3D IMAGE (VOLUME) ORIENTATION AND LOCATION IN SPACE:

There are 3 different methods by which continuous coordinates can
attached to voxels. The discussion below emphasizes 3D volumes, and
the continuous coordinates are referred to as (x,y,z). The voxel
index coordinates (i.e., the array indexes) are referred to as (i,j,k),
with valid ranges:

```
  i = 0 .. dim[1]-1
  j = 0 .. dim[2]-1  (if dim[0] >= 2)
```

k = 0 .. dim[3]-1 (if dim[0] >= 3)
The (x,y,z) coordinates refer to the CENTER of a voxel. In methods
2 and 3, the (x,y,z) axes refer to a subject-based coordinate system,
with
+x = Right +y = Anterior +z = Superior.
This is a right-handed coordinate system. However, the exact direction
these axes point with respect to the subject depends on qform_code
(Method 2) and sform_code (Method 3).

N.B.: The i index varies most rapidly, j index next, k index

slowest.
    Thus, voxel (i,j,k) is stored starting at location
      (i + j*dim[1] + k*dim[1]*dim[2]) * (bitpix/8)
    into the dataset array.

   N.B.: The ANALYZE 7.5 coordinate system is
      +x = Left +y = Anterior +z = Superior
    which is a left-handed coordinate system. This backwardness is
    too difficult to tolerate, so this NIFTI-1 standard specifies the
    coordinate order which is most common in functional neuroimaging.

   N.B.: The 3 methods below all

give the locations of the voxel centers
in the (x,y,z) coordinate system. In many cases, programs will wish
to display image data on some other grid. In such a case, the program
will need to convert its desired (x,y,z) values into (i,j,k) values
in order to extract (or interpolate) the image data. This operation
would be done with the inverse transformation to those described below.

N.B.: **Method 2 uses a factor 'qfac' which is either -1 or 1; qfac is
stored in the otherwise**

unused pixdim[0]. If pixdim[0]=0.0 (which should not occur), we take qfac=1. Of course, pixdim[0] is only used when reading a NIFTI-1 header, not when reading an ANALYZE 7.5 header.

In NIFTI-1 files, dimensions 1,2,3 are for space, dimension 4 is for time, and dimension 5 is for storing multiple values at each spatiotemporal voxel. Some examples:

- A typical whole-brain FMRI experiment's time series:
  - dim[0] = 4
  - dim[1] = 64

pixdim[1] = 3.75 xyzt_units = NIFTI_UNITS_MM

        - dim[2] = 64
pixdim[2] = 3.75
NIFTI_UNITS_SEC
        - dim[3] = 20
pixdim[3] = 5.0
        - dim[4] = 120
pixdim[4] = 2.0
    - A typical T1-weighted anatomical volume:
        - dim[0] = 3
        - dim[1] = 256
pixdim[1] = 1.0 xyzt_units = NIFTI_UNITS_MM
        - dim[2] = 256
pixdim[2] = 1.0
        - dim[3] = 128
pixdim[3] = 1.1
    - A single slice EPI time series:
        - dim[0] = 4
        - dim[1] = 64
pixdim[1] = 3.75 xyzt_units =

NIFTI_UNITS_MM
        - dim[2] = 64
pixdim[2] = 3.75
NIFTI_UNITS_SEC
        - dim[3] = 1
pixdim[3] = 5.0
        - dim[4] = 1200
pixdim[4] = 0.2
     - A 3-vector stored at each
point in a 3D volume:
        - dim[0] = 5
        - dim[1] = 256
pixdim[1] = 1.0 xyzt_units =
NIFTI_UNITS_MM
        - dim[2] = 256
pixdim[2] = 1.0
        - dim[3] = 128
pixdim[3] = 1.1
        - dim[4] = 1
pixdim[4] = 0.0
        - dim[5] = 3
intent_code =

```
NIFTI_INTENT_VECTOR
     - A single time series with
a 3x3 matrix at each point:
        - dim[0] = 5
        - dim[1] = 1
xyzt_units = NIFTI_UNITS_SEC
        - dim[2] = 1
        - dim[3] = 1
        - dim[4] = 1200
pixdim[4] = 0.2
        - dim[5] = 9
intent_code =
NIFTI_INTENT_GENMATRIX
        - intent_p1 = intent_p2
= 3.0    (indicates matrix
dimensions)
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--------------*/
```

METHOD 2 (used when qform_code > 0, which should be the "normal" case):

The (x,y,z) coordinates are given by the pixdim[] scales, a rotation

matrix, and a shift. This

method is intended to represent "scanner-anatomical" coordinates, which are often embedded in the image header (e.g., DICOM fields (0020,0032), (0020,0037), (0028,0030), and (0018,0050)), and represent the nominal orientation and location of the data. This method can also be used to represent "aligned" coordinates, which would typically result from some post-acquisition alignment of the volume to a standard orientation (e.g., the same subject on another day, or a rigid rotation to true anatomical orientation from the tilted position of the subject in the scanner).

The formula for (x,y,z) in terms of header parameters and (i,j,k) is:

```
     [ x ]   [ R11 R12 R13 ]
[         pixdim[1] * i ]
[ qoffset_x ]
     [ y ] = [ R21 R22 R23 ]
```

```
[           pixdim[2] * j ] +
[ qoffset_y ]
     [ z ]   [ R31 R32 R33 ]
[ qfac * pixdim[3] * k ]
[ qoffset_z ]
```

The qoffset_* shifts are in the NIFTI-1 header. Note that the center of the (i,j,k)=(0,0,0) voxel (first value in the dataset array) is

just

(x,y,z)=(qoffset_x,qoffset_y,qoffset_z).

The rotation matrix R is calculated from the quatern_* parameters.

This calculation is described below.

The scaling factor qfac is either 1 or -1. The rotation matrix R

defined by the quaternion parameters is "proper" (has determinant 1).

This may not fit the needs of the data; for example, if the image

grid is

i increases from Left-to-

Right

j increases from Anterior-to-Posterior

k increases from Inferior-to-Superior

Then (i,j,k) is a left-handed triple. In this example, if qfac=1,

the R matrix would have to be

```
[  1   0   0 ]
```

```
     [  0  -1   0 ]  which is
"improper" (determinant = -1).
     [  0   0   1 ]

   If we set qfac=-1, then the R
matrix would be

     [  1   0   0 ]
     [  0  -1   0 ]  which is
proper.
     [  0   0  -1 ]
```

This R matrix is represented by quaternion [a,b,c,d] = [0,1,0,0]

(which encodes a 180 degree rotation about the x-axis).