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# libvaxdata: VAX Data Format Conversion Routines

By Lawrence M. Baker

### Introduction

libvaxdata provides a collection of routines for converting numeric data — integer and floating-point — to and from the formats used on a Digital Equipment Corporation (DEC, later Compaq Computer Corporation, now Hewlett-Packard Company) VAX 32-bit minicomputer (Brunner, 1991). Since the VAX numeric data formats are inherited from those used on a DEC PDP–11 16-bit minicomputer, these routines can be used to convert PDP–11 data as well. VAX numeric data formats are also the default data formats used on DEC Alpha 64-bit minicomputers running OpenVMS (Hewlett-Packard, 2005a, 2005b).

The libvaxdata routines are callable from Fortran or C. It is assumed that the caller uses two's-complement format for integer data and IEEE 754 format (ANSI/IEEE, 1985) for floating-point data. (It would be unusual to find a system that does not use these formats. Nevertheless, you may wish to consult the Fortran or C compiler documentation on your system to be sure.)

Some Fortran compilers support conversion of VAX numeric data on-the-fly when reading or writing unformatted files, either as a compiler option or a run-time I/O option (Hewlett-Packard, 2002, 2005b). This feature may be easier to use than the libvaxdata routines. Consult the Fortran compiler documentation on your system to determine if this alternative is available to you.

## **Description**

The routines in libvaxdata are:

```
16-bit integer byte swap
from vax i2()
from vax i4()
                   32-bit integer byte reversal
                   32-bit VAX F_floating to IEEE S_floating
from vax r4()
from vax d8()
                   64-bit VAX D_floating to IEEE T_floating
from vax q8()
                   64-bit VAX G_floating to IEEE T_floating
                   128-bit VAX H_floating to Alpha X_floating
from vax h16()
                   16-bit integer byte swap
to vax i2()
                   32-bit integer byte reversal
to vax i4()
                   32-bit IEEE S_floating to VAX F_floating
to vax r4()
                   64-bit IEEE T_floating to VAX D_floating
to vax d8()
                   64-bit IEEE T_floating to VAX G_floating
to vax g8()
                   128-bit Alpha X_floating to VAX H_floating
to vax h16()
```

where x\_floating is the nomenclature used on a DEC Alpha for its floating-point formats (Sites and Witek, 1995). S\_floating is the IEEE 754 32-bit Single Format. T\_floating is the IEEE 754 64-bit Double Format. X\_floating is an IEEE 754-conforming 128-bit Double Extended Format.

All calls take 3 arguments, an input array, an output array, and a conversion count:

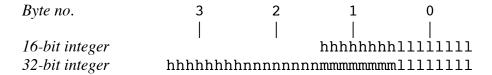
 $\mathbf{C}$ 

#### **Fortran**

where <code>name</code> (NAME) is the name of a libvaxdata routine, <code>n</code> (count) is the number of array elements to be converted, and <code>data\_type</code> is an appropriate data type for the input (in\_array) and output (out\_array) data arrays. The in\_array and out\_array parameters may refer to the same array, since conversion is carried out element-by-element from in\_array to out\_array. The in\_array and out\_array parameters must not otherwise overlap.

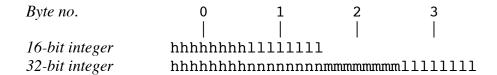
## **Integer Conversions**

VAXes and Intel 80x86 systems (Intel, 2005) store integers in two's-complement format, ordering the bytes in memory from low-order (1) to high-order (h), called little-endian format:



<sup>&</sup>lt;sup>1</sup> The Alpha X\_floating format is not necessarily compatible with another system's IEEE 754-conforming 128-bit floating-point format. In particular, it is *not* compatible with the IEEE 754-conforming 128-bit extended floating-point format implemented in software for IBM XL Fortran for AIX (International Business Machines, 2004). It *is* compatible with the IEEE 754-conforming 128-bit extended floating-point format defined for the Hewlett-Packard PA–RISC (Kane, 1995).

Apple Macintosh systems (Apple Computer, 2005) and most Unix systems (e.g., Sun [Sun Microsystems, 2005a], IBM [Silha, 2005], HP) also store integers in two's-complement format, but use the opposite (big-endian) byte ordering:

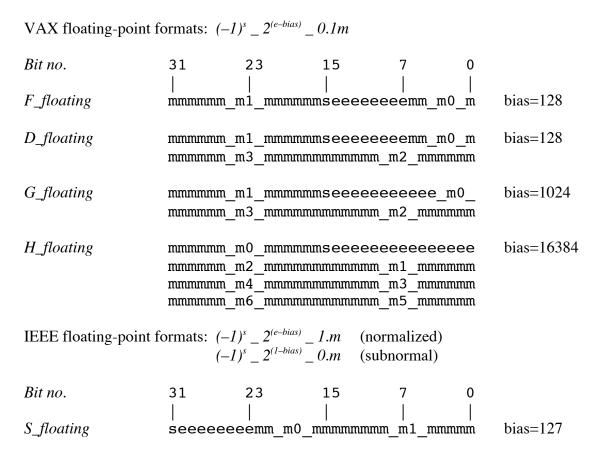


A VAX-format integer is converted to big-endian format by reversing the byte order. No conversion is required when the caller uses little-endian byte order; the data are copied as-is (unless in\_array and out\_array are the same array, in which case the copy is skipped altogether).

## **Floating-Point Conversions**

Intel 80x86 systems (Intel, 2005), Apple Macintosh systems (Apple Computer, 2004), and most Unix systems (Hewlett-Packard, 2002) implement the IEEE 754 floating-point arithmetic standard. VAX and IEEE formats are similar, after the bytes are rearranged. (VAX floating-point formats inherit the PDP–11 memory layout based on 16-bit words in little-endian byte order.)

The high-order bit is a sign bit (s). This is followed by a biased exponent (e), and a (usually) hidden-bit normalized mantissa (m). They differ in the number used to bias the exponent, the location of the implicit binary point for the mantissa, and the representation of exceptional numbers (e.g., ±infinity).



$T_floating$	${\tt see}{\tt ee}{\tt ee}{\tt ee}{\tt ee}{\tt ee}{\tt ee}{\tt em}{\tt 0}{\tt \_mmmmmm\_m1\_mmmmm}$	bias=1023
	mmmmmm_m2_mmmmmmmmmmmmm_m3_mmmmm	
V floating		hiog_16292
X_floating	${\tt see}$	018-10363
	mmmmm_m1_mmmmmmmmmmm_m2_mmmmm	
	mmmmm_m3_mmmmmmmmmmmm_m4_mmmmm	
	mmmmmm m5 mmmmmmmmmmmm m6 mmmmm	

#### VAX format to IEEE format Conversions

After rearranging the bytes, a VAX floating-point number is converted to IEEE floating-point format by subtracting  $(1+VAX\_bias\_IEEE\_bias)$  from the exponent field to (1) adjust from VAX 0.1m hidden-bit normalization to IEEE 1.m hidden-bit normalization and (2) adjust the bias from VAX format to IEEE format. True zero (s=e=m=0) and dirty zero  $(s=e=0, m\neq 0)$  are special cases which must be recognized and handled separately.

Numbers whose absolute value is too small to represent in the normalized IEEE format illustrated above are converted to subnormal format  $(e=0, m\neq 0)$ . Numbers whose absolute value is too small to represent in subnormal format are set to zero (silent underflow).

Overflow during the conversion is not possible; the largest floating-point number in each VAX format is smaller than the largest floating-point number in the corresponding IEEE floating-point format.

If the mantissa of the VAX floating-point number is too large for the corresponding IEEE floating-point format, bits are simply discarded from the right. Thus, the remaining fractional part is chopped, not rounded to the lowest-order bit. This can only occur when the conversion requires IEEE subnormal format.

A VAX floating-point reserved operand (s=1, e=0, m=any) causes a SIGFPE exception to be raised. The converted result is set to zero.

#### **IEEE format to VAX format Conversions**

Conversely, an IEEE floating-point number is converted to VAX floating-point format by adding  $(1+VAX\_bias-IEEE\_bias)$  to the exponent field. +zero (s=e=m=0), -zero (s=1, e=m=0), ±infinity (s=any, e=all-1's, m=0), and NaNs  $(s=any, e=all-1's, m\neq 0)$  are special cases which must be recognized and handled separately. Infinities and NaNs cause a SIGFPE exception to be raised. The result returned has the largest VAX exponent (e=all-1's) and zero mantissa (m=0) with the same sign as the original.

Numbers whose absolute value is too small to represent in the normalized VAX format illustrated above are set to zero (silent underflow). (VAX floating-point formats do not support subnormal numbers.) Numbers whose absolute value exceeds the largest representable VAX-format number cause a SIGFPE exception to be raised (overflow). (VAX floating-point formats do not have reserved bit patterns for infinities or NaNs.) The result returned has the largest VAX exponent and mantissa (e=m=all-1's) with the same sign as the original.

The bytes are then rearranged to the VAX 16-bit word floating-point fomat.

## **Examples**

The following C function, from\_vax\_rhdr(), converts the floating-point data header from a data file written on a VAX:

```
/* VAX Data Conversion Routines */
#include "convert vax data.h"
#ifndef FORTRAN LINKAGE
#define FORTRAN LINKAGE
#endif
/****** from_vax_rhdr() */
void FORTRAN_LINKAGE from_vax_rhdr( const void *inbuf, void *outbuf ) {
  register const float *in;
                                   /* Microsoft C: up to 2 register vars */
                                   /* Microsoft C: up to 2 register vars */
  register float *out;
  int n;
  float in null, out null;
  in = (const float *) inbuf;
  out = (float *) outbuf;
  in null = in[1];
  n = 1;
  from vax r4( &in null, &out null, &n );
                                                       1..38
                                                                binary */
  n = 38;
  from_vax_r4( in, out, &n );
  in += n;
  out += n;
                                                    /*
  *out = ( *in == in null ) ? out null : *in ;
                                                          39
                                                                ASCII */
  in++;
  out++;
  n = 89;
                                                    /* 40..128 binary */
  from vax r4( in, out, &n );
}
     The equivalent Fortran subroutine, FROM VAX RHDR, is:
************* FROM VAX RHDR
     Subroutine FROM_VAX_RHDR( inbuf, outbuf )
     Real inbuf[128], outbuf[128]
     Real in_null, out_null
     in_null = inbuf[2]
```

## Compilation

The C source code for the libvaxdata routines is in convert\_vax\_data.c in the src directory of the distribution kit. The C function prototypes are declared in convert\_vax\_data.h in the same directory.

To compile all routines into a single object module:

```
$ cc -c convert vax data.c
```

To compile a single routine into its own module, define MAKE\_routine\_name, substituting the upper-case name of the routine for routine\_name, and give the object module a name. This is useful, for example, to insert the routines into a library such that a linker may extract only the routines actually needed by a particular program. For example, to compile only from\_vax\_r4():

Two variants of convert\_vax\_data.c are available using IS\_LITTLE\_ENDIAN and APPEND UNDERSCORE.

If IS\_LITTLE\_ENDIAN is defined as 0 (false), then the conversions are performed for a big-endian system; byte reordering is done for all VAX data types. If IS\_LITTLE\_ENDIAN is defined as 1 (true), then byte reordering is done for floating-point formats only; integer formats are identical to their VAX counterparts.

If IS\_LITTLE\_ENDIAN is not defined, then it is defined as 1 (true) if any of the following macros is defined:

```
vax __vax vms DEC VAX C, GNU C on a DEC VAX or a DEC Alpha,
_vms __alpha or DEC C

M_I86 _M_IX86 Microsoft 80x86 C or Microsoft Visual C++ on an
_M_ALPHA Intel 80x86 or a DEC Alpha

i386 i386 Sun C, GNU C, or Intel C on an Intel 80x86
```

x86_64	GNU C or Portland Group C on an AMD Opteron
x86_64	or an Intel EM64T

If APPEND\_UNDERSCORE is defined, the entry point names are compiled with an underscore appended. This is required so that they can be called from Fortran in cases where the Fortran compiler appends an underscore to externally called routines (e.g., Sun Fortran [Sun Microsystems, 2005b]). For example, to create Fortran-callable versions of all the routines in an object module called fconvert\_vax\_data.o on a Sun SPARC system, the compiler command would be:

```
$ cc -c -o fconvert_vax_data.o -DIS_LITTLE_ENDIAN=0 \
-DAPPEND_UNDERSCORE convert_vax_data.c
```

because a SPARC is a big-endian system and Sun Fortran appends an underscore to externally called routines.

convert\_vax\_data.c assumes an ANSI C compiler. Compilation will fail if a char is not 8 bits, a short is not 16 bits, or an int is not 32 bits. convert\_vax\_data.c does not use 64-bit arithmetic.<sup>2</sup>

### **Distribution Kit**

The libvaxdata distribution kit includes make files and batch command files to create a (static) library of separately compiled modules for both Fortran and C programs. A single library is created, called libvaxdata.x, where x is the system suffix for object module libraries (e.g., libvaxdata.a on Unix).

To create the library:

- 1. Download or copy from CD the compressed distribution kit in a format suitable for your system (they are all identical). For example, use libvaxdata.zip on a Windows system.
- 2. Unpack the distribution kit. The most recent versions of Windows, Mac OS X, and Linux have built-in support to unpack the distribution kit directly from the desktop. (E.g., double-click the distribution kit to unpack it or open it, then drag-and-drop the contents from there.) Otherwise, a GUI tool may be available such as WinZip on Windows, or Stuffit Expander on a Macintosh. From a Linix command line, use tar -xzf libvaxdata.tar.gz. On Unix systems without a tar that can decompress an archive, use zcat libvaxdata.tar.gz | tar -xf -. You should see top-level directories named for each supported system type (e.g., linux, macosx, win32, etc.) and one named src, containing the C source files.
- 3. Open a terminal window (Command Prompt on Windows, MPW Shell on Mac OS 9) and navigate to the directory appropriate for your system. For example, Windows users should cd to the libvaxdata\win32 directory. Follow the instructions in the README file there. The command to create the library will be something like:

\_

<sup>&</sup>lt;sup>2</sup> It may be possible to compile a version of libvaxdata for SMP parallel execution, since each conversion is independent. However, this has not been tried. To enable conversions in parallel across the outer loop over the conversion count, it may be necessary to assert that in\_array and out\_array are not aliased (i.e., do not overlap).

```
> vcmake Windows (Visual C++)
$ @Make OpenVMS (CC)
make.mrc Mac OS 9 (MrC)
$ make -f makefile.gcc Unix/Linux/Mac OS X (gcc)
```

4. You can then copy the library to a system-wide directory for everyone to use, such as /usr/local/lib on Unix or Linux, Or, you can copy it to your own library directory, such as ~/lib on Unix or Linux. See the README file for the instructions to use the library from your Fortran and C programs.

The distribution kit includes another useful routine to determine at run-time whether the system uses little-endian byte ordering:

 $\mathbf{C}$ 

```
Prototype int is_little_endian( void );
Usage if ( is little endian() ) ...
```

#### **Fortran**

```
Declaration Integer Function IS_LITTLE_ENDIAN()
Usage If ( IS_LITTLE_ENDIAN() .ne. 0 ) ...
```

The prototype is not defined in convert\_vax\_data.h, so it must be explicitly declared in a C program.

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