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LOW-COST INTERACTIVE IMAGE PROCESSING

Emily G. Johnston, et al

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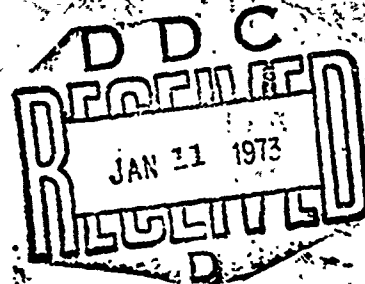
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ABSTRACT

This paper describes how to do useful, nontrivial image processing tasks interactively using only a standard alphanumeric CRT terminal, or even a teletype. Only an ordinary time-sharing system is required; there is no need for a dedicated computer or channel, or even for special priority on the system.

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Introduction

The advantages of interactive processing over batch processing are by now well established. When working in an interactive mode, the programmer obtains quick responses to his actions, and does not have to reconstruct his line of reasoning each time a response is obtained. This is especially important when the data being processed are graphical or pictorial; it is of great benefit to be able to see the results of each processing step displayed immediately. In addition, it is crucial to be able to point to objects in the display, or outline regions in the display, in such a way that the computer knows which objects or regions are intended; this ability is impossibly cumbersome to achieve in batch mode.

Low-cost interactive graphics terminals are now widely available, but one hears much less about interactive image processing systems. Of the available computer image displays, only the more expensive permit any sort of interaction, such as pointing, outlining, or selective modification.

This paper describes an approach to interactive image processing using only a standard alphanumeric CRT terminal--or if necessary, even a teletype. This approach can be implemented on any ordinary time-sharing system; it does not require a dedicated computer, a dedicated channel, or even special priority on the system.

Input

Digitized images, even of moderate size, contain enormous numbers of bits; for example, a commercial TV picture contains about 500 by 500 resolvable points, and if we represent the gray level of each point by a 6-bit number, we have $1\frac{1}{2}$ million bits in the picture. For this reason, it has often been suggested that, when doing image processing on a computer, one should not digitize the entire image and input it to the computer; rather, one should allow the computer to control a scanning device which can read and digitize selected portions of the image on demand. If this suggestion is accepted, it implies a major hardware expense before the image processing itself can even begin.

Fortunately, there are alternatives to the computer-controlled scanner approach, provided that one is willing to trade I/O time for hardware cost. A digitized TV picture occupies only a few yards of magnetic tape; one can store many such pictures on a single tape. If desired, the picture can be transferred to disk or drum storage before beginning its actual processing. I/O limitations may make it somewhat slower to access pictures from disk than to access them by controlling a scanner, but this is a modest price to pay in place of having to buy or build the scanner.

There are also counterarguments to the scanner concept itself. Information obtained by the scanner may not be perfectly repeatable,

since analog signals are involved; in some circumstances, this may be highly objectionable. In many cases, too, the processing to be done on the input image requires many times more storage than does that image itself, so that the storage saving resulting from being able to use the image as a memory is negligible.*

Digitized images on magnetic tape are widely available from many sources, and digitizing services are also available, at a cost of only a few dollars per image. Thus anyone wishing to undertake experimental image processing can provide himself with a data base very cheaply. Experience suggests, moreover, that most experimenters will need only a few digital images for program development and feasibility testing. In the early stages of image processing research, one usually wants to try out many techniques on the same image, not one technique on many images.

One can even do non-trivial image processing research on computer-created images (e.g., defined by stochastic processes).

In fact, it is wise to develop and test one's image processing software using simple test-pattern images, so that there is no doubt what the results of the operations are supposed to look like.

*The processing is inexpensive in terms of storage only when it involves relatively rare events that can be detected in the image as it is scanned, so that most of the image need not be stored.

Output

When processing images interactively, one usually need not look at the entire image after each step. Display of small pieces should generally be adequate for checking that the correct image has been read in, or that a step has been executed correctly. An example is shown in Figure 1; it is a 72-by-44-point image, where each point has one of 32 shades of gray.

An output such as that in Figure 1 requires grayscale display hardware that is not normally available to an ordinary time-sharing system user. Moreover, the time required to output Figure 1, say on a 300-baud line, would be about two minutes (assuming one character per image point). Given a display without grayscale capability, if the user attempted to achieve grayscale by exciting display points repeatedly, the time would become even greater. Moreover, the resulting display is small (Figure 1 already involves considerable defocus), making it hard to interact with the displayed image accurately.

Most of these difficulties can be avoided by using arrays of alphanumeric characters for image output. One now needs only an ordinary alphanumeric terminal (even a teletype will do), though of course a graphics terminal too can be used in this way. Gray shades are represented using characters that have various ratios of character area to background area, ranging from blank to (say) W. One can construct an adequate 8-step

y scale in this way with single characters; and if overstrike is permitted, a 32-step scale can be obtained. Figure 2 shows the image of Figure 1 output in this way, and the character sets used. The overstriking is achieved by eliminating the line feed sent by the computer. Unfortunately, one cannot do "overstriking" on a CRT terminal, but it can be done on the CRT's auxiliary hard-copy printer. There is a vertical/horizontal scale distortion of about 3:2, but this is not objectionable for most purposes. (One can, of course, also use non-gray scale alphanumeric output (e.g., gray levels 0,...,31 = blank, 1,...,9, A,...,V) if one wishes to read gray levels of individual points rather than see the points as an image; see Figure 2e.)

The overstruck gray scale is much better than the single-character scale, but it has the disadvantage of being far more time consuming. Outputting a 72-by-40 single-character image on a CRT terminal operating at 1200 baud takes less than 30 seconds; but outputting an overstruck image of the same size on a teletype at 110 baud takes nearly ten minutes, which is impractically tedious.

If the single-character scheme is used, it is important to pick the gray level ranges that correspond to the characters carefully. A good rule of thumb is to pick the ranges to contain numbers of picture points that are as equal as possible. The 8-level grayscale of Figure 2a-b was designed in

this way. Figure 3a shows the gray-level histogram for the image in Figure 1, as well as the ranges used to produce the 8-level version in Figure 2. Gray level range and threshold selection can, of course, be done interactively. The effects of a poor choice of ranges is shown in Figure 3b.*

Display of small pieces of an image is usually adequate for checking results, and even for interacting by pointing or outlining, since the objects or regions to be outlined will usually be small relative to the entire image. At times, as in the examples in this paper, output of small pieces is all that is needed. If output of entire images is required, overstrike on the line printer can be used (remembering to override the page-skip!); a 500-by-500 point image can be output in four vertical strips, each a page wide and about six pages long. This requires much tearing and pasting, but has the merit of requiring no special equipment. If a microfilm output device with half-tone capability is available, it provides a far more compact output format. Alternatively, one can output images on tape, and take advantage of commercially available tape-to-image equipment.

*Figures 2a and 3b are best compared by viewing from a distance.

Interaction

The ability to execute an image processing operation and display the results already constitutes a high degree of interactive capability, since the user can determine what to do next in near-real time. The chief facility still lacking is the ability to point to objects in the image. It should be realized that in image processing, pointing can usually designate only a single image point, since the image has no underlying structural description that is known to the computer, as it has in computer graphics. In order to designate objects or regions in an image, one must outline these rather than simply point to them.

Region outlining can be done straightforwardly on either an alphanumeric CRT display or teletype printout of an image. In the CRT case,* the piece of picture in question is displayed by the computer in non-protected mode. The user switches the terminal to "batch mode" and uses the terminal cursor controls to position the cursor on the top row of the region to be outlined. At each point where the region boundary intersects the row, the user types a character (different from the one already typed). He then moves the cursor to the end of the row and transmits the "revised" line. The computer can now compare this to the original line and store the locations of the differences. When all rows containing region

*The exact procedure would vary somewhat, depending on the particular terminal used.

boundary points have been processed in this way, the computer can construct the complete region outline (and display it, if desired).

The procedure on a teletype is similar, but more tedious: the user informs the computer that he is about to input an image the same size as the displayed one. He then rolls the teletype paper back to the first line of the displayed image, and enters carriage returns until the top row of the region is reached. For rows that hit the region, the user spaces over to the region boundary points and overstrikes these points with an arbitrary character. Rolling the paper back simply establishes visual registration of the border and picture for the user; the computer is unaware of it, but can still register the two because they are the same size.

Both the CRT and teletype versions of the outlining procedure can be designed to permit correction of errors by re-inputting only the corrected border points, without having to re-outline the entire region. In any case, they are slow enough that errors are unlikely. The alphanumeric display functions as a half-tone which is coarse enough to permit precise outlining, yet provides sufficient grayscale to permit viewing the output as an image rather than as an array of discrete dots. The outlining procedure, it will be noted, requires no special interrupt priority; outlines are transmitted row by row exactly as in the ordinary use of the terminal.

A example of the use of outlining is given in Figure 4, which shows an outline in register with the picture of Figures 2-3. The display of the outlined region is done by a program which determines all points of the image that lie on or inside the outline. Once the outlined region has been extracted from its background, one can compute properties of the region, relating to its shape, texture, etc.

Software

The nature of the software used in an interactive image processing system will depend greatly on the machine being used, the programming talent available, and the types of processing operations to be performed.

Several major packages of image processing programs are available. Two notable examples are Vicar, developed by California Institute of Technology's Jet Propulsion Laboratory, and PAX, developed by the Universities of Illinois and Maryland. These packages are usually embedded in a high-level language such as Fortran. The examples given in this paper were programmed in PAX.

Historical Notes

Most of the major image processing research groups have developed interactive systems, but very few of these have been documented in the published literature. A highly nonrepresentative set of examples is [1-3]. On the use of overstruck characters to represent grayscale see [4].

PAX is a collection of over 100 basic image processing routines that can be called from Fortran programs [5]. Originally a simulator for the ILLIAC III computer, versions of PAX for several different machines are available, notably the IBM 7094 and 360/370 (50 and above); Univac 1108; CDC 3600 and 6600; and DEC-10.

References

1. I. H. Barkdoll and B. L. McGlamery, An on-line image processing system. Proc. ACM Natl. Conf., August 1968, 705-716.
2. L. Hodes, A programming system for the on-line analysis of biomedical images. Comm. ACM 13, May 1970, 279-283.
3. E. Arthurs, W. S. Bartlett, D. J. Ladd, R. L. Salmon, and J. H. Whipple, PICTURELAB--an interactive facility for experimentation in picture processing. Proc Spring Joint Computer Conf., May 1970, 267-273.
4. B. Perry and M. L. Mendelsohn, Picture generation with a standard line printer, Comm. ACM 7, May 1964, 311-313.
5. E. G. Johnston, The PAX user's manual, Computer Science Center, University of Maryland, June 1972.



Figure 1. 72-by-44-point, 32-gray-level image.

<u>Gray level(s)</u>	<u>Character</u>
0-3	blank
4	.
5	-
6	+
7-8	I
9-11	A
12-16	*
17-31	W

Figure 2b. Characters used to represent gray levels in (a).

L L L / / V / , W +LI+W A +///A A W A W A A+V V A A W A L V V V L /IAHAY
 / / , / , V , V //IIL+W A L A L W A V L W + L V A W A+A L L L L V A /YLI
 , / / , L V W+WIIII/V V L V V V V L A// V V V A / A L V V V L L L // /
 , / / , V L A +/ILI V , , / / , L L V +++ W A V A //A V V V L V , W //
 , / L L V A A WIII+ L / , , L V A V V +/A A W L A W W V L , L L / V A/
 / V / L V L W W++IL++ V L , / L V L L V A+/+ A L W W V L , , V V / L W
 / , V V V , A A+/LIL+ V V L V V L A V A WLLL/A L A W L V / , V L L L A
 / / L L L L V WIIILL//W V A V V A W A //+/I++L//W / A V V / V W V A W V
 L V V A A L L /LVVLI+/A W + A W //+/LYLLLL+L//++ /+W L V / V V W A A A
 A L //++A W V /LVVLLIIILIL+/+W //IYVAAAAYYIILL+/I+W V V , , L A //+ /
 W L LL//++W W A/LIYAAPHHVYLL//LLHHRMMRMMAHVVLVLL+ A V L V L W//++//
 / V //+/+// W W //IHRMHRAVIL++LYHRZNOQKMRHHAVVLVVI/ A L V L L W/ILL//
 / L A W++/A A A /IYHRMHRYLII+IVHAZQNGQRAAAAYYIYL/ L V V V V W LI++A
 + A A /++ A L A +IHRMAHRMHVLLYAHZNNNNMMMHVAHAYVI+ L L A V V A W W W
 IL+ A //A V L A IYHMAAAAAIVAHAMZZQGMZQRMHMRMAHHHYI+ V L V A A W W , V
 VLI//+ W V L W//YAHVVAHAAAMZNNNNQZMMMHMMHMRHVLA V A W A W L L L
 YVL+A W A+/// /LVAMRMZMRRVYARQQQZNNQRAHVYVYHARZZQGMVL++W/I+W W A// , /
 VL+ A V A +/I/+LHAARMQORAVYAMQQZNNQRVLLLYVHAMQZQRZMYII++L W L W W , ,
 YL/ V , A A IILYHAMRZMRYVVAZNNZNNRMVI/+IVYHMMZQQZNNMHVI/// L / L L / ,
 /+A / / L A A+LLLVYHHMMVHHMMQQZNNMHL///ILLYHAQNZNNZRAVI++ L , L / , /
 //W , , / L A L//+/LYHAHAIRZNNZNOGRYL++LLLIIVHZQQZQQZQOMYI/W V , , / / ,
 / V L , , / V W//A+ILYHQZNNNNZMRVLLLLIILIAMZNNZNNZMV+/W L L , , / ,
 /+V V , / / V W A A+LIYHMMZNNZNNMRRRAVYVYIILLIYAZNNZNRGRV/ V W L / / / V
 , , L L , L L +/W W/+LYAMZNNZNNHOMRRRRMHAVLLLIYAZNNZNRGRY+ V W , L / / W
 / L V V V L V A W W+LLLAQZNNZNNQZRRRRHRAAVYLIAAQQMRAMMIW V V V L / L L
 A L , , V L L V W W+LLVHQQQQMMZNNQRMRAHHAHHAHVLLHAZZMMARML/ V L A , , ,
 L L L / V L , V V W+/ILIAMQRMQQZRMMYAAAAARRYYAQZRMZMRMY/ A W V , / , ,
 A V / V A V / , V L W/+LAZZNNZMMQZMQRAYAARKMMRAHMZQMRQGRY/ A L / , / / ,
 W V , L W L , / V L A W IHOZNNZRRMMMAHHHAMMHKHQQGRARORLW A L / / , , ,
 V , L V L L , / L L V V /VHOZNNZRRMMVHMKAMMRHMQQMMMMQMV/W L V / , , / W
 / L L W L , , , L L L AIHQJUNZNNZRRMMMMRMRQQRRAARYL V V L / / , V //
 , / L L V , , / , V V A +LAMJUNNNNNHQQRRRZQQZQRHVAVH+ V V , / , , W//+/
 / V A W V / / , , L W //++IAZZNNNNJUNZNNZNNZMMRYVLLIL/ L V , L V L W//
 , V W W V / / / , L /IL++ +LARONNNNNJUNZNNZMMHYHVLYYL/W V L , W / A++//
 / L A V L / / V / V II++W W+IYHQZNNNNQMMQMRVYVLLIYL+A V , , V +/+A//+
 , L A L W / , L V W // L A +IVHMEZNNNNZNNMRAYIYIYYYY/ A A V V W //+////I
 , L V V A V / V V L W+A V W +/+LVVHHRZZZMRHVYVVLVII+W V L A V A +++A +I
 L V L L W / V L V A A L L W W W A LIYAAARMRYVLL++/W L L V V W A W + /I
 V L V L V / L L W A L V W A L L L V /ILLVAHVLL++ A L / , V V A W +///I
 V L L L V , V V A L V A W //W L , L L A A/II+ L V V L , , V A A A/L//++L
 L L W A L , V V W L L A W+++W V , / V V L A V , L L V / , L A +L//+++++
 V W W W V , V L W A L V //++W V , / V , , L , , L V / / / L V LIL//+ A+
 L W++/ A L V L W W L L /ILI+ L , L / , / , , / , L , , / / W/LYI//++//+
 L I//+/W W V L A L V V +LLI+ L L , , / , / / , , / / / W LIYVY+//+//

Figure 2c. Same image, with gray levels represented by pairs of overstruck characters as shown in (a).

<u>Gray level</u>	<u>First character</u>	<u>Second character</u>
0	- in odd columns	
1	. in odd columns	
2	, in odd columns	
3	/ in odd columns	
4	L in odd columns	
5	V in odd columns	
6	A in odd columns	
7	W in odd columns	
8	+	
9	/	
10	I	
11	L	
12	Y	
13	V	
14	A	
15	H	
16	R	
17	M	
18	Q	
19	Z	-
20	N	-
21	N	=
22	Z	=
23	J	1
24	W	/
25	D	/
26	D	1
27	N	1
28	M	1
29	N	Z
30	M	Q
31	W	\$

Figure 2d. Pairs of characters used to represent gray levels in (c).

4544423232533226778BA8776789996767776676676855556766766444545555469AEFEC
 323223322552245699AAB87764476444766655477787455567766865444545455569ACBA
 23333323234555787AAAA95455445254545555476996535566796644454545545478999
 232222332354476689ABA5552522323223444456888676675466996454544552247699
 24223345455467677AAA8545322322455566555789666775466677745544244545335669
 35543445554577788AB88654422432455444455668989767467777554522245553354477
 32225554542566698AB886555545545544645466788996746667445533255645424767
 333444454544567AABBB9975566755546677679989A88B99769765555435547757767657
 445557676745469BDDDBA8996776866777998BCBB88B998869875455432555477676667
 644578886774569BDDDBAABAB89987799ACDEEEEDCCABBB89A877555523254466798697
 774688988777769BAACEEFFFDCBB998BBFFGGHHGHEFDDDBBB886665543544479888996
 97579998987767799AFGHFFGEDAAB88BCFGJKIIGHGFFEDDBDDA97664454444679AB8995
 95446678896666679ACFGHFGFCBAAADFEJIKLIGEEEEEDCACDB974455545455768AB865
 87666798866546678AFFGHEFGHFDDBBCEJGJKLKLHHHDEFECDA86454567555567777774
 AB87669965554467ACFEHEEEEFDEFFHEHJIIHJIGHGHEFFCA87544555467677742554
 DBA99897765546799CEFFDDEFFEEHJLIKKKIJHHHGHGHEFFDB867566677677644444
 CDB865776899969BDEHGHJHGGDCCEGIIJLKIGEFDCDCFEJJYIHD8879A8767769642232
 DB8664556789A98BFEEGHIIGEDCEHIIJLLIGDBBCCDFFEHJIGJHCCAA886744676742222
 CB9653226666AAACFEHGHJHGCCDEJLKJLKHDA98ADCFHJIIJKIHFDA999744354543222
 9867333245666888BDCFFHHDDFFHIIJLKKHFB999ABRCFEILJLJJGEDA86452244332233
 9974222235476689889BCFEFEFGJLLJKIIGCB88BBBAADFJIIJIIHCA977552223323324
 97524423223557799968ABACFIJKIKKKJHGDDBBBBAABAHEHJLJKIJD8977454223223224
 9855522233345776668BACFHJKKJJKLKHGGEDCCABBACEJLJLJGIGD9557744233323456
 877544422245468976798BCEHJJKJLKHGGGHEFFDBBBACEJLJGIGC8456762443323577
 96445455524454667778BBBEIJKJIKLJG66GFEEEDCBAEEIIGEHHA74545442344545
 6644222354444257757888FIIIHJLKHGGHEFFEDDBBFEJHHEGHB945546652222325
 474444345545225555789ABAHEHILGHIJGHHCCEEEHGGCEIJGHJHGHG966474532333222
 67553354655233245447798BEJLJHJHJHIGEECEGHHGFEHJH6GIIGC976745322333324
 77542346744222355446676AFILKJGJGHHGHEFFEHFHFIIIGEGIGGB75664433323224
 542445554442223544455569DFILKJLJG66GFEEEDCBAEEIIGEHHA74545442344545
 354545774422222254445476AFINNKLJJIIGGHHHGGHGIILIGEEGC4755554232235799
 2334454454222332225554668BEHNNKLLKLKKIIGGGJIIJIGFDEFD87555423322257989
 3255657552323522234776998AAEJJILKKNNMKKJIKMLJHGGCCDBAB964452234457467896
 245474745233323323469AB88688BEGIKKLKLNKJIIHGHFCFDBCLB977554224779788989
 35476555453232533256AA887678ACFIKJIKLKLIIHGDCCDBBACB8665423245789886998
 23466444753523455477999443678ADFJJKLJLKHGECACAAACCC976665555779989999A
 2244545464533454544778645477898BDDFFGJJJHGFDCDDDBAA8775547645567888878A
 4554454574325544546767444577767767BACEE66HGCCDBB889744444545477677679A
 544555445435474477674556766645444569ABDEFFDBBB887644333255556667689999A
 544444445422555464445666779974422345456669AA874654554222255666769899888
 44477765452354577547476678887452223355546675425444552332244668889888888
 547676775555477665445699987652223355232442325455432333345568AB9998766
 4678898764445246777644479ABA8745234432233522223325452222333679BCA8998898
 46A9998976745546674554568BBA8645432323322333322232234323477BACDC8899999

Figure 2e. Same image, with gray levels 0,...,31 represented by blank, 1,...,9, A,...,V.

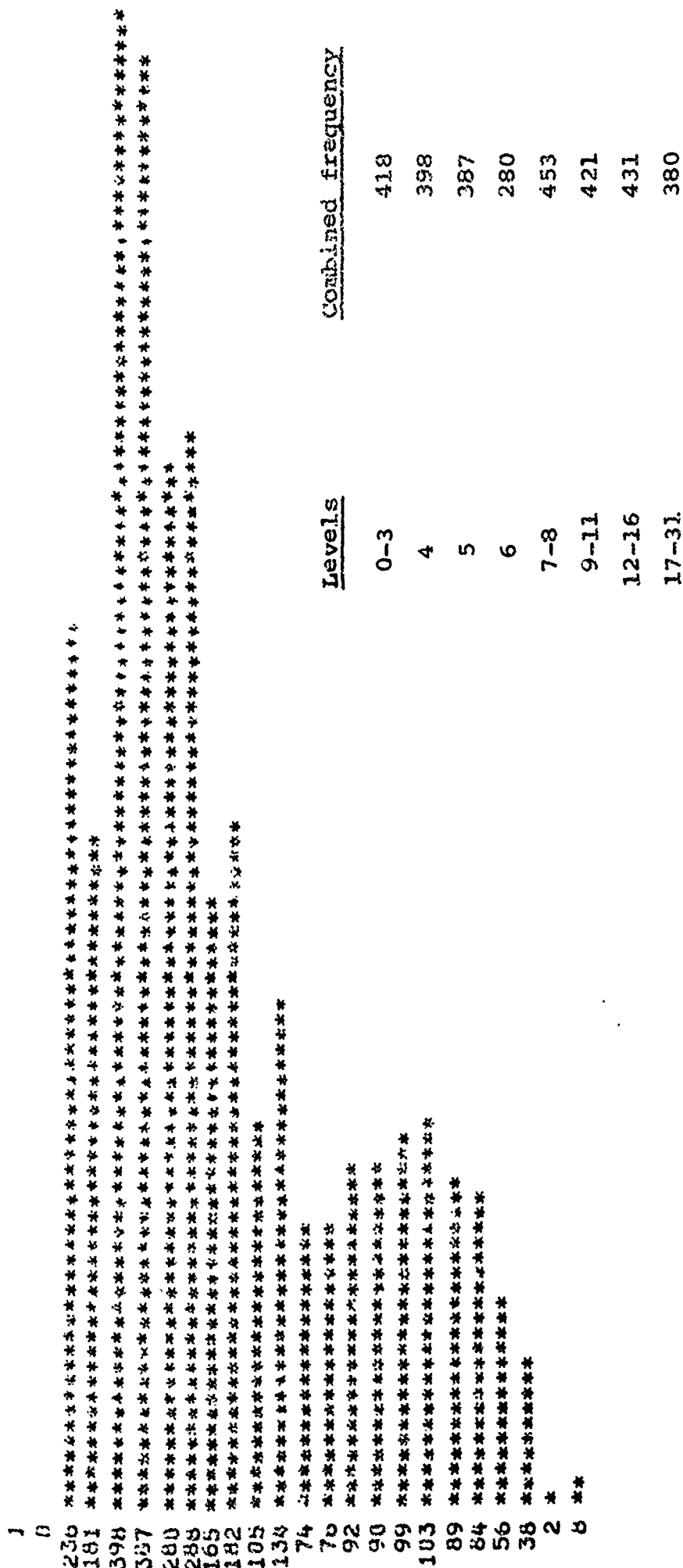


Figure 3a. Gray level histogram for Figure 1; only levels 0,...,23 occur. Table shows ranges used in Figure 2a.



Figure 3b. Effect of a poor choice of gray level
 ranges: 0-3 = blank, 4-7 = ., 8-11 = -,
 12-15 = +, 16-19 = I, 20-23 = A,
 24-27 = *, 28-31 = W. Note that * and W
 are never used.

454443232533226778BA8 77678999676777667567685555676676644545555469AEFFC
323223322552245699AAB8 776447644476665547778745556776686544454555569ACRA
23333323234555787AAAA954554452545455554769965355566796644454545545478999
232222332354476689ABA555252232322344445688867667546699645454544552247699
24223345455467677AA8 545322322455566555789666775466677745544244545335669
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46A9998976745546674554568BBA8645432323322333332223234323477BACDC8899999

Figure 4a. Outline overstruck on a printout of Figure 2e.

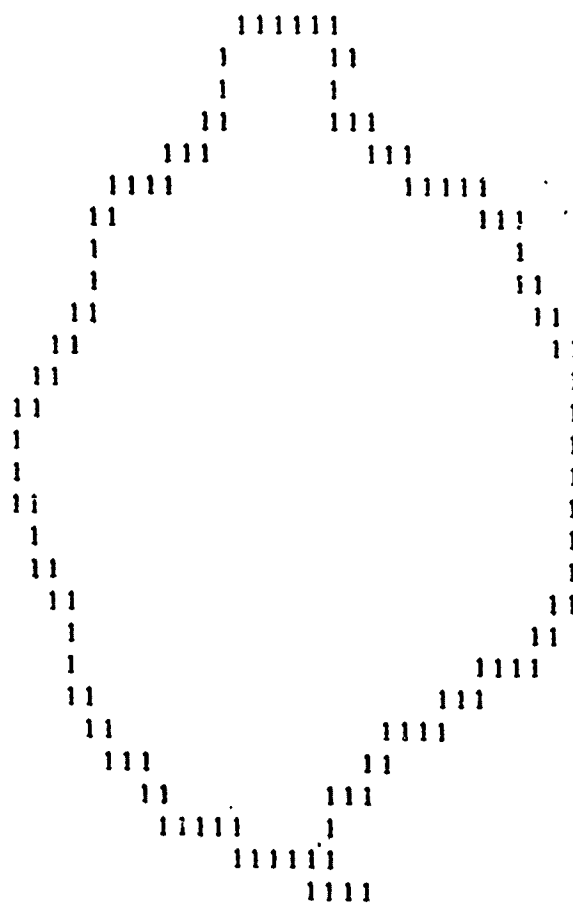


Figure 4b. Printout of the outline alone,
as a check.


```

3 ***
4 ***
12 ****
23 ****
15 ****
15 ****
34 ****
29 ****
90 ****
87 ****
82 ****
56 ****
38 ****
2 **
8 ****

```

The histogram displays a single prominent peak at gray level 8, with a frequency of 8. The x-axis is labeled with gray levels from 0 to 255, and the y-axis is labeled with frequency values from 0 to 100. The peak at level 8 is the only significant feature, confirming that only levels 8, ..., 23 occur in the region.

Figure 4d. Gray level histogram of the outlined region (horizontal scale four times that of Figure 3a). Only levels 8, ..., 23 occur. The region has area 583.