# Intelligent Terminals: The Distributed Computer System at McDonald Observatory

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## *INTRODUCTION*

A special matching facilities grant obtained from the National Science Foundation, in connection with the construction of the 107-inch reflector at McDonald Observatory, included the cost of an IBM 1800 process control computer. This computer was delivered in December, 1967, and has been in routine operation at the Observatory for slightly more than one year. The original system plan was presented as a paper at the meeting of the A.S.P. in June, 1968 and is shown in symbolic form in Figure 1. The essential features of the design were that it be advisory in nature and operate on a time-shared basis to provide assistance to the 107-inch, 82-inch and 36-inch telescopes. Facilities for automatic data acquisition were deferred until this initial plan was completed.

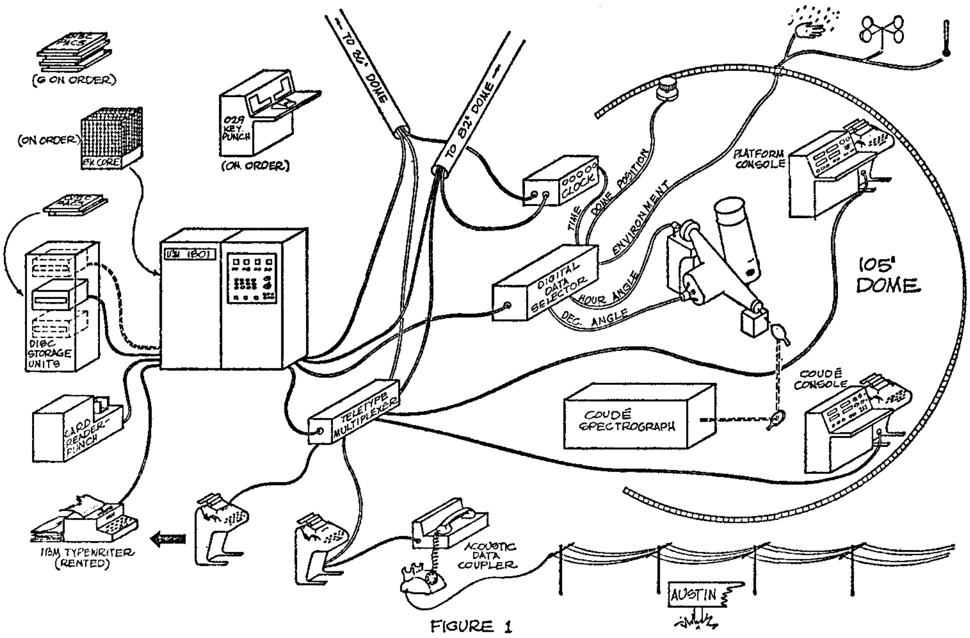

Fig. 1

The essential procedures outlined in this plan, which we have since come to regard as "phase I", have now been realized. We were extremely fortunate that two graduate students, M. M. McCants and D. C. Wells, both professional systems programmers, were available to write the programs required. The computer is used routinely to provide corrected setting positions for planets and selected star lists, and in addition exercises direct control of the 107-inch reflector to find and track the retro-reflector on the moon as an integral part of the lunar laser ranging project. It has also been used to provide Fourier transformed data in real time to aid alignment and calibration of a Connes-type spectrometer designed by Reinhart Beer of the Jet Propulsion Laboratory. It has been used experimentally to acquire data from this instrument, from the photoelectric spectrum scanner at the coudé position of the 107-inch reflector, and from the large Cassegrain spectrum scanner, the latter two instruments designed by R. G. Tull.

## *DATA ACQUISITION: PHASE II*

All this has not been accomplished without some turmoil, of course, and we have come to recognize a fundamental problem which we hope to subdue in our further development. With any time-shared system a certain amount of time must be devoted to overhead operations: swapping programs in and out of core, locating the source of an interrupt, etc. In addition a certain amount of time must be devoted to each "customer", and the sum of these times we call the "attention cycle", the amount of time the computer must spend in satisfying all competing demands. Thus the computing time can be divided into overhead time and a series of attention spans, all adding up to the attention cycle, which measures the amount of time any one customer must wait until attention is returned to him. With our system this time can range from several sec to several min, but cannot be less than a few sec. If we require the computer's full attention, *e.g.* to control a stepping motor or record data at very fast rates, we must "lock out" all other users. This does not endear us to our colleagues on the other telescopes, and has been known to lead to complaint.

An obvious solution to the problem is to obtain a computer for each telescope, which need not be time-shared and can therefore devote its full attention to the local control and data recording requirements. Oddly enough this obvious solution is also a practical one, made possible by the recent development of low-cost, high-performance minicomputers. The total cost of such an installation can be kept reasonable if communication with the IBM 1800 is provided, allowing the small, local computer to exercise direct control and act as a data buffer for time-shared transfer of data blocks.

Figure 2 shows, in block diagram form, a single installation of this type. Control can be exercised via the teletype, via the small computer's front panel switches, or from a separate custom-designed panel operating through the general purpose interface. The C. R. T. display allows the data acquisition process to be monitored and was, at first, considered to be a bit of a luxury. Actual operation of this system has proved it to be essential; "blind" data acquisition, where the observer cannot continually satisfy himself that all is well and working, has proved to be both inefficient and frustrating.

The local computers are 16-bit machines, each with 4096 words of core memory, manufactured by Data General Corporation. They cost, with teletype, $9000 each. They can execute an instruction about every 5 $\mu$s and have both interrupt and direct memory access (DMA) facilities. Our design to date makes use of only the interrupt mechanism; we plan to leave the DMA channel for future use.

It is important to recognize that the local computer will not normally require access to the central computer, and can "stand alone" in almost all cases. The central computer is thus not the "master" directing a set of "slaves" but, in fact, the roles are reversed with the central computer operating as a time-shared slave to the masters at each telescope. This architecture effectively centralizes the expensive peripheral devices such as the card reader and punch, the plotter, and the large-capacity disk storage, but allows the several control computers to make use of them as needed. In case of central computer failure the local computers may have to record data on punched tape for future conversion to cards or processing by the central machine, but this is far preferable to shutting down the mountain when the central computer is sick.

The communication arrangement is shown in Figure 3. At the present time we plan a system of four local computers as shown, with provision for adding a fifth when the 30-inch telescope, now under construction, is completed. Two of the computers are now on hand and are in operation, but with interface facilities somewhat more limited than shown in Figure 2. Data transfer to the 1800 has been successfully demonstrated, and the design of the permanent communication network is now underway. For the present these computers operate in the "stand-alone" mode and have demonstrated how very effective even such a small computer can be.

## *OPERATION OF THE TERMINAL*

The intent of the distributed computer system design is that each installation will be identical in hardware details. The required versatility is obtained from software—the computer programs which direct the operation for each type of investigation. We refer to this design as "software dominant".

General instrument hardware provided to all observers includes both high-speed pulse counting equipment and voltage-to-frequency converters for those who prefer D.C. photometry. Although only a single data channel can be accommodated with the present prototype interface, multiple data channels

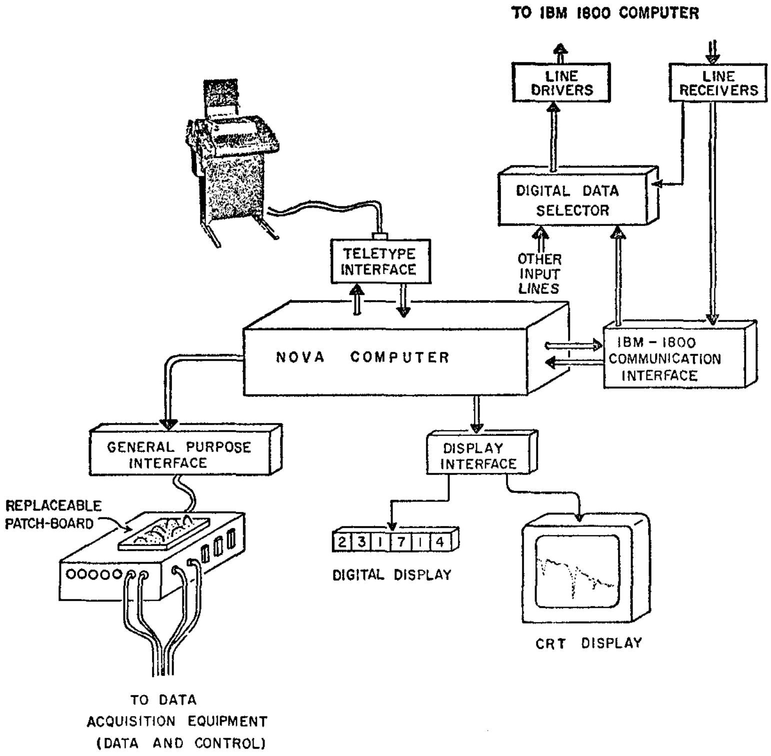
TO IBM 1800 COMPUTER
LINE DRIVERS
LINE RECEIVERS
DIGITAL DATA SELECTOR
OTHER INPUT LINES
TELETYPE INTERFACE
NOVA COMPUTER
IBM - 1800 COMMUNICATION INTERFACE
GENERAL PURPOSE INTERFACE
DISPLAY INTERFACE
REPLACEABLE PATCH-BOARD
00000
2 3 1 7 1 4
DIGITAL DISPLAY
CRT DISPLAY
TO DATA ACQUISITION EQUIPMENT (DATA AND CONTROL)

Fig. 2

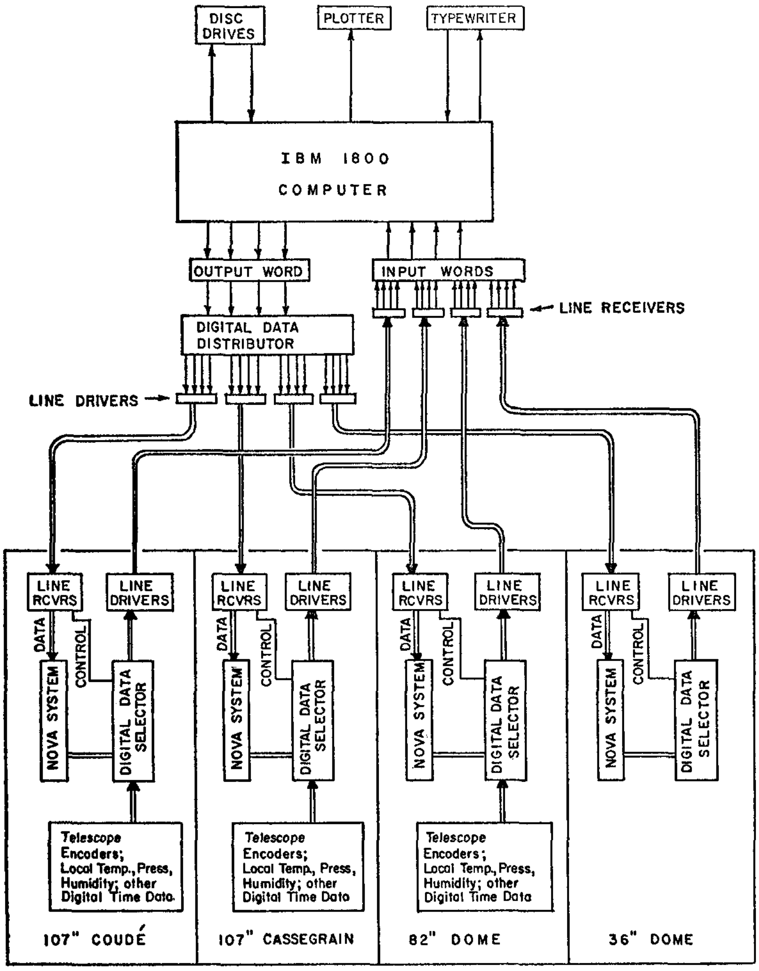
DISC DRIVES
PLOTTER
TYPEWRITER
IBM 1800 COMPUTER
OUTPUT WORD
INPUT WORDS
LINE RECEIVERS
DIGITAL DATA DISTRIBUTOR
LINE DRIVERS
LINE RCVRS
LINE DRIVERS
DATA
CONTROL
NOVA SYSTEM
DIGITAL DATA SELECTOR
Telescope Encoders; Local Temp., Press, Humidity; other Digital Time Data
107" COUDÉ
107" CASSEGRAIN
82" DOME
36" DOME

Fig. 3

are provided for in the final design. Time and frequency signals are distributed to all domes from a central clock, which is monitored by a local rubidium frequency standard and whose long-term behavior is governed by reception of ground-wave transmissions from the Loran C station at Terre Haute, Indiana.

To those used to large computer installations a 4096 word memory sounds pretty small. It does require some care in program design, and cannot, as a general rule, tolerate the inefficient coding generated by compilers, except for jobs of modest size. Nevertheless, a remarkable amount of effective program can be accommodated when *all* of core can be used, in contrast with the IBM 1800 where one-half of the core memory is used up by the TSX operating system and skeleton.

The basic program used in our study of rapid blue variable stars provides input data control and timing via interrupt, printed output on the teletype, and a live display of the accumulating data. The CRT shows the 500 most recent data points; the light curve appears to move to the left to make room for each new data point as it is added. Vertical scaling is automatic. About 2500 data points can be stored, in addition to the program.

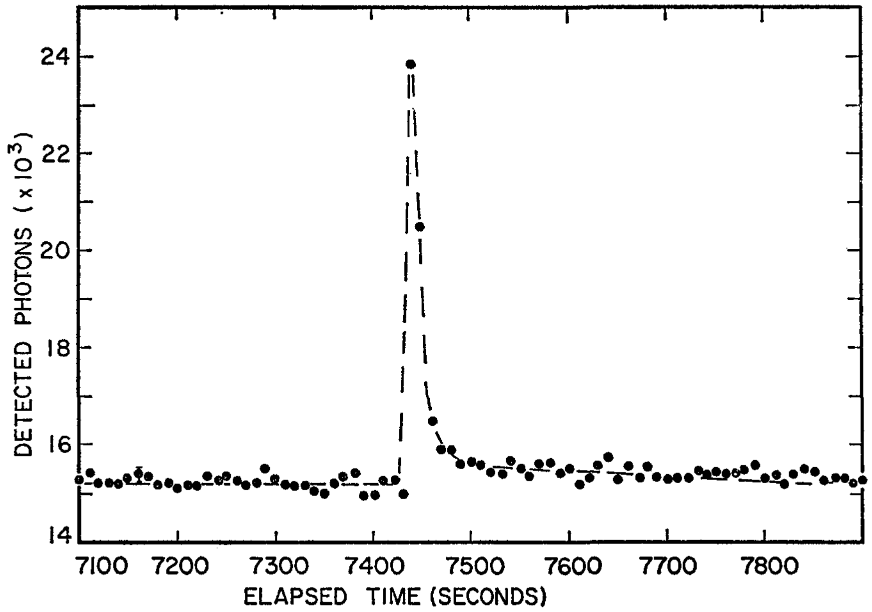

Fig. 4

The display routines are the most elaborate and therefore require the most space. Magnification (by powers of 2) is provided in both axes, so small details can be examined. Vertical position adjustment is cyclic, the displayed curve appearing to "roll" up, with those points lost at the top reappearing at the bottom. Horizontal "rolling" is also provided under switch control, but in this case the display acts as a 500 point "window" which can view any portion of the 2500 data point storage. The internal data buffer is also cyclic, the newest data point replacing the oldest, and provision must be made to transfer out older data before the total storage is filled and erasure begins. For data rates of 1 reading per sec or slower we use the teletype to record data as it enters; for faster rates we must either stop the action until it catches up or transfer the data in blocks to the central computer.

Figure 4 shows some data we obtained while monitoring the blue variable star G44-32 (Warner, van Citters and Nather 1970), studied earlier by Lasker and Hesser (1969). We were operating at 10 sec per reading, and did not expect any really rapid activity because the star has been classified as a white dwarf. The flare activity which we recorded is very limited in detail, although it does show characteristic "tailing off" as the star resumes its former brightness level. This measurement illustrates a common difficulty in this form of investigative program. If the instrumental time scale is chosen short enough to resolve everything that photon noise will allow, the observer is inundated with data; if chosen long enough to limit data output to reasonable volume he may miss, as we did, details of an important event.

This experience has led to the concept of multiple time scale recording, easily implemented because we can change computer programs without making a big project out of it. Data can be recorded at, say, 100 ms per point and the program can examine data blocks for unexpected deviation from "normal". This means that "normal" must be defined algorithmically, but this can be done in many useful cases. If a deviation occurs, the data block of interest can be transferred and held in a separate portion of memory for later examination and printout, but if nothing interesting is observed the data block can be condensed by summing. We thus can get a "snapshot", at high time resolution, of anything unexpected, but are not deluged with data of unwanted resolution. At 100 ms per reading a data point would cross the display screen in 50 sec, allowing plenty of time for an observer to intervene and take a manual "snapshot".

Programs also exist for measuring lunar occultations at 1 ms per reading with cyclic storage, which requires that the program recognize the event and stop data recording before it is erased. A "snapshot" data block can also be held in case the event is not of the proper amplitude, which might imply that the star is an unresolved double and two distinct events, separated in time, can be recorded. We are busily developing other control and data acquisition programs for the spectrum scanners and for the Fourier spectrographic instruments. It is clear we have hardly scratched the surface of the possible in this arena.

## *CONCLUSIONS*

We have come to realize three basic points concerning computer-aided astronomy, which can be stated briefly:

1. Time-sharing and direct computer control of observations are incompatible.
2. "Intelligent Terminals" which are software dominant provide a workable solution to this problem.
3. New observing techniques can be more readily realized in software than in hardware.

## *ACKNOWLEDGEMENTS*

Many valuable discussions of these problems have been held with Charles Slaughter and Donald Trumbo of Kitt Peak National Observatory, and with Dr Edwin Dennison of the Hale Observatories.

## *REFERENCES*

Lasker, B. M. and Hesser, J. E., 1969. *Astrophys. J. Letters*, **158,** L171.
Warner, B., van Citters, G. W. and Nather, R. E., 1970. *Nature*, **226,** 67.

## *DISCUSSION*

J. TINBERGEN: How many people are involved in the maintenance of (*a*) hardware, (*b*) software, of your system?

R. E. NATHER: (*a*) The hardware system is maintained by the observatory staff, but they don't spend full time on it. The observatory staff consists of an electronic engineer and three technicians, but their main concern is the electronic control system for the 107-inch and for the 82-inch, and I would guess that they spend only 10 per cent of their time concerning the maintenance of this system I've described. (*b*) The software isn't termed maintenance in the normal sense. Right now we're in an unusual position, in that I am personally concerned with a fair amount of the observing done with this equipment, and I do my own programming. Two of the graduate students are using it for their theses; the theses have been selected and based on their ability to write programs. So right at the moment the actual programming is being done by the users in the department. We do not have programming staff or anyone assigned to write programs for these small computers. We do have one full-time programmer to handle the IBM 1800 control programs.