CONTENTS

Introduction.

List of existing and proposed hardware.

Central part of the system.

Interactive peripherals: fully operational.

Interactive peripherals: under construction.

Interactive peripherals: being discussed.

Suggested uses in experiments.

Simple digital input and output.

Simple analog input and output.

Keyboard input and output.

Input and output of waveform complexes such as speech.

Input and output of graphic material.

Actual uses so far.

On-line experiments fully handled by MOD 1.

On-line experiments in which MOD 1 handles only part of the system.

Off-line analysis or stimulus generation.
INTRODUCTION

The experimenter can usefully think of a computer as consisting of a central part (which has very considerable powers to generate and record the sequential and temporal form of one or more sequences of events), and a peripheral interactive part (which confronts and responds to his subject).

The power of the central part can be taken for granted - it will almost always be possible to write a program to carry out the sequencing and recording that you require; the only important question about the central part of the system is how long the programming will take.

The most important absolute restriction in the computer is not the centre, but the periphery. In the following discussion we want to try to give some idea of what the existing and proposed peripherals on MOD 1 can and could do.

The discussion will start by listing the equipment, then go on to discuss its possible applications, and then to summarise its actual applications so far.

LIST OF EXISTING AND PROPOSED HARDWARE

The central part of the system:

1. Processor (operations at ca. 500KHz.)
2. Core store (24K 16-bit words).
3. Disc (1 million 16-bit words, transferable at up to 150KHz.)
4. Fast paper tape reader (Characters at 300Hz. or more).
5. Fast paper tape punch (characters at 150Hz.)
6. Three teletypes (characters at 10Hz.) - considered below also.
7. Three clocks (various characteristics - in theory up to 65KHz, but for normal use they tick at a selected frequency below 250Hz.)

Interactive peripherals: fully operational:

1. A system so that binary changes (switches, keys, buttons, logic level changes) interrupt the processor, and tell it which event has just occurred. Connected to this are a variety of buttons, and five-choice key sets, a footpedal, a post-office-type digit matrix, and a voice key.

2. Analog-to-digital and digital-to-analog converters; we have one of each, each multiplexed to eight sample-and-hold circuits. This means we can input or output up to 8 analog voltages at a total sampling rate over all channels in one direction of up to ca. 60+KHz. In terms of sinusoidal response, we can cope with zero to ca. 30+KHz, i.e. well above the main speech frequencies.

3. Keyboard input and typed output are provided by the three teletypes. High quality keyboard input is provided by a Honeywell solid state keyboard which incorporates a standard QWERTY keyboard, a block of function keys, and a Post Office digit matrix.

4. Waveform output is provided by the Wavetek, a single channel programmable waveform generator capable of giving square, triangular, or sinusoidal output over a wide range of frequencies and amplitudes.

5. Visual output is provided by two dual purpose (storage or transient) CRTs connected in parallel. For some purposes they can be used as a single, double-width CRT, or two semi-independent CRTs.
Interactive peripherals: under construction:

These devices and their software controllers will be finished at various points over the rest of this year.

1. A system for binary digital output - basically a bank of 16 switches and/or binary voltage levels which can be operated by a program so that they can generate pulse trains - e.g. to switch external devices on and off (lights, tones, tape-recorders, the Carousel, shutters, tachistoscopes, etc., etc.).

2. A rudimentary word recognition system. With its associated software it will be set up to distinguish one pair of words from a subject - i.e. subjects can respond with 'Yes'/ 'No', 'up'/ 'down', 'one'/ 'two', 'same'/ 'different' etc. rather than having to use two keys.

3. A PAT - a device for generating speech-like sounds under program control.

4. A graphic input device - essentially a type of light pen system to allow the user to point to parts of the CRT.

Interactive peripherals: being discussed:

Complaints, comments and further suggestions welcome.

1. A system for passive digital input; like the system described above for keys, buttons, etc., but instead of interrupting the processor, they merely raise a flag, which the program inspects when it is ready. This will be inappropriate if very exact timing of events is required.

2. A system for multiple digital input, and possibly output, so that simple group experiments could be run, each subject having a couple of keys and possibly a couple of signal lights.
3. Closed circuit TV arrangements so that the CRT output can be blown up and brightened up, again with a view to group experiments.
4. Connecting up a flexible pulse generator such as the Devices 'Digitimer'.
5. Arranging to drive a camera for photographing the CRT, both for sequences of on-off operations such as photographing diagrams you have set up, and for preparation of computer generated cine films for complex stimuli.
6. Exploring the use of the new Devices cheap micro-mini transmitter to link equipment to the computer from any part of the house or garden without any of the restrictions of permanent wiring, and without encumbering subjects.

SUGGESTED USES IN EXPERIMENTS

**Simple digital input and output:**

**Input:**

A digital input is something like a key press, a switch operation, a binary voltage change from some bit of logic circuitry, a squared up pulse, etc., etc. It is active if it interrupts the processor, and passive if it merely raises a flag which the program has to look for when it is ready.
The commonest digital input in an experiment is a key press, but it could also come from some kind of preanalysor, such as a voice-key, or a threshold detector looking for spikes in an electro-physiological record, either direct from a subject, or off-line from a magnetic tape. It could also be a special feed-back signal from some mechanism to indicate that it is ready for a new command; for instance the Carousel might be made to signal back when it had finished its slide changing cycle, so that the computer knows that it can signal for the next one.

All these heterogeneous types of event are treated uniformly by the hardware. An interrupt occurs or a flag is raised to indicate that an event has occurred, and a code word is made available to indicate which event it was.

Programming is usually easy when there are 5-10 milliseconds between inputs. It gets a little more complicated, though still remaining perfectly feasible, at rates up to several orders of magnitude higher than this.

Output:

A digital output is a switch, or a binary voltage level, or a pulse, operated by the computer. Anything that can be operated by a switch, level, or pulse, can be connected to it. At its simplest you can use it to switch a light on or off, or operate a solenoid in some gadget such as a shutter or a Smartie dispenser or a memory drum. You can generate square waves, or trains of pulses or clicks. You can operate the Carousel, or a camera, or a suitable projector, or any other device designed for remote control.

Again, like the digital inputs, programming is easy if you are happy
with, say, centisecond resolution though with care rates of 10KHz or more are perfectly feasible.

**Simple analog input and output:**

**Input:**

The analog inputs can digitise continuously variable voltages to an amplitude resolution of just over 1 part in 2000, and with relatively little distortion for sinusoidal input frequencies from DC to about 30kHz.

That is to say, the computer can very easily read a knob that the subject twiddles, or read the subjects EEG, EKG, EOG, etc., with plenty of time to spare and it can read and store audio inputs with a minimum of extra computation.

There are five obvious groups of applications:

Firstly, the analog inputs can always be used in a degenerate way as passive digital inputs, using two arbitrary voltage levels for the two digital logic levels. This application will be less relevant when our proper passive digital input system is ready.

Secondly, they can be used for DC and very low frequency applications, such as reading a knob or slider that the subject operates. The value read in this way might be used by the program to provide continuous adjustment of some characteristic of a stimulus - e.g. continuous rotation of a display, or adjusting the phase lag between two audio stimuli. Alternatively, it could be the subject's response on a Semantic Differential type of scale.
Thirdly, again at fairly low frequencies, the analog inputs can be used in tracking experiments, connected to a joy-stick, or to monitor the steering wheel and other controls in driving studies.

Fourthly, at intermediate frequencies, they can be used to pick up electro-physiological data. It is trivial for the computer to carry out Bionac-like averaging operations, and it would be feasible for it to carry out simple pattern recognition operations, such as recognising saccades or blinks. More complex pattern recognition operations e.g. on EEG are again theoretically possible, and are limited not by the computer, but by the state of the physiologist's (and programmer's) art. It is also possible to present stimuli contingent on certain electro-physiological inputs - e.g. at a certain phase of EKG, or during or between saccades, etc.

Finally, at high frequencies, it can carry out limited manipulations of audio material without undue distortion. With one analog input connected to a sound source, and one to a knob, and with two analog output channels, the sound can be output with no lag from one output, and with a knob-controlled lag from the other. Simple word manipulations are also possible - e.g. given a pre-recorded set of spoken digits, it could re-order them in various random sequences for inflexion-free stimulus tapes. Using the computer as a temporary buffer for a tape-recorder, it would be possible to set up a system for preparing very accurate timed transcriptions of subjects' spoken responses.
Output:

The analog outputs have the same conversion characteristics as the analog inputs. Again they can be used as if they were digital outputs, but they are intended to be used for operations such as controlling brightness or loudness or the excursion of a pen or a CRT beam, or for generating continuous waveforms of any required kind up to the limiting rate of about 30KHz.

If the program used to drive them contains a suitable random number generator, they can be used to generate noise of any required characteristics, and to superimpose on this some kind of signal at any required time. Depending on the device hooked up to the channel, this could appear as an audio, visual, or even tactile stimulus. Since there are eight channels, cross-modal presentation is perfectly feasible.

Many of the applications discussed above under the analog inputs involve the analog outputs as well - e.g. speech delay.

Simple control of an ordinary CRT is possible, particularly if the beam can be left on all the time. Some types of stimuli would be better prepared this way than on the main system CRT.

Keyboard input and output:

Input:

This is provided by the three teletypes and the special Honeywell keyboard. Keyboard input is of course simply an extension of the digital input system.
Keyboard input is needed mainly for system control - the experimenter, for instance, uses it to set his experiment up. Subjects, however, will clearly have to have a keyboard in experiments on keyboard skills, and in interactive experiments where the subject's key presses are as much commands as responses. It is always possible to use a full keyboard as if it were a single response button by using only one of the keys.

The teletypes include printing and punching mechanisms, are noisy, and have a very long action, so that they are not very suitable for use by subjects for many purposes - the Honeywell keyboard is much smaller, lighter, easier to use, and very quiet, and is normally to be preferred for subject use.

Output:

The only print-out mechanisms available are the three teletypes, and they are obviously essential for controlling the system, and for getting results printed out. They have been used for outputting lists of words to subjects during experiments but they are not ideal for this, since the words are output at only 10 characters a second, and the whole process is noisy and a bit awkward - output on the CRT is much more satisfactory for many purposes. Teletypes are, however, very good for the highly interactive 'problem-solving' type of experiment, where the computer and the subject carry on a fairly elaborate question and answer discussion, and time is not very important.
Input and output of waveform complexes such as speech:

Input:

In theory it is possible to feed analog waveforms directly into the analog inputs and to carry out all analysis and data reduction by software. In practice this can put a very heavy load on the computer if it has to operate in real time, and it is often more convenient and much faster to carry out well defined transformations of the waveform by special purpose analog hardware outside the computer, only feeding the reduced data into the computer, so reducing its load very substantially. So far in our system, the only relevant devices are the two voice key systems, but this category would also include devices such as continuous spectrum analysers.

The simple voice key is a straightforward integrator and threshold type of system that will operate indiscriminately on any word and many other types of sound. The 'two word' system is calibrated for each subject and each pair of words, so that subjects can make simple binary replies such as yes/no. Both systems can obviously be used on-line to the subject, or off-line on tape-recorded material.

Output:

As with complex analog input, so complex analog output tends to put a heavy load on the computer, which can be alleviated considerably by using the computer to control not the actual analog output, but instead the generator that produces the output. This can also result in better output, since the special purpose generator can use analog techniques, and so avoid the distortions due to digital analog conversion.
We have two devices in this category - a programmable waveform generator ("Wavetek") and a specialised speech phoneme generator ("PAT").

The Wavetek can generate one channel of square, triangular, or sinusoidal output of controlled amplitude, frequency, and starting phase. All parameters can be varied while the bus is in action, so a wide variety of audio pulse and tone structures are possible. It could be used online, or off-line for generating stimulus tapes. With a second channel, it could be used to generate beat patterns, or to generate visual Lissajous figures on a CRT.

The PAT will be able to generate something that sounds like speech, with obvious applications to psycholinguists, and also useful spin-off in that it will be easy to generate stimulus tapes of random sequences of words, etc.

Input and output of graphic material:

Input:

The graphic tablet is a device which allows the computer to keep track of the current X and Y coordinates of a 'pencil' that touches it. It can be used on its own, but since it is transparent, it is more often used placed against the CRT. It can therefore be used to point to items of interest on the CRT; to tell the computer where to put something on the CRT, or to actually draw in a shape (e.g. handwriting, drawings, diagrams) which the computer is to store, or possibly to analyse.

Some uses: pointing to recognised items displayed on the CRT, or selecting multiple-choice answers; interacting with the CRT in a diagram-drawing system for preparing diagrams for publication - when arranged to your satisfaction they can be photographed; entering handwritten characters
for pattern recognition experiments.

Output:

Our dual-purpose storage/transient CRTs are by far the most powerful devices in the system as far as the experimenter is concerned. When used in store node, static stimuli of almost unlimited complexity can be drawn up, either to be photographed for off-line use, or for direct on-line use. Any pattern is possible in theory, but the existing software makes it easiest to draw up text and patterns based on straight or circular, continuous or dotted lines. Obvious uses are the presentation of words or lists of words, generation of complex static stimuli such as Julia matrices, stereo-pairs, mazes, and the generation of successive frames for stimulus films to be presented off-line. In transient node the amount of information you can get on the screen before it fades is obviously more limited, but you can still get the equivalent of 10-15 letters up at tachistoscopic speeds, and maintain rather more than that under refresh conditions, re-displaying the material continually, restarting again as soon as you finish. Under these transient conditions, the CRT can be used for tracking experiments and for generating complex moving and changing stimuli - e.g. simulating a driver's eye view of a road as he steers down it.

Graphic output is also possible using ordinary CRTs driven by the analog outputs, or using the Carousel.
ACTUAL USES SO FAR

This section has been written by JRR, not by the authors quoted — I hope it is accurate as far as it goes — if not blame me, not them!

On-line experiments fully handled by DRT!

Broadbent and Gregory:

1) Variations on the following theme: a list of words is presented to the subject on a teletype. The subject recalls as many as possible and the experimenter types the recalled words into the computer. The computer then presents the subject with another list consisting of a mixture of correctly recalled words, unrecalled words, and new words; for a recognition test. The subject responds to each word as it is presented by typing in code letters which indicate source list and confidence. Confidence ratings for correct and incorrect responses are automatically summed.

2) The post office key matrix was linked to a series of twelve tones from the Wavelet. Subjects are asked to generate non-repeating series of tones, and the computer records the times between key presses for all pairs of keys. What is the relation between frequency of use and interval between key presses?

John Fox:

1) Pairs of letters appear on the CRT. The subject presses one of two buttons to signal same/different. Periodically a diagonal line appears on the bottom right of a letter as superimposed noise. Will
subjects subsequently see 'Q' as the letter 'Q' or as the letter 'O' with a noisy line?

2) Pairs of letters appear overlapped on the CRT. The subject presses buttons to indicate whether they are same different. Variations on this explore the effects of using letters with varying degrees of symmetry or other forms of structure.

3) Randomly placed clusters of letters (2-3 in one study, up to 12 in another) appear on the CRT. Some letters are known to S to be irrelevant. He has to report whether the others are all the same, or mixed.

4) A set of characters appears on the CRT. There is a pause of varying length, and then a probe character appears. Was it in the set? The probe may be accompanied by various types of visual noise - dots, slashes, straight lines, or curves.

5) Variations on the foregoing are being considered using handwritten characters. The letters would be entered into the computer using the graphic tablet and stored on the disc to be brought out as required during the experiment.

John Long:

What happens to type-writing skills if the timing of the normal auditory and visual feedback from the printing action becomes flexible, as in the Croed Envoy teletypewriter only more so? A program was written to simulate the relevant types of variable feedback delay, and a series of experiments has been carried out to look at the effects of varying the parameters of this on the rate and accuracy of typists of varying degrees of skill confronted with various types of copying task. The
teletypes and the Honeywell keyboard have been used for input, and the teletypes have been, and the CRT will be, used for output.

Pete McLeod:

1) How late on in a response can a subject make use of now stimulus information? A target and a dot appear on the CRT. The dot begins to move towards the target which then disappears. The subject has to press a key when he thinks the dot has reached the point where the target used to be. In control conditions the target reappears after the key is pressed to give normal knowledge of results. In test conditions, the target reappears just before the subject responds - if this improves his performance, then he must be correcting his response at a very late stage.

2) How long does an image persist subjectively?
   a) The CRT was used to present a line fixed at one end and sweeping out a circle at the other end. As it spins, persistence makes it appear to have a prolonged trailing edge. The angle subtended by this trailing edge gives a measure of persistence.
   b) The CRT was used to present a ladder of horizontal rungs, written cyclically, so that as soon as the beam finishes the top rung, it starts again at the bottom rung. If persistence is less than this cycle time the bottom rung will appear to have faded before it is rewritten. The number of rungs is controlled by a knob on an analog input. S adjusts the knob until the ladder begins to flicker or stops flickering.
John Morton:

1) A forced choice categorising experiment: present a pair of words defining a dimension (e.g. 'edible' and 'inedible') on the CRT. Then present a fixation point followed by a word to be categorised (e.g. 'jams') and the subject presses one of two buttons to show which category it lies in. Choices and distributions of times are recorded. What happens to superordinate vs subordinate words (e.g. 'wine' vs 'reisling')?

2) Can a human supervisor equal or improve on the recommendations of a mathematical model in working out how to organise the cash desks and queues in a supermarket to keep certain parameters within defined limits? The program displays on the CRT a number of queues building up and being served continuously. The subject can interact with this using the keyboard.

John Morton and John Martin:

1) Several series of experiments on the ergonomics of display and keyboard layout in various types of multiple choice and copying situations. Basically the words or digits to be copied or selected from are displayed on the CRT, and the subject responds using a keyset of some kind. Response time distributions and error counts are recorded.

2) Studies of the relation between internal memory structure and external classification structure in information retrieval tasks are in progress. We have a program using the CRT and Honeywell keyboard that allows the subject to sort large (400+) numbers of items into any structure of categories - basically an extension of card sorting to numbers of items and structures too large and too complex for ordinary card sorting to be feasible.
On-line experiments in which MOD 1 handles only part of the system:

Pete McLeod:

A completely separate piece of equipment is used to generate a tracking situation requiring the subject to respond by making discrete lever movements. By making parallel connections from the lever to MOD 1, the computer is used simply as a recording device to note the times of each type of movement, and to form the distributions of intervals between the movements.

Bruce Honning:

The analog outputs have been linked up to Bruce's own CR system for generating sinusoidal gratings and various audio signals. The computer is used to generate random sinusoids of precisely known and sharply delimited bandwidth which are then presented in real time.

Off-line analysis or stimulus generation:

Joan Brand:

Joan uses a very simple assembler for generating the patterns of holes on punched tapes used for controlling other equipment; this is much quicker than hand punching.

Max Hammerton and Bob Wilkinson (2 separate projects):

Computer used for the preparation of typed tables of random digits or letters constrained in specified ways for stimulus materials.
Laurence Hartley:

Magnetic tapes recorded during an experiment contained event marks on various channels. The tapes were played into the computer to form the distributions of intervals between selected event marks.

Bruce Henning:

Used computer to perform very lengthy integrations arising from a theoretical model. These would have been very expensive on Titan, but on MOD 1 they could be left running for hours or even days at no particular cost. In general, this means that it is often possible to carry out computations in the conceptually simplest way, without having to bother with elaborate extensions to enhance programming efficiency.

Byron Morgan:

Cluster analyses on Titan often produce arrangements of points in three-dimensions. Byron has a program which allows him to inspect these clusters on the CRT, rotating them as required.