

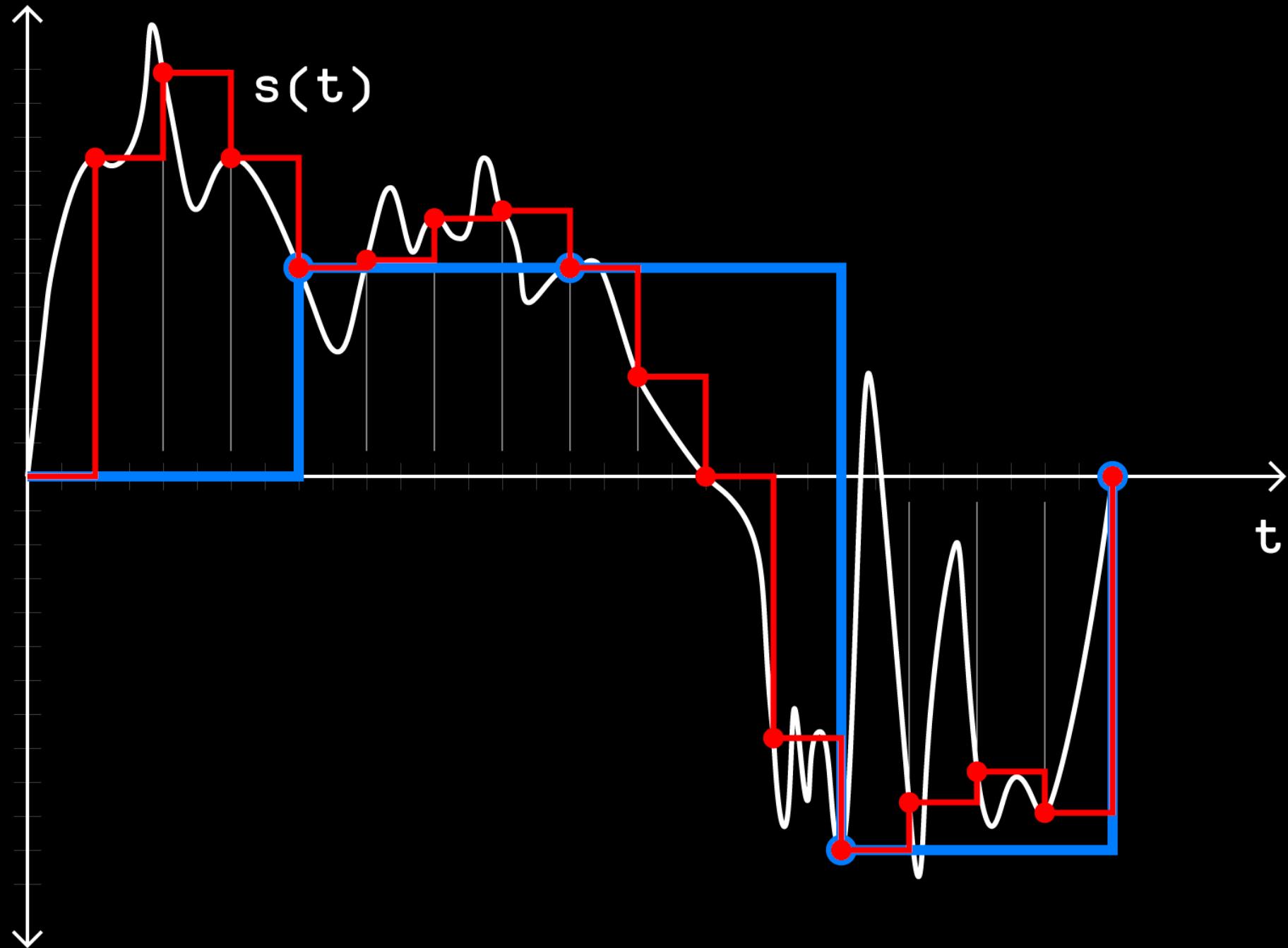
DIGITAL MUSIC WORKSHOP / 00 / DIGITAL SOUND BASICS

DIGITAL MUSIC WORKSHOP / 00 / DIGITAL SOUND BASICS

- samples
- audio processing + synthesis
- programming audio

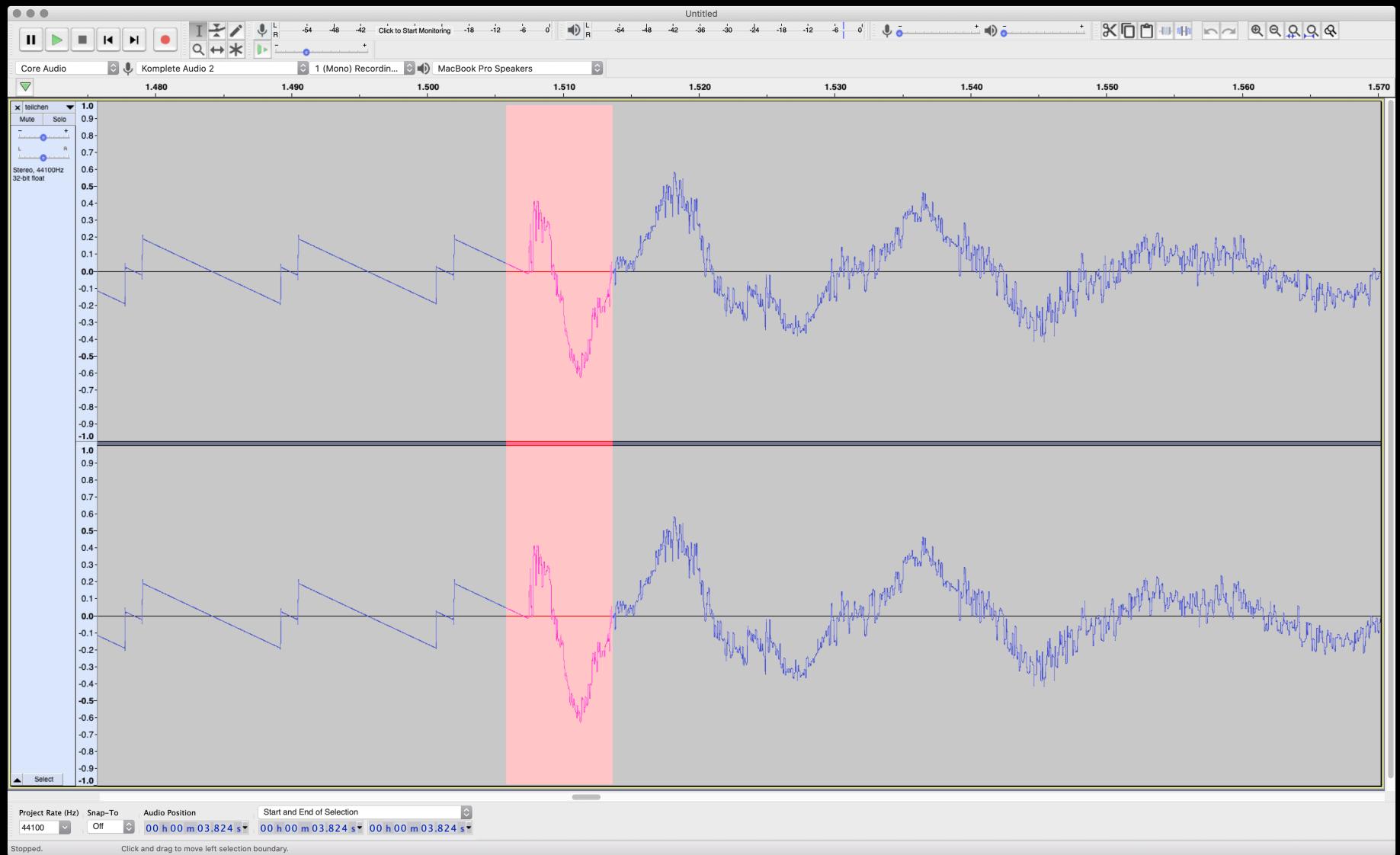
SAMPLES

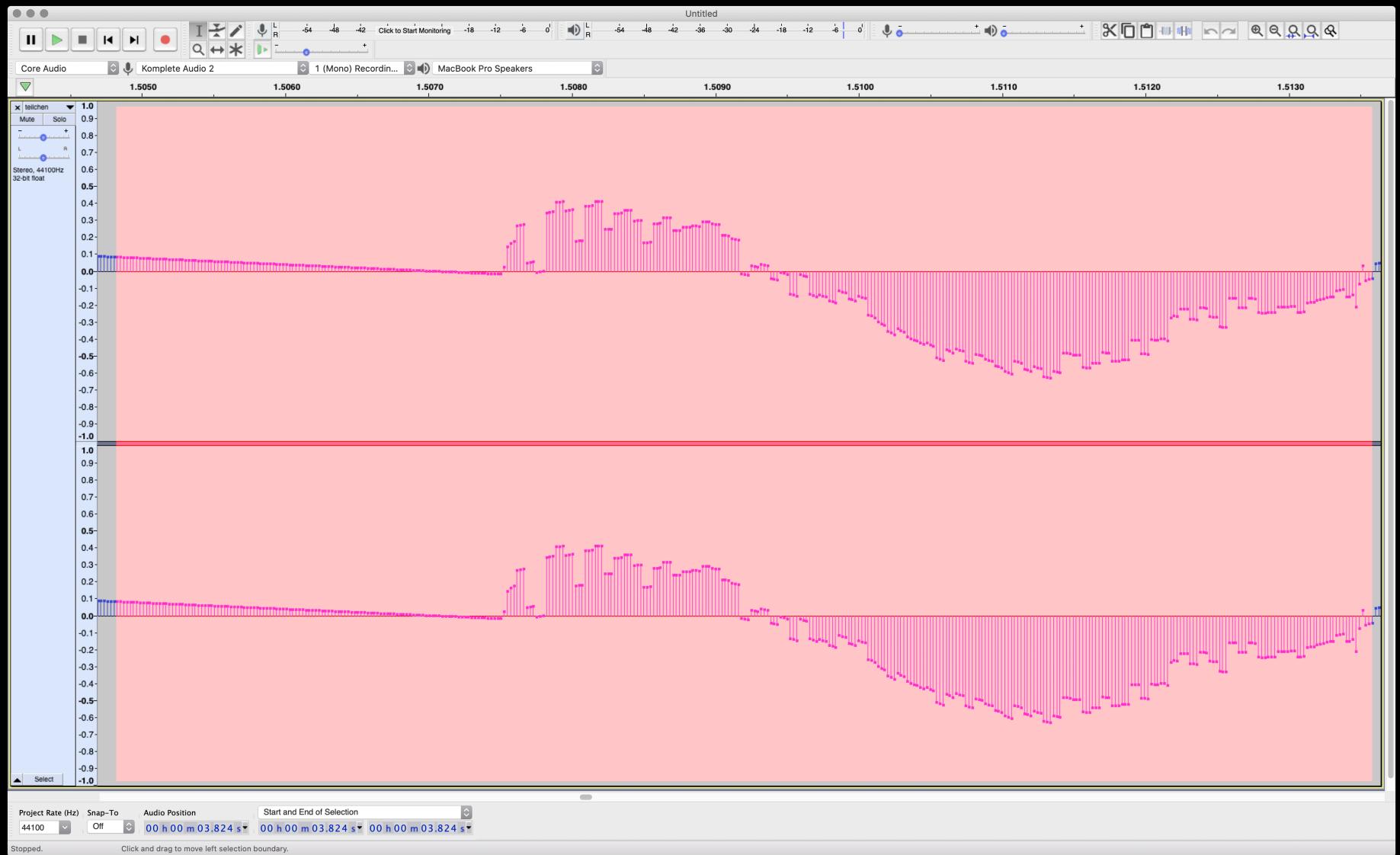
transforming a continuous signal into a sequence of discrete numbers.



SAMPLES

samples viewed in Audacity





SAMPLES

HEX dump of WAV file 16 bits (= 2 bytes) per sample

72 00000800: C3 8D 17 C3 8D 1D C3 88 1D C3 88 1F C3 8B 1F C3 8B 35 C3 81 35 C3 81 C3 A2 C3 8A C3 A2 C3 8A C3 .5..5.
73 00000880: 82 C3 82 C3 82 C3 82 48 C3 82 48 C3 82 E2 84 A2 E2 80 B0 E2 84 A2 E2 80 B0 0F E2 80 B0 0F E2 80 ..H..H..
74 000008A0: B0 74 E2 80 9E 74 E2 80 9E E2 82 AC E2 80 9A E2 82 AC E2 80 9A 3F E2 80 9A 3F E2 80 9A E2 80 A0 ..t..t.....?..?
75 000008C0: C2 B7 E2 80 A0 C2 B7 CB 86 E2 80 A1 CB 86 E2 80 A1 43 E2 80 A1 43 E2 80 A1 C3 A0 EF AC 82 C3 A0 ..C..C..
76 000008E0: EF AC 82 C2 A0 EF AC 81 C2 A0 EF AC 81 09 EF AC 81 09 EF AC 81 49 EF AC 81 49 E2 80 BA 49 E2 80 BA C3 A4 E2 ..I..I..
77 00000900: 80 B9 C3 A4 E2 80 B9 C3 83 E2 82 AC C3 83 E2 82 AC 11 E2 82 AC 11 E2 82 AC 5B E2 81 84 5B E2 81 ..[..[..
78 00000920: 84 C2 A9 C5 B8 C2 A9 C5 B8 CB 9B C3 BF CB 9B C3 BF 5A C3 BF 5A C3 BF CE A9 E2 97 8A CE A9 E2 97 ..Z..Z..
79 00000940: 8A 27 E2 97 8A 27 E2 97 8A C3 B2 C3 B7 C3 B2 C3 B7 11 C3 B7 11 C3 B7 C3 AB E2 80 99 C3 AB E2 80 ..'..'
80 00000960: 99 16 E2 80 99 16 E2 80 99 C2 A2 E2 80 98 C2 A2 E2 80 98 37 E2 80 98 37 E2 80 98 E2 80 BA E2 80 ..7..7..
81 00000980: 9D E2 80 BA E2 80 9D C3 B4 E2 80 9D C3 B4 E2 80 9D 68 E2 80 9D 68 E2 80 9D 43 E2 80 9D 43 E2 80 ..h..h..C..C..
82 000009A0: 9D 22 E2 80 9D 22 E2 80 9D 02 E2 80 9D 02 E2 80 9D E2 80 9E E2 80 9C E2 80 9E E2 80 9C C6 92 E2 ..".."..
83 000009C0: 80 9C C6 92 E2 80 9C E2 80 A2 E2 80 9C E2 80 A2 E2 80 9C C3 A1 E2 80 9C C3 A1 E2 80 9C 68 E2 80 ..h..
84 000009E0: 9C 68 E2 80 9C 4A E2 80 9C 4A E2 80 9C 2B E2 80 9C 2B E2 80 9C 0D E2 80 9C 0D E2 80 9C C3 94 E2 ..h...J...J...+...+..
85
86 00000A00: 80 94 C3 94 E2 80 94 E2 80 93 E2 80 94 E2 80 93 E2 80 94 E2 89 A4 E2 80 94 E2 89 A4 E2 80 94 C3 ..
87 00000A20: AE E2 80 94 C3 AE E2 80 94 76 E2 80 94 76 E2 80 94 58 E2 80 94 58 E2 80 94 3B E2 80 94 3B E2 80 ..v..v..X..X.;;..
88 00000A40: 94 1D E2 80 94 1D E2 80 94 CB 87 E2 80 93 CB 87 E2 80 93 C6 ..
89 00000A60: 92 E2 80 93 C6 92 E2 80 93 C2 B6 E2 80 93 C2 B6 E2 80 93 C3 A2 E2 80 93 C3 A2 E2 80 93 6B E2 80 ..k..
90 00000A80: 93 6B E2 80 93 4E E2 80 93 31 E2 80 93 31 E2 80 93 14 E2 80 93 14 E2 80 93 14 E2 80 93 C2 AF C5 ..
91 00000AA0: 93 C2 AF C5 93 E2 80 B9 C5 93 E2 80 B9 C5 93 C2 AC C5 93 C2 AC 93 C2 A9 C5 93 C2 A9 C5 93 C3 ..
92 00000AC0: AD C5 93 C3 AD C5 93 7C C5 93 7C C5 93 66 C5 93 66 C5 93 51 C5 93 51 C5 93 3C C5 93 3C C5 93 27 ..|..|..f..f..Q..Q..<..<..'|..
93 00000AE0: C5 93 27 C5 93 12 C5 93 12 C5 93 CB 9D C5 92 CB 9D C5 92 C3 8B C5 92 C3 8B C5 92 E2 80 9D C5 92 ..'..}'..
94 00000B00: E2 80 9D C5 92 CE A9 C5 92 CE A9 C5 92 C2 AE C5 92 C2 AE C5 92 C3 AC C5 92 C3 AC C5 92 7D C5 92 ..}..
95 00000B20: 7D C5 92 68 C5 92 68 C5 92 52 C5 92 52 C5 92 3D C5 92 3D C5 92 27 C5 92 27 C5 92 11 C5 92 11 C5 ..).h..h..R..R..=.=.'..'
96 00000B40: 92 CB 9A C3 95 CB 9A C3 95 C3 82 C3 95 C3 82 C3 95 C5 93 C3 95 C5 93 C3 95 CF 80 C3 95 CF 80 C3 ..
97 00000B60: 95 C2 A3 C3 95 C2 A3 C3 95 C3 A7 C3 95 C3 A7 C3 95 77 C3 95 77 C3 95 61 C3 95 61 C3 95 4A C3 95 ..
98 00000B80: 4A C3 95 34 C3 95 34 C3 95 1E C3 95 1E C3 95 08 C3 95 08 C3 95 C3 9A C3 83 C3 9A C3 83 E2 80 B9 ..
99 00000BA0: C3 83 E2 80 B9 C3 83 E2 80 A6 C3 83 E2 80 A6 C3 83 C3 8B C3 83 C3 8B C3 83 C2 AC C3 83 C2 AC C3 ..
100 00000BC0: 83 E2 80 93 C3 83 E2 80 93 C3 83 C3 8B C3 83 C3 8B C3 83 03 C3 95 03 C3 95 21 C3 95 21 C3 95 40 ..!..!..@..
101 00000BE0: C3 95 40 C3 95 62 C3 95 C3 96 C3 95 C3 96 C3 95 C2 B4 C3 95 C2 B4 C3 95 E2 80 9C C3 95 ..@..b..b..
102
103 00000C00: E2 80 9C C3 95 C2 B8 C3 95 C2 B8 C3 95 28 C5 92 28 C5 92 57 C5 92 57 C5 92 62 C5 92 62 C5 92 C3 ..(.(.W..W..b..b..
104 00000C20: 80 C5 93 C3 80 C5 93 E2 89 A0 C3 80 E2 89 A0 C3 80 C3 A2 C2 B7 C3 A2 C2 B7 60 C3 8C 60 C3 8C C3 ..
105 00000C40: 96 C3 8D C3 96 C3 8D C3 A3 C3 8E C3 A3 C3 8E C2 BF C3 8E C2 BF C3 8E 03 C3 8F 03 C3 8F 48 C3 8F ..H..
106 00000C60: 48 C3 8F C3 A8 C3 8F C3 A8 C3 8F C5 B8 C3 8F C5 B8 C3 8F 24 C3 8C 24 C3 8C 71 C3 8C 71 C3 8C C2 ..H.....\$..\$.q..q..
107 00000C80: BF C3 8C C2 BF C3 8C 10 C3 93 10 C3 93 62 C3 93 62 C3 93 C2 B5 C3 93 C2 B5 C3 93 09 C3 94 09 C3 ..b..b..
108 00000CA0: 94 5E C3 94 5E C3 94 C2 B5 C3 94 C2 B5 C3 94 0D EF A3 BF 0D EF A3 BF 67 EF A3 BF 67 EF A3 BF C2 ..^..^.....g..g..
109 00000CC0: AC EF A3 BF C2 AC EF A3 BF 1F C3 92 1F C3 92 7D C3 92 7D C3 92 E2 80 B9 C3 92 E2 80 B9 C3 92 3D ..}{..}..=..
110 00000CE0: C3 9A 3D C3 9A C3 BC 9C 9A C3 BC 9C 9A 02 C3 9B 02 C3 9B 66 C3 9B 66 C3 9B C3 83 C3 9B C3 83 C3 ..-=..f..f..
111 00000DD0: 9B 33 C3 99 33 C3 99 C3 B5 C3 99 C3 B5 C3 99 05 C4 B1 05 C4 B1 70 C4 B1 70 C4 B1 E2 80 B9 C4 B1 ..3..3.....p..p..
112 00000D20: E2 80 B9 C4 B1 49 CB 86 49 CB 86 E2 88 91 CB 86 E2 88 91 CB 86 26 CB 9C 26 CB 9C C3 B1 CB 9C C3 ..I..I.....&..&..
113 00000D40: B1 CB 9C 07 C2 AF 07 C2 AF 79 C2 AF 79 C2 AF C3 8F C2 AF C3 8F C2 AF 5F CB 98 5F CB 98 E2 80 9D ..y..y.....
114 00000D60: CB 98 E2 80 9D CB 98 48 CB 99 48 CB 99 C3 A6 CB 99 C3 A6 CB 99 34 CB 9A 34 CB 9A E2 84 A2 CB 9A ..H..H.....4..4..
115 00000D80: E2 84 A2 CB 9A 21 C2 B8 21 C2 B8 C3 B3 C2 B8 C3 B3 C2 B8 0E CB 9D 0E CB 9D C3 96 CB 9D C3 96 CB ..!..!.....
116 00000DA0: 9D CB 9A CB 9D CB 9A CB 9D 72 CB 9B 72 CB 9B C3 81 CB 9B C3 81 CB 9B 5B CB 87 5B CB 87 C5 92 CB ..
117 00000DC0: 87 C5 92 CB 87 3F 00 3F 00 C3 86 00 C3 86 00 19 01 19 01 C3 84 01 C3 84 01 E2 80 9A 01 E2 80 9A ..?..?.....
118 00000DE0: 01 40 02 40 02 C3 B4 02 C3 B4 02 C3 94 02 C3 94 02 42 03 42 03 C3 AE 03 C3 AE 03 E2 80 B0 03 E2 ..@. @.....B.B..
119
120 00000E00: 80 B0 03 34 04 34 04 C3 89 04 C3 89 04 E2 80 9C 04 E2 80 9C 04 20 05 20 05 6F 05 6F 05 C2 BA 05 ..4..4.....0..0..
121 00000E20: C2 BA 05 0A 06 0A 06 57 06 57 06 E2 80 A2 06 E2 80 A2 06 C3 9A 06 C3 9A 06 4D 07 4D 07 E2 80 9C ..W.W.....M.M..
122 00000E40: 07 E2 80 9C 07 57 08 57 08 E2 82 AC 08 E2 82 AC 08 5F 09 5F 09 E2 80 9E 09 E2 80 9E 09 66 0A 66 ..W.W.....f.f..
123 00000E60: 0A C3 8D 0A C3 8D 0A 6D 0B 6D 0B EF A3 BF 0B EF A3 BF 0B 72 0C 72 0C C4 B1 0C C4 B1 0C 76 0D 76 ..m.m.....r.r.....v.v..
124 00000E80: 0D C2 AF 0D C2 AF 0D 78 0E 78 0E CB 98 0E CB 98 0E 78 0F 78 0F CB 86 0F CB 86 0F 74 10 74 10 C3 ..
125 00000EA0: 9A 10 C3 9A 10 6E 11 6E 11 C3 88 11 C3 88 11 64 12 64 12 E2 80 BA 12 E2 80 BA 12 55 13 55 13 C3 ..
126 00000EC0: 95 13 C3 95 13 43 14 43 E2 88 48 E2 88 48 F1 14 E2 88 48 F1 14 C5 15 C5 15 CB 15 C5 15 10 16 16 C3 ..
127 00000EE0: 84 16 C3 84 16 C3 94 16 C3 94 16 5C 17 5C 17 C2 BB 17 C2 BB 17 33 18 33 18 C3 BA 18 C3 BA 18 C3 BA 18 04 ..\.\.....3..3..
128 00000F00: 19 04 19 6A 19 6A 19 C5 93 19 32 1A 32 1A C3 AF 1A C3 AF 1A C3 99 1A C3 99 1A 55 1B 55 ..j.j.....2.2.....U.U..
129 00000F20: 1B C3 BC 1B C3 BC 1B C2 AB 1B C2 AB 1B C3 9B 1B C3 9B 1B 1C 1C 1C 45 1C 45 1C 6C 1C 6C 1C C3 ..E.E.1..

SAMPLES

- common sample rate + sample depth
 - 44.100Hz, 16bit (CD quality)
 - 48.000Hz, 24bit (more *recent* digital system)
- common sample value range: `FLOAT(-1.0, 1.0)`
- Digital-Analog Converters (DAC) convert samples into analog audio signals
- Analog-Digital Converters (ADC) convert analog audio signals into samples

SAMPLES

@mozzi(out of *historical reasons* mozzi mostly uses 8bit sample resolution)

AUDIO PROCESSING + SYNTHESIS

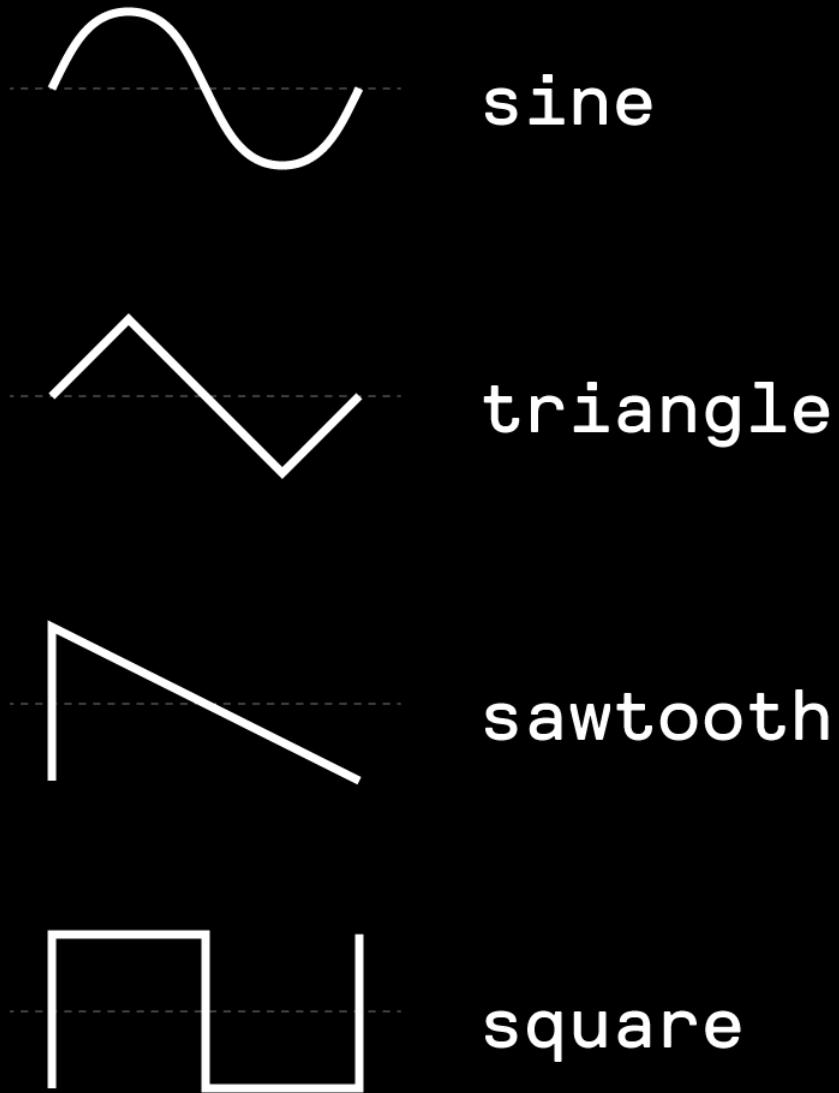
- oscillators
- filters
- envelopes
- effects
- analysis

----- OSCILLATOR -----

oscillator repeatedly create signals at specific frequencies.
oscillators are distinguished by the *waveforms* they produce.

the most common waveforms or -shapes are:

- sine
- triangle
- sawtooth
- square



----- OSCILLATOR -----

- in reference to their electronic origins oscillators are sometimes still referred to as *Voltage-Controlled Oscillators* (VCO).
- oscillators that oscillate at low frequencies ($< 20\text{Hz}$) are referred to as *Low Frequency Oscillators* (LFO).
- *wavetables* are pieces of memory containing waveforms (or other sample data). in audioprogramming wavetables are sometimes used to implement oscillators.
- *oscilloscopes* are used to visualize signals.
- @example(ExampleDSP05Wavetable)

----- OSCILLATOR -----

@mozzi(

a sinewave oscillator with 2048 samples may look like this:

```
#include <0scil.h>
#include <tables/sin2048_int8.h>
0scil <SIN2048_NUM_CELLS, MOZZI_AUDIO_RATE> aSin(SIN2048_DATA);
```

samples are continuously generated with aSin.next()
)

FILTERS

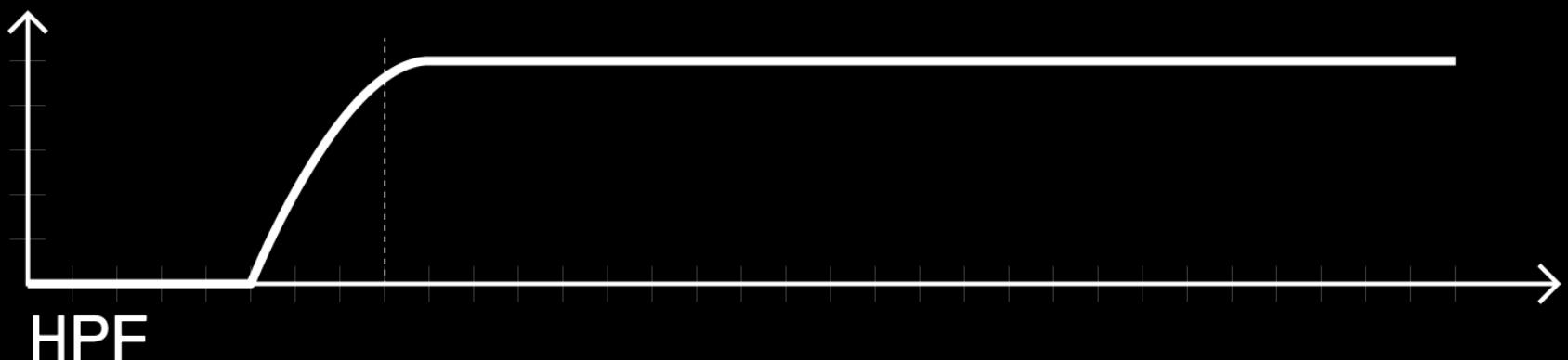
filters are processes that remove unwanted components or features (often frequencies) from a signals.

the most common filters are:

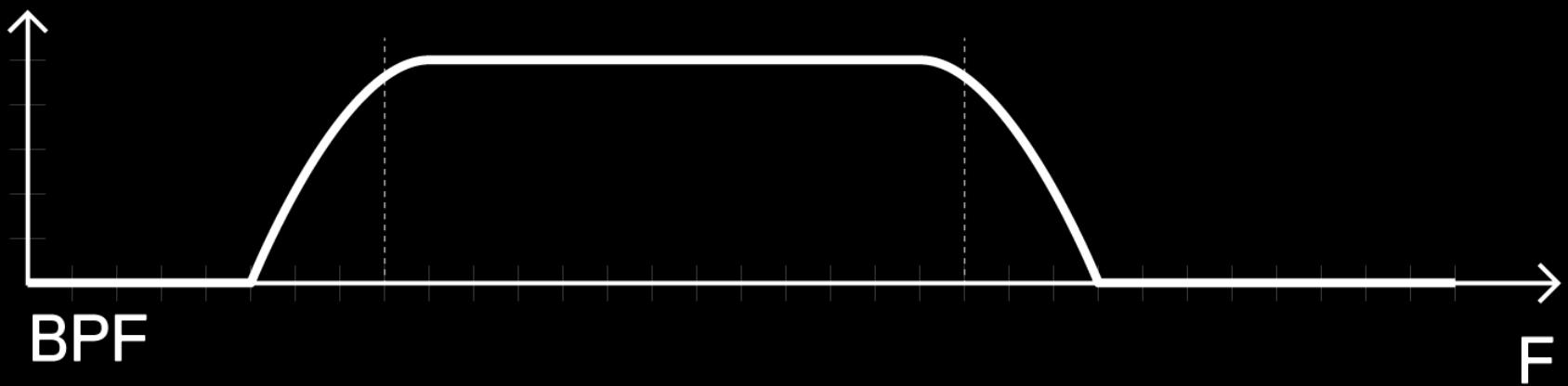
- Low Pass Filter (LPF)
- High Pass Filter (HPF)
- Band Pass Filter (BPF)



LPF



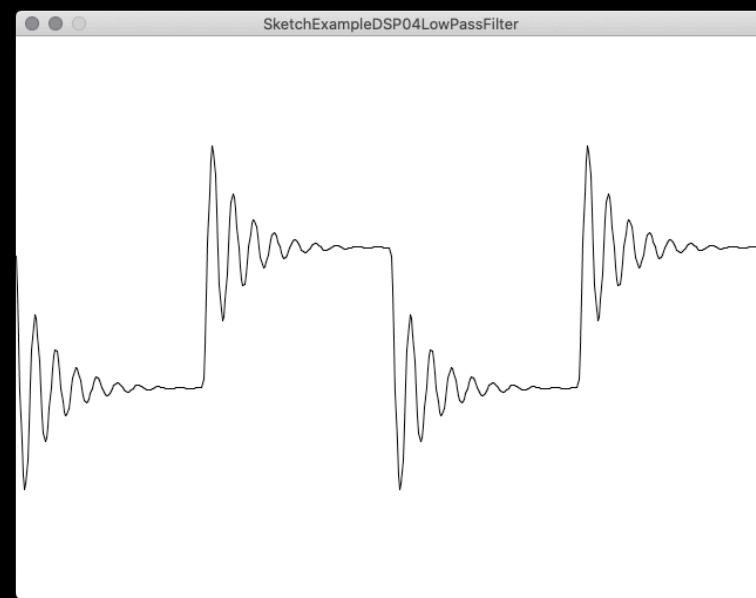
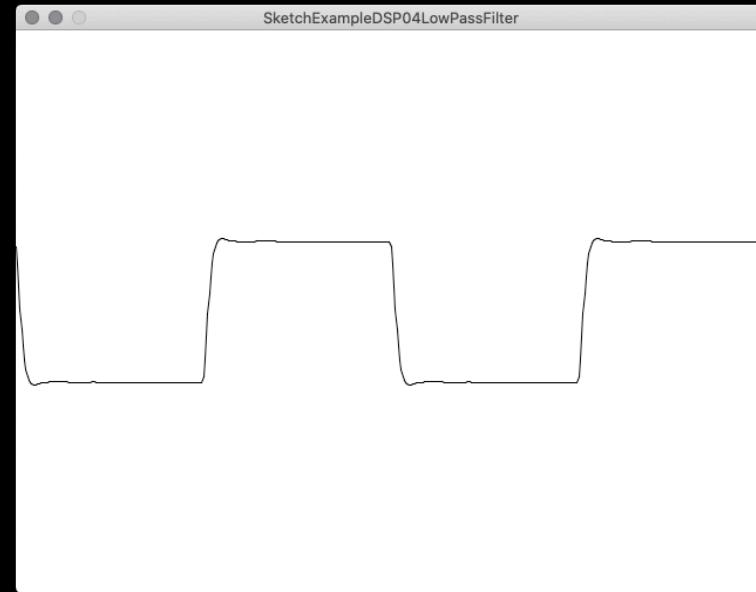
HPF



BPF

FILTERS

- in reference to their electronic origins filters are still sometimes referred to as *Voltage-Controlled Filters* (VCF)
- 2 common parameters in filters are
 - *CutOff Frequency*
 - *Resonance (Q or quality factor)*
- @example(ExampleDSP04LowPassFilter)



----- FILTERS -----

@mozzi(
a low-pass filter may look like this:

```
#include <StateVariable.h>
StateVariable <LOWPASS> svf;
```

e.g cut-off frequency is set with `svf.setCentreFreq(1200)` samples
are continuously filtered with `svf.next(mSample)`
)

ENVELOPES

envelopes describe parameter changes over time.

the most common envelope is the *Attack-Decay-Sustain-Release envelope* (ADSR).



----- ENVELOPES -----

- ADSR envelope synth tutorial part A
- ADSR envelope synth tutorial part B
- @example(ExampleInstruments01ADSR)
- note that envelopes can be applied to other parameters as well
e.g filter or effect values.

EFFECTS

- delay/echo
- reverb
- chorus
- @example(ExampleDSP03Echo)

EFFECTS

@mozzi(
a delay with a buffer with a maximum of 256 samples may look
like this:

```
#include <AudioDelay.h>
AudioDelay <256> aDel;
```

samples are continuously generated with
aDel.next(mSample, mBufferLength)
)

----- ANALYSIS -----

- Peak Follower
- Beat Detection
- Fast Fourier Transformation (FFT) (for an impressively comprehensible explanation on fourier transformations see [3Blue1Brown: But what is the Fourier Transform? A visual introduction.](#))
- `@example(ExampleDSPAnalysis00FFT) + @example(ExampleDSPAnalysis01SonogramFrequencyDistribution)`

SUMMARY

- Subtractive Synthesis (+ Additive Synthesis)
- Digital Signal Processing (DSP)
- analog + digital Modular Synthesizer (see also Eurorack)
- @REF(Curtis Roads: The Computer Music Tutorial)
- @REF(Music DSP)

----- PROGRAMMING AUDIO -----

- visual (nodes + flow) versus text-based (block)
- visual
 - Max
 - Pure Data
- text-based (on desktop)
 - SuperCollider
 - Csound
 - Processing.org (via Libraries)
 - Sound
 - Minim
 - Wellen
- text-based (on microcontrollers (MCU))
 - DaisySP
 - Mozzi
 - KlangWellen

AUDIO APPLICATIONS

an incomplete list of some common audio applications:

- Max @visualprogramming
- Pure Data @visualprogramming
- SuperCollider @text-based
- Csound @text-based
- Ableton Live @DAW
- Logic Pro / GarageBand @DAW
- REAPER @DAW
- Bitwig Studio @DAW
- VCV Rack @modularsynthsimulator
- Audacity @audio-editor
- ocenaudio @audio-editor

WELLEN

Wellen is a framework for exploring and teaching generative music making and algorithmic compositions. it facilitates simple ways of playing musical notes, facilitates easy access to low-level digital signal processing (DSP) and supplies rhythm and timing as well as some standard musical mechanics. the library acts as an adapter to various sound in- + outputs like MIDI, OSC, or digital/analog audio. the library is hosted on github wellen.

WELLEN

- **Ton** playing notes
- **DSP** processing sound
- **Beat** creating rhythm

KEYWORDS

- Period :: one full cycle of an oscillation e.g of a sine wave
- Amplitude :: the height of an oscillation
- Hertz (Hz) :: 1Hz translates to "once per second". e.g a sinewave that oscillates at 100Hz repeats the *period* (i.e one full cycle) 100 times per second. in audio context
- Sample :: a single sample is just a singe number usually within a specific range. in audio context it is common to have a value range from -1.0 to 1.0 for float or -32768 to 32767 for a signed, 16bit integer i.e int16_t
- Sampling Rate (or Sample Rate) :: number of samples per second e.g a sampling rate of 48KHz means 48000 samples per second.

KEYWORDS

- Bit Depth :: resolution or value range of a sample. common sample rates are 8bit (e.g with Mozzi on Arduino Uno), 16bit (e.g CD quality), 24bit (e.g default with most audio hardware) and 32bit.
- Digital-Analog Converters (DAC) :: convert samples into analog audio signals (i.e voltages)
- Analog-Digital Converters (ADC) :: convert analog audio signals into samples
- Audio Codec :: an IC combining DACs + ADCs. Audio Codecs often interfaced via I2S (Inter-Integrated Circuit Sound) for audio signal transmission and controlled via I2C