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EUROPEAN COLLABORATION TOWARDS THE ASTRONOMICAL DATAGRID

iAstro - A Collaboration in Astronomy in the Framework of COST 283 Action "Computational and Information Infrastructure in the Astronomical DataGrid"

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Abstract. The implementation of a European Concerted Research Action designated as COST Action 283 "Computational and Information Infrastructure in the Astronomical DataGrid" is described. The main objective of the Action is to develop innovative and well focused approaches to data and information handling, in the context of astronomy and astrophysics. This includes processing and interpretation of data and, more generally, information, at the time of data capture or later ("archival research", "data mining" and "virtual observatories" and so forth), and including aspects of the collaborative work and man-machine environments needed for this.

1. INTRODUCTION

"The brain does not have a single CPU that processes each command in sequence. Rather, it has millions of processors working together at the same time. Such massively parallel processing will be the future for the electronic intelligence as well."

S. Hawking 'The Universe in a Nutshell'

Exponential improvements in telescope, detector and computer technologies mean that the amount of high-quality observational data available is roughly doubling every year. These extra data are coming mainly from new extremely powerful sky surveys like the Sloan Digital Sky Survey (SDSS) for example. The desire to make the best use of such huge data volumes has led both astronomers and computer scientists to propose the creation of Virtual Observatories (VO).

The idea of VO is to store all observations in digital archives that would be accessed by the whole-world astronomical community over a fast computer network similar to the "classical" Internet using the so-called AstroGrid technology. Such VO projects need to overcome a significant technical challenge – how to provide access to the huge databases and archives of **each (and every)** modern astronomical instrument through a **single** interface. Each database is stored separately and it is not practical to move all the data to one "'central"' location. In many cases such movement would take several years over a good Internet connection.

Other main idea taking to heart in Astronomical DataGrid concept is to provide access to the separate databases and archives using the technology of distributed computing which shares out processing and storage tasks between the various computers involved in the DataGrid network. This would allow astronomers to summon up data to their own computers from any of the external databases and archives sharing in the Astronomical DataGrid. The software to do this doesn't exist yet.

It is obvious that the various VO and Astronomical DataGrid initiatives over the world (like the Astrogrid Consortium in the UK which is one of the Europe-pioneering Astronomical DataGrid projects) should work closely together in order to solve globally all arising problems. For these reasons the European COST Action 283 called "Computational and Information Infrastructure in the Astronomical DataGrid" or simply ***iAstro*** emerged at the end of 2001. The ***iAstro*** initiative brings cross-disciplinary perspectives to bear on above-mentioned areas, in which European scientists currently excel. This Action is centred on the potential related to the Grid, taking astronomy as a leading case. Below the details of ***iAstro*** are described.

2. ACTION OBJECTIVES

The COST 283 Action mission statement is as follows.

The Grid is the infrastructure of the virtual organization of the future, providing high performance and high added value services relating to computational, data, information and knowledge processing requirements. Those involved in ***iAstro*** aim at ensuring best application of new theory and tools in the astronomy application domain, and simultaneously Grid-enabling the most appropriate areas of the application domain. The means applied by ***iAstro*** to achieve these ends are, respectively, further developing and bridging the many ongoing projects (i.e., disseminating exciting theories and good practice aimed at astronomers), and through selection and bringing Grid-appropriate areas of the application into focus (i.e., expressing and focusing application requirements aimed at computer scientists, and data and information analysts). An additional objective is the spreading of new national and international projects, where appropriate and needed.

3. PARTICIPATION AND COORDINATION

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3. 3. WEB SITE

The Action's web area is at `http://www.iAstro.org`. This domain name was purchased, and the site is hosted at Queen's University Belfast. The site contains reports on Management Committee meetings, information on how to subscribe to email distribution lists associated with the Action, and entry points to a long list of national and interantional projects and consortia working on closely related themes.

4. THE STRUCTURE

The Action is structured in the following Working Groups:

- Working Group 1
  - ⋆ Interoperability, data correlation and federation;
  - ⋆ Data quality/correlation/fusion.
- Working Group 2
  - ⋆ Visualization;
  - ⋆ Advanced visual user interfaces for data mining.
- Working Group 3
  - ⋆ Heterogeneous, multimedia data;
  - ⋆ Image/signal restoration;
  - ⋆ Data mining.
- Working Group 4
  - ⋆ Surveys;
  - ⋆ Wide-field imaging;
  - ⋆ Robotic observatories.

5. EXERPTS FROM THE MEMORANDUM OF UNDERSTANDING

Memorandum of Understanding For the implementation of a European Concerted Action Research Action designated as
COST Action 283
"Computational and Information Infrastructure in the Astronomical DataGrid"

The signatories of this Memorandum of Understanding, declaring their common intention to participate in the concerned Action referred to above and described in the Technical Annex of the Memorandum have reached the following understanding

1. The Action will be carried out in accordance with the provisions of the document COST400/94 Rules and Procedures for Implementing COST Actions, the contents of which are fully known to the Signatories.

2. The main objective of the Action is to develop innovative and well focused approaches to data and information handling, in the context of astronomy and astrophysics. This includes processing and interpretation of data and, more generally, information, at the time of data capture or later ("archival research"), and including aspects of the collaborative work and man-machine environments needed for this.

3. The overall cost of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at 6 Million EUR in 2001 prices.

4. The Memorandum of Understanding will take effect of being signed by at least five Signatories.

5. The Memorandum of Understanding will remain in force for a period of 4 years, unless the duration of the Action is modified according to the provisions of the document referred to in Point 1 above.

Technical Annex of the Memorandum

A. Background

Many areas of science, engineering, commerce and the arts are facing continual evolution in needs related to data, information and knowledge. COST Action 283 brings cross-disciplinary perspectives to bear on these areas, in which European scientists currently excel. This Action is centred on the potential related to the Grid, taking astronomy as a leading case. The Action includes representatives of other disciplines among its supporters, and aims at dissemination towards, and collaboration with, newly developing areas of the Grid.

The scientific and public resonance of the astronomy application domain is far-reaching. The application of new data extraction and information understanding technologies to, among many other examples, the Sloan Digital Sky Survey, and to Hubble Space Telescope data stores, have been profiled in the communications media and in outreach work (articles in The Economist, Liberation, and elsewhere). The computer science of relevance to astronomy includes high performance computing (e.g. for theoretical modelling), distributed computing, and dealing with massive databases - very often image databases. The interface areas with telecommunications and software engineering are now so close that they cannot be separated. Information retrieval and cognitive science are strongly represented. There is a continuing perception, however, of a gap between the computer sciences and astronomy. Those who are pioneering new approaches in data mining, distributed computing, Bayesian and spatial modelling, multiresolution vision modelling, new information delivery technologies, and who are active in other fields of computer science, statistics and other disciplines, are very rarely doing such work with astronomy in mind. Both astronomy and the computational sciences have much to gain from collegial linkage.

A selection of important computational issues on the agenda today includes the following.

- What is to be understood by data mining in astronomy, and why is this radically different from commercial and business data mining?
- What are the challenges of semantic description of scientific data and information? Such challenges go far beyond writing a few DTDs.
- Bayesian modelling can help with the all-important problem of model selection. What are the leading scientific decisions requiring such model-based decision making?
- Data and information storage and processing are integrally linked to delivery. What are the new paradigms emerging on the human-machine interface, and what are the implications for image and catalog archives?
- How is science going to change given availability of broadband networks? What are the implications of 3G wireless communication, in conjunction with very high bandwidth backbone links? What are the implications - and the potential - of wide availability of inexpensive, very high quality display devices?

In the recent past (1995-1997), the European Science Foundation supported a Scientific Network on "Converging Computing Methodologies in Astronomy" (CCMA, see http://astro.u-strasbg.fr/ ccma). Out of this consortium grew a number of initiatives - standardization in practices in electronic publishing in astronomy; the development of methods and techniques for wavelets and multiscale transforms, with many publications; and recently a rapidly increasing number of meetings and initiatives related to XML for resource discovery. Links exist in other directions too - the origin of the CCMA network owed a lot to Technical Committee 13 ("Astronomy and Astrophysics") of the International Association for Pattern Recognition, and IAU (International Astronomical Union) committees and working groups. Astronomy has benefited from French Ministry of Education support under the Cognitive Science theme, and 4th and 5th Framework projects (e.g. the 5th Framework IRAIA project on smart information and agent technologies) are relevant to the themes described above and are a spin-off of work in astronomy.

There are a number of other initiatives of direct relevance to this Action. A "thematic network" called OPTICON (Optical-Infrared Coordinated Network for Astronomy) is funded by 5FP. A Fifth Framework proposal on the Virtual Observatory was launched from a consortium linked with the Action in February 2001. In December 2000, a large National Virtual Observatory proposal was submitted to the National Science Foundation ("ITR/IM - Building the Framework for the National Virtual Observatory"). In January 2001, the EC DataGrid initiative was launched. In the UK, a consortium of leading institutes is submitting an AstroGrid proposal to the PPARC research council with a start date of April/May 2001. The First AstroGrid Workshop (http://strule.cs.qub.ac.uk/ fmurtagh/astro-grid) was hosted by Prof Murtagh on January 29-30, 2001. Linkage with the international EC DataGrid project is assured through organisational collaborations on every level - institutional, funded, conference organisational, joint scientific work, and so on. Among other developments which principal participants of this Action are leading is an SPIE conference in San Diego in July/August 2001 on Astronomical Data Analysis, and a conference at Penn State University in July 2001 on Statistical Challenges in Modern Astronomy. Relative to this rich interlocking set of initiatives, the goal of this COST Action is (i) to begin with computer science and engineering perspectives, with a trajectory towards the pressing applications in astronomy, rather than starting with the "science drivers", and (ii) to carry out this work on the European level.

The evolution of broadband networks to IP backbones is (cf. the joint statement by Academia Europaea and European Science Foundation, February 2000, entitled "The need for high bandwidth computer-based networking in Europe") an ongoing area of technology evolution which will greatly benefit the Action. In wireless communication, the advent of much greater bandwidth 3G UMTS technology will motivate the carrying out of scientific work in qualitatively new ways. This Action will contribute actively to such an evolution.

The very diverse set of different initiatives at national and international level clearly justify an Action in which coordination can be undertaken to create higher critical mass and in order to promote convergence towards common solutions, standards and resulting systems and services.

That COST is a particularly appropriate mechanism is due to the collaborative nature of many of these issues - for example, semantic description of scientific data and information cannot be undertaken in isolation; nor can data mining in astronomy take place without close linkages between computer scientists and astronomy. Traditionally, in this area of science, ESA and ESO in Europe have devoted their attention more or less exclusively to the pursuit of scientific installations - ground-based or space-borne observatories. EU research programs have sought commercial drivers. Yet it is precisely the possibility of the linking up with commercial drivers (e.g. in the area of innovative data mining) in the framework of information technology and telecommunications which implies that COST is more appropriate than a less application- driven ESF scientific programme.

Theme area 1 of Action 283: Data centres and data curation for the DataGrid.

Unlike in Earth observation or meteorology, astronomers do not want to interpret data and, having done so, delete it. Variable objects (supernovae, comets, etc.) bear witness to the need for astronomical data to be available indefinitely. The unavoidable problem is the sheer overwhelming quantity of data which is now collected. The only basis for selective choice for what must be kept long-term is to associate more closely the data capture with the information extraction and knowledge discovery processes. It is necessary to understand the current scientific knowledge discovery mechanisms better in order to make the correct selection of data to keep long-term, including the appropriate resolution and refinement levels.

Data ingest to archives and long-term databases therefore requires knowledge discovery (KDD), computational intelligence and cognitive science, with scientific drivers rather than commercial drivers. The small number of custodians and curators of society's (astronomy) memory can also be supported by more and better use of results from the best of Europe's (computer science, software engineering and telecoms) labs and departments.

Theme area 2 of Action 283: Visualization.

The vast quantities of visual data collected now and in the future present us with new problems and opportunities. Critical needs in the associated software systems include compression and progressive transmission, support for differential detail and user navigation in data spaces, and "thinwire" transmission and visualization. The technological infrastructure is one side of the picture.

Another side of this same picture, however, is that the human ability to interpret vast quantities of data is limited. A study by D. Williams, CERN, has quantified the maximum possible volume of data which can conceivably be interpreted at CERN. This points to another more fundamental justification for addressing the critical technical needs indicated above. This is that selective and prioritized transmission, which has been termed intelligent streaming, is increasingly becoming a key factor in human understanding of the real world, as mediated through the computing and networking base. It is necessary to receive condensed, summarized data first, and the understanding of the data can be aided by having more detail added progressively. A hyperlinked and networked world makes this need for summarization more and more acute. The resolution scale needs to be taken into account in the information and knowledge spaces. This is a key aspect of an intelligent streaming system.

A further area of importance for scientific data interpretation is that of storage and display. Long-term storage of astronomical data, as already noted, is part and parcel of society's memory. With the rapid obsolescence of storage devices, considerable efforts must be undertaken to combat social amnesia. Exciting opportunities are opening up, especially in the area of new Internet-delivery platforms, sales of which are forecast to overtake personal computers by about 2004. Can astronomy benefit from these developments? Videogame consoles are a case in point. Sony's earlier PlayStation, offering outstanding graphics and storage based on DVD disks, sold 60 million units. It and other vendors are ensuring Internet- capability of their machines. This is one example of new, thus far unexploited, opportunities, not least in regard to educational spinoffs and public outreach.

Theme area 3 of Action 283: Multimedia data handling.

Astronomy's data centres and image and catalogue archives play an important role in society's collective memory. For example, the SIMBAD database of astronomical objects at Strasbourg Observatory contains data on nearly 3 million objects, based on 7.5 million object identifiers. Constant updating of SIMBAD is a collective cross-institutional effort. The MegaCam camera the Canada-France-Hawaii Telescope (CFHT), Hawaii, will produce images of dimensions 16000 x 16000, 32-bits per pixel. The European Southern Observatory's VLT (Very Large Telescope) is beginning to produce vast quantities of very large images. There are many examples of images of size 1 GB or greater, for a single image. CCD detectors on other telescopes, or automatic plate scanning machines digitizing photographic sky surveys, produce lots more data. Resolution and scale are of key importance, and so also is region of interest. In multiwavelength astronomy, the fusion of information and data is aimed at, and this can be helped by the use of resolution similar to human cognitive processes. Processing (calibration, storage and transmission formats and approaches) and access are not coupled as closely as they could be. Knowledge discovery is the ultimate driver, and it is this which the Action seeks to closely couple to the processing of data, and thereby to data ingest.

B. Objectives and benefits

The objective of the Action is to develop innovative and well focused approaches to data and information handling, in the context of astronomy and astrophysics. This includes processing and interpretation of data and, more generally, information, at the time of data capture or later ("archival research"), and including aspects of the collaborative work and man-machine environments needed for this. To achieve this very broad goal, this Action will address a range of problems on the interface between astronomy and astrophysics, and the computational sciences. Serendipitously this Action will seek to tie together the work of astronomers and computer scientists, to mutual benefit.

The first problem this Action addresses is particularly relevant in the context of the astronomical DataGrid, i.e. the work of data centres, and their critical need for smart tools, especially for data ingest. Data centres require better ways to ingest their databasases and archives, since their current operations are simply not scalable. The individual astronomer has an analogous requirement, to master the heterogeneous and distributed sources of data and information.

Associated with this problem activity, the Action will concentrate efforts on a third-generation search interface for integrated access to distributed information services. This will include user profiling and support of metadata, characteristic of a second-generation system like ISAIA (details below in Section C), and will also include more general (structured and unstructured) online resources, visualization agents, and a natural language interface.

A second problem cluster this Action will address is that of visualization of scientific data, often across the network, and often too involving both virtual (i.e. simulated) data - of the heavens or of the instruments used for observing - and real data. Closely-related are technology trends in ultra high performance display capability (cf. large wall displays; or advances in mobile displays).

A third problem cluster this Action will address is related to very large image storage, transmission and processing. The Action will develop what may be termed high performance data streaming. As an example consider how wavelet and other multiresolution transforms allow for progressive transfer. Consider too how large image delivery based on foveation makes use of the limited region of interest in the image data. Such paradigms, used for storage and transmission of images and video, have implications ultimately for scientific interpretation itself. How can the fusion of information and data, required by multiwavelength astronomy, be built seamlessly into these technologies (including resolution scale, compression, and region of interest)?

Keywords describing the principal areas of activity, targeted at astronomy and astrophysics, include: Cognitive science, collaborative work, knowledge discovery, data mining, computational intelligence, streaming interfaces, multiwavelength astronomy, data and information fusion, Bayesian modelling, display and storage device technology, distributed computing, distributed and heterogeneous databases.

C. Scientific programme

In order to fulfil these objectives, the scientific programme of the Action will be developed according to the following structure:

Data centres and data curation for the DataGrid.

This theme is concerned with the critical need for smart tools especially for data ingest.

A particular focus of the activities is to enhance data and information handling initiatives where participants in this Action have played a leading role, and develop new generation query agents to distributed heterogeneous astronomical databases and catalogues. One such project, involving major astronomical data providers in Europe, the US and Canada, was Astrobrowse. A new initiative is now building on this basis - ISAIA, a query and response agent, which is XML-based and embodies user profiling.

- Sub-themes:
  - distributed data,
  - information summarization,
  - information fusion,
  - metadata.
- Immediate tasks:
  - further development of metadata interoperability standards and of object-oriented databases in astronomy,
  - textual summarization tools,
  - first initiatives in user profiling in astronomy.

Visualization.

This theme is concerned with convergence between display technology and scientific interpretation.

The handling and scientific understanding of data will benefit from new developments in display technology, but not by simply (and crudely) scaling up traditional procedures. Instead, qualitatively new and better ways of navigating information spaces, extracting knowledge from information, etc., have to be developed. It is only by defining and then addressing the specific scientific needs that it will be possible to provide spin-offs back into the commercial and industrial arena (and not the contrary, e.g. by taking, "undigested", currently-practiced data mining approaches from the commercial world).

Through a synergy between computer science and other closely-related methodological disciplines (e.g. statistics), with astronomers and astrophysicists, this Action seeks to have scientists collectively driving new developments in technology and methodology.

- Sub-themes:
  - display of information,
  - fusion of model and observed data,
  - knowledge discovery and data mining.
- Immediate tasks:
  - visualization for knowledge discovery and data mining,
  - further development of visual user interfaces to information spaces (currently in operational use for bibliographical and some catalogue databases).

Multimedia data handling.

This theme is concerned with the particular multimedia information which astronomy deals with: very large images, data of great accuracy and precision (and noise!), fusion of image and non-image information, and the links between observed data and (cosmological, instrument) model data.

- Sub-themes:
  - delivery platforms,
  - networks, wireless,
  - distributed computing,
  - multiband and hyperspectral image data.
- Immediate tasks:
  - display-optimized delivery of large images,
  - distributed image processing across the major image databases.

The three Theme Areas and corresponding Working Groups described in this Action clearly have areas of overlap with each other. Some of the data centres in WG1 are primarily concerned with image data (a major concern of WG3). The handling of image and other multimedia data (in WG2) is close to the priorities of WG3. The results of numerical simulations (cosmological, solar/planetary) in WG2 themselves comprise a data repository, of relevance for WG1, etc. All WGs are related to the DataGrid which is now being developed in Europe and further afield.

The Action web area will contain results of all meetings (programmes, presentations, and - where this proves feasible - a streaming video record on the web of all presentations).

Working visits of between a number of days to a week in duration will be arranged between partners, particularly for the PhD students and research assistants taking part in this work. Each such visit will have a particular theme, and specified targets (optimally part of a scientific paper, or to contribute to a software and/or hardware system).

Coordination visits between partners will also take place, especially to plan workshop themes which are relevant to more than one WG, and to focus aspects of the Action's activities in the broader scope of DataGrid and Virtual Observatory projects.

Interaction with other Grid initiatives.

The UK AstroGrid consortium came together during 2000 to propose a programme of DataGrid developments for UK astronomy to the PPARC research council. The anticipated spend by AstroGrid is around 5M £. The consortium represents a very wide range of data types, skills, and experience, with Edinburgh (sky survey data), Leicester (x-ray mission data), Rutherford Appleton Laboratories (space astronomy, solar and solar/terrestrial physics databases, and Starlink software project), Mullard Space Science Laboratory (solar databases), Cambridge (UK observatory archives), and Belfast (Computer Science). In addition there are formal links to the Edinburgh Parallel Computing Centre and the UK particle physics Grid coordination at Rutherford Appleton Laboratories. The year-1 workpackages focus on

(a) development of a science requirements document, and

(b) testing, assessment, and deployment of datamining hardware and Grid middleware toolkits.

The Working Groups described above in this COST Action match closely the data mining, visualization and information discovery workpackages planned in the AstroGrid work. Key participants in this Action are also core members of the AstroGrid consortium.

The UK AstroGrid is participating in the Fifth Framework AVO (Astrophysical Virtual Observatory) submission in February 2001. AstroGrid is represented as a group, through AstroGrid lead investigator Prof. Andy Lawrence, Royal Observatory Edinburgh. AVO lead investigators are Dr. Peter Quinn (ESO), Prof. Francoise Genova (Strasbourg) - cf. Steering Committee and supporters of this Action - and Dr. Piero Benvenuti (Space Telescope - European Coordinating Facility, located at ESO).

Liaison with relevant US activities will be facilitated through participation in NSF funded activities by a number of the participants in this Action, by possible participation of US experts in the Actions and by regular scientific contributions to conferences and workshops in North America, etc.

It is clear that this COST Action is well integrated with major current developments (just a few of which have been listed in this section). The COST Action coordinates and focuses unique computer and related information science perspectives in a way which is not done directly by the other projects.