Chapter 1

Introduction

1.1 What is a Fundamental Ephemeris?

For the purposes of this book, an *ephemeris* is a table giving the positions (and maybe velocities) of a celestial object. To present an ephemeris of, say, a major planet in our solar system requires many "behind the scenes" computations. Depending on just how precise the ephemeris needs to be these can be quite involved—but the basic computations are the same from one ephemeris to the next. Today, even the desktop computers can be instructed to carry out these tedious, but fortunately repetitive, mathematical details for us with any modern programming language to very high levels of precision.

There are two basic types of fundamental ephemerides: analytical and numerical. Analytical ephemerides are based on closed-form algebraic expressions which yield the object's position and velocity components for a given instant of time. These expressions must be derived from an algebraic solution to the equations of motion for the object. When mutual gravitational perturbations and relativistic perturbations (and there are many others to consider) are taken into account, the expressions necessarily become more complicated. Computer algebra systems such as Mathematica and Maple can be employed to remove some of the drudgery, but the final expressions must be derived explicitly. The primary benefit of analytical ephemerides is that they express the positions and velocity components as explicit functions of time. In general, analytical ephemerides are no longer used in most applications, but a group of astronomers at the Bureau des Longitudes in Paris, France has continued to make advances in this area.

Numerical ephemerides, as the name suggests, rely on a numerical solution to the equation of motion. The output of such a computation is a table of numbers giving the positions and velocities at the desired times. A potential drawback of this method is the sheer size of the tables when the object's position and velocity components are required for a large number of times—for example, a one day interval over several centuries. In practice, the positions and velocities may be "compressed" by fitting them with a well-behaved mathematical function which can replicate the original values to within a very small tolerance for any desired instant of time. This is the approach taken in the production of the Jet Propulsion Laboratory (JPL) planetary ephemerides. Such ephemerides are extremely compact and the effort required to extract the data is minimal for a computer. For the user, not having an explicit algebraic expression may take some getting used to though. Generally speaking, numerical ephemerides have replaced analytical ephemerides. They are the basis for the U.S. Naval Observatory *Astronomical Almanac*.

The positions and velocities obtained from either type of ephemeris are generally not in a form for use by Earth-based observers. Several transformations and correctons may be necessary to reduce the data to a form which can actually be compared to the observed values. These transformations and corrections are the subject of this book.

I have chosen to concentrate on the process of generating the actual ephemeris rather than on specific applications. Ten different persons may have ten different reasons for wanting precise planetary coordinates. A book that attempts to deal with each of these would rapidly become huge. Rather, I have directed my efforts in this book to describing how you can acquire precise starting data and then maintain that precision throughout the creation of a basic ephemeris. Therefore, the concepts of time, coordinate transformations, precession, nutation, aberration, relativistic corrections, and atmospheric refraction are presented here in a rigorous modular form that suggests use as modifiers to the original data. Keplerian two-body motion is also presented as a means of generating ephemerides for objects not included in the JPL ephemeris data files. A generalized suite of routines, based on the JPL export software and suitable for processing any JPL ephemeris data file, is developed, as is an explanation of the data file format. This section conveniently pulls together tidbits of information that previously had to be gleaned from several sources. I have also included a toolbox of matrix, vector, and numerical routines that has been useful. Finally, in Chapter 10 all the concepts developed earlier in this book are brought together in the development of a powerful, easy to use command-line ephemeris program which can serve as a starting point for more advanced applications. Suggestions for enhancements are included as programming exercises.

Nowhere do I give algorithms for finding planetary conjunctions, oppositions, lunar or solar eclipses, lunar phases, or other such events. I consider these to be applications whose existence depends on having suitable positional data. Excellent books, like Jean Meeus' *Astronomical Algorithms* already provide this information. I do, however, include an algorithm for finding rise/transit/set times because I see these as fundamental applications on nearly the same footing as the ephemerides themselves. Conceptually, these times determine whether or not a particular event will be visible from a given location on Earth.

So, this book shows you how to create precise basic ephemerides for celestial bodies ready for modification by the user to meet his or her specific needs. It is the reference and text which I wished was available when I began learning about astronomy and how to compute the positions of the planets.

1.2 The Software Source Code

Software source code is distributed with this book and is to be found in a plastic pouch located on the inside back cover. This source code includes all of the primary subprograms described in the book, including the driver programs, utility routines and functions in PowerBasic and C. The files are organized into three subdirectories, one for the PowerBASIC files, one for the ANSI C files, and one for (PowerBASIC) executables only. The files are distributed in compressed form and are found in a file titled `Fund_eph.ZIP`, this file in turn contains the following directory structure which will be created when expanded to your hard drive:

```
\exec\
\fecsoftb\
\fecsoftc\
```

The `exec` folder holds executable programs. The `fecsoftb` folder contains BASIC source code. The `fecsoftc` contains ANSI C source code.

1.2.1 Program Requirements

The BASIC Code

The BASIC programs were created and compiled with PowerBASIC 3.2 from PowerBASIC, Inc. The PB language system is not required to run the executables, but is needed if you wish to modify and recompile the programs. Information on PowerBASIC can be found on the World Wide Web at the URL http://www.powerbasic.com. The programs will run under MS-DOS, Windows 3.1, Windows 98, and OS/2 Warp 3 and 4.

The driver programs are tersely written and they make extensive use of PowerBASIC's `$include` metastatement—this means that when an external routine is needed, it is included in the main program via an `$include` metastatement. Notice that each such metastatement contains the full path to the required routine's source code file. These metastatements may, of course, be modified by the user in the event that he or she decides not to use the provided directory structure. Consult the PowerBASIC documentation for more details.

The C Code

In order to build the executables, you must have an ANSI C compiler, a make utility, and the GNU file utilities installed on your computer. GNU make was used extensively for testing. After expanding the archive to your hard drive, change to the directory on your hard disk where you installed the code, and type the following at the system prompt:

```
C:\>make -f makefile.XXX
```

where `XXX` is either 'dos' (for DJGPP systems), 'os2' (for EMX systems), or 'unx' (for UNIX or LINUX systems). This will build the executables, leaving the object files intact for later use. The sources were compiled and the resulting executables were tested on the following computer platforms:

1. Compaq AERO 4/33C running MS-DOS 6.2/Win31 (DJGPP)
2. Sony VAIO PCG-731 200Mhz Pentium running Windows 98 (DJGPP)
3. Gateway Pentium P5-90 running MS-DOS 6.22/Win31 (DJGPP)
4. Intel Pentium 166MHz, 32Meg RAM, running OS/2 Warp 4 (EMX, DJGPP)
5. Gateway Pentium Pro 200, 48Meg RAM, running Windows NT (MS Visual C++ 5)
6. LINUX (gcc)
7. Sun SPARC 5 running Solaris and SunOS 4.1.3

1.2.2 Modifying the Source Code

The reader is free to modify the source code and to experiment with it. Indeed, there are even suggestions for such experimentation provided throughout the book. Under no circumstances, however, should the original or modified code be distributed. It is copyrighted and your purchase only entitles you to personal use without written permission from Willmann-Bell. Certain modifications have purposely not been made to the software so that the user can learn more by experimenting.

1.2.3 Programming Conventions

Let me emphasize that I am **not** a professional computer programmer. I consider both the computer and the chosen programming language as tools for solving problems. I also do not claim that my software is always written in the most efficient manner. That is the main reason I decided to make the source code available to users of this book. While many readers will be content with the programs as they stand, others will feel the need to experiment with the source code and to build applications that meet specific needs. I wholeheartedly recommend this form of experimentation.

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