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ECHOES

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Source-Filter Interaction in Speaking and Singing is Nonlinear

Ingo R. Titze

Many aspects of speech production have been successfully described by a linear source-filter theory. Linearity implies that the source-filter combination, which provides the acoustic output at the mouth, can be characterized by mathematical convolution in the time domain (or by multiplication in the frequency domain) of two independent functions representing the source and the filter. With this assumption, the filter cannot influence the source to produce new frequencies or change the overall energy level of the source. It has recently been shown, however, that this assumption is generally not valid, and only under certain conditions is at best an appropriate simplification. The linear theory is applicable to male speech, less to female and child speech, and much less to singing. As long as the dominant source frequencies lie well below the formant (resonance) frequencies of the vocal tract (which occurs in male speech), glottal airflow is influenced only in simple ways by the filter, mainly in terms of flow pulse skewing and pulse ripple. But when formants and harmonics cross, bifurcations in the glottal airflow and the dynamics of vocal fold vibration can occur that may generate secondary frequencies and even change the energy level at the source.

Fig. 1. Human male vocal tract compared to trumpet

It is hypothesized that humans (and perhaps many animals) have the ability to operate their source filter system with either linear or nonlinear coupling. One way to express the degree of coupling is through the relative impedances of the source and filter. For linear source-filter coupling, the source impedance is kept much higher than the input impedance to the vocal tract. This linear coupling is accomplished by adducting the vocal folds firmly and widening the epilarynx tube (a narrow region of the vocal tract above the vocal folds, also known as the laryngeal vestibule; see arrow in Figure 1). The glottal flow is then determined strictly by aerodynamics, while acoustic pressures above and below the glottis have little influence on either the transglottal pressure (which drives the glottal flow) or the intraglottal pressure (which drives the vocal folds). For nonlinear source-filter coupling, the glottal impedance is adjusted to be comparable to the vocal tract input impedance, making the glottal flow highly dependent on acoustic pressures in the vocal tracts (above and below the glottis). This is accomplished by setting specific adduction levels of the vocal folds that match a narrower epilarynx tube. The epilarynx tube serves the same function as the mouthpiece of a trumpet to match the impedance of the main tube to the flow impedance of the lips.

Singing styles (operatic, musical theatre, belting, yodeling) are based on the concept that certain vowels and voice qualities work best with certain pitches, a concept that would have no explanation if the source-filter system were linear. The entire voice register terminology is based on observed phenomena related to interaction within the source-filter building blocks, which includes the trachea. Vocal pedagogues who invented terms like *chest voice* and *head voice* were not so naïve to suggest that the source of sound moves from location to location, but rather that interactions with certain parts of the airway are stronger with certain source-filter adjustments and lead to special sensations along the airway.

Because the vocal tract is relatively short (about 17 cm in comparison to more than 2 m for a stretched-out trumpet horn) and because a speaker or singer wishes to convey all the phonetic variations of a spoken language, the length and shape of the vocal tract cannot be adjusted to resonate many of the source frequencies simultaneously. Thus, unlike in most musical instruments, for which the length and shape of the horn or bore is carefully designed to resonate the dominant source frequencies simultaneously, lining up source frequencies with vocal tract filter resonances is rarely effective in human phonation. In fact, singers deliberately avoid the formant regions

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We hear that . . .

• **James West** received the 2006 National Medal of Technology at the White House on July 27. Jim, who is a professor at Johns Hopkins University and a former president of ASA, was recognized "for co-inventing the electret microphone while working with Gerhard Sessler at Bell Labs in 1962. Ninety percent of the two billion microphones produced annually and used in everyday items such as telephones, hearing aids, camcorders, and multimedia computers employ electret technology."

• **Jan Achenbach** received the National Medal of Science at the White House on July 27. Jan, who is a professor at Northwestern University and an ASA Fellow, was recognized for "seminal contributions to engineering research and education in the area of wave propagation in solids and for pioneering the field of quantitative non-destructive evaluation."

• **Patricia Kuhl**, Professor of Speech and Co-Director of the University of Washington Institute for Learning and Brain Sciences, received an Outstanding Alumni Achievement award from the University of Minnesota.

A letter from the editor:

Once again, we received no Letters to the Editor, so this space will be filled by a Letter from the Editor, who is still getting unpacked after moving to Los Altos Hills (that makes 3 moves in the past 3 years). But the view of the setting sun in the hills as I write this makes it all worthwhile! I invite my acoustics friends to come by and enjoy this view with me. And someday soon I hope to find all those books and papers that have been packed away in boxes.

As you know, we publish an issue of *ECHOES* a month or two before each ASA meeting, and another issue a month or so after each meeting. This issue includes photos from the Salt Lake City meeting as well as an article based on a paper at that meeting. We invite readers to submit photos and meeting notes within a month after the New Orleans meeting.

Likewise, we can use photos and notes from the ICA (International Congress on Acoustics) and the various satellite meetings in Europe this September. The deadline for the Fall issue is September 27, but in case we receive more submissions than we have space, it may be "first come first served."

ECHOES

Newsletter of the Acoustical Society of America

Provided as a benefit of membership to ASA members

The Acoustical Society of America was organized in 1929 to increase and diffuse the knowledge of acoustics and to promote its practical applications.

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Source-Filter Interaction in Speaking and Singing is Nonlinear *continued from page 1*

with harmonic placement. Apparent "formant-harmonic tuning" occurs in high soprano singing (Sundberg, 1977; Joliveau *et al.*, 2004), but close inspection of the data reveals that F_0 is slightly less than the formant frequency F_1. The reason for this is that peak vocal tract *inertance* is sought out, which occurs below resonance. Exact formant-harmonic tuning seems to occur only in so-called *harmonic singing* or *overtone singing*, where a single harmonic is highly reinforced by a formant that is tuned precisely to its frequency (Rachele, 1996). In this exceptional case, peak vocal tract *resistance* seems to be sought out, which occurs exactly at the formant frequency. Linear source-filter coupling is then likely.

Nonlinear source-filter theory predicts a preference in placing harmonics on the left side of a formant (in the inertive reactive region below the formant frequency) as opposed to the right side (in the compliant reactive region above the formant frequency). Fortunately, the vocal tract has more than one formant, so vowels can be chosen such that a "leap over a formant" can be made by a harmonic to land on the upslope of an adjacent formant. Thus, choosing favorable vowels on an ascending pitch scale, for example, is like walking up a tall mountain that has multiple peaks and valleys along the way. You stay on the upslopes and try to leap over the valleys as quickly and effectively as possible.

Figure 2 shows the process. Ten vowels are represented as nearly horizontal lines, with the peaks and valleys in the curves representing the changes in vocal tract *inertance* (inertive reactance divided by angular frequency ω). Vocal tract inertance has been shown to enhance vocal fold vibration (Titze, 1988). The greater the inertance, the more enhancement there will be for a harmonic of the source. Inertance changes rapidly only near the formants. For the uu = /u/ vowel, for example, the first formant is near C_4; for the ih = / I / vowel, the first formant is near C_5; for the ae = / æ / vowel, the first formant is between C_5 and C_6 (note the pitch labels C_2, C_3, C_4, C_5, and C_6 on horizontal axes). For any selected pitch, there will be a series of harmonics cre-

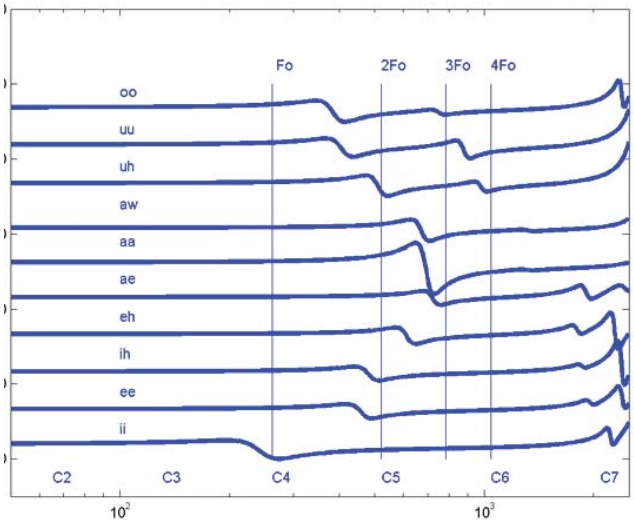

Fig. 2. Vocal tract inertance for 10 vowels as a function of frequency

Source-Filter Interaction

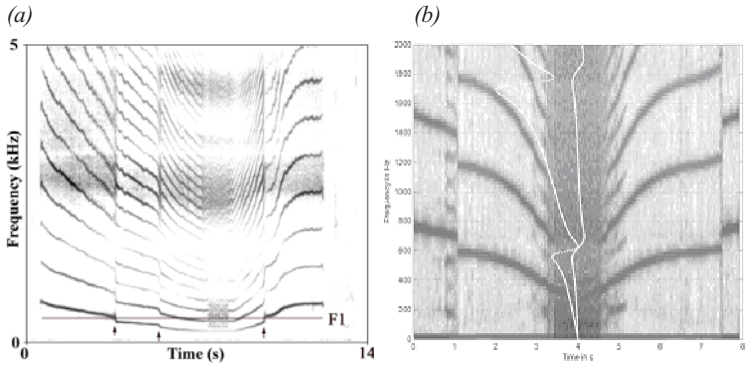

Fig. 3. Spectrograms of pitch glides, (a) female subject, (b) computer simulation with white lines showing the reactance curves for subglottis and supraglottis.

ated at the source. The first four harmonics are shown as vertical lines in Figure 2 for a pitch C_4. Note the location of these harmonics (F_0, $2F_0$, $3F_0$, and $4F_0$, as labeled on top) in the peak and valley terrain of the vowels. Stable and acoustically strong productions result when each of these harmonics resides in high inertance territory, which is to the left of a formant. Whenever a dominant harmonic lands near formant, where inertance rises and falls quickly, vocal fold vibration can be de-stabilized, or the sound output changes suddenly from strong to weak (or vice versa). For the C_4 pitch chosen in the illustration, F_0 is destabilized with the vowel uu = /u/, $2F_0$ is destabilized with the vowel ih = / I /, and /uh/ = /U/, and $3F_0$ is destabilized with the vowels eh = / ɛ / and ae = / æ /. As the pitch changes, of course, different vowels present problems for the harmonics. Thus, the singer modifies the vowels to maintain consistency of harmonic energy throughout the pitch range.

Figure 3a shows a pitch glide performed by a female subject and Figure 3b shows an interactive computer simulation of a similar glide. The degree of source-filter interaction in the simulation was controlled by the cross sectional area of the epilarynx tube. Both subglottal (to the right) and supraglottal (to the left) reactance curves are shown in white on Figure 3b. These are curves similar to those in Figure 2, but vertically oriented. In the simulation, there were two F_0 drops, one at about 1.0 s, where F_0 entered the region of subglottal positive reactance, and another at about 3.0 s, where F_0 entered the region of positive subglottal reactance. A period-3 bifurcation occurred when $2F_0$ entered the compliant region. Some evidence of chaotic vibration was seen around 4.0 s, where the lowest F_0 and the highest vibration amplitude occurred.

In summary, source-filter interaction can be divided into two levels. One level is the interaction of glottal airflow with acoustic vocal tract pressures. This nonlinear interaction produces harmonic distortion frequencies that contribute to the overall source spectrum. It occurs in all speech and singing, for males, females, and children. This interaction contributes to the spectral envelope, even when the spectrum is purely harmonic and no bifurcations occur. A more dramatic level of interaction occurs in high F_0 productions for which the dominant harmonics (F_0, $2F_0$, $3F_0$, and $4F_0$) cross the formants. A variety of new source frequencies can then be produced, including subharmonics, frequency jumps, and deterministic chaos. A control parameter for interaction is the cross sectional area of the epilarynx tube, the equivalent of a mouthpiece of a trumpet. With this parameter, a vocalist has the choice to operate in a nearly linear region, with a slightly reduced power output but maximum harmonic stability. Conversely, greater output power and greater efficiency can be realized in the highly nonlinear region of operation, but at the expense of less harmonic stability.

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Uwe Hansen and the Salt Lake City Jazz Orchestra present a tutorial on Musical Acoustics

New fellows of the Acoustical Society of America receive fellowship certificates from ASA President and Vice President (l to r): ASA President Anthony Atchley, Karim Sabra, Claire Prada, Albert Migliori, Hedwig Gockel, T. Douglas Mast, Paul Barbone, Stephen Elliott, Damian Doria, Michael Bailey, ASA Vice President Whitlow Au.

Echoes from Salt Like City

Katherine Harris receives the Gold Medal from President Anthony Atchley.

President Atchley presents the Rossing Prize in Acoustics Education to William Strong.

From the Student Council

Andrew Ganse

Welcome back from the Salt Lake City meeting! OK, maybe this time it didn't involve sipping cocktails on the beach like the previous meeting in Hawaii, but the students made the most of it all the same. The immensely popular night out with the dueling pianos was described as the very best student outing yet.

The student council filtered through all the nomination letters and voted on the next Mentoring Award recipient, to be presented at the New Orleans meeting in the fall. This award recognizes exceptional mentorship of students and junior colleagues by an ASA member; a full description of the award is available on the ASAStudentZone.org website.

Be sure to consider attending the third workshop on fellowships, grants, and contracts at the New Orleans meeting. A panel session will discuss subjects such as eligibility and applications for funding, and for what purposes the funding is allowed. This workshop is not just for students, but also for post-docs and new researchers.

Plans are already underway at ASA for the summer 2008 meeting in Paris, France. Students should be aware that the cost of the Paris meeting will be substantially more than for domestic ASA meetings (including a significant registration fee), and so will require more advance planning and more applications for financial assistance. But hey, it's Paris!

Ah, but in the meantime we have New Orleans to think about. We can always practice our French there—bring out the beignets!

À bientôt mes amis...

Andrew Ganse is a theoretical seismology graduate student at the University of Washington and the student representative for Underwater Acoustics. (aganse@apl.washington.edu)

Best student paper/young presenter awards (Salt Lake City)

Architectural Acoustics
First: Michelle Vigeant (U. Nebraska-Lincoln)
Second: Yun Jing (Rensselaer)

Acoustical Oceanography
First: Kevin Cockrell (MIT)
Second: Jan Dettmer (U. Victoria)

Biomedical Ultrasound/Bioresponse to Vibration
First: Matt Urban (Mayo Clinic School of Medicine)
Second: Jose Sanchez (U. Illinois)

Engineering Acoustics
First: Brian Anderson (Penn State)
Second: Brian Borowski (Stevens Inst. Tech.)

Musical Acoustics
First: Brian Monson, (U. Arizona)
Second: John Anderson Mills III (U. Texas-Austin)

Noise Young Presenter
Benjamin Shafer (Brigham Young U.)

Signal Processing in Acoustics Young Presenter
Daniel Mennitt (Virginia Tech.)
Georges Dossot (U. Rhode Island)

Speech Communication
First: Yolanda Holt (Ohio State)
Second: Wendy Herd (U. Kansas)

Structural Acoustics and Vibration
First: Samuel Adams (Imperial College)
Second: Richard Dziklinski III (Wayne State U.)

Underwater Acoustics
First: Philip Gillett (Virginia Tech.)
Second: Claire Debever (Scripps Inst. Oceanography)

Gallery of Acoustics (Salt Lake City)

Winner of the Gallery of Acoustics was Takayuki Arai, Sophia University, Tokyo for his entry "Acoustic Demonstrations of Vowel Production Using Vocal-Tract Models"

Scanning the Journals

Thomas D. Rossing

•An invited review of **Lord Rayleigh's contributions to acoustics** by D. Murray Campbell appears in the July issue of *Acoustical Science and Technology*. The paper begins with a brief biography, followed by discussions of some of Rayleigh's more important acoustics papers, including his first on the theory of resonances, the Rayleigh disc, his energy-based approach to the study of vibrating systems (widely known as Rayleigh's principle), and Rayleigh waves that propagate on the surfaces of elastic solids (and now form the basis of surface acoustic wave (SAW) devices.

•Clownfish are prolific singers that produce a wide variety of sounds, and their **sound producing mechanism** is the subject of a paper in the 18 May issue of *Science*. An unusual sonic ligament, responsible for a rapid lower jaw elevation, is the key. The ligament, acting as a cord, forces the mandible to turn around, which forces the mouth to close. Sound results from the collisions of the jaw teeth, transferring energy to the jaws that radiate the sound. Clownfish produce a wide variety of sounds, described as "chirps" and "pops" with energy between 450 and 800 Hz.

•According to an article entitled "How the **brain can hear shapes**" in the 26 May issue of *New Scientist*, seeing may depend less on our eyes than we thought. When you identify an object's shape, a particular part of your brain called the lateral-occipital tactile-visual area (LOtv) "lights up." At first this area was thought to be purely visual, but several years ago it was shown that touch can also activate it. Now it has been discovered that "hearing" a shape can also activate it (see following article in *Nature Neuroscience*. Researchers taught seven sighted volunteers to use a device called "The voice," which converts visual details into sound, using pitch to represent up and down, and volume to reflect brightness. They then performed MRI scans of the volunteers' brains, plus those of two expert blind users of the device,

•The lateral-occipital tactile-visual area (LOtv) is activated when objects are recognized by vision or touch. A paper in *Nature Neuroscience,* the LOtv is also activated in sighted and blind humans who recognize objects by extracting shape information from **visual-to-auditory sensor** substitution soundscapes (see previous article in *New Scientist*). Recognizing objects by their typical sounds or learning to associate specific soundscapes with specific objects do not activate this region.

•Various aspects of the **quartz tuning fork** are discussed in a paper in the May issue of *American Journal of Physics*. Its original purpose was a high quality factor resonator for use as a stable frequency reference, but it has also seen more exotic applications in sensing and scanning probe microscopy. The paper discusses how to tune the quality factor by injecting energy in phase with the current at resonance (quality factor increase) or out of phase (quality factor decrease). The principle of shear force scanning probe microscopy is demonstrated on a simple profiler. The interaction between the tuning fork and the surface under investigation influences the current through the tuning fork by perturbing the resonance frequency of the prong in contact with the sample.

•Waves generated deep inside the Sun and other stars help astronomers see the hidden core where energy-producing fusion reactions occur, according to an article in the 15 June issue of *Science*. These waves, similar in some ways to seismic waves on Earth, come in two main types: gravity waves or "g modes" that are driven by buoyancy, and pressure waves or "p modes," which are **sound waves**. It is possible to understand what is happening inside the Sun by observing the oscillations produced on the solar surface by these modes. P modes are trapped in the Sun's outer layers and only a few penetrate below a fractional radius of 0.2 into the core of the Sun. G modes, on the other hand, are trapped in the core as well as in the radiative zone.

•The "**effective mass of an oscillating spring**" is the subject of a paper in the February issue of *The Physics Teacher*. Measured values for the mass presented in the paper are in good agreement with those calculated using a simple model. The calculation and experimental observations are made with varying number of coils oscillating. The oscillation period is proportional to the number of active coils.

•Some of the ways in which weather in one part of the world affects others is explained by a model based on planetary waves, according to note in the 3 June issue of *Nature Physics*. The interacting **planetary waves**, in particular the interaction of four resonant clusters, each composed of three modes, explains why intraseasonal oscillations affect both the Northern and Southern hemispheres and why these oscillations are more observable in winter.

•Shake a can of mixed nuts and the "**Brazil nut effect**" often brings the largest nuts to the top, an article in the July issue of *Physics World* reminds us. However the "reverse Brazil-nut effect" (see Winter 2005 issue of *ECHOES*) often occurs in containers with particles of different sizes and densities when the larger particles are heavy enough to push the smaller particles out from beneath them or when the shaking is violent enough that gaps between smaller particles become large enough for the large particles to fall through. Now researchers have observed an abrupt transition between the two effects. A glass tube with a mixture of glass spheres 1.4 mm in diameter and brass spheres 2.4 mm in diameter was shaken at 20 Hz. At the end of one hour, a reverse-Brazil nut state was observed, with nearly all the large spheres sinking to the bottom of the tube, but after about 25 hours of shaking, the larger brass spheres suddenly started drifting upwards and within an hour were all at the top of the tube where they remained for the next 180 hours. It is believed that the change was caused by increased friction between the spheres which became scratched and scuffed after hours of vibration. They repolished the scuffed spheres in an ultrasonic cleaner, and again the brass spheres started off at the bottom of the tube for 25 hours before rising again to the top.

•Male **humpback whales** are faced with an interesting dilemma, according to a paper in the 26 May issue of *New Scientist*: should they sing and attract females or should they stay quiet to eat more? Males that sing swim more slowly than those that don't, possibly ending up with less time in the feeding grounds to fatten up for the next winter. Using hydrophones to record capture their song during migration to the Antarctic feeding grounds, scientists at the University of Sydney found that singers averaged 2.5 km/hr, compared to 4 km/hr for non-singing males.

•The May issue of *Acoustical Science and Technology* is a special issue on **applied acoustical systems**. The eight papers (3 on

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Scanning the Journals

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electroacoustics, 4 on speech, and 1 on ultrasonics) were all published first in Japanese in the *Journal of the Acoustical Society of Japan*. According to the foreword to the issue, the ASJ editorial board felt that the two journals have not been too friendly to papers on applied systems and/or acoustic engineering. Thus the guide for contributors has been broadened to include applied problems that are considered to make significant contributions to any field of acoustics or acoustic engineering. One of the papers in the special issue deals with "Speech recognition interface system for digital TV control"; another with "A low-bit-rate audio codec using mel-scaled linear predictive analysis."

- The **balance of scientific power** is moving east as scientists in the Asia-Pacific region learn to collaborate more effectively according to an editorial in the 21 June issue of *Nature*. The Asian research community is particularly strong in the physical sciences. In terms of the raw volume of physics papers published in journals, the region is neck-and-neck with the United States and slightly behind Europe. In engineering, all three regions are in a dead heat, and in photonics, Asia has a commanding lead. In nanoscience and materials, the region accounts for nearly as much as the United States and Europe combined. Areas of common interest, such as global warming, will serve to pull Asian scientists more closely together. At a meeting of the science ministers of South Korea, Japan, and China in January, energy, bioinformatics, disaster prevention, and traditional medicine were identified as holding promise for collaboration.
- A laboratory experiment designed to show the properties of **internal solitary waves** is described in the July issue of *American Journal of Physics*. Since the ocean is vertically stratified in temperature and salinity, and thus in density, internal waves exist below the sea surface. An important class of nonlinear internal waves are the so-called internal solitary waves, which exhibit the shape of a single hump of unchanging form, as opposed to the sinusoidal shape that characterizes linear waves. For the experiment, a Plexiglass tank is partly filled with a layer of water, and a colored salt solution is carefully injected below it. To excite the solitary wave a gate is quickly raised, allowing an extra volume of salt water to propagate away from the end of the tank.
- The second of two papers on modeling the mechanical response of the **reed-mouthpiece-lip system** of a clarinet appears in the May/June issue of *Acta Acustica/Acustica*. In this paper, a non-linear lumped model of the reed-mouthpiece-lip system is formulated, in which the lumped parameters are derived from numerical experiments with a finite-difference simulation based on a distributed reed model. A discrete-time formulation is presented, and its response compared to that of the distributed model. The results are in qualitative agreement with players' experiences and experimental results obtained in prior studies.
- **Perception of pitch** and spatial orientation appear to be linked in our brains, according to a paper in the July issue of *Nature Neuroscience*. Tone-deaf people—also known as "amusics"—were found to have poorer spatial skills than those who have no problem distinguishing between two musical notes. Volunteers were asked to mentally rotate an object and click on a picture of how it would look when rotated. Amusic subjects made more than twice as many errors as the control groups of musicians. The researchers went on to see if their volunteers could perform both tasks, pitch discrimination and object rotation, at the same time. The control groups found this difficult, and took much longer to mentally rotate objects when they also had to discriminate between two notes. This is presumably because the tasks interfered with each other.
- The August issue of *Applied Acoustics* includes a special feature on **Head-Related Transfer Function** and its Applications edited by Kazuhiro Iida. Six papers on the subject are featured.
- A quick study of the perceptual basis for **audio compression** appears in the June issue of *Physics Today*. Because the ear ignores small amounts of noise that accompany a strong signal, much of the information in audio files can be thrown away with little loss of fidelity. Narrowband noise becomes inaudible once it is about 6 dB lower than a music signal with the same frequency range. For a person to enjoy the music, a ratio of 10 dB is more than sufficient. The perceptual quality of an audio coder depends to a large extent on the quality of the psychoacoustical model and the signal processing algorithm for shaping quantization noise according to the model. Present day audio coders apply psychoacoustic models and signal processing techniques to have a nearly 15-fold compression ratio. The greatest potential for further compression is expected from exploiting the perceptual similarity of the various channels of a stereo or multichannel signal. Compression ratios of 100 or more may be possible.
- "**Stop the Decibel Damage**" is the title of a column by Bernadine Healy, former director of the National Institutes of Health, in the July 16 issue of *U.S. News & World Report*. Noise-induced hearing loss creeps up painlessly and silently. Although jet engines and explosions are obvious culprits, it's the power tools and lawn mowers, the blare of music through earphones, the hair dryers and vacuum cleaners that cause damage gradually over time, she reminds us. Although noise avoidance is the best policy, when a loud sound environment is unavoidable, earplugs or muffs can cut noise by 30 dB or more. Just recently, Apple filed a patent for a new software designed to track a headphone user's exposure to loud music and automatically reduce volume as needed.
- The qualitative effect of a **major disturbance, such as an earthquake or a hurricane** on a large body of water, can be simulated in a partially filled wineglass, according to a paper in the July issue of *American Journal of Physics*. A quantitative analysis explains how a resonance can occur on the liquid surface in the wineglass, and a powerboat traveling along the edge of a circular harbor of varying depth and curvature could also cause a resonance.
- The ability to comprehend a phone message in one ear while a friend is talking into the other ear is an important **communication skill** that's heavily influenced one's genes, according to a paper in the August issue of *Human Genetics*. This finding may help researchers better understand a broad and complex group of disorders, called auditory processing disorders (APDs), in which individuals with otherwise normal hearing have trouble making sense to the sounds around them. The researchers point out that our auditory system doesn't end with our ears; it also includes the part of our brain that helps us interpret the sounds we hear. In the tests, in which one-syllable words were fed into the subjects' two ears, identical twins scored higher than fraternal twins who do not share the same genes.

Acoustics in the News

• "Could it be that we're entering a golden age in **concert hall design**?" begins a story in the Arts & Leisure section of the June 3 issue of *The New York Times*. Heading the list of exciting new designs are the Walt Disney Concert Hall in Los Angeles (Frank Gehry), the Elbe Philharmonic Hall in Hamburg (Herzog & de Meuron), and the Paris Philharmonie (Jean Nouvel). The new halls "seek to root classical music firmly in the present and forge an intimate bond among orchestras, audience and music." For more than a century, conventional wisdom for creating a great hall was a narrow, high, rectangular "shoe box" such as Vienna's Musikverein, but to contemporary architects the gold standard is the 2440-seat Berlin Philharmonie, opened in 1963.

An amusing paragraph describes a dinner conversation architect Frank Gehry had in Berlin with acousticians Lothar Cremer and Minoru Nagata at which they discussed the preferable acoustical concert hall model. Cremer preferred a coffin-shaped hall, wider at the orchestra, while Nagata firmly favored a wedge shape. "You're the best acousticians in the world, and you can't agree on this?" Gehry remembers commenting. There was no answer. Acoustically, some of the most respected concert halls built in the past decade include the Suntory Hall in Tokyo and the Kitara Hall in Sapporo, but neither is particularly adventurous.

• Immense coils of hot, electrified gas in the Sun's atmosphere behave like a **musical instrument**, according to a story in the April 20 edition of *BBC News*. Coronal loops, generated by the Sun's magnetic field, carry acoustic waves in much the same way that sound is carried through a pipe organ. Solar explosions called micro-flares generate sound booms which are then propagated along the coronal loops. The corona is an atmosphere of hot, electrically charged gas or plasma that surrounds the Sun. The temperature of the corona should drop the further one moves from the Sun, but, in fact, the coronal temperature is up to 300 times hotter than the Sun's visible surface or photosphere, and no one can explain why.

• Researchers claim to have found **music** encoded in intricate ceiling carvings in the 15th-century Rosslyn Chapel near Edinburgh, Scotland, according to a story in the May 3 issue of *USA Today*. This is the chapel where author Dan Brown set the climax of his best-selling book *The Da Vinci Code*. Thomas Mitchell, a former military code breaker, and his son Stuart, a music teacher, claim to have deciphered the musical notations hewn into stone cubes on the ribs supporting the ceiling. Experts on early Scottish music reserved judgment but did not dismiss the theory.

• Enormous **sound waves** seen rippling through a galaxy cluster are heating up its gas, according to a story in the 25 May issue of *New Scientist*. This may explain why such clusters refuse to cool down. Astronomers discovered in the 1970s that vast reservoirs of gas located in galaxy clusters glow brightly in x-rays. This suggested that the gas should be cooling and contracting as it radiates its energy away. But in 2001, new observations failed to find pools of cool gas, puzzling astronomers. One possible explanation of the heating came in 2003 when the Chandra X-ray Observatory detected enormous ripples in the gas inside the Perseus galaxy cluster. The sound waves were thought to be generated by an active galaxy at the core of the cluster. Richard Mushotzky of NASA's Goddard Space Flight Center compared the results of the study to analyzing music played by an orchestra. "Now, in addition to knowing what notes are being played, we know how loud the notes are," he told *New Scientist*.

• Studying the **hearing of birds** may provide clues to determine how humans learn to talk, according to a story in the 25 May issue of the *Baltimore Sun*. Robert Dooling, a University of Maryland psychologist, and his students have tested the hearing of dozens of birds and attempted to decipher their songs into language. In one experiment they slipped tiny headphones over birds' ears to determine how they respond when they are trained to produce one sound but hear something different as they sing. If a human tries to recite a phrase and hears a recorded version delayed by a quarter-second, he will begin to stutter or get confused. Birds do, too. Dooling and his students have found that the size of the basilar papilla, a structure found in a bird's inner ear, correlates well with its range of hearing. Because birds are related to dinosaurs, the same relationship likely holds true for at least three types of dinosaurs.

• Officials at Purdue University have launched a new inquiry into **bubble fusion** researcher Rusi Taleyarkhan, just months after exonerating him of research misconduct, according to a story in the 18 May issue of *Science*. The inquiry was brought to light by a congressional report that criticized the earlier investigation. The new investigation is expected to take three months.

• The proposed **Philharmonie de Paris** concert hall in the Parc de la Villette is described in the April 14 issue of *The New York Times*. The $260 million concert hall by the French architect Jean Nouvel is scheduled to be opened in 2012. Politics rather than culture may have led to locating the new concert hall in an outlying zone, once crowded with slaughterhouses. La Vilette today offers a science museum, the national conservatory, a rock concert hall, a large exhibition space, and the Cité de la Musique, with its own 1200-seat concert hall and music museum. Nouvel, who designed concert halls in Lucerne and Copenhagen will be assisted by the Australian acoustical firm Marshall Day, associated with Yasuhisa Toyota of Nagata Acoustics of Japan. The 2400-seat concert hall will be in a "vineyard" style, comparable to the Berlin's Philharmonie hall, allowing the public to occupy seats behind the orchestra when those are not needed for a choir. Suspended balconies will be attached to the building by access passages, allowing sound waves to circulate around and behind them. "The idea is that the audience will be in the middle of the music," Nouvel said.

• The SCORE (Stove for Cooking, Refrigeration and Electricity), using **thermoacoustics**, is being developed at the University of Nottingham, according to a story in the 14 May issue of *news@nature.com*. In the SCORE system, burning wood heats a gas-filled pipe at one end. The gas moves from the hot part, where it expands, to the cold part, where it contracts. The pipe then resonates rather like an organ pipe. Acoustic pressure waves can produce electricity, and the sound waves are also used to drive a second engine that operates as a heat pump to remove heat from a refrigeration unit.

Acoustics in the News

Heat from the burning wood can also be used for cooking. SCORE aims to be producing these fridge/stoves in five years.

• Recent anesthetics research shows that action of nerves is based on **sound pulses** rather than electrical signals, according to a story in the March 19 issue of *Science Daily*. Nerves are "wrapped" in a membrane composed of lipids and proteins. According to the traditional explanation of molecular biology, a pulse is sent from one end of the nerve to the other with the help of electrically charged salts that pass through ion channels in the membrane. But according to researchers in Copenhagen the fact that the nerve pulse does not produce heat contradicts the molecular biological theory of an electrical impulse produced by chemical processes. Instead, nerve pulses can be explained much more simply as a sound pulse. If the medium in which the sound propagates has the right properties, it is possible to create localized sound pulses, known as solitons, which propagate without spreading and without changing their shape or losing their strength.

The effect of anesthetics are explained as changes in the melting point of the membrane which has the effect of blocking sound waves. The nerve is put on stand-by, and neither nerve pulses nor sensations are transmitted. The patient is anesthetized and feels nothing.

• There is a connection between an area's **daytime noise levels** and the number of birds singing at night, according to a story in the 25 April issue of *BBC News* online. Light pollution had been considered a major factor since it discourages the birds from roosting, but daytime noise was found to have a much stronger effect. Noise levels were 10 times higher in places where birds were singing at night.

• One of the first citations under New York's new **noise legislation** was issued to a Mister Softee ice cream truck, according to a story in the July 6 issue of *The New York Times*. The legislation, which was signed by Mayor Bloomberg in December 2005 gave the city 18 months to prepare. The fine for failing to turn off the truck's jingle while parked at a curb is expected to be $350.

• About one in six baby boomers have **hearing loss**, according to a story in the July 12 issue of *The New York Times*. In fact, there are more people age 45 to 64 with hearing loss (10 million) than there are people over 65 with hearing loss (9 million). The devices they are wearing to aid their hearing are called "personal communications assistants" (PCAs) rather than hearing aids, and they come in designer colors like sunglasses. Some of them have integrated wireless connectivity, so they can stream a cellphone call or music and audio from a radio into the ears. The executive director of the Better Hearing Institute predicts that buildings will install wireless transmitters so a voice from many feet away can be streamed into the ears of listeners wearing such devices.

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