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ACCESS TO COMMUNICATIONS TECHNOLOGY

ABSTRACT

Early proponents of digital communications technology believed that it would be a powerful tool for disseminating knowledge and advancing civilization. While there is little dispute that the Internet has changed society radically in a relatively short period of time, there are many still unable to take advantage of the benefits it confers because of a lack of access. Whether the lack is due to economic, geographic, or demographic factors, this “digital divide” has serious societal repercussions, particularly as most aspects of life in the twenty-first century, including banking, health care, and education, are increasingly conducted online.

DIGITAL DIVIDE

In its simplest terms, the digital divide refers to the gap between people who have easy, reliable access to the Internet and those who do not. In the United States, that divide occurs in varying contexts. The Federal Communications Commission (FCC) reports that in urban areas, 97 percent of Americans have access to high-speed broadband service. However, only 65 percent of Americans living in rural areas have access to that service. In all, according to the FCC, some 30 million Americans cannot access the benefits of the digital age because of deficiencies in the broadband infrastructure.

Even in regions with good connectivity, there are differences in which households have access to computers and the Internet because of socioeconomic factors. A study conducted by the Pew Research Center in 2019 found that 46 percent of US adults with household incomes below \$30,000 per year did not have a computer at home, while 44 percent did not have broadband Internet at home. Race and ethnicity are also significant factors in the United States’

digital divide: the Pew Research Center reported in 2019 that 42 percent of African American adults and 43 percent of Hispanic adults did not have a desktop or laptop computer at home, compared to only 18 percent of Caucasian adults. Individuals without home computers must instead use smartphones or public facilities such as libraries (which restrict how long a patron can remain online), which severely limits their ability to fill out job applications and complete homework effectively.

There is also a marked divide between digital access in highly developed nations and that which is available in other parts of the world. Globally, the International Telecommunication Union (ITU), a specialized agency within the United Nations that deals with information and communication technologies (ICTs), estimates that as many as 3 billion people living in developing countries may still be unconnected by 2023.

ICT DEVELOPMENT INDEX

The ITU, which had been founded in 1865 to manage the first international telegraph networks, began publishing the ICT Development Index (IDI) in 2009 and continued to do so on an annual basis through 2017. The ITU did not publish the IDI in 2018 or 2019.

The IDI combines eleven key indicators into one benchmark measure that can be used to monitor and compare advancements in ICT (information and communications technology) between countries, and over time. The index is aimed at first tracking individual nations’ ICT readiness: the level of networked infrastructure and access to ICTs as measured by number of fixed-telephone subscriptions, mobile-cellular telephone subscriptions, international Internet bandwidth per Internet user, households with a computer, and households with Internet access.

Next, ICT intensity (the level of use of ICTs in the country) is examined by surveying how many individuals use the Internet, how many have fixed broadband subscriptions, and how many have mobile-broadband subscriptions. Finally, a snapshot of ICT impact (the concrete outcomes of more efficient and effective ICT use) is taken by looking at mean years of schooling, gross secondary enrollment, and gross tertiary enrollment. Those factors serve as proxy indicators of overall skills and abilities.

In 2017, the United States ranked at number sixteen in the IDI. The top five spots were taken by Iceland, South Korea, Switzerland, Denmark, and the United Kingdom.

ACCESSIBILITY FOR PEOPLE WITH PHYSICAL DISABILITIES

People with physical disabilities are also sometimes subject to a digital divide—a state of affairs that is easily overlooked by those who can effortlessly manipulate a mouse, hear output from speakers, and clearly see whatever appears on a screen. True accessibility means, however, that everyone can use the same technology as anyone else, regardless of their level of vision, hearing, or manual dexterity. In the United States, the Americans with Disabilities Act (ADA) sets forth guidelines for digital accessibility, although compliance has not always been widespread. To address that issue, user experience designers are increasingly ensuring that technology can be employed successfully by people with a wide range of functional abilities. Users of desktop computers, for example, can now input information in multiple ways, including via mouse, keyboard, or speech-recognition software.

WHY IT MATTERS

A constantly growing number of essential services are conducted digitally. Thus, those on the wrong side of the digital divide miss out on the long-term benefits of innovative technology. In addition, their day-to-day lives become exponentially harder, as information vital to their health, safety, and financial stability is provided online. Consider, for example, the contrast between clicking a few links on a Department of Motor Vehicles website and waiting for hours to get

in-person help at a local DMV office. Most important, the digital divide perpetuates economic inequality and impedes social mobility given how often school coursework, even for the very youngest students, involves computer use. Additionally, many well-paying jobs rely on employees being at least somewhat computer literate.

There are strong indications that a citizenry with unimpeded access to the Internet can more easily engage civically, leading to healthier democracies and participatory decision-making. Consider the case of North Korea, whose regime has greatly limited global Internet access for its citizens. Growing a more robust information infrastructure can also be a pathway to economic growth for less developed nations, since ICTs tend to be associated with marked improvements in productivity. There are, in short, clear benefits to closing the digital divide—and myriad ramifications to allowing people to remain members of what has been called an “analogue underclass.”

—Mari Rich

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ACOUSTICS

ABSTRACT

Acoustics is the science dealing with the production, transmission, and effects of vibration in material media. If the medium is air and the vibration frequency is between 18 and 18,000 hertz (Hz), the vibration is termed "sound." Acoustics is also used in a broader context to describe sounds in solids and underwater and structure-borne sounds. Because mechanical vibrations, whether natural or human induced, have accompanied humans through the long course of human evolution, acoustics is among the most interdisciplinary sciences. For humans, hearing is a very important sense, and the ability to vocalize greatly facilitates communication and social interaction. Sound can have profound psychological effects; music may soothe or relax a troubled mind, and noise can induce anxiety and hypertension.

DEFINITION AND BASIC PRINCIPLES

The words "acoustics" and "phonics" evolved from ancient Greek roots for hearing and speaking, respectively. Thus, acoustics began with human communication, making it one of the oldest if not the most basic of sciences. Because acoustics is ubiquitous in human endeavors, it is perhaps the broadest and most interdisciplinary of sciences, and its most profound contributions have occurred when it is commingled with an independent field. The interdisciplinary nature of acoustics has often consigned it to a subsidiary role as a minor subdivision of mechanics, hydrodynamics, or electrical engineering. Certainly, the various technical aspects of acoustics could be parceled out

to larger and better established divisions of science, but then acoustics would lose its unique strengths and its source of dynamic creativity. The main difference between acoustics and more self-sufficient branches of science is that acoustics depends on physical laws developed in and borrowed from other fields. Therefore, the primary task of acoustics is to take these divergent principles and integrate them into a coherent whole in order to understand, measure, and control vibration phenomena.

The Acoustical Society of America subdivides acoustics into fifteen main areas, the most important of which are ultrasonics, which examines high-frequency waves not audible to humans; psychological acoustics, which studies how sound is perceived in the brain; physiological acoustics, which looks at human and animal hearing mechanisms; speech acoustics, which focuses on the human vocal apparatus and oral communication; musical acoustics, which involves the physics of musical instruments; underwater sound, which examines the production and propagation of sound in liquids; and noise, which concentrates on the control and suppression of unwanted sound. Two other important areas of applied acoustics are architectural acoustics (including the acoustical design of concert halls and sound reinforcement systems) and audio engineering (recording and reproducing sound).

BACKGROUND AND HISTORY

Acoustics arguably originated with human communication and music. The caves in which the prehistoric humans displayed their most elaborate paintings

have resonances easily excited by the human voice, and stalactites emit musical tones when struck or rubbed with a stick. Paleolithic societies constructed flutes of bird bone, used animal horns to produce drones, and employed rattles and scrapers to provide rhythm.

In the sixth century BCE, Pythagoras was the first to correlate musical sounds and mathematics by relating consonant musical intervals to simple ratios of integers. In the fourth century BCE, Aristotle deduced that the medium that carries a sound must be compressed by the sounding body, and in the third century BCE, philosopher Chrysippus correctly depicted the propagation of sound waves with an expanding spherical pattern. In the first century BCE, the Roman architect and engineer Marcus Vitruvius Pollio explained the acoustical characteristics of Greek theaters, but when the Roman civilization declined in the fourth century CE, scientific inquiry in the West essentially ceased for the next millennium.

In the seventeenth century, modern experimental acoustics originated when the Italian mathematician Galileo explained resonance as well as musical consonance and dissonance, and theoretical acoustics got its start with Sir Isaac Newton's derivation of an expression for the velocity of sound. Although this yielded a value considerably lower than the experimental result, a more rigorous derivation by Pierre-Simon Laplace in 1816 obtained an equation yielding values in complete agreement with experimental results.

During the eighteenth century, many famous mathematicians studied vibration. In 1700, French mathematician Joseph Sauveur observed that strings vibrate in sections consisting of stationary nodes located between aggressively vibrating antinodes and that these vibrations have integer multiple frequencies, or harmonics, of the lowest frequency. He also noted that a vibrating string could simultaneously produce the sounds of several harmonics. In 1755, Daniel Bernoulli proved that this resultant vibration was the independent algebraic sum of the various harmonics. In 1750, Jean le Rond d'Alembert used calculus to obtain the wave equation for a vibrating string. By the end of the eighteenth century, the basic experimental results and theoretical underpinnings of acoustics were extant and in reasonable

agreement, but it was not until the following century that theory and a concomitant advance of technology led to the evolution of the major divisions of acoustics.

Although mathematical theory is central to all acoustics, the two major divisions, physical and applied acoustics, evolved from the central theoretical core. In the late nineteenth century, Hermann von Helmholtz and Lord Rayleigh (John William Strutt), two polymaths, developed the theoretical aspects. Helmholtz's contributions to acoustics were primarily in explaining the physiological aspects of the ear. Rayleigh, a well-educated wealthy English baron, synthesized virtually all previous knowledge of acoustics and also formulated an appreciable corpus of experiment and theory.

Experiments by Georg Simon Ohm indicated that all musical tones arise from simple harmonic vibrations of definite frequency, with the constituent components determining the sound quality. This gave birth to the field of musical acoustics. Helmholtz's studies of instruments and Rayleigh's work contributed to the nascent area of musical acoustics. Helmholtz's knowledge of ear physiology shaped the field that was to become physiological acoustics.

Underwater acoustics commenced with theories developed by the nineteenth-century mathematician Siméon-Denis Poisson, but further development had to await the invention of underwater transducers in the next century.

Two important nineteenth-century inventions, the telephone (patented 1876) and the mechanical phonograph (invented 1877), commingled and evolved into twentieth- and twenty-first-century audio acoustics when united with electronics. Some products in which sound production and reception are combined are microphones, loudspeakers, radios, talking motion pictures, high-fidelity stereo systems, and public sound-reinforcement systems. Improved instrumentation for the study of speech and hearing has stimulated the areas of physiological and psychology acoustics, and ultrasonic devices are routinely used for medical diagnosis and therapy, as well as for burglar alarms and rodent repellants. Underwater transducers are employed to detect and measure moving objects in the water, while audio engineering technology has transformed music performance as well as sound reproduction. Virtually no area of

human activity has remained unaffected by continually evolving technology based on acoustics.

HOW IT WORKS

Ultrasonics. Dog whistles, which can be heard by dogs but not by humans, can generate ultrasonic frequencies of about 25 kilohertz (kHz). Two types of transducers, magnetostrictive and piezoelectric, are used to generate higher frequencies and greater power. Magnetostrictive devices convert magnetic energy into ultrasound by subjecting ferric material (iron or nickel) to a strong oscillating magnetic field. The field causes the material to alternately expand and contract, thus creating sound waves of the same frequency as that of the field. The resulting sound waves have frequencies between 20 Hz and 50 kHz and several thousand watts of power. Such transducers operate at the mechanical resonance frequency where the energy transfer is most efficient.

Piezoelectric transducers convert electric energy into ultrasound by applying an oscillating electric field to a piezoelectric crystal (such as quartz). These transducers, which work in liquids or air, can generate frequencies in the megahertz region with considerable power. In addition to natural crystals, ceramic piezoelectric materials, which can be fabricated into any desired shape, have been developed.

Physiological and Psychological Acoustics. Physiological acoustics studies auditory responses of the ear and its associated neural pathways, and psychological acoustics is the subjective perception of sounds through human auditory physiology. Mechanical, electrical, optical, radiological, or biochemical techniques are used to study neural responses to various aural stimuli. Because these techniques are typically invasive, experiments are performed on animals with auditory systems that are similar to the human system. In contrast, psychological acoustic studies are noninvasive and typically use human subjects.

A primary objective of psychological acoustics is to define the psychological correlates to the physical parameters of sound waves. Sound waves in air may be characterized by three physical parameters: frequency, intensity, and their spectrum. When a sound wave impinges on the ear, the pressure variations in

the air are transformed by the middle ear to mechanical vibrations in the inner ear. The cochlea then decomposes the sound into its constituent frequencies and transforms these into neural action potentials, which travel to the brain where the sound is evidenced. Frequency is perceived as pitch, the intensity level as loudness, and the spectrum determines the timbre, or tone quality, of a note.

Another psychoacoustic effect is masking. When a person listens to a noisy version of recorded music, the noise virtually disappears if the music is being enjoyed. This ability of the brain to selectively listen has had important applications in digitally recorded music. When the sounds are digitally compressed, such as in MP3 (MPEG 1 audio layer-3) systems, the brain compensates for the loss of information; thus one experiences higher fidelity sound than the stored content would imply. Also, the brain creates information when the incoming signal is masked or nonexistent, producing a psychoacoustic phantom effect. This phantom effect is particularly prevalent when heightened perceptions are imperative, as when danger is lurking.

Psychoacoustic studies have determined that the frequency range of hearing is from 20 to about 20,000 Hz for young people, and the upper limit progressively decreases with age. The rate at which hearing acuity declines depends on several factors, not the least of which is lifetime exposure to loud sounds, which progressively deteriorate the hair cells of the cochlea. Moderate hearing loss can be compensated for by a hearing aid; severe loss requires a cochlear implant.

Speech Acoustics. Also known as acoustic phonetics, speech acoustics deals with speech production and recognition. The scientific study of speech began with Thomas Alva Edison's phonograph, which allowed a speech signal to be recorded and stored for later analysis. Replaying the same short speech segment several times using consecutive filters passing through a limited range of frequencies creates a spectrogram, which visualizes the spectral properties of vowels and consonants. During the first half of the twentieth century, Bell Telephone Laboratories invested considerable time and resources to the systematic understanding of all aspects of speech, including vocal tract resonances, voice quality, and

prosodic features of speech. For the first time, electric circuit theory was applied to speech acoustics, and analogue electric circuits were used to investigate synthetic speech.

Musical Acoustics. A conjunction of music, craftsmanship, auditory science, and vibration physics, musical acoustics analyzes musical instruments to better understand how the instruments are crafted, the physical principles of their tone production, and why each instrument has a unique timbre. Musical instruments are studied by analyzing their tones and then creating computer models to synthesize these sounds. When the sounds can be recreated with minimal software complications, a synthesizer featuring realistic orchestral tones may be constructed. The second method of study is to assemble an instrument or modify an existing instrument to perform nondestructive (or on occasion destructive) testing so that the effects of various modifications may be gauged.

Underwater Sound. Also known as hydroacoustics, this field uses frequencies between 10 Hz and 1 megahertz (MHz). Although the origin of hydroacoustics can be traced back to Rayleigh, the deployment of submarines in World War I provided the impetus for the rapid development of underwater listening devices (hydrophones) and sonar (sound navigation ranging), the acoustic equivalent of radar. Pulses of sound are emitted and the echoes are processed to extract information about submerged objects. When the speed of underwater sound is known, the reflection time for a pulse determines the distance to an object. If the object is moving, its speed of approach or recession is deduced from the frequency shift of the reflection, or the Doppler effect. Returning pulses have a higher frequency when the object approaches and lower frequency when it moves away.

Noise. Physically, noise may be defined as an intermittent or random oscillation with multiple frequency components, but psychologically, noise is any unwanted sound. Noise can adversely affect human health and well-being by inducing stress, interfering with sleep, increasing heart rate, raising blood pressure, modifying hormone secretion, and even inducing depression. The environmental effects of noise

are no less severe. The vibrations in irregular road surfaces caused by large rapid vehicles can cause adjacent buildings to vibrate to an extent that is intolerable to the buildings' inhabitants, even without structural damage. Machinery noise in industry is a serious problem because continuous exposure to loud sounds will induce hearing loss. In apartment buildings, noise transmitted through walls is always problematic; the goal is to obtain adequate sound insulation using lightweight construction materials.

Traffic noise, both external and internal, is ubiquitous in modern life. The first line of defense is to reduce noise at its source by improving engine enclosures, mufflers, and tires. The next method, used primarily when interstate highways are adjacent to residential areas, is to block the noise by the construction of concrete barriers or the planting of sound-absorbing vegetation. Internal automobile noise has been greatly abated by designing more aerodynamically efficient vehicles to reduce air turbulence, using better sound isolation materials, and improving vibration isolation.

Aircraft noise, particularly in the vicinity of airports, is a serious problem exacerbated by the fact that as modern airplanes have become more powerful, the noise they generate has risen concomitantly. The noise radiated by jet engines is reduced by two structural modifications. Acoustic linings are placed around the moving parts to absorb the high frequencies caused by jet whine and turbulence, but this modification is limited by size and weight constraints. The second modification is to reduce the number of rotor blades and stator vanes, but this is somewhat inhibited by the desired power output. Special noise problems occur when aircraft travel at supersonic speeds (faster than the speed of sound), as this propagates a large pressure wave toward the ground that is experienced as an explosion. The unexpected sonic boom startles people, breaks windows, and damages houses. Sonic booms have been known to destroy rock structures in national parks. Because of these concerns, commercial aircraft are prohibited from flying at supersonic speeds over land areas.

Construction equipment (such as earthmoving machines) creates high noise levels both internally and externally. When the cabs of these machines are not closed, the only feasible manner of protecting operators' hearing is by using ear plugs. By carefully

designing an enclosed cabin, structural vibration can be reduced and sound leaks made less significant, thus quieting the operator's environment. Although manufacturers are attempting to reduce the external noise, it is a daunting task because quieter components, such as the rubber tractor treads occasionally used to replace metal, are often not as durable.

APPLICATIONS AND PRODUCTS

Ultrasonics. High-intensity ultrasonic applications include ultrasonic cleaning, mixing, welding, drilling, and various chemical processes. Ultrasonic cleaners use waves in the 150 to 400 kHz range on items (such as jewelry, watches, lenses, and surgical instruments) placed in an appropriate solution. Ultrasonic cleaners have proven to be particularly effective in cleaning surgical devices because they loosen contaminants by aggressive agitation irrespective of an instrument's size or shape, and disassembly is not required. Ultrasonic waves are effective in cleaning most metals and alloys, as well as wood, plastic, rubber, and cloth. Ultrasonic waves are used to emulsify two nonmiscible liquids, such as oil and water, by forming the liquids into finely dispersed particles that then remain in homogeneous suspension. Many paints, cosmetics, and foods are emulsions formed by this process.

Although aluminum cannot be soldered by conventional means, two surfaces subjected to intense ultrasonic vibration will bond—without the application of heat—in a strong and precise weld. Ultrasonic drilling is effective where conventional drilling is problematic, for instance, drilling square holes in glass. The drill bit, a transducer having the required shape and size, is used with an abrasive slurry that chips away the material when the suspended powder oscillates. Some of the chemical applications of ultrasonics are in the atomization of liquids, in electroplating, and as a catalyst in chemical reactions.

Low-intensity ultrasonic waves are used for nondestructive probing to locate flaws in materials for which complete reliability is mandatory, such as those used in spacecraft components and nuclear reactor vessels. When an ultrasonic transducer emits a pulse of energy into the test object, flaws reflect the wave and are detected. Because objects subjected to stress emit ultrasonic waves, these signals may be used to interpret the condition of the material as it is increasingly

stressed. Another application is ultrasonic emission testing, which records the ultrasound emitted by porous rock when natural gas is pumped into cavities formed by the rock to determine the maximum pressure these natural holding tanks can withstand.

Low-intensity ultrasonics is used for medical diagnostics in two different applications. First, ultrasonic waves penetrate body tissues but are reflected by moving internal organs, such as the heart. The frequency of waves reflected from a moving structure is Doppler-shifted, thus causing beats with the original wave, which can be heard. This procedure is particularly useful for performing fetal examinations on a pregnant woman; because sound waves are not electromagnetic, they will not harm the fetus. The second application is to create a sonogram image of the body's interior. A complete cross-sectional image may be produced by superimposing the images scanned by successive ultrasonic waves passing through different regions. This ultrasonography procedure, unlike an X ray, displays all the tissues in the cross section and also avoids any danger posed by the radiation involved in X-ray imaging.

Physiological and Psychological Acoustics. Because the ear is a nonlinear system, it produces beat tones that are the sum and difference of two frequencies. For example, if two sinusoidal frequencies of 100 and 150 Hz simultaneously arrive at the ear, the brain will, in addition to these two tones, create tones of 250 and 50 Hz (sum and difference, respectively). Thus, although a small speaker cannot reproduce the fundamental frequencies of bass tones, the difference between the harmonics of that pitch will recreate the missing fundamental in the listener's brain.

Another psychoacoustic effect is masking. When a person listens to a noisy version of recorded music, the noise virtually disappears if the individual is enjoying the music. This ability of the brain to selectively listen has had important applications in digitally recorded music. When sounds are digitally compressed, as in MP3 systems, the brain compensates for the loss of information, thus creating a higher fidelity sound than that conveyed by the stored content alone.

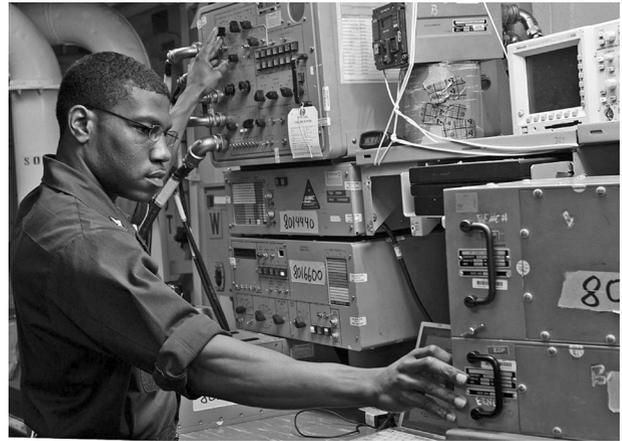
As technology evolved, environmental noise increased concomitantly; lifetime exposure to loud sounds, commercial and recreational, has created an epidemic of hearing loss, most noticeable in the

elderly because the effects are cumulative. Wearing a hearing aid, fitted adjacent to or inside the ear canal, is an effectual means of counteracting this epidemic. The device consists of one or several microphones, which create electric signals that are amplified and transduced into sound waves redirected back into the ear. More sophisticated hearing aids incorporate an integrated circuit to control volume, either manually or automatically, or to switch to volume contours designed for various listening environments, such as conversations on the telephone or where excessive background noise is present.

Speech Acoustics. With the advent of the computer age, speech synthesis moved to digital processing, either by bandwidth compression of stored speech or by using a speech synthesizer. The synthesizer reads a text and then produces the appropriate phonemes on demand from their basic acoustic parameters, such as the vibration frequency of the vocal cords and the frequencies and amplitudes of the vowel formants. This method of generating speech is considerably more efficient in terms of data storage than archiving a dictionary of prerecorded phrases.

Another important, and probably the most difficult, area of speech acoustics is the machine recognition of spoken language. When machine speech recognition programs are sufficiently advanced, the computer is able to listen to a sentence in any reasonable dialect and produce a printed text of the utterance. Two basic recognition strategies exist, one dealing with words spoken in isolation and the other with continuous speech. In both cases, it is desirable to teach the computer to recognize the speech of different people through a training program. Because recognition of continuous speech is considerably more difficult than the identification of isolated words, very sophisticated pattern-matching models must be employed. Speech recognition technologies advanced greatly in the 2010s, with examples included on many smartphones and computers along with virtual personal assistants, such as Apple's Siri. Such systems are able to process full sentences, enact commands, and even respond with synthesized speech in a realistic manner.

Musical Acoustics. The importance of musical acoustics to manufacturers of quality instruments is



A man performs a test on an aircraft carrier's sonar system (photo courtesy of U.S. Navy)

apparent. During the last decades of the twentieth century, fundamental research led, for example, to vastly improved French horns, organ pipes, orchestral strings, and the creation of an entirely new family of violins. Acoustics opens up the possibilities of advanced technologies such as software instruments and other innovative forms of music making and recording.

Underwater Sound. Applications for underwater acoustics include devices for underwater communication by acoustic means, remote control devices, underwater navigation and positioning systems, acoustic thermometers to measure ocean temperature, and echo sounders to locate schools of fish or other biota. Low-frequency devices can be used to explore the seabed for seismic research.

Although primitive measuring devices were developed in the 1920s, it was during the 1930s that sonar systems began incorporating piezoelectric transducers to increase their accuracy. These improved systems and their increasingly more sophisticated progeny became essential for the submarine warfare of World War II. After the war, theoretical advances in underwater acoustics coupled with computer technology have raised sonar systems to ever more sophisticated levels.

Noise. One system for abating unwanted sound is active noise control. The first successful application of active noise control was noise-canceling

headphones, which reduce unwanted sound by using microphones placed in proximity to the ear to record the incoming noise. Electronic circuitry then generates a signal, exactly opposite to the incoming sound, which is reproduced in the earphones, thus canceling the noise by destructive interference. This system enables listeners to enjoy music without having to use excessive volume levels to mask outside noise and allows people to sleep in noisy vehicles such as airplanes. Because active noise suppression is more effective with low frequencies, most commercial systems rely on soundproofing the earphone to attenuate high frequencies. To effectively cancel high frequencies, the microphone and emitter would have to be situated adjacent to the user's eardrum, but this is not technically feasible. Active noise control has also been considered as a means of controlling low-frequency airport noise, but because of its complexity and expense, it was not yet commercially feasible by the early twenty-first century.

CAREERS AND COURSEWORK

Career opportunities occur in academia (teaching and research), industry, and national laboratories. Academic positions dedicated to acoustics are few, as are the numbers of qualified applicants. Most graduates of acoustics programs find employment in research-based industries in which acoustical aspects of products are important, and others work for government laboratories.

Although the subfields of acoustics are integrated into multiple disciplines, most aspects of acoustics can be learned by obtaining a broad background in a scientific or technological field, such as physics, engineering, meteorology, geology, or oceanography. Physics probably provides the best training for almost any area of acoustics. An electrical engineering major is useful for signal processing and synthetic speech research, and a mechanical engineering background is requisite for comprehending vibration. Training in biology is expedient for physiological acoustic research, and psychology coursework provides essential background for psychological acoustics. Architects often employ acoustical consultants to advise on the proper acoustical design of concert halls, auditoriums, or conference rooms. Acoustical consultants also assist with noise reduction problems

and help design soundproofing structures for rooms. Although background in architecture is not a prerequisite for becoming this type of acoustical consultant, engineering or physics is.

Acoustics is rarely offered as a university major; therefore, specialized knowledge is best acquired at the graduate level. Many electrical engineering departments have at least one undergraduate course in acoustics, but most physics departments do not. Nevertheless, a firm foundation in classical mechanics (through physics programs) or a mechanical engineering vibration course will provide, along with numerous courses in mathematics, sufficient underpinning for successful graduate study in acoustics.

SOCIAL CONTEXT AND FUTURE PROSPECTS

Acoustics affects virtually every aspect of modern life; its contributions to societal needs are incalculable. Ultrasonic waves clean objects, are routinely employed to probe matter, and are used in medical diagnosis. Cochlear implants restore people's ability to hear, and active noise control helps provide quieter listening environments. New concert halls are routinely designed with excellent acoustical properties, and vastly improved or entirely new musical instruments have made their debut. Infrasound from earthquakes is used to study the composition of Earth's mantle, and sonar is essential to locate submarines and aquatic life. Sound waves are used to explore the effects of structural vibrations. Automatic speech recognition devices and hearing aid technology are constantly improving.

Many societal problems related to acoustics remain to be tackled. The technological advances that made modern life possible have also resulted in more people with hearing loss. Environmental noise is ubiquitous and increasing despite efforts to design quieter machinery and pains taken to contain unwanted sound or to isolate it from people. Also, although medical technology has been able to help many people with hearing and speech impairments, other individuals still lack appropriate treatments. For example, although voice generators exist, there is considerable room for improvement.

—George R. Plitnik

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ALGEBRA**ABSTRACT**

Algebra is a branch of applied mathematics that goes beyond the practical and theoretical applications of the numbers of arithmetic. Algebra has a definitive structure with specified elements, defined operations, and basic postulates. Such abstractions identify algebra as a system, so there are algebras of different types, such as the algebra of sets, the algebra of propositions, and Boolean algebra. Algebra has connections not only to other areas of mathematics but also to the sciences, engineering, technology, and other applied sciences. For example, Boolean algebra is used in electronic circuit design, programming, database relational structures, and complexity theory.

DEFINITION AND BASIC PRINCIPLES

Algebra is a branch of mathematics. The word “algebra” is derived from an Arabic word that links the content of classical algebra to the theory of equations. Modern algebra includes a focus on laws of operations on symbolic forms and also provides a systematic way to examine relationships between such forms. The concept of a basic algebraic structure arises from understanding an important idea. That is, with the traditional definition of addition and multiplication, the identity, associative, commutative, and distributive properties characterize these operations with not only real numbers and complex numbers but also polynomials, certain

functions, and other sets of elements. Even with modifications in the definitions of operations on other sets of elements, these properties continue to apply. Thus, the concept of algebra is extended beyond a mere symbolization of arithmetic. It becomes a definitive structure with specified elements, defined operations, and basic postulates. Such abstractions identify algebra as a system, and therefore, there are algebras of many different types, such as the algebra of sets, the algebra of propositions, and Boolean algebra.

The algebra of sets, or set theory, includes such fundamental mathematical concepts as set cardinality and subsets, which are a part of the study of various levels of mathematics from arithmetic to calculus and beyond. The algebra of propositions (logic or propositional calculus) was developed to facilitate the reasoning process by providing a way to symbolically represent statements and to perform calculations based on defined operations, properties, and truth tables. Logic is studied in philosophy, as well as various areas of mathematics such as finite mathematics. Boolean algebra is the system of symbolic logic used primarily in computer science applications; it is studied in areas of applied mathematics such as discrete mathematics.

Boolean algebra can be considered a generalization of the algebra of sets and the algebra of propositions. Boolean algebra can be defined as a nonempty set B together with two binary operations, sum (symbol $+$) and product (symbol \times). There is also a unary



George Boole, a pioneer in the field of algebra

operation, complement (symbol \complement). In set B , there are two distinct elements, a zero element (symbol 0) and a unit element (symbol 1), and certain laws or properties hold. The laws and properties table shows how laws and properties used in the algebra of sets and the algebra of propositions relate to those of Boolean algebra.

BACKGROUND AND HISTORY

The Algebra of Sets. In 1638, Italian scientist Galileo published *Discorsi e dimostrazioni matematiche: Intorno a due nuove scienze attenenti alla meccanica e i movimenti locali* (*Dialogues Concerning Two New Sciences*, 1900). In this work, Galileo recognized the basic concept of equivalent sets and distinguishing characteristics of infinite sets. During the nineteenth century, Bohemian mathematician Bernhard Bolzano studied infinite sets and their unique properties; English mathematician George Boole took an algebraic approach to the study of set theory. However, it was German mathematician Georg Cantor who developed a structure

for set theory that later led to the modernization of the study of mathematical analysis.

Cantor had a strong interest in the arguments of medieval theologians concerning continuity and the infinite. With respect to mathematics, Cantor realized that not all infinite sets were the same. In 1874, his controversial work on infinite sets was published. After additional research, he established set theory as a mathematical discipline known as *Mengenlehre* (theory of assemblages) or *Mannigfaltigkeitslehre* (theory of manifolds).

The Algebra of Propositions and Boolean Algebra.

During the nineteenth century, Boole, English mathematician Charles Babbage, German mathematician Gottlob Frege, and Italian mathematician Giuseppe Peano tried to formalize mathematical reasoning by an “algebraization” of logic.

Boole, who had clerical aspirations, regarded the human mind as God’s greatest accomplishment. He wanted to mathematically represent how the brain processes information. In 1847, his first book, *The Mathematical Analysis of Logic: Being an Essay Towards a Calculus of Deductive Reasoning*, was published with limited circulation. He rewrote and expanded his ideas in an 1854 publication, *An Investigation of the Laws of Thought: On Which Are Founded the Mathematical Theories of Logic and Probabilities*. Boole introduced the algebra of logic and is considered the father of symbolic logic.

Boole’s algebra was further developed between 1864 and 1895 through the contributions of British mathematician Augustus De Morgan, British economist William S. Jevons, American logician Charles Sanders Peirce, and German mathematician Ernst Schröder. In 1904, American mathematician Edward V. Huntington’s *Sets of Independent Postulates for the Algebra of Logic* developed Boolean algebra into an abstract algebraic discipline with different interpretations. With the additional work of American mathematician Marshall Stone and Polish American logician Alfred Tarski in the 1930s, Boolean algebra became a modern mathematical discipline, with connections to several other branches of mathematics, including topology, probability, and statistics.

In his 1940 Massachusetts Institute of Technology master’s thesis, Claude Elwood Shannon used

symbolic Boolean algebra as a way to analyze relay and switching circuits. Boole's work thus became the foundation for the development of modern electronics and digital computer technology.

Outside the realm of mathematics and philosophy, Boolean algebra has found applications in such diverse areas as anthropology, biology, chemistry, ecology, economics, sociology, and especially computer science. For example, in computer science, Boolean algebra is used in electronic circuit design, programming, database relational structures, and complexity theory.

HOW IT WORKS

Boolean algebra achieved a central role in computer science and information theory that began with its connection to set theory and logic. Set theory, propositional logic, and Boolean algebra all share a common mathematical structure that becomes apparent in the properties or laws that hold.

Set Theory. The language of set theory is used in the definitions of nearly all mathematical elements, and set theory concepts are integrated throughout the mathematics curriculum from the elementary to the college level. In primary school, basic set concepts may be introduced in sorting, combining, or classifying objects even before the counting process is introduced. Operations such as set complement, union, and intersection can be easily understood in this context.

For example, let the universal set U consist of six blocks, each of which is a different color. A block may be red, orange, yellow, violet, blue, or green. Using set notation, $U = \{\text{red, orange, yellow, violet, blue, green}\}$. Let four of the six blocks be sorted into two subsets, A and B , such that $A = \{\text{red, yellow}\}$ and $B = \{\text{blue, green}\}$. The complement of set A is the set of blocks that are neither red nor yellow, $A^c = \{\text{orange, violet, blue, green}\}$. The union of sets A and B is the set that contains all of the blocks in set A or set B or both, if there were any colors in common: $A \cup B = \{\text{red, yellow, blue, green}\}$. The intersection of sets A and B is the set of blocks that are in set A and in set B , any color that both sets have in common. Because the two sets of blocks have no color in common, $A \cap B = \emptyset$.

Above the primary level, the concepts of logic are introduced. Daily life often requires that one

construct valid arguments, apply persuasion, and make meaningful decisions. Thus, the development of the ability to organize thoughts and explain ideas in clear, precise terms makes the study of reasoning and the analysis of statements most appropriate.

Logic. In propositional algebra, statements are either true or false. A statement may be negated by using "not." Statements can be combined in a variety of ways by using connectives such as "and" and "or." The resulting compound statements are either true or false, based on given truth tables.

A compound statement such as "The First International Conference on Numerical Algebra and Scientific Computing was held in 2006 and took place at the Institute of Computational Mathematics of the Chinese Academy of Sciences in New York" can thus be easily analyzed, especially when written symbolically. The "and" connective indicates that the compound statement is a conjunction. Let p be "The First International Conference on Numerical Algebra and Scientific Computing was held in 2006," a true statement; let q be "(it) took place at the Institute of Computational Mathematics of the Chinese Academy of Sciences in New York," a false statement because the institute is in Beijing. The truth table for the conjunction indicates that the given compound statement is false: $T \wedge F = F$.

Compound symbolic statements may require multistep analyses, but established properties and truth tables are still used in the process. For example, it is possible to analyze the two symbolic compound statements $\sim(p \wedge q)$ and $\sim p \vee \sim q$ and also to verify that they are logically equivalent. The truth tables for each compound statement can be combined in one large table to facilitate the process. The first two columns of the table show all possibilities for the truth values of two statements, p and q . The next three columns show the analysis of each of the parts of the two given compound statements, using the truth tables for negation, disjunction, and conjunction. The last two columns of the table have exactly the same corresponding T and F entries, showing that the truth value will be the same in all cases. This verifies that the two compound statements are logically equivalent. Note that the equivalence of these two propositions is one of De Morgan's laws: $\sim(p \wedge q) = \sim p \vee \sim q$.

Computer Circuits. Shannon showed how logic could be used to design and simplify electric circuits. For example, consider a circuit with switches p and q that can be open or closed, corresponding to the Boolean binary elements, 0 and 1. A series circuit corresponds to a conjunction because both switches must be closed for electric current to flow. A circuit where electricity flows whenever at least one of the switches is closed is a parallel circuit; this corresponds to a disjunction. Because the complement for a given switch is a switch in the opposite position, this corresponds to a negation table. When a circuit is represented in symbolic notation, its simplification may use the laws of logic, such as De Morgan's laws. The simplification may also use tables in the same way as the analysis of the equivalence of propositions, with 1 replacing T and 0 replacing F. Other methods may use Karnaugh maps, the Quine-McCluskey method, or appropriate software.

Computer logic circuits are used to make decisions based on the presence of multiple input signals. The signals may be generated by mechanical switches or by solid-state transducers. The various families of digital logic devices, usually integrated circuits, perform a variety of logic functions through logic gates. Logic gates are the basic building blocks for constructing digital systems. The gates implement the hardware logic function based on Boolean algebra. Two or more logic gates may be combined to provide the same function as a different type of logic gate. This process reduces the total number of integrated circuit packages used in a product.

Boolean expressions can direct computer hardware and also be used in software development by programmers managing loops, procedures, and blocks of statements.

Boolean Searches. Boolean algebra is used in information theory. Online queries are input in the form of logical expressions. The operator "and" is used to narrow a query and "or" is used to broaden it. The operator "not" is used to exclude specific words from a query.

For example, a search for information about "algebra freeware" may be input as "algebra or freeware," "algebra and freeware," or perhaps "algebra and freeware not games." The amount of information received from each query will be different. The first

query will retrieve many documents because it will select those that contain "algebra," those that contain "freeware," and those that contain both terms. The second query will retrieve fewer documents because it will select only those documents that contain both terms. The last query will retrieve documents that contain both "algebra" and "freeware" but will exclude items containing the term "games."

APPLICATIONS AND PRODUCTS

Logic Machines, Calculating Machines, and Computers. The "algebraization" of logic, primarily the work of De Morgan and Boole, was important to the transformation of Aristotelian logic into modern logic, and to the automation of logical reasoning. Several machines were built to solve logic problems, including the Stanhope demonstrator, Jevons's logic machine, and the Marquand machine. In the mid-nineteenth century, Jevons's logic machine, or logic piano, was among the most popular; it used Boolean algebra concepts. Harvard undergraduates William Burkhardt and Theodore Kalin built an electric version of the logic piano in 1947.

In the 1930s, Boolean algebra was used in wartime calculating machines. It was also used in the design of the first digital computer by John Atanasoff and his graduate student Clifford Berry. During 1944–1945, John von Neumann suggested using the binary mathematical system to store programs in computer memory. In the 1930s and 1940s, British mathematician Alan Turing and American mathematician Shannon recognized that binary logic was well suited to the development of digital computers. Just as Shannon's work served as the basis for the theory of switching and relay circuits, Turing's work became the basis for the field of automata theory, the theoretical study of information processing and computer design.

By the end of World War II, it was apparent that computers would soon replace logic machines. Later computer software and hardware developments confirmed that the logic process could be mechanized. Although research work continues to provide theoretical guidelines, automated reasoning programs such as those used in robotics development, are in demand by researchers to resolve questions in mathematics, science, engineering, and technology.

Integrated Circuit Design. Boolean algebra became indispensable in the design of computer microchips and integrated circuits. It is among the fundamental concepts of digital electronics that are essential to understanding the design and function of different types of equipment.

Many integrated circuit manufacturers produce complex logic systems that can be programmed to perform a variety of logical functions within a single integrated circuit. These integrated circuits include gate array logic (GAL), programmable array logic (PAL), the programmable logic device (PLD), and the complex programmable logic device (CPLD).

Engineering approaches to the design and analysis of digital logic circuits involves applications of advanced Boolean algebra concepts, including algorithmic state and machine design of sequential circuits, as well as digital logic simulation. The actual design and implementation of sizeable digital design problems involves the use of computer-aided design (CAD).

Computer Algebra Systems. During the 1960s and 1970s, the first computer algebra systems (CASs) emerged and evolved from the needs of researchers. Computer algebra systems are software that enable users to do tedious and sometimes difficult algebraic tasks, such as simplifying rational functions, factoring polynomials, finding solutions to a system of equations, and representing information graphically in two or three dimensions. The systems offer a programming language for user-defined procedures. Computer algebra systems have not only changed how algebra is taught but also provided a convenient tool for mathematicians, scientists, engineers, and technicians worldwide.

Among the first popular computer algebra systems were Reduce, Scratchpad, Macsyma (later Maxima), and Mu-Math. Later popular systems include MATLAB (matrix laboratory), Mathematica, Maple, and MathCAD.

In 1987, Hewlett-Packard introduced HP-28, the first handheld calculator series with the power of a computer algebra system. In 1995, Texas Instruments released the TI-92 calculator with advanced CAS capabilities based on Derive software. Manufacturers continue to offer devices such as these with increasingly powerful functions; such devices tend to decrease in size and cost with advancements in technology.

CAREERS AND COURSEWORK

The applications of algebra are numerous, which means that those interested in algebra can pursue jobs and careers in a wide range of fields, including business, engineering, and science, particularly computer science.

Data Analyst or Data Miner. Data mining is a broad mathematical area that involves the discovery of patterns and hidden information in large databases, using algorithms. In applications of data mining, career opportunities emerge in e-commerce, security, forensics, medicine, bioinformatics and genomics, astrophysics, and chemical and electric power engineering. Coursework should include a focus on higher level mathematics in such areas as combinatorics, topology, and algebraic structures.

Materials Engineer. Materials science is the study of the properties, processing, and production of such items as metallic alloys, liquid crystals, and biological materials. There are many career opportunities in research, manufacturing, and development in aerospace, electronics, biology, and nanotechnology. The design and analysis of materials depends on mathematical models and computational tools. Course work should include a focus on applied mathematics, including differential equations, linear algebra, numerical analysis, operations research, discrete mathematics, optimization, and probability.

Computer Animator or Digital Artist. Computer animation encompasses many areas, including mathematics, computer science, physics, biomechanics, and anatomy. Career opportunities arise in medical diagnostics, multimedia, entertainment, and fine arts. The algorithms for computer animation come from scientific relationships, statistics, signal processing, linear algebra, control theory, and computational geometry. Recommended mathematics course work includes statistics, discrete mathematics, linear algebra, geometry, and topology.

Financial Analyst. As quantitative methods transform the financial industry, banking, insurance, investment, and government regulatory institutions are among those relying on mathematical tools and

computational models. Such tools and models are used to support investment decisions, to develop and price new securities, to manage risk, and to guide portfolio selection, management, and optimization. Course work should include a focus on the mathematics of finance, linear algebra, linear programming, probability, and descriptive statistics.

SOCIAL CONTEXT AND FUTURE PROSPECTS

Algebra is part of two broad, rapidly growing fields, applied mathematics and computational science. Applied mathematics is the branch of mathematics that develops and provides mathematical methods to meet scientific, engineering, and technological needs. Applied mathematics includes not only discrete mathematics and linear algebra but also numerical analysis, operations research, and probability. Computational science integrates applied mathematics, science, engineering, and technology to create a multidisciplinary field developing and using innovative problem-solving strategies and methodologies.

Applied mathematics and computational science are used in almost every area of science, engineering, and technology. Business also relies on

applied mathematics and computational science for research, design, and manufacture of products that include aircraft, automobiles, computers, communication systems, and pharmaceuticals. Research in applied mathematics therefore often leads to the development of new mathematical models, theories, and applications that contribute to diverse fields.

—June Gastón

FURTHER READING

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ALGORITHMS

ABSTRACT

An algorithm is set of precise, computable instructions that, when executed in the correct order, will provide a solution to a certain problem. Algorithms are widely used in mathematics and engineering, and understanding the design of algorithms is fundamental to computer science.

AN ANCIENT IDEA

The term “algorithm” is derived from the name al-Khwarizmi. Muhammad ibn Musa al-Khwarizmi was a ninth-century Persian mathematician who is credited with introducing the decimal system to the West. He has been celebrated around the world as a pioneer of mathematics and conceptual problem solving.

“Algorithm” has no precise definition. Broadly, it refers to a finite set of instructions, arranged in a specific order and described in a specific language, for solving a particular problem. In other words, an algorithm is like a plan or a map that tells a person or a machine what steps to take in order to complete a given task.

ALGORITHM BASICS

In computer science, an algorithm is a series of instructions that tells a computer to perform a certain function, such as sorting, calculating, or finding data. Each step in the instructions causes the computer to transition from one state to another until it reaches the desired end state.

Any procedure that takes a certain set of inputs (a data list, numbers, information, etc.) and reaches a