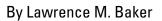


libvaxdata: VAX Data Format Conversion Routines



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libvaxdata: VAX Data Format Conversion Routines

By Lawrence M. Baker

Description

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) 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. They require that the caller use two's-complement format for integer data and IEEE 754 format (ANSI/IEEE, 1985) for floating-point data. They also require that the "natural" size of a C int type (integer) is 32 bits. That is the case for most modern 32-bit and 64-bit computer systems. 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.

The routines in libvaxdata are:

16-bit integer byte swap from_vax_i2() 32-bit integer byte reversal from_vax_i4() 32-bit VAX F floating to IEEE S floating from vax r4() 64-bit VAX D floating to IEEE T floating from vax d8() 64-bit VAX G floating to IEEE T floating from vax g8() 128-bit VAX H floating to Alpha X floating from vax h16() to vax i2() 16-bit integer byte swap 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 q8() 128-bit Alpha X floating to VAX H floating to vax h16()

¹ Later Compaq Computer Corporation, now Hewlett-Packard Company.

 $X_{\rm floating}$ 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.

Usage

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

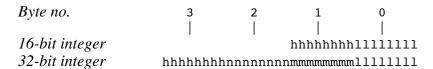
name (C) or NAME (Fortran) is the name of a libvaxdata routine, count contains the number n (specified by the caller) of array elements to be converted, and data_type is the appropriate type of data for the conversion routine.

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.

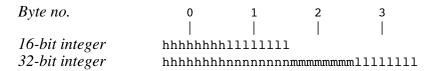
² The Alpha X_floating format is not necessarily compatible with another system's IEEE 754-conforming 128-bit floating-point format. In particular, it is *not* compatible with the IEEE 754-conforming 128-bit extended floating-point format implemented in software for IBM XL Fortran for AIX (International 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).

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:



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:



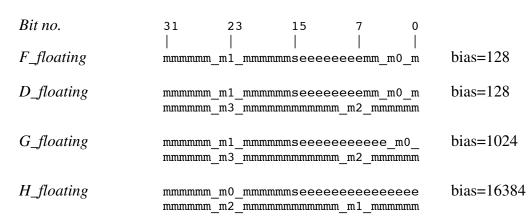
A VAX-format integer is converted to big-endian format by reversing the byte order. No conversion is required when the caller uses little-endian byte order; the data are copied as-is (unless in_array and out_array are the same array, in which case the copy is skipped altogether).

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), 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 $(e.g., \pm infinity)$.

VAX floating-point formats: $(-1)^s \times 2^{(e-bias)} \times 0.1m$



mmmmmm m6 mmmmmmmmmm m5 mmmmmm IEEE floating-point formats: $(-1)^s \times 2^{(e-bias)} \times 1.m$ (normalized) $(-1)^s \times 2^{(1-bias)} \times 0.m$ (subnormal) Bit no. 31 23 15 *S_floating* bias=127seeeeeeemm m0 mmmmmmmm m1 mmmmm bias=1023 *T_floating* seeeeeeeee m0 mmmmmmm m1 mmmmm mmmmmm m2 mmmmmmmmmmm m3 mmmmm *X_floating* bias=16383 seeeeeeeeeeeemmmmmm m0 mmmmm mmmmmm m1 mmmmmmmmmm m2 mmmmm mmmmmm m3 mmmmmmmmmmm m4 mmmmm mmmmmm m5 mmmmmmmmmmm 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. Both VAX zeros are converted to IEEE +zero (s=e=m=0).

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. Both IEEE zeros are converted to VAX true zero (s=e=m=0). 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 */
  register float *out;
                                  /* Microsoft C: up to 2 register vars */
  int n;
  float in null, out null;
  in = (const float *) inbuf;
  out = (float *) outbuf;
  in null = in[1];
  from_vax_r4( &in_null, &out_null, &n );
                                                    /* 1..38 binary */
  from_vax_r4( in, out, &n );
  in += n;
  out += n:
                                                                ASCII */
  *out = ( *in == in_null ) ? out_null : *in ; /*
                                                         39
  in++;
  out++;
                                                    /* 40..128 binary */
  n = 89:
  from_vax_r4( in, out, &n );
}
```

The equivalent Fortran subroutine FROM VAX RHDR is:

Creating the Library

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. The library is named libvaxdata.x, where x is the system suffix for object module libraries (e.g., libvaxdata.a on Unix).

A test program is created in the same directory with the library. Run it after creating the library to verify the conversions.

To create the library and test program:

1. Download one of the distribution kits from the USGS online web site, http://pubs.usgs.gov/of/2005/1424. Two choices are available:

libvaxdata.tar.gz Compressed tar format with Unix-style LF line endings libvaxdata.zip ZIP format with MS–DOS-style CR-LF line endings

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, type

```
$ tar -xzf libvaxdata.tar.gz
```

On Unix systems without a tar that supports gzip archives, type

```
$ gzcat <libvaxdata.tar.gz | tar -xf -</pre>
```

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) and navigate to the directory appropriate for your system. For example, Windows users should cd to the libvaxdata\win32 directory.
- 4. Follow the instructions in the readme.txt file there to create the library and test program. The command will be something like:

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

5. 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 personal library directory, such as ~/lib on Unix or Linux. See the readmde.txt file for the instructions to use the library from your Fortran and C programs.

The following example creates a gcc version of the library on Mac OS X. The libvaxdata folder is on the Mac desktop.

```
$ cd ~/Desktop/libvaxdata/macosx
$ make -f makefile.gcc
test -d `uname -p` || mkdir `uname -p`
cd `uname -p` ; make -f ../makefile.macosx \
                                   CC="gcc" \
CFLAGS="-03 -ansi" \
                                   libvaxdata.a
gcc -03 -ansi -c -o from vax i2.o ../../src/from vax i2.c
gcc -03 -ansi -c -o from_vax_i2_.o ../../src/from_vax_i2_.c
gcc -03 -ansi -c -o from_vax_i4.o ../../src/from_vax_i4.c gcc -03 -ansi -c -o from_vax_i4_.o ../../src/from_vax_i4_.c
gcc -03 -ansi -c -o from vax r4.o ../../src/from vax r4.c
gcc -03 -ansi  -c -o from_vax_r4_.o ../../src/from_vax_r4_.c
gcc -03 -ansi -c -o from_vax_d8.o ../../src/from_vax_d8.c gcc -03 -ansi -c -o from_vax_d8.o ../../src/from_vax_d8.c
gcc -03 -ansi -c -o from_vax_g8.o ../../src/from_vax_g8.c
gcc -03 -ansi  -c -o from_vax_g8_.o ../../src/from_vax_g8_.c
gcc -03 -ansi -c -o from_vax_h16.o ../../src/from_vax_h16.c gcc -03 -ansi -c -o from_vax_h16_.o ../../src/from_vax_h16_
gcc -03 -ansi -c -o from_vax_h16_.o ../../src/from_vax_h16_.c gcc -03 -ansi -c -o to_vax_i2.o ../../src/to_vax_i2.c
gcc -03 -ansi -c -o to vax i2 .o ../../src/to vax i2 .c
gcc -03 -ansi   -c -o to_vax_i4.o ../../src/to_vax_i4.c
gcc -03 -ansi -c -o to_vax_r4_.o ../../src/to_vax_r4_.c
gcc -03 -ansi -c -o to vax d8.o ../../src/to vax d8.c
gcc -03 -ansi -c -o to_vax_h16.o ../../src/to_vax_h16.c
gcc -03 -ansi    -c -o to_vax_h16_.o ../../src/to_vax_h16_.c
gcc -c -o is_little_endian.o ../../src/is_little_endian.c
gcc -c -o is little endian .o ../../src/is little endian .c
ar -r -c libvaxdata.a from_vax_i2.o from_vax_i2.o from_vax_i4.o from_vax_i4.o from_vax_i4.o from_vax_r4.o from_vax_r4.o from_vax_d8.o from_vax_d8.o from_vax_h16.o from_vax_h16.o to_vax_i2.o to_vax_i2.o to_vax_i4.o to_vax_i4.o to_vax_i4.o to_vax_g8.o to_vax_r4.o to_vax_d8.o to_vax_d8.o to_vax_g8.o to
                    to_vax_h16.o to_vax_h16_.o is_little_endian.o is_littl
vax g8 .o
e_endian_.o
ranlib libvaxdata.a
_vax_14_.0 from_vax_r4.0 from_vax_r4_.0 from_vax_d8.0 from_vax_d8_.0 from_vax_g8_.0 from_vax_h16.0 from_vax_h16_.0 to_vax_i2.0 to_vax_i4.0 to_vax_i4_.0 to_vax_i4_.0 to_vax_r4.0 to_vax_d8_.0 to_vax_d8_.0 to_vax_g8_.0 to_vax_h16.0 to vax_h16_.0 is_little_coding.
e endian .o
cd `uname -p`; gcc -o test ../../src/test.c -L. -lvaxdata
```

To test the conversions, run the test program in the directory containing the library. For example, after compiling the Mac OS X library above (which created i386/test), the following command will test the conversions:

```
$ i386/test
```

The output should look like this:

```
12
      1
     -1
    256
   -256
  12345
 -12345
I4
           1
          -1
         256
        -256
       65536
      -65536
    16777216
   -16777216
   123456789
  -123456789
F4
              1
             -1
            3.5
           -3.5
        3.14159
       -3.14159
          1e+37
         -1e+37
          1e-37
         -1e-37
        1.23457
       -1.23457
D8
                        -1
                       3.5
                      -3.5
         3.14159265358979
        -3.14159265358979
                    1e+37
                    -1e+37
                    1e-37
                    -1e-37
         1.23456789012345
        -1.23456789012345
G8
                         1
                       -1
3.5
                      -3.5
         3.14159265358979
        -3.14159265358979
                     1e+37
                    -1e+37
                    1e-37
                    -1e-37
         1.23456789012345
        -1.23456789012345
```

On an Alpha, the output also includes the H16 conversion:

```
H16

1
-1
2
-2
3.141592653589793238462643383279
-3.141592653589793238462643383279
1e+37
-1e+37
1e-37
1-2345678901234567890123456789
-1.2345678901234567890123456789
```

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

```
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; it must be explicitly declared in a C program.

Compilation Options

The C source code for the libvaxdata routines is in src/convert_vax_data.c. The C function prototypes are declared in src/convert vax data.h.

To compile all routines into a single object module (assuming -o is the C compiler option that requests optimization) from one of the system-specific directories:

```
$ cc -c -0 -I../src ../src/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():

```
$ cc -c -0 -o from_vax_r4.o -DMAKE_FROM_VAX_R4 \
    -I../src ../src/convert_vax_data.c
```

Different versions of convert_vax_data.c are produced depending on the definitions of the C preprocessor variables 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:

vaxvax vms vmsalpha	DEC VAX C, GNU C on a DEC VAX or a DEC Alpha, or DEC C
M_I86 _M_IX86 M_ALPHA	Microsoft 80x86 C or Microsoft Visual C++ on an Intel 80x86 or a DEC Alpha
i386 <u>i</u> 386	Sun C, GNU C, or Intel C on an Intel 80x86
x86_64 x86_64	GNU C, Intel C, PathScale C, or Portland Group C on an AMD Opteron 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 -o fconvert_vax_data.o -DIS_LITTLE_ENDIAN=0 \
-DAPPEND_UNDERSCORE -I../src ../src/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 requires 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.³

convert vax data.c does not use 64-bit arithmetic.4

³ On a system whose "natural" size of a C int type (integer) is 16 bits, it may be possible to #define int long and change the test UINT_MAX != 4294967295U to ULONG_MAX != 4294967295UL in convert vax data.c. However, this has not been tested.

⁴ It may be possible to compile a version of libvaxdata for SMP parallel execution, since each conversion is independent. However, this has not been tested. 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).

Version History

Version 1.0, January 6, 2006

Initial release.

Make files for the following platforms and compilers:

Linux: GNU gcc, Intel icc, Portland Group pgcc

Mac OS 9: Apple/Motorola MPW MrC, Metrowerks CodeWarrior mwcc

Mac OS X: GNU gcc, IBM xlc
OpenVMS: VAX CC, DEC CC
Solaris: GNU gcc, Sun cc
Tru64 Unix: HP cc, GNU gcc

Windows: Microsoft CL, Metrowerks CodeWarrior MWCC

Version 1.1, February 2, 2010

Bug fixes:

Corrected output byte ordering for d8/g8/h16 conversions on little endian machines.

Corrected exponent positioning in to_vax_d8().

Corrected typo (VAX_D_EXPONENT_BIAS should be VAX_G_EXPONENT_BIAS) in to_vax_g8().

New features:

Added test program to validate conversions.

Added make files for the following platforms and compilers:

Linux: PathScale pathcc

Mac OS X: Intel icc

Removed make files for the following platforms and compilers:

Mac OS 9: Apple/Motorola MPW MrC, Metrowerks CodeWarrior mwcc

Windows: Metrowerks CodeWarrior MWCC

Version 1.2, April 15, 2010

Bug fixes:

Corrected f4/g8/h16 conversions to IEEE subnormal form.

Additional Notes

As of the Version 1.1 release, make files for the following platforms and compilers are included in the distribution, but the author no longer has the ability to test them:

Linux: Intel icc

Solaris: GNU gcc, Sun cc

Tru64 Unix: GNU gcc

Contact the author for assistance in using the library on these or any other platforms or compilers at baker@usgs.gov. And, please, report any bugs.

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