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IMAGE ANALYSIS : TRANSFER OF TECHNIQUES USED IN ASTRONOMY TO DIFFRACTION

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Abstract - Digital Image Processing is a tool which has been used for many decades in astronomy. Many kinds of image from a wide variety of receivers have to be processed. Therefore huge image processing systems have been achieved.

We outline the hardware and software needed. The Hubble Space Telescope is the incentive behind an international coordination of the software.

A survey of an image processing system is given. Image analysis is the main aim in astronomical applications.

A comparison of the treatments used in astronomy and diffraction shows that the same problems arise in both disciplines. We conclude by comparing an image processing system to a three stage rocket. The first stage is the technical one containing the construction of all the libraries. In the second one these libraries are integrated for building the commands. The last stage is the scientific one. Specialists of a given discipline concerned write procedures to process the images that concerns them.

I - INTRODUCTION

Digital Image Processing (DIP) is a tool which has been used for many decades in astronomy. The first applications were essentially image synthesis for radioastronomy /1/ and Fourier spectrography /2/. But with the introduction of computer-driven microdensitometers and digital image receivers DIP began to be used systematically in many other fields of observational astronomy.
Many different kinds of image have to be processed such as those occurring in direct photography, spectrography, interferograms, etc. The observations of a stellar field, with its set of peaks, give rise to the same sort of problems as those associated with diffraction images.

Different kinds of receivers are now used: photographic plates for large fields, electronographic detectors, Image Tubes, Charge Coupled Devices (CCD), cameras and Image Photon Counting Systems (IPCS).

The range of wavelengths covered is now very large extending from gamma rays to decametric wavelengths.

A large variety of images has to be processed and this has lead to the achievement of huge image processing systems in astronomy. We will find many problems in common between astronomy and neutron diffraction.

II - IMAGE PROCESSING SYSTEMS

An image processing system consists of a set of programs for extracting the information contained in images. The following hardware and software features are needed:

1/ Central Unit: even if images can be processed by a micro-computer, only those with 32 bit processors permit the easy development of programs for handling large images.

2/ Array processors are used to reduce data, often in real time.

3/ Large storage (tens of megabytes) is always necessary.

4/ Graphic displays are essential for plotting curves and measuring positions with cross-wires. They are most frequently used with simple devices.

5/ An electrostatic (or laser) printer/plotter is used to produce curves and grey-tone images.

6/ An image processor allows one to display, on a TV monitor, images with grey-tones, colour, or false colour. Images are stored in memory planes. Some operations can be achieved such as summation, taking ratios, smoothing, histograms, etc. An associated graphic plane allows one to store contours or to plot histograms or profiles. Sometimes an associated disk is required allowing, for example, to make a movie from a set of stored images.

Other peripherals are also often connected with image processing.

DIP requires a very flexible disk operating system. The majority of astronomical laboratories now use VMS on VAX computers. The UNIX system, which is available on a large number of computers, is now beginning to be used too.

Fortran 77, or languages derived from this, are widely used. C language is now beginning to be employed.

For graphics, developers have tried to introduce multi-driver packages, allowing one to pass easily from one kind of display to another. The tendency is to use a GKS-type library.

For internal image structure, a format developed in the MIDAS system seems to be accepted by a large number of astronomers. This format allows one to process multi-dimensional images with a set of standard parameters, such as the number of pixels in each dimension, the starting coordinates or sampling steps. Into some programs we can introduce image descriptors, such as the histogram, the calibration curve or point spread function. Access to image data is performed using the "mapping memory" concept, in which the image is read, or written, only by giving an address on the disk.

In astronomical DIP we often use sets of values which are not images (i.e. sampled functions), but lists of data. A structure has been defined in the MIDAS system (Table structure), using standard parameters, descriptors and mapping memory.

Command languages are generally used in these systems. Often a special language has been built with a complex grammar. The tendency is to use the tools associated with the operating system, leading to commands similar to those of the system.
Some standard procedures have been written to process images in given cases. These procedures are sometimes written with the command languages, as batch sequences, or they are a description of all the steps needed to extract the information.

Documentation is the one main feature common to all the large systems. The programs are often available in many laboratories and used by many astronomers who are not familiar with computer science. So good documentation is essential.

About ten large systems have now been built and are installed in many laboratories. These systems are used by hundreds of astronomers.

III - TENDENCIES

The construction of an image processing system requires so much effort that an international agreement now exists in the astronomical community to develop coordination of the software.

The Hubble Space Telescope is the incentive behind this policy. A European Center Facility (ST/ECF) has the task of coordinating the efforts of American and European laboratories. In the near future ST/ECF will provide packages for given applications.

Some interface routines have been defined in order to facilitate the writing of software in different research centers.

IV - MAIN CONTENT

A large image processing system contains different kinds of operations:

1/ Image handling: image extraction, merging, ...
2/ Image displaying: with image display or with graphic ones (contour, perspective, ....). Positions and image values can be measured.
3/ Geometric corrections: resampling to obtain an image with coordinates corresponding to a reference frame, such as equatorial coordinates or wavelengths.
4/ Photometric corrections to reduce the image by taking into account i/ non-linearity, ii/ variation of sensitivity, iii/ non uniform background or iv/ defective pixels.
5/ Noise reduction with linear smoothing or filtering. Non-linear methods such as Noise Cheating Enhancement /9/, which takes account of non-Gaussian statistics, are also used.
6/ Resolution enhancement with linear deconvolution using Fourier transform. Iterative processes, such as Biraud's /10/, Lannes's /11/, Lucy's /12/, or those of Maximum Entropy /13/ are used more and more often to detect faint features.
7/ Contrast enhancement, using global or local histograms.
8/ Image restoration, which is always a very important application of DIP in astronomy. Fourier restoration is used for radio observations, or for spectroscopy with a Michelson interferometer. But some other kinds of restoration have been achieved. For example using Walsh-Hadamard or Radon transforms /14/. Restorations using the Maximum Entropy principle have been achieved from the spectral energy density, without phase knowledge (speckle interferometry) /15/.
9/ Image Analysis: it is the main purpose in astronomical DIP. Four kinds of analysis can be performed:
   - Global analysis, with extraction of some histogram parameters or values of the Fourier transform.
   - Parametric analysis, in which we compute the values of some given parameters of identified objects. As in the diffraction case, we have to compute the background and then determine the positions and fluxes and extract the profile parameters. Some image modelling is needed, with statistical rules such as Least Squares, Maximum Likelihood Principle, or Minimum Variance Bound Estimator for estimating the parameters. For goodness fits we use tests such as chi-2 or that of Smirnov-Kolmogorov.
   - Automated analysis, using detection with searching for maxima, or with image
Many types of contour lines can be used for segmentation: isophotes, Laplacian or another edge function lines, valley lines to separate all the pixels corresponding to a given peak. The extraction of the field parameters is generally performed in real time, with computation of moments or extrema. These parameters are reduced to obtain positions, emitted fluxes and pattern parameters. Separation between stars and galaxies is achieved using Bayesian classification. Classification of non-stellar objects is performed with cluster analysis, with or without a previous factor analysis. Recognition is made using this classification, by statistical means. Expert systems are beginning to be used now.

- Multi-Image analysis, for observation in different wavelength windows or at a lot of epochs. Geometric correspondence is essential. The classification of pixels, which is the main step, is assumed using linear discriminant analysis and cluster analysis.

Some other operation can be achieved in certain cases, such as image compression or model synthesis.

V - COMPARISON BETWEEN ASTRONOMY AND DIFFRACTION

When we compare treatments used in the two disciplines we find that the same problems arise, even though the ultimate aims are not the same. In the two cases we find the same operations occurring such as background mapping, peak detection and the measurement of positions and intensities. A lot of image enhancements can be obtained with the same tools. Some differences occur, for example when the processing is very dependent on the model fitting.

Since an image processing system is difficult to develop, document and maintain, it is therefore desirable to exchange software between the two disciplines. An image processing system can be compared to a three stage rocket:

1/ The first stage is the technical one and contains the definition and construction of all the libraries: graphic (GKS), Input/Output parameter interfaces (command language), file management of images or tables, and algorithms to be applied to the data. Using a virtual memory system, it is easy to separate the algorithm from the file access. An algorithm written in a standard language such as Fortran 77 is easily transportable. For this stage, we have a set of independent packages, which can be provided by many companies or laboratories.

2/ The second stage is the integration one. In some laboratories, the software from stage one is used to build commands. If the choice of the interfaces is the same in all laboratories (GKS, MIDAS files, similar command language), the software transport from one laboratory to another is simplified. This is the choice made by many astronomical institutes. It could also be made in diffraction processing if some additional algorithms were introduced.

3/ The last stage corresponds to the scientific one. In fact the user of a DIP system always needs to have a set of standard procedures. Only specialists of the discipline concerned can write these.

If we succeed in using a common language for software that is to be applied in a common environment, then we will obtain an instrument for describing procedures to extract the information contained in images which can be universally understood.

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