A MATLAB Script for Predicting Solar Eclipses

This document describes a MATLAB script named `seclipse.m` that can be used to predict local circumstances of solar eclipses. This computer program provides the universal times and topocentric coordinates of the Sun and Moon at the beginning and end of the penumbra contacts, and the time and coordinates at maximum eclipse. The source ephemeris for this routine is a JPL binary ephemeris file.

This application uses several functions ported to MATLAB from the Fortran version of the NOVAS (Naval Observatory Vector Astrometry Subroutines) source code developed at the United States Naval Observatory. Information about NOVAS can be found at www.usno.navy.mil/USNO/astronomical-applications/software-products/novas. The `seclipse` MATLAB script also uses routines from the MICE software suite to read and evaluate the `de440s.bsp` binary ephemeris file. This ephemeris file, platform dependent versions of the MICE mex file, and other MATLAB functions are available at naif.jpl.nasa.gov/naif/toolkit_MATLAB.html. MICE is a MATLAB implementation of the SPICE library created by JPL.

This script uses a combination of one-dimensional minimization and root-finding to solve this classical astronomy problem. The objective function used in these calculations is the difference between the selenocentric (Moon-centered) separation angle between the axis of the lunar shadow and an Earth observer, and the penumbra shadow angle. This function is given by the following expression:

$$f(t) = \cos^{-1}\left(\hat{\mathbf{u}}_{axis} \bullet \hat{\mathbf{u}}_{m-o}\right) - \psi_p$$

where

$$\hat{\mathbf{u}}_{axis} = \text{selenocentric unit vector of the Moon's shadow}$$
$$\hat{\mathbf{u}}_{m-o} = \text{selenocentric unit position vector of the observer}$$
$$\psi_p = \text{penumbra shadow angle}$$

The penumbra shadow angle at the distance of the Earth observer is determined from

$$\psi_p = \sin^{-1}\left(\frac{r_m}{d_m}\right) + \sin^{-1}\left(\frac{r_s + r_m}{d_{m-s}}\right)$$

In this expression r_m is the radius of the Moon, r_s is the radius of the Sun, d_m is the topocentric distance of the Moon, and d_{m-s} is the distance from the Moon to the Sun.

The selenocentric position vector of the Sun is computed from the expression

$$\mathbf{r}_{m-s} = \mathbf{r}_s - \mathbf{r}_m$$

where $\mathbf{r}_s$ is the geocentric position vector of the Sun and $\mathbf{r}_m$ is the geocentric position vector of the Moon. The distance d_{m-s} in the equation above is the scalar magnitude of this vector.

The following is a typical user interaction with this MATLAB script. The screen output created by the script illustrates the local circumstances of a partial solar eclipse. The initial calendar date was December 25, 2000, the search duration was 30 days, and the observer was located at the Chamberlin Observatory in Denver, Colorado. The calendar date and time displayed are on the UTC time scale.

```
local circumstances of solar eclipses
=====================================

please input the initial UTC calendar date
(1 <= month <= 12, 1 <= day <= 31, year = all digits!)
? 12,1,2000

please input the search duration (days)
? 30

please input the geographic latitude of the observer
(-90 <= degrees <= +90, 0 <= minutes <= 60, 0 <= seconds <= 60)
(north latitude is positive, south latitude is negative)
? 39,40,36

please input the geographic longitude of the observer
(0 <= degrees <= 360, 0 <= minutes <= 60, 0 <= seconds <= 60)
(east longitude is positive, west longitude is negative)
? -104,57,12

please input the altitude of the observer (meters)
(positive above sea level, negative below sea level)
? 1644


begin penumbral phase of solar eclipse
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calendar date              25-Dec-2000

universal time             15:29:28.878

UTC Julian date            2451904.1455

solar topocentric azimuth angle     +132d 09m 24.36s

solar topocentric elevation angle   +10d 05m 17.59s

lunar topocentric azimuth angle     +132d 10m 25.51s

lunar topocentric elevation angle   +10d 36m 24.37s


greatest eclipse conditions
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calendar date              25-Dec-2000

universal time             16:43:49.826

UTC Julian date            2451904.1971

solar topocentric azimuth angle     +146d 57m 12.49s

solar topocentric elevation angle   +19d 22m 51.65s

lunar topocentric azimuth angle     +146d 44m 37.17s

lunar topocentric elevation angle   +19d 36m 46.75s
```

```
end penumbral phase of solar eclipse
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calendar date              25-Dec-2000

universal time             18:06:14.692

UTC Julian date            2451904.2543

solar topocentric azimuth angle     +166d 15m 18.44s

solar topocentric elevation angle   +25d 42m 22.41s

lunar topocentric azimuth angle     +165d 41m 32.92s

lunar topocentric elevation angle   +25d 49m 17.46s


event duration                      +02h 36m 45.8132s
```

The following are the results for this same eclipse using the Multiyear Interactive Computer Almanac (MICA) published by the United States Naval Observatory.

```
                     Solar Eclipse of 2000 Dec. 25
                 Sun in Partial Eclipse at this Location
                            Delta T:  64.1s

                        Chamberlin Obs., Denver
              Location:  W104°57'12.0", N39°40'36.0",  1644m
                (Longitude referred to Greenwich meridian)

                                         Sun's           Position     Vertex
                     UT1          Altitude   Azimuth       Angle        Angle
                  d  h  m   s          °          °            °            °
Eclipse Begins    25 15:29:29.6      10.1       132.2        319.7        358.3
Maximum Eclipse   25 16:43:36.3      19.4       146.9
Eclipse Ends      25 18:06:14.6      25.7       166.3         65.6         77.3

          Duration:   2h 36m 45.0s
         Magnitude:   0.396
       Obscuration:  27.3%
```