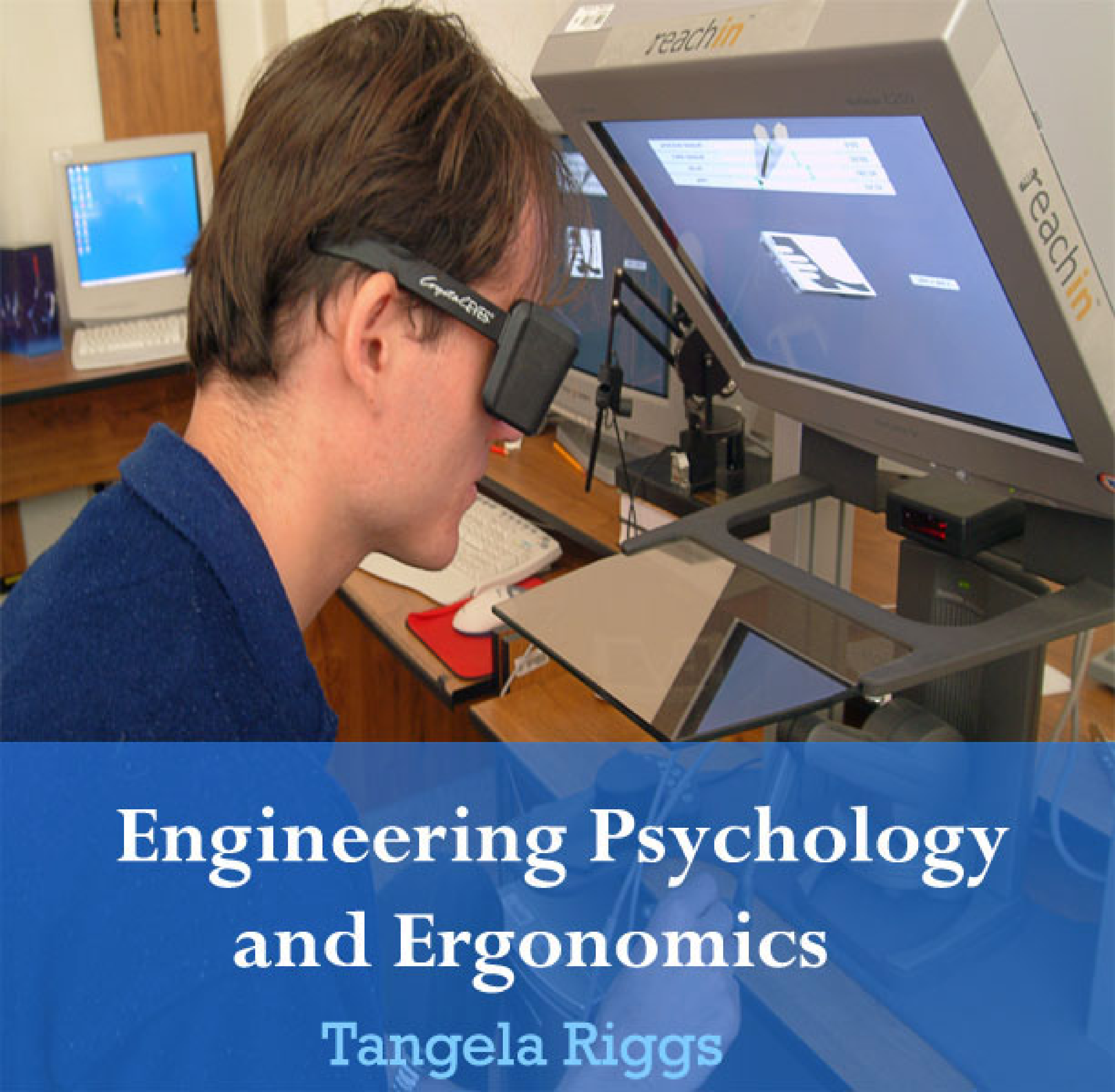

Engineering Psychology and Ergonomics

Tangela Riggs

First Edition, 2012

ISBN 978-81-323-4132-1

Published by:
White Word Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter 1

Ergonomic Keyboard and Human Performance Technology

Ergonomic keyboard

An **ergonomic keyboard** is a computer keyboard designed with ergonomic considerations to minimize muscle strain and a host of related problems.

Keyboard types

Apple Adjustable Keyboard is an adjustable split keyboard

A "fixed-split keyboard" is a single board, with the keys separated into two or three groups, allowing the user to type at a different angle than the typical straight keyboard. A further development of the split concept are keyboards like the Kinesis Advantage line, which place the keys into two depressions set approximately at shoulder width, with function keys set between the key groups for use with the thumbs. In this configuration, very little movement of arms and wrists is required.

An "adjustable split keyboard" has the keyboard split into several independent pieces, so the angle between them can be easily changed. Either of these types of keyboards may include elevated sections at various angles.

Other ergonomic keyboards have fixed, vertically aligned keys, so the user types with their hands perpendicular to the ground, thumbs-up. Still others allow a range of rotation and elevations. A few ergonomic keyboards do not have the typical one key per letter, such as a keyer or a keyless ergonomic keyboard. Datahand eliminates the need for any wrist motion or finger extension.

As sales of ergonomic keyboards increase because of the number of people who develop chronic pain who believe that using the in-line keyboard provided at work, or the keyboard provided by the maker of their PC or built into their laptop, additional designs of ergonomic key boards have reached the market.

Microsoft has introduced two types of ergonomic keyboards. The first design, which Microsoft has made several versions of, uses a curved keyboard with built in numeric key pad on the right hand side. Marked under such names as Comfort Curve Keyboard 2000, Natural Ergonomic Keyboard 4000, Wireless Comfort Desktop 5000, Wireless Keyboard 6000, Wireless Laser Desktop 6000, Wireless Laser Desktop 7000, Natural Ergonomic Desktop 7000.

Microsoft introduced several curved keyboard without a numeric key pad, under the name of Bluetooth Mobile Keyboard 6000, the Arc Keyboard and the Arc Keyboard Special Edition. With a price range between $19.95 for the first design Microsoft introduced, and $129.95 for the highest priced design ergonomic keyboard, Microsoft has become a leader in designing and selling ergonomic keyboards.

Other companies have also introduced their own version of the ergonomic keyboard. One company of note is Key Ovation which makes the Goldtouch ergonomic split keyboard with available Goldtouch wrist pads as a option. Goldtouch has added a compact Goldtouch Go! Travel Keyboard for use by owners of laptops and Goldtouch for Mac Adjustable Keyboard. With a price range between $119.00 to $149.00 for the Goldtouch Smart Card Keyboard for companies and governments agencies that need to keep track of which employees access what data.

Goldtouch also states on their web site that using ergonomic keyboards will pay for themselves with a 40% fewer claims due to RSI. As well as a 80% reduction in RSI-related claim severity (over a 6 month time frame), using Case Studies provided by

Chevron Texaco, San Jose University Research Study, Blue Cross Blue Shield Study, Texaco Belgium, as well as 17 other studies as proof of their statements.

While the Clinton Administration passed a Federal Ergonomic Standard in 1990, it was repealed when George W. Bush took office. California responded to the problem by passing state ergonomic standards that have been upheld in the California court system, applying the law to employers with just 9 employees with just 2 reported documented cases of RMI.

Considerations

Cost

Simple ergonomic keyboards can cost as little as typical keyboards or as much as $995 for high end keyboards.

Advantages

An ergonomic keyboard may reduce muscle strain and reduce risk of carpal tunnel syndrome, but there is no clear evidence of benefit. Manufacturers claim that after a user takes the time to adjust to this style of keyboard, ergnomic keyboards can make typing easier, faster and less awkward, although there is no hard evidence.

Disadvantages

Some ergonomic keyboards are sold at very high prices. Typically ergonomic keyboards also include other premium features such as mechanical or topre switches which radically increase their cost, although does significantly increase lifespan. For simply ergonomically shaped keyboards with no additional features, prices are a little higher than non-shaped keyboards. For a full featured mechanical/topre keyboard, including adjustable splits, prices can be around $250, while premium ergonomic keyboards can cost many hundreds more.

Ergonomic keyboards may take a little practice to get used to, and many people do not want to go to the trouble of adjusting. These keyboards may take more space on a computer table, forcing the mouse to be farther away.

Human performance technology

Human Performance Technology (HPT) - also known as **Human Performance Improvement** (HPI) "uses a wide range of interventions that are drawn from many other disciplines including, total quality management, process improvement, behavioral psychology, instructional systems design, organizational development, and human resources management" (ISPI, 2007).

HPT is a systematic approach to improving individual and organizational performance (Pershing, 2006). HPT is a field of study which is related to Process Improvement, Six Sigma, Lean Six Sigma, Organization Development, Motivation, Instructional technology, Human Factors, learning, performance support systems, knowledge management, and training, and is focused on improving performance at the organization, process and individual performer levels.

HPT stresses a rigorous analysis of the requirements of organization, process and human performance for new design and/or identifying the causes for performance gaps, and attempts to provide new designs and/or solutions to improve and sustain performance, and finally - to evaluate the results against the requirements.

History of HPT

HPT grew out of the fields of educational technology and instructional technology. The term technology is one of the foundational ideas in the field. In application, the word technology refers to applied science. A common misunderstanding is to define technology as media (such as the Internet and Personal Computers).

Another foundational idea of the field comes from Philosophy, in particular epistemology. In short, how can we know the pertinent reality of a situation. Is a human performance problem due to (or best remediated by) an intervention from just one perspective (such as learning). Human Performance Technology has emerged as a field designed to lead practitioners to critically analyse and prescribe, influence business leaders, and develop interventions that are best suited to the performance problem presented.

HPT evolved as a systemic and systematic approach to address complex types of performance issues and to assist in the proper diagnosis and implementation of solutions to close performance gaps among individuals.

The origin of HPT traces mainly to the work of Thomas Gilbert, Geary Rummler, Karen Brethower, Roger Kaufman and Joe Harless. They (Gilbert in particular) were the pioneers of the field. Any serious investigation of early and later citations of Gilbert's work will reveal subsequent academic and professional leaders in the field.

HPT professionals work in many different performance settings such as corporate settings, educational institutions, and the military (Bolin, 2007).

Definitions of the field

Because the field is relatively new, there have been a lot of attempts to define the theory that supports it as a field of professional practice.

The American Society for Training & Development (ASTD) defines *Performance Improvement* as "the process of identifying and analyzing important organizational and individual performance gaps, planning for future performance improvement, designing and developing cost-effective and ethically justifiable interventions to close performance gaps, implementing the interventions, and evaluating the financial and non-financial results."

A 2003–04 Task Force of the International Society for Performance Improvement (ISPI) updated the definition of Human Performance Technology in a March 31, 2004 Report to the ISPI Board: HPT Definition and Criteria Human Performance Technology – An integrated systems approach to improving human performance:

Criteria to judge applications of HPT

1. Is focused on scientific research-based evidence that guide decision making for optimal outcomes ;
2. Considers the larger system;
3. Provides valid and reliable measures of the effectiveness of HPT interventions;
4. Clearly supports the application of HPT interventions that are grounded in prior research or empirical evidence (or are not discouraged by either one). Repeatable HPT success is a hallmark of technology and a foundation of HPT. Conditions vary so it is the expertise of the HPT to research, adapt, and apply.

Assumptions

1. A technology is a set of empirical and scientific principles and their application
2. Human performance technology is the technology concerned with all variables which impact human performance
3. All organizational processes and practices impact the production of valued results, whether positively or negatively and whether those results go measured or unmeasured, acknowledged or not. (Everything that an organization does affects what it accomplishes, whether or not the results are acknowledged or desirable.)
4. The purpose of all organizations is the same: to create value for their stakeholders; this is accomplished by aligning all processes, practices, and resources to maximize the production of that value.
5. We collaborate with and value the expertise of other disciplines; human performance technology becomes the integrator and multiplier.

HPT can become the leverage organizations need to increase improved performance and focus on results using a variety of means and methods.

Standards of practice

The International Society for Performance Improvement (ISPI) codified a series of standards in an effort to raise the quality of HPT practice:

- Focus on Results
- Take a Systems View
- Add Value
- Utilize Partnerships
- Systematic Assessment of Need or Opportunity
- Systematic Cause Analysis
- Systematic Design
- Systematic Development
- Systematic Implementation
- Systematic Evaluation

Chapter 2

Human Factors

Research subject in a human fatigue study.

Human factors science or **human factors technologies** is a multidisciplinary field incorporating contributions from psychology, engineering, industrial design, statistics, operations research and anthropometry. It is a term that covers:

- The science of understanding the properties of human capability (Human Factors Science).
- The application of this understanding to the design, development and deployment of systems and services (Human Factors Engineering).
- The art of ensuring successful application of Human Factors Engineering to a program (sometimes referred to as Human Factors Integration). It can also be called ergonomics.

In general, a *human factor* is a physical or cognitive property of an individual or social behavior which is specific to humans and influences functioning of technological systems as well as human-environment equilibriums.

In social interactions, the use of the term *human factor* stresses the social properties unique to or characteristic of humans.

Human factors involves the study of all aspects of the way humans relate to the world around them, with the aim of improving operational performance, safety, through life costs and/or adoption through improvement in the experience of the end user.

The terms *human factors* and *ergonomics* have only been widely used in recent times; the field's origin is in the design and use of aircraft during World War II to improve aviation safety. It was in reference to the psychologists and physiologists working at that time and the work that they were doing that the terms "applied psychology" and “ergonomics” were first coined. Work by Elias Porter, Ph.D. and others within the RAND Corporation after WWII extended these concepts. "As the thinking progressed, a new concept developed - that it was possible to view an organization such as an air-defense, man-machine system as a single organism and that it was possible to study the behavior of such an organism. It was the climate for a breakthrough."

Specialisations within this field include cognitive ergonomics, usability, human computer/ human machine interaction, and user experience engineering. New terms are being generated all the time. For instance, “user trial engineer” may refer to a human factors professional who specialises in user trials. Although the names change, human factors professionals share an underlying vision that through application of an understanding of human factors the design of equipment, systems and working methods will be improved, directly affecting people’s lives for the better.

Human factors practitioners come from a variety of backgrounds, though predominantly they are psychologists (engineering, cognitive, perceptual, and experimental) and physiologists. Designers (industrial, interaction, and graphic), anthropologists, technical communication scholars and computer scientists also contribute. Though some practitioners enter the field of human factors from other disciplines, both M.S. and Ph.D. degrees in Human Factors Engineering are available from several universities worldwide.

The Formal History of American Human Factors Engineering

The formal history describes activities in known chronological order. This can be divided into 5 markers:

Developments prior to World War I

Prior to WWI the only test of human to machine compatibility was that of trial and error. If the human functioned with the machine, he was accepted, if not he was rejected. There was a significant change in the concern for humans during the American civil war. The US patent office was concerned whether the mass produced uniforms and new weapons could be used by the infantry men. The next development was when the American inventor Simon Lake tested submarine operators for psychological factors, followed by the scientific study of the worker. This was an effort dedicated to improve the efficiency of humans in the work place. These studies were designed by F W Taylor. The next step was the derivation of formal time and motion study from the studies of Frank Gilbreth, Sr. and Lillian Gilbreth.

Developments during World War I

With the onset of WWI, more sophisticated equipment was developed. The inability of the personnel to use such systems led to an increase in interest in human capability. Earlier the focus of aviation psychology was on the aviator himself. But as time progressed the focus shifted onto the aircraft, in particular, the design of controls and displays, the effects of altitude and environmental factors on the pilot. The war saw the emergence of aeromedical research and the need for testing and measurement methods. Still, the war did not create a Human Factors Engineering (HFE) discipline, as such. The reasons attributed to this are that technology was not very advanced at the time and America's involvement in the war only lasting for 18 months.

Developments between World War I and World War II

This period saw relatively slow development in HFE. Although, studies on driver behaviour started gaining momentum during this period, as Henry Ford started providing millions of Americans with automobiles. Another major development during this period was the performance of aeromedical research. By the end of WWI, two aeronautical labs were established, one at Brooks Airforce Base, Texas and the other at Wright field outside of Dayton, Ohio. Many tests were conducted to determine which characteristic differentiated the successful pilots from the unsuccessful ones. During the early 1930s, Edwin Link developed the first flight simulator. The trend continued and more sophisticated simulators and test equipment were developed. Another significant development was in the civilian sector, where the effects of illumination on worker productivity were examined. This led to the identification of the Hawthorne Effect, which suggested that motivational factors could significantly influence human performance.

Developments during World War II

With the onset of the WW II, it was no longer possible to adopt the Tayloristic principle of matching individuals to preexisting jobs. Now the design of equipment had to take into account human limitations and take advantage of human capabilities. This change took time to come into place. There was a lot of research conducted to determine the human capabilities and limitations that had to be accomplished. A lot of this research took off where the aeromedical research between the wars had left off. An example of this is the study done by Fitts and Jones (1947), who studied the most effective configuration of control knobs to be used in aircraft cockpits. A lot of this research transcended into other equipment with the aim of making the controls and displays easier for the operators to use. After the war, the Army Air Force published 19 volumes summarizing what had been established from research during the war.

Developments after World War II

In the initial 20 years after the WW II, most activities were done by the founding fathers: Alphonse Chapanis, Paul Fitts, and Small. The beginning of cold war led to a major expansion of Defense supported research laboratories. Also, a lot of labs established during the war started expanding. Most of the research following the war was military sponsored. Large sums of money were granted to universities to conduct research. The scope of the research also broadened from small equipments to entire workstations and systems. Concurrently, a lot of opportunities started opening up in the civilian industry. The focus shifted from research to participation through advice to engineers in the design of equipment. After 1965, the period saw a maturation of the discipline. The field has expanded with the development of the computer and computer applications.

Founded in 1957, the Human Factors and Ergonomics Society is the world's largest organization of professionals devoted to the science of human factors and ergonomics. The Society's mission is to promote the discovery and exchange of knowledge concerning the characteristics of human beings that are applicable to the design of systems and devices of all kinds.

The Cycle of Human Factors

Human Factors involves the study of factors and development of tools that facilitate the achievement of these goals. In the most general sense, the three goals of human factors are accomplished through several procedures in the human factors cycle, which depicts the human operator (brain and body) and the system with which he or she is interacting. First it is necessary to diagnose or identify the problems and deficiencies in the human-system interaction of an existing system. After defining the problems there are five different approaches that can be used in order to implement the solution. These are as follows:

- *Equipment Design:* changes the nature of the physical equipment with which humans work.
- *Task Design:* focuses more on changing what operators do than on changing the devices they use. This may involve assigning part or all of tasks to other workers or to automated components.
- *Environmental Design:* implements changes, such as improved lighting, temperature control and reduced noise in the physical environment where the task is carried out.
- *Training the individuals:* better preparing the worker for the conditions that he or she will encounter in the job environment by teaching and practicing the necessary physical or mental skills.
- *Selection of individuals:* is a technique that recognizes the individual differences across humans in every physical and mental dimension that is relevant for good system performance. Such a performance can be optimized by selecting operators who possess the best profile of characteristics for the job.

Human Factors Science

Human factors are sets of human-specific physical, cognitive, or social properties which either may interact in a critical or dangerous manner with technological systems, the human natural environment, or human organizations, or they can be taken under consideration in the design of ergonomic human-user oriented equipment. The choice or identification of human factors usually depends on their possible negative or positive impact on the functioning of human-organizations and human-machine systems.

The human-machine model

The simple human-machine model is a person interacting with a machine in some kind of environment. The person and machine are both modeled as information-processing devices, each with inputs, central processing, and outputs. The inputs of a person are the senses (e.g., eyes, ears) and the outputs are effectors (e.g., hands, voice). The inputs of a machine are input control devices (e.g., keyboard, mouse) and the outputs are output display devices (e.g., screen, auditory alerts). The environment can be characterized physically (e.g., vibration, noise, zero-gravity), cognitively (e.g., time pressure, uncertainty, risk), and/or organizationally (e.g., organizational structure, job design). This provides a convenient way for organizing some of the major concerns of human engineering: the selection and design of machine displays and controls; the layout and design of workplaces; design for maintainability; and the design of the work environment.

Example: Driving an automobile is a familiar example of a simple man-machine system. In driving, the operator receives inputs from outside the vehicle (sounds and visual cues from traffic, obstructions, and signals) and from displays inside the vehicle (such as the speedometer, fuel indicator, and temperature gauge). The driver continually evaluates this information, decides on courses of action, and translates those decisions into actions upon the vehicle's controls—principally the accelerator, steering wheel, and brake. Finally, the driver is influenced by such environmental factors as noise, fumes, and temperature.

No matter how important it may be to match an individual operator to a machine, some of the most challenging and complex human problems arise in the design of large man-machine systems and in the integration of human operators into these systems. Examples of such large systems are a modern jet airliner, an automated post office, an industrial plant, a nuclear submarine, and a space vehicle launch and recovery system. In the design of such systems, human-factors engineers study, in addition to all the considerations previously mentioned, three factors: personnel, training, and operating procedures.

- *Personnel* are trained; that is, they are given appropriate information and skills required to operate and maintain the system. System design includes the development of training techniques and programs and often extends to the design of training devices and training aids.

- *Instructions, operating procedures, and rules* set forth the duties of each operator in a system and specify how the system is to function. Tailoring operating rules to the requirements of the system and the people in it contributes greatly to safe, orderly, and efficient operations.

Human Factors Engineering

Human Factors Engineering (HFE) is the discipline of applying what is known about human capabilities and limitations to the design of products, processes, systems, and work environments. It can be applied to the design of all systems having a human interface, including hardware and software. Its application to system design improves ease of use, system performance and reliability, and user satisfaction, while reducing operational errors, operator stress, training requirements, user fatigue, and product liability. HFE is distinctive in being the only discipline that relates humans to technology.

Human factors engineering focuses on how people interact with tasks, machines (or computers), and the environment with the consideration that humans have limitations and capabilities. Human factors engineers evaluate "Human to Human," "Human to Group," "Human to Organizational," and "Human to Machine (Computers)" interactions to better understand these interactions and to develop a framework for evaluation.

Human Factors engineering activities include: 1. Usability assurance 2. Determination of desired user profiles 3. Development of user documentation 4. Development of training programs.

Usability assurance

Usability assurance is an interdisciplinary concept, integrating system engineering with Human Factors engineering methodologies. Usability assurance is achieved through the system or service design, development, evaluation and deployment.

- User interface design comprises physical (ergonomic) design, interaction design and layout design.
- Usability development comprises integration of human factors in project planning and management, including system specification documents: requirements, design and testing.
- Usability evaluation is a continuous process, starting with the operational requirements specification, through prototypes of the user interfaces, through usability alpha and beta testing, and through manual and automated feedback after the system has been deployed.

User Interface Design

Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. This is a well known subject of Human Factors within the Engineering field. There are many different ways to determine human computer interaction at the user interface by usability testing.

Human Factors Evaluation Methods

Human Factors evaluation methods are part of Human Factors methodology, which is part of Human Factors Engineering.

Besides evaluation, Human Factors Engineering also deals with methods for usability assurance, for assessing desired user profiles, for developing user documentation and training programs, etc.

Until recently, methods used to evaluate human factors ranged from simple questionnaires to more complex and expensive usability labs.

Recently, new methods were proposed, based on analysis of logs of the activity of the system users.

Actually, the work in usability labs and that of the new methods is part of Usability Engineering, which is part of Human Factors Engineering.

Brief Summary of Human Factors Evaluation Methods

Ethnographic analysis: Using methods derived from ethnography, this process focuses on observing the uses of technology in a practical environment. It is a qualitative and observational method that focuses on "real-world" experience and pressures, and the usage of technology or environments in the workplace. The process is best used early in the design process.

Focus Groups: Focus groups are another form of qualitative research in which one individual will facilitate discussion and elicit opinions about the technology or process under investigation. This can be on a one to one interview basis, or in a group session. Can be used to gain a large quantity of deep qualitative data, though due to the small sample size, can be subject to a higher degree of individual bias. Can be used at any point in the design process, as it is largely dependent on the exact questions to be pursued, and the structure of the group. Can be extremely costly.

Iterative design: Also known as prototyping, the iterative design process seeks to involve users at several stages of design, in order to correct problems as they emerge. As prototypes emerge from the design process, these are subjected to other forms of analysis as outlined here, and the results are then taken and incorporated into the new design. Trends amongst users are analyzed, and products redesigned. This can become a costly process, and needs to be done as soon as possible in the design process before designs become too concrete.

Meta-analysis: A supplementary technique used to examine a wide body of already existing data or literature in order to derive trends or form hypotheses in order to aid design decisions. As part of a literature survey, a meta-analysis can be performed in order to discern a collective trend from individual variables.

Subjects-in-tandem: Two subjects are asked to work concurrently on a series of tasks while vocalizing their analytical observations. This is observed by the researcher, and can be used to discover usability difficulties. This process is usually recorded.

Surveys and Questionnaires: A commonly used technique outside of Human Factors as well, surveys and questionnaires have an advantage in that they can be administered to a large group of people for relatively low cost, enabling the researcher to gain a large amount of data. The validity of the data obtained is, however, always in question, as the questions must be written and interpreted correctly, and are, by definition, subjective. Those who actually respond are in effect self-selecting as well, widening the gap between the sample and the population further.

Task analysis: A process with roots in activity theory, task analysis is a way of systematically describing human interaction with a system or process to understand how to match the demands of the system or process to human capabilities. The complexity of this process is generally proportional to the complexity of the task being analyzed, and so can vary in cost and time involvement. It is a qualitative and observational process. Best used early in the design process.

Think aloud protocol: Also known as "concurrent verbal protocol", this is the process of asking a user to execute a series of tasks or use technology, while continuously verbalizing their thoughts so that a researcher can gain insights as to the users' analytical process. Can be useful for finding design flaws that do not affect task performance, but may have a negative cognitive affect on the user. Also useful for utilizing experts in order to better understand procedural knowledge of the task in question. Less expensive than focus groups, but tends to be more specific and subjective.

User analysis: This process is based around designing for the attributes of the intended user or operator, establishing the characteristics that define them, creating a persona for the user. Best done at the outset of the design process, a user analysis will attempt to predict the most common users, and the characteristics that they would be assumed to have in common. This can be problematic if the design concept does not match the actual user, or if the identified are too vague to make clear design decisions from. This process is, however, usually quite inexpensive, and commonly used.

"Wizard of Oz": This is a comparatively uncommon technique but has seen some use in mobile devices. Based upon the Wizard of Oz experiment, this technique involves an operator who remotely controls the operation of a device in order to imitate the response of an actual computer program. It has the advantage of producing a highly changeable set of reactions, but can be quite costly and difficult to undertake.

Problems with Human Factors Methods

Problems in how usability measures are employed include:
(1) measures of learning and retention of how to use an interface are rarely employed during methods and

(2) some studies treat measures of how users interact with interfaces as synonymous with quality-in-use, despite an unclear relation.

Weakness of Usability Lab Testing

Although usability lab testing is believed to be the most influential evaluation method, it does have some limitations. These limitations include:
(1) Additional resources and time than other methods
(2) Usually only examines a fraction of the entire market segment
(3) Test scope is limited to the sample tasks chosen
(4) Long term ease-of-use problems are difficult to identify
(5) May reveal only a fraction of total problems
(6) Laboratory setting excludes factors that the operational environment places on the products usability

Weakness of Inspection Methods

Inspection methods (expert reviews and walkthroughs) can be accomplished quickly, without resources from outside the development team, and does not require the research expertise that usability tests need. However, inspection methods do have limitations, which include:
(1) Do not usually directly involve users
(2) Often do not involve developers
(3) Set up to determine problems and not solutions
(4) Do not foster innovation or creative solutions
(5) Not good at persuading developers to make product improvements

Weakness of Surveys, Interviews, and Focus Groups

These traditional human factors methods have been adapted, in many cases, to assess product usability. Even though there are several surveys that are tailored for usability and that have established validity in the field, these methods do have some limitations, which include:
(1) Reliability of all surveys is low with small sample sizes (10 or less)
(2) Interview lengths restricts use to a small sample size
(3) Use of focus groups for usability assessment has highly debated value
(4) All of these methods are highly dependent on the respondents

Weakness of Field Methods

Although field methods can be extremely useful because they are conducted in the users natural environment, they have some major limitations to consider. The limitations include:
(1) Usually take more time and resources than other methods
(2) Very high effort in planning, recruiting, and executing than other methods
(3) Much longer study periods and therefore requires much goodwill among the

participants
(4) Studies are longitudinal in nature, therefore, attrition can become a problem.

Application of Human Factors Engineering

An Example: Human Factors Engineering Applied to the Military

Before World War II, HFE had no significance in the design of machines. Consequently, many fatal human errors during the war were directly or indirectly related to the absence of comprehensive HFE analyses in the design and manufacturing process. One of the reasons for so many costly errors was the fact that the capabilities of the human were not clearly differentiated from those of the machine.

Furthermore, human performance capabilities, skill limitation, and response tendencies were not adequately considered in the designs of the new systems that were being produced so rapidly during the war. For example, pilots were often trained on one generation of aircraft, but by the time they got to the war zone, they were required to fly a newer model. The newer model was usually more complex than the older one and, even more detrimental, the controls may have had opposing functions assigned to them. Some aircraft required that the control stick be pulled back toward the pilot in order to pull the nose up. In other aircraft the exact opposite was required; namely, in order to ascend you would push the stick away from you. Needless to say, in an emergency situation many pilots became confused and performed the incorrect maneuver, with disastrous results.

Along the same line, pilots were subject to substitution errors due mostly to lack of uniformity of control design, inadequate separation of controls, or the lack of a coding system to help the pilot identify controls by the sense of touch alone. For example, in the early days of retractable landing gear, pilots often grabbed the wrong lever and mistakenly raised the landing gear instead of the flaps. Sensory overload also became a problem, especially in cockpit design. The 1950s brought a strong program of standardizing control shapes, locations and overload management.

The growth of human factors engineering during the mid- to late-forties was evidenced by the establishment of several organizations to conduct psychological research on equipment design. Toward the end of 1945, Paul Fitts established what came to be known as the Behavioral Sciences Laboratory at the Army Corps Aeromedical Laboratory in Dayton, Ohio. Around the same time, the U.S. Navy established the Naval Research Laboratory at Anacostia, Maryland (headed by Frank V. Taylor), and the Navy Special Devices Center at Port Washington, New York (headed by Leonard C. Mead). The Navy Electronics Laboratory in San Diego, California, was established about a year later with Arnold M. Small as head.

In addition to the establishment of these military organizations, the human factors discipline expanded within several civilian activities. Contract support was provided by the U.S. Navy and the U.S. Air Force for research at several noted universities, specifically Johns Hopkins, Tufts, Harvard, Maryland, Holyoke, and California

(Berkeley). Paralleling this growth was the establishment of several private corporate ventures. Thus, as a direct result of the efforts of World War II, a new industry known as engineering psychology or human factors engineering was born.

Why is HFE important to the military?

Until today, many project managers and designers are still slow to consider Human Factors Engineering (HFE) as an essential and integral part of the design process. This is sometimes due to their lack of education on the purpose of HFE, in other instances it is due to others being perfectly capable of considering HFE related issues. Nevertheless, progress is being made as HFE is becoming more and more accepted and is now implemented in a wide variety of applications and processes. The U.S. military is particularly concerned with the implementation of HFE in every phase of the acquisition process of its systems and equipment. Just about every piece of gear, from a multi-billion dollar aircraft carrier to the boots that servicemen wear, goes at least in part through some HFE analyses before procurement and throughout its lifecycle.

Lessons learned in the aftermath of World War II prompted the U.S. War Department (now U.S. Department of Defense) to take some steps in improving safety in military operations. U.S. Department of Defense regulations require a comprehensive management and technical strategy for human systems integration (HSI) be initiated early in the acquisition process to ensure that human performance is considered throughout the system design and development process.

HFE applications in the U.S. Army

In the U.S. Army, the term MANPRINT is used as the program designed to implement HSI. The program was established in 1984 with a primary objective to place the human element (functioning as individual, crew/team, unit and organization) on an equal footing with other design criteria such as hardware and software. The entry point of MANPRINT in the acquisition process is through requirements documents and studies.

What is MANPRINT?

MANPRINT (Manpower and Personnel Integration) is a comprehensive management and technical program that focuses attention on human capabilities and limitations throughout the system’s life cycle: concept development, test and evaluation, documentation, design, development, fielding, post-fielding, operation and modernization of systems. It was initiated in recognition of the fact that the human is an integral part of the total system. If the human part of the system can't perform efficiently, the entire system will function sub-optimally.

MANPRINT's goal is to optimize total system performance at acceptable cost and within human constraints. This is achieved by the continuous integration of seven human-related considerations (known as MANPRINT domains) with the hardware and software components of the total system and with each other, as appropriate. The seven

MANPRINT domains are: Manpower (M), Personnel (P), Training (T), Human Factors Engineering (HFE), System Safety (SS), Health Hazards (HH), Soldier Survivability (SSv). They are each expounded on below:

Manpower (M)

Manpower addresses the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for systems. It is the number of personnel spaces (required or authorized positions) and available people (operating strength). It considers these requirements for peacetime, conflict, and low intensity operations. Current and projected constraints on the total size of the Army/organization/unit are also considered. The MANPRINT practitioner evaluates the manpower required and/or available to support a new system and subsequently considers these constraints to ensure that the human resource demands of the system do not exceed the projected supply.

Personnel (P)

Manpower and personnel are closely related. While manpower looks at numbers of spaces and people, the domain of personnel addresses the cognitive and physical characteristics and capabilities required to be able to train for, operate, maintain, and sustain materiel and information systems. Personnel capabilities are normally reflected as knowledge, skills, abilities, and other characteristics (KSAOs). The availability of personnel and their KSAOs should be identified early in the acquisition process and may result in specific thresholds. On most systems, emphasis is placed on enlisted personnel as the primary operators, maintainers, and supporters of the system. Personnel characteristics of enlisted personnel are easier to quantify since the Armed Services Vocational Aptitude Battery (ASVAB) is administered to potential enlistees.

While normally enlisted personnel are operators and maintainers; that is not always the case, especially in aviation systems. Early in the requirements determination process, identification of the target audience should be accomplished and used as a baseline for assessment. Cognitive and physical demands of the system should be assessed and compared to the projected supply. MANPRINT also takes into consideration personnel factors such as availability, recruitment, skill identifiers, promotion, and assignment.

Training (T)

Training is defined as the instruction or education, on-the-job, or self development training required to provide all personnel and units with their essential job skills, and knowledge. Training is required to bridge the gap between the target audiences' existing level of knowledge and that required to effectively operate, deploy/employ, maintain and support the system. The MANPRINT goal is to acquire systems that meet the Army's training thresholds for operation and maintenance. Key considerations include developing an affordable, effective and efficient training strategy (which addresses new equipment, training devices, institutional, sustainment, and unit collective tactical training);

determining the resources required to implement it in support of fielding and the most efficient method for dissemination (contractor, distance learning, exportable packages, etc.); and evaluating the effectiveness of the training.

Training is particularly crucial in the acquisition and employment of a new system. New tasks may be introduced into a duty position; current processes may be significantly changed; existing job responsibilities may be redefined, shifted, or eliminated; and/or entirely new positions may be required. It is vital to consider the total training impact of the system on both the individuals and the organization as a whole.

Human Factors Engineering (HFE)

The goal of HFE is to maximize the ability of an individual or crew to operate and maintain a system at required levels by eliminating design-induced difficulty and error. Human factors engineers work with systems engineers to design and evaluate human-system interfaces to ensure they are compatible with the capabilities and limitations of the potential user population. HFE is conducted during all phases of system development, to include requirements specification, design and testing and evaluation. HFE activities during requirements specification include: evaluating predecessor systems and operator tasks; analyzing user needs; analyzing and allocating functions; and analyzing tasks and associated workload. During the design phase, HFE activities include: evaluating alternative designs through the use of equipment mockups and software prototypes; evaluating software by performing usability testing; refining analysis of tasks and workload; and using modeling tools such as human figure models to evaluate crew station and workplace design and operator procedures. During the testing and evaluation phase, HFE activities include: confirming the design meets HFE specification requirements; measuring operator task performance; and identifying any undesirable design or procedural features.

System Safety (SS)

System Safety is the design features and operating characteristics of a system that serve to minimize the potential for human or machine errors or failures that cause injurious accidents. Safety considerations should be applied in system acquisition to minimize the potential for accidental injury of personnel and mission failure.

Health Hazards (HH)

Health Hazards addresses the design features and operating characteristics of a system that create significant risks of bodily injury or death. Along with safety hazards, an assessment of health hazards is necessary to determine risk reduction or mitigation. The goal of the Health Hazard Assessment (HHA) is to incorporate biomedical knowledge and principles early in the design of a system to eliminate or control health hazards. Early application will eliminate costly system retrofits and training restrictions resulting in enhanced soldier-system performance, readiness and cost savings. HHA is closely related to occupational health and preventive medicine but gets its distinctive character from its emphasis on soldier-system interactions of military unique systems and operations.

Health Hazard categories include acoustic energy, biological substances, chemical substances, oxygen deficiency, radiation energy, shock, temperature extremes and humidity, trauma, vibration, and other hazards. Health hazards include those areas that could cause death, injury, illness, disability, or a reduction in job performance.

Organisational and Social

The seventh domain addresses the human factors issues associated with the socio-technical systems necessary for modern warfare. This domain has been recently added to investigate issues specific to Network Enabled Capability (NEC) also known as Network Centric Warfare (NCW). Elements such as dynamic command and control structures, data assimilation across mulitple platforms and its fusion into information easily understood by distributed operators are some of the issues investigated.

A soldier survivability domain was also proposed but this was never fully integrated into the MANPRINT model.

Domain Integration

Although each of the MANPRINT domains has been introduced separately, in practice they are often interrelated and tend to impact on one another. Changes in system design to correct a deficiency in one MANPRINT domain nearly always impact another domain.

Human Factors Integration

Areas of interest for human factors practitioners may include: training, staffing evaluation, communication, task analyses, functional requirements analyses and allocation, job descriptions and functions, procedures and procedure use, knowledge, skills, and abilities; organizational culture, human-machine interaction, workload on the human, fatigue, situational awareness, usability, user interface, learnability, attention, vigilance, human performance, human reliability, human-computer interaction, control and display design, stress, visualization of data, individual differences, aging, accessibility, safety, shift work, work in extreme environments including virtual environments, human error, and decision making.

Real World Applications of Human Factors - MultiModal Interfaces

Multi-Modal Interfaces

In many real world domains, ineffective communication occurs partially because of inappropriate and ineffective presentation of information. Many real world interfaces both allow user input and provide user output in a single modality (most often being either visual or auditory). This single modality presentation can often lead to data overload in that modality causing the user to become overwhelmed by information and cause him/her to overlook something. One way to address this issue is to use multi-modal interfaces.

Reasons to Use Multimodal Interfaces

- Time Sharing – helps avoid overloading one single modality
- Redundancy – providing the same information in two different modalities helps assure that the user will see the information

- Allows for more diversity in users (blind can use tactile input; hearing impaired can use visual input and output)

- Error Prevention – having multiple modalities allows the user to choose the most appropriate modality for each task (for example, spatial tasks are best done in a visual modality and would be much harder in an olfactory modality)

Examples of Well Known Multi-Modality Interfaces

- Cell Phone – The average cell phone uses auditory, visual, and tactile output through use of a phone ringing, vibrating, and a visual display of caller ID.

- ATM – Both auditory and visual outputs

Early Multi-Modal Interfaces by the Experts

- Bolts “Put That There” – 1980 – used speech and manual pointing

- Cohen and Oviatt’s “Quickset” – multi user speech and gesture input

Worker Safety and Health

One of the most prevalent types of work-related injuries are musculoskeletal disorders. Work-related musculoskeletal disorders (WRMDs) result in persistent pain, loss of functional capacity and work disability, but their initial diagnosis is difficult because they are mainly based on complaints of pain and other symptoms. Every year 1.8 million U.S. workers experience WRMDs and nearly 600,000 of the injuries are serious enough to cause workers to miss work. Certain jobs or work conditions cause a higher rate worker complaints of undue strain, localized fatigue, discomfort, or pain that does not go away after overnight rest. These types of jobs are often those involving activities such as repetitive and forceful exertions; frequent, heavy, or overhead lifts; awkward work positions; or use of vibrating equipment. The Occupational Safety and Health Administration (OSHA) has found substantial evidence that ergonomics programs can cut workers' compensation costs, increase productivity and decrease employee turnover. Therefore, it is important to gather data to identify jobs or work conditions that are most problematic, using sources such as injury and illness logs, medical records, and job analyses.

Job analysis can be carried out using methods analysis, time studies, work sampling, or other established work measurement systems.

- Methods Analysis is the process of studying the tasks a worker completes using a step-by-step investigation. Each task in broken down into smaller steps until each motion the worker performs is described. Doing so enables you to see exactly where repetitive or straining tasks occur.

- Time studies determine the time required for a worker to complete each task. Time studies are often used to analyze cyclical jobs. They are considered "event based" studies because time measurements are triggered by the occurrence of predetermined events.

- Work Sampling is a method in which the job is sampled at random intervals to determine the proportion of total time spent on a particular task. It provides insight into how often workers are performing tasks which might cause strain on their bodies.

- Predetermined time systems are methods for analyzing the time spent by workers on a particular task. One of the most widely used predetermined time system is called Methods-Time-Measurement or MTM. Other common work measurement systems include MODAPTS and MOST.

Chapter 3

Computer-Aided Ergonomics and Human-Machine System

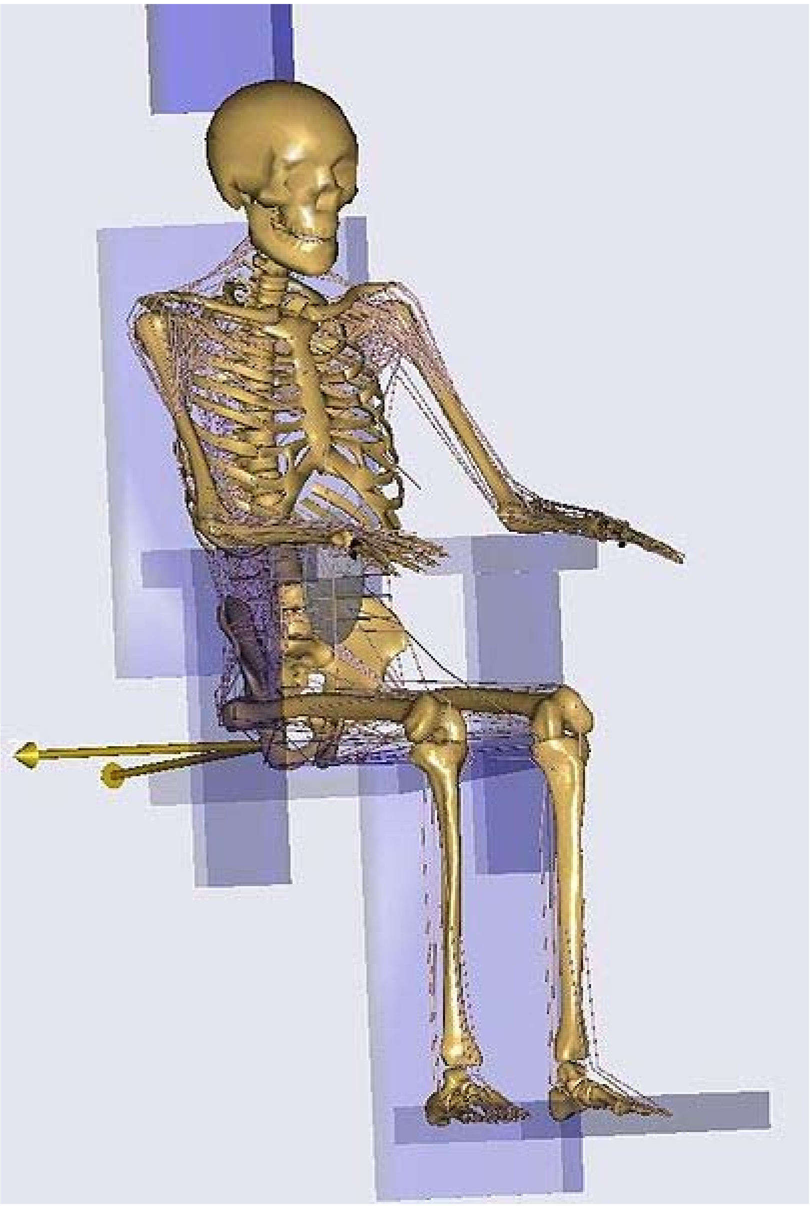
Computer-aided ergonomics

Computer-aided ergonomics is an engineering discipline using computers to solve complex ergonomic problems involving interaction between the human body and its environment. The human body holds a great complexity thus it can be beneficial to use computers to solve problems involving the human body and the environment that surrounds it.

Overview

Computer-aided ergonomics is an interdisciplinary field of work that involves the use of a computer to solve complex problems regarding a human body interacting with an environment. As the title reveals, having a computer to help find the best ergonomic solution in a given situation. Ergonomics traditionally involves many disciplines including biomechanics, anthropometry, mechanical engineering, industrial engineering, kinesiology, health sciences and physiology. Due to the highly interdisciplinary and complex nature of ergonomics it is hard to get a full understanding of a situation. As the human body is a complex system, thus it is beneficial to have a computer system that models the human body as a mechanical system. The human body contains several parts that can be modeled as known mechanical systems, for example bones connected with joints and driven by actuators (muscles).

Example of a system



Example of a skeletal mannequin

One example of a computer system that can be used as a computer-aided ergonomics system is that consider the human body as a dynamic multi-rigid-body system. The human model is a public domain model contains most of the bones, muscles and joints that are present in the human body. The model in total have more than 1000 muscle elements, and many muscle elements have been modeled with the most detailed muscle model theory described by Hill, A.V. in 1938. The muscle model contains information as physiological cross-sectional area, length, penation angle, ratio of red and white fibers and so on. The AnyBody modeling system is capable of modeling almost any human voluntary movement or static situation. One example of a model, could be a seated model, where the human body is placed in a chair, that have a seat, backrest, headrest, leg rest, footrest, and armrest. The model can then calculate the forces acting between the human body and the chair, as well as for example the forces between any given spinal vertebra. This could be used for finding the optimal seated posture for a person, who suffers from lower back pain, assuming that greater load on a vertebra result in greater pain.

Benefits of computer-aided ergonomics

The question is "In what scenario" it would be beneficial to use computer-aided ergonomics compared to traditional ergonomics. First of all computer aided ergonomics using for example a musculo-skeletal modeling system as The [AnyBody Modeling system], would be beneficial in physical ergonomics, which traditional combines aspects from the human anatomical, anthropometric, physiological and biomechanical characteristics related to some physical activity. The model can provide a quantitative foundation for ergonomic design and recommendations. Traditionally "Ergonomics" has been based on recommendations derived from empirical data from various working tasks; if many people get injured from working in a certain posture, it is recommended to avoid working in that posture. However, when applying the recommendations to another related working posture, the posture or the movement often does not match exactly. This means that the theory and recommendations does not apply to the new situation. In this case it could be beneficial to model the situation in order to find out how the reaction forces and muscle activities differ from the first situation, where the recommendations were based on empirical data. A combination of risk factors can be derived from the model output. For example, when designing an office chair, one would like to design it to fulfill several demands; comfortable, relaxing, supporting and so on. Some of the criteria related to the demands might be conflicting for example; comfort is often related to the shear force on the seat, which should be kept as low as possible. The seat shear force could be removed by making a horizontal seat and rising the backrest to 90 degrees however this would not be relaxing. Therefore, a combination of seat and backrest angles needs to be considered in order to find optimal seated postures related to only the two design variables. Computer-aided ergonomics is an interdisciplinary field of work, that involve the use of a computer to solve complex problems that involve a person interacting with an environment. As the title reveals, it is all about having a computer to help finding the best ergonomic solution. Ergonomics involves many disciplines, such as biomechanics, anthropometry, mechanical engineering, industrial engineering, kinesiology, health sciences and physiology. Due to the highly interdisciplinary it is hard to get a full understanding of a situation based on knowledge, unless the knowledge in some way is build into a computer system.

Human-machine system

Human-machine system is a system in which the functions of a human operator (or a group of operators) and a machine are integrated. This term can also be used to emphasize the view of such a system as a single entity that interacts with external environment.

A manual system consists of hand tools and other aids which are coupled by a human operator who controls the operation. Operators of such systems use their own physical energy as the power source. The system could range from a person with a hammer to a person with a super-strength giving exoskeleton.

Human machine system engineering is different from the more general and well known fields like human-computer interaction and sociotechnical engineering in that it focuses on complex, dynamic control systems that often are partially automated (such as flying an airplane). it also studies human problem-solving in naturalistic settings or in high-fidelity simulation environments.

Human-Machine Choreography

The area of human-machine choreography is yet to be extensively explored. How body structure can be extended through machine mechanisms points to how the body can perform beyond its biological form and functions as well as beyond the local space it inhabits. How human movement is transduced into machine motion and then can be both expressed and extended into virtual performance on the web promises new possibilities in both conceptual approach and aesthetic application. For example, incorporating virtual camera views of the performing human-machine system enriches the choreography and intensifies the artistic result.

The Muscle Machine

A prototype of the Muscle Machine with a human pilot

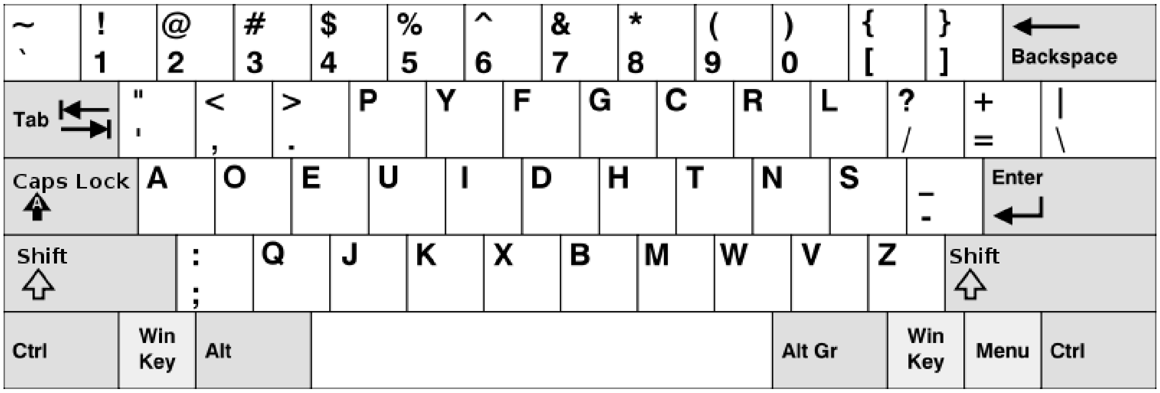
The Muscle Machine is a hybrid human-robot walking machine. Designed by artist James Stelarc (who has also created other such systems), it is an exoskeleton with 6 robotic legs that are controlled by the leg and hand movements of its pilot.

Mechanism

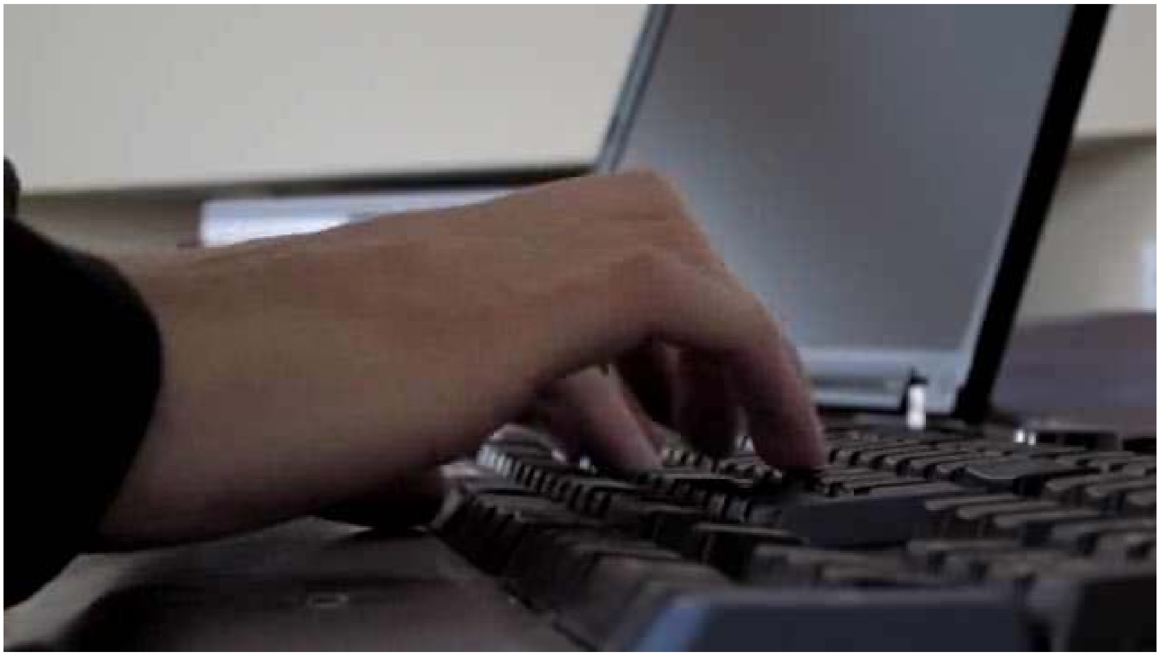
The rubber muscles contract when inflated and extend when exhausted. This results in a more reliable and robust engineering design. The body stands on the ground within the chassis of the machine, which incorporates a lower body exoskeleton connecting it to the robot. Encoders on the hip joints provides the data that will allow the human controller to move and direct the machine as well as vary the speed at which it will travel. The action of the human operator lifting a leg lifts the three alternate machine legs and swings them forward. By turning its torso, the body makes the machine walk in the direction it is facing. Thus the interface and interaction is more direct, allowing an intuitive human-machine choreography. The walking system, with attached accelerometer sensors generates data that is converted to sounds that augment the acoustical pneumatics and machine mechanism operation. Once the machine is in motion, it is no longer applicable to ask whether the human or machine is in control as they become fully integrated and move as one. The 6-legged robot both extends the body and transforms its bipedal gait into a 6-legged insect-like movement. The appearance and movement of the machine legs are both limb-like and winglike motion.

Chapter 4

Dvorak Simplified Keyboard



The modern Dvorak Simplified Keyboard (US layout)



Typing a text excerpt at 115 WPM with the Canadian French Dvorak keyboard layout.

The **Dvorak Simplified Keyboard** is a keyboard layout patented in 1936 by Dr. August Dvorak and his brother-in-law, Dr. William Dealey. Over the years several slight variations were designed by the team led by Dvorak or by ANSI. These variations have been collectively or individually also called the **Simplified Keyboard** or **American Simplified Keyboard** but they all have come to be commonly known as the **Dvorak keyboard** or **Dvorak layout**. Dvorak proponents claim the Dvorak layout uses less finger motion, increases typing rate, and reduces errors compared to the standard QWERTY keyboard. This reduction in finger distance travelled was originally purported to permit faster rates of typing, but in later years was also purported to reduce repetitive strain injuries, including carpal tunnel syndrome.

Although the Dvorak Simplified Keyboard ("DSK") has failed to displace the QWERTY keyboard, it has become easier to access in the computer age, being compatible with all major operating systems (such as Microsoft Windows, Mac OS X, Linux and BSD) in addition to the standard QWERTY layout. Most major operating systems have the option of toggling to the Dvorak layout. It is also supported at the hardware level by some high-end ergonomic keyboards.

Overview

Demonstration of wear pattern when using Dvorak layout on a QWERTY keyboard. There is heavy wear along the home row.

The Dvorak layout was designed to replace the QWERTY keyboard layout (the de facto standard keyboard layout, so named for the starting letters in the top row), in which keys are arranged to avoid mechanical jams on the first generation of economically successful typewriters. The original QWERTY keyboard suffers from many problems that Dvorak himself identified:

- Many common letter combinations require awkward finger motions.
- Many common letter combinations are typed with the same finger.
- Many common letter combinations require a finger to jump over the home row.
- Many common letter combinations are typed with one hand while the other sits idle.
- Most typing is done with the left hand, which for most people is the weaker hand.

- Many common letter combinations are typed by adjacent fingers, which is slower than using other fingers.
- About 30% of typing is done on the lower row, which is the slowest and most difficult row to reach.
- About 52% of keyboard strokes are done in the top row, requiring the fingers to travel away from the home row most of the time.

Dvorak studied letter frequencies and the physiology of people's hands and created a layout to alleviate the problems he identified with the QWERTY layout. The layout he created adheres to these principles:

- Letters should be typed by alternating between hands (which makes typing more rhythmic, increases speed, reduces error, and reduces fatigue).
- For maximum speed and efficiency, the most common letters and digraphs should be the easiest to type. This means that they should be on the home row, which is where the fingers rest, and under the strongest fingers (Thus, about 70% of keyboard strokes on the Dvorak Simplified Keyboard are done on the home row).
- The least common letters should be on the bottom row, which is the hardest row to reach.
- The right hand should do more of the typing, because most people are right-handed.
- Digraphs should not be typed with adjacent fingers.
- Stroking should generally move from the edges of the board to the middle. An observation of this principle is that, for many people, when tapping fingers on a table, it is easier going from little finger to index than vice versa. This motion on a keyboard is called *inboard stroke flow*.

The Dvorak layout is intended for the English language. In other European languages, letter frequencies, letter sequences, and digraphs differ from English. Also, many languages have letters that do not occur in English. For non-English use, these differences lessen the supposed advantages of the original Dvorak keyboard. However, the Dvorak principles have been applied to the design of keyboards for these other languages.

The layout was completed in 1932 and was granted U.S. Patent 2,040,248 in 1936. The American National Standards Institute (ANSI) designated the Dvorak keyboard as an alternative standard keyboard layout in 1982; the standard is X3.207:1991 (previously X4.22-1983), "Alternate Keyboard Arrangement for Alphanumeric Machines". The original ANSI Dvorak layout was available as a factory-supplied option on the original IBM Selectric typewriter.

Some researchers challenge the established view that the Dvorak layout is ergonomically superior to the QWERTY one, and hold that QWERTY emerged through a quite rigorous process of competition and eventual acceptance in the marketplace. However, the findings of these researchers themselves have been challenged. For instance, even though QWERTY did emerge from a process of competition, at the time few, if any, other typing machines had keyboards, therefore the QWERTY keyboard layout itself was subject to very little, if any, competition.

In 1984, the Dvorak layout had an estimated 100,000 users.

Comparison of the QWERTY and Dvorak layouts

Keyboard strokes

Touch typing requires a typist to rest their hands in the home row (QWERTY row starting with "ASDF"). Thus, the more strokes in the home row, the less movement the fingers must do and consequently a typist can type faster, more accurately, and with less strain to the hand and fingers. Motion picture studies prove not only that typing is done fastest in the home row, but also typing is the slowest on the bottom row. Thus, if the fingers must move, it is easier to move them up to the top row (QWERTY row starting with "QWERTY") rather than down to the bottom row (QWERTY row starting with "ZXCV").

Key stroke distribution

Row	QWERTY	Dvorak
Top	52%	22%
Home	32%	70%
Bottom	16%	8%

It is notable that the vast majority of the Dvorak layout's key strokes (70%) are done in the home row (the easiest row to type because that's where the fingers rest). In addition, the Dvorak layout requires the fewest strokes on the bottom row (the most difficult row to type). On the other hand, QWERTY requires typists to move their fingers to the top row for a majority of strokes and has only 32% of the strokes done in the home row.

Because the Dvorak layout concentrates the vast majority of key strokes to the home row, the Dvorak layout uses about 63% of the finger motion required by QWERTY, thus making the Dvorak layout more ergonomic. Because the Dvorak layout requires less finger motion from the typist compared to QWERTY, many users with repetitive strain injuries have reported that switching from QWERTY to Dvorak alleviated or even eliminated their repetitive strain injuries.

The typing loads between hands differs for each of the keyboard layouts. On QWERTY keyboards, 56% of the typing strokes are done by the left hand. As the left hand is weaker for the majority of people, the Dvorak keyboard puts the more often used keys on the right hand side, thereby having 56% of the typing strokes done by the right hand.

Awkward strokes

Awkward strokes are undesirable because they slow down typing, increase typing errors, and increase finger strain. Hurdling is an awkward stroke requiring a single finger to jump directly from one row, over the home row to another row (e.g., typing “minimum” on the QWERTY keyboard). In the English language, there are about 1,200 words that require a hurdle on the QWERTY layout. In contrast, there are few words requiring a hurdle on the Dvorak layout and even fewer requiring a double hurdle.

Hand alternation

Alternating hands while typing is a desirable trait. This is due to the fact that while one hand is typing a letter, the other hand can get in position to type the next letter. Thus, a typist may fall into a steady rhythm and type quickly. However, when a string of letters is done with the same hand, the chances of stuttering are increased and a rhythm can be broken, thus decreasing speed and increasing errors and fatigue. The QWERTY layout has more than 3,000 words that are typed on the left hand alone and about 300 words that are typed on the right hand alone (the aforementioned word "minimum" is a right-hand-only word). In contrast, with the Dvorak layout, only a few words are typed using only the left hand and even fewer with the right hand. This is because a syllable requires at least one vowel, and all the vowels (and "y") are on the left side.

Standard keyboard

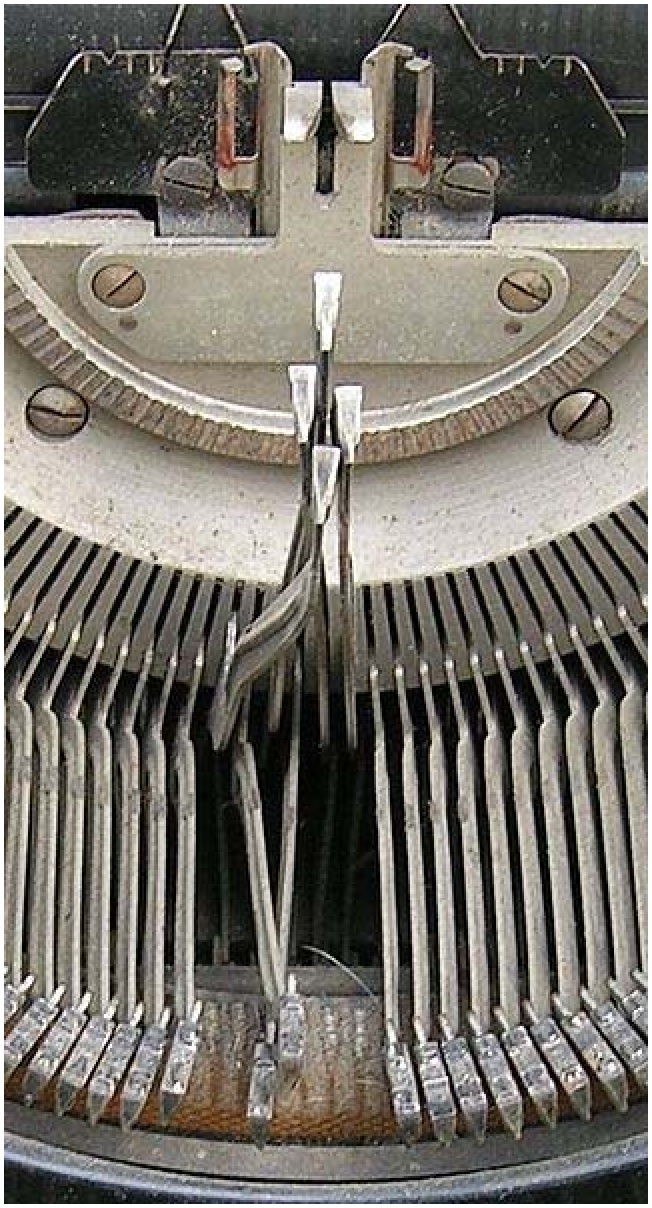
QWERTY enjoys advantages over the Dvorak layout due to its position as the de facto standard keyboard:

- Keyboard shortcuts in most major operating systems, including Windows, are designed for QWERTY users and can be awkward for Dvorak users, such as Ctrl-C (Copy) and Ctrl-V (Paste).
- Some public computers (such as in libraries) will not allow users to change the keyboard to the Dvorak layout
- Some standardized exams will not allow test takers to use the Dvorak layout (e.g. Graduate Record Examination)
- Games can prove nearly impossible to play with the default keyboard mapping, especially those which use W,A,S,D as controls.

History

In order to understand the history of the Dvorak Simplified Layout, one must first understand the history of QWERTY. Thus this section shall first explore the history of QWERTY, then go into the history of the Dvorak Simplified Layout.

History of QWERTY



In typical typewriters neighboring typebars had a great deal of overlap in their paths, making jams common when keys were struck rapidly in succession; avoiding this was the basis of the QWERTY layout.

The history of the keyboard layout starts with the advent of typewriters. Christopher Sholes invented the first typewriter capable of being mass-produced (before Sholes, 51 inventors received patents for their various typewriters, but none was suitable for mass production). Sholes began building his typewriter in 1867, starting with an alphabetical order layout. However, Sholes's typewriter jammed when a typist struck two adjacent keys in succession too quickly, causing the second type bar to jam the first type bar before it could fall back into place. In addition the type bars struck the rear side of the paper, making the jamming unnoticeable until the typist pulled out the paper.

Sholes thus focused his efforts on stopping jams, rearranging the keys to this end. Sholes commissioned a study to determine the most common letters and letter combinations used in the English language. Sholes then used the results of the study to scatter the common letters and combinations across the keyboard. This increased the time in making the jumps between the letters and helped to alleviate the jamming that occurred when two adjacent keys were struck too rapidly in succession. Some claim that he did this to deliberately slow down the typist; however, this claim has been disputed.

When Sholes sold his typewriter design to the Remington company, Remington engineers made an additional change to the layout by transferring the letter “R” to the upper row so their typewriter salesmen could quickly type the word “typewriter” to potential clients by locating all of the necessary letters in the upper row.”

QWERTY vied for dominance amongst a variety of competing formats over a period of years, eventually becoming the standard as both Remington and its chief rival, Underwood, became leaders in typewriter sales using the QWERTY format.

History of the Dvorak layout

August Dvorak was an educational psychologist and professor of education at the University of Washington in Seattle, Washington. Dvorak became interested in the keyboard layout while serving as an advisor to Gertrude Ford, who was writing her master’s thesis on typing errors. Touch typing had come into wide use by that time, so when Dvorak studied the QWERTY layout he concluded that the QWERTY layout needed to be replaced. Dvorak was joined by his brother-in-law William Dealey, who was a professor of education at the then North Texas State Teacher's College in Denton, Texas.

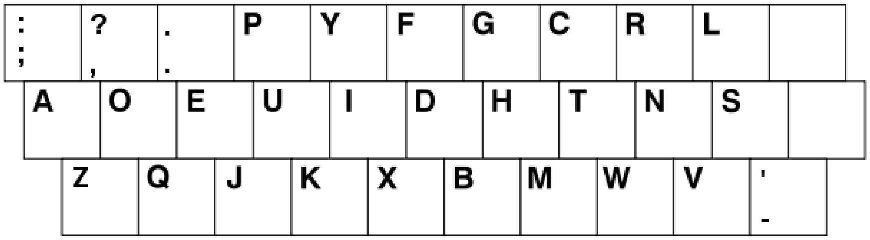
Dvorak and Dealey’s objective was to scientifically design a keyboard to decrease typing errors, speed up typing, and lessen typer fatigue. They engaged in extensive research while designing their keyboard layout. In 1914 and 1915, Dealey attended seminars on the science of motion and later reviewed slow-motion films of typists with Dvorak. Dvorak and Dealey meticulously studied the English language, researching the most used letters and letter combinations. They also studied the physiology of the hand. The result in 1932 was the Dvorak Simplified Keyboard.

In 1933, Dvorak started entering typists trained on his keyboard into the International Commercial Schools Contest, which were typing contests sponsored by typewriter manufacturers consisting of professional and amateur contests. The professional contests had typists sponsored by typewriter companies to advertise their machines. Ten times from 1934–41, Dvorak’s typists won first in their class events. In the 1935 contest alone, nine Dvorak typists won twenty awards. Dvorak typists were so successful that in 1937 the Contest Committee barred Dvorak’s typists for being “unfair competition” until Dvorak protested. In addition, QWERTY typists did not want to be placed near Dvorak typists because QWERTY typists were disconcerted by the noise produced from the fast typing speeds made by Dvorak typists.

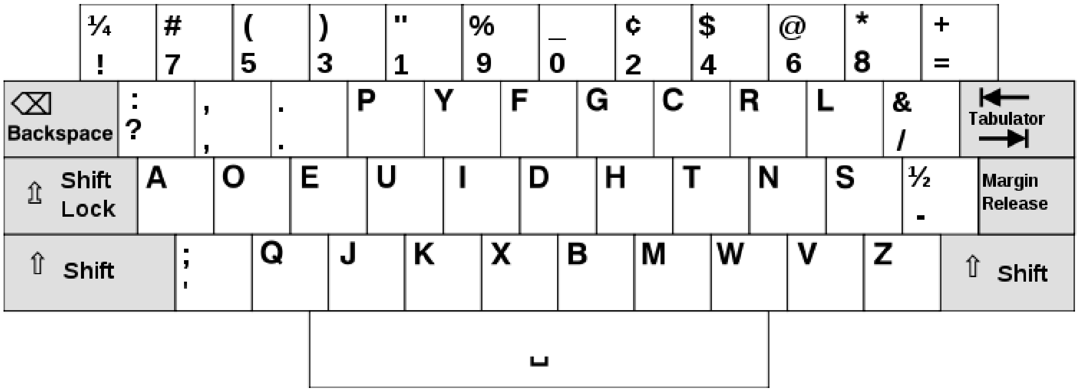
In the 1930s, the Tacoma, Washington, school district ran an experimental program in typing to determine whether to hold Dvorak layout classes. The experiment used 2,700 students to learn the Dvorak layout, and the district found that the Dvorak layout students learned the keyboard in one-third the time it took to learn QWERTY. However, a new school board was elected and chose to close the Dvorak layout classes.

Writer Barbara Blackburn was the fastest English language typist in the world, according to The Guinness Book of World Records. Using the Dvorak Simplified Keyboard, she was able to maintain 150 words per minute (wpm) for 50 minutes, and 170 wpm for shorter periods. She has been clocked at a peak speed of 212 wpm. Blackburn, who failed her QWERTY typing class in high school, first encountered the Dvorak keyboard in 1938, quickly learned to achieve very high speeds, and occasionally toured giving speed-typing demonstrations during her secretarial career. Blackburn died in April 2008.

Original Dvorak layout



The typewriter keyboard layout that Dvorak & Dealey patented



The Dvorak typewriter keyboard layout that was publicly promulgated

Over the decades, symbol keys were shifted around the keyboard leading to variations in the Dvorak layout. In 1982, the American National Standards Institute (“ANSI”) implemented a standard for the Dvorak layout known as ANSI X4.22-1983. This standard gave the Dvorak layout official recognition as an alternative to the QWERTY keyboard.

The layout standardized by the ANSI differs from the original or “classic” layout devised and promulgated by Dvorak. Indeed, the layout promulgated publicly by Dvorak differed slightly from the layout for which Dvorak & Dealey applied for a patent in 1932—most notably in the placement of Z. Today’s keyboards have more keys than the original typewriter did, and other significant differences existed:

- The numeric keys of the classic Dvorak layout are ordered: 7 5 3 1 9 0 2 4 6 8
- In the classic Dvorak layout, the question mark key [?] is in the leftmost position of the upper row, while the forward-slash mark key [/] is in the rightmost position of the upper row.
- The following symbols share keys (the second symbol being printed when the SHIFT key is pressed):
    - colon [:] and question mark [?]
    - ampersand [&] and forward-slash [/].

Modern U.S. keyboard layouts almost always place semicolon and colon together on a single key and forward-slash and question mark together on a single key. Thus, if the keycaps of a modern keyboard are rearranged so that the unshifted symbol characters match the classic Dvorak layout then, sensibly, the result is the ANSI layout.

Modern operating systems

The Dvorak Simplified Keyboard (“DSK”) is included with all major operating systems (such as Microsoft Windows, Mac OS X, Linux and BSD). Changing a computer running on a major operating system to the Dvorak layout can be done within 30 seconds.

Early PCs

Although some word processors could simulate alternative keyboard layouts through software, this was application-specific; if more than one program was commonly used (*e.g.,* a word processor and a spreadsheet), the user could be forced to switch layouts depending on the application. Occasionally, stickers were provided to place over the keys for these layouts.

However, IBM-compatible PCs used an active, “smart” keyboard, where the keyboard was actually a peripheral device (powered by the keyboard port). Striking a key generated a key “code”, which was sent to the computer. Thus, changing to an alternative keyboard layout was most easily accomplished by simply buying a keyboard with the new layout. Because the key codes were generated by the keyboard itself, all software would respond accordingly. In the mid- to late-1980s, a small cottage industry for replacement PC keyboards arose; although most of these were concerned with keyboard “feel” and/or programmable macros, there were several with alternative layouts, such as Dvorak.

Windows

According to Microsoft, versions of the Windows operating system including Windows 95, Windows NT 3.51 and higher have shipped with support for the U.S. Dvorak layout. Free updates to use the layout on earlier Windows versions are available for download from Microsoft.

Earlier versions, such as DOS 6.2/Windows 3.1, included four keyboard layouts: QWERTY, two-handed Dvorak, right-hand Dvorak, and left-hand Dvorak.

In May 2004 Microsoft published an improved version of its Keyboard Layout Creator (MSKLC version 1.3 — current version is 1.4) that allows anyone to easily create any keyboard layout desired, thus allowing the creation and installation of any international Dvorak keyboard layout such as Dvorak Type II (for German), Svorak (for Swedish) etc.

Another advantage of the Microsoft Keyboard Layout Creator over third-party tools for installing an international Dvorak layout is that it allows creation of a keyboard layout that automatically switches to standard (QWERTY) when pressing the control or the windows key.

Unix-based systems

Many operating systems based on UNIX, including OpenBSD, FreeBSD, NetBSD, OpenSolaris, Plan 9, and most Linux distributions, can be configured to use the U.S. Dvorak layout and a handful of variants. However, all current Unix-like systems with X.Org and appropriate keymaps installed (and virtually all systems meant for desktop use include them) are able to use any QWERTY-labeled keyboard as a Dvorak one without any problems or additional configuration. This removes the burden of producing additional keymaps for every variant of QWERTY provided. Runtime layout switching is also possible.

Apple computers

Apple had Dvorak advocates since the company’s early (pre-IPO) days. Several engineers devised hardware and software to remap the keyboard, which were used inside the company and even sold commercially.

Apple II

The Apple II had a keyboard ROM that translated keystrokes into characters. The ROM contained both QWERTY and Dvorak layouts, but the QWERTY layout was enabled by default. A modification could be made by pulling out the ROM, bending up four pins, soldering a resistor between two pins, soldering two others to a pair of wires connected to a DIP switch, which was installed in a pre-existing hole in the back of the machine, then plugging the modified ROM back in its socket. The “hack” was reversible and did no damage. By flipping a switch on the machine’s back panel, the user could switch from one layout to the other. This modification was entirely unofficial but was inadvertently demonstrated at the 1984 Comdex show, in Las Vegas, by an Apple employee whose mission was to demonstrate Apple Logo II. The employee had become accustomed to the Dvorak layout and brought the necessary parts to the show, installed them in a demo machine, then did his Logo demo. Viewers, curious that he always reached behind the machine before and after allowing other people to type, asked him about the modification. He spent as much time explaining the Dvorak keyboard as explaining Logo.

Apple brought new interest to the Dvorak layout with the Apple IIc, which had a mechanical switch above the keyboard whereby the user could switch back and forth between the QWERTY layout and the Dvorak layout: this was the most official version of the IIe Dvorak mod. The IIc Dvorak layout was even mentioned in 1984 ads, which stated that the World's Fastest Typist, Barbara Blackburn, had set a record on an Apple IIc with the Dvorak layout.

The Dvorak layout was also selectable using the built-in control panel applet on the Apple IIGS.

Apple III

The Apple III used a keyboard-layout file loaded from a floppy disk: the standard system-software package included QWERTY and Dvorak layout files. Changing layouts required restarting the machine.

Apple Lisa

The technical documentation available to third-party developers does not mention keyboard mapping, though it was purportedly available through undocumented interfaces.

Mac OS

iBook with alpha and punctuation keys manually rearranged to the Dvorak layout

In its early days, the Macintosh could be converted to the Dvorak layout by making changes to the “System” file: this was not easily reversible and required restarting the machine. This modification was highly unofficial, but it was comparable to many other user-modifications and customizations that Mac users made. Using the “resource editor”, ResEdit, users could create keyboard layouts, icons, and other useful items. A few years later, a third-party developer offered a utility program called MacKeymeleon, which put a menu on the menu bar that allowed on-the-fly switching of keyboard layouts. Eventually, Apple Macintosh engineers built the functionality of this utility into the standard System Software, along with a few layouts: QWERTY, Dvorak, French (AZERTY), and other foreign-language layouts.

Since about 1998, beginning with Mac OS 8.6, Apple has included the Dvorak layout. Apple also includes a Dvorak variant they call “Dvorak — Qwerty ⌘”. With this layout, the keyboard becomes QWERTY when the Command (Apple) key is held down. By keeping familiar keyboard shortcuts like “close” or “copy” on the same keys as ordinary QWERTY, this lets some people use their well-practiced muscle memory and may make the transition easier. Mac OS and subsequently Mac OS X allows “on-the-fly” switching between layouts: a menu-bar icon (by default, a national flag that matches the current language, a ‘DV’ represents Dvorak and a ‘DQ’ represents Dvorak — Qwerty ⌘) brings up a drop-down menu, allowing the user to choose the desired layout. Subsequent keystrokes will reflect the choice, which can be reversed the same way.

Mobile phones and PDAs

A number of mobile phones today are built with either full QWERTY keyboards or software implementations of them on a touch screen. Sometimes the keyboard layout can be changed by means of a freeware third-party utility, such as AnySoftKeyboard for Android, AE Keyboard Mapper for Windows Mobile, or KeybLayout for Symbian OS.

The RIM BlackBerry lines support only QWERTY and its localized variants AZERTY and QWERTZ. Apple's iOS 4.0 supports external Dvorak keyboards.

Resistance to adoption

Although the Dvorak layout is the only other keyboard layout registered with ANSI and is provided with all major operating systems, attempts to convert universally to the Dvorak layout have not succeeded. The failure of the Dvorak layout to displace the QWERTY layout has been the subject of some studies.

In 1956, a General Services Administration study by Earle Strong, which included an experiment involving ten experienced government typists, concluded that Dvorak training would never be able to amortize its costs. The study was a large obstacle for the wide adoption of Dvorak for many firms and government agencies. One criticism of the experiment is that it did not involve any beginning typists; however, Liebowitz notes that it parallels the decision that a real firm or government agency would need to make: Is it worthwhile to retrain its present typists? A second critique of the study points out that the Dvorak typists were not given adequate time to reach their potential competence, and what promise had been demonstrated by the Dvorak typists was ignored by the researchers. Strong's objectivity with regard to the Dvorak keyboard has also been questioned. Seven years before the study began Strong wrote “I have developed a great deal of material on how to get this increased production on the part of typists on the standard keyboard. Consequently, I am not in favor of purchasing new keyboards and retraining typists on the new keyboard. ... I strongly feel that the present keyboard has not been fully exploited, and I am out to exploit it to its utmost in opposition to the change to new keyboards.” Furthermore, there is evidence of a strained business relationship between Strong and Dvorak. When researchers had asked Strong for the data to his study, it was found that Strong had destroyed it.

However, in considering resistance to the adoption of the Dvorak layout, different segments of the market differ in the extent, nature, and motivation of their resistance. Furthermore, the influence of these factors on the different segments of the market has changed over time, following changes in technology and awareness of Dvorak as an alternative keyboard layout. Factors against adoption of the Dvorak layout have included the following:

1. Dvorak introduced his layout during the Great Depression, a time when businesses and people did not have the resources to invest in the new layout.
2. With World War II came the conversion of typewriter manufacturing plants into small arms plants, thus halting production of new typewriters (including the Dvorak Layout).
3. The publication of Earle Strong's aforementioned report.
4. Failure to achieve the general population's awareness that the Dvorak layout existed. This improved somewhat following the Guinness Book of Records 1985 publication of Barbara Blackburn’s achievement of 212 wpm using a Dvorak keyboard, and again in the mid-1990s when computer operating systems began to incorporate the Dvorak layout as an option.
5. Failure to overcome an investment in competence in the QWERTY layout made by a large number of typists and typist trainers prior to the general availability of the Dvorak layout. This investment has proved the most powerful influence up until the 1990s. Typing training in schools and secretarial colleges is almost always done on the QWERTY layout both because it conforms with the expectation of industry and because it is the layout with which most teachers or trainers are already familiar.
6. A reduction in efficiency while learning the Dvorak layout further impedes its adoption by typists already competent with QWERTY, and the organizations that employ them.
7. Failure to persuade large typewriter manufacturers to produce significant volumes of typewriters equipped with Dvorak layouts.
8. Converting standard mechanical typewriters to Dvorak (or any alternative, e.g. international layout) was often impractical and excessively expensive, so switching to Dvorak usually required a new, dedicated machine. A notable exception was the popular IBM Selectric typewriter, which used a single spherical typing element rather than individual character hammers; it could easily be converted by replacing the QWERTY typing element with a Dvorak equivalent. This problem was effectively eliminated with the advent of PCs, where computer programs can change the character produced when a particular key is pressed. This capacity benefited not only Dvorak typists, but those who typed in languages other than English. With early computers, this required the contents of the character-generator ROM to be changed, but with subsequent designs only a table in memory or the disk file storing this table needed to be changed. By the mid 1990s the Dvorak layout was a standard option on most computer systems.
9. Incompatibility between the two keyboard layouts on computers, where keys are assigned additional functions within software programs. In some cases related additional functions are assigned to keys that are physically proximate on the QWERTY layout, but not so in the Dvorak layout; for example, the Unix text editor vi uses the keys H, J, K and L to cause movement to the left, down, up, and right, respectively. With a QWERTY layout, these keys are all together under the right-hand home row, but with the Dvorak layout they are no longer neatly together. In many video games, keys W, A, S and D are used for arrow movements (their inverse-T arrangement on a QWERTY layout mirrors the arrangement of the cursor keys). In the Dvorak layout, this is no longer true,

although most video games allow keys to be remapped, and many will automatically recognize the normal key locations regardless. Common computer keyboard shortcuts for undo, cut, copy and paste operations are Ctrl (or Command) + Z, X, C, and V respectively; conveniently located in the same row in the QWERTY layout, but not on a Dvorak layout. While some applications do compensate for this, these issues do add a layer of complexity to using the many computer applications that do not.

10. Some confusion regarding which of the keyboard layouts designed by August Dvorak is the “real” Dvorak layout. This arose in part due to the existence of, in addition to the standard layout, layouts for left-handed (only) and right-handed (only) use. Also, while Dvorak specified a particular layout for the number sequence at the top of the keyboard, most implementations of the Dvorak layout retain the ‘1,2,3...9,0’ arrangement; most people who want to type numbers quickly will use the numeric keypad rather than the top row.

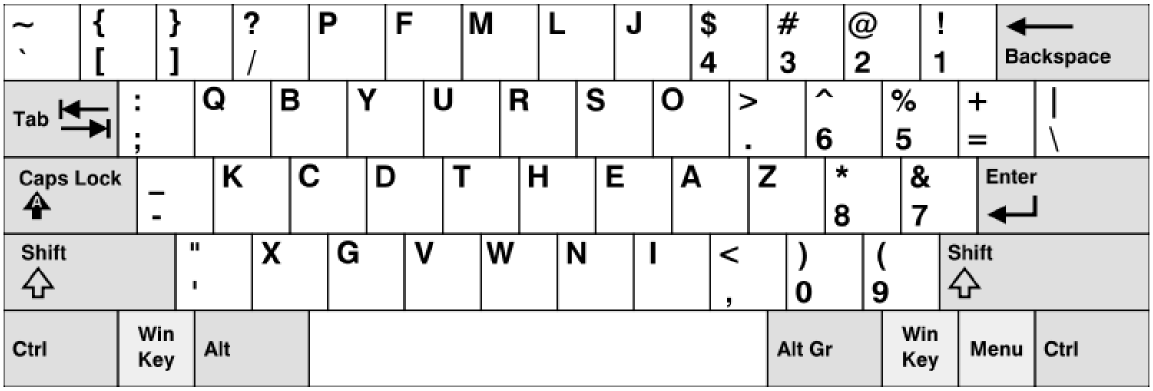
An appreciation of the strength of the resistance factors (particularly the investment in typewriter manufacturing) suggests that the Dvorak layout would need to have been significantly superior to the QWERTY layout in order for the former to displace the latter in widespread use in the past. If the Dvorak layout is inherently at least as efficient as, or more efficient than, the QWERTY layout, then one might expect to see an increasing rate of use as resistance factors (such as lack of awareness, non-programmable machines, and one-style formal training) become less powerful. There are no surveys or studies looking at the rate of use of the Dvorak layout over time.

A discussion of the Dvorak layout is sometimes used as an exercise by management consultants to illustrate the difficulties of change. The Dvorak layout is often used as a standard example of network effects, particularly in economics textbooks, the other standard example being the competition between Betamax and VHS. These examples are used to demonstrate that inferior technologies sometimes succeed simply because they become customary.

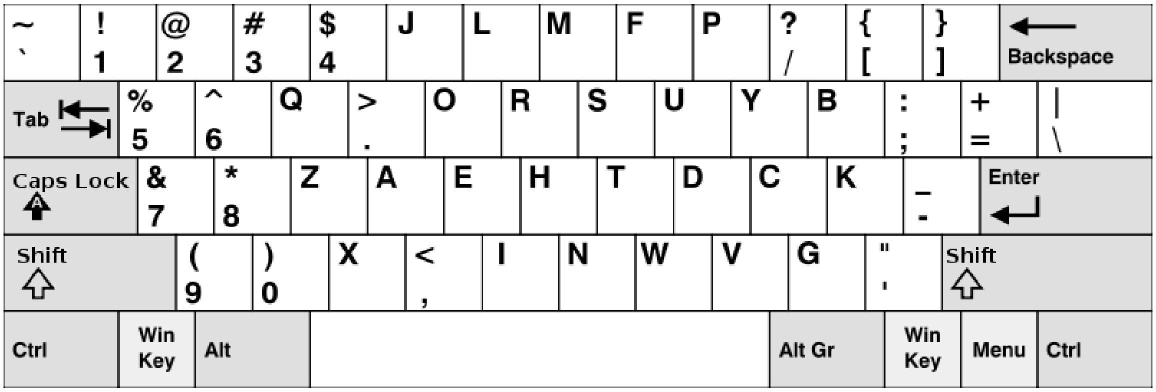
Alternatives

Because of the radical differences between QWERTY and Dvorak, existing typists find that it takes considerable time and effort to make the change. As a consequence, some attempts have been made to design alternative layouts that follow the principles involved in the Dvorak keyboard layout but preserve many of the QWERTY key positions, thereby making it easier for users to make the transition. Programs such as the Microsoft Keyboard Layout Creator and KbdEdit allow this to be done very easily. One such popular variant is the Colemak keyboard layout.

One-handed versions



Left-handed Dvorak layout

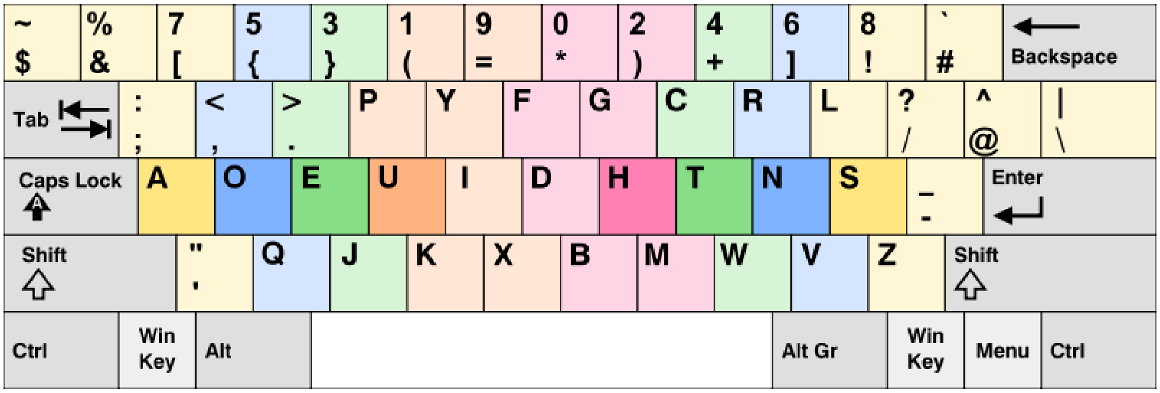


Right-handed Dvorak layout

During the 1960s, Dvorak applied a similar approach of minimizing distance traveled when he designed quite different arrangements for touch-typing with only the left hand or with only the right hand. This can provide increased accessibility to single-handed users who might struggle with excessive lateral hand movement when using two-handed keyboards. Note that the right-handed and left-handed Dvorak layouts not only differ from each other dramatically, but also differ from two-handed Dvorak layout quite dramatically as well. Some users with full use of both hands enjoy the ability to simultaneously type with only a single hand while concurrently controlling a mouse with the other hand, or in the case of police officers, operating vehicular controls with their left hand while touch-typing with their right hand on a dashboard-mounted laptop computer. The arrangements have been designed for each hand to minimize distance traveled by fingers as well as to minimize lateral distance traveled by the hand as a whole. Note that the hand is intended to rest near the center of the keyboard in order to reach the entire keyboard, eliminating the need for the split ergonomic keyboard layout.

Note that the left-handed Dvorak and right-handed Dvorak keyboard layouts are substantially mirror images of each other, with the exception of keys that are wider than the normal keys and the tilde–grave-accent key. Some left-handed Dvorak keyboards have “)(” in strict compliance with the mirror-image concept whereas others have “()” in the customary order. Shown at the right is Dvorak's original ")(" placement of the parentheses, which is the more widely-distributed layout, such as the one that Microsoft supplies with Windows.

Programmer Dvorak

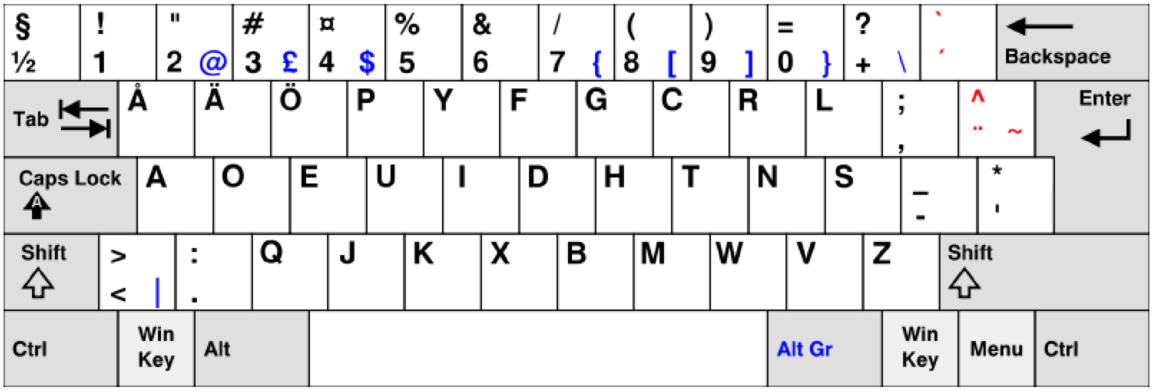


Programmer Dvorak layout

Programmer Dvorak is a keyboard layout developed by electronics engineer Roland Kaufmann and targeted towards people writing source code for C, Java, Pascal, LISP, CSS and XML. The layout is based on the Dvorak Simplified Keyboard, with several enhancements intended to make typing easier for programmers.

While the alphabetic keys are placed as on the original Dvorak layout, most of the others are changed. The most noticeable difference is that the top row is devoted to brackets and other operational characters, and the numbers must be accessed using the shift key (or caps lock, to enable typing long runs of digits.) Differing from most Dvorak-inspired layouts but following August Dvorak’s original design, the base-10 numerals are not placed in ascending order, but in an arrangement more conducive to memorization. Also, unlike most other layouts where the finger is to travel along the left-leaning, straight-line "column" of keys, the top row is intended accessed with a rightward-curving motion of the fingers, with respect to the home row (see picture), instead of a left-leaning straight line.

Other languages



The **Svorak** keyboard layout

Although DSK is implemented in many languages other than English, there are still potential issues. Every Dvorak implementation in other languages leaves the Roman characters in the same position as the English DSK. However, other (occidental) language orthographies can clearly have other typing needs for optimization (many are very different from English). Because Dvorak Simplified Keyboard was optimized for the statistical distribution of letters in English text, keyboards for other languages would likely have drastically different distributions of letter frequencies. Hence, non-QWERTY-derived keyboards for such languages would need a keyboard layout that might look quite different from the Dvorak layout for English.

An implementation for Swedish, known as **Svorak**, places the three extra Swedish vowels (å, ä and ö) on the leftmost three keys of the upper row, which correspond to punctuation symbols on the English Dvorak layout. These punctuation symbols are then juggled with other keys, and the Alt-Gr key is required to access some of them.

Another Swedish version, **Svdvorak** by Gunnar Parment, keeps the punctuation symbols as they were in the English version; the first extra vowel (å) is placed in the far left of the top row while the other two (ä and ö) are placed at the far left of the bottom row.

The Swedish variant that most closely resembles the American Dvorak layout is Thomas Lundqvist's **sv_dvorak**, which places å, ä and ö like Parment's layout, but keeps the American placement of most special characters.

The Norwegian implementation (known as "**Norsk Dvorak**") is similar to Parment's layout, with "æ" and "ø" replacing "ä" and "ö".

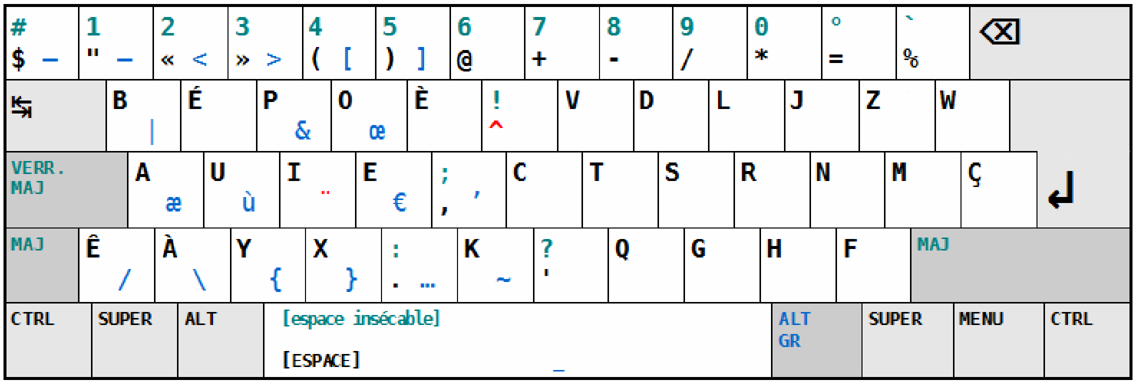
The Danish layout DanskDvorak is similar to the Norwegian.

A Finnish **DAS** keyboard layout follows many of Dvorak's design principles, but the layout is an original design based on the most common letters and letter combinations in the Finnish language. Matti Airas has also made another layout for Finnish. Finnish can also be typed reasonably well with the English Dvorak layout if the letters ä and ö are added. The Finnish **ArkkuDvorak** keyboard layout adds both on a single key and keeps the American placement for each other character. As with **DAS**, the **SuoRak** keyboard is designed by the same principles as the Dvorak keyboard, but with the most common letters of the Finnish language taken into account. Contrary to **DAS**, it keeps the vowels on the left side of the keyboard and most consonants on the right hand side.

The Turkish F keyboard layout (link) is also an original design with Dvorak's design principles, however it's not clear if it is inspired by Dvorak or not. Turkish F keyboard was standardized in 1955 and the layout has been a requirement for imported typewriters since 1963.

There are some non standard **Brazilian** Dvorak keyboard layouts currently in development. The simpler design (also called **BRDK**) is just a Dvorak layout plus some keys from the Brazilian ABNT2 keyboard layout. Another design, however, was specifically designed for writing Brazilian Portuguese, by means of a study that optimized typing statistics, like frequent letters, trigraphs and words.

The most common German Dvorak layout is the German **Type II** layout. It is available for Windows, Linux, and Mac OS X. There is also the **Neo** layout and the **de ergo** layout, both original layouts that also follow many of Dvorak’s design principles. Germans may also use a standard Dvorak layout with ß at the shift+W position (on QWERTY) and the umlaut dots as a dead key accessible via shift+E.



Dvorak, with a French BÉPO layout

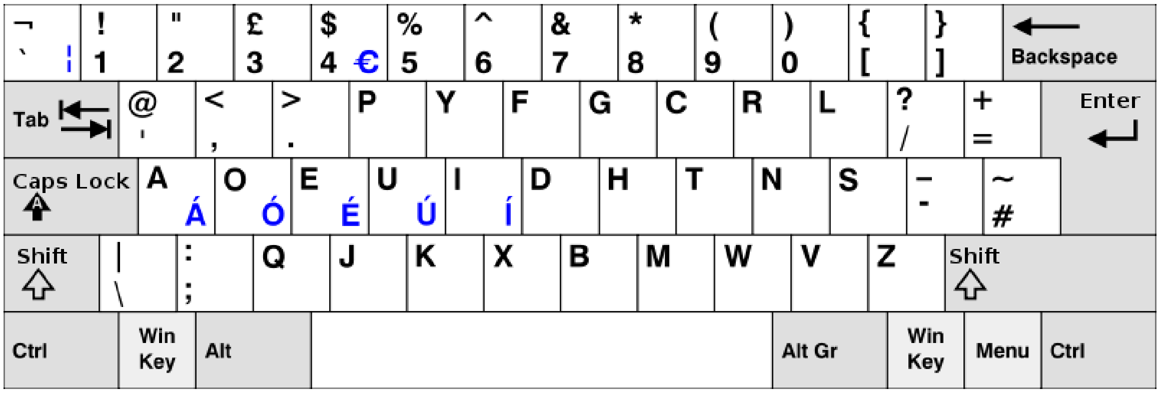
There are also two **French** and a **Spanish** layouts, and also a proposed Esperanto version.

A **Greek** version of the Dvorak layout was released on Valentine’s Day 2007. This layout, unlike other Greek Dvorak layouts, preserves the spirit of Dvorak wherein the vowel keys are all placed on the left side of the keyboard. Currently this version is for Mac OS X.

An Italian Mac layout, optimized for this language and with all the accented vowels on the left, is being developed by Paolo Tramannoni. Several PC versions, consisting in the original layout with accented vowels added, are also being developed.

A **Romanian** version of the Dvorak layout was released in October 2008. It is available for both Windows and Linux.

United Kingdom (British) layouts



Whether Dvorak or QWERTY, a United Kingdom (British) keyboard differs from the U.S. equivalent in these ways: the " and @ are swapped; the backslash/pipe [\ |] key is in an extra position (to the right of the lower left shift key); there is a taller return/enter key, which places the hash/tilde [# ~] key to its lower left corner (see picture).

The most notable difference between the U.S. and UK Dvorak layouts is the [2 "] key remains on the top row, whereas the U.S. [' "] key moves. This means that the query [/ ?] key retains its classic Dvorak location, top left, albeit shifted.

Interchanging the [/ ?] and [' @] keys more closely matches the U.S. layout, and the use of “@” has increased in the information technology age. These variations, plus keeping the numerals in Dvorak's idealised order, appear in the Classic Dvorak and Dvorak for the Left Hand and Right Hand varieties.

Notable users

- Piers Anthony, author of the Xanth novels, often wrote in the 1980s author's notes in the books about how his Dvorak use prevented him from converting to a word processor. This was made even more difficult because he uses an alternative Dvorak layout (swapping the hyphen and apostrophe keys — the apostrophe key on his keyboard is where the hyphen key is on a standard U.S. keyboard (and vice-versa)).
- Barbara Blackburn, world typing speed record holder
- Bram Cohen, inventor of BitTorrent
- Terry Goodkind, author of The Sword of Truth
- Holly Lisle, American author
- Matt Mullenweg, lead developer of WordPress
- Nathan Myhrvold, former CTO of Microsoft
- Steve Wozniak, co-founder Apple Computer

- Eliezer Yudkowsky, artificial intelligence researcher and writer: "I switched to Dvorak after a bout of RSI, and the RSI never came back."

Chapter 5

Activity-Centered Ergonomics

Following Maurice de Montmollin, the French distinguished generally two major trends in ergonomics:

- Ergonomics focuses on the Activity, which emphasizes understanding the work situation as a whole, the demand analysis and framework intervention and the distinction between prescribed work and real work. This school is mainly present in the Francophone countries, such as Brazil and another form in Scandinavia.
- The ergonomics of the Human Factors, focusing on research results General (on the postures, rhythms, moods of work ...) and definition of standards. It is dominant in the United States and Japan.

Definitions

Activity-centered Ergonomics uses knowledge from the physiology of labor, cognitive psychology (memory attention, collection learning ...) and the psycho-physiology (alert, posture, working conditions ...), sociology of organizations (distribution of functions, organizations in the chain of command, the string functional, social psychology, linguistics, among others: in fact all sciences relating to man).

It's based on models of the work situation (especially that of Jacques Christol, Jacques Leplat and Gilbert De Terssac) that focus on the difference *'nature'* between the task (project record, the field of virtual future) and activity (body - the brain of course) who takes positions and makes movements activates the controls, manages (consciously or not) thought processes, communicate with others, organizes his actions etc..

The first feature of the analysis of this activity is that the operator "regulates" the activity, according to its external environment, its internal state (e.g. fatigue) to ensure maximum consistency of performance: accelerating the pace of work to catch up with the delay or face an emergency change procedure against poor results ...

The second dominant feature is the concept of compromise between the requirements of performance (explicitly or implicitly always present) and requirements related to compliance with the rules (Security of management, technical, administrative ...). The

Observer of the work activity notes *'always'* that this compromise exists, and it is not built as would the organizations, focusing on the rule prescribed first. The reality is complex, as in everyday life, where we all respect the speed limit on the road ... unless we're afraid of missing our train, or arrive late to an urgent appointment ...

This "cognitive compromise" is also affected by aspects psychic s of activity, insofar as studies of psychological aspects of work, increasing show that the achievement of production requires more and more not only to compromise with the security (which is never written) but also with its afraid, its stress his emotions etc.. This compromise can be considered "room", without going on the field with operators in business, whether to make a machine, a workstation or a computer interface: the standards and rules are inadequate ever.

Ergonomics Analysis of Work

Ergonomic Analysis of Work (EAW) is the main tool of the Activity-centered ergonomic intervention. It can help to solve several problems related to working conditions or the design of tool s and equipment.

- Aspects of health in work
    - On the physical health including the musculoskeletal disorder (MSD) affecting 12 to 14% of employees
    - On the mental health risks due to particular psycho-social (in stress) can cause anxiety-depressive syndromes (about 8% of employees)
- Aspects of performance
    - Improving productivity
    - Improving quality

EAW, an influenced analysis

EAW, a "located" analysis

It is with the demand analysis and hypothesis he has made during the pre-diagnosis that the ergonomist will be able to choose situations to consider:

- Ensure sufficient mastery of technical data concerning the work situation;
- Build reference tools for description and interpretation of data;
- Give himself a medium for demonstration and communication.

The different elements of influence on work

The work activity is influenced by a multitude of facets. The ergonomist must rely on these aspects and compare the actual work for generating insights relevant to the problems posed

- The technical process : These are views which focus on flows and processing steps of a product or information
- The tools and media : An analysis of the means available to employees to obtain or receive information and act on the process to better prepare some investigations
- The relationship between the variables of a device : In explanation with the operator or guidance, it is possible that reflected different variables to the settings or status of the device technology (e.g. quality). It is then possible to relate with each other.
- Procedures : The sequences of a process as provided corresponds only very rarely that transactions made by employees.
- Dependencies and stops time : The work activity may enroll in a timeframe more or less structured by the process, by advancing the work of other employees, or by events outside the company.
- The layout of the technical device : Often, initial plans of arrangement are now outdated. Indeed, subsequent implementations of equipment have been made.

choice of the situations to analyze

It is rather difficult to extract a maxim or a rule in the choose of a situation that the ergonomist will do. The criteria he will use depending on the problem and the structure of the company. But it may be, for example, situations:

- Where complaints are most numerous
- Where the consequences are more serious
- Where the range of problems is the widest
- Playing a central role in the functioning of the company
- To be processing more or less long term

Analysis by the activity

At first glance, each is tempted by the establishment of relations of direct causation between working conditions and health consequences or effectiveness. A noisy situation makes deaf, carrying heavy loads of produce musculoskeletal disorder, bad lighting, eyestrain, etc.. Unfortunately, this approach has important limitations: protection against noise may prohibit access to the machine, etc. ...

In fact, this approach neglects the fact that these relations necessarily pass through the activity of the employee. Indeed, it makes compromises with respect to constraints (it does not have them) to achieve the goals that are set and to limit the inconvenience caused by the tasks. For this reason, the ergonomist must focus its ergonomic analysis of work activity: it is in and by the activity of the operator in creating the effects of working conditions.

The role, in this context, analysis of the activity is not an evaluation (the workload for example) but the description and explanation of the mechanisms involved

The tools available to the ergonomist

The observation

The observation is a specific feature in the Ergonomic analysis of work compared to other methods. This is to focus on the work as directed, whereas other approaches rely on "representations". Observation can be carried out openly or by focusing on the collection of certain categories of information with specific goals (we call then systematic observation).

- Broad observables categories : Travel, The direction of regards, Communications, Postures, The actions taken or information, Comments on the technical system and context, The collective
- Technical statement, there exist a variety of techniques to conduct surveys. The choice is made by the ergonomist in the constraints and circumstances. We'll list them here: The statements manuals, Video recordings, The Activity Chronic, The Metrics

The verbalizations

To understand the activity, working conditions and their consequences, the verbalization of the employee is essential because: Activity can be reduced to what is observable; The comments and actions take place at one moment, we must re-situate more broadly; The consequences of the activity are not all apparent.

However, there are limits to the verbalization to be taken into account:

- The employee described the work and its consequences in terms of what it believes to be the goals and interests of the speaker;
- The routine operations or learning old are not always mentioned spontaneously;
- Some aspects of the activities lend themselves well to verbal expression.

Other articles

- ergonomics
- Usability
- intervention in Activity-centered ergonomics
- psychosocial risk
- musculoskeletal disorder
- Systems approach

Chapter 6

Ecological Interface Design

Ecological interface design (**EID**) is an approach to interface design that was introduced specifically for complex sociotechnical, real-time, and dynamic systems. It has been applied in a variety of domains including process control (e.g. nuclear power plants, petrochemical plants), aviation, and medicine.

EID differs from some interface design methodologies like User-Centered Design (UCD) in that the focus of the analysis is on the work domain or environment, rather than on the end user or a specific task.

The goal of EID is to make constraints and complex relationships in the work environment perceptually evident (e.g. visible, audible) to the user. This allows more of users' cognitive resources to be devoted to higher cognitive processes such as problem solving and decision making. EID is based on two key concepts from cognitive engineering research: the Abstraction Hierarchy (AH) and the Skills, Rules, Knowledge (SRK) framework.

By reducing mental workload and supporting knowledge-based reasoning, EID aims to improve user performance and overall system reliability for both anticipated and unanticipated events in a complex system.

Overview

Origin and history of EID

Ecological interface design was proposed as a framework for interface design by Kim Vicente, Andrew Scott and Jens Rasmussen in the late 80s and early 90s following extensive research into human-system reliability at the Risø National Laboratory in Denmark (Rasmussen & Vicente *et al*, 1989; Vicente, 2001). The term ecological in EID originates from a school of psychology developed by James J. Gibson known as ecological psychology. This field of psychology focuses on human-environment relationships, in particular in relation to human perception in actual environments rather than in laboratory environments. EID borrows from ecological psychology in that the constraints and relationships of the work environment in a complex system are reflected perceptually (through an interface) in order to shape user behaviour. In order to develop ecological designs, analytical tools developed earlier by researchers at the Risø National Laboratory were adopted, including the Abstraction Hierarchy (AH) and the Skills, Rules, Knowledge (SRK) framework. The EID framework was first applied and evaluated in nuclear power plant systems (Vicente & Rasmussen, 1990, 1992). Scott defined the first model for Ecological design strategies in mainstream industrial interface design in a conference held in Københavns Universitet (University of Copenhagen) in 2000. To date, EID has been applied in a variety of complex systems including computer network management, anaesthesiology, military command and control, and aircraft (Vicente, 2002; Burns & Hajdukiewicz, 2004).

Motivation

Rapid advances in technologies along with economic demands have led to a noticeable increase in the complexity of engineering systems (Vicente, 1999a). As a result, it is becoming more and more difficult for designers to anticipate events that may occur within such systems. Unanticipated events by definition cannot be specified in advance and thus cannot be prevented through training, procedures, or automation. A complex sociotechnical system designed based solely on known scenarios frequently loses the flexibility to support unforeseen events. System safety is often compromised by the operators' inability to adapt to new and unfamiliar situations (Vicente & Rasmussen, 1992). Ecological interface design attempts to provide the operators with the necessary tools and information to become active problem solvers as opposed to passive monitors, particularly during the development of unforeseen events. Interfaces designed following the EID framework aim to lessen mental workload when dealing with unfamiliar and unanticipated events, which are attributed to increased psychological pressure (Vicente, 1999b). In doing so, cognitive resources may be freed up to support efficient problem solving.

In addition to providing operators with the means to successfully manage unanticipated events, EID is also proposed for systems that require users to become experts (Burns & Hajdukiewicz, 2004). Through the use of the Abstraction Hierarchy (AH) and the Skills, Rules, Knowledge (SRK) framework, EID enables novice users to more easily acquire advanced mental models that generally take many years of experience and training to develop. Likewise, EID provides a basis for continuous learning and distributed, collaborative work (Vicente, 1999b). When faced with complex sociotechnical systems, it is not always possible for designers to ask operators what kinds of information they would like to see since each person understands the system at a different level (but rarely fully) and will provide very different answers. The EID framework allows designers to determine what kinds of information are required when it is not possible or feasible to ask users (Burns & Hajdukiewicz, 2004). It is not the intention of EID to replace existing design methodologies such as UCD and task analysis, but to complement them.

UCD and EID: Why use EID at all?

As we can see from today's windows based interfaces User-Centered Design (UCD) has done an excellent job of identifying user preferences and limitations and incorporating them into the interfaces. In the pre-UCD era, interface design was almost an afterthought to a program and was completely dependent on the programmers while totally neglecting the end user.

Benefits of UCD

UCD adds three key ideas:

1. That Interface Design is a field on its own because it bridges between humans and the program/environment.

2. That an understanding of human perception, cognition, and behavior is critical to designing interfaces.

3. That much can be learned by getting feedback from the actual users of the interface, at the early design stages, and then testing through various points in the design (Burns & Hajdukiewicz, 2004)

But there are some problems in this approach as well.

How is EID relevant?

The UCD approach commonly focuses on single user interactions between the user and the interface which is not enough to deal with today's increasingly complex systems where centralized control of information is needed and it is displayed on a variety of interfaces in varying detail. EID is a preferable addition to the complex systems' design process when even very experienced users do not have a complete understanding of how the entire complex system (power plant, nuclear plant, petrochemical refinery etc.) works. It is a known fact that users don't always understand or even feel the need to understand all the relationships behind the complex processes that they control via their interfaces.

Furthermore, the users are not always aware of the constraints that affect the system that they work with, and discovering these constraints can take some extra effort (Burns & Hajdukiewicz, 2004). EID incorporates this constraint based style in the design approach where it examines the constraints of the user domain before getting user input. EID focuses on understanding the complex system – its build, its architecture, and its original intent and then relaying this information to the end user thereby reducing their learning curve and helping them achieve higher level of expertise.

The constraint based style in interface design also facilitates the handling of unanticipated events because, regardless of the event, the constraint is broken and it can be seen by the user who in turn can proactively work with the interface to restore the constrain and fix the system.

This does not in any way take away the usefulness of UCD but stresses the fact that that EID offers some unique insight into the design process and it could be used in conjunction with other cognitive engineering techniques to enhance the user interfaces and increase human reliability in human-machine interactions.

The Abstraction Hierarchy (AH)

The Abstraction Hierarchy (AH) is a 5-level functional decomposition used for modelling the work environment, or more commonly referred to as the work domain, for complex sociotechnical systems (Rasmussen, 1985). In the EID framework, the AH is used to determine what kinds of information should be displayed on the system interface and how the information should be arranged. The AH describes a system at different levels of abstraction using how and why relationships. Moving down the model levels answers how certain elements in the system are achieved, whereas moving up reveals why certain elements exist. Elements at highest level of the model define the purposes and goals of the system. Elements at the lowest levels of the model indicate and describe the physical components (i.e. equipment) of the system. The how and why relationships are shown on the AH as means-ends links. An AH is typically developed following a systematic approach known as a Work Domain Analysis (Vicente, 1999a). It is not uncommon for a Work Domain Analysis to yield multiple AH models; each examining the system at a different level of physical detail defined using another model called the Part-Whole Hierarchy (Burns & Hajdukiewicz, 2004).

Each level in the AH is a complete but unique description of the work domain.

Functional Purpose

The Functional Purpose (FP) level describes the goals and purposes of the system. An AH typically includes more than one system goal such that the goals conflict or complement each other (Burns & Hajdukiewicz, 2004). The relationships between the goals indicate potential trade-offs and constraints within the work domain of the system. For example, the goals of a refrigerator might be to cool food to a certain temperature while using a minimal amount of electricity.

Abstract Function

The Abstract Function (AF) level describes the underlying laws and principles that govern the goals of the system. These may be empirical laws in a physical system, judicial laws in a social system, or even economic principles in a commercial system. In general, the laws and principles focus on things that need to be conserved or that flow through the system such as mass (Burns & Hajdukiewicz, 2004). The operation of the refrigerator (as a heat pump) is governed by the second law of thermodynamics.

Generalised Function

The Generalised Function (GF) level explains the processes involved in the laws and principles found at the AF level, i.e. how each abstract function is achieved. Causal relationships exist between the elements found at the GF level. The refrigeration cycle in a refrigerator involves pumping heat from an area of low temperature (source) into an area of higher temperature (sink).

Physical Function

The Physical Function (PFn) level reveals the physical components or equipment associated with the processes identified at the GF level. The capabilities and limitations of the components such as maximum capacity are also usually noted in the AH (Burns & Hajdukiewicz, 2004). A refrigerator may consist of heat exchange pipes and a gas compressor that can exert a certain maximum pressure on the cooling medium.

Physical Form

The Physical Form (PFo) level describes the condition, location, and physical appearance of the components shown at the PFn level. In the refrigerator example, the heat exchange pipes and the gas compressor are arranged in a specific manner, basically illustrating the location of the components. Physical characteristics may include things as colour, dimensions, and shape.

Causal Abstraction Hierarchy

The hierarchy described before is a *functional* Abstraction Hierarchy representation. A *functional* Abstraction Hierarchy emphasizes the “means-ends” or “how/why” links of the hierarchy. These connections are direct and illustrated across the five levels of the Abstraction Hierarchy.

As the systems get more and more complex, we need to follow the flow structure as well as to understand how the system works. This is when a *causal* Abstraction Hierarchy representation becomes necessary. As the flow patterns become increasingly complex and it becomes increasingly difficult to derive the flows directly from the system diagram, we add causal models to the functional models.

The causal models help to detail the flow structure and understand more complex flow patterns within a specified Abstraction Hierarchy level. A *causal* Abstraction Hierarchy representation has the same structure as a *functional* Abstraction Hierarchy representation but with causal links drawn. Causal links are also known as “within the level” links. These links show how the processes and flows are connected within each level.

The two representations are closely related but are usually developed separately because doing so results in a clearer model which captures most of the system constraints.

In very elaborate flow systems causal models can be used to simplify or abstract the flows. In such a scenario we may find it easier to identify the main feed and product lines at first, then control lines, emergency supply lines, or emergency shunting lines (Burns & Hajdukiewicz, 2004). Causal links are most useful at the Generalized Function and the Abstract Function levels which show flows of materials, processes, mass, or energy.

The Skills, Rules, Knowledge (SRK) framework

The Skills, Rules, Knowledge (SRK) framework or SRK taxonomy defines three types of behaviour or psychological processes present in operator information processing (Vicente, 1999a). The SRK framework was developed by Rasmussen (1983) to help designers combine information requirements for a system and aspects of human cognition. In EID, the SRK framework is used to determine how information should be displayed to take advantage of human perception and psychomotor abilities (Vicente, 1999b). By supporting skill- and rule-based behaviours in familiar tasks, more cognitive resources may be devoted to knowledge-based behaviours, which are important for managing unanticipated events. The three categories essentially describe the possible ways in which information, for example, from a human-machine interface is extracted and understood:

Skill-based level

A skill-based behaviour represents a type of behaviour that requires very little or no conscious control to perform or execute an action once an intention is formed; also known as a sensorimotor behaviour. Performance is smooth, automated, and consists of highly integrated patterns of behaviour in most skill-based control (Rasmussen, 1990). For example, bicycle riding is considered a skill-based behaviour in which very little attention is required for control once the skill is acquired. This automaticity allows operators to free up cognitive resources, which can then be used for higher cognitive functions like problem solving (Wickens & Hollands, 2000).

Rule-based level

A rule-based behaviour is characterised by the use of rules and procedures to select a course of action in a familiar work situation (Rasmussen, 1990). The rules can be a set of instructions acquired by the operator through experience or given by supervisors and former operators.

Operators are not required to know the underlying principles of a system, to perform a rule-based control. For example, hospitals have highly-proceduralised instructions for fire emergencies. Therefore, when one sees a fire, one can follow the necessary steps to ensure the safety of the patients without any knowledge of fire behaviour.

Knowledge-based level

A knowledge-based behaviour represents a more advanced level of reasoning (Wirstad, 1988). This type of control must be employed when the situation is novel and unexpected. Operators are required to know the fundamental principles and laws by which the system is governed. Since operators need to form explicit goals based on their current analysis of the system, cognitive workload is typically greater than when using skill- or rule-based behaviours.

Chapter 7

Usability

Usability is the ease of use and learnability of a human-made object. The object of use can be a software application, website, book, tool, machine, process, or anything a human interacts with. A usability study may be conducted as a primary job function by a *usability analyst* or as a secondary job function by designers, technical writers, marketing personnel, and others. It is widely used in consumer electronics, communication, and knowledge transfer objects (such as a cookbook, a document or online help) and mechanical objects such as a door handle or a hammer.

Usability includes methods of measuring usability and the study of the principles behind an object's perceived efficiency or elegance. In human-computer interaction and computer science, usability studies the elegance and clarity with which the interaction with a computer program or a web site (web usability) is designed. Usability differs from user satisfaction insofar as the former also embraces usefulness.

Introduction

The primary notion of usability is that an object designed with a generalized users' psychology and physiology in mind is, for example:

- More efficient to use—takes less time to accomplish a particular task
- Easier to learn—operation can be learned by observing the object
- More satisfying to use

Complex computer systems find their way into everyday life, and at the same time the market is saturated with competing brands. This has made usability more popular and widely recognized in recent years, as companies see the benefits of researching and developing their products with user-oriented methods instead of technology-oriented methods. By understanding and researching the interaction between product and user, the *usability expert* can also provide insight that is unattainable by traditional company-oriented market research. For example, after observing and interviewing users, the usability expert may identify needed functionality or design flaws that were not anticipated. A method called *contextual inquiry* does this in the naturally occurring context of the users own environment.

In the user-centered design paradigm, the product is designed with its intended users in mind at all times. In the user-driven or participatory design paradigm, some of the users become actual or de facto members of the design team.

The term *user friendly* is often used as a synonym for *usable*, though it may also refer to accessibility. Usability describes the quality of user experience across websites, software, products, and environments.

There is no consensus about the relation of the terms ergonomics (or human factors) and usability. Some think of usability as the software specialization of the larger topic of ergonomics. Others view these topics as tangential, with ergonomics focusing on physiological matters (e.g., turning a door handle) and usability focusing on psychological matters (e.g., recognizing that a door can be opened by turning its handle).

Usability is also important in website development (web usability). According to Jakob Nielsen, "Studies of user behavior on the Web find a low tolerance for difficult designs or slow sites. People don't want to wait. And they don't want to learn how to use a home page. There's no such thing as a training class or a manual for a Web site. People have to be able to grasp the functioning of the site immediately after scanning the home page—for a few seconds at most." Otherwise, most casual users simply leave the site and browse or shop elsewhere.

Definition

ISO defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use." Usability is a qualitative attribute that assesses how easy user interfaces are to use. The word "usability" also refers to methods for improving ease-of-use during the design process. Usability consultant Jakob Nielsen and computer science professor Ben Shneiderman have written (separately) about a framework of system acceptability, where usability is a part of "usefulness" and is composed of:

- Learnability: How easy is it for users to accomplish basic tasks the first time they encounter the design?
- Efficiency: Once users have learned the design, how quickly can they perform tasks?
- Memorability: When users return to the design after a period of not using it, how easily can they re establish proficiency?
- Errors: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
- Satisfaction: How pleasant is it to use the design?

Usability is often associated with the functionalities of the product (cf. ISO definition, below), in addition to being solely a characteristic of the user interface (cf. framework of system acceptability, also below, which separates *usefulness* into *utility* and *usability*). For example, in the context of mainstream consumer products, an automobile lacking a reverse gear could be considered *unusable* according to the former view, and *lacking in utility* according to the latter view.

When evaluating user interfaces for usability, the definition can be as simple as "the perception of a target user of the effectiveness (fit for purpose) and efficiency (work or time required to use) of the Interface". Each component may be measured subjectively against criteria, e.g., Principles of User Interface Design, to provide a metric, often expressed as a percentage. It is important to distinguish between usability testing and usability engineering. Usability testing is the measurement of ease of use of a product or piece of software. In contrast, usability engineering (UE) is the research and design process that ensures a product with good usability.

Usability is a non-functional requirement. As with other non-functional requirements, usability cannot be directly measured but must be quantified by means of indirect measures or attributes such as, for example, the number of reported problems with ease-of-use of a system.

Intuitive interfaces

The term intuitive is often listed as a desirable trait in usable interfaces, often used as a synonym for learnable. Some experts such as Jef Raskin have discouraged using this term in user interface design, claiming that easy to use interfaces are often easy because of the user's exposure to previous similar systems, thus the term 'familiar' should be preferred. As an example: Two vertical lines "||" on media player buttons do not intuitively mean "pause"—they do so by convention. Aiming for "intuitive" interfaces (based on reusing existing skills with interaction systems) could lead designers to discard a better design solution only because it would require a novel approach. This position is sometimes illustrated with the remark that "The only intuitive interface is the nipple; everything else is learned."

Bruce Tognazzini even denies the existence of "intuitive" interfaces, since such interfaces must be able to intuit, i.e., "perceive the patterns of the user's behavior and draw inferences." Instead, he advocates the term "intuitable," i.e., "that users could intuit the workings of an application by seeing it and using it." He continues, however, "But even that is a less than useful goal since only 25 percent of the population depends on intuition to perceive anything."

Investigation

The key principle for maximizing usability is to employ iterative design, which progressively refines the design through evaluation from the early stages of design. The evaluation steps enable the designers and developers to incorporate user and client feedback until the system reaches an acceptable level of usability.

The preferred method for ensuring usability is to test actual users on a working system. Although, there are many methods for studying usability, the most basic and useful is user testing, which has three components:

- Get some representative users.
- Ask the users to perform representative tasks with the design.
- Observe what the users do, where they succeed, and where they have difficulties with the user interface.

It's important to test users individually and let them solve any problems on their own. If you help them or direct their attention to any particular part of the screen, you will bias the test. Rather than running a big, expensive study, it's better to run many small tests and revise the design between each one so you can fix the usability flaws as you identify them. Iterative design is the best way to increase the quality of user experience. The more versions and interface ideas you test with users, the better.

Usability plays a role in each stage of the design process. The resulting need for multiple studies is one reason to make individual studies fast and cheap, and to perform usability testing early in the design process. Here are the main steps:

- Before starting the new design, test the old design to identify good parts you should keep or emphasize, and bad parts that give users trouble.
- Test competitors' designs to get data on a range of alternative designs.
- Conduct a field study to see how users behave in their natural habitat.
- Make mock-ups or paper prototypes of one or more new design ideas and test them. The less time you invest in these design ideas the better, because you'll need to change them based on the test results.
- Refine the design ideas that test best through multiple iterations, gradually moving from low-fidelity prototyping to high-fidelity representations that run on the computer. Test each iteration.
- Inspect the design relative to established usability guidelines, whether from your own earlier studies or published research.
- Once you decide on and implement the final design, test it again. Subtle usability problems always creep in during implementation.

Don't defer user testing until you have a fully implemented design. If you do, it will be impossible to fix the vast majority of the critical usability problems that the test uncovers. Many of these problems are likely to be structural, and fixing them would require major rearchitecting. The only way to a high-quality user experience is to start user testing early in the design process and to keep testing every step of the way.

ISO standards

ISO/TR 16982:2002

ISO/TR 16982:2002 ("Ergonomics of human-system interaction—Usability methods supporting human-centered design") is a standard that provides information on human-centred usability methods that can be used for design and evaluation. It details the advantages, disadvantages, and other factors relevant to using each usability method. It explains the implications of the stage of the life cycle and the individual project characteristics for the selection of usability methods and provides examples of usability methods in context.

The main users of ISO/TR 16982:2002 are project managers. It therefore addresses technical human factors and ergonomics issues only to the extent necessary to allow managers to understand their relevance and importance in the design process as a whole. The guidance in ISO/TR 16982:2002 can be tailored for specific design situations by using the lists of issues characterizing the context of use of the product to be delivered. Selection of appropriate usability methods should also take account of the relevant life-cycle process. ISO/TR 16982:2002 is restricted to methods that are widely used by usability specialists and project managers. It does *not* specify the details of how to implement or carry out the usability methods described.

ISO 9241

ISO 9241 is a multi-part standard that covers a number of aspects of people working with computers. Although originally titled *Ergonomic requirements for office work with visual display terminals (VDTs)*, it has been retitled to the more generic *Ergonomics of Human System Interaction*.

As part of this change, ISO is renumbering the standard so that it can include many more topics. The first part to be renumbered was part 10 (now renumbered to part 110). Part 1 is a general introduction to the rest of the standard. Part 2 addresses task design for working with computer systems. Parts 3–9 deal with physical characteristics of computer equipment. Parts 110 and parts 11–19 deal with usability aspects of software, including Part 110 (a general set of usability heuristics for the design of different types of dialogue) and Part 11 (general guidance on the specification and measurement of usability).

Usability considerations

Usability includes considerations such as:

- Who are the users, what do they know, what can they learn?
- What do users want or need to do?
- What is the users' general background?
- What is the users' context for working?
- What must be left to the machine?

Answers to these are obtained through user and task analysis at the start of the project.

Other considerations

- Can users easily accomplish intended tasks at their desired speed?
- How much training do users need?
- What documentation or other supporting materials are available to help the user? Can users find solutions in these materials?
- What and how many errors do users make when they interact with the product?
- Can the user recover from errors? What do users have to do to recover from errors? Does the product help users recover from errors? For example, does software present comprehensible, informative, non-threatening error messages?
- Does the product meet the special needs of disabled users? (Is it (accessible?)
- Are there substantial differences between the cognitive approaches of various users that affect the design, or does a one-size-fits-all approach work?

Ways to answer these and other questions include user-focused requirements analysis, building user profiles, and usability testing.

Discoverability

Even if software is usable as per the above considerations, it may still be hard to *learn* to use. Other questions that must be asked are:

- Is the user ever expected to do something that is not obvious? (e.g., Are important features only accessible by right-clicking on a menu header, on a text box, or on an unusual GUI element?)
- Are there hints and tips and shortcuts that appear as the user is using the software?
- Should there be instructions in the manual that actually belong as contextual tips shown in the program?
- Is the user at a disadvantage if they don't know certain keyboard shortcuts? A user has the right to know all major and minor keyboard shortcuts and features of an application.
- Is the learning curve (of hints and tips) skewed towards point-and-click users rather than keyboard users?
- Are there any "hidden" or undocumented keyboard shortcuts, that would better be revealed in a "Keyboard shortcuts" Help-Menu item? A strategy to prevent this "undocumented feature disconnect" is to automatically generate a list of keyboard shortcuts from their definitions in the code.

Lund, 1997 usability maxims

When evaluating the design and usability of a website, consider the following:

- Know the user, and YOU are not the user.
- Things that look the same should act the same.

- The information for the decision must be there when the decision is needed.
- Error messages should actually mean something to the user and tell the user how to fix the problem.
- Every action should have a reaction.
- Everyone makes mistakes, so every mistake should be fixable.
- Don't overwhelm the user.
- Consistency, consistency, consistency.
- Minimize the need for a mighty memory.
- Keep it simple.
- The user should always know what is happening.
- The more you do something, the easier it should be to do.
- The user should control the system. The system should not control the user. The user is the boss and the system should show it.
- Eliminate unnecessary decisions and illuminate the rest.
- The best journey has the fewest steps. Shorten the distance between the user and the goal.
- User should be able to do what they want.
- Alert users to an error before things get worse.
- Users should always know how to find out what to do next.
- Strive to empower the user, not speed up the system.
- Things that look different should act different.

These are presented in a descending order determined by their mean rating of importance.

Designing for usability

Any system designed for people should be easy to use, easy to learn, easy to remember, and helpful to users. John Gould and Clayton Lewis recommend that designers striving for usability follow these three design principles

- Early focus on users and tasks
- Empirical measurement
- Iterative design

Early focus on users and tasks

The design team should be user driven and in direct contact with potential users. Several evaluation methods, including personas, cognitive modeling, inspection, inquiry, prototyping, and testing methods may contribute to understanding potential users.

Usability considerations such as who the users are and their experience with similar systems must be examined. As part of understanding users, this knowledge must "...be played against the tasks that the users will be expected to perform." This includes the analysis of what tasks the users will perform, which are most important, and what decisions the users will make while using your system. Designers must understand how cognitive and emotional characteristics of users will relate to a proposed system.

One way to stress the importance of these issues in the designers' minds is to use personas, which are made-up representative users.

Empirical measurement

Test the system early on, and test the system on real users using behavioral measurements. This includes testing the system for both learnability and usability. It is important in this stage to use quantitative usability specifications such as time and errors to complete tasks and number of users to test, as well as examine performance and attitudes of the users testing the system. Finally, "reviewing or demonstrating" a system before the user tests it can result in misleading results. The emphasis of empirical measurement is on measurement, both informal and formal, which can be carried out through a variety of evaluation methods.

Iterative design

Iterative design is a design methodology based on a cyclic process of prototyping, testing, analyzing, and refining a product or process. Based on the results of testing the most recent iteration of a design, changes and refinements are made. This process is intended to ultimately improve the quality and functionality of a design. In iterative design, interaction with the designed system is used as a form of research for informing and evolving a project, as successive versions, or iterations of a design are implemented. The key requirements for Iterative Design are: identification of required changes, an ability to make changes, and a willingness to make changes. When a problem is encountered, there is no set method to determine the correct solution. Rather, there are empirical methods that can be used during system development or after the system is delivered, usually a more inopportune time. Ultimately, iterative design works towards meeting goals such as making the system user friendly, easy to use, easy to operate, simple, etc.

Evaluation methods

There are a variety of usability evaluation methods. Certain methods use data from users, while others rely on usability experts. There are usability evaluation methods for all stages of design and development, from product definition to final design modifications. When choosing a method, consider cost, time constraints, and appropriateness.

Cognitive modeling methods

Cognitive modeling involves creating a computational model to estimate how long it takes people to perform a given task. Models are based on psychological principles and experimental studies to determine times for cognitive processing and motor movements. Cognitive models can be used to improve user interfaces or predict problem errors and pitfalls during the design process. A few examples of cognitive models include:

Parallel Design

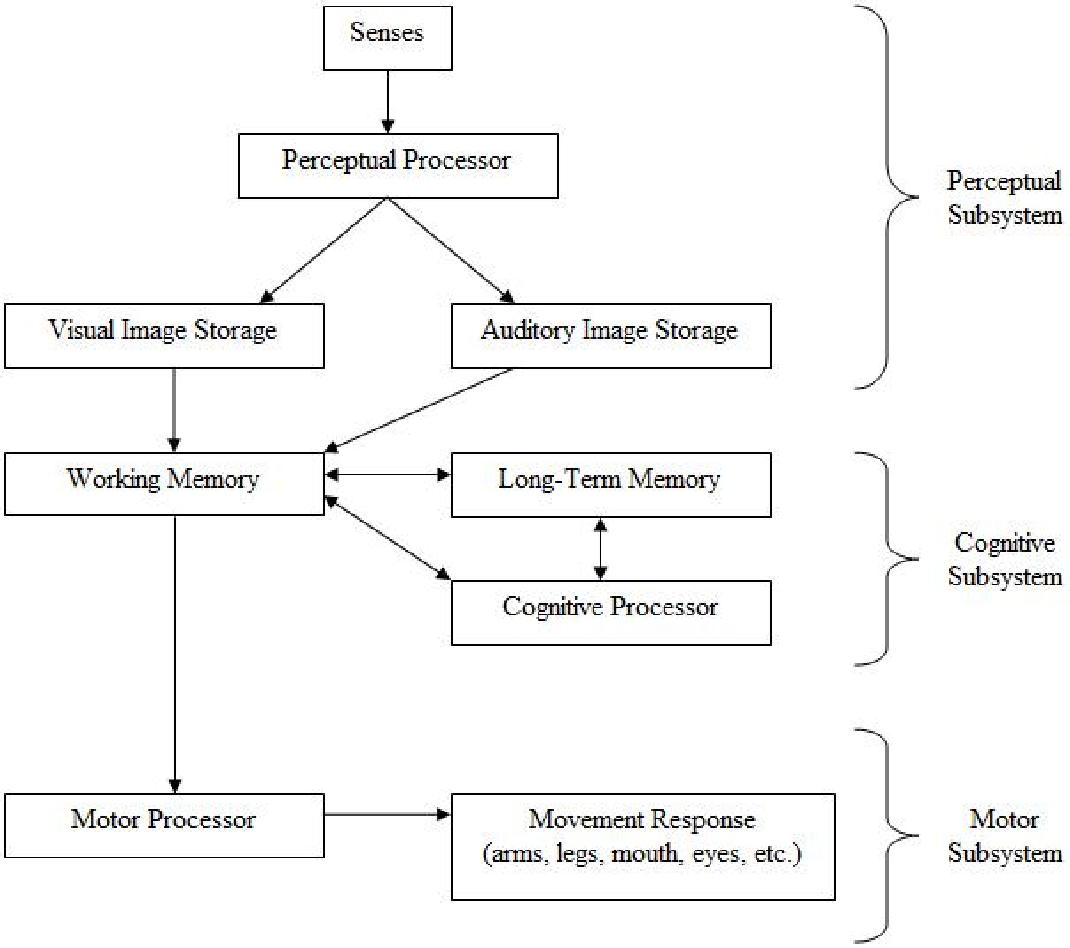
With parallel design, several people create an initial design from the same set of requirements. Each person works independently, and when finished, shares concepts with the group. The design team considers each solution, and each designer uses the best ideas to further improve their own solution. This process helps generate many different, diverse ideas, and ensures that the best ideas from each design are integrated into the final concept. This process can be repeated several times until the team is satisfied with the final concept.

GOMS

GOMS stands for *goals, operator, methods, and selection rules*. It is a family of techniques that analyzes the user complexity of interactive systems. Goals are what the user must accomplish. An operator is an action performed in pursuit of a goal. A method is a sequence of operators that accomplish a goal. Selection rules specify which method satisfies a given goal, based on context.

Human Processor Model

Sometimes it is useful to break a task down and analyze each individual aspect separately. This helps the tester locate specific areas for improvement. To do this, it is necessary to understand how the human brain processes information. A model of the human processor is shown below.



Many studies have been done to estimate the cycle times, decay times, and capacities of each of these processors. Variables that affect these can include subject age, aptitudes, ability, and the surrounding environment. For a younger adult, reasonable estimates are:

Parameter	**Mean**	**Range**
Eye movement time	230 ms	70-700 ms
Decay half-life of visual image storage	200 ms	90-1000 ms
Perceptual processor cycle time	100 ms	50-200 ms
Cognitive processor cycle time	70 ms	25-170 ms
Motor processor cycle time	70 ms	30-100 ms
Effective working memory capacity	7 items	5-9 items

Long-term memory is believed to have an infinite capacity and decay time.

Keystroke level modeling

Keystroke level modeling is essentially a less comprehensive version of GOMS that makes simplifying assumptions in order to reduce calculation time and complexity.

Inspection methods

These usability evaluation methods involve observation of users by an experimenter, or the testing and evaluation of a program by an expert reviewer. They provide more quantitative data as tasks can be timed and recorded.

Card sorts

Card sorting is a way to involve users in grouping information for a website's usability review. Participants in a card sorting session are asked to organize the content from a Web site in a way that makes sense to them. Participants review items from a Web site and then group these items into categories. Card sorting helps to learn how users think about the content and how they would organize the information on the Web site. Card sorting helps to build the structure for a Web site, decide what to put on the home page, and label the home page categories. It also helps to ensure that information is organized on the site in a way that is logical to users.

Tree tests

Tree testing is a way to evaluate the effectiveness of a website's top-down organization. Participants are given "find it" tasks, then asked to drill down through successive text lists of topics and subtopics to find a suitable answer. Tree testing evaluates the findability and labeling of topics in a site, separate from its navigation controls or visual design.

Ethnography

Ethnographic analysis is derived from anthropology. Field observations are taken at a site of a possible user, which track the artifacts of work such as Post-It notes, items on desktop, shortcuts, and items in trash bins. These observations also gather the sequence of work and interruptions that determine the user’s typical day.

Heuristic Evaluation

Heuristic evaluation is a usability engineering method for finding and assessing usability problems in a user interface design as part of an iterative design process. It involves having a small set of evaluators examining the interface and using recognized usability principles (the "heuristics"). It is the most popular of the usability inspection methods, as it is quick, cheap, and easy.

Heuristic evaluation was developed to aid in the design of computer user-interface design. It relies on expert reviewers to discover usability problems and then categorize and rate them by a set of principles (heuristics.) It is widely used based on its speed and cost-effectiveness. Jakob Nielsen's list of ten heuristics is the most commonly used in industry. These are ten general principles for user interface design. They are called "heuristics" because they are more in the nature of rules of thumb than specific usability guidelines.

- *Visibility of system status*: The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
- *Match between system and the real world*: The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
- *User control and freedom*: Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
- *Consistency and standards*: Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
- *Error prevention*: Even better than good error messages is a careful design that prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
- *Recognition rather than recall*: Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
- *Flexibility and efficiency of use*: Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
- *Aesthetic and minimalist design*: Dialogues should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
- *Help users recognize, diagnose, and recover from errors*: Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
- *Help and documentation*: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Thus, by determining which guidelines are violated, the usability of a device can be determined.

Usability Inspection

Usability inspection is a review of a system based on a set of guidelines. The review is conducted by a group of experts who are deeply familiar with the concepts of usability in design. The experts focus on a list of areas in design that have been shown to be troublesome for users.

Pluralistic Inspection

Pluralistic Inspections are meetings where users, developers, and human factors people meet together to discuss and evaluate step by step of a task scenario. As more people inspect the scenario for problems, the higher the probability to find problems. In addition, the more interaction in the team, the faster the usability issues are resolved.

Consistency Inspection

In consistency inspection, expert designers review products or projects to ensure consistency across multiple products to look if it does things in the same way as their own designs.

Activity Analysis

Activity analysis is a usability method used in preliminary stages of development to get a sense of situation. It involves an investigator observing users as they work in the field. Also referred to as user observation, it is useful for specifying user requirements and studying currently used tasks and subtasks. The data collected is qualitative and useful for defining the problem. It should be used when you wish to frame what is needed, or “What do we want to know?”

Inquiry methods

The following usability evaluation methods involve collecting qualitative data from users. Although the data collected is subjective, it provides valuable information on what the user wants.

Task Analysis

Task analysis means learning about users' goals and users' ways of working. Task analysis can also mean figuring out what more specific tasks users must do to meet those goals and what steps they must take to accomplish those tasks. Along with user and task analysis, we often do a third analysis: understanding users' environments (physical, social, cultural, and technological environments).

Focus Groups

A focus group is a focused discussion where a moderator leads a group of participants through a set of questions on a particular topic. Although typically used as a marketing tool, Focus Groups are sometimes used to evaluate usability. Used in the product definition stage, a group of 6 to 10 users are gathered to discuss what they desire in a product. An experienced focus group facilitator is hired to guide the discussion to areas of interest for the developers. Focus groups are typically videotaped to help get verbatim quotes, and clips are often used to summarize opinions. The data gathered is not usually quantitative, but can help get an idea of a target group's opinion.

Questionnaires/Surveys

Surveys have the advantages of being inexpensive, require no testing equipment, and results reflect the users’ opinions. When written carefully and given to actual users who have experience with the product and knowledge of design, surveys provide useful feedback on the strong and weak areas of the usability of a design. This is a very common method and often does not appear to be a survey, but just a warranty card.

Prototyping methods

Rapid Prototyping

Rapid prototyping is a method used in early stages of development to validate and refine the usability of a system. It can be used to quickly and cheaply evaluate user-interface designs without the need for an expensive working model. This can help remove hesitation to change the design, since it is implemented before any real programming begins. One such method of rapid prototyping is paper prototyping.

Testing methods

These usability evaluation methods involve testing of subjects for the most quantitative data. Usually recorded on video, they provide task completion time and allow for observation of attitude.

Remote usability testing

Remote usability testing (also known as unmoderated or asynchronous usability testing) involves the use of a specially modified online survey, allowing the quantification of user testing studies by providing the ability to generate large sample sizes. Additionally, this style of user testing also provides an opportunity to segment feedback by demographic, attitudinal and behavioural type. The tests are carried out in the user’s own environment (rather than labs) helping further simulate real-life scenario testing. This approach also provides a vehicle to easily solicit feedback from users in remote areas.

Thinking Aloud

The Think aloud protocol is a method of gathering data that is used in both usability and psychology studies. It involves getting a user to verbalize their thought processes as they perform a task or set of tasks. Often an instructor is present to prompt the user into being more vocal as they work. Similar to the Subjects-in-Tandem method, it is useful in pinpointing problems and is relatively simple to set up. Additionally, it can provide insight into the user's attitude, which can not usually be discerned from a survey or questionnaire.

RITE Method

Rapid Iterative Testing and Evaluation (RITE) is an iterative usability method similar to traditional "discount" usability testing. The tester and team must define a target population for testing, schedule participants to come in to the lab, decide on how the users behaviors will be measured, construct a test script and have participants engage in a verbal protocol (e.g. think aloud). However it differs from these methods in that it advocates that changes to the user interface are made as soon as a problem is identified and a solution is clear. Sometimes this can occur after observing as few as 1 participant. Once the data for a participant has been collected the usability engineer and team decide if they will be making any changes to the prototype prior to the next participant. The changed interface is then tested with the remaining users.

Subjects-in-Tandem

Subjects-in-tandem is pairing of subjects in a usability test to gather important information on the ease of use of a product. Subjects tend to think out loud and through their verbalized thoughts designers learn where the problem areas of a design are. Subjects very often provide solutions to the problem areas to make the product easier to use.

Component-based usability testing

Component-based usability testing is an approach which aims to test the usability of elementary units of an interaction system, referred to as interaction components. The approach includes component-specific quantitative measures based on user interaction recorded in log files, and component-based usability questionnaires.

Other methods

Cognitive walkthrough

Cognitive walkthrough is a method of evaluating the user interaction of a working prototype or final product. It is used to evaluate the system’s ease of learning. Cognitive walkthrough is useful to understand the user’s thought processes and decision making when interacting with a system, specially for first-time or infrequent users.

Benchmarking

Benchmarking creates standardized test materials for a specific type of design. Four key characteristics are considered when establishing a benchmark: time to do the core task, time to fix errors, time to learn applications, and the functionality of the system. Once there is a benchmark, other designs can be compared to it to determine the usability of the system. Many of the common objectives of usability studies, such as trying to understand user behavior or exploring alternative designs, must be put aside. Unlike many other usability methods or types of labs studies, benchmark studies more closely resemble true experimental psychology lab studies, with greater attention to detail on methodology, study protocol and data analysis.

Meta-Analysis

Meta-Analysis is a statistical procedure to combine results across studies to integrate the findings. This phrase was coined in 1976 as a quantitative literature review. This type of evaluation is very powerful for determining the usability of a device because it combines multiple studies to provide very accurate quantitative support.

Persona

Personas are fictitious characters created to represent a site or product's different user types and their associated demographics and technographics. Alan Cooper introduced the concept of using personas as a part of interactive design in 1998 in his book *The Inmates Are Running the Asylum*, but had used this concept since as early as 1975.

Personas are a usability evaluation method that can be used at various design stages. The most typical time to create personas is at the beginning of designing so that designers have a tangible idea of who the users of their product will be. Personas are the archetypes that represent actual groups of users and their needs, which can be a general description of person, context, or usage scenario. This technique turns marketing data on target user population into a few physical concepts of users to create empathy among the design team, with the final aim of tailoring a product more closely to how the personas will use it.

To gather the marketing data that personas require, several tools can be used, including online surveys, web analytics, customer feedback forms, and usability tests, and interviews with customer-service representatives.

Evaluating with tests and metrics

Regardless to how carefully a system is designed, all theories must be tested using usability tests. Usability tests involve typical users using the system (or product) in a realistic environment. Observation of the user’s behavior, emotions, and difficulties while performing different tasks, often identify areas of improvement for the system.

Prototypes

It is often very difficult for designers to conduct usability tests with the exact system being designed. Cost constraints, size, and design constraints usually lead the designer to creating a prototype of the system. Instead of creating the complete final system, the designer may test different sections of the system, thus making several small models of each component of the system. The types of usability prototypes may vary from using paper models, index cards, hand drawn models, or storyboards.

Prototypes are able to be modified quickly, often are faster and easier to create with less time invested by designers and are more apt to change design; although sometimes are not an adequate representation of the whole system, are often not durable and testing results may not be parallel to those of the actual system.

Metrics

While conducting usability tests, designers must use usability metrics to identify what it is they are going to measure, or the usability metrics. These metrics are often variable, and change in conjunction with the scope and goals of the project. The number of subjects being tested can also affect usability metrics, as it is often easier to focus on specific demographics. Qualitative design phases, such as general usability (can the task be accomplished?), and user satisfaction are also typically done with smaller groups of subjects. Using inexpensive prototypes on small user groups provides more detailed information, because of the more interactive atmosphere, and the designer's ability to focus more on the individual user.

As the designs become more complex, the testing must become more formalized. Testing equipment will become more sophisticated and testing metrics become more quantitative. With a more refined prototype, designers often test effectiveness, efficiency, and subjective satisfaction, by asking the user to complete various tasks. These categories are measured by the percent that complete the task, how long it takes to complete the tasks, ratios of success to failure to complete the task, time spent on errors, the number of errors, rating scale of satisfactions, number of times user seems frustrated, etc. Additional observations of the users give designers insight on navigation difficulties, controls, conceptual models, etc. The ultimate goal of analyzing these metrics is to find/create a prototype design that users like and use to successfully perform given tasks.

After conducting usability tests, it is important for a designer to record what was observed, in addition to why such behavior occurred and modify the model according to the results. Often it is quite difficult to distinguish the source of the design errors, and what the user did wrong. However, effective usability tests will not generate a solution to the problems, but provide modified design guidelines for continued testing.

Benefits of usability

The key benefits of usability are:

- Higher revenues through increased sales
- Increased user efficiency and satisfaction
- Reduced development costs
- Reduced support costs

Corporate integration

An increase in usability generally positively affects several facets of a company's output quality. In particular, the benefits fall into several common areas:

- Increased productivity
- Decreased training and support costs
- Increased sales and revenues
- Reduced development time and costs
- Reduced maintenance costs
- Increased customer satisfaction

Increased usability in the workplace fosters several responses from employees. Along with any positive feedback, "workers who enjoy their work do it better, stay longer in the face of temptation, and contribute ideas and enthusiasm to the evolution of enhanced productivity." In order to create standards, companies often implement experimental design techniques that create baseline levels. Areas of concern in an office environment include (though are not necessarily limited to):

- Working Posture
- Design of Workstation Furniture
- Screen Displays
- Input Devices
- Organizational Issues
- Office Environment
- Software Interface

By working to improve said factors, corporations can achieve their goals of increased output at lower costs, while potentially creating optimal levels of customer satisfaction. There are numerous reasons why each of these factors correlates to overall improvement. For example, making a piece of software's user interface easier to understand would reduce the need for extensive training. The improved interface would also tend to lower the time needed to perform necessary tasks, and so would both raise the productivity levels for employees and reduce development time (and thus costs). It is important to note that each of the aforementioned factors are not mutually exclusive, rather should be understood to work in conjunction to form the overall workplace environment.

Conclusion

Usability is now recognized as an important software quality attribute, earning its place among more traditional attributes such as performance and robustness. Various academic programs focus on usability. Several usability consultancy companies have emerged, and traditional consultancy and design firms offer similar services.

Professional development

Usability practitioners are sometimes trained as industrial engineers, psychologists, kinesiologists, systems design engineers, or with a degree in information architecture, information or library science, or Human-Computer Interaction (HCI). More often though they are people who are trained in specific applied fields who have taken on a usability focus within their organization. Anyone who aims to make tools easier to use and more effective for their desired function within the context of work or everyday living can benefit from studying usability principles and guidelines.

For those seeking to extend their training, the Usability Professionals' Association offers online resources, reference lists, courses, conferences, and local chapter meetings. The UPA also sponsors World Usability Day each November.

Related professional organizations include the Human Factors and Ergonomics Society (HFES) and the Association for Computing Machinery's special interest groups in Computer Human Interaction (SIGCHI), and Computer Graphics and Interactive Techniques (SIGGRAPH).

The Society for Technical Communication also has a special interest group on Usability and User Experience (UUX). They publish a quarterly newsletter called *Usability Interface*.

Chapter 8

Human–Computer Interaction

A mouse is a pointing device that functions by detecting two-dimensional motion relative to its supporting surface.

Human–computer interaction (**HCI**) is the study, planning and design of the interaction between people (users) and computers. It is often regarded as the intersection of computer science, behavioral sciences, design and several other fields of study. Interaction between users and computers occurs at the user interface (or simply *interface*), which includes both software and hardware; for example, characters or objects displayed by software on a personal computer's monitor, input received from users via hardware peripherals such as keyboards and mice, and other user interactions with large-scale computerized systems such as aircraft and power plants. The Association for Computing Machinery defines human-computer interaction as "a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them." An important facet of HCI is the securing of user satisfaction.

Because human-computer interaction studies a human and a machine in conjunction, it draws from supporting knowledge on both the machine and the human side. On the machine side, techniques in computer graphics, operating systems, programming languages, and development environments are relevant. On the human side, communication theory, graphic and industrial design disciplines, linguistics, social sciences, cognitive psychology, and human factors are relevant. Engineering and design methods are also relevant. Due to the multidisciplinary nature of HCI, people with different backgrounds contribute to its success. HCI is also sometimes referred to as **man–machine interaction (MMI)** or **computer–human interaction (CHI)**.

Attention to human-machine interaction is important, because poorly designed human-machine interfaces can lead to many unexpected problems. A classic example of this is the Three Mile Island accident where investigations concluded that the design of the human-machine interface was at least partially responsible for the disaster. Similarly, accidents in aviation have resulted from manufacturers' decisions to use non-standard flight instrument and/or throttle quadrant layouts: even though the new designs were proposed to be superior in regards to basic human-machine interaction, pilots had already ingrained the "standard" layout and thus the conceptually good idea actually had undesirable results.

Goals

A basic goal of HCI is to improve the interactions between users and computers by making computers more usable and receptive to the user's needs. Specifically, HCI is concerned with:

- methodologies and processes for designing interfaces (i.e., given a task and a class of users, design the best possible interface within given constraints, optimizing for a desired property such as learnability or efficiency of use)
- methods for implementing interfaces (e.g. software toolkits and libraries; efficient algorithms)
- techniques for evaluating and comparing interfaces
- developing new interfaces and interaction techniques
- developing descriptive and predictive models and theories of interaction

A long term goal of HCI is to design systems that minimize the barrier between the human's cognitive model of what they want to accomplish and the computer's understanding of the user's task.

Professional practitioners in HCI are usually designers concerned with the practical application of design methodologies to real-world problems. Their work often revolves around designing graphical user interfaces and web interfaces.

Researchers in HCI are interested in developing new design methodologies, experimenting with new hardware devices, prototyping new software systems, exploring new paradigms for interaction, and developing models and theories of interaction.

Differences with related fields

HCI differs from human factors (or ergonomics) in that with HCI the focus is more on users working specifically with computers, rather than other kinds of machines or designed artifacts. There is also a focus in HCI on how to implement the computer software and hardware mechanisms to support human-computer interaction. Thus, human factors is a broader term; HCI could be described as the human factors of computers - although some experts try to differentiate these areas.

HCI also differs from human factors in that there is less of a focus on repetitive work-oriented tasks and procedures, and much less emphasis on physical stress and the physical form or industrial design of the user interface, such as keyboards and mice.

Three areas of study have substantial overlap with HCI even as the focus of inquiry shifts. In the study of personal information management (PIM), human interactions with the computer are placed in a larger informational context - people may work with many forms of information, some computer-based, many not (e.g., whiteboards, notebooks, sticky notes, refrigerator magnets) in order to understand and effect desired changes in their world. In computer supported cooperative work (CSCW), emphasis is placed on the use of computing systems in support of the collaborative work of a group of people. The principles of human interaction management (HIM) extend the scope of CSCW to an organizational level and can be implemented without use of computer systems.

Design principles

When evaluating a current user interface, or designing a new user interface, it is important to keep in mind the following experimental design principles:

- Early focus on user(s) and task(s): Establish how many users are needed to perform the task(s) and determine who the appropriate users should be; someone who has never used the interface, and will not use the interface in the future, is most likely not a valid user. In addition, define the task(s) the users will be performing and how often the task(s) need to be performed.

- Empirical measurement: Test the interface early on with real users who come in contact with the interface on an everyday basis. Keep in mind that results may be altered if the performance level of the user is not an accurate depiction of the real human-computer interaction. Establish quantitative usability specifics such as: the number of users performing the task(s), the time to complete the task(s), and the number of errors made during the task(s).
- Iterative design: After determining the users, tasks, and empirical measurements to include, perform the following iterative design steps:

1. Design the user interface
2. Test
3. Analyze results
4. Repeat

Repeat the iterative design process until a sensible, user-friendly interface is created.

Design methodologies

A number of diverse methodologies outlining techniques for human–computer interaction design have emerged since the rise of the field in the 1980s. Most design methodologies stem from a model for how users, designers, and technical systems interact. Early methodologies, for example, treated users' cognitive processes as predictable and quantifiable and encouraged design practitioners to look to cognitive science results in areas such as memory and attention when designing user interfaces. Modern models tend to focus on a constant feedback and conversation between users, designers, and engineers and push for technical systems to be wrapped around the types of experiences users want to have, rather than wrapping user experience around a completed system.

- **User-centered design**: user-centered design (UCD) is a modern, widely practiced design philosophy rooted in the idea that users must take center-stage in the design of any computer system. Users, designers and technical practitioners work together to articulate the wants, needs and limitations of the user and create a system that addresses these elements. Often, user-centered design projects are informed by ethnographic studies of the environments in which users will be interacting with the system. This practice is similar but not identical to Participatory Design, which emphasizes the possibility for end-users to contribute actively through shared design sessions and workshops.

- **Principles of User Interface Design**: these are seven principles that may be considered at any time during the design of a user interface in any order, namely Tolerance, Simplicity, Visibility, Affordance, Consistency, Structure and Feedback.

Display designs

Displays are human-made artifacts designed to support the perception of relevant system variables and to facilitate further processing of that information. Before a display is designed, the task that the display is intended to support must be defined (e.g. navigating, controlling, decision making, learning, entertaining, etc.). A user or operator must be able to process whatever information that a system generates and displays; therefore, the information must be displayed according to principles in a manner that will support perception, situation awareness, and understanding.

Thirteen principles of display design

Christopher Wickens et al. defined 13 principles of display design in their book *An Introduction to Human Factors Engineering*.

These principles of human perception and information processing can be utilized to create an effective display design. A reduction in errors, a reduction in required training time, an increase in efficiency, and an increase in user satisfaction are a few of the many potential benefits that can be achieved through utilization of these principles.

Certain principles may not be applicable to different displays or situations. Some principles may seem to be conflicting, and there is no simple solution to say that one principle is more important than another. The principles may be tailored to a specific design or situation. Striking a functional balance among the principles is critical for an effective design.

Perceptual principles

1. Make displays legible (or audible). A display's legibility is critical and necessary for designing a usable display. If the characters or objects being displayed cannot be discernible, then the operator cannot effectively make use of them.

2. Avoid absolute judgment limits. Do not ask the user to determine the level of a variable on the basis of a single sensory variable (e.g. color, size, loudness). These sensory variables can contain many possible levels.

3. Top-down processing. Signals are likely perceived and interpreted in accordance with what is expected based on a user's past experience. If a signal is presented contrary to the user's expectation, more physical evidence of that signal may need to be presented to assure that it is understood correctly.

4. Redundancy gain. If a signal is presented more than once, it is more likely that it will be understood correctly. This can be done by presenting the signal in alternative physical forms (e.g. color and shape, voice and print, etc.), as redundancy does not imply repetition. A traffic light is a good example of redundancy, as color and position are redundant.

5. Similarity causes confusion: Use discriminable elements. Signals that appear to be similar will likely be confused. The ratio of similar features to different features causes signals to be similar. For example, A423B9 is more similar to A423B8 than 92 is to 93. Unnecessary similar features should be removed and dissimilar features should be highlighted.

Mental Model Principles

6. Principle of pictorial realism. A display should look like the variable that it represents (e.g. high temperature on a thermometer shown as a higher vertical level). If there are multiple elements, they can be configured in a manner that looks like it would in the represented environment.

7. Principle of the moving part. Moving elements should move in a pattern and direction compatible with the user's mental model of how it actually moves in the system. For example, the moving element on an altimeter should move upward with increasing altitude.

Principles Based on Attention

8. Minimizing information access cost. When the user's attention is diverted from one location to another to access necessary information, there is an associated cost in time or effort. A display design should minimize this cost by allowing for frequently accessed sources to be located at the nearest possible position. However, adequate legibility should not be sacrificed to reduce this cost.

9. Proximity compatibility principle. Divided attention between two information sources may be necessary for the completion of one task. These sources must be mentally integrated and are defined to have close mental proximity. Information access costs should be low, which can be achieved in many ways (e.g. proximity, linkage by common colors, patterns, shapes, etc.). However, close display proximity can be harmful by causing too much clutter.

10. Principle of multiple resources. A user can more easily process information across different resources. For example, visual and auditory information can be presented simultaneously rather than presenting all visual or all auditory information.

Memory Principles

11. Replace memory with visual information: knowledge in the world. A user should not need to retain important information solely in working memory or to retrieve it from long-term memory. A menu, checklist, or another display can aid the user by easing the use of their memory. However, the use of memory may sometimes benefit the user by eliminating the need to reference some type of knowledge in the world (e.g. an expert computer operator would rather use direct commands from memory than refer to a manual). The use of knowledge in a user's head and knowledge in the world must be balanced for an effective design.

12. Principle of predictive aiding. Proactive actions are usually more effective than reactive actions. A display should attempt to eliminate resource-demanding cognitive tasks and replace them with simpler perceptual tasks to reduce the use of the user's mental resources. This will allow the user to not only focus on current conditions, but also think about possible future conditions. An example of a predictive aid is a road sign displaying the distance from a certain destination.

13. Principle of consistency. Old habits from other displays will easily transfer to support processing of new displays if they are designed in a consistent manner. A user's long-term memory will trigger actions that are expected to be appropriate. A design must accept this fact and utilize consistency among different displays.

Human–computer interface

The human–computer interface can be described as the point of communication between the human user and the computer. The flow of information between the human and computer is defined as the loop of interaction. The loop of interaction has several aspects to it including:

- **Task Environment**: The conditions and goals set upon the user.
- **Machine Environment**: The environment that the computer is connected to, i.e. a laptop in a college student's dorm room.
- **Areas of the Interface**: Non-overlapping areas involve processes of the human and computer not pertaining to their interaction. Meanwhile, the overlapping areas only concern themselves with the processes pertaining to their interaction.
- **Input Flow**: The flow of information that begins in the task environment, when the user has some task that requires using their computer.
- **Output**: The flow of information that originates in the machine environment.
- **Feedback**: Loops through the interface that evaluate, moderate, and confirm processes as they pass from the human through the interface to the computer and back.

Current research

Hot topìcs in HCI include:

Group interfaces

Interfaces to allow groups of people to coordinate are common (e.g., for meetings, engineering projects, or authoring joint documents). The Internet has produced a major impact on the nature of organizations and on the division of labor. Current research studies models of the group design process to create systems with increased rationalization of design to help group work.

User Tailorability

End-user development studies how ordinary users could routinely tailor applications to their own needs and use this power to invent new applications based on their understanding of their own domains. Users, with their deeper knowledge of their own knowledge domains, could increasingly be important sources of new applications at the expense of generic systems programmers (with systems expertise but low domain expertise).

Embedded computation

Computation is passing beyond desktop computers into every object for which uses can be found. Embedded systems make the environment alive with little computations and automated processes, from computerized cooking appliances to lighting and plumbing fixtures to window blinds to automobile braking systems to greeting cards. To some extent, this development is already taking place. The expected difference in the future is the addition of networked communications that will allow many of these embedded computations to coordinate with each other and with the user. Human interfaces to these embedded devices will in many cases be very different from those appropriate to workstations.

Augmented reality

A common staple of science fiction, augmented reality refers to the notion of layering relevant information into our vision of the world. Existing projects show real-time statistics to users performing difficult tasks, such as manufacturing. Future work might include augmenting our social interactions by providing additional information about those we converse with.

Factors of change

The means by which humans interact with computers continues to evolve rapidly. Human–computer interaction is affected by the forces shaping the nature of future computing. These forces include:

- Decreasing hardware costs leading to larger memory and faster systems
- Miniaturization of hardware leading to portability
- Reduction in power requirements leading to portability
- New display technologies leading to the packaging of computational devices in new forms
- Specialized hardware leading to new functions
- Increased development of network communication and distributed computing
- Increasingly widespread use of computers, especially by people who are outside of the computing profession

- Increasing innovation in input techniques (i.e., voice, gesture, pen), combined with lowering cost, leading to rapid computerization by people previously left out of the "computer revolution."
- Wider social concerns leading to improved access to computers by currently disadvantaged groups

The future for HCI, based on current promising research, is expected to include the following characteristics:

- **Ubiquitous communication**. Computers are expected to communicate through high speed local networks, nationally over wide-area networks, and portably via infrared, ultrasonic, cellular, and other technologies. Data and computational services will be portably accessible from many if not most locations to which a user travels.

- **High functionality systems**. Systems can have large numbers of functions associated with them. There are so many systems that most users, technical or non-technical, do not have time to learn them in the traditional way (e.g., through thick manuals).

- **Mass availability of computer graphics**. Computer graphics capabilities such as image processing, graphics transformations, rendering, and interactive animation are becoming widespread as inexpensive chips become available for inclusion in general workstations and mobile devices.

- **Mixed media**. Commercial systems can handle images, voice, sounds, video, text, formatted data. These are exchangeable over communication links among users. The separate worlds of consumer electronics (e.g., stereo sets, VCRs, televisions) and computers are partially merging. Computer and print worlds are expected to cross-assimilate each other.

- **High-bandwidth interaction**. The rate at which humans and machines interact is expected to increase substantially due to the changes in speed, computer graphics, new media, and new input/output devices. This can lead to some qualitatively different interfaces, such as virtual reality or computational video.

- **Large and thin displays**. New display technologies are finally maturing, enabling very large displays and displays that are thin, lightweight, and low in power consumption. This is having large effects on portability and will likely enable the development of paper-like, pen-based computer interaction systems very different in feel from desktop workstations of the present.

- **Information Utilities**. Public information utilities (such as home banking and shopping) and specialized industry services (e.g., weather for pilots) are expected to proliferate. The rate of proliferation can accelerate with the introduction of high-bandwidth interaction and the improvement in quality of interfaces.

Academic conferences

One of the top academic conferences for new research in human-computer interaction, especially within computer science, is the annually held ACM's Conference on Human Factors in Computing Systems, usually referred to by its short name CHI. CHI is organized by ACM SIGCHI Special Interest Group on Computer–Human Interaction. CHI is a large, highly competitive conference, with thousands of attendants, and is quite broad in scope.

There are also dozens of other smaller, regional or specialized HCI-related conferences held around the world each year, the most important of which include:

Special purpose

- ASSETS: ACM International Conference on Computers and Accessibility
- CSCW: ACM conference on Computer Supported Cooperative Work.
- DIS: ACM conference on Designing Interactive Systems.
- ECSCW: European Conference on Computer-Supported Cooperative Work. Every second year.
- GROUP: ACM conference on supporting Group work.
- HRI: ACM/IEEE International Conference on Human-robot interaction.
- ICMI: International Conference on Multimodal Interfaces.
- ITS: ACM conference on Interactive Tabletops and Surfaces.
- IUI: International Conference on Intelligent User Interfaces.
- MobileHCI: International Conference on Human-Computer Interaction with Mobile Devices and Services.
- NIME: International Conference on New Interfaces for Musical Expression.
- Ubicomp: International Conference on Ubiquitous computing
- UIST: ACM Symposium on User Interface Software and Technology.

Regional and general HCI

- INTERACT: IFIP TC13 International Conference on Human-Computer Interaction. Biennial, alternating years with AVI.
- AVI: International Working Conference on Advanced Visual Interfaces. Held biennially in Italy, alternating years with INTERACT.
- MexIHC: MexIHC - Mexican Workshops on Human-Computer Interaction
- HCI International: International Conference on Human-Computer Interaction.
- ACHI: International Conferences on Advances in Human-Computer Interaction.
- HCI: British HCI Conference.
- OZCHI: Australasian HCI Conference.
- IHM: Annual French-speaking HCI Conference.
- Graphics Interface: Annual Canadian computer graphics and HCI conference. The oldest regularly scheduled conference for graphics and human-computer interaction.
- NordiCHI: Nordic Conference on Human-Computer Interaction. Biennial.

- UbiHCI: International Workshop on Ubiquitous Human-Computer Interaction-UbiHCI.