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The Chandra Monitoring System

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Abstract. The NASA Great Observatory *Chandra* was launched July 23, 1999 aboard the space shuttle Columbia. The Chandra Science Center (CXC) runs a monitoring and trends analysis program to maximize the science return from this mission. At the time of the launch, the monitoring portion of this system was in place. The system is a collection of multiple threads and programming methodologies acting cohesively.

Real-time data are passed to the CXC. Our real-time tool, ACORN (A Comprehensive object-ORiented Necessity), performs limit checking of performance related hardware. *Chandra* is in ground contact less than 3 hours a day, so the bulk of the monitoring must take place on data dumped by the spacecraft. To do this, we have written several tools which run off of the CXC data system pipelines. MTA_MONITOR_STATIC, limit checks FITS files containing hardware data. MTA_EVENT_MON and MTA_GRAT_MON create quick look data for the focal place instruments and the transmission gratings. When instruments violate their operational limits, the responsible scientists are notified by email and problem tracking is initiated. Output from all these codes is distributed to CXC scientists via HTML interface.

1. Introduction

The goal of the Chandra X-Ray Center's Monitoring and Trends Analysis project (M&TA) is to maximize science return by keeping the science operations team (SOT) informed of the scientific performance of the spacecraft. The SOT then uses this information to maximize the science return of the spacecraft. M&TA occupies a middle ground between *flight operations*, chiefly concerned with the health and safety of the spacecraft, and *validation and verification*, concerned with the scientific validity of the data taken and whether or not they fulfill the observer's requirements.

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M&TA requirements, initially set down four years before launch were for 130 tools which form a miniature data system. These tools ranged from monitoring the temperature stability of the exquisitely accurate mirrors, to the total number of photon's incident on the microchannel plates of the *High Resolution Camera* (HRC) and measuring the total observing efficiency of the observatory. The reality of budgets stepped in; the project was assigned less than 5 man years of programming support, leaving about 2 weeks to develop each tool. This was deemed unrealistic and the entire system was redesigned, leaving the goals intact with careful re–prioritization made with respect to those portions which were flight critical and those which could wait.

What follows is a success story. We redesigned the M&TA system to have a symbiotic relationship with the main of the data system pipeline processing. At each stage of the processing, we have been able to examine the existing data product, evaluate it and rapidly return needed information to the SOT. Along the way, we have developed an infrastructure which was able to operate independent of the overall readiness of individual Chandra X–ray Center Data System (CXCDS) functionality in order to support pre–flight testing. Later, components have been seamlessly merged into the rest of the data system as higher level pipelines come on line. In the following sections, we describe how we handle data of various forms and at various levels of processing.

2. Raw Data

Raw data are the data packets as they come from the spacecraft. These are sent to the CXC in two forms: (1) Realtime data, which arrive at the science center seconds after the recorded events have occurred; and (2) Dump data which are sent to the ground during a 45 minutes pass approximately once every 8 hours. In some sense, these are the most important data the SOT sees as they give the most rapid visibility into the spacecraft's behavior. The main CXC pipeline is required the process raw data by converting it to FITS format. This inevitably requires a minimum data size, adds bulk to the data and time to the processing.

For the M&TA project, raw data are processed by the ACORN tool. This tool is a collection of C++ objects integrated under a Tcl/Tk GUI. Data can either stream into the tool via UDP or can be loaded from individual files. The former method is primarily used for realtime data, the latter for dump data or analysis. When analyzing file based data, ACORN can step through the file either forward or backward at a user adjustable rate. These features are very desirable for data analysis just before or after a specific spacecraft event (such as a safe mode entry).

ACORN uses the NASA compliant databases to decommutate the data. It can output the HEX pattern, calibrated or uncalibrated value for any location in the data stream. It can also sense limit violations and output the nature of these alerts (red or yellow). Alerts are written to disk where the MTA Problem Response System (MTA_PRS) acts on them by cataloging the error and mailing the responsible scientist. The GUI directly displays all selected data to the screen. Multiple display pages can be set up with associated values logically grouped by the user. Data can also be captured in multiple files as tab delimited fields. This allows post processing analysis by any number of software tools including RDB, IDL and EXCEL. ACORN can also stream the tab delimited data the STDOUT. This allows us to use ACORN as part of any UNIX pipeline process.

3. Processed Data

The CXCDS pipelines add a great deal of value to the Chandra data. Raw values are calibrated, events are identified and the spacecraft pointing and dither are taken into account. Instead of performing these calculations anew, the M&TA pipelines interrogate the files generated by the main processing.

3.1. Spacecraft Data

Data produced by CXCDS consists of FITS files. These are generally of two types – table files and event lists. The tabular data tends more to contain spacecraft status information, which instrument is at focus, power consumption by the instruments, spacecraft pointing and radiation count rates for example. These data come through CXCDS in atomic units of about 1 hour. The MTA_MONITOR_STATIC monitors all the spacecraft data as soon as the file is closed by the tool which produces it. Using a collection of C and C++ tools, selected data are checked that they are within expected limits and statistics on the performance of the monitored system (mean, standard deviation, min. max. etc.) are calculated and reported out. The pipeline uses IDL to produce a strip chart for each monitored value. If limit violations occur, they are written to disk and handled by MTA_PRS.

3.2. Event Data

As a data product, X–ray data are fundamentally different than lower energy data in that each individual photon is recorded. The FITS incarnation of this is an event list. This is a file which contains the time, location and energy of each photon which struck a given detector. The MTA_MONITOR_EVENT pipeline uses tools similar too those used to monitor spacecraft data to provide a snapshot of the focal plane at all levels of the processing. Since the focal plane is quite large (up to $32K^2$ pixels), the tool locates the brightest regions and produces full scale representations of those regions. In addition to an image of the focal plane, the pipeline produces histograms of the event shape (grade) and the energy (pulse height) on various scales of instrumental relevance. The data provide the various instrument scientists quick visibility into the performance of the instruments and the pointing reconstruction.

3.3. Gratings Data

One of the unique aspects of the Chandra mission are the transmission gratings. The M&TA project has 7 tasks specifically for the monitoring of the gratings, the bulk of these are handled via the High energy transmission grating Analysis tool Kit (HAK). The HAK code is a collection of IDL procedures developed during ground calibration with an eye toward flight. This pipeline consecutively produces an image of the focal plane, plots a timing analysis, finds the zero order and characterizes it, finds the dispersed spectrum, identifies lines and fits the line. The outputs are RDB and ISIS files (Houck et al. 2000) containing line energy and width data.

4. The Interface

The most critical part of any software design is not the functionality. This is usually determined by the problem. The most critical aspect is the user interface, the software must be easy and intuitive to use or it will be eschewed and the programming effort will be duplicated by users. Our interface problem was complicate by several different programmers of various skill levels using different software. All the output however, is directed to a series of web pages. The top level web page http://asc.harvard.edu/mta/sot.html allows the user the view realtime data (processed by ACORN), telemetry (processed by MTA_MONTIOR_STATIC), photons (Processed by MTA_MONITOR_EVENT) or alerts. In addition to being able to view the data from anywhere in the world, it is easy for the user to view the data to navigate to deeper levels of the web hierarchy which is arranged by date, subsystem and observation ID. It is also easy for the data system to secure proprietary data as needed.

5. Trending

The trending functions of the Monitoring and Trends Analysis system are currently the least robust. The long term plan is to have an integrated system using the full CXCDS data base. It was clear early during the development of the system these resources would be unavailable by flight. Our approach was to use the statistics generated by the earlier pipelines. We simply convert the HTML tables back into text. These data have low time resolution, typically one day, and are not easily time correlated. However these products provide access to the performance of all spacecraft systems over the duration of the mission.

6. The Future

Development of the M&TA system is ongoing, currently fulfilling a little less than half of our pre–flight requirements. The pre–flight development focused on broad scope tools such as event monitoring and data inspection (Petreshock et al. 2000). Over the next year we will continue the development of broad focus tools, such as the databases and computations of existing data. We will also begin to develop tools targeted at specific problems such as charge transfer inefficiency, telemetry saturation, and focus quality.

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References

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