Historical paper written by Ivan Sutherland, who designed and built the first head-mounted display in the 1960s.

separately on the neck of the image tube. The character generator comprises a special control cycle for 16 steps maximum with a clock frequency of 1.2 mc/s. The average number of steps being 6 a writing time of approximately 5 μs per character is achieved.

Besides the individual character writing time the display capacity of the display unit is determined by the character positioning time. Since with alphanumerical information several characters are, as a rule, composed in a word or phrase, the positioning time results from the switchover time from one character position to the next within one word. The gap between two characters generally is but 2.5 mm and can be run through by the electron beam within about 5 μs. The total time required for the display of one character consequently is about 10 μs. This means that the display unit is capable of writing up to 100,000 characters per second.

For the display of vectors origin and end of a vector are preset. When the electron beam has been adjusted to the origin, the coil current for the end coordinate and the beam current are switched on, the straight line between origin and end coordinate being written within 8 μs. The maximum vector length is approximately 6 cm.

For the display of an individual character the display unit must be provided with 6 bits for character selection and 18 bits for character positioning. The vector display requires 36 bits. However, as a rule, the contents of the picture are not composed of independently positioned characters and vectors but of associated groups of characters or vectors. It is therefore sufficient to indicate the coordinate of the character or vector group once from the computer, the calculation of the subsequent coordinates being left to the control unit of the display unit.

Character or vector groups are defined by a certain number of words each of which has 24 bits. If for instance a flight number, comprising 5 characters, is to be displayed, the computer delivers a group of two words, i.e., 48 bits, to the control unit, as compared to 120 bits which are required by the cathode-ray tube.

Similar economy is achieved in the instance of a polygon curve consisting of a sequence of vectors put together. Origin and end of two consecutive vectors always being identical, it is sufficient to supply just the end point of the subsequent vector by the computer. With the polygon curve writing mode the group of words may have any length. The control unit recognizes a total of 6 different characteristic groups of words.

The computer supplies the information via the interface electronic, in such a way that associated word groups are preferably stored together. The word groups are characterized by a preceding control word. It contains, in addition to the recognition code for the given types of word groups, control bits for the selection of the character form oblique/erect, the height of the characters big/small, and the brightness full/half. The store has a capacity of 1.024 words of 24 bits each, so that information can be supplied to two display units.

In order to operate the display unit, a suitable input facility is required. This is achieved by the rolling-ball control. According to the revolution of a plastics ball, pulses are produced for the x and y directions which are counted and added to the position coordinates. By means of the rolling-ball control multifarious control instructions and information for the computer can be composed on the screen and transferred to the computer by key operation.

The functional capacity of the display unit is of such variety that its applications cover a wide range in data processing and transmission. Electronic data display offers itself at the end of a data-transmission link via telegraph and telephone channels. Moreover, television and alphanumerical information can be made available by wireless transmission to a great number of users from a central station.

THE ULTIMATE DISPLAY

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We live in a physical world whose properties we have come to know well through long familiarity. We sense an involvement with this physical world which gives us the ability to predict its properties well. For example, we can predict where objects will fall, how well-known shapes look from other angles, and how much force is required to push objects against friction. We lack corresponding familiarity with the forces on charged particles, forces in nonuniform fields, the effects of nonprojective geometric transformations, and high-inertia, low friction motion. A display connected to a digital computer gives us a chance to gain familiarity with concepts not realizable in the physical world. It is a looking glass into a mathematical wonderland.

Computer displays today cover a variety of capabilities. Some have only the fundamental ability to plot dots. Displays being sold now generally have built in line-drawing capability. An ability to draw simple curves would be useful. Some available displays are able to plot very short line segments in arbitrary directions, to form characters or more complex curves. Each of these abilities has a history and a known utility.

It is equally possible for a computer to construct a picture made up of colored areas. Knowlton's straints" in Sketchpad.[2] By working with such displays of mathematical phenomina we can learn to know them as well as we know our own natural world. Such knowledge is the major promise of computer displays.

The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked.

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PRINCIPLES AND PROBLEMS OF CONSOLE DESIGN

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The concept of console, as several of us are using it today, includes more than the physical equipment through which the man interacts with the computer. It includes also the language through which the interaction takes place, the implementation of that language by way of computer programs, and some of the attitudes, skills, and capabilities of the man himself.

The extended console is thus a subsystem. It is the subsystem that mediates the communication and interaction between the user's need-goal and cognitive-heuristic functions, on the one hand, and the computer's clerical-service and algorithmic functions, on the other.

The physical components of the console I would like to have now include keyboards, typing units, oscilloscopes, light pen, a RAND Tablet, function switches, camera, projector, microphone, loudspeaker, telephone, clock, light switch, and assorted ingenious controls such as the bowling ball.

The skill, linguistic, and software components are harder to specify. Some of their characteristics are dealt with in the following principles and problems.

PRINCIPLES

1. *Transfer-teach-escalate.* Most users of interactive computing will be new users. It is therefore important, at least at first, to make consoles and interaction procedures compatible with existing skills and habits. That will ensure "positive transfer" from the old ways to the new. However, that will not be enough. We should take advantage of the fact that the console, and the computer and programs behind it, can teach the user how to exploit the services available to him and how to contribute to their progressive development. Thus the level of use can be made to "escalate" from the beginner's jerky conversation with a typewriter-calculator to the expert's confident command of a large, diverse, and ever-growing system of facilities and services.

2. *Terse in, verbose out.* The user should interact with the computer in a style as terse and abbreviated—and as idiosyncratic—as he pleases, but he should receive "final copy" in which all expression is full and complete. Final output and permanent internal records should be suitable for communication.

3. *Rapport and synergy.* "Rapport is better than conversation." The interaction between man and computer should display the synergy of good muscular coordination and the subtle interplay of practiced teamwork. The interaction should not be limited to back-and-forth "ping-pong" conversation.

4. *Multidimensionality.* It is easy to provide a matrix of buttons, one button for each possible step of processing, and to ask the user merely to select and push one button and then another and then another. The modes of signaling that are effective in human communication—speech, typing, writing, reading, recognizing objects and pictures—all turn out upon analysis to be multidimensional, to employ simultaneous variation of several variables. Man-computer communication must take that fact into account.

5. *Reinforcement.* The computer should respond punctually and politely. The role of its responses as "reinforcers" is potentially very important in a world in which many people are too busy to contribute to the flow of positive reinforcement. The existing knowledge of "reinforcement scheduling" (Skinner) should be applied.

6. *Arm's-length processing.* At first, users will have to build their designs and structures of thought out of elements—points, lines, characters, and the like. But interaction languages and facilities should be arranged to facilitate accumulation of the products of intellectual effort. The ability to command the computer at a high level of abstraction should be developed. ("Replace the largest weight in every 'unsuccessful' third-level adder with a weight twice as large, and readjust the others proportionally.")