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## 1. Introduction

Over the last five years geographic information systems (GIS) have been given a very high priority by national research councils throughout Western Europe and North America. In the USA, the National Science Foundation has awarded $ 5.5 million over a period of five years (1988-1992) to establish a National Center for Geographic Information and Analysis (NCGIA) based on the University of California at Santa Barbara, the State University of New York at Buffalo and the University of Maine at Orono (see NCGIA 1988). In the Netherlands, the Dutch Science Council (NWO) funded a consortium including the University of Utrecht, the Technical University of Delft, the Agricultural University of Wageningen and the International Institute for Aerospace Survey and Earth Sciences at Enschede to set up a National Centre of Expertise for geographic data processing, providing 1.8 million Dutch Guilders for a period of four years (1988-1991). The UK initiative, the Regional Research Laboratory initiative (RRL) was launched in 1987 and funded by the Economic and Social Research Council (ESRC) with more than £ 2 million British pounds over a five year period (1987-1991) to establish centres of excellence throughout the UK in the fields of data handling, database management, spatial analysis, software development, training and advice. The whole project is co-ordinatated from the University of Sheffield by Ian Masser and includes eight centres set up for Scotland, Northern Ireland, the North East, the North West, the Midlands, Liverpool, Manchester, Wales, the South West and the South East. These centres involve teams of researchers from Birbeck College and London School of Economics in the University of London, Queens University in Belfast, the New University of Ulster, the University of Wales College of Cardiff, and the Universities of Bath, Lancaster, Leicester, Loughborough and Newcastle as well as the University of Liverpool and Manchester (see Masser, 1988). In contrast to the American and the Dutch initiatives the British one is multi-disciplinary in character, a model which has a lot of attractivity to be adopted in Austria, too.

Every major university with some degree of self esteem has now its own GIS experts, every national planning agency is establishing a geographical information system and even middle and large sized towns increasingly use GIS technology. The decision to develop a GIS centred on socio-economic data and issues (termed Wirtschaftsgeographisches GIS, abbreviated WIGeo-GIS) in the Department of Economic and Social Geography at the Vienna

University of Economic and Business Administration was made by the Head of the Department in December 1988, immediately after his appointment. The decision was based on three major arguments outlined below.

**First**, there is, and will continue to be, a very substantial and even increasing demand for computer-based information systems which enable to handle very large databases at different spatial scales and enable to analyse and model spatial phenomena and processes in socio-economic space-time systems. This argument refers to the remarkable growth of interest in GIS as a modelling and decision making tool in academia (spatial oriented economic and social sciences), in the public sector (urban and regional planning, public utilities planning and management, transportation planning, natural resource planning and environmental assessment, land use planning, city marketing, etc.) and the private sector (geo-marketing, facility siting and locational analysis, distribution planning, etc.) (see NCGIA 1988).

**Second**, advances in the nature and applicability of socio-economic oriented geographical information systems require not only knowledge of computational, statistical and modelling techniques of spatial data, but also knowledge drawn from a variety of disciplines in the social and economic sciences which are well established at the University of Economics and Business Administration.

**Finally**, GIS may provide a context, an information resource, and an environment for geographical thinking and applied research, supporting interdisciplinary rather than closed discipline-based research activities and cooperation, accomodating in principle pluralistic research styles and imposing no inherent restrictions on subject matter or approach (see Openshaw, 1991, Abler, 1987).

The Ministry of Science and Research provided an endowment of 2 million AS over a period of three years (1990-1992). The implementation phase started in August 1990 and lasted 6 months. The lab is in operation since February 1991.

## 2. Geographic Information Systems: Some Characteristics

A geographical information system may be defined as a computer-based information system which attempts to capture, store, manipulate, analyse and display spatially referenced and associated attribute data, to assist a user in solving more or less complex research, planning and management problems. The ability of geographic information systems to handle and analyse spatial data sets, frequently being heterogenous and often comprised of data sources with differing scales, accuracies and areal coverage, is usually seen as the major characteristic distinguishing geographic information systems from information systems developed to serve the needs for business data processing and from CAD-systems. There seems to be a consensus in the GIS literature that typical geographic information systems may be viewed to embody (see Fischer and Nijkamp, 1991):

* a **database of spatially referenced data** consisting of locational and associated tabular attribute (thematic) data,
* appropriate **software components** encompassing procedures for the interrelated transactions from input via storage and retrieval, and the adhering manipulation and spatial analysis functions to output, and
* associated **hardware components** including high-resolution graphic display, large-capacity storage devices which are organized and interfaced in an efficient and effective manner to allow rapid data storage, retrieval and management capabilities and to facilitate the analysis.

Geographical information systems fulfill four main functions: data input processing, management, manipulation and analysis, and display of spatially referenced data. Data input processing covers all aspects of transforming locational (topological) and non-spatial (attribute) information from printing and digital files into a GIS database. Management refers to the handling of permanent alpha-numeric (attribute) and locational data. Manipulation and analysis concerns a wide range of procedures such as attribute and spatial aggregation, geometric operations (rotation, translation, scaling, etc.), data structure conversion (raster to vector and vector to raster conversion), spatial operations (connectivity and neighbourhood operations), (spatial) statistical analysis and modelling. Display includes all operations which generate final GIS products.

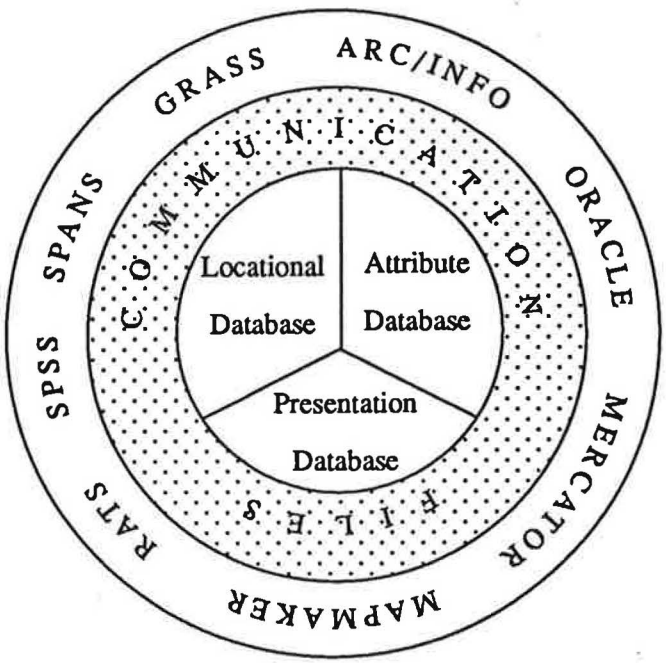
The above mentioned three components (database, software components and hardware components) will be briefly described in the following sections.

## 3. Database Design and Data

The central database of WIGeo-GIS is composed of three distinct databases: the topological or locational database, the attribute (alpha-numeric) database and the presentation database in which all data necessary for the layout and the visualisation of products are stored. Figure 1 shows how the databases are surrounded by a shell of facilities for retrieval, manipulation, analysis and presentation. The spatial objects defined in terms of spatial primitives (point, line segment and polygon) form the link between the topological and the attribute databases.

The location of the spatial objects (administrative units, point locations or any other type of spatial unit) and their topology description are stored in the topological database. Descriptive information about spatial object-types, (attribute) variables and time periods are in the attribute database together with textual information and appropriate formats as well as authorisation information.

**Figure 1: Conceptual Framework of the Geographic Database**



Currently, the Settlement and Infrastructure Database pertaining to Austria is the major spatial database available in WIGeo-GIS. The geometric data digitized in vector mode on a 1 : 500.000 scale are divided into a variety of layers which can be split into three main groups: settlements covering up to now not yet all urban areas and regions in Austria; transport including road and rail networks; administrative areas including communities, political districts and provinces. The data are held at the WIGeo-GIS database. WIGeo-GIS has access to a wide variety of spatially referenced socio-economic information about population and households, housing, employment, industry, tourism, agriculture, from the national online statistical information system (ISIS). This system may be interrogated and the data downloaded via FTP.

At present, ARC/INFO, a vector-based GIS software package, is used for organising and managing the three databases. ARC/INFO developed by ESRI (USA) enables to integrate data from a wide range of different sources, such as analogue maps, satellite images, scanned aerial photography, CAD files, video photologs, and relational database management systems. The relational database management system, INFO, allows the user to create and to manage spatially referenced tables of attribute data. The structure of INFO as relational database management system (RDBMS), however, is old-fashioned and less powerful than other systems, like ORACLE, INFORMIX and INGRES (see Evers and Scholten, 1991).

## 4. Hardware System Architecture

WIGeo-GIS is an integrated system where all the applications can use the same data sets and the same hardware components. Figure 2 shows the basic hardware system architecture in the major components of data input, processing and output. The system architecture is essentially based on a RISC workstation (Sun SparcStation 1+). The Sun is supplemented by an AT 386 clone (donated by the Austrian Science Foundation), a cluster of three MacIntosh SEs (one donated by the Austrian National Bank) and a MacIntosh IIcx. Hardcopy is provided by an ABB-GOERZ thermal transfer plotter for screen dump facilities, a high quality A0 Bruning pen plotter station (denoted by the Austrian Science Foundation) which enables production of output on A4, A3, A2, A1 and A0 maps, and a (postscript) Apple laser printer. A Summagraphics Microgrid II digitizing tablet with a 16-button cursor for

**Figure 2: WIGeo-GIS Hardware System Architecture 1991**

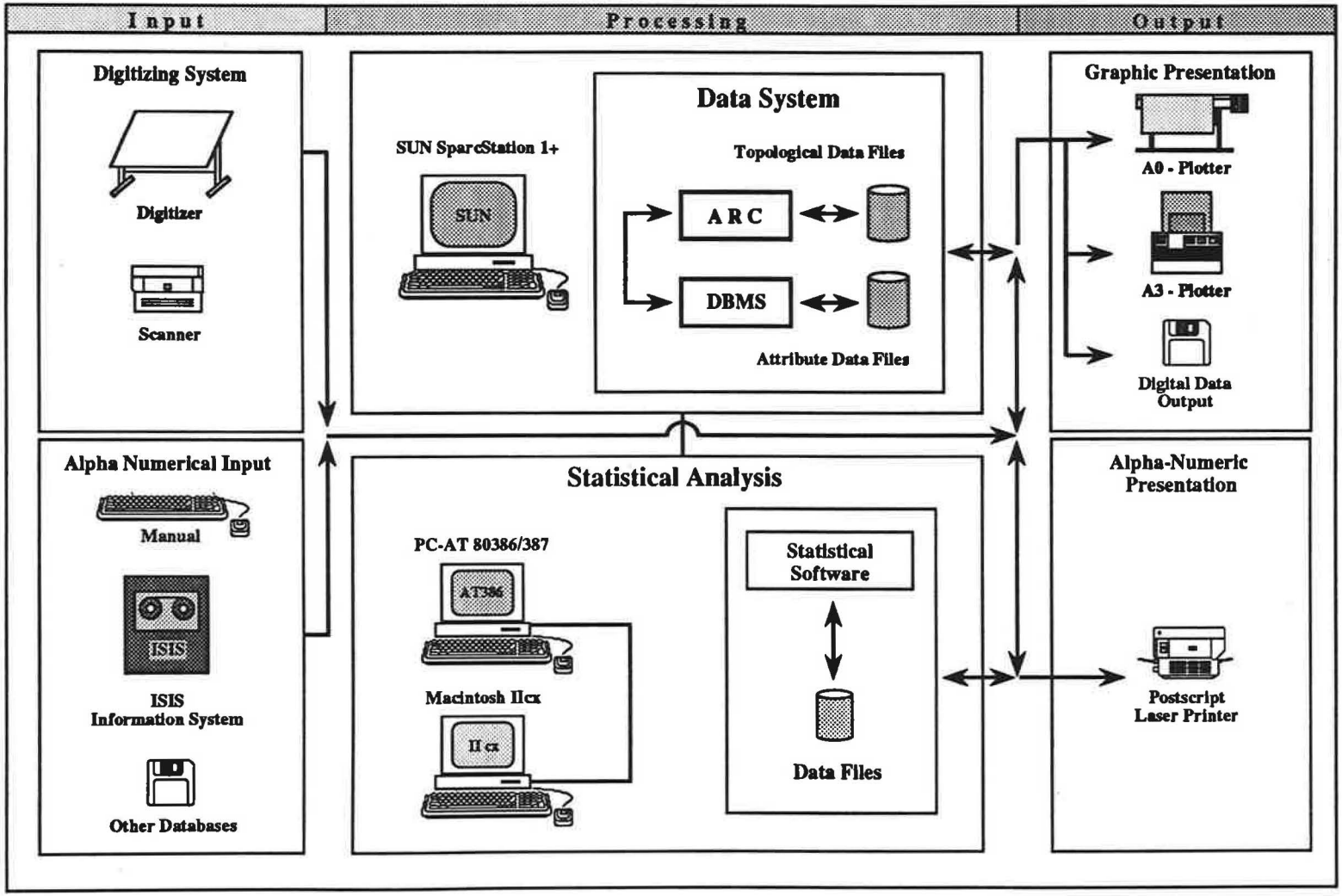
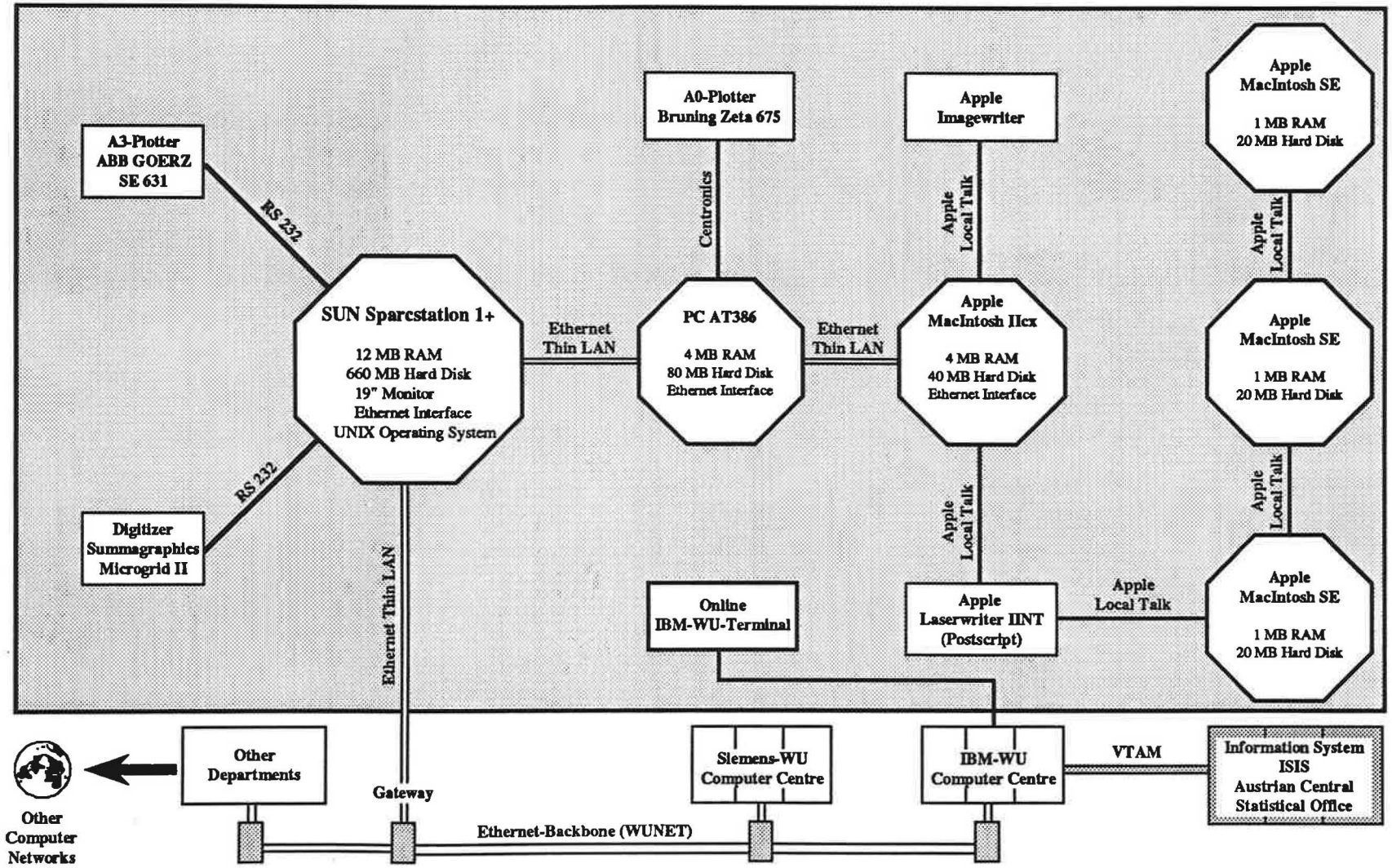


**Figure 3: WIGeo-GIS Network 1991**



tracing data elements is available to convert analogue maps and other graphic data with high accuracy and precision to a digital format.

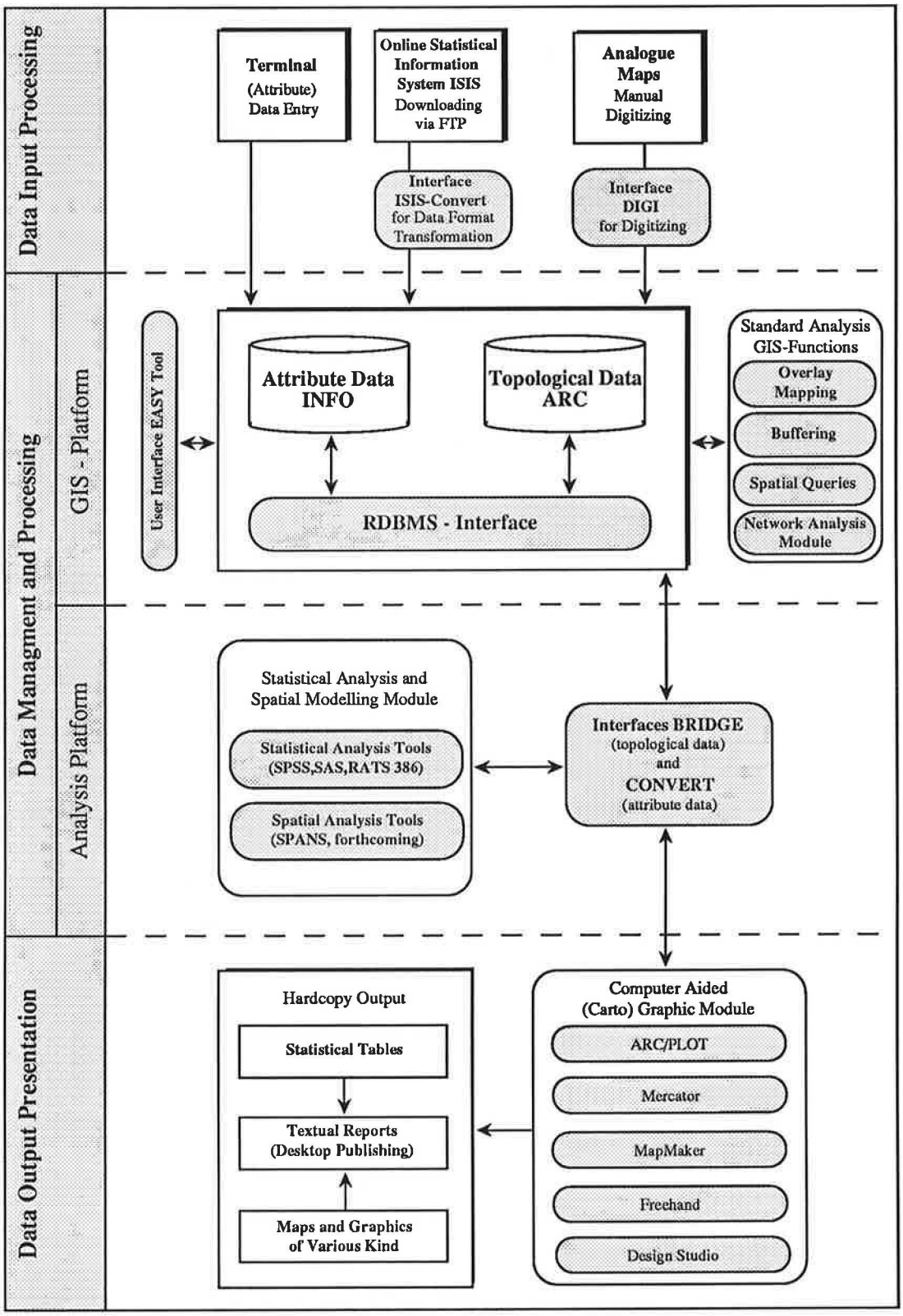
The Sun workstation, the micros and peripherals are network-linked with each other to meet different user demands efficiently and effectively, to improve performance and lower workstation memory consumption. The WIGeo-GIS network (see Figure 3) is a Ethernet Thin LAN based on TCP/IP. The network is linked to the Ethernet Backbone (WUNET), which connects all the departments of the Vienna University of Economics and Business Administration and the IBM and Siemens mainframes, and provides access (via VTAM) to the online statistical system ISIS of the Austrian Central Statistical Office as well as, via the European Academic Research Network (EARN), to other information systems located inside or outside Austria.

## 5. Software System Architecture

Figure 4 shows the software system architecture of WIGeo-GIS, i.e. the organisational context within which the software modules, programs and interfaces perform certain tasks and communicate with each other and data stores. The architecture reflects the three major components of a geographic information system: data input processing, database management and data processing, data output presentation. The system provides limited topological data capture capability by manual digitizing only. Background maps may be obtained as digital maps on tape. Foreground topological data are digitized manually and may be overlayed on the background map data. Attribute data belonging to the map foreground features may be entered from alpha-numeric terminals. Socio-economic data are downloaded from the information system ISIS.

Three different platforms - each based on standard software packages - have been designed to meet the user demands of WIGeo-GIS: the GIS platform, the statistical analysis and spatial modelling platform, and the presentation platform. The GIS platform is essentially based upon the ARC/INFO software package which runs on the Sun SparcStation and the AT 386. In addition to the standard analysis functions (overlay mapping, buffering and spatial queries) of ARC/INFO, the NETWORK subsystem functionally linked to

**Figure 4: WIGeo-GIS Software System Architecture 1991**



ARC/INFO aNd the raster oriented public domain GIS software system GRASS are available.

Specifications of the platform in terms of modules, hardware components and communication tools are listed below:

**GIS Platform**

*GIS Modules*

ARC/INFO 5.0.1 (SUN)

PC ARC/INFO 3.4D (MS DOS PC)

NETWORK (SUN, MS DOS PC)

GRASS 4.0 (SUN)

*Computer Hardware*

SUN SparcStation 1+ (12 Mbytes RAM)

PC AT 386 (387 Co-Processor, 4 Mbytes RAM)

*Operating Systems*

Sun OS 4.1 (BSD)

MS DOS 5.0 (Beta Release)

*Data Storage*

660 Mbytes SCSI harddisk (SUN)

80 Mbytes harddisk (AT 386)

*Tape Drive*

150 Mbytes (SUN)

*Network*

Ethernet, Thin Lan based upon TCP/IP protocol (services provided: TELNET, FTP, RP), KERMIT

*Graphic Standards for Data Visualisation*

Graphics: Open Windows 2.0, Sunview (SUN)

Microsoft Windows 3.0 (AT 386)

Hard copy: HPGL (Bruning Plotter Station Zeta 675)
HPGL (ABB GOERZ Thermal Transfer Plotter)
Postscript (Apple Laser Printer NTX)

*Programming Languages*

F77, C, Quick Basic 4.5

*Relational Database Management Systems*

INFO (SUN; forthcoming ORACLE)
dBASE III+ (MS DOS)

ARC/INFO provides highly developed software tools for handling, selecting and displaying spatial information, but is weaker in the analytical and modelling capabilities. This lack is widely recognized as a major shortcoming (see Clarke, 1990, Goodchild, 1991). ARC/INFO offers merely a rather limited range of spatial operations including topological map overlay, buffer generation, feature extraction, network analysis, and only some primitive statistical facilities such as summary statistics for point, line or polygon features.

The statistical analysis and modelling platform serves to increase the analytical and modelling capabilities of WIGeo-GIS to meet users´ demands outside the narrow range of the above mentioned operations. The platform (currently in the stage of implementation) is based upon two types of software packages:

* standard statistical software packages such as SPSS, SAS, GAUSS (not yet available) and RATS 386 for the manipulation of non-spatial data, and
* the quadtree-based GIS software system SPANS for more sophisticated types of spatial analysis.

Attribute and topological date are downloaded from the central GIS database and via interfaces (BRIDGE for topological data and CONVERT for attribute data) transformed to the statistical system data format required. It is also possible to re-export data from the statistical analysis to the GIS platform.

The third platform, the product generation and presentation platform, performs the task to generate print-ready high resolution products such as maps of

various kind (thematic maps, choropleth maps, line maps, etc.), business graphics, statistical tables and text in desktop publishing quality. Product generation is provided by software products (MapMaker, Freehand, Design Studio, MacDraw, Super Paint, PageMaker) in a MacIntosh environment, and additionally by the mapping software Mercator running on the AT 386.

Specifications of the platform are listed below:

**Presentation Platform**

*GIS Presentation Modules*

MapMaker (Mac)

Mercator (MS DOS PC)

*Computer Hardware*

MacIntosh IIcx (4 Mbytes RAM)

MacIntosh SE (1 Mbyte RAM)

*Operating System*

Mac 6.04

MS DOS 5.0 (Beta Release)

*Data Storage*

40 Mbytes (MacIntosh IIcx)

80 Mbytes (PC AT 386)

*Floppy Drives*

3.5" (1.44 Mbytes)

*Network*

Ethernet, Thin Lan based upon TCP/IP protocol (services provided: TELNET, FTP, RP), KERMIT, VERSATERM

*Graphics Standards for Data Visualization*

Graphics: Microsoft Windows 3.0 (AT 386), Mac

Hardcopy: HPGL (Bruning Plotter Station Zeta 675)

HPGL (ABB GOERZ Thermal Transfer Plotter)

Postscript (Apple Laser Printer NTX)

## 6. Research and Development Activities

Major research endeavours in the field of geographical information systems and spatial analysis require a critical mass of personnel in the field which the Department of Economic and Social Geography at the Vienna University of Economics and Business Administration currently does not have. This shortcoming hindering the development and application of geographical information systems is perceived to be at least partly a consequence of the university organisation law operating in Austria. In order ro reduce this impediment to some extent, an informal working group (termed WIGeo-GIS working group) has been established in fall 1990 which is composed of the Head of the Department and six well-trained MA and Ph.D. students who enthusiastically commit theirselves to research and development activities in the field. The skills of this working group are mixed and methodological, technical and substantive in nature. One of these students is employed part-time as student assistent, two others are partly employed on funded projects (Austrian National Science Foundation, Wirtschaftsuniversitätspreis 1991 der Wiener Handelskammer).

To produce graduates - engaged in the various study programs at the Vienna University of Economics and Business Administration (Business Administration, Economics, Commerce and Business Education) - with a basic training in GIS necessary for MA and Ph.D. theses, a modest program of three annual courses has been developed. This program consists of a course designed to acquaint students with fundamentals in GIS and computer cartography, an intermediate-level course covering both theoretical and applied aspects of GIS and dynamic modelling, and a third course on spatial statistics and analysis. The courses are being taught by lecturing staff coming from the University of Vienna and the Austrian Academy of Sciences. The GIS program - offered as a specialisation in the general economic and social geography study program - started in the academic year 1989/90.

The development and research activities of the WIGeo-GIS Working Group cover both technical and research activities. Currently, technical issues clearly predominate. Four major technical areas have been or are being addressed.

**First**, in the pilot phase (August 1990 - January 1991) major efforts have been devoted to establish an Ethernet Thin LAN based upon TCP/IP protocol providing services such as TELNET, FTP, RP, KERMIT and VERSATERM.

The **second** issue refers to the development of a user-friendly human-computer interface. To become proficient in ARC/INFO requires extensive training and often knowledge of how computers operate which MA and Ph.D. students as well as other users generally do not have. In order to overcome this problem, a user interface, termed EASY Tool, has been developed which handles the interaction between users and the database in assisting them to access and analyse information in an efficient manner, and, moreover, in assisting in map composition and layout. The interface employing pull-down and pop-up menus relieves the user from the burden to learn the programming/query language of ARC/INFO to access the information on the format/organisation of the database.

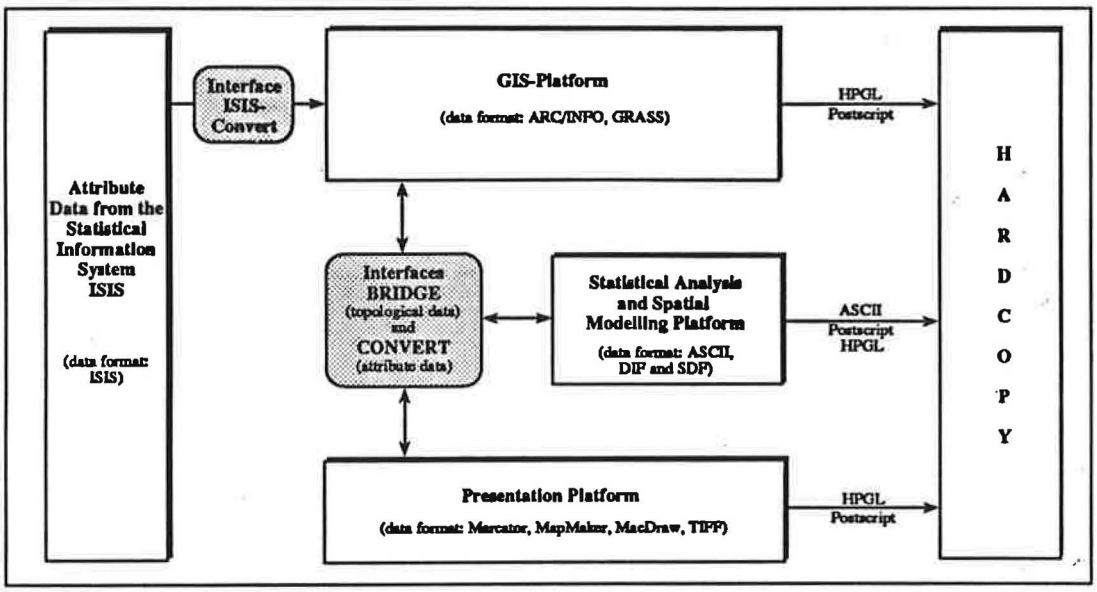
**Third**, two data acquisition interfaces have been written. The first one, termed DIGI, is a digitizing program for topological data which stores the digitized data in ASCII data format, and, thus, facilitates topological data transfer to the presentation platform (Mercator, MapMaker). The second interface, ISIS-CONVERT, is a data extraction and conversion program for socio-economic atttribute data from the statistical information system ISIS which transforms the data required from ISIS to the ASCII data format.

**Fourth**, a general send and print utility program, termed OUTPUT, has been developed which enables to send HPGL files across the local area network to that computer system which is directly linked with the peripheral device required.

**Fifth**, development of spatial data exchange software is a major priority to allow interlinkages between the three platforms of WIGeo-GIS. Figure 5 shows the architecture of data integration in WIGeoGIS. The current interfaces CONVERT (for attribute data) and BRIDGE (for topological data) use ordinary operating system files (ASCII data format) and relate descriptive information about the ARC/INFO data files to the operating system files. This method of linking GIS, spatial analysis and mapping software runs very slowly and will be replaced in the near future by the more powerful method of interfacing the platforms through shared data files. Using this approach the encoded

ARC/INFO files will be accessed by the statistical and mapping software packages by programs which call special subroutines to handle ARC/INFO data files (see Kehris, 1990).

**Figure 5: Data Integration in WIGeo-GIS**




As far as future technical issues are concerned , decisions have been made, first to extract ARC from ARC/INFO and to couple it to an ORACLE relational database, in order to facilitate file sharing between the platforms, and second, to implement the software package SPANS for improving the spatial analytical functionality of WIGeo-GIS by developing SPANS-based modules.

There are several GIS-related research activities which are mainly exploratory in nature. These include state of the art reviews on

* the role of artificial intelligence methods and expert systems to increase the intelligence of WIGeo-GIS,
* possibilities to integrate spatial analysis functions to increase the analytical and modelling capabilities of WIGeo-GIS, and
* possibilities of integrating sounds, pictures, videos and animation into the GIS database by using new hypermedia software tools.

Other GIS applications and projects currently under way are applied and less fundamental research oriented. They include inter alia

* a small scale pilot project funded by the Viennese Chamber of Commerce (Wirtschaftsuniversitätspreis 1991), in which preliminary steps are directed towards developing a geographical database containing socio-economic attribute and network data for the city of Vienna and analysing optimal routing along transport networks, and
* the support of the large scale research project "Austria in European Communication Networks: Barriers to Information Exchange in a Knowledge Processing Society" (funded by the Austrian Fonds zur Förderung der wissenschaftlichen Forschung) through WIGeo-GIS methodologies.

## 7. Summary and Conclusions

WIGeo-GIS is an integrated system where all the applications can use the same database and the same hardware devices. The information system is based upon standard software components. The distributed approach offers the possibility to add new hardware and software, without facing the necessity to redesign the whole WIGeo-GIS philosophy.

From the point of view of the software system architecture, three plattforms may be distinguished: the GIS platform in the strict sense (UNIX and MS DOS operating environments), the statistical analysis and spatial modelling platform (MS DOS operating environment), and the output presentation platform (MS DOS and MacIntosh operating environments). The crucial task of the transfer of datasets between the different software platforms has been solved by using a Local Area Network based upon TCP/IP protocol, by writing interfaces for data conversion and by including numerous public domain programs. Several ways have been discussed to improve the perfomance of WIGeo-GIS in future.

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