

T H E

```
      SSSS          00000          FFFFFFFFFFFFFFFF          AAAAAA
    SSSSSSSSS      000000000000      FFFFFFFFFFFFFFFF          AAAAAAA
  SSSSSSSSSSS      000000000000      FFFFFFFFFFFFFFFF          AAAA AAAA
    SSSS      S      000000      00000      FFFF          AAAA AAAA
  SSSSS      00000      0000      FFFFF          AAAA AAAA
  SSSSSSSSS      0000      00000      FFFFFFFFFFFFFFFF          AAAA AAAA
    SSSSSSSSS      00000      0000      FFFFFFFFFFFFFFFF          AAAAAAAAAAAAA
      SSSS      0000      0000      FFFF          AAAAAAAAAAAAA
S      SSSS      00000      00000      FFFF          AAAAAAAAAAAAA
  SSSSSSSSSSS      000000000000      FFFF          AAAA AAAA
  SSSSSSSSS      0000000000      FFFF          AAAA AAAA
    SSSS          00000          FFFF          AAAA AAAA
```

S O F T W A R E

L I B R A R I E S

International Astronomical Union

Division 1: Fundamental Astronomy

Commission 19: Rotation of the Earth

Standards Of Fundamental Astronomy Review Board

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THE IAU-SOFA SOFTWARE LIBRARIES

SOFA stands for "Standards Of Fundamental Astronomy". The SOFA software libraries are a collection of subprograms, in source-code form, which implement official IAU algorithms for fundamental-astronomy computations. The subprograms at present comprise 108 "astronomy" routines supported by 52 "vector/matrix" routines, available in both Fortran77 and C implementations.

THE SOFA INITIATIVE

SOFA is an IAU Service which operates under Division 1 (Fundamental Astronomy) and reports through Commission 19 (Rotation of the Earth).

The IAU set up the SOFA initiative at the 1994 General Assembly, to promulgate an authoritative set of fundamental-astronomy constants and algorithms. At the subsequent General Assembly, in 1997, the appointment of a SOFA Review Board and the selection of a site for the SOFA Center (the outlet for SOFA products) were announced.

The SOFA initiative was originally proposed by the IAU Working Group on Astronomical Standards (WGAS), under the chairmanship of Toshio Fukushima. The proposal was for "...new arrangements to establish and maintain an accessible and authoritative set of constants, algorithms and procedures that implement standard models used in fundamental astronomy". The SOFA Software Libraries implement the "algorithms" part of the SOFA initiative. They were developed under the supervision of an international panel called the SOFA Review Board. The current membership of this panel is listed in an appendix.

A feature of the original SOFA software proposals was that the products would be self-contained and not depend on other software. This includes basic documentation, which, like the present file, will mostly be plain ASCII text. It should also be noted that there is no assumption that the software will be used on a particular computer and Operating System. Although OS-related facilities may be present (Unix make files for instance, use by the SOFA Center of automatic code management systems, HTML versions of some documentation), the routines themselves will be visible as individual text files and will run on a variety of platforms.

ALGORITHMS

The SOFA Review Board's initial goal has been to create a set of callable subprograms. Whether "subroutines" or "functions", they are all referred to simply as "routines". They are designed for use by software developers wishing to write complete applications; no runnable, free-standing applications are included in SOFA's present plans.

The algorithms are drawn from a variety of sources. Because most of the routines so far developed have either been standard "text-book" operations or implement well-documented standard algorithms, it has not been necessary to invite the whole community to submit algorithms, though consultation with authorities has occurred where necessary. It should also be noted that consistency with the conventions published by the International Earth Rotation Service was a stipulation in the original SOFA proposals, further constraining the software designs. This state of affairs will continue to exist for some time, as there is a large backlog of agreed extensions to work on. However, in the future the Board may decide to call for proposals, and is in the meantime willing to look into any suggestions that are received by the SOFA Center.

SCOPE

The routines currently available are listed in the next two chapters of this document.

The "astronomy" library comprises 108 routines (plus one obsolete Fortran routine that now appears under a revised name). The areas addressed include calendars, time scales, ephemerides, precession-nutation, star space-motion, and star catalog transformations.

The "vector-matrix" library, comprising 52 routines, contains a collection of simple tools for manipulating the vectors, matrices and angles used by the astronomy routines.

There is no explicit commitment by SOFA to support historical models, though as time goes on a legacy of superseded models will naturally accumulate. There is, for example, no support of B1950/FK4 star coordinates, or pre-1976 precession models, though these capabilities could be added were there significant demand.

Though the SOFA software libraries are rather limited in scope, and are likely to remain so for a considerable time, they do offer distinct advantages to prospective users. In particular, the routines are:

- * authoritative: they are IAU-backed and have been constructed with great care;
- * practical: they are straightforward to use in spite of being precise and rigorous (to some stated degree);
- * accessible and supported: they are downloadable from an easy-to-find place, they are in an integrated and consistent form, they come with adequate internal documentation, and help for users is available.

VERSIONS

Once it has been published, an issue will not be revised or updated and will remain accessible indefinitely. Subsequent issues may, however, include corrected versions under the original routine name and filenames. However, where a different model is introduced, it will have a different name.

The issues will be referred to by the date when they were announced. The frequency of re-issue will be decided by the Board, taking into account the importance of the changes and the impact on the user community.

DOCUMENTATION

At present there is little free-standing documentation about individual routines. However, each routine has preamble comments which specify in detail what the routine does and how it is used.

The file sofa_pn.pdf describes the SOFA tools for precession-nutation and other aspects of Earth attitude and includes example code and (see the appendix) diagrams showing the interrelationships between the routines supporting the latest (IAU 2006/2000A) models.

PROGRAMMING LANGUAGES AND STANDARDS

The SOFA routines are available in two programming languages at present: Fortran77 and ANSI C. Related software in other languages is under consideration.

The Fortran code conforms to ANSI X3.9-1978 in all but two minor respects: each has an IMPLICIT NONE declaration, and its name has a prefix of "iau_" and may be longer than 6 characters. A global edit to erase both of these will produce ANSI-compliant code with no change in its function.

Coding style, and restrictions on the range of language features, have been much debated by the Board, and the results comply with the majority view. There is (at present) no document that defines the standards, but the code itself offers a wide range of examples of what is acceptable.

The Fortran routines contain explicit numerical constants (the INCLUDE statement is not part of ANSI Fortran77). These are drawn from the file constslis, which is listed in an appendix. Constants for the SOFA/C functions are defined in a header file sofam.h.

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.

Each of the language version includes a "testbed" main-program that can be used to verify that the SOFA routines have been correctly compiled on the end user's system. The Fortran and C versions are called t_sofa_f.for and t_sofa_c.c respectively. The testbeds execute every SOFA routine and check that the results are within expected accuracy margins. It is not possible to guarantee that all platforms will meet the rather stringent criteria that have been used, and an occasional warning message may be encountered on some systems.

COPYRIGHT ISSUES

Copyright for all of the SOFA software and documentation is owned by the IAU SOFA Review Board. The Software is made available free of charge for all classes of user, including commercial. However, there are strict rules designed to avoid unauthorized variants coming into circulation. It is permissible to distribute derived works and other modifications, but they must be clearly marked to avoid confusion with the SOFA originals.

Further details are included in the block of comments which concludes every routine. The text is also set out in an appendix to the present document.

ACCURACY

The SOFA policy is to organize the calculations so that the machine accuracy is fully exploited. The gap between the precision of the underlying model or theory and the computational resolution has to be kept as large as possible, hopefully leaving several orders of magnitude of headroom.

The SOFA routines in some cases involve design compromises between rigor and ease of use (and also speed, though nowadays this is seldom a major concern).

ACKNOWLEDGEMENTS

The Board is indebted to a number of contributors, who are acknowledged in the preamble comments of the routines concerned.

The Board's effort is provided by the members' individual institutes.

Resources for operating the SOFA Center are provided by Her Majesty's Nautical Almanac Office, operated by the United Kingdom Hydrographic Office. Support for the contributions of the SOFA Review Board chair is provided by the European Southern Observatory under arrangements with the UK Science and Technology Facilities Council through its astronomy programs at the Rutherford Appleton Laboratory.

SOFA Astronomy Library

PREFACE

The routines described here comprise the SOFA astronomy library. Their general appearance and coding style conforms to conventions agreed by the SOFA Review 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.

Except for a single obsolete Fortran routine, which has no C equivalent, 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 principal function of the SOFA Astronomy Library is to provide definitive algorithms. A secondary function is to provide software suitable for convenient direct use by writers of astronomical applications.

The astronomy routines call on the SOFA vector/matrix library routines, which are separately listed.

The routines are designed to exploit the full floating-point accuracy of the machines on which they run, and not to rely on compiler optimizations. Within these constraints, the intention is that the code corresponds to the published formulation (if any).

Dates are always Julian Dates (except in calendar conversion routines) and are expressed as two double precision numbers which sum to the required value.

A distinction is made between routines that implement IAU-approved models and those that use those models to create other results. The former are referred to as "canonical models" in the preamble comments; the latter are described as "support routines".

Using the library requires knowledge of positional astronomy and time-scales. These topics are covered in "Explanatory Supplement to the Astronomical Almanac", P. Kenneth Seidelmann (ed.), University Science Books, 1992. Recent developments are documented in the journals, and references to the relevant papers are given in the SOFA code as required. The IERS Conventions are also an essential reference. The routines concerned with Earth attitude (precession-nutation etc.) are described in the SOFA document `sofa_pn.pdf`.

ROUTINES

Calendars

CAL2JD	Gregorian calendar to Julian Day number
EPB	Julian Date to Besselian Epoch
EPB2JD	Besselian Epoch to Julian Date
EPJ	Julian Date to Julian Epoch

EPJ2JD Julian Epoch to Julian Date
JD2CAL Julian Date to Gregorian year, month, day, fraction
JDCALF Julian Date to Gregorian date for formatted output

Time scales

DAT Delta(AT) (=TAI-UTC) for a given UTC date
DTDB TDB-TT

Earth rotation angle and sidereal time

EE00 equation of the equinoxes, IAU 2000
EE00A equation of the equinoxes, IAU 2000A
EE00B equation of the equinoxes, IAU 2000B
EE06A equation of the equinoxes, IAU 2006/2000A
EECT00 equation of the equinoxes complementary terms, IAU 2000
EQEQ94 equation of the equinoxes, IAU 1994
ERA00 Earth rotation angle, IAU 2000
GMST00 Greenwich mean sidereal time, IAU 2000
GMST06 Greenwich mean sidereal time, IAU 2006
GMST82 Greenwich mean sidereal time, IAU 1982
GST00A Greenwich apparent sidereal time, IAU 2000A
GST00B Greenwich apparent sidereal time, IAU 2000B
GST06 Greenwich apparent ST, IAU 2006, given NPB matrix
GST06A Greenwich apparent sidereal time, IAU 2006/2000A
GST94 Greenwich apparent sidereal time, IAU 1994

Ephemerides (limited precision)

EPV00 Earth position and velocity
PLAN94 major-planet position and velocity

Precession, nutation, polar motion

BI00 frame bias components, IAU 2000
BP00 frame bias and precession matrices, IAU 2000
BP06 frame bias and precession matrices, IAU 2006
BPN2XY extract CIP X,Y coordinates from NPB matrix
C2I00A celestial-to-intermediate matrix, IAU 2000A
C2I00B celestial-to-intermediate matrix, IAU 2000B
C2I06A celestial-to-intermediate matrix, IAU 2006/2000A
C2IBPN celestial-to-intermediate matrix, given NPB matrix, IAU 2000
C2IXY celestial-to-intermediate matrix, given X,Y, IAU 2000
C2IXYS celestial-to-intermediate matrix, given X,Y and s
C2T00A celestial-to-terrestrial matrix, IAU 2000A
C2T00B celestial-to-terrestrial matrix, IAU 2000B
C2T06A celestial-to-terrestrial matrix, IAU 2006/2000A
C2TCIO form CIO-based celestial-to-terrestrial matrix
C2TEQX form equinox-based celestial-to-terrestrial matrix
C2TPE celestial-to-terrestrial matrix given nutation, IAU 2000
C2TXY celestial-to-terrestrial matrix given CIP, IAU 2000
EO06A equation of the origins, IAU 2006/2000A
EORS equation of the origins, given NPB matrix and s
FW2M Fukushima-Williams angles to r-matrix
FW2XY Fukushima-Williams angles to X,Y
NUM00A nutation matrix, IAU 2000A
NUM00B nutation matrix, IAU 2000B
NUM06A nutation matrix, IAU 2006/2000A
NUMAT form nutation matrix
NUT00A nutation, IAU 2000A
NUT00B nutation, IAU 2000B
NUT06A nutation, IAU 2006/2000A
NUT80 nutation, IAU 1980
NUTM80 nutation matrix, IAU 1980
OBL06 mean obliquity, IAU 2006
OBL80 mean obliquity, IAU 1980
PB06 zeta,z,theta precession angles, IAU 2006, including bias
PFW06 bias-precession Fukushima-Williams angles, IAU 2006
PMAT00 precession matrix (including frame bias), IAU 2000
PMAT06 PB matrix, IAU 2006
PMAT76 precession matrix, IAU 1976
PN00 bias/precession/nutation results, IAU 2000
PN00A bias/precession/nutation, IAU 2000A

PN00B bias/precession/nutation, IAU 2000B
 PN06 bias/precession/nutation results, IAU 2006
 PN06A bias/precession/nutation results, IAU 2006/2000A
 PNM00A classical NPB matrix, IAU 2000A
 PNM00B classical NPB matrix, IAU 2000B
 PNM06A classical NPB matrix, IAU 2006/2000A
 PNM80 precession/nutation matrix, IAU 1976/1980
 P06E precession angles, IAU 2006, equinox based
 POM00 polar motion matrix
 PR00 IAU 2000 precession adjustments
 PREC76 accumulated precession angles, IAU 1976
 S00 the CIO locator s , given X, Y , IAU 2000A
 S00A the CIO locator s , IAU 2000A
 S00B the CIO locator s , IAU 2000B
 S06 the CIO locator s , given X, Y , IAU 2006
 S06A the CIO locator s , IAU 2006/2000A
 SP00 the TIO locator s' , IERS 2003
 XY06 CIP, IAU 2006/2000A, from series
 XYS00A CIP and s , IAU 2000A
 XYS00B CIP and s , IAU 2000B
 XYS06A CIP and s , IAU 2006/2000A

Fundamental arguments for nutation etc.

FAD03 mean elongation of the Moon from the Sun
 FAE03 mean longitude of Earth
 FAF03 mean argument of the latitude of the Moon
 FAJU03 mean longitude of Jupiter
 FAL03 mean anomaly of the Moon
 FALP03 mean anomaly of the Sun
 FAMA03 mean longitude of Mars
 FAME03 mean longitude of Mercury
 FANE03 mean longitude of Neptune
 FAOM03 mean longitude of the Moon's ascending node
 FAPA03 general accumulated precession in longitude
 FASA03 mean longitude of Saturn
 FAUR03 mean longitude of Uranus
 FAVE03 mean longitude of Venus

Star space motion

PVSTAR space motion pv-vector to star catalog data
 STARPV star catalog data to space motion pv-vector

Star catalog conversions

FK52H transform FK5 star data into the Hipparcos system
 FK5HIP FK5 to Hipparcos rotation and spin
 FK5HZ FK5 to Hipparcos assuming zero Hipparcos proper motion
 H2FK5 transform Hipparcos star data into the FK5 system
 HFK5Z Hipparcos to FK5 assuming zero Hipparcos proper motion
 STARPM proper motion between two epochs

Obsolete

C2TCEO former name of C2TCIO

CALLS: FORTRAN VERSION

CALL iau_BI00 (DPSIBI, DEPSBI, DRA)
 CALL iau_BP00 (DATE1, DATE2, RB, RP, RBP)
 CALL iau_BP06 (DATE1, DATE2, RB, RP, RBP)
 CALL iau_BPN2XY (RBPN, X, Y)
 CALL iau_C2I00A (DATE1, DATE2, RC2I)
 CALL iau_C2I00B (DATE1, DATE2, RC2I)
 CALL iau_C2I06A (DATE1, DATE2, RC2I)
 CALL iau_C2IBPN (DATE1, DATE2, RBPN, RC2I)
 CALL iau_C2IXY (DATE1, DATE2, X, Y, RC2I)
 CALL iau_C2IXYS (X, Y, S, RC2I)
 CALL iau_C2T00A (TTA, TTB, UTA, UTB, XP, YP, RC2T)
 CALL iau_C2T00B (TTA, TTB, UTA, UTB, XP, YP, RC2T)
 CALL iau_C2T06A (TTA, TTB, UTA, UTB, XP, YP, RC2T)


```

CALL iau_C2TCEO ( RC2I, ERA, RPOM, RC2T )
CALL iau_C2TCIO ( RC2I, ERA, RPOM, RC2T )
CALL iau_C2TEQX ( RBPN, GST, RPOM, RC2T )
CALL iau_C2TPE ( TTA, TTB, UTA, UTB, DPSI, DEPS, XP, YP, RC2T )
CALL iau_C2TXY ( TTA, TTB, UTA, UTB, X, Y, XP, YP, RC2T )
CALL iau_CAL2JD ( IY, IM, ID, DJM0, DJM, J )
CALL iau_DAT ( IY, IM, ID, FD, DELTAT, J )
D = iau_DTDB ( DATE1, DATE2, UT, ELONG, U, V )
D = iau_EE00 ( DATE1, DATE2, EPSA, DPSI )
D = iau_EE00A ( DATE1, DATE2 )
D = iau_EE00B ( DATE1, DATE2 )
D = iau_EE06A ( DATE1, DATE2 )
D = iau_EECT00 ( DATE1, DATE2 )
D = iau_EO06A ( DATE1, DATE2 )
D = iau_EORS ( RNPB, S )
D = iau_EPB ( DJ1, DJ2 )
CALL iau_EPB2JD ( EPB, DJM0, DJM )
D = iau_EPJ ( DJ1, DJ2 )
CALL iau_EPJ2JD ( EPJ, DJM0, DJM )
CALL iau_EPV00 ( DJ1, DJ2, PVH, PVB, J )
D = iau_EQEQ94 ( DATE1, DATE2 )
D = iau_ERA00 ( DJ1, DJ2 )
D = iau_FAD03 ( T )
D = iau_FAE03 ( T )
D = iau_FAF03 ( T )
D = iau_FAJU03 ( T )
D = iau_FAL03 ( T )
D = iau_FALP03 ( T )
D = iau_FAMA03 ( T )
D = iau_FAME03 ( T )
D = iau_FANE03 ( T )
D = iau_FAOM03 ( T )
D = iau_FAPA03 ( T )
D = iau_FASA03 ( T )
D = iau_FAUR03 ( T )
D = iau_FAVE03 ( T )
CALL iau_FK52H ( R5, D5, DR5, DD5, PX5, RV5,
: RH, DH, DRH, DDH, PXH, RVH )
CALL iau_FK5HIP ( R5H, S5H )
CALL iau_FK5HZ ( R5, D5, DATE1, DATE2, RH, DH )
CALL iau_FW2M ( GAMB, PHIB, PSI, EPS, R )
CALL iau_FW2XY ( GAMB, PHIB, PSI, EPS, X, Y )
D = iau_GMST00 ( UTA, UTB, TTA, TTB )
D = iau_GMST06 ( UTA, UTB, TTA, TTB )
D = iau_GMST82 ( UTA, UTB )
D = iau_GST00A ( UTA, UTB, TTA, TTB )
D = iau_GST00B ( UTA, UTB )
D = iau_GST06 ( UTA, UTB, TTA, TTB, RNPB )
D = iau_GST06A ( UTA, UTB, TTA, TTB )
D = iau_GST94 ( UTA, UTB )
CALL iau_H2FK5 ( RH, DH, DRH, DDH, PXH, RVH,
: R5, D5, DR5, DD5, PX5, RV5 )
CALL iau_HFK5Z ( RH, DH, DATE1, DATE2, R5, D5, DR5, DD5 )
CALL iau_JD2CAL ( DJ1, DJ2, IY, IM, ID, FD, J )
CALL iau_JDCALF ( NDP, DJ1, DJ2, IYMD, J )
CALL iau_NUM00A ( DATE1, DATE2, RMATN )
CALL iau_NUM00B ( DATE1, DATE2, RMATN )
CALL iau_NUM06A ( DATE1, DATE2, RMATN )
CALL iau_NUMAT ( EPSA, DPSI, DEPS, RMATN )
CALL iau_NUT00A ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUT00B ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUT06A ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUT80 ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUTM80 ( DATE1, DATE2, RMATN )
D = iau_OBL06 ( DATE1, DATE2 )
D = iau_OBL80 ( DATE1, DATE2 )
CALL iau_PB06 ( DATE1, DATE2, BZETA, BZ, BTHETA )
CALL iau_PFW06 ( DATE1, DATE2, GAMB, PHIB, PSIB, EPSA )
CALL iau_PLAN94 ( DATE1, DATE2, NP, PV, J )
CALL iau_PMAT00 ( DATE1, DATE2, RBP )
CALL iau_PMAT06 ( DATE1, DATE2, RBP )
CALL iau_PMAT76 ( DATE1, DATE2, RMATP )
CALL iau_PN00 ( DATE1, DATE2, DPSI, DEPS,

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```

:          EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN00A ( DATE1, DATE2,
:          DPSI, DEPS, EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN00B ( DATE1, DATE2,
:          DPSI, DEPS, EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN06 ( DATE1, DATE2, DPSI, DEPS,
:          EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN06A ( DATE1, DATE2,
:          DPSI, DEPS, RB, RP, RBP, RN, RBPN )
CALL iau_PNM00A ( DATE1, DATE2, RBPN )
CALL iau_PNM00B ( DATE1, DATE2, RBPN )
CALL iau_PNM06A ( DATE1, DATE2, RNPB )
CALL iau_PNM80 ( DATE1, DATE2, RMATPN )
CALL iau_P06E ( DATE1, DATE2,
:          EPS0, PSIA, OMA, BPA, BQA, PIA, BPIA,
:          EPSA, CHIA, ZA, ZETAA, THETAA, PA, GAM, PHI, PSI )
CALL iau_POM00 ( XP, YP, SP, RPOM )
CALL iau_PRO0 ( DATE1, DATE2, DPSIPR, DEPSPR )
CALL iau_PREC76 ( EP01, EP02, EP11, EP12, ZETA, Z, THETA )
CALL iau_PVSTAR ( PV, RA, DEC, PMR, PMD, PX, RV, J )
D = iau_S00 ( DATE1, DATE2, X, Y )
D = iau_S00A ( DATE1, DATE2 )
D = iau_S00B ( DATE1, DATE2 )
D = iau_S06 ( DATE1, DATE2, X, Y )
D = iau_S06A ( DATE1, DATE2 )
D = iau_SP00 ( DATE1, DATE2 )
CALL iau_STARPM ( RA1, DEC1, PMR1, PMD1, PX1, RV1,
:          EP1A, EP1B, EP2A, EP2B,
:          RA2, DEC2, PMR2, PMD2, PX2, RV2, J )
CALL iau_STARPV ( RA, DEC, PMR, PMD, PX, RV, PV, J )
CALL iau_XYS06 ( DATE1, DATE2, X, Y )
CALL iau_XYS00A ( DATE1, DATE2, X, Y, S )
CALL iau_XYS00B ( DATE1, DATE2, X, Y, S )
CALL iau_XYS06A ( DATE1, DATE2, X, Y, S )

```

CALLS: C VERSION

```

iauBi00 ( &dpsibi, &depsbi, &dra );
iauBp00 ( datel, date2, rb, rp, rbp );
iauBp06 ( datel, date2, rb, rp, rbp );
iauBpn2xy ( rbpn, &x, &y );
iauC2i00a ( datel, date2, rc2i );
iauC2i00b ( datel, date2, rc2i );
iauC2i06a ( datel, date2, rc2i );
iauC2ibpn ( datel, date2, rbpn, rc2i );
iauC2ixy ( datel, date2, x, y, rc2i );
iauC2ixys ( x, y, s, rc2i );
iauC2t00a ( tta, ttb, uta, utb, xp, yp, rc2t );
iauC2t00b ( tta, ttb, uta, utb, xp, yp, rc2t );
iauC2t06a ( tta, ttb, uta, utb, xp, yp, rc2t );
iauC2tcio ( rc2i, era, rpom, rc2t );
iauC2teqx ( rbpn, gst, rpom, rc2t );
iauC2tpe ( tta, ttb, uta, utb, dpsib, deps, xp, yp, rc2t );
iauC2txy ( tta, ttb, uta, utb, x, y, xp, yp, rc2t );
i = iauCal2jd ( iy, im, id, &djm0, &djm );
i = iauDat ( iy, im, id, fd, &deltat );
d = iauDtdb ( datel, date2, ut, elong, u, v );
d = iauEe00 ( datel, date2, epsa, dpsib );
d = iauEe00a ( datel, date2 );
d = iauEe00b ( datel, date2 );
d = iauEe06 ( datel, date2 );
d = iauEect00 ( datel, date2 );
d = iauEo06 ( datel, date2 );
d = iauEors ( rnpb, s );
d = iauEpb ( dj1, dj2 );
iauEpb2jd ( epb, &djm0, &djm );
d = iauEpj ( dj1, dj2 );
iauEpj2jd ( epj, &djm0, &djm );
i = iauEpv00 ( dj1, dj2, pvh, pvh );
d = iauEseq94 ( datel, date2 );
d = iauEra00 ( dj1, dj2 );
d = iauFad03 ( t );

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```

d = iauFae03 ( t );
d = iauFaf03 ( t );
d = iauFaju03 ( t );
d = iauFal03 ( t );
d = iauFalp03 ( t );
d = iauFama03 ( t );
d = iauFame03 ( t );
d = iauFane03 ( t );
d = iauFaom03 ( t );
d = iauFapa03 ( t );
d = iauFasa03 ( t );
d = iauFaur03 ( t );
d = iauFave03 ( t );
    iauFk52h ( r5, d5, dr5, dd5, px5, rv5,
              &rh, &dh, &drh, &ddh, &pxh, &rvh );
    iauFk5hip ( r5h, s5h );
    iauFk5hz ( r5, d5, datel, date2, &rh, &dh );
    iauFw2m ( gamb, phib, psi, eps, r );
    iauFw2xy ( gamb, phib, psi, eps, &x, &y );
d = iauGmst00 ( uta, utb, tta, ttb );
d = iauGmst06 ( uta, utb, tta, ttb );
d = iauGmst82 ( uta, utb );
d = iauGst00a ( uta, utb, tta, ttb );
d = iauGst00b ( uta, utb );
d = iauGst06 ( uta, utb, tta, ttb, rnpb );
d = iauGst06a ( uta, utb, tta, ttb );
d = iauGst94 ( uta, utb );
    iauH2fk5 ( rh, dh, drh, ddh, pxh, rvh,
              &r5, &d5, &dr5, &dd5, &px5, &rv5 );
    iauHfk5z ( rh, dh, datel, date2,
              &r5, &d5, &dr5, &dd5 );
i = iauJd2cal ( dj1, dj2, &iy, &im, &id, &fd );
i = iauJdcalf ( ndp, dj1, dj2, iymdf );
    iauNum00a ( datel, date2, rmatn );
    iauNum00b ( datel, date2, rmatn );
    iauNum06a ( datel, date2, rmatn );
    iauNumat ( epsa, dpsi, deps, rmatn );
    iauNut00a ( datel, date2, &dpsi, &deps );
    iauNut00b ( datel, date2, &dpsi, &deps );
    iauNut06a ( datel, date2, &dpsi, &deps );
    iauNut80 ( datel, date2, &dpsi, &deps );
    iauNutm80 ( datel, date2, rmatn );
d = iauObl06 ( datel, date2 );
d = iauObl80 ( datel, date2 );
    iauPb06 ( datel, date2, &bzeta, &bz, &btheta );
    iauPfw06 ( datel, date2, &gamb, &phib, &psib, &epsa );
i = iauPlan94 ( datel, date2, np, pv );
    iauPmat00 ( datel, date2, rbp );
    iauPmat06 ( datel, date2, rbp );
    iauPmat76 ( datel, date2, rmatp );
    iauPn00 ( datel, date2, dpsi, deps,
            &epsa, rb, rp, rbp, rn, rbpn );
    iauPn00a ( datel, date2,
            &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPn00b ( datel, date2,
            &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPn06 ( datel, date2, dpsi, deps,
            &epsa, rb, rp, rbp, rn, rbpn );
    iauPn06a ( datel, date2,
            &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPnm00a ( datel, date2, rbpn );
    iauPnm00b ( datel, date2, rbpn );
    iauPnm06a ( datel, date2, rnpb );
    iauPnm80 ( datel, date2, rmatpn );
    iauP06e ( datel, date2,
            &eps0, &psia, &oma, &bpa, &bqa, &pia, &bpia,
            &epsa, &chia, &za, &zetaa, &thetaa, &pa,
            &gam, &phi, &psi );
    iauPom00 ( xp, yp, sp, rpom );
    iauPr00 ( datel, date2, &dpsipr, &depspr );
    iauPrec76 ( ep01, ep02, ep11, ep12, &zeta, &z, &theta );
i = iauPvstar ( pv, &ra, &dec, &pmr, &pmd, &px, &rv );
d = iauS00 ( datel, date2, x, y );

```

```
d = iauS00a ( datel, date2 );
d = iauS00b ( datel, date2 );
d = iauS06 ( datel, date2, x, y );
d = iauS06a ( datel, date2 );
d = iauSp00 ( datel, date2 );
i = iauStarpm ( ral, decl1, pmr1, pmd1, px1, rv1,
               ep1a, ep1b, ep2a, ep2b,
               &ra2, &dec2, &pmr2, &pmd2, &px2, &rv2 );
i = iauStarpv ( ra, dec, pmr, pmd, px, rv, pv );
iauXys06 ( datel, date2, &x, &y );
iauXys00a ( datel, date2, &x, &y, &s );
iauXys00b ( datel, date2, &x, &y, &s );
iauXys06a ( datel, date2, &x, &y, &s );
```

SOFA Vector/Matrix Library

PREFACE

The routines described here comprise the SOFA vector/matrix library. Their general appearance and coding style conforms to conventions agreed by the SOFA Review 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 hms
A2AF decompose radians into d ' "
D2TF decompose days into hms

CALLS: FORTRAN VERSION

CALL iau_A2AF (NDP, ANGLE, SIGN, IDMSF)
CALL iau_A2TF (NDP, ANGLE, SIGN, IHMSF)
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)
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_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 )

```

CALLS: C VERSION

```

    iauA2af ( ndp, angle, &sign, idmsf );
    iauA2tf ( ndp, angle, &sign, ihmsf );
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, rp );
    iauRxp ( r, pv, rp );
    iauRxr ( a, b, atb );
    iauRy ( theta, r );
    iauRz ( psi, r );
    iauS2c ( theta, phi, c );
    iauS2p ( theta, phi, r, p );
    iauS2pv ( theta, phi, r, td, pd, rd, pv );
    iauS2xp ( s1, s2, pv );
d = iauSepp ( a, b );
d = iauSeps ( al, ap, bl, bp );
    iauSxp ( s, p, sp );
    iauSxp ( s, pv, sp );

```



```
iauTr      ( r, rt );  
iauTrxp   ( r, p, trp );  
iauTrxpv  ( r, pv, trpv );  
iauZp     ( p );  
iauZpv    ( pv );  
iauZr     ( r );
```

```

void iauA2af(int ndp, double angle, char *sign, int idmsf[4])
/*
**  - - - - -
**   i a u A 2 a f
**  - - - - -
**
**  Decompose radians into degrees, arcminutes, arcseconds, fraction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    ndp      int      resolution (Note 1)
**    angle    double   angle in radians
**
**  Returned:
**    sign     char     '+' or '-'
**    idmsf    int[4]   degrees, arcminutes, arcseconds, fraction
**
**  Called:
**    iauD2tf      decompose days to hms
**
**  Notes:
**
**  1) The argument ndp is interpreted as follows:
**
**      ndp      resolution
**      :        ...0000 00 00
**      -7       1000 00 00
**      -6       100 00 00
**      -5       10 00 00
**      -4       1 00 00
**      -3       0 10 00
**      -2       0 01 00
**      -1       0 00 10
**      0        0 00 01
**      1        0 00 00.1
**      2        0 00 00.01
**      3        0 00 00.001
**      :        0 00 00.000...
**
**  2) The largest positive useful value for ndp is determined by the
**  size of angle, the format of doubles on the target platform, and
**  the risk of overflowing idmsf[3].  On a typical platform, for
**  angle up to 2pi, the available floating-point precision might
**  correspond to ndp=12.  However, the practical limit is typically
**  ndp=9, set by the capacity of a 32-bit int, or ndp=4 if int is
**  only 16 bits.
**
**  3) The absolute value of angle may exceed 2pi.  In cases where it
**  does not, it is up to the caller to test for and handle the
**  case where angle is very nearly 2pi and rounds up to 360 degrees,
**  by testing for idmsf[0]=360 and setting idmsf[0-3] to zero.
**
*/

```

```

void iauA2tf(int ndp, double angle, char *sign, int ihmsf[4])
/*
**  - - - - -
**   i a u A 2 t f
**  - - - - -
**
**  Decompose radians into hours, minutes, seconds, fraction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    ndp      int      resolution (Note 1)
**    angle    double   angle in radians
**
**  Returned:
**    sign     char     '+' or '-'
**    ihmsf    int[4]   hours, minutes, seconds, fraction
**
**  Called:
**    iauD2tf      decompose days to hms
**
**  Notes:
**
**  1) The argument ndp is interpreted as follows:
**
**      ndp      resolution
**      :        ...0000 00 00
**      -7       1000 00 00
**      -6       100 00 00
**      -5       10 00 00
**      -4       1 00 00
**      -3       0 10 00
**      -2       0 01 00
**      -1       0 00 10
**      0        0 00 01
**      1        0 00 00.1
**      2        0 00 00.01
**      3        0 00 00.001
**      :        0 00 00.000...
**
**  2) The largest positive useful value for ndp is determined by the
**  size of angle, the format of doubles on the target platform, and
**  the risk of overflowing ihmsf[3].  On a typical platform, for
**  angle up to 2pi, the available floating-point precision might
**  correspond to ndp=12.  However, the practical limit is typically
**  ndp=9, set by the capacity of a 32-bit int, or ndp=4 if int is
**  only 16 bits.
**
**  3) The absolute value of angle may exceed 2pi.  In cases where it
**  does not, it is up to the caller to test for and handle the
**  case where angle is very nearly 2pi and rounds up to 24 hours,
**  by testing for ihmsf[0]=24 and setting ihmsf(0-3) to zero.
**
**  */

```

```
double iauAnp(double a)
/*
**  - - - - -
**   i a u A n p
**  - - - - -
**
**  Normalize angle into the range  $0 \leq a < 2\pi$ .
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a          double      angle (radians)
**
**  Returned (function value):
**    double      angle in range 0-2pi
**
**/
```

```
double iauAnpm(double a)
/*
**  - - - - -
**   i a u A n p m
**  - - - - -
**
**  Normalize angle into the range  $-\pi \leq a < +\pi$ .
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a          double      angle (radians)
**
**  Returned (function value):
**    double      angle in range  $\pm\pi$ 
**
**  */
```

```

void iauBi00(double *dpsibi, double *depsbi, double *dra)
/*
**  - - - - -
**   i a u B i 0 0
**  - - - - -
**
**  Frame bias components of IAU 2000 precession-nutation models (part
**  of MHB2000 with additions).
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Returned:
**    dpsibi,depsbi  double  longitude and obliquity corrections
**    dra            double  the ICRS RA of the J2000 mean equinox
**
**  Notes:
**
**  1) The frame bias corrections in longitude and obliquity (radians)
**     are required in order to correct for the offset between the GCRS
**     pole and the mean J2000 pole.  They define, with respect to the
**     GCRS frame, a J2000 mean pole that is consistent with the rest of
**     the IAU 2000A precession-nutation model.
**
**  2) In addition to the displacement of the pole, the complete
**     description of the frame bias requires also an offset in right
**     ascension.  This is not part of the IAU 2000A model, and is from
**     Chapront et al. (2002).  It is returned in radians.
**
**  3) This is a supplemented implementation of one aspect of the IAU
**     2000A nutation model, formally adopted by the IAU General
**     Assembly in 2000, namely MHB2000 (Mathews et al. 2002).
**
**  References:
**
**     Chapront, J., Chapront-Touze, M. & Francou, G., Astron.
**     Astrophys., 387, 700, 2002.
**
**     Mathews, P.M., Herring, T.A., Buffet, B.A., "Modeling of nutation
**     and precession  New nutation series for nonrigid Earth and
**     insights into the Earth's interior", J.Geophys.Res., 107, B4,
**     2002.  The MHB2000 code itself was obtained on 9th September 2002
**     from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**
*/

```

```

void iauBp00(double date1, double date2,
             double rb[3][3], double rp[3][3], double rbp[3][3])
/*
**   - - - - -
**   i a u B p 0 0
**   - - - - -
**
**   Frame bias and precession, IAU 2000.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status: canonical model.
**
**   Given:
**     date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     rb          double[3][3]    frame bias matrix (Note 2)
**     rp          double[3][3]    precession matrix (Note 3)
**     rbp         double[3][3]    bias-precession matrix (Note 4)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments. For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable. The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution. The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The matrix rb transforms vectors from GCRS to mean J2000 by
**      applying frame bias.
**
**   3) The matrix rp transforms vectors from J2000 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**   4) The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession. It is
**      the product rp x rb.
**
**   5) It is permissible to re-use the same array in the returned
**      arguments. The arrays are filled in the order given.
**
**   Called:
**     iauBi00      frame bias components, IAU 2000
**     iauPr00      IAU 2000 precession adjustments
**     iauIr        initialize r-matrix to identity
**     iauRx        rotate around X-axis
**     iauRy        rotate around Y-axis
**     iauRz        rotate around Z-axis
**     iauCr        copy r-matrix
**     iauRxx       product of two r-matrices
**
**   Reference:
**     "Expressions for the Celestial Intermediate Pole and Celestial
**     Ephemeris Origin consistent with the IAU 2000A precession-
**     nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)

```

**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/


```

void iauBp06(double date1, double date2,
             double rb[3][3], double rp[3][3], double rbp[3][3])
/*
**  - - - - -
**  i a u B p 0 6
**  - - - - -
**
**  Frame bias and precession, IAU 2006.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    rb          double[3][3]    frame bias matrix (Note 2)
**    rp          double[3][3]    precession matrix (Note 3)
**    rbp         double[3][3]    bias-precession matrix (Note 4)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The matrix rb transforms vectors from GCRS to mean J2000 by
**     applying frame bias.
**
**  3) The matrix rp transforms vectors from mean J2000 to mean of date
**     by applying precession.
**
**  4) The matrix rbp transforms vectors from GCRS to mean of date by
**     applying frame bias then precession.  It is the product rp x rb.
**
**  Called:
**    iauPfw06      bias-precession F-W angles, IAU 2006
**    iauFw2m       F-W angles to r-matrix
**    iauPmat06     PB matrix, IAU 2006
**    iauTr         transpose r-matrix
**    iauRxr        product of two r-matrices
**
**  References:
**
**    Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**    Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

void iauBpn2xy(double rbpn[3][3], double *x, double *y)
/*
**  - - - - -
**   i a u B p n 2 x y
**  - - - - -
**
**  Extract from the bias-precession-nutation matrix the X,Y coordinates
**  of the Celestial Intermediate Pole.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    rbpn      double[3][3]  celestial-to-true matrix (Note 1)
**
**  Returned:
**    x,y       double        Celestial Intermediate Pole (Note 2)
**
**  Notes:
**
**  1) The matrix rbpn transforms vectors from GCRS to true equator (and
**     CIO or equinox) of date, and therefore the Celestial Intermediate
**     Pole unit vector is the bottom row of the matrix.
**
**  2) The arguments x,y are components of the Celestial Intermediate
**     Pole unit vector in the Geocentric Celestial Reference System.
**
**  Reference:
**
**     "Expressions for the Celestial Intermediate Pole and Celestial
**     Ephemeris Origin consistent with the IAU 2000A precession-
**     nutation model", Astronomy & Astrophysics, 400, 1145-1154
**     (2003)
**
**     n.b. The celestial ephemeris origin (CEO) was renamed "celestial
**     intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/

```

```

void iauC2i00a(double date1, double date2, double rc2i[3][3])
/*
**   - - - - -
**   i a u C 2 i 0 0 a
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date using the
** IAU 2000A precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rc2i          double[3][3] celestial-to-intermediate matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 3) A faster, but slightly less accurate result (about 1 mas), can be
** obtained by using instead the iauC2i00b function.
**
** Called:
**   iauPnm00a    classical NPB matrix, IAU 2000A
**   iauC2ibpn    celestial-to-intermediate matrix, given NPB matrix
**
** References:
**
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154
** (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),

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** IERS Technical Note No. 32, BKG (2004)
**
*/

```

void iauC2i00b(double date1, double date2, double rc2i[3][3])
/*
**   - - - - -
**   i a u C 2 i 0 0 b
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date using the
** IAU 2000B precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rc2i          double[3][3] celestial-to-intermediate matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 3) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauC2i00a function.
**
** Called:
**   iauPnm00b    classical NPB matrix, IAU 2000B
**   iauC2ibpn    celestial-to-intermediate matrix, given NPB matrix
**
** References:
**
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154
** (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),

```

** IERS Technical Note No. 32, BKG (2004)
**
*/

```

void iauC2i06a(double date1, double date2, double rc2i[3][3])
/*
**   - - - - -
**   i a u _ c 2 i 0 6 a
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date using the
** IAU 2006 precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rc2i          double[3][3] celestial-to-intermediate matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** Called:
**   iauPnm06a    classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauS06       the CIO locator s, Given X,Y, IAU 2006
**   iauC2ixys    celestial-to-intermediate matrix, Given X,Y and s
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG
**
*/

```

```

void iauC2ibpn(double date1, double date2, double rbpn[3][3],
              double rc2i[3][3])
/*
**   - - - - -
**   i a u C 2 i b p n
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date given
** the bias-precession-nutation matrix. IAU 2000.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**   rbpn         double[3][3] celestial-to-true matrix (Note 2)
**
** Returned:
**   rc2i         double[3][3] celestial-to-intermediate matrix (Note 3)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rbpn transforms vectors from GCRS to true equator (and
** CIO or equinox) of date. Only the CIP (bottom row) is used.
**
** 3) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 4) Although its name does not include "00", This function is in fact
** specific to the IAU 2000 models.
**
** Called:
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauC2ixy    celestial-to-intermediate matrix, given X,Y
**
** References:
**   "Expressions for the Celestial Intermediate Pole and Celestial
**   Ephemeris Origin consistent with the IAU 2000A precession-
**   nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial

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** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

void iauC2ixy(double date1, double date2, double x, double y,
              double rc2i[3][3])
/*
**  - - - - -
**   i a u C 2 i x y
**  - - - - -
**
** Form the celestial to intermediate-frame-of-date matrix for a given
** date when the CIP X,Y coordinates are known.  IAU 2000.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double      TT as a 2-part Julian Date (Note 1)
**   x,y         double     Celestial Intermediate Pole (Note 2)
**
** Returned:
**   rc2i        double[3][3] celestial-to-intermediate matrix (Note 3)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y components
** of the unit vector in the Geocentric Celestial Reference System.
**
** 3) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 4) Although its name does not include "00", This function is in fact
** specific to the IAU 2000 models.
**
** Called:
**   iauC2ixys    celestial-to-intermediate matrix, given X,Y and s
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```



```

void iauC2ixys(double x, double y, double s, double rc2i[3][3])
/*
**  - - - - -
**   i a u C 2 i x y s
**  - - - - -
**
** Form the celestial to intermediate-frame-of-date matrix given the CIP
** X,Y and the CIO locator s.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   x,y      double      Celestial Intermediate Pole (Note 1)
**   s        double      the CIO locator s (Note 2)
**
** Returned:
**   rc2i     double[3][3]  celestial-to-intermediate matrix (Note 3)
**
** Notes:
**
** 1) The Celestial Intermediate Pole coordinates are the x,y
**    components of the unit vector in the Geocentric Celestial
**    Reference System.
**
** 2) The CIO locator s (in radians) positions the Celestial
**    Intermediate Origin on the equator of the CIP.
**
** 3) The matrix rc2i is the first stage in the transformation from
**    celestial to terrestrial coordinates:
**
**       [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
**    where [CRS] is a vector in the Geocentric Celestial Reference
**    System and [TRS] is a vector in the International Terrestrial
**    Reference System (see IERS Conventions 2003), ERA is the Earth
**    Rotation Angle and RPOM is the polar motion matrix.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRz      rotate around Z-axis
**   iauRy      rotate around Y-axis
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauC2s(double p[3], double *theta, double *phi)
/*
**  - - - - -
**   i a u C 2 s
**  - - - - -
**
**  P-vector to spherical coordinates.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    p      double[3]    p-vector
**
**  Returned:
**    theta  double      longitude angle (radians)
**    phi    double      latitude angle (radians)
**
**  Notes:
**
**  1) The vector p can have any magnitude; only its direction is used.
**
**  2) If p is null, zero theta and phi are returned.
**
**  3) At either pole, zero theta is returned.
**
*/

```

```

void iauC2t00a(double tta, double ttb, double uta, double utb,
              double xp, double yp, double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t 0 0 a
**  - - - - -
**
** Form the celestial to terrestrial matrix given the date, the UT1 and
** the polar motion, using the IAU 2000A nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   tta,ttb  double      TT as a 2-part Julian Date (Note 1)
**   uta,utb  double      UT1 as a 2-part Julian Date (Note 1)
**   xp,yp    double      coordinates of the pole (radians, Note 2)
**
** Returned:
**   rc2t     double[3][3]  celestial-to-terrestrial matrix (Note 3)
**
** Notes:
**
** 1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
** apportioned in any convenient way between the arguments uta and
** utb.  For example, JD(UT1)=2450123.7 could be expressed in any of
** these ways, among others:
**
**           uta           utb
**
**   2450123.7           0.0      (JD method)
**   2451545.0          -1421.3    (J2000 method)
**   2400000.5           50123.2    (MJD method)
**   2450123.5           0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution is
** acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  In the case of uta,utb, the
** date & time method is best matched to the Earth rotation angle
** algorithm used:  maximum precision is delivered when the uta
** argument is for 0hrs UT1 on the day in question and the utb
** argument lies in the range 0 to 1, or vice versa.
**
** 2) The arguments xp and yp are the "coordinates of the pole", in
** radians, which position the Celestial Intermediate Pole in the
** International Terrestrial Reference System (see IERS Conventions
** 2003).  In a geocentric right-handed triad u,v,w, where the
** w-axis points at the north geographic pole, the v-axis points
** towards the origin of longitudes and the u axis completes the
** system, xp = +u and yp = -v.
**
** 3) The matrix rc2t transforms from celestial to terrestrial
** coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), RC2I is the
** celestial-to-intermediate matrix, ERA is the Earth rotation
** angle and RPOM is the polar motion matrix.
**
** 4) A faster, but slightly less accurate result (about 1 mas), can
** be obtained by using instead the iauC2t00b function.
**
** Called:

```

```
**      iauC2i00a    celestial-to-intermediate matrix, IAU 2000A
**      iauEra00    Earth rotation angle, IAU 2000
**      iauSp00     the TIO locator s', IERS 2000
**      iauPom00    polar motion matrix
**      iauC2tcio   form CIO-based celestial-to-terrestrial matrix
**
** Reference:
**
**      McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**      IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

void iauC2t00b(double tta, double ttb, double uta, double utb,
               double xp, double yp, double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t 0 0 b
**  - - - - -
**
** Form the celestial to terrestrial matrix given the date, the UT1 and
** the polar motion, using the IAU 2000B nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   tta,ttb  double      TT as a 2-part Julian Date (Note 1)
**   uta,utb  double      UT1 as a 2-part Julian Date (Note 1)
**   xp,yp    double      coordinates of the pole (radians, Note 2)
**
** Returned:
**   rc2t     double[3][3]  celestial-to-terrestrial matrix (Note 3)
**
** Notes:
**
** 1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
** apportioned in any convenient way between the arguments uta and
** utb.  For example, JD(UT1)=2450123.7 could be expressed in any of
** these ways, among others:
**
**           uta           utb
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution is
** acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  In the case of uta,utb, the
** date & time method is best matched to the Earth rotation angle
** algorithm used:  maximum precision is delivered when the uta
** argument is for 0hrs UT1 on the day in question and the utb
** argument lies in the range 0 to 1, or vice versa.
**
** 2) The arguments xp and yp are the "coordinates of the pole", in
** radians, which position the Celestial Intermediate Pole in the
** International Terrestrial Reference System (see IERS Conventions
** 2003).  In a geocentric right-handed triad u,v,w, where the
** w-axis points at the north geographic pole, the v-axis points
** towards the origin of longitudes and the u axis completes the
** system, xp = +u and yp = -v.
**
** 3) The matrix rc2t transforms from celestial to terrestrial
** coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), RC2I is the
** celestial-to-intermediate matrix, ERA is the Earth rotation
** angle and RPOM is the polar motion matrix.
**
** 4) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauC2t00a function.
**
** Called:

```



```
**      iauC2i00b   celestial-to-intermediate matrix, IAU 2000B
**      iauEra00   Earth rotation angle, IAU 2000
**      iauPom00   polar motion matrix
**      iauC2tcio  form CIO-based celestial-to-terrestrial matrix
**
```

```
** Reference:
```

```
**
**      McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**      IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

void iauC2t06a(double tta, double ttb, double uta, double utb,
               double xp, double yp, double rc2t[3][3])
/*
**   - - - - -
**   i a u C 2 t 0 6 a
**   - - - - -
**
** Form the celestial to terrestrial matrix given the date, the UT1 and
** the polar motion, using the IAU 2006 precession and IAU 2000A
** nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   tta,ttb double      TT as a 2-part Julian Date (Note 1)
**   uta,utb double      UT1 as a 2-part Julian Date (Note 1)
**   xp,yp   double      coordinates of the pole (radians, Note 2)
**
** Returned:
**   rc2t     double[3][3] celestial-to-terrestrial matrix (Note 3)
**
** Notes:
**
** 1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
** apportioned in any convenient way between the arguments uta and
** utb. For example, JD(UT1)=2450123.7 could be expressed in any of
** these ways, among others:
**
**           uta           utb
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution is
** acceptable. The J2000 and MJD methods are good compromises
** between resolution and convenience. In the case of uta,utb, the
** date & time method is best matched to the Earth rotation angle
** algorithm used: maximum precision is delivered when the uta
** argument is for 0hrs UT1 on the day in question and the utb
** argument lies in the range 0 to 1, or vice versa.
**
** 2) The arguments xp and yp are the "coordinates of the pole", in
** radians, which position the Celestial Intermediate Pole in the
** International Terrestrial Reference System (see IERS Conventions
** 2003). In a geocentric right-handed triad u,v,w, where the
** w-axis points at the north geographic pole, the v-axis points
** towards the origin of longitudes and the u axis completes the
** system, xp = +u and yp = -v.
**
** 3) The matrix rc2t transforms from celestial to terrestrial
** coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), RC2I is the
** celestial-to-intermediate matrix, ERA is the Earth rotation
** angle and RPOM is the polar motion matrix.
**
** Called:
**   iauC2i06a celestial-to-intermediate matrix, IAU 2006/2000A
**   iauEra00  Earth rotation angle, IAU 2000

```

```
**      iauSp00      the TIO locator s', IERS 2000
**      iauPom00     polar motion matrix
**      iauC2tcio    form CIO-based celestial-to-terrestrial matrix
**
** Reference:
**
**      McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**      IERS Technical Note No. 32, BKG
**
**/
```

```

void iauC2tcio(double rc2i[3][3], double era, double rpom[3][3],
               double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t c i o
**  - - - - -
**
** Assemble the celestial to terrestrial matrix from CIO-based
** components (the celestial-to-intermediate matrix, the Earth Rotation
** Angle and the polar motion matrix).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rc2i      double[3][3]   celestial-to-intermediate matrix
**   era       double        Earth rotation angle
**   rpom      double[3][3]   polar-motion matrix
**
** Returned:
**   rc2t      double[3][3]   celestial-to-terrestrial matrix
**
** Notes:
**
** 1) This function constructs the rotation matrix that transforms
** vectors in the celestial system into vectors in the terrestrial
** system. It does so starting from precomputed components, namely
** the matrix which rotates from celestial coordinates to the
** intermediate frame, the Earth rotation angle and the polar motion
** matrix. One use of the present function is when generating a
** series of celestial-to-terrestrial matrices where only the Earth
** Rotation Angle changes, avoiding the considerable overhead of
** recomputing the precession-nutation more often than necessary to
** achieve given accuracy objectives.
**
** 2) The relationship between the arguments is as follows:
**
**      [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003).
**
** Called:
**   iauCr      copy r-matrix
**   iauRz      rotate around Z-axis
**   iauRxr     product of two r-matrices
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG
**
*/

```

```

void iauC2teqx(double rbpn[3][3], double gst, double rpom[3][3],
              double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t e q x
**  - - - - -
**
** Assemble the celestial to terrestrial matrix from equinox-based
** components (the celestial-to-true matrix, the Greenwich Apparent
** Sidereal Time and the polar motion matrix).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rbpn      double[3][3]   celestial-to-true matrix
**   gst       double         Greenwich (apparent) Sidereal Time
**   rpom      double[3][3]   polar-motion matrix
**
** Returned:
**   rc2t      double[3][3]   celestial-to-terrestrial matrix (Note 2)
**
** Notes:
**
** 1) This function constructs the rotation matrix that transforms
** vectors in the celestial system into vectors in the terrestrial
** system. It does so starting from precomputed components, namely
** the matrix which rotates from celestial coordinates to the
** true equator and equinox of date, the Greenwich Apparent Sidereal
** Time and the polar motion matrix. One use of the present function
** is when generating a series of celestial-to-terrestrial matrices
** where only the Sidereal Time changes, avoiding the considerable
** overhead of recomputing the precession-nutation more often than
** necessary to achieve given accuracy objectives.
**
** 2) The relationship between the arguments is as follows:
**
**       [TRS] = rpom * R_3(gst) * rbpn * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003).
**
** Called:
**   iauCr      copy r-matrix
**   iauRz      rotate around Z-axis
**   iauRxr     product of two r-matrices
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauC2tpe(double tta, double ttb, double uta, double utb,
              double dpsl, double depl, double xp, double yp,
              double rc2t[3][3])
/*
**   - - - - -
**   i a u C 2 t p e
**   - - - - -
**
**   Form the celestial to terrestrial matrix given the date, the UT1,
**   the nutation and the polar motion.  IAU 2000.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     tta,ttb    double          TT as a 2-part Julian Date (Note 1)
**     uta,utb    double          UT1 as a 2-part Julian Date (Note 1)
**     dpsl,depl  double          nutation (Note 2)
**     xp,yp      double          coordinates of the pole (radians, Note 3)
**
**   Returned:
**     rc2t       double[3][3]    celestial-to-terrestrial matrix (Note 4)
**
**   Notes:
**
**   1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
**      apportioned in any convenient way between the arguments uta and
**      utb.  For example, JD(UT1)=2450123.7 could be expressed in any of
**      these ways, among others:
**
**          uta          utb
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution is
**      acceptable.  The J2000 and MJD methods are good compromises
**      between resolution and convenience.  In the case of uta,utb, the
**      date & time method is best matched to the Earth rotation angle
**      algorithm used:  maximum precision is delivered when the uta
**      argument is for 0hrs UT1 on the day in question and the utb
**      argument lies in the range 0 to 1, or vice versa.
**
**   2) The caller is responsible for providing the nutation components;
**      they are in longitude and obliquity, in radians and are with
**      respect to the equinox and ecliptic of date.  For high-accuracy
**      applications, free core nutation should be included as well as
**      any other relevant corrections to the position of the CIP.
**
**   3) The arguments xp and yp are the "coordinates of the pole", in
**      radians, which position the Celestial Intermediate Pole in the
**      International Terrestrial Reference System (see IERS Conventions
**      2003).  In a geocentric right-handed triad u,v,w, where the
**      w-axis points at the north geographic pole, the v-axis points
**      towards the origin of longitudes and the u axis completes the
**      system, xp = +u and yp = -v.
**
**   4) The matrix rc2t transforms from celestial to terrestrial
**      coordinates:
**
**          [TRS] = RPOM * R_3(GST) * RBPN * [CRS]
**
**          = rc2t * [CRS]
**
**      where [CRS] is a vector in the Geocentric Celestial Reference
**      System and [TRS] is a vector in the International Terrestrial

```

```
** Reference System (see IERS Conventions 2003), RBPN is the
** bias-precession-nutation matrix, GST is the Greenwich (apparent)
** Sidereal Time and RPOM is the polar motion matrix.
**
** 5) Although its name does not include "00", This function is in fact
** specific to the IAU 2000 models.
**
** Called:
**   iauPn00      bias/precession/nutation results, IAU 2000
**   iauGmst00   Greenwich mean sidereal time, IAU 2000
**   iauSp00     the TIO locator s', IERS 2000
**   iauEe00     equation of the equinoxes, IAU 2000
**   iauPom00    polar motion matrix
**   iauC2teqx   form equinox-based celestial-to-terrestrial matrix
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

void iauC2txy(double tta, double ttb, double uta, double utb,
              double x, double y, double xp, double yp,
              double rc2t[3][3])
/*
**   - - - - -
**   i a u C 2 t x y
**   - - - - -
**
**   Form the celestial to terrestrial matrix given the date, the UT1,
**   the CIP coordinates and the polar motion.  IAU 2000.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     tta,ttb  double          TT as a 2-part Julian Date (Note 1)
**     uta,utb  double          UT1 as a 2-part Julian Date (Note 1)
**     x,y      double          Celestial Intermediate Pole (Note 2)
**     xp,yp    double          coordinates of the pole (radians, Note 3)
**
**   Returned:
**     rc2t     double[3][3]    celestial-to-terrestrial matrix (Note 4)
**
**   Notes:
**
**   1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
**      apportioned in any convenient way between the arguments uta and
**      utb.  For example, JD(UT1)=2450123.7 could be expressed in any o
**      these ways, among others:
**
**           uta          utb
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 and MJD methods are good compromises
**   between resolution and convenience.  In the case of uta,utb, the
**   date & time method is best matched to the Earth rotation angle
**   algorithm used:  maximum precision is delivered when the uta
**   argument is for 0hrs UT1 on the day in question and the utb
**   argument lies in the range 0 to 1, or vice versa.
**
**   2) The Celestial Intermediate Pole coordinates are the x,y
**      components of the unit vector in the Geocentric Celestial
**      Reference System.
**
**   3) The arguments xp and yp are the "coordinates of the pole", in
**      radians, which position the Celestial Intermediate Pole in the
**      International Terrestrial Reference System (see IERS Conventions
**      2003).  In a geocentric right-handed triad u,v,w, where the
**      w-axis points at the north geographic pole, the v-axis points
**      towards the origin of longitudes and the u axis completes the
**      system, xp = +u and yp = -v.
**
**   4) The matrix rc2t transforms from celestial to terrestrial
**      coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
**   where [CRS] is a vector in the Geocentric Celestial Reference
**   System and [TRS] is a vector in the International Terrestrial
**   Reference System (see IERS Conventions 2003), ERA is the Earth
**   Rotation Angle and RPOM is the polar motion matrix.

```



```
**
** 5) Although its name does not include "00", This function is in fact
**     specific to the IAU 2000 models.
**
** Called:
**   iauC2ixy      celestial-to-intermediate matrix, given X,Y
**   iauEra00     Earth rotation angle, IAU 2000
**   iauSp00      the TIO locator s', IERS 2000
**   iauPom00     polar motion matrix
**   iauC2tcio    form CIO-based celestial-to-terrestrial matrix
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

int iauCal2jd(int iy, int im, int id, double *djm0, double *djm)
/*
**  - - - - -
**   i a u C a l 2 j d
**  - - - - -
**
**   Gregorian Calendar to Julian Date.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     iy,im,id  int      year, month, day in Gregorian calendar (Note 1)
**
**   Returned:
**     djm0      double   MJD zero-point: always 2400000.5
**     djm       double   Modified Julian Date for 0 hrs
**
**   Returned (function value):
**     int      status:
**              0 = OK
**             -1 = bad year   (Note 3: JD not computed)
**             -2 = bad month  (JD not computed)
**             -3 = bad day    (JD computed)
**
**   Notes:
**
**   1) The algorithm used is valid from -4800 March 1, but this
**      implementation rejects dates before -4799 January 1.
**
**   2) The Julian Date is returned in two pieces, in the usual SOFA
**      manner, which is designed to preserve time resolution.  The
**      Julian Date is available as a single number by adding djm0 and
**      djm.
**
**   3) In early eras the conversion is from the "Proleptic Gregorian
**      Calendar"; no account is taken of the date(s) of adoption of
**      the Gregorian Calendar, nor is the AD/BC numbering convention
**      observed.
**
**   Reference:
**
**     Explanatory Supplement to the Astronomical Almanac,
**     P. Kenneth Seidelmann (ed), University Science Books (1992),
**     Section 12.92 (p604).
**
*/

```

```
void iauCp(double p[3], double c[3])
/*
**  - - - - -
**   i a u C p
**  - - - - -
**
**   Copy a p-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p      double[3]    p-vector to be copied
**
**   Returned:
**     c      double[3]    copy
**
**/
```

```
void iauCpv(double pv[2][3], double c[2][3])
/*
**  - - - - -
**   i a u C p v
**  - - - - -
**
**   Copy a position/velocity vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     pv      double[2][3]    position/velocity vector to be copied
**
**   Returned:
**     c       double[2][3]    copy
**
**   Called:
**     iauCp          copy p-vector
**
**/
```

```
void iauCr(double r[3][3], double c[3][3])
/*
**  - - - - -
**    i a u C r
**  - - - - -
**
**  Copy an r-matrix.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    r          double[3][3]    r-matrix to be copied
**
**  Returned:
**    char[]     double[3][3]    copy
**
**  Called:
**    iauCp          copy p-vector
**
**/
```

```

void iauD2tf(int ndp, double days, char *sign, int ihmsf[4])
/*
**  - - - - -
**  i a u D 2 t f
**  - - - - -
**
**  Decompose days to hours, minutes, seconds, fraction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    ndp      int      resolution (Note 1)
**    days     double   interval in days
**
**  Returned:
**    sign     char     '+' or '-'
**    ihmsf    int[4]   hours, minutes, seconds, fraction
**
**  Notes:
**
**  1) The argument ndp is interpreted as follows:
**
**      ndp      resolution
**      :      ...0000 00 00
**      -7      1000 00 00
**      -6      100 00 00
**      -5      10 00 00
**      -4      1 00 00
**      -3      0 10 00
**      -2      0 01 00
**      -1      0 00 10
**      0       0 00 01
**      1       0 00 00.1
**      2       0 00 00.01
**      3       0 00 00.001
**      :       0 00 00.000...
**
**  2) The largest positive useful value for ndp is determined by the
**  size of days, the format of double on the target platform, and
**  the risk of overflowing ihmsf[3].  On a typical platform, for
**  days up to 1.0, the available floating-point precision might
**  correspond to ndp=12.  However, the practical limit is typically
**  ndp=9, set by the capacity of a 32-bit int, or ndp=4 if int is
**  only 16 bits.
**
**  3) The absolute value of days may exceed 1.0.  In cases where it
**  does not, it is up to the caller to test for and handle the
**  case where days is very nearly 1.0 and rounds up to 24 hours,
**  by testing for ihms[0]=24 and setting ihmsf[0-3] to zero.
**
*/

```



```

**      impossible.  To guard against gross errors, a year five or more
**      after the release year of the present function (see parameter
**      IYV) is considered dubious.  In this case a warning status is
**      returned but the result is computed in the normal way.
**
**      For both too-early and too-late years, the warning status is
**      j=+1.  This is distinct from the error status j=-1, which
**      signifies a year so early that JD could not be computed.
**
**      2) If the specified date is for a day which ends with a leap second,
**      the UTC-TAI value returned is for the period leading up to the
**      leap second.  If the date is for a day which begins as a leap
**      second ends, the UTC-TAI returned is for the period following the
**      leap second.
**
**      3) The day number must be in the normal calendar range, for example
**      1 through 30 for April.  The "almanac" convention of allowing
**      such dates as January 0 and December 32 is not supported in this
**      function, in order to avoid confusion near leap seconds.
**
**      4) The fraction of day is used only for dates before the
**      introduction of leap seconds, the first of which occurred at the
**      end of 1971.  It is tested for validity (zero to less than 1 is
**      the valid range) even if not used;  if invalid, zero is used and
**      status j=-4 is returned.  For many applications, setting fd to
**      zero is acceptable;  the resulting error is always less than 3 ms
**      (and occurs only pre-1972).
**
**      5) The status value returned in the case where there are multiple
**      errors refers to the first error detected.  For example, if the
**      month and day are 13 and 32 respectively, j=-2 (bad month)
**      will be returned.
**
**      6) In cases where a valid result is not available, zero is returned.
**
**      References:
**
**      1) For dates from 1961 January 1 onwards, the expressions from the
**      file ftp://maia.usno.navy.mil/ser7/tai-utc.dat are used.
**
**      2) The 5ms timestep at 1961 January 1 is taken from 2.58.1 (p87) of
**      the 1992 Explanatory Supplement.
**
**      Called:
**      iauCal2jd      Gregorian calendar to Julian Day number
**
*/

```



```

double iauDtdb(double date1, double date2,
               double ut, double along, double u, double v)
/*
**   - - - - -
**   i a u D t d b
**   - - - - -
**
**   An approximation to TDB-TT, the difference between barycentric
**   dynamical time and terrestrial time, for an observer on the Earth.
**
**   The different time scales - proper, coordinate and realized - are
**   related to each other:
**
**           TAI           <- physically realized
**           :
**   offset           <- observed (nominally +32.184s)
**           :
**           TT           <- terrestrial time
**           :
**   rate adjustment (L_G) <- definition of TT
**           :
**           TCG           <- time scale for GCRS
**           :
**   "periodic" terms   <- iauDtdb is an implementation
**           :
**   rate adjustment (L_C) <- function of solar-system ephemeris
**           :
**           TCB           <- time scale for BCRS
**           :
**   rate adjustment (-L_B) <- definition of TDB
**           :
**           TDB           <- TCB scaled to track TT
**           :
**   "periodic" terms   <- -iau_DTDB is an approximation
**           :
**           TT           <- terrestrial time
**
**   Adopted values for the various constants can be found in the IERS
**   Conventions (McCarthy & Petit 2003).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status: canonical model.
**
**   Given:
**   date1,date2  double date, TDB (Notes 1-3)
**   ut           double universal time (UT1, fraction of one day)
**   along        double longitude (east positive, radians)
**   u            double distance from Earth spin axis (km)
**   v            double distance north of equatorial plane (km)
**
**   Returned (function value):
**           double TDB-TT (seconds)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**   convenient way between the two arguments. For example,
**   JD(TT)=2450123.7 could be expressed in any of these ways,
**   among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution

```

```

**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**      Although the date is, formally, barycentric dynamical time (TDB),
**      the terrestrial dynamical time (TT) can be used with no practical
**      effect on the accuracy of the prediction.
**
**      2) TT can be regarded as a coordinate time that is realized as an
**      offset of 32.184s from International Atomic Time, TAI.  TT is a
**      specific linear transformation of geocentric coordinate time TCG,
**      which is the time scale for the Geocentric Celestial Reference
**      System, GCRS.
**
**      3) TDB is a coordinate time, and is a specific linear transformation
**      of barycentric coordinate time TCB, which is the time scale for
**      the Barycentric Celestial Reference System, BCRS.
**
**      4) The difference TCG-TCB depends on the masses and positions of the
**      bodies of the solar system and the velocity of the Earth.  It is
**      dominated by a rate difference, the residual being of a periodic
**      character.  The latter, which is modeled by the present function,
**      comprises a main (annual) sinusoidal term of amplitude
**      approximately 0.00166 seconds, plus planetary terms up to about
**      20 microseconds, and lunar and diurnal terms up to 2 microseconds.
**      These effects come from the changing transverse Doppler effect
**      and gravitational red-shift as the observer (on the Earth's
**      surface) experiences variations in speed (with respect to the
**      BCRS) and gravitational potential.
**
**      5) TDB can be regarded as the same as TCB but with a rate adjustment
**      to keep it close to TT, which is convenient for many applications.
**      The history of successive attempts to define TDB is set out in
**      Resolution 3 adopted by the IAU General Assembly in 2006, which
**      defines a fixed TDB(TCB) transformation that is consistent with
**      contemporary solar-system ephemerides.  Future ephemerides will
**      imply slightly changed transformations between TCG and TCB, which
**      could introduce a linear drift between TDB and TT; however, any
**      such drift is unlikely to exceed 1 nanosecond per century.
**
**      6) The geocentric TDB-TT model used in the present function is that of
**      Fairhead & Bretagnon (1990), in its full form.  It was originally
**      supplied by Fairhead (private communications with P.T.Wallace,
**      1990) as a Fortran subroutine.  The present C function contains an
**      adaptation of the Fairhead code.  The numerical results are
**      essentially unaffected by the changes, the differences with
**      respect to the Fairhead & Bretagnon original being at the 1e-20 s
**      level.
**
**      The topocentric part of the model is from Moyer (1981) and
**      Murray (1983), with fundamental arguments adapted from
**      Simon et al. 1994.  It is an approximation to the expression
**       $(v/c) \cdot (r/c)$ , where  $v$  is the barycentric velocity of
**      the Earth,  $r$  is the geocentric position of the observer and
**       $c$  is the speed of light.
**
**      By supplying zeroes for  $u$  and  $v$ , the topocentric part of the
**      model can be nullified, and the function will return the Fairhead
**      & Bretagnon result alone.
**
**      7) During the interval 1950-2050, the absolute accuracy is better
**      than +/- 3 nanoseconds relative to time ephemerides obtained by
**      direct numerical integrations based on the JPL DE405 solar system
**      ephemeris.
**
**      8) It must be stressed that the present function is merely a model,
**      and that numerical integration of solar-system ephemerides is the
**      definitive method for predicting the relationship between TCG and
**      TCB and hence between TT and TDB.
**
**      References:
**

```

** Fairhead, L., & Bretagnon, P., *Astron.Astrophys.*, 229, 240-247
** (1990).
**
** IAU 2006 Resolution 3.
**
** McCarthy, D. D., Petit, G. (eds.), *IERS Conventions* (2003),
** *IERS Technical Note No. 32*, BKG (2004)
**
** Moyer, T.D., *Cel.Mech.*, 23, 33 (1981).
**
** Murray, C.A., *Vectorial Astrometry*, Adam Hilger (1983).
**
** Seidelmann, P.K. et al., *Explanatory Supplement to the*
** *Astronomical Almanac*, Chapter 2, University Science Books (1992).
**
** Simon, J.L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
** Francou, G. & Laskar, J., *Astron.Astrophys.*, 282, 663-683 (1994).
**
*/

```

double iauEe00(double date1, double date2, double epsa, double dpsl)
/*
**   - - - - -
**   i a u E e 0 0
**   - - - - -
**
** The equation of the equinoxes, compatible with IAU 2000 resolutions,
** given the nutation in longitude and the mean obliquity.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double   TT as a 2-part Julian Date (Note 1)
**   epsa        double   mean obliquity (Note 2)
**   dpsl        double   nutation in longitude (Note 3)
**
** Returned (function value):
**   double      equation of the equinoxes (Note 4)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0       (JD method)
**           2451545.0          -1421.3     (J2000 method)
**           2400000.5           50123.2    (MJD method)
**           2450123.5           0.2       (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The obliquity, in radians, is mean of date.
**
** 3) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** 4) The result is compatible with the IAU 2000 resolutions. For
** further details, see IERS Conventions 2003 and Capitaine et al.
** (2002).
**
** Called:
**   iauEect00   equation of the equinoxes complementary terms
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauEe00a(double datel, double date2)
/*
**  - - - - -
**   i a u E e 0 0 a
**  - - - - -
**
** Equation of the equinoxes, compatible with IAU 2000 resolutions.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   datel,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double       equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The TT date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           datel           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** 3) The result is compatible with the IAU 2000 resolutions.  For
** further details, see IERS Conventions 2003 and Capitaine et al.
** (2002).
**
** Called:
**   iauPr00      IAU 2000 precession adjustments
**   iauObl80     mean obliquity, IAU 1980
**   iauNut00a    nutation, IAU 2000A
**   iauEe00     equation of the equinoxes, IAU 2000
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003).
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004).
**
*/

```

```

double iauEe00b(double date1, double date2)
/*
**   - - - - -
**   i a u E e 0 0 b
**   - - - - -
**
** Equation of the equinoxes, compatible with IAU 2000 resolutions but
** using the truncated nutation model IAU 2000B.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** 3) The result is compatible with the IAU 2000 resolutions except
** that accuracy has been compromised for the sake of speed. For
** further details, see McCarthy & Luzum (2001), IERS Conventions
** 2003 and Capitaine et al. (2003).
**
** Called:
**   iauPr00 IAU 2000 precession adjustments
**   iauObl80 mean obliquity, IAU 1980
**   iauNut00b nutation, IAU 2000B
**   iauEe00 equation of the equinoxes, IAU 2000
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D.D. & Luzum, B.J., "An abridged model of the
** precession-nutation of the celestial pole", Celestial Mechanics &
** Dynamical Astronomy, 85, 37-49 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauEe06a(double date1, double date2)
/*
**   - - - - -
**   i a u E e 0 6 a
**   - - - - -
**
** Equation of the equinoxes, compatible with IAU 2000 resolutions and
** IAU 2006/2000A precession-nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** Called:
**   iauAnpm      normalize angle into range +/- pi
**   iauGst06a    Greenwich apparent sidereal time, IAU 2006/2000A
**   iauGmst06    Greenwich mean sidereal time, IAU 2006
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG
**
*/

```

```

double iauEect00(double date1, double date2)
/*
**  - - - - -
**   i a u E e c t 0 0
**  - - - - -
**
** Equation of the equinoxes complementary terms, consistent with
** IAU 2000 resolutions.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   date1,date2  double   TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double       complementary terms (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The "complementary terms" are part of the equation of the
** equinoxes (EE), classically the difference between apparent and
** mean Sidereal Time:
**
**           GAST = GMST + EE
**
** with:
**
**           EE = dps_i * cos(eps)
**
** where dps_i is the nutation in longitude and eps is the obliquity
** of date.  However, if the rotation of the Earth were constant in
** an inertial frame the classical formulation would lead to
** apparent irregularities in the UT1 timescale traceable to side-
** effects of precession-nutation.  In order to eliminate these
** effects from UT1, "complementary terms" were introduced in 1994
** (IAU, 1994) and took effect from 1997 (Capitaine and Gontier,
** 1993):
**
**           GAST = GMST + CT + EE
**
** By convention, the complementary terms are included as part of
** the equation of the equinoxes rather than as part of the mean
** Sidereal Time.  This slightly compromises the "geometrical"
** interpretation of mean sidereal time but is otherwise
** inconsequential.
**
** The present function computes CT in the above expression,
** compatible with IAU 2000 resolutions (Capitaine et al., 2002, and
** IERS Conventions 2003).

```



```
**
** Called:
**   iauFal03   mean anomaly of the Moon
**   iauFalp03 mean anomaly of the Sun
**   iauFaf03   mean argument of the latitude of the Moon
**   iauFad03   mean elongation of the Moon from the Sun
**   iauFaom03  mean longitude of the Moon's ascending node
**   iauFave03  mean longitude of Venus
**   iauFae03   mean longitude of Earth
**   iauFapa03  general accumulated precession in longitude
**
** References:
**
** Capitaine, N. & Gontier, A.-M., Astron. Astrophys., 275,
** 645-650 (1993)
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** IAU Resolution C7, Recommendation 3 (1994)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
** /
```

```

double iauEo06a(double date1, double date2)
/*
**  - - - - -
**   i a u E o 0 6 a
**  - - - - -
**
** Equation of the origins, IAU 2006 precession and IAU 2000A nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      equation of the origins in radians
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The equation of the origins is the distance between the true
** equinox and the celestial intermediate origin and, equivalently,
** the difference between Earth rotation angle and Greenwich
** apparent sidereal time (ERA-GST).  It comprises the precession
** (since J2000.0) in right ascension plus the equation of the
** equinoxes (including the small correction terms).
**
** Called:
**   iauPnm06a    classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy   extract CIP X,Y coordinates from NPB matrix
**   iauS06      the CIO locator s, given X,Y, IAU 2006
**   iauEors     equation of the origins, Given NPB matrix and s
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauEors(double rnpb[3][3], double s)
/*
**  - - - - -
**   i a u E o r s
**  - - - - -
**
** Equation of the origins, given the classical NPB matrix and the
** quantity s.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rnpb  double[3][3]  classical nutation x precession x bias matrix
**   s     double       the quantity s (the CIO locator)
**
** Returned (function value):
**   double       the equation of the origins in radians.
**
** Notes:
**
** 1) The equation of the origins is the distance between the true
**    equinox and the celestial intermediate origin and, equivalently,
**    the difference between Earth rotation angle and Greenwich
**    apparent sidereal time (ERA-GST). It comprises the precession
**    (since J2000.0) in right ascension plus the equation of the
**    equinoxes (including the small correction terms).
**
** 2) The algorithm is from Wallace & Capitaine (2006).
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauEpb(double dj1, double dj2)
/*
**  - - - - -
**   i a u E p b
**  - - - - -
**
**   Julian Date to Besselian Epoch.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     dj1,dj2      double      Julian Date (see note)
**
**   Returned (function value):
**     double      Besselian Epoch.
**
**   Note:
**
**     The Julian Date is supplied in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding dj1 and
**     dj2.  The maximum resolution is achieved if dj1 is 2451545D0
**     (J2000).
**
**   Reference:
**
**     Lieske,J.H., 1979. Astron.Astrophys.,73,282.
**
*/

```

```

void iauEpb2jd(double epb, double *djm0, double *djm)
/*
**  - - - - -
**   i a u E p b 2 j d
**  - - - - -
**
**   Besselian Epoch to Julian Date.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epb      double      Besselian Epoch (e.g. 1957.3D0)
**
**   Returned:
**     djm0     double      MJD zero-point: always 2400000.5
**     djm      double      Modified Julian Date
**
**   Note:
**
**     The Julian Date is returned in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding djm0 and
**     djm.
**
**   Reference:
**
**     Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**
*/

```

```

double iauEpj(double dj1, double dj2)
/*
**  - - - - -
**   i a u E p j
**  - - - - -
**
**   Julian Date to Julian Epoch.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     dj1,dj2    double    Julian Date (see note)
**
**   Returned (function value):
**     double    Julian Epoch
**
**   Note:
**
**     The Julian Date is supplied in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding dj1 and
**     dj2.  The maximum resolution is achieved if dj1 is 2451545D0
**     (J2000).
**
**   Reference:
**
**     Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**
*/

```

```

void iauEpj2jd(double epj, double *djm0, double *djm)
/*
**  - - - - -
**  i a u E p j 2 j d
**  - - - - -
**
**  Julian Epoch to Julian Date.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    epj      double      Julian Epoch (e.g. 1996.8D0)
**
**  Returned:
**    djm0     double      MJD zero-point: always 2400000.5
**    djm      double      Modified Julian Date
**
**  Note:
**
**    The Julian Date is returned in two pieces, in the usual SOFA
**    manner, which is designed to preserve time resolution.  The
**    Julian Date is available as a single number by adding djm0 and
**    djm.
**
**  Reference:
**
**    Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**
*/

```

```

int iauEpv00(double date1, double date2,
             double pvh[2][3], double pvb[2][3])
/*
**   - - - - -
**   i a u E p v 0 0
**   - - - - -
**
** Earth position and velocity, heliocentric and barycentric, with
** respect to the Barycentric Celestial Reference System.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TDB date (Note 1)
**
** Returned:
**   pvh          double[2][3]    heliocentric Earth position/velocity
**   pvb          double[2][3]    barycentric Earth position/velocity
**
** Returned (function value):
**   int          status: 0 = OK
**                   +1 = warning: date outside
**                   the range 1900-2100 AD
**
** Notes:
**
** 1) The TDB date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways, among
** others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution.  The MJD method and the date & time methods are both
** good compromises between resolution and convenience.  However,
** the accuracy of the result is more likely to be limited by the
** algorithm itself than the way the date has been expressed.
**
** n.b. TT can be used instead of TDB in most applications.
**
** 2) On return, the arrays pvh and pvb contain the following:
**
**   pvh[0][0]  x      }
**   pvh[0][1]  y      } heliocentric position, AU
**   pvh[0][2]  z      }
**
**   pvh[1][0]  xdot   }
**   pvh[1][1]  ydot   } heliocentric velocity, AU/d
**   pvh[1][2]  zdot   }
**
**   pvb[0][0]  x      }
**   pvb[0][1]  y      } barycentric position, AU
**   pvb[0][2]  z      }
**
**   pvb[1][0]  xdot   }
**   pvb[1][1]  ydot   } barycentric velocity, AU/d
**   pvb[1][2]  zdot   }
**
** The vectors are with respect to the Barycentric Celestial

```



```

**      Reference System.  The time unit is one day in TDB.
**
**      3) The function is a SIMPLIFIED SOLUTION from the planetary theory
**      VSOP2000 (X. Moisson, P. Bretagnon, 2001, Celes. Mechanics &
**      Dyn. Astron., 80, 3/4, 205-213) and is an adaptation of original
**      Fortran code supplied by P. Bretagnon (private comm., 2000).
**
**      4) Comparisons over the time span 1900-2100 with this simplified
**      solution and the JPL DE405 ephemeris give the following results:
**
**
**              RMS      max
**      Heliocentric:
**          position error  3.7  11.2  km
**          velocity error  1.4   5.0  mm/s
**
**      Barycentric:
**          position error  4.6  13.4  km
**          velocity error  1.4   4.9  mm/s
**
**      Comparisons with the JPL DE406 ephemeris show that by 1800 and
**      2200 the position errors are approximately double their 1900-2100
**      size.  By 1500 and 2500 the deterioration is a factor of 10 and
**      by 1000 and 3000 a factor of 60.  The velocity accuracy falls off
**      at about half that rate.
**
**      5) It is permissible to use the same array for pvh and pvb, which
**      will receive the barycentric values.
**
**/

```

```

double iauEqeq94(double date1, double date2)
/*
**  - - - - -
**   i a u E q e q 9 4
**  - - - - -
**
** Equation of the equinoxes, IAU 1994 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double      TDB date (Note 1)
**
** Returned (function value):
**   double      equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** Called:
**   iauNut80      nutation, IAU 1980
**   iauObl80      mean obliquity, IAU 1980
**
** References:
**
**   IAU Resolution C7, Recommendation 3 (1994).
**
**   Capitaine, N. & Gontier, A.-M., 1993, Astron. Astrophys., 275,
**   645-650.
**
*/

```

```

double iauEra00(double dj1, double dj2)
/*
**  - - - - -
**   i a u E r a 0 0
**  - - - - -
**
** Earth rotation angle (IAU 2000 model).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   dj1,dj2   double    UT1 as a 2-part Julian Date (see note)
**
** Returned (function value):
**   double    Earth rotation angle (radians), range 0-2pi
**
** Notes:
**
** 1) The UT1 date dj1+dj2 is a Julian Date, apportioned in any
**    convenient way between the arguments dj1 and dj2.  For example,
**    JD(UT1)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           dj1           dj2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  The date & time method is
** best matched to the algorithm used:  maximum precision is
** delivered when the dj1 argument is for 0hrs UT1 on the day in
** question and the dj2 argument lies in the range 0 to 1, or vice
** versa.
**
** 2) The algorithm is adapted from Expression 22 of Capitaine et al.
**    2000.  The time argument has been expressed in days directly,
**    and, to retain precision, integer contributions have been
**    eliminated.  The same formulation is given in IERS Conventions
**    (2003), Chap. 5, Eq. 14.
**
** Called:
**   iauAnp           normalize angle into range 0 to 2pi
**
** References:
**
**   Capitaine N., Guinot B. and McCarthy D.D, 2000, Astron.
**   Astrophys., 355, 398-405.
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauFad03(double t)
/*
**  - - - - -
**   i a u F a d 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean elongation of the Moon from the Sun.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   D, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFae03(double t)
/*
**  - - - - -
**   i a u F a e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Earth.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Earth, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFaf03(double t)
/*
**  - - - - -
**   i a u F a f 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of the Moon minus mean longitude of the ascending
**  node.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   F, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**     McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**     IERS Technical Note No. 32, BKG (2004)
**
**     Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**     Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFaju03(double t)
/*
**  - - - - -
**   i a u F a j u 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Jupiter.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Jupiter, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFal03(double t)
/*
**  - - - - -
**   i a u F a l 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean anomaly of the Moon.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double  l, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```



```

double iauFalp03(double t)
/*
**  - - - - -
**   i a u F a l p 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean anomaly of the Sun.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double  l', radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFama03(double t)
/*
**  - - - - -
**   i a u F a m a 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Mars.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Mars, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFame03(double t)
/*
**  - - - - -
**   i a u F a m e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Mercury.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Mercury, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFane03(double t)
/*
**  - - - - -
**   i a u F a n e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Neptune.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Neptune, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is adapted from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFaom03(double t)
/*
**  - - - - -
**   i a u F a o m 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of the Moon's ascending node.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   Omega, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFapa03(double t)
/*
**  - - - - -
**   i a u F a p a 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  general accumulated precession in longitude.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   general precession in longitude, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003).  It
**     is taken from Kinoshita & Souchay (1990) and comes originally
**     from Lieske et al. (1977).
**
**  References:
**
**     Kinoshita, H. and Souchay J. 1990, Celest.Mech. and Dyn.Astron.
**     48, 187
**
**     Lieske, J.H., Lederle, T., Fricke, W. & Morando, B. 1977,
**     Astron.Astrophys. 58, 1-16
**
**     McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**     IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauFasa03(double t)
/*
**  - - - - -
**   i a u F a s a 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Saturn.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Saturn, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFaur03(double t)
/*
**  - - - - -
**   i a u F a u r 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Uranus.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Uranus, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is adapted from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```



```

double iauFave03(double t)
/*
**  - - - - -
**   i a u F a v e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Venus.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Venus, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

void iauFk52h(double r5, double d5,
              double dr5, double dd5, double px5, double rv5,
              double *rh, double *dh,
              double *drh, double *ddh, double *pxh, double *rvh)
/*
** -----
**   i a u F k 5 2 h
** -----
**
** Transform FK5 (J2000) star data into the Hipparcos system.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given (all FK5, equinox J2000, epoch J2000):
**   r5      double   RA (radians)
**   d5      double   Dec (radians)
**   dr5     double   proper motion in RA (dRA/dt, rad/Jyear)
**   dd5     double   proper motion in Dec (dDec/dt, rad/Jyear)
**   px5     double   parallax (arcsec)
**   rv5     double   radial velocity (positive = receding)
**
** Returned (all Hipparcos, epoch J2000):
**   rh      double   RA (radians)
**   dh      double   Dec (radians)
**   drh     double   proper motion in RA (dRA/dt, rad/Jyear)
**   ddh     double   proper motion in Dec (dDec/dt, rad/Jyear)
**   pxh     double   parallax (arcsec)
**   rvh     double   radial velocity (positive = receding)
**
** Notes:
**
** 1) This function transforms FK5 star positions and proper motions
**    into the system of the Hipparcos catalogue.
**
** 2) The proper motions in RA are dRA/dt rather than
**    cos(Dec)*dRA/dt, and are per year rather than per century.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure
**    rotation and spin; zonal errors in the FK5 catalogue are
**    not taken into account.
**
** 4) See also iauH2fk5, iauFk5hz, iauHfk5z.
**
** Called:
**   iauStarpv  star catalog data to space motion pv-vector
**   iauFk5hip  FK5 to Hipparcos rotation and spin
**   iauRxp     product of r-matrix and p-vector
**   iauPxp     vector product of two p-vectors
**   iauPpp     p-vector plus p-vector
**   iauPvstar  space motion pv-vector to star catalog data
**
** Reference:
**
**   F.Mignard & M.Froeschle, Astron. Astrophys. 354, 732-739 (2000).
**
*/

```

```

void iauFk5hip(double r5h[3][3], double s5h[3])
/*
**  - - - - -
**   i a u F k 5 h i p
**  - - - - -
**
**   FK5 to Hipparcos rotation and spin.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Returned:
**     r5h   double[3][3]  r-matrix: FK5 rotation wrt Hipparcos (Note 2)
**     s5h   double[3]     r-vector: FK5 spin wrt Hipparcos (Note 3)
**
**   Notes:
**
**   1) This function models the FK5 to Hipparcos transformation as a
**      pure rotation and spin; zonal errors in the FK5 catalogue are
**      not taken into account.
**
**   2) The r-matrix r5h operates in the sense:
**
**          P_Hipparcos = r5h x P_FK5
**
**      where P_FK5 is a p-vector in the FK5 frame, and P_Hipparcos is
**      the equivalent Hipparcos p-vector.
**
**   3) The r-vector s5h represents the time derivative of the FK5 to
**      Hipparcos rotation.  The units are radians per year (Julian,
**      TDB).
**
**   Called:
**     iauRv2m      r-vector to r-matrix
**
**   Reference:
**
**     F.Mignard & M.Froeschle, Astron. Astrophys. 354, 732-739 (2000).
**
*/

```

```

void iauFk5hz(double r5, double d5, double date1, double date2,
              double *rh, double *dh)
/*
**  - - - - -
**   i a u F k 5 h z
**  - - - - -
**
** Transform an FK5 (J2000) star position into the system of the
** Hipparcos catalogue, assuming zero Hipparcos proper motion.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   r5          double      FK5 RA (radians), equinox J2000, at date
**   d5          double      FK5 Dec (radians), equinox J2000, at date
**   date1,date2 double      TDB date (Notes 1,2)
**
** Returned:
**   rh          double      Hipparcos RA (radians)
**   dh          double      Hipparcos Dec (radians)
**
** Notes:
**
** 1) This function converts a star position from the FK5 system to
** the Hipparcos system, in such a way that the Hipparcos proper
** motion is zero.  Because such a star has, in general, a non-zero
** proper motion in the FK5 system, the function requires the date
** at which the position in the FK5 system was determined.
**
** 2) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure
** rotation and spin; zonal errors in the FK5 catalogue are not
** taken into account.
**
** 4) It was the intention that Hipparcos should be a close
** approximation to an inertial frame, so that distant objects
** have zero proper motion; such objects have (in general)
** non-zero proper motion in FK5, and this function returns those
** fictitious proper motions.
**
** 5) The position returned by this function is in the FK5 J2000
** reference system but at date date1+date2.
**
** 6) See also iauFk52h, iauH2fk5, iauHfk5z.
**
** Called:
**   iauS2c          spherical coordinates to unit vector
**   iauFk5hip       FK5 to Hipparcos rotation and spin
**   iauSxp          multiply p-vector by scalar
**   iauRv2m        r-vector to r-matrix

```

```
**      iauTrxp      product of transpose of r-matrix and p-vector
**      iauPxp      vector product of two p-vectors
**      iauC2s      p-vector to spherical
**      iauAnp      normalize angle into range 0 to 2pi
**
** Reference:
**
**      F.Mignard & M.Froeschle, 2000, Astron.Astrophys. 354, 732-739.
**
*/
```

```

void iauFw2m(double gamb, double phib, double psi, double eps,
             double r[3][3])
/*
**  - - - - -
**   i a u F w 2 m
**  - - - - -
**
**   Form rotation matrix given the Fukushima-Williams angles.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     gamb      double          F-W angle gamma_bar (radians)
**     phib      double          F-W angle phi_bar (radians)
**     psi       double          F-W angle psi (radians)
**     eps       double          F-W angle epsilon (radians)
**
**   Returned:
**     r         double[3][3]    rotation matrix
**
**   Notes:
**
**   1) Naming the following points:
**
**         e = J2000 ecliptic pole,
**         p = GCRS pole,
**         E = ecliptic pole of date,
**         and P = CIP,
**
**         the four Fukushima-Williams angles are as follows:
**
**         gamb = gamma = epE
**         phib = phi = pE
**         psi = psi = pEP
**         eps = epsilon = EP
**
**   2) The matrix representing the combined effects of frame bias,
**       precession and nutation is:
**
**         NxPxB = R_1(-eps).R_3(-psi).R_1(phib).R_3(gamb)
**
**   3) Three different matrices can be constructed, depending on the
**       supplied angles:
**
**       o To obtain the nutation x precession x frame bias matrix,
**         generate the four precession angles, generate the nutation
**         components and add them to the psi_bar and epsilon_A angles,
**         and call the present function.
**
**       o To obtain the precession x frame bias matrix, generate the
**         four precession angles and call the present function.
**
**       o To obtain the frame bias matrix, generate the four precession
**         angles for date J2000.0 and call the present function.
**
**       The nutation-only and precession-only matrices can if necessary
**       be obtained by combining these three appropriately.
**
**   Called:
**     iauIr      initialize r-matrix to identity
**     iauRz      rotate around Z-axis
**     iauRx      rotate around X-axis
**
**   Reference:
**
**     Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
*/

```



```

void iauFw2xy(double gamb, double phib, double psi, double eps,
              double *x, double *y)
/*
**  - - - - -
**   i a u F w 2 x y
**  - - - - -
**
**   CIP X,Y given Fukushima-Williams bias-precession-nutation angles.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     gamb      double      F-W angle gamma_bar (radians)
**     phib      double      F-W angle phi_bar (radians)
**     psi       double      F-W angle psi (radians)
**     eps       double      F-W angle epsilon (radians)
**
**   Returned:
**     x,y       double      CIP X,Y ("radians")
**
**   Notes:
**
**   1) Naming the following points:
**
**         e = J2000 ecliptic pole,
**         p = GCRS pole
**         E = ecliptic pole of date,
**         and P = CIP,
**
**         the four Fukushima-Williams angles are as follows:
**
**         gamb = gamma = epE
**         phib = phi = pE
**         psi = psi = pEP
**         eps = epsilon = EP
**
**   2) The matrix representing the combined effects of frame bias,
**       precession and nutation is:
**
**         NxPxB = R_1(-epsA).R_3(-psi).R_1(phib).R_3(gamb)
**
**       X,Y are elements (3,1) and (3,2) of the matrix.
**
**   Called:
**     iauFw2m      F-W angles to r-matrix
**     iauBpn2xy   extract CIP X,Y coordinates from NPB matrix
**
**   Reference:
**
**     Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
*/

```



```

double iauGmst00(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G m s t 0 0
**  - - - - -
**
** Greenwich mean sidereal time (model consistent with IAU 2000
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich mean sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs. For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect). The J2000 and MJD methods are good compromises
** between resolution and convenience. For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** Rotation Angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession. If UT1 is used for
** both purposes, errors of order 100 microarcseconds result.
**
** 3) This GMST is compatible with the IAU 2000 resolutions and must be
** used only in conjunction with other IAU 2000 compatible
** components such as precession-nutation and equation of the
** equinoxes.
**
** 4) The result is returned in the range 0 to 2pi.
**
** 5) The algorithm is from Capitaine et al. (2003) and IERS
** Conventions 2003.
**
** Called:
**   iauEra00   Earth rotation angle, IAU 2000
**   iauAnp     normalize angle into range 0 to 2pi
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),

```

** IERS Technical Note No. 32, BKG (2004)
**
*/

```

double iauGmst06(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G m s t 0 6
**  - - - - -
**
** Greenwich mean sidereal time (consistent with IAU 2006 precession).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich mean sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs.  For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect).  The J2000 and MJD methods are good compromises
** between resolution and convenience.  For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** rotation angle function, called internally:  maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession.  If UT1 is used for
** both purposes, errors of order 100 microarcseconds result.
**
** 3) This GMST is compatible with the IAU 2006 precession and must not
** be used with other precession models.
**
** 4) The result is returned in the range 0 to 2pi.
**
** Called:
**   iauEra00   Earth rotation angle, IAU 2000
**   iauAnp    normalize angle into range 0 to 2pi
**
** Reference:
**
** Capitaine, N., Wallace, P.T. & Chapront, J., 2005,
** Astron.Astrophys. 432, 355
**
*/

```

```

double iauGmst82(double dj1, double dj2)
/*
**  - - - - -
**   i a u G m s t 8 2
**  - - - - -
**
** Universal Time to Greenwich mean sidereal time (IAU 1982 model).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   dj1,dj2    double    UT1 Julian Date (see note)
**
** Returned (function value):
**   double     Greenwich mean sidereal time (radians)
**
** Notes:
**
** 1) The UT1 date dj1+dj2 is a Julian Date, apportioned in any
** convenient way between the arguments dj1 and dj2. For example,
** JD(UT1)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           dj1           dj2
**
**           2450123.7D0           0D0           (JD method)
**           2451545D0           -1421.3D0        (J2000 method)
**           2400000.5D0          50123.2D0        (MJD method)
**           2450123.5D0           0.2D0          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 and MJD methods are good compromises
** between resolution and convenience. The date & time method is
** best matched to the algorithm used: maximum accuracy (or, at
** least, minimum noise) is delivered when the dj1 argument is for
** 0hrs UT1 on the day in question and the dj2 argument lies in the
** range 0 to 1, or vice versa.
**
** 2) The algorithm is based on the IAU 1982 expression. This is
** always described as giving the GMST at 0 hours UT1. In fact, it
** gives the difference between the GMST and the UT, the steady
** 4-minutes-per-day drawing-ahead of ST with respect to UT. When
** whole days are ignored, the expression happens to equal the GMST
** at 0 hours UT1 each day.
**
** 3) In this function, the entire UT1 (the sum of the two arguments
** dj1 and dj2) is used directly as the argument for the standard
** formula, the constant term of which is adjusted by 12 hours to
** take account of the noon phasing of Julian Date. The UT1 is then
** added, but omitting whole days to conserve accuracy.
**
** Called:
**   iauAnp           normalize angle into range 0 to 2pi
**
** References:
**
** Transactions of the International Astronomical Union,
** XVIII B, 67 (1983).
**
** Aoki et al., Astron. Astrophys. 105, 359-361 (1982).
**
*/

```

```

double iauGst00a(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G s t 0 0 a
**  - - - - -
**
** Greenwich apparent sidereal time (consistent with IAU 2000
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich apparent sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs. For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect). The J2000 and MJD methods are good compromises
** between resolution and convenience. For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** Rotation Angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession-nutation. If UT1 is
** used for both purposes, errors of order 100 microarcseconds
** result.
**
** 3) This GAST is compatible with the IAU 2000 resolutions and must be
** used only in conjunction with other IAU 2000 compatible
** components such as precession-nutation.
**
** 4) The result is returned in the range 0 to 2pi.
**
** 5) The algorithm is from Capitaine et al. (2003) and IERS
** Conventions 2003.
**
** Called:
**   iauGmst00   Greenwich mean sidereal time, IAU 2000
**   iauEe00a    equation of the equinoxes, IAU 2000A
**   iauAnp      normalize angle into range 0 to 2pi
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**

```

** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

double iauGst00b(double uta, double utb)
/*
**  - - - - -
**   i a u G s t 0 0 b
**  - - - - -
**
**  Greenwich apparent sidereal time (consistent with IAU 2000
**  resolutions but using the truncated nutation model IAU 2000B).
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    uta,utb    double    UT1 as a 2-part Julian Date (Notes 1,2)
**
**  Returned (function value):
**    double    Greenwich apparent sidereal time (radians)
**
**  Notes:
**
**  1) The UT1 date uta+utb is a Julian Date, apportioned in any
**  convenient way between the argument pair.  For example,
**  JD=2450123.7 could be expressed in any of these ways, among
**  others:
**
**          uta          utb
**
**          2450123.7          0.0      (JD method)
**          2451545.0         -1421.3   (J2000 method)
**          2400000.5          50123.2   (MJD method)
**          2450123.5          0.2      (date & time method)
**
**  The JD method is the most natural and convenient to use in cases
**  where the loss of several decimal digits of resolution is
**  acceptable.  The J2000 and MJD methods are good compromises
**  between resolution and convenience.  For UT, the date & time
**  method is best matched to the algorithm that is used by the Earth
**  Rotation Angle function, called internally:  maximum precision is
**  delivered when the uta argument is for 0hrs UT1 on the day in
**  question and the utb argument lies in the range 0 to 1, or vice
**  versa.
**
**  2) The result is compatible with the IAU 2000 resolutions, except
**  that accuracy has been compromised for the sake of speed and
**  convenience in two respects:
**
**  . UT is used instead of TDB (or TT) to compute the precession
**  component of GMST and the equation of the equinoxes.  This
**  results in errors of order 0.1 mas at present.
**
**  . The IAU 2000B abridged nutation model (McCarthy & Luzum, 2001)
**  is used, introducing errors of up to 1 mas.
**
**  3) This GAST is compatible with the IAU 2000 resolutions and must be
**  used only in conjunction with other IAU 2000 compatible
**  components such as precession-nutation.
**
**  4) The result is returned in the range 0 to 2pi.
**
**  5) The algorithm is from Capitaine et al. (2003) and IERS
**  Conventions 2003.
**
**  Called:
**    iauGmst00    Greenwich mean sidereal time, IAU 2000
**    iauEe00b     equation of the equinoxes, IAU 2000B
**    iauAnp       normalize angle into range 0 to 2pi
**
**  References:
**

```

** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D.D. & Luzum, B.J., "An abridged model of the
** precession-nutation of the celestial pole", Celestial Mechanics &
** Dynamical Astronomy, 85, 37-49 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/


```

double iauGst06(double uta, double utb, double tta, double ttb,
                double rnpb[3][3])
/*
**  - - - - -
**   i a u G s t 0 6
**  - - - - -
**
**   Greenwich apparent sidereal time, IAU 2006, given the NPB matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     uta,utb  double          UT1 as a 2-part Julian Date (Notes 1,2)
**     tta,ttb  double          TT as a 2-part Julian Date (Notes 1,2)
**     rnpb     double[3][3]    nutation x precession x bias matrix
**
**   Returned (function value):
**     double          Greenwich apparent sidereal time (radians)
**
**   Notes:
**
**   1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
**      Julian Dates, apportioned in any convenient way between the
**      argument pairs.  For example, JD=2450123.7 could be expressed in
**      any of these ways, among others:
**
**          Part A          Part B
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3       (J2000 method)
**          2400000.5          50123.2      (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable (in the case of UT; the TT is not at all critical
**      in this respect).  The J2000 and MJD methods are good compromises
**      between resolution and convenience.  For UT, the date & time
**      method is best matched to the algorithm that is used by the Earth
**      rotation angle function, called internally:  maximum precision is
**      delivered when the uta argument is for 0hrs UT1 on the day in
**      question and the utb argument lies in the range 0 to 1, or vice
**      versa.
**
**   2) Both UT1 and TT are required, UT1 to predict the Earth rotation
**      and TT to predict the effects of precession-nutation.  If UT1 is
**      used for both purposes, errors of order 100 microarcseconds
**      result.
**
**   3) Although the function uses the IAU 2006 series for s+XY/2, it is
**      otherwise independent of the precession-nutation model and can in
**      practice be used with any equinox-based NPB matrix.
**
**   4) The result is returned in the range 0 to 2pi.
**
**   Called:
**     iauBpn2xy  extract CIP X,Y coordinates from NPB matrix
**     iauS06     the CIO locator s, given X,Y, IAU 2006
**     iauAnp     normalize angle into range 0 to 2pi
**     iauEra00   Earth rotation angle, IAU 2000
**     iauEors    equation of the origins, given NPB matrix and s
**
**   Reference:
**
**     Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauGst06a(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G s t 0 6 a
**  - - - - -
**
** Greenwich apparent sidereal time (consistent with IAU 2000 and 2006
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich apparent sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs. For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect). The J2000 and MJD methods are good compromises
** between resolution and convenience. For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** rotation angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession-nutation. If UT1 is
** used for both purposes, errors of order 100 microarcseconds
** result.
**
** 3) This GAST is compatible with the IAU 2000/2006 resolutions and
** must be used only in conjunction with IAU 2006 precession and
** IAU 2000A nutation.
**
** 4) The result is returned in the range 0 to 2pi.
**
** Called:
**   iauPnm06a   classical NPB matrix, IAU 2006/2000A
**   iauGst06    Greenwich apparent ST, IAU 2006, given NPB matrix
**
** Reference:
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauGst94(double uta, double utb)
/*
**  - - - - -
**   i a u G s t 9 4
**  - - - - -
**
** Greenwich apparent sidereal time (consistent with IAU 1982/94
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double   Greenwich apparent sidereal time (radians)
**
** Notes:
**
** 1) The UT1 date uta+utb is a Julian Date, apportioned in any
** convenient way between the argument pair.  For example,
** JD=2450123.7 could be expressed in any of these ways, among
** others:
**
**           uta           utb
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** Rotation Angle function, called internally:  maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) The result is compatible with the IAU 1982 and 1994 resolutions,
** except that accuracy has been compromised for the sake of
** convenience in that UT is used instead of TDB (or TT) to compute
** the equation of the equinoxes.
**
** 3) This GAST must be used only in conjunction with contemporaneous
** IAU standards such as 1976 precession, 1980 obliquity and 1982
** nutation.  It is not compatible with the IAU 2000 resolutions.
**
** 4) The result is returned in the range 0 to 2pi.
**
** Called:
**   iauGmst82   Greenwich mean sidereal time, IAU 1982
**   iauEgeq94   equation of the equinoxes, IAU 1994
**   iauAnp      normalize angle into range 0 to 2pi
**
** References:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992)
**
** IAU Resolution C7, Recommendation 3 (1994)
**
*/

```

```

void iauH2fk5(double rh, double dh,
              double drh, double ddh, double pxh, double rvh,
              double *r5, double *d5,
              double *dr5, double *dd5, double *px5, double *rv5)
/*
**  - - - - -
**  i a u H 2 f k 5
**  - - - - -
**
**  Transform Hipparcos star data into the FK5 (J2000) system.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given (all Hipparcos, epoch J2000):
**  rh      double    RA (radians)
**  dh      double    Dec (radians)
**  drh     double    proper motion in RA (dRA/dt, rad/Jyear)
**  ddh     double    proper motion in Dec (dDec/dt, rad/Jyear)
**  pxh     double    parallax (arcsec)
**  rvh     double    radial velocity (positive = receding)
**
**  Returned (all FK5, equinox J2000, epoch J2000):
**  r5      double    RA (radians)
**  d5      double    Dec (radians)
**  dr5     double    proper motion in RA (dRA/dt, rad/Jyear)
**  dd5     double    proper motion in Dec (dDec/dt, rad/Jyear)
**  px5     double    parallax (arcsec)
**  rv5     double    radial velocity (positive = receding)
**
**  Notes:
**
**  1) This function transforms Hipparcos star positions and proper
**     motions into FK5 J2000.
**
**  2) The proper motions in RA are dRA/dt rather than
**     cos(Dec)*dRA/dt, and are per year rather than per century.
**
**  3) The FK5 to Hipparcos transformation is modeled as a pure
**     rotation and spin; zonal errors in the FK5 catalogue are
**     not taken into account.
**
**  4) See also iauFk52h, iauFk5hz, iauHfk5z.
**
**  Called:
**  iauStarpv  star catalog data to space motion pv-vector
**  iauFk5hip  FK5 to Hipparcos rotation and spin
**  iauRv2m    r-vector to r-matrix
**  iauRxp     product of r-matrix and p-vector
**  iauTrxp    product of transpose of r-matrix and p-vector
**  iauPxp     vector product of two p-vectors
**  iauPmp     p-vector minus p-vector
**  iauPvstar  space motion pv-vector to star catalog data
**
**  Reference:
**
**  F.Mignard & M.Froeschle, Astron. Astrophys. 354, 732-739 (2000).
**
*/

```

```

void iauHfk5z(double rh, double dh, double date1, double date2,
              double *r5, double *d5, double *dr5, double *dd5)
/*
**  - - - - -
**   i a u H f k 5 z
**  - - - - -
**
** Transform a Hipparcos star position into FK5 J2000, assuming
** zero Hipparcos proper motion.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rh          double      Hipparcos RA (radians)
**   dh          double      Hipparcos Dec (radians)
**   date1,date2 double      TDB date (Note 1)
**
** Returned (all FK5, equinox J2000, date date1+date2):
**   r5          double      RA (radians)
**   d5          double      Dec (radians)
**   dr5         double      FK5 RA proper motion (rad/year, Note 4)
**   dd5         double      Dec proper motion (rad/year, Note 4)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure rotation
** and spin; zonal errors in the FK5 catalogue are not taken into
** account.
**
** 4) It was the intention that Hipparcos should be a close
** approximation to an inertial frame, so that distant objects have
** zero proper motion; such objects have (in general) non-zero
** proper motion in FK5, and this function returns those fictitious
** proper motions.
**
** 5) The position returned by this function is in the FK5 J2000
** reference system but at date date1+date2.
**
** 6) See also iauFk52h, iauH2fk5, iauFk5zhh.
**
** Called:
**   iauS2c          spherical coordinates to unit vector
**   iauFk5hip       FK5 to Hipparcos rotation and spin
**   iauRxp          product of r-matrix and p-vector
**   iauSxp          multiply p-vector by scalar
**   iauRxr          product of two r-matrices
**   iauTrxp         product of transpose of r-matrix and p-vector

```

```
**      iauPxp      vector product of two p-vectors
**      iauPv2s    pv-vector to spherical
**      iauAnp     normalize angle into range 0 to 2pi
**
** Reference:
**
**      F.Mignard & M.Froeschle, 2000, Astron.Astrophys. 354, 732-739.
**
**/
```

```
void iauIr(double r[3][3])
/*
**  - - - - -
**   i a u I r
**  - - - - -
**
**   Initialize an r-matrix to the identity matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Returned:
**     r      double[3][3]    r-matrix
**
**   Called:
**     iauZr      zero r-matrix
**
**/
```

```

int iauJd2cal(double dj1, double dj2,
              int *iy, int *im, int *id, double *fd)
/*
**  - - - - -
**   i a u J d 2 c a l
**  - - - - -
**
**   Julian Date to Gregorian year, month, day, and fraction of a day.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     dj1,dj2   double   Julian Date (Notes 1, 2)
**
**   Returned (arguments):
**     iy        int      year
**     im        int      month
**     id        int      day
**     fd        double   fraction of day
**
**   Returned (function value):
**     int       status:
**             0 = OK
**            -1 = unacceptable date (Note 3)
**
**   Notes:
**
**   1) The earliest valid date is -68569.5 (-4900 March 1).  The
**      largest value accepted is 10^9.
**
**   2) The Julian Date is apportioned in any convenient way between
**      the arguments dj1 and dj2.  For example, JD=2450123.7 could
**      be expressed in any of these ways, among others:
**
**           dj1           dj2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
**   3) In early eras the conversion is from the "proleptic Gregorian
**      calendar"; no account is taken of the date(s) of adoption of
**      the Gregorian calendar, nor is the AD/BC numbering convention
**      observed.
**
**   Reference:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992),
**   Section 12.92 (p604).
**
*/

```



```

int iauJdcalf(int ndp, double dj1, double dj2, int iymdf[4])
/*
** - - - - -
**   i a u J d c a l f
** - - - - -
**
** Julian Date to Gregorian Calendar, expressed in a form convenient
** for formatting messages: rounded to a specified precision.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   ndp      int      number of decimal places of days in fraction
**   dj1,dj2  double   dj1+dj2 = Julian Date (Note 1)
**
** Returned:
**   iymdf    int[4]   year, month, day, fraction in Gregorian
**                   calendar
**
** Returned (function value):
**   int      status:
**           -1 = date out of range
**           0 = OK
**           +1 = NDP not 0-9 (interpreted as 0)
**
** Notes:
**
** 1) The Julian Date is apportioned in any convenient way between
** the arguments dj1 and dj2. For example, JD=2450123.7 could
** be expressed in any of these ways, among others:
**
**           dj1          dj2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** 2) In early eras the conversion is from the "Proleptic Gregorian
** Calendar"; no account is taken of the date(s) of adoption of
** the Gregorian Calendar, nor is the AD/BC numbering convention
** observed.
**
** 3) Refer to the function iauJd2cal.
**
** 4) NDP should be 4 or less if internal overflows are to be
** avoided on machines which use 16-bit integers.
**
** Called:
**   iauJd2cal   JD to Gregorian calendar
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 12.92 (p604).
**
*/

```

```

void iauNum00a(double date1, double date2, double rmatn[3][3])
/*
**   - - - - -
**   i a u N u m 0 0 a
**   - - - - -
**
** Form the matrix of nutation for a given date, IAU 2000A model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rmatn        double[3][3]    nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ , where
** the p-vector  $V(\text{true})$  is with respect to the true equatorial triad
** of date and the p-vector  $V(\text{mean})$  is with respect to the mean
** equatorial triad of date.
**
** 3) A faster, but slightly less accurate result (about 1 mas), can be
** obtained by using instead the iauNum00b function.
**
** Called:
**   iauPn00a      bias/precession/nutation, IAU 2000A
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 3.222-3 (p114).
**
*/

```

```

void iauNum00b(double date1, double date2, double rmatn[3][3])
/*
**  - - - - -
**   i a u N u m 0 0 b
**  - - - - -
**
** Form the matrix of nutation for a given date, IAU 2000B model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rmatn        double[3][3]    nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ , where
**    the p-vector  $V(\text{true})$  is with respect to the true equatorial triad
**    of date and the p-vector  $V(\text{mean})$  is with respect to the mean
**    equatorial triad of date.
**
** 3) The present function is faster, but slightly less accurate (about
**    1 mas), than the iauNum00a function.
**
** Called:
**   iauPn00b      bias/precession/nutation, IAU 2000B
**
** Reference:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992),
**   Section 3.222-3 (p114).
**
*/

```

```

void iauNum06a(double date1, double date2, double rmatn[3][3])
/*
**   - - - - -
**   i a u N u m 0 6 a
**   - - - - -
**
** Form the matrix of nutation for a given date, IAU 2006/2000A model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rmatn        double[3][3]    nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ , where
**    the p-vector  $V(\text{true})$  is with respect to the true equatorial triad
**    of date and the p-vector  $V(\text{mean})$  is with respect to the mean
**    equatorial triad of date.
**
** Called:
**   iauObl06      mean obliquity, IAU 2006
**   iauNut06a     nutation, IAU 2006/2000A
**   iauNumat      form nutation matrix
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 3.222-3 (p114).
**
*/

```

```

void iauNumat(double epsa, double dpsl, double depl, double rmatn[3][3])
/*
**  - - - - -
**   i a u N u m a t
**  - - - - -
**
**   Form the matrix of nutation.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epsa      double      mean obliquity of date (Note 1)
**     dpsl,depl double      nutation (Note 2)
**
**   Returned:
**     rmatn     double[3][3]  nutation matrix (Note 3)
**
**   Notes:
**
**   1) The supplied mean obliquity epsa, must be consistent with the
**      precession-nutation models from which dpsl and depl were obtained.
**
**   2) The caller is responsible for providing the nutation components;
**      they are in longitude and obliquity, in radians and are with
**      respect to the equinox and ecliptic of date.
**
**   3) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ ,
**      where the p-vector  $V(\text{true})$  is with respect to the true
**      equatorial triad of date and the p-vector  $V(\text{mean})$  is with
**      respect to the mean equatorial triad of date.
**
**   Called:
**     iauIr      initialize r-matrix to identity
**     iauRx      rotate around X-axis
**     iauRz      rotate around Z-axis
**
**   Reference:
**
**     Explanatory Supplement to the Astronomical Almanac,
**     P. Kenneth Seidelmann (ed), University Science Books (1992),
**     Section 3.222-3 (p114).
**
*/

```

```

void iauNut00a(double date1, double date2, double *dpsi, double *deps)
/*
**   - - - - -
**   i a u N u t 0 0 a
**   - - - - -
**
**   Nutation, IAU 2000A model (MHB2000 luni-solar and planetary nutation
**   with free core nutation omitted).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:   canonical model.
**
**   Given:
**     date1,date2   double   TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     dpsi,deps    double   nutation, luni-solar + planetary (Note 2)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The nutation components in longitude and obliquity are in radians
**      and with respect to the equinox and ecliptic of date.  The
**      obliquity at J2000 is assumed to be the Lieske et al. (1977)
**      value of 84381.448 arcsec.
**
**      Both the luni-solar and planetary nutations are included.  The
**      latter are due to direct planetary nutations and the
**      perturbations of the lunar and terrestrial orbits.
**
**   3) The function computes the MHB2000 nutation series with the
**      associated corrections for planetary nutations.  It is an
**      implementation of the nutation part of the IAU 2000A precession-
**      nutation model, formally adopted by the IAU General Assembly in
**      2000, namely MHB2000 (Mathews et al. 2002), but with the free
**      core nutation (FCN - see Note 4) omitted.
**
**   4) The full MHB2000 model also contains contributions to the
**      nutations in longitude and obliquity due to the free-excitation
**      of the free-core-nutation during the period 1979-2000.  These FCN
**      terms, which are time-dependent and unpredictable, are NOT
**      included in the present function and, if required, must be
**      independently computed.  With the FCN corrections included, the
**      present function delivers a pole which is at current epochs
**      accurate to a few hundred microarcseconds.  The omission of FCN
**      introduces further errors of about that size.
**
**   5) The present function provides classical nutation.  The MHB2000
**      algorithm, from which it is adapted, deals also with (i) the
**      offsets between the GCRS and mean poles and (ii) the adjustments
**      in longitude and obliquity due to the changed precession rates.

```

```

**      These additional functions, namely frame bias and precession
**      adjustments, are supported by the SOFA functions iauBi00 and
**      iauPr00.
**
** 6) The MHB2000 algorithm also provides "total" nutations, comprising
**      the arithmetic sum of the frame bias, precession adjustments,
**      luni-solar nutation and planetary nutation. These total
**      nutations can be used in combination with an existing IAU 1976
**      precession implementation, such as iauPmat76, to deliver GCRS-
**      to-true predictions of sub-mas accuracy at current dates.
**      However, there are three shortcomings in the MHB2000 model that
**      must be taken into account if more accurate or definitive results
**      are required (see Wallace 2002):
**
**      (i) The MHB2000 total nutations are simply arithmetic sums,
**          yet in reality the various components are successive Euler
**          rotations. This slight lack of rigor leads to cross terms
**          that exceed 1 mas after a century. The rigorous procedure
**          is to form the GCRS-to-true rotation matrix by applying the
**          bias, precession and nutation in that order.
**
**      (ii) Although the precession adjustments are stated to be with
**          respect to Lieske et al. (1977), the MHB2000 model does
**          not specify which set of Euler angles are to be used and
**          how the adjustments are to be applied. The most literal
**          and straightforward procedure is to adopt the 4-rotation
**          epsilon_0, psi_A, omega_A, xi_A option, and to add DPSIPR
**          to psi_A and DEPSPR to both omega_A and eps_A.
**
**      (iii) The MHB2000 model predates the determination by Chapront
**          et al. (2002) of a 14.6 mas displacement between the J2000
**          mean equinox and the origin of the ICRS frame. It should,
**          however, be noted that neglecting this displacement when
**          calculating star coordinates does not lead to a 14.6 mas
**          change in right ascension, only a small second-order
**          distortion in the pattern of the precession-nutation
**          effect.
**
**      For these reasons, the SOFA functions do not generate the "total
**      nutations" directly, though they can of course easily be
**      generated by calling iauBi00, iauPr00 and the present function
**      and adding the results.
**
** 7) The MHB2000 model contains 41 instances where the same frequency
**      appears multiple times, of which 38 are duplicates and three are
**      triplicates. To keep the present code close to the original MHB
**      algorithm, this small inefficiency has not been corrected.
**
** Called:
**      iauFal03      mean anomaly of the Moon
**      iauFaf03      mean argument of the latitude of the Moon
**      iauFaom03     mean longitude of the Moon's ascending node
**      iauFame03     mean longitude of Mercury
**      iauFave03     mean longitude of Venus
**      iauFae03      mean longitude of Earth
**      iauFama03     mean longitude of Mars
**      iauFaju03     mean longitude of Jupiter
**      iauFasa03     mean longitude of Saturn
**      iauFaur03     mean longitude of Uranus
**      iauFapa03     general accumulated precession in longitude
**
** References:
**
**      Chapront, J., Chapront-Touze, M. & Francou, G. 2002,
**      Astron.Astrophys. 387, 700
**
**      Lieske, J.H., Lederle, T., Fricke, W. & Morando, B. 1977,
**      Astron.Astrophys. 58, 1-16
**
**      Mathews, P.M., Herring, T.A., Buffet, B.A. 2002, J.Geophys.Res.
**      107, B4. The MHB_2000 code itself was obtained on 9th September
**      2002 from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**

```

** Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
** Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
** Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
** Astron.Astrophys.Supp.Ser. 135, 111
**
** Wallace, P.T., "Software for Implementing the IAU 2000
** Resolutions", in IERS Workshop 5.1 (2002)
**
*/


```

void iauNut00b(double date1, double date2, double *dpsi, double *deps)
/*
**   - - - - -
**   i a u N u t 0 0 b
**   - - - - -
**
**   Nutation, IAU 2000B model.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  canonical model.
**
**   Given:
**     date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     dpsi,deps   double      nutation, luni-solar + planetary (Note 2)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The nutation components in longitude and obliquity are in radians
**      and with respect to the equinox and ecliptic of date.  The
**      obliquity at J2000 is assumed to be the Lieske et al. (1977)
**      value of 84381.448 arcsec.  (The errors that result from using
**      this function with the IAU 2006 value of 84381.406 arcsec can be
**      neglected.)
**
**      The nutation model consists only of luni-solar terms, but
**      includes also a fixed offset which compensates for certain long-
**      period planetary terms (Note 7).
**
**   3) This function is an implementation of the IAU 2000B abridged
**      nutation model formally adopted by the IAU General Assembly in
**      2000.  The function computes the MHB_2000_SHORT luni-solar
**      nutation series (Luzum 2001), but without the associated
**      corrections for the precession rate adjustments and the offset
**      between the GCRS and J2000 mean poles.
**
**   4) The full IAU 2000A (MHB2000) nutation model contains nearly 1400
**      terms.  The IAU 2000B model (McCarthy & Luzum 2003) contains only
**      77 terms, plus additional simplifications, yet still delivers
**      results of 1 mas accuracy at present epochs.  This combination of
**      accuracy and size makes the IAU 2000B abridged nutation model
**      suitable for most practical applications.
**
**   The function delivers a pole accurate to 1 mas from 1900 to 2100
**   (usually better than 1 mas, very occasionally just outside
**   1 mas).  The full IAU 2000A model, which is implemented in the
**   function iauNut00a (q.v.), delivers considerably greater accuracy
**   at current dates; however, to realize this improved accuracy,
**   corrections for the essentially unpredictable free-core-nutation

```

```

**      (FCN) must also be included.
**
** 5) The present function provides classical nutation. The
** MHB_2000_SHORT algorithm, from which it is adapted, deals also
** with (i) the offsets between the GCRS and mean poles and (ii) the
** adjustments in longitude and obliquity due to the changed
** precession rates. These additional functions, namely frame bias
** and precession adjustments, are supported by the SOFA functions
** iauBi00 and iauPr00.
**
** 6) The MHB_2000_SHORT algorithm also provides "total" nutations,
** comprising the arithmetic sum of the frame bias, precession
** adjustments, and nutation (luni-solar + planetary). These total
** nutations can be used in combination with an existing IAU 1976
** precession implementation, such as iauPmat76, to deliver GCRS-
** to-true predictions of mas accuracy at current epochs. However,
** for symmetry with the iauNut00a function (q.v. for the reasons),
** the SOFA functions do not generate the "total nutations"
** directly. Should they be required, they could of course easily
** be generated by calling iauBi00, iauPr00 and the present function
** and adding the results.
**
** 7) The IAU 2000B model includes "planetary bias" terms that are
** fixed in size but compensate for long-period nutations. The
** amplitudes quoted in McCarthy & Luzum (2003), namely
**  $D\psi = -1.5835$  mas and  $D\epsilon = +1.6339$  mas, are optimized for
** the "total nutations" method described in Note 6. The Luzum
** (2001) values used in this SOFA implementation, namely  $-0.135$  mas
** and  $+0.388$  mas, are optimized for the "rigorous" method, where
** frame bias, precession and nutation are applied separately and in
** that order. During the interval 1995-2050, the SOFA
** implementation delivers a maximum error of 1.001 mas (not
** including FCN).
**
** References:
**
** Lieske, J.H., Lederle, T., Fricke, W., Morando, B., "Expressions
** for the precession quantities based upon the IAU /1976/ system of
** astronomical constants", Astron.Astrophys. 58, 1-2, 1-16. (1977)
**
** Luzum, B., private communication, 2001 (Fortran code
** MHB_2000_SHORT)
**
** McCarthy, D.D. & Luzum, B.J., "An abridged model of the
** precession-nutation of the celestial pole", Cel.Mech.Dyn.Astron.
** 85, 37-49 (2003)
**
** Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
** Francou, G., Laskar, J., Astron.Astrophys. 282, 663-683 (1994)
**
** /

```

```

void iauNut06a(double date1, double date2, double *dpsi, double *deps)
/*
**   - - - - -
**   i a u N u t 0 6 a
**   - - - - -
**
**   IAU 2000A nutation with adjustments to match the IAU 2006
**   precession.
**
**   Given:
**     date1,date2   double   TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     dpsi,deps    double   nutation, luni-solar + planetary (Note 2)
**
**   Status:   canonical model.
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1           date2
**
**           2450123.7           0.0       (JD method)
**           2451545.0        -1421.3     (J2000 method)
**           2400000.5         50123.2     (MJD method)
**           2450123.5           0.2       (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The nutation components in longitude and obliquity are in radians
**      and with respect to the mean equinox and ecliptic of date,
**      IAU 2006 precession model (Hilton et al. 2006, Capitaine et al.
**      2005).
**
**   3) The function first computes the IAU 2000A nutation, then applies
**      adjustments for (i) the consequences of the change in obliquity
**      from the IAU 1980 ecliptic to the IAU 2006 ecliptic and (ii) the
**      secular variation in the Earth's dynamical flattening.
**
**   4) The present function provides classical nutation, complementing
**      the IAU 2000 frame bias and IAU 2006 precession.  It delivers a
**      pole which is at current epochs accurate to a few tens of
**      microarcseconds, apart from the free core nutation.
**
**   Called:
**     iauNut00a   nutation, IAU 2000A
**
**   References:
**
**     Chapront, J., Chapront-Touze, M. & Francou, G. 2002,
**     Astron.Astrophys. 387, 700
**
**     Lieske, J.H., Lederle, T., Fricke, W. & Morando, B. 1977,
**     Astron.Astrophys. 58, 1-16
**
**     Mathews, P.M., Herring, T.A., Buffet, B.A. 2002, J.Geophys.Res.
**     107, B4.  The MHB_2000 code itself was obtained on 9th September
**     2002 from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**
**     Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**     Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**

```

** Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
** Astron.Astrophys.Supp.Ser. 135, 111
**
** Wallace, P.T., "Software for Implementing the IAU 2000
** Resolutions", in IERS Workshop 5.1 (2002)
**
*/

```

void iauNut80(double date1, double date2, double *dpsi, double *deps)
/*
**  - - - - -
**   i a u N u t 8 0
**  - - - - -
**
**  Nutation, IAU 1980 model.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi         double      nutation in longitude (radians)
**    deps         double      nutation in obliquity (radians)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The nutation components are with respect to the ecliptic of
**     date.
**
**  Called:
**    iauAnpm          normalize angle into range +/- pi
**
**  Reference:
**
**    Explanatory Supplement to the Astronomical Almanac,
**    P. Kenneth Seidelmann (ed), University Science Books (1992),
**    Section 3.222 (p111).
**
*/

```

```

void iauNutm80(double date1, double date2, double rmatn[3][3])
/*
**  - - - - -
**   i a u N u t m 8 0
**  - - - - -
**
** Form the matrix of nutation for a given date, IAU 1980 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2    double          TDB date (Note 1)
**
** Returned:
**   rmatn          double[3][3]    nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ ,
** where the p-vector  $V(\text{true})$  is with respect to the true
** equatorial triad of date and the p-vector  $V(\text{mean})$  is with
** respect to the mean equatorial triad of date.
**
** Called:
**   iauNut80      nutation, IAU 1980
**   iauObl80      mean obliquity, IAU 1980
**   iauNumat      form nutation matrix
**
*/

```

```

double iauObl06(double date1, double date2)
/*
**  - - - - -
**   i a u O b l 0 6
**  - - - - -
**
** Mean obliquity of the ecliptic, IAU 2006 precession model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      obliquity of the ecliptic (radians, Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5         50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result is the angle between the ecliptic and mean equator of
**    date date1+date2.
**
** Reference:
**
** Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
*/

```

```

double iauObl80(double date1, double date2)
/*
**  - - - - -
**   i a u O b l 8 0
**  - - - - -
**
** Mean obliquity of the ecliptic, IAU 1980 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      obliquity of the ecliptic (radians, Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result is the angle between the ecliptic and mean equator of
**    date date1+date2.
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Expression 3.222-1 (p114).
**
*/

```



```

void iauP06e(double date1, double date2,
             double *eps0, double *psia, double *oma, double *bpa,
             double *bqa, double *pia, double *bpia,
             double *epsa, double *chia, double *za, double *zetaa,
             double *thetaa, double *pa,
             double *gam, double *phi, double *psi)
/*
**  - - - - -
**    i a u P 0 6 e
**  - - - - -
**
**  Precession angles, IAU 2006, equinox based.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical models.
**
**  Given:
**    date1,date2  double  TT as a 2-part Julian Date (Note 1)
**
**  Returned (see Note 2):
**    eps0         double  epsilon_0
**    psia         double  psi_A
**    oma         double  omega_A
**    bpa         double  P_A
**    bqa         double  Q_A
**    pia         double  pi_A
**    bpia        double  Pi_A
**    epsa        double  obliquity epsilon_A
**    chia        double  chi_A
**    za         double  z_A
**    zetaa       double  zeta_A
**    thetaa      double  theta_A
**    pa         double  p_A
**    gam         double  F-W angle gamma_J2000
**    phi         double  F-W angle phi_J2000
**    psi         double  F-W angle psi_J2000
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) This function returns the set of equinox based angles for the
**     Capitaine et al. "P03" precession theory, adopted by the IAU in
**     2006.  The angles are set out in Table 1 of Hilton et al. (2006):
**
**     eps0  epsilon_0  obliquity at J2000
**     psia  psi_A     luni-solar precession
**     oma   omega_A   inclination of equator wrt J2000 ecliptic
**     bpa   P_A       ecliptic pole x, J2000 ecliptic triad
**     bqa   Q_A       ecliptic pole -y, J2000 ecliptic triad
**     pia   pi_A      angle between moving and J2000 ecliptics
**     bpia  Pi_A      longitude of ascending node of the ecliptic

```

```

**      epsa  epsilon_A  obliquity of the ecliptic
**      chia  chi_A      planetary precession
**      za    z_A        equatorial precession: -3rd 323 Euler angle
**      zetaa zeta_A     equatorial precession: -1st 323 Euler angle
**      thetaa theta_A   equatorial precession: 2nd 323 Euler angle
**      pa    p_A        general precession
**      gam   gamma_J2000 J2000 RA difference of ecliptic poles
**      phi   phi_J2000  J2000 codeclination of ecliptic pole
**      psi   psi_J2000  longitude difference of equator poles, J2000
**
**      The returned values are all radians.
**
**      3) Hilton et al. (2006) Table 1 also contains angles that depend on
**      models distinct from the P03 precession theory itself, namely the
**      IAU 2000A frame bias and nutation. The quoted polynomials are
**      used in other SOFA functions:
**
**      . iauXy06  contains the polynomial parts of the X and Y series.
**
**      . iauS06   contains the polynomial part of the s+XY/2 series.
**
**      . iauPfw06 implements the series for the Fukushima-Williams
**      angles that are with respect to the GCRS pole (i.e. the variants
**      that include frame bias).
**
**      4) The IAU resolution stipulated that the choice of parameterization
**      was left to the user, and so an IAU compliant precession
**      implementation can be constructed using various combinations of
**      the angles returned by the present function.
**
**      5) The parameterization used by SOFA is the Fukushima-Williams angles
**      referred directly to the GCRS pole. These are the final four
**      arguments returned by the present function, but are more
**      efficiently calculated by calling the function iauPfw06. SOFA
**      also supports the direct computation of the CIP GCRS X,Y by
**      series, available by calling iauXy06.
**
**      6) The agreement between the different parameterizations is at the
**      1 microarcsecond level in the present era.
**
**      7) When constructing a precession formulation that refers to the GCRS
**      pole rather than the dynamical pole, it may (depending on the
**      choice of angles) be necessary to introduce the frame bias
**      explicitly.
**
**      8) It is permissible to re-use the same variable in the returned
**      arguments. The quantities are stored in the stated order.
**
**      Reference:
**
**      Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
**      Called:
**      iauObl06      mean obliquity, IAU 2006
**
** /

```

```

void iauP2pv(double p[3], double pv[2][3])
/*
**  - - - - -
**   i a u P 2 p v
**  - - - - -
**
**   Extend a p-vector to a pv-vector by appending a zero velocity.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p      double[3]      p-vector
**
**   Returned:
**     pv     double[2][3]   pv-vector
**
**   Called:
**     iauCp      copy p-vector
**     iauZp      zero p-vector
**
*/

```

```

void iauP2s(double p[3], double *theta, double *phi, double *r)
/*
**  - - - - -
**   i a u P 2 s
**  - - - - -
**
**   P-vector to spherical polar coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p          double[3]    p-vector
**
**   Returned:
**     theta      double       longitude angle (radians)
**     phi        double       latitude angle (radians)
**     r          double       radial distance
**
**   Notes:
**
**   1) If P is null, zero theta, phi and r are returned.
**
**   2) At either pole, zero theta is returned.
**
**   Called:
**     iauC2s      p-vector to spherical
**     iauPm      modulus of p-vector
**
*/

```

```

double iauPap(double a[3], double b[3])
/*
**  - - - - -
**   i a u P a p
**  - - - - -
**
** Position-angle from two p-vectors.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   a      double[3]  direction of reference point
**   b      double[3]  direction of point whose PA is required
**
** Returned (function value):
**   double    position angle of b with respect to a (radians)
**
** Notes:
**
** 1) The result is the position angle, in radians, of direction b with
**    respect to direction a.  It is in the range  $-\pi$  to  $+\pi$ .  The
**    sense is such that if b is a small distance "north" of a the
**    position angle is approximately zero, and if b is a small
**    distance "east" of a the position angle is approximately  $+\pi/2$ .
**
** 2) The vectors a and b need not be of unit length.
**
** 3) Zero is returned if the two directions are the same or if either
**    vector is null.
**
** 4) If vector a is at a pole, the result is ill-defined.
**
** Called:
**   iauPn      decompose p-vector into modulus and direction
**   iauPm      modulus of p-vector
**   iauPxp     vector product of two p-vectors
**   iauPmp     p-vector minus p-vector
**   iauPdp     scalar product of two p-vectors
**
*/

```

```

double iauPas(double al, double ap, double bl, double bp)
/*
**   - - - - -
**   i a u P a s
**   - - - - -
**
**   Position-angle from spherical coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     al      double      longitude of point A (e.g. RA) in radians
**     ap      double      latitude of point A (e.g. Dec) in radians
**     bl      double      longitude of point B
**     bp      double      latitude of point B
**
**   Returned (function value):
**     double      position angle of B with respect to A
**
**   Notes:
**
**   1) The result is the bearing (position angle), in radians, of point
**      B with respect to point A.  It is in the range  $-\pi$  to  $+\pi$ .  The
**      sense is such that if B is a small distance "east" of point A,
**      the bearing is approximately  $+\pi/2$ .
**
**   2) Zero is returned if the two points are coincident.
**
*/

```

```

void iauPb06(double date1, double date2,
             double *bzeta, double *bz, double *btheta)
/*
**  - - - - -
**  i a u P b 0 6
**  - - - - -
**
**  This function forms three Euler angles which implement general
**  precession from epoch J2000.0, using the IAU 2006 model. Frame
**  bias (the offset between ICRS and mean J2000.0) is included.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    bzeta       double    1st rotation: radians cw around z
**    bz          double    3rd rotation: radians cw around z
**    btheta      double    2nd rotation: radians ccw around y
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5           0.2         (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The traditional accumulated precession angles zeta_A, z_A,
**     theta_A cannot be obtained in the usual way, namely through
**     polynomial expressions, because of the frame bias.  The latter
**     means that two of the angles undergo rapid changes near this
**     date.  They are instead the results of decomposing the
**     precession-bias matrix obtained by using the Fukushima-Williams
**     method, which does not suffer from the problem.  The
**     decomposition returns values which can be used in the
**     conventional formulation and which include frame bias.
**
**  3) The three angles are returned in the conventional order, which
**     is not the same as the order of the corresponding Euler
**     rotations.  The precession-bias matrix is
**     R_3(-z) x R_2(+theta) x R_3(-zeta).
**
**  4) Should zeta_A, z_A, theta_A angles be required that do not
**     contain frame bias, they are available by calling the SOFA
**     function iauP06e.
**
**  Called:
**    iauPmat06  PB matrix, IAU 2006
**    iauRz      rotate around Z-axis
**
*/

```

```

double iauPdp(double a[3], double b[3])
/*
**  - - - - -
**   i a u P d p
**  - - - - -
**
**  p-vector inner (=scalar=dot) product.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a      double[3]      first p-vector
**    b      double[3]      second p-vector
**
**  Returned (function value):
**    double      a . b
**
*/

```



```

void iauPfw06(double date1, double date2,
              double *gamb, double *phib, double *psib, double *epsa)
/*
**   - - - - -
**   i a u P f w 0 6
**   - - - - -
**
**   Precession angles, IAU 2006 (Fukushima-Williams 4-angle formulation).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status: canonical model.
**
**   Given:
**     date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     gamb         double    F-W angle gamma_bar (radians)
**     phib         double    F-W angle phi_bar (radians)
**     psib         double    F-W angle psi_bar (radians)
**     epsa         double    F-W angle epsilon_A (radians)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**   2) Naming the following points:
**
**          e = J2000 ecliptic pole,
**          p = GCRS pole,
**          E = mean ecliptic pole of date,
**      and  P = mean pole of date,
**
**      the four Fukushima-Williams angles are as follows:
**
**          gamb = gamma_bar = epE
**          phib = phi_bar = pE
**          psib = psi_bar = pEP
**          epsa = epsilon_A = EP
**
**   3) The matrix representing the combined effects of frame bias and
**      precession is:
**
**          PxB = R_1(-epsa).R_3(-psib).R_1(phib).R_3(gamb)
**
**   4) The matrix representing the combined effects of frame bias,
**      precession and nutation is simply:
**
**          NxPxB = R_1(-epsa-dE).R_3(-psib-dP).R_1(phib).R_3(gamb)
**
**      where dP and dE are the nutation components with respect to the
**      ecliptic of date.
**
**

```

```
** Reference:
**
**   Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
** Called:
**   iauObl06      mean obliquity, IAU 2006
**
**/
```

```

int iauPlan94(double date1, double date2, int np, double pv[2][3])
/*
**   - - - - -
**   i a u P l a n 9 4
**   - - - - -
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Approximate heliocentric position and velocity of a nominated major
** planet:  Mercury, Venus, EMB, Mars, Jupiter, Saturn, Uranus or
** Neptune (but not the Earth itself).
**
** Given:
**   date1 double      TDB date part A (Note 1)
**   date2 double      TDB date part B (Note 1)
**   np    int         planet (1=Mercury, 2=Venus, 3=EMB, 4=Mars,
**                       5=Jupiter, 6=Saturn, 7=Uranus, 8=Neptune)
**
** Returned (argument):
**   pv    double[3][2] planet pos,vel (heliocentric, J2000, AU,AU/d)
**
** Returned (function value):
**   int    status:  -1 = illegal NP (outside 1-8)
**                0 = OK
**                +1 = warning: year outside 1000-3000
**                +2 = warning: failed to converge
**
** Notes:
**
** 1) The date date1+date2 is in the TDB time scale (in practice TT can
** be used) and is a Julian Date, apportioned in any convenient way
** between the two arguments.  For example, JD(TDB)=2450123.7 could
** be expressed in any of these ways, among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution.  The MJD method and the date & time methods are both
** good compromises between resolution and convenience.  The limited
** accuracy of the present algorithm is such that any of the methods
** is satisfactory.
**
** 2) If an np value outside the range 1-8 is supplied, an error status
** (function value -1) is returned and the pv vector set to zeroes.
**
** 3) For np=3 the result is for the Earth-Moon Barycenter.  To obtain
** the heliocentric position and velocity of the Earth, use instead
** the SOFA function iauEpv00.
**
** 4) On successful return, the array pv contains the following:
**
**           pv[0][0]  x      }
**           pv[1][0]  y      }  heliocentric position, AU
**           pv[2][0]  z      }
**
**           pv[0][1]  xdot   }
**           pv[1][1]  ydot   }  heliocentric velocity, AU/d
**           pv[2][1]  zdot   }
**
** The reference frame is equatorial and is with respect to the

```

```

**      mean equator and equinox of epoch J2000.
**
** 5) The algorithm is due to J.L. Simon, P. Bretagnon, J. Chapront,
**     M. Chapront-Touze, G. Francou and J. Laskar (Bureau des
**     Longitudes, Paris, France). From comparisons with JPL
**     ephemeris DE102, they quote the following maximum errors
**     over the interval 1800-2050:
**
**           L (arcsec)   B (arcsec)   R (km)
**
** Mercury             4             1           300
** Venus               5             1           800
** EMB                 6             1          1000
** Mars               17             1          7700
** Jupiter            71             5         76000
** Saturn             81            13        267000
** Uranus            86             7        712000
** Neptune           11             1        253000
**
** Over the interval 1000-3000, they report that the accuracy is no
** worse than 1.5 times that over 1800-2050. Outside 1000-3000 the
** accuracy declines.
**
** Comparisons of the present function with the JPL DE200 ephemeris
** give the following RMS errors over the interval 1960-2025:
**
**           position (km)   velocity (m/s)
**
** Mercury             334             0.437
** Venus              1060             0.855
** EMB                2010             0.815
** Mars               7690             1.98
** Jupiter            71700             7.70
** Saturn            199000             19.4
** Uranus            564000             16.4
** Neptune           158000             14.4
**
** Comparisons against DE200 over the interval 1800-2100 gave the
** following maximum absolute differences. (The results using
** DE406 were essentially the same.)
**
**           L (arcsec)   B (arcsec)   R (km)   Rdot (m/s)
**
** Mercury             7             1           500       0.7
** Venus              7             1          1100       0.9
** EMB                 9             1          1300       1.0
** Mars               26             1          9000       2.5
** Jupiter            78             6         82000       8.2
** Saturn             87            14        263000      24.6
** Uranus            86             7        661000      27.4
** Neptune           11             2        248000      21.4
**
** 6) The present SOFA re-implementation of the original Simon et al.
**     Fortran code differs from the original in the following respects:
**
**     * C instead of Fortran.
**
**     * The date is supplied in two parts.
**
**     * The result is returned only in equatorial Cartesian form;
**       the ecliptic longitude, latitude and radius vector are not
**       returned.
**
**     * The result is in the J2000 equatorial frame, not ecliptic.
**
**     * More is done in-line: there are fewer calls to subroutines.
**
**     * Different error/warning status values are used.
**
**     * A different Kepler's-equation-solver is used (avoiding
**       use of double precision complex).
**
**     * Polynomials in t are nested to minimize rounding errors.

```

```
**
**      * Explicit double constants are used to avoid mixed-mode
**      expressions.
**
**      None of the above changes affects the result significantly.
**
**      7) The returned status indicates the most serious condition
**      encountered during execution of the function. Illegal np is
**      considered the most serious, overriding failure to converge,
**      which in turn takes precedence over the remote date warning.
**
**      Called:
**      iauAnp          normalize angle into range 0 to 2pi
**
**      Reference: Simon, J.L, Bretagnon, P., Chapront, J.,
**      Chapront-Touze, M., Francou, G., and Laskar, J.,
**      Astron. Astrophys. 282, 663 (1994).
**
**/
```

```
double iauPm(double p[3])
/*
**  - - - - -
**   i a u P m
**  - - - - -
**
**  Modulus of p-vector.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    p      double[3]      p-vector
**
**  Returned (function value):
**    double      modulus
**
**/
```

```

void iauPmat00(double date1, double date2, double rbp[3][3])
/*
**  - - - - -
**   i a u P m a t 0 0
**  - - - - -
**
** Precession matrix (including frame bias) from GCRS to a specified
** date, IAU 2000 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbp          double[3][3]    bias-precession matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbp} * V(\text{J2000})$ , where
**    the p-vector  $V(\text{J2000})$  is with respect to the Geocentric Celestial
**    Reference System (IAU, 2000) and the p-vector  $V(\text{date})$  is with
**    respect to the mean equatorial triad of the given date.
**
** Called:
**   iauBp00          frame bias and precession matrices, IAU 2000
**
** Reference:
**
** IAU: Trans. International Astronomical Union, Vol. XXIVB; Proc.
** 24th General Assembly, Manchester, UK. Resolutions B1.3, B1.6.
** (2000)
**
*/

```

```

void iauPmat06(double date1, double date2, double rbp[3][3])
/*
**  - - - - -
**   i a u P m a t 0 6
**  - - - - -
**
**  Precession matrix (including frame bias) from GCRS to a specified
**  date, IAU 2006 model.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    rbp          double[3][3]    bias-precession matrix (Note 2)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The matrix operates in the sense  $V(\text{date}) = \text{rbp} * V(\text{J2000})$ , where
**     the p-vector  $V(\text{J2000})$  is with respect to the Geocentric Celestial
**     Reference System (IAU, 2000) and the p-vector  $V(\text{date})$  is with
**     respect to the mean equatorial triad of the given date.
**
**  Called:
**    iauPfw06      bias-precession F-W angles, IAU 2006
**    iauFw2m       F-W angles to r-matrix
**
**  References:
**
**    Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**    Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```



```

void iauPmat76(double date1, double date2, double rmatp[3][3])
/*
**  - - - - -
**   i a u P m a t 7 6
**  - - - - -
**
**  Precession matrix from J2000 to a specified date, IAU 1976 model.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2 double          ending date, TDB (Note 1)
**
**  Returned:
**    rmatp          double[3][3] precession matrix, J2000 -> date1+date2
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The matrix operates in the sense  $V(\text{date}) = \text{RMATP} * V(\text{J2000})$ ,
**     where the p-vector  $V(\text{J2000})$  is with respect to the mean
**     equatorial triad of epoch J2000 and the p-vector  $V(\text{date})$ 
**     is with respect to the mean equatorial triad of the given
**     date.
**
**  3) Though the matrix method itself is rigorous, the precession
**     angles are expressed through canonical polynomials which are
**     valid only for a limited time span.  In addition, the IAU 1976
**     precession rate is known to be imperfect.  The absolute accuracy
**     of the present formulation is better than 0.1 arcsec from
**     1960AD to 2040AD, better than 1 arcsec from 1640AD to 2360AD,
**     and remains below 3 arcsec for the whole of the period
**     500BC to 3000AD.  The errors exceed 10 arcsec outside the
**     range 1200BC to 3900AD, exceed 100 arcsec outside 4200BC to
**     5600AD and exceed 1000 arcsec outside 6800BC to 8200AD.
**
**  Called:
**    iauPrec76    accumulated precession angles, IAU 1976
**    iauIr        initialize r-matrix to identity
**    iauRz        rotate around Z-axis
**    iauRy        rotate around Y-axis
**    iauCr        copy r-matrix
**
**  References:
**
**    Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**    equations (6) & (7), p283.
**
**    Kaplan,G.H., 1981. USNO circular no. 163, pA2.
**

```



```

void iauPmp(double a[3], double b[3], double amb[3])
/*
**  - - - - -
**   i a u P m p
**  - - - - -
**
**   P-vector subtraction.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]      first p-vector
**     b      double[3]      second p-vector
**
**   Returned:
**     amb    double[3]      a - b
**
**   Note:
**     It is permissible to re-use the same array for any of the
**     arguments.
**
*/

```

```

void iauPn(double p[3], double *r, double u[3])
/*
**  - - - - -
**   i a u P n
**  - - - - -
**
**   Convert a p-vector into modulus and unit vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p          double[3]          p-vector
**
**   Returned:
**     r          double             modulus
**     u          double[3]         unit vector
**
**   Notes:
**
**   1) If p is null, the result is null.  Otherwise the result is a unit
**      vector.
**
**   2) It is permissible to re-use the same array for any of the
**      arguments.
**
**   Called:
**     iauPm          modulus of p-vector
**     iauZp          zero p-vector
**     iauSxp         multiply p-vector by scalar
**
*/

```

```

void iauPn00(double date1, double date2, double dpsi, double deps,
            double *epsa,
            double rb[3][3], double rp[3][3], double rbp[3][3],
            double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 0
**  - - - - -
**
**  Precession-nutation, IAU 2000 model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based
**  use indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**      date1,date2  double          TT as a 2-part Julian Date (Note 1)
**      dpsi,deps   double          nutation (Note 2)
**
**  Returned:
**      epsa        double          mean obliquity (Note 3)
**      rb          double[3][3]    frame bias matrix (Note 4)
**      rp          double[3][3]    precession matrix (Note 5)
**      rbp        double[3][3]    bias-precession matrix (Note 6)
**      rn         double[3][3]    nutation matrix (Note 7)
**      rbpn       double[3][3]    GCRS-to-true matrix (Note 8)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The caller is responsible for providing the nutation components;
**     they are in longitude and obliquity, in radians and are with
**     respect to the equinox and ecliptic of date.  For high-accuracy
**     applications, free core nutation should be included as well as
**     any other relevant corrections to the position of the CIP.
**
**  3) The returned mean obliquity is consistent with the IAU 2000
**     precession-nutation models.
**
**  4) The matrix rb transforms vectors from GCRS to J2000 mean equator
**     and equinox by applying frame bias.
**
**  5) The matrix rp transforms vectors from J2000 mean equator and
**     equinox to mean equator and equinox of date by applying
**     precession.
**
**  6) The matrix rbp transforms vectors from GCRS to mean equator and
**     equinox of date by applying frame bias then precession.  It is
**     the product rp x rb.
**
**

```

```

** 7) The matrix rn transforms vectors from mean equator and equinox of
** date to true equator and equinox of date by applying the nutation
** (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the order given.
**
** Called:
**   iauPr00      IAU 2000 precession adjustments
**   iauObl80     mean obliquity, IAU 1980
**   iauBp00     frame bias and precession matrices, IAU 2000
**   iauCr       copy r-matrix
**   iauNumat    form nutation matrix
**   iauRxr      product of two r-matrices
**
** Reference:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/

```

```

void iauPn00a(double date1, double date2,
              double *dpsi, double *deps, double *epsa,
              double rb[3][3], double rp[3][3], double rbp[3][3],
              double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**   i a u P n 0 0 a
**  - - - - -
**
**  Precession-nutation, IAU 2000A model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based
**  use indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double          nutation (Note 2)
**    epsa        double          mean obliquity (Note 3)
**    rb          double[3][3]    frame bias matrix (Note 4)
**    rp          double[3][3]    precession matrix (Note 5)
**    rbp        double[3][3]    bias-precession matrix (Note 6)
**    rn          double[3][3]    nutation matrix (Note 7)
**    rbpn       double[3][3]    GCRS-to-true matrix (Notes 8,9)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2)  The nutation components (luni-solar + planetary, IAU 2000A) in
**      longitude and obliquity are in radians and with respect to the
**      equinox and ecliptic of date.  Free core nutation is omitted;
**      for the utmost accuracy, use the iauPn00 function, where the
**      nutation components are caller-specified.  For faster but
**      slightly less accurate results, use the iauPn00b function.
**
**  3)  The mean obliquity is consistent with the IAU 2000 precession.
**
**  4)  The matrix rb transforms vectors from GCRS to J2000 mean equator
**      and equinox by applying frame bias.
**
**  5)  The matrix rp transforms vectors from J2000 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession.  It is
**      the product rp x rb.
**

```

```

** 7) The matrix rn transforms vectors from mean equator and equinox
** of date to true equator and equinox of date by applying the
** nutation (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2000B Celestial Intermediate
** Pole are elements (3,1-3) of the matrix rbpn.
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the order given.
**
** Called:
**   iauNut00a      nutation, IAU 2000A
**   iauPn00       bias/precession/nutation results, IAU 2000
**
** Reference:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/

```



```

void iauPn00b(double date1, double date2,
              double *dpsi, double *deps, double *epsa,
              double rb[3][3], double rp[3][3], double rbp[3][3],
              double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 0 b
**  - - - - -
**
**  Precession-nutation, IAU 2000B model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based
**  use indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double          nutation (Note 2)
**    epsa        double          mean obliquity (Note 3)
**    rb          double[3][3]    frame bias matrix (Note 4)
**    rp          double[3][3]    precession matrix (Note 5)
**    rbp         double[3][3]    bias-precession matrix (Note 6)
**    rn          double[3][3]    nutation matrix (Note 7)
**    rbpn       double[3][3]    GCRS-to-true matrix (Notes 8,9)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2)  The nutation components (luni-solar + planetary, IAU 2000B) in
**      longitude and obliquity are in radians and with respect to the
**      equinox and ecliptic of date.  For more accurate results, but
**      at the cost of increased computation, use the iauPn00a function.
**      For the utmost accuracy, use the iauPn00 function, where the
**      nutation components are caller-specified.
**
**  3)  The mean obliquity is consistent with the IAU 2000 precession.
**
**  4)  The matrix rb transforms vectors from GCRS to J2000 mean equator
**      and equinox by applying frame bias.
**
**  5)  The matrix rp transforms vectors from J2000 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession.  It is
**      the product rp x rb.
**
**

```

```
** 7) The matrix rn transforms vectors from mean equator and equinox
** of date to true equator and equinox of date by applying the
** nutation (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2000B Celestial Intermediate
** Pole are elements (3,1-3) of the matrix rbpn.
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the stated order.
**
** Called:
**   iauNut00b      nutation, IAU 2000B
**   iauPn00       bias/precession/nutation results, IAU 2000
**
** Reference:
**
**   Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
**   "Expressions for the Celestial Intermediate Pole and Celestial
**   Ephemeris Origin consistent with the IAU 2000A precession-
**   nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003).
**
**   n.b. The celestial ephemeris origin (CEO) was renamed "celestial
**   intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** /
```

```

void iauPn06(double date1, double date2, double dpsi, double deps,
             double *epsa,
             double rb[3][3], double rp[3][3], double rbp[3][3],
             double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 6
**  - - - - -
**
**  Precession-nutation, IAU 2006 model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based use
**  indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**      date1,date2  double          TT as a 2-part Julian Date (Note 1)
**      dpsi,deps   double          nutation (Note 2)
**
**  Returned:
**      epsa        double          mean obliquity (Note 3)
**      rb          double[3][3]    frame bias matrix (Note 4)
**      rp          double[3][3]    precession matrix (Note 5)
**      rbp         double[3][3]    bias-precession matrix (Note 6)
**      rn          double[3][3]    nutation matrix (Note 7)
**      rbpn       double[3][3]    GCRS-to-true matrix (Note 8)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**  2)  The caller is responsible for providing the nutation components;
**      they are in longitude and obliquity, in radians and are with
**      respect to the equinox and ecliptic of date.  For high-accuracy
**      applications, free core nutation should be included as well as
**      any other relevant corrections to the position of the CIP.
**
**  3)  The returned mean obliquity is consistent with the IAU 2006
**      precession.
**
**  4)  The matrix rb transforms vectors from GCRS to J2000 mean equator
**      and equinox by applying frame bias.
**
**  5)  The matrix rp transforms vectors from J2000 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession.  It is
**      the product rp x rb.
**

```

```
** 7) The matrix rn transforms vectors from mean equator and equinox
** of date to true equator and equinox of date by applying the
** nutation (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2000B Celestial Intermediate
** Pole are elements (3,1-3) of the matrix rbpn.
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the stated order.
**
** Called:
**   iauPfw06      bias-precession F-W angles, IAU 2006
**   iauFw2m      F-W angles to r-matrix
**   iauCr        copy r-matrix
**   iauTr        transpose r-matrix
**   iauRxr       product of two r-matrices
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
**/
```

```

void iauPn06a(double date1, double date2,
              double *dpsi, double *deps, double *epsa,
              double rb[3][3], double rp[3][3], double rbp[3][3],
              double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 6 a
**  - - - - -
**
**  Precession-nutation, IAU 2006/2000A models:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based use
**  indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double          nutation (Note 2)
**    epsa        double          mean obliquity (Note 3)
**    rb          double[3][3]    frame bias matrix (Note 4)
**    rp          double[3][3]    precession matrix (Note 5)
**    rbp        double[3][3]    bias-precession matrix (Note 6)
**    rn         double[3][3]    nutation matrix (Note 7)
**    rbpn       double[3][3]    GCRS-to-true matrix (Notes 8,9)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**  2)  The nutation components (luni-solar + planetary, IAU 2000A) in
**      longitude and obliquity are in radians and with respect to the
**      equinox and ecliptic of date.  Free core nutation is omitted;
**      for the utmost accuracy, use the iauPn06 function, where the
**      nutation components are caller-specified.
**
**  3)  The mean obliquity is consistent with the IAU 2006 precession.
**
**  4)  The matrix rb transforms vectors from GCRS to mean J2000 by
**      applying frame bias.
**
**  5)  The matrix rp transforms vectors from mean J2000 to mean of date
**      by applying precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean of date by
**      applying frame bias then precession.  It is the product rp x rb.
**
**  7)  The matrix rn transforms vectors from mean of date to true of
**      date by applying the nutation (luni-solar + planetary).
**
**

```

```
** 8) The matrix rbpn transforms vectors from GCRS to true of date
** (CIP/equinox). It is the product rn x rbp, applying frame bias,
** precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2006/2000A Celestial
** Intermediate Pole are elements (1,1-3) of the matrix rbpn.
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the stated order.
**
** Called:
**   iauNut06a      nutation, IAU 2006/2000A
**   iauPn06       bias/precession/nutation results, IAU 2006
**
** Reference:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**/
```

```

void iauPnm00a(double date1, double date2, double rbpn[3][3])
/*
**   - - - - -
**   i a u P n m 0 0 a
**   - - - - -
**
** Form the matrix of precession-nutation for a given date (including
** frame bias), equinox-based, IAU 2000A model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbpn         double[3][3]  classical NPB matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbpn} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{date})$  is with respect to the true equatorial triad
** of date date1+date2 and the p-vector  $V(\text{J2000})$  is with respect to
** the mean equatorial triad of the Geocentric Celestial Reference
** System (IAU, 2000).
**
** 3) A faster, but slightly less accurate result (about 1 mas), can be
** obtained by using instead the iauPnm00b function.
**
** Called:
**   iauPn00a      bias/precession/nutation, IAU 2000A
**
** Reference:
**
** IAU: Trans. International Astronomical Union, Vol. XXIVB; Proc.
** 24th General Assembly, Manchester, UK. Resolutions B1.3, B1.6.
** (2000)
**
*/

```

```

void iauPnm00b(double date1, double date2, double rbpn[3][3])
/*
**   - - - - -
**   i a u P n m 0 0 b
**   - - - - -
**
** Form the matrix of precession-nutation for a given date (including
** frame bias), equinox-based, IAU 2000B model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbpn          double[3][3] bias-precession-nutation matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbpn} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{date})$  is with respect to the true equatorial triad
** of date date1+date2 and the p-vector  $V(\text{J2000})$  is with respect to
** the mean equatorial triad of the Geocentric Celestial Reference
** System (IAU, 2000).
**
** 3) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauPnm00a function.
**
** Called:
**   iauPn00b          bias/precession/nutation, IAU 2000B
**
** Reference:
**
** IAU: Trans. International Astronomical Union, Vol. XXIVB; Proc.
** 24th General Assembly, Manchester, UK. Resolutions B1.3, B1.6.
** (2000)
**
*/

```



```

void iauPnm06a(double date1, double date2, double rnpb[3][3])
/*
**   - - - - -
**   i a u P n m 0 6 a
**   - - - - -
**
** Form the matrix of precession-nutation for a given date (including
** frame bias), IAU 2006 precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rnpb          double[3][3] bias-precession-nutation matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rnpb} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{date})$  is with respect to the true equatorial triad
** of date date1+date2 and the p-vector  $V(\text{J2000})$  is with respect to
** the mean equatorial triad of the Geocentric Celestial Reference
** System (IAU, 2000).
**
** Called:
**   iauPfw06      bias-precession F-W angles, IAU 2006
**   iauNut06a     nutation, IAU 2006/2000A
**   iauFw2m       F-W angles to r-matrix
**
** Reference:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855.
**
*/

```

```

void iauPnm80(double date1, double date2, double rmatpn[3][3])
/*
**  - - - - -
**   i a u P n m 8 0
**  - - - - -
**
** Form the matrix of precession/nutation for a given date, IAU 1976
** precession model, IAU 1980 nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2    double          TDB date (Note 1)
**
** Returned:
**   rmatpn         double[3][3]    combined precession/nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rmatpn} * V(\text{J2000})$ ,
** where the p-vector  $V(\text{date})$  is with respect to the true equatorial
** triad of date date1+date2 and the p-vector  $V(\text{J2000})$  is with
** respect to the mean equatorial triad of epoch J2000.
**
** Called:
**   iauPmat76      precession matrix, IAU 1976
**   iauNutm80      nutation matrix, IAU 1980
**   iauRxr         product of two r-matrices
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 3.3 (p145).
**
*/

```

```

void iauPom00(double xp, double yp, double sp, double rpom[3][3])
/*
**  - - - - -
**   i a u P o m 0 0
**  - - - - -
**
** Form the matrix of polar motion for a given date, IAU 2000.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   xp,yp   double   coordinates of the pole (radians, Note 1)
**   sp      double   the TIO locator s' (radians, Note 2)
**
** Returned:
**   rpom    double[3][3]   polar-motion matrix (Note 3)
**
** Notes:
**
** 1) The arguments xp and yp are the "coordinates of the pole", in
** radians, which position the Celestial Intermediate Pole in the
** International Terrestrial Reference System (see IERS Conventions
** 2003). In a geocentric right-handed triad u,v,w, where the
** w-axis points at the north geographic pole, the v-axis points
** towards the origin of longitudes and the u axis completes the
** system, xp = +u and yp = -v.
**
** 2) The argument sp is the TIO locator s', in radians, which
** positions the Terrestrial Intermediate Origin on the equator. It
** is obtained from polar motion observations by numerical
** integration, and so is in essence unpredictable. However, it is
** dominated by a secular drift of about 47 microarcseconds per
** century, and so can be taken into account by using s' = -47*t,
** where t is centuries since J2000. The function iauSp00
** implements this approximation.
**
** 3) The matrix operates in the sense V(TRS) = rpom * V(CIP), meaning
** that it is the final rotation when computing the pointing
** direction to a celestial source.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRz      rotate around Z-axis
**   iauRy      rotate around Y-axis
**   iauRx      rotate around X-axis
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauPpp(double a[3], double b[3], double apb[3])
/*
**  - - - - -
**   i a u P p p
**  - - - - -
**
** P-vector addition.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   a      double[3]      first p-vector
**   b      double[3]      second p-vector
**
** Returned:
**   apb    double[3]      a + b
**
** Note:
**   It is permissible to re-use the same array for any of the
**   arguments.
**
*/

```

```

void iauPpsp(double a[3], double s, double b[3], double apsb[3])
/*
**  - - - - -
**   i a u P p s p
**  - - - - -
**
**   P-vector plus scaled p-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]    first p-vector
**     s      double       scalar (multiplier for b)
**     b      double[3]    second p-vector
**
**   Returned:
**     apsb   double[3]    a + s*b
**
**   Note:
**     It is permissible for any of a, b and apsb to be the same array.
**
**   Called:
**     iauSxp      multiply p-vector by scalar
**     iauPpp      p-vector plus p-vector
**
*/

```

```

void iauPr00(double date1, double date2, double *dpsipr, double *depspr)
/*
**  - - - - -
**   i a u P r 0 0
**  - - - - -
**
** Precession-rate part of the IAU 2000 precession-nutation models
** (part of MHB2000).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   date1,date2    double  TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   dpsipr,depspr double  precession corrections (Notes 2,3)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5         50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The precession adjustments are expressed as "nutation
**    components", corrections in longitude and obliquity with respect
**    to the J2000 equinox and ecliptic.
**
** 3) Although the precession adjustments are stated to be with respect
**    to Lieske et al. (1977), the MHB2000 model does not specify which
**    set of Euler angles are to be used and how the adjustments are to
**    be applied.  The most literal and straightforward procedure is to
**    adopt the 4-rotation epsilon_0, psi_A, omega_A, xi_A option, and
**    to add dpsipr to psi_A and depspr to both omega_A and eps_A.
**
** 4) This is an implementation of one aspect of the IAU 2000A nutation
**    model, formally adopted by the IAU General Assembly in 2000,
**    namely MHB2000 (Mathews et al. 2002).
**
** References:
**
** Lieske, J.H., Lederle, T., Fricke, W. & Morando, B., "Expressions
** for the precession quantities based upon the IAU (1976) System of
** Astronomical Constants", Astron.Astrophys., 58, 1-16 (1977)
**
** Mathews, P.M., Herring, T.A., Buffet, B.A., "Modeling of nutation
** and precession  New nutation series for nonrigid Earth and
** insights into the Earth's interior", J.Geophys.Res., 107, B4,
** 2002.  The MHB2000 code itself was obtained on 9th September 2002
** from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**
** Wallace, P.T., "Software for Implementing the IAU 2000
** Resolutions", in IERS Workshop 5.1 (2002).
**

```



```

void iauPrec76(double ep01, double ep02, double ep11, double ep12,
               double *zeta, double *z, double *theta)
/*
**  - - - - -
**   i a u P r e c 7 6
**  - - - - -
**
**   IAU 1976 precession model.
**
**   This function forms the three Euler angles which implement general
**   precession between two epochs, using the IAU 1976 model (as for
**   the FK5 catalog).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  canonical model.
**
**   Given:
**     ep01,ep02  double      TDB starting epoch (Note 1)
**     ep11,ep12  double      TDB ending epoch (Note 1)
**
**   Returned:
**     zeta       double      1st rotation: radians cw around z
**     z          double      3rd rotation: radians cw around z
**     theta      double      2nd rotation: radians ccw around y
**
**   Notes:
**
**   1) The epochs ep01+ep02 and ep11+ep12 are Julian Dates, apportioned
**   in any convenient way between the arguments epn1 and epn2.  For
**   example, JD(TDB)=2450123.7 could be expressed in any of these
**   ways, among others:
**
**           epn1          epn2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
**   The JD method is the most natural and convenient to use in cases
**   where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 method is best matched to the way the
**   argument is handled internally and will deliver the optimum
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**   The two epochs may be expressed using different methods, but at
**   the risk of losing some resolution.
**
**   2) The accumulated precession angles zeta, z, theta are expressed
**   through canonical polynomials which are valid only for a limited
**   time span.  In addition, the IAU 1976 precession rate is known to
**   be imperfect.  The absolute accuracy of the present formulation
**   is better than 0.1 arcsec from 1960AD to 2040AD, better than
**   1 arcsec from 1640AD to 2360AD, and remains below 3 arcsec for
**   the whole of the period 500BC to 3000AD.  The errors exceed
**   10 arcsec outside the range 1200BC to 3900AD, exceed 100 arcsec
**   outside 4200BC to 5600AD and exceed 1000 arcsec outside 6800BC to
**   8200AD.
**
**   3) The three angles are returned in the conventional order, which
**   is not the same as the order of the corresponding Euler
**   rotations.  The precession matrix is
**   R_3(-z) x R_2(+theta) x R_3(-zeta).
**
**   Reference:
**
**   Lieske, J.H., 1979, Astron.Astrophys. 73, 282, equations
**   (6) & (7), p283.
**

```



```
void iauPv2p(double pv[2][3], double p[3])
/*
**  - - - - -
**  i a u P v 2 p
**  - - - - -
**
**  Discard velocity component of a pv-vector.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    pv      double[2][3]    pv-vector
**
**  Returned:
**    p       double[3]       p-vector
**
**  Called:
**    iauCp      copy p-vector
**
**/
```

```

void iauPv2s(double pv[2][3],
             double *theta, double *phi, double *r,
             double *td, double *pd, double *rd)
/*
**  - - - - -
**   i a u P v 2 s
**  - - - - -
**
**   Convert position/velocity from Cartesian to spherical coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:   vector/matrix support function.
**
**   Given:
**     pv      double[2][3]  pv-vector
**
**   Returned:
**     theta   double        longitude angle (radians)
**     phi     double        latitude angle (radians)
**     r       double        radial distance
**     td      double        rate of change of theta
**     pd      double        rate of change of phi
**     rd      double        rate of change of r
**
**   Notes:
**
**   1) If the position part of pv is null, theta, phi, td and pd
**      are indeterminate. This is handled by extrapolating the
**      position through unit time by using the velocity part of
**      pv. This moves the origin without changing the direction
**      of the velocity component. If the position and velocity
**      components of pv are both null, zeroes are returned for all
**      six results.
**
**   2) If the position is a pole, theta, td and pd are indeterminate.
**      In such cases zeroes are returned for all three.
**
*/

```

```

void iauPvdpv(double a[2][3], double b[2][3], double adb[2])
/*
**  - - - - -
**   i a u P v d p v
**  - - - - -
**
**   Inner (=scalar=dot) product of two pv-vectors.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[2][3]      first pv-vector
**     b      double[2][3]      second pv-vector
**
**   Returned:
**     adb     double[2]         a . b (see note)
**
**   Note:
**
**     If the position and velocity components of the two pv-vectors are
**     ( ap, av ) and ( bp, bv ), the result, a . b, is the pair of
**     numbers ( ap . bp , ap . bv + av . bp ). The two numbers are the
**     dot-product of the two p-vectors and its derivative.
**
**   Called:
**     iauPdp      scalar product of two p-vectors
**
*/

```

```

void iauPvm(double pv[2][3], double *r, double *s)
/*
** - - - - -
**   i a u P v m
** - - - - -
**
** Modulus of pv-vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   pv      double[2][3]   pv-vector
**
** Returned:
**   r      double          modulus of position component
**   s      double          modulus of velocity component
**
** Called:
**   iauPm          modulus of p-vector
**
*/

```

```

void iauPvmpv(double a[2][3], double b[2][3], double amb[2][3])
/*
**  - - - - -
**   i a u P v m p v
**  - - - - -
**
**   Subtract one pv-vector from another.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[2][3]    first pv-vector
**     b      double[2][3]    second pv-vector
**
**   Returned:
**     amb    double[2][3]    a - b
**
**   Note:
**     It is permissible to re-use the same array for any of the
**     arguments.
**
**   Called:
**     iauPmp      p-vector minus p-vector
**
*/

```

```

void iauPvppv(double a[2][3], double b[2][3], double apb[2][3])
/*
**  - - - - -
**   i a u P v p p v
**  - - - - -
**
**   Add one pv-vector to another.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[2][3]    first pv-vector
**     b      double[2][3]    second pv-vector
**
**   Returned:
**     apb    double[2][3]    a + b
**
**   Note:
**     It is permissible to re-use the same array for any of the
**     arguments.
**
**   Called:
**     iauPpp      p-vector plus p-vector
**
*/

```

```

int iauPvstar(double pv[2][3], double *ra, double *dec,
              double *pmr, double *pmd, double *px, double *rv)
/*
**  - - - - -
**   i a u P v s t a r
**  - - - - -
**
** Convert star position+velocity vector to catalog coordinates.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given (Note 1):
**   pv      double[2][3]   pv-vector (AU, AU/day)
**
** Returned (Note 2):
**   ra      double         right ascension (radians)
**   dec     double         declination (radians)
**   pmr     double         RA proper motion (radians/year)
**   pmd     double         Dec proper motion (radians/year)
**   px      double         parallax (arcsec)
**   rv      double         radial velocity (km/s, positive = receding)
**
** Returned (function value):
**   int      status:
**           0 = OK
**          -1 = superluminal speed (Note 5)
**          -2 = null position vector
**
** Notes:
**
** 1) The specified pv-vector is the coordinate direction (and its rate
**    of change) for the date at which the light leaving the star
**    reached the solar-system barycenter.
**
** 2) The star data returned by this function are "observables" for an
**    imaginary observer at the solar-system barycenter. Proper motion
**    and radial velocity are, strictly, in terms of barycentric
**    coordinate time, TCB. For most practical applications, it is
**    permissible to neglect the distinction between TCB and ordinary
**    "proper" time on Earth (TT/TAI). The result will, as a rule, be
**    limited by the intrinsic accuracy of the proper-motion and
**    radial-velocity data; moreover, the supplied pv-vector is likely
**    to be merely an intermediate result (for example generated by the
**    function iauStarpv), so that a change of time unit will cancel
**    out overall.
**
**    In accordance with normal star-catalog conventions, the object's
**    right ascension and declination are freed from the effects of
**    secular aberration. The frame, which is aligned to the catalog
**    equator and equinox, is Lorentzian and centered on the SSB.
**
**    Summarizing, the specified pv-vector is for most stars almost
**    identical to the result of applying the standard geometrical
**    "space motion" transformation to the catalog data. The
**    differences, which are the subject of the Stumpff paper cited
**    below, are:
**
**    (i) In stars with significant radial velocity and proper motion,
**    the constantly changing light-time distorts the apparent proper
**    motion. Note that this is a classical, not a relativistic,
**    effect.
**
**    (ii) The transformation complies with special relativity.
**
** 3) Care is needed with units. The star coordinates are in radians
**    and the proper motions in radians per Julian year, but the
**    parallax is in arcseconds; the radial velocity is in km/s, but
**    the pv-vector result is in AU and AU/day.

```



```

**
** 4) The proper motions are the rate of change of the right ascension
** and declination at the catalog epoch and are in radians per Julian
** year. The RA proper motion is in terms of coordinate angle, not
** true angle, and will thus be numerically larger at high
** declinations.
**
** 5) Straight-line motion at constant speed in the inertial frame is
** assumed. If the speed is greater than or equal to the speed of
** light, the function aborts with an error status.
**
** 6) The inverse transformation is performed by the function iauStarpv.
**
** Called:
**   iauPn          decompose p-vector into modulus and direction
**   iauPdp         scalar product of two p-vectors
**   iauSxp         multiply p-vector by scalar
**   iauPmp         p-vector minus p-vector
**   iauPm          modulus of p-vector
**   iauPpp         p-vector plus p-vector
**   iauPv2s        pv-vector to spherical
**   iauAnp         normalize angle into range 0 to 2pi
**
** Reference:
**
**   Stumpff, P., 1985, Astron.Astrophys. 144, 232-240.
**
*/

```

```

void iauPvu(double dt, double pv[2][3], double upv[2][3])
/*
**  - - - - -
**   i a u P v u
**  - - - - -
**
**   Update a pv-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     dt      double      time interval
**     pv      double[2][3]  pv-vector
**
**   Returned:
**     upv     double[2][3]  p updated, v unchanged
**
**   Notes:
**
**   1) "Update" means "refer the position component of the vector
**      to a new date dt time units from the existing date".
**
**   2) The time units of dt must match those of the velocity.
**
**   3) It is permissible for pv and upv to be the same array.
**
**   Called:
**     iauPpsp  p-vector plus scaled p-vector
**     iauCp   copy p-vector
**
** */

```

```

void iauPvup(double dt, double pv[2][3], double p[3])
/*
**  - - - - -
**   i a u P v u p
**  - - - - -
**
**   Update a pv-vector, discarding the velocity component.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     dt      double          time interval
**     pv      double[2][3]    pv-vector
**
**   Returned:
**     p       double[3]       p-vector
**
**   Notes:
**
**   1) "Update" means "refer the position component of the vector to a
**      new date dt time units from the existing date".
**
**   2) The time units of dt must match those of the velocity.
**
*/

```

```

void iauPvxpv(double a[2][3], double b[2][3], double axb[2][3])
/*
**  - - - - -
**   i a u P v x p v
**  - - - - -
**
** Outer (=vector=cross) product of two pv-vectors.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   a      double[2][3]      first pv-vector
**   b      double[2][3]      second pv-vector
**
** Returned:
**   axb    double[2][3]      a x b
**
** Notes:
**
** 1) If the position and velocity components of the two pv-vectors are
**    ( ap, av ) and ( bp, bv ), the result, a x b, is the pair of
**    vectors ( ap x bp, ap x bv + av x bp ). The two vectors are the
**    cross-product of the two p-vectors and its derivative.
**
** 2) It is permissible to re-use the same array for any of the
**    arguments.
**
** Called:
**   iauCpv      copy pv-vector
**   iauPxp     vector product of two p-vectors
**   iauPpp     p-vector plus p-vector
**
*/

```

```

void iauPxp(double a[3], double b[3], double axb[3])
/*
**  - - - - -
**   i a u P x p
**  - - - - -
**
**  p-vector outer (=vector=cross) product.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a      double[3]      first p-vector
**    b      double[3]      second p-vector
**
**  Returned:
**    axb    double[3]      a x b
**
**  Note:
**    It is permissible to re-use the same array for any of the
**    arguments.
**
*/

```

```

void iauRm2v(double r[3][3], double w[3])
/*
**  - - - - -
**   i a u R m 2 v
**  - - - - -
**
**   Express an r-matrix as an r-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     r      double[3][3]   rotation matrix
**
**   Returned:
**     w      double[3]      rotation vector (Note 1)
**
**   Notes:
**
**   1) A rotation matrix describes a rotation through some angle about
**      some arbitrary axis called the Euler axis.  The "rotation vector"
**      returned by this function has the same direction as the Euler axis,
**      and its magnitude is the angle in radians.  (The magnitude and
**      direction can be separated by means of the function iauPn.)
**
**   2) If r is null, so is the result.  If r is not a rotation matrix
**      the result is undefined; r must be proper (i.e. have a positive
**      determinant) and real orthogonal (inverse = transpose).
**
**   3) The reference frame rotates clockwise as seen looking along
**      the rotation vector from the origin.
**
** */

```

```

void iauRv2m(double w[3], double r[3][3])
/*
**  - - - - -
**   i a u R v 2 m
**  - - - - -
**
**   Form the r-matrix corresponding to a given r-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     w      double[3]      rotation vector (Note 1)
**
**   Returned:
**     r      double[3][3]   rotation matrix
**
**   Notes:
**
**   1) A rotation matrix describes a rotation through some angle about
**      some arbitrary axis called the Euler axis.  The "rotation vector"
**      supplied to This function has the same direction as the Euler
**      axis, and its magnitude is the angle in radians.
**
**   2) If w is null, the unit matrix is returned.
**
**   3) The reference frame rotates clockwise as seen looking along the
**      rotation vector from the origin.
**
*/

```

```

void iauRx(double phi, double r[3][3])
/*
**  - - - - -
**   i a u R x
**  - - - - -
**
** Rotate an r-matrix about the x-axis.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   phi      double          angle (radians)
**
** Given and returned:
**   r        double[3][3]    r-matrix
**
** Sign convention:  The matrix can be used to rotate the reference
** frame of a vector.  Calling this function with positive phi
** incorporates in the matrix an additional rotation, about the x-axis,
** anticlockwise as seen looking towards the origin from positive x.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRxr     product of two r-matrices
**   iauCr      copy r-matrix
**
*/

```



```

void iauRxp(double r[3][3], double p[3], double rp[3])
/*
**  - - - - -
**   i a u R x p
**  - - - - -
**
**  Multiply a p-vector by an r-matrix.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    r      double[3][3]   r-matrix
**    p      double[3]      p-vector
**
**  Returned:
**    rp     double[3]      r * p
**
**  Note:
**    It is permissible for p and rp to be the same array.
**
**  Called:
**    iauCp      copy p-vector
**
*/

```

```

void iauRxpv(double r[3][3], double pv[2][3], double rpv[2][3])
/*
**  - - - - -
**   i a u R x p v
**  - - - - -
**
** Multiply a pv-vector by an r-matrix.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r          double[3][3]   r-matrix
**   pv         double[2][3]   pv-vector
**
** Returned:
**   rpv        double[2][3]   r * pv
**
** Note:
**   It is permissible for pv and rpv to be the same array.
**
** Called:
**   iauRxp          product of r-matrix and p-vector
**
*/

```

```

void iauRxr(double a[3][3], double b[3][3], double atb[3][3])
/*
**  - - - - -
**   i a u R x r
**  - - - - -
**
** Multiply two r-matrices.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   a      double[3][3]   first r-matrix
**   b      double[3][3]   second r-matrix
**
** Returned:
**   atb    double[3][3]   a * b
**
** Note:
**   It is permissible to re-use the same array for any of the
**   arguments.
**
** Called:
**   iauCr      copy r-matrix
**
*/

```

```

void iauRy(double theta, double r[3][3])
/*
**  - - - - -
**   i a u R y
**  - - - - -
**
** Rotate an r-matrix about the y-axis.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   theta  double          angle (radians)
**
** Given and returned:
**   r      double[3][3]    r-matrix
**
** Sign convention:  The matrix can be used to rotate the reference
** frame of a vector.  Calling This function with positive theta
** incorporates in the matrix an additional rotation, about the y-axis,
** anticlockwise as seen looking towards the origin from positive y.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRxr     product of two r-matrices
**   iauCr      copy r-matrix
**
*/

```

```

void iauRz(double psi, double r[3][3])
/*
**  - - - - -
**   i a u R z
**  - - - - -
**
** Rotate an r-matrix about the z-axis.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   psi      double          angle (radians)
**
** Given and returned:
**   r        double[3][3]    r-matrix, rotated
**
** Sign convention:  The matrix can be used to rotate the reference
** frame of a vector.  Calling This function with positive psi
** incorporates in the matrix an additional rotation, about the z-axis,
** anticlockwise as seen looking towards the origin from positive z.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRxr     product of two r-matrices
**   iauCr      copy r-matrix
**
*/

```

```

double iauS00(double date1, double date2, double x, double y)
/*
**  - - - - -
**   i a u S 0 0
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, given the CIP's X,Y
** coordinates. Compatible with IAU 2000A precession-nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**   x,y         double      CIP coordinates (Note 3)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems: the two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator. The quantity s remains below 0.1 arcsecond
** throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be. This
** function requires X,Y to be supplied by the caller, who is
** responsible for providing values that are consistent with the
** supplied date.
**
** 4) The model is consistent with the IAU 2000A precession-nutation.
**
** Called:
**   iauFal03      mean anomaly of the Moon
**   iauFalp03     mean anomaly of the Sun
**   iauFaf03      mean argument of the latitude of the Moon
**   iauFad03      mean elongation of the Moon from the Sun
**   iauFaom03     mean longitude of the Moon's ascending node
**   iauFave03     mean longitude of Venus
**   iauFae03      mean longitude of Earth
**   iauFapa03     general accumulated precession in longitude
**
** References:
**
**   Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,

```

** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", *Astronomy & Astrophysics*, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** McCarthy, D. D., Petit, G. (eds.), *IERS Conventions* (2003),
** *IERS Technical Note No. 32*, BKG (2004)
**
*/

```

double iauS00a(double datel, double date2)
/*
**  - - - - -
**   i a u S 0 0 a
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, using the IAU 2000A
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   datel,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           datel          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems.  The two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator.  The CIO locator s remains a small fraction of
** 1 arcsecond throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be.  The present
** function uses the full IAU 2000A nutation model when predicting
** the CIP position.  Faster results, with no significant loss of
** accuracy, can be obtained via the function iauS00b, which uses
** instead the IAU 2000B truncated model.
**
** Called:
**   iauPnm00a    classical NPB matrix, IAU 2000A
**   iauBnp2xy    extract CIP X,Y from the BPN matrix
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** References:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**

```


** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

double iauS00b(double date1, double date2)
/*
**  - - - - -
**   i a u S 0 0 b
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, using the IAU 2000B
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems.  The two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator.  The CIO locator s remains a small fraction of
** 1 arcsecond throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be.  The present
** function uses the IAU 2000B truncated nutation model when
** predicting the CIP position.  The function iauS00a uses instead
** the full IAU 2000A model, but with no significant increase in
** accuracy and at some cost in speed.
**
** Called:
**   iauPnm00b    classical NPB matrix, IAU 2000B
**   iauBnp2xy    extract CIP X,Y from the BPN matrix
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** References:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**

```

** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

double iauS06(double date1, double date2, double x, double y)
/*
**  - - - - -
**    i a u S 0 6
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, given the CIP's X,Y
** coordinates. Compatible with IAU 2006/2000A precession-nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**   x,y         double      CIP coordinates (Note 3)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems: the two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator. The quantity s remains below 0.1 arcsecond
** throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be. This
** function requires X,Y to be supplied by the caller, who is
** responsible for providing values that are consistent with the
** supplied date.
**
** 4) The model is consistent with the "P03" precession (Capitaine et
** al. 2003), adopted by IAU 2006 Resolution 1, 2006, and the
** IAU 2000A nutation (with P03 adjustments).
**
** Called:
**   iauFal03      mean anomaly of the Moon
**   iauFalp03     mean anomaly of the Sun
**   iauFaf03      mean argument of the latitude of the Moon
**   iauFad03      mean elongation of the Moon from the Sun
**   iauFaom03     mean longitude of the Moon's ascending node
**   iauFave03     mean longitude of Venus
**   iauFae03      mean longitude of Earth
**   iauFapa03     general accumulated precession in longitude
**
** References:

```

**
** Capitaine, N., Wallace, P.T. & Chapront, J., 2003, Astron.
** Astrophys. 432, 355
**
** McCarthy, D.D., Petit, G. (eds.) 2004, IERS Conventions (2003),
** IERS Technical Note No. 32, BKG
**
*/

```

double iauS06a(double datel, double date2)
/*
**  - - - - -
**   i a u S 0 6 a
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, using the IAU 2006
** precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   datel,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           datel          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems.  The two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator.  The CIO locator s remains a small fraction of
** 1 arcsecond throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series is
** more compact than a direct series for s would be.  The present
** function uses the full IAU 2000A nutation model when predicting
** the CIP position.
**
** Called:
**   iauPnm06a    classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauS06       the CIO locator s, given X,Y, IAU 2006
**
** References:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astronomy & Astrophysics, 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**

```

**
**
**
**
**
**
*/

McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
IERS Technical Note No. 32, BKG

Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981

```

void iauS2c(double theta, double phi, double c[3])
/*
**  - - - - -
**   i a u S 2 c
**  - - - - -
**
**   Convert spherical coordinates to Cartesian.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     theta   double      longitude angle (radians)
**     phi     double      latitude angle (radians)
**
**   Returned:
**     c       double[3]   direction cosines
**
*/

```



```

void iauS2p(double theta, double phi, double r, double p[3])
/*
**  - - - - -
**   i a u S 2 p
**  - - - - -
**
**   Convert spherical polar coordinates to p-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     theta  double      longitude angle (radians)
**     phi    double      latitude angle (radians)
**     r      double      radial distance
**
**   Returned:
**     p      double[3]    Cartesian coordinates
**
**   Called:
**     iauS2c      spherical coordinates to unit vector
**     iauSxp      multiply p-vector by scalar
**
*/

```

```

void iauS2pv(double theta, double phi, double r,
             double td, double pd, double rd,
             double pv[2][3])
/*
**  - - - - -
**   i a u S 2 p v
**  - - - - -
**
**   Convert position/velocity from spherical to Cartesian coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     theta  double          longitude angle (radians)
**     phi    double          latitude angle (radians)
**     r      double          radial distance
**     td     double          rate of change of theta
**     pd     double          rate of change of phi
**     rd     double          rate of change of r
**
**   Returned:
**     pv     double[2][3]    pv-vector
**
*/

```

```

void iauS2xpv(double s1, double s2, double pv[2][3], double spv[2][3])
/*
**  - - - - -
**   i a u S 2 x p v
**  - - - - -
**
** Multiply a pv-vector by two scalars.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   s1      double          scalar to multiply position component by
**   s2      double          scalar to multiply velocity component by
**   pv      double[2][3]    pv-vector
**
** Returned:
**   spv     double[2][3]    pv-vector: p scaled by s1, v scaled by s2
**
** Note:
**   It is permissible for pv and spv to be the same array.
**
** Called:
**   iauSxp          multiply p-vector by scalar
**
*/

```

```

double iauSepp(double a[3], double b[3])
/*
**  - - - - -
**   i a u S e p p
**  - - - - -
**
**   Angular separation between two p-vectors.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]    first p-vector (not necessarily unit length)
**     b      double[3]    second p-vector (not necessarily unit length)
**
**   Returned (function value):
**     double      angular separation (radians, always positive)
**
**   Notes:
**
**   1) If either vector is null, a zero result is returned.
**
**   2) The angular separation is most simply formulated in terms of
**      scalar product. However, this gives poor accuracy for angles
**      near zero and pi. The present algorithm uses both cross product
**      and dot product, to deliver full accuracy whatever the size of
**      the angle.
**
**   Called:
**     iauPxp      vector product of two p-vectors
**     iauPm      modulus of p-vector
**     iauPdp      scalar product of two p-vectors
**
*/

```

```

double iauSeps(double al, double ap, double bl, double bp)
/*
**  - - - - -
**   i a u S e p s
**  - - - - -
**
**   Angular separation between two sets of spherical coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     al      double      first longitude (radians)
**     ap      double      first latitude (radians)
**     bl      double      second longitude (radians)
**     bp      double      second latitude (radians)
**
**   Returned (function value):
**     double      angular separation (radians)
**
**   Called:
**     iauS2c      spherical coordinates to unit vector
**     iauSepp     angular separation between two p-vectors
**
*/

```

```

double iauSp00(double date1, double date2)
/*
**   - - - - -
**   i a u S p 0 0
**   - - - - -
**
** The TIO locator s', positioning the Terrestrial Intermediate Origin
** on the equator of the Celestial Intermediate Pole.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double the TIO locator s' in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The TIO locator s' is obtained from polar motion observations by
** numerical integration, and so is in essence unpredictable.
** However, it is dominated by a secular drift of about
** 47 microarcseconds per century, which is the approximation
** evaluated by the present function.
**
** Reference:
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

int iauStarpm(double ral, double decl,
              double pmr1, double pmd1, double px1, double rv1,
              double ep1a, double ep1b, double ep2a, double ep2b,
              double *ra2, double *dec2,
              double *pmr2, double *pmd2, double *px2, double *rv2)
/*
** - - - - -
**   i a u S t a r p m
** - - - - -
**
** Star proper motion:  update star catalog data for space motion.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   ral    double    right ascension (radians), before
**   decl   double    declination (radians), before
**   pmr1   double    RA proper motion (radians/year), before
**   pmd1   double    Dec proper motion (radians/year), before
**   px1    double    parallax (arcseconds), before
**   rv1    double    radial velocity (km/s, +ve = receding), before
**   ep1a   double    "before" epoch, part A (Note 1)
**   ep1b   double    "before" epoch, part B (Note 1)
**   ep2a   double    "after" epoch, part A (Note 1)
**   ep2b   double    "after" epoch, part B (Note 1)
**
** Returned:
**   ra2    double    right ascension (radians), after
**   dec2   double    declination (radians), after
**   pmr2   double    RA proper motion (radians/year), after
**   pmd2   double    Dec proper motion (radians/year), after
**   px2    double    parallax (arcseconds), after
**   rv2    double    radial velocity (km/s, +ve = receding), after
**
** Returned (function value):
**   int     status:
**           -1 = system error (should not occur)
**           0 = no warnings or errors
**           1 = distance overridden (Note 6)
**           2 = excessive velocity (Note 7)
**           4 = solution didn't converge (Note 8)
**           else = binary logical OR of the above warnings
**
** Notes:
**
** 1) The starting and ending TDB dates ep1a+ep1b and ep2a+ep2b are
**    Julian Dates, apportioned in any convenient way between the two
**    parts (A and B).  For example, JD(TDB)=2450123.7 could be
**    expressed in any of these ways, among others:
**
**           epna           epnb
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) In accordance with normal star-catalog conventions, the object's
**    right ascension and declination are freed from the effects of
**    secular aberration.  The frame, which is aligned to the catalog
**    equator and equinox, is Lorentzian and centered on the SSB.

```

```

**
** The proper motions are the rate of change of the right ascension
** and declination at the catalog epoch and are in radians per TDB
** Julian year.
**
** The parallax and radial velocity are in the same frame.
**
** 3) Care is needed with units. The star coordinates are in radians
** and the proper motions in radians per Julian year, but the
** parallax is in arcseconds.
**
** 4) The RA proper motion is in terms of coordinate angle, not true
** angle. If the catalog uses arcseconds for both RA and Dec proper
** motions, the RA proper motion will need to be divided by cos(Dec)
** before use.
**
** 5) Straight-line motion at constant speed, in the inertial frame,
** is assumed.
**
** 6) An extremely small (or zero or negative) parallax is interpreted
** to mean that the object is on the "celestial sphere", the radius
** of which is an arbitrary (large) value (see the iauStarpv
** function for the value used). When the distance is overridden in
** this way, the status, initially zero, has 1 added to it.
**
** 7) If the space velocity is a significant fraction of c (see the
** constant VMAX in the function iauStarpv), it is arbitrarily set
** to zero. When this action occurs, 2 is added to the status.
**
** 8) The relativistic adjustment carried out in the iauStarpv function
** involves an iterative calculation. If the process fails to
** converge within a set number of iterations, 4 is added to the
** status.
**
** Called:
** iauStarpv    star catalog data to space motion pv-vector
** iauPvu      update a pv-vector
** iauPdp      scalar product of two p-vectors
** iauPvstar   space motion pv-vector to star catalog data
**
** */

```



```

int iauStarpv(double ra, double dec,
              double pmr, double pmd, double px, double rv,
              double pv[2][3])
/*
**   - - - - -
**   i a u S t a r p v
**   - - - - -
**
** Convert star catalog coordinates to position+velocity vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given (Note 1):
**   ra      double      right ascension (radians)
**   dec     double      declination (radians)
**   pmr     double      RA proper motion (radians/year)
**   pmd     double      Dec proper motion (radians/year)
**   px      double      parallax (arcseconds)
**   rv      double      radial velocity (km/s, positive = receding)
**
** Returned (Note 2):
**   pv      double[2][3]  pv-vector (AU, AU/day)
**
** Returned (function value):
**   int      status:
**           0 = no warnings
**           1 = distance overridden (Note 6)
**           2 = excessive speed (Note 7)
**           4 = solution didn't converge (Note 8)
**           else = binary logical OR of the above
**
** Notes:
**
** 1) The star data accepted by this function are "observables" for an
** imaginary observer at the solar-system barycenter. Proper motion
** and radial velocity are, strictly, in terms of barycentric
** coordinate time, TCB. For most practical applications, it is
** permissible to neglect the distinction between TCB and ordinary
** "proper" time on Earth (TT/TAI). The result will, as a rule, be
** limited by the intrinsic accuracy of the proper-motion and
** radial-velocity data; moreover, the pv-vector is likely to be
** merely an intermediate result, so that a change of time unit
** would cancel out overall.
**
** In accordance with normal star-catalog conventions, the object's
** right ascension and declination are freed from the effects of
** secular aberration. The frame, which is aligned to the catalog
** equator and equinox, is Lorentzian and centered on the SSB.
**
** 2) The resulting position and velocity pv-vector is with respect to
** the same frame and, like the catalog coordinates, is freed from
** the effects of secular aberration. Should the "coordinate
** direction", where the object was located at the catalog epoch, be
** required, it may be obtained by calculating the magnitude of the
** position vector pv[0][0-2] dividing by the speed of light in
** AU/day to give the light-time, and then multiplying the space
** velocity pv[1][0-2] by this light-time and adding the result to
** pv[0][0-2].
**
** Summarizing, the pv-vector returned is for most stars almost
** identical to the result of applying the standard geometrical
** "space motion" transformation. The differences, which are the
** subject of the Stumpff paper referenced below, are:
**
** (i) In stars with significant radial velocity and proper motion,
** the constantly changing light-time distorts the apparent proper
** motion. Note that this is a classical, not a relativistic,
** effect.

```

```

**
**      (ii) The transformation complies with special relativity.
**
**
**  3) Care is needed with units.  The star coordinates are in radians
**      and the proper motions in radians per Julian year, but the
**      parallax is in arcseconds; the radial velocity is in km/s, but
**      the pv-vector result is in AU and AU/day.
**
**  4) The RA proper motion is in terms of coordinate angle, not true
**      angle.  If the catalog uses arcseconds for both RA and Dec proper
**      motions, the RA proper motion will need to be divided by cos(Dec)
**      before use.
**
**  5) Straight-line motion at constant speed, in the inertial frame,
**      is assumed.
**
**  6) An extremely small (or zero or negative) parallax is interpreted
**      to mean that the object is on the "celestial sphere", the radius
**      of which is an arbitrary (large) value (see the constant PXMIN).
**      When the distance is overridden in this way, the status,
**      initially zero, has 1 added to it.
**
**  7) If the space velocity is a significant fraction of c (see the
**      constant VMAX), it is arbitrarily set to zero.  When this action
**      occurs, 2 is added to the status.
**
**  8) The relativistic adjustment involves an iterative calculation.
**      If the process fails to converge within a set number (IMAX) of
**      iterations, 4 is added to the status.
**
**  9) The inverse transformation is performed by the function
**      iauPvstar.
**
** Called:
**   iauS2pv      spherical coordinates to pv-vector
**   iauPm        modulus of p-vector
**   iauZp        zero p-vector
**   iauPn        decompose p-vector into modulus and direction
**   iauPdp       scalar product of two p-vectors
**   iauSxp       multiply p-vector by scalar
**   iauPmp       p-vector minus p-vector
**   iauPpp       p-vector plus p-vector
**
** Reference:
**
**   Stumpff, P., 1985, Astron.Astrophys. 144, 232-240.
**
**/

```

```
void iauSxp(double s, double p[3], double sp[3])
/*
**  - - - - -
**   i a u S x p
**  - - - - -
**
** Multiply a p-vector by a scalar.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   s      double      scalar
**   p      double[3]   p-vector
**
** Returned:
**   sp     double[3]   s * p
**
** Note:
**   It is permissible for p and sp to be the same array.
**
**/
```

```

void iauSxpv(double s, double pv[2][3], double spv[2][3])
/*
**  - - - - -
**  i a u S x p v
**  - - - - -
**
**  Multiply a pv-vector by a scalar.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    s      double      scalar
**    pv     double[2][3]  pv-vector
**
**  Returned:
**    spv    double[2][3]  s * pv
**
**  Note:
**    It is permissible for pv and psv to be the same array
**
**  Called:
**    iauS2xpv      multiply pv-vector by two scalars
**
*/

```

```
void iauTr(double r[3][3], double rt[3][3])
/*
**  - - - - -
**   i a u T r
**  - - - - -
**
**   Transpose an r-matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     r          double[3][3]   r-matrix
**
**   Returned:
**     rt         double[3][3]   transpose
**
**   Note:
**     It is permissible for r and rt to be the same array.
**
**   Called:
**     iauCr          copy r-matrix
**
**/
```

```

void iauTrxp(double r[3][3], double p[3], double trp[3])
/*
**  - - - - -
**   i a u T r x p
**  - - - - -
**
** Multiply a p-vector by the transpose of an r-matrix.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r      double[3][3]  r-matrix
**   p      double[3]    p-vector
**
** Returned:
**   trp    double[3]    r * p
**
** Note:
**   It is permissible for p and trp to be the same array.
**
** Called:
**   iauTr      transpose r-matrix
**   iauRxp    product of r-matrix and p-vector
**
*/

```

```

void iauTrxpv(double r[3][3], double pv[2][3], double trpv[2][3])
/*
**  - - - - -
**   i a u T r x p v
**  - - - - -
**
**   Multiply a pv-vector by the transpose of an r-matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     r          double[3][3]    r-matrix
**     pv         double[2][3]    pv-vector
**
**   Returned:
**     trpv       double[2][3]    r * pv
**
**   Note:
**     It is permissible for pv and trpv to be the same array.
**
**   Called:
**     iauTr      transpose r-matrix
**     iauRxpv   product of r-matrix and pv-vector
**
*/

```

```

void iauXy06(double date1, double date2, double *x, double *y)
/*
**   - - - - -
**   i a u X y 0 6
**   - - - - -
**
** X,Y coordinates of celestial intermediate pole from series based
** on IAU 2006 precession and IAU 2000A nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2 double      TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y          double     CIP X,Y coordinates (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The X,Y coordinates are those of the unit vector towards the
** celestial intermediate pole. They represent the combined effects
** of frame bias, precession and nutation.
**
** 3) The fundamental arguments used are as adopted in IERS Conventions
** (2003) and are from Simon et al. (1994) and Souchay et al.
** (1999).
**
** 4) This is an alternative to the angles-based method, via the SOFA
** function iauFw2xy and as used in iauXys06a for example. The two
** methods agree at the 1 microarcsecond level (at present), a
** negligible amount compared with the intrinsic accuracy of the
** models. However, it would be unwise to mix the two methods
** (angles-based and series-based) in a single application.
**
** Called:
**   iauFal03      mean anomaly of the Moon
**   iauFalp03     mean anomaly of the Sun
**   iauFaf03      mean argument of the latitude of the Moon
**   iauFad03      mean elongation of the Moon from the Sun
**   iauFaom03     mean longitude of the Moon's ascending node
**   iauFame03     mean longitude of Mercury
**   iauFave03     mean longitude of Venus
**   iauFae03      mean longitude of Earth
**   iauFama03     mean longitude of Mars
**   iauFaju03     mean longitude of Jupiter
**   iauFasa03     mean longitude of Saturn
**   iauFaur03     mean longitude of Uranus
**   iauFane03     mean longitude of Neptune
**   iauFapa03     general accumulated precession in longitude

```


**
** References:
**
** Capitaine, N., Wallace, P.T. & Chapront, J., 2003,
** Astron.Astrophys., 412, 567
**
** Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
** McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
** IERS Technical Note No. 32, BKG
**
** Simon, J.L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
** Francou, G. & Laskar, J., Astron.Astrophys., 1994, 282, 663
**
** Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M., 1999,
** Astron.Astrophys.Supp.Ser. 135, 111
**
** Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

void iauXys00a(double date1, double date2,
               double *x, double *y, double *s)
/*
**  - - - - -
**   i a u X y s 0 0 a
**  - - - - -
**
** For a given TT date, compute the X,Y coordinates of the Celestial
** Intermediate Pole and the CIO locator s, using the IAU 2000A
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y         double    Celestial Intermediate Pole (Note 2)
**   s           double    the CIO locator s (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y
** components of the unit vector in the Geocentric Celestial
** Reference System.
**
** 3) The CIO locator s (in radians) positions the Celestial
** Intermediate Origin on the equator of the CIP.
**
** 4) A faster, but slightly less accurate result (about 1 mas for
** X,Y), can be obtained by using instead the iauXys00b function.
**
** Called:
**   iauPnm00a    classical NPB matrix, IAU 2000A
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauXys00b(double date1, double date2,
               double *x, double *y, double *s)
/*
**  - - - - -
**   i a u X y s 0 0 b
**  - - - - -
**
** For a given TT date, compute the X,Y coordinates of the Celestial
** Intermediate Pole and the CIO locator s, using the IAU 2000B
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double   TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y         double   Celestial Intermediate Pole (Note 2)
**   s          double   the CIO locator s (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y
** components of the unit vector in the Geocentric Celestial
** Reference System.
**
** 3) The CIO locator s (in radians) positions the Celestial
** Intermediate Origin on the equator of the CIP.
**
** 4) The present function is faster, but slightly less accurate (about
** 1 mas in X,Y), than the iauXys00a function.
**
** Called:
**   iauPnm00b   classical NPB matrix, IAU 2000B
**   iauBpn2xy   extract CIP X,Y coordinates from NPB matrix
**   iauS00      the CIO locator s, given X,Y, IAU 2000A
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauXys06a(double date1, double date2,
               double *x, double *y, double *s)
/*
**  - - - - -
**   i a u X y s 0 6 a
**  - - - - -
**
** For a given TT date, compute the X,Y coordinates of the Celestial
** Intermediate Pole and the CIO locator s, using the IAU 2006
** precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double  TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y         double  Celestial Intermediate Pole (Note 2)
**   s           double  the CIO locator s (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y components
** of the unit vector in the Geocentric Celestial Reference System.
**
** 3) The CIO locator s (in radians) positions the Celestial
** Intermediate Origin on the equator of the CIP.
**
** 4) Series-based solutions for generating X and Y are also available:
** see Capitaine & Wallace (2006) and iauXy06.
**
** Called:
**   iauPnm06a  classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy  extract CIP X,Y coordinates from NPB matrix
**   iauS06     the CIO locator s, given X,Y, IAU 2006
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```
void iauZp(double p[3])
/*
**  - - - - -
**   i a u Z p
**  - - - - -
**
** Zero a p-vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Returned:
**   p          double[3]          p-vector
**
**/
```

```
void iauZpv(double pv[2][3])
/*
**  - - - - -
**   i a u Z p v
**  - - - - -
**
**   Zero a pv-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Returned:
**     pv      double[2][3]      pv-vector
**
**   Called:
**     iauZp      zero p-vector
**
**/
```

```
void iauZr(double r[3][3])
/*
**  - - - - -
**   i a u Z r
**  - - - - -
**
**   Initialize an r-matrix to the null matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Returned:
**     r      double[3][3]   r-matrix
**
**/
```

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* United Kingdom
*

*-----

SOFA Fortran constants

These must be used exactly as presented below.

```
* Pi
  DOUBLE PRECISION DPI
  PARAMETER ( DPI = 3.141592653589793238462643D0 )

* 2Pi
  DOUBLE PRECISION D2PI
  PARAMETER ( D2PI = 6.283185307179586476925287D0 )

* Radians to hours
  DOUBLE PRECISION DR2H
  PARAMETER ( DR2H = 3.819718634205488058453210D0 )

* Radians to seconds
  DOUBLE PRECISION DR2S
  PARAMETER ( DR2S = 13750.98708313975701043156D0 )

* Radians to degrees
  DOUBLE PRECISION DR2D
  PARAMETER ( DR2D = 57.29577951308232087679815D0 )

* Radians to arc seconds
  DOUBLE PRECISION DR2AS
  PARAMETER ( DR2AS = 206264.8062470963551564734D0 )

* Hours to radians
  DOUBLE PRECISION DH2R
  PARAMETER ( DH2R = 0.2617993877991494365385536D0 )

* Seconds to radians
  DOUBLE PRECISION DS2R
  PARAMETER ( DS2R = 7.272205216643039903848712D-5 )

* Degrees to radians
  DOUBLE PRECISION DD2R
  PARAMETER ( DD2R = 1.745329251994329576923691D-2 )

* Arc seconds to radians
  DOUBLE PRECISION DAS2R
  PARAMETER ( DAS2R = 4.848136811095359935899141D-6 )
```

SOFA C constants

The constants used by the C version of SOFA are defined in the header file sofam.h.

```

#ifndef SOFAMHDEF
#define SOFAMHDEF

/*
** - - - - -
**   s o f a m . h
** - - - - -
**
** Macros used by SOFA library.
**
** This file is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** This revision:   2009 January 29
**
** Copyright1
*/

#include "sofa.h"

/* Seconds of time per radian */
#define DS2R (7.272205216643039903848712e-5)

/* Pi */
#define DPI (3.141592653589793238462643)

/* 2Pi */
#define D2PI (6.283185307179586476925287)

/* Degrees to radians */
#define DD2R (1.745329251994329576923691e-2)

/* Radians to arcseconds */
#define DR2AS (206264.8062470963551564734)

/* Arcseconds to radians */
#define DAS2R (4.848136811095359935899141e-6)

/* Arcseconds in a full circle */
#define TURNAS (1296000.0)

/* Milliarcseconds to radians */
#define DMAS2R (DAS2R / 1e3)

/* Length of tropical year B1900 (days) */
#define DTY (365.242198781)

/* Reference epoch (J2000), Julian Date */
#define DJ00 (2451545.0)

/* Julian Date of Modified Julian Date zero */
#define DJM0 (2400000.5)

/* Reference epoch (J2000), Modified Julian Date */
#define DJM00 (51544.5)

/* Seconds per day. */
#define DAYSEC (86400.0)

/* Days per Julian year */
#define DJY (365.25)

/* Days per Julian century */
#define DJC (36525.0)

/* Days per Julian millennium */
#define DJM (365250.0)

/* AU (m) */
#define DAU (149597870e3)

/* Speed of light (AU per day) */
#define DC (DAYSEC / 499.004782)

```

```
/* dint(A) - truncate to nearest whole number towards zero (double) */
#define dint(A) ((A)<0.0?ceil(A):floor(A))

/* dnint(A) - round to nearest whole number (double) */
#define dnint(A) ((A)<0.0?ceil((A)-0.5):floor((A)+0.5))

/* dsign(A,B) - magnitude of A with sign of B (double) */
#define dsign(A,B) ((B)<0.0?-A:A)

#endif

/* Copyright2 */
```

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