Scan-display of high-resolution images using the Apple II

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Two programs are presented for the scan-display of high-resolution images using the Apple II+ and Apple IIe. The first program permits the user to move a rectangular aperture about the video screen to reveal different portions of a stationary image. The second program scrolls an image vertically within a horizontal window, giving rise to the impression of an object moving behind a stationary slit. These programs should be useful in the study of anorthoscopic perception, motion perception, perceptual integration of successively displayed information, and other topics in visual perception.

This paper presents two programs incorporating machine-language routines for scan-display of high-resolution (HIRES) images on the Apple II+ and Apple IIe. The first program, APERTURE, permits the user to move a rectangular aperture about the video screen, thus revealing different portions of a stationary image stored in memory; movement of the aperture "in front of" the image is controlled by the Apple paddle inputs. The second program, ANORTHOSCOPIC, scrolls an image vertically within a narrow horizontal window, giving rise to the impression of an object moving behind a stationary slit. This program was designed for use in the study of anorthoscopic perception (Anstis & Atkinson, 1967; Parks, 1965; Rock, 1981).

The two BASIC program listings are given in Tables 1 and 2. The machine language routine for each is stored in the data statements beginning at line 500 and is POKEd into memory in line 10. For both programs, the image being scanned is stored in Page 2 of HIRES screen memory (\$4000-\$5999) and is displayed on Page 1 (\$2000-\$3999). Because successive rows of the Apple video screen are not represented sequentially in screen memory, the scanning routines make use of lookup tables to optimize speed. Table 3 lists the BASIC program (LOOKUP) that computes the lookup tables for HIRES Pages 1 and 2 and stores them beginning at \$6000. (APERTURE uses only the table for Page 2.)

To avoid beat-like interaction (aliasing) between the graphical output of the Apple and the video frame rate (59.92 Hz in the American Apple and 50.32 Hz in the Eurapple; see Sather, 1983), each machine language routine synchronizes output to the video blanking signal. Synchronization has been described in earlier articles (Cavanagh & Anstis, 1980; Diener & Smees, 1984; Reed, 1979). For the Apple IIe the vertical blanking signal is

Table 1
APERTURE Program

```

10 FOR I = 768 TO 986: READ V: POKE I,V: NEXT
20 HOME : IF PEEK (64435) = 6 THEN GOSUB 1000
30 POKE 249,12: POKE 250,2: REM HEIGHT AND WIDTH
40 HOME : PRINT "PRESS C TO CHANGE HEIGHT AND WIDTH"
50 PRINT "PRESS S TO SEE FULL IMAGE"
60 PRINT "PRESS ANY OTHER KEY TO SEE SCANNED IMAGE"
70 GET A$
80 IF A$ = "C" THEN GOSUB 2000
90 IF A$ = "S" THEN 3000
100 HGR : POKE - 16302,0: CALL 768
110 POKE - 16368,0: TEXT : GOTO 40
500 REM MACHINE LANGUAGE SUBROUTINE
510 DATA 169,0,133,206,133,6,133,7,162,1
520 DATA 32,30,251,132,235,169,127,205,99,192
530 DATA 48,251,205,99,192,16,251,165,249,133
540 DATA 238,166,7,138,224,128,16,7,160,96
550 DATA 132,207,76,49,3,160,97,132,207,10
560 DATA 168,177,206,133,251,200,177,206,56,233
570 DATA 32,133,252,24,165,6,101,251,133,251
580 DATA 160,0,152,145,251,200,145,251,196,250
590 DATA 208,249,232,198,238,208,202,164,235,152
600 DATA 74,74,74,133,6,152,41,7,133,239
610 DATA 169,0,166,239,240,6,56,42,202,76
620 DATA 104,3,133,237,73,255,133,236,165,249
630 DATA 133,238,162,0,32,30,251,132,7,152
640 DATA 170,138,224,128,16,7,160,96,132,207
650 DATA 76,147,3,160,97,132,207,10,168,177
660 DATA 206,133,253,200,177,206,133,251,56,233
670 DATA 32,133,252,24,165,6,101,253,133,253
680 DATA 133,251,160,0,165,236,49,253,145,251
690 DATA 200,177,253,145,251,196,250,208,247,165
700 DATA 237,49,253,145,251,232,198,238,208,187
710 DATA 173,0,192,48,13,162,3,160,255,136
720 DATA 208,253,202,208,248,76,8,3,96
1000 REM APPLE IIE SETUP
1010 POKE 786,25: REM POKE LOW ORDER BYTE OF $C019
1020 REM MODIFY CODE FOR IIE
1030 POKE 790,234: POKE 791,234: POKE 792,234
1040 POKE 793,234: POKE 794,234: RETURN
2000 REM CHANGE HEIGHT/WIDTH
2010 PRINT : INPUT "ENTER WIDTH (MULTIPLE OF 7) ";WD
2020 WI = INT (WD / 7)
2030 INPUT "ENTER HEIGHT ";HT
2040 POKE 249,HT: POKE 250,WI: RETURN
3000 REM DISPLAY FULL IMAGE
3010 HOME : PRINT "PRESS ANY KEY TO RETURN TO MENU"
3020 FOR T = 1 TO 1500: NEXT
3030 POKE - 16297,0: POKE - 16304,0: POKE - 16299,0
3040 GET B$: HOME : TEXT : GOTO 40

```

accessible to software at decimal address 49177 (\$C019). As described in Cavanagh and Anstis (1980) and Reed (1979), this signal can be made accessible at memory location 49251 (\$C063) in the Apple II+ by connecting a jumper cable between Pin 8 of integrated circuit socket

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Table 2
ANORTHOSCOPIC Program

```

10 FOR I = 768 TO 883: READ V: POKE I,V: NEXT
20 HOME : IF PEEK (64435) = 6 THEN GOSUB 1000
30 YT = 0: REM TOP OF IMAGE BEING SCANNED
40 YB = 180: REM BOTTOM OF IMAGE BEING SCANNED
50 XB = 0: REM LEFTMOST BYTE OF WINDOW
60 HE = 40: REM HORIZONTAL EXTENT OF WINDOW IN BYTES
70 WI = 10: REM WINDOW WIDTH IN PIXELS
80 PRINT "PRESS C TO CHANGE WINDOW WIDTH"
90 PRINT "PRESS S TO SEE FULL IMAGE"
100 PRINT "PRESS ANY OTHER KEY TO SEE SCANNED IMAGE": GET A$
110 IF A$ = "C" THEN PRINT : INPUT "ENTER WINDOW WIDTH ";WI
120 IF A$ = "S" THEN 2000
130 POKE 255,YT: POKE 206,YB: POKE 236,XB
140 POKE 237,HE: POKE 239,WI
150 HGR : POKE - 16302,0: CALL 768: HOME : TEXT : GOTO 80
500 REM MACHINE LANGUAGE SUBROUTINE
510 DATA 169,0,133,8,133,6,169,98,133,9
520 DATA 169,90,133,207,169,127,205,99,192,48
530 DATA 251,205,99,192,16,251,165,239,133,238
540 DATA 166,206,138,224,128,16,7,160,96,132
550 DATA 7,76,48,3,160,97,132,7,10,168
560 DATA 177,6,133,253,200,177,6,133,254,165
570 DATA 207,10,168,177,8,133,251,200,177,8
580 DATA 133,252,24,165,236,101,253,133,253,24
590 DATA 165,236,101,251,133,251,160,0,177,253
600 DATA 145,251,200,196,237,208,247,232,230,207
610 DATA 198,238,208,184,198,206,165,206,197,255
620 DATA 240,3,76,10,3,96
1000 REM APPLE IIE SETUP
1010 REM POKE LOW ORDER BYTE OF $C019
1020 POKE 785,25: POKE 790,25: RETURN
2000 REM DISPLAY FULL IMAGE
2010 HOME : PRINT "PRESS ANY KEY TO RETURN TO MENU"
2020 FOR T = 1 TO 1500: NEXT
2030 POKE - 16297,0: POKE - 16304,0: POKE - 16299,0
2040 GET B$: HOME : TEXT : GOTO 80

```

Table 3
LOOKUP Program

```

10 HOME
20 PRINT "CALCULATING LOOKUP TABLES"
30 ST = 8192: REM STARTING ADDRESS PG1
40 T2 = 24576: REM START OF TABLE FOR PG2
50 T1 = 25088: REM START OF TABLE FOR PG1
60 FOR I = 0 TO 2
70 SI = ST + 40 * I
80 FOR J = 0 TO 7
90 SJ = SI + 128 * J
100 FOR K = 0 TO 7
110 A1 = SJ + 1024 * K: REM ADDRESS PG1
120 A2 = A1 + 9192: REM ADDRESS PG2
130 H1 = INT (A1 / 256):L1 = A1 - H1 * 256
140 H2 = INT (A2 / 256):L2 = A2 - H2 * 256
150 POKE T1,L1:T1 = T1 + 1: POKE T1,H1:T1 = T1 + 1
160 POKE T2,L2:T2 = T2 + 1: POKE T2,H2:T2 = T2 + 1
170 NEXT K: NEXT J: NEXT I

```

B11 and Pin 4 of socket J14 (the game I/O connector). The machine language subroutines are written for the Apple II+; if an Apple IIe is used, the setup subroutine beginning at line 1000 in each program POKes the appropriate memory location into the machine language routines (as well as modifying the code in the aperture routine).

EXPLICATION OF MACHINE CODE ROUTINES

The source listings for the two machine code routines are given in Tables 4 and 5. Both routines make extensive use of available zero page locations. The APERTURE routine has two main sections. During each cycle, one section (lines 66-139) transfers a small portion of the

stored image in Page 2 into Page 1 for display. The other section (lines 32-65) erases the previously displayed portion. Ancillary sections initialize the routine, determine the paddle values, and wait for the video scan blanking pulse (lines 25-29). The two paddle values are read in separate sections of the routine to minimize their interaction. An explication of the main transfer section follows.

Beginning in line 67, the routine reads the value of PDL(1), which represents the horizontal or X value of the left edge of the aperture. This X value is divided by 8 to determine at which of the 32 bytes in the X dimension the aperture is located. This value is called XBYTE and is later added to the address of the leftmost byte in that row. The same PDL(1) value is then ANDed with \$07 to find the three least significant bits. These bits indicate where the position being indicated by PDL(1) is within XBYTE. The resulting value is called PREMASK. It is used to create RMASK and LMASK, the respective masks for the rightmost and leftmost bytes defining the aperture. LMASK and RMASK are fixed for a given scan of the aperture, because the sides of the aperture are vertical. They are therefore determined before the scanning of the image begins. The same is true of the determination of the uppermost position of the aperture, which is controlled by PDL(0), which represents the Y dimension. This value is placed in the X register.

For each image frame, transfer and display of the image occurs row by row and, within each row, column by column. For each row scan, the value of the X register is transferred to the Y register and then doubled as an offset in the indirect, indexed mode to determine the address of the leftmost position of that row from the lookup table. The address returned is the Page 2 address; the corresponding Page 1 address is obtained by subtracting \$20 from the high-order byte. The next step is to find the starting address within the row that corresponds to the leftmost position of the aperture; this is accomplished by adding XBYTE to the starting address of that row and storing this result. At this point scanning of the image column-by-column within the top row begins. The first byte of the stored pattern (in Page 2) is ANDed with LMASK to determine which bits will be turned on, and the masked byte is moved to Page 1. Next the middle bytes of the scanned image are simply moved from Page 2 to Page 1, and then the rightmost byte is masked by RMASK and moved to Page 1. With this row completed, the Y value on the screen (contained in the X register) is incremented and scanning of the next row begins.

The structure of the ANORTHOSCOPIC routine is much simpler. Because the displayed image has a constant screen position from one frame to the next, no erase section is required. In addition, only whole bytes are moved from Page 2 to Page 1, so that no masks are utilized. Furthermore, the starting Y value of each frame is obtained by decrementing Y2BOT rather than by reading a paddle. The only way in which the routine is more complex than the APERTURE routine is that the Y value of the image being scanned (Y2BOT) is not the same as

Table 4
Source Listing of APERTURE Routine

```

0300:      1      ORG  $300
FB1E:      2 PADDLE EQU  $FB1E
C000:      3 STROBE EQU  $C000
00FB:      4 PG1LO  EQU  $FB
00FC:      5 PG1HI  EQU  $FC
00FD:      6 PG2LO  EQU  $FD
00FE:      7 PG2HI  EQU  $FE
00CE:      8 LOOKL  EQU  $CE
00CF:      9 LOOKH  EQU  $CF
00F9:     10 HEIGHT EQU  $F9
00FA:     11 WIDTH  EQU  $FA
0006:     12 XBYTE  EQU  $06
0007:     13 YVAL  EQU  $07
00EB:     14 PDL1   EQU  $EB
00EC:     15 LMASK  EQU  $EC
00ED:     16 RMASK  EQU  $ED
00EE:     17 ROW   EQU  $EE
00EF:     18 PREMASK EQU  $EF
0300:A9 00 19 LDA  $300
0302:85 CE 20 STA  LOOKL
0304:85 06 21 STA  XBYTE
0306:85 07 22 STA  YVAL
0308:A2 01 23 START LDX  $301
030A:20 1E FB 24 JSR  PADDLE
030D:84 EB 25 STY  PDL1      ;HORIZ PADDLE
030F:A9 7F 26 LDA  $7F
0311:CD 63 C0 27 LOOP1 CMP  $C063
0314:30 FB 28 BMI  LOOP1
0316:CD 63 C0 29 LOOP2 CMP  $C063
0319:10 FB 30 BPL  LOOP2
031B:      31 *ERASE OLD IMAGE
031B:A5 F9 32 LDA  HEIGHT
031D:85 EE 33 STA  ROW
031F:A6 07 34 LDX  YVAL
0321:8A      35 ERWLOOP TXA
0322:E0 80 36 CPX  $80      ;YVAL>127?
0324:10 07 37 BPL  EOVER
0326:A0 60 38 LDY  $60
0328:84 CF 39 STY  LOOKH
032A:4C 31 03 40 JMP  EMULT
032D:A0 61 41 EOVER LDY  $61
032F:84 CF 42 STY  LOOKH
0331:0A      43 EMULT ASL  A      ;MULT X 2
0332:A8      44 TAY
0333:B1 CE 45 LDA  (LOOKL),Y ;LOWBYTE
0335:85 FB 46 STA  PG1LO
0337:C8      47 INY
0338:B1 CE 48 LDA  (LOOKL),Y ;HIGHBYTE
033A:38      49 SEC
033B:E9 20 50 SBC  $20
033D:85 FC 51 STA  PG1HI
033F:18      52 CLC
0340:A5 06 53 LDA  XBYTE
0342:65 FB 54 ADC  PG1LO      ;STARTBYTE
0344:85 FB 55 STA  PG1LO
0346:A0 00 56 LDY  $00
0348:98      57 TYA
0349:91 FB 58 STA  (PG1LO),Y ;ERASE
034B:C8      59 ECLLOOP INY
034C:91 FB 60 STA  (PG1LO),Y ;ERASE
034E:C4 FA 61 CPY  WIDTH
0350:D0 F9 62 BNE  ECLLOOP
0352:E8      63 INX      ;INCREMENT YVAL
0353:C6 EE 64 DEC  ROW
0355:D0 CA 65 BNE  ERWLOOP
0357:      66 *SCAN PICTURE
0357:A4 EB 67 LDY  PDL1      ;HORIZ PADDLE
0359:98      68 TYA
035A:4A      69 LSR  A      ;DIVIDE BY 8
035B:4A      70 LSR  A
035C:4A      71 LSR  A
035D:85 06 72 STA  XBYTE
035F:98      73 TYA
0360:29 07 74 AND  $07      ;3 LS BITS
0362:85 EF 75 STA  PREMASK
0364:A9 00 76 LDA  $00
0366:A6 EF 77 LDX  PREMASK
0368:F0 06 78 SHIFT BEQ  MASKS
036A:38      79 SEC
036B:2A      80 ROL  A
036C:CA      81 DEX
036D:4C 68 03 82 JMP  SHIFT
0370:85 ED 83 MASKS STA  RMASK      ;RIGHT MASK

```

```

0372:49 FF 84 EOR  $FF      ;FIND INVERSE
0374:85 EC 85 STA  LMASK      ;LEFT MASK
0376:A5 F9 86 LDA  HEIGHT
0378:85 EE 87 STA  ROW
037A:A2 00 88 LDX  $00
037C:20 1E FB 89 JSR  PADDLE
037F:84 07 90 STY  YVAL      ;VERT PADDLE
0381:98      91 TYA
0382:AA      92 TAX      ;YVAL IN X REG
0383:8A      93 ROWLOOP TXA
0384:E0 80 94 CPX  $80      ;YVAL>127?
0386:10 07 95 BPL  OVER
0388:A0 60 96 LDY  $60
038A:84 CF 97 STY  LOOKH
038C:4C 93 03 98 JMP  MULTPL
038F:A0 61 99 OVER LDY  $61
0391:84 CF 100 STY  LOOKH
0393:0A      101 MULTIPL ASL  A      ;MULT X 2
0394:A8      102 TAY
0395:B1 CE 103 LDA  (LOOKL),Y ;LOWBYTE
0397:85 FD 104 STA  PG2LO
0399:C8      105 INY
039A:B1 CE 106 LDA  (LOOKL),Y ;HIGHBYTE
039C:85 FE 107 STA  PG2HI
039E:38      108 SEC
039F:E9 20 109 SBC  $20
03A1:85 FC 110 STA  PG1HI
03A3:18      111 CLC
03A4:A5 06 112 LDA  XBYTE
03A6:65 FD 113 ADC  PG2LO      ;STARTBYTE
03A8:85 FD 114 STA  PG2LO
03AA:85 FB 115 STA  PG1LO
03AC:A0 00 116 LDY  $00
03AE:A5 EC 117 LDA  LMASK
03B0:31 FD 118 AND  (PG2LO),Y ;MASK BYTE
03B2:91 FB 119 STA  (PG1LO),Y ;DISPLAY LEFT BYTE
03B4:C8      120 COLLOOP INY
03B5:B1 FD 121 LDA  (PG2LO),Y
03B7:91 FB 122 STA  (PG1LO),Y ;DISPLAY MIDDLE
03B9:C4 FA 123 CPY  WIDTH
03BB:D0 F7 124 BNE  COLLOOP
03BD:A5 ED 125 LDA  RMASK
03BF:31 FD 126 AND  (PG2LO),Y ;MASK BYTE
03C1:91 FB 127 STA  (PG1LO),Y ;DISPLAY RIGHT BYTE
03C3:E8      128 INX      ;INCREMENT YVAL
03C4:C6 EE 129 DEC  ROW
03C6:D0 BB 130 BNE  ROWLOOP
03C8:AD 00 C0 131 LDA  STROBE
03CB:30 0D 132 BMI  RETURN
03CD:A2 03 133 LDX  $03
03CF:A0 FF 134 DELAY1 LDY  $FF
03D1:88      135 DELAY2 DEY
03D2:D0 FD 136 BNE  DELAY2
03D4:CA      137 DEX
03D5:D0 F8 138 BNE  DELAY1
03D7:4C 08 03 139 JMP  START
03DA:60      140 RETURN RTS      ;TO BASIC

```

the top of the display window (Y1) on Page 1, so that the lookup table must be consulted separately for each page for every row that is scanned.

USER INSTRUCTIONS

The procedure for using either program is simple. (Apple IIe users can proceed directly; Apple II+ users need to first install the jumper cable.) The sequence of steps is to run LOOKUP, load the HIRES image into Page 2, and then run whichever program is desired. The command for loading an image labeled PIC.1 into Page 2 is BLOAD PIC.1,A\$4000. After the lookup table is created for the first time by running LOOKUP, the table can be saved to disk using BSAVE TABLE,A\$6000,L\$400. On subsequent occasions the setup time can be shortened by typing BLOAD TABLE rather than by running LOOKUP.

Table 5
Source Listing of ANORTHOSCOPIC Routine

0300:	1	ORG	\$300	
00FB:	2	PG1LO	EQU	\$FB
00FC:	3	PG1HI	EQU	\$FC
00FD:	4	PG2LO	EQU	\$FD
00FE:	5	PG2HI	EQU	\$FE
0006:	6	LOOKL2	EQU	\$06
0007:	7	LOOKH2	EQU	\$07
0008:	8	LOOKL1	EQU	\$08
0009:	9	LOOKH1	EQU	\$09
00FF:	10	Y2TOP	EQU	\$FF
00CE:	11	Y2BOT	EQU	\$CE
00CF:	12	Y1	EQU	\$CF
00EC:	13	XBYTE	EQU	\$EC
00ED:	14	WIDTH	EQU	\$ED
00EE:	15	ROW	EQU	\$EE
00EF:	16	HEIGHT	EQU	\$EF
0300:A9 00	17	LDA	#\$00	
0302:85 08	18	STA	LOOKL1	
0304:85 06	19	STA	LOOKL2	
0306:A9 62	20	LDA	#\$62	
0308:85 09	21	STA	LOOKH1	
030A:A9 5A	22	START	LDA	#\$5A
030C:85 CF	23	STA	Y1	
030E:A9 7F	24	LDA	#\$7F	
0310:CD 63 C0	25	LOOP1	CMP	\$C063
0313:30 FB	26	BMI	LOOP1	
0315:CD 63 C0	27	LOOP2	CMP	\$C063
0318:10 FB	28	BPL	LOOP2	
031A:A5 EF	29	LDA	HEIGHT	
031C:85 EE	30	STA	ROW	
031E:A6 CE	31	LDX	Y2BOT	;Y2 IN X REG
0320:8A	32	ROWLOOP	TXA	
0321:E0 80	33	CPX	#\$80	;Y2>127?
0323:10 07	34	BPL	OVER	
0325:A0 60	35	LDY	#\$60	
0327:84 07	36	STY	LOOKH2	
0329:4C 30 03	37	JMP	MULTIPL	
032C:A0 61	38	OVER	LDY	#\$61
032E:84 07	39	STY	LOOKH2	
0330:0A	40	MULTIPL	ASL	A ;MULT X 2
0331:A8	41	TAY		
0332:B1 06	42	LDA	(LOOKL2),Y ;LOWBYTE PG2	
0334:85 FD	43	STA	PG2LO	
0336:C8	44	INY		
0337:B1 06	45	LDA	(LOOKL2),Y ;HIGHBYTE PG2	
0339:85 FE	46	STA	PG2HI	
033B:A5 CF	47	LDA	Y1	
033D:0A	48	ASL	A ;MULT X 2	
033E:A8	49	TAY		
033F:B1 08	50	LDA	(LOOKL1),Y ;LOWBYTE PG1	
0341:85 FB	51	STA	PG1LO	
0343:C8	52	INY		
0344:B1 08	53	LDA	(LOOKL1),Y ;HIGHBYTE PG1	
0346:85 FC	54	STA	PG1HI	
0348:18	55	CLC		
0349:A5 EC	56	LDA	XBYTE	
034B:65 FD	57	ADC	PG2LO	;STARTBYTE PG2
034D:85 FD	58	STA	PG2LO	
034F:18	59	CLC		
0350:A5 EC	60	LDA	XBYTE	
0352:65 FB	61	ADC	PG1LO	;STARTBYTE PG1
0354:85 FB	62	STA	PG1LO	
0356:A0 00	63	LDY	#\$00	
0358:B1 FD	64	COLLOOP	LDA	(PG2LO),Y
035A:91 FB	65	STA	(PG1LO),Y ;TRANSFER IMAGE	
035C:C8	66	INY		
035D:C4 ED	67	CPY	WIDTH	
035F:D0 F7	68	BNE	COLLOOP	
0361:E8	69	INX		;INCREMENT Y2
0362:E6 CF	70	INC	Y1	;INCREMENT Y1
0364:C6 EE	71	DEC	ROW	
0366:D0 B8	72	BNE	ROWLOOP	
0368:C6 CE	73	DEC	Y2BOT	
036A:A5 CE	74	LDA	Y2BOT	
036C:C5 FF	75	CMP	Y2TOP	
036E:F0 03	76	BEQ	RETURN	
0370:4C 0A 03	77	JMP	START	
0373:60	78	RETURN	RTS	;TO BASIC

LIMITATIONS

The Apple HIRES screen is 280 pixels wide $\times$ 192 pixels high for black-and-white images. The APER-

TURE program permits the user to select the height and width of the aperture; height can be varied in steps of 1, but the width variable is limited to multiples of 7, because each row scan involves sequencing through an integral number of bytes. (Only 7 horizontal pixels on the display screen are represented by each byte of display memory; the high-order bit is not displayed.) Smooth high-speed scanning of an image is possible for apertures up to a size of about 28 pixels $\times$ 28 pixels. Replacing the one-shot paddle timing with true analog-to-digital conversion should permit smooth scanning with still larger apertures. Whatever the size limit, portions of the displayed image near the top of the screen are distorted for large apertures because of the time it takes to erase the old displayed image and redraw the new one following the vertical blanking signal. Another minor limitation of the routine is that the leftmost edge of the aperture has a maximum value of 255, corresponding to the value of Paddle 1; for small aperture widths, this means that the rightmost portion of the Apple screen (values close to 279) will not be displayed. Finally, multicolored images can be displayed using the program, but there will be some color distortion near the sides of the aperture.

The ANORTHOSCOPIC program was written for vertical scrolling within a horizontal window rather than for horizontal scrolling within a vertical window because the former permits faster scrolling. Because the graphic output is synchronized to the video frame rate, images are scrolled vertically at the rate of 59.92 rows/sec (50.32 rows/sec for the Eurapple). This scrolling rate remains constant for window widths in the vertical dimension ranging from 1 to 19 pixels when a window extending across the screen is used. Using narrower horizontal extents permits larger vertical extents for the same scrolling rate. Consequently, the program is quite useful for precisely controlled investigations of anorthoscopic perception. For those familiar with assembly language programming, the routine can be modified to allow multiple windows on the screen (e.g., for stereoscopic presentation), control of the image scanning using paddles, and movement of the display window concomitant with scan of the stored image. Multicolored images can be displayed without distortion.

APPLICATIONS

The potential uses of APERTURE are varied. One application is to use a graphics touch tablet to control the aperture, using the finger in a visual simulation of tactual exploration. Similarly, driving the aperture locations with suitable eye-monitoring equipment would provide a simple method of controlling field-of-view during visual exploration. Finally, aperture scanning, whether controlled by eye movements, joystick, graphics tablet, or Space Pen (Soniture, Inc.), could be useful in investigating the perceptual integration of sequentially sampled information (Hochberg, 1978) and for determining which spatial features are most critical in visual illusions, pattern perception, and depiction of three-dimensional objects. An advantage of using the computer over some of

the traditional methods for studying these questions is that the path of the scanning aperture can be made available for analysis with very little additional programming effort.

One application of ANORTHOSCOPIC is in the investigation of anorthoscopic perception. In pilot work, the program has proven highly satisfactory. One advantage of computer control over conventional methods is that the window width can easily be made "infinitesimally narrow" (in this case, 1 pixel) so that information about direction of image motion (upward or downward) and local line orientation, information that is normally available in windows of finite width (more than 1 pixel), can be eliminated. Another advantage is that the remainder of the graphics screen can be manipulated independently of the scanned image, using machine language or the graphics commands of Applesoft BASIC. Aside from the study of anorthoscopic perception, another potential application of this program is in investigation of the "aperture problem" in the context of motion perception (Adelson & Movshon, 1982; Hildreth, 1984; Marr, 1982; Nakayama, 1985). A virtue of using this type of program to "move" the stored image in Page 2, rather than programming the moving patterns using the graphics primitives of, say, Applesoft, is that the image velocity within the window is completely independent of pattern complexity.

Researchers who do not wish to create their own high-resolution images are referred to Prill (1984). Prill has created Apple HIRES images of 73 of the 260 drawings of familiar objects developed by Snodgrass and Vanderwart (1980), for which there are a number of normative ratings. These 73 pictures, together with a number of image manipulation programs, are available from Prill for

a nominal charge (K. A. Prill, Department of Psychology, University of Missouri, Columbia MO 65211).

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