Technology Systems

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Computer System

Computer

A **computer** is a programmable machine designed to sequentially and automatically carry out a sequence of arithmetic or logical operations. The particular sequence of operations can be changed readily, allowing the computer to solve more than one kind of problem.

Conventionally a computer consists of some form of memory for data storage, at least one element that carries out arithmetic and logic operations, and a sequencing and control element that can change the order of operations based on the information that is stored. Peripheral devices allow information to be entered from external source, and allow the results of operations to be sent out.

A computer's processing unit executes series of instructions that make it read, manipulate and then store data. Conditional instructions change the sequence of instructions as a function of the current state of the machine or its environment.

The first electronic computers were developed in the mid-20th century (1940–1945). Originally, they were the size of a large room, consuming as much power as several hundred modern personal computers (PCs).

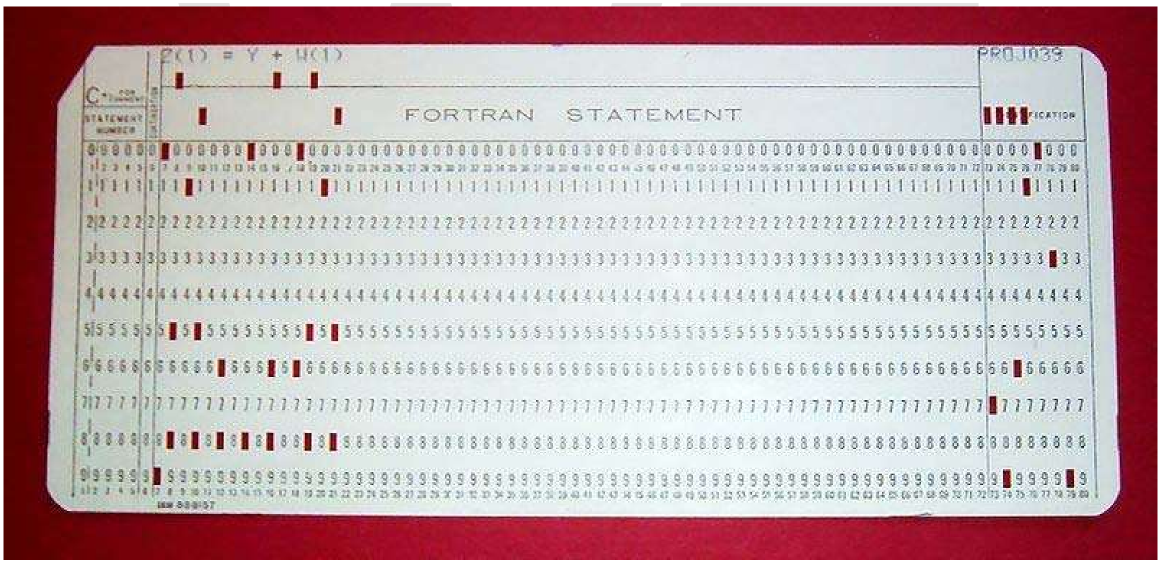
Modern computers based on integrated circuits are millions to billions of times more capable than the early machines, and occupy a fraction of the space. Simple computers are small enough to fit into mobile devices, and can be powered by a small battery. Personal computers in their various forms are icons of the Information Age and are what most people think of as "computers". However, the embedded computers found in many devices from MP3 players to fighter aircraft and from toys to industrial robots are the most numerous.

Programs

The defining feature of modern computers which distinguishes them from all other machines is that they can be programmed. That is to say that some type of instructions (the program) can be given to the computer, and it will carry process them. While some computers may have strange concepts "instructions" and "output", modern computers based on the von Neumann architecture are often have machine code in the form of an imperative programming language.

In practical terms, a computer program may be just a few instructions or extend to many millions of instructions, as do the programs for word processors and web browsers for example. A typical modern computer can execute billions of instructions per second (gigaflops) and rarely makes a mistake over many years of operation. Large computer programs consisting of several million instructions may take teams of programmers years to write, and due to the complexity of the task almost certainly contain errors.

Stored program architecture



A 1970s punched card containing one line from a FORTRAN program. The card reads: "Z(1) = Y + W(1)" and is labelled "PROJ039" for identification purposes.

This section applies to most common RAM machine-based computers.

In most cases, computer instructions are simple: add one number to another, move some data from one location to another, send a message to some external device, etc. These instructions are read from the computer's memory and are generally carried out (executed) in the order they were given. However, there are usually specialized instructions to tell the computer to jump ahead or backwards to some other place in the program and to carry on executing from there. These are called "jump" instructions (or branches). Furthermore, jump instructions may be made to happen conditionally so that different sequences of instructions may be used depending on the result of some previous calculation or some external event. Many computers directly support subroutines by providing a type of jump that "remembers" the location it jumped from and another instruction to return to the instruction following that jump instruction.

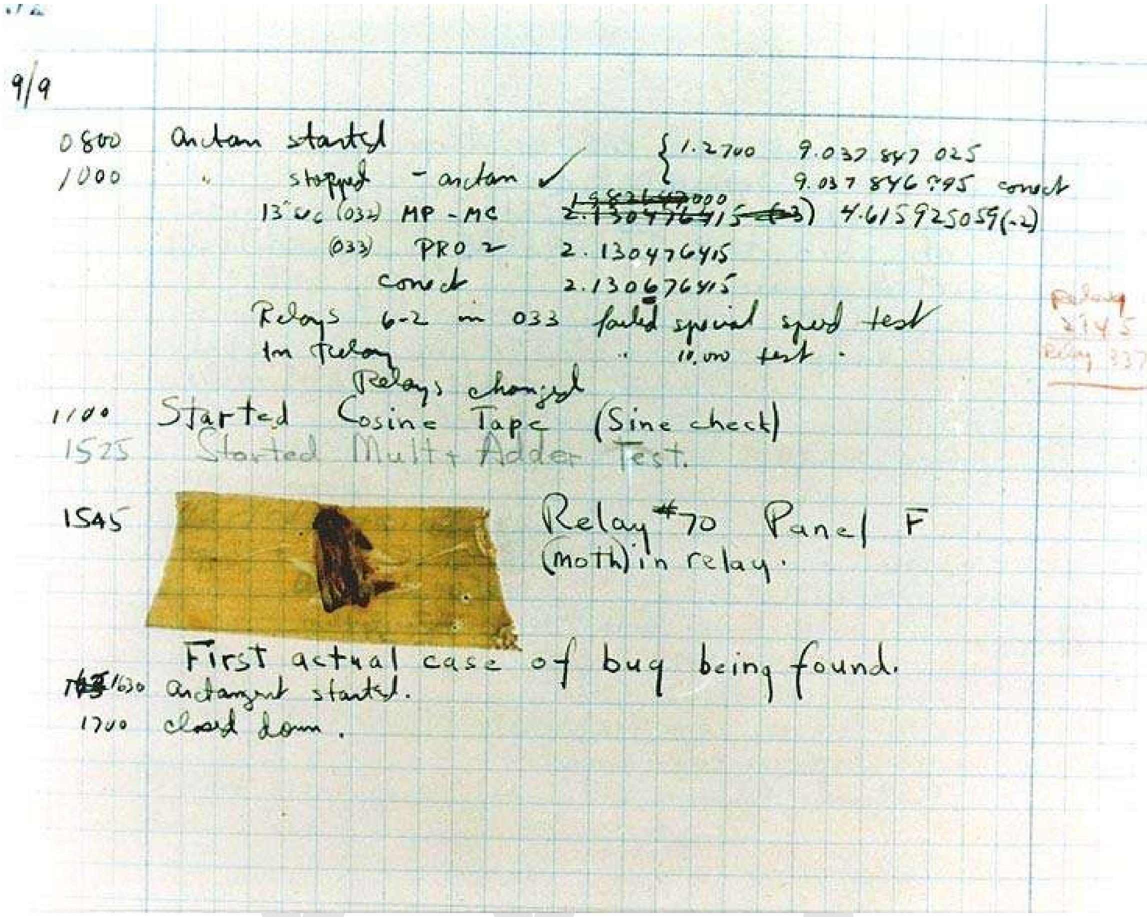
Program execution might be likened to reading a book. While a person will normally read each word and line in sequence, they may at times jump back to an earlier place in the text or skip sections that are not of interest. Similarly, a computer may sometimes go back and repeat the instructions in some section of the program over and over again until some internal condition is met. This is called the flow of control within the program and it is what allows the computer to perform tasks repeatedly without human intervention.

Comparatively, a person using a pocket calculator can perform a basic arithmetic operation such as adding two numbers with just a few button presses. But to add together all of the numbers from 1 to 1,000 would take thousands of button presses and a lot of time—with a near certainty of making a mistake. On the other hand, a computer may be programmed to do this with just a few simple instructions. For example:

```
      mov #0, sum     ; set sum to 0
      mov #1, num     ; set num to 1
loop: add num, sum    ; add num to sum
      add #1, num     ; add 1 to num
      cmp num, #1000  ; compare num to 1000
      ble loop        ; if num <= 1000, go back to 'loop'
      halt            ; end of program. stop running
```

Once told to run this program, the computer will perform the repetitive addition task without further human intervention. It will almost never make a mistake and a modern PC can complete the task in about a millionth of a second.

Bugs



The actual first computer bug, a moth found trapped on a relay of the Harvard Mark II computer

Errors in computer programs are called "bugs". Bugs may be benign and not affect the usefulness of the program, or have only subtle effects. But in some cases they may cause the program to "hang"—become unresponsive to input such as mouse clicks or keystrokes, or to completely fail or "crash". Otherwise benign bugs may sometimes be harnessed for malicious intent by an unscrupulous user writing an "exploit"—code designed to take advantage of a bug and disrupt a computer's proper execution. Bugs are usually not the fault of the computer. Since computers merely execute the instructions they are given, bugs are nearly always the result of programmer error or an oversight made in the program's design.

Rear Admiral Grace Hopper is credited for having first used the term 'bugs' in computing after a dead moth was found shorting a relay of the Harvard Mark II computer in September 1947.

Machine code

In most computers, individual instructions are stored as machine code with each instruction being given a unique number (its operation code or opcode for short). The command to add two numbers together would have one opcode, the command to multiply them would have a different opcode and so on. The simplest computers are able to perform any of a handful of different instructions; the more complex computers have several hundred to choose from—each with a unique numerical code. Since the computer's memory is able to store numbers, it can also store the instruction codes. This leads to the important fact that entire programs (which are just lists of these instructions) can be represented as lists of numbers and can themselves be manipulated inside the computer in the same way as numeric data. The fundamental concept of storing programs in the computer's memory alongside the data they operate on is the crux of the von Neumann, or stored program, architecture. In some cases, a computer might store some or all of its program in memory that is kept separate from the data it operates on. This is called the Harvard architecture after the Harvard Mark I computer. Modern von Neumann computers display some traits of the Harvard architecture in their designs, such as in CPU caches.

While it is possible to write computer programs as long lists of numbers (machine language) and while this technique was used with many early computers, it is extremely tedious and potentially error-prone to do so in practice, especially for complicated programs. Instead, each basic instruction can be given a short name that is indicative of its function and easy to remember—a mnemonic such as ADD, SUB, MULT or JUMP. These mnemonics are collectively known as a computer's assembly language. Converting programs written in assembly language into something the computer can actually understand (machine language) is usually done by a computer program called an assembler. Machine languages and the assembly languages that represent them (collectively termed low-level programming languages) tend to be unique to a particular type of computer. For instance, an ARM architecture computer (such as may be found in a PDA or a hand-held videogame) cannot understand the machine language of an Intel Pentium or the AMD Athlon 64 computer that might be in a PC.

Higher-level languages and program design

Though considerably easier than in machine language, writing long programs in assembly language is often difficult and is also error prone. Therefore, most practical programs are written in more abstract high-level programming languages that are able to express the needs of the programmer more conveniently (and thereby help reduce programmer error). High level languages are usually "compiled" into machine language (or sometimes into assembly language and then into machine language) using another computer program called a compiler. High level languages are less related to the workings of the target computer than assembly language, and more related to the language and structure of the problem(s) to be solved by the final program. It is therefore often possible to use different compilers to translate the same high level language program into the machine language of many different types of computer. This is part of the means by which software like video games may be made available for different computer architectures such as personal computers and various video game consoles.

The task of developing large software systems presents a significant intellectual challenge. Producing software with an acceptably high reliability within a predictable schedule and budget has historically been difficult; the academic and professional discipline of software engineering concentrates specifically on this challenge.

Function

A general purpose computer has four main components: the arithmetic logic unit (ALU), the control unit, the memory, and the input and output devices (collectively termed I/O). These parts are interconnected by busses, often made of groups of wires.

Inside each of these parts are thousands to trillions of small electrical circuits which can be turned off or on by means of an electronic switch. Each circuit represents a bit (binary digit) of information so that when the circuit is on it represents a "1", and when off it represents a "0" (in positive logic representation). The circuits are arranged in logic gates so that one or more of the circuits may control the state of one or more of the other circuits.

The control unit, ALU, registers, and basic I/O (and often other hardware closely linked with these) are collectively known as a central processing unit (CPU). Early CPUs were composed of many separate components but since the mid-1970s CPUs have typically been constructed on a single integrated circuit called a *microprocessor*.

Control unit

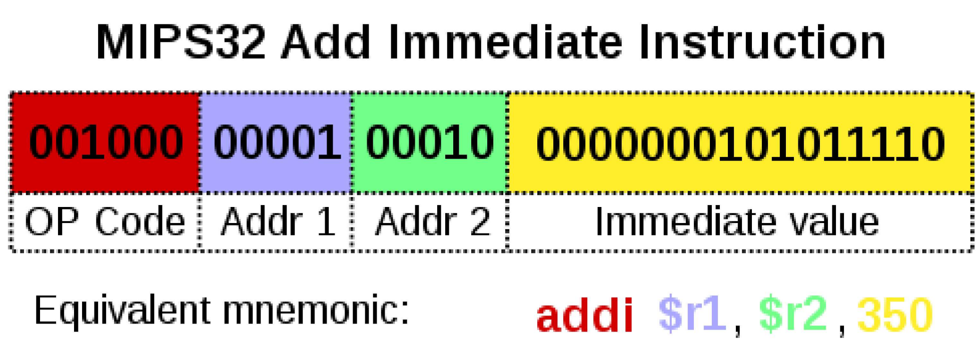


Diagram showing how a particular MIPS architecture instruction would be decoded by the control system.

The control unit (often called a control system or central controller) manages the computer's various components; it reads and interprets (decodes) the program instructions, transforming them into a series of control signals which activate other parts of the computer. Control systems in advanced computers may change the order of some instructions so as to improve performance.

A key component common to all CPUs is the program counter, a special memory cell (a register) that keeps track of which location in memory the next instruction is to be read from.

The control system's function is as follows—note that this is a simplified description, and some of these steps may be performed concurrently or in a different order depending on the type of CPU:

1. Read the code for the next instruction from the cell indicated by the program counter.
2. Decode the numerical code for the instruction into a set of commands or signals for each of the other systems.
3. Increment the program counter so it points to the next instruction.
4. Read whatever data the instruction requires from cells in memory (or perhaps from an input device). The location of this required data is typically stored within the instruction code.
5. Provide the necessary data to an ALU or register.
6. If the instruction requires an ALU or specialized hardware to complete, instruct the hardware to perform the requested operation.
7. Write the result from the ALU back to a memory location or to a register or perhaps an output device.
8. Jump back to step (1).

Since the program counter is (conceptually) just another set of memory cells, it can be changed by calculations done in the ALU. Adding 100 to the program counter would cause the next instruction to be read from a place 100 locations further down the program. Instructions that modify the program counter are often known as "jumps" and allow for loops (instructions that are repeated by the computer) and often conditional instruction execution (both examples of control flow).

It is noticeable that the sequence of operations that the control unit goes through to process an instruction is in itself like a short computer program—and indeed, in some more complex CPU designs, there is another yet smaller computer called a microsequencer that runs a microcode program that causes all of these events to happen.

Arithmetic/logic unit (ALU)

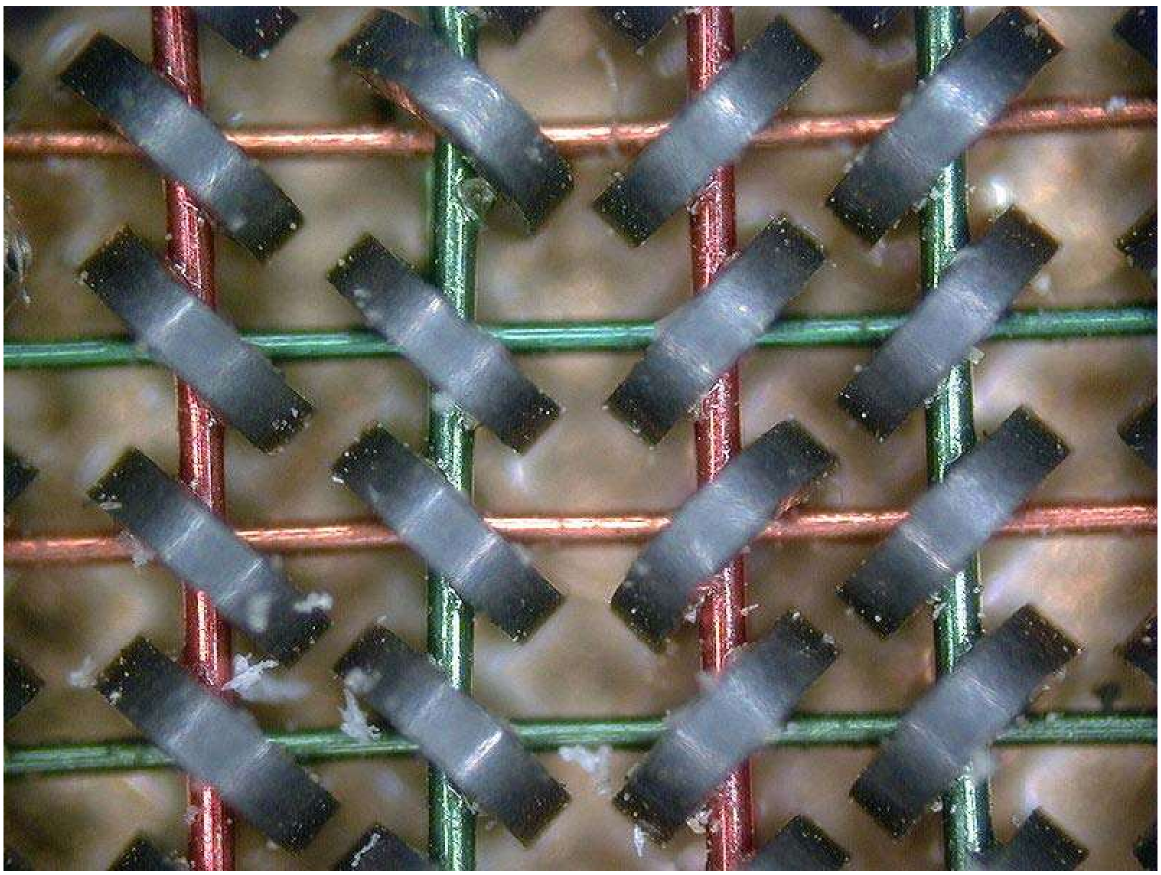
The ALU is capable of performing two classes of operations: arithmetic and logic.

The set of arithmetic operations that a particular ALU supports may be limited to adding and subtracting or might include multiplying or dividing, trigonometry functions (sine, cosine, etc.) and square roots. Some can only operate on whole numbers (integers) whilst others use floating point to represent real numbers—albeit with limited precision. However, any computer that is capable of performing just the simplest operations can be programmed to break down the more complex operations into simple steps that it can perform. Therefore, any computer can be programmed to perform any arithmetic operation—although it will take more time to do so if its ALU does not directly support the operation. An ALU may also compare numbers and return boolean truth values (true or false) depending on whether one is equal to, greater than or less than the other ("is 64 greater than 65?").

Logic operations involve Boolean logic: AND, OR, XOR and NOT. These can be useful both for creating complicated conditional statements and processing boolean logic.

Superscalar computers may contain multiple ALUs so that they can process several instructions at the same time. Graphics processors and computers with SIMD and MIMD features often provide ALUs that can perform arithmetic on vectors and matrices.

Memory



Magnetic core memory was the computer memory of choice throughout the 1960s, until it was replaced by semiconductor memory.

A computer's memory can be viewed as a list of cells into which numbers can be placed or read. Each cell has a numbered "address" and can store a single number. The computer can be instructed to "put the number 123 into the cell numbered 1357" or to "add the number that is in cell 1357 to the number that is in cell 2468 and put the answer into cell 1595". The information stored in memory may represent practically anything. Letters, numbers, even computer instructions can be placed into memory with equal ease. Since the CPU does not differentiate between different types of information, it is the software's responsibility to give significance to what the memory sees as nothing but a series of numbers.

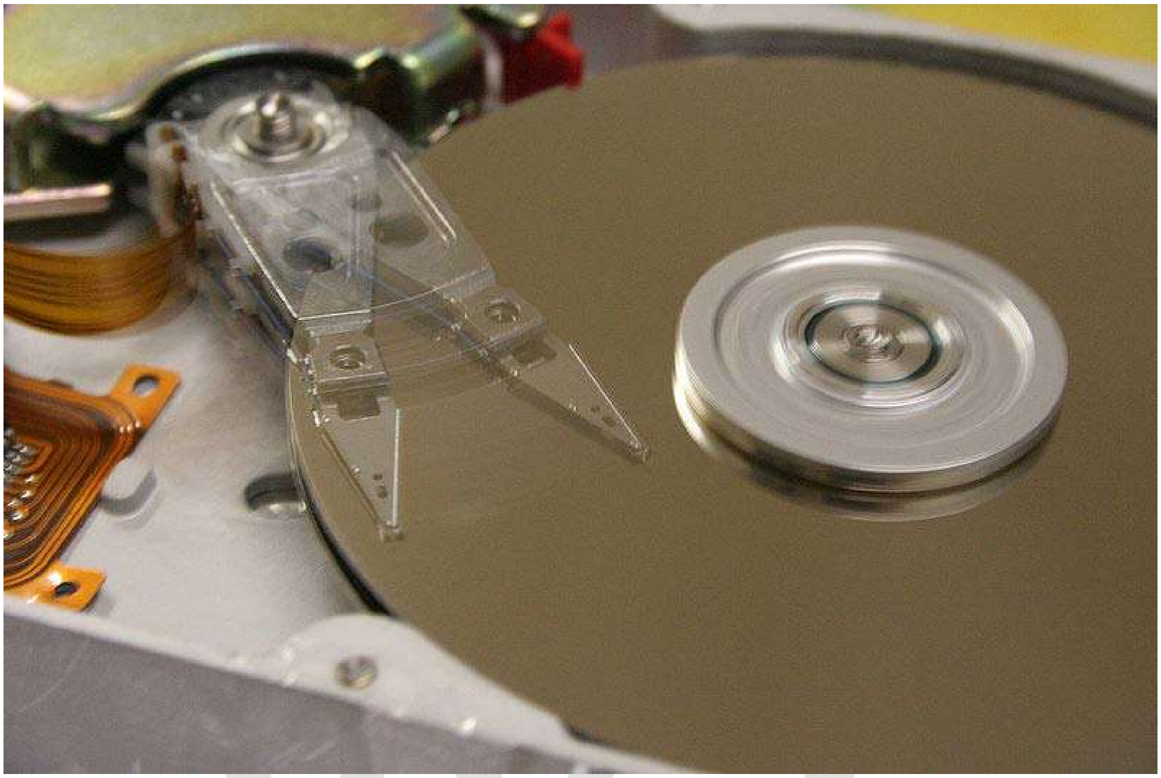
In almost all modern computers, each memory cell is set up to store binary numbers in groups of eight bits (called a byte). Each byte is able to represent 256 different numbers ($2^8 = 256$); either from 0 to 255 or −128 to +127. To store larger numbers, several consecutive bytes may be used (typically, two, four or eight). When negative numbers are required, they are usually stored in two's complement notation. Other arrangements are possible, but are usually not seen outside of specialized applications or historical contexts. A computer can store any kind of information in memory if it can be represented numerically. Modern computers have billions or even trillions of bytes of memory.

The CPU contains a special set of memory cells called registers that can be read and written to much more rapidly than the main memory area. There are typically between two and one hundred registers depending on the type of CPU. Registers are used for the most frequently needed data items to avoid having to access main memory every time data is needed. As data is constantly being worked on, reducing the need to access main memory (which is often slow compared to the ALU and control units) greatly increases the computer's speed.

Computer main memory comes in two principal varieties: random-access memory or RAM and read-only memory or ROM. RAM can be read and written to anytime the CPU commands it, but ROM is pre-loaded with data and software that never changes, so the CPU can only read from it. ROM is typically used to store the computer's initial start-up instructions. In general, the contents of RAM are erased when the power to the computer is turned off, but ROM retains its data indefinitely. In a PC, the ROM contains a specialized program called the BIOS that orchestrates loading the computer's operating system from the hard disk drive into RAM whenever the computer is turned on or reset. In embedded computers, which frequently do not have disk drives, all of the required software may be stored in ROM. Software stored in ROM is often called firmware, because it is notionally more like hardware than software. Flash memory blurs the distinction between ROM and RAM, as it retains its data when turned off but is also rewritable. It is typically much slower than conventional ROM and RAM however, so its use is restricted to applications where high speed is unnecessary.

In more sophisticated computers there may be one or more RAM cache memories which are slower than registers but faster than main memory. Generally computers with this sort of cache are designed to move frequently needed data into the cache automatically, often without the need for any intervention on the programmer's part.

Input/output (I/O)



Hard disk drives are common storage devices used with computers.

I/O is the means by which a computer exchanges information with the outside world. Devices that provide input or output to the computer are called peripherals. On a typical personal computer, peripherals include input devices like the keyboard and mouse, and output devices such as the display and printer. Hard disk drives, floppy disk drives and optical disc drives serve as both input and output devices. Computer networking is another form of I/O.

Often, I/O devices are complex computers in their own right with their own CPU and memory. A graphics processing unit might contain fifty or more tiny computers that perform the calculations necessary to display 3D graphics. Modern desktop computers contain many smaller computers that assist the main CPU in performing I/O.

Multitasking

While a computer may be viewed as running one gigantic program stored in its main memory, in some systems it is necessary to give the appearance of running several programs simultaneously. This is achieved by multitasking i.e. having the computer switch rapidly between running each program in turn.

One means by which this is done is with a special signal called an interrupt which can periodically cause the computer to stop executing instructions where it was and do something else instead. By remembering where it was executing prior to the interrupt, the computer can return to that task later. If several programs are running "at the same time", then the interrupt generator might be causing several hundred interrupts per second, causing a program switch each time. Since modern computers typically execute instructions several orders of magnitude faster than human perception, it may appear that many programs are running at the same time even though only one is ever executing in any given instant. This method of multitasking is sometimes termed "time-sharing" since each program is allocated a "slice" of time in turn.

Before the era of cheap computers, the principal use for multitasking was to allow many people to share the same computer.

Seemingly, multitasking would cause a computer that is switching between several programs to run more slowly — in direct proportion to the number of programs it is running. However, most programs spend much of their time waiting for slow input/output devices to complete their tasks. If a program is waiting for the user to click on the mouse or press a key on the keyboard, then it will not take a "time slice" until the event it is waiting for has occurred. This frees up time for other programs to execute so that many programs may be run at the same time without unacceptable speed loss.

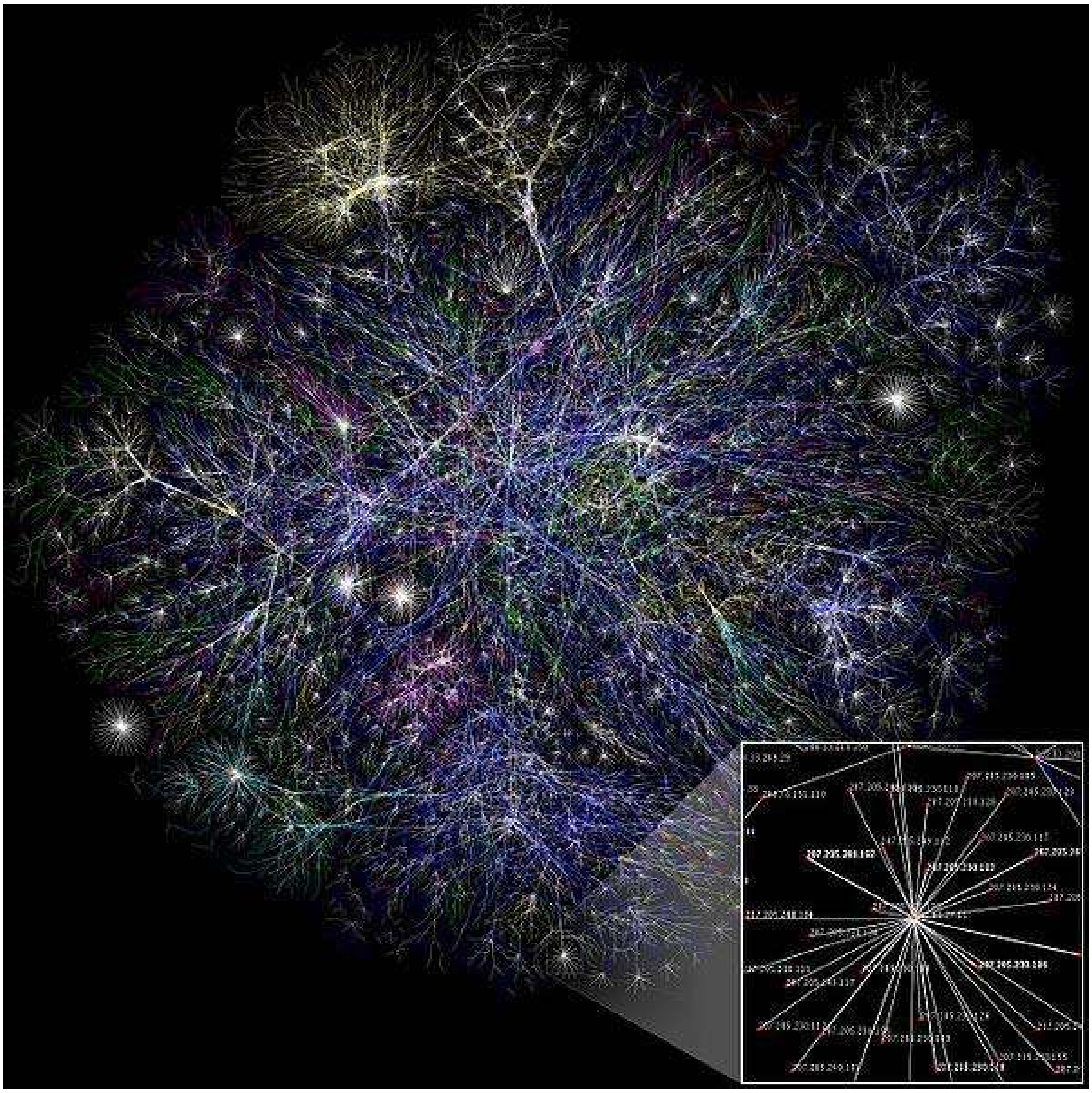
Multiprocessing

Cray designed many supercomputers that used multiprocessing heavily.

Some computers are designed to distribute their work across several CPUs in a multiprocessing configuration, a technique once employed only in large and powerful machines such as supercomputers, mainframe computers and servers. Multiprocessor and multi-core (multiple CPUs on a single integrated circuit) personal and laptop computers are now widely available, and are being increasingly used in lower-end markets as a result.

Supercomputers in particular often have highly unique architectures that differ significantly from the basic stored-program architecture and from general purpose computers. They often feature thousands of CPUs, customized high-speed interconnects, and specialized computing hardware. Such designs tend to be useful only for specialized tasks due to the large scale of program organization required to successfully utilize most of the available resources at once. Supercomputers usually see usage in large-scale simulation, graphics rendering, and cryptography applications, as well as with other so-called "embarrassingly parallel" tasks.

Networking and the Internet



Visualization of a portion of the routes on the Internet.

Computers have been used to coordinate information between multiple locations since the 1950s. The U.S. military's SAGE system was the first large-scale example of such a system, which led to a number of special-purpose commercial systems like Sabre.

In the 1970s, computer engineers at research institutions throughout the United States began to link their computers together using telecommunications technology. This effort was funded by ARPA (now DARPA), and the computer network that it produced was called the ARPANET. The technologies that made the Arpanet possible spread and evolved.

In time, the network spread beyond academic and military institutions and became known as the Internet. The emergence of networking involved a redefinition of the nature and boundaries of the computer. Computer operating systems and applications were modified to include the ability to define and access the resources of other computers on the network, such as peripheral devices, stored information, and the like, as extensions of the resources of an individual computer. Initially these facilities were available primarily to people working in high-tech environments, but in the 1990s the spread of applications like e-mail and the World Wide Web, combined with the development of cheap, fast networking technologies like Ethernet and ADSL saw computer networking become almost ubiquitous. In fact, the number of computers that are networked is growing phenomenally. A very large proportion of personal computers regularly connect to the Internet to communicate and receive information. "Wireless" networking, often utilizing mobile phone networks, has meant networking is becoming increasingly ubiquitous even in mobile computing environments.

Misconceptions

A computer does not need to be electric, nor even have a processor, nor RAM, nor even hard disk. The minimal definition of a computer is anything that transforms information in a purposeful way. However the traditional definition of a computer is a device having memory, mass storage, processor (CPU), and Input & Output devices. Anything less would be a simple processor.

Required technology

Computational systems as flexible as a personal computer can be built out of almost anything. For example, a computer can be made out of billiard balls (billiard ball computer); this is an unintuitive and pedagogical example that a computer can be made out of almost anything. More realistically, modern computers are made out of transistors made of photolithographed semiconductors.

Historically, computers evolved from mechanical computers and eventually from vacuum tubes to transistors.

There is active research to make computers out of many promising new types of technology, such as optical computing, DNA computers, neural computers, and quantum computers. Some of these can easily tackle problems that modern computers cannot (such as how quantum computers can break some modern encryption algorithms by quantum factoring).

Computer architecture paradigms

Some different paradigms of how to build a computer from the ground-up:

RAM machines

These are the types of computers with a CPU, computer memory, etc., which understand basic instructions in a machine language. The concept evolved from the Turing machine.

Brains

Brains are massively parallel processors made of neurons, wired in intricate patterns, that communicate via electricity and neurotransmitter chemicals.

Programming languages

Such as the lambda calculus, or modern programming languages, are virtual computers built on top of other computers.

Cellular automata

For example, the game of Life can create "gliders" and "loops" and other constructs that transmit information; this paradigm can be applied to DNA computing, chemical computing, etc.

Groups and committees

The linking of multiple computers (brains) is itself a computer

Logic gates are a common abstraction which can apply to most of the above digital or analog paradigms.

The ability to store and execute lists of instructions called programs makes computers extremely versatile, distinguishing them from calculators. The Church–Turing thesis is a mathematical statement of this versatility: any computer with a minimum capability (being Turing-complete) is, in principle, capable of performing the same tasks that any other computer can perform. Therefore any type of computer (netbook, supercomputer, cellular automaton, etc.) is able to perform the same computational tasks, given enough time and storage capacity.

Limited-function computers

Conversely, a computer which is limited in function (one that is not "Turing-complete") cannot simulate arbitrary things. For example, simple four-function calculators cannot simulate a real computer without human intervention. As a more complicated example, without the ability to program a gaming console, it can never accomplish what a programmable calculator from the 1990s could (given enough time); the system as a whole is not Turing-complete, even though it contains a Turing-complete component (the microprocessor). Living organisms (the body, not the brain) are also limited-function computers designed to make copies of themselves; they cannot be reprogrammed without genetic engineering.

Virtual computers

A "computer" is commonly considered to be a physical device. However, one can create a computer program which describes how to run a different computer, i.e. "simulating a computer in a computer". Not only is this a constructive proof of the Church-Turing thesis, but is also extremely common in all modern computers. For example, some programming languages use something called an interpreter, which is a simulated computer built on top of the basic computer; this allows programmers to write code (computer input) in a different language than the one understood by the base computer (the alternative is to use a compiler). Additionally, virtual machines are simulated computers which virtually replicate a physical computer in software, and are very commonly used by IT. Virtual machines are also a common technique used to create emulators, such game console emulators.

Further topics

- Glossary of computers

Artificial intelligence

A computer will solve problems in exactly the way they are programmed to, without regard to efficiency nor alternative solutions nor possible shortcuts nor possible errors in the code. Computer programs which learn and adapt are part of the emerging field of artificial intelligence and machine learning.

Hardware

The term **hardware** covers all of those parts of a computer that are tangible objects. Circuits, displays, power supplies, cables, keyboards, printers and mice are all hardware.

History of computing hardware

First Generation (Mechanical/Electromechanical)	Calculators	Antikythera mechanism, Difference engine, Norden bombsight
	Programmable Devices	Jacquard loom, Analytical engine, Harvard Mark I, Z3
Second Generation (Vacuum Tubes)	Calculators	Atanasoff–Berry Computer, IBM 604, UNIVAC 60, UNIVAC 120
	Programmable Devices	Colossus, ENIAC, Manchester Small-Scale Experimental Machine, EDSAC, Manchester Mark 1, Ferranti Pegasus, Ferranti Mercury, CSIRAC, EDVAC, UNIVAC I, IBM 701, IBM 702, IBM 650, Z22
Third Generation (Discrete transistors and SSI, MSI, LSI	Mainframes	IBM 7090, IBM 7080, IBM System/360,

Integrated circuits)		BUNCH
	Minicomputer	PDP-8, PDP-11, IBM System/32, IBM System/36
	Minicomputer	VAX, IBM System i
Fourth Generation (VLSI integrated circuits)	4-bit microcomputer	Intel 4004, Intel 4040
	8-bit microcomputer	Intel 8008, Intel 8080, Motorola 6800, Motorola 6809, MOS Technology 6502, Zilog Z80
	16-bit microcomputer	Intel 8088, Zilog Z8000, WDC 65816/65802
	32-bit microcomputer	Intel 80386, Pentium, Motorola 68000, ARM architecture
	64-bit microcomputer	Alpha, MIPS, PA-RISC, PowerPC, SPARC, x86-64
	Embedded computer	Intel 8048, Intel 8051
	Personal computer	Desktop computer, Home computer, Laptop computer, Personal digital assistant (PDA), Portable computer, Tablet PC, Wearable computer
Theoretical/experimental	Quantum computer, Chemical computer, DNA computing, Optical computer, Spintronics based computer	

Other Hardware Topics

Peripheral device (Input/output)	Input	Mouse, Keyboard, Joystick, Image scanner, Webcam, Graphics tablet, Microphone
	Output	Monitor, Printer, Loudspeaker
	Both	Floppy disk drive, Hard disk drive, Optical disc drive, Teleprinter
Computer busses	Short range	RS-232, SCSI, PCI, USB
	Long range (Computer networking)	Ethernet, ATM, FDDI

Software

Software refers to parts of the computer which do not have a material form, such as programs, data, protocols, etc. When software is stored in hardware that cannot easily be modified (such as BIOS ROM in an IBM PC compatible), it is sometimes called "firmware" to indicate that it falls into an uncertain area somewhere between hardware and software.

Computer software

Operating system	Unix and BSD	UNIX System V, IBM AIX, HP-UX, Solaris (SunOS), IRIX, List of BSD operating systems
	GNU/Linux	List of Linux distributions, Comparison of Linux distributions
	Microsoft Windows	Windows 95, Windows 98, Windows NT, Windows 2000, Windows XP, Windows Vista, Windows 7
	DOS	86-DOS (QDOS), PC-DOS, MS-DOS, DR-DOS, FreeDOS
	Mac OS	Mac OS classic, Mac OS X
	Embedded and real-time	List of embedded operating systems
	Experimental	Amoeba, Oberon/Bluebottle, Plan 9 from Bell Labs
Library	Multimedia	DirectX, OpenGL, OpenAL
	Programming library	C standard library, Standard Template Library
Data	Protocol	TCP/IP, Kermit, FTP, HTTP, SMTP
	File format	HTML, XML, JPEG, MPEG, PNG
User interface	Graphical user interface (WIMP)	Microsoft Windows, GNOME, KDE, QNX Photon, CDE, GEM, Aqua
	Text-based user interface	Command-line interface, Text user interface
Application	Office suite	Word processing, Desktop publishing, Presentation program, Database management system, Scheduling & Time management, Spreadsheet, Accounting software
	Internet Access	Browser, E-mail client, Web server, Mail transfer agent, Instant messaging
	Design and manufacturing	Computer-aided design, Computer-aided manufacturing, Plant management, Robotic

	manufacturing, Supply chain management
Graphics	Raster graphics editor, Vector graphics editor, 3D modeler, Animation editor, 3D computer graphics, Video editing, Image processing
Audio	Digital audio editor, Audio playback, Mixing, Audio synthesis, Computer music
Software engineering	Compiler, Assembler, Interpreter, Debugger, Text editor, Integrated development environment, Software performance analysis, Revision control, Software configuration management
Educational	Edutainment, Educational game, Serious game, Flight simulator
Games	Strategy, Arcade, Puzzle, Simulation, First-person shooter, Platform, Massively multiplayer, Interactive fiction
Misc	Artificial intelligence, Antivirus software, Malware scanner, Installer/Package management systems, File manager

Programming languages

Programming languages provide various ways of specifying programs for computers to run. Unlike natural languages, programming languages are designed to permit no ambiguity and to be concise. They are purely written languages and are often difficult to read aloud. They are generally either translated into machine code by a compiler or an assembler before being run, or translated directly at run time by an interpreter. Sometimes programs are executed by a hybrid method of the two techniques. There are thousands of different programming languages—some intended to be general purpose, others useful only for highly specialized applications.

Programming languages

Lists of programming languages	Timeline of programming languages, List of programming languages by category, Generational list of programming languages, List of programming languages, Non-English-based programming languages
Commonly used Assembly languages	ARM, MIPS, x86
Commonly used high-level programming languages	Ada, BASIC, C, C++, C#, COBOL, Fortran, Java, Lisp, Pascal, Object Pascal

Commonly used Scripting languages	Bourne script, JavaScript, Python, Ruby, PHP, Perl

Professions and organizations

As the use of computers has spread throughout society, there are an increasing number of careers involving computers.

Computer-related professions

Hardware-related	Electrical engineering, Electronic engineering, Computer engineering, Telecommunications engineering, Optical engineering, Nanoengineering
Software-related	Computer science, Desktop publishing, Human–computer interaction, Information technology, Information systems, Computational science, Software engineering, Video game industry, Web design

The need for computers to work well together and to be able to exchange information has spawned the need for many standards organizations, clubs and societies of both a formal and informal nature.

Organizations

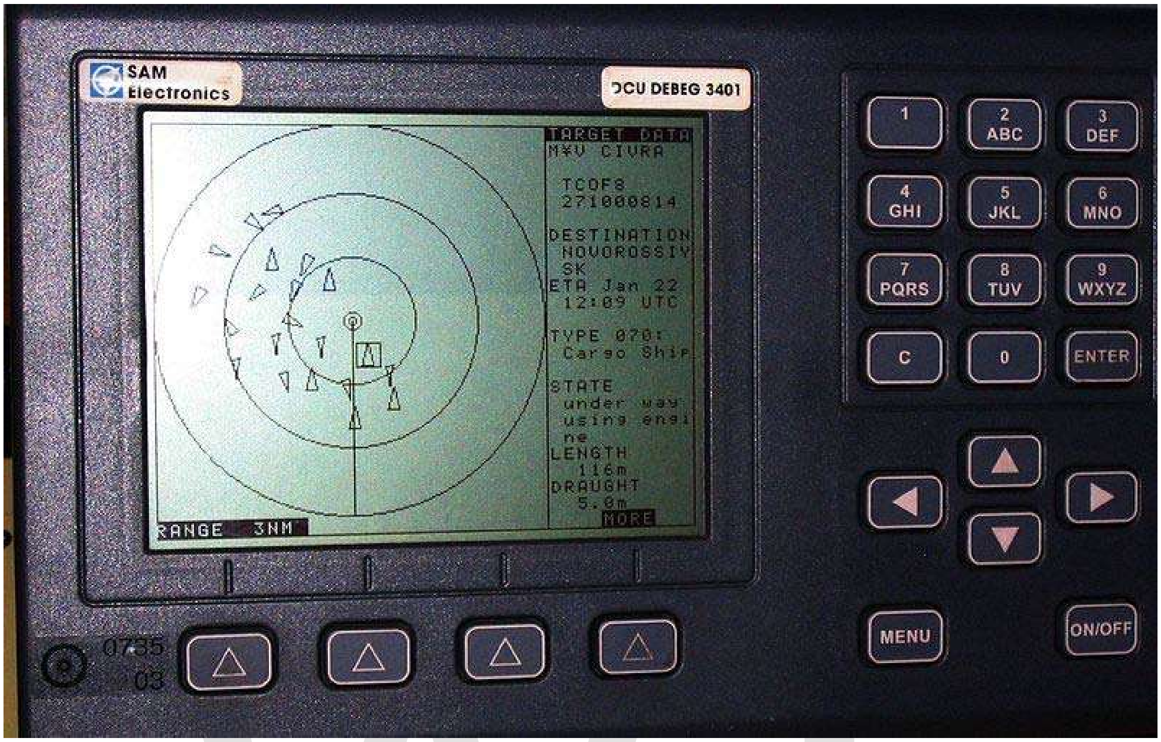
Standards groups	ANSI, IEC, IEEE, IETF, ISO, W3C
Professional Societies	ACM, AIS, IET, IFIP, BCS
Free/Open source software groups	Free Software Foundation, Mozilla Foundation, Apache Software Foundation

Chapter-2

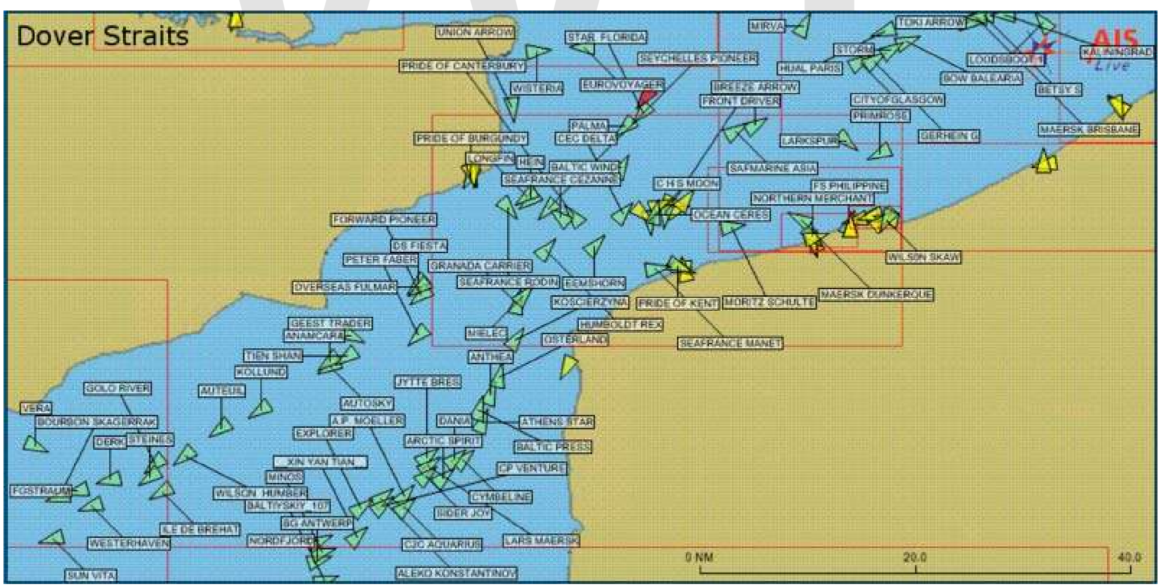
Automatic Identification System

The **Automatic Identification System** (**AIS**) is an automated tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and VTS stations. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport.

A marine traffic coordinator using AIS and radar to manage vessel traffic.



An AIS-equipped system on board a ship presents the bearing and distance of nearby vessels in a radar-like display format.



A graphical display of AIS data on board a ship.

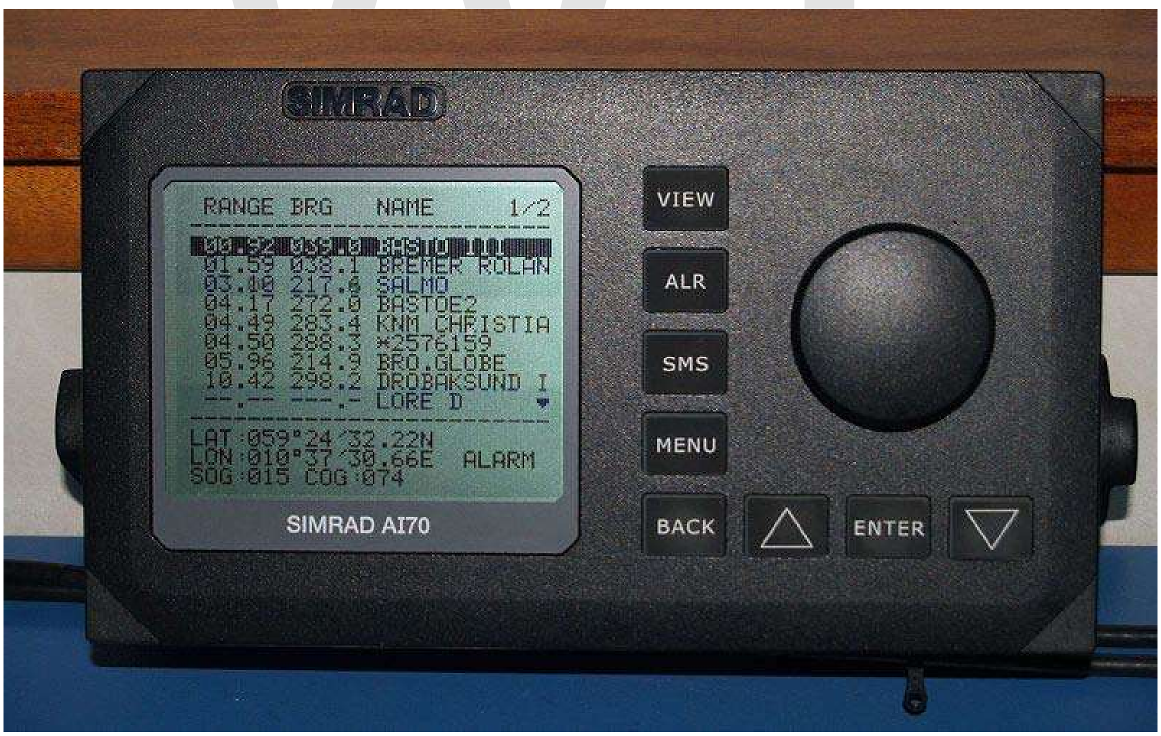
Information provided by AIS equipment, such as unique identification, position, course, and speed, can be displayed on a screen or an ECDIS. AIS is intended to assist a vessel's watchstanding officers and allow maritime authorities to track and monitor vessel movements. AIS integrates a standardized VHF transceiver with a positioning system such as a LORAN-C or GPS receiver, with other electronic navigation sensors, such as a gyrocompass or rate of turn indicator. Ships outside AIS radio range can be tracked with the Long Range Identification and Tracking (LRIT) system with less frequent transmission.

The International Maritime Organization's (IMO) International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 or more tons, and all passenger ships regardless of size. It is estimated that more than 40,000 ships currently carry AIS class A equipment. In 2007, the new Class B AIS standard was introduced which enabled a new generation of low cost AIS transceivers. This has triggered multiple additional national mandates from Singapore, China, Turkey and North America affecting hundreds of thousands of vessels.

Applications and limitations

Collision avoidance

AIS is used in navigation primarily for collision avoidance. Due to the limitations of VHF radio communications, and because not all vessels are equipped with AIS, the system is meant to be used primarily as a means of lookout and to determine risk of collision rather than as an automated collision avoidance system, in accordance with the International Regulations for Preventing Collisions at Sea (COLREGS).



A vessel's text-only AIS display, listing nearby vessels' range, bearings, and names

When a ship is navigating at sea, the movement and identity of other ships in the vicinity is critical for navigators to make decisions to avoid collision with other ships and dangers (shoal or rocks). Visual observation (unaided, binoculars, night vision), audio exchanges (whistle, horns, VHF radio), and radar or Automatic Radar Plotting Aid (ARPA) are historically used for this purpose. However, a lack of positive identification of the targets on the displays, and time delays and other limitation of radar for observing and calculating the action and response of ships around, especially on busy waters, sometimes prevent possible action in time to avoid collision.

While requirements of AIS are only to display a very basic text information, the data obtained can be integrated with a graphical electronic chart or a radar display, providing consolidated navigational information on a single display.

Vessel traffic services

In busy waters and harbors, a local Vessel Traffic Service (VTS) may exist to manage ship traffic. Here, AIS provides additional traffic awareness and provides the service with information on the kind of other ships and their movement.

Aids to navigation

AIS was developed with the ability to broadcast positions and names of objects other than vessels, like navigational aid and marker positions. These aids can be located on shore, such as in a lighthouse, or on the water, on platforms or buoys. The US Coast Guard suggests that AIS might replace RACON, or radar beacons, currently used for electronic navigation aids.

The ability to broadcast navigational aid positions has also created the concepts of *Synthetic AIS* and *Virtual AIS*. In the first case, an AIS transmission describes the position of physical marker but the signal itself originates from a transmitter located elsewhere. For example, an on-shore base station might broadcast the position of ten floating channel markers, each of which is too small to contain a transmitter itself. In the second case, it can mean AIS transmissions that indicate a marker which does not exist physically, or a concern which is not visible (i.e., submerged rocks, or a wrecked ship). Although such virtual aids would only be visible to AIS equipped ships, the low cost of maintaining them could lead to their usage when physical markers are unavailable.

Search and rescue

For coordinating resources on scene of marine search and rescue operation, it is important to know the position and navigation status of ships in the vicinity of the ship or person in distress. Here AIS can provide additional information and awareness of the resources for on scene operation, even though AIS range is limited to VHF radio range. The AIS standard also envisioned the possible use on SAR Aircraft, and included a message (AIS Message 9) for aircraft to report position.

To aid SAR vessels and aircraft in locating people in distress a standard for an AIS-SART AIS Search and Rescue Transmitter is currently being developed by the International Electrotechnical Commission (IEC), the standard is scheduled to be finished by the end of 2008 and AIS-SARTs will be available on the market from 2009.

Accident Investigation

AIS information received by VTS is important for accident investigation to provide the accurate time, identity, position by GPS, compass heading, course over ground (COG), Speed (by log/SOG) and rate of turn (ROT) of the ships involved for accident analysis, rather than limited information (position, COG, SOG) of radar echo by radar.

The maneuvering information of the events of the accident is important to understand the actual movement of the ship before accident, particularly for collision, grounding accidents.

A more complete picture of the events could be obtained by Voyage Data Recorder (VDR) data if available and maintained on board for details of the movement of the ship, voice communication and radar pictures during the accidents. However, VDR data are not maintained due to the limited 12 hours storage by IMO requirement.

Other reference:

- Automatic Identification System (AIS): A Human Factors Approach

Binary messages

The Saint Lawrence Seaway uses AIS binary messages (message type 8) to provide information about water levels, lock orders, and weather. The Panama Canal uses AIS type 8 messages to provide information about rain along the canal and wind in the locks.

Computing and networking

Several computer programs have been created for use with AIS data. Some programs (such as ShipPlotter and gnuais) use a computer to demodulate the raw audio from a modified marine VHF radio telephone when tuned to the AIS broadcast frequency (Channel 87 and 88) into AIS data. Some programs can re-transmit the AIS information to a local or global network allowing the public or authorized users to observe vessel traffic from the web. Some programs display AIS data received from a dedicated AIS receiver onto a computer or chartplotter. Most of these programs are not AIS transmitters, thus they will not broadcast your vessel's position but may be used as an inexpensive alternative for smaller vessels to help aid navigation and avoid collision with larger vessels that are required to broadcast their position. Ship enthusiasts also use receivers to track and find vessels to add to their photo collections.

AIS data on the Internet

AIS position data are available on the Internet through privately operated geographic information systems. In December 2004, the International Maritime Organization's (IMO) Maritime Safety Committee condemned the Internet publication of AIS data as follows:

In relation to the issue of freely available automatic identification system (AIS)-generated ship data on the world-wide web, the publication on the world-wide web or elsewhere of AIS data transmitted by ships could be detrimental to the safety and security of ships and port facilities and was undermining the efforts of the Organization and its Member States to enhance the safety of navigation and security in the international maritime transport sector.

Others have countered that AIS provides the same information that can be obtained with a pair of binoculars and that ships have the option of turning off AIS when they are in areas with security concerns.

Range limitations and space-based tracking

Shipboard AIS transponders have a horizontal range that is highly variable but typically only about 74 kilometers (46 mi). They reach much further vertically, up to the 400 km orbit of the International Space Station (ISS).

In June 2008, ORBCOMM launched new low-earth orbit (LEO) satellites for their machine-to-machine communications constellation. In parallel with ORBCOMM's contract with the United States Coast Guard to launch its AIS receiver-equipped Concept Demonstration Satellite (CDS), all of these new satellites were equipped with AIS receivers. ORBCOMM became the first commercial service provider of satellite AIS, having licensed satellite AIS data service to qualified government and commercial subscribers since the beginning of 2009. Additionally, ORBCOMM has incorporated AIS receivers in its next 18 ORBCOMM Generation 2 (0G2) satellites under development. As additional satellites are launched, ORBCOMM will increase its capability by providing greater redundancy and more frequent updates of AIS data. ORBCOMM's established terrestrial network of 15 Gateway Earth Stations around the world ensures timely delivery of the satellite AIS data to its subscribers.

ORBCOMM has also contracted with Luxspace to provide 2 dedicated AIS detection satellites, one a polar orbiting satellite, and the other an equatorial orbiting satellite, to be launched mid-2011.

On April 28, 2008, Canadian company COM DEV International, became the first company to launch a space-based AIS nano-satellite designed to detect AIS signals from space, and is currently deploying a full micro-satellite constellation, global ground network and centralized data processing center in order to offer global AIS data services. The service is operational and available worldwide as of mid-2010 through exactEarth, COM DEV's data services subsidiary. exactEarth uses a patent-pending ground and space-based processing technology to minimize interference of collided AIS signals, therefore dramatically improving detection compared with all other satellite-based systems. As more satellites are launched, refresh rates will continue to increase as well.

In November 2009, the STS-129 space shuttle mission attached two antennas - an AIS VHF antenna, and an Amateur Radio antenna to the Columbus module of the ISS. Both antennas were built in cooperation between ESA and the ARISS team (Amateur Radio on ISS). Starting from May 2010 the European Space Agency is testing two different AIS receivers, one from Luxspace (GdL), one from FFI (Norway) in the frame of technology demonstration for space-based ship monitoring. This is a first step towards a satellite-based AIS-monitoring service.

In 2009, LUXSPACE, a Grand Duchy of Luxembourg based company has launched PathFinder2, (ex-Rubin) and is now the only European company to have an operational system in orbit providing data from all over the world on a daily basis. The satellite is operated in cooperation with SES ASTRA and REDU Space Services.

In 2007, a previous test of space-based AIS tracking by the U.S. TacSat-2 satellite suffered from signal corruption because the AIS signals interfered with each other.

In July 2009, SpaceQuest launched AprizeSat-3 and AprizeSat-4 with AIS receivers. These receivers have been able to pick up the USCG's SART search and rescue test beacons off of Hawaii in 2010. In July 2010, SpaceQuest and exactEarth of Canada announced an arrangement whereby data from AprizeSat-3 and AprizeSat-4 would be incorporated into the exactEarth system and made available worldwide as part of their exactAIS(TM)service.

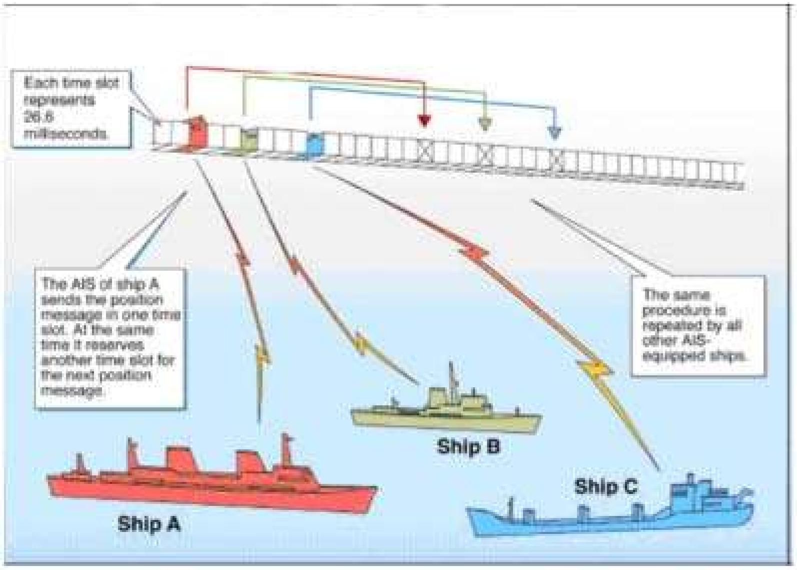
On July 12, 2010, The Norwegian AISSat-1 satellite was successfully launched into polar orbit. The purpose of the satellite is to improve surveillance of maritime activities in the High North. AISSat-1 is a nano satellite measuring 20 x 20 x 20 cm. It weighs six kilograms and is shaped like a cube.

Type Testing and Approval

Class A AIS products are for ships over 300 tonnes or which are SOLAS vessels and are required to meet the guidelines set out in the Marine Equipment Directive.

Class B AIS products are for non-SOLAS vessels. They need testing and certification under the R&TTE Directive for the European Union and FCC and Industry Canada certification for North America.

How AIS works



System Overview from US Coast Guard

Basic overview

AIS transponders automatically broadcast information, such as their position, speed, and navigational status, at regular intervals via a VHF transmitter built into the transponder. The information originates from the ship's navigational sensors, typically its global navigation satellite system (GNSS) receiver and gyrocompass. Other information, such as the vessel name and VHF call sign, is programmed when installing the equipment and is also transmitted regularly. The signals are received by AIS transponders fitted on other ships or on land based systems, such as VTS systems. The received information can be displayed on a screen or chart plotter, showing the other vessels' positions in much the same manner as a radar display.

The AIS standard comprises several sub-standards 'Types' which specify individual product types. The specification for each product type provides a detailed technical specification which ensures the overall integrity of the global AIS system within which all the product types must operate. The major product types described in the AIS system standards are:

Class A
: Vessel mounted AIS transceiver (transmit and receive) which operates using self-organised time-division multiple-access (SOTDMA). Class A's must have an integrated display, transmit at 12 W, interface capability with multiple ship systems, and offer a sophisticated selection of features and functions. Default transmit rate is every few seconds. AIS Class A type compliant devices receive all types of AIS messages.

Class B

Vessel mounted AIS transceiver (transmit and receive) which operates using carrier-sense time-division multiple-access (CSTDMA). Class Bs transmit at 2 W and are not required to have an integrated display: Class Bs can be connected to most display systems which the received messages will be displayed in lists or overlayed on charts. Default transmit rate is normally every 30 seconds, but this can be varyed according to vessel speed or instructions from base stations. The Class B type standard requires integrated GPS and certain LED indicators. Class B equipment receives all types of AIS messages.

Base station

Shore based AIS transceiver (transmit and receive) which operates using SOTDMA. Base stations have a complex set of features and functions which in the AIS standard are able to control the AIS system and all devices operating therein. Ability to interrogate individual transponders for status reports and or transmit frequency changes.

Aids to navigation (AtoN)

Shore or buoy based transceiver (transmit and receive) which operates using fixed-access time-division multiple-access (FATDMA). Designed to collect and transmit data related to sea and weather conditions as well as relay AIS messages to extend network coverage.

AIS receivers are not specified in the AIS standards, because they do not transmit. The main threat to the integrity of any AIS system are non-compliant AIS transmissions, hence careful specifications of all transmitting AIS devices. However, it is well to note that AIS transceivers all transmit on multiple channels as required by the AIS standards. As such single-channel, or multiplexed, receivers will not receive all AIS messages. Only dual-channel receivers will receive all AIS messages.

Message Types

There are 26 different types of messages capable of being sent by an AIS transponder.

Detailed description: Class A units

Each AIS transponder consists of one VHF transmitter, two VHF TDMA receivers, one VHF Digital Selective Calling (DSC) receiver, and links to shipboard display and sensor systems via standard marine electronic communications (such as NMEA 0183, also known as IEC 61162). Timing is vital to the proper synchronization and slot mapping (transmission scheduling) for a Class A unit. Therefore, every unit is required to have an internal time base, synchronized to a global navigation satellite system (e.g. GPS) receiver. This internal receiver may also be used for position information. However, position is typically provided by an external receiver such as GPS, LORAN or an inertial navigation system and the internal receiver is only used as a backup for position information. Other information broadcast by the AIS, if available, is electronically obtained from shipboard equipment through standard marine data connections. Heading information, position (latitude and longitude), "speed over ground", and rate of turn are normally provided by all ships equipped with AIS. Other information, such as angle of heel, pitch and roll, destination, and ETA may also be provided.

An AIS transponder normally works in an autonomous and continuous mode, regardless of whether it is operating in the open seas or coastal or inland areas. AIS transponders use two different frequencies, VHF maritime channels 87B (161.975 MHz) and 88B (162.025 MHz), and use 9.6 kbit/s Gaussian minimum shift keying (GMSK) modulation over 25 or 12.5 kHz channels using the High-level Data Link Control (HDLC) packet protocol. Although only one radio channel is necessary, each station transmits and receives over two radio channels to avoid interference problems, and to allow channels to be shifted without communications loss from other ships. The system provides for automatic contention resolution between itself and other stations, and communications integrity is maintained even in overload situations.

In order to ensure that the VHF transmissions of different transponders do not occur at the same time, the signals are time multiplexed using a technology called Self-Organized Time Division Multiple Access (STDMA). The design of this technology is patented, and whether this patent has been waived for use by SOLAS vessels is a matter of debate between the manufacturers of AIS systems and the patent holder, though the United States Patent and Trademark Office (USPTO) canceled all claims in the original patent on March 30, 2010. In order to make the most efficient use of the bandwidth available, vessels that are anchored or moving slowly transmit less frequently than those that are moving faster or are maneuvering. The update rate ranges from 3 minutes for achored or moored vessels, to 2 seconds for fast moving or maneuvering vessels, the latter being similar to that of conventional marine radar.

Each AIS station determines its own transmission schedule (slot), based upon data link traffic history and an awareness of probable future actions by other stations. A position report from one station fits into one of 2,250 time slots established every 60 seconds on each frequency. AIS stations continuously synchronize themselves to each other, to avoid overlap of slot transmissions. Slot selection by an AIS station is randomized within a defined interval and tagged with a random timeout of between 0 and 8 frames. When a station changes its slot assignment, it announces both the new location and the timeout for that location. In this way new stations, including those stations which suddenly come within radio range close to other vessels, will always be received by those vessels.

The required ship reporting capacity according to the IMO performance standard is a minimum of 2,000 time slots per minute, though the system provides 4,500 time slots per minute. The SOTDMA broadcast mode allows the system to be overloaded by 400 to 500% through sharing of slots, and still provides nearly 100% throughput for ships closer than 8 to 10 nmi to each other in a ship to ship mode. In the event of system overload, only targets further away will be subject to drop-out, in order to give preference to nearer targets, which are of greater concern to ship operators. In practice, the capacity of the system is nearly unlimited, allowing for a great number of ships to be accommodated at the same time.

The system coverage range is similar to other VHF applications, essentially depending on the height of the antenna, but is slightly better due to the use of digital VHF instead of analog VHF. Its propagation is better than that of radar, due to the longer wavelength, so it is possible to reach around bends and behind islands if the land masses are not too high. *The look-ahead* distance at sea is nominally 20 nmi (37 km). With the help of repeater stations, the coverage for both ship and VTS stations can be improved considerably.

The system is backward compatible with digital selective calling systems, allowing shore-based GMDSS systems to inexpensively establish AIS operating channels and identify and track AIS-equipped vessels, and is intended to fully replace existing DSC-based transponder systems.

Shore-based AIS network systems are now being built up around the world. One of the biggest fully operational, real time systems with full routing capability is in China. This system was built between 2003 and 2007 and was delivered by Saab TransponderTech. The entire Chinese coastline is covered with approximately 250 base stations in hot-standby configurations including 70 computer servers in three main regions. Hundreds of shore based users, including about 25 VTS centers, are connected to the network and are able to see the maritime picture, and can also communicate with each ship using SRM's (Safety Related Messages). All data are in real time. The system was designed to improve the safety and security of ships and port facilities. It is also designed according to an SOA architecture with socket based connection and using IEC AIS standardized protocol all the way to the VTS users. The base stations have hot-standby units (IEC 62320-1) and the network is the third generation network solution.

By the beginning of 2007, a new worldwide standard for AIS base stations was approved, the IEC 62320-1 standard. The old IALA recommendation and the new IEC 62320-1 standard are in some functions incompatible, and therefore attached network solutions have to be upgraded. This will not affect users, but system builders need to upgrade software to accommodate the new standard. A standard for AIS base stations has been long awaited. Currently ad-hoc networks exist with class A mobiles. Base stations can control the AIS message traffic in a region, which will hopefully reduce the number of packet collisions.

Broadcast information

An AIS transceiver sends the following data every 2 to 10 seconds depending on a vessel's speed while underway, and every 3 minutes while a vessel is at anchor:

- The vessel's Maritime Mobile Service Identity (MMSI) – a unique nine digit identification number.
- Navigation status – "at anchor", "under way using engine(s)", "not under command", etc.
- Rate of turn – right or left, from 0 to 720 degrees per minute
- *Speed over ground* – 0.1-knot (0.19 km/h) resolution from 0 to 102 knots (189 km/h)

- Positional accuracy:
    - Longitude – to 0.0001 minutes
    - Latitude – to 0.0001 minutes
- *Course over ground* – relative to true north to 0.1°
- True heading – 0 to 359 degrees (for example from a gyro compass)
- Time stamp – UTC time accurate to the nearest second when these data were generated

In addition, the following data are broadcast every 6 minutes:

- IMO ship identification number – a seven digit number that remains unchanged upon transfer of the ship's registration to another country
- Radio call sign – international radio call sign, up to seven characters, assigned to the vessel by its country of registry
- Name – 20 characters to represent the name of the vessel
- Type of ship/cargo
- Dimensions of ship – to nearest meter
- Location of positioning system's (e.g., GPS) antenna on board the vessel - in meters aft of bow and meters port of starboard
- Type of positioning system – such as GPS, DGPS or LORAN-C.
- Draught of ship – 0.1 meter to 25.5 meters
- Destination – max. 20 characters
- ETA (estimated time of arrival) at destination – UTC month/date hour:minute

Detailed description: Class B units

Class B transponders are designed for carriage by sub-SOLAS vessels. Each consists of one VHF transmitter, two VHF Carrier Sense Time Division Multiple Access (CSTDMA) receivers, one of which is multiplexed with the VHF Digital Selective Calling (DSC) receiver, and a GPS active antenna. Although the data output format supports heading information, in general units are not interfaced to a compass, so these data are seldom transmitted. Output is the standard AIS data stream at 38.400 kbit/s, as RS232 and/or NMEA formats. To prevent overloading of the available bandwidth, transmission power is restricted to 2 W, giving a range of about 5–10 mi.

At the time of writing (November 2009) almost all Class B units use boards from Software Radio Technology (SRT). Exceptions to this are Furuno and AMEC.

Four messages are defined for class B units:

Message 14: Safety Related Message

This message is transmitted on request for the user – some transponders have a button that enables it to be sent, or it can be sent through the software interface. It sends a pre-defined safety message.

Message 18: Standard Class B CS Position Report

This message is sent every 3 minutes where *speed over ground* (SOG) is less than 2 knots, or every 30 seconds for greater speeds.

MMSI, time, SOG, COG, longitude, latitude, true heading

Message 19: Extended Class B Equipment Position Report

This message was designed for the SOTDMA protocol, and is too long to be transmitted as CSTDMA. However a coast station can poll the transponder for this message to be sent.

MMSI, time, SOG, COG, longitude, latitude, true heading, ship type, dimensions.

Message 24: Class B CS Static Data Report

This message is sent every 6 minutes, the same time interval as for Class A transponders. Because of its length, this message is divided into two parts, sent within one minute of each other.

Note that this message was defined after the original AIS specifications, so some Class A units may need a firmware upgrade to be able to decode this message.

MMSI, boat name, ship type, call sign, dimensions, and equipment vendor id.

Detailed description: AIS Receivers

A number of manufacturers offer AIS receivers, designed for monitoring AIS traffic. These may have two receivers, for monitoring both frequencies simultaneously, or they may switch between frequencies (thereby missing messages on the other channel, but at reduced price). In general they will output RS232, NMEA, USB or UDP data for display on electronic chart plotters or computers.

Chapter-3

Flight Control Modes (Electronic)

New aircraft designs like this Boeing 777 rely on sophisticated flight computers to aid and protect the aircraft in flight. These are governed by computational laws which assign flight control modes during flight

Aircraft with fly-by-wire flight controls require computer *controlled flight control modes* that are capable of determining the operational mode (computational law) of the aircraft.

A reduction of electronic flight control can be caused by the failure of a computational device, such as the flight control computer or an information providing device, such as the ADIRU.

Electronic flight control systems (EFCS) also provide augmentation in normal flight, such as increased protection of the aircraft from overstress or providing a more comfortable flight for passengers by recognizing and correcting for turbulence and providing yaw damping.

Two aircraft manufacturers produce commercial passenger aircraft with primary flight computers that can perform under different flight control modes (or laws). The most well-known are the *Normal, Alternate, Direct* and *Mechanical Laws* of the Airbus A320-A380.

Boeing's fly-by-wire system is used in the Boeing 777. Boeing also has two other commercial aircraft under development, the 787 and the 747-8, which will use fly-by-wire controls.

These newer generation of aircraft use the lighter weight electronic systems to increase safety and performance while lowering aircraft weight. Since these systems can also protect the aircraft from overstress situations, the designers can therefore reduce over-engineered components, further reducing weight.

Philosophies of design

Aircraft designers have created a set of flight control modes that include redundant electronics to safeguard against system failures. Failures can occur singly or combined to render systems inoperable. Pilots must be able to control the aircraft with some, or even none, of the computational electronics functioning. In the case of Airbus the back-ups are the direct and mechanical modes. Boeing's direct mode removes many of the computational 'limitations'.

In older aircraft, control is through the pilot's control column, rudder pedals, trim wheel or throttles that mechanically move cables, pulleys or hydraulic servo valves. These then move control surfaces or change engine settings.

Many newer aircraft replace these mechanical controls with fly-by-wire systems. These aircraft have flight control computers which operate control surfaces, inform the pilot and provide performance information. In older aircraft the pilot's mechanical controls are resisted by the forces acting on the control surface, but nothing prevents the aircraft from stalling, over-speeding or an excessive bank angle at high speed. Fly-by-wire systems limit control surface movements to ensure that aircraft limits are not exceeded.

Another function of flight control laws is to assess the performance of the aircraft under various conditions, such as takeoff, landing or normal cruise when flight control computers partially or completely fail. Designers build in the ability to by-pass the computers or for the standby systems to operate without the computers.

Flight control laws (Airbus)

A330-200 in flight mode

Airbus aircraft designs after the A300/A310 are almost completely controlled by fly-by-wire equipment. These newer aircraft, including the A320, A330, A340, A350 and A380 operate under Airbus flight control Laws. The flight controls on the Airbus 330, for example, are all electronically controlled and hydraulically activated. Some surfaces, such as the rudder, can also be mechanically controlled. While in normal flight the computers act to prevent excessive forces in the pitch and roll.

Airbus 320-100 Cockpit

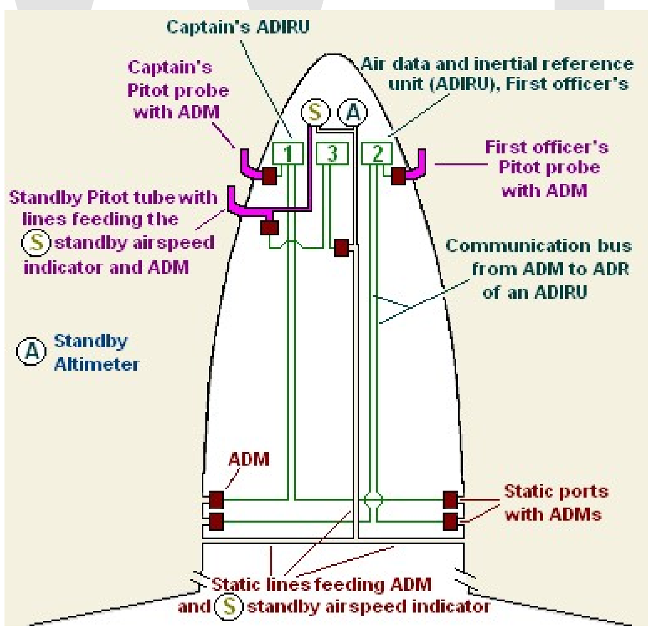


Illustration of the Air-data reference system on Airbus A330

The aircraft is controlled by three primary control computers (Captain's, First Officer's and Standby) and two secondary control computers (Captain's and First Officer's). In addition there are two Flight Control Data Computers (FCDC) that read information from the sensors, such as air data (airspeed, altitude). This is fed along with GPS data, into three processing units known as ADIRUs (Air data/inertial reference units) which act both as an air data reference and inertial reference. ADIRUs are part of the air data inertial reference system, which, on the Airbus is linked to eight air data modules: three are linked to pitot tubes and five are linked to static sources. Information from the ADIRU is fed into one of several flight control computers (Primary and secondary flight control). The computers also receive information from the control surfaces of the aircraft and from the pilots aircraft control devices and autopilot. Information from these computers is sent both to the pilot's primary flight display and also to the control surfaces.

There are four named flight control laws, however *Alternate Law* consists of two modes, *Alternate Law 1* and *Alternate Law 2*. Each of these modes have different sub modes: ground mode, flight mode and flare, plus a back-up *Mechanical Law*.

Normal law

Normal Law differs depending on the stage of flight. These include:

- Stationary at the gate
- Taxiing from the gate to a runway or from a runway back to the gate
- Beginning the take-off roll
- Initial climb
- Cruise climb and cruise flight at altitude
- Final descent, flare and landing.

Normal Law is different depending on the stage of flight. During the transition from take-off to cruise there is a 5 second transition, from descent to flare there is a two second delay and from flare to ground there is another 2 second transition in *Normal Law*.

Ground mode

The aircraft behaves as in direct mode: The autotrim feature is turned off and there is a direct response of the elevators to control column (or sidestick on Airbus) inputs. The horizontal stabilizer is set to 4° up but manual settings (e.g. for center of gravity) override this setting. After the wheels leave the ground, a 5 second transition occurs where *Normal Law - flight mode* takes over from ground mode.

Flight mode

The flight mode of *Normal Law* provides five types of protection: Pitch attitude, load factor limitations, high speed, high-AOA and bank angle. Flight mode is operational from take-off to 100 feet above the ground, but can be lost as a result of pilot commands or system failures. Loss of *Normal Law* as a result of a system failure results in *Alternate Law 1* or *2*.

Unlike conventional controls, in *Normal Law flight mode* the sidestick provides a load factor proportional to stick deflection which is independent of aircraft speed. When the stick is neutral and the load factor is 1g the aircraft remains in level flight without the pilot changing the elevator trim. The aircraft also maintains a proper pitch angle once a turn has been established, up to 33° bank. The system prevents further trim up when the angle of attack is excessive, the load factor exceeds 1.3g or when the bank angle exceeds 33°.

Alpha protection (α-Prot) prevents stalling and the effects of windshear. The protection engages when the angle of attack is between α-Prot and α-Max and limits the angle of attack commanded by the pilot's sidestick or, if autopilot is engaged, it disengages the autopilot.

High speed protection will automatically recover from an overspeed. There are two speed limitations for high altitude aircraft, V_{MO} (Velocity Maximum Operational) and M_{MO} (Mach Maximum Operational) the two speeds are the same at approximately 31,000 feet, below which overspeed is determined by V_{MO} and above 31,000 feet by M_{MO}.

Flare mode

A380 in take off

This mode is automatically engaged when the radar altimeter indicates 100 feet above ground. At 50 feet the aircraft trims the nose slightly down. During the flare, *Normal Law* provides high-AOA protection and bank angle protection. The load factor is permitted to be from 2.5g to -1g, or 2.0g to 0g when slats are extended. Pitch attitude is limited to +30 to -15° which is reduced to 25° as the aircraft slows.

Alternate law

The are four reconfiguration modes for the Airbus fly-by-wire aircraft, two *Alternate Law (1 and 2)*, *Direct Law* and *Mechanical Law*. The ground mode and flare modes for *Alternate Law* are identical to those modes for *Normal Law*.

Alternate law 1 (ALT1) mode combines a *Normal Law* lateral mode with the load factor, bank angle protections retained. High angle of attack protection may be lost and low energy (level flight stall) protection is lost. High speed and high angle of attack protections enter alternative law mode.

ALT1 maybe entered if there are faults in the horizontal stabilizer, an elevator, yaw-damper actuation, slat or flap sensor, or a single air data reference fault.

Alternate law 2 (ALT2) loses *Normal Law* lateral mode (replaced by roll direct mode and yaw alternate mode) along with pitch attitude protection, bank angle protection and low energy protection. Load factor protection is retained. High angle of attack and high speed protections are retained unless the reason for *Alternate 2 Law* mode is the failure of two air-data references or if the two remaining air data references disagree.

ALT2 mode is entered when 2 engines flame out (on dual engine aircraft), faults in two inertial or air-data references, with the autopilot being lost, except with an ADR disagree. This mode may also be entered with an all spoilers fault, certain ailerons fault, or pedal transducers fault.

Direct law

Direct mode (DIR) loses normal lateral mode and all protections, the aircraft assumes *Alternate Law* yaw mode and *Direct Law* roll mode. Elevator can then only be controlled by the manual trim. Control surface motion is directly related to the sidestick and rudder pedal motion.

DIR is entered if there is failure of three inertial reference units or the primary flight computers, faults in two elevators, flame out in two engines (on a two engine aircraft) or when the captain's primary flight computer is inoperable.

Mechanical law

In the *Mechanical Law* back-up mode, pitch is controlled by the mechanical trim system and lateral direction is controlled by the rudder pedals operating the rudder mechanically.

Boeing 777 Primary Flight Control System

The cockpit of the 777 is similar to 747-400, a fly-by-wire control simulating mechanical control

The fly-by-wire electronic flight control system of the Boeing 777 differs from the Airbus EFCS. The design principle is to provide a system that responds similarly to a mechanically controlled system. Because the system is controlled electronically the flight control system can provide flight envelope protection.

The electronic system is subdivided between 2 levels, the 4 actuator control electronics (ACE) and the 3 primary flight computers (PFC). The ACEs control actuators (from those on pilot controls to control surface controls and the PFC). The role of the PFC is to calculate the control laws and provide feedback forces, pilot information and warnings.

Standard Protections and augmentations

The flight control system on the 777 is designed to restrict control authority beyond certain range by increasing the back pressure once the desired limit is reached. This is done via electronically controlled backdrive actuators (controlled by ACE). The protections and augmentations are: bank angle protection, turn compensation, stall protection, over-speed protection, pitch control, stability augmentation and thrust asymmetry compensation. The design philosophy is: "to inform the pilot that the command being given would put the aircraft outside of its normal operating envelope, but the ability to do so is not precluded."

Normal mode

In *Normal mode* the PFCs transmit actuator commands to the ACEs, which convert them into analog servo commands. Full functionality is provided, including all enhanced performance, envelope protection and ride quality features.

Secondary mode

Boeing *Secondary mode* is comparable to the Airbus *Alternate Law*, with the PFCs supplying commands to the ACEs. However, EFCS functionality is reduced, including loss of flight envelope protection. Like the Airbus system, this state is entered when a number of failures occur in the EFCS or interfacing systems (e.g. ADIRU or SAARU).

Direct mode

In *Direct mode* each ACE decodes pilot commands directly from the pilot controller transducers. This mode can be manually or automatically entered. Automatic entry occurs when there is a failure of all PFCs, ACEs, and/or loss of a control data bus.

Chapter-4

Error Analysis for the Global Positioning System

Artist's conception of GPS Block II-F satellite in orbit

The **analysis of errors computed using the Global Positioning System** is important for understanding how GPS works, and for knowing what magnitude errors should be expected. The Global Positioning System makes corrections for receiver clock errors and other effects but there are still residual errors which are not corrected. The Global

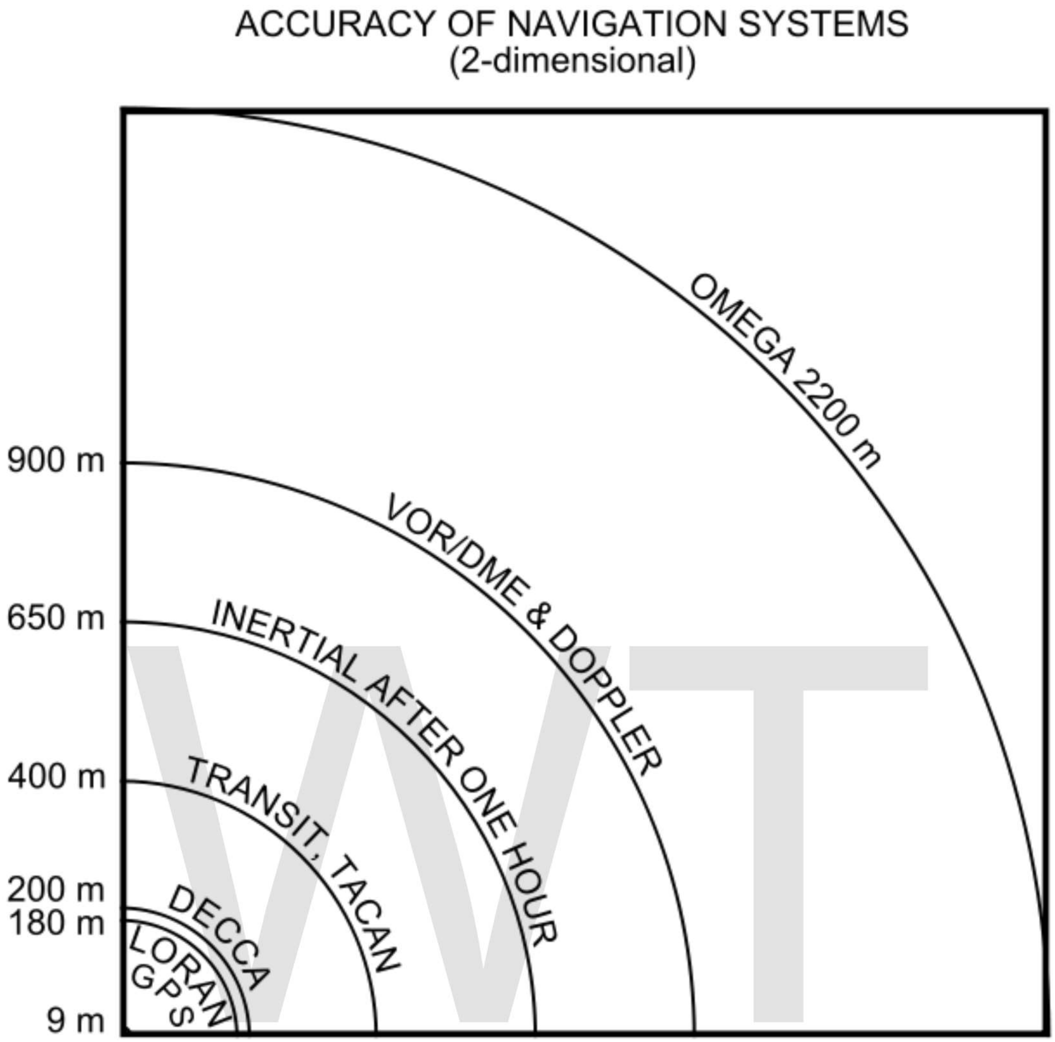
Positioning System (GPS) was created by the United States Department of Defense (DOD) in the 1970s. It has come to be widely used for navigation both by the U.S. military and the general public.

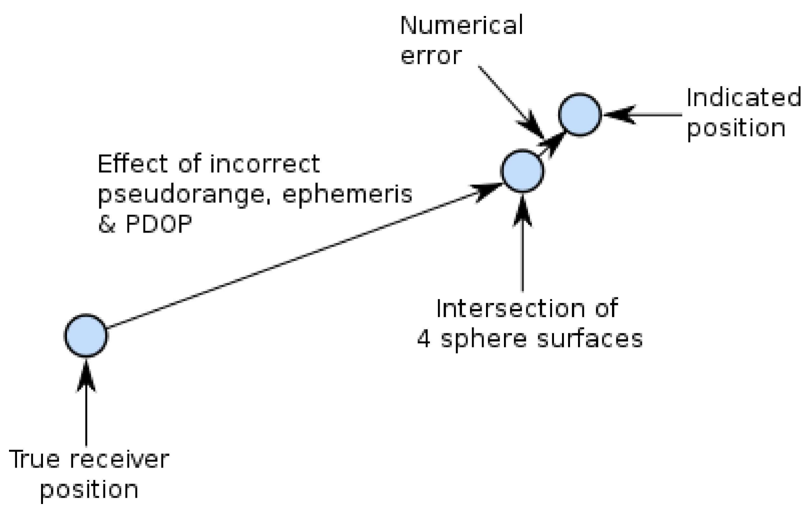
User vehicle position is computed by the receiver based on data received from the satellites. Errors depend on geometric dilution of position and the sources listed in the table below.

Overview

Sources of User Equivalent Range Errors (UERE)

Source	Effect (m)
Signal arrival C/A	±3
Signal arrival P(Y)	±0.3
Ionospheric effects	±5
Ephemeris errors	±2.5
Satellite clock errors	±2
Multipath distortion	±1
Tropospheric effects	±0.5
σ_RC/A	±6.7
σ_RP(Y)	±6.0





Geometric Error Diagram Showing Typical Relation of Indicated Receiver Position, Intersection of Sphere Surfaces, and True Receiver Position in Terms of Pseudorange Errors, PDOP, and Numerical Errors

User equivalent range errors (UERE) are shown in the table. There is also a numerical error with an estimated value, σ_{num}, of about 1 meter. The standard deviations, σ_R, for the coarse/acquisition and precise codes are also shown in the table. These standard deviations are computed by taking the square root of the sum of the squares of the individual components (i.e., RSS for root sum squares). To get the standard deviation of receiver position estimate, these range errors must be multiplied by the appropriate dilution of precision terms and then RSS'ed with the numerical error. Electronics errors are one of several accuracy-degrading effects outlined in the table above. When taken together, autonomous civilian GPS horizontal position fixes are typically accurate to about 15 meters (50 ft). These effects also reduce the more precise P(Y) code's accuracy. However, the advancement of technology means that today, civilian GPS fixes under a clear view of the sky are on average accurate to about 5 meters (16 ft) horizontally.

The term user equivalent range error (UERE) refers to the error of a component in the distance from receiver to a satellite. These UERE errors are given as ± errors thereby implying that they are unbiased or zero mean errors. These UERE errors are therefore used in computing standard deviations. The standard deviation of the error in receiver position, σ_{rc}, is computed by multiplying PDOP (Position Dilution Of Precision) by σ_R, the standard deviation of the user equivalent range errors. $\sigma_R$is computed by taking the square root of the sum of the squares of the individual component standard deviations.

PDOP is computed as a function of receiver and satellite positions. A detailed description of how to calculate PDOP is given in the section, geometric dilution of precision computation (GDOP).

$\sigma_R$for the C/A code is given by:

$$\sigma_R = \sqrt{3^2 + 5^2 + 2.5^2 + 2^2 + 1^2 + 0.5^2}\,\mathrm{m} \;=\; 6.7\,\mathrm{m}$$

The standard deviation of the error in estimated receiver position σ_{rc}, again for the C/A code is given by:

$$\sigma_{rc} = \sqrt{PDOP^2 \times \sigma_R^2 + \sigma_{num}^2} = \sqrt{PDOP^2 \times 6.7^2 + 1^2}\,\mathrm{m}$$

The error diagram on the left shows the inter relationship of indicated receiver position, true receiver position, and the intersection of the four sphere surfaces.

Signal arrival time measurement

The position calculated by a GPS receiver requires the current time, the position of the satellite and the measured delay of the received signal. The position accuracy is primarily dependent on the satellite position and signal delay.

To measure the delay, the receiver compares the bit sequence received from the satellite with an internally generated version. By comparing the rising and trailing edges of the bit transitions, modern electronics can measure signal offset to within about one percent of a bit pulse width, $\frac{0.01}{(1.023 \times 10^6/\mathrm{s})}$, or approximately 10 nanoseconds for the C/A code. Since GPS signals propagate at the speed of light, this represents an error of about 3 meters.

This component of position accuracy can be improved by a factor of 10 using the higher-chiprate P(Y) signal. Assuming the same one percent of bit pulse width accuracy, the high-frequency P(Y) signal results in an accuracy of $\frac{(0.01 \times 300,000,000 \mathrm{~m/s})}{(10.23 \times 10^6/\mathrm{s})}$ or about 30 centimeters.

Atmospheric effects

Inconsistencies of atmospheric conditions affect the speed of the GPS signals as they pass through the Earth's atmosphere, especially the ionosphere. Correcting these errors is a significant challenge to improving GPS position accuracy. These effects are smallest when the satellite is directly overhead and become greater for satellites nearer the horizon since the path through the atmosphere is longer. Once the receiver's approximate location is known, a mathematical model can be used to estimate and compensate for these errors.

Ionospheric delay of a microwave signal depends on its frequency. It arises from ionized atmosphere. This phenomenon is known as dispersion and can be calculated from measurements of delays for two or more frequency bands, allowing delays at other frequencies to be estimated. Some military and expensive survey-grade civilian receivers calculate atmospheric dispersion from the different delays in the L1 and L2 frequencies, and apply a more precise correction. This can be done in civilian receivers without decrypting the P(Y) signal carried on L2, by tracking the carrier wave instead of the modulated code. To facilitate this on lower cost receivers, a new civilian code signal on L2, called L2C, was added to the Block IIR-M satellites, which was first launched in 2005. It allows a direct comparison of the L1 and L2 signals using the coded signal instead of the carrier wave.

The effects of the ionosphere generally change slowly, and can be averaged over time. Those for any particular geographical area can be easily calculated by comparing the GPS-measured position to a known surveyed location. This correction is also valid for other receivers in the same general location. Several systems send this information over radio or other links to allow L1-only receivers to make ionospheric corrections. The ionospheric data are transmitted via satellite in Satellite Based Augmentation Systems (SBAS) such as Wide Area Augmentation System (WAAS) (available in North America and Hawaii), EGNOS (Europe and Asia) or Multi-functional Satellite Augmentation System (MSAS) (Japan), which transmits it on the GPS frequency using a special pseudo-random noise sequence (PRN), so only one receiver and antenna are required.

Humidity also causes a variable delay, resulting in errors similar to ionospheric delay, but occurring in the troposphere. This effect both is more localized and changes more quickly than ionospheric effects, and is not frequency dependent. These traits make precise measurement and compensation of humidity errors more difficult than ionospheric effects.

Changes in receiver altitude also change the delay, due to the signal passing through less of the atmosphere at higher elevations. Since the GPS receiver computes its approximate altitude this error is relatively simple to correct, either by applying a function regression or correlating margin of atmospheric error to ambient pressure using a barometric altimeter.

Multipath effects

GPS signals can also be affected by multipath issues, where the radio signals reflect off surrounding terrain; buildings, canyon walls, hard ground, etc. These delayed signals can cause inaccuracy. A variety of techniques, most notably narrow correlator spacing, have been developed to mitigate multipath errors. For long delay multipath, the receiver itself can recognize the wayward signal and discard it. To address shorter delay multipath from the signal reflecting off the ground, specialized antennas (e.g., a choke ring antenna) may be used to reduce the signal power as received by the antenna. Short delay reflections are harder to filter out because they interfere with the true signal, causing effects almost indistinguishable from routine fluctuations in atmospheric delay.

Multipath effects are much less severe in moving vehicles. When the GPS antenna is moving, the false solutions using reflected signals quickly fail to converge and only the direct signals result in stable solutions.

Ephemeris and clock errors

While the ephemeris data is transmitted every 30 seconds, the information itself may be up to two hours old. If a fast time to first fix (TTFF) is needed, it is possible to upload a valid ephemeris to a receiver, and in addition to setting the time, a position fix can be obtained in under ten seconds. It is feasible to put such ephemeris data on the web so it can be loaded into mobile GPS devices..

The satellite's atomic clocks experience noise and clock drift errors. The navigation message contains corrections for these errors and estimates of the accuracy of the atomic clock. However, they are based on observations and may not indicate the clock's current state.

These problems tend to be very small, but may add up to a few meters (tens of feet) of inaccuracy.

For very precise positioning (e.g., in geodesy), these effects can be eliminated by differential GPS: the simultaneous use of two or more receivers at several survey points.

In the 1990s when receivers were quite expensive, some methods of *quasi-differential* GPS were developed, using only *one* receiver but reoccupation of measuring points. At the TU Vienna the method was named *qGPS* and adequate software of post processing was developed.

Geometric dilution of precision computation (GDOP)

The concept of geometric dilution of precision was introduced in the section, *error sources and analysis*. Computations were provided to show how PDOP was used and how it affected the receiver position error standard deviation.

When visible GPS satellites are close together in the sky (i.e., small angular separation), the DOP values are high; when far apart, the DOP values are low. Conceptually, satellites that are close together cannot provide as much information as satellites that are widely separated. Low DOP values represent a better GPS positional accuracy due to the wider angular separation between the satellites used to calculate GPS receiver position. HDOP, VDOP, PDOP and TDOP are respectively Horizontal, Vertical, Position (3-D) and Time Dilution of Precision.

Figure 3.1 Dilution of Precision of Navstar GPS data from the U.S. Coast Guard provide a graphical indication of how geometry affect accuracy.

We now take on the task of how to compute the dilution of precision terms. As a first step in computing DOP, consider the unit vector from the receiver to satellite i with components $\frac{(x_i - x)}{R_i}$, $\frac{(y_i - y)}{R_i}$, and $\frac{(z_i - z)}{R_i}$ where the distance from receiver to the satellite, R_i, is given by:

$$R_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2}$$

where $x, y, and\ z$ denote the position of the receiver and $x_i, y_i, and\ z_i$ denote the position of satellite i. These x, y, and z components may be components in a North, East, Down coordinate system a South, East, Up coordinate system or other convenient system. Formulate the matrix *A* as:

$$A = \begin{bmatrix} \frac{(x_1-x)}{R_1} & \frac{(y_1-y)}{R_1} & \frac{(z_1-z)}{R_1} & c \\ \frac{(x_2-x)}{R_2} & \frac{(y_2-y)}{R_2} & \frac{(z_2-z)}{R_2} & c \\ \frac{(x_3-x)}{R_3} & \frac{(y_3-y)}{R_3} & \frac{(z_3-z)}{R_3} & c \\ \frac{(x_4-x)}{R_4} & \frac{(y_4-y)}{R_4} & \frac{(z_4-z)}{R_4} & c \end{bmatrix}$$

The first three elements of each row of A are the components of a unit vector from the receiver to the indicated satellite. The elements in the fourth column are c where c denotes the speed of light. Formulate the matrix, Q, as

$$Q = \left(A^T A\right)^{-1}$$

This computation is in accordance with Chapter 11 of The global positioning system by Parkinson and Spilker where the weighting matrix, P, has been set to the identity matrix. The elements of the Q matrix are designated as:

$$Q = \begin{bmatrix} d_x^2 & d_{xy}^2 & d_{xz}^2 & d_{xt}^2 \\ d_{xy}^2 & d_y^2 & d_{yz}^2 & d_{yt}^2 \\ d_{xz}^2 & d_{yz}^2 & d_z^2 & d_{zt}^2 \\ d_{xt}^2 & d_{yt}^2 & d_{zt}^2 & d_t^2 \end{bmatrix}$$

The Greek letter σ is used quite often where we have used d. However the elements of the Q matrix do not represent variances and covariances as they are defined in probability and statistics. Instead they are strictly geometric terms. Therefore d as in dilution of precision is used. PDOP, TDOP and GDOP are given by

$$PDOP = \sqrt{d_x^2 + d_y^2 + d_z^2},$$
$$TDOP = \sqrt{d_t^2} = |d_t|, \text{ and}$$
$$GDOP = \sqrt{PDOP^2 + TDOP^2}$$

in agreement with "Section 1.4.9 of PRINCIPLES OF SATELLITE POSITIONING".

The horizontal dilution of precision, $HDOP = \sqrt{d_x^2 + d_y^2}$, and the vertical dilution of precision, $VDOP = \sqrt{d_z^2}$, are both dependent on the coordinate system used. To correspond to the local horizon plane and the local vertical, x, y, and z should denote positions in either a North, East, Down coordinate system or a South, East, Up coordinate system.

Derivation of DOP equations

The equations for computing the geometric dilution of precision terms have been described in the previous section. Here we, describes the derivation of these equations. The method used here is similar to that used in "Global Positioning System (preview) by Parkinson and Spiker"

Consider the position error vector, $\mathbf{e}$, defined as the vector from the intersection of the four sphere surfaces corresponding to the pseudoranges to the true position of the receiver. $\mathbf{e} = e_x\hat{x} + e_y\hat{y} + e_z\hat{z}$ where bold denotes a vector and $\hat{x}$, $\hat{y}$, and $\hat{z}$ denote unit vectors along the x, y, and z axes respectively. Let e_t denote the time error, the true time minus the receiver indicated time. Assume that the mean value of the three components of $\mathbf{e}$ and e_t are zero.

$$A\begin{bmatrix} e_x \\ e_y \\ e_z \\ e_t \end{bmatrix} = \begin{bmatrix} \frac{(x_1-x)}{R_1} & \frac{(y_1-y)}{R_1} & \frac{(z_1-z)}{R_1} & c \\ \frac{(x_2-x)}{R_2} & \frac{(y_2-y)}{R_2} & \frac{(z_2-z)}{R_2} & c \\ \frac{(x_3-x)}{R_3} & \frac{(y_3-y)}{R_3} & \frac{(z_3-z)}{R_3} & c \\ \frac{(x_4-x)}{R_4} & \frac{(y_4-y)}{R_4} & \frac{(z_4-z)}{R_4} & c \end{bmatrix} \begin{bmatrix} e_x \\ e_y \\ e_z \\ e_t \end{bmatrix} = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} \quad (1)$$

where $e_1,\ e_2,\ e_3,\ and\ e_4$ are the errors in pseudoranges 1 through 4 respectively. This equation comes from linearizing the equation relating pseudoranges to receiver position, satellite positions, and receiver clock errors as shown in. Multiplying both sides by A^{-1} there results

$$\begin{bmatrix} e_x \\ e_y \\ e_z \\ e_t \end{bmatrix} = A^{-1} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} \quad (2)$$

.

Transposing both sides:

$$\begin{bmatrix} e_x & e_y & e_z & e_t \end{bmatrix} = \begin{bmatrix} e_1 & e_2 & e_3 & e_4 \end{bmatrix} \left(A^{-1}\right)^T \quad (3).$$

Post multiplying the matrices on both sides of equation (2) by the corresponding matrices in equation (3), there results

$$\begin{bmatrix} e_x \\ e_y \\ e_z \\ e_t \end{bmatrix} \begin{bmatrix} e_x & e_y & e_z & e_t \end{bmatrix} = A^{-1} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} \begin{bmatrix} e_1 & e_2 & e_3 & e_4 \end{bmatrix} \left(A^{-1}\right)^T \quad (4)$$

.

Taking the expected value of both sides and taking the non-random matrices outside the expectation operator, E, there results:

$$E\left(\begin{bmatrix} e_x \\ e_y \\ e_z \\ e_t \end{bmatrix} \begin{bmatrix} e_x & e_y & e_z & e_t \end{bmatrix}\right) = A^{-1}\, E\left(\begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} \begin{bmatrix} e_1 & e_2 & e_3 & e_4 \end{bmatrix}\right) \left(A^{-1}\right)^T \quad (5)$$

Assuming the pseudorange errors are uncorrelated and have the same variance, the covariance matrix on the right side can be expressed as a scalar times the identity matrix. Thus

$$\begin{bmatrix} \sigma_x^2 & \sigma_{xy}^2 & \sigma_{xz}^2 & \sigma_{xt}^2 \\ \sigma_{xy}^2 & \sigma_y^2 & \sigma_{yz}^2 & \sigma_{yt}^2 \\ \sigma_{xz}^2 & \sigma_{yz}^2 & \sigma_z^2 & \sigma_{zt}^2 \\ \sigma_{xt}^2 & \sigma_{yt}^2 & \sigma_{zt}^2 & \sigma_t^2 \end{bmatrix} = \sigma_R^2 \; A^{-1}\left(A^{-1}\right)^T = \sigma_R^2 \; \left(A^T A\right)^{-1} \quad (6)$$

since $A^{-1}\left(A^{-1}\right)^T \left(A^T A\right) = I$

Note: $\left(A^{-1}\right)^T = \left(A^T\right)^{-1}$,since $I = \left(AA^{-1}\right)^T = \left(A^{-1}\right)^T A^T$

Substituting for $\left(A^T A\right)^{-1} = Q$ there follows

$$\begin{bmatrix} \sigma_x^2 & \sigma_{xy}^2 & \sigma_{xz}^2 & \sigma_{xt}^2 \\ \sigma_{xy}^2 & \sigma_y^2 & \sigma_{yz}^2 & \sigma_{yt}^2 \\ \sigma_{xz}^2 & \sigma_{yz}^2 & \sigma_z^2 & \sigma_{zt}^2 \\ \sigma_{xt}^2 & \sigma_{yt}^2 & \sigma_{zt}^2 & \sigma_t^2 \end{bmatrix} = \sigma_R^2 \begin{bmatrix} d_x^2 & d_{xy}^2 & d_{xz}^2 & d_{xt}^2 \\ d_{xy}^2 & d_y^2 & d_{yz}^2 & d_{yt}^2 \\ d_{xz}^2 & d_{yz}^2 & d_z^2 & d_{zt}^2 \\ d_{xt}^2 & d_{yt}^2 & d_{zt}^2 & d_t^2 \end{bmatrix} \quad (7)$$

From equation (7), it follows that the variances of indicated receiver position and time are

$$\sigma_{rc}^2 = \sigma_x^2 + \sigma_y^2 + \sigma_z^2 = \sigma_R^2 \left(d_x^2 + d_y^2 + d_z^2\right) = PDOP^2 \sigma_R^2$$ and
$$\sigma_t^2 = \sigma_R^2 d_t^2 = TDOP^2 \sigma_R^2$$

The remaining position and time error variance terms follow in a straightforward manner.

Selective availability

GPS includes a (currently disabled) feature called *Selective Availability* (*SA*) that adds intentional, time varying errors of up to 100 meters (328 ft) to the publicly available navigation signals. This was intended to deny an enemy the use of civilian GPS receivers for precision weapon guidance.

SA errors are actually pseudorandom, generated by a cryptographic algorithm from a classified *seed* key available only to authorized users (the U.S. military, its allies and a few other users, mostly government) with a special military GPS receiver. Mere possession of the receiver is insufficient; it still needs the tightly controlled daily key.

Before it was turned off on May 1, 2000, typical SA errors were about 50 m (164 ft) horizontally and about 100 m (328 ft) vertically. Because SA affects every GPS receiver in a given area almost equally, a fixed station with an accurately known position can measure the SA error values and transmit them to the local GPS receivers so they may correct their position fixes. This is called Differential GPS or *DGPS*. DGPS also corrects for several other important sources of GPS errors, particularly ionospheric delay, so it continues to be widely used even though SA has been turned off. The ineffectiveness of SA in the face of widely available DGPS was a common argument for turning off SA, and this was finally done by order of President Clinton in 2000.

DGPS services are widely available from both commercial and government sources. The latter include WAAS and the U.S. Coast Guard's network of LF marine navigation beacons. The accuracy of the corrections depends on the distance between the user and the DGPS receiver. As the distance increases, the errors at the two sites will not correlate as well, resulting in less precise differential corrections.

During the 1990-91 Gulf War, the shortage of military GPS units caused many troops and their families to buy readily available civilian units. This significantly impeded the U.S. military's own battlefield use of GPS, so the military made the decision to turn off SA for the duration of the war.

In the 1990s, the FAA started pressuring the military to turn off SA permanently. This would save the FAA millions of dollars every year in maintenance of their own radio navigation systems. The amount of error added was "set to zero" at midnight on May 1, 2000 following an announcement by U.S. President Bill Clinton, allowing users access to the error-free L1 signal. Per the directive, the induced error of SA was changed to add no error to the public signals (C/A code). Clinton's executive order required SA to be set to zero by 2006; it happened in 2000 once the U.S. military developed a new system that provides the ability to deny GPS (and other navigation services) to hostile forces in a specific area of crisis without affecting the rest of the world or its own military systems.

Selective Availability is still a system capability of GPS, and could, in theory, be reintroduced at any time. In practice, in view of the hazards and costs this would induce for U.S. and foreign shipping, it is unlikely to be reintroduced, and various government agencies, including the FAA, have stated that it is not intended to be reintroduced.

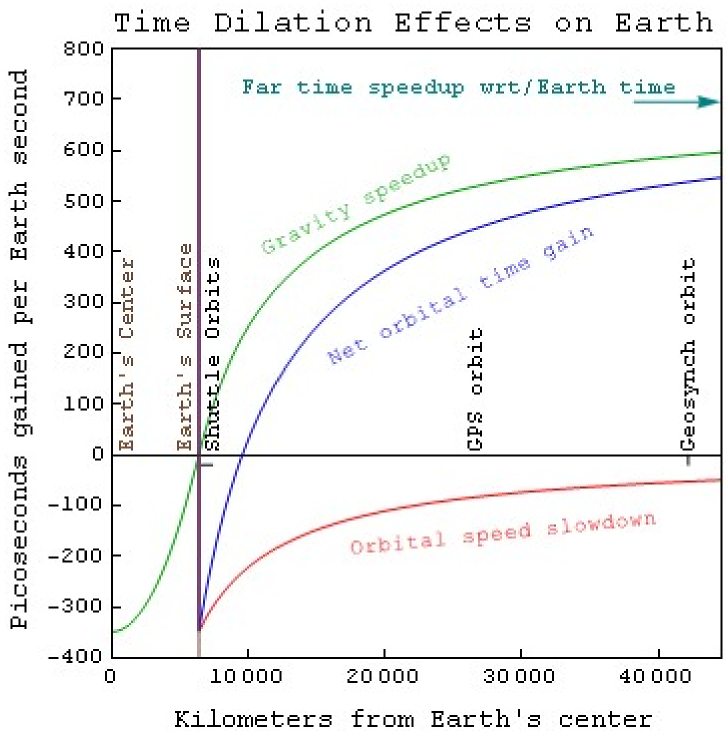
One interesting side effect of the Selective Availability hardware is the capability to add corrections to the outgoing signal of the GPS cesium and rubidium atomic clocks to an accuracy of approximately 2×10^{-13} This represented a significant improvement over the raw accuracy of the clocks.

On 19 September 2007, the United States Department of Defense announced that future GPS III satellites will not be capable of implementing SA, eventually making the policy permanent.

Antispoofing

Another restriction on GPS, antispoofing, remains on. This encrypts the *P-code* so that it cannot be mimicked by a transmitter sending false information. Few civilian receivers have ever used the P-code, and the accuracy attainable with the public C/A code is so much better than originally expected (especially with DGPS) that the antispoof policy has relatively little effect on most civilian users. Turning off antispoof would primarily benefit surveyors and some scientists who need extremely precise positions for experiments such as tracking tectonic plate motion.

Relativity



Satellite clocks are slowed by their orbital speed but sped up by their distance out of the Earth's gravitational well.

A number of sources of error exist due to relativistic effects that would render the system useless if uncorrected. Three relativistic effects are the time dilation, gravitational frequency shift, and eccentricity effects. For example, the relativistic time *slowing* due to the speed of the satellite of about 1 part in 10^{10}, the gravitational time dilation that makes a satellite run about 5 parts in 10^{10} *faster* than an Earth based clock, and the Sagnac effect due to rotation relative to receivers on Earth. These topics are examined below, one at a time.

Special and general relativity

According to the theory of relativity, due to their constant movement and height relative to the Earth-centered, non-rotating approximately inertial reference frame, the clocks on the satellites are affected by their speed. Special relativity predicts that the frequency of the atomic clocks moving at GPS orbital speeds will tick more slowly than stationary ground clocks by a factor of $\frac{v^2}{2c^2} \approx 10^{-10}$, or result in a delay of about 7 μs/day, where the orbital velocity is v = 4 km/s, and c = the speed of light. The time dilation effect has been measured and verified using the GPS.

The effect of gravitational frequency shift on the GPS due to general relativity is that a clock closer to a massive object will be slower than a clock farther away. Applied to the GPS, the receivers are much closer to Earth than the satellites, causing the GPS clocks to be faster by a factor of 5×10^(-10), or about 45.9 μs/day. This gravitational frequency shift is noticeable.

When combining the time dilation and gravitational frequency shift, the discrepancy is about 38 microseconds per day, a difference of 4.465 parts in 10^{10}. Without correction, errors in the initial pseudorange of roughly 10 km/day would accumulate. This initial pseudorange error is corrected in the process of solving the navigation equations. In addition the elliptical, rather than perfectly circular, satellite orbits cause the time dilation and gravitational frequency shift effects to vary with time. This eccentricity effect causes the clock rate difference between a GPS satellite and a receiver to increase or decrease depending on the altitude of the satellite.

To compensate for the discrepancy, the frequency standard on board each satellite is given a rate offset prior to launch, making it run slightly slower than the desired frequency on Earth; specifically, at 10.22999999543 MHz instead of 10.23 MHz. Since the atomic clocks on board the GPS satellites are precisely tuned, it makes the system a practical engineering application of the scientific theory of relativity in a real-world environment. Placing atomic clocks on artificial satellites to test Einstein's general theory was proposed by Friedwardt Winterberg in 1955.

Sagnac distortion

GPS observation processing must also compensate for the Sagnac effect. The GPS time scale is defined in an inertial system but observations are processed in an Earth-centered, Earth-fixed (co-rotating) system, a system in which simultaneity is not uniquely defined. A Lorentz transformation is thus applied to convert from the inertial system to the ECEF system. The resulting signal run time correction has opposite algebraic signs for satellites in the Eastern and Western celestial hemispheres. Ignoring this effect will produce an east-west error on the order of hundreds of nanoseconds, or tens of meters in position.

Natural sources of interference

Since GPS signals at terrestrial receivers tend to be relatively weak, natural radio signals or scattering of the GPS signals can desensitize the receiver, making acquiring and tracking the satellite signals difficult or impossible.

Space weather degrades GPS operation in two ways, direct interference by solar radio burst noise in the same frequency band or by scattering of the GPS radio signal in ionospheric irregularities referred to as scintillation. Both forms of degradation follow the 11 year solar cycle and are a maximum at sunspot maximum although they can occur at anytime. Solar radio bursts are associated with solar flares and Coronal Mass Ejections (CMEs) and their impact can affect reception over the half of the Earth facing the sun. Scintillation occurs most frequently at tropical latitudes where it is a night time phenomenon. It occurs less frequently at high latitudes or mid-latitudes where magnetic storms can lead to scintillation. In addition to producing scintillation, magnetic storms can produce strong ionospheric gradients that degrade the accuracy of SBAS systems.

Artificial sources of interference

In automotive GPS receivers, metallic features in windshields, such as defrosters, or car window tinting films can act as a Faraday cage, degrading reception just inside the car.

Man-made EMI (electromagnetic interference) can also disrupt or jam GPS signals. In one well-documented case it was impossible to receive GPS signals in the entire harbor of Moss Landing, California due to unintentional jamming caused by malfunctioning TV antenna preamplifiers. Intentional jamming is also possible. Generally, stronger signals can interfere with GPS receivers when they are within radio range or line of sight. In 2002 a detailed description of how to build a short-range GPS L1 C/A jammer was published in the online magazine Phrack.

The U.S. government believes that such jammers were used occasionally during the 2001 war in Afghanistan, and the U.S. military claims to have destroyed six GPS jammers during the Iraq War, including one that was destroyed with a GPS-guided bomb. A GPS jammer is relatively easy to detect and locate, making it an attractive target for anti-radiation missiles. The UK Ministry of Defence tested a jamming system in the UK's West Country on 7 and 8 June 2007.

Some countries allow the use of GPS repeaters to allow the reception of GPS signals indoors and in obscured locations; however, under EU and UK laws, the use of these is prohibited as the signals can cause interference to other GPS receivers that receive data from both GPS satellites and the repeater.

Due to the potential for both natural and man-made noise, numerous techniques continue to be developed to deal with the interference. The first is to not rely on GPS as a sole source. According to John Ruley, "IFR pilots should have a fallback plan in case of a GPS malfunction". Receiver Autonomous Integrity Monitoring (RAIM) is a feature included in some receivers, designed to provide a warning to the user if jamming or another problem is detected. The U.S. military has also deployed since 2004 their Selective Availability / Anti-Spoofing Module (SAASM) in the Defense Advanced GPS Receiver (DAGR). In demonstration videos the DAGR was shown to detect jamming and maintain its lock on the encrypted GPS signals during interference which caused civilian receivers to lose lock.

Chapter-5

Glass Cockpit

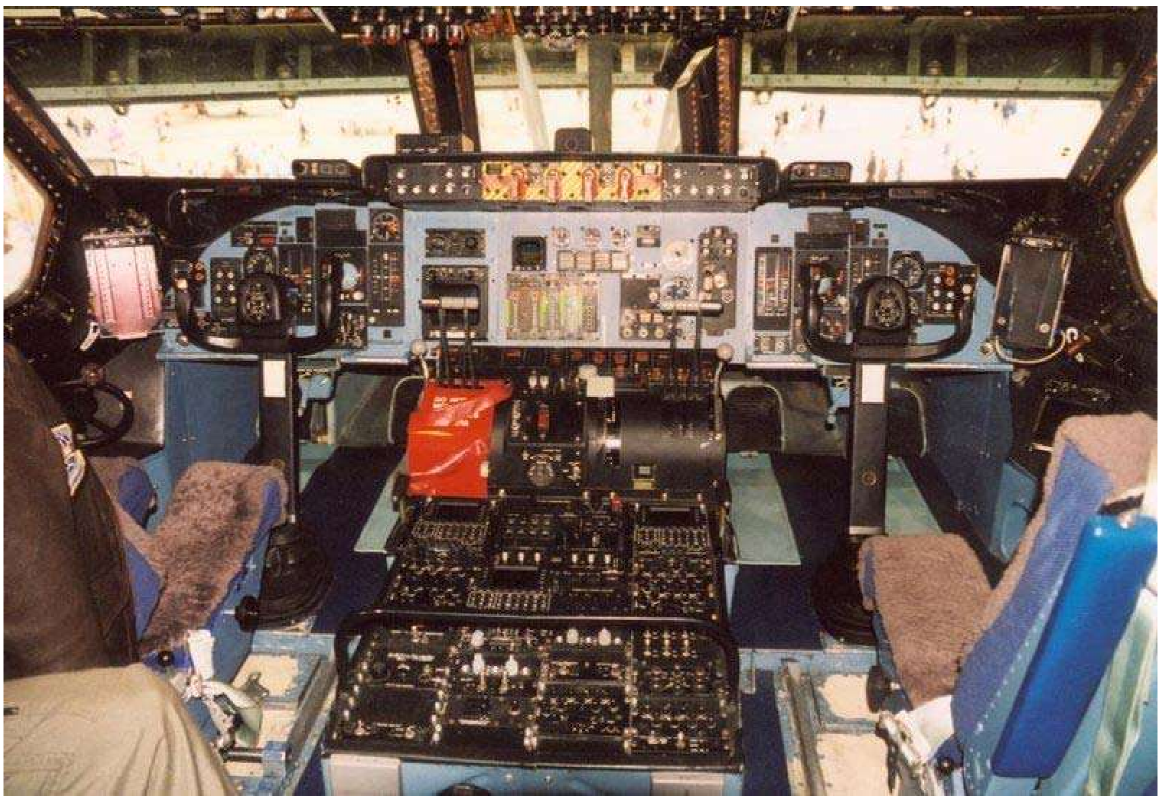
The Airbus A380 glass cockpit featuring "pull out keyboards and 2 wide computer screen on the sides for pilots".

A **glass cockpit** is an aircraft cockpit that features electronic instrument displays. Where a traditional cockpit relies on numerous mechanical gauges to display information, a glass cockpit uses several displays driven by flight management systems, that can be adjusted to display flight information as needed. This simplifies aircraft operation and navigation and allows pilots to focus only on the most pertinent information. They are also popular with airline companies as they usually eliminate the need for a flight engineer. In recent years the technology has become widely available in small aircraft.

As aircraft displays have modernized, the sensors that feed them have modernized as well. Traditional gyroscopic flight instruments have been replaced by electronic Attitude and Heading Reference Systems (AHRS) and Air Data Computers (ADCs), improving reliability and reducing cost and maintenance. GPS receivers are usually integrated into glass cockpits.

Early glass cockpits, found in the McDonnell Douglas MD-80/90, Boeing 737 Classic, 757 and 767-200/-300, and in the Airbus A300-600 and A310, used Electronic Flight Instrument Systems (EFIS) to display attitude and navigational information only, with traditional mechanical gauges retained for airspeed, altitude and vertical speed. Later glass cockpits, found in the Boeing 737NG, 747-400, 767-400, 777, A320 and later Airbuses, Ilyushin Il-96 and Tupolev Tu-204 have completely replaced the mechanical gauges and warning lights in previous generations of aircraft.

History



Instrument panel of a C-5A

New instrument panel for C-5 as part of AMP program

Prior to the 1970s, air transport operations were not considered sufficiently demanding to require advanced equipment like electronic flight displays. Also, computer technology was not at a level where sufficiently light and powerful circuits were available. The increasing complexity of transport aircraft, the advent of digital systems and the growing air traffic congestion around airports began to change that.

The average transport aircraft in the mid-1970s had more than one hundred cockpit instruments and controls, and the primary flight instruments were already crowded with indicators, crossbars, and symbols, and the growing number of cockpit elements were competing for cockpit space and pilot attention. As a result, NASA conducted research on displays that could process the raw aircraft system and flight data into an integrated, easily understood picture of the flight situation, culminating in a series of flights demonstrating a full glass cockpit system.

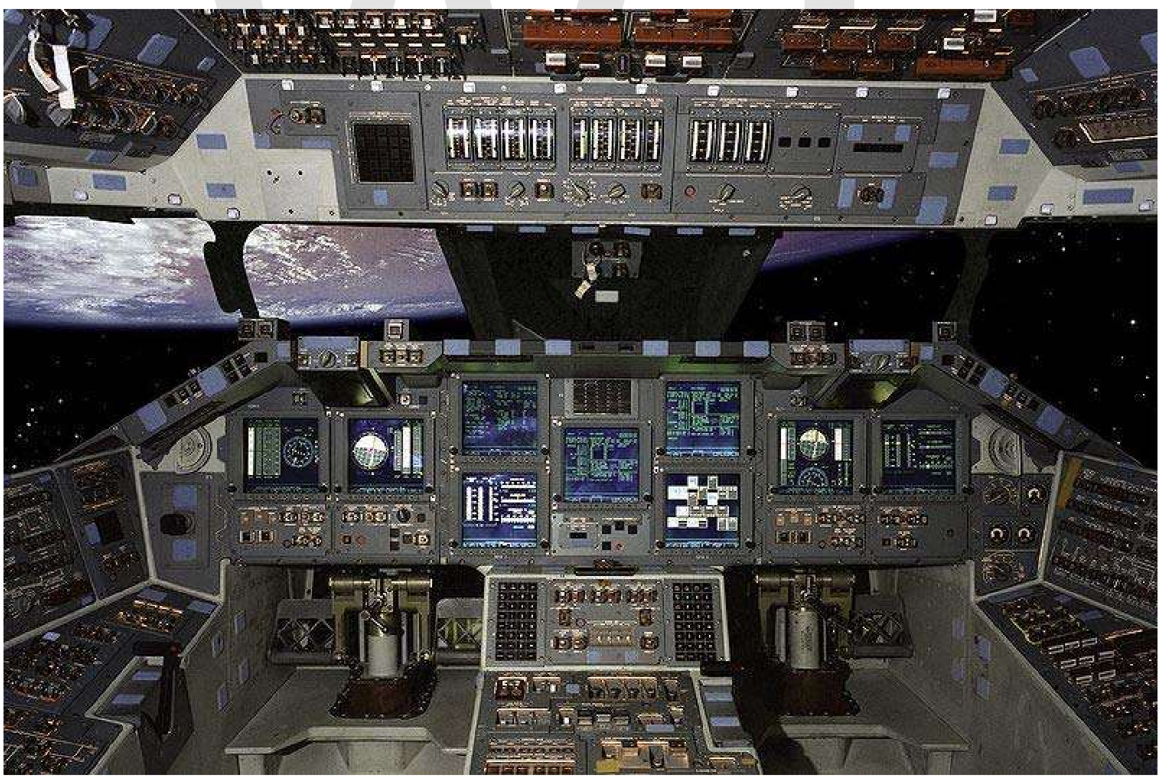
The success of the NASA-led glass cockpit work is reflected in the total acceptance of electronic flight displays beginning with the introduction of the MD-80 in 1979. Airlines and their passengers alike have benefited. The safety and efficiency of flights has been increased with improved pilot understanding of the aircraft's situation relative to its environment (or "situational awareness").

By the end of the 1990s, Liquid crystal display (LCD) panels were increasingly favored among aircraft manufacturers because of their efficiency, reliability and legibility. Earlier LCD panels suffered from poor legibility at some viewing angles and poor response times, making them unsuitable for aviation. Modern aircraft such as the Boeing 737 Next Generation, 777, 717, 747-400ER, 767-400ER, 747-8, and 787, Airbus A320 family (later versions), A330 (later versions), A340-500/600, A340-300 (later versions), A380 and A350 are fitted with glass cockpits consisting of LCD units.

The glass cockpit has become standard equipment in airliners, business jets, and military aircraft. It was even fitted into NASA's Space Shuttle orbiters *Atlantis*, *Columbia*, *Discovery*, and *Endeavour*, and the current Russian Soyuz TMA model spacecraft that was launched in 2002. By the end of the century glass cockpits began appearing in general aviation aircraft as well. By 2005, even basic trainers like the Piper Cherokee and Cessna 172 were shipping with glass cockpits as options (which nearly all customers chose), and many modern aircraft such as the Diamond Aircraft twin-engine travel and training aircraft DA42, and Cirrus Design SR20 and SR22 are available with glass cockpit only.

Usage

In commercial aviation



The Space Shuttle glass cockpit

Unlike the previous era of glass cockpits—where designers merely copied the look and feel of conventional electromechanical instruments onto cathode ray tubes—the new displays represent a true departure. They look and behave very similarly to other computers, with windows and data that can be manipulated with point-and-click devices. They also add terrain, approach charts, weather, vertical displays, and 3D navigation images.

The improved concepts enable aircraft makers to customize cockpits to a greater degree than previously. All of the manufacturers involved have chosen to do so in one way or another—such as using a trackball, thumb pad or joystick as a pilot-input device in a computer-style environment. Many of the modifications offered by the aircraft manufacturers improve situational awareness and customize the human-machine interface to increase safety.

Modern glass cockpits might include Synthetic Vision (SVS) or Enhanced Vision systems (EVS). Synthetic Vision systems display a realistic 3D depiction of the outside world (similar to a flight simulator), based on a database of terrain and geophysical features in conjunction with the attitude and position information gathered from the aircraft navigational systems. Enhanced Vision systems add real-time information from external sensors, such as an infrared camera.

All new airliners such as the Airbus A380, Boeing 787 and private jets such as Bombardier Global Express and Learjet use glass cockpits.

In general aviation

Garmin G1000 displays in a Cessna 182

Certain general aviation aircraft, such as the 4-seat Diamond Aircraft DA40, DA42 and DA50 and the 4-seat Cirrus Design SR20 and SR22, are available with glass cockpits. Systems such as the Garmin G1000 are now available on many new GA aircraft, including the classic Cessna 172. Some small aircraft can also be modified post-production to replace steam gauges.

Glass cockpits are also popular as a retrofit for older private jets and turboprops such as Dassault Falcons, Raytheon Hawkers, Bombardier Challenger, Cessna Citations, Gulfstreams, King Airs, Learjets, Astras and many others. Aviation service companies work closely with equipment manufacturers to address the needs of the owners of these aircraft.

Safety

As aircraft operation becomes more dependent on glass cockpit systems, flight crews must be trained to deal with possible failures. In one glass-cockpit aircraft, the Airbus A320, fifty incidents of glass-cockpit blackout have occurred. On 25 January 2008 United Airlines Flight 731 experienced a serious glass-cockpit blackout, losing half of the

ECAM displays as well as all radios, transponders, TCAS, and attitude indicators. Partially due to good weather and daylight conditions, the pilots were able to land successfully at Newark Airport without radio contact. Airbus has offered an optional fix, which the US NTSB has suggested to the US FAA as mandatory, but the FAA has yet to make it a requirement. A preliminary NTSB factsheet is available. In 2010, the NTSB published a study done on 8,000 general aviation light aircraft. The study found that, although aircraft equipped with glass cockpits had a lower overall accident rate, they also had a larger chance of being involved in a fatal accident. The NTSB Chairman said in response to the study,

"Training is clearly one of the key components to reducing the accident rate of light planes equipped with glass cockpits, and this study clearly demonstrates the life and death importance of appropriate training on these complex systems... While the technological innovations and flight management tools that glass cockpit equipped airplanes bring to the general aviation community should reduce the number of fatal accidents, we have not – unfortunately – seen that happen."

Chapter-6

Automatic Vehicle Location

Automatic vehicle location (**AVL** or ~**locating**; **telelocating** in EU) is a means for automatically determining the geographic location of a vehicle and transmitting the information to a requester.

Most commonly, the location is determined using GPS, and the transmission mechanism is SMS, GPRS, a satellite or terrestrial radio from the vehicle to a radio receiver. GSM and EVDO are the most common services applied, because of the low data rate needed for AVL, and the low cost and near-ubiquitous nature of these public networks. The low bandwidth requirements also allow for satellite technology to receive telemetry data at a moderately higher cost, but across a global coverage area and into very remote locations not covered well by terrestrial radio or public carriers. Other options for determining actual location, for example in environments where GPS illumination is poor, are dead reckoning, i.e. inertial navigation, or active RFID systems or cooperative RTLS systems. With advantage, combinations of these systems may be applied. In addition, terrestrial radio positioning systems utilizing an LF (Low Frequency) switched packet radio network were also used as an alternative to GPS based systems.

Applications

Application with vehicles

Automatic vehicle locating is a powerful concept for managing fleets of vehicles, as service vehicles, emergency vehicles, and especially precious construction equipment, also public transport vehicles (buses and trains). It is also used to track mobile assets, such as non wheeled construction equipment, non motorized trailers, and mobile power generators.

Application with vehicle drivers and crews

The other purpose of tracking is to provide graded service or to manage a large driver and crewing staff effectively. For example, suppose an ambulance fleet has an objective of arriving at the location of a call for service within six minutes of receiving the request.

Using an AVL system allows to evaluate the locations of all vehicles in service with driver and other crew in order to pick the vehicle that will most likely arrive at the destination fastest, (meeting the service objective).

Types of systems

Simple direction finding

Amateur radio and some cellular or PCS wireless systems use **direction finding or triangulation** of transmitter signals radiated by the mobile. This is sometimes called **radio direction finding** or **RDF**. The simplest forms of these systems calculate the bearing from two fixed sites to the mobile. This creates a triangle with endpoints at the two fixed points and the mobile. Trigonometry tells you roughly where the mobile transmitter is located. In wireless telephone systems, the phones transmit continually when off-hook, making continual tracking and the collection of many location samples possible. This is one type of location system required by Federal Communications Commission Rules for wireless Enhanced 911.

Former LORAN-based locating

Motorola offered a 1970s-era system based on the United States Coast Guard LORAN maritime navigation system. The LORAN system was intended for ships but signal levels on the US east- and west-coast areas were adequate for use with receivers in automobiles. The system may have been marketed under the Motorola model name *Metricom*. It consisted of an LF LORAN receiver and data interface box/modem connected to a separate two-way radio. The receiver and interface calculated a latitude and longitude in degrees, decimal degrees format based on the LORAN signals. This was sent over the radio as MDC-1200 or MDC-4800 data to a system controller, which plotted the mobile's approximate location on a map. The system worked reliably but sometimes had problems with electrical noise in urban areas. Sparking electric trolley poles or industrial plants which radiated electrical noise sometime overwhelmed the LORAN signals, affecting the system's ability to determine the mobile's geolocation. Because of the limited resolution, this type of system was impractical for small communities or operational areas such as a pit mine or port.

Signpost systems

To track and locate vehicles along fixed routes, a technology called **Signpost transmitters** is employed. This is used on transit routes and rail lines where the vehicles to be tracked continually operated on the same linear route. A transponder or RFID chip along the vehicle route would be polled as the train or bus traverses its route. As each transponder was passed, the moving vehicle would query and receive an ack, or handshake, from the signpost transmitter. A transmitter on the mobile would report passing the signpost to a system controller. This allows supervision, a call center, or a dispatch center to monitor the progress of the vehicle and assess whether or not the vehicle was *on schedule*. These systems are an alternative inside tunnels or other conveyances where GPS signals are blocked by terrain.

Today's GPS-based locating

The low price and ubiquity of Global Positioning System or GPS equipment has lent itself to more accurate and reliable telelocation systems. GPS signals are impervious to most electrical noise sources and don't require the user to install an entire system. Usually only a receiver to collect signals from the satellite segment is installed in each vehicle and radio or GSM to communicate the collected location data with a dispatch point.

Large private telelocation or AVL systems send data from GPS receivers in vehicles to a dispatch center over their private, user-owned radio backbone. These systems are used for businesses like parcel delivery and ambulances. Smaller systems which don't justify building a separate radio system use cellular or PCS data services to communicate location data from vehicles to their dispatching center. Location data is periodically polled from each vehicle in a fleet by a central controller or computer. In the simplest systems, data from the GPS receiver is displayed on a map allowing humans to determine the location of each vehicle. More complex systems feed the data into a computer assisted dispatch system which automates the process. For example, the computer assisted dispatch system may check the location of a call for service and then pick a list of the four closest ambulances. This narrows the dispatcher's choice from the entire fleet to an easier choice of four vehicles.

Some wireless carriers such as Nextel have decided GPS was the best way to provide the mandated location data for wireless Enhanced 9-1-1. Newer Nextel radios have embedded GPS receivers which are polled if 9-1-1 is dialed. The 9-1-1 center is provided with latitude and longitude from the radio's GPS receiver. In centers with computer assisted dispatch, the system may assign an address to the call based on these coordinates or may project an icon depicting the caller's location onto a map of the area.

Sensor-augmented AVL

The main purpose of using AVL is not only to locate the vehicles, but also to obtain information about engine data, fuel consumption, driver data and sensor data from i.e. doors, freezer room on trucks or air pressure. Such data can be obtained via the CAN-bus, via direct connections to AVL systems or via open bus systems such as UFDEX that both sends and receives data via SMS or GPRS in pure ASCII text format. Because most AVL consists of two parts, GPS and GSM modem with additional embedded AVL software contained in a microcontroller, most AVL systems are fixed for its purposes unless they connect to an open bus system for expansion possibilities.

With an open bus system the users can send invoices based on goods delivered with exact location, time and date data where if connected to scale, RFID or barcode readers, can make a fairly good automated system to avoid human errors.

In countries with high prices on gasoline external fuel sensors are used to prevent cases of fuel theft.

Logbook functions

Another scenario for sensor functions is to connect the AVL to driver information, to collect data about driving time, stops, or even driver absence from the vehicle. If the driver/worker conditions is such as the hourly rates for driving and working outside is not the same, this can be monitored by sensors, by using iButton or other personal identification devices. Later by analyzing log-file it is possible to get reports on any kind of events, like stops, visited streets, speed limits violations, etc.

Differentiating between Automatic Vehicle Location and Events Activated Tracking Systems

It might be helpful to draw a distinction between vehicle location systems which track automatically and event activated tracking systems which track when triggered by an event. There is increasingly crossover between the different systems and those with experience of this sector will be able to draw on a number of examples which break the rule.

A.V.L (Automatic Vehicle Location) This type of vehicle tracking is normally used in the fleet or driver management sector. The unit is configured to automatically transmit it's location at a set time interval, e.g. every 5 minutes. The unit is activated when the ignition is switched on/off.

E.A.T.S (Events Activated Tracking system) This type of system is primarily used in connection with vehicle or driver security solutions. If, for example a thief breaks into your car and attempts to steal it, the tracking system can be triggered by the immobiliser unit or motion sensor being activated. A monitoring bureau, will then be automatically notified that the unit has been activated and begin tracking the vehicle.

Some products on the market are a hybrid of both AVL and EATS technology. However industry practice has tended to lean towards a separation of these functions. It is worth taking note that vehicle tracking products tend to fall in to one, not both of the technologies.

AVL technology is predominately used when applying vehicle tracking to fleet or driver management solutions. The use of Automatic Vehicle Location is given in the following scenario; A car breaks down by the side of the road and the occupant calls a vehicle recovery company. The vehicle recovery company has several vehicles operating in the area. Without needing to call each driver to check his location the dispatcher can pinpoint the nearest recovery vehicle and assign it to the new job. If you were to incorporate the other aspects of vehicle telematics into this scenario; the dispatcher, rather than phoning the recovery vehicle operative, could transmit the job details directly to the operative's mobile data device, who would then use the in-vehicle satellite navigation to aid his journey to the job.

EATS technology is predominately used when applying vehicle tracking to vehicle security solutions. An example of this distinction is given in the following scenario; A construction company owns some pieces of plant machinery that are regularly left unattended, at weekends, on building sites. Thieves break onto one site and a piece equipment, such as a digger, is loaded on the back of a flat bed truck and then driven away. Typically the ignition wouldn't need to be turned on and as such most of the AVL products available wouldn't typically be activated. Only products that included a unit that was activated by a motion sensor or GeoFence alarm event, would be activated.

Both AVL and EATS systems track, but often for different purposes.

Special applications of automatic vehicle locating

Vehicle location technologies can be used in the following scenarios:

- **Fleet management:** when managing a fleet of vehicles, knowing the real-time location of all drivers allows management to meet customer needs more efficiently. Vehicle location information can also be used to verify that legal requirements are being met: for example, that drivers are taking rest breaks and obeying speed limits.

- **Passenger Information:** Real-time Passenger information systems use predictions based on AVL input to show the expected arrival and departure times of Public Transport services.

- **Asset tracking:** companies needing to track valuable assets for insurance or other monitoring purposes can now plot the real-time asset location on a map and closely monitor movement and operating status. For example, haulage and logistics companies often operate trucks with detachable load carrying units. In this case, trailers can be tracked independently of the cabs used to drive them. Combining vehicle location with inventory management that can be used to reconcile which item is currently on which vehicle can be used to identify physical location down to the level of individual packages.

- **Field worker management:** companies with a field service or sales workforce can use information from vehicle tracking systems to plan field workers' time, schedule subsequent customer visits and be able to operate these departments efficiently.

- **Covert surveillance:** vehicle location devices attached covertly by law enforcement or espionage organizations can be used to track journeys made by individuals who are under surveillance

Chapter-7

Public Address

Horn loudspeakers are often used to broadcast sound to outdoor locations

A **public address system** (**PA system**) is an electronic amplification system with a mixer, amplifier and loudspeakers, used to reinforce a sound source, *e.g.*, a person giving a speech, a DJ playing prerecorded music, and distributing the sound throughout a venue or building.

Simple PA systems are often used in small venues such as school auditoriums, churches, and small bars. PA systems with a larger number of speakers are widely used in institutional and commercial buildings, to read announcements or declare states of emergency. Intercom systems, which are often used in schools, also have microphones in each room so that the occupants can reply to the central office.

There is disagreement over when to call these audio systems sound reinforcement systems or PA systems. Some audio engineers distinguish between the two by technology and capability, while others distinguish by intended use, e.g., sound reinforcement systems are for live music, whereas PA systems are for reproduction of speech and recorded music in buildings and institutions. This distinction is important in some regions or markets, while in other regions or markets the terms are interchangeable. In colloquial British English, a PA system installed for public address in a building is sometimes referred to as a Tannoy system after the company of that name now owned by TC Electronic Group.

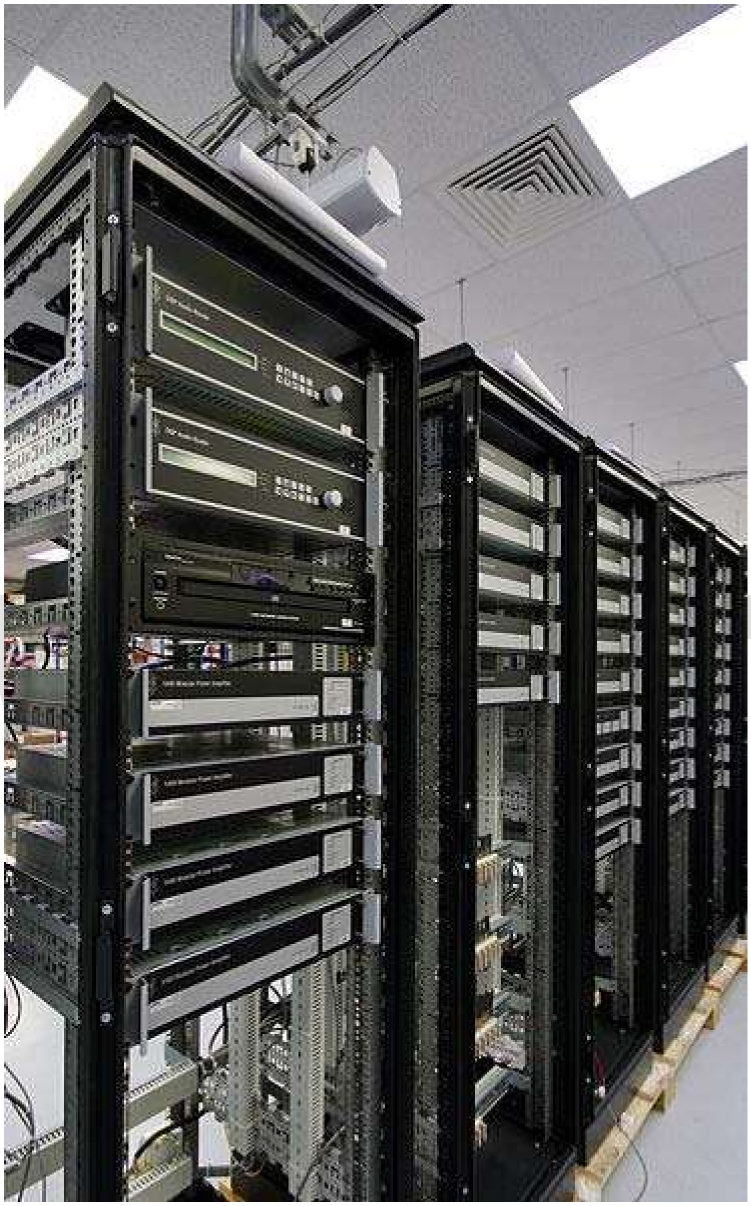
Small systems

Public address system in a school

The simplest PA systems consist of a microphone, a modestly-powered mixer amplifier and one or more loudspeakers. Simple PA systems of this type, often providing 50 to 200 watts of power, are often used in small venues such as school auditoriums, churches, and small bars. A sound source such as a CD player or radio may be connected to a PA system so that music can be played through the system.

Public address systems typically consist of input sources, preamplifiers and/or signal routers, amplifiers, control and monitoring equipment, and loudspeakers. Input sources refer to the microphones and CD Players that provide a sound input for the system. These input sources are fed into the preamplifiers and signal routers that determine the zones to which the audio signal is fed. The preamplified signals are then passed into the amplifiers. Depending on a country's regulations these amplifiers will amplify the audio signals to 50V, 70V or 100V speaker line level. Control equipment monitors the amplifiers and speaker lines for faults before it reaches the loudspeakers. This control equipment is also used for separating zones in a PA system. The loudspeaker is used to transduce electrical signals into analog sound signals.

Large systems



Public Address System consisting of amplifiers, mixers and routers for a major international airport

Some PA systems have speakers that cover an entire campus of a college or industrial site, or an entire outdoor complex (e.g., an athletic stadium). More than often this PA system will be used as voice alarm system that make announcement during emergency to evacuate the occupants in a building.

Telephone paging systems

Some analog or IP private branch exchange (PBX) telephone systems use a paging facility that acts as a liaison between the telephone and a PA amplifier. In other systems, paging equipment is not built into the telephone system. Instead the system includes a separate paging controller connected to a trunk port of the telephone system. The paging controller is accessed as either a designated directory number or central office line. In many modern systems, the paging function is integrated into the telephone system, and allows announcements to be played over the phone speakers.

Many retailers and offices choose to use the telephone system as the sole access point for the paging system, because the features is integrated. Many schools and other larger institutions are no longer using the large, bulky microphone PA systems and have switched to telephone system paging, as it can be accessed from many different points in the school.

PA over IP

PA over IP refers to PA paging and intercom systems that use an Ethernet or GSM-R network instead of a centralized amplifier to distribute the audio signal to all paging locations in a building or campus. Network-attached amplifiers and intercom units are used to provide the communication function. At the transmission end, a computer application transmits a digital audio stream via the local area network, using audio from the computer's sound card inputs or from stored audio recordings. At the receiving end, specialized intercom modules receive these network transmissions and reproduce the analog audio signal. These are small specialized network appliances addressable by an IP address just like any other computer on the network.

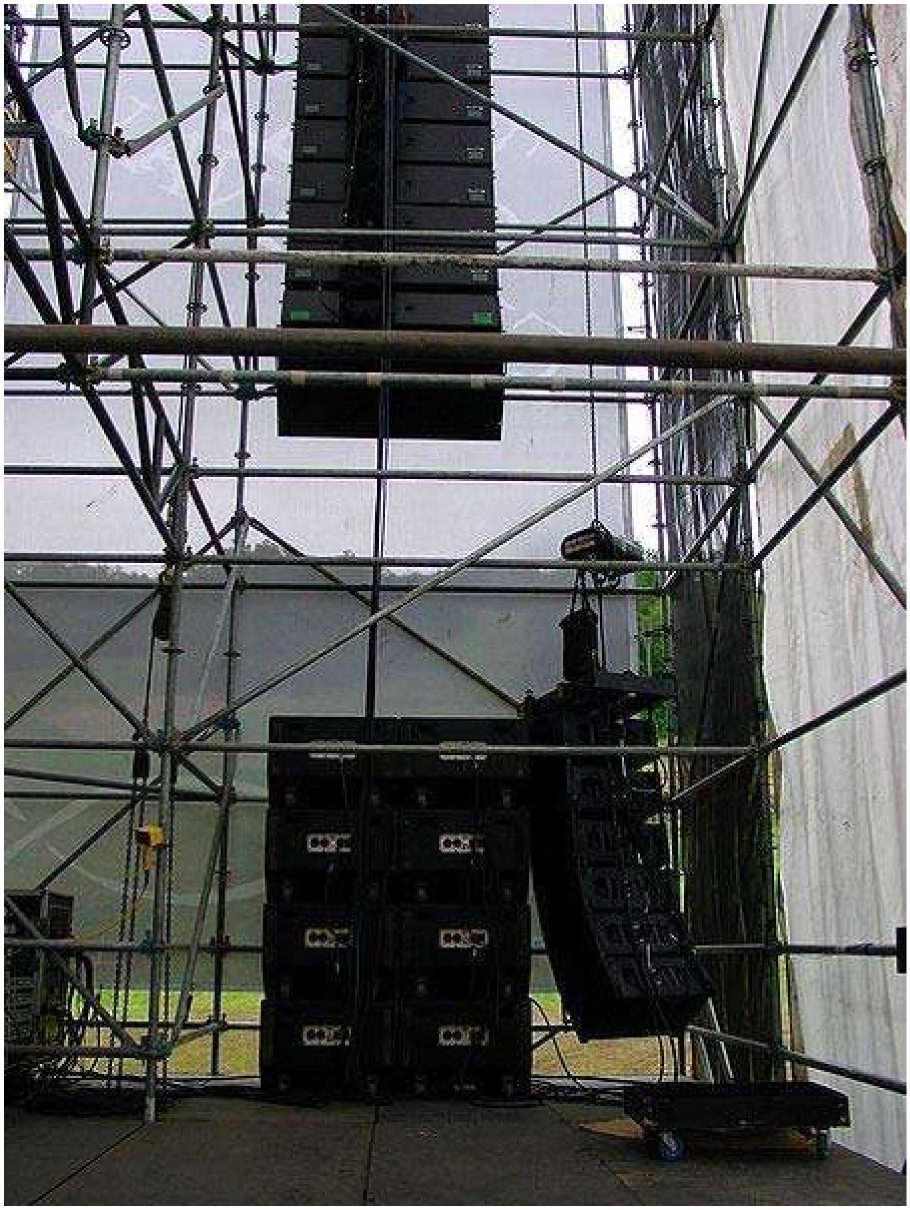
Such systems are inter-connected by the networking infrastructure and thus allow loss less transmission to remote locations across the Internet or a local area or campus network. It is also possible to provide for multiple or relocatable transmission control stations on such a network.

Long line PA

London Underground Employee making a Long Line Public Address system announcement using an RPA01 Radio Microphone at Bank Station

A Long-line public address (LLPA) system is any public address system with a distributed architecture, normally across a wide geographic area. Systems of this type are commonly found in the rail, light rail and metro industries and allow announcements to be triggered from one or several locations to the rest of the network over low bandwidth legacy copper, normally PSTN lines using DSL modems, or media such as optical fiber, or GSM-R, or IP-based networks. Rail systems typically have an interface with a passenger information system (PIS) server, at each station linked to train describers which state the location of rolling stock on the network from sensors on trackside signaling equipment. The PIS system invokes a stored message to be played from a local or remote digital voice announcement system, or a series of message fragments to be assembled in the correct order. For example: //the//13.29//virgin_trains//sleeper_service//from//London_Paddington//to//Penzance//....// will depart from platform//five//this train is formed of //12_carriages//. Messages are routed via an IP network and are played on local amplification equipment. Taken together, the PA, routing, DVA, passenger displays and PIS interface are referred to as the customer information system (CIS), a term which itself is often used interchangeably with passenger information system.

PA on Tour



A line array speaker system and subwoofer cabinets at a live music concert

As the number of album and singles sales falls each year, artists are relying more and more upon the income from live performances and tours. Touring bands will source a large line-array PA system from an audio equipment hire company with reliable service to take from venue to venue along with various other equipment such as lighting and projection. PA hire companies typically will provide "sound solutions" for a myriad of purposes. Local companies may specialise in small systems tailored to clubs, pubs and small outdoor events whereas larger companies will cater for concert halls.

Large venue systems

For popular music concerts, a more powerful and more complicated PA System is used to provide live sound reproduction. In a concert setting, there are typically two complete PA systems: the "main" system and the "monitor" system. Each system consists of microphones, a mixing board, sound processing equipment, amplifiers, and speakers.

- The "main" system (also known as "Front of House", commonly abbreviated FOH), which provides the amplified sound for the audience, will typically use a number of powerful amplifiers driving a range of large, heavy-duty loudspeakers including low-frequency speaker cabinets called subwoofers, full-range speaker cabinets, and high-range horns. A large club may use amplifiers to provide 3000 to 5000 watts of power to the "main" speakers; an outdoor concert may use 10,000 or more watts.
- The "monitor" system reproduces the sounds of the performance and directs them towards the onstage performers (typically using wedge-shaped monitor speaker cabinets), to help them to hear the instruments and vocals. In British English, the monitor system is referred to as the "foldback". The monitor system in a large club may provide 500 to 1000 watts of power to several foldback speakers; at an outdoor concert, there may be several thousand watts of power going to the monitor system.

At a concert in which live sound reproduction is being used, sound engineers and technicians control the mixing boards for the "main" and "monitor" systems, adjusting the tone, levels, and overall volume of the performance.

Acoustic feedback

All PA systems have a potential for audio feedback, which occurs when sound from the speakers returns to the microphone and is then re-amplified and sent through the speakers again. Sound engineers take several steps to prevent feedback, including ensuring that directional microphones are not pointed towards speakers, keeping the onstage volume levels down, and lowering gain levels at frequencies where the feedback is occurring, using a graphic equalizer, a parametric equalizer, or a notch filter.

Chapter-8

Measuring Instrument

In the physical sciences, quality assurance, and engineering, measurement is the activity of obtaining and comparing physical quantities of real-world objects and events. Established standard objects and events are used as units, and the process of measurement gives a number relating the item under study and the referenced unit of measurement. **Measuring instruments**, and formal test methods which define the instrument's use, are the means by which these relations of numbers are obtained. All measuring instruments are subject to varying degrees of instrument error and measurement uncertainty.

Scientists, engineers and other humans use a vast range of instruments to perform their measurements. These instruments may range from simple objects such as rulers and stopwatches to electron microscopes and particle accelerators. Virtual instrumentation is widely used in the development of modern measuring instruments.

Time, energy, power and action

Time

Time measurement device.

Time-points in the *past* can be measured with respect to the *present* of an observer. Time-points in the *future* can be fixed. But there seems to exist no device that can set time to a predetermined value (time machine), like it is possible with other physical quantities (for example: distance or volume). The time-point called *present* seems to move in one direction only, the future. Entropy production and cause-and-effect observations of events correlate to this observation.

For more information on time, especially standards, also consult the time portal.

- Atomic clock
- Calendar (by counting days)
- Chronometer, Chronograph
- Clock

- Egg timer
- Hourglass
- Pendulum clock
- Radio clock
- Radiometric dating
- Stopwatch
- Sundial
- Transit telescope
- Water clock

Energy

Changing energy carriers, linear momentum to angular momentum. No measurement primarily intended.

Example: In a plant that furnishes pumped-storage hydroelectricity, mechanical work and electrical work is done by machines like electric pumps and electrical generators. The pumped water stores mechanical work. The amount of energy put into the system equals the amount of energy which comes out of the system, less that amount of energy used to overcome friction.

Such examples suggested the derivation of some unifying concepts: Instead of discerning (transferred) forms of work or stored work, there has been introduced one single physical quantity called energy. Energy is assumed to have substance-like qualities; energy can be apportioned and transferred. Energy cannot be created from nothing, or to be annihilated to nothing, thus energy becomes a conserved quantity, when properly balanced.

Describing the transfer of energy two dictions, two ways of wording are used:

(energy carriers exchanging energy) Physical interactions occur by carriers (linear momentum, electric charge, entropy) exchanging energy. For example, a generator transfers energy from angular momentum to electric charge.

(energy forms transforming energy) Energy forms are transformed; for example mechanical energy into electrical energy by a generator.

Often the energy value results from multiplying two related quantities: (a generalized) potential (relative velocity, voltage, temperature difference) times some substance-like quantity (linear momentum, electrical charge, entropy). — Thus energy has to be measured by first choosing a carrier/form. The measurement usually happens indirectly, by obtaining two values (potential and substance-like quantity) and by multiplying their values.

Power (flux of energy)

A physical system that exchanges energy may be described by the amount of energy exchanged per time-interval, also called power or flux of energy.

Action

Action describes energy summed up over the time a process lasts (time integral over energy). Its dimension is the same as that of an angular momentum.

- A phototube provides a voltage measurement which permits the calculation of the quantized action (Planck constant) of light.

Mechanics

This includes basic quantities found in Classical- and continuum mechanics; but strives to exclude temperature-related questions or quantities.

Length (distance)

- Altimeter, height
- Architect's scale
- Caliper
- Electronic distance meter
- Engineer's scale
- Frequency comb
- Gauge blocks
- Opisometer
- Feeler gauge, used in metal working to measure size of gaps
- Radar antenna, indirect by runtime measurement of electromagnetic waves around the microwave region (radar)

- GPS, indirect by runtime measurement of electromagnetic waves in the GHz-range
- Interferometer
- Laser rangefinder, indirect by runtime measurement of coherent electromagnetic waves around the visible light region (lidar)
- Metric scale
- Micrometer
- Odometer
- Rule
- Surveyor's wheel
- Tachymeter
- Tape measure
- Taximeter, measure usually includes a time component as well
- Travelling microscope
- Ultrasound distance measure, indirect by runtime measurement of sound waves (sonar, Echo sounding)
- Urethra gauge, cylindrical circumferencial measurement device.

Volume

A measuring cup, a common instrument used to measure volume.

- buoyant weight (solids)
- overflow trough (solids)
- Measuring cup (grained solids, liquids)
- Flow measurement devices (liquids)
- Graduated cylinder (liquids)
- Pipette (liquids)
- Eudiometer, pneumatic trough (gases)

(if the mass density of a solid is known, weighing allows to calculate the volume)

For the ranges of volume-values see: Orders of magnitude (volume)

Mass- or volume flow measurement

- Gas meter
- Mass flow meter
- Metering pump
- Water meter

Speed (flux of length)

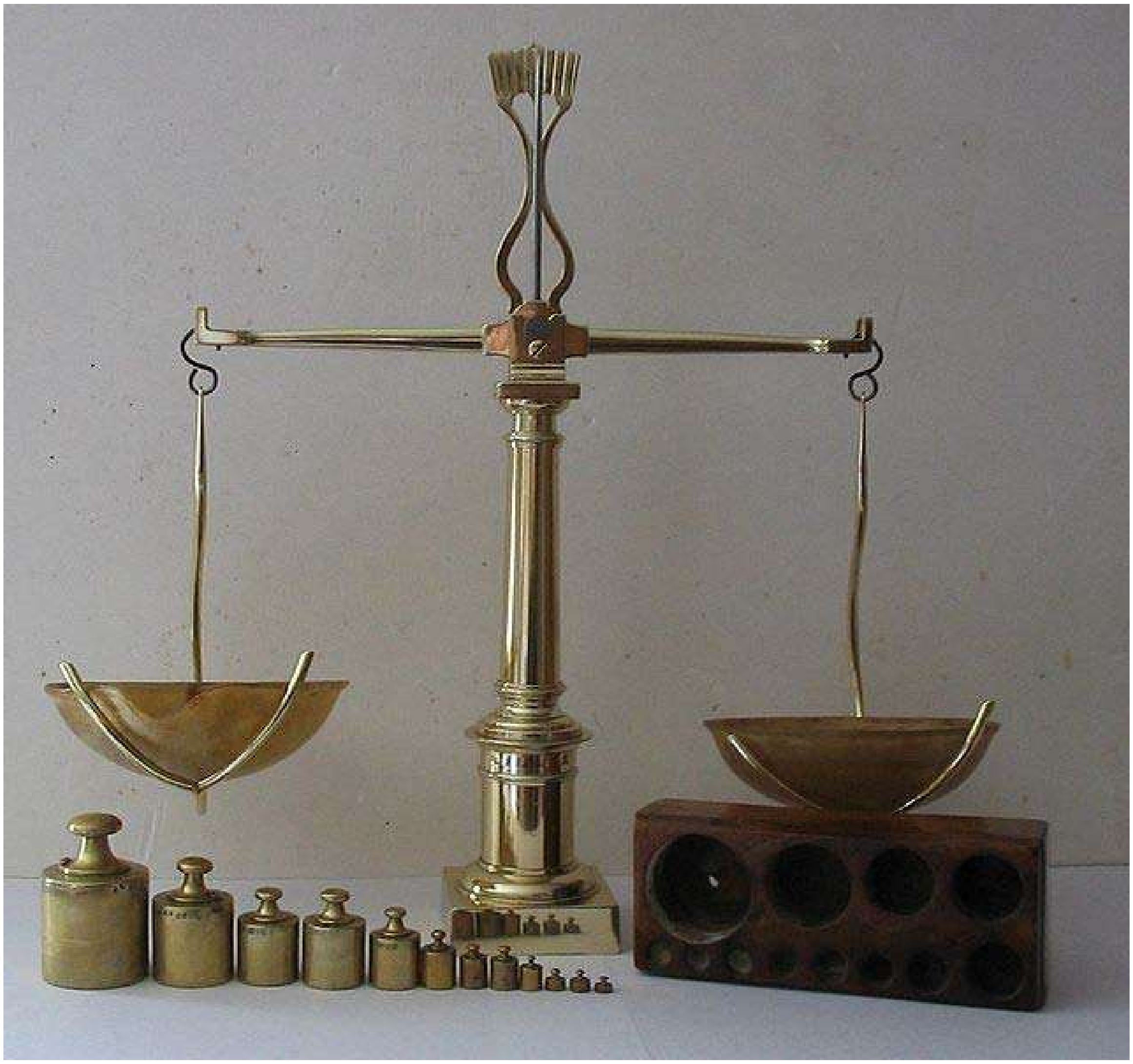
- Airspeed indicator
- Radar gun, a Doppler radar device, using the Doppler effect for indirect measurement of velocity.
- Speedometer
- Tachometer (speed of rotation)
- Tachymeter
- Variometer

For the ranges of speed-values see: Orders of magnitude (speed)

Acceleration

- Accelerometer

Mass



A pair of scales: An instrument for measuring mass in a force field by balancing forces.

- Balance
- Automatic checkweighing machines
- Katharometer
- Weighing scales
- Inertial balance
- Mass spectrometers measure the mass-to-charge ratio, not the mass

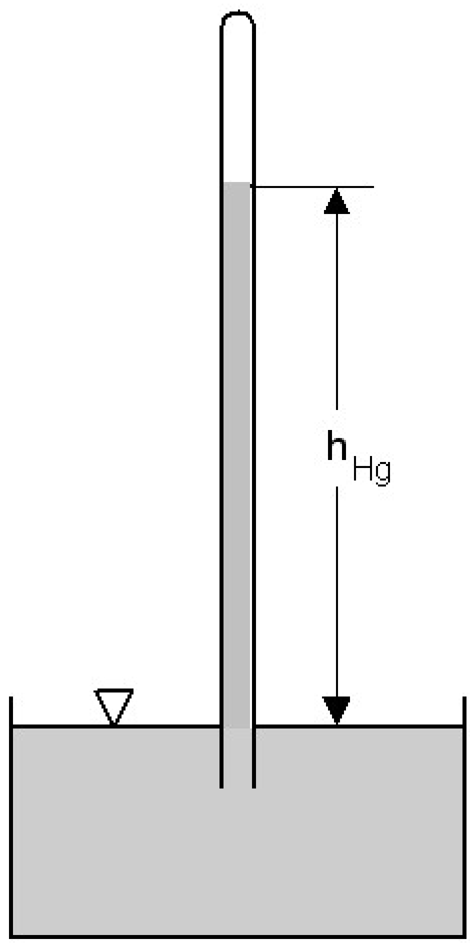
For the ranges of mass-values see: Orders of magnitude (mass)

Linear momentum

- Ballistic pendulum

Force (flux of linear momentum)

- Force gauge
- Spring scale
- Strain gauge
- Torsion balance
- Tribometer



Measuring absolute pressure in an accelerated reference frame: The principle of a mercury (Hg) barometer in the gravitational field of the earth.

Pressure (flux density of linear momentum)

- Anemometer (used to determine wind speed)
- Barometer used to measure the atmospheric pressure.
- Manometer see pressure measurement
- Pitot tube (used to determine speed)
- Tire-pressure gauge in industry and mobility

For the ranges of pressure-values see: Orders of magnitude (pressure)

Timeline of temperature and pressure measurement technology

Angle

- Circumferentor
- Cross staff
- Goniometer
- Graphometer
- Protractor
- Quadrant
- Reflecting instruments
    - Octant
    - Reflecting circles
    - Sextant
- Theodolite

Angular velocity or rotations per time unit

- Stroboscope
- Tachometer

Torque

- Dynamometer
- De Prony brake
- Torque wrench

Orientation in three-dimensional space

Level

- Dumpy level
- Laser line level
- Spirit level
- Tiltmeter

Direction

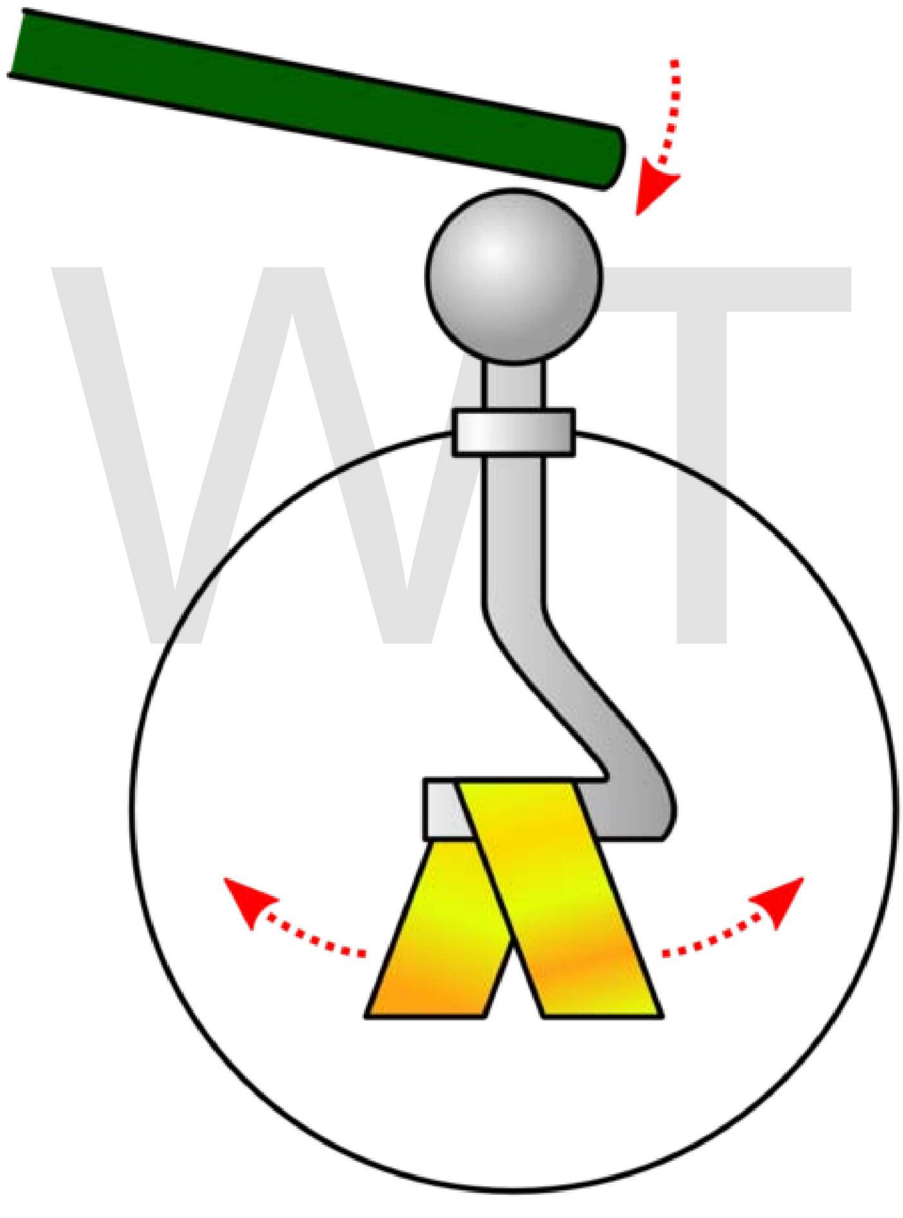
- Gyroscope

Energy carried by mechanical quantities, mechanical work

- Ballistic pendulum, indirectly by calculation and or gauging

Electricity, electronics and electrical engineering

Considerations related to electric charge dominate electricity and electronics. Electrical charges interact via a field. That field is called electric if the charge doesn't move. If the charge moves, thus realizing an electric current, especially in an electrically neutral conductor, that field is called magnetic. Electricity can be given a quality — a potential. And electricity has a substance-like property, the electric charge. Energy (or power) in elementary electrodynamics is calculated by multiplying the potential by the amount of charge (or current) found at that potential: potential times charge (or current).



An instrument for detecting net charges, the electroscope.

Electric charge

- Electrometer is often used to reconfirm the phenomenon of contact electricity leading to triboelectric sequences.
- Torsion balance used by Coulomb to establish a relation between charges and force.

Electric current (current of charge)

- Ammeter
- Clamp meter
- Galvanometer

Voltage (electric potential difference)

- Oscilloscope allows to quantify time depended voltages
- Voltmeter

Electric resistance, electrical conductance (and electrical conductivity)

- Ohmmeter
- Time-domain reflectometer characterizes and locates faults in metallic cables by runtime measurements of electric signals.
- Wheatstone bridge

Electric capacitance

- Capacitance meter

Electric inductance

- Inductance meter

Energy carried by electricity or electric energy

- Electric energy meter
- Electricity meter

Power carried by electricity (current of energy)

- Wattmeter

These are instruments used for measuring electrical properties.

Electric field (negative gradient of electric potential, voltage per length)

- Field mill

Magnetic field

- Compass
- Hall effect sensor
- Magnetometer
- Proton magnetometer
- SQUID

Combination instruments

- Multimeter, combines the functions of ammeter, voltmeter and ohmmeter as a minimum.
- LCR meter, combines the functions of ohmeter, capacitance meter and inductance meter. Also called *component bridge* due to the bridge circuit method of measurement.

Thermodynamics

Temperature-related considerations dominate thermodynamics. There are two distinct thermal properties: A thermal potential — the temperature. For example: A glowing coal has a different thermal quality than a non-glowing one.

And a substance-like property, — the entropy; for example: One glowing coal won't heat a pot of water, but a hundred will.

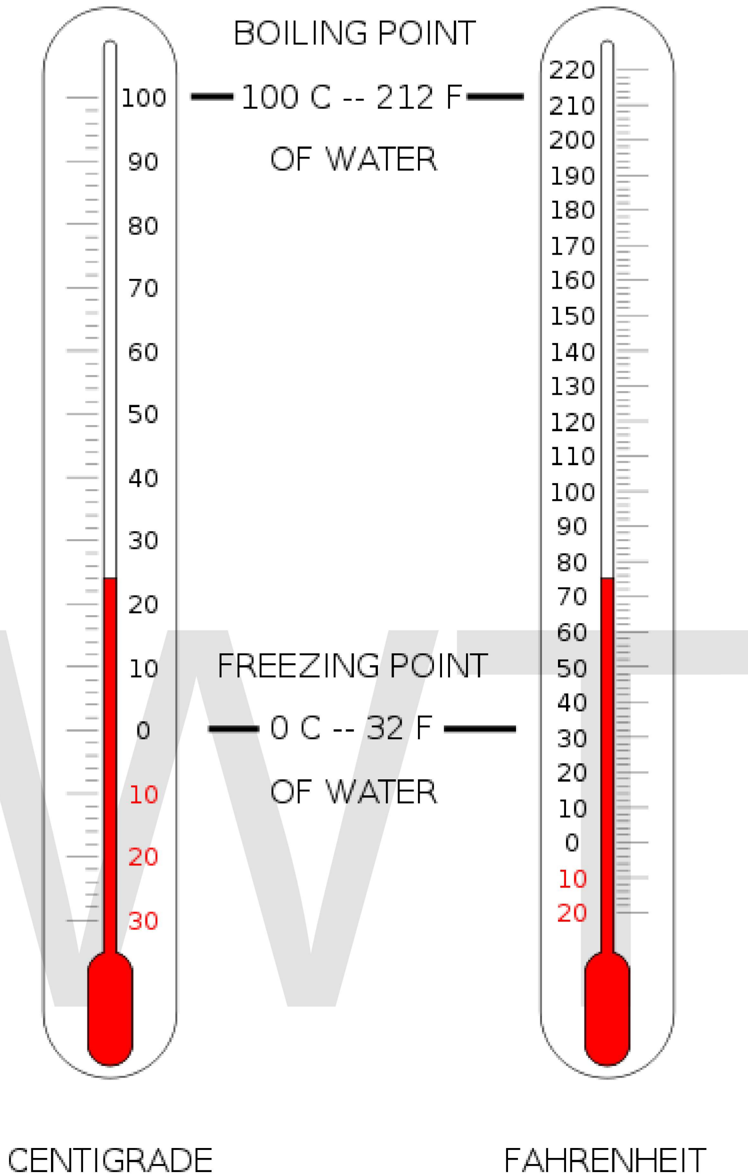
Energy in thermodynamics is calculated by multipying the thermal potential by the amount of entropy found at that potential: temperature times entropy.

Entropy can be created by friction but not annihilated.

Amount of substance (or mole number)

A physical quantity introduced in chemistry; usually determined indirectly. If mass and substance type of the sample are known, then atomic- or molecular masses (taken from a periodic table, masses measured by mass spectrometry) give direct access to the value of the amount of substance. If specific molar values are given, then the amount of substance of a given sample may be determined by measuring volume, mass or concentration.

- Gas collecting tube gases



Thermometer

Temperature

- Electromagnetic spectroscopy
- Galileo thermometer
- Gas thermometer principle: relation between temperature and volume or pressure of a gas (Gas laws).
    - constant pressure gas thermometer
    - constant volume gas thermometer
- Liquid crystal thermometer
- liquid thermometer principle: relation between temperature and volume of a liquid (Coefficient of thermal expansion).

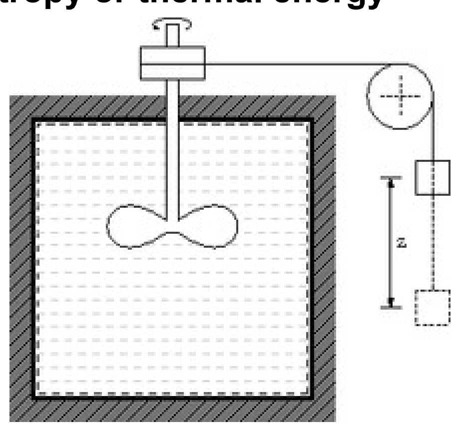
- Alcohol thermometer
- Mercury-in-glass thermometer

- Pyranometer principle: solar radiation flux density relates to surface temperature (Stefan–Boltzmann law)
- Pyrometers principle: temperature dependence of spectral intensity of light (Planck's law), i.e. the color of the light relates to the temperature of its source, range: from about −50 °C to +4000 °C, note: measurement of thermal radiation (instead of thermal conduction, or thermal convection) means: no physical contact becomes necessary in temperature measurement (pyrometry). Also note: thermal space resolution (images) found in Thermography.
- Resistance thermometer principle: relation between temperature and electrical resistance of metals (platinum) (Electrical resistance), range: 10 to 1,000 kelvins, application in physics and industry
- solid thermometer principle: relation between temperature and length of a solid (Coefficient of thermal expansion).
  - Bi-metallic strip
- Thermistors principle: relation between temperature and electrical resistance of ceramics or polymers, range: from about 0.01 to 2,000 kelvins (−273.14 to 1,700 °C)
- Thermocouples principle: relation between temperature and voltage of metal junctions (Seebeck effect), range: from about −200 °C to +1350 °C
- Thermometer
- Thermopile is a set of connected thermocouples
- Triple Point cell used for calibrating thermometers.

Imaging technology

- Thermographic camera uses a microbolometer for detection of heat-radiation.

Energy carried by entropy or thermal energy



An active calorimeter lacking a temperature measurement device.

This includes thermal capacitance or temperature coefficient of energy, reaction energy, heat flow ... Calorimeters are called passive if gauged to measure emerging energy carried by entropy, for example from chemical reactions. Calorimeters are called active or heated if they heat the sample, or reformulated: if they are gauged to fill the sample with a defined amount of entropy.

- Actinometer measures the heating power of radiation.
- constant-temperature calorimeter, phase change calorimeter for example an ice calorimeter or any other calorimeter observing a phase change or using a gauged phase change for heat measurement.
- constant-volume calorimeter, also called bomb calorimeter
- constant-pressure calorimeter, enthalpy-meter or coffee cup calorimeter
- Differential Scanning Calorimeter
- Reaction calorimeter

Entropy

Entropy is accessible indirectly by measurement of energy and temperature.

Entropy transfer

Phase change calorimeter's energy value divided by absolute temperature give the entropy exchanged. Phase changes produce no entropy and therefore offer themselves as an entropy measurement concept. Thus entropy values occur indirectly by processing energy measurements at defined temperatures, without producing entropy.

- constant-temperature calorimeter, phase change calorimeter
- Heat flux sensor uses thermopiles which are connected thermocouples to determine current density or flux of entropy.

Entropy content

The given sample is cooled down to (almost) absolute zero (for example by submerging the sample in liquid helium). At absolute zero temperature any sample is assumed to contain no entropy. Then the following two active calorimeter types can be used to fill the sample with entropy until the desired temperature has been reached:

- constant-pressure calorimeter, enthalpy-meter, active
- constant-temperature calorimeter, phase change calorimeter, active

Entropy production

Processes transferring energy from a non-thermal carrier to heat as a carrier do produce entropy (Example: mechanical/electrical friction, established by Count Rumford). Either the produced entropy or heat are measured (calorimetry) or the transferred energy of the non-thermal carrier may be measured.

- calorimeter

- (any device for measuring the work which will or would eventually be converted to heat and the ambient temperature)

Entropy lowering its temperature—without losing energy—produces entropy (Example: Heat conduction in an isolated rod; "thermal friction").

- calorimeter

temperature coefficient of energy or "heat capacity"

Concerning a given sample, a proportionality factor relating temperature change and energy carried by heat. If the sample is a gas, then this coefficient depends significantly on being measured at constant volume or at constant pressure. (The terminiology preference in the heading indicates that the classical use of heat bars it from having substance-like properties.)

- constant-volume calorimeter, bomb calorimeter
- constant-pressure calorimeter, enthalpy-meter

specific temperature coefficient of energy or "specific heat"

The temperature coefficient of energy divided by a substance-like quantity (amount of substance, mass, volume) describing the sample. Usually calculated from measurements by a division or could be measured directly using a unit amount of that sample.

Coefficient of thermal expansion

- Dilatometer
- Strain gauge

Melting temperature (of a solid)

- Thiele tube
- Kofler bench
- Differential Scanning Calorimeter gives melting point and enthalpy of fusion.

Boiling temperature (of a liquid)

- Ebullioscope a device for measuring the boiling point of a liquid. This device is also part of a method that uses the effect of boiling point elevation for calculating the molecular mass of a solvent.

More on continuum mechanics

This includes mostly instruments which measure macroscopic properties of matter: In the fields of solid state physics; in condensed matter physics which considers solids, liquids and in-betweens exhibiting for example viscoelastic behavior. Furthermore fluid mechanics, where liquids, gases, plasmas and in-betweens like supercritical fluids are studied.

Density

This refers to particle density of fluids and compact(ed) solids like crystals, in contrast to bulk density of grainy or porous solids.

- Aerometer liquids
- Dasymeter gases
- Gas collecting tube gases
- Hydrometer liquids
- Pycnometer liquids
- resonant frequency and Damping Analyser (RFDA) solids

Hardness of a solid

- Durometer

Shape and surface of a solid

- Holographic interferometer
- Laser produced speckle pattern analysed.
- resonant frequency and Damping Analyser (RFDA)
- Tribometer

Deformation of condensed matter

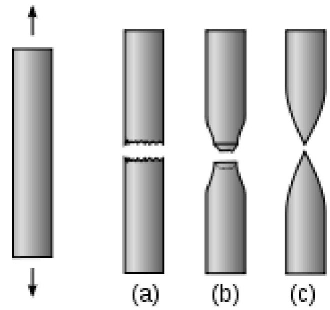
- Strain gauge all below

Elasticity of a solid (Elastic moduli)

- resonant frequency and Damping Analyser (RFDA), using the impulse excitation technique: A small mechanical impulse causes the sample to vibrate. The vibration depends on elastic properties, density, geometry and inner structures (lattice or fissures).

Plasticity of a solid

- Cam plastometer
- Plastometer



Measurement results (a) brittle (b) ductile with breaking point (c) ductile without breaking point.

Tensile strength, ductility or malleability of a solid

- Universal Testing Machine

Granularity of a solid or of a suspension

- Grindometer

Viscosity of a fluid

- Rheometer
- Viscometer

Optical activity

- Polarimeter

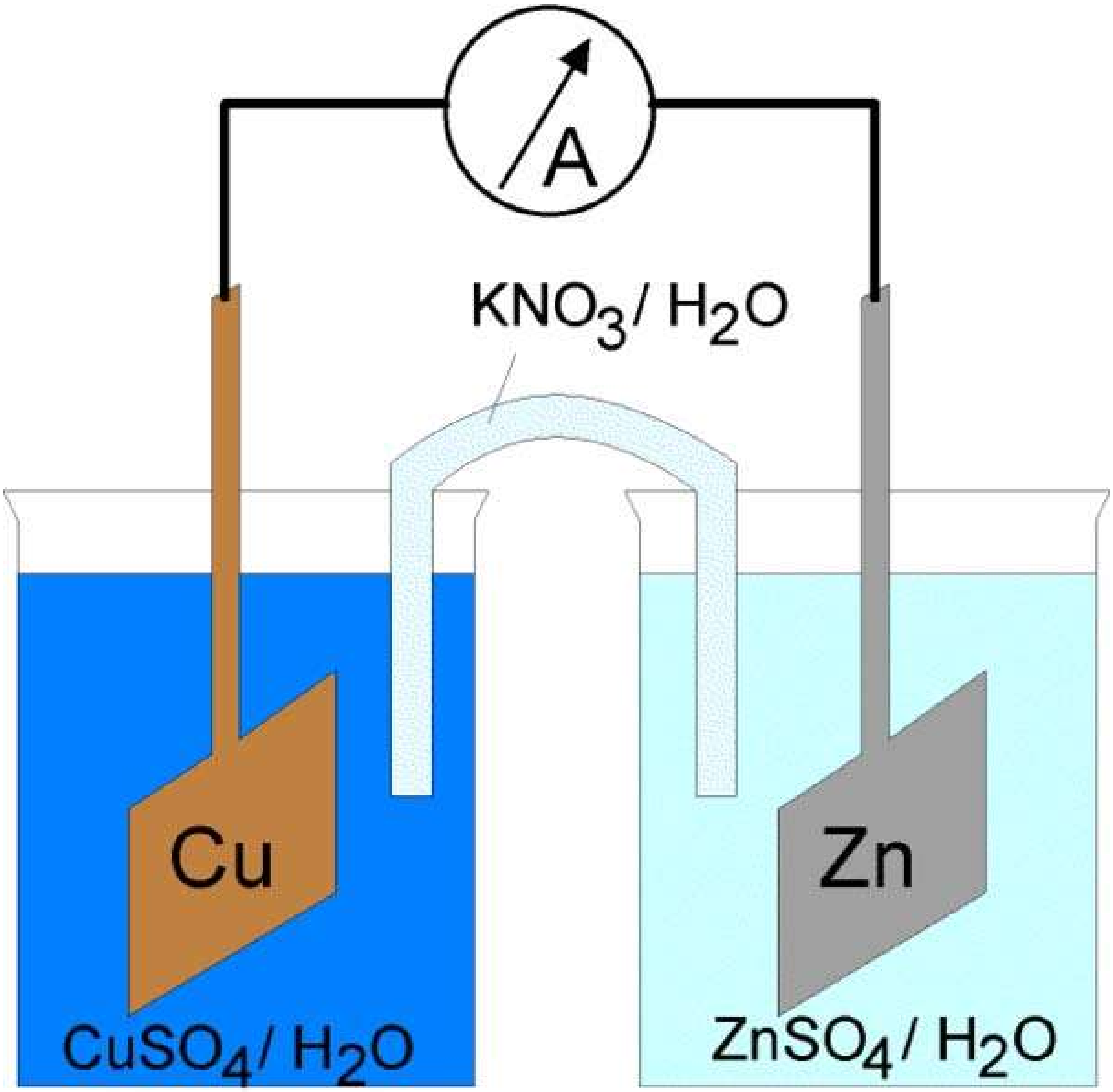
Surface tension of liquids

- Tensiometer

Imaging technology

- Tomograph, device and method for non-destructive analysis of multiple measurements done on a geometric object, for producing 2- or 3-dimensional images, representing the inner structure of that geometric object.
- Wind tunnel

More on electric properties of condensed matter, gas



The electrochemical cell: A device for measuring substance potentials.

Permittivity, relative static permittivity, (dielectric constant) or electric susceptibility

- Capacitor

Such measurements also allow to access values of molecular dipoles.

Magnetic susceptibility or magnetization

- Gouy balance

Substance potential or chemical potential or molar Gibbs energy

Phase conversions like changes of aggregate state, chemical reactions or nuclear reactions transmuting substances, from reactants to products, or diffusion through membranes have an overall energy balance. Especially at constant pressure and constant temperature molar energy balances define the notion of a substance potential or chemical potential or molar Gibbs energy, which gives the energetic information about whether the process is possible or not - in a closed system.

Energy balances that include entropy consist of two parts: A balance that accounts for the changed entropy content of the substances. And another one that accounts for the energy freed or taken by that reaction itself, the Gibbs energy change. The sum of reaction energy and energy associated to the change of entropy content is also called enthalpy. Often the whole enthalpy is carried by entropy and thus measurable calorimetrically.

For standard conditions in chemical reactions either molar entropy content and molar Gibbs energy with respect to some chosen zero point are tabulated. Or molar entropy content and molar enthalpy with respect to some chosen zero are tabulated.

The substance potential of a redox reaction is usually determined electrochemically current-free using reversible cells.

- Redox electrode

Other values may be determined indirectly by calorimetry. Also by analyzing phase-diagrams.

Sub-microstructural properties of condensed matter, gas

- Infrared spectroscopy
- Neutron detector
- Radio frequency spectrometers for Nuclear magnetic resonance and for Electron paramagnetic resonance
- Raman spectroscopy

Crystal structure

- An X-ray tube, a sample scattering the X-rays and a photographic plate to detect them. This constellation forms the scattering instrument used by X-ray crystallography for investigating crystal structures of samples. Amorphous solids lack a distinct pattern and are identifyable thereby.

Imaging technology, Microscope

- Electron microscope
    - Transmission electron microscope

- Optical microscope uses reflectiveness or refractiveness of light to produce an image.
- Scanning acoustic microscope
- Scanning probe microscope
    - Atomic force microscope (AFM)
    - Scanning electron microscope
    - Scanning tunneling microscope (STM)
- Focus variation
- X-ray microscope

Rays ("waves" and "particles")

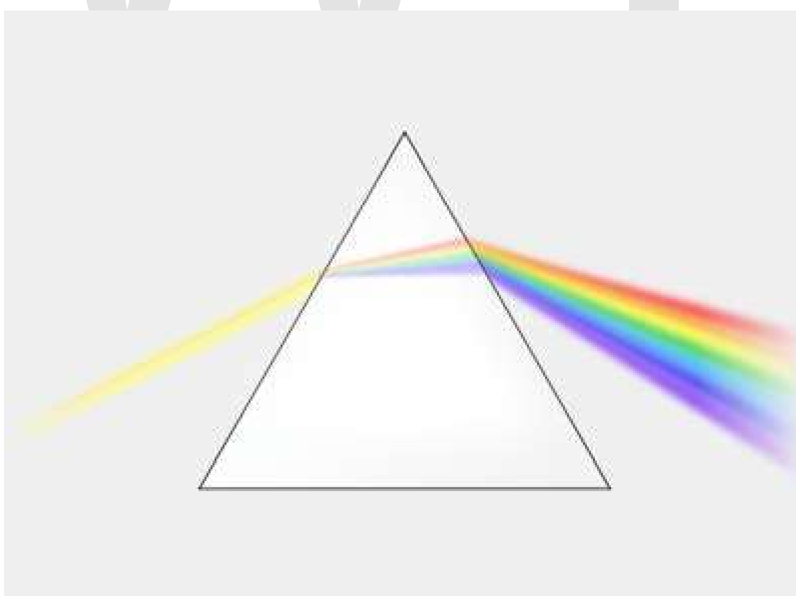
Sound, compression waves in matter

Microphones in general, sometimes their sensitivity is increased by the reflection- and concentration principle realized in acoustic mirrors.

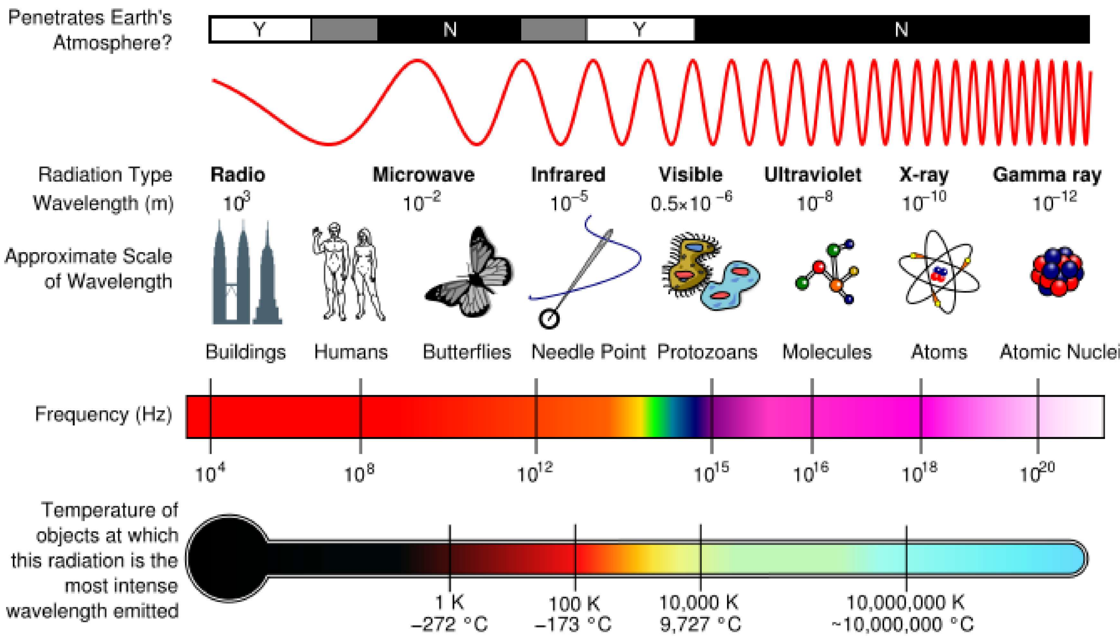
- Laser microphone
- Seismometer

Sound pressure

- microphone or hydrophone properly gauged
- Shock tube
- Sound level meter



A device for unmixing sun-light: the prism.



The electromagnetic spectrum

Light and radiation without a rest mass, non-ionizing

- Antenna (radio)
- bolometer measuring the energy of incident electromagnetic radiation.
- camera
- EMF meter
- Interferometer used in the wide field of Interferometry
- Optical power meter
- Microwave power meter
- Photographic plate
- Photomultiplier
- Phototube
- Radio telescope
- Spectrometer
- T-ray detectors

Photon polarization

- Polarizer

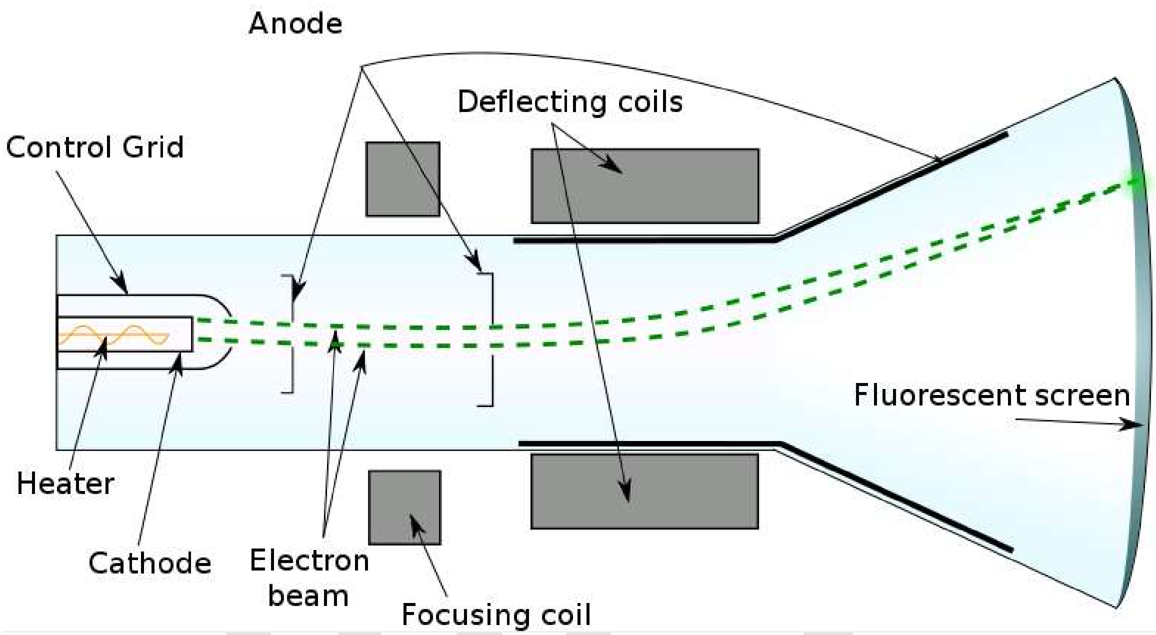
Pressure (current density of linear momentum)

- Nichols radiometer

radiant flux

The measure of the total power of light emitted.

- Integrating sphere for measuring the total radiant flux of a light source



A Cathode ray tube.

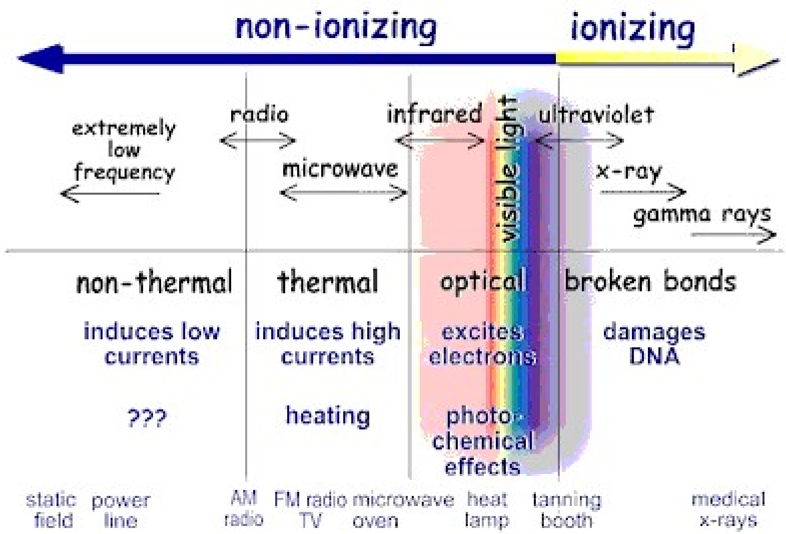
Radiation with a rest mass, particle radiation

Cathode ray

- Crookes tube
- Cathode ray tube, a phosphor coated anode

Atom polarization and electron polarization

- Stern-Gerlach experiment



Another visualization of the electromagnetic spectrum.

Ionizing radiation

Ionizing radiation includes rays of "particles" as well as rays of "waves". Especially X-rays and Gamma rays transfer enough energy in non-thermal, (single) collision processes to separate electron(s) from an atom.

A cloud chamber detecting alpha-rays.

particle flux

- Bubble chamber
- Cloud chamber
- Dosimeter, a technical device realizes different working principles.
- Geiger counter
- Microchannel plate detector
- Photographic plate
- Photostimulable phosphors
- Scintillation counter, Lucas cell
- Semiconductor detector

Identification and content

This could include chemical substances, rays of any kind, elementary particles, quasiparticles. Many measurement devices outside here may be used or at least become part of an identification process. For identification and content concerning chemical substances.

Substance content in mixtures, substance identification

- Carbon dioxide sensor
- chromatographic device, gas chromatograph separates mixtures of substances. Different velocites of the substance types accomplish the separation.
- Colorimeter (measures absorbance, and thus concentration)
- gas detector
- Gas detector in combination with mass spectrometer,
- mass spectrometer identifies the chemical composition of a sample on the basis of the mass-to-charge ratio of charged particles.
- Nephelometer or turbidimeter
- oxygen sensor (= lambda sond)
- Refractometer, indirectly by determining the refractive index of a substance.
- Smoke detector
- Ultracentrifuge, separates mixtures of substances. In a force field of a centrifuge, substances of different densities separate.

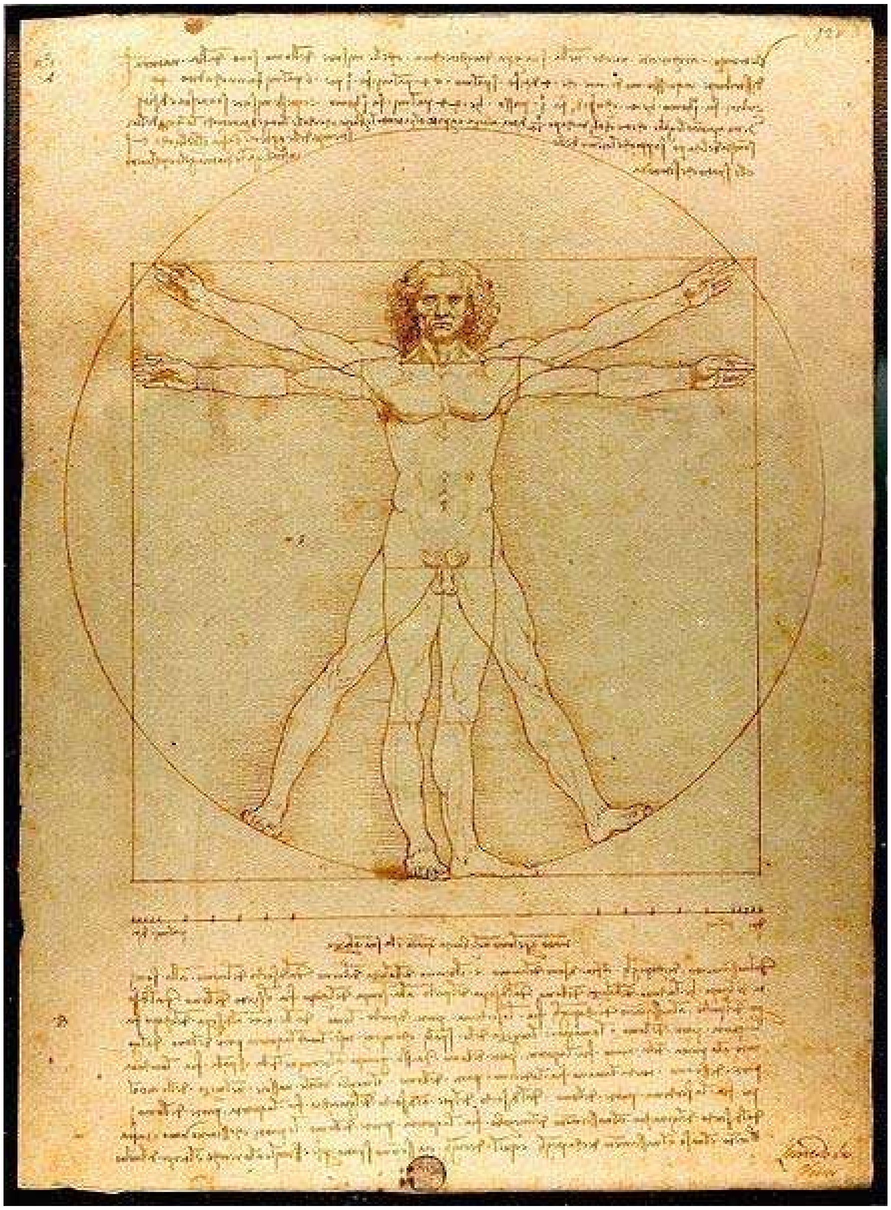
pH: Concentration of protons in a solution

- pH meter
- Saturated calomel electrode

Humidity

- Hygrometer measures the density of water in air
- Lysimeter measures the balance of water in soil

Human senses and human body



Vitruvian Man by Leonardo da Vinci, Gallerie dell'Accademia, Venice (1485-90)

Sight

Luminuos flux, photometry

A measure of the perceived power of light, luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light.

- Integrating sphere for measuring the total luminuos flux of a light source

illuminance, photometry

- Densitometer
- Light meter
- Lux meter
- Photometer

Hearing

Loudness in phon

- Headphone, loudspeaker, sound pressure gauged, for measuring an equal-loudness contour of a human ear.
- Sound level meter calibrated to a equal-loudness contour of the human auditory system behind the human ear.

Smell

- Olfactometer

Temperature (sense and body)

Body temperature or Core temperature

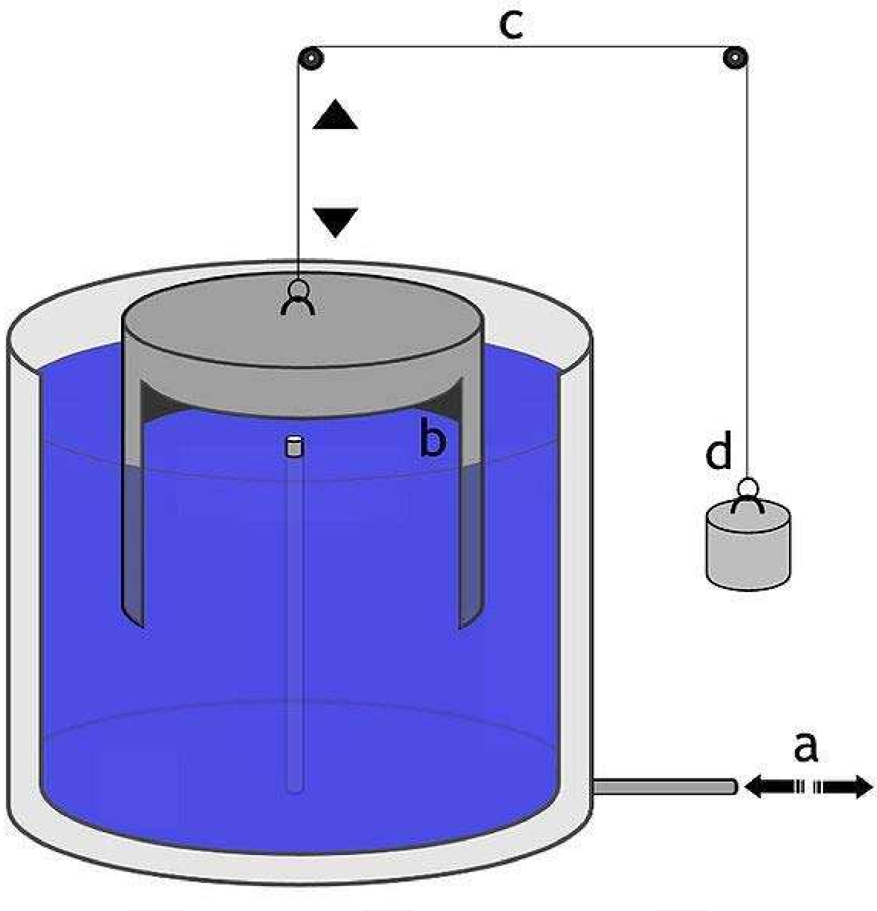
- Medical thermometer

circulatory system (mainly heart and blood vessels for distributing substances fast)

Blood-related parameters are listed in a blood test.

- Electrocardiograph records the electrical activity of the heart
- Glucose meter for obtaining the status of blood sugar.
- Sphygmomanometer, a blood pressure meter used to determine blood pressure in medicine.

Respiratory system (lung and airways controlling the breathing process)



A spirometer, inhaling into pipe a fills volume b, the rest balances forces.

- Spirometer

concentration or partial pressure of carbon dioxide in the respiratory gases

- Capnograph

nervous system (nerves transmitting and processing information electrically)

- Electroencephalograph records the electrical activity of the brain

musculoskeletal system (muscles and bones for movement)

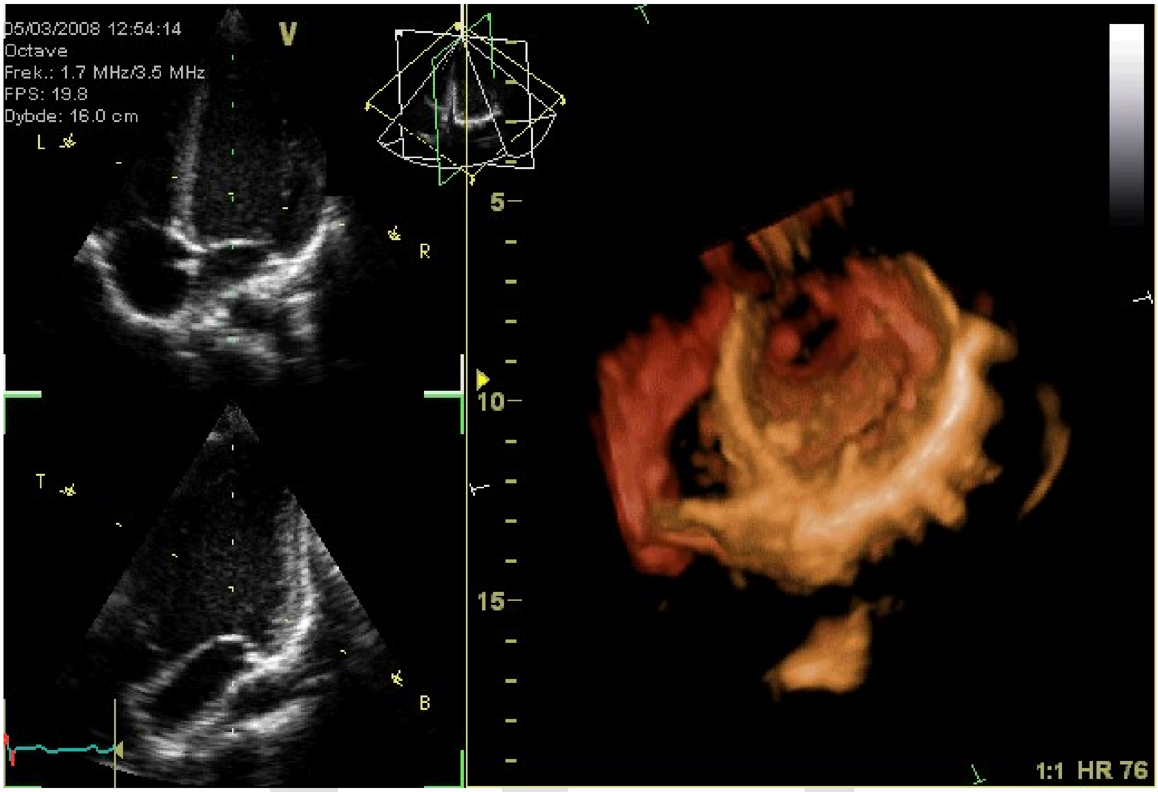
power, work of muscles

- Ergometer

metabolic system

- Body fat meter

Medical imaging



An echocardiogram processed into a three dimensional representation.

- Computed tomography
- Magnetic resonance imaging
- Medical ultrasonography
- Radiology
- Tomograph, device and method for non-destructive analysis of multiple measurements done on a geometric object, for producing 2- or 3-dimensional images, representing the inner structure of that geometric object.

Astronomy

- Radio antenna
- Telescope

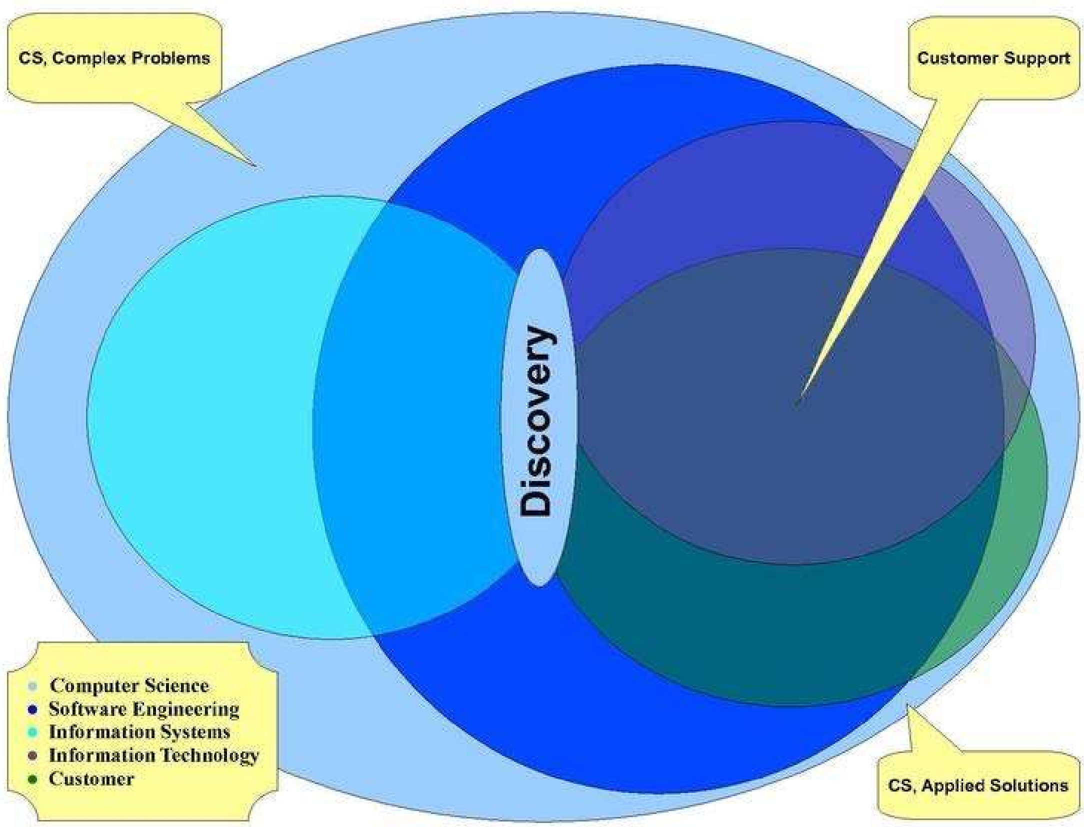
Military

Some instruments, such as telescopes and sea navigation instruments, have had military applications for many centuries. However, the role of instruments in military affairs rose exponentially with the development of technology via applied science, which began in the mid-19th century and has continued through the present day. Military instruments as a class draw on most of the categories of instrument described throughout here, such as navigation, astronomy, optics and imaging, and the kinetics of moving objects. Common abstract themes that unite military instruments are seeing into the distance, seeing in the dark, knowing an object's geographic location, and knowing and controlling a moving object's path and destination.

Special features of these instruments may include ease of use, speed, reliability and accuracy; nevertheless additionally one might hope seeing them as instruments whose existence, not use, ultimately helps in establishing a humane and humanistic peace between individual humans as well as groups of them.

Chapter-9

Information Systems



CS, SE, IS, IT, & Customer Venn Diagram where functionality spans left and design spans right stemming from discovery.

Information Systems (IS) is an academic/professional discipline bridging the business field and the well-defined computer science field that is evolving toward a new scientific area of study. An information systems discipline therefore is supported by the theoretical foundations of information and computations such that learned scholars have unique opportunities to explore the academics of various business models as well as related algorithmic processes within a computer science discipline. Typically, information systems or the more common *legacy* information systems include people, procedures, data, software, and hardware (by degree) that are used to gather and analyze digital information. Specifically computer-based information systems are complementary networks of hardware/software that people and organizations use to collect, filter, process, create, & distribute data (computing). *Computer* Information System(s) (CIS) is often a track within the computer science field studying computers and algorithmic processes, including their principles, their software & hardware designs, their applications, and their impact on society. Overall, an IS discipline emphasizes functionality over design.

As illustrated by the Venn Diagram on the right, the history of **information systems** coincides with the history of computer science that began long before the modern discipline of computer science emerged in the twentieth century. Regarding the circulation of information and ideas, numerous legacy information systems still exist today that are continuously updated to promote ethnographic approaches, to ensure data integrity, and to improve the social effectiveness & efficiency of the whole process. In general, information systems are focused upon processing information within organizations, especially within business enterprises, and sharing the benefits with modern society.

Overview

Silver et al. (1995) provided two views on (IS) and IS-centered view that includes software, hardware, data, people, and procedures. A second managerial view includes people, business processes and Information Systems.

There are various types of information systems, for example: transaction processing systems, office systems, decision support systems, knowledge management systems, database management systems, and office information systems. Critical to most information systems are information technologies, which are typically designed to enable humans to perform tasks for which the human brain is not well suited, such as: handling large amounts of information, performing complex calculations, and controlling many simultaneous processes.

Information technologies are a very important and malleable resource available to executives. Many companies have created a position of Chief Information Officer (CIO) that sits on the executive board with the Chief Executive Officer (CEO), Chief Financial Officer (CFO), Chief Operating Officer (COO) and Chief Technical Officer (CTO).The CTO may also serve as CIO, and vice versa. The Chief Information Security Officer (CISO), who focuses on information security management.

Definition

Silver et al. defined Information Systems as follows:

Information systems are implemented within an organization for the purpose of improving the effectiveness and efficiency of that organization. Capabilities of the information system and characteristics of the organization, its work systems, its people, and its development and implementation methodologies together determine the extent to which that purpose is achieved

The Discipline of Information Systems

Several IS scholars have debated the nature and foundations of Information Systems which has its roots in other reference disciplines such as Computer Science, Engineering, Mathematics, Management Science, Cybernetics, and others

The Impact on Economic Models

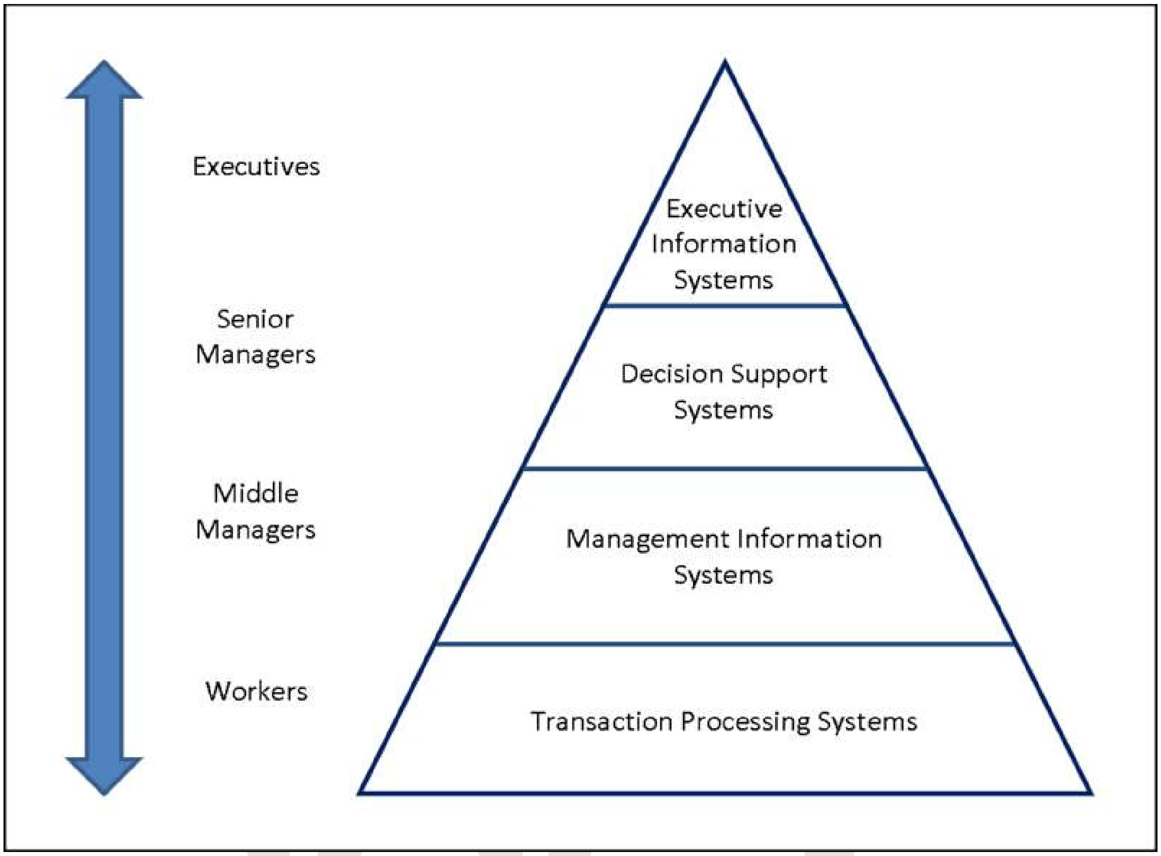
- Microeconomic theory model
- Transaction Cost theory
- Agency Theory

Differentiating IS from Related Disciplines

Similar to computer science, other disciplines can be seen as both related disciplines and foundation disciplines of IS. But, while there may be considerable overlap of the disciplines at the boundaries, the disciplines are still differentiated by the focus, purpose and orientation of their activities.

In a broad scope, the term **Information Systems** (IS) is a scientific field of study that addresses the range of strategic, managerial and operational activities involved in the gathering, processing, storing, distributing and use of information, and its associated technologies, in society and organizations. The term information systems is also used to describe an organizational function that applies IS knowledge in industry, government agencies and not-for-profit organizations. ***Information Systems*** often refers to the interaction between algorithmic processes and technology. This interaction can occur within or across organizational boundaries. An information system is not only the technology an organization uses, but also the way in which the organizations interact with the technology and the way in which the technology works with the organization's business processes. Information systems are distinct from information technology (IT) in that an information system has an information technology component that interacts with the processes components.

Types of information systems



A four level pyramid model of different types of Information Systems based on the different levels of hierarchy in an organization

The 'classic' view of Information systems found in the textbooks of the 1980s was of a pyramid of systems that reflected the hierarchy of the organization, usually Transaction processing systems at the bottom of the pyramid, followed by Management information systems, Decision support systems and ending with Executive information systems at the top. Although the pyramid model remains useful, since it was first formulated a number of new technologies have been developed and new categories of information systems have emerged, some of which no longer fit easily into the original pyramid model.

Some examples of such systems are:

- Data warehouses
- Enterprise resource planning
- Enterprise systems
- Expert systems
- Geographic information system
- Global information system
- Office Automation

Information systems career pathways

Information Systems have a number of different areas of work:

- Information systems strategy
- Information systems management
- Information systems development
- Information systems security
- Information systems iteration
- Information system organization

There are a wide variety of career paths in the information systems discipline. "Workers with specialized technical knowledge and strong communications skills will have the best prospects. Workers with management skills and an understanding of business practices and principles will have excellent opportunities, as companies are increasingly looking to technology to drive their revenue."

Information systems development

Information technology departments in larger organizations tend to strongly influence information technology development, use, and application in the organizations, which may be a business or corporation. A series of methodologies and processes can be used in order to develop and use an information system. Many developers have turned and used a more engineering approach such as the System Development Life Cycle (SDLC) which is a systematic procedure of developing an information system through stages that occur in sequence. An Information system can be developed in house (within the organization) or outsourced. This can be accomplished by outsourcing certain components or the entire system. A specific case is the geographical distribution of the development team (Offshoring, Global Information System).

A computer based information system, following a definition of Langefors, is:

- a technologically implemented medium for recording, storing, and disseminating linguistic expressions,
- as well as for drawing conclusions from such expressions.

which can be formulated as a generalized information systems design mathematical program

Geographic Information Systems, Land Information systems and Disaster Information Systems are also some of the emerging information systems but they can be broadly considered as Spatial Information Systems. System development is done in stages which include:

- Problem recognition and specification
- Information gathering

- Requirements specification for the new system
- System design
- System construction
- System implementation
- Review and maintenance

Information systems research

Information systems research is generally interdisciplinary concerned with the study of the effects of information systems on the behavior of individuals, groups, and organizations. Hevner et al. (2004) categorized research in IS into two scientific paradigms including *behavioral science* which is to develop and verify theories that explain or predict human or organizational behavior and *design science* which extends the boundaries of human and organizational capabilities by creating new and innovative artifacts.

Salvatore March and Gerald Smith proposed a framework for researching different aspects of Information Technology including outputs of the research (research outputs) and activities to carry out this research (research activities). They identified research outputs as follows:

1. *Constructs* which are concepts that form the vocabulary of a domain. They constitute a conceptualization used to describe problems within the domain and to specify their solutions.
2. A *model* which is a set of propositions or statements expressing relationships among constructs.
3. A *method* which is a set of steps (an algorithm or guideline) used to perform a task. Methods are based on a set of underlying constructs and a representation (model) of the solution space.
4. An *instantiation* is the realization of an artifact in its environment.

Also research activities including:

1. *Build* an artifact to perform a specific task.
2. *Evaluate* the artifact to determine if any progress has been achieved.
3. Given an artifact whose performance has been evaluated, it is important to determine why and how the artifact worked or did not work within its environment. Therefore *theorize* and *justify* theories about IT artifacts.

Although Information Systems as a discipline has been evolving for over 30 years now, the core focus or identity of IS research is still subject to debate among scholars such as. There are two main views around this debate: a narrow view focusing on the IT artifact as the core subject matter of IS research, and a broad view that focuses on the interplay between social and technical aspects of IT that is embedded into a dynamic evolving context. A third view provided by calling IS scholars to take a balanced attention for both the IT artifact and its context.

Since information systems is an applied field, industry practitioners expect information systems research to generate findings that are immediately applicable in practice. However, that is not always the case. Often information systems researchers explore behavioral issues in much more depth than practitioners would expect them to do. This may render information systems research results difficult to understand, and has led to criticism.

To study an information system itself, rather than its effects, information systems models are used, such as EATPUT.

The international body of Information Systems researchers, the Association for Information Systems (AIS), and its Senior Scholars Forum Subcommittee on Journals (23 April 2007), proposed a 'basket' of journals that the AIS deems as 'excellent', and nominated: Management Information Systems Quarterly (MISQ), Information Systems Research (ISR), Journal of Association of Information Systems (JAIS), Journal of Management Information Systems (JMIS), European Journal of Information Systems (EJIS), and Information Systems Journal (ISJ).

Chapter-10

Control Engineering

Control systems play a critical role in space flight

Control engineering or **Control systems engineering** is the engineering discipline that applies control theory to design systems with predictable behaviors. The practice uses sensors to measure the output performance of the device being controlled (often a vehicle) and those measurements can be used to give feedback to the input actuators that can make corrections toward desired performance. When a device is designed to perform without the need of human inputs for correction it is called automatic control (such as cruise control for regulating a car's speed). Multi-disciplinary in nature, control systems engineering activities focus on implementation of control systems mainly derived by mathematical modeling of systems of a diverse range.

Overview

Modern day control engineering (also called control systems engineering) is a relatively new field of study that gained a significant attention during 20th century with the advancement in technology. It can be broadly defined as practical application of control theory. Control engineering has an essential role in a wide range of control systems, from simple household washing machines to high-performance F-16 fighter aircraft. It seeks to understand physical systems, using mathematical modeling, in terms of inputs, outputs and various components with different behaviors; use control systems design tools to develop controllers for those systems; and implement controllers in physical systems employing available technology. A system can be mechanical, electrical, fluid, chemical, financial and even biological, and the mathematical modeling, analysis and controller design uses control theory in one or many of the time, frequency and complex-s domains, depending on the nature of the design problem.

History

Automatic control Systems were first developed over two thousand years ago. The first feedback control device on record is thought to be the ancient water clock of Ktesibios in Alexandria Egypt around the third century B.C. It kept time by regulating the water level in a vessel and, therefore, the water flow from that vessel. This certainly was a successful device as water clocks of similar design were still being made in Baghdad when the Mongols captured the city in 1258 A.D. A variety of automatic devices have been used over the centuries to accomplish useful tasks or simply to just entertain. The latter includes the automata, popular in Europe in the 17th and 18th centuries, featuring dancing figures that would repeat the same task over and over again; these automata are examples of open-loop control. Milestones among feedback, or "closed-loop" automatic control devices, include the temperature regulator of a furnace attributed to Drebbel, circa 1620, and the centrifugal flyball governor used for regulating the speed of steam engines by James Watt in 1788.

In his 1868 paper "On Governors", J. C. Maxwell (who discovered the Maxwell electromagnetic field equations) was able to explain instabilities exhibited by the flyball governor using differential equations to describe the control system. This demonstrated the importance and usefulness of mathematical models and methods in understanding complex phenomena, and signaled the beginning of mathematical control and systems theory. Elements of control theory had appeared earlier but not as dramatically and convincingly as in Maxwell's analysis.

Control theory made significant strides in the next 100 years. New mathematical techniques made it possible to control, more accurately, significantly more complex dynamical systems than the original flyball governor. These techniques include developments in optimal control in the 1950s and 1960s, followed by progress in stochastic, robust, adaptive and optimal control methods in the 1970s and 1980s. Applications of control methodology have helped make possible space travel and communication satellites, safer and more efficient aircraft, cleaner auto engines, cleaner and more efficient chemical processes, to mention but a few.

Before it emerged as a unique discipline, control engineering was practiced as a part of mechanical engineering and control theory was studied as a part of electrical engineering, since electrical circuits can often be easily described using control theory techniques. In the very first control relationships, a current output was represented with a voltage control input. However, not having proper technology to implement electrical control systems, designers left with the option of less efficient and slow responding mechanical systems. A very effective mechanical controller that is still widely used in some hydro plants is the governor. Later on, previous to modern power electronics, process control systems for industrial applications were devised by mechanical engineers using pneumatic and hydraulic control devices, many of which are still in use today.

Control theory

There are two major divisions in control theory, namely, classical and modern, which have direct implications over the control engineering applications. The scope of classical control theory is limited to single-input and single-output (SISO) system design. The system analysis is carried out in time domain using differential equations, in complex-s domain with Laplace transform or in frequency domain by transforming from the complex-s domain. All systems are assumed to be second order and single variable, and higher-order system responses and multivariable effects are ignored. A controller designed using classical theory usually requires on-site tuning due to design approximations. Yet, due to easier physical implementation of classical controller designs as compared to systems designed using modern control theory, these controllers are preferred in most industrial applications. The most common controllers designed using classical control theory are PID controllers.

In contrast, modern control theory is carried out strictly in the complex-s or the frequency domain, and can deal with multi-input and multi-output (MIMO) systems. This overcomes the limitations of classical control theory in more sophisticated design problems, such as fighter aircraft control. In modern design, a system is represented as a set of first order differential equations defined using state variables. Nonlinear, multivariable, adaptive and robust control theories come under this division. Being fairly new, modern control theory has many areas yet to be explored. Scholars like Rudolf E.

Kalman and Aleksandr Lyapunov are well-known among the people who have shaped modern control theory.

Control systems

Control engineering is the engineering discipline that focuses on the modeling of a diverse range of dynamic systems (e.g. mechanical systems) and the design of controllers that will cause these systems to behave in the desired manner. Although such controllers need not be electrical many are and hence control engineering is often viewed as a subfield of electrical engineering. However, the falling price of microprocessors is making the actual implementation of a control system essentially trivial. As a result, focus is shifting back to the mechanical engineering discipline, as intimate knowledge of the physical system being controlled is often desired.

Electrical circuits, digital signal processors and microcontrollers can all be used to implement Control systems. Control engineering has a wide range of applications from the flight and propulsion systems of commercial airliners to the cruise control present in many modern automobiles.

In most of the cases, control engineers utilize feedback when designing control systems. This is often accomplished using a PID controller system. For example, in an automobile with cruise control the vehicle's speed is continuously monitored and fed back to the system which adjusts the motor's torque accordingly. Where there is regular feedback, control theory can be used to determine how the system responds to such feedback. In practically all such systems stability is important and control theory can help ensure stability is achieved.

Although feedback is an important aspect of control engineering, control engineers may also work on the control of systems without feedback. This is known as open loop control. A classic example of open loop control is a washing machine that runs through a pre-determined cycle without the use of sensors.

Control engineering education

At many universities, control engineering courses are taught in Electrical and Electronic Engineering, Mechatronics Engineering, Mechanical engineering, and Aerospace engineering; in others it is connected to computer science, as most control techniques today are implemented through computers, often as Embedded systems (as in the automotive field). The field of control within chemical engineering is often known as process control. It deals primarily with the control of variables in a chemical process in a plant. It is taught as part of the undergraduate curriculum of any chemical engineering program, and employs many of the same principles in control engineering. Other engineering disciplines also overlap with control engineering, as it can be applied to any system for which a suitable model can be derived.

Control engineering has diversified applications that include science, finance management, and even human behavior. Students of control engineering may start with a linear control system course dealing with the time and complex-s domain, which requires a thorough background in elementary mathematics and Laplace transform (called classical control theory). In linear control, the student does frequency and time domain analysis. Digital control and nonlinear control courses require z transformation and algebra respectively, and could be said to complete a basic control education. From here onwards there are several sub branches.

Recent advancement

Originally, control engineering was all about continuous systems. Development of computer control tools posed a requirement of discrete control system engineering because the communications between the computer-based digital controller and the physical system are governed by a computer clock. The equivalent to Laplace transform in the discrete domain is the z-transform. Today many of the control systems are computer controlled and they consist of both digital and analog components.

Therefore, at the design stage either digital components are mapped into the continuous domain and the design is carried out in the continuous domain, or analog components are mapped in to discrete domain and design is carried out there. The first of these two methods is more commonly encountered in practice because many industrial systems have many continuous systems components, including mechanical, fluid, biological and analog electrical components, with a few digital controllers.

Similarly, the design technique has progressed from paper-and-ruler based manual design to computer-aided design, and now to computer-automated design (CAutoD), which has been made possible by evolutionary computation. CAutoD can be applied not just to tuning a predefined control scheme, but also to controller structure optimisation, system identification and invention of novel control systems, based purely upon a performance requirement, independent of any specific control scheme.