Glossary

1/f noise: A type of random noise that increases in amplitude at lower frequencies. It is widely observable in physical systems, but not well understood. See *white noise* for comparison.

-3dB cutoff frequency: The division between a filter's passband and transition band. Defined as the frequency where the frequency response is reduced to -3dB (0.707 in amplitude).

"A" law: Companding standard used in Europe. Allows digital voice signals to be represented with only 8 bits instead of 12 bits by making the quantization levels unequal. See *mu law* for comparison.

AC: Alternating Current. Electrical term for the portion of a signal that fluctuates around the average (DC) value.

Accuracy: The error in a measurement (or a prediction) that is repeatable from trial to trial. Accuracy is limited by systematic (repeatable) errors. See *precision* for comparison.

Additivity: A mathematical property that is necessary for linear systems. If input a produces output p, and if input b produces output q, then an input of $a+b$ produces an output of $p+q$.

Aliasing: The process where a sinusoid changes from one frequency to another as a result of sampling or other nonlinear action. Usually results in a loss of the signal's information.

Amplitude modulation: Method used in radio communication for combining an information carrying signal (such as audio) with a carrier wave. Usually carried out by multiplying the two signals.

Analysis: The forward Fourier transform; calculating the frequency domain from the time domain. See *synthesis* for comparison.

Antialias filter: Low-pass analog filter placed before an analog-to-digital converter. Removes frequencies above one-half the sampling rate that would alias during conversion.

ASCII: A method of representing letters and numbers in binary form. Each character is assigned a number between 0 and 127. Very widely used in computers and communication.

Aspect ratio: The ratio of an image's width to its height. Standard television has an aspect ratio of 4:3, while motion pictures have an aspect ratio of 16:9.

Assembly: Low-level programming language that directly manipulates the registers and internal hardware of a microprocessor. See *high-level language* for comparison.

Associative property of convolution: Written as: $(a[n] * b[n]) * c[n] = a[n] * (b[n] * c[n])$. This is important in signal processing because it describes how cascaded stages behave.

Autocorrelation: A signal correlated with itself. Useful because the Fourier transform of the autocorrelation is the power spectrum of the original signal.

Backprojection: A technique used in computed tomography for reconstructing an image from its views. Results in poor image quality unless used with a more advanced method.

BASIC: A high-level programming language known for its simplicity, but also for its many weaknesses. Most of the programs in this book are in BASIC.

Basilar membrane: Small organ in the ear that acts as a spectrum analyzer. It allows different fibers in the cochlear nerve to be stimulated by different frequencies.

Basis functions: The set of waveforms that a decomposition uses. For instance, the basis functions for the Fourier decomposition are unity amplitude sine and cosine waves.

Bessel filter: Analog filter optimized for linear phase. It has almost no overshoot in the step response and similar rising and falling edges. Used to smooth time domain encoded signals.

Bidirectional filtering: Recursive method used to produce a zero phase filter. The signal is first filtered from left-to-right, then the intermediate signal is filtered from right-to-left.

Bilinear transform: Technique used to map the s-plane into the z-plane. Allows analog filters to be converted into equivalent digital filters.

Binning: Method of forming a histogram when the data (or signal) has numerous quantization levels, such as in floating point numbers.

Biquad: An analog or digital system with two poles and up to two zeros. Often cascaded to create a more sophisticated filter design.

Bit reversal sorting: Algorithm used in the FFT to achieve an interlaced decomposition of the signal. Carried out by counting in binary with the bits flipped left-for-right.

Blackman window: A smooth curve used in the design of filters and spectral analysis, calculated from: $0.42 - 0.5\cos(2\pi n/M) + 0.08\cos(4\pi n/M)$, where n runs from 0 to M.

Brightness: The overall lightness or darkness of an image. See *contrast* for comparison.

Butterfly: The basic computation used in the FFT. Changes two complex numbers into two other complex numbers.

Butterworth filter: Separates one band of frequencies from another; fastest roll-off while keeping the passband flat; can be analog or digital. Also called a *maximally flat* filter.

C: Common programming language used in science, engineering and DSP. Also comes in the more advanced *C++*.

Carrier wave: Term used in amplitude modulation of radio signals. Refers to the high frequency sine wave that is combined with a lower frequency information carrying signal.

Cascade: A combination of two or more stages where the output of one stage becomes the input for the next.

Causal signal: Any signal that has a value of zero for all negative numbered samples.

Causal system: A system that has a zero output until a nonzero value has appeared on its input (i.e., the input *causes* the output). The impulse response of a causal system is a causal signal.

Central Limit Theorem: Important theorem in statistics. In one form: a sum of many random numbers will have a Gaussian pdf, regardless of the pdf of the individual random numbers.

Cepstrum: A rearrangement of "spectrum." Used in homomorphic processing to describe the spectrum when the time and frequency domains are switched.

Charge coupled device (CCD): The light sensor in electronic cameras. Formed from a thin sheet of silicon containing a two-dimensional array of light sensitive regions called *wells*.

Chebyshev filter: Used for separating one band of frequencies from another. Achieves a faster roll-off than the Butterworth by allowing ripple in the passband. Can be analog or digital.

Chirp system: Used in radar and sonar. An impulse is converted into a longer duration signal before transmission, and compressed back into an impulse after reception.

Circular buffer: Method of data storage used in real time processing; each newly acquired sample replaces the oldest sample in memory.

Circular convolution: Aliasing that can occur in the time domain when frequency domain signals are multiplied. Each period in the time domain overflows into adjacent periods.

Circularity: The appearance that the end of a signal is connected to its beginning. This arises when considering only a single period of a periodic signal.

Classifiers: A parameter extracted from and representing a larger data set. For example: size of a region, amplitude of a peak, sharpness of an edge, etc. Used in pattern recognition.

Closing: A morphological operation defined as an erosion operation followed by a dilation operation.

Cochlea: Organ in the ear where sound in converted into a neural signal.

Cochlear nerve: Nerve that transmits audio information from the ear to the brain.

Coefficient-of-variation (CV): Common way of

stating the variation (noise) in data. Defined as: 100% × standard deviation / mean.

Commutative property of convolution: Written as: $a[n] \ast b[n] = b[n] \ast a[n]$.

Companding: An "s" shaped nonlinearity allows voice signals to be digitized using only 8 bits instead of 12 bits. Europe uses "*A*" *law*, while the United States uses the *mu law* version.

Complex conjugation: Changing the sign of the imaginary part of a complex number. Often denoted by a star placed next to the variable. Example: if $A = 3 + 2j$, then $A^* = 3 - 2j$.

Complex DFT: The discrete Fourier transform using complex numbers. A more complicated and powerful technique than the *real* DFT.

Complex exponential: A complex number of the form: e^{a+bj}. They are useful in engineering and science because Euler's relation allows them to represent sinusoids.

Complex Fourier transform: Any of the four members of the Fourier transform family written using complex numbers. See *real Fourier transform* for comparison.

Complex numbers: The *real numbers* (used in everyday math) plus the *imaginary numbers* (numbers containing the term j, where $j = \sqrt{-1}$). Example: $3 + 2j$.

Complex plane: A graphical interpretation of complex numbers, with the real part on the x-axis and the imaginary part on the y-axis. This is analogous to the *number line* used with ordinary numbers.

Composite video: An analog television signal that contains synchronization pulses to separate the fields or frames.

Computed tomography (CT): A method used to reconstruct an image of the interior of an object from its x-ray projections. Widely used in medicine; one of the earliest applications of DSP. Old name: CAT scanner.

Continuous signal: A signal formed from continuous (as opposed to discrete) variables. Example: a *voltage* that varies with *time*. Often used interchangeably with *analog signal*.

Contrast: The difference between the bright-ness of an object and the brightness of the background. See *brightness* for comparison.

Converge: Term used in iterative methods to indicate that progress is being made toward a solution ("The algorithm is converging") or that a solution has been reached ("The algorithm has converged").

Convolution integral: Mathematical equation that defines convolution in continuous systems; analogous to the *convolution sum* for discrete systems.

Convolution kernel: The impulse response of a filter implemented by convolution. Also known as the *filter kernel* and the *kernel*.

Convolution sum: Mathematical equation defining convolution for discrete systems.

Cooley and Tukey: J.W. Cooley and J.W. Tukey, given credit for bringing the FFT to the world in a paper they published in 1965.

Correlation: Mathematical operation carried out the same as convolution, except a left-for-right flip of one signal. This is an optimal way to detect a known waveform in a signal.

Cross-correlation: The signal formed when one signal is correlated with another signal. Peaks in this signal indicate a similarity between the original signals. See also *autocorrelation*.

Cutoff frequency: In analog and digital filters, the frequency separating the passband from the transition band. Often measured where the amplitude is reduced to 0.707 (-3dB).

CVSD: Continuously Variable Slope Delta modulation, a technique used to convert a voice signal into a continuous binary stream.

DC: Direct Current. Electrical term for the portion of the signal that does not change with time; the average value or mean. See *AC* for comparison.

Decibel SPL: Sound Pressure Level. Log scale used to express the intensity of a sound wave: 0 dB SPL is barely detectable; 60 dB SPL is normal speech, and 140 dB SPL causes ear damage.

Decimation: Reducing the sampling rate of a digitized signal. Generally involves low-pass filtering followed by discarding samples. See *interpolation* for comparison.

Decomposition: The process of breaking a signal into two or more additive components. Often refers specifically to the *forward Fourier transform*,

breaking a signal into sinusoids.

Deconvolution: The inverse operation of convolution: if $x[n] * h[n] = y[n]$, find $x[n]$ given only $h[n]$ and $y[n]$. Deconvolution is usually carried out by dividing the frequency spectra.

Delta encoding: A broad term referring to techniques that store data as the difference between adjacent samples. Used in ADC, data compression and many other applications.

Delta function: A normalized impulse. The discrete delta function is a signal composed of all zeros, except the sample at zero that has a value of one. The continuous delta function is similar, but more abstract.

Delta-sigma: Analog-to-digital conversion method popular in voice and music processing. Uses a very high sampling rate with only a single bit per sample, followed by decimation.

Dependent variable: In a signal, the dependent variable depends on the value of the indepen-dent variable. Example: when a voltage changes over time, time is the independent variable and voltage is the dependent variable.

Difference equation: Equation relating the past and present samples of the output signal with past and present samples of the input signal. Also called a *recursion equation*.

Dilation: A morphological operation. When applied to binary images, dilation makes the objects larger and can combine disconnected objects into a single object.

Discrete cosine transform (DCT): A relative of the Fourier transform. Decomposes a signal into cosine waves. Used in data compression.

Discrete derivative: An operation for discrete signals that is analogous to the derivative for continuous signals. A better name is the *first difference*.

Discrete Fourier transform (DFT): Member of the Fourier transform family dealing with time domain signals that are *discrete* and *periodic*.

Discrete integral: Operation on discrete signals that is analogous to the integral for continuous signals. A better name is the *running sum*.

Discrete signal: A signal that uses quantized variables, such as a digitized signal residing in a computer.

Discrete time Fourier transform (DTFT): Member of the Fourier transform family dealing with time domain signals that are *discrete* and *aperiodic*

Dithering: Adding noise to an analog signal before analog-to-digital conversion to prevent the digitized signal from becoming "stuck" on one value.

Domain: The independent variable of a signal. For example, a voltage that varies with time is in the *time domain*. Other common domains are the *spatial domain* (such as images) and the *frequency domain* (the output of the Fourier transform).

Double precision: A standard for floating point notation that used 64 bits to represent each number. See *single precision* for comparison.

DSP microprocessor: A type of microprocessor designed for rapid math calculations. Often has a pipeline and/or Harvard architecture. Also called a RISC.

Dynamic range: The largest amplitude a system can deal with divided by the inherent noise of the system. Also used to indicate the number of bits used in an ADC. Can also be used with parameters other than amplitude; see *frequency dynamic range*.

Edge enhancement: Any image processing algorithm that makes the edges more obvious. Also called a *sharpening* operation.

Edge response: In image processing, the output of a system when the input is an edge. The sharpness of the edge response is often used as a measure of the resolution of the system.

Elliptic filter: Used to separate one band of frequencies from another. Achieves a fast roll-off by allowing ripple in the passband and the stopband. Can be used in both analog and digital designs.

End effects: The poorly behaved ends of a filtered signal resulting from the filter kernel not being completely immersed in the input signal.

Erosion: A morphological operation. When applied to binary images, erosion makes the objects smaller and can break objects into two or more pieces.

Euler's relation: The most important equation in complex math, relating sine and cosine waves with

complex exponentials.

Even/odd decomposition: A way of breaking a signal into two other signals, one having even symmetry, and the other having odd symmetry.

Even order filter: An analog or digital filter having an even number of poles.

False-negative: One of four possible outcomes of a target detection trial. The target is present, but incorrectly indicated to be not present.

False-positive: One of four possible outcomes of a target detection trial. The target is not present, but incorrectly indicated to be present.

Fast Fourier transform (FFT): An efficient algorithm for calculating the discrete Fourier transform (DFT). Reduces the execution time by *hundreds* in some cases.

FFT convolution: A method of convolving signals by multiplying their frequency spectra. So named because the FFT is used to efficiently move between the time and frequency domains.

Field: Interlaced television displays the even lines of each frame (image) followed by the odd lines. The even lines are called the *even field*, and the odd lines the *odd field*.

Filter kernel: The impulse response of a filter implemented by convolution. Also known as the *convolution kernel* and the *kernel*.

Filtered backprojection: A technique used in computed tomography for reconstructing an image from its views. The views are *filtered* and then *backprojected*.

Finite impulse response (FIR): An impulse response that has a finite number of nonzero values. Often used to indicate that a filter is carried out by using convolution, rather than recursion.

First difference: An operation for discrete signals that mimics the first derivative for continuous signals; also called the *discrete derivative*.

Fixed point: One of two common ways that computers store numbers; usually used to store integers. See *floating point* for comparison.

Flat-top window: A window used in spectral analysis; provides an accurate measurement of the amplitudes of the spectral components. The windowed-sinc filter kernel can be used.

Floating point: One of the two common ways that computers store numbers. Floating point uses a form of scientific notation, where a mantissa is raised to an exponent. See *fixed point* for comparison.

Forward transform: The analysis equation of the Fourier transform, calculating the frequency domain from the time domain. See *inverse transform* for comparison.

Fourier reconstruction: One of the methods used in computed tomography to calculate an image from its views.

Fourier series: The member of the Fourier transform family that deals with time domain signals that are *continuous* and *periodic*.

Fourier transform: A family of mathematical techniques based on decomposing signals into sinusoids. In the complex version, signals are decomposed into complex exponentials.

Fourier transform pair: Waveforms in the time and frequency domains that correspond to each other. For example, the rectangular pulse and the sinc function.

Fovea: A small region in the retina of the eye that is optimized for high-resolution vision.

Frame: An individual image in a television signal. The NTSC television standard uses 30 frames per second.

Frame grabber: A analog-to-digital converter used to digitize and store a frame (image) from a television signal.

Frequency domain: A signal having frequency as the independent variable. The output of the Fourier transform.

Frequency domain aliasing: Aliasing that occurs occurring in the frequency domain in response to an action taken in the time domain. Aliasing during sampling is an example.

Frequency domain convolution: Convolution carried out by multiplying the frequency spectra of the signals.

Frequency domain encoding: One of two main ways that information can be encoded in a signal. The information is contained in the amplitude, frequency, and phase of the signal's component sinusoids. Audio signals are the best example. See *time domain encoding* for comparison.

Frequency domain multiplexing: A method of combining signals for simultaneous transmis-sion by shifting them to different parts of the frequency spectrum.

Frequency dynamic range: The ratio of the largest to the lowest frequency a system can deal with. Analog systems usually have a much larger frequency dynamic range than digital systems.

Frequency resolution: The ability to distinguish or separate closely spaced frequencies.

Frequency response: The magnitude and phase changes that sinusoids experience when passing through a linear system. Usually expressed as a function of frequency. Often found by taking the Fourier transform of the impulse response.

Fricative: Human speech sound that originates as random noise from air turbulence, such as: *s, f, sh, z, v* and *th*. See *voiced* for comparison.

Full-width-at-half-maximum (FWHM): A common way of measuring the width of a peak in a signal. The width of the peak is measured at one-half of the peak's maximum amplitude.

Fundamental frequency: The frequency that a periodic waveform repeats itself. See *harmonic* for comparison.

Gamma curve: The mathematical function or look-up table relating a stored pixel value and the brightness it appears in a displayed image. Also called a *grayscale transform*.

Gaussian: A bell shaped curve of the general form: e^{x^2}. The Gaussian has many unique properties. Also called the *normal distribution*.

Gibbs effect: When a signal is truncated in one domain, ringing and overshoot appear at edges and corners in the other domain.

GIF: A common image file format using LZW (lossless) compression. Widely used on the world wide web for graphics. See *TIFF* and *JPEG* for comparison.

Grayscale: image A digital image where each pixel is displayed in shades of gray between black and white; also called a black and white image.

Grayscale stretch: Greatly increasing the contrast of a digital image to allow the detailed examination of a small range of quantization levels. Quantization levels outside of this range are displayed as saturated black or white.

Grayscale transform: The conversion function between a stored pixel value and the brightness that appears in a displayed image. Also called a *gamma curve*.

Halftone: A common method of printing images on paper. Shades of gray are created by various patterns of small black dots. Color halftones use dots of red, green and blue.

Hamming window: A smooth curve used in the design of filters and spectral analysis, calculated from: $0.54 - 0.46\cos(2\pi n/M)$, where n runs from 0 to M.

Harmonics: The frequency components of a periodic signal, always consisting of integer multiples of the fundamental frequency. The fundamental is the first harmonic, twice this frequency is the second harmonic, etc.

Harvard Architecture: Internal computer layout where the program and data reside in separate memories accessed through separate busses; common in microprocessors used for DSP. See *Von Neumann Architecture* for comparison.

High fidelity: High quality music reproduction, such as provided by CD players.

High-level language: Programming languages such as C, BASIC and FORTRAN.

High-speed convolution: Another name for FFT convolution.

Hilbert transformer: A system having the frequency response: Mag = 1, Phase = 90°, for all frequencies. Used in communications systems for modulation. Can be analog or digital.

Histogram equalization: Processing an image by using the integrated histogram of the image as the grayscale transform. Works by giving large areas of the image higher contrast than the small areas.

Histogram: Displays the distribution of values in a signal. The x-axis show the possible values the samples can take on; the y-axis indicates the number of samples having each value.

Homogeneity: A mathematical property of all linear systems. If an input x[n] produces an output of y[n], then an input $kx[n]$ produces an output of ky[n], for any constant k.

Homomorphic: DSP technique for separating signals combined in a nonlinear way, such as by multiplication or convolution. The nonlinear

problem is converted to a linear one by an appropriate transform.

Huffman encoding: Data compression method that assigns frequently encountered characters fewer bits than seldom used characters.

Hyperspace: Term used in target detection and neural network analysis. One parameter can be graphically interpreted as a *line*, two parameters a *plane*, three parameters a *space*, and more than three parameters a *hyperspace*.

Imaginary part: The portion of a complex number that has a j term, such as 2 in $3 + 2j$. In the real Fourier transform, the *imaginary part* also refers to the portion of the frequency domain that holds the amplitudes of the sine waves, even though j terms are not used.

Impulse: A signal composed of all zeros except for a very brief pulse. For discrete signals, the pulse consists of a single nonzero sample. For continuous signals, the width of the pulse must be much shorter than the inherent response of any system the signal is used with.

Impulse decomposition: Breaking an N point signal into N signals, each containing a single sample from the original signal, with all the other samples being zero. This is the basis of convolution.

Impulse response: The output of a system when the input is a normalized impulse (a delta function).

Impulse train: A signal consisting of a series of equally spaced impulses.

Independent variable: In a signal, the dependent variable depends on the value of the independent variable. Example: when a voltage changes over time, time is the independent variable and voltage is the dependent variable.

Infinite impulse response (IIR): An impulse response that has an infinite number of nonzero values, such as a decaying exponential. Often used to indicate that a filter is carried out by using recursion, rather than convolution.

Integers: Whole numbers: $\cdots -2, -1, 0, 1, 2, \cdots$. Also refers to numbers stored in fixed point notation. See *floating point* for comparison.

Interlaced decomposition: Breaking a signal into its even numbered and odd numbered samples. Used in the FFT.

Interlaced video: A video signal that displays the even lines of each image followed by the odd lines. Used in television; developed to reduce flicker.

Interpolation: Increasing the sampling rate of a digitized signal. Generally done by placing zeros between the original samples and using a low-pass filter. See *decimation* for comparison.

Inverse transform: The synthesis equation of the Fourier transform, calculating the time domain from the frequency domain. See *forward transform* for comparison.

Iterative: Method of finding a solution by gradually adjusting the variables in the right direction until convergence is achieved. Used in CT reconstruction and neural networks.

JPEG: A common image file format using transform (lossy) compression. Widely used on the world wide web for graphics. See *GIF* and *TIFF* for comparison.

Kernel: The impulse response of a filter implemented by convolution. Also known as the *convolution kernel* and the *filter kernel*.

Laplace transform: Mathematical method of analyzing systems controlled by differential equations. A main tool in the design of electric circuits, such as analog filters. Changes a signal in the time domain into the s-domain

Learning algorithm: The procedure used to find a set of neural network weights based on examples of how the network should operate.

Line pair: Imaging term for *cycle*. For example, 5 cycles per mm is the same as 5 line pairs per mm.

Line pair gauge: A device used to measure the resolution of an imaging system. Contains a series of light and dark lines that move closer together at one end.

Line spread function (LSF): The response of an imaging system to a thin line in the input image.

Linear phase: A system with a phase that is a straight line. Usually important because it means the impulse response has left-to-right symmetry, making rising edges in the output signal look the same as falling edges. See also *zero phase*.

Linear system: By definition, a system that has the properties of additivity and homogeneity.

Lossless compression: Data compression technique that exactly reconstructs the original data, such as LZW compression.

Lossy compression: Data compression methods that only reconstruct an approximation to the original data. This allows higher compression ratios to be achieved. JPEG is an example.

Matched filtering: Method used to determine where, or if, a know pattern occurs in a signal. Matched filtering is based on correlation, but implemented by convolution.

Mathematical equivalence: A way of using complex numbers to represent real problems. Based on Euler's relation equating sinusoids with complex exponentials. See *substitution* for comparison.

Mean: The average value of a signal or other group of data.

Memoryless: Systems where the current value of the output depends only on the current value of the input, and not past values.

MFLOPS: Million-Floating-Point-Operations-Per-Second; a common way of expressing computer speed. See *MIPS* for comparison.

MIPS: Million-Instructions-Per-Second; a common way of expressing computer speed. See *MFLOPS* for comparison.

Mixed signal: Integrated circuits that contain both analog and digital electronics, such as an ADC placed on a Digital Signal Processor.

Modulation transfer function (MTF): Imaging jargon for the *frequency response*.

Morphing: Gradually warping an image from one form to another. Used for special effects, such as a man turning into a werewolf.

Morphological: Usually refers to simple non-linear operations performed on binary images, such as erosion and dilation.

Moving average filter: Each sample in the output signal is the average of many adjacent samples in the input signal. Can be carried out by convolution or recursion.

MPEG: Compression standard for video, such as digital television.

Mu law: Companding standard used in the United States. Allows digital voice signals to be represented with only 8 bits instead of 12 bits by making the quantization levels unequal. See "*A*" *law* for comparison.

Multiplexing: Combining two or move signals together for transmission. This can be carried out in many different ways.

Multirate: Systems that use more than one sampling rate. Often used in ADC and DAC to obtain better performance, while using less electronics.

Natural frequency: A frequency expressed in radians per second, as compared to cycles per second (hertz). To convert frequency (in hertz) to natural frequency, multiply by 2π.

Negative frequencies: Sinusoids can be written as a positive frequency: $\cos(\omega t)$, or a negative frequency: $\cos(-\omega t)$. Negative frequencies are included in the complex Fourier transform, making it more powerful.

Normal distribution: A bell shaped curve of the form: e^{x^2}. Also called a *Gaussian*.

NTSC: Television standard used in the United States, Japan, and other countries. See *PAL* and *SECAM* for comparison.

Nyquist frequency, Nyquist rate: These terms refer to the sampling theorem, but are used in different ways by different authors. They can be used to mean four different things: the highest frequency contained in a signal, twice this frequency, the sampling rate, or one-half the sampling rate.

Octave: A factor of two in frequency.

Odd order filter: An analog or digital filter having an odd number of poles.

Opening: A morphological operation defined as a dilation operation followed by an erosion operation.

Optimal filter: A filter that is "best" in some specific way. For example, Wiener filters produce an optimal signal-to-noise ratio and matched filters are optimal for target detection.

Overlap add: Method used to break long signals into segments for processing.

PAL: Television standard used in Europe. See *NTSC* for comparison.

Parallel stages: A combination of two or more stages with the same input and added outputs.

Parameter space: Target detection jargon. One parameter can be graphically interpreted as a *line*, two parameters a *plane*, three parameters a *space*, and more than three parameters a *hyperspace*.

Parseval's relation: Equation relating the energy in the time domain to the energy in the frequency domain.

Passband: The band of frequencies a filter is designed to pass unaltered.

Passive sonar: Detection of submarines and other undersea objects by the sounds they produce. Used for covert surveillance.

Phasor transform: Method of using complex numbers to find the frequency response of *RLC* circuits. Resistors, capacitors and inductors become R, $-j/\omega C$, and $j\omega L$, respectively.

Pillbox: Shape of a filter kernel used in image processing: circular region of a constant value surrounded by zeros.

Pitch: Human perception of the fundamental frequency of an continuous tone. See *timbre* for comparison.

Pixel: A contraction of "picture element." An individual sample in a digital image.

Point spread function (PSF): Imaging jargon for the impulse response.

Pointer: A variable whose value is the address of another variable.

Poisson statistics: Variations in a signal's value resulting from it being represented by a finite number of particles, such as: x-rays, light photons or electrons. Also called *Poisson noise* and *statistical noise*.

Polar form: Representing sinusoids by their magnitude and phase: $M\cos(\omega t + \phi)$, where M is the magnitude and ϕ is the phase. See *rectangular form* for comparison.

Pole: Term used in the Laplace transform and z-transform. When the s-domain or z-domain transfer function is written as one polynomial divided by another polynomial, the roots of the denominator are the *poles* of the system, while the roots of the numerator are the *zeros*.

Pole-zero diagram: Term used in the Laplace and z-transforms. A graphical display of the location of the poles and zeros in the s-plane or z-plane.

Precision: The error in a measurement or prediction that is not repeatable from trial to trial. Precision is determined by random errors. See *accuracy* for comparison.

Probability distribution function (pdf): Gives the probability that a *continuous* variable will take on a certain value.

Probability mass function (pmf): Gives the probability that a *discrete* variable will take on a certain value. See *pdf* for comparison.

Pulse response: The output of a system when the input is a pulse.

Quantization error: The error introduced when a signal is quantized. In most cases, this results in a maximum error of ±½ LSB, and an rms error of $1/\sqrt{12}$ LSB. Also called *quantization noise*.

Random error: Errors in a measurement or prediction that are not repeatable from trial to trial. Determines *precision*. See *systematic error* for comparison.

Radar: Radio Detection And Ranging. Echo location technique using radio waves to detect aircraft.

Real DFT: The discrete Fourier transform using only real (ordinary) numbers. A less powerful technique than the complex DFT, but simpler. See *complex DFT* for comparison.

Real FFT: A modified version of the FFT. About 30% faster than the standard FFT when the time domain is completely real (i.e., the imaginary part of the time domain is zero).

Real Fourier transform: Any of the members of the Fourier transform family using only real (as opposed to imaginary or complex) numbers. See *complex Fourier transform* for comparison.

Real part: The portion of a complex number that does not have the j term, such as 3 in $3 + 2j$. In the real Fourier transform, the *real* part refers to the part of the frequency domain that holds the amplitudes of the cosine waves, even though no j terms are present.

Real time processing: Processing data as it is acquired, rather than storing it for later use.

Example: DSP algorithms for controlling echoes in long distance telephone calls.

Reconstruction filter: A low-pass analog filter placed after a digital-to-analog converter. Smoothes the stepped waveform by removing frequencies above one-half the sampling rate.

Rectangular form: Representing a sinusoid by the form: $A\cos(\omega t) + B\sin(\omega t)$, where A is called the *real part* and B is called the *imaginary part* (even though these are not imaginary numbers).

Rectangular window: A signal with a group of adjacent points having unity value, and zero elsewhere. Usually multiplied by another signal to select a section of the signal to be processed.

Recursion coefficients: The weighing values used in a recursion equation. The recursion coefficients determine the characteristics of a recursive (IIR) filter.

Recursion equation: Equation relating the past and present samples of the output signal with the past and present values of the input signal. Also called a *difference equation*.

Region-of-convergence: The term used in the Laplace and z-transforms. Those regions in the s-plane and z-planes that have a defined value.

RGB encoding: Representing a color image by specifying the amount of red, green, and blue for each pixel.

RISC: Reduced Instruction Set Computer, also called a DSP microprocessor. A fewer number of programming commands allows much higher speed math calculations. The opposite is the Complex Instruction Set Computer, such as the Pentium.

ROC curve: A graphical display showing how threshold selection affects the performance of a target detection problem.

Roll-off: Jargon used to describe the sharpness of the transition between a filter's passband and stopband. A *fast* roll-off means the transition is sharp; a *slow* roll-off means it is gradual.

Root-mean-square (rms): Used to express the fluctuation of a signal around *zero*. Often used in electronics. Defined as the square-root of the mean of the squares. See *standard deviation* for comparison.

Round-off noise: The error caused by rounding the result of a math calculation to the nearest quantization level.

Row major order: A pattern for converting an image to serial form. Operates the same as English writing: left-to-right on the first line, left-to-right on the second line, etc.

Run-length encoding: Simple data compression technique with many variations. Characters that are repeated many times in succession are replaced by codes indicating the character and the length of the run.

Running sum: An operation used with discrete signals that mimics integration of continuous signals. Also called the *discrete integral*.

s-domain: The domain defined by the Laplace transform. Also called the *s-plane*.

Sample spacing: The spacing between samples when a continuous image is digitized. Defined as the center-to-center distance between pixels.

Sampling aperture: The region in a continuous image that contributes to an individual pixel during digitization. Generally about the same size as the sample spacing.

Sampling theorem: If a continuous signal composed of frequencies less than f is sampled at $2f$, all of the information contained in the continuous signal will be present in the sampled signal. Frequently called the *Shannon* sampling theorem or the *Nyquist* sampling theorem.

SECAM: Television standard used in Europe. See NTSC for comparison.

Seismology: Branch of geophysics dealing with the mechanical properties of the earth.

Separable: An image that can be represented as the product of its vertical and horizontal profiles. Used to improve the speed of image convolution.

Sharpening: Image processing operation that makes edges more abrupt.

Shift and subtract: Image processing operation that creates a 3D or embossed effect.

Shift invariance: A property of many systems. A shift in the input signal produces nothing more than a shift in the output signal. Means that the characteristics of the system do not changing with time (or other independent variable).

Sigmoid: An "s" shaped curve used in neural networks.

Signal: A description of how one parameter varies with another parameter. Example: a *voltage* that varies with *time*.

Signal restoration: Returning a signal to its original form after it has been changed or degraded in some way. One of the main uses of *filtering*.

Sinc function: Formally defined by the relation: $sinc(a) = sin(\pi a)/\pi a$. The π terms are often hidden in other variables, making it in the general form: $sin(x)/x$. Important because it is the Fourier transform of the rectangular pulse.

Single precision: A floating point notation that used 32 bits to represent each number. See *double precision* for comparison.

Single-pole digital filters: Simple recursive filters that mimic *RC* high-pass and low-pass filters in electronics.

Sinusoidal fidelity: An important property of linear systems. A sinusoidal input can only produce a sinusoidal output; the amplitude and phase may change, but the frequency will remain the same.

Sonar: Sound Navigation And Ranging. The use of sound to detect submarines and other underwater objects. *Active sonar* uses echo location, while *passive sonar* only listens.

Source code: A computer program in the form written by the programmer; distinguished from *executable code*, a form that can be directly run on a computer.

Spatial domain: A signal having distance (space) as the independent variable. Images are signals in the spatial domain.

Spectral analysis: Understanding a signal by examining the amplitude, frequency, and phase of its component sinusoids. The primary tool of spectral analysis is the Fourier transform.

Spectral inversion: Method of changing a filter kernel such that the corresponding frequency response is flipped top-for-bottom. This can change low-pass filters to high-pass, band-pass to band-reject, etc.

Spectral leakage: Term used in spectral analysis. Since the DFT can only be taken of a finite length signal, the frequency spectrum of a sinusoid is a peak with tails. These tails are referred to as *leakage* from the main peak.

Spectral reversal: Technique for changing a filter kernel such that the corresponding frequency response is flipped left-for-right. This changes low-pass filters into high-pass filters.

Spectrogram: Measurement of how an audio frequency spectrum changes over time. Usually displayed as an image. Also called a *voiceprint*.

Standard deviation: A way of expressing the fluctuation of a signal around its average value. Defined as the square-root of the average of the deviations squared, where the deviation is the difference between a sample and the mean. See *root-mean-square* for comparison.

Static linearity: Refers to how a linear system acts when the signals are not changing (i.e., they are *DC* or *static*). In this case, the output is equal to the input multiplied by a constant.

Statistical noise: Variations in a signal's value resulting from it being represented by a finite number of particles, such as: x-rays, electrons, or light photons. Also called *Poisson statistics* and *Poisson noise*.

Steepest descent: Strategy used in designing iterative algorithms. Analogous to finding the bottom of a valley by always moving in the down-hill direction.

Step response: The output of a system when the input is a step function.

Stopband: The band of frequencies that a filter is designed to block.

Stopband attenuation: The amount by which frequencies in the stopband are reduced in amplitude, usually expressed in decibels. Used to describe a filter's performance.

Substitution: A way of using complex numbers to represent a physical problem, such as electric circuit design. In this method, *j* terms are added to change the physical problem to a complex form, and then removed to move back again. See *mathematical equivalence* for comparison.

Switched capacitor filter: Analog filter that uses rapid switching to replace resistors. Made as easy-to-use integrated circuits. Often used as antialias filters for ADC and reconstruction filters for DAC.

Synthesis: The inverse Fourier transform, calculating the time domain from the frequency domain. See *analysis* for comparison.

System: Any process that produces an output signal in response to an input signal.

Systematic error: Errors in a measurement or prediction that are repeatable from trial to trial. Systematic errors determines *accuracy*. See *random error* for comparison.

Target detection: Deciding if an object or condition is present based on measured values.

TIFF: A common image file format used in word processing and similar programs. Usually not compressed, although LZW compression is an option. See *GIF* and *JPEG* for comparison.

Timbre: The human perception of harmonics in sound. See *pitch* for comparison.

Time domain: A signal having time as the independent variable. Also used as a general reference to any domain the data is acquired in.

Time domain aliasing: Aliasing occurring in the time domain when an action is taken in the frequency domain. Circular convolution is an example.

Time domain encoding: Signal information contained in the shape of the waveform. See *frequency domain encoding* for comparison.

Transfer function: The output signal divided by the input signal. This comes in several different forms, depending on how the signals are represented. For instance, in the s-domain and z-domain, this will be one polynomial divided by another polynomial, and can be expressed as *poles* and *zeros*.

Transform: A procedure, equation or algorithm that changes one group of data into another group of data.

Transform compression: Data compression technique based on assigning fewer bits to the high frequencies. *JPEG* is the best example.

Transition band: Filter jargon; the band of frequencies between the passband and stopband where the roll-off occurs.

True-negative: One of four possible outcomes of a target detection trial. The target is not present, and is correctly indicated to be not present.

True-positive: One of four possible outcomes of a target detection trial. The target is present, and correctly indicated to be present.

Unit circle: The circle in the z-plane at $r = 1$. The values along this circle are the frequency response of the system.

Unit impulse: Another name for *delta function*.

Von Neumann Architecture: Internal computer layout where both the program and data reside in a single memory; very common. See *Harvard Architecture* for comparison.

Voiced: Human speech sound that originates as pulses of air passing the vocal cords. Vowels are an example of voiced sounds. See *fricative* for comparison.

Well: Short for *potential well*; the region in a CCD that is sensitive to light.

White noise: Random noise that has a flat frequency spectrum. Occurs when each sample in the time domain contains no information about the other samples. See *1/f noise* for comparison.

Wiener filter: Optimal filter for increasing the signal-to-noise ratio based on the frequency spectra of the signal and noise.

Windowed-sinc: Digital filter used to separate one band of frequencies from another.

z-domain: The domain defined by the z-transform. Also called the *z-plane*.

z-transform: Mathematical method used to analyze discrete systems that are controlled by difference equations, such as recursive (IIR) filters. Changes a signal in the time domain into a signal in the z-domain.

Zero: A term used in the Laplace & z-transforms. When the s-domain or z-domain transfer function is written as one polynomial divided by another polynomial, the roots of the numerator are the *zeros* of the system. See also *pole*.

Zero phase: A system with a phase that is entirely zero. Occurs only when the impulse response has left-to-right symmetry around the origin. See also *linear phase*.

Zeroth-order hold: A term used in DAC to describe that the analog signal is maintained at a constant value between conversions, resulting in a staircase appearance.

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