The Radio Shack color computer in the experimental psychology laboratory: An evaluation

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The Radio Shack color computer is examined from the viewpoint of capabilities needed to program, time, control, and acquire data from typical cognitive psychology experiments. Its capabilities are compared with those of the alternative inexpensive microcomputers discussed in an earlier article (Reed, 1980). The paper also includes a 6809 assembly language routine that permits the measurement of reaction times in video horizontal scan (HS = 4/63 msec) units without hardware modifications and an RSCC BASIC program for unbiased conversion of HS units to milliseconds.

As recently as a year ago, the least expensive micro-computer system capable of running most cognitive psychology experiments cost about \$1,400. While the same system would still cost about \$1,100 or so today, recent technological developments, such as single-chip display control and memory management circuits, have given us a new generation of much cheaper but nevertheless quite capable small computers. These new machines—the Atari 400, the Commodore VIC, and the Radio Shack color computer—appear to have been designed primarily for home entertainment rather than hobbyist experimentation, and so they do not have the sophisticated hardware expansion capabilities of the older hobby computers. They do, however, have the advantages of good display capabilities and much lower cost. Since many psychology students already have access to cassette tape recorders and standard television sets, the effective cost to a student is just the cost of the computer unit. Recent issues of *Byte* have carried advertisements for Radio Shack color computers for as little as \$310, with random-access memory expansion to 16 KB available for an additional \$16. The total cost is comparable to that of a set of textbooks for a sequence of graduate-level courses. I decided to check out the laboratory potential of the new machines and to see whether it was possible, at long last, to give each student a portable experimental laboratory of her or his own.

Of the three machines listed above, the Atari 400 appears to have the most powerful display generator in its hardware. Unfortunately, its keyboard provides no tactile feedback, which makes it unsuitable for measurement of reaction times. The Commodore VIC appears to have the most limited display capability of the three. While technical specifications of its graphics capabilities were not available as of November 1981, the VIC's text display is limited to 22 characters/row, considerably less than the other two machines. It is equipped with a typewriter-like smooth travel keyboard, which makes it

only marginally suitable for reaction time data acquisition applications. Among the three, the Radio Shack color computer comes closest to meeting the "portable experimental psychology laboratory" requirements. Its keyboard gives crisp, snappy tactile feedback, as good as that of most response keys used in traditional psychology laboratories. The display can generate a matrix of up to 256 x 192 picture elements, so that visual stimuli should approach the quality obtainable with an Apple II (280 x 192 pixels). The rest of this paper examines the capabilities of the color computer in greater detail.

PROCESSOR

The Radio Shack color computer uses a Motorola 6809 (specifically, 6809E) microprocessor. While this processor uses the same external bus as the older 6800 and 6502, its internal organization incorporates several improvements that make it much easier to use for laboratory applications than its predecessor. First, its machine language is inherently relocatable, so that programs may be written and assembled without the user's having to know, or care, where in the computer's memory each program will reside during execution. Second, the entire "context," that is, the state of the processor and of all its registers (with the obvious exception of the pointer to the stack being used), can be saved (or later recovered) with a single instruction. This is automatically done by the processor for IRQ- and NMI-generated interrupts, so that the user is free from having to worry about which registers get altered during interrupt handlers and subroutines. Third, the instruction set is exceptionally clean and modular. Only 44 instruction types need to be remembered by any assembly language programmer, together with 10 register names, eight testable conditions, and 24 addressing modes. All the logically conceivable combinations of

instructions and addressing modes are available in the instruction set, so there is no need to remember which are available with which, as was the case on the 6502. Together, these features make assembly language programming, often unavoidable when precise timing is required, easy enough for just about any psychology student.

The instruction set includes several commands not available on earlier processors, three of which are worth mentioning. CWAI (clear condition codes and wait for interrupt) and SYNC (synchronize with masked interrupt input) make it possible to synchronize the processor to an external input with single-cycle precision. On the 6502, the tightest synchronization loop available could only synchronize processing within six cycles of an external signal. LEA (load effective address) facilitates the handling of arbitrarily dimensioned arrays without explicit arithmetic manipulation of address variables. Since data obtained in psychological experiments frequently have the form of arrays, this capability is an obvious advantage. So is the availability of auto-increment and autodecrement addressing modes, analogous to the corresponding modes in C, at the machine instruction level. Other features, such as the availability of up to four stacks in hardware, are less directly relevant to experimental psychology applications, but they do make it fairly likely that 6809 versions of high-level control application languages, such as C or FORTH, will be fast enough to use in experiment control when available.

VIDEO DISPLAY

The color computer uses a VDG (video display generator) integrated circuit (IC) in conjunction with the SAM (synchronous address multiplexer) IC to generate video displays from random-access memory. The computer provides a variety of text and graphic displays ranging from uppercase-only text (512 bytes/screen) to 256 x 192 pixel graphics (6 KB/screen). Unlike the computers discussed in Reed (1980), the color computer's display may originate at any 500-byte boundary in memory. With 16 KB of memory, the user can reserve up to 12.5 KB for video displays: enough for 25 uppercase text pages, or one high-resolution page for critical stimuli plus 13 text pages for subject instructions, fixation frames, masks, blank screens, feedback information, and so on. With 32 KB of RAM, four high-resolution frames and six text frames could be held in memory simultaneously.

Unlike older machines, the color computer needs no hardware modifications for access to the vertical scan synchronization pulse: The hardware connection, to an interrupt-generating input, is already present on the board. A similar connection to the horizontal sync pulse is also provided and can be used to obtain partial-screen displays, effectively increasing the number of available

high-resolution frames in memory, by means of frame switching. These inputs may be used for precise timing as well, as discussed below.

While the VDG is built to display text at a density of 16 lines of 32 characters each, the high-resolution format is usable with arbitrary alphabets defined by the user, at up to 24 lines of 43 characters/display. Kitsz (1981) presents an alternative approach, particularly useful to users of unexpanded machines with only a limited amount of memory, using read-only memory character generators to extend the range of characters displayable in text mode. The same article also contains a simple circuit for connecting the color computer to a standard video monitor, bypassing the built-in radio frequency modulator for applications requiring high-definition displays (or in order to use a monitor already in the laboratory).

CASSETTE TAPE-RECORDER INTERFACE

The Radio Shack color computer is equipped for starting and stopping a cassette tape recorder (or two recorders, one for reading programs or data or sound, and another for recording data) under program control. Programs and data files are read in from and recorded on cassette tape by file name, and unattended operation (for overnight data processing, for example) with program overlays can be readily implemented using closed-loop tape cassettes. Sound from cassette can be played back and combined sequentially with sounds from the built-in digital-to-analog (D/A) converter, or from an external source, under program control. This permits highly repeatable sequencing of prerecorded voice instructions and experimental trials in psychological experiments.

ANALOG INPUTS AND OUTPUTS

The computer comes with a built-in 6-bit (2% of full-scale resolution) D/A and analog-to-digital (A/D) converter. The output of the D/A converter is available at the cassette connector. The "paddle" connectors provide four analog inputs, switchable under software control, to the A/D converter. Existing internal sound connections to the D/A output permit the generation of auditory stimuli with precisely defined waveforms.

DIGITAL I/O

As stated above, the keyboard appears suitable for response collection in most psychological experiments. Two digital I/O lines are available on the "paddle" connectors. If more digital lines are needed, they can be tapped from the keyboard connector up to a total of 15. Two interrupt inputs, FIRQ (buffered and switchable) and NMI (direct) are available on the card-edge expansion connector.

TIMING

The availability of horizontal as well as vertical synchronization pulses at interrupt-generating inputs makes precise timing of video stimuli (Reed, 1979) possible without hardware additions or modifications. An assembly language program to measure reaction times in horizontal scan (HS) units is given in Appendix A. Since each HS unit is equal to $4/63$ msec, a program for unbiased conversion of HS units to milliseconds, such as the one presented in BASIC in Appendix B, must incorporate a "rerandomization" procedure. It can be shown that the increment of reaction time variance due to this procedure is less than $.02/\text{msec}^2$, compared with typical participant-generated reaction time variances of hundreds or thousands of square milliseconds.

NETWORKING

The color computer incorporates an RS-232 interface for connection to hard-copy devices (printers, teleprinters, plotters) or remote mainframes (through modems or directly). Radio Shack sells networking hardware for color computers, and software for networking at up to 9.6 kbaud is frequently advertised in *80-Microcomputing*, *Byte*, and similar magazines.

EXPANSION

In laboratories using several "minimal" color computers for experiments, it may be useful to have an "expanded" color computer serve as network controller and software development station. Hardware for simultaneous connection of a printer and a second RS-232 device, such as a network controller, has been advertised in microcomputing magazines. So have packages of software for editing, assembling, and debugging real-time programs for the color computer. With 64-KB random-access memory chips, it has become possible to build up to 128 KB of memory into the machine, although

current Radio Shack offerings stop at 32 KB with 16-KB chips.

The card-edge "expansion" connector on the side of the color computer is capable of supporting a wide variety of peripherals. Although now used only for game cartridges, floppy disk systems, and up to 16 KB of random-access memory outside the SAM's memory management range, the RSCC expansion bus may be expected to permit future connection of auxiliary processors (thanks to a tristating HALT line) and of virtually unlimited amounts of external memory and memory-mapped peripherals (thanks to the SLENB line, which disables internal device selection to free the entire address space for use by external devices).

In terms of software, the RSCC extended BASIC is among the most powerful versions of the language available, including as it does music, graphics, and text-formatting capabilities, string-to-numeric and numeric-to-string conversion capabilities in octal and hexadecimal as well as decimal, built-in editing and renumbering capabilities, and well-designed functions for reserving space for, and interacting with, machine language subprograms. A version of PASCAL for the color computer is being advertised in microcomputer magazines, and it is likely that additional languages, word processors, and so on, will become available with text-display software using the high-resolution video capability. In summary, the Radio Shack color computer appears to be a viable alternative, as a laboratory microcomputer, to other micros costing two or three times as much.

REFERENCES

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Appendix A
TRSCC Routine for RT in Horizontal Scan Units

RTIMER	PSHS	#FF	17	save everything
	LDA	#FF	2	make page FF
	TFR	A,DP	6	the direct page
	ORCC	#50	3	mask interrupts and
	ORCC	#50	3	rep in case interrupted
	LDA	#38	2	open direction
	STA	03,DP	4	registers for input
	STA	01,DP	4	and output
	CLB		2	set all keyboard
	STB	02,DP	4	column bits to input
	LDA	#7F	2	and row bits
	STA	00,DP	4	to output
	LDA	#3D	2	open
	STA	03,DP	4	data
	STA	01,DP	4	registers for I/O
	STB	00,DP	4	output zero on kbd rows

	LDA	#34	2	disable
	STA	21,DP	4	all other
	STA	23,DP	4	interrupts
	LDX	#0000	3	preset registers
	LEAU	.X	4	for counting HS pulses
	LDB	PRESETLO	2	and limit to preset
	LDY	PRESETHI	4	number of video frames
	LDA	00,DP	4	clear interrupt flags
	LDA	02,DP	4	initialized in 96 cycles
SYNCH	SYNC		4+	wait for interrupt
	LEAX	#01,X	5	increment low 16 bits
	BNE	TIMECHK	3	and if zero reached
TIMECHK	LEAU	#01,U	5	also hi 16 of HS count
	LDA	03,DP	4	check for VS interrupt
	BPL	RESETINTS	3	and if flagged then
	CLA		2	the low 8 bits of VS
	ADDD	#0001	4	are incremented and the
	LEAY	A,Y	5	count extended to hi 16
RESETINTS	BEQ	TIMEOUT	3	to check for timeout
	LDA	00,DP	4	otherwise clear HS flag
	LDA	02,DP	4	and VS; check keyboard
	COMA		2	go back if not pressed
PRESSED	BEQ	SYNCH	3	loop is 51+ cycles long
	STU	RT3,PCR	6	pressed: store hi 16 &
	STX	RT1,PCR	6	low 16 bits of HS count
	BRA	FINISH	3	then finish up
TIMEOUT	STY	RT3,PCR	7	if timed out put zeros
	STY	RT1,PCR	7	in place of HS count
FINISH	LDA	#3C	2	to finish disable both
	STA	03,DP	4	VS and
	STA	01,DP	4	HS interrupts
	LDA	00,DP	4	and clear
	LDA	02,DP	4	both interrupt flags
	PULS	#FF	17	restore old context
	RTS		5	and return
RT3-RT0	DATA	4 BYTES		

Appendix B

Horizontal Scan Units to Milliseconds BASIC Conversion Routine

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RHST=PEEK(RT2)+256*PEEK(RT3)
RHST=PEEK(RT1)+256*RHST
RHST=2+PEEK(RT0)+256*RHST : REM RHST IS RT IN HS UNITS (63/4MSEC)
THI=INT(RHST/63)
RHST=RHST-63*THI
THI=4*THI
R=RND(4)
IF RHST <= 14 THEN TLO=0
IF RHST = 15 THEN IF R = 1 THEN TLO=0 ELSE TLO=1
IF RHST >= 16 AND RHST <= 30 THEN TLO=1
IF RHST = 31 THEN IF R <=2 THEN TLO=1 ELSE TLO=2
IF RHST >= 32 AND RHST <= 46 THEN TLO=2
IF RHST = 47 THEN IF R = 4 THEN TLO=3 ELSE TLO=2
IF RHST >= 49 THEN TLO=3
T(TRIAL)=THI+TLO

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