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E. Kapetanios
Institut für Angewandte Informatik
Energie- und Stoffumsetzungen in der Umwelt

Kernforschungszentrum Karlsruhe

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Epaminondas Kapetanios

Kernforschungszentrum Karlsruhe GmbH, Karlsruhe

Kernforschungszentrum Karlsruhe GmbH
Postfach 3640, 76021 Karlsruhe

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Eine Vorstudie für ein Wissenschaftsinformationssystem für das MIPAS Satellitenexperiment

Ein Wissenschaftsinformationssystem für das MIPAS Satellitenexperiment wird in seiner grundlegenden Software- und Hardwarearchitektur präsentiert. Es wird sich sowohl auf den MIPAS Datenverarbeitungs- und Archivierungsknoten des Bodensegments einer geplanten Satellitenmission für die Fernerkundung atmosphärischer Parameter, als auch auf die Unterstützung der Experimentatoren in ihrer wissenschaftlichen Umgebung beziehen. In dieser Vorstudie wird auch die weitere Vorgehensweise für einen detaillierten Systementwurf spezifiziert. Das System besteht aus zwei logischen Komponenten, einer *operationalen Datenbank* für die Generierung, Speicherung und Verwaltung der aus dem Satelliten erfassten grossen MIPAS Datenmengen, und einer *Forschungs- und Entwicklungsdatenbank*, die über eine Schnittstelle zu der operationalen Datenbank verfügt, für die Erstellung einer abstrakteren und benutzerfreundlichen Schnittstelle, die die experimentelle Unterstützung der beteiligten Wissenschaftler und die Extraktion der benötigten Informationen ermöglicht.

A preliminary study of a scientific information system for MIPAS satellite experiment

A scientific information system for MIPAS satellite experiment will be presented according to its main hardware and software configuration. It will be considered as a MIPAS data processing and archiving node of the ground segment of the planned satellite mission for the remote sensing of atmospheric parameters, as well as an information system supporting the researchers in their scientific environment. In this preliminary study, the methodology of a more detailed system design has also been specified. The system consists of two logical components, an *operational database* for the generation, storage and management of vast amounts of MIPAS data received from the satellite, and the *research and development database*, which must be interfaced to the operational one, providing a more abstract and user-friendly interface for the scientific community enabling experimentation and the extraction of the information needed.

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Introduction

In the last fifteen years the interest in atmospheric phenomena like the depletion of the stratospheric ozone layer and the greenhouse effect has grown significantly. An explanation of their occurance and behavior can only be given by the understanding of the complex chemistry in the atmosphere and the coupling with dynamical processes. In order to understand the complexity of the processes that determine the concentration of trace species in the atmosphere, more comprehensive measurements have to be taken supposing that they meet the requirements of a simultaneous detection, both in time and space, of relevant trace gases, of a global measurement for all seasons, and of the diurnal variations of trace gases to be obtained.

The most appropriate instrument to meet these requirements is a Limb Sounder on a space platform measuring the emitted radiance from the atmosphere. MIPAS (**M**ichelson **I**nterferometer for **P**assive **A**tmospheric **S**ounding) has been chosen by ESA (**E**uropean **S**pace **A**gency) amongst other proposed limb sounders as core segment of ESA's polar platform. It is a high resolution Fourier Transform Spectrometer and covers the mid-IR spectral region from 4.15 to $14.6 \mu m$. Its scientific objectives are the concentration profiles of more than twenty trace gases between the upper troposphere and the lower thermosphere concerning with stratospheric chemistry (global ozone problem and polar stratospheric chemistry), climate research (global distribution of climate relevant constituents and clouds), dymanics (stratospheric transport, tropospheric - stratospheric exchange), and tropospheric chemistry (upper troposphere).

The measurement data, obtained by MIPAS on the space platform, will be transmitted to the earth together with scientific data coming from other complementary instruments participating in the same mission according to the scientific objective of the polar space platform. After the identification and separation of MIPAS specific raw data taking place at the ground station equipped with data acquisition facilities from the satellite platform, the MIPAS raw data must be further transmitted to the MIPAS user center where the received data will be processed in order to extract more abstract levels of information. In addition, the received and extracted data products must be stored, managed and efficiently accessed, providing a worldwide communication facility. For an effective production and management of MIPAS data, a **scientific information system** must be designed and implemented aiming at the support of MIPAS scientific experiment based on a space platform. The design of the scientific information system needed, according to the specification requirements described by the scientific users, will be the subject of this preliminary study.

The development of a scientific information system requires an adequate network of inter-disciplinary work requiring collaboration of scientists of various disciplines with computer scientists. Especially, in case of MIPAS experiment on a space platform, a strong cooperation between MIPAS scientists concerning with atmospheric research and computer scientists concerning with information systems development is considered to be essential, in order to overcome the communication problems leading to an ineffective scientific information system. The scientific objective of developing an information system for MIPAS experiment is to enable the MIPAS scientists to derive the maximum benefit from the available data. Collecting staggering volumes of data without having adequate methods for effectively using the data and producing useful information, will not change the conduct of research. The lack of suitable information technology is most serious in less traditional applications, like those in scientific application areas where collections of very large volumes of numerical data, geographical data, and other unstructured data are used in often unforeseen ways.

The scientific information system, considered in this study, can offer improvements in the capability to store, access, and analyse much larger volumes of MIPAS scientific data, along with the capability to present results in visual form. In order to build an effective system, it is necessary to understand what the information needs of MIPAS domain scientists are. This is described in the first chapter considering: a) a definition of users' requirements (section 1.1) in terms of a description of the purpose and scope of the required system, its operational environment, its essential features, and its desirable ones, b) a description of the operational requirements based on the issues of the related workloads of the data to be provided to the system, on the manipulation of the provided data, and on the resultant actions and responses of the system according to the data manipulation (section 1.2).

A suitable scientific information system must be provided in order to meet the requirements specified in the first chapter. Its design approach is the subject of the second chapter related to both software and hardware issues. The information technology that must be applied is based on additional requirements implied by the changing operational process model, by the particular requirements of scientific database management systems and the suitable visualization facilities. They are all described in section 2.1. In the following section 2.2, the design approach of the scientific information system is presented in terms of software and hardware configuration issues. The first deals with two main components supporting the near real-time MIPAS data generation during the satellite mission as well as the scientific data management and information access according to research requirements, and the latter deals with the hardware and network configuration upon which the scientific information system is going to be built.

Chapter 1

Requirements Analysis

The specification of requirements for an Information System supporting MIPAS atmospheric experiment, should never be expressed in terms of implementation details or design of the software. It should only consider implementation possibilities and implications before a final requirement document is completed. An iterative procedure for the definition of the users' requirements goes hand in hand with the further study and confirmation of feasibility and eventually with the harmonisation of the new requirements with the existing software.

The specification of the required system as a bespoke system will need to address the total system. On the other hand, the specification will need especially to address the modification required to a part of the existing packages in order to be integrated into the new system. Describing the requirements of the system will be done based on general principles irrespective of the source of supply of the required system. The principles are relevant to small and very large systems as well as to a bespoke system or a combination of it, whereby the latter will be dominating. The specification of requirements, as recommended by [fSSC90, Ins90], will be separated in two parts. The first part gives a general idea of the task to be performed using computing equipment. The second part gives a more detailed description of the specification. The ultimate aim of this phase is to achieve a system requirement specification in terms of **what** should be done and not **how** it's done. These considerations will lead to a preliminary design of the system (in hardware and software terms) needed to meet the specified requirements.

1.1 The definition of system requirements

At this point, a generalized summary of requirements, a description of the nature of the problem and the principal constraints (time, cost, security etc.) upon any acceptable solution must be presented. It would be an introduction to the prospective user's organization for potential suppliers. The summary will include the following sections:

- An introduction to the users' requirements.

- A description of the environment in which the required system will operate.
- A list of essential features of the required system.
- A list of the desirable features as a qualitative contribution to flexibility and integration of the required system.
- Time limits for obtaining and operating the system.

1.1.1 Introduction to the users' requirements

The main purpose and scope of the required system is to support a scientific experiment concerning atmospheric research. The numerical data captured during a satellite mission by MIPAS instrument must be efficiently processed, stored and managed, as well as more abstract data products which are going to be extracted during processing of the raw data. The required system is faced with a great amount of data delivered by the MIPAS instrument and with the concepts related to scientific applications.

MIPAS (**M**ichelson **I**nterferometer for **P**assive **A**tmospheric **S**ounding) is a high resolution Fourier Transform Spectrometer covering the mid–IR spectral region from 4.15 to 14.6μm, and is envisaged as a core instrument of the first polar platform of ESA (**E**uropean **S**pace **A**gency) . MIPAS will provide global observations of a number of photochemically interrelated trace gases in the middle atmosphere, in the tropopause region and in the upper troposphere. The data delivered by MIPAS will provide important contributions to the development of a better understanding in the research areas of stratospheric chemistry (global ozone problem, polar stratospheric chemistry), of global climatology (global distribution of climate relevant constituents), of atmospheric dynamics (stratospheric transport, exchange between troposphere and stratosphere), and of upper tropospheric chemistry (correlation of gas distribution with human activities). The data are obtained with complete global coverage, for all seasons and independent on illumination conditions, allowing measurements of the diurnal variation of trace species. In general terms speaking, the MIPAS data products extracted from the transmitted data will be *interferograms calibrated high resolution spectra*, *geophysical parameters* like trace gas concentrations, temperature profiles, mixing ratios, and *global maps* of atmospheric constituents in geophysical coordinates. Figure 1.1 gives an overview of the main components of MIPAS subsystem[1]. It consists of the *space segment* (the instrument installed on the satellite platform) and the *ground segment* for processing the data captured by the space segment. The MIPAS ground segment will be the subject of this preliminary study.

Developing a system for processing and managing the MIPAS data leads to a Scientific Information System which will enable the interaction with the scientific experiment, providing a user–friendly environment. Furthermore, the participation of MIPAS instrument in planned or future satellite missions leads to the notion of an **open system** in order

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[1] according to the system *satellite mission*

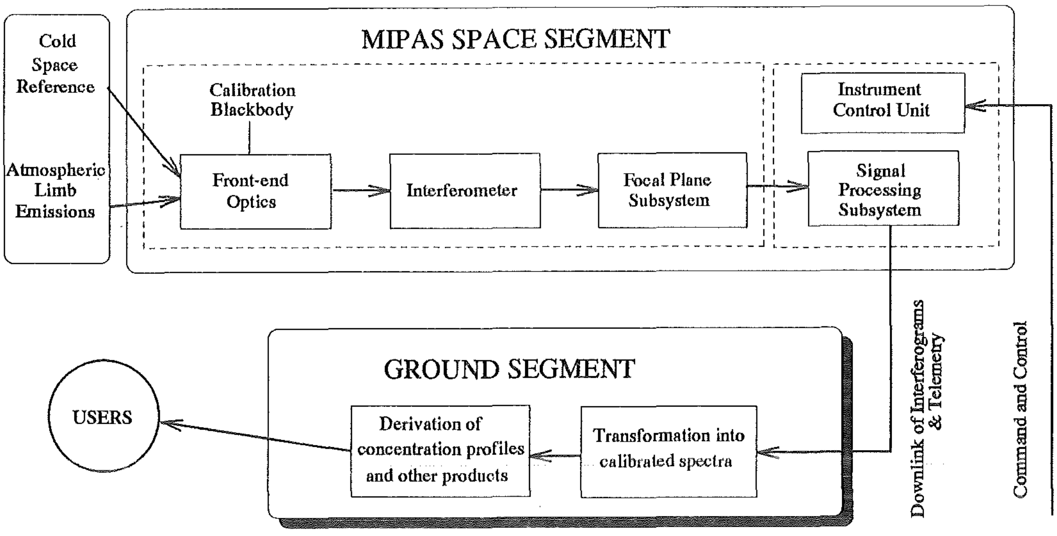

Figure 1.1: MIPAS Subsystem Breakdown

to enable the interoperability and the exchange of scientific information not only among the participating instruments of a satellite mission, but also among researchers involved in the same field. "Earth observation from space offers unique opportunities for obtaining information on a global scale that is directly relevant to our endeavours to understand the global environment and how is changing"[oEOS92]. Relating to these perspectives, the environment of the required system is going to be defined in the following section.

1.1.2 Environment of the required system

At first, the physical environment of the required system must be defined. Any peculiarities in the physical environment may affect its operational one. In figure 1.2 the physical environment of the required system, from the perspective of the planned satellite mission[2] by ESA, has been depicted. The interface between the required system and the preprocessing and archiving center is considered to be the **raw MIPAS instrument data**. The thick line shows the transmission way of the MIPAS data towards the required system. In this case, the module of *preprocessing and archiving facilities* deals with the separation of MIPAS specific data from the data captured by other instruments, and the archiving of transmitted raw data from the space platform. The modules of *Data Acquisition Facilities* and *preprocessing - archiving facilities* relate to the module ground stations of figure 1.3.

In figure 1.3, the physical environment of the required system - from the perspective of the ground segment - is presented according to its role as a MIPAS data processing and archiving node of the ground segment for the planned satellite mission. The module

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[2] ENVISAT

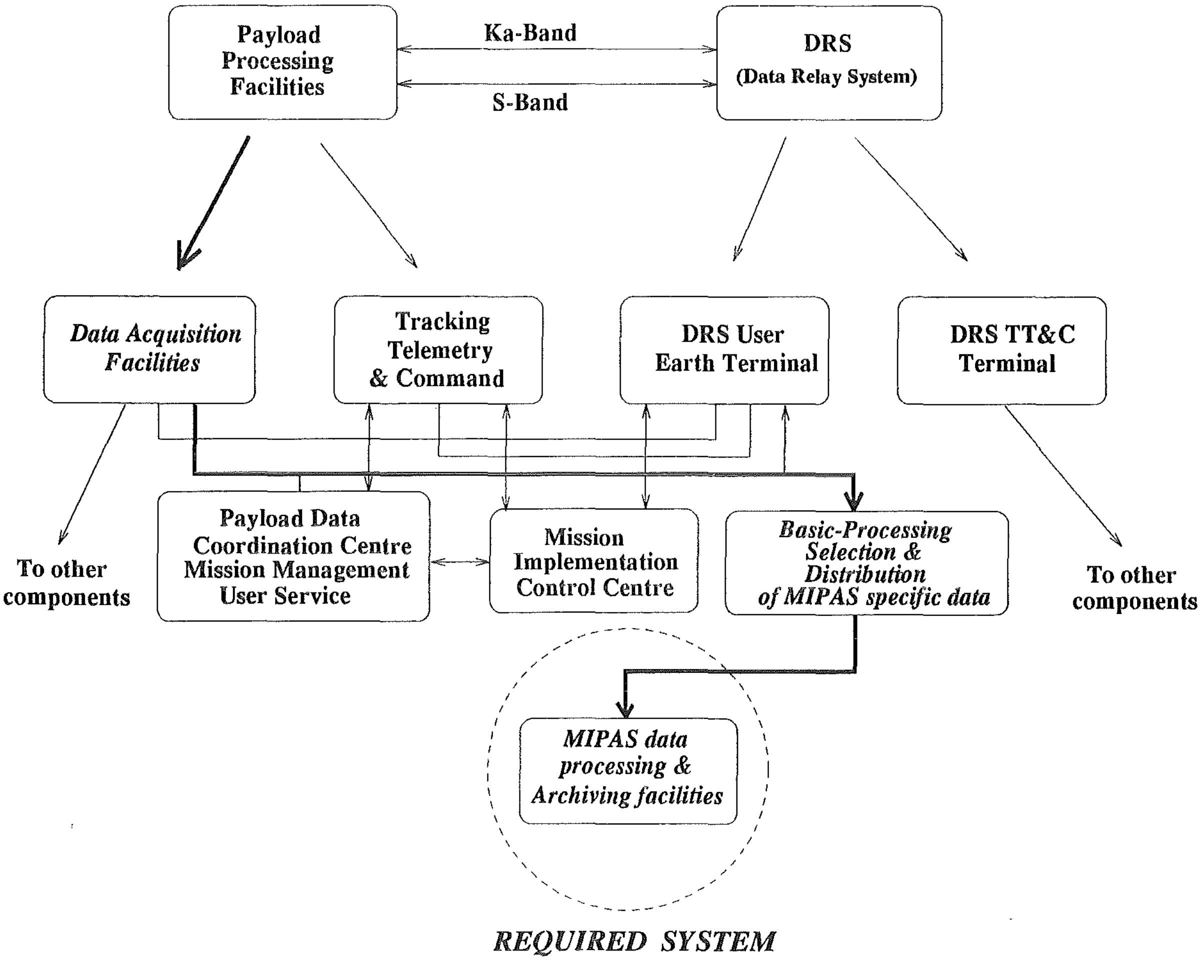

Figure 1.2: The flow of data towards the required system

Mission Payload Data and Coordination Centre refers to the central user service needed for the mixture and coordination of scientific results related to each instrument of the same satellite mission in order to obtain information in a global scale, as well as to the place needed for the elaboration of a scheduled mission plan according to sensor requests transmitted from the various processing and archiving data centers. The Module *Mission Management* refers to the Mission Management and Control Center where the detailed mission plans are going to be converted into the appropriate commands needed to operate the satellite. The command sequences will be verified and forwarded to the *Telemetry and Tracking Command* Module, from which they will be uplinked to the satellite during the next satellite pass.

Regarding the two perspectives of the physical environment of the required system mentioned above, its operational environment has to be defined taking in account the

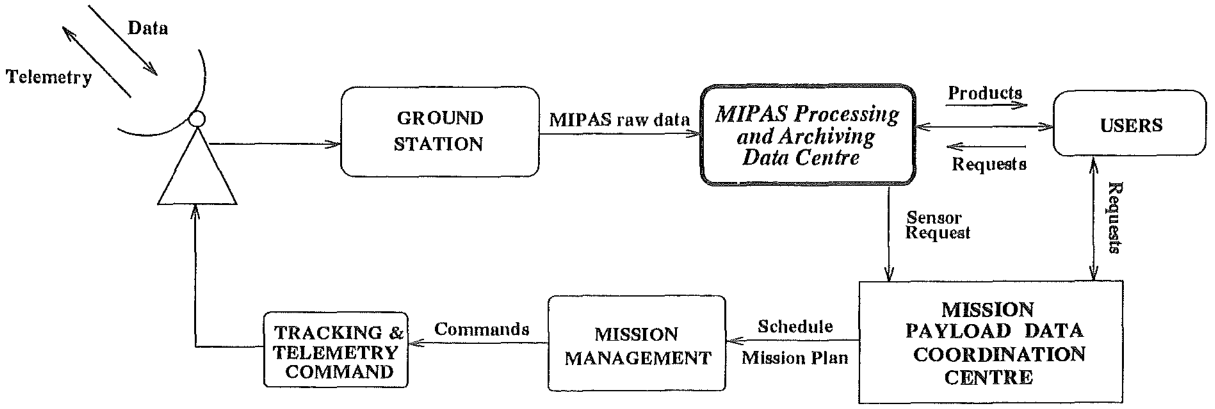

Figure 1.3: The physical environment of MIPAS Data Processing and Archiving Node

boundary conditions implied by its physical environment and the scientific community dealing with MIPAS experiment. In figure 1.4, the operational environment of the system is depicted. A short explanation of what its main components are will follow.

- **Ground station data acquisition center** deals with the acquisition and processing facilities of data received from the satellite. It also deals with telemetry, tracking and telecommands of the satellite mission. After the identification of MIPAS specific data, the transmission to the required system must begin for the further processing and efficient storage - management of the extracted data products, i.e. interferograms, calibrated spectra and so on.

- **Mission Payload Data Centre** need to have access to the extracted scientific results (information of the highest level) by the required system in order to extract and provide knowledge about global data products related to all scientific instruments of the same mission.

- **Mission Coordination Centre** where MIPAS sensor requests are going to be passed in order to elaborate a scheduled mission plan which will be converted into the commands required to operate the satellite at the Mission Management and Control Centre (MMCC). MIPAS instrument control requests will be transmitted in response to unreliable and erroneous data recognized by the quick-look facilities during the MIPAS data products generation.

- **MIPAS data users** are the scientists involved in MIPAS experiment (internal). They receive the MIPAS data products in order to extract the scientific results needed for atmospheric research. They can also observe the processes of extracting the defined data products by quick–look facilities provided by the system. Moreover, they can improve these processes by inserting new algorithms or modifying old ones, and thus would initiate the reprocessing of already extracted data products. To this component belongs the scientific community which is dealing with the MIPAS experiment but has only the possibility to interact with the required system during remote sessions (external).

- **External Users** are conceived to be any users who are not directly involved with MIPAS experiment. These users are interested in very high level products providing information in a conceivable way (e.g., trace gases distribution maps). They could be any authorities or organizations which may refer to the extracted scientific results.

1.1.3 Essential features

After having defined the boundaries of the system in terms of its environment definition, where the user requirements have to be placed, the essential features have to be distinguished from the desirable ones. The identification of the **essential** and the **desirable** features allows the proposal of a cost–effective solution with some compromises. The essential features characterizing the required system are listed in the following.

- The capacity to handle stated volumes of information.
- Time limits need to be met by the required system for delivering of the data products.
- A very high availability must be provided. The system must be available 24 hours a day and 7 days a week for about 4 years.
- The ability to recover from system failure without affecting the operation of the system.
- No information is to be lost if the required system fails.
- The survival of the data produced and managed by the system for 10+ years.
- The ability to identify, reject and report the receipt of erroneous information.
- The accuracy of results.
- The ability to identify and resist unauthorized instructions.
- The ability to communicate with other existing systems.
- The ability to function without manual supervision (operational supervision enabled with minimal costs).

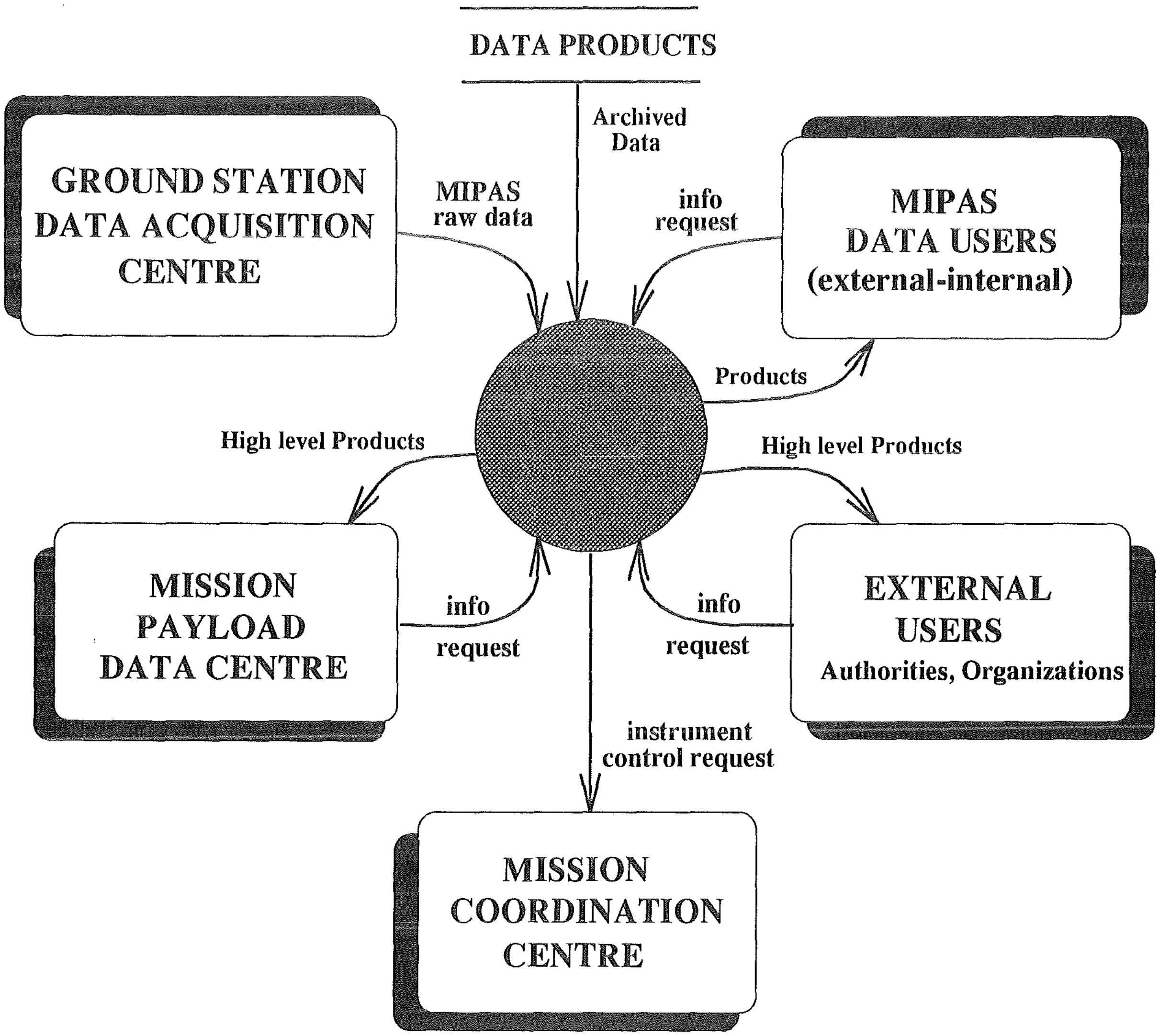

Figure 1.4: The operational environment of the required system

1.1.4 Desirable features

The quality of the system is not only determined by attaining to the essential features but also by attaining to those features that the prospective users would like and are obtainable within what is considered to be reasonable limits of time, cost and security. In this sense some of the desirable features of the system should be:

- The capability to accomodate increases in workloads.
- A facility for the user to make enhancements unassisted.
- The response time of the required system.
- National and international standards with which the required system needs to comply.
- Portability of archived data and scientific results.

The design and implementation of the required system is related to a number of weighted factors based not only on the essential and desirable features but also on schedule and life cycle costs. The scheme of a *trade tree* (figure 1.5), as it has been defined in [Sai90] representing the *system effectiveness model*, has been chosen in order to create a comparison basis for possible solutions of the proposed system design and implementation. A trade tree is a useful means for organizing the effort of choosing the most suitable solution among possible solutions, which will be evaluated according to a decision analysis process based on the weighted criteria. These criteria are weighted from the most important (100) to the least important (0). At each level, the weighted scores must reflect the importance of each criterium in accordance to the parent node. That means, the totals of the scores of the children nodes at one level must be the score of the parent node. The weighted scores for the required system can be seen in figure 1.5. The candidate design and implementation solution should be analysed and scored with respect to the trade tree.

1.2 The description of system requirements

In this section, a more detailed description of the specified user requirements will take place, trying to derive the main characteristics of the required system in both terms of hardware and software. At first, the information to be provided to the required system and the related workloads have to be defined. Secondly, the manipulation of the provided information by the system has to be described. This will be done with the well known specification tool of Data Flow Diagrams (DFD). Furthermore, the resultant actions leading to information received by the required system and the sequence in which is going to be produced should be described. The description of these requirements will be restricted on the definition of the main operational characteristics of the system with respect to the specification needs of a preliminary study.

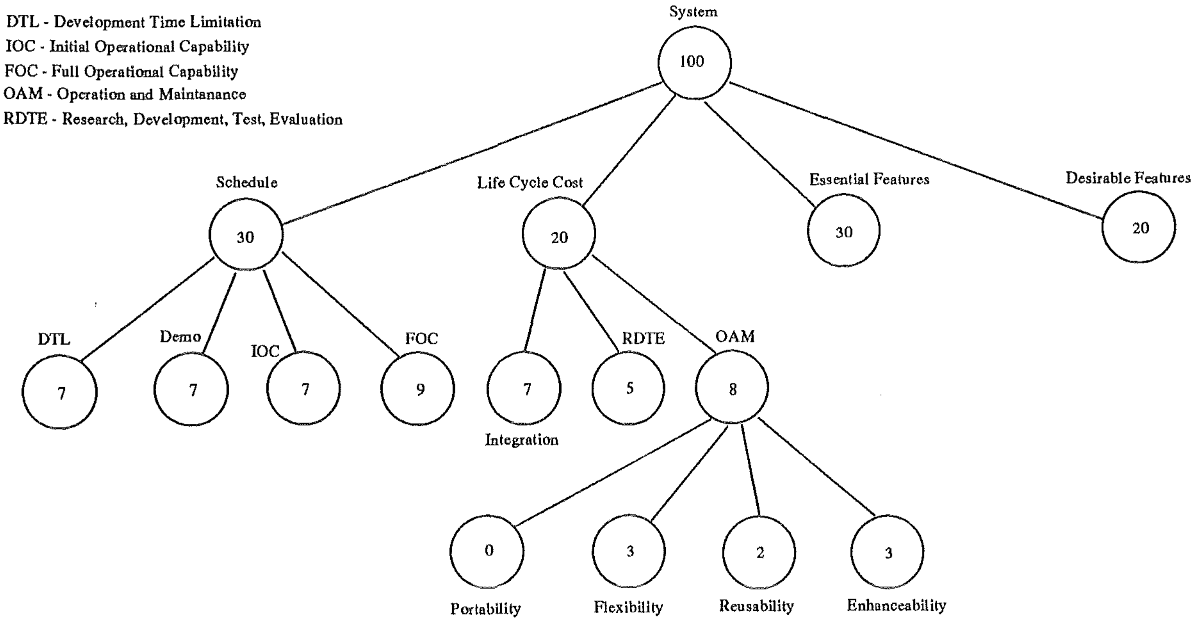

Figure 1.5: System Effectiviness Model

1.2.1 The data to be provided

The information to be provided to the required system will be delivered by the ground station after the separation of MIPAS specific raw data, as is shown in figures 1.4 and A.1. The estimated MIPAS data rate, as it has been defined in [Aer92], is **620 Kbps (0,6 Mbps)** or **6,3 GBytes/day**. The data are going to be delivered by the ground station, when they will be available, through a high-speed dissemination network (appr. 2 Mbit/sec) providing a data transfer throughput of about 0.5 Mbit/sec. A lower bandwidth dissemination network can also be considered, presupposing that there would be an appropriate storage capacity at the ground station for the received data from the satellite platform. It could be effectively used in case of the semi real-time data production, covering also the need of having a smaller size of datasets (for quick-look facilities) at the MIPAS researchers, within 2-3 hours after being observed by the satellite.

The way of communication depends on the location of the ground station. A satellite communication network, like APOLLO, using the European Communication Satellites (ECS) could be used for the data transfer directly from the ground station providing a mobile ground station terminal at the MIPAS research centre. Another possibility could be the data transfer through the main control or data centre, e.g. at Darmstadt in Germany, which is already connected to the ECS, and further transmitted by a high-speed Wide Area Network (WAN), like WIN (the German Scientific Network), to which the MIPAS research centre is connected. Data acquisition from the satellite platform will take place every time the satellite comes in contact with the ground station (a polar orbit mission and not a geostationary one).

According to the duration of the satellite mission, data will be delivered on a daily basis and for four (4) years. In order to estimate the loads that the required system needs to accomodate pertaining to the mission which has been planned so far, the extracted data products, which also have to be archived and eventually reprocessed, must be considered too. In the next table, the total amount of data (after four (4) years) has been estimated approximately in accordance to a reduction factor, as it has been specified by MIPAS scientific users, concerning the amount of data produced at the previous lower data level.

Class	**Data Type**	**Red. factor**	**Worst case**	**Best case**
Level 1a	Interferograms	$1-3$	9 TB (6,3 GB/day)	3 TB (2.1 GB/day)
Level 1b	Calibrated Spectra	$2-5$	4,5 TB (3,2 GB/day)	0,6 TB (0,4 GB/day)
Level 2	Trace Gas Concentration	1000	4,6 GB (3,27 MB/day)	0,6 GB (0,4 MB/day)
Level 3	2D-3D Maps	$2-3$	2,2 GB (1,5 MB/day)	2,2 GB (1,5 MB/day)
Level 4	Special products	(Level 2)x10	46 GB (32,7 MB/day)	6 GB (4MB/day)
		Total amount	ca. 14 TB	ca. 4 TB

The transmission of the delivered data must be achievable at a sustained bit error rate of 10^{-7}. Moreover, the structure of the raw data given to the required system cannot be defined in details because there is no formatting standards specified up to now. An indication of this structure can only be given in the following, according to [fSDS89] which defines the main items composing the transferred information.

- Global Identification Information
- Data Description for Supplementary Data
- Data Description for Application Data
    - Supplementary Data Instance (repeated n times)
    - Application Data Instance (repeated m times)
    - Identification Information
    - Data Description for Navigation Data
    - Navigation Data Instance

1.2.2 Manipulation of the provided data

Describing what will happen with the data entering the required system presupposes the selection of a requirement tool which could enable a more powerful and extensive specification when we are dealing with the world than dealing with the target system.

Approaches of developing such requirements specification tools have made use of models capturing not only the functional but also the non-functional requirements of the system. The specification of many kinds of knowledge about the world is essential to requirements engineering [BGM85]. Up to now, the major non-functional requirements have already been specified, and therefore, we will concentrate on the functional ones.

There are three main aspects of the specification which must be addressed during the design phase, the process oriented specification (e.g. SADT, PSL/PSA), the data oriented specification (e.g. Entity-Relationship Diagram) and control oriented specification in terms of the time-dependent behavior of the system (e.g. State Transition Diagrams, Stimulus-Response paths). Selecting a specification tool for the needs of the preliminary study implies the effort of examining a number of alternative formal foundations - like *finite-state machines, data/control flow, N-squared charts, functional block diagrams etc.* [Sai90, Rom90, TR90] - considering the abilility of leading to the three main aspects mentioned above. The *dataflow model* has been selected and used in order to express the flow of data within the required system according to the manipulation of the provided information. As a graphical tool, the *Data Flow Diagram* can give an overview of **what** is required to be done with the MIPAS specific raw data.

From the dataflow model the process oriented specification can be extracted applying techniques like *Modern Structured Analysis* [You89], the data oriented specification can also be attained [Sai90, CN87] (it's the only tool which can lead to a definition of the required system in database issues) and the control oriented specification can be also attained by enhancing the Data Flow Diagram with control flows [War86]. Other issues like hierarchy and functional flow, which are not addressed well by DFDs, are not considered to be essential for the nature of the required system (they are more appropriate for commercial applications whereby organizational characteristics must be defined explicitly too). More details about these aspects of specification can be found in the next chapter.

1.2.2.1 Functional requirements

The functional requirements of the system have been specified by Data Flow Diagrams (see Appendix A) starting from the highest level of specification (figure A.1) and going into more detailed descriptions of the data flow for the processes concerning the extraction of higher level data products. The DFDs consist of processes (bubbles), data stores (parallel lines), terminators (sources, sinks), and data arcs showing the flow of data between them. Looking at the figure A.1, the main processes of the required system are depicted according to the data flows among them. The following processes have been defined:

1. **The extraction of higher level products.** After receiving the MIPAS raw data the process of the production of higher levels data must be activated. In the next lower level of the specification for this process (figure A.2) the data products are shown which must be also archived. These products are:

- *Interferograms*
- *Calibrated Spectra*
- *Trace gas concentrations*
- *2D/3D Maps*

2. **The extraction of special products.** The process of extracting special products will be activated by the MIPAS scientific users in a parallel mode to the process defined above. Special products will be a scientific result extracted from the data products *calibrated spectra* and *trace gas concentrations.* The next lower level specification of this process is shown in figure A.8. Special products such as *global maps of column amounts* O_3, NO_y have to be archived too.

3. **Quick-look monitoring facilities.** The facility of receiving quick-look data (low-precision data) in semi real-time (2-3 hours after satellite observation) at the MIPAS investigators site. This enables the development of physics behind the operation of the MIPAS instrument more fully, when the prime investigators become more familiar with the radiometric corrections and calibration routines that will be required. With this purpose, calibration processes must be controlled and observed by MIPAS prime investigators.

4. **Monitoring of data production.** The facility of monitoring the data products generation process is needed, showing the activation of the generation processes in a predefined manner. Furthermore, the observation of interferograms and calibrated spectra is considered essential in order to react appropriately to a performance degradation of the MIPAS instrument.

5. **Management of data products.** The storage and management of extracted data products as well as of special products are considered to be specified by this process. Furthermore, the information needed by the operational environment of the system has to be provided in a user-friendly way. This includes all types of archived data which will be produced by the system and a big diversity of users varying from scientists to evironmental organizations. It implies a variety of user interfaces which have to be considered during the design of the system as an information source. Statements concerning the storage and management of scientific data with respect to their multidimensional structure and the great amount of data to be managed will follow in the next chapter, especially, about the particularities of scientific databases.

6. **Reprocessing of extracted data products.** The processing environment of the data production is not considered to be stable. The development of new algorithms and the replacement or enhancement of old ones activates the reprocessing of already extracted data products and the modification or deletion of data which have been produced in the processing environment to be changed. The changes in the processing environment are restricted on the processes of calibrated spectra and

trace gas concentration production (figure A.2). Hence, they can affect all the data products which had been created subsequently before.

7. **Enable the evaluation of simulation models.** Considering the role of the required system of supporting a scientific environment like MIPAS experiment, the need of enabling an insight into complex, computation-intensive problems is inevitable. This can be achieved only by vilualization techniques giving scientists the insight they need. The development of mathematical and simulation models in accordance to the visualization techniques brings the results in closer approximations to reality and thus enhances the possibilities for new knowledge and understanding. In addition, large collections of numerical values are needed when simulation models are running. The problem is to convey this information to scientists so that they can use it effectively in the human creative and analytic processes [Nie91].

In figures A.3, A.4, A.5, A.6, the next lower specification level has been defined concerning the process of *Higher Level Data Production.* In a more low specification level, the process of trace gas concentration production (process 1.3) has been specified (figure A.7). It is based on the current implementation of this processing step [vC90] regarding the modified software packages FASCOD2[3] and SCAIS[4]. It represents an essential model and not the physical model [You89]. That means, a model of *what* could satisfy the users' requirements assuming we had a perfect technology available. Starting with the development of the current physical model of an existing system and continuing with the development of the current logical model, and consequently, of a new logical model which can be transformed to a new physical model according to the classical approach didn't work for a number of reasons referred in [You89]. Starting with an essential model, the communication with the users and the understanding of the system are improved.

1.2.2.2 Operational requirements

There are two main operational requirements of the required system. The extraction of higher level data in an automated batch mode and the very small number of operators needed for the whole system, especially, for the storage and management of the great amount of data. The latter is faced in the next chapter (see section 2.1.2.2). The first has to be expressed explicitly in order to specify the relationships of the processes (functions) over time.

Looking at the data flow diagrams of Apendix A specifying the main functions of the required system, there is no indication of its internal behavior in order to respond successfully to the events occuring in its environment. This cannot be done only with the dataflow model. Beside it, a more powerful tool must be used in order to express the internal behavior of the system based upon a set of time-dependent operations. This means that the control of the system has been described, in the sense that sequences of

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[3] Fast Atmospheric Signature CODe 2

[4] Simulation Code for Atmospheric Infrared Spectra

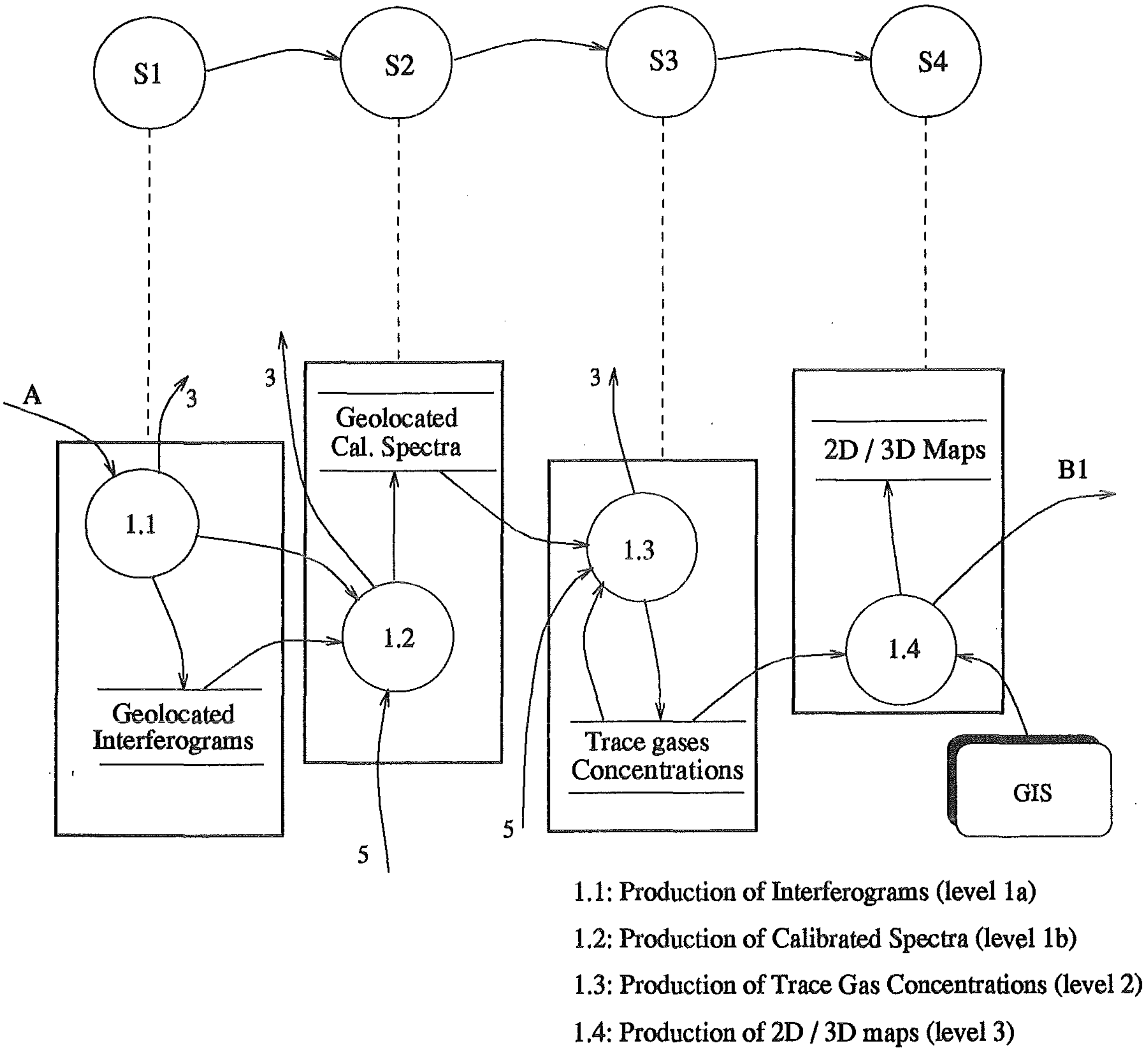

Figure 1.6: Preliminary Behavioral Model

operations which occur in response to external or internal stimuli are timely specified. In figure 1.6, a preliminary behavioral model has been defined using *State*[5] *Transition Diagrams* [Har87, Hea90, Dav88b] related to the process of extracting higher level data, as a response to the occuring event of MIPAS specific raw data transmission. *It expresses the users' requirement of extracting higher level data in an automated batch mode* and not the whole required system. The notion of a *state* is based on the *Moore model* [Dav90]. According to this model, a state also includes the response to the certain stimulus.

It is not the scope of this study to specify in details the internal behavior of the required system. This requires a more detailed specification of the system functions. In the

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[5] A *state* is defined as a set of operations expressing what happens in a given state of the system.

preliminary behavioral model of figure 1.6, the process of extraction higher level data is considered to be the system of which the behavior must be defined. It has been specified in the highest level giving the timely sequence of the processes which will be activated in response to the external event of MIPAS raw data transmission. The states have been related to the Data Flow Diagram of figure A.2 in order to give a more comprehensive impression of what is happening within a state. The transitions from one state to another is activated by internal events (depicted as arrows) which are regarded as *lambda*[6] events [RBP+91]. Interpreting the preliminary behavioral model, the process of production of Calibrated spectra must be activated after the creation of the necessary interferograms (this will be the *lambda* event causing the transition from state S1 to state S2) and consequently, the process of production of Trace Gas Concentrations after the production of the necessary Calibrated Spectra (this will be the *lambda* event causing the transition from state S2 to state S3), followed by the construction of two-three dimensional maps. Therefore, each data level extraction process can be activated in a parallel mode to other data level extraction processes following the synchronization requirements which will be specified.

State Transition Diagrams can also be leveled like Data Flow Diagrams. In addition, the notions of parallelism and concurrency can be expressed too [Har87, Hea90] defining the behavior of the system with more specification details. This must be done in a more detailed description which will follow this preliminary study.

1.2.2.3 Performance requirements

Performance requirements are those requirements where numerical values can be attributed to measurable variables. If these numerical values are not available they should be derived from estimations based on the system characteristics. Therefore, only some qualitative statements have to be made. Realistic figures are going to be considered during the implementation phase, and consequently, the design of the system has to be refined.

The algorithms for the extraction of higher level data can be evaluated by a variety of criteria. The required performance for these algorithms can only be estimated in terms of an abstract machine (a computer model), like the random access machine, the random access stored program machine, and the Turing machine. The *time complexity* of an algorithm expressing the time needed by an algorithm as a function of the *size* of a problem is considered to be the criterium used at most [AHU74]. The *asymptotic time complexity* - it limits the behavior of the complexity as the size of the problem increases - of an algorithm determines ultimately the size of problems that can be solved by an algorithm.

In figure 1.7, some estimations have been depicted, based on the assumptions of an

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[6] events causing an automatique transition of one state to the next one after the completion of the activity in the previous state.

Algorithm (FFT)	Time Complexity	Maximum problem size					
		1 sec	$3,2^{-5}$ sec	1 sec	0,032 sec	1 sec	0,0032 sec
A_1	n	10^9	32000	10^6	32000	10^7	32000
A_2	n^2	31622	179	1000	179	3162	179
A_3	$n \log_2 n$	$3{,}955 \times 10^7$	2800	$6{,}3 \times 10^4$	2800	$5{,}25 \times 10^5$	2800
Interferograms of one day		A_2 about 8 minutes A_3 about 32 seconds		A_2 about 6 days A_3 about 9 hours		A_2 about 14 hours A_3 about 53 minutes	

Figure 1.7: Time limits based on time complexity of an algorithm

abstract machine, on the expression of the time complexity as the number of time units required to process an input of size n. It has been also assumed that one unit of time equals one nanosecond, one microsecond, and 10^{-7} sec respectively. If an algorithm A_1 is considered to have *time complexity* n, then algorithm A_1 can process in one second 10^9, 10^6, and 10^7 data respectively. The same algorithm would need $3,2^{-5}$ sec, 0,032 sec, and 0,0032 sec respectively, for the processing of 32000 data (an array of arbitrary units in interferograms).

Looking at the first data levels, which will be the most time consuming processing phases, dominating algorithms with a known complexity, like Fast Fourier Transformation (FFT), can be compared on the basis that algorithm A_1 is an imaginary case. In figure 1.7, the FFT with algorithm A_2 for a given time complexity of *Order* n^2, and the FFT with algorithm A_3 as the optimal solution of *Order* $nlog_2n$ [AHU74] have been depicted in order to show the difference in the time needed by these algorithms, considering the three cases illustrated above and an input size of 32000 data. It is shown that using algorithm A_3 for FFT with time complexity of $O(nlog_2n)$, 16 times more data can be processed in the same time. Assuming also that all interferograms of one day are available when requested and reside on the main memory of the abstract machine, the time needed by FFT algorithm A_2 in order to process the interferograms of one day (ca. 86400) has been defined to be about 8 minutes (one data processing time equals one nanosecond), about 6 days (one data processing time equals one microsecond), and about 14 hours (one data processing time equals 10^{-7} second). Accordingly, the time needed by FFT algorithm A_3 is defined to be 32 seconds, 9 hours, and 53 minutes respectively.

It should also be mentioned here that the speed-up of the maximum problem size, assuming that another computer model is considered to be ten times faster than the current computer model, is going to be affected only $3{,}16S_2$ considering the algorithm A_2, and approximately $10S_3$ for large S_3 considering the algorithm A_3 [AHU74], whereby S_2, S_3 are the maximum problem sizes of the algorithms. In the following, some qualitative statements have also to be taken in account.

- **High data transfer rate.** Considering the MIPAS raw data transmission rate defined in [Aer92] (0,6 Mbit/sec), a data transfer rate over the communication network providing the MIPAS specific data to the required system is needed which should be about 2 Mbit/sec in order to cope with increased loads caused by asynchronous MIPAS data transfer and to support a data transfer throughput up to 620 kbit/sec.
- **Low data production time.** The production of higher level data must be achieved in a very fast processing mode in order to avoid a performance degradation of the system - it will be the consequence of the always increasing ratio between MIPAS raw data and on-line stored data which must be further processed - that could finally lead to an inability of the system to accomodate new MIPAS raw data. It should be stated here that a performance degradation can also be caused by activating the reprocessing of already extracted data products (process 5 in figure A.1). A degradation performance in this case must not significantly affect the ratio mentioned previously leading to the same problem as well.
- **Efficient Management of Mass Storage System.** It's not only the always increasing computational power which will affect the efficient management of a Mass Storage System. The storage component of the system must be configured in order to overcome the discrepancies between computational power and secondary/tertiary memory. It's of great significance for the purpose of managing terabytes of data efficiently.
- **Visualization and animation requirements.** Having a system supporting scientific experiments, the increasing demands of the scientific community considering performance for visualization and animation processes cannot be neglected. Dealing with MIPAS experiment posed in a scientific environment, these demands have to be taken in account seriously, if the required system should provide an environment of doing research.
- **Quick response to information requests.** Users interested in high level of information related to MIPAS data products should have the ability of accessing the information they need in a very effective way encouraging the interaction with a Scientific Information System. Long time responses could lead to a frustration discouraging the users that they want to obtain the information needed, and thus is considered to be a communication degradation which is not supposed to be the case according to the informative nature of MIPAS satellite experiment concerning with atmospheric research.

1.2.3 System output: Interface and access requirements

Talking about interface requirements for the system in relation with its operational environment, the kind of the data as system output requested by the users as well as the diversity of the user community (it ranges from scientists to simple users) are regarded to be the main factors which influence the form the interface will take. The nature of the information provided to the users includes:

- Numerical data, e.g. calibrated spectra, trace gas distributions, needed by scientific users.
- Reports (text) annotating scientific data and results required by the whole user community.
- Graphical representation of trace gas concentrations (data level 3) and of some special products in form of maps. It will be requested by the whole user community.
- Graphical representation of MIPAS data products for their creation monitoring in real time mode (quick-look facilities).
- Animation facilities and monitoring of data products generation processes. Numerical data must be transformed in a more conceivable way of representation. Both will be used by MIPAS scientists.

The access frequency of the information delivered by the required system can only be defined at this stage in access properties based on *when* the information is required from the system. It follows that:

- Monitoring data are requested on *regural specified intervals.*
- Graphical representation of trace gas concentrations will be presented *when available.*
- Information access of various data products is requested *on demand.*

1.2.4 Reliability requirements

The high-availability of the system is one of the main requirements which characterize the nature of the required system. The ability of receiving the transmitted data on a 24hour basis and for four (4) years is essential. Moreover, the ability of reading data for a long time period (in terms of decades) after their creation adds one more essential requirement with respect to the nature of an experiment dealing with atmospheric research and contributing to the study of global climate change.

1.2.5 Global climate change requirements

Looking at the system from another point of view, as a contribution part to Earth System Science and the emerging perspective on the functioning of our global environment, the interconnections between the atmosphere, ocean, cryosphere, solid earth and biosphere need particular attention. With respect to this role of the MIPAS ground segment as a scientific information system, some requirements more have to be specified like **multi-disciplinary interfaces**, **evolvement with time**, and **data archeology**.

Multi-disciplinary interfaces should enable the cooperation among different scientific groups according to acceptable information integrity and exchange standards. It must be able to cope with metadata and assessment information too.

Evolvement with time concerns with the accomodation of new ideas and the ignorance of poor ones, the design of the system should provide the ability of accessing data and information about data independent of particular hardware and software systems. If we consider the history of data systems, it is noted that there have been many changes on time scales of two to five years. It is unlikely that a data system designed today will remain constant for the next decade. The major design problem will be the maintanance of flexibility in order to accomodate changes in hardware to store data and in software to help access data.

Data archeology refers to the data that must be readily saved for many years after the end of the mission. It would be a bad practice to change the data formats every time a new idea comes along. A relative stability must be provided so that errors are not introduced by frequent conversion and handling. *The system should be conceived of as an entity that operates on data and provides easy access, not as an entity that owns the data.*

Chapter 2

Towards the system design

Thinking in terms of system design, a system architecture is expected to be defined concerning software and hardware issues according to the requirements specification as they have been defined in the previous chapter. The notion of modularization as a mechanism for improving the flexibility and comprehensibility of the system will be applied for the design of the required system. The criteria for the effectiveness of modularization, as they have been specified in [Par84], will be the guidance for dividing the system in modules. It should be made clear that it is not the scope of this preliminary study to define the architecture of the system in a detailed manner. *It should only give the directions of looking for detailed specifications and should define the skeleton of the system needed for the implementation phase.*

Based on the functional requirements of section 1.2.2 the required system can be specified in its main functional components shown in figure 2.1, and the interconnections between them. In order to come closer to the design skeleton, the conceptual design of the information system will be focused with respect to the interactions of the *data storage and management* component mainly with the components of *processes and transactions* and *argorithm development* (section 2.1). Furthermore, the components of *visualization* and *information and data retrieval* with its special issues concerning the MIPAS scientific environment, as it has been specified by the requirements in sections 1.2.2.1 and 1.2.3, will contribute to the design specification of the system (section 2.1.3). In section 2.2 the main architecture of the scientific information system, in terms of software and hardware configuration needed, is going to be presented, considering the storage and performance requirements specified in the previous chapter, as well as the design issues described in the following section.

At this stage, the design specification of the processes for the higher level data production, as well as for the other processes, will not be considered. Nevertheless, it constitutes only a part of the process-oriented specification aspect of the system (there are also the data- and control-oriented specification aspects), and will contribute to a refinement of the system architecture part related to the implementation of the processing algorithms.

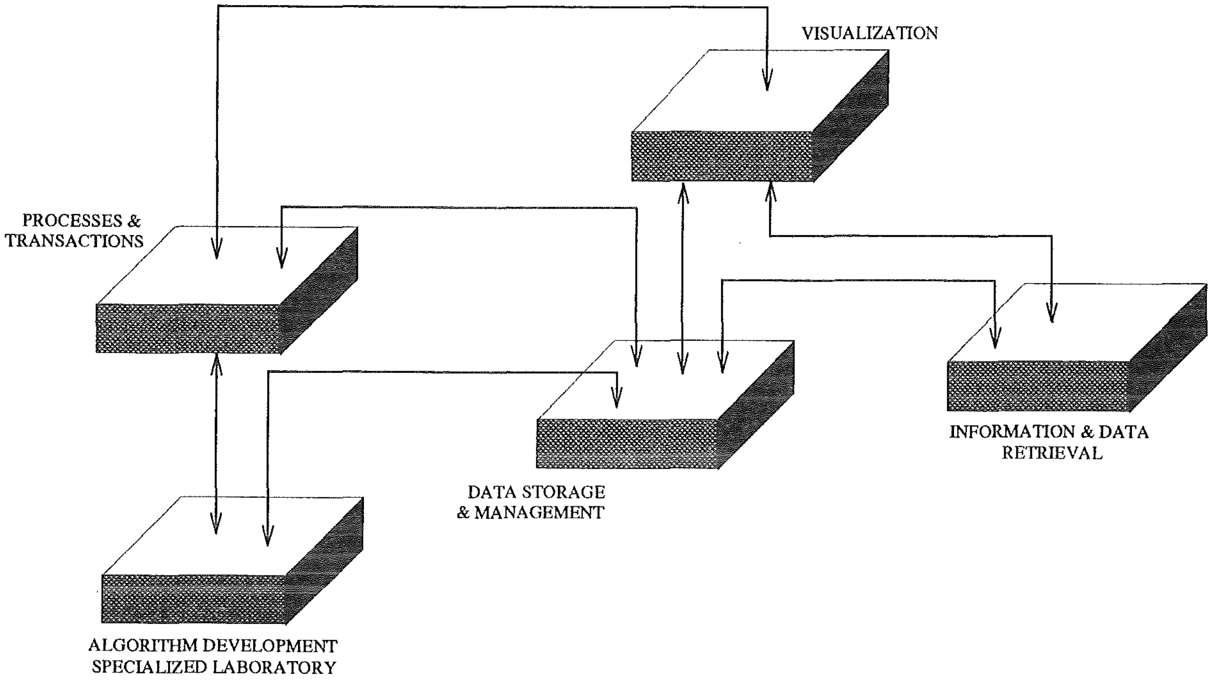

Figure 2.1: The functional components of the required system

It must also be mentioned that the data-oriented specification is restricted on the architectural issues of managing MIPAS data and it concerns with database conceptual design. The process-, control- and data-oriented system specification aspects must be related to each other in order to capture the knowledge needed for the system evolvement (see section 2.1.1).

2.1 Scientific Information System design issues

An information system, when observed as a whole, is like a symbolic machine that is able to perceive, manipulate, store, produce and transmit information[SFSE89].

The scientific information system is considered to be composed by two main components, the *storage component* and the *process component.* The first component includes files, records, databases and, even, work areas in central memory. The second one includes the application programs, transactions, operating systems and so on. Looking at the functional components of the system depicted in figure 2.1, the *processes and transactions* component plays the role of the *process component*, and the *data storage and management* component plays the role of the *storage component.* Considering their interactions with the component of *algorithm development*, **the dynamics of the system** must be captured too, expressed by its evolvement throughout time. Therefore, the process of the system conceptual design as a knowledge base is going to be defined in section 2.1.1, integrating the process-, control- and data-oriented specification aspects. Moreover, the storage component and its particularities, in relation to scientific data and their mass storage requirements, have been focused in section 2.1.2.

2.1.1 The design process as knowledge

The development or modification of an algorithm by a specialized laboratory would cause the reprocessing of already extracted data in order to improve the results taken so far. It increases the need of a tight compartmentalization of the storage and process component - considered as passive and active components respectively - because we must know what has happened during the operation of the system and the activation of the processes, i.e. what kinds of data have been produced by which processes in which time period. Besides the consequences have to be implied that a change in the processing environment would probably have for other data products extracted according to the processing sequence towards higher level data. This presupposes also the capture of the behavioral requirements of the system with respect to the time-dependent process activation.

In order to illustrate this requirement, the traditional approach of developing an information system, shown in figure 2.2, has been represented, regarding both storage and process components. They have been expressed in terms of database and application design techniques. The first captures the data oriented specification and the second the process oriented one. In addition, the control oriented specification (time-dependent behavior) should be captured too, related to the application design.

Dealing with database design, the **static properties** of an information system can be expressed in terms of entities and their relationships which must be modelled in order to capture the structure of the miniworld that must be analysed (database conceptual design). This conceptual model is mapped on the logical model of a DBMS dependent model (e.g. relational, network etc.), which in turn is mapped on a implementation dependent model (physical model). On the other hand, dealing with the application design, the **dynamic properties** of the system are taken into consideration, describing what is happening within the system in terms of activated processes and their time-dependent behavior. In order to meet the requirements of a changing operational processing environment, like MIPAS scientific experiment, the knowledge concerning the design of the information system from both points of view - database and application design - must be captured and expressed in an adaptive way, enabling an evolutionary design and evolvement of the required system. This pool of knowledge, specified as *design process knowledge* [BJM$^+$89, Jar90], is based on a conceptual model expressing both static and dynamic properties of the system. This can be achieved by expressing the relationships between structured design and control specification, from the application design view, and data modeling, from the database design view (figure 2.2).

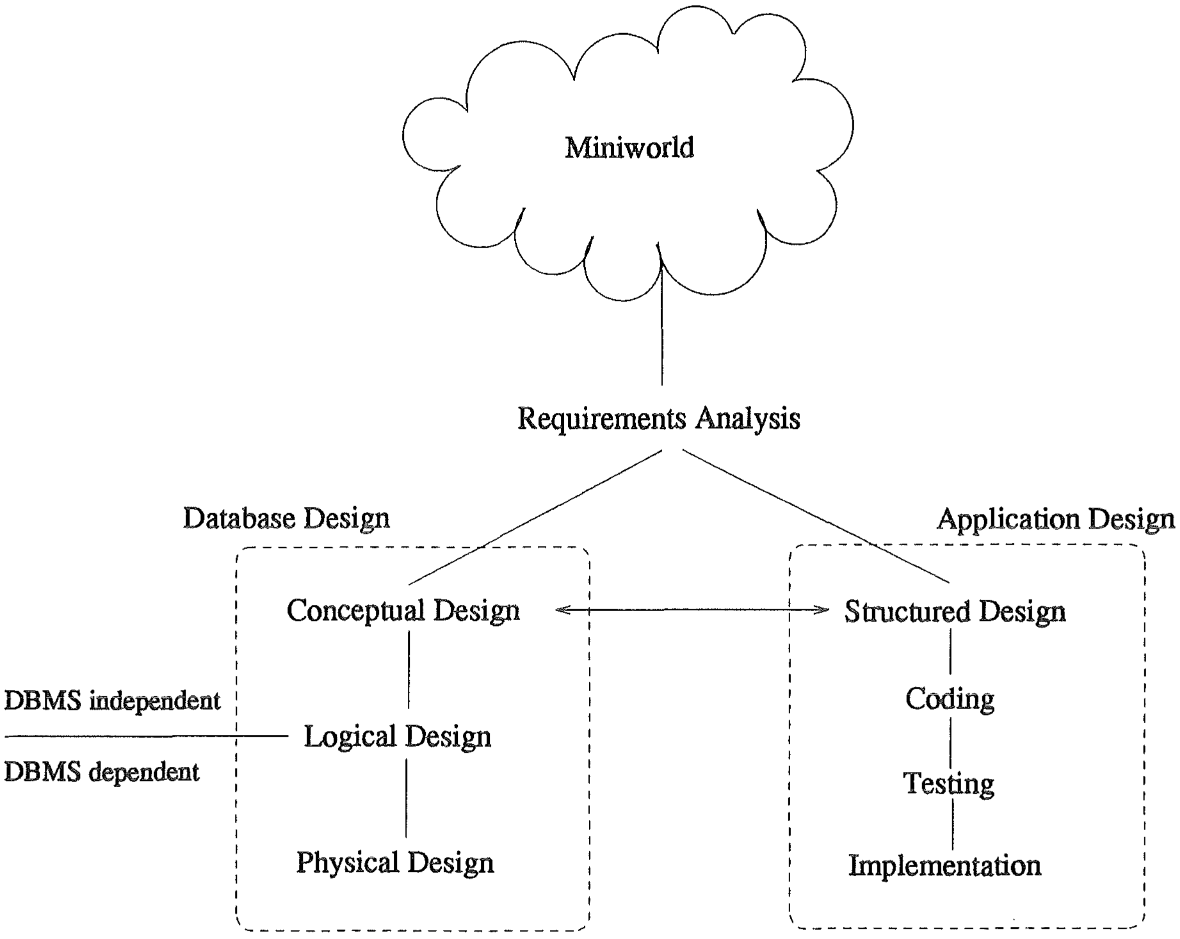

Figure 2.2: The two directions of database and application oriented design

At this point, a justification of choosing the requirements specification tool of section 1.2.2 is given, aiming at building the required knowledge pool. This forces the selection of a specification tool, like data flow diagrams, which enables to follow both directions, the application design, applying e.g., structured analysis techniques [Mar79, You89], as well as database design, applying e.g., entity-relationship model and its extensions or enhancements [Kin87, Rea87, LN87, Adi87]. Furthermore, building the required knowledge base, the structured analysis in the application design must be linked to the entity-relationship model, as it has been specified in [CN87] (a linkage between object-orientation and structured analysis and design is possible too, pertaining to the integration of both aspects [War89]).

So far, expressing data, processes and their relationships in the same conceptual model constituting the knowledge pool needed, an answer to the question of what data have been produced by which processes in which time period can be given. But it is not sufficient if some decisions have to be taken about what would be the consequences for subsequent data products based on the modified ones, e.g., trace gas distributions based on calibrated spectra that have been reprocessed and consequently modified. The notion of time-dependent behavior must be also captured in the same knowledge base illuminating the sequence of processing throughout time. Expressing the time relationships between processes constituting a defined processing chain, like the extraction of higher data levels in figure A.2, consequences of reprocessing data products can be implied with respect to these time relationships. Moreover, a requirements specification tool for the time-dependent behavior of the system should be used as the basis for the definition of the time-dependent relationships of the processes integrated in the same knowledge base model. This tool must also be able to relate easily to the data flow diagrams, in order to refer to both static and dynamic specifications of the required system from the same specification tool. In section 1.2.2, a state transition diagram has been chosen among different alternatives [Dav88b, Dav90, Hea90], because of its semantic richness of hierarchical alternatives and its multiple viewpoints. As a graphical tool can be easily related to an extension of the data flow diagrams to represent control and timing [War86].

Up to now, the design of the required system has been considered in relation to the interactions between the components of *data storage and management*, *processes and transactions* and *algorithm development* (see figure 2.1). Proceeding to the architectural issues of the system, the component of *data storage and management* will be focused, taking in account the properties and particularities of scientific data on the example of MIPAS satellite experiment.

2.1.2 On scientific databases

Focusing on the component of *data storage and management* of the required system, the database design steps of conceptual, logical and physical design must be followed (figure 2.2). On the conceptual database design level, a semantic data model will be used which can express concepts capturing more meaning of the *Universe of Discourse* under consideration [Bro84]. This high-level data model provides an independence from DBMS[1] specific data model and implementation which stores and manages the data *providing an information oriented access and not a file oriented one to the data. Dealing with the system design and not only with database design, the requirements specification of selecting a database management system is essential at this stage.* This must be done according to the peculiarities appearing in scientific experiments data, like MIPAS scientific experiment, in order to define a database management system capable of coping with the *MIPAS Universe of Discourse* (section 2.1.2.1). In the section 2.1.2.2, the connection to a mass storage system needed for accomodating the amount of data created by the MIPAS experiment (see section 1.2.1) is considered to be essential for the physical database design level.

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[1] Data Base Management System

2.1.2.1 Scientific data on the example of MIPAS experiment

Observing MIPAS scientific data, five main differences can be pointed out which distinguish scientific data from commercial data managed by commercial applications oriented DBMS. These are:

- **The temporal value of the data**
- **The way the data values are aggregated**
- **The metadata needed to access the stored scientific data**
- **The variety of data types**
- **The potential amount of data to be stored and retrieved**

The temporal value of the data and the way in which the data values are aggregated are related to the logical structure of the scientific data expressed as **multidimensional data structures**. It is shown in figure 2.3 that MIPAS scientific data, like interferograms, calibrated spectra and trace gas distributions, have the property of multidimensionality in their structure representing the way in which their values are aggregated. Their structure is depicted according to the notation used in [Kim89]. It is described in terms of two types of attributes, *category* attribute and *summary* attribute. According to this notation, a category attribute is analogous to a key attribute (e.g. time, geolocation, Line of Sight, etc.), and a summary attribute is a non-key attribute (e.g. radiation density values, arbitrary units, etc.). The multidimensionality arises from the fact that a combination of category attributes forms a key attribute for each of the summary values. In figure 2.3, the nodes marked with C symbolize a cluster node representing a summary attribute, and the nodes marked with X symbolize a cross-product representing the combination of category attributes. Multidimensionality can be modelled efficiently only by complex data types which must be supported by the database management system [SW85].

Furthermore, the dimension of time, considering the temporal value of the data, adds an important feature for the scientific database. It refers to the change of coordinates over time, known also as *time variation* [SOW84], i.e. the points for which the data values are measured or computationally change their position from one time unit to another. The data products will be often accessed across the time dimension, a case that increases the need of supporting temporal data.

There are not only the data products that must be stored and retrieved. **Metadata** are needed too, aiming at the information required to identify datasets of interest as well as their content, validity and sources. There is no agreed-upon standard formulation of an ideal metadata set for MIPAS scientific database. The following subjects seem to be of great interest with respect to the nature of MIPAS experiment:

1. General identifying information such as: Who collected the data, where and when the data have been collected.

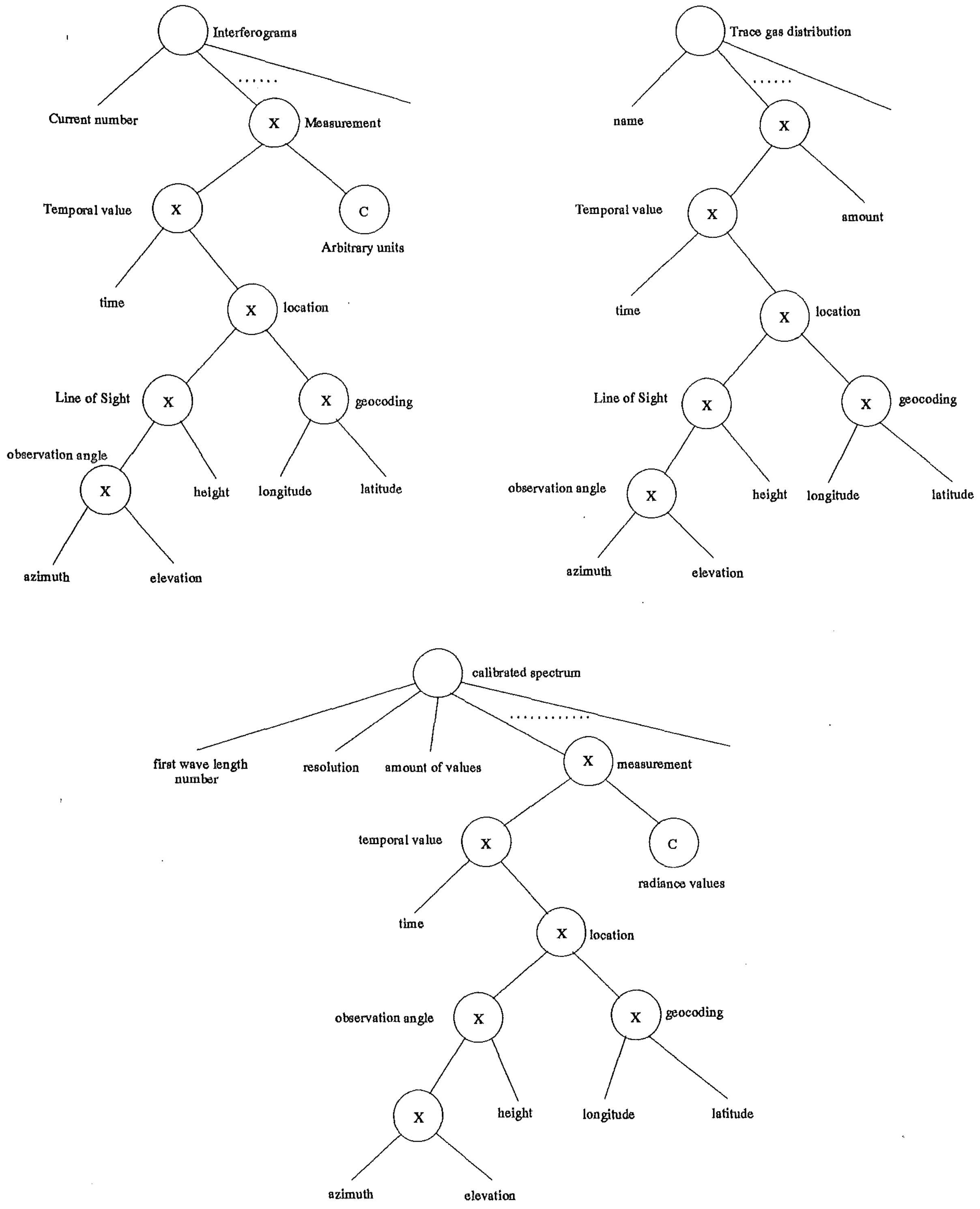

Figure 2.3: The multidimensionality of MIPAS scientific data

2. Configuration data (device characteristics) describing the initial structure of the MIPAS experiment or simulation models.
3. Instrumentation data describing the instrument conditions during the satellite mission. This information is crucial for the correct analysis of the experiment data.
4. Transformation operators applied to the data (e.g., calibrations)
5. Documentation relating to or derived from the data along with relevant publications, reports and bibliography.
6. Location data, e.g., what data exists and where is it, if the data are relevant to my interests.

The best solution for the MIPAS scientific database is to blur the distinction between experimental data and metadata, and to handle them in an interoperable way. As a result, the metadata can be searched, modified and associated with the rest of the data in the same system which will be presented as a single system.

A variety of data types is accompanying the MIPAS scientific experiment too. Numerical data up to level of trace gas distributions as well as spatial objects, in terms of two-dimensional cross sections of trace gas concentrations in the atmosphere and their three-dimensional maps related to earth coordinates which are created from the numerical values of trace gas distributions, and text (publications, metadata) as a unique data type in addition to alphanumerical fields, constitute a heterogeneous collection of data which, in fact, can be thought of as multiple databases. *It is therefore necessary that the relationships between these data sets can be described so that the data analysis can be properly specified.*

Considering the main differences between scientific and commercial applications data, as stated above, is expected that the database management system should provide the facilities of

- An adequate model for multidimensional data, because data are grouped and such groupings must be efficiently stored and processed. The conventional relational model is not adequate for multidimensional or complex structures.
- An adequate transaction management for long transactions, whereby the case of atomicity and recovery has been reconsidered. In scientific applications *add-on* and *read* processes are the predominant processes and not the *updates* ones, like in most commercial applications.
- An opened environment enabling complex operations to be defined easily without substantial speed penalty.
- Definition of a variety of accessing strategies in accordance to more efficient file structures.

- Flexible support for visualization as a part of scientific data analysis.

The potential amount of data (4-14 TBytes) that must be accomodated and managed by the storage component of the system implies the notion of an infinite storage capacity providing high-level abstractions that underlie a modern storage system. **The storage system** is defined to be the portion of the computing facility responsible for the long term storage of large amounts of data [omsst90, Mil88]. It contains a variety of storage media that offer a range of trade-offs among cost, performance, reliability, density and capacity requirements. It includes hardware devices for storing the data, the communication media for transferring the stored data, and the software modules for storage management and hardware control. In order to provide high-level abstractions for such a mass storage system enabling a logical level and not a physical level communication with the whole amount of data produced and extracted by MIPAS scientific experiment, a storage and file management software based on the **reference model** developed by the IEEE Technical Committee on Mass Storage Systems and Technology [omsst90, Mil88] is specified and described in the following section. Design issues with regard to the hardware devices and the communication media are considered in the hardware configuration of the system described in section 2.2.2.

2.1.2.2 The mass storage system management

Accomodating and managing such amounts of data, like MIPAS data, a variety of storage media is inevitable. They can be categorized by their hardware characteristics (device type, access time, capacity, data transfer rate, etc.) in three main levels, i.e. cashe memory storage, on-line storage, nearline/backup storage. The last can provide a great and cheap storage capacity reaching PetaBytes of stored data. On the hardware issues of a mass storage system some more details can be found in section 2.2.2. In order to manage and control all these storage levels, a suitable storage and file management system must be provided and supported by the system configuration.

What is expected by the storage and file management system of a mass storage system needed for MIPAS experiment, is hiding the details of system operation or behavior from the users providing higher level abstractions of the mass storage system. This feature is known as *transparency*, and will reduce the complexity of interacting with the mass storage system. Some of the results of the transparency provided are a) hiding of file migration among different storage levels (e.g., from nearline to on-line storage media), b) the access to all data without knowing on which level the data are stored, c) dealing with globally unique names which are independent of resource and accessor location. According to this definition, *the operation of the mass storage system is considered to be achieved without manual interference from outside.* Only manager facilities of the system must be provided.

As mentioned above, a reference model has been specified (figure 2.4), on which the storage and file management system of a mass storage system should be based in order

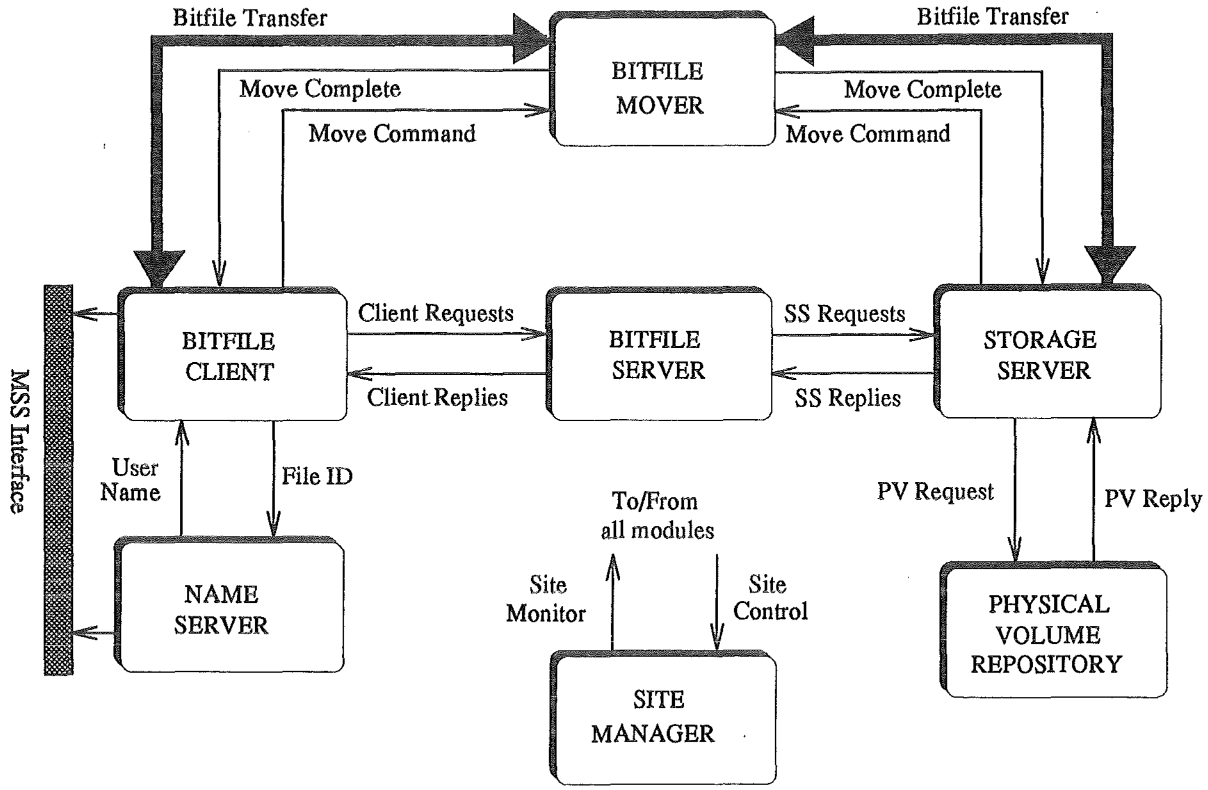

Figure 2.4: The Mass Storage System Reference Model

to fulfill the transparency requirements described previously. The model consists of seven modules which are defined in the following:

- **Bitfile Server.** It handles the logical aspects of bitfile storage and retrieval. The word *bitfile* refers to a bit string that is completely unconstrained by size and structure. Working on the model does not concern any particular file management system. The major components of a bitfile server are the bitfile server request processor, a bitfile descriptor manager and its descriptor table, a migration manager, a bitfile ID authenticator, a space limit manager and its space limit table.

- **Storage Server.** It handles the physical aspects of bitfile storage. It is considered to be an intelligent storage controller and its suite of storage devices. It consists of a physical storage system (containing the physical bitfile-storage medium), a logical-to-physical volume manager, a physical device manager, a means of command authentication and a part of an intimate connection to the bitfile mover. As a result, the abstract objects of the storage server that are visible to the bitfile server are logical volumes and bit string segment descriptors. It provides a separation of logical and physical volumes.

- **Physical Volume Repository.** It handles manually or robotically retrievable shelf storage of physical media volumes. It consists of devices used to read and write volumes and the drivers to control the devices. There is a broad spectrum of physical storage systems covered by characteristics in terms of random or sequential access, rewritable or write-once media, capacity and performance.

- **Bitfile Client.** It handles the logical aspects of bitfile storage and retrieval. It provides the storage system interface to the user at the terminal or to the application being processed. It translates user and application requests for storage services into bitfile server requests and provides communication with the appropriate bitfile servers and movers as determined by the name server mapping. It may combine the services provided by multiple bitfile servers, bitfile movers and name servers to form the higher-level abstract objects of an integrated storage service.

- **Bitfile Mover.** It provides the components and protocols for high-speed data transfer.

- **Name Server.** It provides the retention of bitfile IDs and the conversion of human-oriented names to bitfile IDs. It is central to achieving the location transparency needed by the system.

- **Site Manager.** He monitors the operations, collects statistics, establishes policy, and exerts control over policy parameters and site operation. It consists of a collection of functions that are primarily concerned with the control, performance and utilization of the storage system. They involve human decision making and are often site-dependent. With site management, the resources of the storage system can be allocated to the best use for the overall benefit of the system. Migration policy can be set by developing and implementing procedures for those policies specified. A new migration policy can be defined according to changes in the requirements of processing and storage facilities of the system as time progresses.

2.1.3 Visualization issues

Visualization is the method of computing that gives visual form to complex data. Visualization allows the scientists to see the unseen. [DB90b]

There is still a lot to be seen by scientists dealing with atmospheric research, like MIPAS scientific environment. The ability to visualize complex computations of MIPAS data products generation in terms of a quick-look monitoring facility, as well as those of simulation models development, is absolutely essential to ensure the integrity of analyses, to provoke insights, and to compare those insights with others. Moreover, visualization of the MIPAS third level data products, stored as spatial objects which have been extracted from the numerical values of trace gas distributions, can provide an insight to the chemical reactions occuring in the atmospheric layers and to keep track of the trace gas concentrations among these layers. The study of atmospheric phenomena through computer graphics showing on the screen what has been captured by numerical data can be further supported by animation throughout time.

The role of visualization in quick-look and monitoring facilities will be the identification and control of syntactical and logical errors. The role of visualization in the development and evaluation of simulation models is twofold. Going through the main stages of a computational simulation (see figure 2.5-(a)), visualization can be used to monitor and steer the computational simulation (interactive graphics), and to improve the visual display of the data by altering the viewing transformations, related to the analysis stage. The role of visualization in viewing trace gas concentrations and their changes throughout time in the atmosphere (third level data products) is the interpretation and analysis of the occuring phenomena resulting to scientific conclusions which may be used as assumptions for the modeling phase of the computational simulation. Despite of the differences between the roles of visualization in MIPAS scientific environment, there is a common basis on which visualization can be considered implicating a common frame in which system architecture issues can be made.

Defining the common frame needed, the scientific visualization facilities must be categorized into four functional areas: defining models, constructing models, rendering models and displaying models.

- **Defining a model.** Model definition is the process of creating a spatial database. Their representation is either defined by geometric primitives in a graphical database, like the MIPAS data products of level three, or by schemas in a visual knowledge base. This subject is illustrated in the following paragraph.
- **Constructing a model.** It is the task of building the model. It is the most computationally intensive task where the power of supercomputers is most needed, especially in real time simulation models.
- **Rendering the model.** In this functional area, the rendering software takes the model structure and produces images, usually with color, hidden surfaces removed, lighting sources and surface attributes. Rendering is also computationally intensive and can be done either on supercomputers or specialized graphics workstations.
- **Displaying a model.** It is the glue used to combine or enhance images analysed or generated by the components above. The computer-generated images will be shown on display hardware for user viewing or recording.

These visualization tasks can be distributed across different machine types. The four software functions of defining, constructing, rendering and displaying models may be implemented on different computer hardware. The implementation alternatives can be categorized in three main models according to the **Three-Tiered Model** for computational science and engineering defined in [MDB87, DB90b, DB90a]. This model is presented in

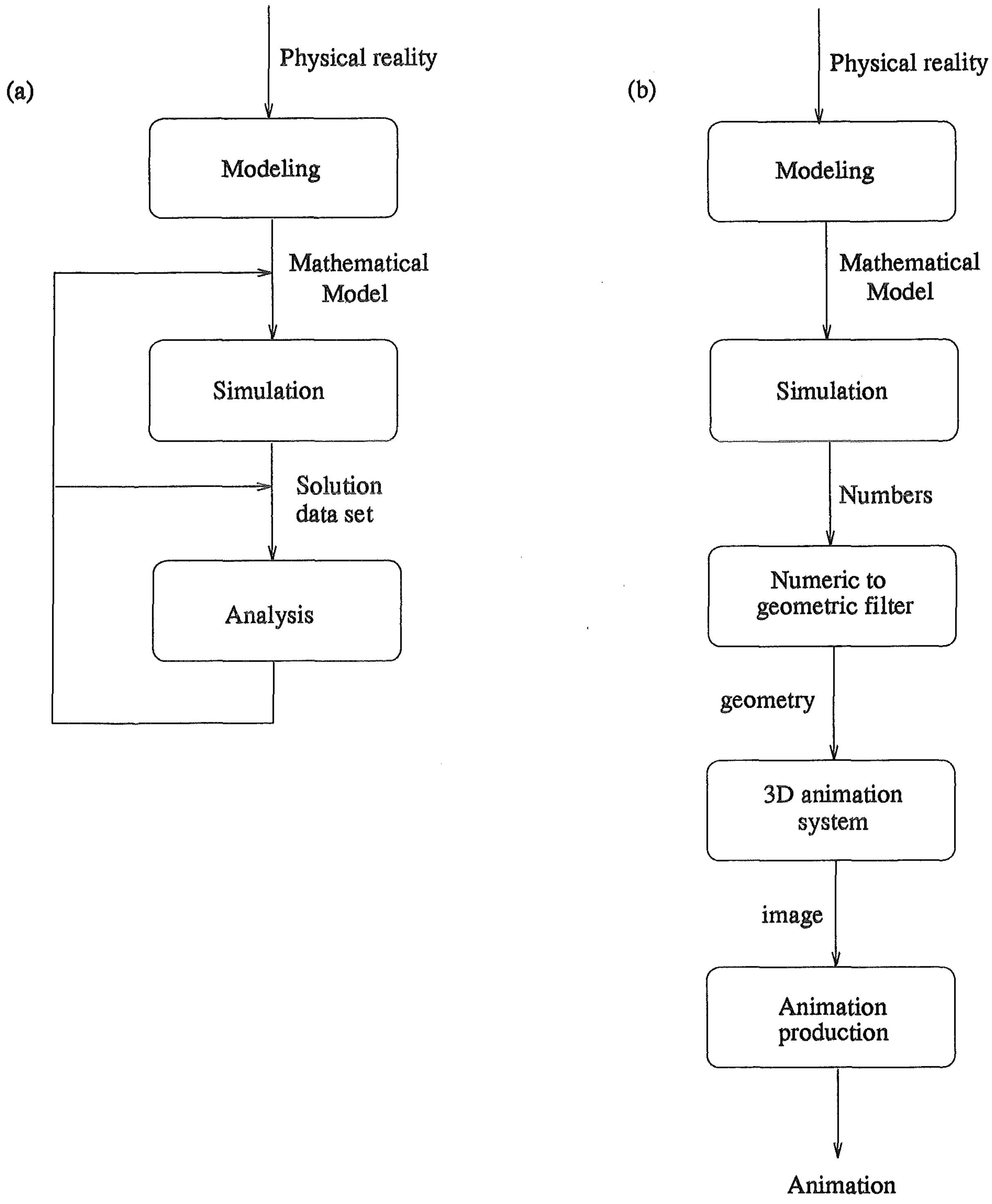

Figure 2.5: The stages of computational simulation

Attributes	Models		
	Model A	Model B	Model C
Hardware	Supercomputer or super image computer	Mini-supercomputer or image computer	Advanced workstations (Mini/micro image computers)
Bandwidth (bits/sec)	$>10^9$	10^7- 10^8	10^3- 10^6
Location (where users interact with the display screen)	Machine room (at the center)	Laboratory on a high-speed LAN (local area network)	Laboratory on a lower-speed LAN or on a high-speed regional network
Software (in addition to discipline-specific data generation and processing)	Commercial packages for output only (no steering)	Some interaction has become available	Commercial packages and tools are widely available for both computation and interaction
Administration	Strength: Support staff Weakness: Centralization	Strength: Discipline-specific visualization goals Weakness: Small support staff	Strength: Decentralization Weakness: Small support staff

Figure 2.6: Visualization facility three-tiered hierarchy

figure 2.6.

Model A is the supercomputer-oriented approach which has often the first three software functions implemented on a supercomputer. The created images are later displayed on a CRT or recorded onto film or video.

Models B and C are predicated by the workstation-oriented view using supercomputers for number-crunching model calculations or analyses and specialized graphics workstations are used to render and display the results. The model development (the second function) can be also split between the workstation and the supercomputer.

Additional models D, E and F which corresponds to personal computers, alphanumeric CRT terminals and batch output, respectively, also exist. Advanced visualization technology cannot be represented by them, and hence, they are not included in the model environment considered.

The visualization facilities for MIPAS experiment will be built with respect to model B considering advanced workstations and not image computers for the following reasons.

- Workstations offer a cost/effective complement to supercomputers. The total cost of setting up a model A facility is 100 times higher than that of model B, and the total cost of setting up a model B is 10 times higher than that of model C [MDB91]. A lower total cost by employing specialized graphics hardware can be achieved too.
- Workstations aid in the development of simulation models. They support excellent graphics and interactive rendering of results.
- Workstations can be used to guide the computations performed on supercomputers because they permit effective remote support.
- Rendering of an image on a workstation requires a modest bandwidth which is significantly smaller than that needed to handle already rendered images. Supercomputers can be free of dealing with graphics and can concentrate on generating data.
- A laboratory on a high-speed LAN can only support the discipline-specific visualization goals of MIPAS satellite experiment according to the diversity of visualization facilities which must be provided.

Quick-look and monitoring facilities will also be supported by the model B because of the real time environment of these functions. For the computational representation of third level data products, the following paragraph should give an insight.

There are two types of spatial data representation in visualization, two-dimensional and multi-dimensional (the most common being three-dimensional) [MDB91]. The higher level data products of MIPAS experiment will be represented by 2D displays and 3D data with surface[2] models. The MIPAS data will also be visualized using 2D displays although they are functions of more than two parameters. This implies 2D projections of the multidimensional data sets for MIPAS experiment, like 2D cross sections or projections of the data over a user selected plane. Choosing 2D displays is forced by the fact that volume graphics are still in their infancy. The representation of 3D data by surface models means that the surface model is stored as programs and data rather than as pixel maps[3] to

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[2] an alternative could be a volume model requiring storage capacities 2 orders of magnitude greater than what is required by surface models

[3] it is the case of representing 2D image data

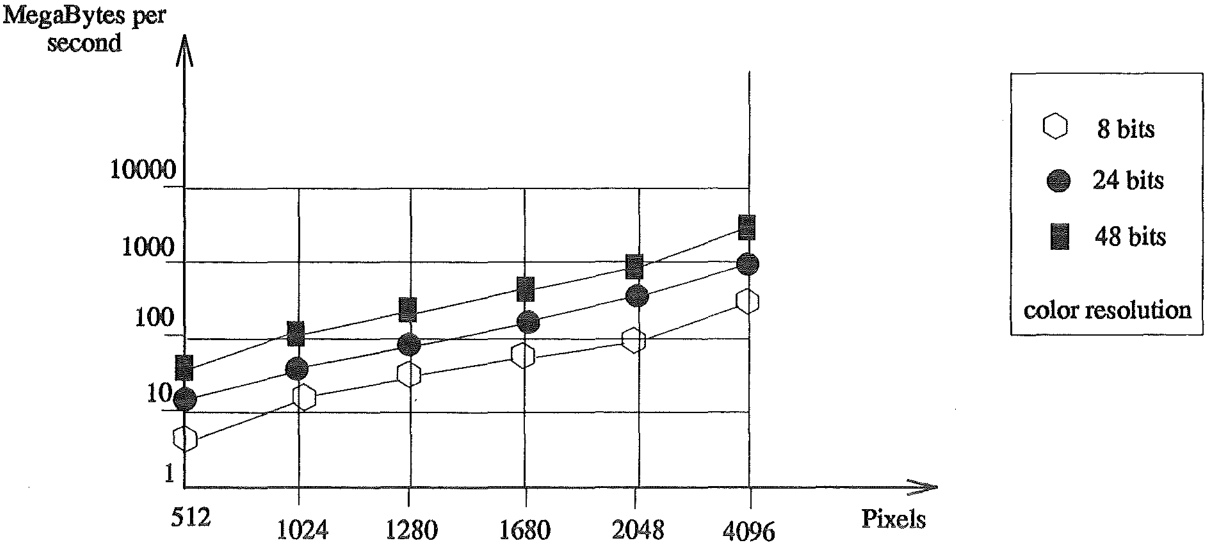

Figure 2.7: Transfer rate required for animation of image data at 15 fps

preserve underlying structure descriptions and to economize on storage space. Uncompressed 2D images of 3D data can vary from 256 kilobytes (512x512 with 256 colors) to 24 megabytes (2048x2048 with 2^{36} colors plus 12 bits of mixing information). The images of MIPAS experiment are generated synthetically rather that captured from nature, and therefore, storage requirements can be considerably reduced by storing only the program and the model data [MDB91].

The construction of the third level data model is due to the trace gas concentrations calculated by the preceding processes (see figure 1.6). The construction of the simulation model is due to the mathematical model transforming the physical model to be simulated (see figure 2.5), and finally, the construction of the model needed for monitoring of data production is due to the process used for the specified data production. For the last two cases, there is no storage requirements for the spatial objects constituting the visualization model.

Animation contributes to a more comprehensive understanding of atmospheric phenomena due to MIPAS experiment scope. In its broadest sense, it means movement and frequently connotes the complex motion of many objects (trace gases moving among the atmospheric layers), possibly articulated, moving simultaneously and interacting with one another (chemical reactions happening in the atmosphere). It is desirable for the visualization of complex processes and should be part of the visualization took kit.

Showing computational images in animation mode presupposes a required data transfer rate of the network connecting computational server and graphics display devices. The sustained data transfer rate needed for animation of image data can be seen as a function of spatial and color resolution in figure 2.7. It is only indicative because it is relative to many factors affecting the communication performance needed. The chart of figure 2.7 assumes that the data can be computed at a rate of 8 Gflops and that the problem requires at least 50 operations per grid point [Per90]. It is shown that under these conditions a network rate of 60 MBytes/sec is required to achieve 15 frames per second for an image at 1280x1024 resolution.

2.2 The system architecture

In this section, the system architecture in terms of software and hardware configuration is going to be defined, specifying the skeleton of the scientific information system needed in order to meet the requirements of the MIPAS satellite experiment. At first, the software configuration of the system in relation to the aspect of creating, storing, managing and providing information in order to support atmospheric research will be described (section 2.2.1). Secondly, the hardware configuration issues of the system will be considered in section 2.2.2 according to the requirements and characteristics of the system specified so far.

2.2.1 The system software configuration

The software configuration of the system is portrayed in figure 2.8. Starting with the way of storing and managing the data produced during the mission, a suitable **scientific database** has to be configured capable of meeting the requirements coming up when the management of scientific data is considered (see section 2.1.2). The proposed scientific database consists of two main components which will be known as the **Operational Database** and the **Research and Development Database**.

This separation has been made considering the access characteristics to the data products and their efficient management. On one side, the operational data (MIPAS data products) provide a rather uncomplicated structure and will be managed by a long field data server which can be accessed by information provided by catalogs. On the other side, researchers are faced with multidimensional structures and various object types (experimental data, graphics, text, video, etc.) which should support the access to the scientific data according to their context and their interobject relationships. The *Research and Development Database* must be built up from the Operational Database concerning only with scientific data that are *actually needed* by the MIPAS researchers. A mechanism must be provided in order to communicate with and access the Operational Database in case of searching for data not available at the researchers' site. In this way, data products generation and distribution can take place directly through the *Operational Database* and its Mass Storage File and Management System, bypassing the Research and Development Database and avoiding a performance degradation expected if a DBMS was considered to be directly involved for this purpose.

2.2.1.1 Research and Development Database

Concerning with the variety of MIPAS scientific data types of numerical data, graphical objects, text for metadata, an efficient storage requires a database management system with an architecture similar to a **multimedia database** architecture [Loc88] capable of dealing with the numerical data and their graphical representations managed by an Object-Oriented Database Management System (**OODBMS**), dealing with spatial objects managed by a **Spatial DBMS**, and dealing with **metadata** - predominantly with

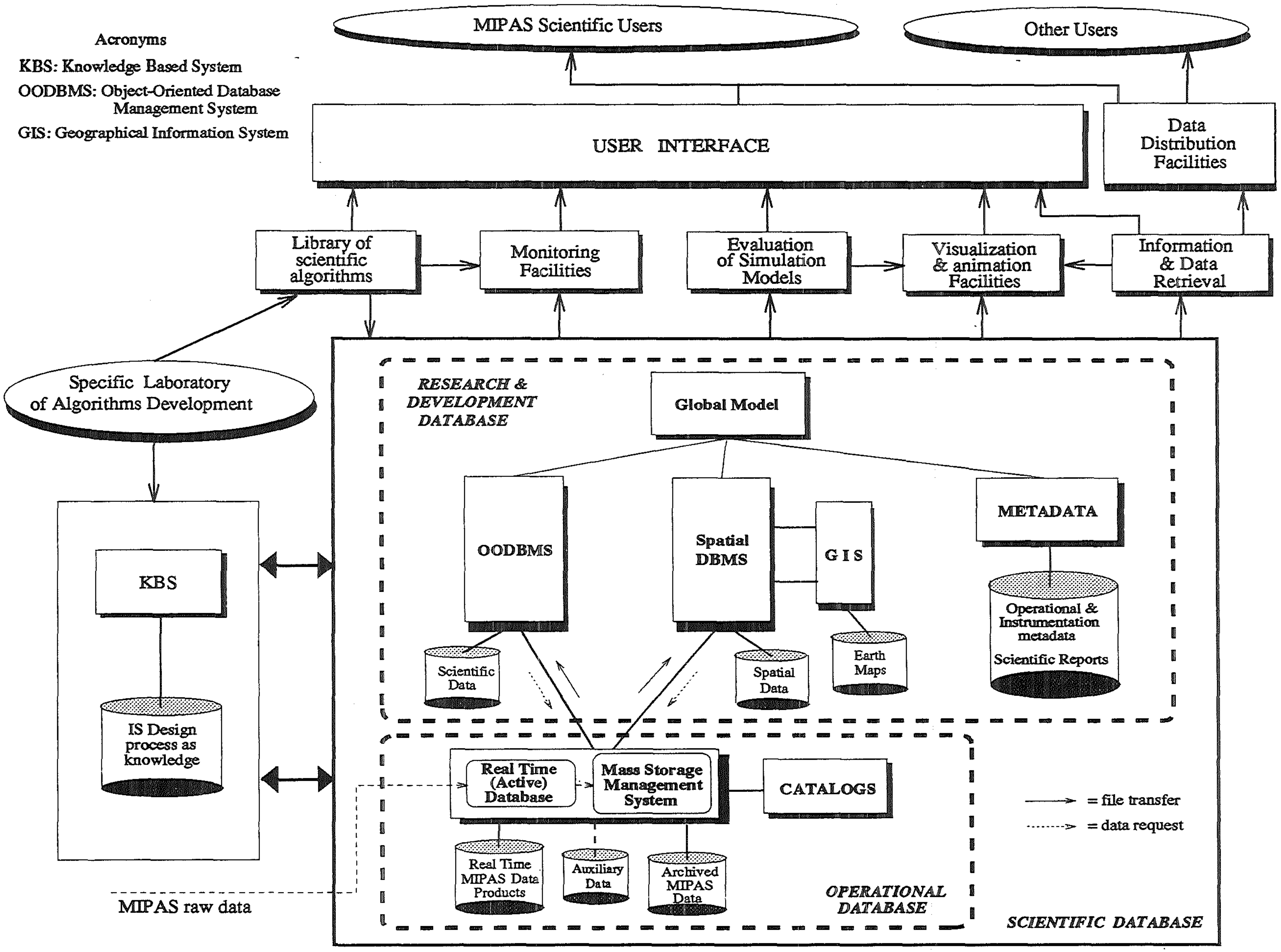

Figure 2.8: The architecture of the scientific information system

text. Each one of them is considered as a local DBMS with its site autonomy retaining complete control over local data and processing, a key aspect of multidatabases [BHP92]. A **global model** will capture semantically the interobject relationships as well as any intraobject relationships captured by the local DBMSs acting in autonomy. This will provide a global view at high level of information to the end user searching for the data she/he needs following any direction she/he wants. Therefore, for example, the access from the description of the conditions under which some scientific results have been captured (metadata) can lead to the related numerical or graphical data, and the other direction, from scientific data to the related metadata for explanations needed in order to understand scientific results and experimental conditions. The autonomy provided by the *Research and Development Database* architecture for the management of MIPAS scientific data supports a high degree of decentralization among various data management types and it doesn't make necessary to develop a DBMS from scratch trying to cope with the inefficiencies arising out of scientific data management. It is also regarded to be essential for the following reasons.

Handling spatial data models by an extended database management system which also handles the rest of the data would not be acceptable as it places too much burden on the system in order to manage an always increasing number of files [LODL91]. Hence, a storage manager that should be useful for a long time must not have a performance degradation effect on the system. The independent handling of spatial objects is also implied by the need to support spatial data models in terms of spatial operations and access methods which are not provided by traditional DBMSs, and if so, with a considerable performance degradation effect for systems managing terabytes of data [HC91]. The spatial data model used by MIPAS scientific database for the graphical representation of trace gases distribution in the atmosphere will be a three-dimensional raster model (4-dimensional considering *time* as the fourth dimension for purposes of animation) which prescribes the geometric elements as cells in an integer space, a model which ties back to the atomic theory of Democritus and the modern inheritors [Chr87] (known also as *tessellated data structure* [ROG]). Spatial operations like *Overlay, Containment, Connectivity, adjacency* etc. and access methods like R-Trees and Grid-Files should be provided too. The spatial model, that must be specified in details, concerns with the atmospheric layers of troposphere, stratosphere and mesosphere. This should also be related to the earth maps (vector based data) provided by a Geographical Information System in relation with suitable projections with respect to the given earth coordinates.

The construction of the spatial database - according to the definition in section 2.1.3 - will follow the production of trace gas concentrations (see figure 1.6). This implies the capture of the relationship between the spatial model expressing the trace gas concentrations with known relations to space and the model expressing the relationships among scientific data (numerical data products and their graphical representation) managed by the Object-Oriented Database System (OODBMS). This can be achieved by a higher level model defined as the *Global Model* in the software configuration of the system [Fra].

This also enables to keep track of data production and visual representation, concerning the data levels two and three respectively, needed when trace gas concentrations must be reprocessed and modified, and therefore, the spatial database instances have to be redefined too.

The database management system managing the numerical data of the scientific database should provide the facilities of coping with multidimensional data, transaction management of long transactions, complex operations, definition of a variety of accessing strategies, as it has been mentioned in section 2.1.2 considering the main differences between scientific and commercial applications data. Furthermore, one more aspect needs attention in order to integrate the database management system suitably in its configuration environment.

The first aspect is the notion of **extensibility** which must be supported by the OODBMS in order to tackle the problem of providing efficient scientific database support [LJAF92]. The flexibility obtained by the extensibility features of the OODBMS is essential for the specification of abstract data types (ADTs) as well as for the transaction and buffer management, for the storage structures to be defined when the scientific data are accessed, and finally, for the capability of using external storage managers.

The last one is crucial for the connection of the OODBMS with the mass storage and file management system (SFMS) specified in section 2.1.2.2, the core segment of the *Operational Database* from which the actual or the most interesting data to the researchers are going to be provided. This can lead to a context oriented access to the mass storage system through the OODBMS and not a file oriented access provided by the *Operational Database.* The mass storage system can be accessed through the OODBMS that is based on the virtual disk concept and not on hierarchical mass storage systems. The connection can be achieved through the *Name Server* (see figure 2.4), a module which leaves its user inteface open, addressing only its function. That means that naming conventions for the file space can support many operating systems. For instance, the name space could look like Unix, VMS, or a database management system [Inc92]. *Connecting the OODBMS with the SFMS, an infinite storage and management facility can be achieved regarding the hierarchical structure and management of mass storage systems that follow the concept of the reference model.*

Last, but not least, is the storage and management of metadata which are essential for scientific databases (see section 2.1.2). According to the metadata definition in [Rad91], *metadata is the metaknowledge concerning the precise definition and classification of data involved in a kind of self-explanatory way.* Metadata is the data about data, i.e. a systematic descriptive information about data content, operational and instrument conditions, the way the data have been manipulated, and so on. Metadata is considered to be crucial for the communication and integration of the system to its operational environment. Moreover, metadata is considered to be various scientific reports related to MIPAS experiment and based on the scientific results extracted from the generated data products.

Metadata will be managed independently, as it is shown in figure 2.8, because they differ substantially from the scientific data in terms of its typical data types, structures, access patterns and update requirements [McC82]. Moreover, metadata management by the same DBMS could have a substantial performance penalty of the system. The main difference between metadata type and scientific data is that metadata resembles bibliographic information corresponding to textual functions, whereas scientific data are primarily numeric and require numeric functions. Scientific access patterns tend to involve large numbers of entity instances for a relatively small number of attributes as opposed to metadata access involving a high proportion of metadata attributes information for a relatively small number of instances of particular metadata entities [McC82]. The metadata is mainly used for data definition, documentation, data selection, support of data manipulation and data display by providing standard default labeling for different types of data and analysis output.

With respect to the usage and importance of metadata, its integration to the scientific database should also be achieved by the *Global Model* already mentioned. At this level, the relationships between the metadata information and the scientific and spatial data to be described can be captured, in order to facilitate an abstract level of information coming out of the required system and improving its integration to its operational environment.

2.2.1.2 Operational Database

It concerns with MIPAS data products generation and monitoring as well as data management and storage in long terms. It will provide a long field data server upon which the *Research and Development Database* is going to be built. At this level, the data model to be specified is rather simple, without complicated structures. It refers, mainly, to time series data, event data and raw data blocks. The MIPAS raw data is considered to be gathered at near real time, and therefore, a real time operational database system must be used. In addition to MIPAS data generation and monitoring, it will provide data products selection and distribution to its operational environment through suitable access mechanisms. Information about the file oriented access to the generated data products will be provided by related *catalogs.* It's also suggested that the most recently used data, attributes and pointer tables are cached for high performance. Old data will automatically be discarded as new data is written. The old data will be sent to the mass storage system for archivation and preservation. They will be managed by the mass storage and file management system running on the control computer (large file server).

The *Operational Database* must also provide the characteristics of an *active* database system (as opposed to a *passiv* one). The automatic MIPAS data products generation will be based on an event/triggering mechanism which will trigger a related process after the occurance of an internal event (e.g., the completion of the creation of a predefined calibrated spectra set will trigger the creation process of trace gas concentrations). According to definitions given in [Cha89, MD89], an active database system is characterized by its ability to monitor and react to both database and nondatabase events in a timely and efficient manner. In contrast, a *passive* DBMS can only manipulate data in response to explicit requests from applications, that is queries or transactions are executed only when explicitly requested.

As a *real-time* database system, a series of features for real-time applications (MIPAS data products generation) should be provided which are not supported otherwise. Some characteristical features are the high data rate processing, fast access time to the data being generated, reorganisation free operation, main memory files, high priority based access, applications specific buffer management, message routing, support of dual-host configuration and disk mirroring providing high availability, quicklook operating.

Another essential component of the software configuration of the system is a **K**nowledge **B**ased **S**ystem (KBS) providing the knowledge needed to meet the requirement of a changing operational process model specified in section 1.2.2.1 as *reprocessing of extracted data products.* These changes must be reflected in the system itself in order to determine the MIPAS data which has been affected not only by the change under consideration but also by the propagated ones, and consequently, to activate a reprocessing mechanism aiming at the extraction of new data products. *This facility can only be provided if the knowledge about the design process of the system itself is captured* [BMG82, BGM85, BJM$^+$89, Jar90]. The design process will include both the *static* and the *dynamic* properties of the system being designed in relation to the definitions made in section 2.1.1. It is obvious that an interaction between the knowledge based system and the scientific database is needed considering the access of already stored data and their interconnections (static properties captured by the conceptual database design). It puts the configured system closer to the notion of *interoperability.*

The *visualization and monitoring facilities* are going to be supported by the related software components needed for *rendering* and *displaying* the model as it has been already defined in section 2.1.3. *evaluation of simulation models* developed by MIPAS scientists need also to interface with the scientific database, monitoring the results in real time. Access to the information required by the system should be provided by a user-friendly interface allowing the communication with the underlying database in a rather natural way of thinking (*information retrieval* component). The specification of transactions and/or the ability to specify queries in a deductive mode - not only procedural - should be based on this component. Moreover, *data distribution* facilities should extend the communication facilities provided by the underlying system structure in order to make the MIPAS scientific data and results available all over the world.

2.2.2 The system hardware configuration

Meeting the requirements of MIPAS satellite experiment, we don't need only satellite platforms but also hardware ones. In this section, the main design issues of the required system in terms of its hardware configuration is going to be presented. It has been portrayed in figure 2.9 with respect to architectural considerations made in order to provide a high availability, performance and flexibility of the system. This can be achieved only by having a computational environment which consists of various computational elements that make the environment seamless using existing technology [SC92]. Each of the computational elements is involved in specified processes contributing to a high level of modularization needed for the purposes of high availability and flexibility. The performance of the whole system is considered to be increased attaining a degree of **parallelism** which is essential for high performance systems [DC92].

There are two main components which characterize the configuration of figure 2.9. They are related to the *Research and Development Database*, and the *Operational Database*, respectively, as they have been specified previously. The first component - considered as a front-end to the scientific community - will be based on a **Client-Server** architecture providing a distributed environment when dealing with actual data or data of interest which will be locally stored and managed by local database servers. The second component - considered as a back-end of the whole system - deals with the receipt of the delivered MIPAS raw data and the generation, management and preservation of MIPAS data products. It consists of three main modules - the Computational Server, the Control Computer or Large File Server and the Mass Storage System - which are going to be presented with more details in the following, together with the networking facilities upon which the two components and the computational modules of the system will be connected with each other.

2.2.2.1 The Local Area Network

The connectivity among these computational modules is provided by a High-Speed Local Area Network (HSLAN) which can be seen as a two-part HSLAN, a back-end very high speed data link connecting the computational server with the Control Computer and the mass storage system, and a front-end HSLAN over which the client-server architecture will be considered. This logical separation of the network is essential because of the two main roles of the required system, its *operational role* according to the MIPAS data products generation and preservation, and its *experimental role* according to the management of local scientific data. This implicates two categories of data traffic in the communication network: one category concerning with *real-time* data streams and large file transfers (e.g., quick-look facilities, monitoring of data products generation processes, data products generation and archivation) leading to *long messages* transfer, and another one concerning with query/response and control data traffic leading to *short messages* transfer [FM]. Furthermore, a connection of the investigator's local file servers to the back-end HSLAN is suggested considering the big size file transfers while building up the *Research and Development Database.* Accordingly, the Computational Server and the Control Computer should also be connected to the front-end HSLAN for queries and control data concerning the *Operational Database* directly. A data link from the back-end HSLAN to a frame buffer (graphics workstation) should enable animation which presupposes a high data transmission rate (e.g., 30 Frames/sec with a 1000x1000 pixels monitor and 24 bits color requires 90 MBytes/sec).

Choosing a suitable network environment depends on a number of factors, including mean message size, intermessage interval, conversation length, etc. The lenght of the message can be used as a rule of thumb in such cases [FM]. The architectural approach, defined so far, is considered to be attractive because of the combination of these categories regarding both roles of the required system. For the second category and as front-end of the network configuration, the Fiber Distributed Data Interface (FDDI) is suggested. For the first category and as back-end of the network configuration, a very high speed data link over a switch node (e.g., ULTRANET, HIPPI) must be available, which can support a sustained data transmission rate needed for the purposes of *long message* transfers and the effective evaluation of great amounts of data regarding file transfers and visualisation/animation perspectives.

The question of the network performance arises when the selection of a local network has to be made in order to support a certain collection of devices, certain data traffic characteristics, and is expected that the network has adequate capacity for the expected load. *It is not only the data transfer rate given as a theoretical performance which determines the selection of a local network.* Some more parameters affecting the network performance must also be considered such as *Propagation Delay* and *Transmission time* [Sta84]. Analysing the local network performance the two most useful parameters, which must be taken in account, are the data rate (R) of the medium, and the average signal propagation delay (D) between stations on the network [Sta84]. In fact, it is the product of these two terms (RxD) the most important parameter for the performance of a local network. Speaking in terms of the maximum possible utilization of the network, the parameter a determines an upper bound on the utilization of the local network. The parameter a is expressed as $a = \frac{LenghtofDataPathinBits}{LengthofPacket}$ denoted as $a = \frac{RD}{L}$, which can also be expressed as $a = \frac{PropagationTime}{TransmissionTime}$. Typical values of the range of a are from about 0.01 to 0.1. The ideal case is $a = 0$, which allows 100% utilization. As an example, two networks with the same data transfer rate (50 Mb/s) and the same cable lenght (1 Km) are considered having a different Packet Size (10000 bits and 100 bits respectively). It is shown in [Sta84] that they have a totally different utilization parameter of $a = 0.025$ and of $a = 2.5$ respectively.

The choice of FDDI, which employs an optical fiber medium with 100 Mbits/sec theoritical performance and is based on a token ring protocol, is suggested as the front-end HSLAN. The reason of choosing FDDI is that it is based on token ring protocol which has been compared to the other most important LAN protocols CSMA/CD and token bus [Sta84]. According to this comparison, the token ring is the least sensitive to workload,

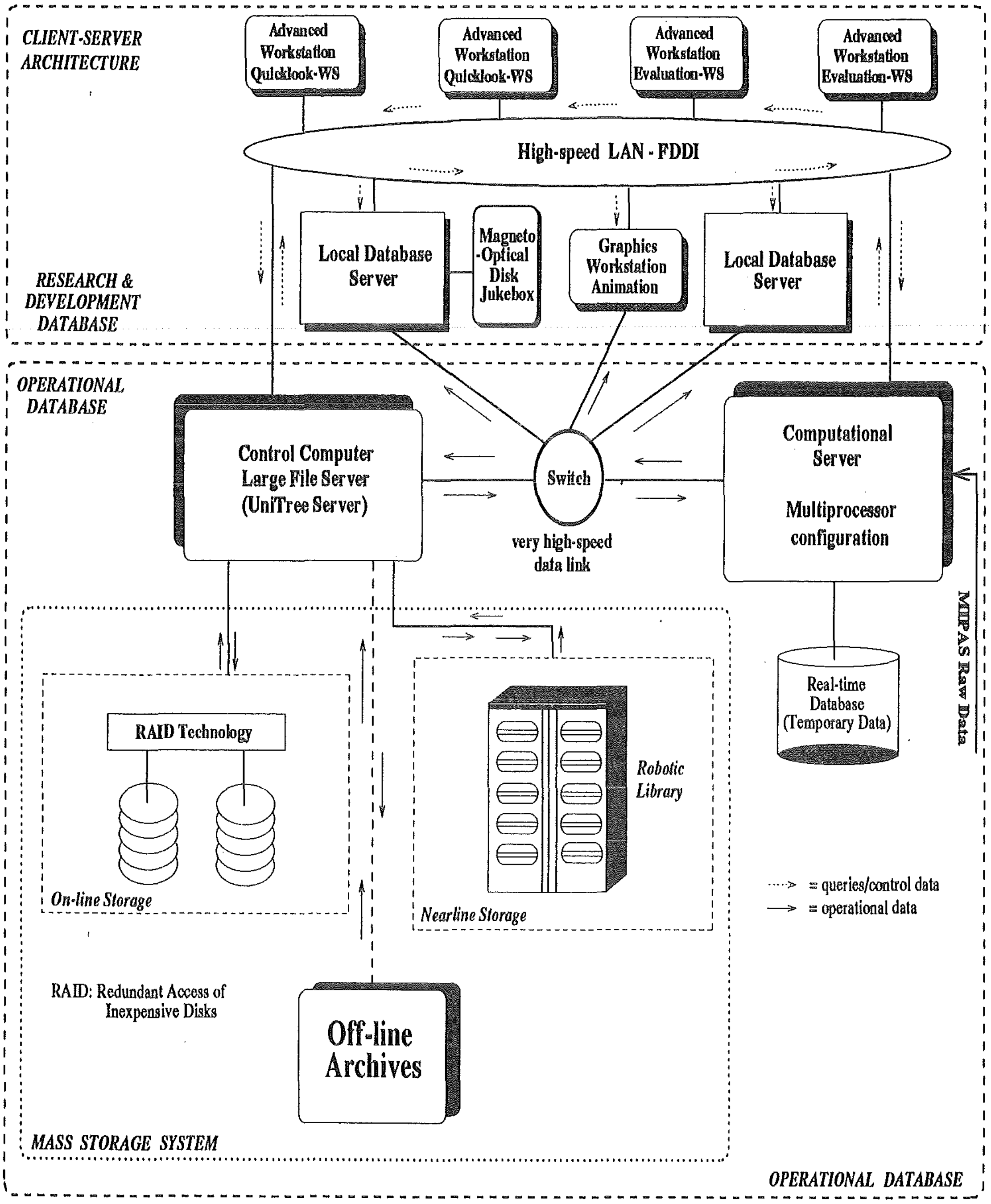

Figure 2.9: The hardware configuration of the system

whereas the CSMA/CD will be instable under heavy load. This happens because of the increased offered load which lead to a throughput declination achieved by an increased frequency of packet collision. The comparison has been made according to a performance model assuming a local network with N active stations and a maximum normalized propagation delay of a. It is further assumed that each station is always prepared to transmit a packet.

Moreover, the superior reliability, availability and serviceability, even in the face of physical damage to the network, offered by a ring topology is regarded to be very important for the characteristics of MIPAS satellite experiment [Ros89]. Other advantages include interconnection simplicity, a sufficient bandwidth that allows a bit-serial transmission as a feature of optical fiber that don't adapt well to bus configurations, the ease of initial configuration and reconfiguration according to network requirements change, the isolation of failing stations or fiber links through the user of appropriate protocols, and finally, it appears to best satisfy the requirements of high-performance networks operating from 20 to 500 Mbits/sec where high connectivity and large extents are needed [Ros89].

It has been mentioned previously that all computational modules of the system are connected to each other via FDDI, with a perspective of using it for the transfer of *short messages* in case of queries and control data. For the transfer of long files among the computational server, the control computer, the local file servers and the frame buffer, a very high-speed data link (ULTRANET) as back-end HSLAN is necessary, making use of a switch node which enables independent data transfer ways. ULTRANET is also suggested amongst others, because of the communication software already existing, supporting this networking facility. *An attractive configuration is regarded to be the direct connection of the on-line and nearline storage to the switch node, enabling a direct access to the mass storage system without passing through the large file server.* At the moment, this architecture is not efficiently supported by the communication software, and therefore, is not going to be considered further.

2.2.2.2 The back-end part configuration

2.2.2.2.1 The computational module On the computational module, the MIPAS data products generation is going to be performed as well as construction of visualization models (see section 2.1.3). Considering the MIPAS data processing chain, the most computationally intensive algorithms are regarded to be the FFT[4] and the retrieval-inversion process of second level. For these computationally intense processes and the processing requirements of constructing a visual model, a computer architecture is suggested providing a high performance environment for both vector and scalar processes, in relation to the diversity in terms of vectorizable and non-vectorizable processes in the processing steps of MIPAS data, and an increasing level of parallelism in terms of multiprocessor configuration and not only within a single processor. The latter can support a high

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[4] Fast Fourier Transformation

performance achieved by splitting down the MIPAS data processing chain or the whole scientific processing environment, i.e. the MIPAS data production processes, the reprocessing activation of already extracted data, the construction of visualization model, etc. Besides a *very high degree of performance flexibility can also be achieved for the life cycle of the system having the ability to easily extend the processing units without affecting significantly the hardware configuration of the system.*

All of this parallelism, integrated into a single computer system (supercomputer architecture) or into the system itself (multiple computer systems) leads to an entire spectrum of performance which is difficult to be measured for many reasons [Lub88]. The only way to narrow the performance range is to carefully characterize the applications composing the workload. Although workload characterization can serve to focus the performance range of a computer system, variability of the workload with time and the additional processing requirements of the MIPAS scientific environment (e.g., reprocessing, construction of visual model, etc.) mean that we must understand the realistic bounds in the performance spectrum. Hence, an obtainable flexibility of the architecture is considered to be essential for the high performance of the whole system.

An emphasis has been given in the architecture of the computational server because the given peak performance in MFLOPS[5] can be regarded as a myth. The performance of such an architecture depends on the mathematical algorithm, the implementation, the language and finally the compiler [Lub88, Mar88, Dav88a, CKPK90, Mar87]. Some already existing benchmarks can be considered as improvements over peak execution rates commonly quoted by vendors, but it is difficult to be confident in the estimation ability of few lines of code, particularly, if the algorithm implemented is not even used in the workload of the evaluated system [CKPK90].

Even in vector/parallel and scalar/sequential processing facilities, which should be supported by the provided architecture, the performance ratio of their speed respectively, within a single system, is restricted on a class of small CPU bound problems that are not affected by I/O, paging, memory contention, cache hits, etc. [Mar87]. *The benefit gained by utilizing this architectural feature depends on the degree to which the total workload of the system is vectorized* (the same holds true for parallel architectures). Otherwise, the performance of the system will be dominated by its performance on the fraction of the workload that is executed at the lower processing rate [Mar87, Lub88]. This is a lesson taken by Amdahl's law

$$S_v = \frac{1}{f_s + \frac{(1-f_s)}{r}}$$

where r=the ideal vector to scalar performance ratio, f_s=the fraction of work that must be performed in scalar mode, and s_v=the speedup potential due to vectorization.

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[5] Millions FLoating Point Operations Per Second

A parallel architecture exploiting asynchronous parallelism at a multiple-processor level can provide a higher level of performance flexibility as response to a slowing down of the continuing upward performance spiral afforded by synchronous parallelism provided by single processors [Lub88, HSN81]. *Changes in the workload of the system can be efficiently accomodated by the required system based on a parallel architecture appearing as consisted of multiple computer systems.* The performance ratio between vector and scalar speed characterizing one computer system has to be determined in accordance to the fraction of the workload that can be vectorized, as stated above. The performance requirements of the scalar and vector processors needed has to be determined taking in account the workload of the system as a whole and not only the workload indicated by the processing algorithms for the MIPAS data products generation.

2.2.2.2.2 The architecture of the mass storage system The mass storage system is the computational module responsible for the storage, management and preservation of the MIPAS operational data, providing a high availability and the capacity to handle the stated volumes of data (see section 1.2.1), hiding the physical structure of the mass storage system from end users with a guarantee of no data loss, and supporting an access transparency to the various storage levels.

Dealing with the TeraBytes of MIPAS data, a cost/effective storage hierarchy must be defined which is characterized by the access policy and the storage media used in each level. At first, the *on-line storage* is based upon magnetic disks and will function as a disk cache memory for the whole mass storage system. One level lower, the *nearline storage* is based upon cheaper storage media (e.g., optical disks, tapes, cassettes) capable of storing massive data amounts, which are managed in an automatical way by a robotic library. *The nearline storage data are less actual than the on-line data, but they can be accessed on-line, and not off-line like data archives.* The nearline storage is considered to be essential for the extension of the on-line storage capacity, regarding several TeraBytes of data that cannot be accomodated by on-line storage media only (magnetic disks) in a cost/effective way regarding existing technology. The control of on-line and nearline storage media is supported by the *control computer* using the terminology specified in [Inc92]. Its function is regarded as the function of a large file server managing the whole amount of data stored in the storage hierarchies, hiding their physical location at the same storage level as well as among different storage levels. This can be achieved by the **S**torage and **F**ile **M**anagement **S**ystem (SFMS) running on the control computer and described in more details in section 2.1.2.2. It will be responsible for the migration of data (according to a migration policy established) between on-line and nearline storage levels.

The *control computer* and the *Mass Storage System* consisting of the on-line and nearline storage components will be described with more details in the following paragraphs with respect to the requirements of high availability, MIPAS data storage capacity, performance and flexibility. The ability of expanding the storage capacity with an off-line shelf/secure archiving facility should also be supported, enabling reusability of the mass storage system during a new satellite mission, and long liveness of the MIPAS data produced by a completed mission. During a certain mission, the technology used for nearline storage should guarantee no data loss, and therefore, can also be used as back-up facility.

The control computer The main characteristics of the control computer, in terms of its configuration issues, are stated below, with respect to its role as a Large File Server for the network, concerning with large file transfers requested by the computational/investigator's local file server, with the operational database (access and dissemination of operational data), and with file migration between on-line and nearline storage levels. *The CPU of the control computer should have three capabilities important to its utilization.*

- A powerful I/O subsystem is necessary in order to move data in and out of storage using high-speed communication network types, like ULTRANET, for the connection with the computational server, and FDDI for its use as information pool (see section 2.2.2.1).
- The processor itself should be powerful enough in order to handle not only the access to the data and files but also the network protocols involved in file transfers, because these can place a large burden on the machine.
- A usually expected increase in file transfer and other workload should not lead to a degradation of CPU performance. Hence, another important issue is the manner in which the CPU can be upgraded, considering the upgrade cost, the time for installation, and the possible impact of daily operation.
- Considering the role of the control computer as a file server, a large main memory should often function as a first level storage (cache memory). This could avoid an excessive swapping appearing when a large number of users are being serviced regarding also the amount of memory required by the Storage and File Management System. Besides, fast I/O communication channels with secondary/tertiary memory devices should strengthen its function as a file server.

Additionally, concerning with the role of a large file server as an economical storage of a computational server with a supercomputer or multicomputer system architecture (clustered processors), as specified above, the capability to move data efficiently to and from the computational server, in order to meet the requirement of rapidly processing huge amounts of data, is strictly combined with the interface of the high-speed data channel which must be supported too. Concerning with the **operating system** of the large file server, there are several features regarded as important that must be provided. Among them, the most important are the provisions for sharing memory between processes, asynchronous, non-blocking I/O, the ability to store large files, file access control and security features, and comprehensive accounting capabilities. Asynchronous I/O and shared memory buffers can have a significant impact on performance [Inc92].

The on-line storage The on-line storage level can be seen as a disk cache or stage store of the mass storage system. It is one of the most critical factors affecting the overall cost and performance of the mass storage system. On this storage level the most timely critical and actual data are going to be stored. The size of the on-line storage is going to be determined taking in account the cost added to the system and the performance which is strongly dependent on the ratio between on-line storage capacity and nearline storage capacity. If this ratio is inadequate, the phenomenon of *file thrashing* will appear leading to an unacceptable system performance. This situation is analogous to page thrashing in a virtual memory computer system. Approximately, a ratio 1:10 of on-line/nearline is considered to be adequate [Inc92].

In order to decide about the on-line storage capacity available by the Mass Storage System providing a cost/effective solution, the data manipulation and migration policy (considering the operational database) must be taken in account. The migration policy can be specified by the system operator defining the migration parameters provided by the *site manager* of the Storage and File Management System (see section 2.1.2.2). In this way, priorities can be set up and changed regarding changes in the performance requirements of the system. On the other hand, an amount of archived data of interest will be migrated towards the investigators' local file servers (Research and Development Database). Under the condition of having the most actual data (last 1-2 months) on-line stored and disseminated when needed, an amount of ca. 150 Gbytes should be provided by on-line storage level. Besides, a degree of parallelism at the nearline storage level (multiple drives) and fast I/O channels (high data rate) between control computer and robotic library contribute to an improvement of the mass storage performance deteriorated by the on-line/nearline storage ratio considered so far.

Another important issue affecting the performance and reliability of the on-line storage (indirectly of the mass storage system) is the way of its implementation. General speaking, it should be able to accomodate several implementation means, i.e. IPI disks used singly or with software striping, parallel disk arrays, parallel transfer disks or a mix of them. Speaking in terms of high reliability, **parallel disk arrays** are especially beneficial for the mass storage system with a performance upgrade depending on the appropriate level, as it will be clear in the next paragraph. Furthermore, the controller reliability will affect the reliability of the on-line storage too, which can be increased by having multiple controller paths to the on-line storage (this will be a feature of the large file server design).

Parallel Disk Arrays are perhaps the most exciting development of the past decade in computer storage technology. It has been known as RAID technology for **R**eliable or **R**edundant **A**rrays of **I**nexpensive **D**isks and has been developed over the last few years by researchers at the University of California in Berkeley. RAID is the potential solution to the I/O bottleneck that limits the performance of many computer systems today. In addition to high data transfer rate, RAID provide two other important benefits: *fault tolerant operation* increasing the high availability and reliability, and a *large capacity at*

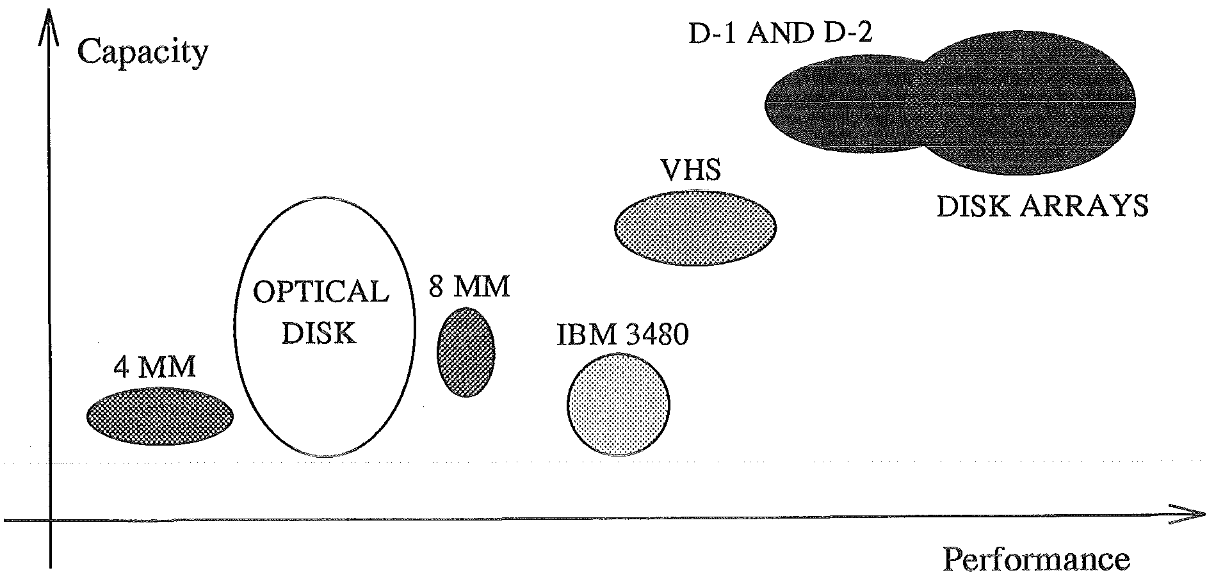

Figure 2.10: A comparison of RAID technology with some other storage technologies

an economical cost. It is expected that RAID will be available by 1992 as standard on-line storage from 90% of large file servers [Inc92]. In figure 2.10, it is shown how disk arrays compare with some other common storage technologies.

The basic concept of a disk array is read or write operations from or to multiple drives at the same time. This leads to an improvement of the rate at which data can be read or written to disks. Therefore, the effective speed of an application execution can be increased by a factor of three[6], if the I/O wait time is minimized. Improving productivity of mass storage systems we do not need faster and faster processors, but high-speed on-line storage that can be accessed rapidly and reliably. Fault tolerant operation and high reliability is achieved through extra parity drives generated by the controller hardware as data is written to the data disks, and stored on parity disks. *This information allows data of a failed drive to be reconstructed even while the operation of the disk array continues.* That means, the mass storage system can continue servicing user requests for file creation and file retrieval even while the bad disk is replaced with a good one and the lost data can be reconstructed. Furthermore, low cost is achieved through the use of widely available commodity disk drives. These can be supported by a wide variety of manufacturers ensured by standard interface protocols in a disk array.

A typical disk array is an array of small (usually 5.25" or 8") disk drives operated together as one unit by an intelligent controller. There are several variations of RAID architecture, known as RAID levels, based on the way of data striping. Each level is po-

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[6] Based on results published by CRAY Research

tentially suited to particular types of applications. It begins with level 1, where there is a full redundancy using an extra disk and controller for each disk containing data for the case of failure, but is too expensive because twice the amount of storage has to be paid. A high reliability remains on the next levels 2,3,4,5, but the redundancy is restricted enormously at a 10-20% of the total on-line storage amount using an intelligent calculation of parity information.

According to the data manipulation characteristics of the *Operational* and *Reseach - Development* database, RAID level 3 and level 5 seem to be the most suitable RAID architectures. RAID level 3 is suitable for large reads and small writes leading to a high performance file transfer. It is suggested for the on-line storage of the operational database where a high performance file transfer is expected. RAID level 5 can provide both high bandwidth I/O and high transaction rate with a limitation for high write speeds. These are expected to be the data manipulation features in the Research and Development Database. RAID level 5 should be supported by the investigators' local file servers.

There are also two other alternatives to similarly stripe disks: *Software Disk Striping* and *Parallel Transfer Disks* (PTDs). With Software Disk Striping it is possible to implement the RAID architecture either through software executing on the host or through firmware executing on a controller. The first is quicker and cheaper than the latter. *The main drawback of this method is that it works best for large files and in cases where there is excess CPU power available.*

The second alternative is through Parallel Transfer Disk drive which is a disk unit with multiple recording surfaces accessed by multiple channels in parallel using a single Head Disk Assembly which transfers data in parallel from several disks. *The major drawbacks of this approach are cost, reliability, and proprietary interfaces* [Inc92].

The nearline storage A *robotic storage library* is considered to be the storage medium at this mass storage system level. It will constitute the Physical Volume Repository of the reference model specified in section 2.1.2.2. The robotic storage library will allow an automated access to data which are not timely critical and are less actual than the data stored at on-line storage. They are migrated from the on-line storage media according to the migration policy established by the *site manager*. They can be accessed in on-line and not in off-line mode like archives. It provides an on-line storage access capacity of several TeraBytes needed by the required system with respect to the requirements of accessing stored data without manual intervention minimizing the operational cost of the system, and the on-line manipulation of huge amounts of data in a timely effective way (information to be provided and disseminated can be accessed without consideration of its physical location and manual transfer from archives to on-line storage).

There is a variety of robotic libraries for various media types (e.g., optical disks, tapes, cassettes) and with a range capacity from a few gigabytes to several terabytes. The various media types can affect the user-perceived performance of the mass storage system which depends in part on time required to restore files that have been migrated to nearline storage. Additionally, the protection security (see also reliability) can be affected by the media type chosen for the robotic library. A high reliability at this storage level is expected having also the advantage of using nearline storage for back-up and preservation purposes during the satellite mission.

Concerning with the amount of data to be stored and preserved during MIPAS satellite experiment as well as with the data manipulation strategy (dominantly storage and dissemination of long files - large reads) taking place in the operational database, the usage of magnetic tapes, like VHS and D1-D2 technology, as a storage medium for the robotic library is still the most appropriate media selection offering, under these conditions, the best cost/performance for the nearline layer, despite the development of several new storage technologies such as optical disks or optical tapes [Inc92]. WORM[7] optical disk technology (they are not erasable) is not suitable for MIPAS data products because of their reprocessing requirements (possible modifications). On the other hand, comparing the new magnetic tape technology with erasable optical disks, a better cost/performance and capacity/performance relation has been shown (see figure 2.10).

Erasable optical disks, like Magneto Optical disks, shall be used at the investigators' local file servers expanding the available storage capacity of the Research and Development Database. They are considered to be inefficient comparing with conventional magnetic disk arrays used as on-line storage (tests have shown that only 1/4 of the total throughput of magnetic disks is reached by read operations, and 10 times slower write operations by Magneto Optical disks), as well as in relation to the suggested RAID technology. For smaller amounts of data than the amounts stored at the mass storage system and for a faster positioning of the required data blocks, according to the data access characteristics in the Research and Development Database, they are the most suitable nearline storage medium to be installed.

Going back to the operational database, the helical scan recorded tapes is the type of magnetic tapes under consideration. The diagonal stripes from the bottom of the tape to the top in a helical fashion, in which the data are laid, is a recording method that provide a higher performance and capacity range than the magnetic tapes using longitudinal scan recording. There are four major types of helical and rotary magnetic tapes: The 4mm digital audio tape, the 8mm video camera tape, the standard VHS home video tape and the D-1/D-2 format tapes. The IBM 3480 tape technology will be also included, because its wide usage often forms the point of comparison for tape products in general. All of these tape technologies can be compared on the basis of various parameters (capacity, shelf life, data transfer rate, etc.), as has been depicted in figure 2.11 [Inc92]. The shelf life of these magnetic tape types is at least 10 years (e.g., VHS: 10-15 years, IBM 3840:

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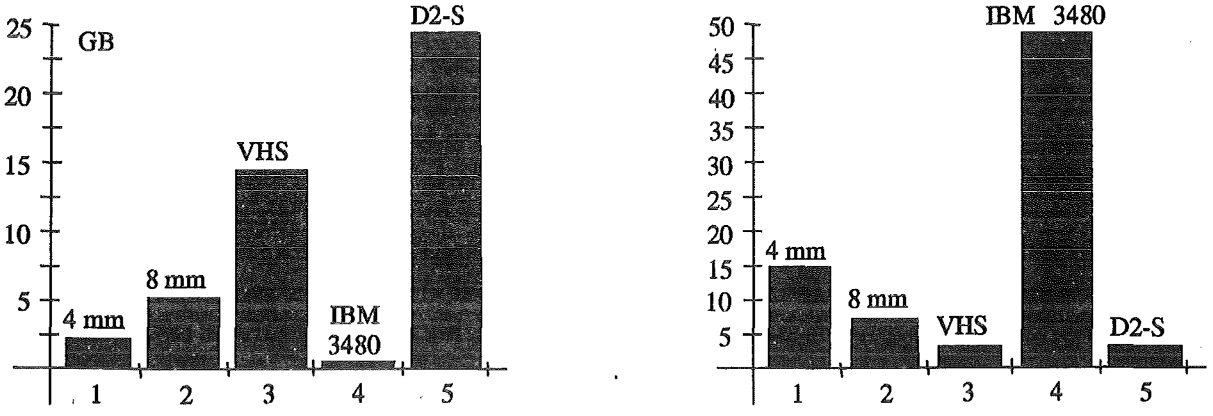
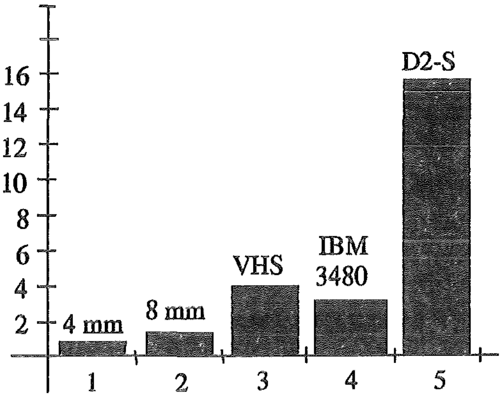
[7] **W**rite **O**nce **R**ead **M**ultiple



Capacity/Cartridge

Cost/GB ($)



Data Transfer Rate (MBytes/sec)

Figure 2.11: A comparison of the main magnetic tape types

30 years, D-2: 17-20 years), and provide a high degree of reliability with an error rate range from 1 error in 10^{11} (VHS) to 1 error in 10^{14} (D-2) achieved through the use of three levels of Reed-Solomon encoding. A degradation of the error rate in relation to the shelf life has not been reported according to the tests done. It should also be mentioned here, that a throughput increase can be expected through multiple recorders mounted in the same robotic library allowing parallel access to several magnetic tapes loaded, and through the suitable controllers installed.

The management of mass storage system The main purpose of the mass storage system is to provide a *virtual disk* to the computational server of the system and to the end users accessing the data and information they need. This must be done providing a file service with large amounts of cheap storage. The management of files stored in the storage levels, described above, is possible with software packages which can meet the requirement of simulating a uniform storage level hiding the physical design issues of the mass storage system. Such a software package is called *Storage and File Management System* (SFMS) according to the terminology used in [Inc92]. It should follow the IEEE reference model specified and described in section 2.1.2.2. There are some SFMSs which can approach or fulfill the mass storage reference model and are supported by several hardware platforms on the level of the control computer. Among them, Control Data Omniserver, AMASS, Common File System (CFS), etc. It is argued that UniTree at most follows the proposed IEEE reference model. For further information about the logical structure and the concepts of a SFMS based on the reference model, see section 2.1.2.2.

2.2.2.3 The front-end part configuration

It is based on a client-server architecture where the local database servers concern with scientific data management - in general, a local database server concerning with numerical data and metadata (the place where the OODBMS will be running), and another one concerning with spatial data and the earth maps (the place where the spatial DBMS will be running) - that are mostly needed for experimentation, studies and extracting of scientific reports. Scientific data will be processed and visualized at advanced workstations capable of graphical representation facilities. Scientific data (especially numerical data) not available locally will be requested from the large file server (the mass storage system at the operational database) and will be transferred to the local database servers which need them. Spatial data, generated in real-time operational mode, and metadata are going to be stored and managed locally.

The local database servers will provide a RISC (Reduced Instruction Set Computer) architecture based on at least 32-bit processor, because of the better performance comparing with CISC (Complex Instruction Set Computer) computers. They should be considered as minicomputer according to their performance category. It's expected that a performance greater than 40 MIPS (expressed in million instructions per second) will be available, and a main memory capacity, which can be easily expanded, greater than 64 MBytes RAM (with respect to its role as a file server). Furthermore, especially for the spatial data server, a graphic processor, a graphic accelerator and a graphic adapter should also be considered integrated in the architecture with an internal system bus at a transmission rate greater than 30 MBytes/sec.

The advanced workstations are also equipped with at least 32-bit processors and 32-bit data bus. Graphics terminals with a resolution of approximately 1 million pixels (1000x1000), an at least 4 MBytes main memory (storage capacity for one image of 1024x1280 resolution with colors determined by 3 Bytes (24 bits)), used as a frame buffer, would be appropriate elements for visual representation of scientific results. Moreover, a graphics workstation would enable the visualization and animation of complex visualization models at an animation rate of 10-15 frames/sec. Larger frame buffers and graphic processors, but above all, a high data transfer rate (indicative: 90 MBytes/sec sustained data transfer rate for 30 frames/sec) between computational server and frame buffers are considered to be essential for this purpose.

For the storage of spatial data and various scientific results which must be exchanged and used by other information systems during, for example, scientific campaigns, a magneto-optical disk jukebox could be regarded as connected to the front-end network through a local database server.

2.3 Summary

A design approach of the required scientific information system for MIPAS satellite experiment, in terms of hardware and software configuration issues, has been described in this preliminary study, in order to meet the requirements specified by the MIPAS scientific team. At first, the essential and desirable requirements of the system have been clarified in relation with the main purpose and scope of the system, as well as the physical environment in which it will operate. Furthermore, a more detailed description of the system requirements followed in order to extract the main characteristics of the system according to its function. These are based on the issues of the data to be provided to the system and its related workloads, on the way in which the manipulation of the provided data take place, on the resultant actions or the information received by the system as a response to the data manipulation.

Afterwards, the design approach of the required system has been presented considering software and hardware configuration issues. The design approach has been implied by the need of capturing the design process of the system as knowledge, in order to cope with a changing operational process model, by the need of meeting the particularities and challenges of scientific databases including the need of providing suitable visualization/animation facilities and an appropriate simulation environment. The system architecture portraying the design approach of the system is based upon two main components, the *operational* and the research and development database, two different processing environments considering their functionality. *The operational database will function as a long field data server for the research and development database.* It deals with MIPAS data generation, management and preservation in long terms, as well as with data access and dissemination based on file oriented access facilities.

On the other hand, a content and context access to experiment data must also be provided for the needs of the MIPAS researchers community. It presupposes the capture of interrelationships of different object types (numerical data, graphical objects, spatial data, metadata-text), which will be managed by suitable database systems. An Object-Oriented Database Management System (OODBMS) is going to manage the numerical data and their related graphical objects, a spatial database (SDBMS) is going to manage the graphical representation of trace gases related to the earth and its atmospheric layers, and a database system is going to manage the metadata in terms of instrumentation and operational description, as well as scientific reports based on the MIPAS data products extracted. A mechanism based on a *Global Model* is going to provide experiment data access according to the interobjects relationships enabling the references of any object type from another one. This makes possible, for example, the access to the related numerical or spatial data with the help of metadata, as well as the explanation of experiment data, in numerical or graphical form, supplied by the related metadata.

The design approach for the hardware configuration of the system considers also two main parts, a front-end based on a client-server architecture via FDDI, related to the research and development database, and a back-end based on a hierarchical mass storage system, its control computer and a computational server with a multi- or clustered processors architecture via a high speed data link (ULTRANET) over a switch node. The latter is related to the operational database. The back-end network (ULTRANET) will be used mostly for file transfers, whereas the front-end network (FDDI) will be used mostly for query/response and control data.

The system has been conceived so that can gradually accomodate changes in workloads and the performance requirements. This is possible by developing a flexible system which can provide data which can be readily saved for decades. In addition, changes in hardware and software to help access the data will also occur. It is unlikely that the system defined today will remain so in the next decade. Considering the history of data systems, it is noted that there have been many changes on time scales of two or five years. A flexible system architecture could enable these changes relying on a basic data archive which can support relative stability so that errors are not introduced by frequent conversion and handling. *The whole system has been designed as an entity that operates on data and provides easy access, and not as an entity that owns the data.*

The development of a data system concerning with atmospheric research and participating in a long term program of documenting the Earth system on a global scale presupposes an understanding of the physical and chemical processes that influence the Earth system. The data system must not fail because of the increase in data volume. On the other hand, scientists are not considered to be good data managers. Therefore, the required system must be developed in an interagency and in an **interdisciplinary** way between the scientists concerning with the chemical processes in the atmosphere and the computer scientists concerning with the data system architecture, in order to overcome the problems that have been recorded so far during the development of systems dealing with scientific applications and experiments [FJP90]. The following citation from [FJP90] shows the increasing need, expressed in the scientific world, of an interdisciplinary environment for the successful development and implementation of scientific information systems.

Scientists and Data Systems Computer Scientists need to work together from the onset of a project to define system requirements and interfaces. There has been poor communication of the problems and needs of the individual sciences to the computer scientists who could meet those needs, because the computer scientists are not listening hard enough. And in the opposite direction individual collections of discipline scientists sometimes elect to invent ad hoc data system solutions, which after the fact are poorer than those which the computer science specialists could have provided. Neither field is at fault; communication between disciplines with different attidutes, paradigms and skills is just difficult. However, the objectives are important and resources are limited. Solving the problem case by case is important.

Acknowledgements I am grateful to Hermann Oelhaf, Cornelis Blom and Thomas v. Clarmann, scientific employees of the Institute of Meteorology and Climate Research for their cooperation and valuable discussions we had.

Appendix A

Data Flow Diagrams

A.1 Abbreviations in Data Flow Diagrams

ATMIFG Atmospheric Interferograms

ATMSP Atmospheric Spectra

BBIFG Black Body Interferograms

BBSP Black Body Spectra

CCSDS Consultive Committe for Space Data Systems

DSIFG Deep Space Interferograms

DSSP Deep Space Spectra

HK House-Keeping

ID Instrument Data

LOS Line of Sight

LTE Local Thermodymanic Equilibrium

ND Navigation Data

SD Satellite Data

TP Temperature

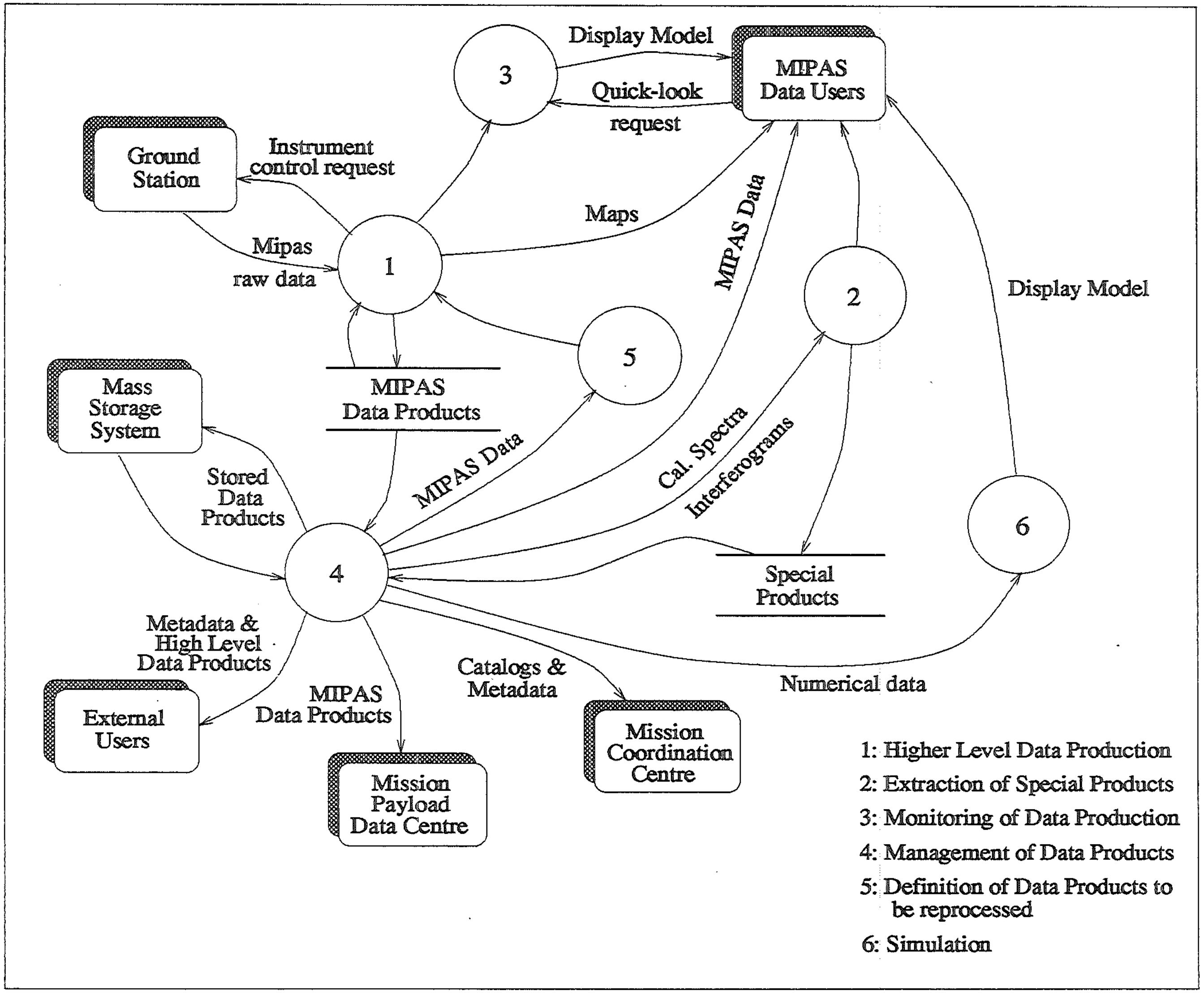


Figure A.1: Data Flow Diagram of the required system

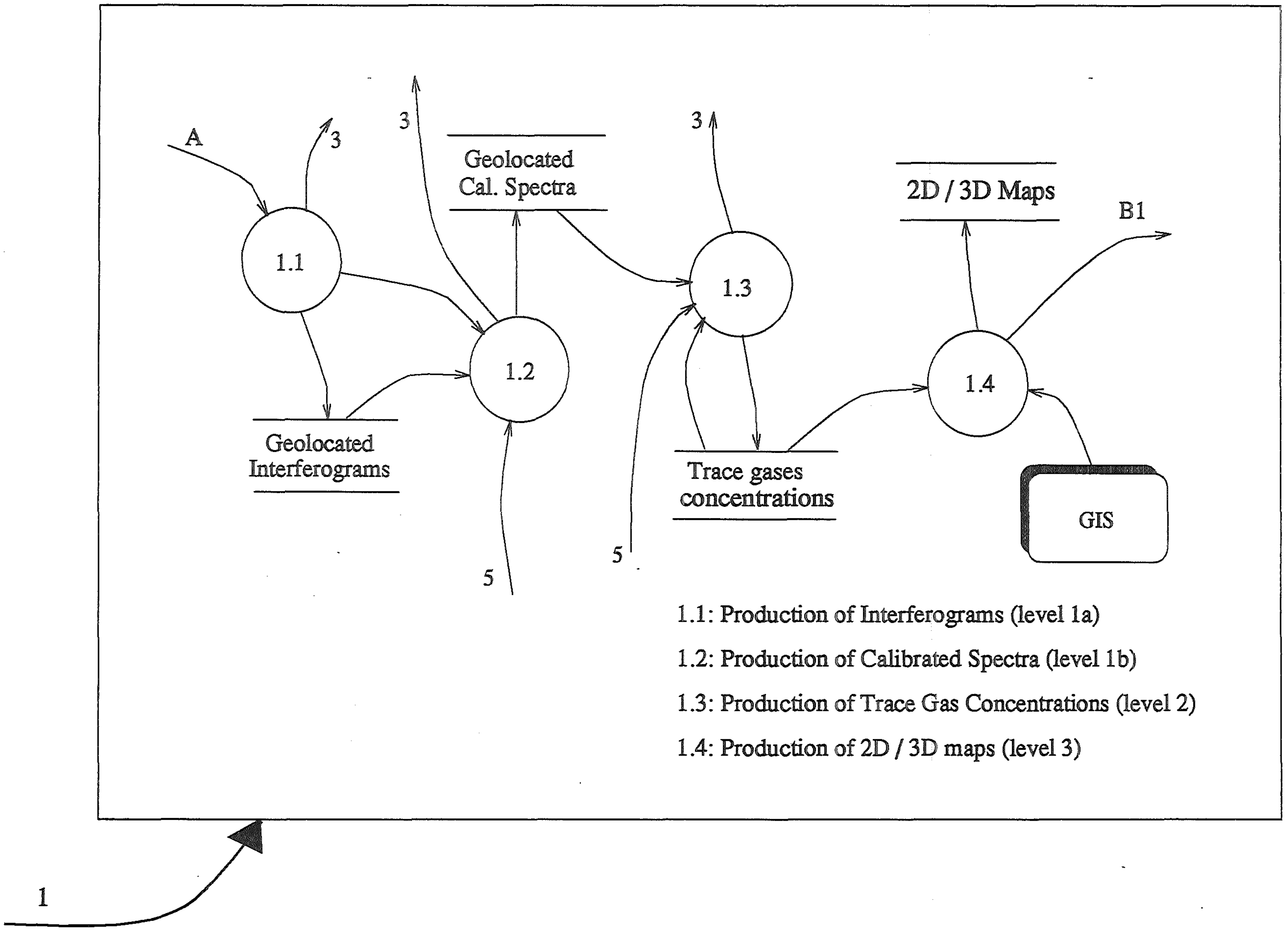


Figure A.2: Data Flow Diagram of MIPAS Data Products Generation

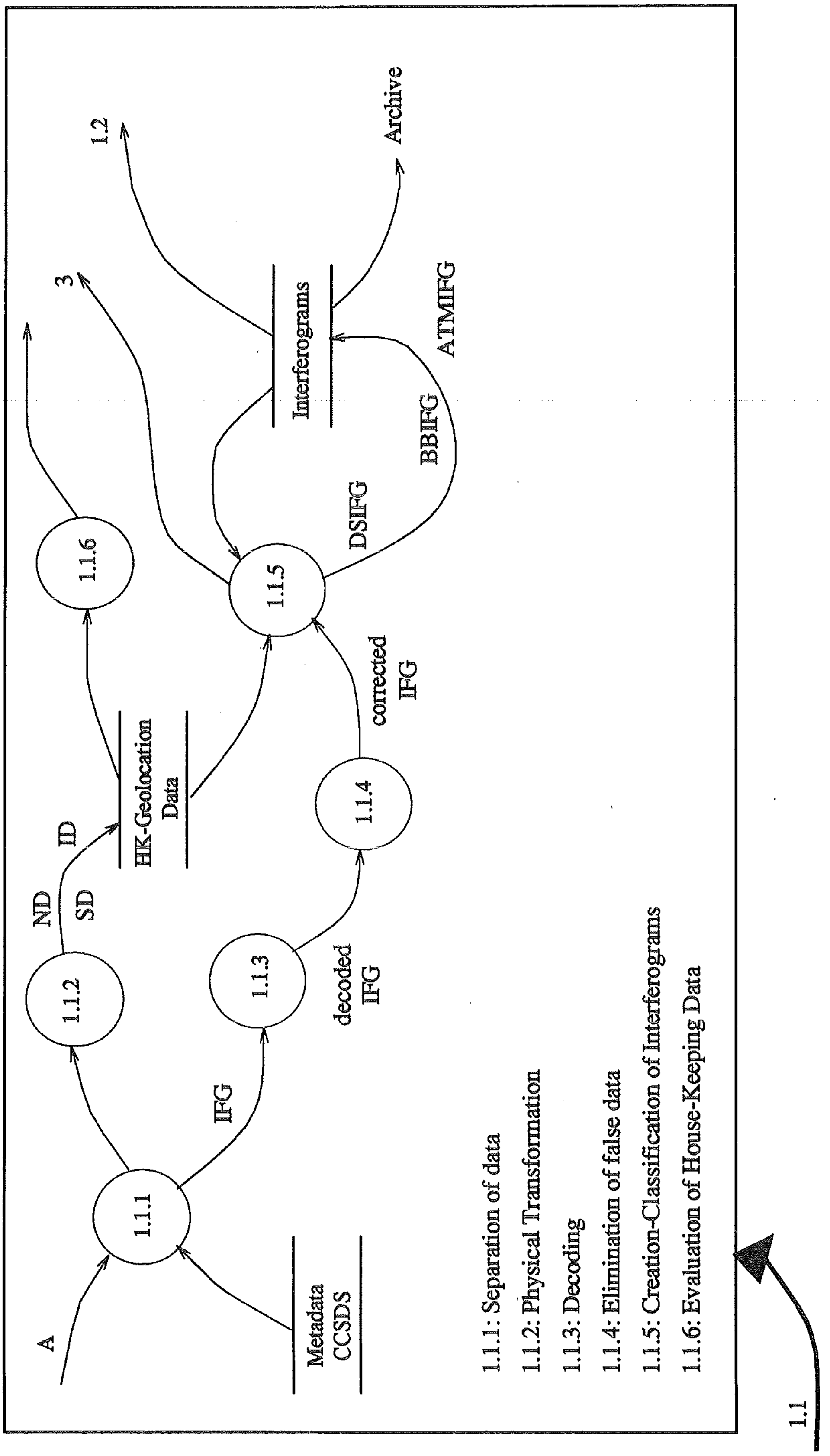


Figure A.3: Data Flow Diagram of Inteferograms Generation - Level 1a

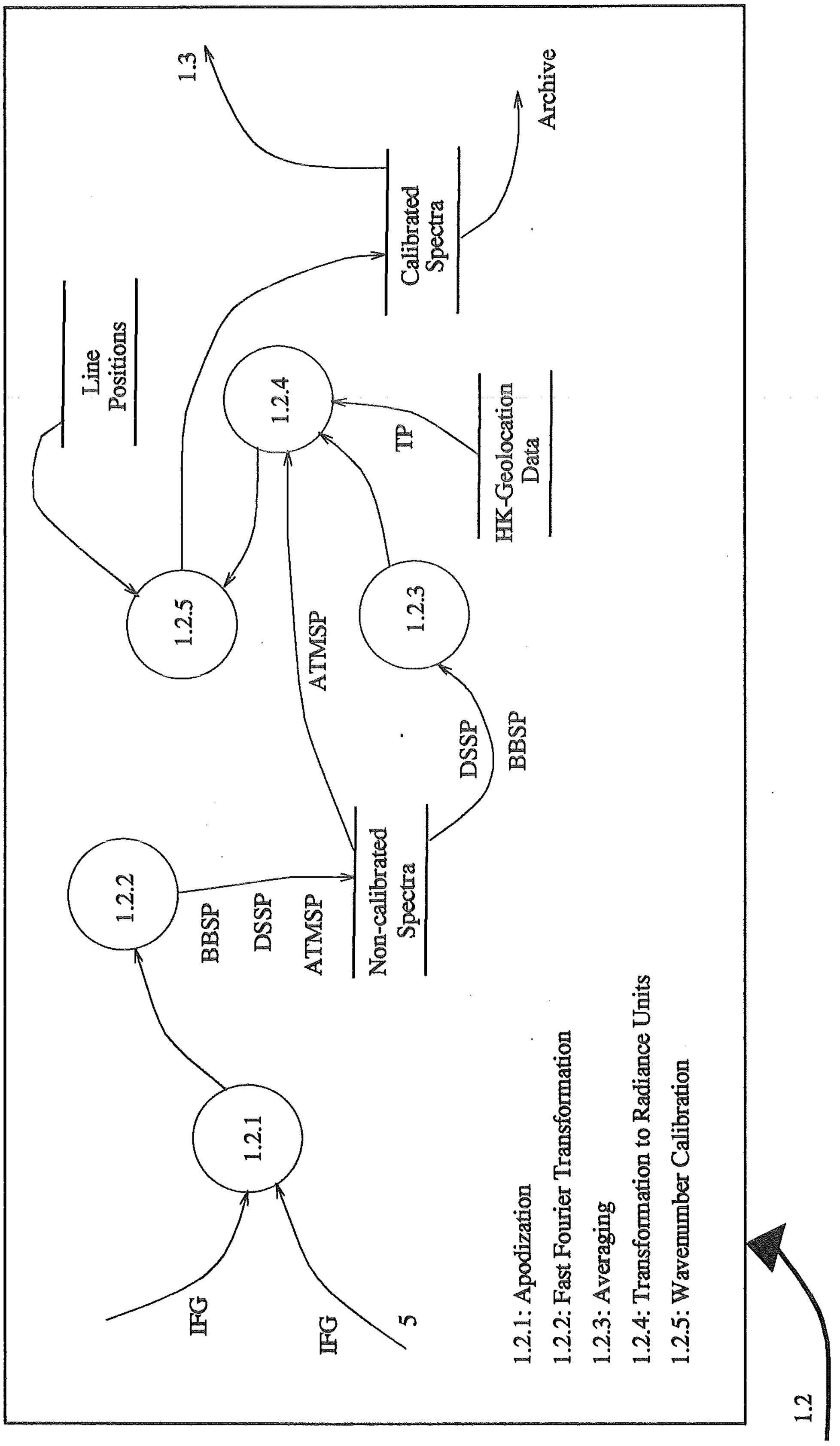


Figure A.4: Data Flow Diagram of Calibrated Spectra Generation - Level 1b

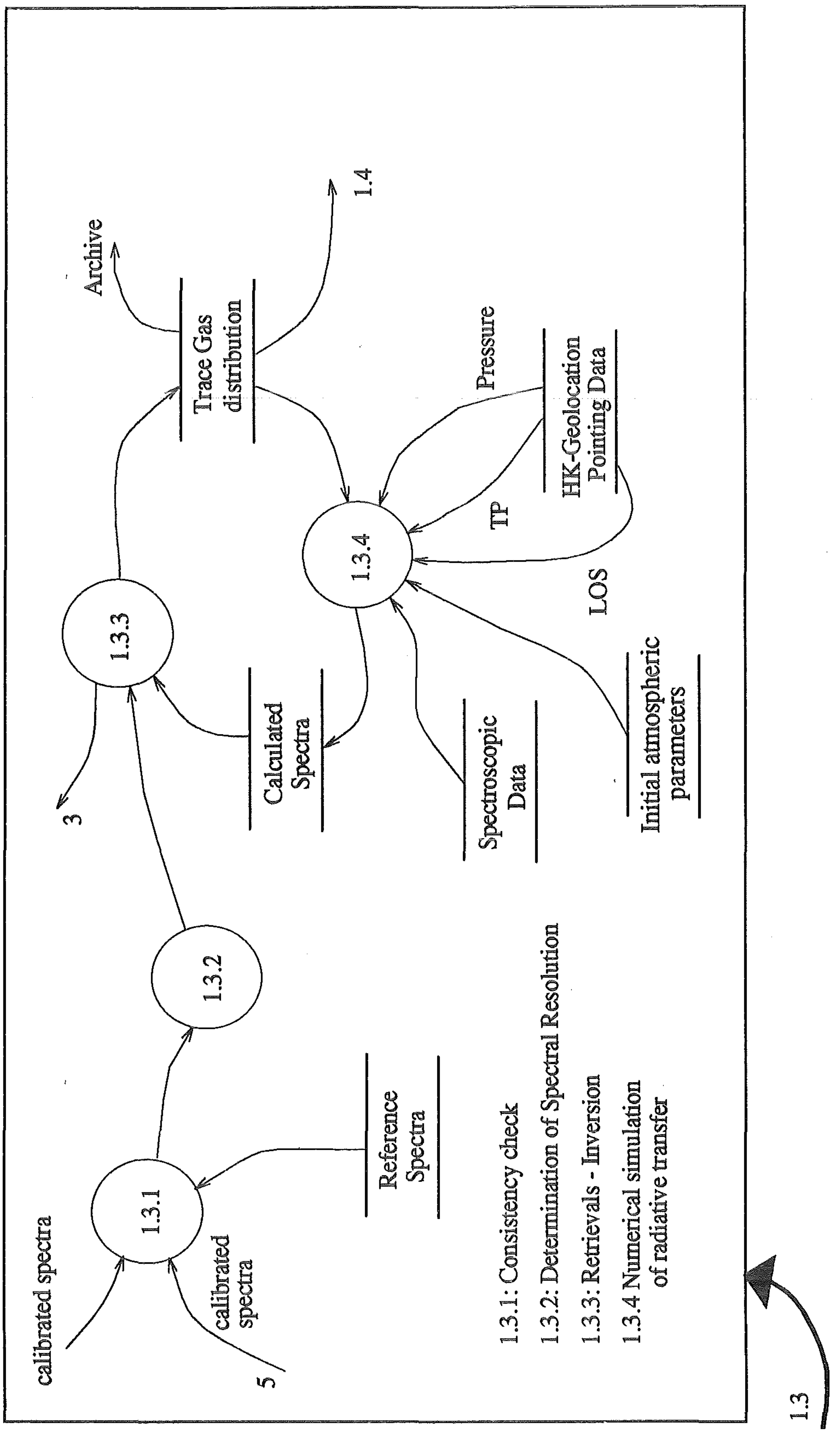


Figure A.5: Data Flow Diagram of Trace Gas Concentrations Generation - Level 2

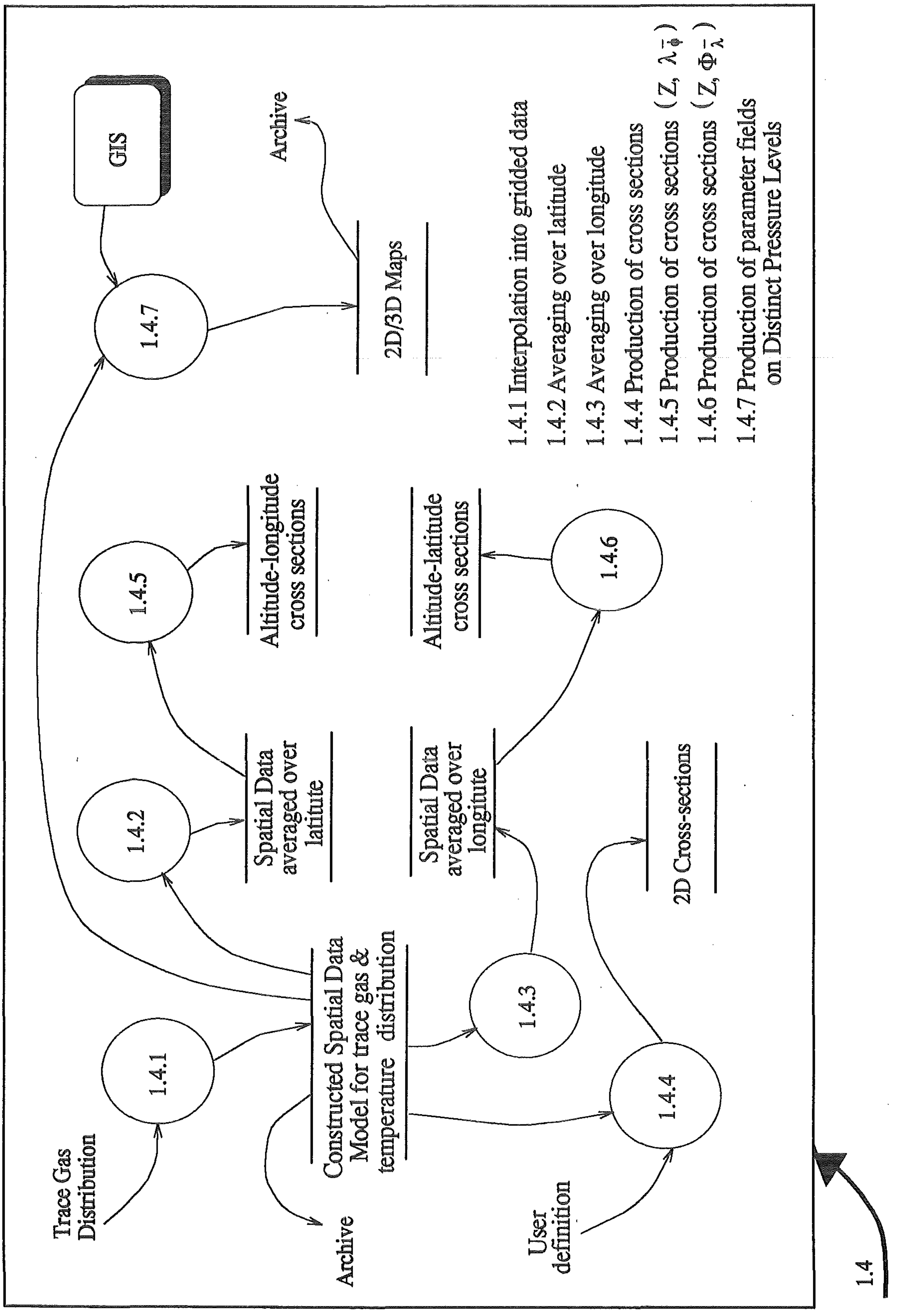


Figure A.6: Data Flow Diagram of Spatial Data Construction and Visualization - Level 3

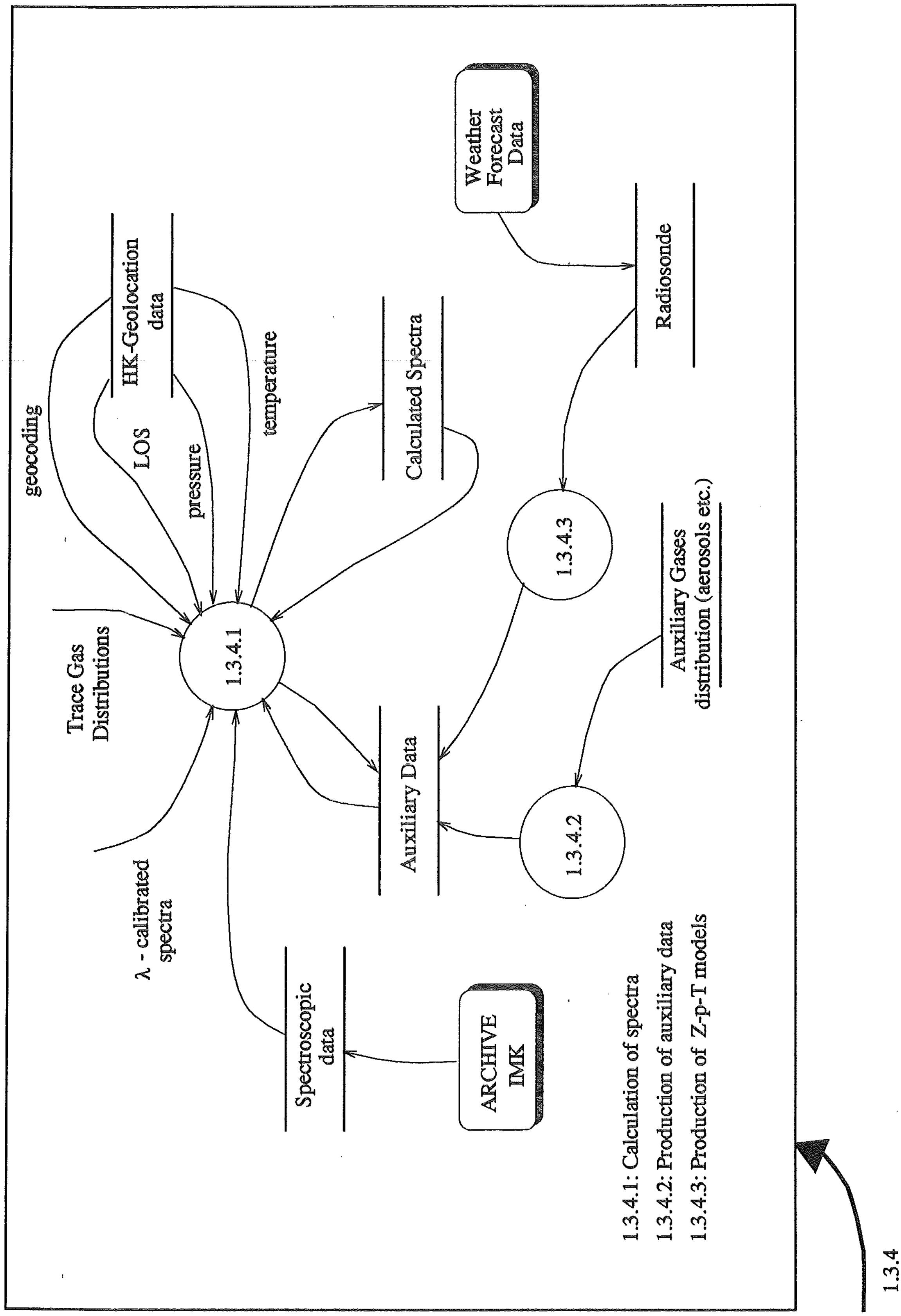


Figure A.7: Data Flow Diagram of Numerical Simulation of Radiation Transmittance

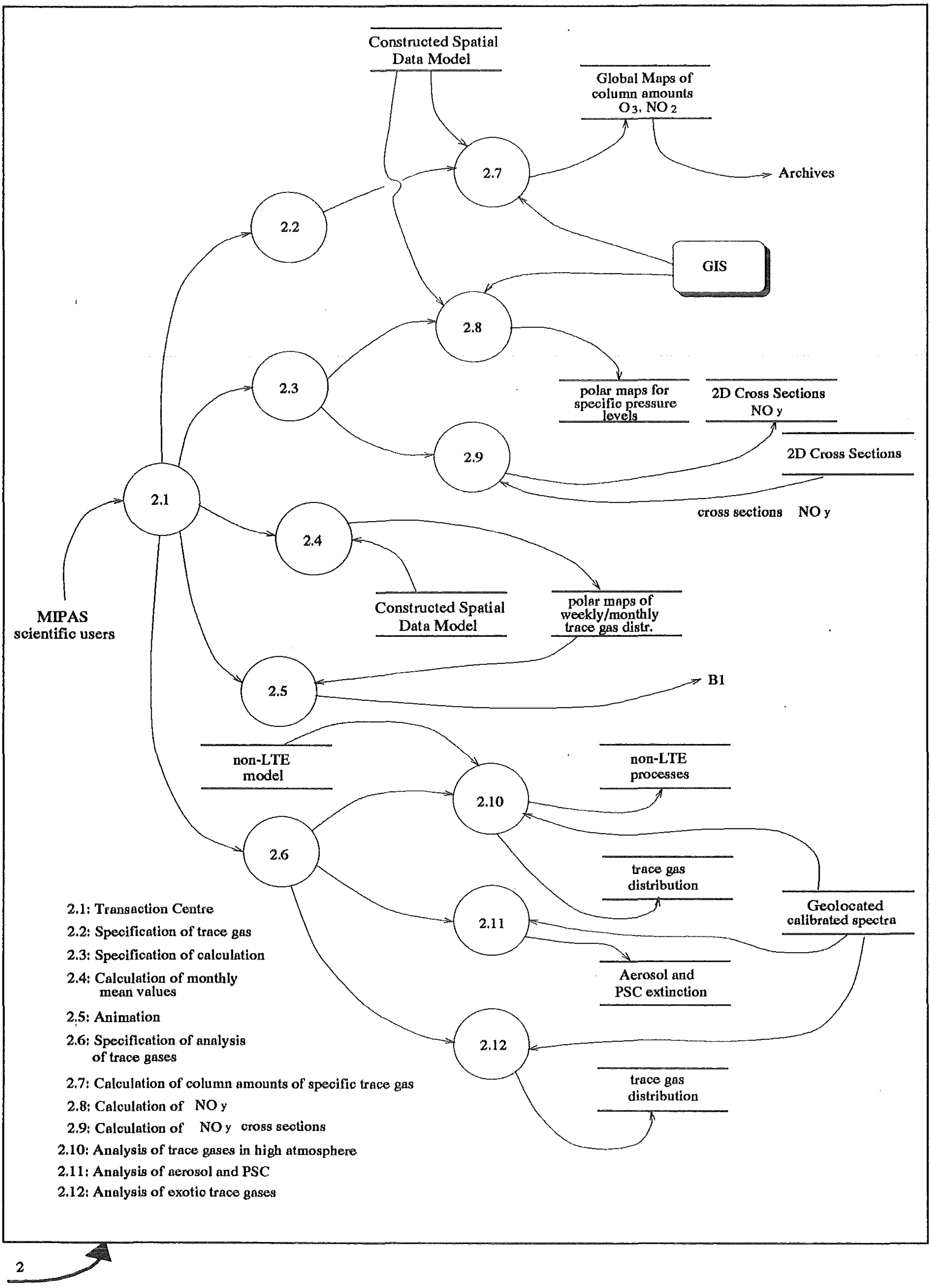


Figure A.8: Data Flow Diagram of MIPAS Special Products Generation

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