A Real-Time Interactive Control System for Meteorological Operations

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ABSTRACT

A man-machine control system is described which is designed specifically for use with computerized data processing in operational numerical weather analysis and prognosis.

The equipment configuration and organization of programs and data libraries in this system at the Melbourne World Meteorological Center is briefly described, together with an account of the computer activities and data flow needed in the weather analysis and prognosis data processing system.

A manually interactive automatic control system, consisting of a data-driven real-time monitor program on the one hand and a data-driven visual display program on the other, was programmed to operate in parallel with all programmed meteorological activities.

The interactive portion of the control system serves as the primary interface between the meteorologist and the computer equipment and operational program complex, allowing him facilities to select directly and modify the characteristics of both the data and programs being used.

The flexibility of the system is well suited to the nature of weather data processing in the Southern Hemisphere, which, as a result of vast sparse data regions, must admit of a high degree of manual interaction for acceptable results.

The implementation of the interactive control system results in a large saving of time in manual handling of programs and data, and reduces human error, at the same time adhering to, and warning of departures from, a preset time table of operations.

1. Introduction

This paper describes an approach to the problem of providing a satisfactory time saving interactive interface for operational meteorologists working with a digital computer used for real-time meteorological weather analysis and prognosis. Such a computerized interactive control system has been implemented in association with real-time meteorological data processing carried out in the World Meteorological Center, Melbourne, Australia.

The computer configuration used for synoptic weather analysis and weather forecasting includes an IBM 360/65 (256, 000 bytes[2]) central processor with large volume lower speed disc pack secondary storage (IBM 2311/2314). Peripheral equipment includes incremental graph plotters, C. R. T. keyboard input/output display stations (IBM 2260), magnetic tape and paper tape drives, and optional card reader. This configuration is used for operational processing and is fully backed by a standby 360/65 system. However, this standby system is also used on a non-real-time basis for other operational data processing and for research purposes including the development of more refined atmospheric models for weather analysis and prognosis.

An analysis of the computer processing required for the total function of real-time weather analysis and prognosis is ordered by defining modules of work, scaling from the total function down to individual machine operations. Table 1 shows the scale and relation of work modules on which this system is based.

The items in Table 1 illustrate simply the static break-up of the modules of work which are performed in the computer-based system and tells nothing of the dynamic sequencing of work which is required in the active system.

When in actual operation the control of the work module sequencing is brought about as follows. The total function is supervised by an operational meteorologist whose primary concern is the quality and timeliness of the output products. The responsibility for correctly sequencing all work modules is carried out jointly through the interactive control system and the machine operating system. The interactive control system itself

Table 1. Scale and relationship of work modules in weather analysis and prognosis data processing.

Item	Module
Total weather analysis and prognosis function	Activity
Activity	Computer program
Program overlay segment	Sub-routines
Sub-routines	Code section
Code section	Fortran statement
High-level language statement (e.g., Fortran)	Machine instruction

[1] Present affilation: Commonwealth Meteorology Research Center, Melbourne.

[2] See the Appendix for definitions of terms.

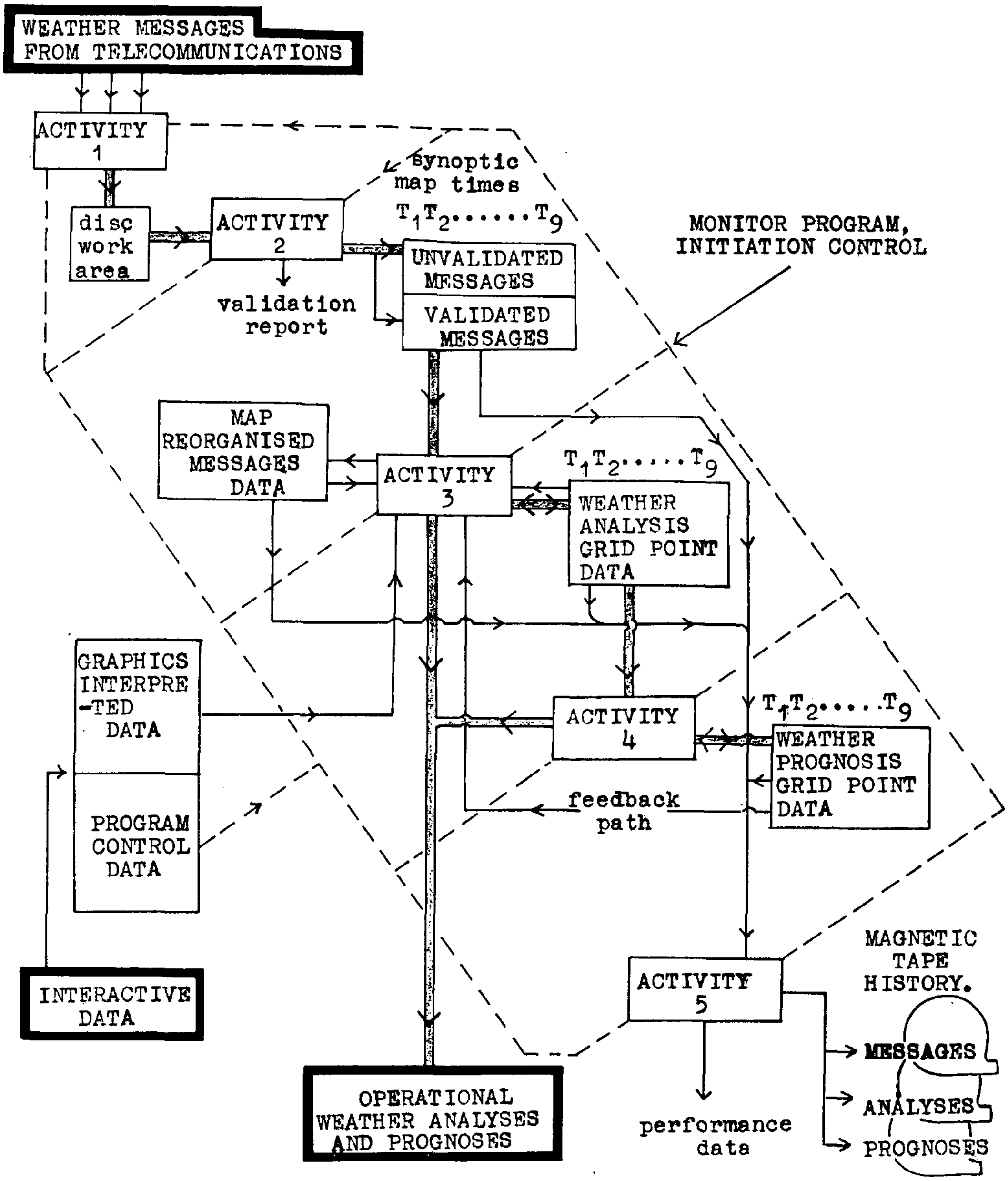

FIG. 1. Real-time weather analysis and prognosis work-activity, system-data paths.

is divided into two components, 1) the monitor program which directly controls the sequencing of activities and programs, and 2) the interactive graphics program through which the sequencing of sub-routines and computer code sections and the nature of the calculations may be controlled within the limits of the flexibility provided by program control parameters.

It is important in preparing programs for operational weather analysis and prognosis to maintain flexibility in operation to permit a monitoring meteorologist to reset or optimize the character and content of the processed output over a range of seasonal conditions and user requirements. If this is not done problems of program design and writing occur, and real-time meteorological and computer operations become poorly controlled, expensive and inefficient. The design philosophy on all computer program has therefore emphasized the selection and provision of sufficient external control parameters alterable by a meteorologist without the need for programming activity.

The computer-based system required for operational weather analysis and prognosis divides itself into five main work activities which in active operation may be sequenced almost independently depending on the balance of demands in output quality and timeliness. In order to give the reader, not fully conversant with the

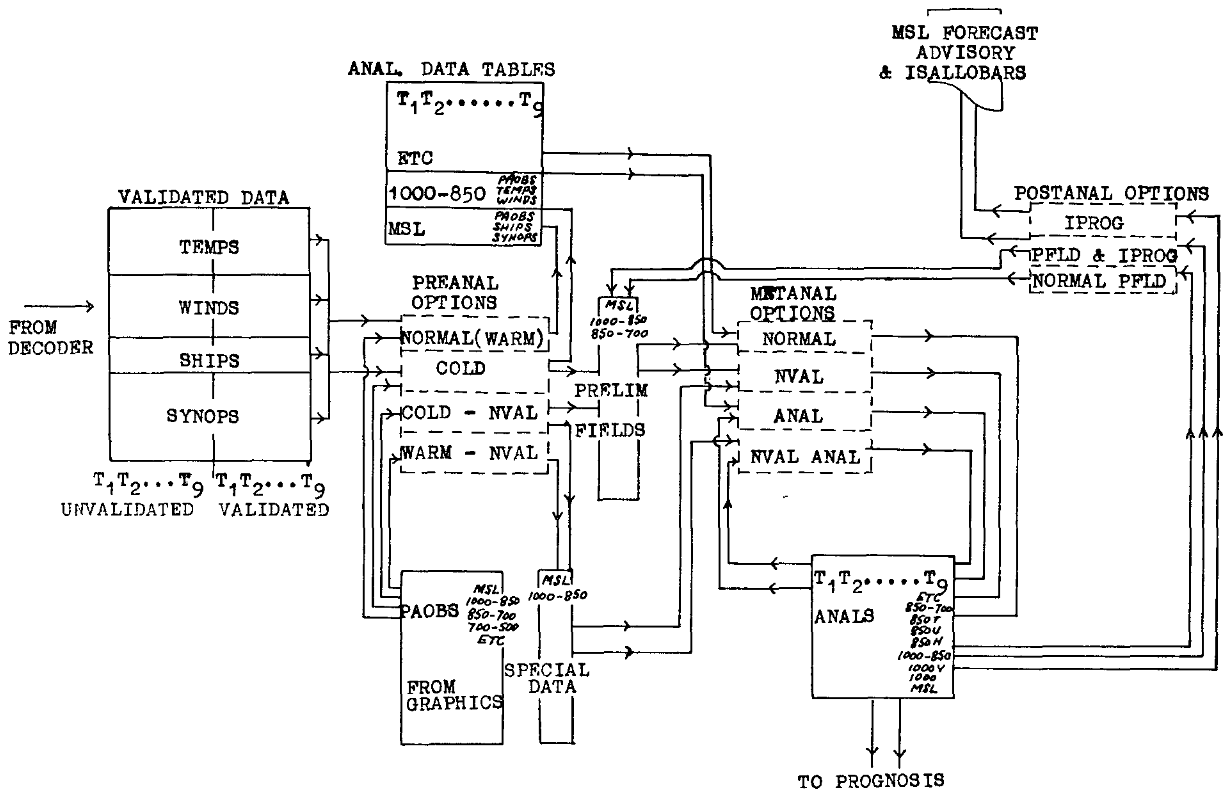

FIG. 2. Alternate data paths in Activity 3 of the weather analysis and prognosis ADP System.

computer operations required, a more meaningful background before proceeding with the discussion of the control system, a description of these five activities is set out below. Fig. 1 shows the individual activities in a typical real-time sequence. Fig. 2 shows an example of the possible alternative data paths which may be taken through Activity 3 using the flexibility provided by some of the program control parameters. Figs. 3 and 4 illustrate the two-component interactive control system and its connection with the activity programs.

a. Activity 1

Raw data are input from communications channels either on paper tape or magnetic tape. Meteorological messages are recognized, edited, decoded and sorted by synoptic map time, station identifier, and message part number. Unresolved or garbled messages are indicated to enable manual correction and feedback into the system. There are four programs in this activity and typical overall execution time is between 5–10 min for data originating from the Australian region.

b. Activity 2

Decoded information originating from weather stations for a map time is entered in station identifier sequence onto a cyclic overwriting data set containing unvalidated and validated data for all synoptic weather map times during a preceding 24 hr. As the newest collection of data is received it overwrites the oldest data in the 24-hr holding period. Before new data are merged a comprehensive series of validity checks are applied, including message internal redundancy, spatial consistency, hydrostatic, temporal and vertical consistency, and pressure reduction validity. Suspect and corrected data are printed out, and in addition a selected station display of information in the form of weather symbols on a map base may be obtained from an incremental plotter. An additional output is a printer display on a map base indicating the actual reporting station network for each atmospheric analysis level. There are three programs in this activity and typical overall processing time for the Australian region data ranges between 5–7 min.

c. Activity 3

Weather data specially needed for analysis purposes are extracted from the cyclic "validated" data set, reorganized by weather map level and placed on another 24-hr cyclic overwriting data set. At the same time data acquired through the interactive graphics activity is added to each map level data set. Data received from the total network of reports are then processed by a "weather analysis" model so as to produce a meteoro-

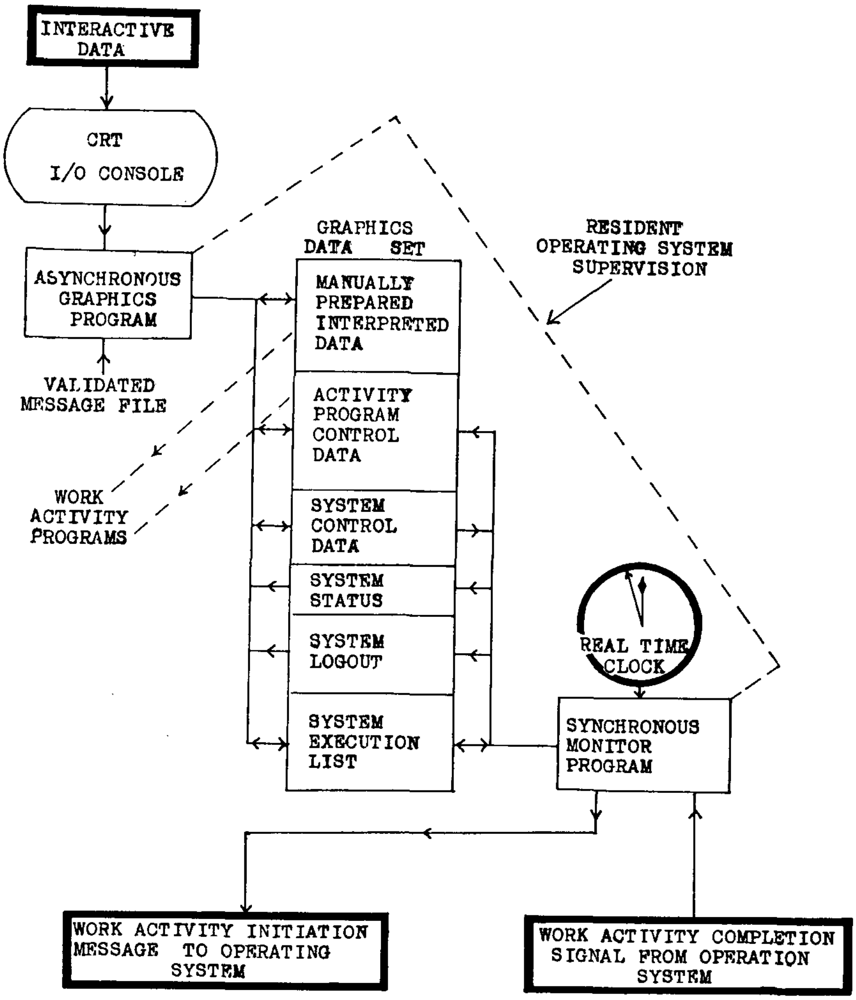

FIG. 3. Real-time weather analysis and prognosis control-system data paths.

logically consistent and acceptable display of weather variables for a defined portion of the Southern Hemisphere at eight map levels in the atmosphere. The "weather analysis" model makes use of special diagnostic physical relationships, based on the governing equations of atmospheric motion (for example, the geostrophic and linearized "balance" and thermal wind equations) and also statistical space correlations, in order to resolve a range of atmospheric scales of motion. The output from the analysis model is a regular matrix of "grid" values which are processed further to produce continuous isopleths of weather parameters on a geographical

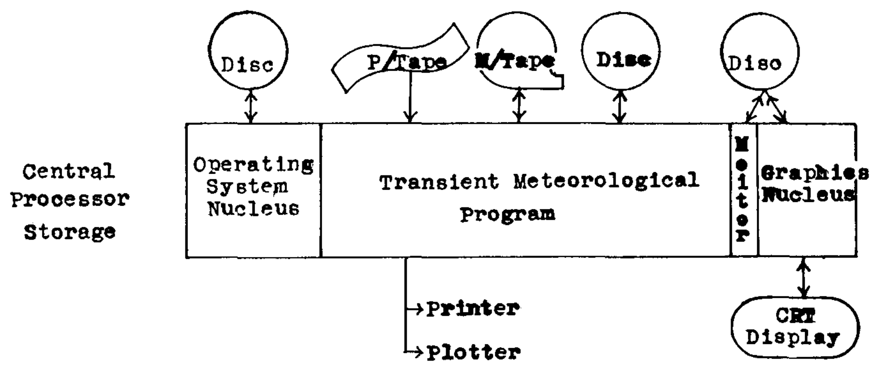

FIG. 4. Real-time system multi-program partitions and peripheral equipment.

map base from an incremental plotter. Weather variables analyzed include mean sea level pressure, wind, humidity and topography of various atmospheric constant pressure surfaces. There are three programs in this activity and typical overall execution times range from ~3–30 min depending on the number of map levels required. Further details on the actual analysis model used are contained in Maine and Seaman (1967).

d. Activity 4

The initial state of the atmosphere is read from the cyclic 24-hr analysis data set and input to a "weather prognosis model which integrates governing equations of atmospheric motion to obtain a predicted future state compatible with the motion scale range defined by the analysis model. The type of prognosis required may be very refined as in the case of the primitive equation model which predicts wind, temperature, moisture and pressure simultaneously at specified atmospheric levels. More simple means may also be used as in the equivalent barotropic model of the atmosphere which predicts flow at a mid-level of the atmosphere. Atmospheric layer thickness advections are also used in association with the barotropic model to predict flow at other levels. The prognosis model feeds back to the analysis model a predicted state for the next analysis time which is incorporated into the analysis especially in regions of sparse data. The main analysis times in an Australian region analyses system are 6 hr apart and the simple method of layer thickness advection is fairly satisfactory for analysis feedback purposes. However, for longer periods and in regions of no-data reports in the Southern Hemisphere, a primitive equation prediction is desirable for more reliable prognosis and consistent satisfactory analysis feedback.

Two programs, one for simple advective analysis feedback and one for barotropic prediction (Maine, 1967) are used currently and the overall execution time is ~10 min; however, a refined primitive equation prognosis model may take from 0.5–2 hr to execute depending on how far ahead in time and the area for which the prediction is required.

Analysis feedback data are written into a preliminary field data set and prognosis data are again written to a cyclic overwriting 24-hr prognosis data set. These prognoses are then displayed on an incremental plotter as required.

e. Activity 5

Data resident on all cyclic 24-hr files (validated and unvalidated messages, special analysis data, analysis and prognosis grid point data) are written onto permanent magnetic tape storage so as to maintain a history of input weather messages, and weather analyses and prognoses. A statistical verification program is included to compare analyses with respective prognoses so as to establish an objective measure of prognosis performance. There are two programs in this group and total execution time is ~15 min.

2. Computer organization and program libraries

It is important to the interactive control system for the machine operating system to be capable of multi-programmed operation, that is, concurrent operation of two or more programs resident in the machine at the one time. In multi-programming, the high-speed core storage is partitioned into several protected parts and in the system described here the partitioning is as follows, in order of central processor service priority:

1) Resident operating system nucleus (0S 360 release 16/17).
2) Resident graphics display control program.
3) Resident real-time monitor program.
4) Transient work activity program.

An additional higher priority partition could be provided for direct on-line handling of communications data. The feasibility of this, however, will be governed by the balance between operating system task switching times, the data flow rate, and the requirements of other real-time jobs competing for processor time. Since on-line communications have not yet been implemented on the main processor of the Bureau computer, all subsequent discussions assume no resident on-line communications.

The size of the resident program partitions are such that about 75% of the total core storage is available for a transient activity program. Neither the resident monitor, graphics, or systems nucleus programs have a printer actively allocated and all input and output is to and from disc data sets or to the keyboard display units. Both line printer and incremental plotters are allocated directly on-line to the transient problem program as required and thus enable the monitoring meteorologist to inspect results during computation, i.e., at the earliest possible time.

The programs described in this paper were implemented initially under 0S.360 release 16 of the company supplied operating system. This release supported and modified by the Bureau of Meteorology software group provides the following features necessary for the operation of the control system:

1) Interpartition communication between concurrently executing programs.
2) Capability to start the operating system "disc reader interpreter" from a user program on a procedure of job control language stored in a library on magnetic disc.

All computer programs are stored as individual members in the secondary storage disc pack units attached to the computer system, and it is a feature of the operating system that a job control language is used to put any particular program member into execution. Therefore, it is convenient to have stored on the disc units a library containing the complete job control language and data set definitions required to put into execution jobs consisting of either particular programs, or complete activities in the form of jobs. A job is a unit of work which the monitor program handles and which the operating system initiates, and it is a feature of all programs in the system that standard over-sets of data set definitions are made coping with all expected input-output requirement variations.

3. Control system design requirements

The primary design criteria of the control system have been established so as to meet the following needs:

1) On-line intervention facilities allowing modification to programs and data in order to optimize quality and timeliness of meteorological output.

2) Up-to-date presentation of a system status report and log of the progress in execution of work in the system.

3) A schedule of tasks able to be varied conveniently and executed automatically in real time.

4) The requirement to use the computer system for other nonstandard work during slack periods of the real-time schedule.

5) Semi-automatic facilities to cope with either program or hardware component failure or malfunction.

The first and the last two needs are handled by the interactive "graphics" program which may be regarded as the actual interface between the meteorologist and the system of computer programs. The remaining two points are dealt with by the "monitor" program which uses data provided by the "graphics" program to initiate the execution of a required meteorological activity or program.

The central element of the control system is the graphics data set, which is a sectionalized direct access data set. All input and output for graphics and monitor programs is to and from this disc data set, and in addition, problem programs themselves access this data set for program parameters and data. A full description of the graphics data set is given in the next section.

4. Graphics control data set

a. Pseudo observations or bogus data section

From the point of view of the meteorologist this is one of the most important sections since information which may have been interpreted from satellite pictures and other sources is lodged here. An element of information in this section may contain such data as 1) report identification, 2) type of information and applicable map level, 3) location of station, 4) scalar element (e.g. pressure), 5) vector element (e.g. wind), and 6) area of influence of information.

A sequential list of this information arranged by order of weather map analysis level is maintained automatically by the graphics program. The list may have information merged, deleted or changed as required by the analyst during the running of any of the programs except the multilevel weather analysis programs, when this information is used as a sequential input file.

b. Execution list of meteorological jobs

This section is a list structure of records, each of which describes attributes of various meteorological jobs. Link addresses within the list point forward to the next standard job but, in addition, a second address pointer has been arranged to allow an out-of-list jump on a certain switch condition. Forward pointing link addresses are used by the monitor in finding the next job in sequence to be run, and are used for interrogation purposes by the graphics program. Each job to be initiated by the monitor program has a specific record associated with it in the execution list. The record information includes 1) the name of the library member containing the control cards required to execute the job steps; 2) GMT time and date of data to be used for input and for output; 3) local time of execution of job; 4) switch variables allowing input of program and/or program control data from disc and/or card reader; 5) switch variables causing immediate execution of a job, delaying the monitor while job records are completed, or unconditional branch address to another job record; and 6) special primary parameter overrides defined for the job.

The monitor program accesses the execution table stored on magnetic disc randomly; however, the graphics program may access this section of the file in either sequential or random fashion.

c. Program parameters and control data section

This section of the graphics data set holds all the program parameters required for the satisfactory execution of a particular job. Each transient problem program, when activated, reads the first record of this section placed there by the monitor, to find the start address of its parameters and data within the section. All parameter data may be modified by the graphics program and the processing characteristics of a particular job may therefore be manipulated before actual processing begins. For example, typical parameters included in the multilevel analysis program include options to produce analysis grid point or isopleth displays, and maximum number and pass radii of analysis data scans and smoothing options. A meteorologist may therefore easily regulate, for example, the quality and quantity of printed output. All programs have a repertoire of external parameters and control data designed to cover a range of variations likely to be encountered during operational running. At a different level of complexity there is also a range of internal program parameters which usually require recompilation of the program by the operating system in order to make a variation. Only those variables not likely to be altered by operational meteorologists are assigned to this class.

d. System status and operations log

The monitor program updates a small status area on the graphics file on the occurrence of the following conditions: job started, job finished, or waiting, with a non-real-time additional job queue having been entered by the operator. Status messages may be viewed at any time while the system is running using the graphics program.

The remainder of this section is given over to a log containing the history of actual job records executed, actual time started, and total time spent in the job. The log section has capacity only for the last 100 jobs executed, the oldest job then being cyclically overwritten on the most recent job. A pointer at the head of the log indicates the most recent entry.

e. Index of graphic functions

This section of the graphics file contains several tables which describe the operation, or function control, codes which are required to interact with the graphics program. Whenever an illegal function control code is entered into the graphics program from the display unit the user is referred to this index of legal functions.

f. Reserve data section

This section contains special information such as the list of all valid names for real time jobs and the pointers to the parameter data in the parameter section for each job.

5. Interactive graphics program features and functions

The first component of the control system is the graphics program whose purpose is to provide access to old data within the computer system and to enable the addition of new data.

Information interpreted from weather satellite photographs, aircraft weather reports, or simply corrective data for the analysis model in sparse data regions is typed by operator onto a graphics data set through an IBM 2260 keyboard console. Important control data tables for each program and time schedules in the system may be scanned and modified. The graphics program, therefore, becomes the effective interface between the meteorologist, the monitor program itself, and the monitor controlled execution of meteorological jobs. The program is permanently resident in a small partition, with high central processor service priority. The program is constructed as a series of overlays each performing a specific function and invoked in response to the entry of a function control code. The function control code is a group of characters entered in the top left-hand corner of the display station screen. For general data set handling the control code is assembled as follows:

First character	Data set identification operand
Second character	Function identification or operation to be performed
Remainder (2–11 characters)	Optional codes qualifying the operation or specifying a data type or actual location within the data set

The sequence of events following the entry of a function control code into the system is as follows. Control passes from the operating system interrupt handler into a program module which is capable of starting input-output operations between the visual display buffer and a specified area of high-speed core accessable to a user functional (Fortran) program. The service module first performs a read operation on the activated 2260 unit and then control passes into the main user graphic program which analyzes the received function control code and calls the appropriate program overlay segments into the graphics partition. The overlay program performs the required function, writes into a common area of core store the visual display data, and hands control back to the service module. The common area is then written onto the display buffer, and control is handed back to the operating system which then continues the interrupted processing if no further interrupts are pending.

The nucleus of this graphics overlay program operates essentially as a two-dimensional switch, one coordinate specifying an operation (e.g., modify, display, etc.) and the other the data section or data set to be operated on (e.g., pseudo observations, execution list, etc.). The nucleus of the program also checks for all illegal control codes and writes diagnostic error messages. In addition, the last control code request on each display unit in operation is retained in order to simplify checking of illegal sequence of control codes. For example, in this system, modification of existing data is not allowed unless the immediately preceeding function on that unit was a display of the data which was to be modified.

In addition to functions involving the special graphics data set alone, the graphics program is also capable of interrogating the file of validated meteorological data which is a focal point of the real-time weather analysis system. This allows a meteorologist to examine simply and quickly the values of wind, temperature, humidity or geopotential vertically above an observing station.

Table 2 indicates typical codes and their meanings. In all cases when a display is called for, if the start loca-

TABLE 2. Typical function control codes used by the graphics interactive program.

Function control code	Function preformed
60	Clear all user inserted weather analysis interpreted data (psuedo observations) from graphics data set.
61	Display standard form in which to enter psuedo observation data.
62	Merge each psuedo observation found on the display screen into the relevant analysis data level group.
65ANRRR	Display a portion of the user entered psuedo observation data starting at relative record number RRR for analysis level AN.
66	Copy back the modified psuedo observation, data-displayed, observation.
55RRR	Display the execution list from relative record RRR.
56	Copy back the modified execution list displayed.
57TTMM	Display the time sequence of records after local time TT hr MM min.
75RRR	Display the program parameters commencing from record RRR.
76	Copy back the modified program parameters displayed.
07	Display status of real time machine, time to next sequential job, and the relevant execution list entry.
05N	Display page N of the index of function control codes.

tion is near the end of a data section of the graphics file, the display does not extend out of the section but recycles from the section origin. In special cases where new data is added to the data set (e.g., function 62), limited validity checks are applied to the data before it is accepted. In most functions an attempt has been made to anticipate the users' next logical function choice and to return these in position so as to minimize operator delays.

In addition to the direct operations on the direct graphic operations in Table 2, there are several other combined functions involving the monitor program also. It should be appreciated that the graphics system is capable of inserting special jobs into the execution list itself and therefore of having the monitor schedule such jobs at an appropriate time. For example, psuedo-observation data may be punched out in cards from the graphics data set or a special recovery job may be required to be scheduled. The graphics program may also be used to cancel an active job instantly. Other graphics operations (codes 95, 96, 97) refer to display and modification of observation data in a special validated data file by referring to the international station number and message type. If, for example, radiosonde flight data are required to be displayed, then this vertically sequenced data is assembled from the validated, data-message, time-organized files.

6. Monitor program features and functions

The second component of the control system is the monitor program whose purpose is to initiate the input and execution of a transient activity or problem program according to a background timetable set up in the graphics data set execution list. Information contained in this list enables the monitor to dispatch to the transient program the time and location of the data it is to use during execution.

The automatic control activity of the monitor is carried out in conjunction with the standard operating system. The execution list basic to the control function consists briefly of an ordered list of entries defining the action and the time it is required to start. The monitor program is instructed in psuedo-computer fashion by supplying it with an "operation code" (activity name, program or operation) and a source and destination "data address" (map data time). The execution list is a true list structure and thus implicitly contains the equivalent of a "program sequence counter." Unconditional jumps, loops and delays may be defined within the execution table. In a sense, therefore, the execution list may be regarded as a writable "meteorological language" possessing a directed rather than sequential succession of syntax.

When the monitor commences execution it is directed through a reserved section of the graphics data set to the first job for execution in the list. Time checking of this job record is commenced if this is indicated by the switch variables, and at the appropriate real time the control card images for the job named in the execution list are selected from the disc library and an operating system disc "reader interpreter" is started on this library member. The operating system subsequently fetches the required programs from a library of executable programs and scheduling of the job proceeds under the operating system. Immediately the operating system disc reader starts the monitor goes into a wait condition, pending either 1) completion of the transient program through either abnormal or normal termination, or 2) an operator response to cancellation of job (retry when ready).

The latter condition is required in the event of an abnormal output from a transient program caused through incorrect data. The monitor normally regains control by having a special compulsory job-step-execute immediately after the transient program step has finished. This program communicates the occurrence of an event in the lower partition (transient program termination) with the monitor partition, and the higher priority monitor partition regains control. In addition to initiating jobs the monitor maintains both the status report area and the log section of the graphics data set. When a job is started, time entries and execution list data are recorded in the log, which overwrites itself progressively after a certain time. Depending on the operation timetable, there may be periods when sufficient time is available to execute non-real-time jobs. In this event a special dummy job name is used which results in use of the card reader for input to execute a stream of non-real-time jobs. Once the monitor has detected an operator request to use the card reader and if there is sufficient slack time in the timetable, the card reader is started and the monitor waits to regain control. Control is not handed back until the event-posting job step referred to previously is inserted manually. It is therefore possible for the meteorologist to run test jobs or extra jobs while still retaining the monitor program at ready.

7. System recovery

Recovery of the system of real-time programs may be catered for by making periodical strategic data set dumps and data set update dumps throughout processing, using magnetic tape. If the failure is serious enough, an entire disc pack could be reconstituted at any time from the magnetic tape data. This process is to be initiated using the graphic facility which will insert a special recovery job into the execution list. In the event of failure of the graphics program the monitor program is automatically posted, and the standard procedure is to complete the current job processing and then switch all processing to input data from the card reader until the graphics program is restored. Should the monitor itself fail, a reversion to manual handling of programs is required in association with active graphics. At the present time the complete semi-automatic recovery system indicated above is not fully implemented, and if a program fails on a recoverable condition it is usually restarted from the program beginning, with the exception of the analysis and prognosis model programs which may restart from a given map level or a given time, respectively.

8. Concluding remarks

In operational, real-time, meteorological-data processing, significant time may be lost in manually manipulating computer programs and data. It is a purpose of the interactive control system just described to give an operational meteorologist facilities to select directly and modify the characteristics of both the data being used and the operation being performed, and to warn of and prevent possible departures from a preset timetable of operations. The system is capable of providing this and other needed functions such as processor status interrogation and extra job scheduling; job cancellation and job recovery were implemented with a view to increasing the overall utility of this interactive control system.

Acknowledgments. It is a pleasure to acknowledge the work carried out by Mr. D. Hincksman for converting the monitor from the original Fortran into assembler language. The provision of the program coding to interface the monitor with the IBM operating system was carefully provided by Mr. G. Knox.

Mr. G. Holuigue provided the IBM 2260 input-output program module interfacing directly with the operating system. Mr. J. Young assisted with the further development and operational modifications to the graphics overlay modules.

APPENDIX

Definitions

Byte	Equivalent to eight binary bits on the 360/65.
Data set	A logical collection of information usually placed on secondary computer storage. A data set is often referred to as a file when on magnetic tape.
Disc reader interpreter	A part of the machine operating system which reads job control information from the input and places it on a job queue data set.
List structure	A sequence of linked items of data.

REFERENCES

Maine, R., 1967: Experiments with the barotropic model in the Australian region. *Australian Meteor. Mag.*, **15**, 169–189.

——, and R. S. Seaman, 1967: Developments for an operational automatic weather analysis system in the Australian region. *Australian Meteor. Mag.*, **15**, 13–31.