Pre-Conference Packet

First Annual
Computer Users Conference

"PLANNING FOR THE 1980's"

January 5 - 6, 1981
National Center for Atmospheric Research

- Conference Program
- Workshop Outline
- Overview of Keynote Session
- Scientific Computing Division Issues

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INTRODUCTION

The First Annual Computer User's Conference will be held January 5-6, 1981 at NCAR's Mesa Laboratory in Boulder. This packet contains pre-conference distribution material.

Planning for the 1980's is the theme of the conference. Some of the goals include the following topics.

1. To give computer users an opportunity to participate in medium- to long-range planning activities and to make recommendations concerning planning and policy documents of the Scientific Computing Division.

2. To provide a forum for introducing new ideas and to recommend hardware and software changes that would facilitate the scientific user's research.

3. To provide a forum for SCD staff in providing an improved service for those who depend on SCD services in their research efforts.

4. To provide a forum where users may share problem solutions with other users.

5. To enable users to communicate with other users and the NCAR staff about the service in an informal and direct way.

The Pre-Conference distribution contains planning documents and papers prepared by the Division Director and various members of the staff. Dr. Macintyre's report emphasizes the "key to successful planning—anticipating real needs and opportunities before they arise." Planning also assumes that the goals of the SCD are clearly defined. Both scientific and technical goals are important considerations. The scientific goal emphasizes service to scientific users in the area of computing at the appropriate level to support the primary goals defined by the scientific problem.

The technical goals are to provide state-of-the-art facilities in computer software and hardware. Members of the SCD staff have prepared material on mass store needs, data needs, graphics and other software tools. These topics will be covered in the session on SCD Issues for the 80's. There will be a discussion of the newly-acquired Input/Output Satellite Computer (IOS), its impact on the present configuration, and user services that will be enhanced by this procurement.

A number of workshops are planned on research goals and the computing needs in an integrated national research effort in the atmospheric sciences. The topics include Astrophysics, Oceanography, Climate, Cloud Physics, Mesoscale Modelling, and others. Research goals that are identified in these workshops will assist the NCAR SCD in determining its role in providing the quality and amount of computing required.
A consulting service and SCD documentation exhibits will be among the information displays at the conference. We in the Scientific Computing Division hope that you will enjoy the conference.

Jeanne Adams

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NCAR SCD FIRST ANNUAL COMPUTER USERS CONFERENCE COMMITTEE

Jeanne Adams, Linda Besen, Ann Cowley, Buck Frye (Chair), Cicely Ridley

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WITH SPECIAL THANKS TO THE FOLLOWING PEOPLE...

Darlene Atwood, Betty Bloom, Ben Domenico, Vonda Giesey, Barb Ostermann
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NCAR SCD FIRST ANNUAL COMPUTER USERS CONFERENCE

PROGRAM

MONDAY, JANUARY 5

8:30 a.m.  Registration, Coffee and Rolls

9:00 a.m.  KEYNOTE SESSION
Main Seminar Room  Welcoming Remarks  W. Hess, W. Macintyre
               Overview of SCD Organization  M. Drake
               SCD Long Range Plan  W. Macintyre

10:30 a.m.  Break

11:00 a.m.  WORKSHOPS ON RESEARCH GOALS
Damon Room  Astrophysics and Upper Atmosphere  D. Hummer
Chapman Room  Basic Fluid Dynamics and Oceanography  B. Semtner
Directors Conf. Room  Climate  T. Vonder Haar
Captain Mary Room  Cloud Physics  H. Orville
Fleishmann Bldg.  Weather Prediction, Mesoscale Modeling  C. Kreitzberg
12:30 p.m.  Lunch

1:30 p.m.  SCD ISSUES FOR THE 1980's
Main Seminar Room  Introduction  J. Adams
               I/O Satellite  D. Fulker
               Data Needs  R. Jenne
               Mass Store  P. Rotar
               Graphics  L. Henderson
               Software Tools  R. Rew

3:30 p.m.  Break

3:45 p.m.  WORKSHOPS ON COMPUTING NEEDS
Damon Room  Astrophysics and Upper Atmosphere  D. Hummer
Chapman Room  Basic Fluid Dynamics and Oceanography  B. Semtner
Directors Conf. Room  Climate  T. Vonder Haar
Captain Mary Room  Cloud Physics  H. Orville
Fleishmann Bldg.  Weather Prediction, Mesoscale Modeling  C. Kreitzberg

5:15 p.m.  RECEPTION

TUESDAY, JANUARY 6

9:00 a.m.  SUMMARY AND CONCLUSION
Main Seminar Room  Introduction  W. Macintyre
               Workshop Summaries  Discussion Leaders
               Overall Summary  C. Kreitzberg

10:30 a.m.  Break

10:45 a.m.  SCD Response and Concluding Remarks  W. Macintyre
Main Seminar Room
WORKSHOPS ON RESEARCH GOALS

A. The three broad goals proposed in the report, The Atmospheric Sciences: National Objectives for the 1980's, are:

1. To improve our understanding and weather prediction capabilities, with emphasis on precipitation in cyclonic storms and severe storm processes.

2. To understand the climate system and its variability over periods of seasons to decades.

3. To elucidate the biogeochemical cycles and budgets and their relationships to atmospheric processes.

B. Are there other goals and planning documents that would be useful for the 1980's?

C. Some strategies to achieve these research goals might include the following:

1. The increased number of weather observations and the improved methods of communicating and analyzing such observations should be used in a focused, coordinated program to improve short-term weather forecasts.

2. Theoretical and modeling studies as well as field experiments that use very fine-scale observing networks should aim toward improving predictions of the amounts of precipitation and the timing and duration of storms.

3. Computer modeling should be used to identify short-term, potentially predictable components of climate such as drought or severe winters, and to find their precursors such as changes in sea surface temperatures.

4. Computer modeling should be used to determine the climatic effects of alteration of the earth's surface by natural and human activities.

5. To elucidate the global atmospheric chemical cycles problem, an effective attack must include a sharp increase in global chemical measurements, including measurements from balloons, aircraft, and satellites; laboratory work to determine and refine chemical reaction rates; and development of combined chemical and dynamic models of the atmosphere.

6. To explore the nature and effects of regional atmospheric chemical and pollution processes, an effective effort will require surface and airborne field measurements, laboratory work to define pertinent chemical processes, and development of models capable of describing regional atmospheric chemistry.
WORKSHOPS ON COMPUTING NEEDS

A. To realize the research goals and strategies for the 1980's, the computing needs of the atmospheric science community must be estimated. The following questions are pertinent:

1. How fast and flexible should access to data communications be?
2. What data communications transmission rates will be effective?
3. How much computing capacity and power will be sufficient?
4. What degree of compatibility in use of computing service is necessary for effectiveness?
5. What capabilities in vector and raster graphics displays will be needed?
6. What online and archival storage and storage access will be sufficient?
7. What kind of software tools and utilities will be needed?

B. The relative roles of large, centralized computing facilities and smaller local ones must be weighed. What computing services should NCAR provide in the 1980's? To what extent are these consistent with the SCD Long-Range Plan?
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Other institutions planning to send representatives include: University of Colorado, University of Michigan, and University of Oklahoma.
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
SCIENTIFIC COMPUTING DIVISION

PLANNING DOCUMENT
NOVEMBER 17, 1980

DRAFT PREPARED FOR
FIRST ANNUAL USERS MEETING
JANUARY 5-6, 1981
PREPARED BY WALTER M. MACINTYRE
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SCD PLANNING ASSUMPTIONS

The key to successful planning is to anticipate real needs and opportunities before they arise. Plans to meet these needs, and to take advantage of these opportunities, normally should involve costs that remain within the envelope of the funding that can reasonably be expected to be available. However, a vital organization must be able to respond promptly to major new initiatives and to secure the funding required by that response even though the additional costs may be a major perturbation on the budget. This program plan has been developed with these considerations in mind. The plan will be implemented in such a way as to enable the SCD to make a swift and credible response to any proposal to institute a major new scientific program.

Planning assumes that the goals of an organization are clearly defined. Definition of the SCD's goals involves an appreciation of the fact that the SCD serves two quite distinct publics, the NCAR scientific staff and the atmospheric science community external to NCAR. Since the SCD is the only computing resource available to the majority of the NCAR staff, it is essential that the SCD provide a complete computing service to the NCAR staff. The SCD will continue to provide to the atmospheric science community at large those facilities and services that cannot reasonably be expected to be available on the various campuses. Furthermore, it is crucial that NCAR continue to be regarded as the place where atmospheric scientists can confidently expect to have access to state-of-the-art computing technology.

Planning also involves devising a set of priorities which can be used as a guide in minimizing the effects of budgetary stringency or, conversely, maximizing the return, measured in scientific output, on normal levels of funding.
or on new budgetary initiatives. The priorities used in developing a program plan should reflect national priorities in development of the various components of the atmospheric sciences. This plan assumes the priorities defined in the report* of the National Research Council Committee on Atmospheric Sciences.

As understood in the SCD, the scientific range of the computations required by the atmospheric science community include basic atmospheric physics and fluid dynamics, the dynamics of the oceans and solar physics. The chemistry of the atmosphere also makes a heavy demand on computing resources and is an area of steadily increasing importance to NCAR's mission. To these must be added some elements of the biology and chemistry of the land and seas, since there is a clear interaction between biology and atmospheric science in agriculture and in the study of urban smog. Events such as "el nino" have economic implications (e.g. fisheries) as well as climatic. The absorption of CO₂ by the oceans could well affect marine life before it can affect the climate.

Probably the most serious deficiency in the NCAR central computing facility is the heterogeneity both in hardware and software (mainly operating systems). Another serious deficiency lies in the organization of the configuration. These two deficiencies have meant in the past that in periods of fiscal stringency at NCAR, the Computing Facility had no way of making a meaningful cut in expenditures (and, of course, services) without shutting down the Facility entirely. They have also made the NCAR system unnecessarily complex from the user's point of view.

The overriding priority that will govern the implementation of this plan, whether in the procurement of equipment or in the development of software, will be to ensure that the resulting system will be sufficiently flexible to accommodate both budgetary expansion and contraction. In the case of hardware, the configuration must be capable of continuing to operate, albeit at reduced capacity, after withdrawal from service of significant components. The software similarly must be modular, and flexible enough to manage the remaining hardware, albeit with reduced throughput.

Part of that flexibility depends on a change in the SCD's procurement philosophy. The SCD must begin to lease (not lease-purchase) at least some of the hardware, purchasing only those elements which are central to the function of the facility and whose useful life is expected to be long.

Important hardware procurement criteria will be the ease with which the vendor supplied operating system can be integrated with existing systems and the degree to which it provides interfaces to software derived from other sources.

**SCD PLANNING OBJECTIVES**

The scientific goal of the SCD is to develop and maintain that level of scientific expertise necessary to provide the appropriate levels of computing service required by NCAR and non-NCAR scientists in performing their computations. The technical goals of the SCD are to have available, in good time, the hardware and software required to carry out these computations.
The specific steps required to attain these goals are enumerated below.

1. Provision of adequate hardware capacity to meet the growing needs of atmospheric science in the 1980's.

2. Provision of appropriate general purpose software to meet the changing needs of atmospheric science in the 1980's.

3. Studies in data structures and numerical methods appropriate to the systems and the needs of the 1980's.

4. Provision of improved mechanisms to instruct the user community in the use of the SCD's evolving systems, both hardware and software.

5. Management of procurements to provide compatible hardware and software systems.

6. Change to lease (not lease-purchase) in procurement of certain systems.

Objectives 5 and 6 involve management procedures, and will not be addressed further in this document.

PROGRAM PRIORITIES

A. HARDWARE PRIORITIES

Priority 1: Provision of computer capacity adequate to the needs of the atmospheric science community.

Priority 2: Provision of a hierarchical, on-line storage system of capacity in the range $10^{13} - 10^{15}$ bits. The technology is
available currently almost to meet the lower figure; on-line storage of $10^{13}$ bits should be easily attainable in FY85.

Priority 3: Provision of wide band-width digital communications between the SCD and remote sites.

Priority 4: Provision of support for interactive vector and raster graphics both within NCAR and at remote sites. (This is a combined hardware/software item and is discussed in Appendix A.)

The order of priorities represents not only an assessment of the individual importance of the several elements to the atmospheric sciences. The order represents a relation among the elements in that a higher priority item can be implemented without any substantial commitment to those of lower priority. However, the converse is not true, e.g. priority 4 cannot be implemented properly until all others have been implemented.

While the priorities are expressed in hardware terms, there are software imperatives that cannot be ignored. A major requirement is improved data management systems, for which a prerequisite is a set of highly compatible operating systems on NCAR's computers. Ideally, any user of the SCD computing facilities should be able to access all machines via a uniform control language. An important selection criterion in procurement of hardware will be the degree to which the vendor-supplied operating system is compatible with that ideal. A further criterion will be the ease with which the vendor's system interfaces with commercially available software; where required software is available, SCD will purchase whenever possible, thus saving substantial development costs.
PRIORITY 1 - ADEQUATE COMPUTING CAPACITY

The top priority must be to provide computing capacity adequate to the needs of the atmospheric science community; this community includes individuals whose work is supported by agencies other than the NSF. While no single new project with major demands on our resources has been authorized at this point (11/17/80), normal growth must be provided for. Moreover, there is the real possibility that major new initiatives may develop in the near term, particularly in oceanography; the SCD must be able to respond promptly and effectively to these. Normal growth arises in several ways. One is through the increase in the amount of use external to NCAR which has been observed in recent years. The number of CCU's used by non-NCAR scientists has risen from 864 in FY79 to 1,140 in FY80—an increase of 32%.

A second follows from the increase of activity in atmospheric science resulting from the recent real increase in funding levels from agencies other than NSF. This has arisen from a renewed national interest in atmospheric science and oceanography. A third is the increase in productivity of scientists induced by the general availability of interactive computing (sometimes misnamed time-sharing). A fourth is the growth of computing activity as new instruments and large cooperative programs generate increasingly large quantities of new data. Not only do these data require substantial computer capacity simply for cleaning them up, interpreting and correlating them; in addition, the availability of new data, in increasing quantity and of steadily improving quality, acts as an encouragement and challenge to the theorists.
Without appropriate and adequate computers at NCAR, much of the benefit of increased research in the atmospheric sciences could be lost.

Of course, there are two ways to meet any supply/demand problem— increase the supply, or restrict demand! Restricting demand can be done in two ways, assuming competing projects are of comparable "merit". All projects can be supported at a less than optimal level, in fact at a continuously decreasing level. This particular policy is a cop-out and simply ensures that no project is adequately supported. It is, therefore, unacceptable.

The second way of reducing demand involves selection of some projects for full support and denial of all but minimal support to the others. Employment of such a procedure assumes that hard decisions on priorities will have been made within the atmospheric science community. Although it might well mean denial of support for excellent work, allocation of computing resources would have to be based on such priorities if supply cannot be increased. In that case, the priorities used will be those defined in the recent report* of the NRC Committee on Atmospheric Science.

It is the SCD position that the supply/demand problem must be solved by increasing supply. Increasing supply to meet steadily increasing demand means regular growth in the computer capacity of the SCD.

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PRIORITY 2 - ON-LINE STORAGE

As a second priority, NCAR's current hierarchical storage system must be improved and enhanced. Currently, data are staged from archival storage, usually conventional 1/2" magnetic tape, to the TBM, from the TBM to the magnetic disc storage of the relevant computer, and thence to the computer itself. There are several problems with the existing system.

i. The on-line capacity is low:

- 510 x 10^9 bits for the TBM.
- 39 x 10^9 bits for the CRAY discs.
- 20 x 10^9 bits for the 7600 discs.

ii. Access to data sets is relatively slow, especially if the data are not on one of the on-line TBM tapes. Access times of a few hours have been reported, and times of one hour are not uncommon. Such delays are inherent in a heavily loaded magnetic tape-based system.

iii. Over the next five years, the on-line storage needs of NCAR will increase by at least two orders of magnitude to around 10^{13} bits. Furthermore, access times of the order of one hour will become utterly intolerable as system load builds. The demands of major new programs may push this requirement still higher.

iv. The storage system is highly heterogeneous resulting in rather complex storage access procedures for the user. Complexity leads to confusion, confusion leads to errors, and errors lead to lost-wasted-time, human and computer. It is essential that the new hierarchical storage system be as transparent to the user as
possible. Ideally, the working scientist should not need to know on which of the media his data are stored; a single command should stage his data into the computer regardless of where the data happen to be resident.

Mass storage is an area of technology in which change, and progress, is extremely rapid. As an example, today one can buy a magnetic disc system with the same capacity as the TBM, with data set access times of a few milliseconds and costing the same number of dollars as the TBM did five years ago. With a different technology, a magnetic strip system with ten times the capacity of the TBM, and a maximum access time of the order of a few seconds, can also be purchased at the price of the TBM five years ago. The TBM has a data density of $10^5$ bits cm.$^{-2}$ The current thin film magnetic disk technology has a limiting data density of $10^7$ bits cm.$^{-2}$ A new technology, which should be on the market within four years, optical discs, offers a read only storage medium with data density currently at around $10^8$ bits cm.$^{-2}$ Efforts are being made to develop a read/write capability in the optical disk systems and also to increase still further the data density. Finally, in the initial research stages are devices, using wholly different physics, with densities of the order of $10^{12}$ bits cm.$^{-2}$ These new devices are unlikely to be available in fewer than 8-10 years; however, it is interesting to note that NCAR's minimal needs in five years' time, $10^{13}$ bits, would be accommodated on ten square centimeters of such a device! Clearly the cost of on-line storage of very high volumes of data is going to decrease quite steeply over the next ten years.
A strategy must be developed that will enable NCAR to take advantage of rapidly falling mass storage costs. It is crucial that the SCD have the flexibility to move rapidly from one mass storage technology to the next as the combination of technical requirements and financial considerations permit, and to do so with minimum inconvenience to the atmospheric science community. This flexibility will require a change from purchase of hardware by the SCD to relatively short team lease (2-3 years). It will also demand the development of data handling software in which the user interface will remain unchanged as the various storage media replace each other.

PRIORITY 3 - DIGITAL COMMUNICATIONS

The SCD computers are accessed by dial-up or leased line telephone connections from nearly 100 laboratories. Procurements in process will increase the speed and flexibility of such access and permit a modest increase in the number of remote job entry stations. The transmission rates over data communications lines will also increase substantially, providing more cost-effective use of the equipment.

It is expected that as the improvements become apparent in NCAR's facilities for providing a remote computing service, the demand will rise rapidly. This increase in demand will have to be met.

However, the major part of the digital communications growth will stem from other developments. Provision must be made for high band-width (5 MHz) digital communications within the next five years. Several developments are responsible for this:
i. A substantial increase in the flow of data coming into NCAR, and so to the SCD, from large, cooperative projects, including satellite data.

ii. Commercial, high band-width, satellite-based digital communications systems are being launched. With these communications systems providing data rates c. 3 Mbit/sec., it becomes feasible to use the research data sets located at NCAR for computations, including interactive raster graphics, at remote sites. Such a development will increase by several orders of magnitude the data base accessible to atmospheric scientists with sophisticated, mini-computer controlled graphics systems. The result should be a greatly enhanced productivity in these laboratories, and a substantial enhancement in the range of the work carried out should also be evident.

iii. It can be anticipated that commercial digital networks may begin using these satellite based communications systems. At that point, the SCD could provide considerably improved access to its computers for its users by becoming a host on such a network. At current data rates, and with existing protocols, the SCD can reap no advantage from the use of national digital networks.

B. STAFF ASSIGNMENT PRIORITIES

i. Systems Section

The highest priority in the systems section is the maintenance of the integrity of the current operating systems, including the
software running the internal NCAR network. This is a major task
given the variety of equipment for which the section is responsible.
Furthermore, diminished effort in this area will exact a price later
in lost time arising from software failures. In the long term, as
the older hardware is replaced by new, mutually compatible units,
some decrease in this type of activity can be expected, but the
level of effort will never become small. Nevertheless, by about
1985, some reassignment of the maintenance effort should be possi-
ble. "Ab initio" operating system development at NCAR will not be
revived.

The second priority is systems support of activities in other sec-
tions, notably User Services and Data Support. An example is modi-
ication of existing or projected systems software to permit imple-
mentation of a uniform file descriptor. Priorities within this
category will be those set for the applications areas.

ii. User Services Section

The function of this Section is to facilitate the efficient use of
the SCD hardware and software by all the scientists using SCD facil-
ities. This is a tall order and one for which the Section is seri-
ously understaffed.

The first priority of this Section will be to expedite access by
existing users to existing systems. This involves increased or
renewed activity in three areas:

1. Formal courses offered on a regular schedule.
2. Extension of the Consulting Project.

3. Heavy emphasis on user-oriented documentation of software systems.

Two additional FTE have been requested in FY82 for the Consulting Project. Teaching and documentation effort will be enhanced by a redeployment of existing staff.

The second priority is the development, with the Systems and Data Support Sections, of a uniform file definition procedure which, ideally, will define and/or access a file or file set regardless of the physical location of the file.

The third priority is the development and maintenance of the community climate model in collaboration with the Atmospheric Analysis and Prediction Division. A further two FTE have been requested in FY82 for this activity.

The fourth priority is completion of the general data processing system, GENPRO II. This system in fact is relatively close to completion and, apart from maintenance activity, should not impose any demand on User Services staff beyond FY81.

The fifth priority is modification and/or documentation of a number of locally developed software systems. One of these, the NCAR Graphics System, is a batch-mode system that is well-documented and widely used. Interactive access to this system will gradually be implemented, beginning with the relatively simple provision of online pre-viewing of pictures produced in batch mode before they are
recorded on film. Other examples are the preprocessors PP1, IFTRAN and FLOTRAN. These preprocessors have not received the attention in SCD they merit, and they will be developed and documented to the level where they can be easily and reliably used by the general atmospheric science community.

Although these developments are ranked in five priority levels, SCD is fully committed to their completion. The priorities relate to timing rather than intrinsic importance and reflect in a general way the number of SCD computer users associated with or affected by each one.

A further development, that will require discussion, is advanced interactive vector graphics and an NCAR interactive raster graphics system. This development is one that will require investment in hardware as well as software. The question here is whether standard systems should be developed or bought by SCD or whether independent development at several different sites will proceed regardless of SCD action. Raster graphics is discussed in more detail in Appendix A.

iii. Numerical Methods Section

The responsibilities of this Section lie in two related areas. These are support of the community climate model development and in scrutinizing existing numerical methods in relation to the apparent architecture of tomorrow's large machines. These machines are likely to be highly parallel in structure and it is far from clear how computations in the atmospheric sciences can best take advantage
of this feature. Central memory on these machines is also likely to be very much larger than is available today.

This section, at two FTE, is below optimum size for its responsibilities. Two additional FTE have been requested in the FY82 budget.

iv. Data Support Section

This section has two development priorities that are difficult to order. One is to take part in the development of new data structures and uniform data file definition in collaboration with the User Services and Systems Sections. As the collective owner of the largest collection of data in the NCAR archives, and also in view of its ongoing responsibilities, the Section cannot ignore these developments.

The second is connected to UCAR's recent statement of increased interest in and emphasis on the dynamics of the oceans. The Section will have to expand its activities to include certain oceanographic data.

To accommodate these additional responsibilities, the staff will be increased by three FTE. One has already been provided by internal reassignment; two new FTE have been requested in FY82.
APPENDIX A

INTERACTIVE RASTER GRAPHICS

The SCD at NCAR has developed one of the finest libraries of graphics software in the world. It is a library that is used primarily in batch mode and is used in generating most of the nine million frames per year of microfilm output produced at the SCD. It is primarily designed to handle vector graphics where a diagram or picture is composed by drawing a number of vectors, of varying length and orientation, which are defined by specifying coordinates of the points at each end of the vector. From the beginning, the SCD has been regarded as having responsibility for developing for multi-user, portable software in the atmospheric sciences, and for setting software standards. Vector graphics is the one area where these responsibilities have been met. It is proposed to extend the existing vector graphics system to cover interactive raster graphics as well.

In recent years raster graphics have extended the range and power of computer graphics. In raster graphics the smallest portion of the graphics CRT screen that can be conveniently resolved is called a picture cell, or a pixel. In the most general case, the picture is built up by contributions of the individual pixels in the array of pixels comprising the screen. Thus the position of each pixel is predefined by its coordinates in the array. The contribution of each pixel to the picture arises from two attributes of the pixel—intensity and color. In simpler systems, color is omitted and only intensity is specified, giving a "black" and white picture. Usually intensity is specified by 8 bits of information, corresponding to a gray scale of 256 steps. Color may be specified by additional bits, from 4 to 8, giving 16 to 256.
shades of color.

In modern systems, the screen resolution is $1 \times 10^3$, giving $10^6$ pixels per picture. Thus to define a picture in black and white raster graphics requires $8 \times 10^6$ bits ($10^6$ bytes). For color pictures, the amount of information required is 1.5 to 2 times larger than for black and white. Thus an enormous amount of information has to be stored to represent even the simplest pictures in raster graphics mode. However, the quality of the reproduction of the picture is very high, superior to that of the best quality domestic television sets.

Clearly raster graphics complements the more economical vector graphics in applications where resolution of very fine detail is required, or where a picture contains a great deal of information.

The amount of information required to generate a raster picture is enormous. Two megabytes or more are required simply to reproduce a full screen picture, yet these two megabytes may be derived from data sets hundreds of megabytes in size. It is easy to see that raster graphics terminals require dedicated minicomputers to handle the flow of the data and some degree of manipulation of them.

It is clear that one of the most important applications of minicomputers in the atmospheric sciences will be the control of raster graphics devices. However, minicomputers in modest configurations (up to $k$250) cannot be expected to store all the data sets from which pictorial output might be desired. These data sets must be stored in a large, appropriately organized system, i.e. at NCAR. The data may then be accessed in two ways. A preliminary selection and reorganization of the data can be carried out on the SCD
computers and an appropriate subset transmitted to the remote site to be processed further by the minicomputer there and displayed on the screen. Alternatively, NCAR data sets may be transmitted unchanged to the remote site, and all manipulation carried out at the minicomputer there.

Thus the SCD will play a crucial supporting role in the developing field of computer graphics, e.g. storage of data, organized in a form easy to access, and provision of simple utilities to reorganize those data to meet the needs of a variety of projects. The SCD will be unable to play this role without the computing capacity, the on-line storage and the digital communications given as the first three hardware priorities. The alternative to providing this capability at the SCD in NCAR will be substantial upgrading of numerous minicomputers across the country. Not only would this not be cost-effective, but it would be scientifically counter productive. If each minicomputer site processes, stores and organizes the same data in its own way, it won't be long before the data aren't the same anymore!

The only way to ensure that several different approaches to the same problem can be compared is to ensure that they are unambiguously based on the same data. This point is crucial.
APPENDIX B

MINICOMPUTERS AND SUPERCOMPUTERS

No discussion of SCD plans can be complete without a mention of the role played by the small computer. The continuously decreasing cost of computer hardware has made available, over the last ten years, increasingly substantial mini- and micro- computers at a price sufficiently low that they can be dedicated to the use of individuals, groups of individuals, or for the control of individual instruments. These small computers complement the services offered by the central facility in important ways; this observation applies both within NCAR and at the non-NCAR sites.

For interactive graphics other than simple vector variety, a minicomputer is usually necessary for the generation of images; the interactive graphics terminal itself may or may not provide storage for the image currently on display. Such a system, with adequate main and secondary storage, may function as a stand alone interactive graphics device. However, given a wide band communications link between the graphics system and the main NCAR computers, an additional dimension can be added to the graphics system. Images generated after complex computations on the NCAR computers can be viewed at a remote site. Alternatively, images derived from very large data sets stored at the SCD can be transmitted to a remote site and viewed there. The remotely situated graphics system thus has its capability considerably enhanced by access to the very large storage and computational facilities at NCAR. A similar stand-alone capability is unlikely to be cost-effective, particularly if the additional capacity is needed only for occasional use.
A second important area where minicomputers are essential is in the execution of interactive programs which involve heavy computations and/or disk input/output. How heavy is "heavy" is a matter for fine judgement which includes the cost of the minicomputer, the capacity of and load on the centrally administered interactive facility (whether at NCAR or the local campus), the degree to which interaction with the computer is essential to the work, and, of course, the scientific importance of the work.

A third application in which dedicated computers are required is real time use--control of instruments and equipment either where a very rapid response to a signal has to be computed, or where signal averaging techniques must be used to extract the desired signal from a very noisy source. The real time computer may or may not provide a cost effective way of processing further the collected data. Frequently the data will be transmitted to a larger multi-programmed central computer for additional processing and/or interpretation.

Numerous applications, e.g. the interactive editing of graphical displays, have elements characteristic of all of the above modes of operation.

Typically, centrally administered facilities are more cost-effective than minicomputers for interactive text editing and program development. However, one condition for this statement to be valid is that the execution of user programs on the central facility at interactive priority must be carefully monitored. A few users, running from their terminals programs, at interactive priority, with large CPU or I/O requirements, can seriously degrade the system's response to other interactive users.

Thus the decision as to whether to provide a dedicated minicomputer for the use of one person, or a small group of people, is an extremely complex one.
Quite apart from the above considerations, psychological factors cannot be ignored. Many people simply like very much the freedom and flexibility provided by possession of their own computer, and will often insist on procurement of one where an impartial cost/benefit analysis might well indicate otherwise.

A further point is that it doesn’t take many requests for $300,000-$400,000 small computers to add up to the equivalent cost for a rather large centrally administered system.

Each application for the procurement of a minicomputer, particularly the larger ones, should be evaluated dispassionately by the criteria detailed above.
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GRAPHICS: OPTIONS, AND PLANS FOR THE 1980's

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INTRODUCTION

The Scientific Computing Division (SCD) is on the verge of significant enhancements of the graphics services offered to SCD users. This expansion is one aspect of a general diversification of NCAR's centralized computing services. Presented in this document are:

- Definite plans for graphics enhancements.
- Goals for which plans of realization are still under consideration.
- Attractive options which have not yet been targeted as goals.

The remainder of the document is divided into three sections. For readers who are intimately familiar with the current status of SCD graphics services and with recent advances in the computer graphics industry, only the third section, "Plans and Options," will be of interest. For others, a framework for interpreting the remainder of the document will be found in the first section, "Background and Context."

The second section further develops this context by presenting the current status of NCAR's graphics services and work in progress. While this is not the place to deal in detail with the character and current state of the system, we shall at least touch upon the major points—users are often surprised to find that facilities already exist to meet some of their immediate needs. (More system details and an interesting scenario for distributed graphics and interactive computing may be found in the article by T. Wright in the Fall 1979 issue of Atmospheric Technology. The article by L. Henderson in the Proceedings of the Spring 1980 DECUS Symposium gives a thorough overview of the nature of the system.)

Throughout, discussion is generally limited to those facilities under consideration as SCD centralized services. Ideally, SCD services would be a
superset of those generally useful services available on non-SCD satellites, so that those users who are reliant solely upon SCD services would have a full set of useful tools. Whether or not this superset is eventually realized, we will attempt here to identify its components as options. The discussion of SCD plans and options (e.g., for the I/O satellite) could be equally well applied to determining the requirements of general purpose satellites being set up by other NCAR groups. SCD activities, additionally, are opening some attractive options to users of non-SCD satellites and remote users, and these will be mentioned.
BACKGROUND AND CONTEXT

HISTORICAL SETTING

Since the mid-1960's NCAR has been a pioneer in the use of computer graphics to extend the power of its mainframe computers and to assist in the comprehension of the results of complex computations. The convenience of online graphics devices and the resulting level of picture production at NCAR were relatively rare among similar scientific institutions. To complement and enhance the utility of graphics display devices, NCAR has built a software system whose richness of high-level capabilities relieves much of the tedium of constructing complicated and meaningful images. Concepts at the heart of the modern system, software portability and display device independence, appeared at NCAR in the mid-1970's; their realization here pre-dates not only other current systems of a similar nature, but appears to pre-date the earliest vestiges of the graphics standardization efforts which embody the same central concepts.

INDUSTRY TRENDS

The end of the 1970's has seen an explosion in the computer graphics industry. A vast selection of new hardware display devices is now available, incorporating a seemingly endless varieties of display format and technology. At the most expensive end of the spectrum are devices with apparent hardwired intelligence that one would formerly associate with extensive computations on large mainframes. At the other end are devices simple and cheap enough that a hobbyist could consider having one at home.

Software availability is vastly better now as well. Aside from software sup-
plied by the hardware vendors themselves, a number of general purpose packages, often based on tentative graphics standards and such successful systems as NCAR's, can now be purchased from exclusive software vendors. Special purpose graphics and image processing software is widely available as well, often in the public domain as spin-offs from such programs as the National Space Program.

The benefits to the computer user of this revolution in graphics technology are numerous: well-engineered systems provide comfortable and natural interfaces for users; in the same vein, distributed graphics terminals, small plotters, etc., give more personalized service and more user control of the end product; and more importantly, the prompt return and display of results greatly increases user productivity, much as online editors do when replacing batch editors.

**NEW OPPORTUNITIES**

The maturing of the computer graphics industry has enormously accelerated the pace of change of the state of the art. In many areas of the field, the state of the art has moved well beyond what NCAR's SCD chooses to or is able to offer. This recent lag is due in part to the fact that SCD's graphics services have been closely bound to the character of the general computing environment at NCAR. For many years, the environment consisted of a few large mainframes and mass storage systems, accessible in batch mode only. This has been reflected in a passive graphics system directed at hardcopy media.

Now, however, there is a proliferation of general purpose satellite computers, both within the SCD (e.g., the soon to be installed I/O satellite), and within other divisions. These offer convenient, fast, interactive access to
significant computing power for a growing number of users. Most have some sort of communications link to the mainframes and mass storage, and many have now or will have fast, high-capacity links. These changes open the opportunity for the SCD to partake of the benefits of the graphics hardware and software revolution described above, and to maintain its computer graphics facilities near the state of the art through the next half-decade.
CURRENT STATUS OF SCD GRAPHICS SERVICES

HARDWARE

The dd80’s

The first graphics devices that NCAR acquired were the dd80 microfilm recorders. These products of early-1960's technology have been generating several million frames of film output per year, both printer simulation and line graphics, for the last decade. They are nearing the end of their useful life, and may soon be impractical to maintain. Although adequate for rough, quick-look graphics, their accuracy is insufficient for much of NCAR's work and they lack flexibility in output options and film formats.

The DicomEd

In 1977, NCAR acquired a DicomEd COM (Computer Output Microfilm) system for eventual replacement of the dd80s. The system consists of two film transports controlled by a minicomputer, and represents the state of the art in COM systems. The recorders are very high resolution compared to the dd80, and offer 256 gray levels instead of 2. They can produce either vector or raster graphics, or printer simulation via a fast hardware character generator. Available film formats include 35mm or 16mm film (sprocketted or unsprocketted), and 105mm microfiche (24X or 48X). The latter format promises to be the most popular, because of the huge number of frames one can easily maintain in a small space, the ease of reading, and the cheapness of adequate fiche viewers. Other options include variable image scaling, hardware frame rotation, etc. The system's use is relatively light currently, but is growing steadily since a field upgrade last year stabilized it. Access to the transports is still only in offline mode via tape, but the project to complete its online connec-
tion to NCAR's hyperchannel network is nearly complete. This event will certainly lead to a big increase in usage.

**Other**

With the exception of a few graphics terminals connected to the SCD satellites, the SCD itself has no other graphics display hardware. Some other divisions have their own satellites now, with equipment such as graphics terminals (including color raster monitors), electrostatic printer/plotters, flatbed plotters, and color impact printer/plotters. The HAO satellite, the NWP satellite, and the RSF RDSS system are examples. These systems and other remote stations are linked with the SCD graphics services mainly by use of a common software system.

**SOFTWARE**

**Functionality**

Currently, the SCD is maintaining a graphics software system consisting of somewhere over 50,000 lines of code. Most of this is in the high-level utility routines, which perform such functions as contouring, mapping, etc. This high degree of functional completeness is not found in many other scientific data representation graphics systems, and in part accounts for the popularity of NCAR's system. About 20 utility packages are now supported, and at least 3 others have been identified for addition to the system.

**Characteristics**

The graphics software generated and maintained by the SCD is what is called a vector graphics system--its capabilities are oriented toward producing vector or line drawings. In fact, currently there are no facilities for producing filled or shaded regions other than with half-tone simulation. The package
can further be characterized as primarily passive—it contains no input or picture alteration facilities per se. This does not mean that the system cannot be used interactively (in fact there are at least two interactive implementations within NCAR); it means that once an element of a given picture has been generated, it cannot be altered in that same picture in the fashion of design and layout graphics systems.

Two design criteria are critical to the success of a graphics software system in a distributed processing environment: the system should be easily transportable from one computer to another, and the user's view of the system should be independent of any intended graphics display devices. The first criterion is met at NCAR by using the FORTRAN language and observing good program portability and coding standards. Device independence is attained by having the package output a file of device-independent, graphics instructions known as metacode. This metafile can then be translated at any time, locally or remotely, to drive any given graphics device.

**Portability Status**

Achievement of portability of the basic level plot package is substantially complete, although some recently identified enhancements could make life easier for implementors. Versions now exist for all major computer models, and one can expect relatively painless success if one undertakes to install the system on a new computer system. Indeed, in the last two years, several hundred copies of the system have been distributed, many of them to researchers wishing to establish the system on computers at their home institutions.

Achievement of the portability goal for the higher level utility packages is perhaps 75% complete. Many of the heaviest used packages are done, but a sub-
stantial amount of work remains in order to make implementation of the whole system on a new computer as painless as it ought to be.

**Device Independence Status**

Work on the metacode foundation of the system is substantially complete. The system now includes a portable "skeleton" metacode translator which allows interfacing a new device to the system with a minimum of work (a week often suffices). All SCD-supported hardware is now driveable via metacode. The wide range of non-SCD hardware mentioned above is accessible via metacode as well. Additionally, graphics files from mainframe executions are routinely being transmitted through RJE links for translation and display at remote sites. All that is required for this mode of operation is a display device and a very modest amount of computing power for the metacode translation.

**Support Tools**

This brings us to the last class of graphics software: graphics support tools. Such tools do not generate pictures, but aid in the management of files destined for graphics devices. A pair of portable programs has been completed for encoding and decoding binary metafiles before and after transmission through NCAR's current RJE facilities. Programs to prepare text files for recording on the DICOMED fiche unit, or any other graphics device for that matter, have been completed. Work is in progress on software to aid in transmission of metafiles and text files to graphics devices with connections to NCAR's hyperchannel network. Finally, as mentioned, work is in an advanced stage on a software system for the online operation of the DICOMED recorders.
FUTURE PLANS AND OPTIONS

INTERACTIVE GRAPHICS

The acquisition of publicly available graphics display terminals connected to an interactive computing system is of the highest priority for the enhancement of SCD graphics services. A number of the autonomous satellite computers currently have such facilities, but the user without access to such a system is forced to rely on film production. The frustration and lowered productivity of waiting a couple of hours for film turnaround have been pointed out, and are probably familiar to many readers.

We suspect a substantial proportion of images produced at NCAR end up in "recycling" with one or zero viewings; wide availability of monitor viewing facilities should help alleviate such waste and somewhat reduce the demand for increasingly expensive film hardcopy.

Before dealing with SCD plans to realize interactive viewing facilities, the varieties of interactive graphics need to be distinguished. The term "interactive graphics" covers an exceedingly broad range of activities. This range can be divided conveniently into three groups characterized by the level of user interaction. These are presented in an increasing level of complexity, cost to implement, and cost of machine resources to support. For each, the difficulty to implement with currently available SCD tools is noted. Additionally, some estimate (necessarily subjective) of the current utility to SCD users is given. For the most part, the comments apply to either vector or raster display technologies. The latter usually incurs somewhat higher host machine costs; these are not too serious in the case of vector applications displayed on raster terminals that accept vector-type instructions (e.g.,
pseudo-raster terminals), but can be very serious where the host must completely construct the pixel array for the refresh buffer. The three levels of interaction are:

1. Interactive examination of batch-generated picture files.
2. Construction of images and simultaneous viewing of the same during execution of an interactive program.
3. Construction and extensive interactive modification of displayed images themselves.

In the first mode, one typically runs (locally or remotely) a batch program which generates an instruction file for a sequence of images. This is dispatched to one's interactive display station, where one may skip around in the picture-file examining images. The file may then be discarded, or all or part of it may be redirected to a hardcopy device (local or remote). This level of interaction is trivial to provide in the context of the SCD's metacode system, and would represent a quantum leap in the quality and quantity of graphics service to SCD users. Demands on machine resources for this level are relatively light as long as picture files are kept to a reasonable size. In reality, this is not much of a restriction; NCAR's typically large graphics files result in part from the current inconvenience of getting graphical output, which the described mode of interaction alleviates.

A typical scenario for the second level has a user writing and running an interactive applications program, say a modeling calculation, and embedding in the program calls to normal SCD graphics routines (contouring, graphing, etc). After calculating and displaying a set of results on the graphics screen, the user interactively tunes the controlling parameters of the model and iterates again. An important point in this scenario is that the user does not need to alter elements of a picture under construction, but merely displays the
results. Given that restriction, this service is relatively easy to provide, requiring probably a few man-weeks to implement the full portable graphics system on the interactive machine. The gain to the general user population is substantial, though not as great initially, we believe, as the gain when the first level is offered. This is primarily because the user with existing batch programs gets the benefits of the first level by simply logging on the system and typing a command. For the second level, the user must develop interactive applications on a new system. Demands on machine resources are somewhat higher than those of the first level, because the user is doing more extensive computations at interactive priority.

The highest level of interaction is characteristic of interactive design and layout systems. In this mode, the image has become, in some sense, the end goal rather than a tool supporting other goals. There is some use for this level of interaction for polishing picture details for publication and presentation, document construction, etc. We believe, however, its utility is substantially lower to the general SCD user population than the first two levels, which are both concerned with data representation. Display hardware to support this level is generally among the most expensive available, and tax on host machine resources is typically quite high, particularly if the display technology is raster. As degradation of interactive response can be a problem when such systems are available on general purpose satellites, they are often put up on special dedicated processors. The current SCD graphics software system is ill-suited to this level of interaction, and would either have to be substantially revised or, more wisely, supplemented with commercially available software.
I/O SATELLITE FACILITIES

With the installation of the I/O satellite in the spring of 1981, SCD will for the first time be offering access to interactive computing. A number of terminals will be available in public areas, and some of these are destined to have graphics display capabilities. For relatively little extra cost, other useful display devices can be added to the system. The consideration of these additional options is still in progress, hence they are presented here as options instead of definite plans.

Graphics Terminals

Display monitors available can be divided into two large classes: storage tube and refresh. Although there is some overlap in the cost ranges, storage tube monitors are generally the least expensive. They are limited to line graphics display and alphanumeric information, but have surprisingly good resolution for the cost. Cross hairs are often available for input, but storage terminals lack the range of facilities available in the refresh class. They are well-suited for display of typical NCAR vector graphics images where interactive modification of the picture is not required.

The refresh class of terminals includes both stroke and raster display technologies. Although the price floor of this class is falling, it is still somewhat high due to the more complex electronics necessary to handle screen refresh from image memory. A much higher level of terminal interaction is generally available through the use of multiple image planes, dynamic remapping of images through lookup tables, hardware scroll, zoom, highlighting and erasure, and input facilities ranging from cross hairs to lightpens and joysticks. The raster terminals allow for area fill as well, and both are avail-
able with color. At the high end of the price and performance range are high resolution highly-interactive color raster display and image processing systems. These require substantial computing and data flow support. Their attachment to a dedicated special purpose processor is generally preferable to burdening a general public system with them.

Initially, at least, most of the graphics terminals should be the less expensive storage variety, and the similarly inexpensive pseudo-raster devices. If resources permit, the inclusion of a stroke refresh terminal should be considered. One motivation for this is that it would allow color, which adds another dimension to line displays and thus allows clear presentation of more complex images. Another motivation is that it allows more sophisticated incremental picture construction under interactive control, as mentioned above under the second level of interaction.

Pseudo-raster or raster terminals on the I/O satellite would open up data representation algorithms not currently available, i.e., those involving solid area fill. If they were included in the satellite's equipment, their use would have to be circumscribed to avoid the sort of system degradation previously mentioned. Their use here as standard display monitors would be acceptable, but modes of operation which take full advantage of their unique capabilities should be avoided. Their unique utility should not be ignored, and we will later discuss a more preferable way for SCD to offer the services of high-quality, color raster displays.

**Hardcopy**

For about the cost of another modest graphics terminal, a simple hardcopy device could be added to the I/O satellite. Users would find such a device very
convenient, as it would allow them to immediately and cheaply obtain one or
two hard plots of images of interest in an interactive session. There is
quite a range of such devices now available, including electrostatic
printer/plotters, impact printer/plotters, and desktop pen plotters. These
devices can be run as slaves off of a terminal or a set of terminals, and/or
can be driven directly from a host processor. The effort to integrate them
into a system in the context of the current SCD graphics system is relatively
trivial, as for the modest display terminals. The burdens they place on the
host processor are also similar.

In higher price ranges, and in some cases at the edge of the state of the art,
one finds color inkjet plotters, XEROX color copiers, terminal-driven color
hardcopy (35mm slides and 8X10 glossies), laser printers, and graphics pro-
grammable phototypesetters. These are probably inappropriate for the I/O
satellite, but could find great utility at a high-performance, color raster
workstation.

**HIGH-PERFORMANCE, COLOR RASTER GRAPHICS**

As mentioned previously, at the top end of the price and performance range of
graphics technology is the class of high-performance, color raster display
systems. The characteristics of these "terminals" include, but are not lim-
ited to, high resolution, significant hardwired intelligence, sophisticated
image transformation and manipulation capabilities, multiple internal image
planes, and extensive color palettes. Their use often consumes significant
CPU and mass storage resources of their host processors. Their capabilities
are clearly excessive for everyday use in the display of the type of graphics
NCAR produces most of.
There are applications, however, for which there is no substitute for these capabilities, and the SCD currently has no facilities to service these needs. One such application is the reconstruction and enhancement of digitally-recorded photographic data. Another is the interactive examination and editing of large datasets from radar systems. While tools for such data-intensive projects are the most immediate need, these graphics systems (particularly when augmented by color hardcopy) would also be useful for preparation of presentation-quality slides and graphics.

Some such facilities now exist within NCAR, but demand for their use is apparently exceeding the capacity of the systems. The SCD is currently considering how best to provide a centrally-available, color raster workstation. The utility of such a system would be greatly enhanced by a central location which permitted connection to the SCD hyperchannel, allowing high-speed data flow between it and the mainframes and mass store system. If the dedicated processor controlling the system had sufficient excess capacity, it could even be used to handle some of the auxiliary graphics equipment discussed for the I/O satellite, if that machine were to become overburdened.

**COM**

The DICOMED systems should adequately handle NCAR's black-and-white COM needs for the next few years. The imminent completion of the online connection project will relieve SCD users of a rather hazardous dependence on the aging dd80s.

One interesting option exists for future enhancement of the DICOMEDs: color. Color capability is a purely add-on feature for the transports NCAR now has. The addition of the feature to both transports would be cost competitive with
acquisition of one of the terminal-driven, color hardcopy devices mentioned above. The quality of color images that the DICOMED system can produce is without comparison. If the color raster workstation discussed above is realized in the near future, the color upgrade of the DICOMEDs would be an attractive supplement to that system. If the system is not immediately realized, a color upgrade would provide a substitute for some of its capabilities.

Whatever form of color hardcopy is considered, there is one complication which must be taken into account: processing. Currently, NCAR's film processing facilities handle only black-and-white. A color processing operation would be a large expense, and a venture into a field in which NCAR has no experience. If such hard color services are provided, a reasonable initial approach to the problem would be to contract for periodic commercial processing service, say once or twice a week. While such a scheme may seem inconvenient at first thought, it would in reality be much less so if a user were able to tune his/her color plots on a color monitor before shooting final productions runs on film. The expense of color film compared with black-and-white would dictate such a modus operandi even if more frequent or in-house processing were available. One possible technological breakthrough in the film industry should be watched for: the production of a color transparency film that requires no processing (as Polaroid prints do not). There have been strong rumors recently that one of the major film manufacturers is going to announce such a product within a year.
SOFTWARE PROJECTS

Unfinished Business
As implied in earlier sections, some program portability work remains to be done on the vector graphics software system. This work is not inherently difficult, but it is time-consuming. At the time of the installation of the CRAY-1, a large commitment of staff was dedicated to the portability effort. This effort led quickly to the successful implementation of most of the system on the CRAY-1. It also accomplished enough to make feasible the implementation of the system on almost any computer. Better understanding of portability problems and much practical experience have been valuable side benefits, and these have made it possible to target what remains to be done so that propagation of the entire system is easy instead of just feasible.

Unfortunately, the portability project has been nearly static for the past two years, because available staff has been diverted to immediate problems. As the diversification of computing equipment and graphics devices within SCD and the rest of NCAR proceeds, it is of the highest priority to complete this project. It does not take many implementations until the extra weeks or months of programmer effort exceed the effort which would be required to finish the project. Aside from the savings of technical talent resources, the general user population benefits by minimization of the delay in establishing familiar software services on new computing systems.

Most of the work required, and the most urgent, pertains to the utility-level software. Some rearrangements of the internals of the core-level plotting software, the System Plot Package (SPP), would help alleviate some of the more common implementation problems which have come to light in this part of the
software package.

Also mentioned earlier was some remaining work in expanding the functionality of the utilities family. In the last year one new member, non-gridded contouring, has been added. Two or three members remain to be added. Foremost among them is a stripped down, minimal-options version of the automatic graphing package for implementors on small minicomputers as well as for those larger-machine users whose program sizes create space problems. A threedimensional analogue of the software dashed-line family would be useful. There have been a number of requests for a histogram-drawing utility.

The largest current commitments of the software effort are to the DICOMED Online Operating Software (DOOS) and graphics support tools (i.e., printer simulation support, network transmission, etc.). These projects will continue at the current level of effort until early 1981, when they will be substantially complete.

New Implementations

The arrival of the I/O satellite and the associated graphics devices will require the implementation of the standard vector graphics software system. For each display device type attached to the system, one version of the skeleton metacode translator must be adapted. Effort here is typically a couple of man-weeks per adaptation. Adaptations for truly raster devices, i.e., those for which pixel arrays must be loaded into refresh memory, will require the inclusion of a vector-to-raster conversion module in the translator. This will require a little extra effort, as it has only been done in a crude way so far within the SCD. The problem is well-solved and amply published. It is worth noting that cheap vector-to-raster hardware "black boxes" have just

- 20 -
started to appear commercially; these developments should be followed attentively as they promise to free the CPU of significant load where such conversions are required.

The SPP and the most popular utilities must be installed as well. The effort here is highly dependent on the characteristics of the chosen computer and implementor's familiarity with it, but a couple of man-months should be an upper limit for accomplishing a significant amount of the required work.

Development

The arrival of new hardware capabilities will necessitate some software development work in addition to the implementations mentioned above.

For the vector graphics system, the most notable new factors in the future are color raster displays with its orientation toward solid areas and interaction. Because the metacode is easily extendable, at least some level of service to new techniques can usually be accommodated without seriously violating the overall integrity of the system. Although this is true even when the new techniques are somewhat alien to the foundations of the system, one must recognize that there are reasonable limits on how far the system can be stretched in these cases. The metacode vector graphics system, for example, will never be extended to cover pattern recognition and image processing (PRIP) applications which are inherently pixel or raster oriented.

Accommodation of color will require no changes. Although SCD currently has no color devices, the options are already in place for program manipulation of color displays.

Currently, the system has no way of dealing directly with solid or filled
areas. This is an extension which has been in early planning stages for several months. The first level of the planned extension is fairly straightforward, is not at all alien to the foundations of the current system, and will provide users with a primitive for specifying arbitrarily filled areas. This capability could then be used, in fact, to completely fill the picture with solid areas, effectively simulating a raster-type display. The use of color in conjunction with filled areas will be no problem. The chosen approach will allow efficient use of devices with hardware fill capabilities or even raster scan capabilities, but will be usable as well with devices which can only draw lines. The second level of the planned extension will be the incorporation of the feature into current utilities, and/or the construction of new utilities with data representation algorithms which can take advantage of an area-fill primitive (e.g., generation of isopleth maps). This is not inherently difficult, but will be more time-consuming than stage one.

True raster graphics, such as the presentation of digital photographic images on raster screens, is clearly beyond the flexibility of the vector graphics metacode system. The auxiliary software tools that one uses in conjunction with such applications, spectrum filtering, image enhancement, etc., are even more remote from the philosophy and direction of the current graphics services. To provide such software, for example on a high-performance, color raster workstation if such were acquired, would mean starting from scratch. To generate a complete family of such useful software in-house would require a substantial research and development effort. Happily, it should not be necessary to develop everything ourselves. First, some such software has already been developed within NCAR, and could possibly serve as a basis for a new system. Additionally, as a result of various national scientific projects, mili-
tary projects, attention lavished on the field by commercial media, and the efforts of vendors, there is an enormous amount of high-quality raster display and image processing software now available. Our needs could probably be reasonably met either by purchasing vendor software or by taking something from the public domain and adapting it to our needs.

As pointed out earlier, providing interactive vector graphics services at the two least complex levels of interaction can be comfortably handled with current software with no significant development required. The addition to the skeleton translator of a general purpose, user-interaction module for guiding interactive metafile viewing sessions would be a nice enhancement, but does not represent any significant development effort.

The highest level of graphical interaction is quite beyond the capabilities of the present system. Since the general utility of this graphics mode to the SCD users is unclear at this point, it seems most prudent to let development be driven by demand. If significant demand arises, two options exist for meeting it. First, the present system can be extensively reworked to include the segmentation and input facilities necessary to support high-level interaction. Second, a suitable core-level package could be obtained commercially; there are offerings now that cost about the same as a medium-priced terminal.
National Center for Atmospheric Research
Scientific Computing Division

A NEW INPUT/OUTPUT SATELLITE COMPUTER SYSTEM
FOR THE NCAR SCIENTIFIC COMPUTING DIVISION

Author: David Fulker

draft prepared for
The First Annual Users Group Conference
THE PRESENT CONFIGURATION

The present configuration of computers at the NCAR Scientific Computing Division (SCD) may be described as: the focus of large computations is the CRAY-1 system, currently accessible only via the Control Data 7600, but soon to have an operational interface to the Network Systems Corporation (NSC) Hyperchannel (NCAR's internal high-speed network). The CRAY-1 operates only in batch mode, and at present, its jobs are submitted either as card decks to the 7600 or as remote jobs through the MODCOMP II; as the CRAY-1 has no printers, all output is returned via the same routes. The MODCOMP based Remote Job Entry (RJE) system provides batch submission facilities for about 125 sites representing some 74 universities and research organizations.

Each of the two major systems (the 7600 and the CRAY-1) has a large disk subsystem, but the workload requires auxiliary storage of immense proportions satisfied by a 40,000 volume magnetic tape library and by an Ampex Terabit Memory System (TMS-4). Data may be exchanged directly between the TMS-4 and either the 7600 or the CRAY-1, but the tape library is accessible only to the 7600 as the CRAY-1 has no tape drives. Also accessible only to the 7600 is the Program LIBrary (PLIB) subsystem. This software subsystem provides 7600 disk storage for small files, usually program source files, with automatic offloading to the TMS-4 so that such files survive disk purges.
THE NEED FOR AN INPUT/OUTPUT SYSTEM

The above configuration places heavy reliance on three systems that are relatively old and likely to become obsolete—the MODCOMP II, the Control Data 7600, and the Ampex TMS-4. In fact, many users are essentially without computer power unless all three are operating and able to meet the following needs:

- All remote users, including most university users, submit jobs and receive output via the MODCOMP.
- Most users store their programs via the PLIB subsystem which requires both the 7600 and the TMS-4.
- Program modifications are performed by most users with the 7600 batch editor.
- Most graphical output is processed through the 7600.

Noticeably absent from the current configuration are facilities for interactive computing, even for the preparation of programs. The SCD does maintain two small interactive systems, PDP 11/70's, for use by its own staff, but the general user must rely totally upon the batch systems. This is most cumbersome for those NCAR researchers who, unlike university researchers, have virtually no access to interactive computing.

The weaknesses identified above are similar in that they tend to be input/output (I/O) intensive. To partially resolve these weaknesses, the SCD plans to augment its current configuration with an Input/Output Satellite (IOS) computer system. During the summer of 1979, this acquisition was begun with the appointment of an IOS Procurement Committee comprising experts from each of the SCD technical sections. Prior to the formal procurement steps,
the committee clarified and refined a set of needs that could realistically be met by an IOS computer system, constrained by budgetary factors that precluded a full-scale 7600 replacement.
FUNCTIONS OF THE IOS COMPUTER SYSTEM

The IOS Procurement Committee gathered information, and continually refined its concept of the IOS functions until April 1980, when the formal Request for Proposal (RFP) was sent to 13 computer system manufacturers. The information gathering included discussions with and presentations by 11 computer manufacturers, numerous meetings with users both internal and external to NCAR, studies of current usage statistics (especially for RJE, tapes, and unit record equipment), and a questionnaire survey of users (to which 70 responses were received).

These efforts resulted in the following functional definition of a suitable IOS computer system.

GENERAL CHARACTERISTICS

The system is characterized by very high reliability and minimal degradation even with many users. The IOS is efficient and easy to use, both from the systems programmer and the user standpoints. The system is equipped with reasonable security mechanisms and comprehensive accounting for all subsystems.

REMOTE ACCESS

The IOS includes a state of the art data communications subsystem to support various forms of remote access. This subsystem is sufficiently flexible to support a broad range of remote devices including very simple terminals, batch stations, and full-fledged computer systems. The technology of the IOS will permit the SCD to adopt communications protocols that fit its future needs, even if those needs include high-bandwidth links (i.e., satellites); access to public, packet-switching networks; or file transport mechanisms. The IOS
could functionally replace the MODCOMP II, except that the precise protocol
details will not be duplicated.

**INPUT/OUTPUT PERIPHERALS**

As initially configured, the IOS will provide printing, card reading, and han-
dling of 7- and 9-track tapes at all densities. With minor expansion, the IOS
will be capable of supporting the entire printing and card reading as now pro-
vided by the 7600. With further expansion, the current 7600 tape handling
load can also be accommodated. Although the IOS can provide functional
replacement for the current 7600 printing, card reading, and tape handling
activities, the current 7600/TMS-4 activity is not within the capabilities of
the initial IOS configuration.

**FILE MANAGEMENT**

Interactive editing and management of files will be supported by the IOS. The
system is capable of assuming the current 7600 PLIB and batch editing func-
tions. This includes archiving files from the IOS disks to some backup
storage medium, but may require more stringent size restrictions than are now
applied to PLIB.

**NCAR INTERNAL NETWORK**

It will be a logical and straightforward process to interface the IOS to the
NSC Hyperchannel. This will provide the critical connection between the new
system and all other components of the NCAR scientific computing environment.
It will also be straightforward to devise and implement facilities that give users easy and logical access to the entire computing environment via the IOS.
IOS HARDWARE

The IOS will incorporate state of the art hardware for high performance, and very high integrity and reliability. The system is of modest size in the initial configuration, but is easily expandable via field upgrades in all respects. The architecture of the system is highly suited to a multi-task, multi-user environment, and is efficient for high-speed I/O, permitting several independent I/O operations to occur simultaneously at full speed.

Major hardware components are listed below:

- The central processing unit is fast and has numerous features that make it exceptionally well suited to the IOS.

- The memory exceeds one million bytes, has excellent access and transfer characteristics, and has error correction features.

- The disk subsystem exceeds one billion bytes, and has excellent access and transfer characteristics.

- The tape subsystem includes four high-speed drives that encompass 7- and 9-track recording at all common densities. These drives are suited for very heavy use, and the subsystem may be expanded to include at least eight drives.

- The communications processor is a powerful auxiliary computer system that is closely coupled to the central processor, and relieves it of the low-level communications handling.

- There are at least 48 ports on the initial configuration, supporting a variety of synchronous and asynchronous lines encompassing speeds from 300 to 9600 bps. The system can support speeds in excess of 50,000 bps, and can be expanded to support at least 250 ports.

- An NSC adapter is readily available to interface the IOS to NCAR's NSC Hyperchannel.
IOS SOFTWARE

The software for the IOS is easy to use and easy to modify, including changes for implementing an interface to the NSC Hyperchannel. Documentation for the software is comprehensive and easy to use, and the source code for the software is available. Major software components are listed below:

- The operating system is designed to complement the hardware in providing an efficient multi-task, multi-user environment, and in supporting high-speed overlapped I/O.

- An interactive command interpreter provides convenient access to the system functions, especially those for file and tape management. The interpreter can also process stored commands or procedures that contain conditional control structures.

- Mechanisms are provided that will permit comprehensive control over user access to resources. It will be possible, for example, to define classes of users, and to control the activities available to each class as well as determining the priorities for such activities.

- The data communications subsystem supports several protocols including those for asynchronous ASCII terminals and for synchronous remote batch stations. The flexibility also exists for implementing other protocols as may be desired for future high-speed links or for public, packet-switching networks.

- The tape processing software is flexible enough to handle all anticipated tape formats including very long physical records which are common in the NCAR tape library. The system permits direct user control over most tape processing including error conditions.

- The system contains various features to facilitate recovery from failures. These include warm restarts, hardware diagnostics, memory dumps, and error logs.

- Other important software items include an interactive text editor, a FORTRAN-77 compiler, a high-level systems language, a linking loader, and system accounting features.
IOS USER FEATURES

The IOS is being planned as a system that is easy to use. The system functions are invoked by a simple, interactive command language. When sequences of commands are frequently repeated, the user (or the SCD) can create procedures to simplify complex tasks. Interactive editing will undoubtedly improve the process of creating programs for the CRAY-1, and in some cases, the IOS will be capable of performing test compilations and occasional simplified test runs.

The IOS is equipped with interactive "help" facilities that provide the user with access to pertinent documentation. Among its IOS development plans, the SCD has included an online documentation system that will extend this "help" concept to include documentation for other SCD systems. Another possible development item is an extension of the IOS file management system to assist the user in handling files on other SCD systems including the CRAY-1 and the TMS-4.
STATUS OF THE IOS PROCUREMENT

The procurement has been highly competitive, with proposals being submitted by a number of major computer manufacturers. Delivery of a system, fully satisfying the above characteristics, is expected by the summer of 1981. Actual I/O use of the system will be delayed, possibly by several months, until the NSC Hyperchannel connection has been fully checked out. To avoid overwhelming the system before field upgrades can be implemented, initial use is likely to be somewhat restricted—-as actual performance is observed, restrictions will be lifted gradually, and upgrades planned where necessary.

The IOS is an important step in the endless process of replacing old equipment with new, a necessary process for meeting the computing needs of the atmospheric science community. This process is not without problems, and the SCD will attempt to ease the impact on users who depend heavily on the status quo. For example, the IOS will be unable to duplicate all aspects of the MODCOMP RJE protocols, so the SCD will try to choose the best approach to the consequent transition. Believing that such problems are tractable, the SCD is excited about the IOS, and its potential for providing a new level of service for NCAR computer users.
National Center for Atmospheric Research
Scientific Computing Division

SOFTWARE TOOLS

Author: Russell Rew

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SUMMARY

This talk will summarize the needs for better software tools on NCAR computers and offer tentative plans for satisfying some of these needs.

The term "software tool" refers to a program that deals with programs or other textual objects as data; it is a computerized aid to the development, testing or maintenance of software. A FORTRAN compiler is a familiar example of a software tool. Others are FORTRAN preprocessors, editors, static and dynamic program analysis aids, standards verifiers, documentation tools, and maintenance aids.

In response to a recognition that the cost of unaided software development and maintenance can be exorbitant and the quality of resulting programs poor, NCAR has developed and acquired a sizable collection of software tools over the last decade. Some of these tools have been popular with NCAR users, even though they were not supported at a very high level. This collection has suffered from some of the same kinds of problems that occur with large miscellaneous collections of numerical software thrown together into a library:

- lack of portability,
- lack of uniformity of user interface,
- insufficient generality, and
- a requirement that the user invest a large amount of time learning how to use the software effectively.

A solution to some of these problems may be near due to advances in language standards, an understanding of which primitives are most appropriate to support software tools, and experience with several successful tool collections. It is now possible to write many useful tools portably, and it has recently been demonstrated that an interface for tools can be embedded in several dif-
ferent vendor operating systems to provide a uniform environment that facilitates the use of software tools in different computing environments. The availability of this sort of interface makes a systematized collection of tools much more than the sum of its parts.

At least one widely-used existing collection of tools [1] and another currently funded large-scale development project [2] promise to solve many of the current problems with the uneven quality and difficult maintenance of software tools on a variety of different computing systems. Support of these two packages on NCAR computers will help to provide users with the benefits of a large collection of tools that can make the production of reliable software more cost-effective than it has been in the past.
REFERENCES


National Center for Atmospheric Research
Scientific Computing Division

OUTLINE OF PLANS FOR THE NEXT SEVERAL YEARS

Author: Roy Jenne

draft prepared for
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INTRODUCTION

The Data Support Section (DSS) maintains many large sets of analyzed grid data and observed data from the National Meteorological Center (NMC), the National Climatic Center (NCC), the U.S. Navy (USN), and the U.S. Air Force (USAF). Other countries and laboratories also provide data. The archives are still largely described in Jenne, 1975.

Significant efforts are required to simply update and maintain the data archive and to serve user needs. Some data is obtained for the archive to meet a specific request. More often, data is acquired in anticipation of research needs by assessing the general needs of the research community in combination with specific current and past requests. There are also continuing efforts toward improving the quality and accessibility of data in the archive.
DATA NEEDS AND PLANS

A brief summary of data needs for the next several years will now be given. R. Jenne has prepared a report, "Planning Guidance for the World Climate Data System," for the World Meteorological Organization (WMO). It reviews data requirements for research and applied climate studies. The needs for specific data activities in the following categories are considered:

- Upper air data
- Surface data
- Hydrological data
- Ocean data
- Radiation, clouds, chemistry, particles, solar effects
- Satellite data
- Proxy data
- Geographical and economic data

The WMO report will serve as a guide for our data activities; NCAR will emphasize the data needed for research rather than applications. Since many datasets are useful for both purposes, it is expected that the use of our datasets for applied research problems such as crop modeling and energy questions will increase.

To support research, we will increase the amount and availability of our present sources of surface and upper-air meteorological data. Our present ability to support ocean and climate research with satellite and conventional ocean data is poor. Because of the existing and increasing need for ocean data, we will push to improve support for these projects.

The discipline of meteorology has emphasized dynamics for about 30 years. We
expect increasing research that couples actual sensed weather and hydrology with the atmospheric dynamics. This means that the archives of hydrological data will have to increase. Some mesoscale modeling activities already have a need for better data support.

One of the main factors of uncertainty in the climate models that predict global climate changes due to increasing atmospheric CO$_2$ is the cloud feedback question. To solve the problems, satellite and conventional cloud data will be needed. Since some of the satellite archives are extremely large, we hope that it will primarily be possible to obtain intermediate-sized archives that are prepared by others. National and world planning is slowly progressing, and has the possibility of making this problem easier for us.
SPECIFIC DATA TASKS

The approach to increasing our data capabilities will be to accomplish a number of selected projects ourselves, and to interact with other organizations and nations to stimulate their efforts. The big task is usually to prepare, sometimes from hard copy, and structure datasets. When a set has been prepared in any reasonable form, it should not be difficult to send a copy to another installation. Much of our time will be spent updating datasets, handling other routine tasks, and helping customers. Some of our planned dataset development tasks follow:

UPPER-AIR DATA

We plan to:

- Continue to obtain the real time global data on tape from NMC. Finishing the task of preparing major subsets (i.e., raobs, aircraft, cloud winds, etc.) from 1963 will make the data easier to access.

- Obtain delayed processed data from additional countries (e.g., India, Brazil, U.S.S.R.) back to 1950, if possible.

- Make available the 1940-60 data from many nations that was prepared by the USAF at Asheville, North Carolina.

SURFACE DATA

We plan to:

- Obtain more data from NMC in real time when the need is specified by the universities.

- Continue to obtain the real time global data on tape in delayed mode.

- Make available the 1900-1960 data from many nations, prepared by the USAF at Asheville, North Carolina.

- Obtain the complete set of the USN land-synoptic and ship-synoptic data from 1966 when it was prepared by the USN.

- Prepare the archive of the U.S. daily surface co-op station data that should soon be sent by NCC at Asheville, North Carolina.
- Obtain daily time series of precipitation and temperature from selected stations around the world.

- Improve the dataset of year-month station precipitation and temperature data (in cooperation with Chester Newton of the Empirical Studies Group, and the national and international groups).

**HYDROLOGICAL DATA**

The daily surface data above will support some of these hydrological data needs for the U.S. area.

- Work internationally to obtain better sets of data with stations spaced as close as about 70 km. Attempt to obtain sets with 100-300 km spacing first. Some of these 300 km scale data are in the USAF set above. Do not try to obtain the 5-10 km data. Obtain selected sets of compacted radar data when prepared by others, and with user agreement.

- Obtain selected river flow data within two years. Be prepared to obtain additional data as the user need develops.

**OCEAN DATA**

We plan to:

- Obtain the best present sets of ocean ship observations. An Asheville and a United Kingdom set should be obtainable within a year. Progress has been slow.

- Obtain the ocean temperature and salinity at depth data.

- Obtain sets of drifting buoy data.

- Continue to push for a better set of ocean bathymetry data than the one degree average depths now available. National progress has been slow and a strong need for higher resolution data is now present.

Many types of satellite ocean data will involve our attention in cooperation with other groups.

**RADIATION, CLOUDS, SATELLITE DATA, ETC.**

The emphasis will be on obtaining intermediate-sized sets of satellite data to support cloud studies, ocean studies, and convective precipitation. Many of our tasks will be done by other groups. If a major part of the Ocean Data
User Support (ODUS) system is centered at UCAR-NCAR, then more of the processing will be done here.

Sets of heat budget data will be obtained to support modeling efforts. The main preparation efforts will be elsewhere.

PALEOCLIMATIC DATA

We are now working with Alan Hecht, NSF, and others to prepare a technical note with status and inventory information about proxy data. We plan to archive only a limited amount of proxy data, usually in the form of analyzed data such as ice-age conditions, to support modeling efforts or for studies of climatic change.

GEOPHICAL AND ECONOMIC DATA

We have noted the need for ocean depth data. If research interests develop more strongly in applied areas, we will need datasets such as soil types, energy use, crop acreage, etc. We will put a small effort into identifying available datasets, not into preparing data.
ACCESS TO INFORMATION ABOUT DATA

Users have a need for easy access to summary information about datasets, access to more detailed inventories for specific observing stations and grid point arrays, and to lists of data storage volume numbers (backup tape numbers are not released). We plan to provide online access to a large selection of such information.

In 1975, NCAR published "Data Sets for Meteorological Research." We plan to include the more recent information in the text, "The Global Data Base for Climatic Research," which should be finished in 1981. NOAA is including information from it in a publication which should be out in early 1981. We intend to update the 1975 publication in several years.

In about 1983-84, we plan to put a number of our dataset write-ups and associated "grey literature" texts onto microfiche so that users can more easily obtain a larger fraction of the total volume to browse through.

We will continue to provide information about our computer programs that may be useful to others. There will also be some effort devoted to gathering routines that other people have developed such as a program to plot a Skew-T diagram.
INTERACTIVE MANIPULATION OF DATA

We will emphasize the preparation of datasets that can be used for calculations, graphics output, etc. They could also be used in interactive graphics systems. Since the development costs of such systems are high, the DSS will not develop such systems for use at NCAR until the user need is more clear than it is now. If the need clearly develops, as for the ODUS system or other research, we may be able to use some of NASA's systems under development. If not, the participation of other sections of the SCD in such an effort would be desirable.
National Center for Atmospheric Research
Scientific Computing Division

MASS STORAGE GOALS, CHARACTERISTICS, PERSPECTIVE, AND OUTLOOK

Author: Paul Rotar

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MASS STORAGE SYSTEMS: A BRIEF OVERVIEW

A mass storage system (MSS) attempts to provide the greatest possible online storage capacity at the lowest cost-per-bit that the current technology will allow. It provides access times and data transfer rates commensurate with host requirements. An MSS minimizes normal media mounting/demounting activity. Through offline storage, an overflow capability exists so that there is no upper limit to the amount of available storage.

MSS is usually considered to be the tertiary level of storage within a storage hierarchy, where secondary storage is a magnetic disk subsystem and primary storage is the main memory (See Figure 1, A Data Storage Hierarchy).
Figure 1. A Data Storage Hierarchy
A mass storage system can be coupled to a given host system in several ways. Two of the most common procedures are loosely coupled and tightly coupled.

A tightly coupled system exists when the MSS is directly connected to a host's channels. A loosely coupled system exists when the MSS is connected to a local computer Network which services the data activities of several computers connected to the Network. In both cases, data is moved between the host's staging disks and the storage medium of the MSS. Within the tightly coupled environment, the host uses the staging disks as a direct extension of its own disk system. Whereas, in the loosely coupled environment, the data moves between the host's staging disks across the Network's channels to the MSS. Depending upon system configuration, these two coupling methods can have varying impacts on data migration between the MSS and host systems.

Data and data migration are defined according to amount and access and are managed accordingly. Data that is accessed many times per day is not removed from a host's secondary storage. Data that is used infrequently migrates to tertiary storage which reduces the online data management requirements. Data migration can reduce the requirement for more expensive secondary storage by paying the migration time penalty.

One of the criteria for selection of an MSS is the cost-per-bit of tertiary storage. The cost-per-bit can refer to media cost only or it can refer to the total cost of making a bit available online. The total online cost is proportional to the number of users and their accesses. These various views of cost-per-bit question can seriously impact MSS comparisons.
HISTORY AND EXPERIENCE WITH THE NCAR AMPEX TBM*

At the time of the procurement, the TBM* and the Control Data SCROLL were the only available MSS devices. Before the end of the procurement cycle, Control Data withdrew their bid of the SCROLL system. Several months after the completion of the procurement procedure, IBM and CDC announced cartridge storage systems.

The TBM* was acquired and then expanded in three phases. Figure 2, AMPEX TBM* Hardware Configuration, shows the current system.

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*TBM is a registered trademark of the AMPEX Corporation
Figure 2. AMPEX TBM Hardware Configuration
Phase One began with a basic configuration. This configuration provided enough hardware for testing, software development and system use. This phase saw no system component redundancy. In Phase Two, two additional dual transport modules and a second data channel were obtained. At this point, the system had some component redundancy. In Phase Three, a second channel interface unit (CIU) was obtained. The second CIU provided a redundant data path between the 7600 and the TBM*. This CIU was to become the data path between the CRAY1 and the TBM* in 1980. Each phase has been accompanied by significant software improvements which have greatly increased the usefulness of the system.

Phase One (March 1976 - February 1978) was devoted solely to hardware integration and software development and testing. Some of the problems encountered in Phase One were excessive head wear, software problems, and operational difficulties stemming from a 30-step tape mounting procedure. During the acceptance test, and shortly thereafter, the TBM* was used to maximum capacity, though there was not enough hardware to handle the data load from the CDC7600. It was hoped that overloading the TBM* would produce any unanticipated problems. Soon, subtle data failures began to occur. The number of checksum errors on data returned from the system began to rise and the use of the system rapidly declined. This problem is illustrated in Figure 3, Bits Moved Between the 7600 and the TBM* (Total of Bits Read and Written), from May through September 1977.
Figure 3. Bits Moved Between the 7600 and the TBM
(Total of Bits Read and Written)
By the June 1, 1977, most users were avoiding the TBM® because of these intermittent data errors. In July, these errors were traced to a failure in the TBM's® data channel where they occurred only in certain cases for data copied from one video tape reel to another. Once the problem was understood and corrected by AMPEX engineering, use of the TBM® began to increase. Over the lifetime of the system, this remains as the most serious error encountered.

During Phase Two (February 1978 - August 1979), many software improvements were made to enhance operational procedures and provide better user access to the TBM®. The head wear problem was solved when AMPEX changed the material used in the heads from the fastwearing alkesil heads to ferrite heads. The ferrite heads provided an order of magnitude better head life. The system's stability and restart procedures were improved. However, the number of videotapes being mounted each day had increased and was causing operational and throughput problems. The worst case was 90 tapes mounted in a 24-hour period.

During Phase Three (September 1979 - January 1980), software enhancements reduced the number of daily mounts of videotapes to about 30 a day.

A fourth software phase has recently been completed. The objective of this phase was to connect the TBM® to the CRAY1. The TBM® now serves both the CDC7600 and the CRAY1. The cost of equipment and maintenance to provide this service is shown in Figure 4, Equipment Costs for the TBM® Mass Storage System.
Figure 4: Equipment Costs for the TEM* Mass Storage System

<table>
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<tr>
<th>Items</th>
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<th>Annual Maintenance</th>
<th>Years</th>
<th>Maintenance</th>
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<td>$1,000,778</td>
<td>$143,000</td>
<td>'77</td>
<td>$143,000</td>
</tr>
<tr>
<td>1st add on (2 DTM)</td>
<td>237,248</td>
<td>183,000</td>
<td>'78</td>
<td>183,000, 54,937 parts</td>
</tr>
<tr>
<td>2nd add on 100 reels of video tape</td>
<td>759,559</td>
<td>220,000</td>
<td>'80-'86</td>
<td>1,540,000</td>
</tr>
<tr>
<td>Total</td>
<td>$2,057,585</td>
<td>Total maintenance</td>
<td>$2,021,000</td>
<td></td>
</tr>
</tbody>
</table>

Daily Cost = \[\frac{[(2,057,585 + 2,021,000)/10]/12]/30\] = $1,133
As use of the CRAY/TBM connection increases, the stored data can be manipulated (without user or host system intervention) so that the active data remains online and immediately available. The growth of stored data is controllable. All data is properly formatted and packed into minimum space, reducing storage requirements and transmission times. TBM* storage growth and control is illustrated in Figure 5, TBM* Storage Growth and Control.
Figure 5. TBM Storage Growth and Control

Purge rule: After 90 days remove everything not read or written to TBM in the previous 90 days.
This diagram shows the disk growth and reduction with respect to time as quarterly purges of unused data are performed. The TBM* library clearly contains a high percentage of active data. Catalog handling techniques are now available which prevent data loss and allow catalogs to be dumped to the normally used areas of the storage media without requiring specially reserved blocks.

The TBM* has provided valuable lessons about requirements for any new data archival system. A clearer picture has emerged about the functions required at both the host and archival systems. A greater appreciation exists for the memory and computational requirements of a future data archival system. Only small amounts of these resources were available on the small mini-computer when the TBM* was purchased. Reasonable amounts of memory, I/O and computational power are required to control and manage a mass storage device. A very important fact has become evident after using the TBM* for several years.

Once data is written, most activity against the data is for read-only, with only a few rewrites of the data performed. Therefore, if the media could not be reused, a non-rewritable storage system could be viable, providing media costs were low. Thus, the mass storage system could include video disk technology which uses non-rewritable media.

In summary, for the efforts outlined the TBM* provides:

a. An MSS which is tightly coupled to two major host systems
b. An online capacity of 504 gigabits
c. An effective data migration capability from a pool of 2500 gigabits
d. Very low cost-per-bit for archival storage
e. Good offline data management
f. Controlled storage growth

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g. Software capability to provide more host interfaces
WHERE DO WE GO FROM HERE?

There are some opinions that NCAR should never again attempt to install a mass storage system that is not adequately configured and installed as a turn key system. Using this criteria, all of the development problems are assumed to be avoided. In the future, every effort will be made to avoid extensive development cycles. At issue, however, is whether some development and natural system evolution can be avoided if real gains in performance and data storage capacity within the local Network are to be made in the 1980's.

A replacement for the TBM* has been budgeted for FY83. Overlapping funds will allow use of both systems through FY85. During this period, the data on the TBM* must be offloaded onto the replacement MSS.

Initial planning for a replacement MSS has been very conservative. The TBM* technology of the mid 60's would be replaced with MSS technology of the mid 70's. Anticipated gains will be made in reduced maintenance costs and possible reduced access times for data residing on a closely coupled system.

Some immediate solutions to NCAR's mass storage needs can be constructed from a group of currently available components that may be viewed as building blocks. These components are:

a. The Network Systems Corporation (NSC) Network adapters
b. A small-scale computer to serve as MSS control processor and catalog manager
c. Various magnetic cartridge storage devices
d. An automatic tape library device
e. A pool of staging disks

Utilizing appropriate groupings of these items, NCAR can construct a mid-70's
MSS technology to replace TBM*. A set of MSS characteristics can be selected to match planned configurations through the mid 80's.

Examples of possible MSS choices will be configured using some of the above building blocks. A useful storage system can be configured by using items a, b, and e. This system would consist of a large disk farm with 500 gigabits of storage and would cost around $2 million. Such a configuration is loosely coupled, provides very rapid access times, good data transfer rates and a high cost-per-bit. Offline media would be disk packs or the data moved to 1/2\" tape and archived. This system will be referred to as Option I and is shown in Figure 6.
Some other options have been constructed around Option I. These options trade off limited disk farm space for expanded magnetic cartridge or standard tape space. Some disk space is still required for staging purposes in all cases.

Option II is shown in Figure 7. This configuration adds the Automatic Tape Library (ATL) to Option I. The ATL is an automated online tape library for standard 1/2" tapes. It stores, locates, retrieves and mounts 1/2" tape reels under computer control. This option allows a reduction of disk space to 100 gigabits. The 100 gigabit capacity estimate is based on current use of disk space on the CRAY1 and 7600. Option II is estimated to cost $1.3 million. This MSS provides a terabit of storage and can be expanded to 10 terabits or more if floor space can be made available. It is assumed that more than one volume or dataset will be packed onto each reel so that insofar as possible, each reel is full of information. When data management software is developed to handle compression of data to remove obsolete data sets, this configuration would be closely analogous in function to the present TBM* system.

Option III is shown in Figure 8. This configuration adds a tape cartridge storage device. Such a device provides faster access that the ATL to datasets not currently resident on the disk pool. A 1.3 terabit system could be configured to provide:

- 300 gigabits of cartridge storage for short files requiring rapid access
- 1000 gigabits of ATL storage for full tape files requiring reasonable access
- 40 gigabits of disk pool storage

This configuration is estimated to cost $1.9 million. This system would provide a broader performance range than Options I or II.
Figure 9, Performance and Cost Comparisons, Options I, II and III, shows performance and cost comparisons for each of the proposed options.
Figure 9. Performance and Cost Comparisons, Options I, II, and III

<table>
<thead>
<tr>
<th>Option</th>
<th>Approx. Cost</th>
<th>Online Gigabits</th>
<th>Cost $/bit</th>
<th>Access</th>
<th>Data Rate</th>
<th>Overflow Capability</th>
<th>Expansibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$2.3 x 10^6$</td>
<td>500</td>
<td>4.6 x 10^{-6}</td>
<td>.07 secs</td>
<td>24 Mbit/sec</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>2</td>
<td>$1.3 x 10^6$</td>
<td>1000</td>
<td>1/4 x 10^{-6}</td>
<td>94 secs</td>
<td>12 Mbit/sec</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>3</td>
<td>1.9 x 10^6</td>
<td>1800</td>
<td>1 x 10^{-6}</td>
<td>19 secs</td>
<td>Up to 12 Mbit</td>
<td>P</td>
<td>G</td>
</tr>
</tbody>
</table>

E = Excellent
G = Good
P = Poor
Other variations can easily be constructed from the building blocks. The data throughput for large files provided by the ATL device in Option II is considered better than the data throughput for large files provided by the cartridge device in Option III. The data access time of Option II assumes each reel of tape is packed with multiple volumes of data so that each access to a given volume includes search time to the desired volume. This search time is assumed to average out at 1/2 of the tape. If the normal situation of one dataset per volume exists, then the access time is 20 seconds, the required time to search one-fourth of a tape. This one condition alone changes the capacity of a maximum system from 10,000 to 630 gigabits. The one dataset/volume criteria would eliminate the need for any offline data management required by the MSS to compress obsolete information and to gather frequently used small files into optimum locations on each reel. Several more tradeoffs exist as such systems are configured and their corresponding software is defined.

Each option outlined has been loosely coupled to various hosts through the Network. If Option III were tightly coupled to an appropriate host, significant improvements in access times could be achieved with the cartridge device. The cartridge device/disk pool combination can be considered a virtual disk system. The host in a tightly coupled environment has random access to all data on the cartridge system in the same way as it does to data on a storage system comprised only of disks. The other nodes on the Network can then be loosely coupled to the storage system via the host which is tightly coupled.

A non-major vendor for a configuration discussed in Option III exists. This vendor supplies software to couple this system via a Network into selected hosts' systems. The MSS provides data to the Network on a record-by-record
basis. This method can provide a very convenient service to certain types of host systems on the Network. The data migration times across the Network for any significant amount of data are not expected to adequately satisfy the appetites of the class VI machines. This approach is considered inadequate if attempted on each system within the NCAR Network.

The TBM* can hold 504 gigabits online and can select data from about 2500 gigabits overall. The growth of this data has been carefully controlled by quarterly purges but conservative estimates signify that it will reach 67,500 volumes or 4.7 terabits by the mid 80's and 107,500 volumes or 7.5 terabits by the end of the decade. The replacement of the CDC7600 with a sixth class computer and the CRAY1A with a seventh class computer, along with the addition of raster graphics capability and an increase in the amount of satellite data, could make these figures seem extremely conservative. This data growth rate is one of the contributing factors pointing to the urgency of obtaining replacement equipment. The amount of TBM* data cannot rise beyond the point which disallows off-loading to a replacement MSS in some reasonable period of time. Current plans call for a 2-year overlap of MSS funding from FY83 through FY85. During this period a new MSS must be installed and all good data off-loaded from the TBM* onto the new MSS. Since the TBM* has been successful, the momentum of use will prevent easy discarding of it in favor of a less expensive more capable successor. Only Option I offers easy upgrades as technology improves. Each of the above options provides for some operation cost reduction. In the case of Option I, access time is also reduced.

New technology must become available in conjunction with the production of the new MSS's that can service the class VI machines' data requirement in the 80's. The current CRAY1A channels can operate up to .27 gigabits/sec. The
computers to be installed as CDC7600 and CRAY1A replacements can be expected to perform at this speed. The data rates possible on today's MSS's vary from .005 to .012 gigabits/second. These rates are at least an order of magnitude slower than those of the host's channel's. Such rates place too great a burden on any migration scheme. Further, the growth of NCAR's storage requirements cannot be gracefully accommodated on present devices.
DATA RECORDING TECHNOLOGY

In the mid- to late-1980's different media and recording techniques may provide significant improvements over the devices considered as immediate replacements for the TBM*. These future devices will use one of the following data recording technologies:

- Laser recording on optical disks
- Photographic recording on special film
- Magnetic recording on tape or disk
- Electron beam recording

Optical disks use a laser to remove metal and generate a hole to represent a data bit. Density is limited by the diffraction of visible light and up to 2 gigabits/in² should be possible.

Photographic techniques are limited both by diffraction of light and film granularity. Current systems yield .1 gigabits/in² and up to .5 gigabits/in² should be possible. Photographic techniques require a development process before data can be read back. This process may eliminate use of the photographic techniques depending on its complexity and turnaround time for read back.

Magnetics are limited by particle size which determines tape signal to noise ratio and coercivity which determines read energy. Densities now approach .01 gigabits/in². .03 gigabits/in² have been recorded in a laboratory environment and .07 gigabits/in² may be possible. Electron beam recording potentially can record at the extremely small spot size of 1 to 2 angstroms as compared to the 2000-3000 angstrom limit of optical methods.

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A real density may not be as important as volumetric density. Considering the two leading contenders for advanced recording technology, optical disks and magnetics, magnetics may produce 100 gigabits/in$^3$ vs 50 gigabits/in$^3$ for optical disks. Therefore, volumetric considerations allow magnetics to remain a useful storage method in spite of advances in optical recording.

For any of the above technologies to be viable contenders for the MSS market, some manufacturer must integrate the technology, hardware interfaces and software to produce a commercially available product. Figure 10, Cost Comparisons Among Laboratory Models, shows some comparisons among companies which are known to have laboratory models. The companies are unnamed since the numbers given have been arrived at through unverifiable means, in some cases.
<table>
<thead>
<tr>
<th>Company</th>
<th>Storage Media Type</th>
<th>Access Time</th>
<th>Bits/MBd</th>
<th>Volumetric Density</th>
<th>Media Cost</th>
<th>Cost/bit</th>
<th>Error Rate with BDAC</th>
<th>Data Reuse</th>
<th>Avail. Intfs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Magnetic</td>
<td>130 Sec.</td>
<td>$300 to $500 per MBd depending on quantity</td>
<td>$300 to $500 per MBd depending on quantity</td>
<td>500 MBd per sec.</td>
<td>Unknown to existing TMS systems or special</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Video Disk</td>
<td>50 m/sec.</td>
<td>10 MBd per sec.</td>
<td>10 MBd per sec.</td>
<td>Unknown unknown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Video Disk</td>
<td>500 m/sec.</td>
<td>$11 to $175 per MBd depending on quantity</td>
<td>$11 to $175 per MBd depending on quantity</td>
<td>500 MBd per sec.</td>
<td>D3C, PDP or similar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Optical Slides</td>
<td>5 sec. Slide to Slide</td>
<td>5 MBd per sec.</td>
<td>5 MBd per sec.</td>
<td>Unknown Unknown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The table represents a cost comparison among laboratory models. The data includes access times, bit transfer rates, media costs, and error rates with BDAC.
<table>
<thead>
<tr>
<th></th>
<th>Read Units</th>
<th>Write Units</th>
<th>Read and Write Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4 drives per cntr.</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>B</td>
<td>6 drives per cntr.</td>
<td>Yes (B-1) $49,000</td>
<td>Yes (A-1) $56,000</td>
</tr>
<tr>
<td>C</td>
<td>2 or more &quot;Jukebox&quot; configurations</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>D</td>
<td>2 data paths per unit</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
None of these companies appear to be building a complete MSS prior to the mid to late 80's. Producing the laboratory device is the first step. Building controllers, host interfaces and writing software to drive the MSS and manage the catalog comprise the other 80% of the overall effort. The market for high performance devices is not very large and most companies prefer to build lower performance, more marketable equipment. The combination of software and marketing difficulties eliminate most of these devices from the realm of realization.

One way for NCAR to configure an MSS and overcome some of the same problems mentioned above is to connect a controller and several drive devices from one of the above manufacturer's machine to the current TBM*.

This solution offers the advantage that the necessary software currently exists and the vendor would not need to provide anything except hardware. Used in conjunction with one of the options described earlier, a balanced system, providing very good performance both for short datasets on front end systems and long datasets on class VI machines, is obtainable.