Analysis Environments for Other High Energy (X-ray) Missions

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Overview

- Missions: ROSAT, ASCA, RXTE, Beppo-SAX, XMM-Newton, Chandra
  NB: much lower energies ($\sim$ 0.2–100 keV) and much higher count rates ($\sim$ 1–100 cps)
- Two Stage Process
  - **Filtering and Extraction (Reduction)**: Preparation of data for analysis
    * Removing bad data: SAA passages, Earth angles, etc.
    * Selecting from good data: cuts in energy, time, position, etc.
    * Creating data products: counts spectra, light curves, images and the associated response function products (energy redistribution matrices, exposure maps, etc.)
  - **Science Analysis**: Spectral, temporal, and spatial
    * Use "standard" analysis software

    $\Rightarrow$ Require data to be in standard formats (OGIP, `http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_recomm.html`)

Filtering and Extraction: Tools

- Usually restricted to data extraction tasks and relatively low-level science analysis.
- FTOOLS (HEASARC)
  - Suite of programs designed to perform specific tasks on FITS files. (`http://heasarc.gsfc.nasa.gov/lheasoft/ftools/`)
  - Consists of **general** tasks to examine and manipulate FITS files and **mission-specific** tasks such as calculating response matrices, deadtime corrections, instrument backgrounds, etc.
  - Example: filtering an event file on energy and inclination

    ```
    $ fselect input_file output_file 'E > 1 && inc < 30'
    ```

  - Some later FTOOLS are Perl scripts that execute common sequences of more basic FTOOLS tasks. Such scripting is greatly facilitated by the compartmentalization of the tasks and the ability run each FTOOL from the unix shell.
  - Used by ROSAT, ASCA, RXTE, XMM-Newton, etc. (i.e., any mission with a strong HEASARC connection, either in terms of user support or mission origin)
- CIAO (Chandra Interactive Analysis of Observations) Tools (`http://cxc.harvard.edu/ciao/intro_tools.html`)
  - Like FTOOLS but designed for use with Chandra data.
  - Uses a more inclusive "data model", i.e., other data formats are accepted in addition to OGIP.

Extraction Environments

- Extraction tasks can be done entirely from the unix command line by running various tools (notable exception: ASCA).
- Extraction environments allow these various tasks to be performed more easily
- Accomplished via a combination of FTOOLS and native capabilities.
- Main benefits:
  - Keeps track of complex file names and directory structures; also creates and disposes of intermediate files.
  - Allows interactive plotting of the data to aid the user in determining which data selections to apply
  - Examples:
    * Xselect: Intended to be a general environment for extracting data for X-ray missions, but mission specific tasks were included for ASCA. (`http://heasarc.gsfc.nasa.gov/docs/software/ftools/xselect`)
    * XMM-Newton Science Analysis System (SAS) (`http://heasarc.gsfc.nasa.gov/docs/xmm/sas/sas.html`)
    * The CIAO tools `firstlook` and `filtwin` (`http://cxc.harvard.edu/ciao/ahelp/[firstlook, filtwin]`)

Sample Xselect Session for ASCA-GIS data

(Ref.: `http://heasarc.gsfc.nasa.gov/docs/asca/abc/node7.html`)

```
$ xselect
                        **  XSELECT V1.3   **

>Enter session name>[xsel] A1060
                                  ...
A1060:ASCA> set mkfdir ..
A1060:ASCA> set datadir ..
A1060:ASCA> set instrument gis2
A1060:ASCA-GIS2> set datamode ph
A1060:ASCA-GIS2> make obscat
> Default filter for the catalogue (NONE for none, DEF for default) >[DEF]
Using default selection expression:
ONTIME>100&&NEVENTS>0&&HV_RED=='OFF'&&HVH_LVL==3&&HVL_LVL==4

******************** Observation Catalogue **********************

Data Directory is: /usr/day/asca/data/a1060/
HK Directory is: /usr/day/asca/data/a1060/
```

```
        OBJECT   DATAMODE BIT_RATE DATE-OBS TIME-OBS ONTIME   NEVENTS  PHA_BINS
      1 A1060    PH       MEDIUM   28/06/93 23:46:14 .146E+04     2225     1024
      2 A1060    PH       MEDIUM   29/06/93 00:20:06 .114E+04     2060     1024
      3 A1060    PH       HIGH     29/06/93 00:49:00 .136E+04     3254     1024
...
     39 A1060    PH       MEDIUM   29/06/93 23:57:42 .262E+04     3458     1024
     40 A1060    PH       HIGH     30/06/93 00:41:32 .106E+04     2595     1024
     41 A1060    PH       HIGH     30/06/93 01:04:46 .392E+03      918     1024

A1060:ASCA-GIS2> select obscat BIT_RATE.eq.'HIGH'

A1060:ASCA-GIS2 > choose 1-**

   Setting datamode to PH

Got the minimum time resolution of the chosen data:  0.62500E-01,
```

```
Getting Min and Max for Energy Column...
Got min and max for PI:     0   1023

Number of files read in:   25

Files currently in use:

   1   ft930628_2345_1426G200770H.fits
   2   ft930628_2345_1426G201770H.fits
   3   ft930628_2345_1426G201970H.fits
...
  23   ft930629_1426_0123G206370H.fits
  24   ft930629_1426_0123G206970H.fits
  25   ft930629_1426_0123G207170H.fits
A1060:ASCA-GIS2-PH> select mkf
>Boolean expression for filter file selection >[]
elv.gt.5.and.cor.gt.6.and.g2_l1.gt.0.and.saa.eq.0
```

```
A1060:ASCA-GIS2-PH> filter region ring.reg
                          ...
A1060:ASCA-GIS2-PH> extract events
 Extractor 1.0r
 XPI 2.1u
 Doing file: /usr/day/asca/data/a1060/redux/A1060_work1001.xsl
100% completed
    Total      Good    Bad: Region      Time     Phase       PHA
     5339      2623           1498      1218         0         0
 Writing events file

 Doing file: /usr/day/asca/data/a1060/redux/A1060_work1024.xsl
100% completed
    Total      Good    Bad: Region      Time     Phase       PHA
      841       604            237         0         0         0
 Writing events file
100% completed
================================================================
   Grand Total      Good   Bad:  Region      Time     Phase       PHA
         73565     47039          21402      5124         0         0
```

Possible Lessons for LAT Data Extraction

- Compartmentalization of tasks (FTOOLS)
- User-level Selections (post-U1 extraction)
- User-level Extraction Environment
  - LAT data may consist of many files
  - Should allow some low-level, "quick-look" analysis (e.g., histogramming over event attributes, variability estimation, etc.) to see the effect of various cuts
    $\Rightarrow$ interactive plotting and image display
  - Scriptability (for implementing standard extraction recipes or repeated sequences of commands.)
  - Should devote some effort to make it user-friendly (intuitive commands, easily specified parameters and options, a GUI), but a certain amount of complexity is inevitable
    $\Rightarrow$ good documentation

Science Analysis: Spectral Fitting

- Standard X-ray spectral fitting packages are essentially minimization programs (like `minuit`) with predefined spectral models (physical and phenomenological) designed to accept OGIP data formats
- Examples:
  - Xspec — HEASARC spectral fitting program. The *standard* program used by X-ray astronomers. Accepts input in the form of counts organized by detector channel and folds spectral models through an energy redistribution matrix. (`http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/index.html`)
  - Other programs:
    - ISIS (`http://space.mit.edu/CXC/ISIS/`) — Similar to Xspec, but uses a better integrated scripting language and can more easily import other spectral models
    - Sherpa (`http://cxc.harvard.edu/ciao/download/doc/sherpa_html_manual/`) — Uses the more general Chandra data model (i.e., input is not restricted to OGIP formats), allows greater flexibility for choosing merit functions and optimization methods, and is intended to allow joint spatial and spectral fitting (still pending)

- Useful Features:
  - multi-instrument/multi-dataset fitting
  - allow complex model definitions:

    ```
    xspec> model absori*(cutoffpl + gaussian)
    ```

    This model has 12 parameters (2 photon indices, total column density, plasma temperature, redshift, abundances, etc.)
  - "tying" and "untying" of parameters across datasets and model components
  - "freezing" and "thawing" of parameters
  - can specify valid parameter ranges
  - able to plot intermediate results
  - can define or select merit function
  - can select optimization method
  - scriptable

LAT Issues for Spectral Analysis

- Multi-instrument fitting: Since the current OGIP formats for spectral data are not appropriate for LAT data, it may be desirable to enable the LAT spectral analysis software to read and fit OGIP-conforming spectral files in addition to LAT data
- Should be able to monitor how parameters change during fitting process — e.g., a strip-chart plot of selected parameters and the merit function as the fitting proceeds
- Although standard models for LAT data will be fairly simple (i.e., power-laws), we should have the ability to import source specific models (e.g., blazar or pulsar spectral models) via Xspec-like table models or ISIS-like modules

Science Analysis (Continued)

- Spatial: Ximage, Sherpa
  - Not much we can learn from X-ray missions.
- Temporal: Xronos
  - Again, very little cross-over, except perhaps for long pointed observations.
  - We should be able to perform common tasks:
    - epoch-folding
    - power-spectrum/auto-correlation or some form of variability estimation
    - cross-correlation or some form of interband lag analysis
    - spectral variability detection (akin to light curves of hardness-ratios)

Useful Existing Software

- `fv` and other Futils that allow for ready manipulation of FITS file contents
- `ds9` for image display