|---|---|
| `dos.receive.block` | `CHAN OF SP fs, ts,` `VAL INT32 location,` `INT bytes.read, []BYTE block,` `BYTE result` |
| `dos.send.block` | `CHAN OF SP fs, ts,` `VAL INT32 location,` `VAL []BYTE block,` `INT len, BYTE result` |
| `dos.call.interrupt` | `CHAN OF SP fs, ts,` `VAL INT16 interrupt,` `VAL[dos.interrupt.regs.size]BYTE register.block.in,` `BYTE carry.flag,` `[dos.interrupt.regs.size]BYTE register.block.out,` `BYTE result` |
| `dos.read.regs` | `CHAN OF SP fs, ts,` `[dos.read.regs.size] BYTE registers,` `BYTE result` |
| `dos.port.read` | `CHAN OF SP fs, ts,` `VAL INT16 port.location,` `BYTE value, result` |
| `dos.port.write` | `CHAN OF SP fs, ts,` `VAL INT16 port.location,` `VAL BYTE value, BYTE result` |

### 1.12.1 Procedure definitions

**dos.receive.block**

```
PROC dos.receive.block (CHAN OF SP fs, ts,
                         VAL INT32 location,
                         INT bytes.read,
                         []BYTE block,
                         BYTE result)
```

Reads a block of data, starting at `location`, from host memory. `location` is arranged as the segment in the top two bytes and the offset in the lower two bytes, both unsigned. The number bytes requested is `SIZE[block]`; the number of bytes read is returned in `bytes.read`. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The read operation was successful. |
| `spr.bad.packet.size` | Too many bytes were requested to be read: (`SIZE[block]`) > `dos.max.receive.block.buffer.size`. |
| ≥`spr.operation.failed` | The read failed, so `bytes.read` = 0. If `result` ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

**dos.send.block**

```
PROC dos.send.block (CHAN OF SP fs, ts,
                      VAL INT32 location,
                      VAL []BYTE block,
                      INT len, BYTE result)
```

Writes a block of data to host memory, starting at `location`. The location is arranged as the segment in the top two bytes and the offset in the lower two bytes, both unsigned.

The number of bytes requested to be written is `SIZE[block]`; the number of bytes written is returned in `len`. The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The write operation was successful. |
| `spr.bad.packet.size` | Too many bytes were requested to be written: (`SIZE[block]`) > `dos.max.send.block.buffer.size`. |
| ≥`spr.operation.failed` | The write failed. If `result` takes a value ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

## dos.call.interrupt

```
PROC dos.call.interrupt
    (CHAN OF SP fs, ts,
     VAL INT16 interrupt,
     VAL [dos.interrupt.regs.size] BYTE register.block.in,
     BYTE carry.flag,
     [dos.interrupt.regs.size] BYTE register.block.out,
     BYTE result)
```

Invokes an interrupt call on the host PC, with the processor's registers initialized to requested values. On return from the interrupt the values stored in the processor's registers are returned in `register.block.out`, along with the value of the carry flag on the PC, which is stored in `carry.flag`.

The interrupt number is specified by `interrupt`. The registers are represented by a block of bytes called `register.block.in`. This block stores the values to be written to the registers. Each register value occupies 4 bytes of a block. On the IBM PC the 2 most significant bytes are ignored as this machine has only 2 byte registers (16 bit registers). The layout of registers in the block is as follows:

| Register | Start position in block (least significant byte) | End position in block (most significant byte) |
|---|---|---|
| ax | 0 | 3 |
| bx | 4 | 7 |
| cx | 8 | 11 |
| dx | 12 | 15 |
| di | 16 | 19 |
| si | 20 | 23 |
| cs | 24 | 27 |
| ds | 28 | 31 |
| es | 32 | 35 |
| ss | 36 | 39 |

**Note**, however, that the `cs` and `ss` registers cannot be set.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The interrupt was successful. |
| `≥spr.operation.failed` | The interrupt failed. If `result` takes a value ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual*.) |

`dos.read.regs`

```
PROC dos.read.regs
               (CHAN OF SP fs, ts,
               [dos.read.regs.size] BYTE registers,
               BYTE result)
```

Reads the current values of some registers of the PC. The values of the registers are returned as a block of bytes, each register occupying 4 bytes of the block:

| Register | Start position in block (least significant byte) | End position in block (most significant byte) |
|---|---|---|
| ax | 0 | 3 |
| bx | 4 | 7 |
| cx | 8 | 11 |
| dx | 12 | 15 |

On the IBM PC the 2 most significant bytes are ignored as this machine has only 2 byte registers (16 bit registers).

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The read was successful. |
| ≥`spr.operation.failed` | The read failed. If `result` takes a value ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

`dos.port.read`

```
PROC dos.port.read (CHAN OF SP fs, ts,
                    VAL INT16 port.location,
                    BYTE value, result)
```

Reads the value at the port, specified by the port address `port.location`. The port address being in the input/output space of the PC is an unsigned number between 0 and 64K.

No check is made to ensure that the value received from the port (if any) is valid. The value returned in `value` is that of the given address at the moment the port is read by the host file server.

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The read was successful. |
| `≥spr.operation.failed` | The read failed. If `result` takes a value ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

## dos.port.write

```
PROC dos.port.write (CHAN OF SP fs, ts,
                     VAL INT16 port.location,
                     VAL BYTE value, BYTE result)
```

Writes `value` to the port specified by the port address `port.location`. The port address being in the input/output space of the PC is an unsigned number between 0 and 64K.

No check is made to ensure that the value written to the port has been correctly read by the device connected to the port (if any).

The result returned can take any of the following values:

| | |
|---|---|
| `spr.ok` | The write was successful. |
| `≥spr.operation.failed` | The write failed. If `result` takes a value ≥ `spr.operation.failed` then this denotes a server returned failure. (See section C.2 in the *Toolset Reference Manual.*) |

# Appendices

# A Language extensions

This appendix describes language extensions that are supported by the occam 2 compiler.

**Note:** These extensions are compiler-dependent and do not extend the syntax of the occam 2 language as defined in the *occam 2 Reference Manual.*

## A.1 Syntax

### A.1.1 Compiler keywords

The following additional keywords are supported by the occam 2 compiler:

```
ASM GUY IN INLINE VECSPACE WORKSPACE
```

### A.1.2 Compiler directives

The following directives are supported by the occam 2 compiler:

```
#INCLUDE  #USE  #COMMENT  #IMPORT  #OPTION  #PRAGMA
```

For more information see section 1.12 of the *Toolset Reference Manual.*

### A.1.3 String escape characters

The syntax of the non-printable character '`*`', as defined in section I of the *occam 2 Reference Manual* has been extended. The first character of a literal string may now take the value '`*l`' or '`*L`', which is used to represent the length of the string, excluding the character itself. For example, the following statements define the same string:

```
VAL string1 is "*lFred" :
VAL string2 is "*#04Fred" :
```

'`*l`' (or '`*L`') is illegal if the string (excluding the '`*l`') is longer than 255 bytes, and will be reported as an error.

The characters `*`, `'` and `"` may be used in the following form:

| | | | | |
|---|---|---|---|---|
| `*c` | `*C` | carriage return | = | `*#0D` |
| `*l` | `*L` | string length | ≤ | `*#FF` |
| `*n` | `*N` | newline | = | `*#0A` |
| `*t` | `*T` | tab | = | `*#08` |
| `*s` | `*S` | space | = | `*#20` |
| `*'` | | quotation mark | | |
| `*"` | | double quotation mark | | |
| `**` | | asterisk | | |

Any byte value can be represented by `*#` followed by two hexadecimal digits.

### A.1.4 Tabs

- The compiler expands tabs in source files to be every eighth character position. Tabs are permitted anywhere in a line but are not expanded within strings or character constants.

### A.1.5 Relaxations on syntax

- There is no limit on the number of significant characters in identifiers, and the case of characters is significant.

## A.2 Channel operations

The following operations on channels are now permitted:

- Channels can be retyped
- Channels can be constructed from other channels ('channel constructors')
- Protocols of type `ANY` can be named ('anarchic protocols')

### A.2.1 Retyping channels

Channels may be retyped:

- to and from data items
- between protocols of different types.

Data items map onto a pointer to the channel word. This can be used, for example, to determine the address of the channel word, or to create an array of channels pointing at particular addresses:

```
CHAN OF protocol c :
VAL INT x RETYPES c :   -- Must be a VAL RETYPE
...   use x as the address of the channel word
```

**Note**: This operation (retyping a channel to a data item) can be achieved more portably by means of the `LOAD.INPUT.CHANNEL` predefine. See sections 13.4 of the *occam 2 Toolset User Guide* and 1.3.7 in this manual.

The following code demonstrates how to create a channel array whose channels point at arbitrary addresses.

```
[10]INT x :
SEQ
  ...  initialise elements of x to the addresses of
  ...  the channel words
  [10]CHAN OF protocol c RETYPES x :
  ...  use channel array c
```

Retyping between channel protocols allows the protocol on a channel to be changed, for example, in order to pass it as a parameter to another routine:

```
PROTOCOL PROT32 IS INT32 :
PROC p (CHAN OF INT32 x)
  x ! 99(INT32)
:
PROC q1 (CHAN OF PROT32 y)
  SEQ
    p (y)                         -- this is illegal
    CHAN OF INT32 z RETYPES y :
    p (z)                         -- this is legal
:
```

This facility should be used with care; further details are given in section 13.2 of the *occam 2 Toolset User Guide*.

### A.2.2 Channel constructors

Arrays of channels may be constructed out of a list of other channels, see section 13.2 of the *occam 2 Toolset User Guide*. For example:

```
PROC p (CHAN OF protocol a, [2]CHAN OF protocol b)
  [3]CHAN OF protocol c IS [a, b[0], b[1]] :
    -- channel constructor
  ALT i = 0 FOR SIZE c
    c[i] ? data
      ...
:
```

### A.2.3 'Anarchic' protocols

`PROTOCOL`s may now be declared of type `ANY`. This means that a channel of that protocol can communicate a *single* item of any type. Sequential protocols can include an item of type **ANY**. This suppresses type-checking of a *single* element in a communication list. Note that these should be contrasted against **CHAN OF ANY**, where the keyword **ANY** matches any number of items.

The following addition is made to the occam syntax in the *occam 2 Reference Manual*:

*simple.protocol* = **ANY**

For example:

```
PROTOCOL p0 IS ANY :
CHAN OF p0 c0 :
SEQ
  c0 ! 88
  c0 ! 'b'
  c0 ! 6 :: "heaven"

PROTOCOL p1 IS INT ; ANY :
CHAN OF p1 c1 :
SEQ
  c1 ! 0; 88
  c1 ! 1; 'b'
  c1 ! 2; 6 :: "heaven"
```

Note: **CHAN OF ANY** is now considered obsolescent and the named protocol construct described above should be used in preference.

CHAN OF ANY

The facility which allows a channel declared as **CHAN OF ANY** can be passed as an actual parameter in place of a formal channel parameter of *any* protocol is still supported but is obsolescent. A channel of a specific protocol *cannot* be passed in place of a formal channel parameter of **CHAN OF ANY**. Communications on a channel declared as **CHAN OF ANY** must be identical at both ends of the channel.

## A.3 Low level programming

### A.3.1 ASM

The keyword **ASM** introduces a section of transputer assembly code. See appendix D of the *occam 2 Toolset User Guide*.

### A.3.2 PLACE statements

The **PLACE** statement in occam allows a channel, a variable, an array, or a input/output channel for a memory mapped device (port), to be placed at an absolute location in memory, workspace, or vector space.

The syntax of the supported `PLACE` statements extends the definition of an allocation as defined in the *occam 2 Reference Manual*:

| | | |
|---|---|---|
| *allocation* | = | `PLACE` *name* `AT` *expression* |
| | \| | `PLACE` *name* `AT WORKSPACE` *expression* |
| | \| | `PLACE` *name* `IN WORKSPACE` |
| | \| | `PLACE` *name* `IN VECSPACE` |

The `PLACE` statement must be inserted immediately following the declaration of the variable to which it refers e.g.

```
int x, y, z :
PLACE x .....
PLACE y .....        is correct

int x :
int y :
PLACE x .....        is incorrect
```

The address used in a `PLACE` allocation is converted to a transputer address by considering the address to be a word offset from `MOSTNEG INT`.

For example, in order to access a `BYTE` memory mapped peripheral located at machine address `#1234`, on a 32-bit processor:

```
PORT OF BYTE peripheral :
PLACE peripheral AT (#1234 >< (MOSTNEG INT)) >> 2 :
peripheral ! 0 (BYTE)
```

The numbers used as `PLACE` addresses are word offsets from the bottom of address space. For example, `PLACE` *scalar channel* `AT` *n* places the channel word at that address, and `PLACE` *array of channels* `AT` *n*, places the array of pointers at that address.

The `PLACE` *name* `IN WORKSPACE` and `PLACE` *name* `IN VECSPACE` statements place variables explicitly in program workspace and vector space respectively. The allocation of workspace and vectorspace by the compiler is described in Appendix B of this manual. Section 13.1 of the *occam 2 Toolset User Guide* also describes allocation.

### A.3.3 `INLINE` keyword

`INLINE` may be used immediately before the `PROC` or `FUNCTION` keyword of any procedure or function declaration. It will cause the body of the procedure or function to be expanded inline in any call, and the declaration will not be compiled as a normal routine. Use of `INLINE` procedures or functions may increase the size of the object module but will also avoid the overheads incurred in executing extra calls.

The `INLINE` statement extends the syntax of a definition as defined in the *occam 2 Reference Manual*:

*definition* = `PROTOCOL` *name* `IS` *simple.protocol:*
| `PROTOCOL` *name* `IS` *sequential.protocol:*
| `PROTOCOL` *name*
  `CASE`
    *{tagged.protocol}*
*:*
| `[INLINE] PROC` *name* ( $\{_0$ , *formal* } )
   *procedure.body*
*:*
| $\{_1$ , *primitive type* } `[INLINE] FUNCTION` *name*
  ( $\{_0$ , *formal* } ) *function.body*
*:*
| $\{_1$ , *primitive type* } `[INLINE] FUNCTION` *name*
  ( $\{_0$ , *formal* } ) `IS` *expression.list:*
| *specifier name* `RETYPES` *element:*
| `VAL` *specifier name* `RETYPES` *expression:*

**Examples:**

```
INT INLINE FUNCTION sum3 (VAL INT x, y, z,) IS x + (y + z):

INLINE PROC seterror ()
  error := TRUE
:
```

A call to the `FUNCTION sum3`:

```
so.write.int(fs, ts, sum3(p,q,r),0)
```

would be expanded by the compiler thus:

```
so.write.int(fs, ts, p + (q + r),0)
```

**Note:** the declaration is marked with the keyword, but the call is affected. This means that you cannot inline expand procedures and functions which have been declared by a `#USE` directive; to achieve that effect you may put the source of the routine, marked with the `INLINE` keyword, in a separate file, and include this file with an `#INCLUDE` directive.

## A.4 Counted array input

The semantics of counted array input are extended from those described in the *occam 2 Reference Manual*.

The new semantics are as follows:

```
message ? len :: buffer
```

This input receives an integer value which is assigned to the variable `len`, and that number of components, which are assigned to the first components of the array `buffer`. The assignments to `len` and `buffer` happen in parallel and therefore the same rules apply as for parallel assignment. That is, the name `len` may not appear free in `buffer`, and vice versa.

In occam 2 the count was input first and the parallel assignment rules did not apply. Some occam 2 programs are invalidated by the new rule.

As a concession to backwards compatibility, the compiler permits communications of the form:

*channel.exp* `?` *name* `::` `[` *array.exp* `FROM 0 FOR` *name* `]`

These are transformed by the compiler into the equivalent modern form:

*channel.exp* `?` *name* `::` *array.exp*

## A.5 Retyping arrays

Multi-dimensional arrays defined by a `RETYPES` definition may have one element whose value is not explicitly stated. This may be any one of the elements. For example:

```
[6]INT a, f :
[2][ ]INT b RETYPES a :
[ ][3]INT c RETYPES f :

[24]INT d :
[2][ ][6] e RETYPES d :
```

## A.6 Obsolescent features

The following language constructs are considered to be obsolescent, and may be removed in future versions of the compiler:

- `CHAN OF ANY` as defined in the *occam 2 Reference Manual* is obsolescent. It should be replaced by a named `PROTOCOL` (which may be of type `ANY`), to give greater security. Any declaration of a channel of type `CHAN OF ANY` will be flagged by a warning by the compiler.
- The language extension which provides the ability to pass an actual parameter of type `CHAN OF ANY` to a procedure whose formal parameter is of a different channel type is obsolescent. Channel `RETYPE` should be used to make the type conversion explicit.

- The ability to write the following counted array input is obsolescent.

  *channel.exp* ? *name* : : [ *array.exp* **FROM** 0 **FOR** *name* ]

  The following equivalent construct should be used instead.

  *channel.exp* ? *name* : : *array.exp*

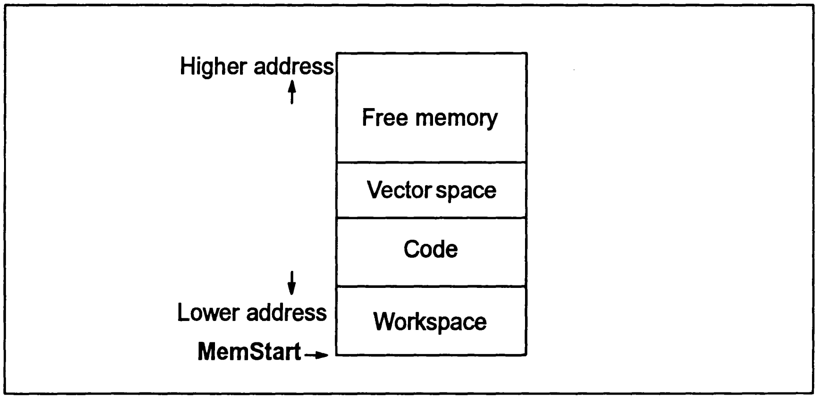
- The **GUY** construct is obsolescent; the **ASM** construct should be used instead.

# B Implementation of occam on the transputer

This appendix defines the toolset implementation of occam on the transputer. It describes how the compiler allocates memory and gives details of type mapping, hardware dependencies and language. The appendix ends with the syntax definition of the language extensions implemented by the occam compiler.

## B.1 Memory allocation by the compiler

The code for a whole program occupies a contiguous section of memory. When a program is loaded onto a transputer in a network, memory is allocated in the following order starting at **MemStart**: workspace; code; separate vector space. This is shown below:

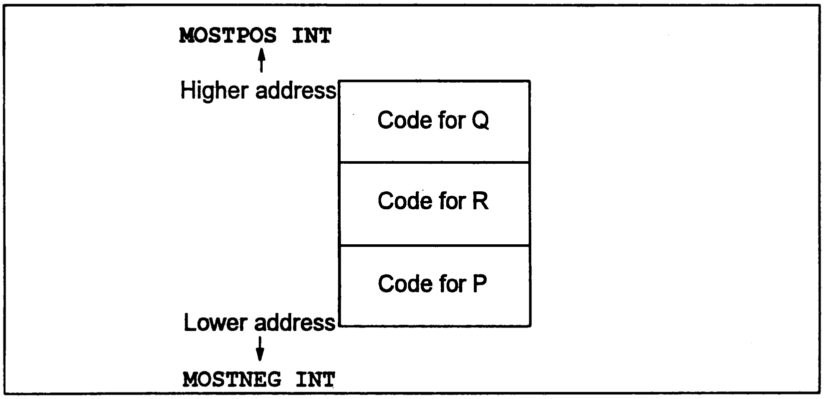


### B.1.1 Procedure code

The compiler places the code for any nested procedures at higher addresses (nearer `MOSTPOS INT`) than the code for the enclosing procedure. Nested procedures are placed at increasingly lower addresses in the order in which their definitions are completed. For the code in the following example:

```
PROC P()
  PROC Q ()
    ...  code for Q
  :
  PROC R ()
    ...  code for R
  :
  ...  code for P
:
```

the layout of the code in memory is:



### B.1.2 Compilation modules

The order in which compilation modules are placed in memory, including those referenced by a `#PRAGMA LINKAGE` directive, is controlled by a linker directive. Modules are placed in priority order, with the highest priority module being placed at the lowest available address.

**Note**: the compiler will attempt to optimize floating point routines such as `REAL32OP` and `REAL32OPERR` by giving them a high priority. This can be overridden by using the compiler directive `#PRAGMA LINKAGE` in conjunction with the linker directive `#section`.

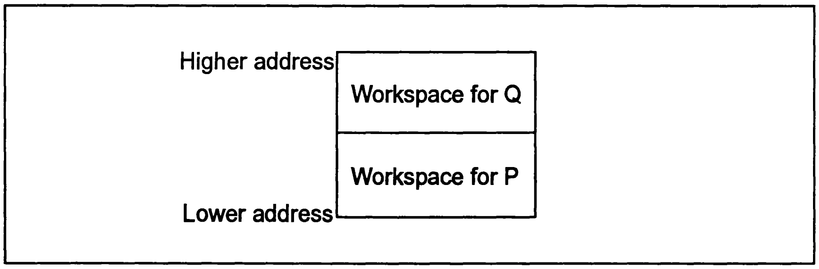
### B.1.3 Workspace

Workspace is placed lowest in memory, before the arithmetic handling library, so that it has priority usage of the on-chip RAM, if the processor is configured to have any.

Workspace is allocated from higher to lower address (i.e. the workspace for a called procedure is nearer `MOSTNEG INT` than the workspace for the caller). For example:

```
PROC P ()
  ...   code
  here
  ...   code
:
PROC Q ()
  P ()
:
```

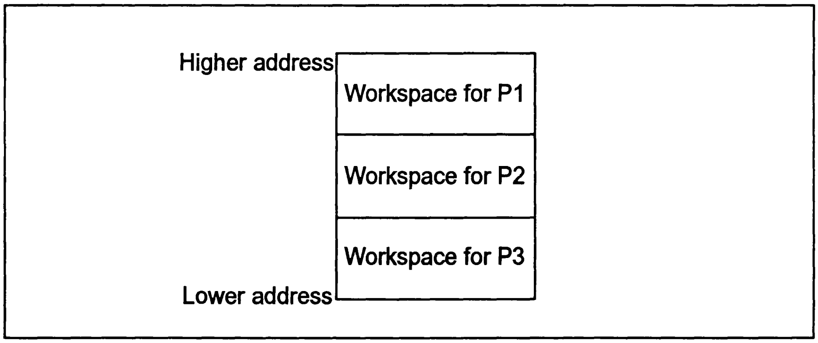
In the above example when Q is called, it will in turn call P. At the point labelled **here**, the data layout in memory will be:



In a PAR or PRI PAR construct the last textually defined process is allocated the lowest addressed workspace. For example:

```
PAR
  ... P1
  ... P2
  ... P3
```

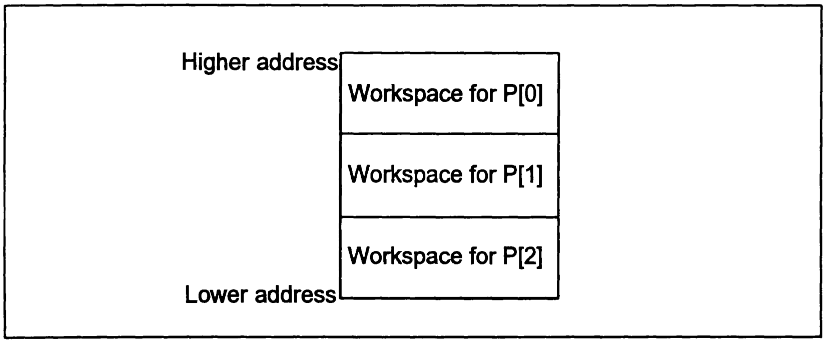
the workspace layout for the parallel processes will be:



In a replicated PAR construct the instance with the highest replication count is allocated the lowest workspace address. For example:

```
PAR i = 0 FOR 3
  P [i]
```

the workspace layout for the parallel processes will be:



Unless separate vector space is disabled, most arrays are allocated in a separate data space, known as vector space, see section B.1.4. The allocation is done in a similar way to the allocation of workspace, except that the data space for a called procedure is at a *higher* address than the data space of its caller.

The variables within a single procedure or parallel process are allocated on the basis of their estimated usage. The variables which the compiler estimates will be used the most, are allocated lower addresses in the current workspace.

From within a called procedure the parameters appear immediately above the local variables. When an unsized vector is declared as a formal procedure parameter an extra `VAL INT` parameter is also allocated to store the size of the array passed as the actual parameter. This size is the number of elements in the array. One extra parameter is supplied for each dimension of the array unsized in the call, in the order in which they appear in the declaration.

If a procedure requires separate vector space, it is supplied by the calling procedure. A pointer to the vector space supplied is given as an additional parameter. If the procedure is at the outer level of a compilation unit, the vector space pointer is supplied after all the actual parameters. Otherwise it is supplied before all the actual parameters.

### B.1.4 Vectorspace

By default, arrays larger than 8 bytes are allocated into a separate stack known as the *vectorspace*. This scheme optimizes use of the workspace, creating more compact and quicker code. It can also make better use of a transputer's on-chip RAM. The default scheme may be overridden by an option on the command line, a directive in the source code, or, for specific variables only, by a place statement.

This can be overridden per compilation unit by the `V` command line switch or `#OPTION "V"` directive. This will force all variables into the workspace. Secondly, the current 'default' may be overridden on an array-by-array basis by using extra allocations as follows:

```
[100]BYTE a :
PLACE a IN WORKSPACE :   -- forces a to reside in
workspace

[100]BYTE b :
PLACE b IN VECSPACE :    -- forces b to reside in
vectorspace
```

Only arrays may be placed in vectorspace; scalar variables must reside in workspace. Arrays smaller than 8 bytes may be explicitly placed in vectorspace.

It may be desirable to change the default vectorspace allocation for various reasons. Using vectorspace can actually slow down execution, since an extra parameter is passed to each subroutine which requires it. However, this cost is normally overwhelmed by the reduction in workspace size, and the associated compaction in the number of prefix instructions required to address local variables. In certain circumstances it may be useful to place a commonly used array into workspace, particularly if it is heavily used in array assignment (block moves). Alternatively it may be useful to place most arrays in workspace, but move any large arrays into vectorspace.

## B.2 Type mapping

This section defines all the occam types and how they are represented on the each target processor.

All objects are word aligned, i.e. the lowest byte of the object is on a word boundary. For objects of type BOOL and BYTE, the padding above the object is guaranteed to be all bits zero: for all other objects, the value of any padding bytes is undefined.

Arrays are packed, i.e. there are no spaces between the elements. (**Note**: that an object of type BOOL has one byte for each element).

Table A.1 summarizes the type mapping, for further information on data types see Section 3 of the *occam 2 Reference Manual.*

Protocol tags are represented by 8-bit values. The compiler allocates tag values for each protocol from 0 (BYTE) upwards in order of declaration.

Values accessed through RETYPES must be aligned to the natural alignment for that data type; BYTEs and BOOLs may be aligned to any byte; INT16s on a 32 bit processor must be aligned to a half-word boundary and all other data types must be aligned to a word boundary. This will be checked at run-time if it cannot be checked at compile time. For example:

```
[20]BYTE array:                   -- This will be word aligned

INT32 x RETYPES [array FROM 1 FOR 4] : -- Run-time check is inserted

INT32 y RETYPES [array FROM i FOR 4] : -- Run-time check is inserted

INT32 z RETYPES [array FROM 8 FOR 4] : -- No run-time check inserted
```

Channels may be RETYPEd. This allows the protocol on a channel to be changed, in order to pass it as a parameter to another routine. This facility should be used with care, see section A.2.1.

| Type | Storage | Range of values |
|---|---|---|
| BOOL | 1 byte | FALSE, TRUE |
| BYTE | 1 byte | 0 to 255 |
| INT16 | 2 bytes | –32768 to 32767 |
| INT32 | 4 bytes | –2,147,483,648 to 2,147,483,647 |
| INT64 | 8 bytes | $-2^{63}$ to $(2^{63}-1)$ |
| INT (On 32–bit processors) | 4 bytes | –2,147,483,648 to 2,147,483,647 |
| INT (On 16–bit processors) | 2 bytes | –32768 to 32767 |
| REAL32 | 4 bytes | IEEE single precision format |
| REAL64 | 8 bytes | IEEE double precision format |
| CHAN (On 32–bit processors) | 8 bytes | Channels are implemented as a pointer to a channel word. |
| CHAN (On 16–bit processors) | 4 bytes | |
| PORT OF D | As for D | |
| TIMER | None | |

Table A.1 occam data types

## B.3 Implementation of channels

The data type of a channel is '*pointer to channel*'. When mapping channels to specific transputer links, the channel word is placed at the specified address for scalar channels. Arrays of channels are mapped as arrays of pointers to channels.

As a result of this PLACEing arrays of channels is implemented such that:

```
PLACE array.of.channels AT n:
```

places the array of pointers at that address.

```
PLACE scalar.channel AT n:
```

places the channel word at that address.

An example of the placement of channels on links is given in Chapter 13 of the *User Guide*.

Arrays of channels may be constructed out of a list of other channels. For example:

```
PROC p (CHAN OF protocol a, [2]CHAN OF protocol b)
  [3]CHAN OF protocol c IS [a, b[0], b[1]] :
  -- channel constructor

  ALT i = 0 FOR SIZE c
    c[i] ? data
      ...
:
```

Channel constructors extend the facilities for manipulating channels; further information is given in section 13.2 of the *User Guide*.

## B.4 Transputer timers (clocks)

The transputer has two timers which can be accessed by the programmer. They are used for real time programming, timing events, data logging, timing out, delays and so on.

Two timers are provided to give low and high resolution timing. The timers themselves are word length registers which are incremented regularly and related to the speed of the input clock. The low resolution timer goes 64 times slower than the high resolution timer. These speeds are independent of transputer model, processor speed, and word length.

| Priority | Low | High |
|---|---|---|
| Time between ticks | 64μs | 1μs |
| Ticks per sec | 15625 | 1000000 |
| Approx. cycle time (16 bit) | 4s | 65ms |
| Approx. cycle time (32 bit) | 76h | 1h 10m |

The high resolution timer is always used by high priority processes, so is often called the high priority timer. The low resolution timer is always used by low priority processes.

### B.4.1 TIMER variables

TIMER variables in occam give access to the transputer timers. The syntax of timer input is similar to channel input.

Timers can have only one of two possible values, corresponding to the high and low priority transputer clocks. The clock which is read depends on the priority of the enclosing process. When comparing clock values the same timer variable should be used, and the value *must* be input from the same process or from a process of the same priority. If the same timer is used in processes with different priorities, the results are undefined.

A common use of timers is to time a process, for example, a channel input:

```
TIMER clock:
SEQ
  clock ? start
  chan ? y
  clock ? end
  delay := end MINUS start
```

The `MINUS` operator performs a 'modulo' subtraction and is used to give a relative difference because the transputer timers operate on a wrap-around principle. The maximum period that can be timed is limited to clock-cycle-time divided by 2 i.e. on 16 bit transputers, about 33ms at high priority and 2s at low priority. If the period being measured is likely to be greater than this then a delay period based on multiples of clock cycles should be built in.

### B.4.2 `TIMER`s as formal parameters

When calling occam from C, any formal `TIMER` parameter in the occam procedure or function must be ignored by the calling C code, and no actual parameter should be passed. When calling occam routines from other occam routines an actual parameter should be passed in the normal way.

## B.5 `CASE` statement

The `CASE` statement is implemented as a combination of explicit test, binary searches, and jump tables, depending on the relative density of the selection values. The choice has been made to optimize the general case where each selection is equally probable. The compiler does not make any use of the order of the selections as they are written in the source code.

## B.6 `ALT` statement

No assumption can be made about the relative priority of the guards of an `ALT` statement; if priority is required, you must use a `PRI ALT`.

## B.7 Formal parameters

If a name is used more than once in a single formal parameter list, the *last* definition is used.

## B.8 Hardware dependencies

- The number of priorities supported by the transputer is 2, (i.e. high and low), so a `PRI PAR` may have two component processes. The compiler does not permit a `PRI PAR` statement to be nested inside the high priority branch of another. This is checked at compile time, even across separately compiled units.

- The low priority clock increments at a rate of 15 625 ticks per second, or one tick = 64 microseconds (IMS T212, T222, T225, M212, T400, T414, T425, T800, T801 and T805).
- The high priority clock increments at a rate of 1 000 000 ticks per second, or one tick = 1 microsecond (IMS T212, T222, T225, M212, T400, T414, T425, T800, T801 and T805).
- `TIMER` channels cannot be placed in memory with a `PLACE` statement.

## B.9 Summary of implementation restrictions

- `FUNCTION`s may not return arrays, not even with fixed sizes.
- Multiple assignment of arrays of unknown size is not permitted.
- Replicated `PAR` count must be constant.
- There must be exactly two branches in a `PRI PAR`.
- Replicated `PRI PAR`s are not permitted.
- Nested `PRI PAR`s are not permitted.
- `PLACE` statements must immediately follow the declaration of the variable to which they refer.
- Compiler pragmas `SHARED` and `PERMITALIASES` must immediately follow the declaration of the variable to which they refer.
- Table sizes must be known at compile time, for example:

```
PROC p ([]INT a, []INT b)
  VAL [] []INT x IS [a] :   -- this is illegal
  VAL    []INT y IS b :     -- this is legal
:
```

- Constant arrays which are indexed by replicator variables are not considered to be constants for the purposes of compiler constant folding, even if the start and limit of the replicator are also constant. This restriction does not apply during usage checking.
- `FUNCTION`s which use `ALT` replicator variables as free variables may not be called in the guard of the same `ALT`. An error is reported at compile time if this occurs. Example:

```
PROC P([10]CHAN OF INT c
  ALT i = 0 FOR 10
    INT FUNCTION f() IS 9 - i :
    INT x:
    c[f()] ? x      -- call of 'f()' is illegal
      SEQ
        ...
        ALT
          c[f()] ? x    -- this is legal.
```

This can be resolved by passing the replicator variable into the `FUNCTION` as a parameter:

```
PROC P([10]CHAN OF INT c
  ALT i = 0 FOR 10
    INT FUNCTION f(VAL INT i) IS 9 - i :
    INT x:
    c[f(i)] ? x     -- call of 'f(i)' is legal
      SKIP
```

- Maximum array size is 64 Kbytes on 16-bit processors, 2 Gbytes on 32-bit processors. No dimension of any array may exceed `MOSTPOS INT`.
- Maximum filename length is 128 characters.
- Maximum 256 tags allowed in `PROTOCOL`s.
- Maximum number of lexical levels is 254. (Applies to nested `PROC`s and replicated `PAR`s).
- The compiler places restrictions on the syntax which is permitted at the outermost level of a compilation unit; i.e. not enclosed by any function or procedure.

  – No variable declarations are permitted.

  – No abbreviations containing function calls or `VALOF`s are allowed, even if they are actually constant. For example:

```
VAL x IS (VALOF
            SKIP
            RESULT 99
         ) :               -- This is illegal.
VAL m IS max (27, 52) :  -- This is also illegal.
```

# C Alias and usage checking rules

## C.1 Alias checking

This section describes the alias checking that is implemented by the compiler.

In the following text 'assigned to' means 'assigned to by assignment or input'.

### C.1.1 Introduction

Alias checking is the name given to the series of checks made by the compiler on occam 'abbreviations' to ensure that an object is known by a single name within a given scope i.e. no 'aliases' exist. In practice this means that:

- named abbreviations must be used correctly within the code
- expressions used to define abbreviations (plus any subscripts within them) must be valid and within range
- variables in defining expressions must not be changed.

The same rules apply to *retyped* names, since retyping is simply another form of abbreviation.

Alias checking is governed by a strict set of rules. This enables many checks to be done at compile time, reducing the need for runtime checking code. Some checks, however, can only be performed at runtime.

Alias checking can be disabled in a compilation unit or for specific variables. It is then up to the programmer to ensure that the rules are complied with, or the behavior of the program is *undefined*.

The formal rules for alias checking are set out below. For further details see the *occam 2 Reference Manual.*

### C.1.2 Rules

#### Scalar variables

**(Rule 1)** If a scalar variable appears in the abbreviated expression of a `VAL` abbreviation, for example:

`x` in `VAL a IS x + 2 :`

then that variable may not be assigned to or abbreviated by a non-`VAL` abbreviation anywhere within the scope of the `VAL` abbreviation.

**(Rule 2)** If a scalar variable is abbreviated in a non-`VAL` abbreviation, for example:

`x` in `a IS x :`

then that variable may not be referenced anywhere within the scope of the abbreviation.

**Arrays**

The rules for arrays attempt to treat each element of the array as an individual scalar variable. They allow the maximum freedom possible without introducing run time checking code except at points of abbreviation. In the following text the word constant means any expression that can be evaluated at compile time. If an array is referenced in the expression of a `VAL` abbreviation, for example:

`x` in `VAL a IS x[i] :`

then the following rules apply to the use of the array within the scope of the abbreviation:

**(Rule 3)** If the subscript is constant then elements of the array may be assigned to as long as they are only subscripted by constant values different from the abbreviated subscript. Any element of the array may also appear anywhere in the expression of a `VAL` abbreviation. Any other elements of the array may be non-`VAL` abbreviated, and run time checking code is generated if subscripts used in the abbreviation are not constant.

**(Rule 4)** If the subscript is not constant then no element of the array may be assigned to unless it is first non-`VAL` abbreviated. The non-`VAL` abbreviation will have to generate run time code to check that it does not overlap the `VAL` abbreviation. The array may be used in the expression of a `VAL` abbreviation.

Elements of the array may be accessed anywhere within the scope of the abbreviation except where restricted by further abbreviations. If an array is abbreviated in a non-`VAL` abbreviation, for example:

`x` in `a IS x[i] :`

then the following rules apply to the use of the array within the scope of the abbreviation:

**(Rule 5)** If the subscript is constant then elements of the array may be read and assigned to as long as they are accessed by constant subscripts different from the abbreviated subscript. Other elements of the array may be abbreviated in further `VAL` and non-`VAL` abbreviations, and run time checking code is generated if subscripts used in the abbreviation are not constants.

**(Rule 6)** If the subscript is not constant then the array may not be referenced at all except in abbreviations where run time checking code is needed to check that the abbreviations do not overlap.

**(Rule 7)** Variables used in subscripts of the array being abbreviated act as if they have been `VAL` abbreviated. In the above example 'i' acts as if it has been `VAL` abbreviated and cannot be altered in the scope of the abbreviation. Where elements of the array being abbreviated are used in the subscript of the array then the abbreviation is checked as if the subscript expression was `VAL` abbreviated just before the non-`VAL` abbreviation. For example:

```
a IS x[x[2]] :
```

is checked as if it was written:

```
VAL subscript IS x[2] :
a IS x[subscript] :
```

which (by Rule 6 above) will generate run time checking code.

### C.1.3 Alias checking disabled

**Note**: the compiler will be able to generate the most efficient code when all alias checks are *enabled*.

When alias checking is disabled, either on a compilation unit or on specific variables, the compiler cannot guarantee no aliasing on the affected variables. It is then the programmer's responsibility to ensure that the following rules are not broken.

The set of 'aliasable' variables consists of either the set of *all* variables declared in the compilation unit (if the whole compilation unit has alias checking turned off by the '`A`' command line option or the `#OPTION "A"` directive), or the set of all variables which have been marked by the pragma `PERMITALIASES`. See chapter 1 in the *Toolset Reference Manual.*

In the presence of 'aliasable' variables, the behavior of a program is defined in the intuitive model, where all reads and assignments to 'aliasable' variables are executed strictly in the order in which they are written; they may not be re-ordered by an optimizer. Note also that because of retyping it cannot be assumed that a write to an 'aliasable' variable of one type will not affect an 'aliasable' variable of another type.

When variables are 'aliasable' the following rules apply.

#### VAL abbreviations

Suppose we have a `VAL` abbreviation of the form:

VAL *name* IS *expression* :

If *name* is 'aliasable', then

> all component variables of *expression* are automatically inferred to be 'aliasable' by the compiler and may be modified in the scope of the abbreviation,

and therefore:

> *name* must not be used after any component variable of *expression* is modified.

If this constraint is not met, the behavior of the program is *undefined*, and results will be implementation-dependent.

For example:

```
VAL x IS a[i] :
#PRAGMA PERMITALIASES x
SEQ
  ...  use 'x'                -- This is OK
  ...  modify 'i' or 'a[i]'   -- This is OK if 'x' is
                              -- 'aliasable'
  ...  use 'x'                -- This is undefined
```

**Non-VAL abbreviations**

Suppose we have a non-VAL abbreviation of the form:

*name* IS *element* :

If *name* is 'aliasable', then:

> any variable used in a subscript to select a component or components of an array reference in *element* may be modified in the scope of the abbreviation. (All such variables are automatically inferred to be 'aliasable' by the compiler.)

and therefore:

> *name* must not be used after a variable used in a subscript to select a component or components of an array referenced in *element* has been modified.

If this constraint is not met, the behavior of the program is *undefined*, and results will be implementation-dependent.

If the base variable of *element* is 'aliasable' then:

> the actual element referred to by such an abbreviation *may* be modified within the scope of the abbreviation. *name* is automatically inferred to be

> 'aliasable' by the compiler, and the abbreviation is implemented as though *name* is a pointer to the *element.*

An alias may subsequently be created, either by referring to *element* explicitly in the scope of the abbreviation, or by using another abbreviation within the scope.

**Multiple assignment**

In a multiple assignment, the destinations of the assignment are written to as though they are in parallel. Therefore:

> variables listed as the left hand side of a multiple assignment *must not* be aliased.

It is up to the programmer to ensure that this rule is complied with. If it is not, the behavior of the program is *undefined.*

Note that it is perfectly legal for the destinations of an assignment to alias expressions used on the right hand side of an assignment. Thus destination variables *may* be aliased with actual parameters to a `FUNCTION`.

**Procedure parameters**

It is assumed that only (non-`VAL`) formal parameters of a procedure which are 'aliasable' may be aliased, either with each other, with the `VAL` parameters, or with 'aliasable' free variables.

If an actual parameter to a procedure aliases another actual parameter, or aliases a free variable used by the procedure, then:

> the *formal* parameter must be marked as 'aliasable'. Note that this also applies across separately compiled units.

Since the rules for procedure parameters derive from those for abbreviations, the following constraint applying to `VAL` abbreviations also applies. That is:

> any variable used in an actual parameter corresponding to a `VAL` formal parameter must not be modified in the body of the procedure prior to the final read of the formal parameter.

It is up to the programmer to ensure that these rules are complied with. If they are not, the behavior of the program is *undefined.*

**Interaction with usage checking**

Since the usage checking algorithms rely on lack of aliasing, any 'aliasable' variable is automatically inferred to be 'shared', see section C.2.8.

## C.2 Usage checking

This section describes the usage checking that is implemented by the compiler.

### C.2.1 Introduction

Usage checking is the name given to the series of checks made by the compiler to ensure that parallel processes do not share variables, channels span only two processes, and communication down channels is unidirectional. Using a set of rules means that many checks can be done at compile time, reducing the need for runtime checking code.

### C.2.2 Usage rules of occam

The usage checking rules of occam 2 are as follows:

- No variable assigned to, or input to, in any component of a parallel may be used in any other component.
- No channel may be used for input in more than one component process of a parallel.
- No channel may be used for output in more than one component of a parallel.
- A variable which is named on the right hand side of a non-VAL abbreviation is considered to be modified, whether or not it actually is.
- Formal array parameters of a routine are considered to be wholly accessed if any component of the array is accessed, whether or not by a constant subscript. Similarly, free arrays (i.e. arrays which are accessed non-locally) of any routine are also considered to be wholly accessed if any component of the array is accessed.

### C.2.3 Checking of non-array elements

Variables and channels which are not elements of arrays are checked according to the rules of occam 2.

### C.2.4 Checking of arrays of variables and channels

Where possible, the compiler treats each element of an array as an independent variable. This makes it possible to assign to the first and second elements of an array in parallel.

For usage checking to operate in this way, it must be possible for the compiler to evaluate all possible subscript values of an array. The compiler is capable of evaluating expressions consisting entirely of constant values and operators (but not function calls). Where a replicator is used in an expression the compiler can evaluate the expression for all values of the index provided that the replicator's base and count can be evaluated. **Note**: however, that as each iteration of the routine is checked, this can slow the compiler down.

Where an array subscript contains variables, a function call, or the index of a replicator where the base or the count cannot be evaluated, the compiler assumes that all possible subscripts of the array may be used. This may cause a spurious error. For example, consider the following program fragment

```
x := 1
PAR
  a[0] := 1
  a[x] := 2
```

The compiler reports the assignment to a[x] as a usage error. The fragment could be changed to:

```
VAL x IS 1:
PAR
  a[0] := 1
  a[x] := 2
```

This would be accepted by the compiler because x can be evaluated at compile time.

The compiler checks segments of arrays similarly to simple subscripts. Where the base and count of a segment can be evaluated, each segment is treated as though it has been used individually. Where the base or count cannot be evaluated, the compiler behaves as if the whole array has been used. For example, the following code is accepted without generating an error:

```
PAR
  [a FROM 4 FOR 4] := x
  a[8] := 2
  [a FROM 9 FOR 3] := y
```

## C.2.5 Arrays as procedure parameters

Any variable array which is the parameter of a procedure is treated as a single entity. That is, if any element of the array is referenced, the compiler treats the whole array as being referenced. Similarly, if any variable array, or element of a variable array is used free in a procedure then the compiler treats it as if every element were used. For example, the compiler reports an error in the following code because it considers every element of a to have been used when p(a) occurred.

```
PROC p([]INT a)
  a[1] := 2
:
PAR
  p(a)
  a[0] := 2
```

Similarly, where one element of an array of channels is used for input or output within a procedure, the compiler treats the array as if all elements were used in the same way. For example, the compiler reports an error in the following code because it considers an output has been performed on every element of c when p() occurred.

```
PROC p()
  c[1] ! 2     -- c free in p
:
PAR
  p()
  c[0] ! 1
```

### C.2.6 Abbreviating variables and channels

The compiler treats an element which is abbreviated in an element abbreviation as if it had been assigned to, whether or not it is actually updated. If this causes an apparently correct program to be rejected the program should be altered to use a VAL abbreviation. For example, the compiler reports an error in the following code because it considers the first component of the PAR to have been assigned to b.

```
PAR
  a IS b :
  x := a
  y := b
```

This could be changed to:

```
PAR
  VAL a IS b :
  x := a
  y := b
```

Where a channel is an abbreviation of a channel array element, the compiler behaves as if the whole of the channel array had been used unless the element is an array element with constant subscripts, a constant segment of an array (i.e. with constant base and count) or a constant segment with constant subscripts.

### C.2.7 Channels

A channel formal parameter, or a free channel of a procedure, may not be used for both input and output in a procedure. This check is disabled if usage checking is disabled.

### C.2.8 Usage checking disabled

**Note**: the compiler will be able to generate the most efficient code when all usage checks are *enabled*.

The compiler supports two switches which can be used to disable either Usage checking only, or both Alias and Usage checking together. Usage checking can be disabled on a compilation unit by the '`N`' command line switch or argument to the `#OPTION` compiler directive. Usage checking can also be turned off on specific variables using the `SHARED` pragma. See chapter 1 in the *Toolset Reference Manual* for more details.

When usage checking is disabled it is the programmer's responsibility to ensure that variables and channels are used correctly according to certain rules. if they are not the behavior of the program is *undefined.*

The set of 'shared' variables consists of either the set of *all* variables declared in the compilation unit, if the whole compilation unit has usage checking disabled, or the set of all variables which have been marked by the pragma `SHARED`.

The effects of disabling usage checking are best defined by what happens at a synchronization point – a point where the relative progress of two processes is known. A synchronization point is defined to be one of the following:

- A communication (on a channel, timer, or port)
- The beginning or end of a `PAR` construct.

A program using shared variables is valid provided that:

- If between two synchronization points of a process, a process reads a shared variable, then the variable is not updated by any other process at any time between these two points.

  (This means that an implementation is at liberty to read the shared variable from memory after the first synchronization point, and then to 'cache' a local copy of the variable, if it wishes.)

- If between two synchronization points of a process, a process updates a shared variable, then the variable is neither read nor updated by any other process at any time between these two points.

  (This means that an implementation is at liberty to read the shared variable from memory after the first synchronization point, and then to 'cache' a local copy of the variable, if it wishes, as long as it ensures that the variable is written back to memory before the second synchronization point.)

- Each element of an array is considered to be a separate variable for the purpose of these rules.

If either of these constraints is broken, the behavior of the program is *undefined.* It is up to the programmer to ensure that these constraints are met.

Channels may be considered 'shared' in the same way that variables may be. A program using shared channels is valid provided that:

- If a process communicates on a shared channel, then the channel is not used for communication in the same direction by any other process at any time between the previous and the following synchronization points.
- No branch of a PAR may use a channel for both input and output.
- Each element of an array is considered to be a separate channel for the purpose of these rules.

If either of these constraints is broken, the behavior of the program is *undefined*. It is up to the programmer to ensure that these constraints are met.

If any variable or channel which is shared is passed as an actual parameter to a procedure or function, then the corresponding formal parameter must also be marked as shared. **Note:** that this also applies across separately compiled units. It is up to the programmer to ensure that this is done, otherwise the behavior of the program is *undefined*.

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