Preliminary Design of a Distributed Planetary Image Data Archive Based on an ATM Network

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Abstract. Various space agencies offer image archives from satellite missions and the Earth. Searching for specific image data still remains a tedious process. Determination of the exact image contents is often hard because of low quality quicklooks. When one receives data they are stored on a CD or tape and usually exceed the area of interest by far. The proposed GDSS (Graz Distributed Server System) applies to archives holding full resolution data of an entire planet. GDSS itself holds quicklooks of all available images throughout the archives and surface maps at different levels of detail representing all known areas of the planets. It can be searched by remote access via a flexible high speed ATM network with a special client software that is capable of searching and visualizing the planetary surface and quicklooks of the available images. The remote access remains invisible to the user. In addition certain authorized users can place orders for full resolution data which will cover exactly the area defined by the user. Data management concepts and storage methods have been developed for a NASA data set of planet Venus. Yet the proposed concepts can also be applied to Earth based remote sensing data. Currently a testbed is being built and initial experiments are being performed.

1 Introduction

Getting an exact region of interest in a large set of image data is a tedious process due to either searching through low quality quicklooks or using poster photo-prints. This experience is shared by many researches, and in this paper it is exemplified by the 500 GByte image set of planet Venus which was produced by NASA's Magellan satellite. NASA's Planetary Data System (PDS) [1] offers access to the entire image data set from Magellan. We report on ideas and results in organising this data set for ease of access from remote sites. This work is result of the European Magellan Data Node (EMDN) [2] which is organised as part of NASA's PDS under an agreement between NASA, the Austrian Space Agency and the Institute for Computer Graphics at the University of Technology, Graz.

During the Magellan mission to Venus about 98% of the planet's surface was mapped by the spacecraft's sensors. The data set consists of SAR images (>5200 orbits) with a total volume of about 500 GByte [3, 4]. The orbits (polar, north to south) are grouped into three cycles defined by different look angles of the SAR sensor. Images from Cycles 1 and 3 can be used for same side stereo processing because of their different look angles.

We propose that access image data like Magellan's be based on the Graz Distributed Server

System (GDSS). It is designed for giving a geographically dispersed scientific community easy and unified access to planetary data. GDSS' graphical user interface (GUI) supports search capabilities both with low resolution image versions as well as full resolution data retrieval from attached archives. The basic ideas in GDSS are not restricted to the Magellan data set of Venus. This serves as a first example. Data management concepts, access to parallel computing resources and network design developed within GDSS can also be used for Earth based remote sensing data.

2 Related work

Earth observation with its large spatially organised data has spawned various systems for image cataloging and remote retrieval. Examples include „Spacepicture“ [5], VISTA (Visual Interface for Space and Terrestrial Analysis) [6,7] and GISIS (Graphical Intelligent Satellite Information System) [8], which are designed to give remote access to various remote sensing data. GISIS supports the user with an intuitive graphical user interface and a detailed zoomable 2D vector map of the earth. VISTA supports a 3D vector representation of Earth. The European Commission CEO (Center of Earth Observation) has initialised the development of a new 2D/3D browser named EWSE (European Wide Service Exchange) [9]. It has some special new features which allow registered users to search, input, update and customise the information content via their WWW browser. Furthermore the Ionia AVHRR Net Browser [10], the Arno project [11] and the Landsat/Spot browser by the Canadian Center for Remote Sensing and Earth Observation [12] should be mentioned.
There exist only a few systems that handle planetary data retrieval. ImageNet from CORE software technology Inc. [13] supports data browsing and retrieval via a raster and vector GUI. Publicly accessible applications for planetary data retrieval, provided by the member institutions of the PDS, allow searching databases for named features, or for image coverage by defining either a point or a region of interest. Two projects have recently started jointly at NASA's Jet Propulsion Laboratory (JPL), the California Institute of Technology and US-geological survey (USGS): PIA (Planetary Image Access) [14] and IPA (Interactive Planetary Atlas) [15].
All known planetary archive systems are greatly limited in their abilities in terms such as image cropping to the extent defined by the user, charging and accounting, a flexible network with high bandwidth, user management and dealing with distributed archives. Image data are conventionally organised by type of sensor or satellite and not by their spatial coverage. It is the image's position or its coverage that a scientific user most likely uses in his queries.

3 Design goals

Raster Image Oriented Browsing Interface: Earth-based data search and retrieval systems can take advantage of many named features on our planet. Apart from that a large portion of the surface is covered with water. These advantages do not exist on a planet like Venus, therefore a storage space and bandwidth saving vector representation of the planet's surface cannot meaningfully relieve the search process.
That is why GDSS will need a zoomable raster image oriented map browser with different levels of detail (LOD) for the whole planetary surface. The LOD provide an overview of the entire planet as well as a detailed representation of surface segments.

Search for Points of Interest / Regions of Interest: The system needs to handle queries for points and regions of interest via a spatial database. This is based on lossy compressed quicklooks at a reduction >1:25 of the full resolution data. At this scale the overview of all available images for a special surface point or region of interest becomes manageable.

Coverage Requests: Venus' Magellan images may be the subject of queries regarding the coverage with stereo, by a specific cycle or of a particular feature. The coverage result will be visualized at the client site by overlaying colored areas (e.g. green areas showing stereo coverage, red areas showing features and so on) on the pixel map. Clicking on these areas will retrieve all quicklooks satisfying the user's coverage criteria.

Searching for Meta Information: Besides points and regions of interest, one may want to use additional criteria to a query which can act as a filtering function on the data, one may think of multiple images covering an area in the form of an image stack. Additional criteria may address a cycle number, a date or time, type of sensor, data processing, history with a computation algorithm, processing parameters etc., the satellite itself, or the geometric resolution.

Client-Server Architecture: The underlying concept of GDSS is a distributed client-server architecture [16]. The backbone of this layout is an ATM network. The emerging ATM technology can be regarded as a main part of the worldwide data highway in the near future. It:

- provides users with fast interactive access to the map browser;
- guarantees transparency (the whole network structure is hidden from the end user);
- guarantees a requested bandwidth throughout a session (Quality Of Service);
- offers a best utilization of unused bandwidth;
- supports connection-oriented services (single point of contact).

As a result we propose to build the GDSS on top of nationally and internationally emerging ATM high speed data communication links. It is important to note that without such a flexible network structure the idea of a distributed client-server architecture would not be useful.

Intelligent Local Caching: An intelligent local image cache keeps response times as short as possible and reduces network traffic. The main weakness of each caching strategy is the update problem. This problem has already been efficiently solved within the Hyper-G system [17, 18] using the so called p-flood [19] procedure. GDSS will use a similar algorithm.

Local server data prediction: There exists a Central Server which will store complete browsing maps in different levels of detail for a planet, using a special rectangular data structure denoted as „map tiles". During interactive browsing the client downloads and visualizes the tiles. To achieve the speed for granting interactivity the Local Server needs to predict which data will be used next. It loads the tiles around the current user position and also the tiles of the adjacent superior and inferior level of detail.

Batchjob Processing: A well-defined batchjob interface for standard procedures which can be processed in the background without supervision by the user is provided. The procedures may include retrieval of full resolution data or time consuming complex queries while the Central

Server is highly utilized. This capability is especially important when the network connection is slow.

User group management: We plan that clients can be connected to one Local Server, resulting in a need for some group management facilities. These may include:

- building user groups who have access to any subset of the image data
- the definition of user rights (read, local write access permissions, authorization for full resolution data retrieval, authorisation for services)
- defining priorities (e.g. students may have lower priority than scientific personnel)

Network Security and Accounting: For commercial use a system must provide accounting facilities. Hence GDSS is supposed to grant identification, authorisation and charging. In such cases the system must guarantee privacy of communication.

Network management capabilities: Extensive O&M (observation and maintenance) features must be available to the system administrator. These are in detail:

- performance observation and tuning;
- monitoring (active connections, current users in the system, ..);
- security management;
- fault management (diagnostic tools, trouble ticket generation, ...);
- configuration (comfortable scalability and extension).

Remote Data Processing: There may be special image processing facilities available on the distributed system. Therefore it would be useful to have a special remote processing interface for typical image processing algorithms. While histogram manipulation, contrast/brightness correction, filtering etc. are standard procedures, shape from shading is not. The system needs to support computing at a Central Server, with delivery of the results to the user. This service must make use of the GDSS's accounting feature, since the use of computing power and software resources are not necessarily free. This feature makes it possible to share expensive remote sensing software and hardware by a geographically dispersed scientific community without the need to install such software at multiple sites.

4 System design

4.1 General Layout

The system can be thought of consisting of five main components, as illustrated in Figure 1:

- Image Archives
- Local Server
- Retrieval Client
- Central Server

* Network

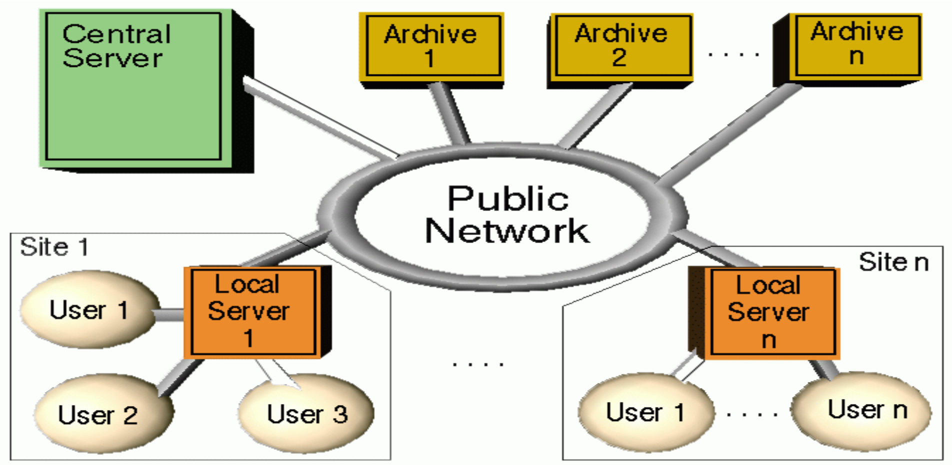

Figure 1: *General Layout of the GDSS*. The Central Server (CS) holds the browsing map and quickviews of all attached archives. The CS is accessed from clients via a local server at each site. The location of the various archives is invisible to clients.

Image Archives: Image Archives are maintained by commercial vendors or public institutions but have to fulfill special requirements in order to become participant of GDSS:

* A global map at different LOD and compressed quicklooks of all image data have to be created once. A database of meta info and image coverage must be built.
* The archive must be on-line (24 hours a day, 7 days a week) to handle requests from the Central Server.
* The archive must be able to handle GQP (General Query Protocol) requests, the standard query and data retrieval protocol of GDSS.
* The archive must update the data on the Central Server each time new images data are added.
* Automatic full resolution data retrieval should be possible.

Local Server: One Local Server has to be set up at every user site (see Figure 1). The Local Server is responsible for local caching, User management, Accounting and Batchjob processing.
It is the main purpose of data caching to keep network traffic low. The size of the cache and the caching strategy can be configured individually. User management includes identification, authorisation and charging. Each user has to be identified prior to authorisation (access restrictions, receipt of non-free data, ...) so that a charging procedure can take effect. The Batchjob processing feature enables the user to define jobs (e.g. downloading actions) which can be postponed by the Local Server and/or the Central Server and processed at times with less system load average, network traffic, or cost e.g. during the night.

Retrieval Client: The Retrieval Client consists of two major parts, the query definition dialog and the map browser. A set of menus and forms supports the composition of user queries. The user can also specify any coordinates with the mouse pointer in the map browser window.
The map can be overlaid with vector or raster data. Vector data can be image borders, contour lines, names and extents of topographic features and user defined graphics like regions of

interest, point marks or personal annotations. Raster data are quicklooks of available images. Color coding can be used to mark areas with a predefined image coverage (e.g. areas with stereo coverage).

Central Server: It is the main component of GDSS and will be separately described in the next section.

Network: This component is the most important of GDSS because the overall system performance and functionality depend on the efficiency of the underlying network technology.
An ATM network is the ideal backbone for a system having high requirements to the available bandwidth like the GDSS. ATM has been proposed in 1991 by the former CCITT (now: ITU-T) as the standard for B-ISDN with its 5 ATM Adaptation Layers (AAL) [20] it can transport all existing and future B-ISDN services such as connection-oriented connection-less as well as isochronous services [21].
ATM is the only currently known network technology supporting a high bandwidth with up to 2.4 GBit/sec, OC-48 [22], a guaranteed Quality Of Service and WAN geographical scope [23, 24, 25]. Hence ATM is likely to become a world wide integrating network technology in the near future. Using the existing Internet as a backbone will not be acceptable. The congestion control of the Internet Protocol (IP) is not able to handle connection oriented services nor is it able to guarantee a dedicated bandwidth. ATM defines standard interfaces to existing protocols (Ethernet, FDDI, Token Ring), which makes LAN integration of the Local Server sites easy. To grant international worldwide scope usage of the TCP/IP protocol is recommended. TCP/IP, which is settled at OSI layers 3 (network) and 4 (transport) makes the GDSS independent of the underlying physical components. Because IP over ATM still suffers from lack of performance, there are several ongoing research projects investigating TCP/IP over ATM [26, 27] for performance improvements.
ATM's power, scalability and flexible maintenance promise to be sufficient to meet the requirements of GDSS.

4.2 Design of the Central Server (CS)

Figure 2 outlines the main modules and communication paths of the CS.

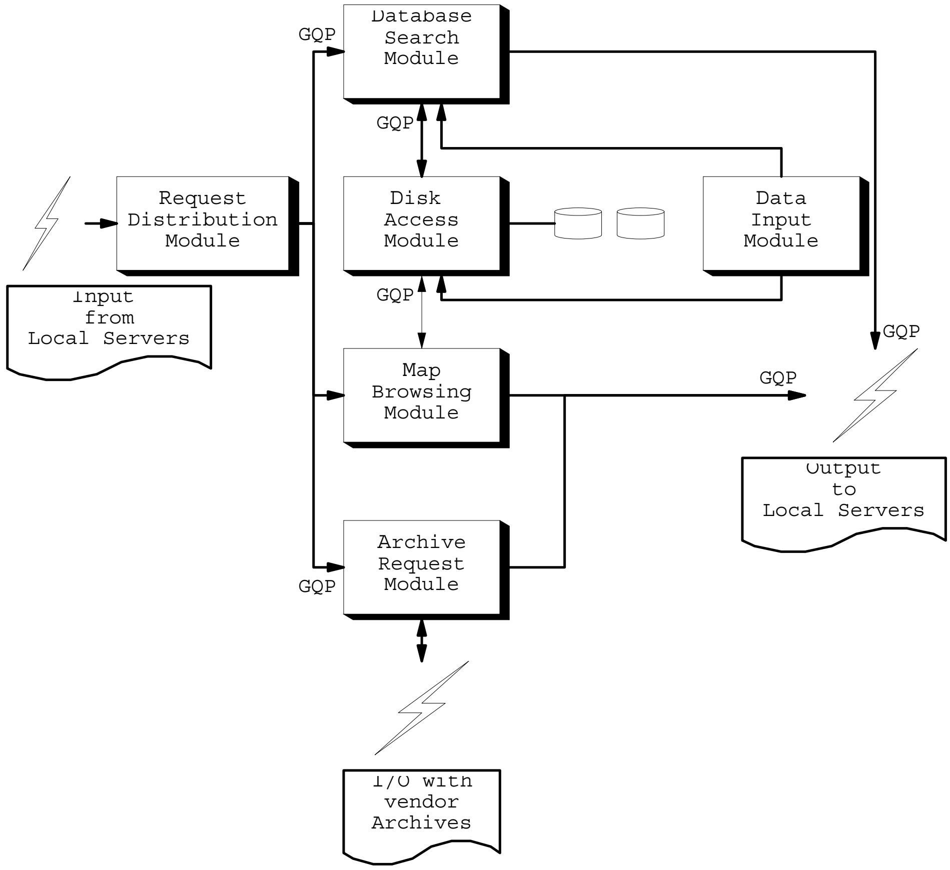

Figure 2: The main modules of the Central Server, with the internal dataflow and the links to external components such as vendor archives or Local Servers.

General Query Protocol (GQP): The GQP connects the components of the GDSS on the OSI layer 4 (transport). GQP is a simple ASCII protocol similar to the HTTP (Hyper Text Transfer Protocol) [28] of the WWW to optimally address the issues of the GDSS.
The advantage of the new protocol is its ability to meet the GDSS' requirements and to unite the GDSS' modules. If, for example, the RDBMS of the CS is to be changed, then just the GQP-to-SQL module would have to be adapted.
GQP handles four categories of queries, **I Spatial queries** concern points and regions of interest, coverage, request for full resolution data, etc.; **II Service requests** address remote image processing with filtering, shape from shading, etc.; **III Administrative queries** concern status requests, setting up and dismissal of a connection, request account balance, etc.; **IV Data update commands** include input/update image data or/and the coverage database. The archives themselves must support queries for full resolution data (cat. 1) and data update commands (cat. 3).

Request distribution module: The Request distribution module has two main functions, (1) it is responsible for security tasks (identification, authorization) (2) it has to manage the distribution of incoming requests. Each Local Server connecting to GDSS has to identify itself to the CS when a connection is established. This is important when accounting takes place. It is up to the Local Server administrator to authorize users (e.g. order non-free data, using non-free data processing services). Because GDSS uses a Distributed User Management strategy the CS does not need to concern itself with individual users but just takes an entire site into consideration. The incoming requests are put into three waiting queues. From these queues the requests are then distributed to the three main modules of the CS, the Database Search Module, the Map Browsing Module or the Archive Request Module.

Database Search Module: The Database Search Module is a massively parallel RDBMS [29] handling multiple spatial requests at the same time. This module of the CS is responsible for coverage and quickview requests. The data base does not hold any image data. Requests for images are passed to the Disk Access Module. The Database Search Module database holds coverage data and meta info of the image data. If an update takes place, the database usually will be modified too. For each planet a separate coverage and meta info database has to be generated. That can be accomplished by using the GQP data update commands (cat. 3).

Map Browsing Module: The purpose of the Map Browsing Module is to provide the user with fast delivery of requested map tiles that should be currently displayed on the screen. This process should be interactive and is most time critical in the CS. The Map Browsing Module passes the requests to several parallel running Map Browsing servers which send their requests to the Disk Access Module. This makes sense because the Disk Access Module itself is parallelized as well and can handle more than one request at the same time. The resulting tile streams are delivered back to the requesting Local Server.

Archive Request Module: This module holds as many waiting queues as archives are attached to GDSS. The GQP queries are sent from there to the archives. The archives respond with the requested full resolution data and optionally with the billable costs. If the price has a non zero value, the account server will be started and accounting with the Local Server takes place. This transaction is subject to high security because someone could manipulate the price sent to the Local Server for confirmation. Privacy will be accomplished with a common key system [30]. When the accounting process is finished, the full resolution data are passed to the cropping server, which crops the data exactly to the area defined by the user. The result, usually an image stack, is sent to the user.

Disk Access Module: The browsing maps of the whole planetary surface are stored here at different levels of detail with the successive 2:1 reductions of these maps forming a resolution pyramid. Furthermore 1:4 reduced quicklooks will be kept within this module. An additional color reduction to 8 bits is applied to all image data. In combination with low quality JPEG [31] compression a data reduction of 100:1 or better is possible.
Advantages of a central Disk Access Module are the easy update facility, and the highly optimized fast image delivery. The module queues incoming requests by three levels of priority. Currently requested map tiles have the highest priority, followed by ordered quicklooks. The lowest priority have map tiles loaded on prediction. This order has been chosen to optimize the likelihood of an interactive browsing process. Map tiles loaded on prediction have the lowest priority, because it would not be acceptable to block users loading currently needed map tiles.

Data Input Module: The Data Input Module is responsible for bringing in data as well as updating existing data. These processes affect the image data, the coverage and the meta info databases of the Database Search Module. Furthermore the module has to pass messages to all attached Local Servers to delete the invalid data from their local cache. The Data Input Module can be accessed by all attached archives as the single point of contact when a new archive joins GDSS. This module is responsible for the entire registration procedure.

5 Implementation

We have begun with a testbed for GDSS using a total of 3 institutions, initially all of them in Austria. The University of Vienna participates through the Vienna Parallel Computing Center (VCPC) with its massively parallel computer Meiko CS-2, setting it up as a CS. At two institutes of the University of Technology, Graz a Local Server will be set up with several user workstations attached to each server. An ATM network at OC-3 (155 MBit/s) and two FORE Systems switches (ASX-200, ASX-100) are currently in place for initial trials.

6 Future work

A functional prototype of the proposed GDSS will be implemented by the second half of 1997. This implementation will initially focus on the Magellan data set, the needs of PDS scientists and their hardware platforms.
In addition the efficiency and the functionality of the suggested network layout will be tested using the CACI COMNET-III network simulator. With this simulator it is possible to realize a realistic implementation of GDSS using an ATM WAN and including applications and data transfer.
The stimulus for this project drives from the planetary image processing community, as reflected in NASA's PDS. We are, however, optimistic that Earth-observation projects such as the European Commision's Center for Earth Observation (CEO) or national programs such as Austrias Multi-Image Synergistic Satellite Information for the Observation of Nature (MISSION) will also greatly benefit from the ideas, software and experiences of the GDSS.

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