March 10, 1989

Paul Rotar wrote this for a report on NCAR highlights of history. The report was never published.

The Evolution of Supercomputing at NCAR

This document traces the evolution of supercomputing at NCAR, highlights the contributions made to the support of science by the Scientific Computing Division (SCD), and provide a historical perspective of SCD’s activities.

A supercomputer is defined as the highest performing scientific processor available at a given point in time. Supercomputing however, may be more broadly defined as the use by a group of researchers or an institution of a computer system that provides the best obtainable performance (at that point in time) considering all of the variables comprising scientific computer architectures. These variables include Central Processing Unit (CPU) speed, memory size, input/output (I/O) performance, data archival capacity, graphics, networking, and overall software performance for the mix of scientific projects of interest to that group.

Supercomputing is difficult to define because its definition changes with time as more powerful computers are introduced. Perhaps a more appropriate description would be advanced scientific computing. In the past, other terms were in use at NCAR: an advanced computer for array processing (ACAP), an advanced vector computer (AVC), a fifth-generation computer, a sixth-generation computer, etc. It remained for others to coin the term “supercomputer” that has named advanced computing in the 1980s.

Startup

Computing at NCAR had somewhat more humble beginnings than implied by the terms supercomputing or advanced scientific computing. An IBM 1620 was installed at the High Altitude Observatory (HAO) in 1962 and arrangements were made that allowed NCAR scientists to use resources on the IBM 709 at the University of Colorado (CU) and on the IBM 7090 at the National Bureau of Standard’s ((NBS) now called the National Institute of Standards and
Technology (NIST)]. These arrangements were informal and classified as "gentlemen's agreements." They were important because computing was provided at a nominal cost and at the same time assisted the university in paying for its equipment.

A computing facility (CF), formed under the leadership of Dr. Glenn Lewis, was housed in the Physical Sciences Research building on the Boulder CU campus. Lewis hired staff to augment those that had been with NCAR since the earliest days. By the end of 1962, about ten persons were in the SCD.

SCD was organized to serve the needs of NCAR science. It was not immediately an official UCAR policy to provide computing to the national community. SCD spent the early months of 1963 planning the development of a local service. SCD sought permission to withdraw from the agreements with the university and NBS in order to make funds available to purchase a computer.

There was disagreement about the timing and performance of the first advanced computer that would be installed at NCAR. Dr. Thornton C. Fry, acting as a consultant on advanced computing, was of the opinion that NCAR should wait until the Control Data Corporation (CDC) 6600 was ready in 1965. Mainframes available in 1963 were not sufficiently powerful to permit much progress on the problems of interest. He along with Axel Wiin-Nielson and Sidney Fernbach (Director of the Computing Facility at Livermore) had supported this schedule in a report to the Executive Committee in April 1962.

SCD engaged in a study of available mainframes that might serve in the interim while awaiting a more powerful system: the Philco-Ford 2000, the CDC 3600, the IBM 7094 II, the Burroughs 5500, etc. SCD staffers were also preparing a computer survey that compared the competing architectures expected in the '65 time frame. The results of the survey were published in May 1964.

In April 1963, Wiin-Nielson, tiring of the debate and delay, had a change of heart and
instructed Glenn Lewis to proceed with the procurement of an interim machine, the CDC 3600, since sufficient information was at hand to justify its selection.

This was a call to action that recognized that building an advanced computing capability was an evolutionary process and that SCD and its staff would grow in competence with its own system to nurture. Also, the CDC 6600 seemed ill-defined in 1963 by the standards of the day. Its performance had to be judged from rather skimpy information about its architecture.

The 6600 was a distributed architecture (central scientific processor supported by ten very fast peripheral machines) and was actually a reduced instruction set (RISC) machine many years before such a term was invented. It also turned out that the CDC 6600 had a number of serious design problems that would impact the user community. Of course, these were not envisioned at the time. On the other hand, the CDC 3600 was at the evolutionary end of complex instruction set mainframe computers (CISC) and was well understood by the computing community.

However, the call to action provided only the administrative go-ahead. The funding (even with CU and NBS out of the picture) was less than the $67,000 a month needed to directly lease the CDC 3600. SCD negotiated an arrangement whereby Control Data was able to use about a hundred hours a month and was willing to accept about $40,000 a month.

Installation of the First Mainframe Computer

The Control Data 3600 was delivered in November 1963 and installed in an unfinished building being constructed just to the south of the Physical Sciences Research Building. It was to this building, now the home of the Western Interstate Commission on Higher Education (WICHE), that SCD moved late in 1963.

By the summer of 1963, SCD staff judged that Control Data was not going to complete their operating system by installation time. Paul Rotar and Dave Kitts put together enough of a
system to be able to utilize the CDC 3600. By early 1964, SCD was able to provide service on
the CDC 3600.

By the end of 1964 (the CF’s first year of operation), usage of the CDC 3600 had grown from 50
300 hours per month and the SCD had run approximately 19,000 jobs.

SCD became a national facility in March 1964. Its mission was to provide large-scale comput-
ing facilities to NCAR and the national community engaging in atmospheric and related
research. Shortly thereafter, an advisory panel was formed. In the panel’s August, ’64 meet-
ing, it approved the acquisition of the CDC 6600 which had been tentatively ordered a month
earlier for delivery in late 1965.

When service to a national community was discussed in SCD at this time, it was in the context
of permitting visitors to come to NCAR and share in the use of the equipment. Technology for
effective remote use was still almost a decade away.

The Installation of the CDC 6600 and CDC 7600

Early in 1965, it became apparent that software development by CDC for its 6600 was not on
a realistic schedule. There were two systems: SIPROS and COS. A test of ten codes showed
that only one would run on either system. Thus, SCD began development of an operating sys-
tem that would be ready to install on the machine when it arrived late in ’65. This decision to
develop operating software for the CDC 6600 set the character of the facility until the advent
of the Cray era.

The CDC 6600 system was designed and implemented by the Systems Section consisting of
Paul Rotar, Dave Kitts, Bob Working and Gene Schumacher (on loan from CDC). Systems
staff had written a simulator for the CDC 6600 which provided an assemble, load-and-go
environment for testing the CDC 6600 operating software modules on the CDC 3600. The
development and use of these simulation systems allowed SCD to prepare systems software for
future machines and to enhance the existing software without disrupting the users because the
simulators ran in the users' environment.

In order to maintain some service while the machine room was being retrofitted for the CDC
6600, as well as provide computing until the acceptance of the 6600, the Operation's Section
planned a move of the CDC 3600 to a building at Martin Marietta's Prince Street plant where
it was operated through April of 1966.

The CDC 6600 was delivered in late December 1965. It was operated for nearly a year at the
30th street location until the Mesa building was ready in December 1966. Shortly after the
6600 became operational at 30th street, it became apparent that the positional access time of
225 ms for the disks on the machine severely inhibited its performance. This was solved by
acquiring some drums and then generating the software to access the drums. The drums were
rotating magnetic data storage devices similar to disks but with a large number of fixed
read/write heads that eliminated the positioning time associated with moving access arms.
This provided NCAR with a system with a superb response time which not only was impres-
sive, but delighted the users and initiated an era of rapid work turnaround for the scientific
community.

The drums were a particularly interesting challenge because Control Data staff had told us
that they could not be made to work on a CDC 6600. Ignoring their advice, we ordered four
drums, wrote a driver, and indeed on the initial tests, data would not stream from the drums.
Only one byte per revolution was moved. The drums stood in mute testimony to our folly until
Gil Green, then a Control Data regional technical representative, changed the interlace in the
| drum controller to permit every other byte to be skipped which better matched the data
channel's speed.

Although the CDC 6600 was to serve until 1977, there was an ongoing study of possible
replacements spurred by the desire for capability beyond the CDC 6600 based on research
needs in the areas of the general circulation model, the dynamics of a convective cloud, and turbulent flow and interactions.

While SCD closely monitored the progress of an early array processor, the ILLIAC IV, it became clear by 1970 that the addition of capability beyond the 6600 would be provided by either a CDC 7600 or an IBM System 360, Model 195. The CDC 7600 won by a slight margin in benchmark tests run in early 1970. It was delivered in May 1971. The 7600 generally ran at five times the speed of the 6600. It represented the last time this large a general increase of speed has been available from a single processor. Also, because the operating system had been developed in house, users had a uniform software environment on both the 6600 and 7600 which was difficult because machines’ architectures differed substantially. Most users could run on either system without changes. Such a uniform software environment would not return again until the late 1980s when UNIX began to be used on the supercomputers at NCAR.

On the down side, the CDC 7600 was very unstable. Its low mean-time-to-failure forced us to put extremely good job and file recovery procedures into the system. However, this took a few years to accomplish and by then the aggravation level was quite high for the CF’s users. Ted Hildebrand, the SCD director, fully supported the combined 6600/7600 software effort. Without this support it is probable that the CDC 7600 would have been a failure.

Vectors and the CRAY-1A Era; 1976 to 1986

NCAR’s proposed participation in the Global Atmospheric Research Program (GARP) and the First GARP Global Experiment (FGGE) world weather experiments, December 1978 through November 1979, provided SCD with the justification to seek a more powerful computer than the CDC 7600. SCD developed a plan for our participation in FGGE. It turned out that we ultimately did a little data reduction, but not much else for GARP. However, the Cray was critically needed to permit further development of models at NCAR and at the universities.
In 1974, the outlook for computational capability beyond the CDC 7600 was not very good. The CDC STAR suffered from software problems and required very long vectors. The Texas Instruments ASC had software problems and all system and support functions like compiling were slow to the extreme although user code execution was respectable. The ILLIAC IV appeared to be unusable in our environment. By this time, SCD was disinclined to produce another operating system (it had already produced three).

Gerald Browning wondered whatever had happened to Seymour Cray. Acting on this, Stuart Patterson, SCD manager, and Paul Rotar made a trip to Cray's Halley Laboratory in Chippewa Falls, Wisconsin in 1974. Although the CRAY-1A was only partially built, the design reflected a simplicity not found in the other computers and we felt that although many technical and financial objections had to be overcome, the CRAY-1A would at a minimum, spur the competition and in the best case be a viable upgrade to the CDC 7600.

In 1975, a request for proposal (RFP) was issued for the next machine. The CDC 7600 was straining under a severe overload. SCD was over-subscribed. Turnaround time had become intolerable. The ability to provide rapid turnaround for short jobs had broken down completely. Mass storage software development activities further loaded the machine. The RFP and subsequent negotiations resulted in an order for a CRAY-1A. This was a bold move that anticipated successful software development and put NCAR in line for the second machine built by Cray Research, Inc.

The CRAY-1A was delivered in July 1977. It was accepted in December. The CDC 7600 acted as a front-end. Incoming work flowed through the 7600 which also retrieved necessary archival files for use on the Cray from the online TBM mass storage. This further increased the load on the 7600. Also, the users' jobs migrated to the Cray rather slowly and continued to use the 7600 for data handling chores.

The CRAY-1A was very stable compared to the CDC 7600 and represented a significant
change in mean-time-to-failure rates and expectations. In very good times, the 7600 hardware or software failed at least once a day, often four to five or more times, whereas the Cray would run for several days and most often failed only because of disk problems.

The Cray probably was only about 2.3 times faster than the 7600 unless the program was highly vectorizable. Then an order of magnitude was possible, but overall its throughput was estimated at about 4.5 times the 7600. The ability to handle vectors well has become a hallmark of an advanced computer.

The CRAY-1A permitted advances in modeling severe storms. Models were developed by Cotton at CSU, by Takahashi at U of H, Wilhelmsen at the U of Ill, by Clark and Hall at NCAR and by Klemp at NCAR. It also permitted progress in climate models.

Because of growth in demand, the CDC 7600 was replaced by a low-cost, used CRAY-1A in the spring of 1983. SCD and the NCAR scientific community had engaged in a lengthy debate over whether it was appropriate to bring in a fast scalar processor because of the heavy data processing component of the workload or to get a second CRAY-1A. Proponents of the scalar processor including the SCD director, Walter MacIntyre, felt that a fast scalar processor with good I/O could better handle the tapes and TBM archive, i.e., it was better suited for data processing which certainly was a high percentage of our workload. Opponents felt that the Cray would provide more numerical computing even though it might be inefficiently used for the data processing necessary to support the atmospheric sciences. In the end, the scalar processor lost out to the second CRAY-1A because both the price and its abilities in the modeling area were superior.

Multiprocessing and the CRAY X-MP/48

The second CRAY-1A was but a small step. During 1982, a committee met and produced a document entitled "Scientific Justification for an Advanced Vector Computer." This
justification was to form the basis for the acquisition of a class VII machine to replace the CRAY-1As which were considered to be class VI machines.

A class VI machine may be defined as a "fast" vector uniprocessor with two to four million words of memory capable of sustaining 10 million floating point operations per second (Mflops) in vector mode on a scientific job mix. Typically, its peak execution rate was 50 Mflops. By contrast, a class VII machine was a "fast" four-way, shared memory, vector multiprocessor with 8 to 16 million words of memory capable of sustaining 50 Mflops in multiprocessor mode with peak speeds of 250 Mflops. The term "supercomputer" replaced the class VI and VII designation by the mid-80s.

The report said that the AVC was essential for continuing scientific progress; many critical problems require too much speed and memory to be efficiently run on a class VI machine. These problems included more realistic climate simulations, tornado modeling, storm-scale precipitation models, coupled three-dimensional chemical-dynamical models, thermosphere-ionosphere interactions, growth and evolution of sunspots, ocean circulation, and dynamic models of ocean-atmospheric interactions.

The CRAY X-MP/48 was delivered as the AVC in October 1986 and replaced the second CRAY-1A. The four-processor X-MP/48 opened the door to parallel execution of models by partitioning a model into a number of asynchronously executable parts. Although this mode of use called multitasking has not been extensively used, a gradual evolution into parallel computing will be necessary to provide reasonable scientific response times for advanced models. Bob Chervin converted a version of the Community Climate Model for parallel use on the X-MP and achieved a speedup of 3.7 over the single processor code.

The first CRAY-1A was decommissioned on January 27, 1989 and was powered off on February 1 after twelve years of service.

In September, after negotiations between the SCD director, Bill Buzbee, and the University of
Colorado, SCD became the operational facility for the University of Colorado's Center for Applied Parallel Processing (CAPP) with the installation of a Thinking Machines Corporation's connection machine model CM-2. This has provided us with an up-to-date test bed for applications on a massively parallel system.

In 1988, SCD's Computational Support Section set up a parallel geodynamics project with Paul Swarztrauber and Dick Sato, designed to provide information on the suitability of the CM-2's single instruction multiple data stream (SIMD) architecture for modeling atmospheric science problems. It has run the shallow-water equations on cartesian coordinates using finite difference methods. For this idealized problem, a speed of 1.3 billion floating point operations per second (Gflops) was obtained when the results were scaled from the available 8,000 processors to a 65,000-processor machine. The next step, now completed, was to implement a spectral method solution to the same equations. Results were sufficiently good to encourage an attempt to implement these equations using spherical geometry. Therefore, the presence of the CM-2 at NCAR is providing us with an opportunity to test this technology which is believed by some to be scalable to trillion floating point operations per second (Teraflop) performance. By summer of 1989, the parallel geodynamics project is expected to evolve into a joint effort with the European Center for Medium Range Weather Forecasting (ECMWF).

The following table summarizes the characteristics and estimates the increase in capability for each of the supercomputers that have supported science at NCAR:

<table>
<thead>
<tr>
<th>Date</th>
<th>Computer</th>
<th>Memory</th>
<th>Cycle</th>
<th>Processors</th>
<th>Performance</th>
</tr>
</thead>
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<tr>
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<td>CDC 3600</td>
<td>32</td>
<td>~1400</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12/65</td>
<td>CDC 6600</td>
<td>64</td>
<td>100</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>7/71</td>
<td>CDC 7600</td>
<td>64</td>
<td>27.5</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
Performance improved about 430 times from 1963 to 1986 while system cost increased by about a factor of 6.

Planning for the Future

A committee was chaired by Peter Gilman in 1986 to develop guidelines for the future directions of the supercomputing environment. In a report entitled "UCAR and NCAR Strategies in Supercomputing," it recommended: 1) focus SCD on large simulations and data sets, 2) assess technology and prepare for future systems, 3) expand distributed computing, 4) take an active role in the national data communications effort, 5) help develop a National Geosciences Data System, 6) provide a balanced, effective computational environment and 7) develop additional funding strategies to enhance the total NCAR-university computing environment to fully meet the needs of the atmospheric, ocean, and related sciences.

Supporting Services

An Operations Section was formed in 1963 under Ed Germann. Aside from their primary responsibility to run the computer systems for the users, they planned many machine room layouts as the computing activities migrated to the Mesa and subsequently expanded there. The operators kept the equipment running and took the brunt of the instability of new systems and the difficulties associated with the TBM mass storage operation.

The Operations Section handled the keypunching needed for program preparation and data input in the years from 1963 to 1981. From 1981 to 1984, some data input continued on keypunches and punched cards. The data input service outlasted the keypunches and continued until 1986.
To handle the graphics, a film processing laboratory has been in operation from 1964. Fred Walden was a key figure in setting up the processors, keeping things in adjustment so that movies were possible, and assisting with the production of color movies.

Operations performed the maintenance on the smaller systems and terminals. Their maintenance people have strung most of the terminal cables throughout the Mesa Laboratory.

By 1964, David Robertson was working on graphics routines for offline plotters. These routines were to evolve into the NCAR Graphics package.

By the fall of '65, SCD had attached a Data Display-80 (DD80) microfilm graphics device to a data channel of the CDC 3600. Normally, microfilm and all other graphics devices were and still are "offline." The direct connection allowed us to provide excellent service and its use rapidly increased. With this, SCD launched its microfilm graphics service which was to grow in prominence as the years passed. At the end of '65, our first computer-generated weather movie was made for David Houghton using the DD80. In 1967, a color movie was produced by Warren Washington from GCM output which showed the earth with continental outlines, contoured varying pressure fields, and pressure highs and lows. NCAR was providing the atmospheric sciences with graphic capability that was generally not available to scientists in other disciplines.

Tom Wright continued the development and packaging of the NCAR Graphics routines eventually building the "System Plot Package," as well as many utilities for plotting and contouring. In the late '70s, Lofton Henderson headed the standardization effort aimed at the Graphics Kernal System (GKS) standard.

The NCAR Graphics software is now in widespread use in the universities where it was originally obtained without charge. It is also widely used elsewhere. Estimates are that it is installed at 1,000 sites. The latest version based on GKS is at 400 to 500 sites.
Higher-resolution microfilm graphics (approximately an order of magnitude better than the DD80) were needed and the Dicomed system was purchased in 1978. The Dicomed Operating System (DOOS) software was developed over the next few years by John Humbrecht and Lof ton Henderson. The Dicomed was needed to replace the DD80s which were becoming non-maintainable. The DD80s were removed in 1981.

In 1988, SCD introduced a color microfilm capability based on the computer graphics metafiles (CGM) produced by the latest NCAR GKS software. This can produce 35-mm color slides and 16- or 35-mm color movies for any scientific application that uses either NCAR’s GKS graphics routines or any other GKS system which produces CGM graphics files.

SCD's Data Support Section had its beginnings in 1965 when Roy Jenne was hired to lead the effort. Roy, Dennis Joseph, and Alan Kay began to collect and format data from the National Meteorological Center (NMC) and other sources. Emphasis was placed on the NMC data. A general inventory showing the number of grids available for each month for each source was published. The Data Support Section provided data to many non-NCAR scientists both US and foreign. This service has continued and expanded to the present day. In 1987 and 1988, the Data Support Section prepared and sent data to nearly 40 scientific groups who were working on climate change studies for the Environmental Protection Agency (EPA).

Over the years, the Data Support Section worked with many scientists, laboratories, government agencies, data centers, and countries to build, import, cleanup, and classify what is now a rather comprehensive archive serving the atmospheric science community. Indeed, it is the best archive of analyses of atmospheric and ocean surface conditions in the world. The archive is used for major national and international atmospheric and ocean research projects. Data has been imported from the major field experiments such as FGGGE, the Monsoon Experiment (MONEX), the GARP Atlantic Tropical Experiment (GATE), TWERLE, etc. A set of seventy-two million ship observations from 1854 to 1979 were gathered with the cooperation of the National Oceanic and Atmospheric Administration's (NOAA) Boulder and Ashville
facilities and the navy. This is the world's best set of ship data. An emphasis is given to data
sets that have potential for multiple uses and continuous records, and which permit monitoring
changes in the global atmosphere and oceans.

In 1985, the Data Support Section was instrumental in recovering the NOAA satellite sounder
data, TOVS (Tiros Operational Vertical Sounder). The storage system at NOAA was closed
before all of the data could be moved from the non-standard videotapes on which it had been
stored to normally available media. SCD had only agreed to recover data gathered in the mid-
dle 3 years of a 6.5 year effort which was totally missing in the NOAA archives, but SCD de-
ciphered the format of the videotapes and saved all of it. This contained information about the
largest warming of the Pacific Ocean temperatures in recorded history.

By early 1989, this archive contained 300 datasets in 35,000 files with 14 terabits (TB) of data.
About 20 new datasets are added and 9 are updated each year. Datasets include:

* Daily grid point analysis data
  Northern hemisphere surface grids from 1899
  Upper air grids from 1946
  Related monthly data

* Upper air observed data
  Telecommunications data from 1962
  From selected countries from 1946
  Aircraft and satellite cloud winds

* Surface observations
  Hourly North American data from December 1976
  Global 3-hour synoptic from July 1976
  Daily station from 1979
  Many earlier data
*Marine ship data
  Individual observations and monthly statistics
*Geophysical data
  Land elevation, ocean depth
  Vegetation cover, soils, etc
*Climatological data, grid points
  Surface and upper air for the world
  Clouds
*Physical oceanographic data
*Satellite data
*Incoherent scatter radar data
  for atmospheric elevations from 60 km to 500 km
*GCM model output for changing CO₂
  Data to show climate change as CO₂ changes

Users may obtain copies of data on tape or use it at NCAR. In 1988, 820 tapes and 140 floppy disks were sent to 300 scientists. Many scientists use the data online. The Data Support Section also provides a menu of many data manipulation routines that have simplified access to the archives and permit scientists to easily move data to the array structures used in their programs.

The Computational Support Section had its beginnings about 1963 when John Gary came on board, although it had no formal structure or official membership. Staff began to establish a library of routines. They made important contributions to our mathematical libraries in the areas of differential equations, matrix analysis, eigensystems, statistics, FFTs, roots and others. They conducted research into numerical algorithms used in atmospheric research. They also assisted with the development of new versions of the GCM. By 1973, it was known as the
Applied Mathematics and Library Development Section under Alan Cline. A few years later in 1975 under Paul Swarztrauber, it became known as the Advanced Methods Group.

Gerald Browning and Professor Heinz Kreiss (UCLA) have used a mathematical theory called the bounded derivative principle to develop accurate, well posed systems for atmospheric and oceanographic computations that permit proper consideration of previously discarded time-dependent terms and significantly improve the numerical accuracy.

Paul Swarztrauber developed a direct method for solving separable elliptic equations which was published in 1974 and as of 1989 remains the fastest method. In 1977, he developed methods of cyclic reduction, Fourier analysis and combinations of them solving Poisson’s equation on a rectangle. He demonstrated that a direct solution of Poisson’s equation could be obtained in much less time than before. In 1979, he published a parallel algorithm for solving general tridiagonal linear systems and he demonstrated that a system of N equations could be solved in a time proportional to Log N on a computer with N processors. In 1986, he developed several FFTs for special sequences such as odd and even that have sine and cosine expansions respectively and took advantage of symmetry to reduce the amount of computation. He has also developed FFTs for multiprocessors and for massively parallel architectures.

Important software packages resulting from Computational Support efforts include:

FISHPACK (Swarztrauber, Sweet, Adams). A group of routines for solving elliptic partial differential equations. Over 1,300 copies have been distributed worldwide.

FFTPACK (Swarztrauber). A group of routines for symmetric FFTs. This has become part of most major mathematical libraries including the Sandia, Los Alamos, Air Force Weapons Laboratory Technical Exchange Committee (SLATEC) and the International Mathematical and Statistical Library (IMSL) and is used in most institutions.

SPHEREPACK (Swarztrauber). A group of routines for harmonic analysis on the sphere.
MUDPACK (Adams). A group of programs for solving elliptic partial differential equations which is more general than FISHPACK.

To some extent, scheduling scientific programming services was closely held in the SCD. For many years all programming support for the scientists at NCAR was derived from a programming pool in the Applications Programmers section of the CF. By 1973, it was under the leadership of Joe Oliger. There were four groups in the section, one for each NCAR division. Programmers were frequently assigned to more than one scientist. In 1975, at the height of this service there were 36 programmers in the pool, but with demand at twice this number. It could be fairly argued that the SCD therefore controlled the priority and schedule of the science.

A useful by-product of this programming pool was the creation of a large base of shared application software. SCD staff contributed software to a locally supported library. Contributions were generalized, documented according to an established standard, and tested. NCAR Graphics evolved from a collection of individual utilities. Code portability was emphasized. Much of this software has survived and is in daily use.

With the arrival of the CRAY-1A, there was a need to provide a broad range of new support services. As a result, the level of direct scientific programming support fell to a totally unacceptable level. After years of acrimony and indecision the applications programming activity was ordered moved to the NCAR divisions by Francis Bretherton in 1978.

The User Services Section was formed under the leadership of Margaret Drake from the Applications Programmers section in February 1979. It provided information on SCD services and procedures, as well as software libraries and tools. While they now provide many necessary functions, SCD lost its direct interface with the science at NCAR. By the early 80s, User Services encompassed data communications, information services, software libraries, and multiuser software.
A major item of multiuser software was the GENPRO data processing package. The current
version was written by Bob Lackman, Bonnie Gaenik, Herb Poppe, and Ken Hanson in the
1981-1983 timeframe. It is a most flexible set of routines to assist scientists assimilate field
data. David Kennison wrote a FORTRAN preprocessor and editing package called "FRED"
that was used until the CDC 7600 was removed. David also worked on IFTRAN which allows
one to write structured code.

Training Activities

Beginning in 1963, a small work-study program for college juniors or above was taught in an
exploratory, hands-on environment. A more formal summer work-study program in scientific
computing was initiated in 1966. Students from different universities interested in astro-
geophysics were given a short training course covering advanced programming techniques,
assembly language, and large-scale meteorological programs. They were then assigned to
NCAR scientists for direct research experience on computer-oriented projects. Many of the
students continued their association with NCAR and the program was of great benefit to the
CF.

From 1973 until 1979, a Training, Documentation, and University Liaison section was
managed by Jeanne Adams. In the 1980s, these activities reverted to the User Services Sec-
tion.

Science Supported at the Center

The development of the General Circulation Model (GCM) of the atmosphere was begun in
1964 by Warren Washington and Akira Kasahara. This model, with a 5 degree horizontal
resolution and 2 layers, and its successors were to be major consumers of machine and human
resources in SCD over the years and pointed the way for SCD to develop many supporting ser-
vices that were beneficial to all users of the CF.
A second generation of the General Circulation Model was completed in 1969. The GCM has been important in the history of computing at NCAR. Its needs shaped our services in the areas of processor characteristics, graphics, and mass storage.

By 1973, effort was put into the development of fine mesh, limited area models with the goal of obtaining short-range forecasts. These models incorporated small-scale dynamical and thermodynamical physics. SCD staff that worked on the GCM included Joe Oliger, Gerald Browning, Robert Wellick, and Dick Sato.

The GCM activity evolved beginning with simple numerical stability studies gradually becoming more elaborate with the analysis of the importance and relevance of terms, simplifying the equations to represent the atmosphere's actual flow. With experience, finite difference schemes were exchanged for the spectral modeling techniques introduced by ECMWF.

The GCM was made available to the atmospheric science community as a Community Climate Model (CCM) in the late 1970s. Dick Sato and David Williamson imported the ECMWF model in 1981 and converted it into what is now the CCM used by many of the (CF) users.

The following table shows the approximate percentage of usage of center resources by the fields of atmospheric science during some selected years. GCM activity is included in the table under the headings of climate and weather prediction.

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</table>
During the 60s, remote services were to a large extent not possible. SCD did provide a mail-in service. Researchers would come to NCAR and get their model running and then return to their universities. They would then use the mail to initiate work and receive output.

Staff assigned to consult with remote users was fairly minimal. Leased telephone lines for use as data communication links always exceeded the finances of outside researchers. Costs ran about $1,000 a month for telephone lines. Practical equipment for remote communication did not become available until late in the 60s.

SCD lacked funds for communications equipment until the early 70s when rather minimal funds were made available for the acquisition of devices capable of connecting leased telephone lines to the peripheral systems of the CDC 6600 and 7600 computers. When communication links were first installed they were connected directly to interface devices installed on the CDC 6600 and later on the CDC 7600. These connections were never satisfactory for a number of reasons: if a communications controller failed, it frequently caused a failure of the mainframe to which it was attached; software development and maintenance was directly done on the supercomputer in a dedicated mode which adversely affected service; and communications software competed directly with scientific applications software for memory and cycles.

A policy evolved that communications costs to the Mesa would be borne by the user. SCD would be responsible for equipment needed to access the computers, but would not otherwise pay for remote access.

A debate ensued over the U.S. Department of Defense Advanced Research Projects Agency network (ARPANET). Could it serve as the communication link with the remote community? Should we develop our own remote job entry (RJE) software or join forces with the U of Ill and
use ANTS (ARPA Net Terminal Service) that they were developing? ARPA, though initially free, was supposed to be evolving toward a paid service. In the end, the lack of ubiquity (unlike the current situation, ARPA did not reach many of the locations where our users were), uncertain rates, security, and military issues caused us to back away from the ARPANET. ARPA kept us on the network maps for years.

In 1973, John Firor, the NCAR director, made funding available to obtain a minicomputer to be used as the RJE gateway. A MODCOMP II minicomputer was acquired in June 1974 as the RJE computer and was able to handle a variety of leased and dial-up communication lines. System’s staff David Robertson, Gene Schumacher, Marie Working, and David Kitts wrote the RJE software. By 1975, we were no longer isolated from the remote community. University usage of the SCD grew by 1980 to 40% of the available time with 200 remote users from 62 universities.

In the spring of 1981, an IBM 4341 was installed and it slowly took over the RJE activities and was a front end for other divisions and universities. It was connected to a commercial communications service "Uninet" which reduced communication costs for remote users. By the late 80s remote access was possible over a large variety of networks: National Science Foundation Network (NSFnet), University Satellite Network (USAN), Computer Science Network (CSNET), Because It’s Time Network (BITNET), etc. and through many gateways. A second IBM 4341 was installed in 1983 and both were replaced by an IBM 4381 in 1986.

Non-NCAR university scientists are eligible to use 45% of the resources. Although both allocation mechanisms and usage accounting exist, no actual user charges are assessed. The allocation of resources without direct user fees has carried over into the other five NSF National Supercomputer Centers where although it has the shortcoming of lacking a "market mechanism," it will remain in place into the ’90s.

Troubles in the Computing Division
Staff morale was a recurring problem in the late 60s and early 70s. By 1973, there was a "Palace" revolt. The lack of structure in the staff (almost everyone was classified either as a programmer, i.e., professional staff, or an operator with no grade levels in either class) coupled with the perception of a heavy-handed management approach, and other problems caused the Facilities Division director, David Atlas, to order a reorganization of SCD. The SCD was then reorganized with more levels of management in formally designated sections. Programmer and other staff levels were defined complete with standardized job descriptions for each level. Growth paths were identified for the staff.

The Search for Mass Storage

The introduction of the CDC 7600 caused SCD to intensify the search for a mass storage, i.e., archival storage device that could begin to replace the use of magnetic tapes. Several devices that recorded on strips of magnetic media had been considered as early as the 3600 era, but these had not become very successful products. Slowly, more promising candidates appeared. These included the CDC SCROLL, the Ampex Terabit Memory (TBM) and a laser device, Unicon, that recorded on coated mylar strips. Such a device was needed because by the mid-70s our tape library exceeded 40,000 volumes.

Of the devices listed, only the Ampex TBM, which recorded data on two-inch videotapes, survived. By the time the procurement procedure for the TBM was complete, IBM announced the IBM 3850 tape cartridge device which would have been suitable. The Ampex TBM system initially delivered was a minimal configuration that could not handle the storage needs. It was sufficient to permit Mike Hendrickson, Gil Green, and others to develop software for the 7600 interface and access as well as permit the vendor to continue the development of control and catalog software.

The TBM went through a series of upgrades that added enough hardware to keep it at the ragged edge of our needs until the 80s. After Ampex discontinued the product about 1979, the
Systems Section continued to enhance the software. SCD learned how to manage large amounts of data and found that rewrite capability on mass storage media is unnecessary. This information allowed us to consider optical storage in the 80s. Otherwise optical storage would have been out of the question since it could not then be rewritten.

In 1983, SCD became interested in the optical storage unit that Storage Technology Corporation (STC) was developing and offered to participate in its testing. A preproduction model 7640, 4-gigabyte (GB) optical drive from STC was installed at NCAR to permit software development and testing in a scientific environment. By late 1984, the optical storage unit was abandoned by STC at the time of the bankruptcy proceedings, but the design, planning, and initial implementation of the interconnection hardware and controlling software for the optical disk were of a general nature. This design permitted us to revert to magnetic technologies and provide a new mass storage system (MSS) based on a large cache (120 GB) of IBM’s 3380 disks, IBM 3480 tape cartridge devices for archiving, and specially designed Network Systems Corporation (NSC) HYPERchannel adapters.

This new system allowed for general access by any NCAR computer to the MSS through the network via the mass store control processor (MSCP). It also has a "fast path" that allows a supercomputer to move data directly to the cache and cartridges once the storage media is positioned. When NCAR’s TBM data was transferred to the cartridge system in 1986, the TBM was used to copy NOAA’s satellite data from their TBM tapes. It was then removed from service.

Mass storage continues to be an enabling technology in the supercomputing arena. The future is clouded by the same issues (market size, complexity, mass producibility of media, capacity, etc.) that have prevented a complete commercially available product to be available in the past.

The following chart shows the growth of data archived on NCAR’s mass storage systems. The
table does not account for backup copies which doubled the volume of TBM data from 1976 through 1986.

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Networking and Distributed Computing

After the mid-70s, SCD staff began to think about distributed computing and networking. Distributed processing was seen as a way to introduce an element of interactive processing, especially job preparation and editing, into SCD’s batch environment. Also, it would provide a more reasonable method of incorporating new functions into the overall computational environment than the existing practice of attempting to extend the software in the supercomputer itself. In 1977, these activities resulted in the SCD’s acquisition of a pair of Digital Equipment Corporation’s (DEC) PDP11/70s and Berkeley’s version of UNIX as the first step toward distributed computing.

Distributed processing was anticipated to provide a path to decentralize and simplify handling of standard half-inch magnetic tape. For years these had been directly driven by mainframes through the CDC 7600 itself. This function frustrated early attempts to remove the 7600 itself. In the end, the half-inch tapes and the driver software were even moved to the CRAY-1As because of the difficulty of handling the amount of this data on smaller systems and because of the variety of tape formats.

Relatively high-performance networking was needed to interconnect the systems in the machine room as well as in the rest of NCAR. The 7600 and CRAY-1A were initially networked through a protocol jointly designed by Cray Research, Inc., Gil Green, and Gene Schumacher of the SCD staff. Cray Research, Inc. provided the interface devices.
However, it was soon time to look for a more general solution to networking because there was no method of interconnecting all of the proposed systems using either the Cray interfaces or the software protocol. Dave Kitts developed a mechanism whereby non-CRAY-1A channel commands could be issued to devices connected to the CRAY-1A’s data channels from user level programs so that the CRAY-1A could drive foreign devices from its channels. This enabled us to implement a more general network as well as connect many of the needed peripheral devices onto the CRAY-1A. This was a key development that allowed us to integrate the CRAY-1A into a larger network.

NSC HYPERchannel equipment was seen as a general solution to the interconnect problem. SCD envisioned a network control computer isolating the higher-performance equipment (CDC 7600, CRAY-1A) from the lower-performance front ends, i.e., performing an impedance matching and protocol conversion function. A Systems Engineering Lab (SEL 32/55) system was acquired for this, but its most important use was to permit the network software to be developed independently of the production systems. In the end, both high- and low-performance systems were able to exist on the same network without any special separation.

By January 1981, the HYPERchannel had replaced the channel-to-channel 7600-Cray interconnection. This was the beginning of the NCAR local computer network which is now called the mainframe and server network (MASnet). Walter Macintyre approved the acquisition and implementation of a terminal switching device that permitted any terminal at NCAR to access any SCD computer system.

During 1978 and 1979, a plan was developed to handle expected funding cuts. These plans included an I/O computer that would handle front-end tasks and magnetic tapes. This machine was expected to permit SCD to remove the CDC 7600 and save the not insignificant annual maintenance costs. Although the budgetary problems were not as severe as expected, an IBM 4341 was obtained in 1981 to serve as the I/O computer and was added to the growing NCAR local network.
Hard copy graphics and publication quality printing were made possible in 1985 by the introduction of a Xerox laser printer system that was driven from the I/O computer.

In early 1984, a committee was formed, with Bernie O'Lear as chairperson, to write a proposal for an experimental satellite data network. As a result, SCD won an award in June 1985 from the Networking section of NSF's Office for Advanced Scientific Computing (OASC) for the development of a satellite data network. This significantly extended our communications capability.

The network grew from 2 systems (the CDC 7600 and the SEL) in 1980 to at least 14 systems by 1986. In 1987, a separate section, the Distributed Computing Section, was formed with Joe Choy as section head to better coordinate all of the effort and eventually provide a straightforward functionally unified computing environment at NCAR.

Sometime in 1989, the operating system on the X-MP supercomputers will be a version of UNIX. This will provide a unification of most of the operating software on the network and provide the center's users with a nearly uniform user interface to the entire supercomputing complex. Prior to UNIX on the supercomputers, SCD had specialized in rapid batch turnaround and provided very good service for short job checkout. Batch remained the primary focus of activity until a conversion to UNIX began in 1989.

Staff

Initially, programmers were hired only if they were experienced and had a degree in mathematics or the physical sciences. Blackboard mathematical quizzes during interviews under Glenn Lewis became legendary. Some people who failed to be hired as a result of these interviews came on board under later directors. As SCD expanded, a wider range of skills became necessary.

Space permits this to be a historical summary and only a few of the staff and then only some
of the contributions from each are mentioned. Over the years, an estimated 350 persons, most of whom are listed below, worked to nurture the NCAR supercomputing environment. A number are listed in more than one section because they held positions in different sections. A break down of the growth of staff by section follows:

<table>
<thead>
<tr>
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<th>Admin</th>
<th>Operations</th>
<th>User Services</th>
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<th>Data Analysis</th>
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Funding

The following table shows the direct SCD funding in 5-year intervals. The actual cost of SCD is somewhat higher (estimated at 25%) when power, space, and other indirect services are considered.

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The Directors:

Glenn Lewis-62/66, John Gary-67/ Aug69, Ted Hildebrand -
Aug69/73, PNS-74 (Acting), G. Stu Patterson-75/79, Walter
Macintyre-Apr 80/Apr 86, Margaret Drake-May '79/April '80 & Sept
present

Staff

Sources:

An Institutional History - The University Corporation for Atmospheric Research and The National Center for Atmospheric Research 1960-1970

Scientific Justification for an Advanced Vector Computer

NCAR Computing Facility Annual Reports 1964-1971

National Center for Atmospheric Research

Annual Scientific Reports 1977-1987

Atmospheric Technology No. 3 September 1973

SLATEC Chart on Machine Classes
List of staff that has ever worked at SCD

SCD Staff List

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<tr>
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Herbert Poppe
William Ragin
James Weber
Greg Woods

Operations Section

Evelyn Andrus
Donald Austin
Donna Barday
Julia Bartram
Terry Basnett
Arthur R. Baxter, Jr.
Carol Beardsley
Wanda Bernal
Robert Biro
Sharon Blackmon
Betty Bloom
Melissa Breedlove
Sally Brown
Glenn Brown
Mary Buck
Donald W. Cellars
Douglas Chaney
Steven Chapel
Betsy Chen
Pat Colantino
Gaynez Connell
Jay Cook
Patricia Cordell
Santiago E. Cordova
Ernest Cox
Sylvia Darmour
Glen Davenport
Edgar Davis
Harold Davis Jr.
Donna DeCuir
Russell Dent
Albert DeSarro
Cynthia Del Pizzo/Martin
Randy Eastin
David Ellerin
Salvador Farfan
Richard Frank
Wendell Franks
George Fuente
Marlene Furmanek
Edward A. Germann
Nancy Goldstein
Stan Grenz
Martin Halstad
Ken Hansen

Delbert Harris
Lois Harrison
Suzanne Hedgecock
Ed Heitschel
Rita Hemsher
Catherine Hobart
I. Claire Hogle
Darrell Holley
Candace Holzman
Nancy Hubbard
Suzanne Hunter
Jesse James III
Gary Jensen
Sue Jensen
William Jones
Wanda Keeney
Cynthia Keep
Benjamin Klepac
Richard Lindenmoyer
David Long
Stephen Long
Walter Lukasik
Mike Magers
Claire Martineau
Jack Martindale
Rod McDonald
Stan McLaughlin
Susan McLaughlin
Gary Meeker
Rosemary Mitchell
Pamela Moore
Long Moua
Cynthia Meyers
Robert Niffenegger
Richard Patrick
Richard Oye
Kelton Penner
Berten E. Pelca
Sharon Phillips
Bonnie Pieper
Gary Pierce
Vickie Pinedo
Scott Quinn
Joyce Reed
H. Matthew Reynolds
Andrew Robertson
David Robertson
James Robinson
Nancy Romero/Waldron
Roxanne Romero
Paul Rotar
David Rowland
Susan Scarborough  
Susan Schemel  
Larry Scott  
Valerie Shanahan  
Shelby Sheffield  
Georgianna Short  
Judith Slater  
Georgia Sprague  
James E. Stranberg  
Larry Stevinson  
Steven Storm  
Dave Strayer  
Mary Trembour  
Alfonso Trujillo  
Ruth Toutenhoofd  
Fred Walden  
Kenneth Walton  
Michael Ward  
James Weber  
Raymond Wehry  
Wesley Wildcat  
Gerald Willett  

Ruth Mossman  
Donald Morris  
Marc Nelson  
Bernard O’Lear  
Jamia Oliver  
Deidra O’Neal  
William Ragain  
David Robertson  
Paul A. Rotar  
Craig Ruff  
Eugene Schumacher  
Duke Smith  
John Snyder  
Wallace Swanson  
Erich Thanhardt  
Mark Uris  
Sandra Walker  
Vincent B. Wayland, Jr.  
Robert Working  
Marie Working

User Services Section

Jeanne Adams  
John Adams  
Gary Aitken  
Dan Anderson  
Lynne Andrade  
Edward Arnold  
Edward Ash  
James Randolph Back  
Frank Banks  
Stephen Bankes  
Britt Bassett  
Linda Besen  
Brian Bevrt  
Robert Biro  
Gerald Browning  
Suzanne Brossard  
Dorothy J. Bundy  
James Burgeimer  
Ginger Caldwell  
Jay Chalmers  
Celia Chen  
Joe Choy  
Frederick Clare  
Leonard Cohen  
Donna Converse  
Jay Cook  
Dee Copelan  
Ann Cowley  
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Susan Cross
Nancy Dawson
Astrid Deirmendjian
Benedict Domenico
John Donnelly
Patrick Downey
Margaret Drake
Michael Ellingson
Chester Ellis
Michael Ernst
Raymond C. Fabec
Salvatore Farfan
Dora Fahey
Dean Frey
William Frye
David Fulker
Sandra J. Fuller
Bonnie Gaclnik
Frieda Garcia
Grant Gray
Vincent Greene
Christine Guzy
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Adrianne Link
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David Maxey
Gregory McArthur
Alan McClellan
Cassandra McCullough
Darrell McDowell
Amber McEwen
Beverly McIntyre
Gary Meeker
Kenneth Miller
Jack Miller
Donald Morris
Peter Morreale
Cindy Myers
Fred Nagle
Robert Nicol
Bernard O'Lear
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Richard Oye
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Russell Rew
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Gerard Roach
David Robertson
Richard K. Sato
Gwelda Scohy
Tania Sizer
D. Duke Smith
Susan Smith
Robert Smith
John Snyder
John Sopka
Marla Sparn/Meehl
Kari Stordahl
Paul Swarztrauber
John Szajgin
Joyce Takamini
Linda Thiel/Ballard
Erich Thanhardt
Ruth Toutenhoofd
Richard Valent
Jo Walsh
Laren Wagner
Eric Wainwright
Hugh Walker
Brett Wayne
Ron White
James Weber
Robert Wellick
Nancy Werner
Larry Williams
Gloria Williamson
Donald Williston
Thomas J. Wright
Marie Working

University Liaison Section

Jeanne Adams
Linda Besen
Benedict Domenico
Sara Ladd
Russell Rew
John Snyder