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SOFA Vector/Matrix Library  
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## PREFACE

The routines described here comprise the SOFA vector/matrix library. Their general appearance and coding style conforms to conventions agreed by the SOFA Board, and their functions, names and algorithms have been ratified by the Board. Procedures for soliciting and agreeing additions to the library are still evolving.

## PROGRAMMING LANGUAGES

The SOFA routines are available in two programming languages at present: Fortran 77 and ANSI C.

There is a one-to-one relationship between the two language versions. The naming convention is such that a SOFA routine referred to generically as "EXAMPL" exists as a Fortran subprogram `iau_EXAMPL` and a C function `iauExempl`. The calls for the two versions are very similar, with the same arguments in the same order. In a few cases, the C equivalent of a Fortran SUBROUTINE subprogram uses a return value rather than an argument.

## GENERAL PRINCIPLES

The library consists mostly of routines which operate on ordinary Cartesian vectors (x,y,z) and 3x3 rotation matrices. However, there is also support for vectors which represent velocity as well as position and vectors which represent rotation instead of position. The vectors which represent both position and velocity may be considered still to have dimensions (3), but to comprise elements each of which is two numbers, representing the value itself and the time derivative. Thus:

- \* "Position" or "p" vectors (or just plain 3-vectors) have dimension (3) in Fortran and [3] in C.
- \* "Position/velocity" or "pv" vectors have dimensions (3,2) in Fortran and [2][3] in C.
- \* "Rotation" or "r" matrices have dimensions (3,3) in Fortran and [3][3] in C. When used for rotation, they are "orthogonal"; the inverse of such a matrix is equal to the transpose. Most of the routines in this library do not assume that r-matrices are necessarily orthogonal and in fact work on any 3x3 matrix.
- \* "Rotation" or "r" vectors have dimensions (3) in Fortran and [3] in C. Such vectors are a combination of the Euler axis and angle and are convertible to and from r-matrices. The direction is the axis of rotation and the magnitude is the angle of rotation, in radians. Because the amount of rotation can be scaled up and down simply by multiplying the vector by a scalar, r-vectors are useful for representing spins about an axis which is fixed.
- \* The above rules mean that in terms of memory address, the three velocity components of a pv-vector follow the three position components. Application code is permitted to exploit this and all other knowledge of the internal layouts: that x, y and z appear in that order and are in a right-handed Cartesian coordinate system etc. For example, the `cp` function (copy a p-vector) can be used to copy the velocity component of a pv-vector (indeed, this is how the `CPV` routine is coded).
- \* The routines provided do not completely fill the range of operations that link all the various vector and matrix options, but are confined to functions that are required by other parts of the SOFA software or which are likely to prove useful.

In addition to the vector/matrix routines, the library contains some routines related to spherical angles, including conversions to and from sexagesimal format.

Using the library requires knowledge of vector/matrix methods, spherical trigonometry, and methods of attitude representation. These topics are covered in many textbooks, including "Spacecraft Attitude Determination and Control", James R. Wertz (ed.), Astrophysics and Space Science Library, Vol. 73, D. Reidel Publishing Company, 1986.

#### OPERATIONS INVOLVING P-VECTORS AND R-MATRICES

##### Initialize

ZP	zero p-vector
ZR	initialize r-matrix to null
IR	initialize r-matrix to identity

##### Copy/extend/extract

CP	copy p-vector
CR	copy r-matrix

##### Build rotations

RX	rotate r-matrix about x
RY	rotate r-matrix about y
RZ	rotate r-matrix about z

##### Spherical/Cartesian conversions

S2C	spherical to unit vector
C2S	unit vector to spherical
S2P	spherical to p-vector
P2S	p-vector to spherical

##### Operations on vectors

PPP	p-vector plus p-vector
PMP	p-vector minus p-vector
PPSP	p-vector plus scaled p-vector
PDP	inner (=scalar=dot) product of two p-vectors
PXP	outer (=vector=cross) product of two p-vectors
PM	modulus of p-vector
PN	normalize p-vector returning modulus
SXP	multiply p-vector by scalar

##### Operations on matrices

RXR	r-matrix multiply
TR	transpose r-matrix

##### Matrix-vector products

RXP	product of r-matrix and p-vector
TRXP	product of transpose of r-matrix and p-vector

##### Separation and position-angle

SEPP	angular separation from p-vectors
SEPS	angular separation from spherical coordinates
PAP	position-angle from p-vectors
PAS	position-angle from spherical coordinates

##### Rotation vectors

RV2M	r-vector to r-matrix
RM2V	r-matrix to r-vector

#### OPERATIONS INVOLVING PV-VECTORS

## Initialize

ZPV            zero pv-vector

## Copy/extend/extract

CPV            copy pv-vector  
P2PV           append zero velocity to p-vector  
PV2P           discard velocity component of pv-vector

## Spherical/Cartesian conversions

S2PV           spherical to pv-vector  
PV2S           pv-vector to spherical

## Operations on vectors

PVPPV          pv-vector plus pv-vector  
PVMPV          pv-vector minus pv-vector  
PVDPV          inner (=scalar=dot) product of two pv-vectors  
PVXPV          outer (=vector=cross) product of two pv-vectors  
PVM            modulus of pv-vector  
SXPV           multiply pv-vector by scalar  
S2XPV          multiply pv-vector by two scalars  
PVU            update pv-vector  
PVUP           update pv-vector discarding velocity

## Matrix-vector products

RXPV           product of r-matrix and pv-vector  
TRXPV          product of transpose of r-matrix and pv-vector

## OPERATIONS ON ANGLES

ANP            normalize radians to range 0 to 2pi  
ANPM           normalize radians to range -pi to +pi  
A2TF           decompose radians into hours, minutes, seconds  
A2AF           decompose radians into degrees, arcminutes, arcseconds  
AF2A           degrees, arcminutes, arcseconds to radians  
D2TF           decompose days into hours, minutes, seconds  
TF2A           hours, minutes, seconds to radians  
TF2D           hours, minutes, seconds to days

## CALLS: FORTRAN VERSION

CALL iau\_A2AF ( NDP, ANGLE, SIGN, IDMSF )  
CALL iau\_A2TF ( NDP, ANGLE, SIGN, IHMSF )  
CALL iau\_AF2A ( S, IDEG, IAMIN, ASEC, RAD, J )  
D = iau\_ANP ( A )  
D = iau\_ANPM ( A )  
CALL iau\_C2S ( P, THETA, PHI )  
CALL iau\_CP ( P, C )  
CALL iau\_CPV ( PV, C )  
CALL iau\_CR ( R, C )  
CALL iau\_D2TF ( NDP, DAYS, SIGN, IHMSF )  
CALL iau\_IR ( R )  
CALL iau\_P2PV ( P, PV )  
CALL iau\_P2S ( P, THETA, PHI, R )  
CALL iau\_PAP ( A, B, THETA )  
CALL iau\_PAS ( AL, AP, BL, BP, THETA )  
CALL iau\_PDP ( A, B, ADB )  
CALL iau\_PM ( P, R )  
CALL iau\_PMP ( A, B, AMB )  
CALL iau\_PN ( P, R, U )  
CALL iau\_PPP ( A, B, APB )  
CALL iau\_PPSP ( A, S, B, APSB )  
CALL iau\_PV2P ( PV, P )  
CALL iau\_PV2S ( PV, THETA, PHI, R, TD, PD, RD )  
CALL iau\_PVDPV ( A, B, ADB )  
CALL iau\_PVM ( PV, R, S )  
CALL iau\_PVMPV ( A, B, AMB )

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CALL iau_PVPPV ( A, B, APB )
CALL iau_PVU   ( DT, PV, UPV )
CALL iau_PVUP  ( DT, PV, P )
CALL iau_PVXPV ( A, B, AXB )
CALL iau_PXP   ( A, B, AXB )
CALL iau_RM2V  ( R, P )
CALL iau_RV2M  ( P, R )
CALL iau_RX    ( PHI, R )
CALL iau_RXP   ( R, P, RP )
CALL iau_RXPV  ( R, PV, RPV )
CALL iau_RXR   ( A, B, ATB )
CALL iau_RY    ( THETA, R )
CALL iau_RZ    ( PSI, R )
CALL iau_S2C   ( THETA, PHI, C )
CALL iau_S2P   ( THETA, PHI, R, P )
CALL iau_S2PV  ( THETA, PHI, R, TD, PD, RD, PV )
CALL iau_S2XPV ( S1, S2, PV )
CALL iau_SEPP  ( A, B, S )
CALL iau_SEPS  ( AL, AP, BL, BP, S )
CALL iau_SXP   ( S, P, SP )
CALL iau_SXPV  ( S, PV, SPV )
CALL iau_TF2A  ( S, IHOURL, IMIN, SEC, RAD, J )
CALL iau_TF2D  ( S, IHOURL, IMIN, SEC, DAYS, J )
CALL iau_TR    ( R, RT )
CALL iau_TRXP  ( R, P, TRP )
CALL iau_TRXPV ( R, PV, TRPV )
CALL iau_ZP    ( P )
CALL iau_ZPV   ( PV )
CALL iau_ZR    ( R )

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CALLS: C VERSION

```

        iauA2af ( ndp, angle, &sign, idmsf );
        iauA2tf ( ndp, angle, &sign, ihmsf );
i = iauAf2a ( s, ideg, iamin, asec, &rad );
d = iauAnp ( a );
d = iauAnpm ( a );
        iauC2s ( p, &theta, &phi );
        iauCp ( p, c );
        iauCpv ( pv, c );
        iauCr ( r, c );
        iauD2tf ( ndp, days, &sign, ihmsf );
        iauIr ( r );
        iauP2pv ( p, pv );
        iauP2s ( p, &theta, &phi, &r );
d = iauPap ( a, b );
d = iauPas ( al, ap, bl, bp );
d = iauPdp ( a, b );
d = iauPm ( p );
        iauPmp ( a, b, amb );
        iauPn ( p, &r, u );
        iauPpp ( a, b, apb );
        iauPpsp ( a, s, b, apsb );
        iauPv2p ( pv, p );
        iauPv2s ( pv, &theta, &phi, &r, &td, &pd, &rd );
        iauPvdpv ( a, b, adb );
        iauPvm ( pv, &r, &s );
        iauPvmpv ( a, b, amb );
        iauPvppv ( a, b, apb );
        iauPvu ( dt, pv, upv );
        iauPvup ( dt, pv, p );
        iauPvxp ( a, b, axb );
        iauPxp ( a, b, axb );
        iauRm2v ( r, p );
        iauRv2m ( p, r );
        iauRx ( phi, r );
        iauRxp ( r, p, rp );
        iauRxp ( r, pv, rpv );
        iauRxr ( a, b, atb );
        iauRy ( theta, r );
        iauRz ( psi, r );
        iauS2c ( theta, phi, c );

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```
    iauS2p   ( theta, phi, r, p );
    iauS2pv  ( theta, phi, r, td, pd, rd, pV );
    iauS2xpv ( s1, s2, pv );
d = iauSepp ( a, b );
d = iauSeps ( al, ap, bl, bp );
    iauSxp   ( s, p, sp );
    iauSxpv  ( s, pv, spv );
i = iauTf2a ( s, ihour, imin, sec, &rad );
i = iauTf2d ( s, ihour, imin, sec, &days );
    iauTr    ( r, rt );
    iauTrxp  ( r, p, trp );
    iauTrxpv ( r, pv, trpv );
    iauZp    ( p );
    iauZpv   ( pv );
    iauZr    ( r );
```