IMAGE PROCESSING OVER THE ARPA COMPUTER NETWORK

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Summary A Communication system has been developed by the University of Southern California for providing digital image processing services over the ARPA computer network. In this system a user at a remote site may have images digitized at the USC site and transmitted over the network, or the user may supply an image for precision display. Also, image processing programs may be executed on the U.S. C. image processing system using the VICAR image processing language.

Introduction In 1969 the Advanced Research Projects Agency (ARPA) established a computer network linking the computational facilities of several universities and research groups throughout the nation. As a member of the network, the University of Southern California Image Processing Laboratory provides image processing hardware and software services to other network members. This paper describes the computer network and the USC image processing facilities. Also included, is a discussion of image transmission techniques and image processing operations that can be performed over the network.

ARPA Computer Network The ARPA Computer Network, as of mid-1972, consists of about thirty sites or nodes. Figure 1 is a topological map of the network with a listing of the major computers at each node. Communication over the network is handled by Interface Message Processor (IMP) units that interface the host computer at each node to 50kB leased telephone lines. Another type of interface unit called a Terminal Interface Message Processor (TIP) allows connection to the network by a terminal with or without a host computer. The communication link is a store and forward type of communication system in which each IMP or TIP along a message route, temporarily stores the message, and forwards the message to the next node along the route. The transmission route is determined solely by the IMP's or TIP's, without any central control, so as to minimize the transit time and efficiently utilize the transmission link.

Long messages are partitioned into packets of about 1000 bits for transmission. Each host computer provides a Network Control Program (NCP) that establishes the connection between the local host and a remote site. After the connection has been established the local host becomes transparent to the user; the user interacts directly with the remote site until the connection is terminated.

The ARPA computer network is an exciting and important resource for image processing operations. Specialized image digitization and display equipment, which is often extremely expensive and delicate to operate, can be located at a few sites and be made available to all members of the network. Large computers, such as the ILLIAC IV, are available on the network for compute bound image processing problems. Finally, with the network it is possible to share source images, computer software, and research results within the research community much more readily.

Image Processing Hardware Facilities Figure 2 is a general block diagram depicting the hardware facilities utilized by the USC Image Processing Laboratory (IPL) for various image acquisition, computation, and display operations. The IPL facility consists of a Hewlett-Packard 2100 which is used to command and control all the image acquisition and display devices.

At present a conventional flying spot scanner is used for image digitization and most hard copy replay of color and monochrome images on photographic prints. The device can raster scan transparencies up to 70 millimeters square with resolutions up to 1024 by 1024 pixels. The scan time varies but is usually less than I minute per frame. Normal analog to digital conversion is eight bits. Replay is usually accomplished using Polaroid film but 35 millimeter replay is also available. Color digitization and replay is accomplished serially under computer control using a color filter wheel and a white CRT phosphur.

The Muirhead color facsimile device is a two unit drum transmitter and receiver. Its capabilities include 100 line/inch resolution with simultaneous six bit/color quantization as well as replay of the three primary colors on an 8 by 10 inch print. The scan time for this device is 12 minutes.

The real time display of monochrome and color digital images is accomplished using an Aerojet General display device. This device utilizes a standard shadow mask CRT with 576 horizontal and 525 vertical lines of resolution. A digital disk is included with the device which makes possible a refresh rate of 60 fields/second at 64 quantization levels for each of the red, green, and blue primaries.

In addition to the previously mentioned devices, a flat bed scanning microdensitometer will be added in early 1973. This device will scan and replay 16, 35 and 70 millimeter color or monochrome roll film On a registered transport under computer control as well as prints or transparencies up to 1Z inches square. Specifications call for a minimum aperture size of 2 microns square, 8 bits of precision, a scanning velocity of 8 inches/second in the direction of travel and a 0 to 4 specular density range. Color digitization is sequential using a color wheel under program control, and replay is monochrome with color reconstruction photographically. These devices, taken as a whole, provide a wide range of resolution, accuracy and time trade offs for digitization and display.

The IPL computers and peripherals are hardwire interfaced to the Engineering Computer Laboratory (ECL) IBM 360/44. Images are transferred from the disk on the HP 2100 to a disk on this machine. The processed image is then stored on disk and transferred back to the HP 2100 when the operator requests. Plans also call for Fortran and machine language programs to be entered from the HP 2100 which will describe the processing tasks to be undertaken on a stored image. The 360/44 is currently laser linked to the University Computer Center (UCC) 370/155 and to the ARPA computer network by the TIP terminal. There is also remote job entry from the ECL to UCC facility. Thus, image processing tasks can be undertaken at ECL for the UCC computer with image transfer each way. Both the forementioned machines have appropriate versions of the VICAR image processing language available for use.

Image Processing Software Capability The software configuration at this laboratory consists of VICAR and VICAR independent software systems. The VICAR (Video Image Communication and Retrieval) system was acquired from the Jet Propulsion Laboratory and a modified form has been operational at USC for the past year. The purpose of VICAR is to facilitate the acquisition, digital processing, and recording of image data on a production basis by scientific personnel not familiar with systems programming. VICAR usage can be divided into the categories of system programming, applications programming, and problem programming. The system programmer requires knowledge of applications and problem programming only in a global sense. The applications programmer is capable only of using existing problem programs and requires no knowledge of either system or problem programming. The results of processing an image with problem programs, GRID, MAPGRID and CONCAT are shown in Figure 3a, b, and c. The problem programmer must have knowledge of application program protocol but need not have system programming knowledge. From a system viewpoint, the operation of VICAR is very similar to that of a standard utility program. The application programmer submits a card deck containing a limited number of VICAR control statements to define the processing tasks. These statements include READ and WRITE tape instructions in 7 or 9 track, 8 or 6 bit formats, disk data set RESERVE cards and program EXECUTE cards. All tape and disk labels and job control statements are generated so as to be transparent to the user. Up to 14 simultaneous I/O requests can be made. User labels as well as history and systems labels, are routinely placed at prescribed locations preceding the image data on a tape or disk file. This information can be retrieved and used for picture annotation purposes such as shown in Figure 3d. This is one display option of the problem program MASK. In a likewise manner, labels can be deleted in total or in part at the user’s option. The problem programmer unlike the applications programmer can add programs to the program library which can be executed by himself or by an applications programmer. A problem program can be written either in Fortran or Assembly Language and differs from a normal subroutine only in its I/O structure. In addition to normal Fortran I/O which is optional, several VICAR I/O statements must be included. Most existing conventional subroutines can be easily converted to VICAR problem programs through a modification of its I/O structure. At present VICAR contains over 30 application programs which perform such varied tasks as Fourier transformations, picture annotation, line plotting and filter design.

The VICAR independent system at UCC is less flexible but is I/O compatible with VICAR. Since VICAR programs have an I/O structure which is line by line, it is easily possible to process images of up to 4096 by 4096 pixels. VICAR independent processing inputs N by N blocks of pictoral data and operates on this block in core. Thus N greater than 512 is not feasible on any of our machines. Job Control statements are necessary, but are kept to a minimum and are of a standard form. This VICAR independent processing is useful for experimental processing of lower resolution images where VICAR sophistication and production capabilities are not necessary. There are approximately 60 conventional Fortran and BAL subroutines currently in use. They perform such diverse functions as image scaling, linear and non-linear filtering, various unitary transformations, and pictorial pattern recognition. Often these subroutines can be converted to VICAR problem programs by addition of the VICAR I/O protocol. An example of VICAR independent processing is depicted in figures 3e and f. It should also be mentioned that the HP 2100 executes many program tasks which do not require the use of the larger machines.

USC/ARPANET Image Processing System The University of Southern California image processing hardware and software facilities previously discussed are available for use over the ARPA computer network. A remote site user may:

(a) read an image from an image file and transfer the image to the remote site;

(b) store an image, transferred from the remote site, on an image file;

(c) display and make a hard copy of an image stored on an image file;

(d) digitize a hard copy image and store on an image file;

(e) execute a VICAR language image processing program.

The use of the USC/ARPANET image processing system by a remote site user requires, as a minimal configuration, a computer terminal connected to a TIP. With this configuration image processing jobs can be initiated from the remote site with operations performed on previously stored images and hard copy image results returned to the user by mail. The next level of capability entails the addition of an image recording device at the remote site for display of processed images. A complete remote site system -would also include an image scanner and digitizer for supplying input images.

Figure 4 contains a block diagram describing the information flow in the USC/ARPANET image processing system. In operation a user at a remote site establishes a connection with the USC network control program and notifies the NCP that an image processing job is to executed. A data transfer program receives a request for an image processing job from the NCP and then acts as a monitor for control of the job instructions and data. The remote user's job parameters, consisting of instructions defining the image processing operations to be performed and image data locations, are stored in a job file preparatory to execution. If the user submits a VICAR program, the source program is stored in a VICAR program file. Any image data supplied by the remote user is stored on a mass image file. When the remote user's job is ready for execution the data transfer program transfers the appropriate image data and instructions to the processors. For example, if a VICAR job is to be performed the data transfer program transfers the remote user's VICAR language source program and the input images to be processed from the image files to the VICAR language processor on the IBM 370/155. After the VICAR processing is completed, the output image is returned to the image file, and subsequently returned to the remote site through the TIP.

The majority of messages transmitted over the network are of short length and can be placed in a single packet. However, bulk files such as digital images usually exceed the packet length, and therefore, must be partitioned for transmission. The partitioning is automatically handled by the host and user network control programs, and is not of concern to the user. For digital image processing operations, images are usually coded with eight bits (one byte) per picture element. Furthermore, images are often restricted in size to a binary integer, e. g. (256x256, 512x512, etc.) in order to take advantage of fast computational algorithms which impose this restriction. In the interest of standardization, the USC/ARPANET image processing system has been designed to handle image files with a record length of 256N bytes per record where N is an integer. The number of records in a file can be specified by the user, and is not restricted to a binary integer. At present the fastest transmission speed over the ARPANET is 50kbs. Considering the transmission control data that automatically is added to each message packet and transmission delays Encountered at each node, the average user data rate is likely to be about 25kbs. At this rate the time required to transmit a 256x256 byte image is about 21 sec. A 1024x1024 images requires about 5. 6 min. for transmission. Plans are underway to provide a higher speed transmission service for the network. Also, image bandwidth reduction techniques are being considered to decrease the transmission time.

References A series of papers on the ARPA computer network. AFIPS Proc. of the Spring Joint Computer Conf. , Vol. 36, 1970, pp. 551567.

A series of papers on the ARPA computer network. AFIPS Proc. of the Spring Joint Computer Conf. , Vol. 38, 1972,.

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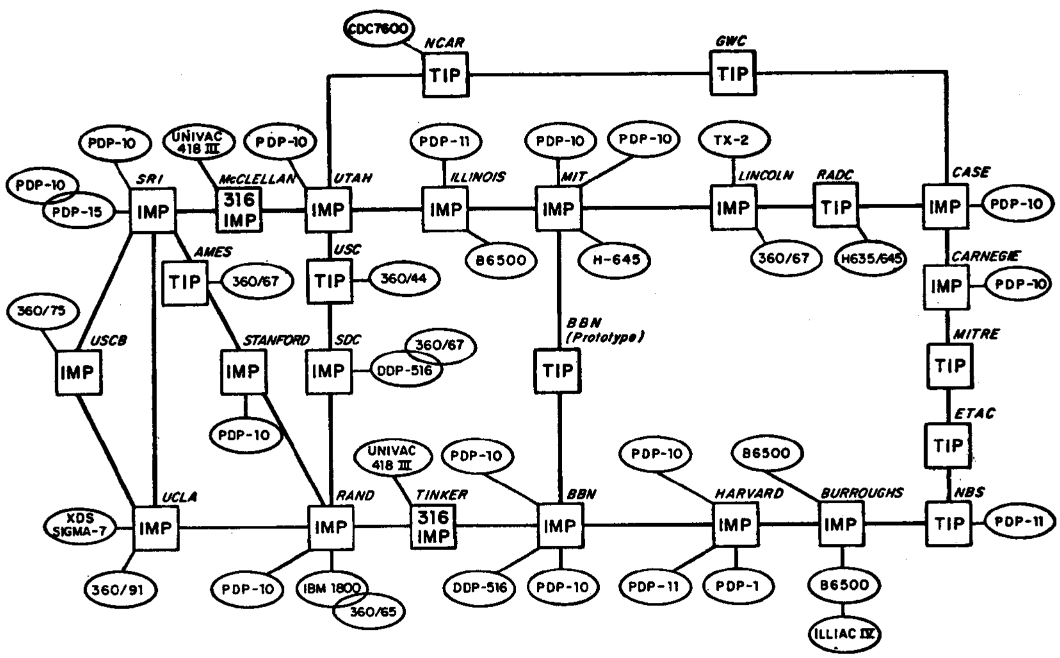


FIGURE 1. ARPA NET, MID-1972

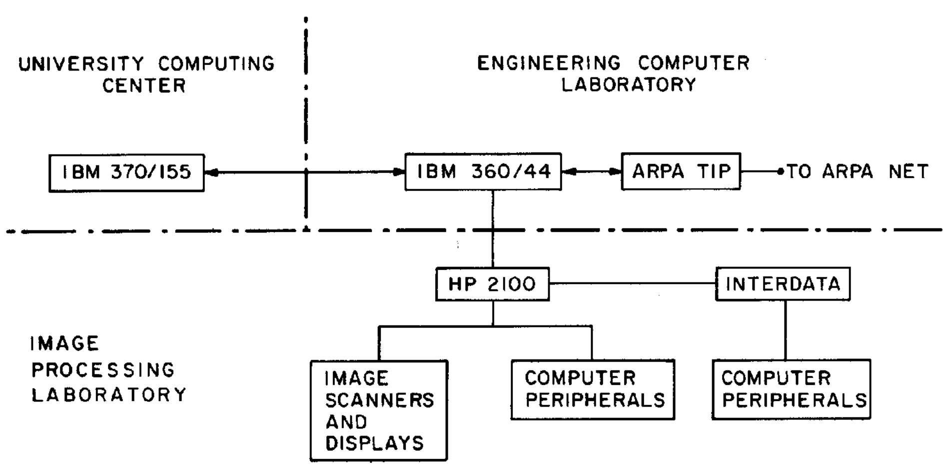
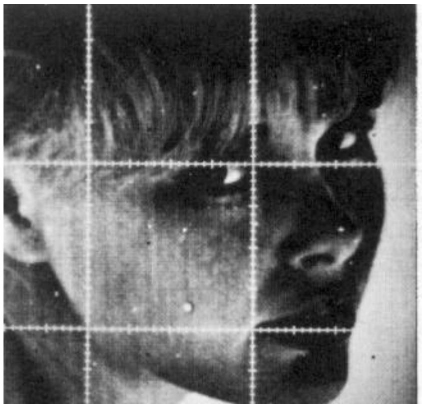
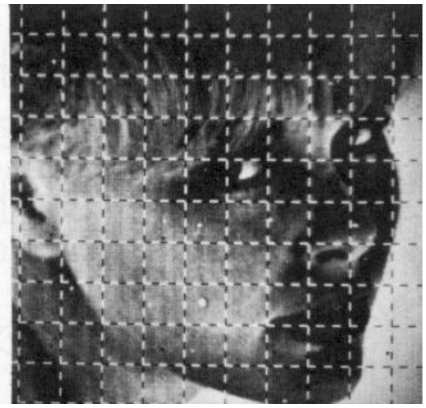


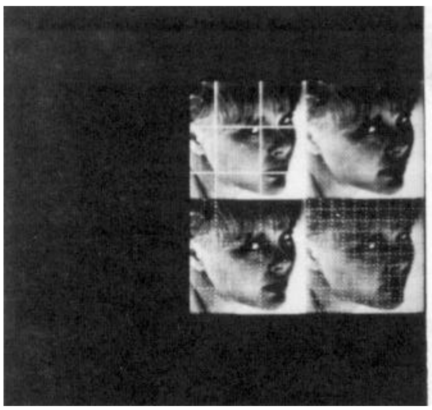
FIGURE 2. USC IMAGE PROCESSING LABORATORY FACILITIES

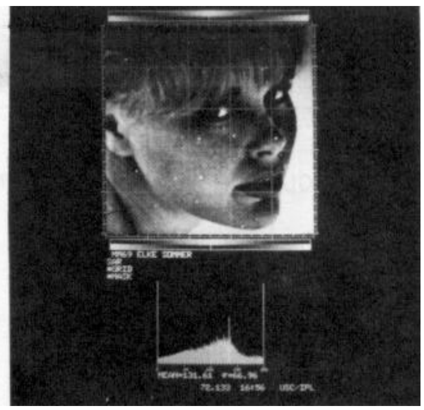




a) Output of GRID

b) Output of MAPGRID





C) Output of CONCAT

d) Output of MASK

e) Original Image

f) Image processed by Gaussian isotropic high frequency emphasis filter followed by histogram equalization

Figure 3. Examples of Processed Images

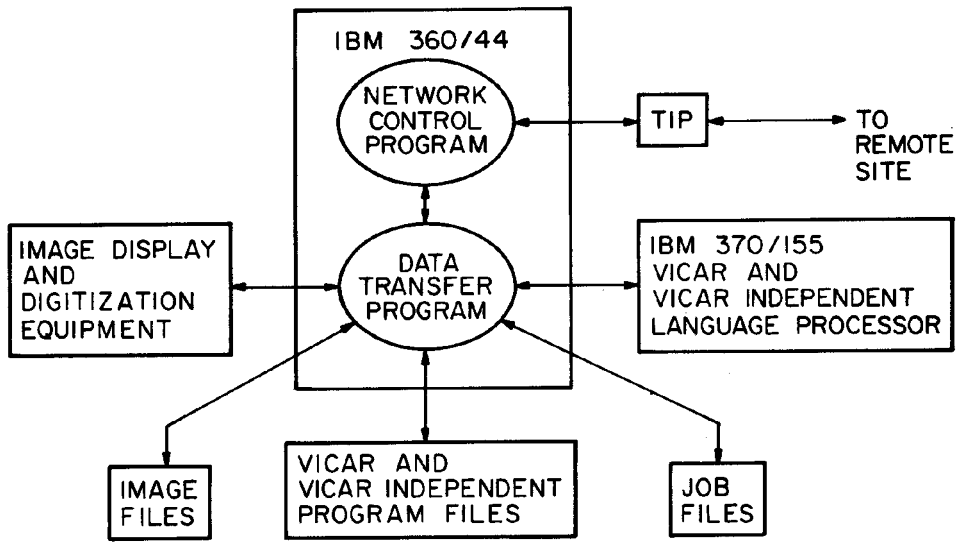


FIGURE 4. USC/ARPANET IMAGE PROCESSING SYSTEM