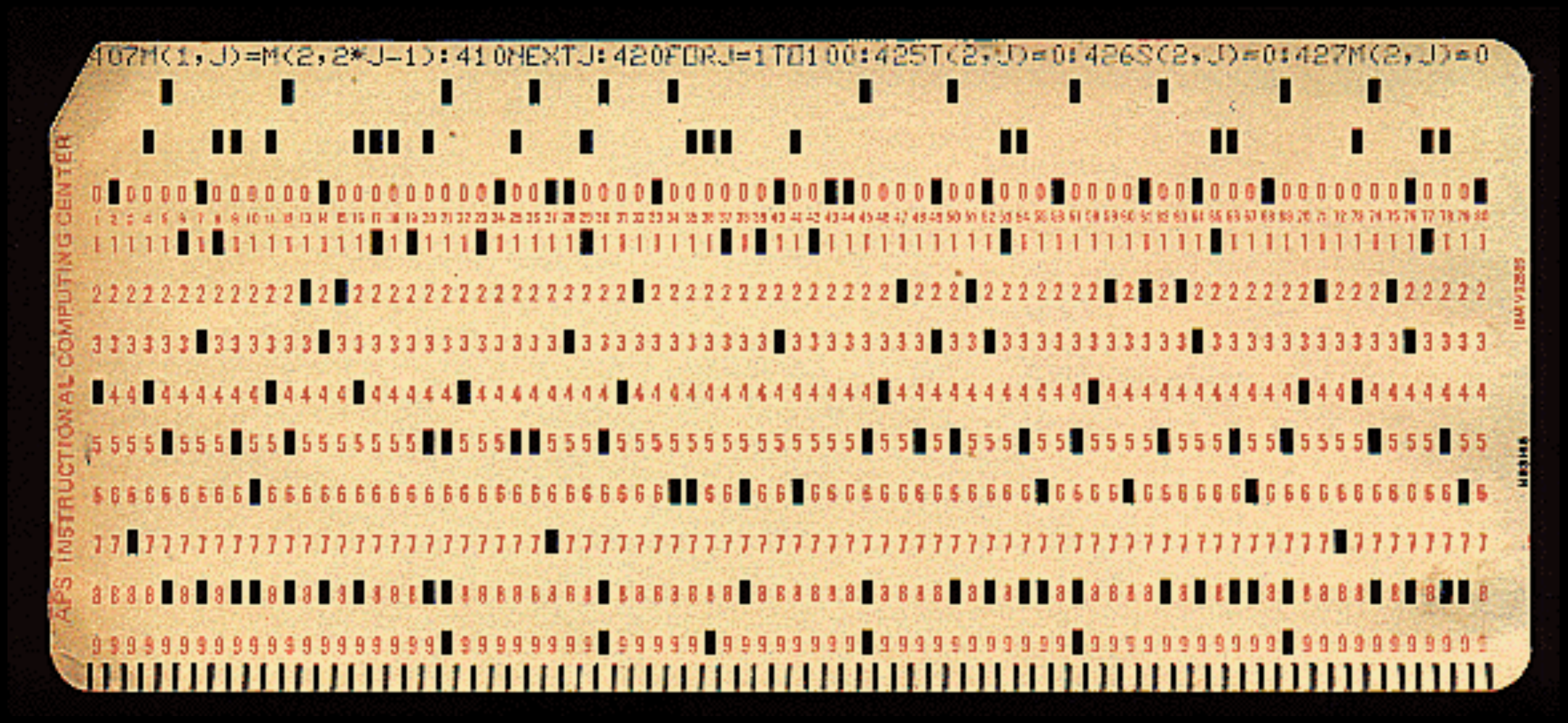


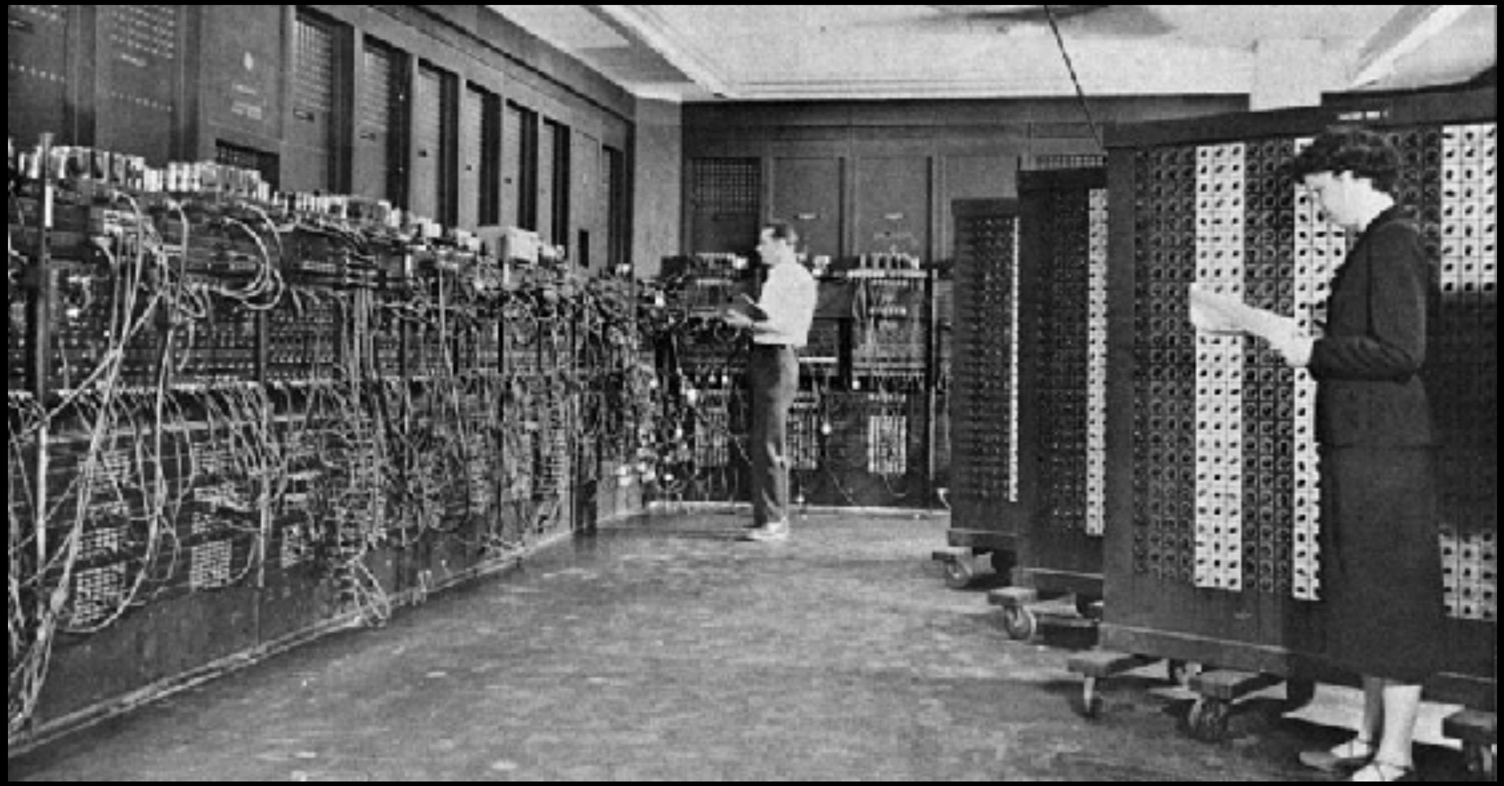
DIGITAL AUDIO & COMPUTER MUSIC

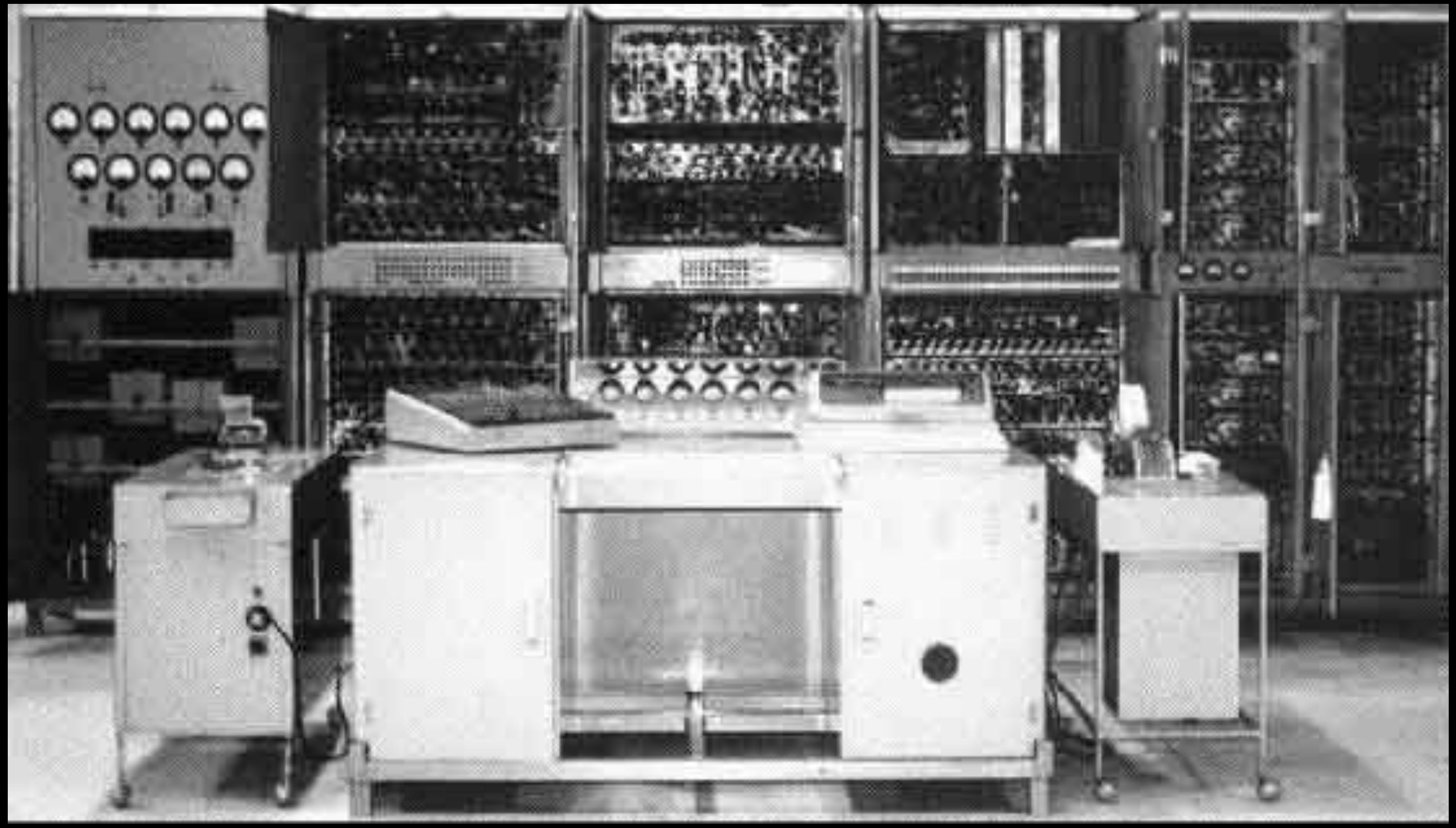
Patchwork (1977)
Laurie Spiegel

brief history of early computer audio

basics of digital audio

some early computer music





BEFORE 1957

1928: Harold Nyquist at Bell Labs develops Nyquist Theorem

1938: pulse code modulation (pcm) technique developed

1946: ENIAC, first general purpose computer

195?: Digitally synthesized sounds

in the earliest computers, sound was used to signify operation

BELL LABS & MAX MATHEWS

At Bell Labs in 1957, Mathews created the first sound generating computer program, called... *Music*

Pioneered early Fourier analysis using a prototype analog-digital converter in the 60s

MAX MATHEWS

Often cited as the "Father of Computer Music"

He continued to develop *Music (the program)* throughout the 1960s

first real-time computer system *Groove* in 1968

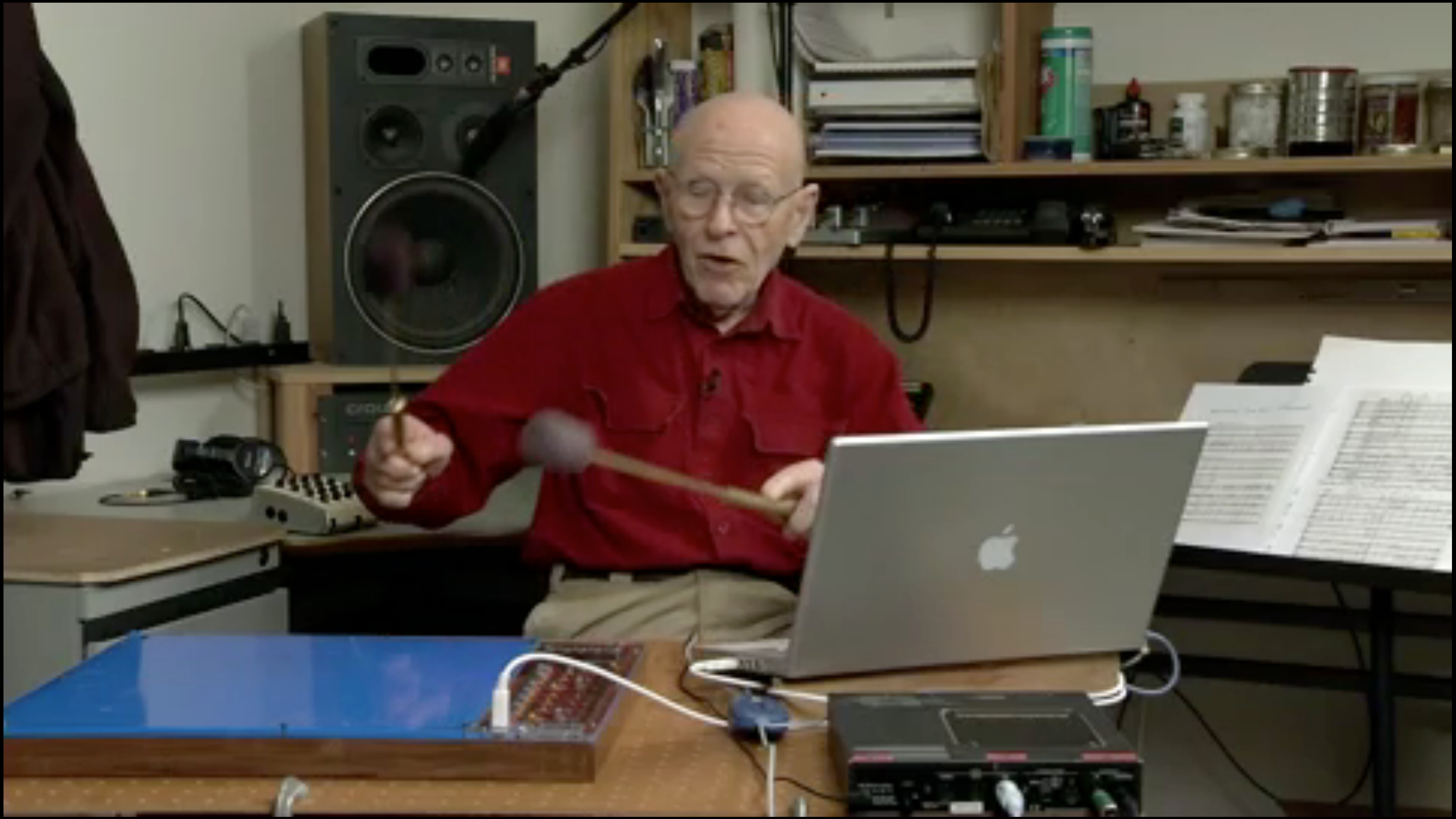
a conductor program and instrument called the Radio Baton
(tracked x-y-z positions - we have one here!)

From 1987 to 2011, Professor of Research at Stanford University.

The program *Max/MSP* is named in his honor

What now is the musical challenge of the future? I believe it is the limits in our understanding of the human brain; and specifically knowing what sound waves, sound patterns, timbres and sequences humans recognize as beautiful and meaningful music – and why!

Max Mathews



In 1961, Mathews arranged and recorded “Daisy Bell” for computer synthesized voice.

Stanley Kubrick was researching what a telephone would look like for his 1968 film, *2001 Space Odyssey* and heard Mathew’s version of the well-known tune and referenced it in the climatic scene.

12
7
8
9
10
11
12
WT

Computer Music in the 60s & 70s

Large mainframe computers at institutions, shared by multiple departments

Slooooooooowwwwwwwww

Composers who worked at Bell Labs with Max Mathews in the 60s and 70s included: James Tenney, F. B. Moore, Jean Claude Risset, John Chowning, Laurie Spiegel and Charles Dodge

JAMES TENNEY

Worked at Bell Labs from 1961-1963, composing 6 pieces.

Analog #1 (Noise Study) is an exploration of noise through filtering (digital subtractive synthesis).

Developed while listening to commutes through the Holland Tunnel

In my two-and-a-half years [at Bell Labs] here I have begun many more compositions than I have completed, asked more questions than I could find answers for, and perhaps failed more often than I have succeeded. But I think it could not have been much different. The medium is new and requires new ways of thinking and feeling. Two years are hardly enough to have become thoroughly acclimated to it, but the process has at least been begun.

James Tenney, 1964

Excerpt from *Analog #1 (Noise Study)* (1961)

Basics of Digital Audio

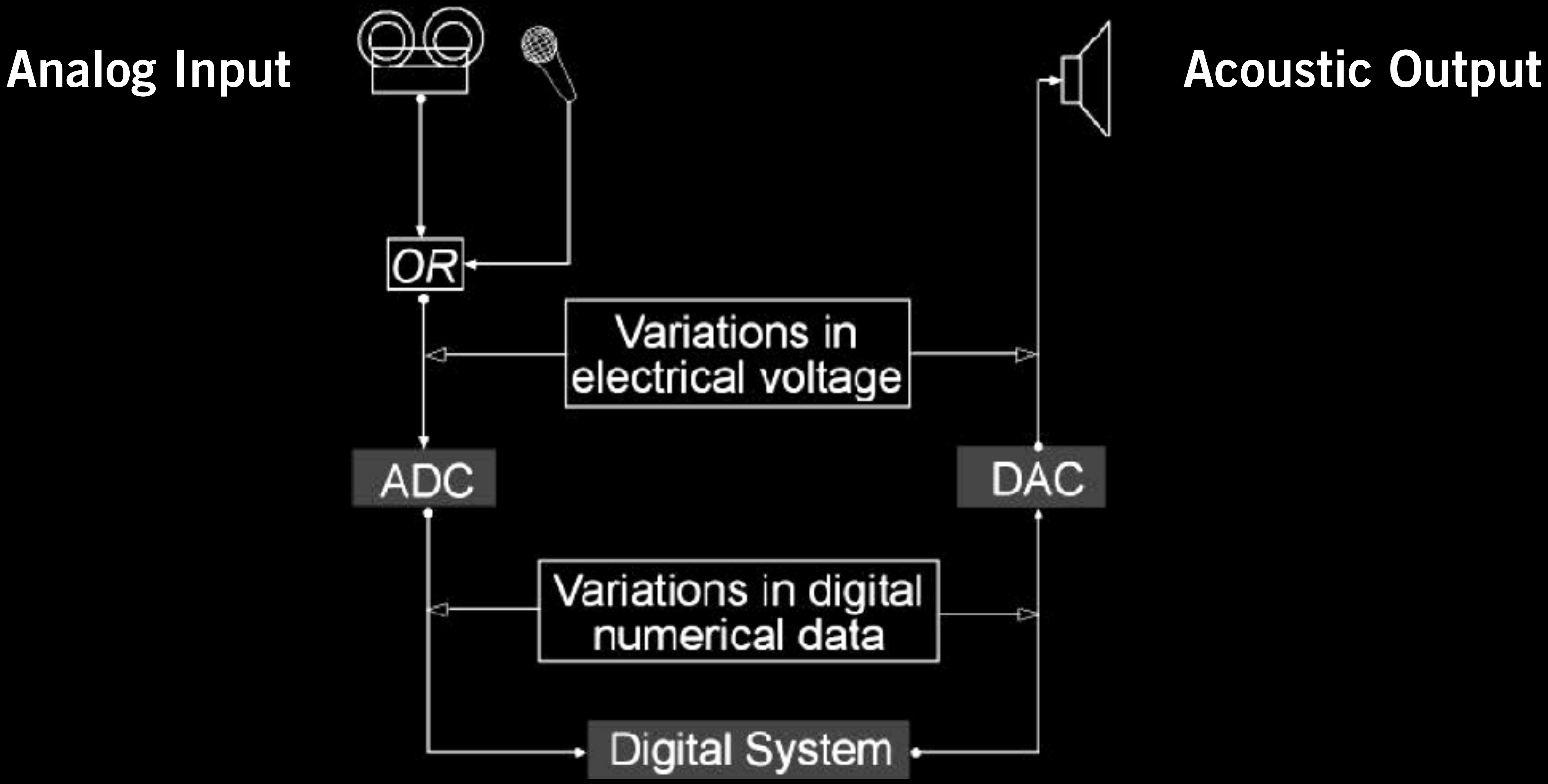
Encoding - Analog to Digital Convertor (ADC) takes “snapshots” of electrical signals

Decoding - Digital to Analog Convertor (DAC) converts numbers into continuous electrical signals.

Quantization - The process of taking an analog signal and converting it into a finite series of discrete levels.

Levels stored as numbers stored as bits (binary).

Big Picture Signal Flow



DIGITAL ENCODING

Digital is discrete, Analog is continuous

Sampling Rate and **Bit Depth** work together to determine the resolution and accuracy of the digital representation

Two Parameters of Digital Encoding

Pulse-code modulation (PCM)

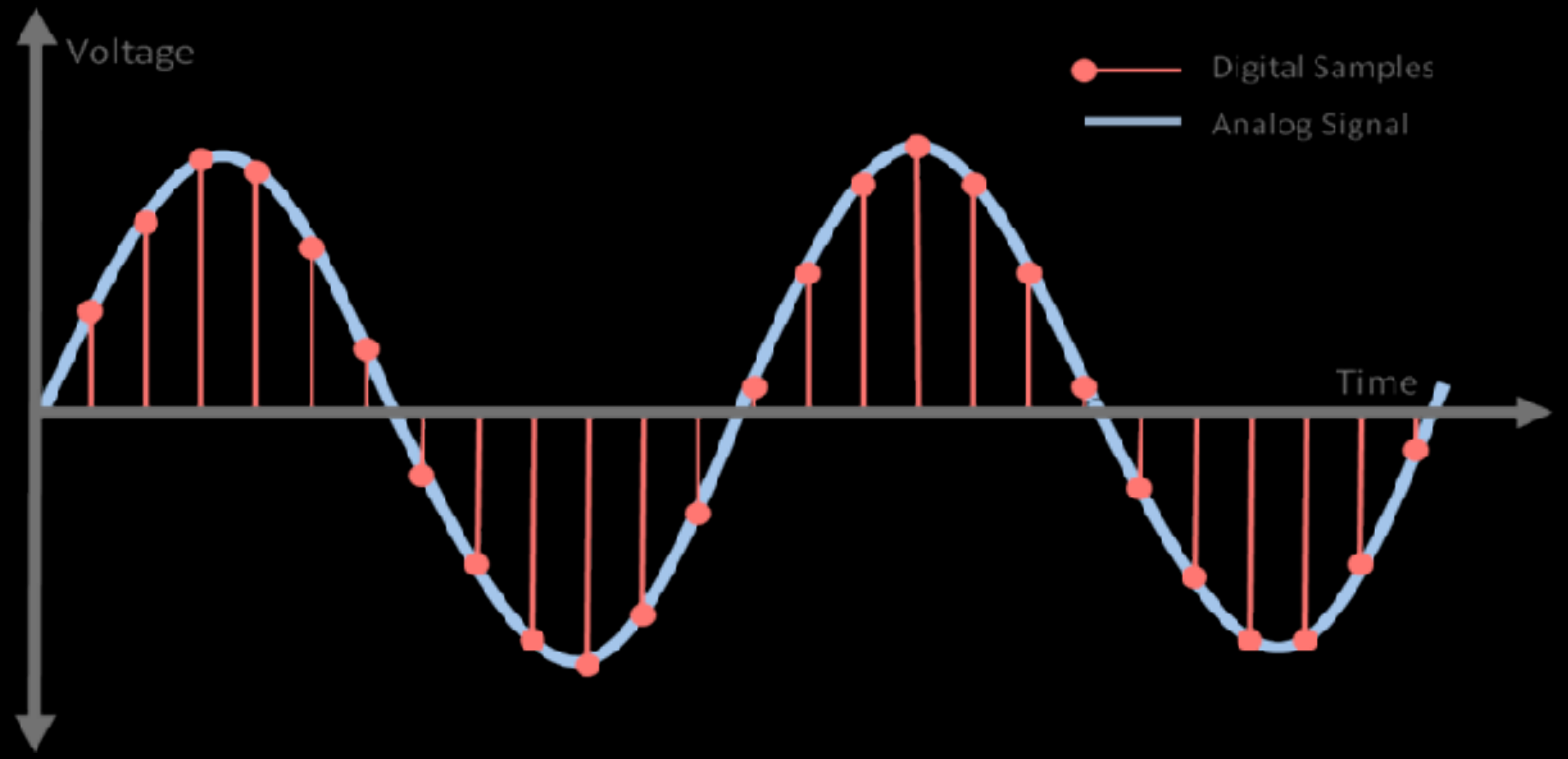
Sampling Rate

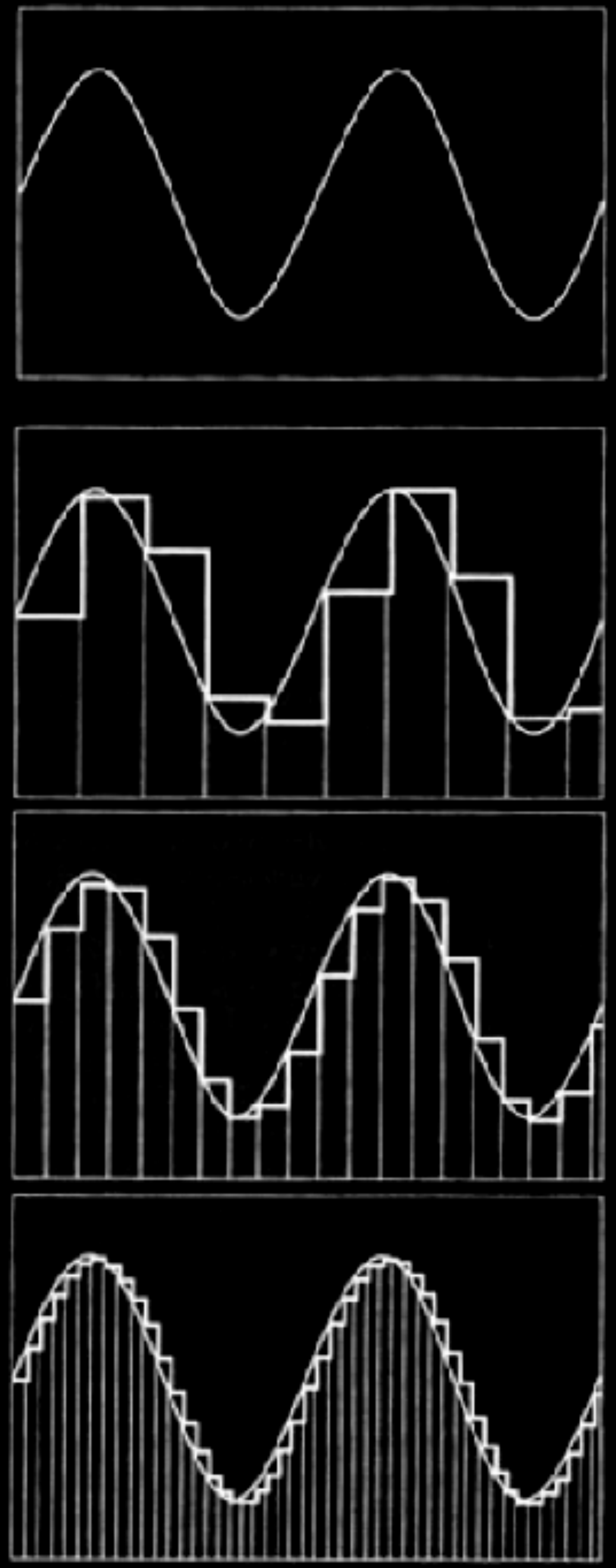
How quickly are the amplitudes of a signal measured? (time interval)

Bit Depth

How accurate are amplitude measurements when sampled? (pressure resolution)

Sample Rate - Film Analogy*





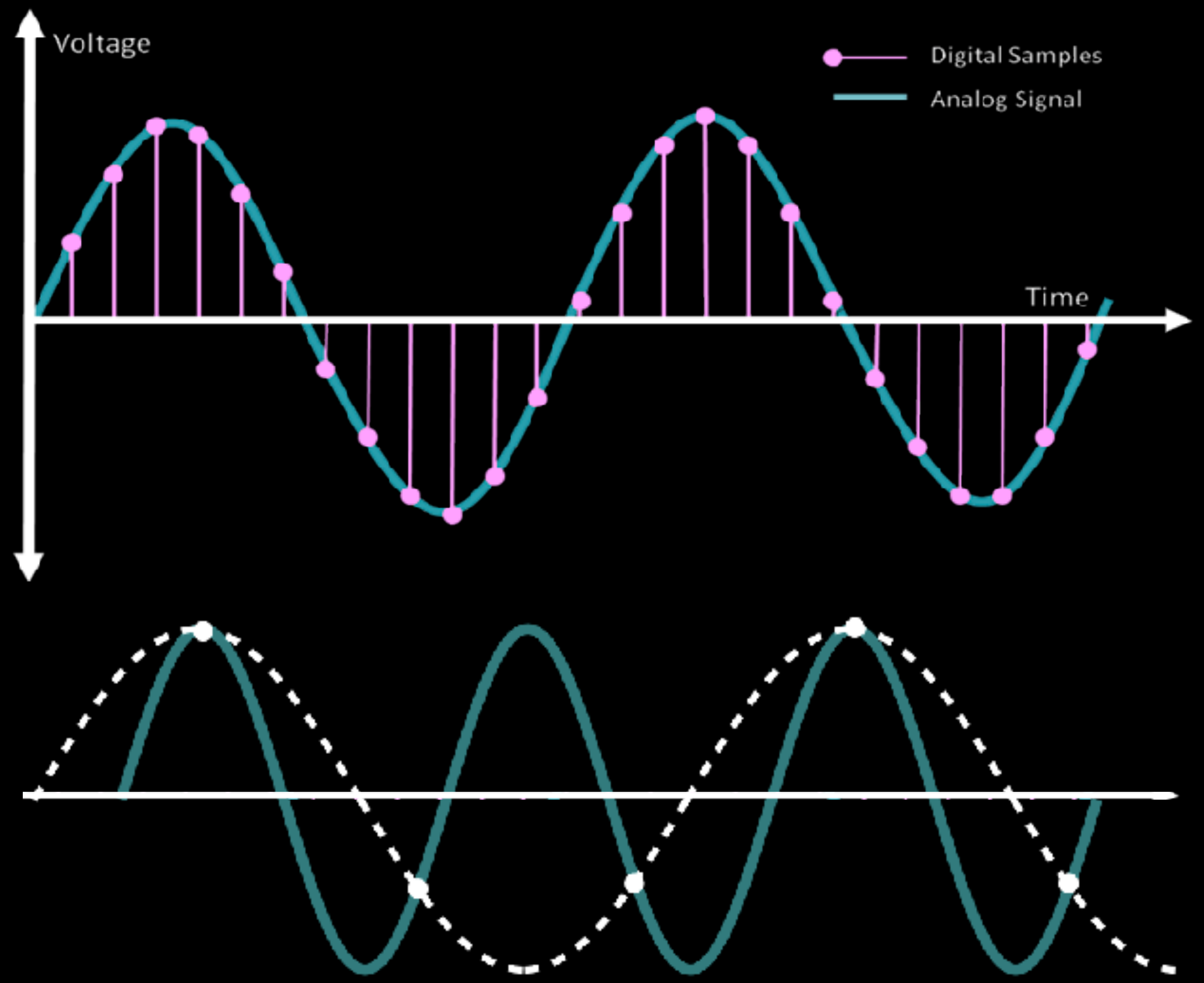
Sampling Rate

measured in hertz (Hz)

the faster we sample, the better chance we have of getting an accurate picture of the signal

in order to represent all sounds within the range of human hearing (20,000 Hz) we require a sampling rate of (at least) 40,000 Hz. (Nyquist Theorem)

Unwanted artifacts are audible when the sampling rate drops below 2x the highest frequency. (Aliasing)



Nyquist Theorem

to accurately represent a signal, the sampling rate must be at least twice the highest frequency contained in the signal.

In mathematical terms:

$$f_s \geq 2f_c$$

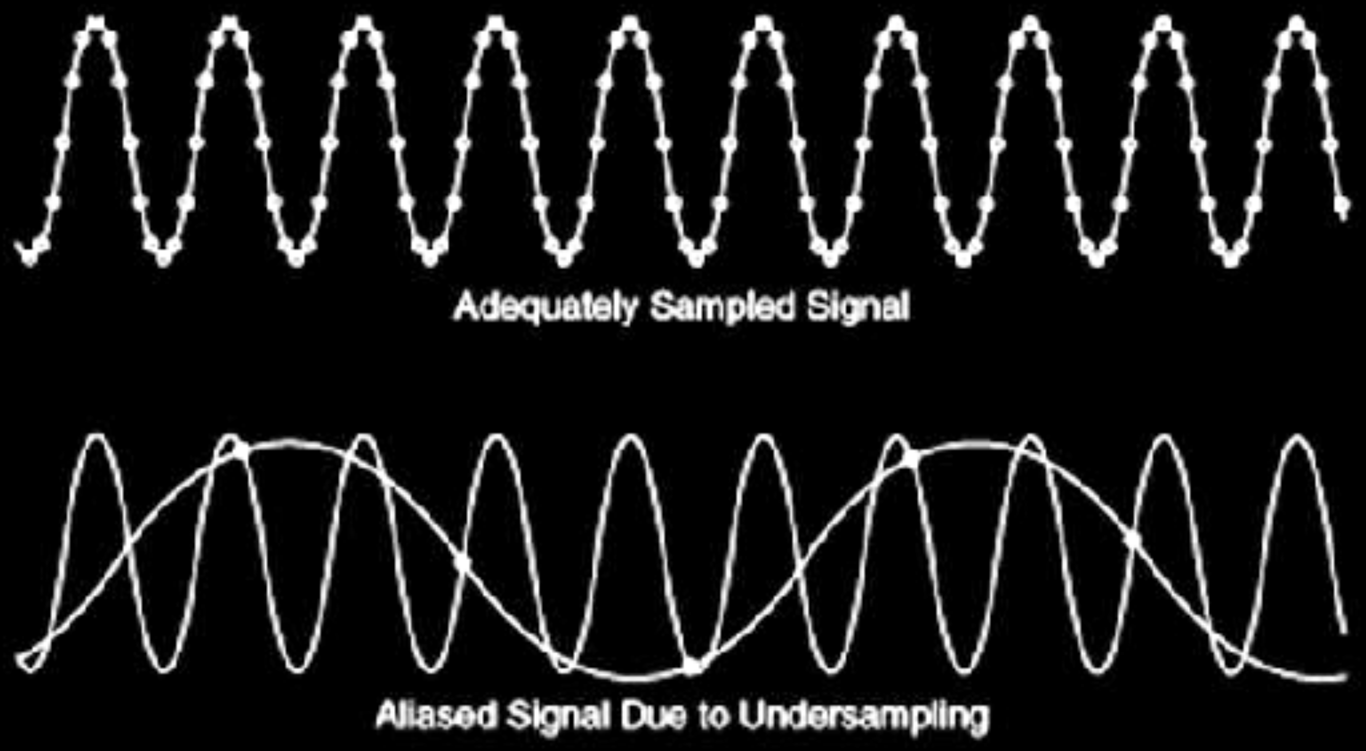
where f_s is the sampling rate and f_c is the highest frequency contained in the signal

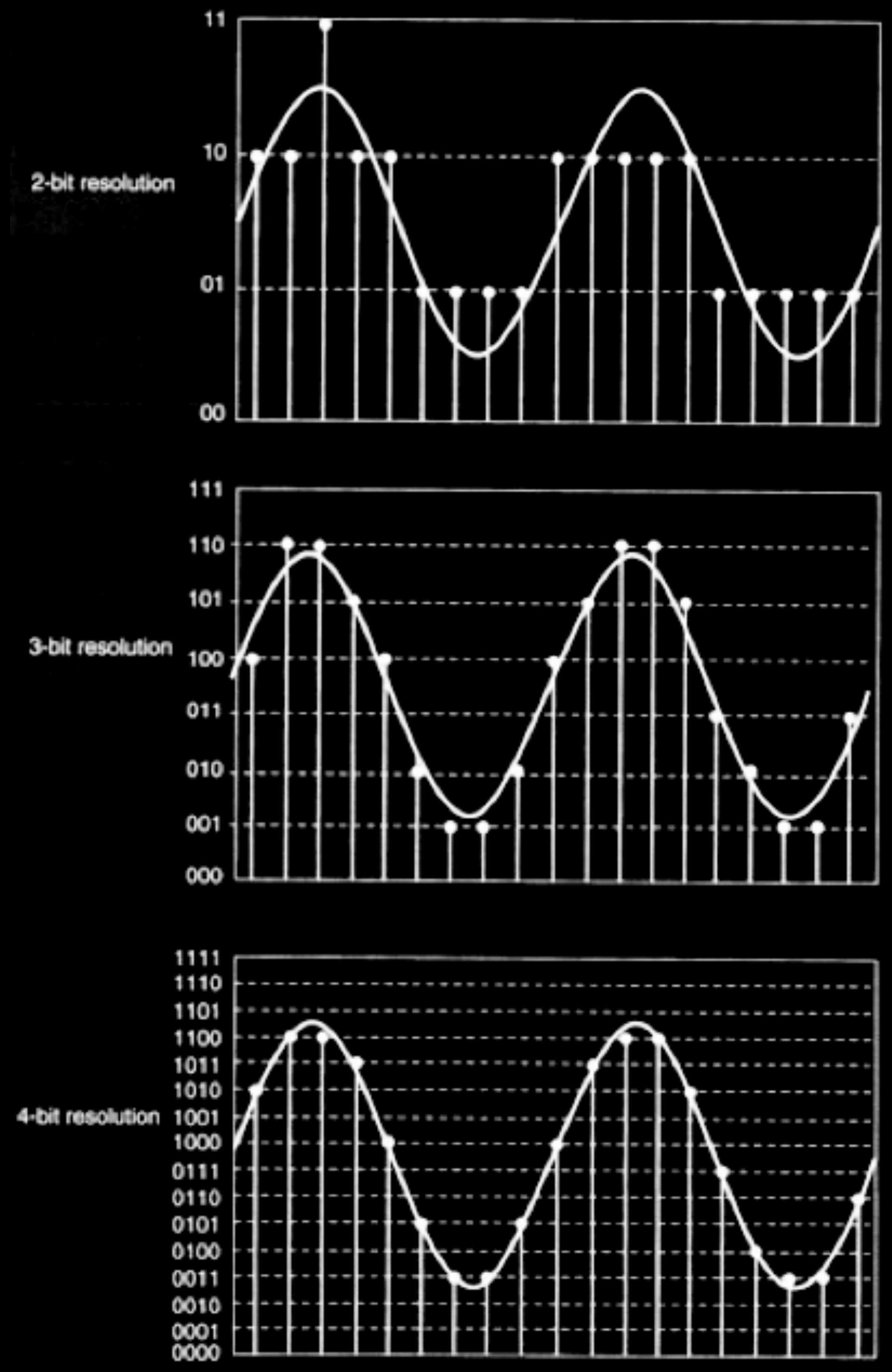
Aliasing

a result of undersampling

you not only lose information about the signal, but you get the wrong information.

the signal takes on a different “persona” -- a false presentation or “alias”





Bit Depth

represents how accurately the analog wave can be represented.

A higher bit depth will have less noise and a better dynamic range.

16 bit-depth is the standard for CD audio. (65,536 values)

Professional audio systems have options for higher bit depths (DVD audio supports 24) and sampling rates (up to 96 and 192 kHz).

Binary

What is a bit? a binary digit

On/Off

Bits are a way of storing binary numbers

The number of bits tells us how many numbers (things, positions, values) are available

One bit encodes two possible values
0 1

Two bits encode four possible values
00 01 10 11

bit resolution

number of bits	$2^{\# \text{ of bits}}$	number of values
1	2^{1}	2
2	2^{2}	4
3	2^{3}	8
4	2^{4}	16
8	2^{8}	256
16	2^{16}	65,536
32	2^{32}	4,294,967,296
64	2^{64}	$2^{32} \times 2^{32}$

8 BITS = 1 BYTE

This is a Byte. It is read from right to left.

11111111

Each bit is represented as a doubling of the previous value

1 1 1 1 1 1 1 1

128 + 64 + 32 + 16 + 8 + 4 + 2 + 1

An entire Byte has 256 values when all the bits are "on" and added together

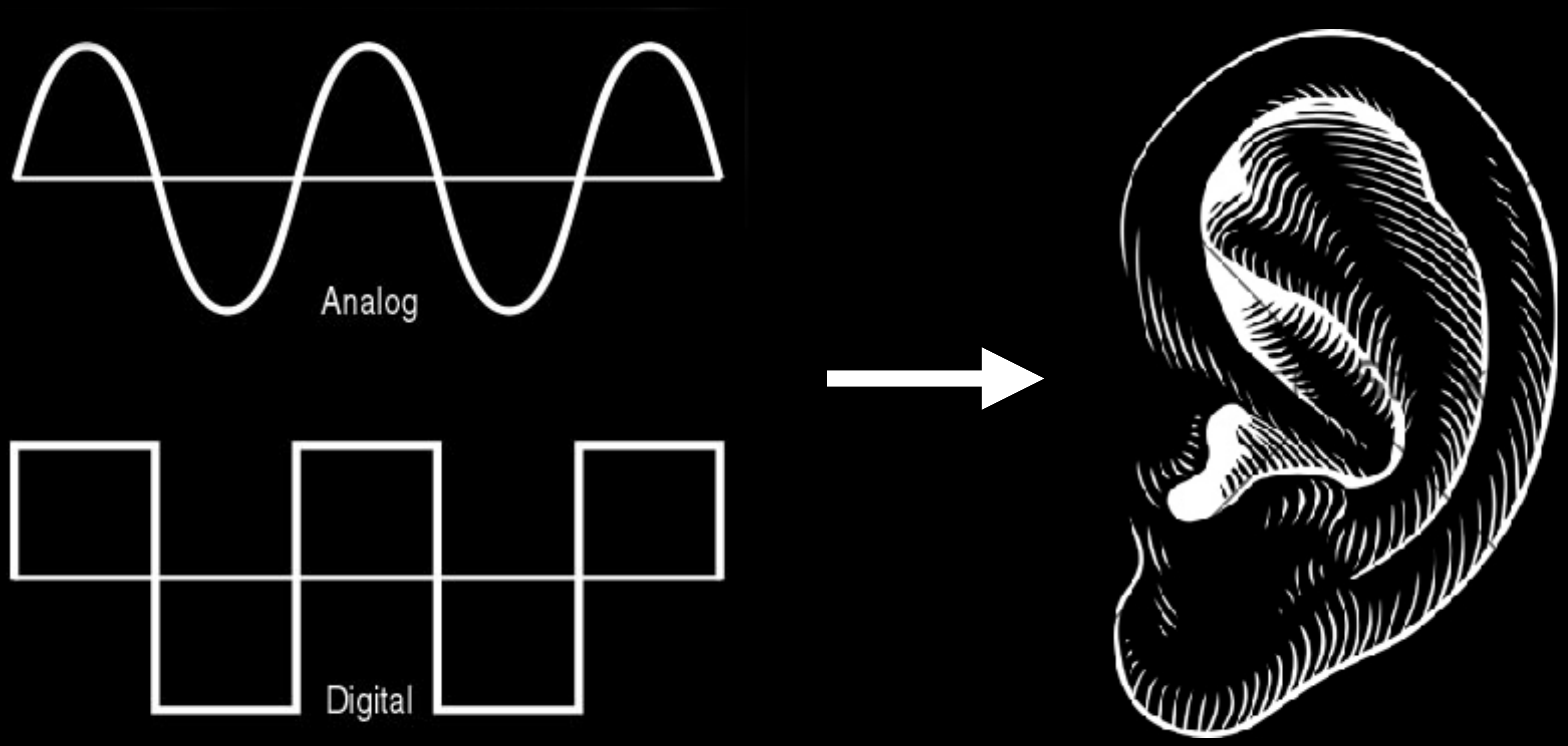
EXAMPLE

Byte = 00001001

= 9

Decimal = 8 + 1

Misconception



Differences between digital and analog

digital analog
digital analog
digital analog
digital analog
digital analog
digital analog

Fairlight C.M.I, 1979

Synclavier, 1977

Digital Synthesis

Bit depth and sample rate describe the resolution and accuracy of digital synthesis systems as well.

instead of using recorded sounds to generate sample numbers, we often simply generate the numbers

Initially computers used Additive Synthesis, but...

Common Types of Synthesis

Additive synthesis	complex tones can be created by the summation, or addition, of simpler tones (organ, telharmonium, fairlight CMI, Fourier theorem, Max Mathews)
Subtractive synthesis	sound sculpting—start with noise (many frequencies), and then filter them (James Tenney)
Formant synthesis	a type of subtractive synthesis based on the resonant physical structure of the sound-producing medium, think speech (Paul Lansky)
Granular synthesis	combining very short sonic events called 'grains' to generate complex textures (Xenakis)
Frequency Modulation (FM Synthesis)	the frequency of a simple waveform (carrier wave) is modulated by another frequency (modulator wave)(John Chowning)

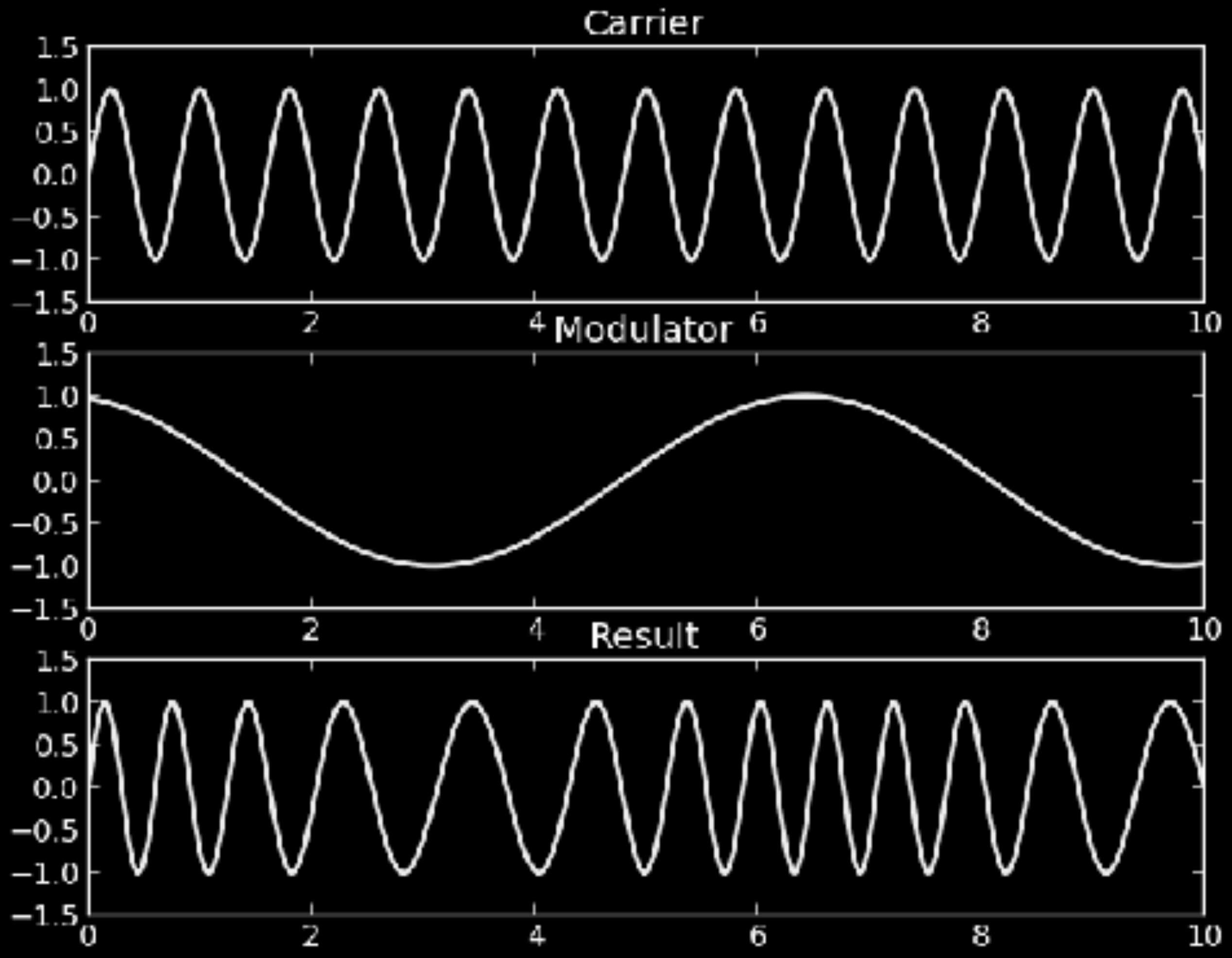
FM SYNTHESIS

Frequency modulation first used in radio

FM synthesis developed by John Chowning in the early 1970s

efficient algorithm - little computation to generate rich sound palettes.

Yamaha DX7 (1980), one of the most popular synths of all time



The Synthesis of Complex Audio Spectra by Means of Frequency Modulation

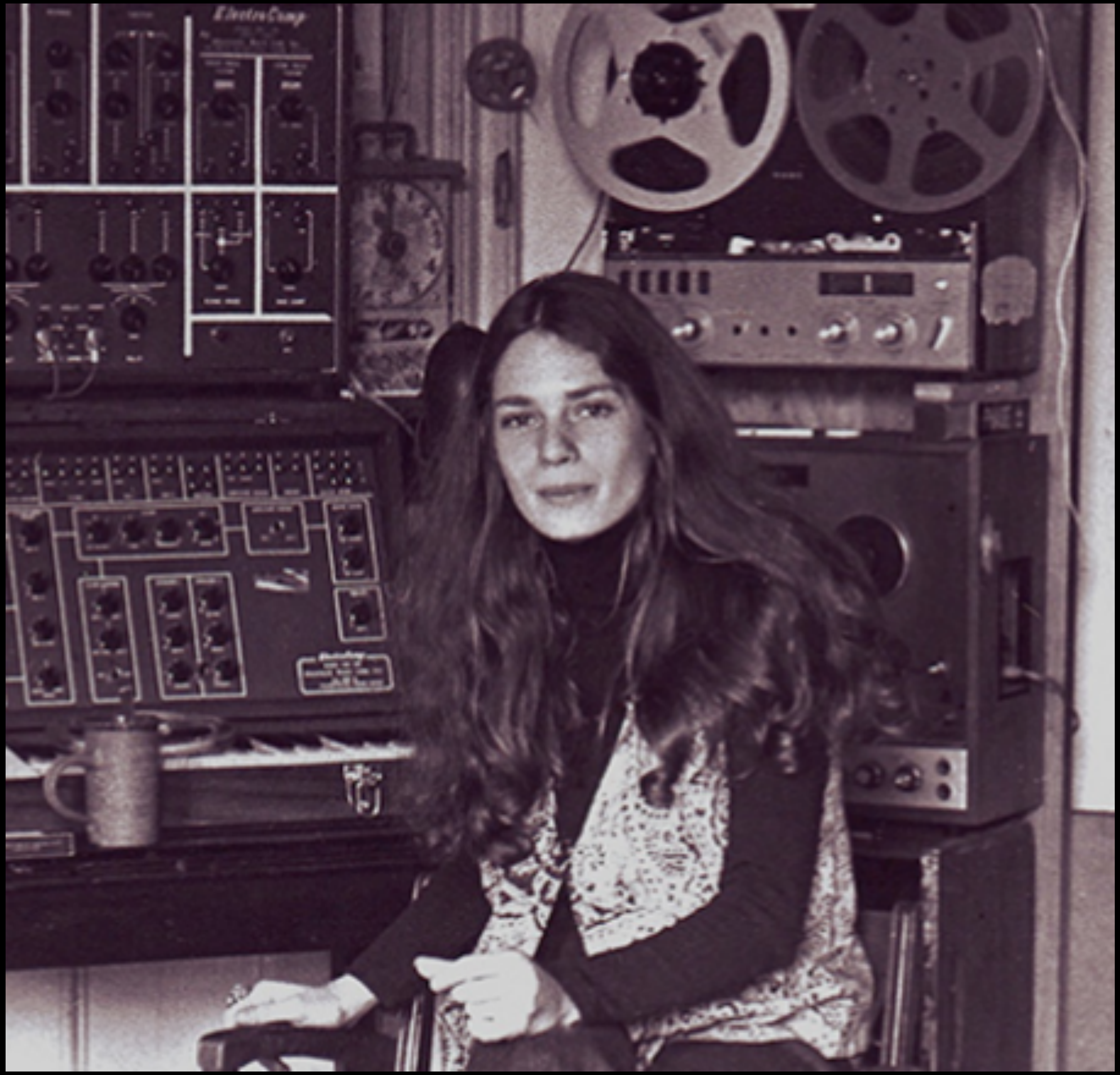
JOHN M. CHOWNING

Stanford Artificial Intelligence Laboratory, Stanford, California

A new application of the well-known process of frequency modulation is shown to result in a surprising control of audio spectra. The technique provides a means of great simplicity to control the spectral components and their evolution in time. Such dynamic spectra are diverse in their subjective impressions and include sounds both known and unknown.

Chowning with Max Mathews and his radio baton

Excerpt from Stria (1977)



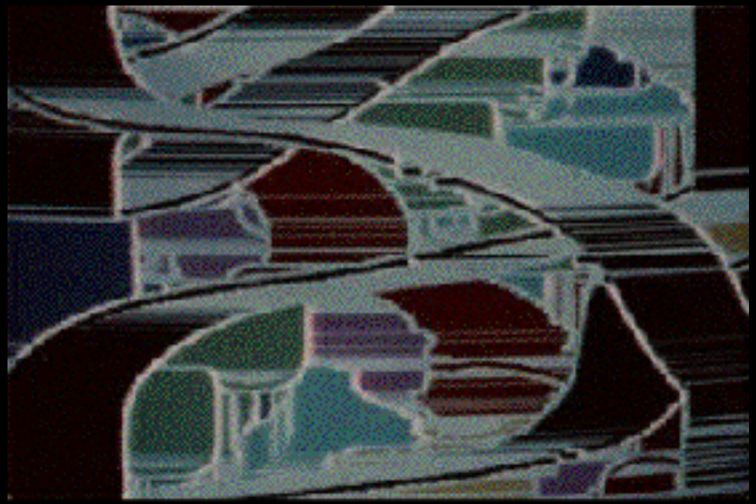
LAURIE SPIEGEL

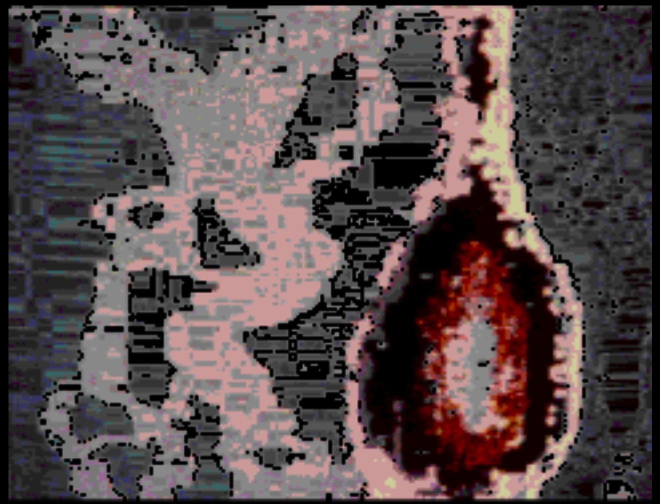
worked with Max Mathews at Bell Labs

pioneered hybrid digital/analog composition methods

built *Music Mouse - An Intelligent Instrument* (1986)

experimented with early computer animation





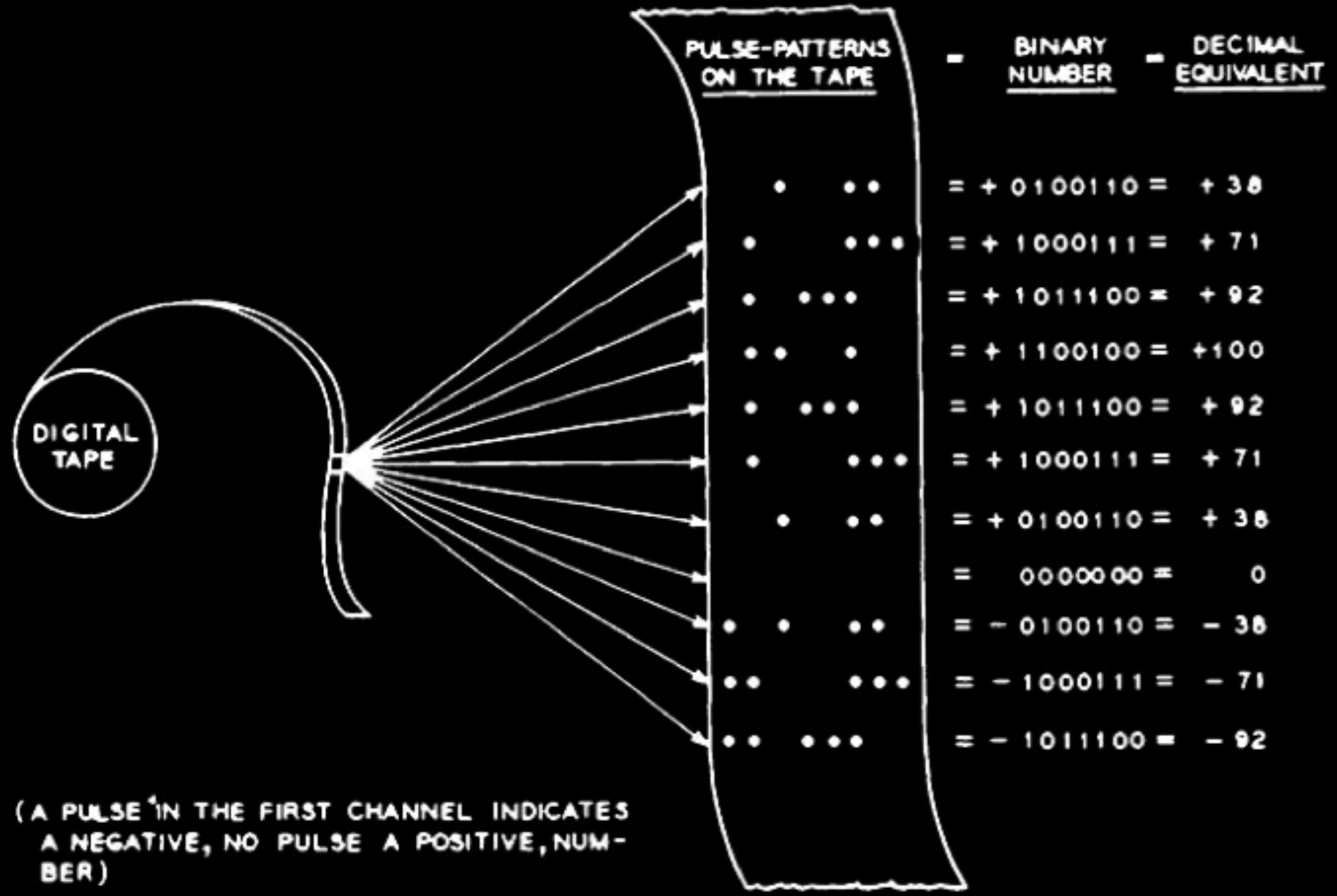


FIGURE 3
REPRESENTATION OF SAMPLE NUMBERS ON DIGITAL TAPE

THE EXPANDING UNIVERSE

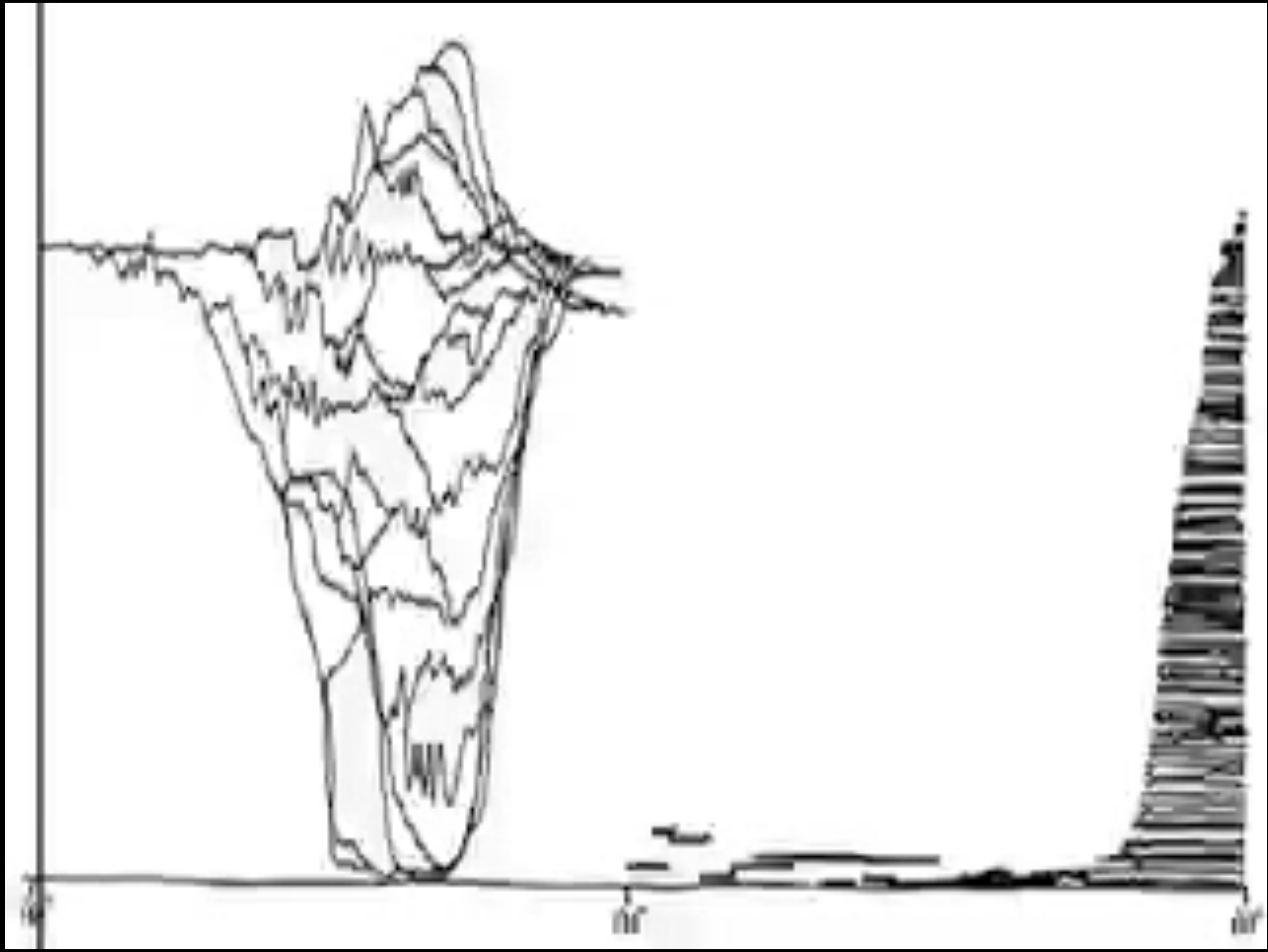
LAURIE SPIEGEL

Written between 1973-1978

Composed using the Groove system developed by Max Mathews

G.R.O.O.V.E
Generating Realtime Operations On Voltage-controlled Equipment

"I automate whatever can be automated to be freer to focus on those aspects of music that can't be automated. The challenge is to figure out which is which." L.S.

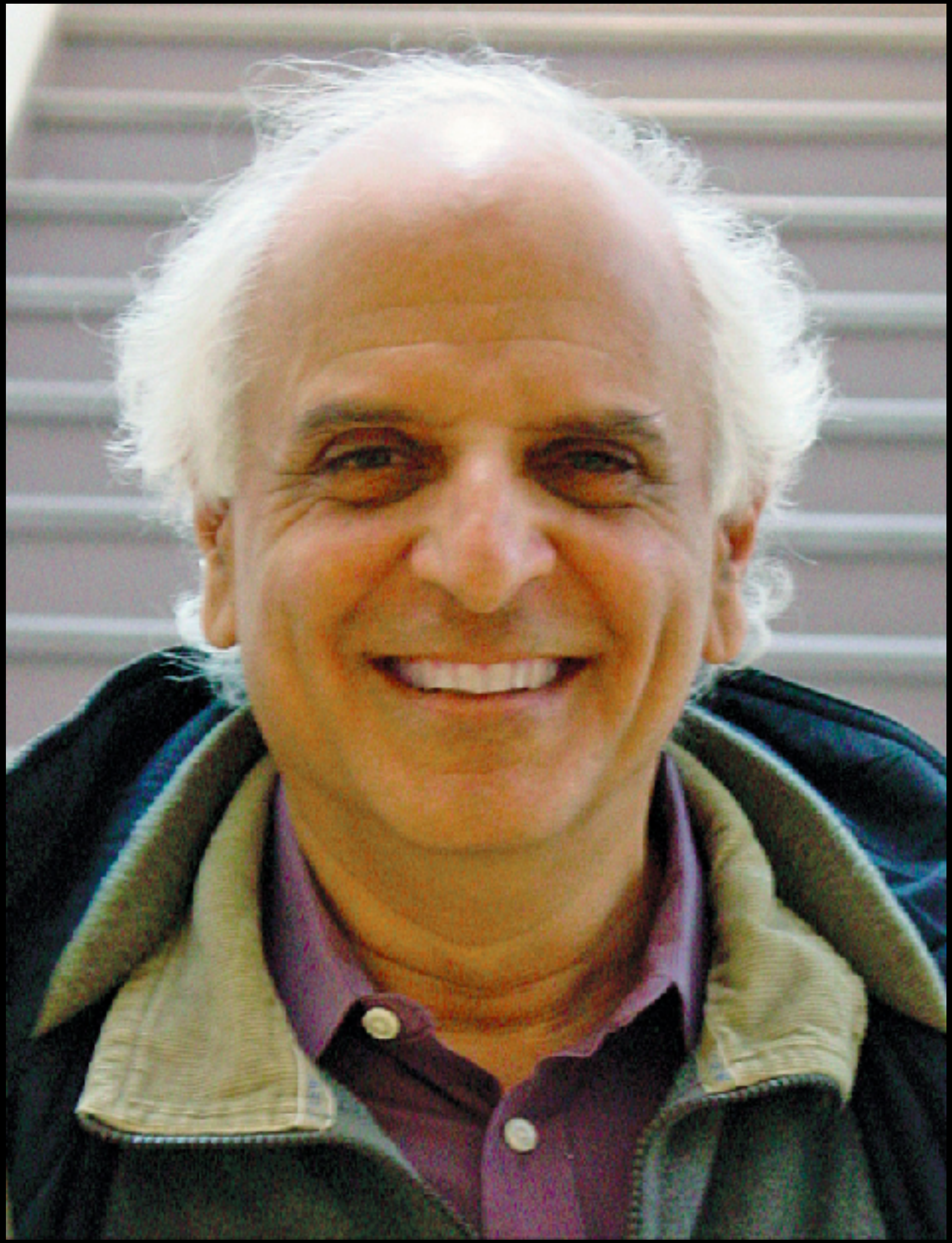


IANNIS XENAKIS

granular synthesis, computer-aided methods

graphic synthesis, graphic scores, UPIC

excerpt from “Mycenae Alpha” (1978)



PAUL LANSKY

digital voices and formant synthesis, linear predictive coding

excerpt from “Idle Chatter Junior” (1985)

Radiohead sampled his "Mild und Leise" (1973) in their song “Idioteque” on Kid A (2000)

teaches at Princeton