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

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   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,
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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:

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  - 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 =
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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]

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

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

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      [  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).