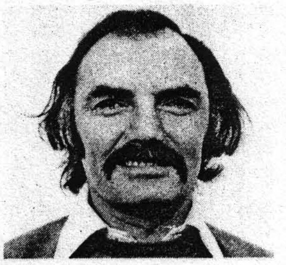
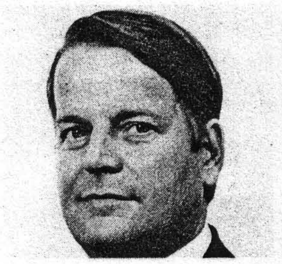
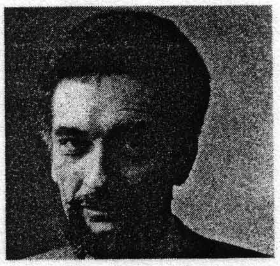
COMPUTER-AIDED ANIMATION



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After completing a degree in mechanical engineering, **Colin Besant** researched into reactor physics at Imperial College for his PhD. After a year with Rolls-Royce and Associates, he joined the UKAEA to work on development of the steam-generating heavy-water reactor at Winfrith Heath, Dorset. He returned to Imperial College in 1968 as a lecturer in the Mechanical Engineering Department and is currently researching into computer-aided design.

Tony Diment studied at University College of Wales, Aberystwyth, and obtained an MSc at Queen Mary College, London. His subsequent research in nuclear engineering at QMC is being submitted for a PhD and at present he is Operations Manager of Video Animation Ltd.

After studying chemistry and engineering at technical college and a period in Australian industry, **Stan Hayward** began scriptwriting in 1958. He has written for magazines, newspapers, radio, television and films, and has worked for the National Film Board of Canada. Returning to England after writing scripts about computers in New York, he began to work in computer animation and now specialises in computer graphics.

Following an apprenticeship with the North Western Electricity Board, **Alan Jebb** graduated in electrical engineering from the University of Manchester and then completed a one-year nuclear course at Imperial College. He became an R & D engineer with the CEGB, and lectured in control engineering at The City University from 1960 to 1965. Since then he has lectured at Imperial College, obtaining a PhD in reactor kinetics and control, and is now specialising in computer-aided design and instrumentation and control for the road-transport industry.

After graduating in chemistry from Queen Mary College, London, in 1953, **Peter Hawkes** worked as a research chemist in various industries. In 1958 he joined AEI Ltd, becoming Section Leader in charge of component development for electronic telephone apparatus. In the early 1960s he was responsible for early UK work on microelectronic integrated circuits for computer-controlled telephone exchanges, which led to an interest in computers and computing. He joined NRDC from GEC Ltd in 1968 and has been responsible for Corporation projects in the mini-computer and peripherals fields.

The concept of animated films is associated in most people's minds with cartoons such as those of Walt Disney. However, animation of hand-drawn images is a large field, ranging from the mundane area of film or television credit titles to special effects with applications in education and industry and, finally, entertainment.

The making of animated films by conventional manual methods is very costly, since the process contains many almost repetitive and non-creative stages which are time consuming and in most cases difficult to perform consistently. A large number of pictures is required for even a schoolboy's flick book. Successive pictures making up the sequence incorporate slight changes, but the magnitude of these is critical if the motion is to look correct. For example, the changes between the pictures are not uniform with respect to time, particularly at the beginning and end of a motion.

Introduction

This article describes a project which aims to reduce the cost and time required to make animated films by introducing a degree of automation into the design and production stages. The project is based on the notion that a suitably programmed digital computer can carry out the repetitive draughting and clerical steps required. This can be contemplated because many such steps are describable in an appropriate computer language. Once a suitable computer program has been developed and proved in production, it can be applied again and again as needed to new drawings in subsequent films. If they are sufficiently versatile, the cost of a digital computer and its programs will be more than offset by savings in film production time.

Stan Hayward, a leading figure in the animation world, has spent some time studying the various ways of applying digital and analogue computers to animation. A few years ago he discussed his ideas with NRDC, proposing a system that could be used for many film-making processes, and it became clear that an innovation of the type he was contemplating would require the involvement of technical and commercial partners.

He subsequently met Colin Besant and Alan Jebb of the Department of Mechanical Engineering, Imperial College of Science and Technology, London. They had already devised and built a computer-aided design system called CADMAC. This system had a great deal in common with the system required by Stan Hayward to develop and exploit his ideas. They therefore decided to formulate, with Hayward, a development project around a CADMAC system consisting of a minicomputer, a storage-tube display and a digitising /plotting table. The aim was to develop computer programs and gradually add on new hardware in order to perform many of the functions involved in making animated films.

Two financial partners were sought to sponsor the work, one being the Corporation because of its interest in supporting speculative commercial projects arising from university research. The second organisation approached was Television International Operations Ltd (TVI), which was considered a natural commercial partner for such a project—an established

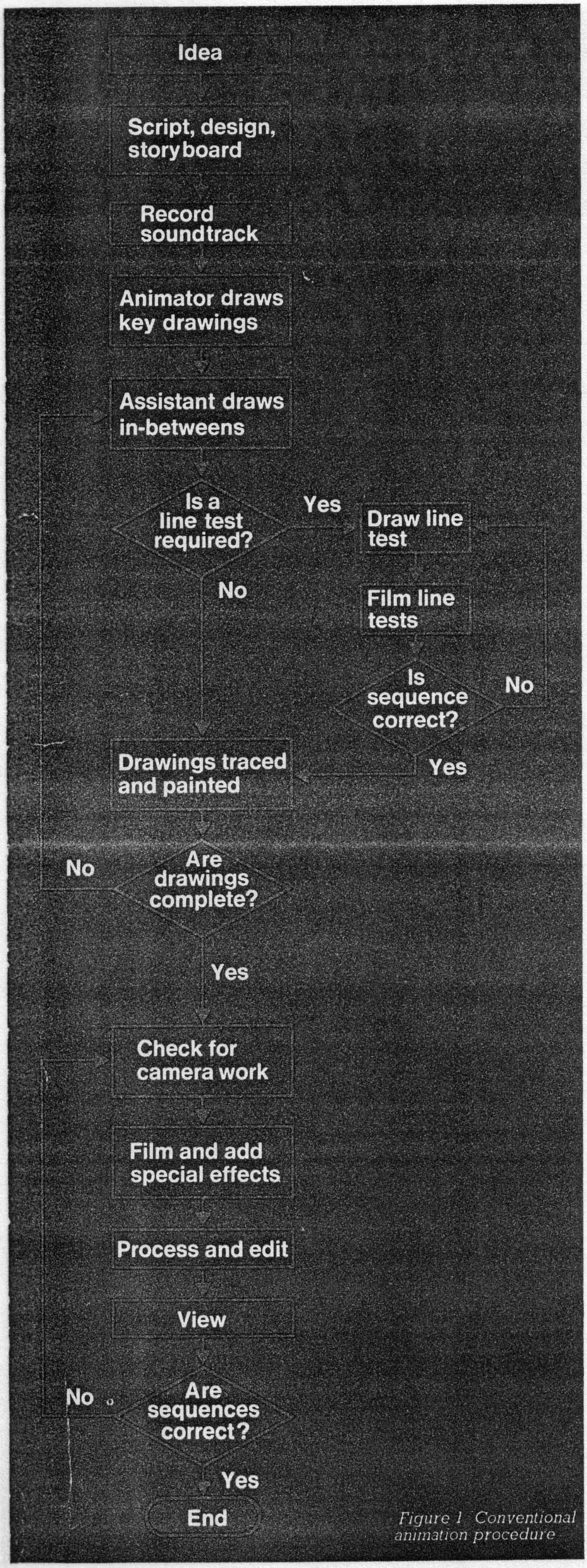


Figure 1 Conventional animation procedure

company hiring out equipment and studio facilities for television-programme production. As a vehicle for the animation project, the five partners formed, late in 1972, a company named Video Animation Ltd (VAL). VAL thereupon set about developing a comprehensive computer animation system and exploiting it commercially.

Making an animated film

The flowchart in Figure 1 shows the stages that must be completed, using conventional techniques, before a finished film can be seen. It is only quite late in the process that the animator has the option of seeing whether the animation is as he imagined. At this stage many thousands of pictures may have been drawn and, if a mistake is found, or if the film is not what was envisaged by the sponsor, many weeks of work are wasted and deadlines may have been missed. Even if a 'line test' has been done to check the pictures in essence and proved successful, the problems have by no means been overcome, since at this stage camera movements, matching of soundtrack to vision, and editing must still be done.

Many of the animated film making steps can be simulated using a digital computer and, to a large extent, the mechanical aspects of producing a film are thus bypassed. The flowchart in Figure 2 shows the stages required using a computer system. The VAL system has specifically been designed to perform all the mundane tasks, leaving animators and designers free to concentrate on the creative aspects. The aim has been to integrate the user into the system by applying interactive computing techniques to the conventional animation process.

The facility

The computer configuration for the VAL animation system is shown in Figure 3. It is based around a CADMAC system consisting of a Digital Equipment Corporation PDP 11/40 computer with 32K words of core memory, two 1.2 million word magnetic disc units with removable cartridges, and a Trend high-speed paper-tape reader/punch. The main input and output device on the computer is a combined digitiser/plotter and the display component is a Tektronix storage tube. The CADMAC system was chosen as the basis for the animation system because it was completely self contained with a computer which was well suited to program development, due not least to its excellent FORTRAN IV compiler. The CADMAC suppliers, Computer Equipment Company Ltd, delivered the system in July 1973.

The digitiser converts the features of a drawing into a set of computer data. The conversion is effected by the operator tracing the outlines of the drawing with a cursor, the movements of which are automatically recorded by the computer.

The storage tube is one of the cheapest and most effective displays for a minicomputer-based system, since it makes few demands on the computer when in use. The system also contains a flat-bed plotter, which is necessary for outputting artwork onto the clear acetate 'cel' sheets used by animators.

The CADMAC hardware was judged the most cost-effective available and also permitted later expansion with other peripherals such as tablets, a scan convertor and a high-speed flat-bed plotter. Furthermore, a sophisticated suite of drafting programs had already been developed by the Imperial College team.

The initial development programme

VAL decided to subcontract the initial development work to the computer-aided-design unit of the Department of Mechanical Engineering, Imperial

College. The College has had years of experience in collaborative research and development projects with industry.

Staff were mostly recruited from mechanical-engineering graduates of Imperial College. Undergraduate students often perform difficult feasibility studies as a special project in their final year at the College. It is in these projects that speculative ideas are often tested and the hard work and ingenuity of the students play significant roles in the success of the project. The students often wish to stay with a project after they have graduated, by either working for the company which sponsors the work or by continuing on the work as a research student.

TVI provided help in the form of overall project management and general commercial services such as accountancy. It has also given considerable assistance in the field of market research, which can so critically affect the direction of a development project.

The development work was divided into two areas, the main one being the design of methods and software to enable the basic hardware to perform for film designers and animators. The second area was concerned with an investigation of output devices, particularly with possible direct transfer of digital information into video and hence onto videotape.

Programming was first directed towards a two-dimensional system that would permit an animator to input drawings to the computer, enabling them to be stored and subsequently scaled, duplicated, rotated, translated, etc, by giving simple commands to the system.

Current user facilities
A general idea of these will now be given.

Input
The system is controlled from the digitiser or the DEC writer keyboard. The surface of the digitiser is divided into two areas : a work area for tracing drawings and a menu. The user operates the system by moving a cursor, containing control buttons, over the digitiser surface. The menu is the command area and consists of a large number of named squares. Digitising a given square will activate a particular program within the computer which will enable the user to perform some task on the work area. Typical input commands on the menu include 'set origin' and 'set scale'. Original artwork or rough sketches are placed on the work area and are copied into the computer by passing the cursor over the drawing and by utilising the control buttons and various menu commands to aid this process. The digitised 'drawing' is then filed on a magnetic disc and can be further manipulated by the use of other menu commands. All actions performed by the system are displayed on the screen of the visual display unit so that the user can see what is being fed to the computer or how the computer is manipulating a previously digitised drawing. The menu was designed so that unskilled users can not only trace in their own artwork but store, display, manipulate, edit and output it with less than one hour's training in machine operation. Aided by the messages on the screen, they soon learn to issue commands with confidence.

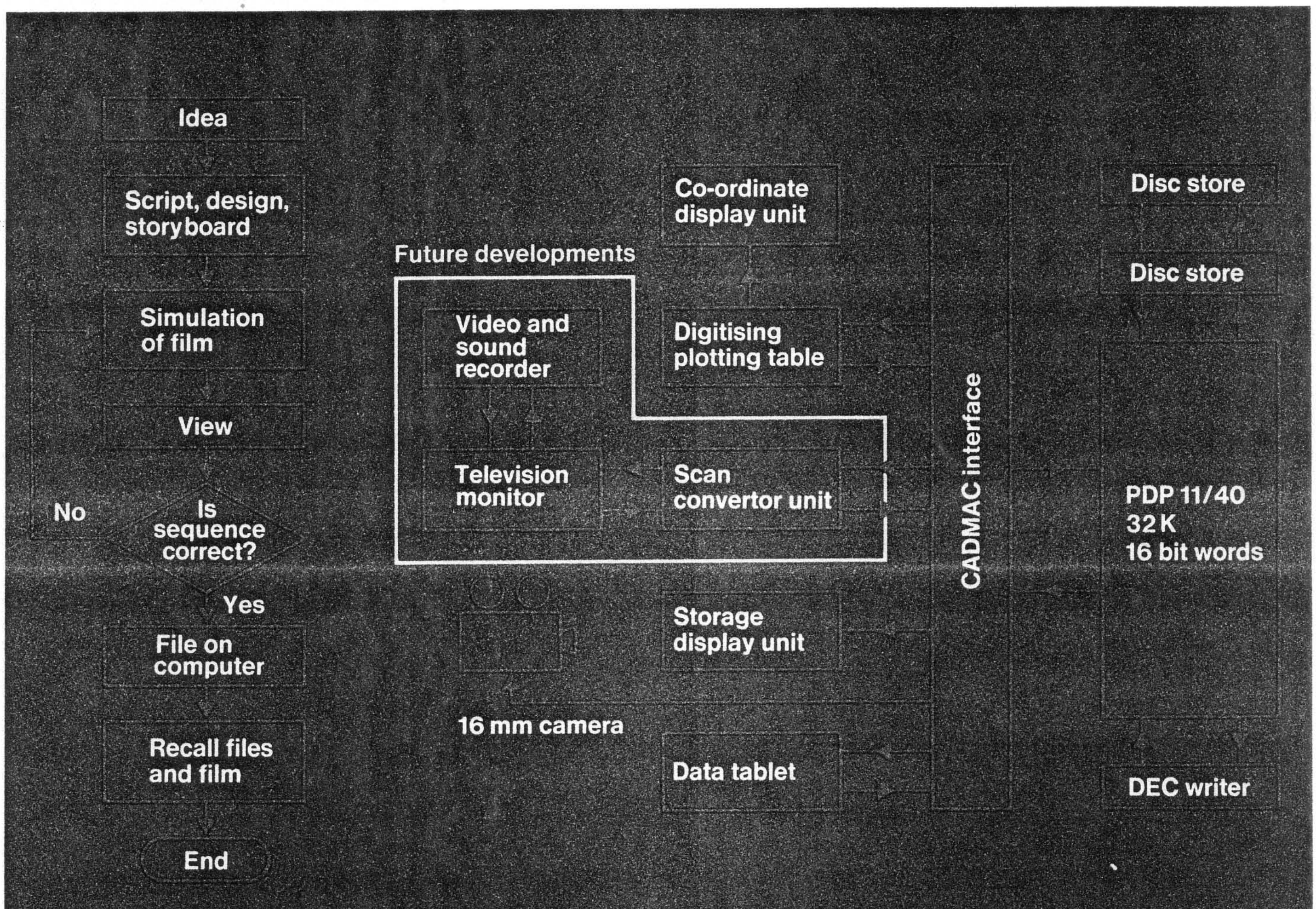


Figure 2 Animation with computer *Figure 3 Block diagram of the CADMAC computer*

Detailed picture construction and manipulation
Pictures may be built up by digitising a drawing, by freehand sketching or by assembling building blocks from a picture alphabet previously filed on the disc. This alphabet is made up of symbols, 'macros' and alphanumeric character sets.

The symbols are geometric units such as circles, arcs and rectangles which may be joined together to form complex shapes. The size and position of the symbols is determined by the user. Designs can be stepped and repeated into arrays. They can also be mirror imaged.

A 'macro' is defined as an entire picture which has been filed as one basic unit, which may then be expanded as required.

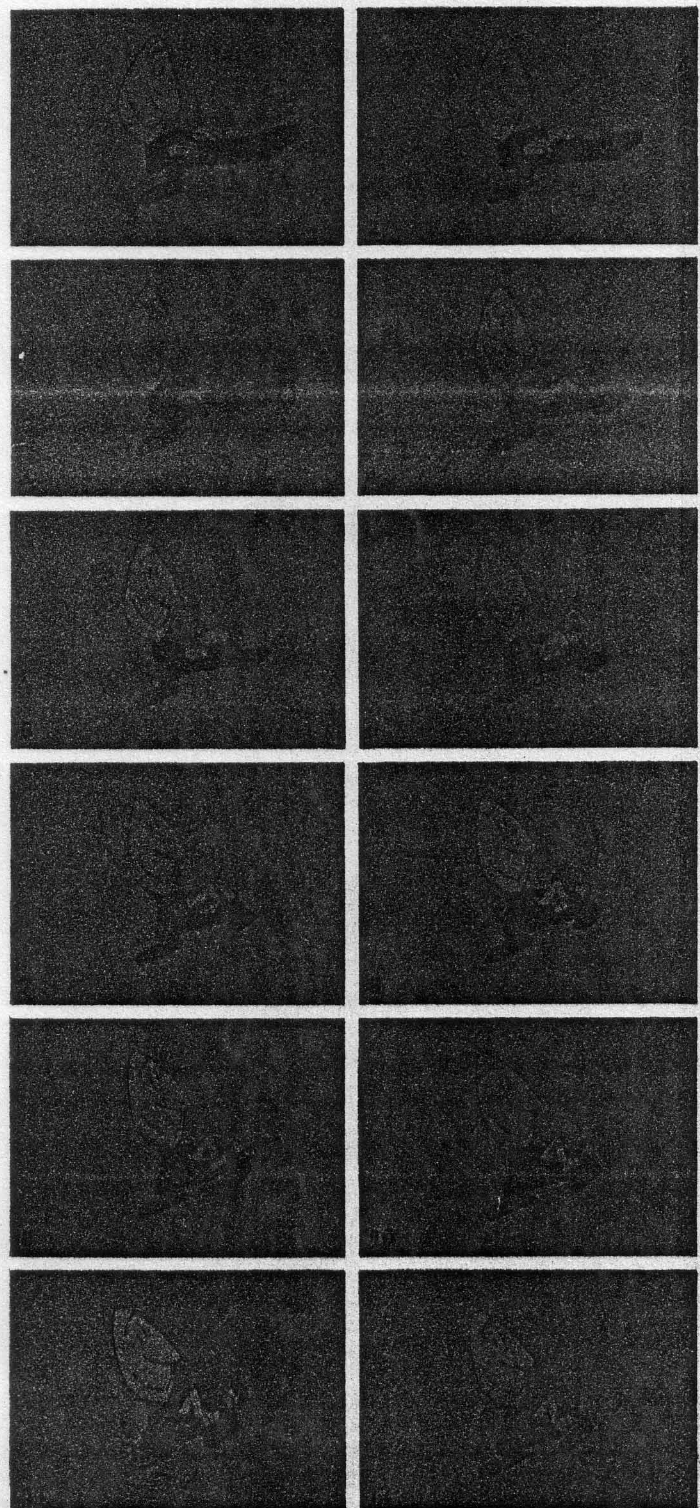
Each picture may be filed in the file area of the menu. At present 100 files may be accessed directly by the user. Each picture may comprise picture components which can be placed in subfiles ; the system allows 60 picture components to be associated with each file. The limit on the number of files is set at the discretion of the user.

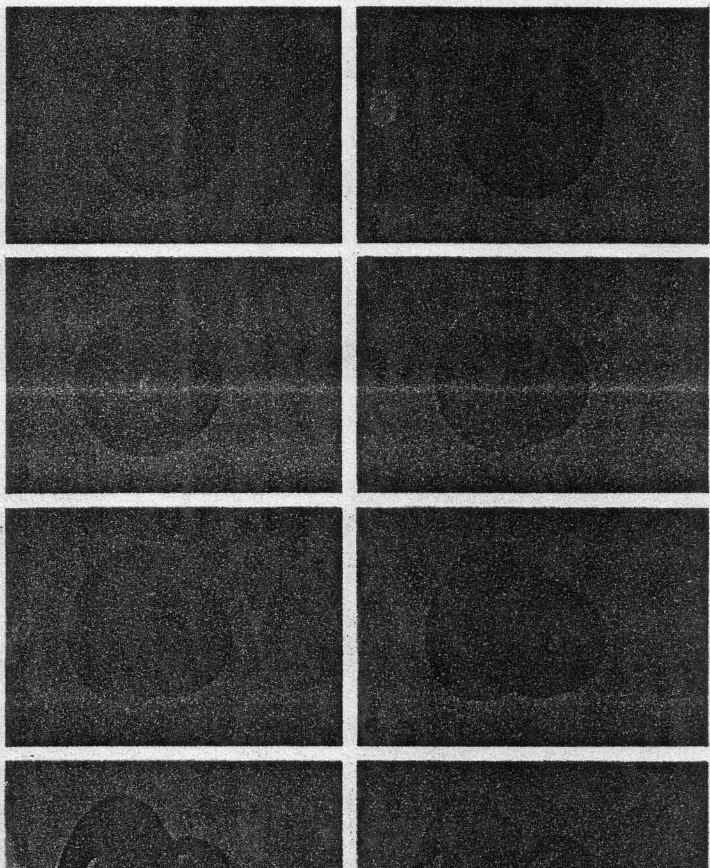
Digitised data are made up of discrete points joined by straight lines. The line quality may be improved either by continuous digitising, in which the status of the pen is constantly sampled and stored as it moves or by curve fitting the scattered data using cubic-spline fits. In the latter case a curve is fitted through any number of points with continuity of slope and curvature.

Having assembled and edited a master picture or pictures, standard or tailormade manipulations can be applied to give animation effects. Manipulations currently available include spin, flip, twist, squash–stretch, tube, sphere, skew, explode and sine. The corresponding effects will be obvious, except perhaps for tube, sphere and sine. Tube and sphere imply the apparent rotation of, say, a film title around a cylindrical or spherical surface. Sine gives periodic sine-wave distortions to the picture elements.

Alphabets

In addition to the standard alphanumeric symbols, the system has a special lettering symbol useful for





Left: Figure 4 A cartoon character removing trousers

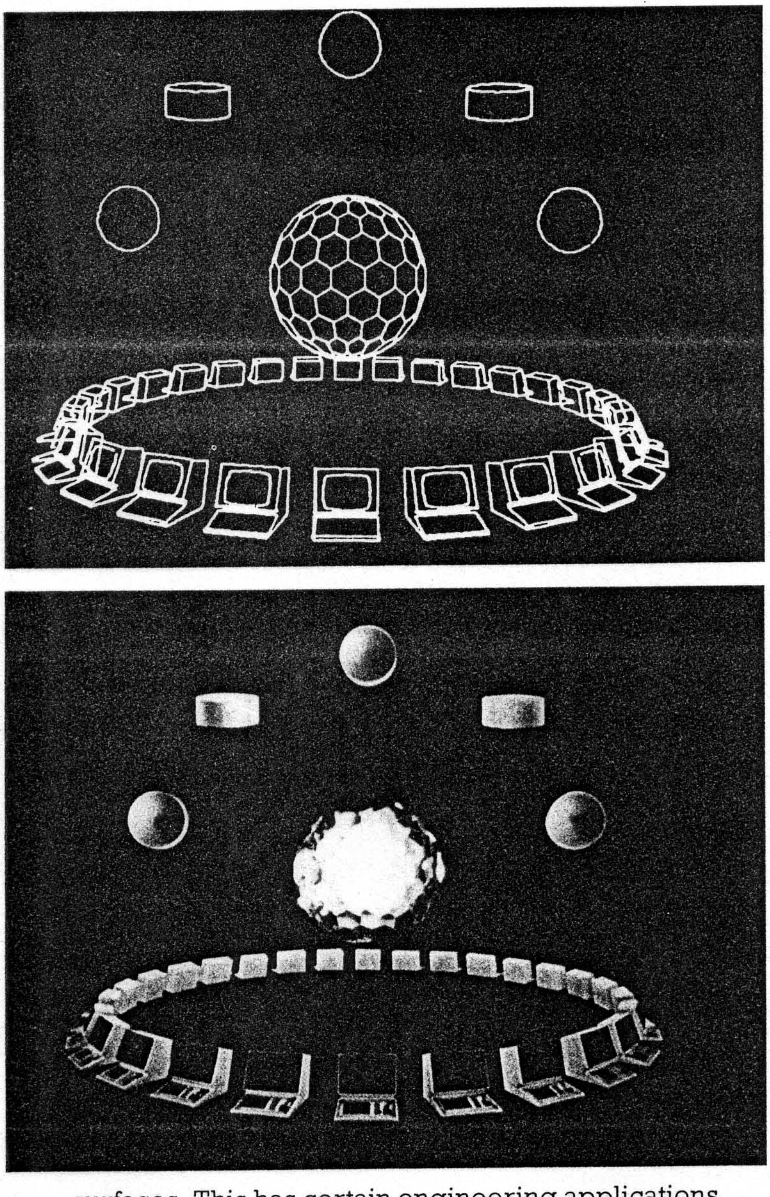
Above: Figure 5 Clutch disassembly—an example of engineering application of animation assembling film titles. This symbol displays bold type letters when the character string is typed on the keyboard.

Blockfilling

This routine is used mainly to blockfill or crosshatch bounded regions. It is often employed to fill in the bold typefaces of the letter symbols. In any bounded region that is subdivided in a mesh pattern it produces a chequerboard pattern by filling alternate units of the mesh. The raster format of the data has useful algebraic and geometric properties which make it possible to:

- ☐ Compute the area contained by a closed boundary.
- ☐ Determine whether a point is within a closed boundary.
- ☐ Generate the boundaries representing the union or intersection of several three-dimensional surfaces. This has certain engineering applications, for example in determining the contours of intersecting pipes.

Below: Figure 6 The computer output and finished artwork used in an animated sequence from a presentation film made for the ICL 2900 series



In-betweening

In order to create a continuity between two drawings that depict the start and finish of a movement, a number of intermediate drawings must be provided. These are called 'in-betweens' and are a tedious part of any animation process, as they involve a considerable amount of repetition but no real original creative work.

The intermediate drawings are generated automatically by interpolating between key drawings stored on separate files. The action is non-linear, tending to accelerate at the start and decelerate at the finish. This is called faring, and is generated by a method termed cosine interpolation.

An example of 'in-betweening', as performed on the VAL system, is shown in Figure 4, which depicts a sequence of a cartoon man removing his trousers. It is quite common for the computer to produce 20 'in-between' drawings based on two master drawings.

Camera-compound simulation

The artwork is normally drawn on the flat-bed plotter and then coloured by hand so that it is ready for photography.

Pan and zoom are movements that have to be planned well before the artwork is committed to photography. These movements are determined from a field guide which represents the area that can be photographed on an animation stand and plotted as N–S–E–W co-ordinates and field sizes on an exposure sheet. The field guide consists of a transparent rectangular chart normally with a standard aspect ratio of 36 × 50, subdivided by vertical, horizontal and diagonal lines into divisions having the same proportions. There are usually 12 field sizes on a field guide ranging from the largest 'size 12' field, representing the total area, to the nearest close-up 'size 1' field.

To be visually pleasing, movements again should accelerate at the start and decelerate at the finish. An unaided animator who has to plan and plot all these non-linear movements well in advance along three axes can rarely visualise the finished results.

The camera movement routine simulates these triaxial movements with a display corresponding to the view as seen through a camera viewfinder. A picture stored in a file is made to follow movement commands input via the keyboard. The input is in the same format as the entries on an animator's standard exposure sheet. For example, 5(6S–4E) to 2(10N–10W) represents a pan from bottom right quadrant to the top left-hand corner, combined with a 2.5× zoom in.

Output

Each frame drawn on the machine or called down from a file is displayed on the storage tube. This means the user can replay and edit each frame of the film.

The frame-projection rate in the finished film is usually 24 per second but a single drawing will usually suffice for two successive frames. On average 12 separate drawings are therefore needed for a 1 s sequence in the final film.

There are currently two ways in which the user can record the selected images on film base:

Line tests: A 16 mm camera is fixed on an optical bench and positioned in front of the display screen. Each frame is then displayed and filmed. This method is similar in principle to the conventional animation method, except that the drawings are held in the computer file and not on clear acetate ('cel'). This method is limited to black and white but has the advantage that the editing is completed automatically. It is also very fast and provides the user with a quick and cheap view of the animation.

Full-colour animation: The other means of output is the flat-bed plotter. Even here the system is totally compatible with conventional animation, since the plotter is simply commanded to plot the drawings held in file onto cel. Each cel may then be taken off the plotter and placed onto the painter's table. Although it is possible to produce three colours electronically from a greyscale film, it has been decided to continue with conventional methods of hand painting for the present, as much more control may be exercised over the tonal quality of the film. This approach also enables VAL to offer two levels of service : simple line artwork on cel to a specified design or a fully coloured animated film with sound if required.

As mentioned earlier, the computer simulates camera movements and it is at the output stage that the benefit of this accrues. Before each cel is drawn, the field size and centre of the picture to be drawn are set up. The plotter retains the current origin for that sequence, but the centre may be subsequently altered and it does not have to coincide with the centre of the cel. This has advantages in camera movements such as pans and zooms. Also the software allows the choice of academy picture size (cinema) or television format, ensuring that no part of the picture is lost on viewing. The software also allows only a part of the total picture stored on file to be plotted and no time is lost on plotting because the plotting routine only recognises data within the area defined for plotting. If the output is required on paper it is possible to call up a paper-fitting routine ; this is useful for technical design drawings.

Three-dimensional system

A separate three-dimensional system has been developed. At the present stage this system allows three-dimensional objects to be moved and displayed as two-dimensional representations. It is not yet capable of full user–machine interaction. Jobs are undertaken at the 'programmer' level rather than the 'user' level. While with two dimensions the emphasis is on simulating conventional surface animation techniques and in developing special visual effects, with the three-dimensional work the main problem is to interact spatially on a flat working surface. This is done by dividing the surface into several areas corresponding to orthogonal projection planes. Solid objects may be digitised from projection drawings or contour maps. The program determines which plane is being used and stores the data accordingly. A library of three-dimensional symbols is also being created. These symbols can be used as building blocks for simple geometrical structures.

The display of three-dimensional objects is similar to a two-dimensional display once the view of the object has been selected. However, apart from cosmetic reasons, three-dimensional display requires greater pictorial processing, especially with static pictures, if the observer is to be able to perceive depth. Visualisation can be aided by brightness modulation, shading, hidden-line removal, perspective transformation, or real-time movement. Algorithms for all these techniques have been devised with some degree of success.

Recent and projected hardware developments

The plotting of artwork onto cel can now be carried out faster by using a new high-speed flat-bed plotter developed at Imperial College.

Output onto microfilm has been tried and seems useful for certain engineering applications. It is planned to develop this area in conjunction with the University of London Computing Centre.

Input facilities are being improved by the addition of a computer writing tablet which allows the animator or designer to draw freehand on paper with an ordinary pen, with the computer simultaneously recording the drawing.

Finally, a digital to video transfer system is being developed which will permit artwork to be coloured electronically and directly transferred onto videotape. A scan convertor system has been built for the transfer of digital to video and this is now being tested.

Applications

The application of the VAL system to the conventional animation market for commercials, special effects, titles and character animation is now well tried and understood.

Two potentially important application areas for computer animation are in education and industry. The teaching possibilities are considerable and already work is being undertaken for the BBC and the Open University.

Simulation, via the use of computer animation, could play a role in reducing engineering training costs. The VAL system is capable of producing 'moving blueprints', since the animation software works from a similar data base to that of engineering design software. An example of an industrial application is shown in Figure 5, where the sequence demonstrates the dissembly of a multiple-plate clutch. Servicing of complex mechanisms could be described better by animation techniques than with printed manuals alone.

Communication with potential users has not presented any serious problems, since the philosophy behind the system is totally consistent with conventional animation techniques. Most important of all is the fact that the use of the system does not mask the identity of the designer's work.

Anyone requiring an animated film can utilise the VAL system and associated services in a number of ways. The system can be used to produce a quick and cheap line test, final film on 16 mm or 35 mm in colour, videotape or microfilm. Designers or animators can either use the system themselves or pass on key artwork to VAL staff for processing.

A typical line test together with the final artwork is shown in Figure 6. This work was produced for International Computers Ltd and used by them in introducing their new 2900 computer system.

Future trends

The results from the present VAL system have been encouraging. The quality of the final product is high and there is a significant reduction in costs over conventional methods. However, the most beneficial aspect in using the system is probably in the saving of time. A 15 s animated commercial, which took only four days to complete using the system, was recently shown on Tyne Tees Television. This included time for sound recording and synthetising, as well as film processing.

The trend of computer graphics is towards colour and real-time display. The trend of video is towards digital techniques and single-frame editing. The trend in film making is towards the numerical control of hardware such as rostrum cameras. The current VAL system is compatible with any likely future development in these areas and use will be made of these new facilities as and when they become available.

Acknowledgements

We are grateful to all those individuals in TVI, VAL and Imperial College whose work has contributed to the results described ; and to ICL for permission to reproduce Figure 6.

Further reading

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