

Human-Computer Interaction: Input Devices

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All aspects of human-computer interaction, from the high-level concerns of organizational context and system requirements to the conceptual, semantic, syntactic, and lexical levels of user interface design, are ultimately funneled through physical input and output actions and devices. The fundamental task in computer input is to move information from the brain of the user to the computer. Progress in this discipline attempts to increase the useful bandwidth across that interface by seeking faster, more natural, and more convenient means for a user to transmit information to a computer. This article mentions some of the technical background for this area, surveys the range of input devices currently in use and emerging, and considers future trends in input.

BACKGROUND

A designer looks at the interaction tasks necessary for a particular application [Foley et al. 1990]. Interaction tasks are low-level primitive inputs required from the user, such as entering a text string or choosing a command. For each such task, the designer chooses an appropriate interaction device and interaction technique. An interaction technique is a way of using a physical device to perform an interaction task. There may be several different ways of using the same device to perform the same task: for example, one can use a mouse to select a command by using a pop-up menu, a fixed menu (or palette), multiple clicking, circling the desired command, or even writing the name of the command with the mouse.

User performance with many types of manual input depends on the speed with which the user can move his or her hand to a target. Fitts' Law, a key foundation in input design [Card 1983], predicts the time required to move based on the distance to be moved and the size of the destination target. The time is proportional to the logarithm of the distance divided by the target width. This leads to a tradeoff between distance and target width: it takes as much additional time to reach a target that is twice as far away as it does to reach one that is half as large.

Another way of characterizing many input devices is by their control-display ratio, the ratio between the movement of the input device and the corresponding movement of the object it controls. For example, if a mouse (the control) must be moved one inch on the desk in order to move a cursor two inches on the screen (the display), the device has a 1:2 control-display ratio.

HANDS—DISCRETE INPUT

Keyboards attached to workstations, terminals, or portable computers are one of the principal input devices in use today. Most use a typewriter-like "QWERTY" keyboard layout, typically augmented with additional keys for moving the cursor, entering numbers, and special functions. There are other layouts and also chord keyboards, where a single hand presses combinations of up to five keys to represent different characters.

HANDS—CONTINUOUS INPUT

A much wider variety of devices is in use for continuous input from the hands. A number of studies and taxonomies attempt to organize this range of possibilities [Foley et al. 1990; MacKinlay et al. 1990]; most devices used for manual pointing or locating can be categorized in these ways:

- Type of Motion*: Linear vs. rotary; for example, a mouse measures linear motion (in two dimensions); a knob, rotary.
- Absolute or Relative Measurement*: Mouse measures relative motion; Polhemus magnetic tracker, absolute.
- Physical Property Sensed*: Position (or angle) or force (torque). Mouse measures position; isometric joystick, force.
- Number of Dimensions*: One, two, or three linear and/or one, two, or three angular; mouse measures two linear dimensions; knob measures one angular dimension; Polhemus measures three linear and three angular dimensions.
- Direct vs. Indirect Control*: Mouse is indirect (move it on the table to point to a spot on the screen); touch screen is direct (touch the desired spot on the screen directly).
- Position vs. Rate Control*. Moving a mouse changes the position of the cursor; moving a rate-control joystick changes the speed with which the cursor moves.
- Integral vs. Separable Dimensions*. Mouse allows easy, coordinated movement across two dimensions simultaneously (integral); a pair of knobs (as in an Etch-a-Sketch toy) does not (separable).

Devices within this taxonomy include one-dimensional valuators (e.g., knob or slide pot), 2D locators (mouse, joystick, trackball, data tablet, touch screen), and 3D locators (Polhemus and Ascension magnetic trackers, Logitech ultrasonic tracker, Spaceball). Glove-input

devices report the configuration of the fingers of the user's hand, allowing gestures to be used as input.

OTHER BODY MOVEMENTS

Foot position, head position (with a 3D tracker), and even the direction of gaze of the eyes [Bolt 1981; Jacob 1991] can also be used as computer inputs.

VOICE

Another type of input comes from the user's speech. Carrying on a full conversation with a computer as one might with another person is well beyond the state of the art today and, even if possible, may be a naive goal. Nevertheless, speech can be used as input with unrecognized speech [Schmandt 1993], discrete word recognition, or continuous speech recognition. Even if the computer could recognize all the user's words in continuous speech, the problem of understanding natural language is a significant and unsolved one. It can be avoided by using an artificial language of special commands or even a fairly restricted subset of natural language.

VIRTUAL REALITY INPUTS

Virtual reality systems rely on combinations of the 3D devices discussed above, typically a magnetic tracker to sense head position and orientation to determine the position of the virtual camera for scene rendering plus a glove or other 3D hand input device to allow the user to reach into the displayed environment and interact with it.

FUTURE DIRECTIONS

One way to predict the future of input is to look at some of the characteristics of emerging new computers. The desktop workstation seems to be an artifact of past technology in display devices and in electronic hardware. In the future, it is likely that computers smaller and larger than today's workstation will appear, and

the workstation-size machine may disappear. This will be a force driving the design and adoption of future input mechanisms. Small computers are already appearing—laptops, palmtops, and wearables—and straining the limits of keyboard usage. At the same time, computers will be getting larger. As display technology improves and as more of one's tasks become computer-based, an office-sized computer can be envisioned with a display as large as a desk or wall (and with resolution approaching that of a paper desk). Such a computer leaves considerable freedom for possible input means. A large, fixed installation could accommodate a special-purpose console or "cockpit" for high-performance interaction. In collaborative work, the large display may be fixed, but users move about the room, interacting with each other and with small, mobile input devices.

Another trend, seen in the emergence of virtual reality, is that computer input and output are becoming more like interacting with the real world. For input, this means attempting to make the user's input actions as close as possible to the thoughts that motivated those actions, that is, to reduce the "Gulf of Execution" [Hutchins et al. 1986], the gap between the user's intentions and the actions necessary to input them into the computer. Doing so exploits skills humans have acquired through evolution and experience. Direct-manipulation interfaces [Schneiderman 1983] have enjoyed great success, particularly with new users, largely because they draw on analogies to existing human skills (pointing, grabbing, moving objects in space) rather than trained behaviors. Virtual reality interfaces, too, gain their strength by exploiting the user's pre-existing abilities and expectations. Instead of inputting strings of characters, users interact with a virtual reality in more natural and expressive ways—moving their heads, hands, or feet. Future input mechanisms may continue this trend toward naturalness and expressivity by allowing users to perform "natural" gestures or operations and transducing them for computer in-

put. More parts or characteristics of the user's body can be measured for this purpose and then interpreted as input.

Yet another way to predict the future of input devices is to consider the progression that begins with laboratory devices used to measure some physical attribute of a person. As they become more robust, they may be used as practical medical instruments. As they become convenient, non-invasive, and inexpensive, they may find use as future computer input devices. The eye tracker is such an example. Measurements such as blood pressure, heart rate, respiration rate, eye pupil diameter, galvanic skin response, and even EEG (electroencephalogram) signals are possible candidates for inputs in the future. Perhaps the final frontier in user input and output devices will someday be to measure and stimulate neurons directly, rather than via the body's transducers.

REFERENCES

- BOLT, R. A. 1981. Gaze-orchestrated dynamic windows. *Comput. Graph.* 15, 3 (Aug) 109–119.
- CARD, S. K., MORAN, T. P., AND NEWELL, A. 1983. *The Psychology of Human-Computer Interaction*. Lawrence Erlbaum, Hillsdale, NJ.
- FOLEY, J. D., VAN DAM, A., FEINER, S. K., AND HUGHES, J. F. 1990. *Computer Graphics: Principles and Practice*. Addison-Wesley, Reading, MA.
- HUTCHINS, E. L., HOLLAN, J. D., NORMAN, D. A. 1986. Direct manipulation interfaces. In *User Centered System Design: New Perspectives on Human-computer Interaction*. D. A. Norman and S. W. Draper (Eds.), Lawrence Erlbaum, Hillsdale, NJ, 87–124.
- JACOB, R. J. K. 1991. The use of eye movements in human-computer interaction techniques: What you look at is what you get. *ACM Trans. Inf. Syst.* 9, 3 (April), 152–169.
- MACKINLAY, J. D., CARD, S. K., AND ROBERTSON, G. G. 1990. A semantic analysis of the design space of input devices. *Human-Computer Interaction* 5, 145–190.
- SCHMANDT, C. 1993. From desktop audio to mobile access: Opportunities for voice in computing. In *Advances in Human-Computer Interaction 4*. H. R. Hartson and D. Hix, (Eds.), Ablex, Norwood, NJ. 251–283.
- SHNEIDERMAN, B. 1983. Direct manipulation: A step beyond programming languages. *IEEE Computer* 16, 8, 57–69.