

Long-Term Archiving and Data Access: Modelling and Standardization

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Abstract

This paper reports on the multiple difficulties inherent in the long-term archiving of digital data, and in particular on the different possible causes of definitive data loss.

It defines the basic principles which must be respected when creating long-term archives. Such principles concern both the **archival systems** and the **data**.

The archival systems should have two primary qualities: independence of architecture with respect to technological evolution, and genericness, i.e., the capability of ensuring identical service for heterogeneous data. These characteristics are implicit in the Reference Model for Archival Services, currently being designed within an ISO-CCSDS framework. A system prototype has been developed at the French Space Agency (CNES) in conformance with these principles, and its main characteristics will be discussed in this paper.

Moreover, the data archived should be capable of abstract representation regardless of the technology used, and should, to the extent that it is possible, be organized, structured and described with the help of existing standards. The immediate advantage of standardization is illustrated by several concrete examples.

Both the positive facets and the limitations of this approach are analyzed. The advantages of developing an object-oriented data model within this context are then examined.

1. Introduction

The observations and data gathered during spaceborne scientific payloads carried on board satellites or interplanetary probes are archived on the ground in the form of digital data, which are generally accessible to the PI teams or to larger communities. After more 30 years of experience in this field, the following facts have been observed:

- the volume represented by this data is always on the increase;
- some of the data has been lost because the physical medium became unreadable;
- other data has been or is likely to be lost because its structure was dependent on operating systems which are now obsolete;
- other data has been lost because an exhaustive and correct data description was no longer available;
- it has turned out to be impossible to keep as many access softwares in operating order as there are sets of data - essentially for reasons related to cost. Consequently, some of the data, while not actually lost, is no longer accessible;
- knowledge - or rather human expertise - concerning the oldest data is quickly disappearing.

Within this context, a safeguard plan for conserving data archived on 70,000 magnetic tapes at the French Space Agency (CNES) has recently been implemented. This data represents, for the most part, a priceless scientific heritage which should remain of great interest for several decades to come, or even longer. The cost of producing this data represents, in fact, the cost of all scientific space missions since the 1960's, which is, needless to say, enormous.

In practice, most of the observations made above are valid in many other fields (scientific, cultural, audio-visual, industrial, etc.). They boil down to the contradictions between the need to archive data in the long term and the speed at which the technology being used becomes outdated. Generally speaking, the loss of digital data is very often 'insidious', as the digital data is not physically 'visible'. Due to this fact, its degradation does not strike the mind as strongly as the deterioration of a book, for example, whose characters get less and less readable with time, or like an historical monument which crumbles to the ground.

This analysis led us to undertake a thorough technical study of the problems posed by long-term archiving. We reached the conclusion that the setting up and maintenance of long-term archival services can only be achieved if certain stringent conditions are imposed **on the archival systems and data.**

In order to avoid any ambiguity in the vocabulary, let us specify that by the term **archival system**, we mean a hardware and software system responsible for the main archival functions: insertion of the data supplied by the data producers, conservation of the data and anything needed for interpreting it, access to the information concerning the data and dissemination of the data to the users. Such a system is itself a component of an archival service, which is the human organization which, in particular, maintains this system in operating order.

Briefly, it may be said that archival systems should respect two main requirements:

- **the independence of their architecture** with respect to technological evolution: any archival system relies on rapidly evolving technologies and must thus be able to evolve along with these technologies. Nevertheless, its architecture should be such that technological evolutions in one field (the physical media containing the data, for example, or else the user interface) should not have repercussions leading to an uncontrollable chain reaction throughout the system. The system components must thus not be correlated among themselves. This characteristic led us to reflect on the modelling of archival services, and to design a Reference model for these services [4].

- **the genericness**, i.e. the capability of ensuring an identical service for heterogeneous data. The primary aim of this genericness is to reduce the volume of software to be maintained.

At the same time, the data should also take into account two other requirements:

- **its independence with respect to any technology**: the data should be capable of an abstract representation which is completely independent of the technology being used,

- **the application of standards** to the data in terms of structuring, organization, description, etc. The application of such standards is a necessary condition if the objective of genericness, defined at the system level, is to be attained.

An archival system prototype was developed by CNES in 1995 to test such an approach.

later in this article we will analyze - through the lessons learned in our experiments - the consequences of the requirements specified for the system level and for the data and metadata level.

2. The problem on the system level

It has been seen that any archival system is based on rapidly evolving technology. Our purpose should thus be to construct a modular system in which each component is sufficiently independent from the others to be able to evolve individually without calling either the system architecture or the principles of inter-component communication into question.

At the level of the MMI component, the emergence of W3 is a typical example of rapid technological change. The use of X11-type client-server systems has very quickly become outdated. Many access systems have thus become obsolete. Only those systems designed with an independent MMI component were able to adapt easily to this new technology.

These considerations first led us to look for a solution in terms of a general model for a long-term archival service which would be totally independent of technological advances. Other teams, in particular in the USA, have taken a similar approach and it soon became clear that we shared a common view of the problem on the first level of the model.

This first level of the archival service model was no more than an outline and an elaboration of an actual Reference Model which is currently being used within an ISO-CCSDS framework [4]. We shall thus limit ourselves to a rough description of this first model, and then go on to describe a system prototype developed by us in conformance with this preliminary model version, along with the lessons learned from this prototype.

It seems useful first of all to define the limits of an archival service and to identify the external elements interacting with this service. The following four external elements may thus be distinguished:

- the data producers,
- the data users,
- the system administrator,
- the authority responsible for choices and for decisions regarding policy and financing.

At the level of the model diagram shown below (figure 1), we have not included the latter since its interaction at the level of the archival system is limited.

The service itself consists of five major functions (or sub-services) with respect to the data : (see figure 1)

- **ingest**, which serves as the interface between the data producers and the service. This function controls the conformance of data and metadata provided by the producers with respect to the requirements defined by the archival service (standardization, etc.) and performs the actual insertion of this data and metadata into the service.
- physical data **storage**, involving an interface which hides the internal architecture. This storage may be designed to comply with the IEEE Mass Storage System Reference Model,
- data **management**, based on the organization of metadata,
- **access** to metadata which makes it possible for the service to check the user's access rights and for the user to be aware of the available data and to define a query,

- **dissemination** which makes it possible to retrieve the data from the storage service, to extract the parts in which the user is interested, and to deliver these parts to him.

Note: The distinction between external and internal elements must be made clear before the limits of a long-term data archival and access system may be defined. In our approach, the formatting of the data into a normalised and long-lasting format is done by the data producer rather than by the archival system. Similarly, any processing for the purpose of data analysis is the responsibility of the data user, while the service is uniquely responsible for delivering the data corresponding to the user's query.

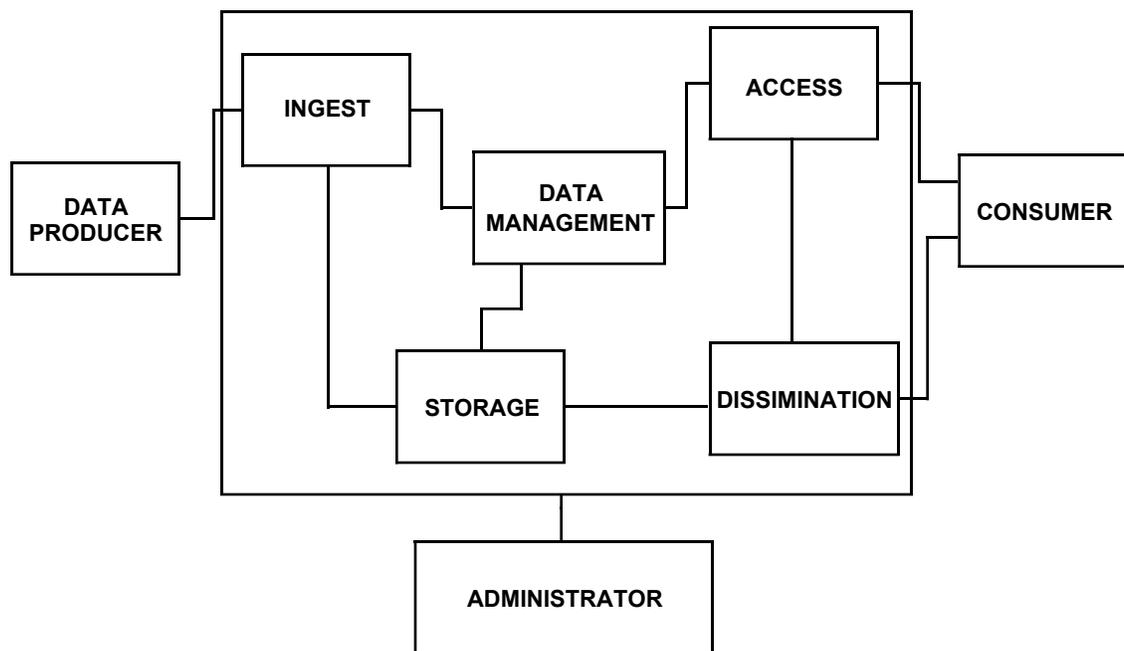


Figure 1: Preliminary view of the archival service model

Architecture of the first prototype

An archival system prototype was designed essentially on the basis of the modelling principles defined above, by making use of components already installed and used by CNES. Each component will be specified below, along with its description.

The system proposes access to chronologically ordered data. Within the system, a 'set of data' is characterized by a set of homogeneous data acquired in the same experiment, and having undergone the same processing. The principal components of a user query are the set of data and one or more time intervals with which it is associated.

- The storage system used is STAF (*Service de Transfert et d'Archivage des Fichiers*, or "File Transfer and Archival Service"). This system for the long-term physical preservation of data was set up at CNES 2 years ago. It functions in a heterogeneous environment, and is based on a client-server architecture. The client, responsible for data archiving and retrieval, functions on different host systems (UNIX, NOS-VE, etc.). This type of architecture makes the storage technology, and thus its evolution, invisible to the user (see figure 2).

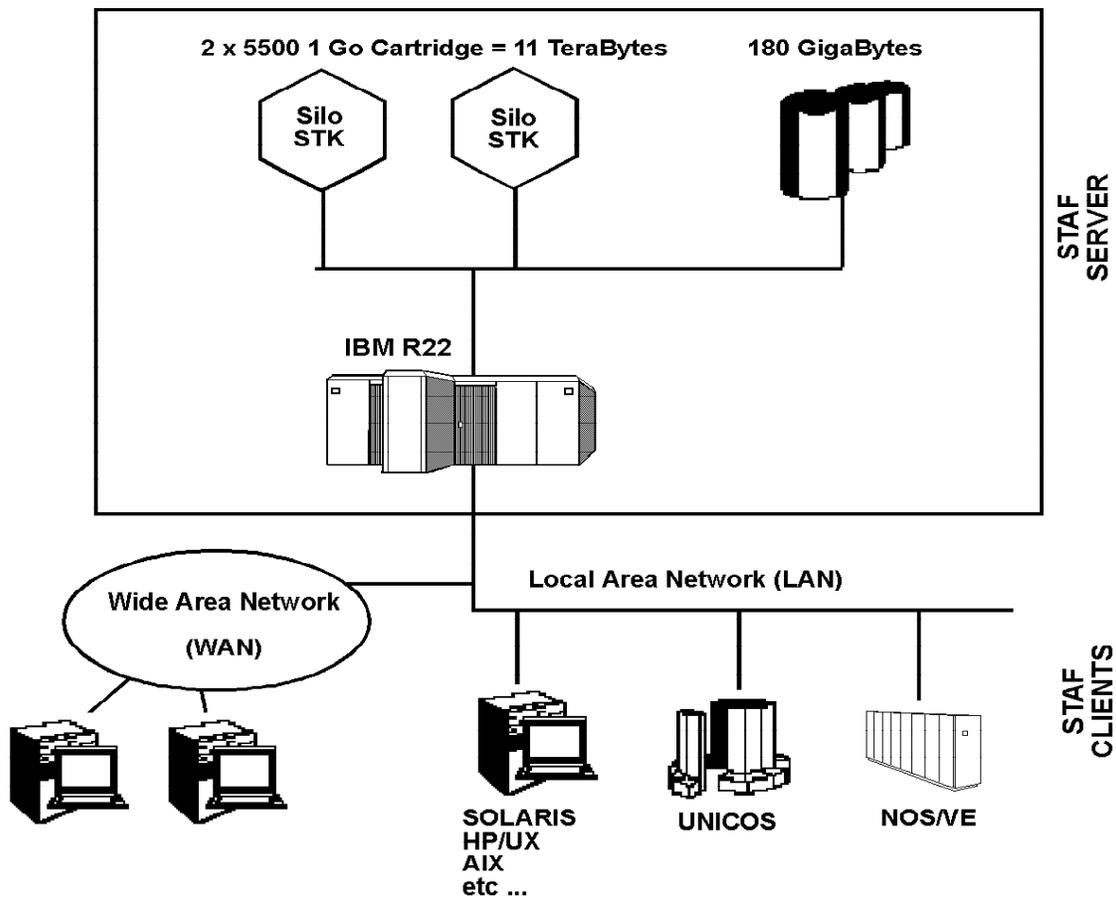


Figure 2: STAF diagram

- Metadata is managed by means of an ORACLE relational data base (cf. figure 3). This concerns for the most part the set of references for data placed in the storage service. The data base also manages :
 - the data protection,
 - the management of browse data (quick-looks),
 - the resources and quotas allotted to each user.

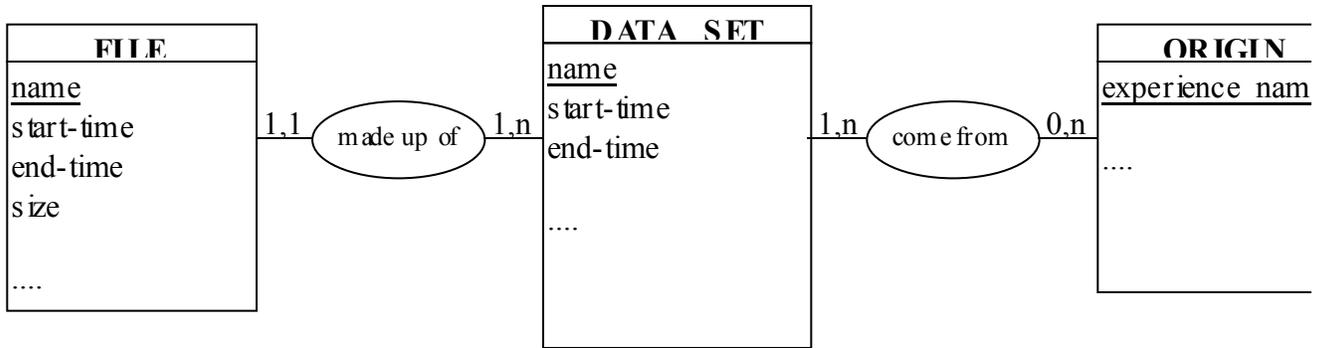


Figure 3: The main elements managed by the data base

- The data ingest service inserts only the metadata into the system, at the level of the data manager. This is performed by software based on the Oracle SQL*loader tools. The insertion of the data itself at the level of the storage function is independently performed by the data producers.
- The access service is based on a WWW server. The latter is linked to the data base by means of a cgi-bin written in Pro*C. The WWW server is responsible for checking the user's identification. This service is a critical point in the system, as it provides system access throughout the Internet. It has thus undergone a security study, to prevent any ill-intentioned intrusion.
- The data dissemination service is the set of generic programs enabling both the retrieval of data from the archive and its delivery, either by means of an FTP onto the user station or, at the level of the server station, into a W3 directory owned by that user. These programs, written in C, depend on a standardized date format, and use EAST descriptions [2] to extract the parts in which the user is interested from the archived files (see § 3.2).

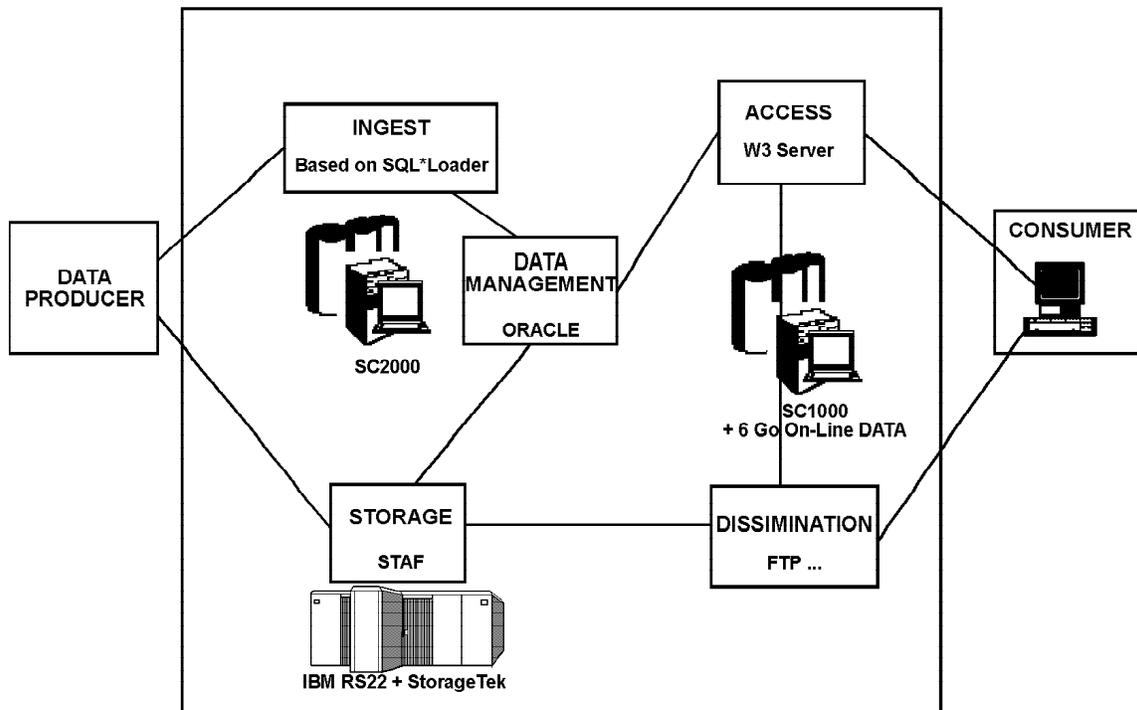


Figure 4 : The prototype architecture

3. The problem as far as the data and metadata are concerned

3.1 Fundamental rules for data independence with respect to the technology

The first fundamental rule, which is clearly necessary, is the independence of the data with respect to the machines, the operating systems and its environment in general. Any digital data item can be abstractly represented by a sequence of bits divided into fields. Each field may be subdivided into sub-fields, and the latter may be further subdivided until indivisible units of information are reached. The first rule requires in particular:

- that the bit sequence contain no information inserted by the operating system which created it: only the relevant bits defined by the user shall be included. Consequently, the use of any file structure into which the operating system has inserted information to help in administration or control is strictly forbidden.
- that the coding of elementary fields be performed in conformance with recognized standards (ISO/IEC 646 for characters, IEEE for floating-point numbers, standard representations of images and graphs, etc.) and that any representation specific to a given manufacturer be prohibited.

The second rule to be applied concerns the necessity of having an exact and exhaustive description of the bit sequence available: the position of each elementary field, a description of this field's coding, the nature and meaning of the information contained in this field. This second rule prohibits, for example, reading and writing data through the blind use of software tools which do not provide thorough knowledge of the bit sequence in its abstract representation.

While these requirements are elementary, they are far from having always been respected. They apply both to data and to metadata, and are necessary if the aim of data independence is to be attained. They apply to the abstract representation of the data rather than to its actual physical storage, which depends on the technology available at a given moment. They may naturally meet with difficulties related to a lack of standards in a given field.

3.2 The application of advanced data standards and the key to system genericness

The infinite diversity of information representations which may be imagined is such that it is certainly useless to try to provide advanced and generic data access facilities without first investing in the standardization of these representations. Let us consider two simple examples which we have encountered, concerning the standardization of times and dates on the one hand, and the standardization of descriptions on the other hand.

Standardization of times and dates : in certain scientific disciplines such as Space Physics, data is often organized chronologically. We discovered in the older data that the variety of time and date representation formats was almost as large as the number of existing data sets. Given such a situation, when a user is interested in data for a given time frame, two options exist :

- either to supply the archived files containing this time frame, which is hardly satisfactory,
- or to develop and implement at the archival system level a specific extraction program for each set of data, an unrealistic approach with respect to the long-term perspective.

It quickly became obvious that a standardization of times and dates would resolve this problem in a satisfactory manner. We therefore selected the standardization proposed by CCSDS [1], which is more complete than the ISO standard in this field. For our first prototype, we were able to develop a general program for the extraction of data corresponding to one or more time frames defined by the user from one or more files. This program makes it possible, as shown in figure 5 below, to extract only that data which corresponds strictly to the time frame requested by the user. The extraction function is entirely independent of the archive structure:

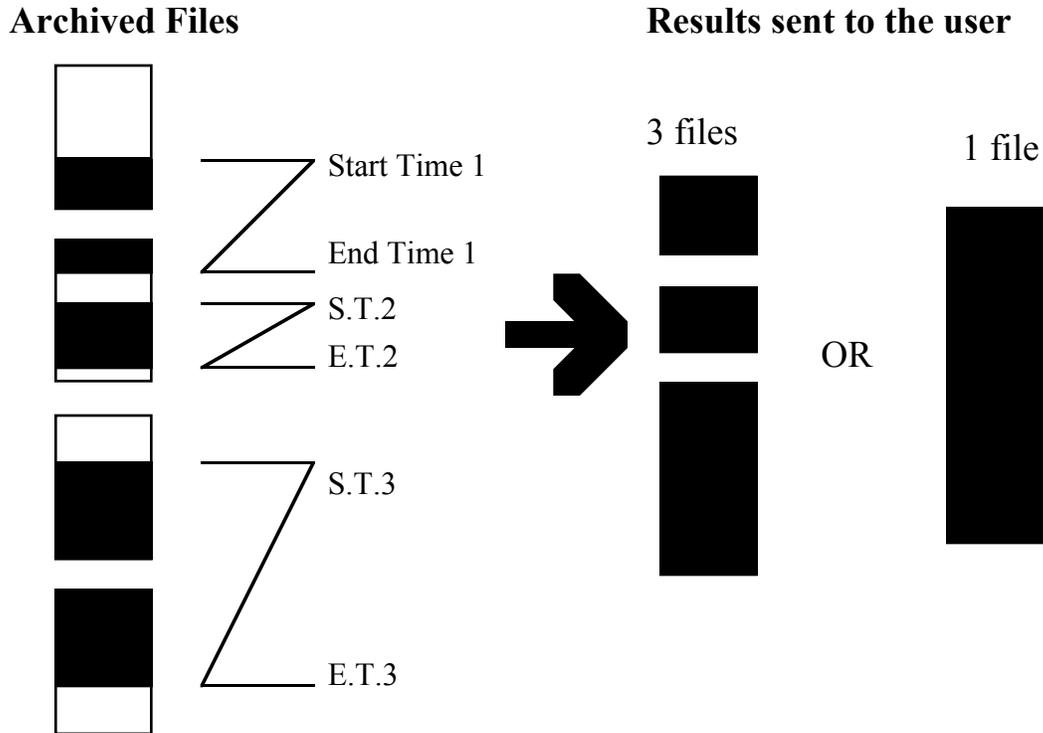


Figure 5: Extraction of chronologically ordered data

Standardized data descriptions : we discovered that the data was often described either incompletely (certain fields are left out of the description) or incorrectly (due to changes in the data creation program which were not carried over to the description documents). Moreover, the form of the description generally differs from one project to the next. The beginnings of a solution to this difficult and crucial problem in long-term archiving were found through the standardization of data description languages.

Our experiment, in our first prototype, was based on the EAST language (Enhanced Ada SubseT, [2]). This is a formal language around which certain general tools have been or are currently being developed. Worth mentioning in this field, in particular, are the Data Description Record Generator, the Data Generator, the Data Interpreter and the Data Formatter [3].

The interactive creation of data descriptions in EAST is performed with the help of a graphical interface, and the use of these descriptions for reading and writing data makes it possible to guarantee, during construction, the consistency between the data and its description.

Within this framework, we experimented with the use of a generic tool enabling the user to select a subset of information fields present in the archive.

The use of this tool involves two stages:

- a first stage in which the user selects the fields in which he is interested. A hierarchical tree representation of the different data fields is constructed on the basis of the EAST description. Using this representation, the user identifies and marks the fields in which he is interested (WWW interface).
- a second stage in which data is extracted from an archive and then 'filtered' so as to preserve only those fields requested by the user. (cf. Figure 6)

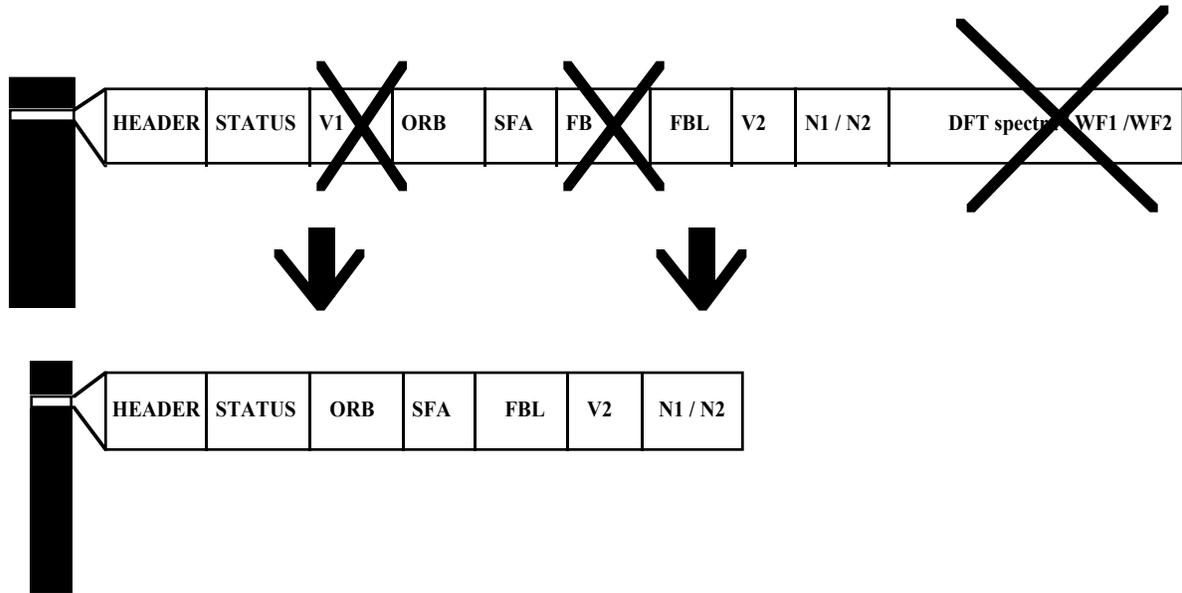


Figure 6 : Field extraction

The above are two meaningful examples with which we have experimented. They illustrate the correlation between the level of data and metadata standardization which we were able to attain and our capacity to preserve and keep the data accessible in the long-term.

4. Learned lessons

Positive points to be retained from the experiment with this first prototype

The aim of genericness within the field of chronologically organized data was achieved. Once the data producers began to respect the requirements set forth with respect to time and date standardization, we noted that it became very easy to access new data and hence that our approach had not simply been idealistic. At the present time, the system offers access to 32 different sets of data acquired during 5 space missions (INTERBALL,

Sweden VIKING, ISEE1, VOYAGER, GEOS). No specific tool had to be developed to make this data accessible through our prototype.

The service provided to the user is much better than the simple extraction of data from an archive, and since the volume of data transmitted to the user corresponds only to that data in which he is actually interested, there is a much more free space on the network to perform these transmissions.

Scientists do not naturally apply standards simply on principle. On the other hand, in a case such as that of times and dates, when the experiment teams applied the standard at the moment of data production, they perceived it as a way of immediately obtaining a better access service.

The limitations

The use of a relational model is the main limitation of our system. Adding a new selection criterion other than those defined at the moment of installation involves serious modifications both in the relational model of the metadata management function and in presentation at the level of the access function. This limitation curbs the open-endedness of the system.

5. Conclusion: towards an object-oriented data model

Without going into the details of work currently being performed on the object-oriented modelling of a long-term archival service, we shall explain a few important concepts:

- Data with shared characteristics can be collected into sets known as 'collections'. These collections can then be grouped together into 'collection groups', the collection groups themselves can be grouped together as well, and so on. Moreover, a collection may belong to several distinct collection groups. This representation led us to the construction of a directed graph.
- In order to define a query, a user will navigate through a directed graph which groups the data together according to scientific field, selection criteria or any other shared characteristic. To reach the data itself, each group offers selection criteria by means of which the user may select a given daughter group. This approach will provide the user with an infinite number of possibilities when searching for interesting data: if he wishes to create a new search route, he need only install the new groups needed to propose it.
- The lowest level group is a data collection grouping together a set of elementary logical data objects, while these logical objects are themselves made up of storage objects, i.e. in the general case, files. This approach, which may seem complicated at first glance, provides the system with considerable flexibility. A collection could correspond to a virtual data set, created at the same moment as it is being accessed.

For example, a set of image data can, at the level of storage, be made to correspond either to files containing several images or to files containing only a part of an image: through this approach, this becomes invisible to the system, which enables access to a collection of images reconstituted during this access, either by cutting up a file or by concatenating several files.

- Selection criteria for specific cases are available at the level of the groups or collections, and the same approach could also permit transformation or delivery criteria which could be applied to the data collections.

References

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