“How did they make that sound?”

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Outline

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First look inside a synthesizer

I sometimes open up a synthesizer VST in a lesson.

The reaction is usually something like...

First look inside a synthesizer

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DON'T PANIC!

Calm down.

Take it one piece at a time...

Why learn synthesis?

Why bother with the complexity?

To develop your personal, individual sound.

- If you only use presets, you sound like other people.
- If you *tweak* presets to do what you want, you sound unique.

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- You can use MIDI more effectively.

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Necessary element of some music styles!

- Dance music is *all* about new tone colors.
- You can't make *good* dance music just from presets.

Overview

We'll start with common features of synthesizers.

- Found in basically every synthesizer.
- Learn these and you can find your way around *many* instruments.

Discuss details of a couple of synthesis techniques.

- Subtractive (analog-style).
- Frequency Modulation.

Recreate two example sounds.

- "How did they do that?"

Absynth

In this lecture, we'll use *Abysnth*.

- From Native Instruments.
  Makers of Kontakt, FM8, Massive, Battery, Reaktor etc.
- http://www.native-instruments.com/en/products/komplete/synths/absynth-5/

"Semi-modular" design.

Modular synthesizers give you small, simple *modules*.

- You're free to patch them together how you like.
- Powerful, but more complex to learn.

Absynth uses modules, but patching is not totally free.

- Somewhat simpler to use.
- Still has a lot of flexibility!

Synthesis techniques in Absynth

Absynth supports *many* common synthesis techniques:

- Subtractive (analog-style).
- Frequency Modulation.
- Ring modulation.
- Sample playback.
- Granular synthesis.

A single Absynth instrument can use any of these, together.

- Three oscillator–filter–modulator chains.
- The chains are independent.
- No problem to mix, e.g., analog-style, FM and a sample player.

Outline

One piece at a time...

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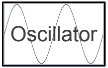
When you know the patterns, you can make sense of just about any VST synthesizer!

Let's start by looking at the standard components.
These are in almost every synthesizer.

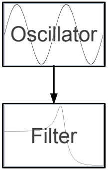
Synthesis components 1: Oscillator

All electronic instruments start with a noise-maker

- **Oscillator:** Generates an artificial waveform
  - Repeating waveforms have pitch
  - Randomized waveforms sound like noise
- **Sample player:** Uses a sound file
  - Kontakt *source modules*
- **External audio input** from the soundcard
  - Microphone
  - Line input (electric guitar, e.g.)
  - Cubase/Logic track
  - *Absynth* from Native Instruments supports this



Synthesis components 2: Filter



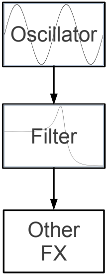
Filters change the tone color.

- All sounds are a mix of frequencies.
- Filters boost some frequencies, and cut others.

Most electronic instruments have filters

- Standard filters are CPU-cheap to process
- Powerful and easy-to-control effect

Synthesis components 3: Other FX



Standard effects

- Chorus, distortion, delay
- Also CPU-cheap
- *Fatten up* a sound easily

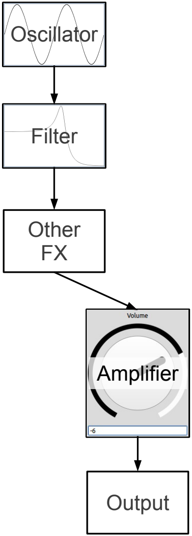
Nonstandard effects

- Complex synth instruments have *lots* of places to put effects
  - Absynth, FM8...
- Too many to try to list

Synthesis components 4: Amplifier and output

At the end of the chain:

- Volume control
- Output
  - Sometimes, multiple outputs



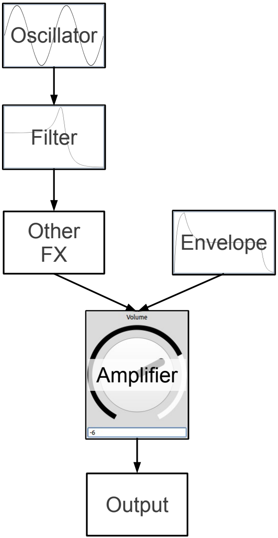
Synthesis components 5: Envelope

An *envelope* shapes the beginning, middle and end of the note

- It works on the volume control
- The top of the envelope is the volume control's setting
- The bottom is silent

You don't want a waveform to start or stop instantly!

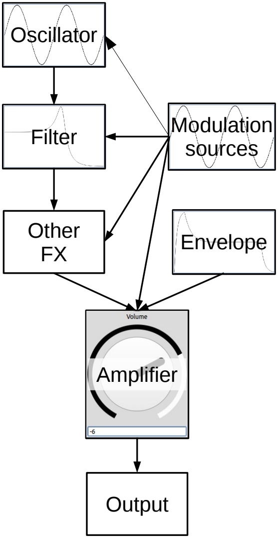
- Click or pop



Synthesis components 6: Modulation

All these components have *control inputs*.

- *Modulating* a control means that it changes continuously.
- Typical modulation sources
  - *LFOs* (Low Frequency Oscillators)
  - Extra *envelopes*
  - *External control*: MIDI, automation
- Simple synths may have just one LFO and one modulation envelope
- Complex synths (*Abysnth*) have several LFOs and even more envelopes



Synthesizer VSTs have these elements

You can find all of these components in VSTs.

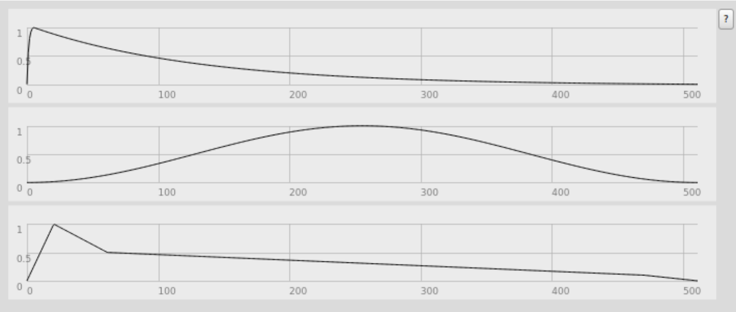
With practice, you can open any VST and recognize the components.

Envelopes

Some notes on *envelopes*.

An *envelope* is a signal with an adjustable shape.

- Usually controls a note's volume:
  You put a note in an envelope to give it a beginning and end.
- Usually rises from a low level, then falls back to the start.
- Usually connected to note-on and note-off.

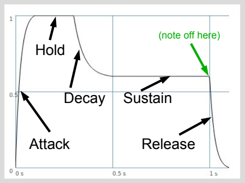


ADSR envelopes

ADSR is the most common envelope shape.

Attack [– optional Hold] – Decay – Sustain – Release

Attack	Rising from 0 to the peak level in **A** seconds
Hold	Stay at the peak level for **H** seconds
Decay	Falling to a middle level in **D** seconds
Sustain	**S** is the middle level (*not* a time) The envelope level *holds* here
Release	Falling to silence in **R** seconds



Importance of a note's attack

In ADSR, a lot happens at the beginning.

The beginning of a note tells us a lot about the source.

- Flute and trumpet: The tone colors are similar.
- The attacks are very different!
- That's how we tell them apart.

ADSR gives you a lot of control over the beginning.

Elements of a note attack

Volume (amplitude) changes.

Hard attack:

- Fast *attack* and *decay*.
- Lower *sustain* level $\rightarrow$ bigger initial volume spike.

Soft attack:

- Slower A and D, smaller volume spike.

Tone color changes.

- The attack is usually *brighter* than the sound's body.
- Brighter $=$ more high frequency content.
- How to make it brighter depends on the synthesis technique.

Envelopes' influence on controls

Two ways that an envelope can affect a control.

(For example, a volume or filter control.)

- You set the control to a high level.
  Then, the envelope brings the level down.
- Or, you set the control to a low level.
  And the envelope pushes it up.

The behavior depends on the VST instrument.

- *Absynth* follows the first style:
  Envelopes etc. always bring a control *down*.

To find out: Read the manual and experiment.

Mono vs. poly

Should the instrument play single notes or chords?

Monophonic Single notes: Melody, bass.

Polyphonic Chords: Pads, keyboards, any harmony.

Mono synths: Look for the *glide* control!

Fingered glide is expressive!

- A note *reattacks* if it has space before it.
- If a note overlaps the last one, it *slurs*.

Almost all synthesizers have this option.

- Called *fingered*, *legato*, *held*, perhaps other names.

Fingered glide in Abysnth

Perform → Note → Legato

Fingered glide in Monologue

Master section → Glide mode → Held

Summary

Almost all synthesizers have a few standard components:

- Sound sources: Oscillator, sample player, external input.
- Filters: Change the tone color.
- Envelopes: Give shape to a note.
- Modulators: LFOs, external controls (MIDI or automation).

Glide mode for expression!

Learn to recognize these components.

This helps you understand what you see onscreen.

Outline

Subtractive synthesis basics

What does “subtractive” mean?

Subtractive synthesis basics

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- We start with a *bright* waveform—lots of harmonics.
- Then we use filters to *subtract* some harmonics from the spectrum.

Very popular technique. Why?

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Very popular technique. Why?

- The most common waveforms resemble natural processes.
- Filters work a lot like our ears—easy to relate to.
- Controls are intuitive.
- Easy to do in analog circuitry.
  So, it was the first widely used synthesis technique.
  (FM synthesis is almost impossible without digital audio.)

Sonic character of subtractive synthesis

Classic, “vintage” synthesizer sound.

Because it’s based on “vintage” analog circuits.

- Fat pads, leads and basses (Native Instruments’ *Massive*).
- *Lots* of familiar techno/house sounds.
- Filter *resonance* is especially characteristic.

Examples:

- Wendy Carlos: J.S. Bach, Two-part Invention in F major.
- Josh Wink, “Higher State of Consciousness”
- Spacetime Continuum, “Kairo” (*Emit Ecaps*).

Components

The standard parts of synthesizers are here:

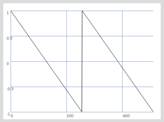
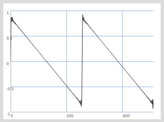
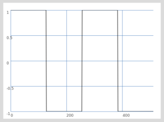
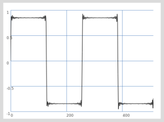
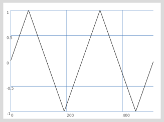
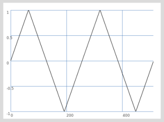
- The sound source is called an *oscillator*.
  Oscillators produce a few standard wave shapes.
- *Filters* are the key to making unique sounds!
- *Envelopes* control volume and tone color.

Note: Absynth doesn't do "true" analog-style synthesis.

- It uses *wavetable* oscillators.
- A wavetable holds one cycle of the waveform.
- This is repeated over and over, at the requested frequency.
- Analog-style oscillators use math to avoid *aliasing*.
  Aliasing: What happens to frequencies too high for the sampling rate.

Oscillators: Typical waveforms

The most common waveforms are:

Waveform	Ideal shape	Band-limited
Sawtooth		
Square		
Triangle		

Noise oscillators

There's usually a *noise* oscillator.

- Many instruments have a slight burst of noise in the attack.
- The noise oscillator simulates this.
- You can "tune" the noise using filter resonance!

Absynth is not good at noise.

- Wavetable oscillators repeat the waveform.
- All repeating waveforms have some sense of pitch.
- Noise does not repeat: No clear pitch.

Frequency content of waveforms

Important idea: Fourier theorem.

All repeating waves are the sum of sinewaves.

Harmonic series

The standard analog waveforms are *harmonic*.

All of the sinewaves are related by whole numbers.

- The base pitch is the *fundamental*: f.
- Then, the harmonics are $2f, 3f, 4f$...

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The different shapes come from different *amplitudes*.

- Amplitude = strength.
- **Sawtooth:** Amplitude $= 1 \div$ harmonic number.
- **Square:** Same, but every even harmonic is 0.

Multiple oscillators

Fatten up the sound by using more oscillators.

- One oscillator is boring: dry, sterile.
- Mixing several oscillators is an "additive" element, applied to subtractive synthesis.

Common "tricks" for multiple oscillators:

- Fatter, richer sound by setting them slightly out of tune.
  - Look for a *fine* tuning control.
  - Absynth has a tab ("Uni") to play several oscillators within one unit.
- Oscillators an octave apart produce stronger bass.

Filters

Filters are the main control over tone color.
Often, a tone color that changes over time.

Typical filter types:

Low pass	Keep low frequencies, cut high frequencies.
High pass	Keep high frequencies, cut low frequencies.
Band pass	Keep middle frequencies, cut low and high.

Slope of filter response curve

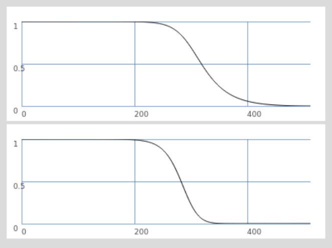
Sometimes filters may be identified with extra information.

E.g., in Absynth, *LPF –6dB* or *LPF 2 Pole*.

These refer to how sharply the filter cuts off frequencies.

Often given in *dB/octave*:

- At –6 dB/octave, if 1000 Hz is -10 dB, 2000 Hz will be -16 dB.
- At –12 dB/octave, 2000 Hz would be -22 dB.



dB/octave, stages, poles

Stages or *poles* are different names for the same thing.

- *Stages*: Steeper curve by cascading filters.
  - One stage: Signal → filter → output.
  - Two stages: Signal → filter → filter → output.
- The term *poles* comes from mathematical filter analysis.
  You need to know only: More poles = steeper filter.

In general:

Attenuation	**Stages**	**Poles**
–6 dB/oct	(simpler filter)	1
–12 dB/oct	1	2
–24 dB/oct	2	4

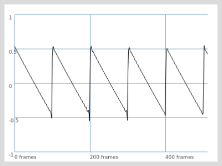
Resonance control

Resonance boosts energy around the cutoff frequency.

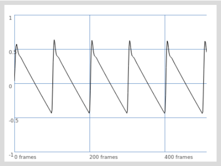
This has the effect of adding a sine wave component to the corners of the input.

- Low resonance, below, reduces the normal band-limited "wiggling."
- High resonance adds even more, at a specific frequency.

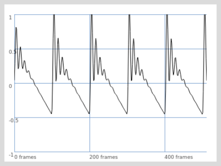
Sawtooth, no filter



Low resonance



High resonance



Typical uses of subtractive synthesis

Basslines: Lowpass filter with a low cutoff.

Sawtooth: Warmer, richer. Square: Aggressive!

“Spacey” pads and leads.

- Especially with big filter sweeps.
- Filter sweeps are more obvious with resonance.
- Use envelopes or automation.

Dance music: Filters on drums are classic.

Non-standard subtractive synthesis

Standard:

- Oscillator provides pitch.
- Filter shapes tone color.

Non-standard:

- Filter *resonance* has its own pitch!

This is the basis of *modal* synthesis.

Modal synthesis

"Mode": Vibration patterns when an object is struck.

- Hitting it adds energy.
- The vibrational energy bounces around in the object.
- These follow specific patterns.
- Each paths has its own pitch.
- This is the "mode."

Modal synthesis simulates this:

Exciter A short noise signal, for the impact.

Ringing filters One filter = one mode.

Fairly realistic bell sounds.

Software for modal synthesis

Most VST plug-ins cannot do this.

- You need a bank of parallel filters.
- Very few synthesizer plug-ins allow this.

You might try *Tassman 4*.

Modular synthesizer from Applied Acoustics Systems.

I will demonstrate using SuperCollider.

- Free-form patching is even easier than in a VST!
- You could also do this in Max/MSP or Pure Data.

Outline

Frequency Modulation (FM) synthesis

Discovered by John Chowning at Stanford, 1973.

The initial experiment:

- Play a sine wave with vibrato (LFO on pitch).
- Slowly raise the LFO's frequency, until it isn't low frequency anymore.
- When the modulating wave gets up into audio frequencies:
  - You stop hearing vibrato.
  - The *tone color* changes.

Important words for FM synthesis

Terms you need to know:

Carrier	The oscillator whose frequency is being modulated. This is the signal you actually hear.
Modulator	The oscillator controlling the carrier's frequency.
Mod index	The width of the vibrato.
Mod ratio	Modulator frequency ÷ carrier frequency.

Where are these in Absynth?

In Absynth, most of it is in the oscillator's *Mod* tab.

The *carrier* waveform and frequency are *Main*.

The *modulator* parameters are *Mod*.

- Modulator waveform;
- Modulation index;
- Modulator frequency:
  - By default, a MIDI-note transposition.
  - *Ratio* is more useful for FM.
  - Integer ratios (2:1, 3:1 etc.) produce clean pitch.
  - Fractions (1.7128:1) produce strange, metallic tone colors.

Effect of modulation index

FM synthesis works by adding *sidebands* to the spectrum.

Assuming the carrier and modulator are sine waves:

- Let's say the carrier frequency is f_c.
- Modulator frequency $= f_m = f_c \cdot k$.
- Sidebands appear at *integer multiples* of the modulator frequency:
  $f_c \pm f_m$, $f_c \pm 2f_m$, $f_c \pm 3f_m$ etc.

The mod index makes the sidebands louder.

- Low mod index: Only a few sidebands are audible.
- High mod index: Many sidebands are audible, at higher frequencies.

Effect of modulation ratio

In general, higher ratio $\rightarrow$ brighter, thinner sound.

- **Ratio = 1.0:** Wooden sound.
- **Ratio = 2.0:** Like a square wave (clarinet).
- **Higher:** Somewhat metallic, like electric piano tines.
- **Ratio = 0.5:** *Very nice* for basses.

Those are nice, round numbers.

What about complicated ratios like 1.72386?

- Sideband frequencies have a complex relationship.
- Sounds out of tune, metallic, bell-like.
  Mod Index envelope can make a naturalistic decay!

FM synthesis + Wavetables

Wavetables add another dimension.

- The early research was done with sine waves.
- The carrier and modulator may use any waveform, however.

Very cool results from a more complex modulator wave.

- A few weaker harmonics: Slight extra buzz or edge.
- Thicker modulator: Intense vocal-like effects.
  - Especially good for basses!
  - Try with distortion as well.

Adding harmonics to the carrier: Additive effect.

Not as exciting, but useful (especially for organs).

Modulating controls

Tone color: *Mod Index* is the key.

- Fast spike: Percussive attack.
- Slow changes: *cresc.* and *dim.*

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- Slow changes: *cresc.* and *dim.*

Changing *Mod ratio* can sound really strange.

- Causes sidebands to slide up and down.
- You shouldn't expect naturalistic results.
- Nice trick: Change randomly between integer ratios.
  - Most synth plug-ins don't give you that much control.
  - Absynth is one of them.
  - Easy in a programming environment like SuperCollider.

What is FM good for?

Metallic or wooden decaying sounds.

- Slowly-decaying envelope on mod index.
- Electric pianos especially.

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Sidebands are somewhat like vocal formants.

- Carrier = formant center frequency.
  Modulator = desired pitch.
- Surprise use of this: Dubstep wobble basses.

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Deliberate aliasing for weird percussion.

- High mod index at high pitch produces frequencies too high for the sampling rate.
- These produce strange, unpredictable tone colors.

Outline

Advanced use

Let's re-create the fast layer from "Kairo."

Varies from dark and staccato to bright and sustained.

- Bright vs. dark: Filter cutoff frequency.
- Staccato vs. legato: Filter envelope decay time.
  - Long decay: Cutoff stays high; sound "slurs" between notes.
  - Short decay: Cutoff sweeps quickly to low frequencies.

Attach separate MIDI controllers to these two.

Now you can automate them in the project.

- How to connect them? Different for every instrument.

How did they make that?

Example: Underworld, "Rez"

Big clue: Some notes are "out of tune."

- They follow the *harmonic series*:
  If f is the fundamental, harmonics are $2f, 3f, 4f$...
- Standard oscillators produce exact harmonics.
- A resonant filter "pulls out" the harmonics.
  (Here, not much low frequency: Bandpass filter.)

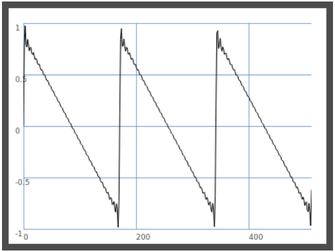
Resonant filter + distortion = stronger resonance.

Band limited impulse waves

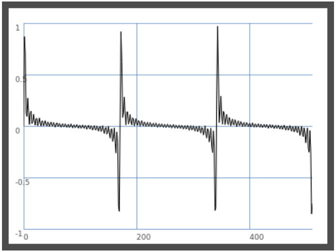
For stronger harmonics, use an impulse wave.

- Sawtooth: Higher partials are weaker.
  If k is the harmonic number, strength is $\frac{1}{k}$.
- Impulse: All partials have the same strength!

Sawtooth: $\text{Amp} = \frac{1}{k}$



Impulse: $\text{Amp} = 1$



Filtering

Lowpass is the normal type of filter.

Keep all low frequencies; cut the high end.

Here, we want to draw out the midrange pitch.

- We don't need the bass end.
- High frequencies of an impulse wave are too buzzy.

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Use a **bandpass** filter.

Bandpass filters can cut the volume a lot.

- Amplify the signal.
- Also, use fewer harmonics in the impulse.
  Each extra harmonic makes all the others less powerful.

Distortion

Distortion makes a resonant filter stronger.

I don't know why. It just does.

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  More volume going in = more distortion.
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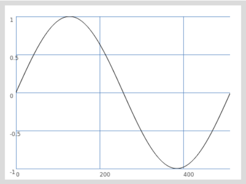
  Distortion plug-ins add some other processing.
- *Volume*: Make it softer at the end.
  Distortion makes it louder. Bring it under control.

Waveshaping

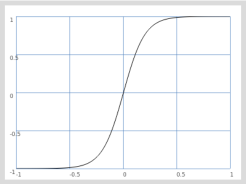
In Absynth, use *Waveshaping*.

- This “bends” the signal according to a *transfer function*.
- Distortion should use an S-shaped function.

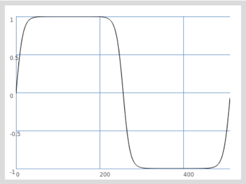
Sinewave



Transfer function

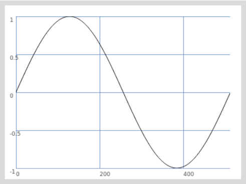


Distorted result

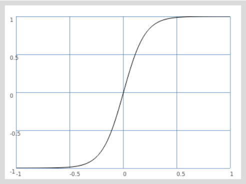


Waveshaping

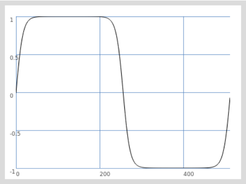
Sinewave



Transfer function



Distorted result

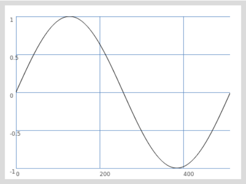


Here, the distorted wave is more like a square.

What's the difference between a sinewave and a square?

Waveshaping

Sinewave



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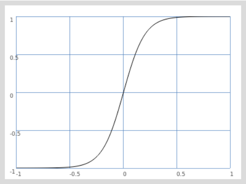
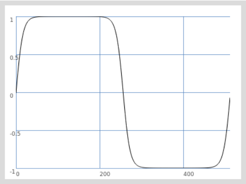


Distorted result



Here, the distorted wave is more like a square.

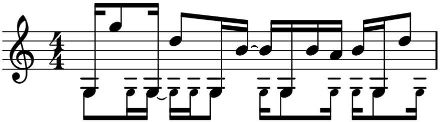
What's the difference between a sinewave and a square?

- The square adds *odd harmonics*: $3f, 5f, 7f$...
- The distorted wave will sound brighter!

Effects

Studio effects are also part of synth sound design.

- Interesting clue: Repeated low G's.



Stereo delay

- One delay = 8th-note; the other = dotted-8th.
- Bonus: This expands the feeling of space.

Outline

Next steps

What should you do, to learn more?

Experiment!

Open up synthesizer VSTs and *play with them*.

- 3–4 days every week, 15–30 minutes.
- Don't worry how it sounds—just try, and see what happens.

Choose a technique and try something new with it.

Especially, something you didn't try before.

- You tried MIDI control of filter cutoff?
  OK. Today, try an envelope or LFO.

This is the #1 most important thing!

You start to learn what action produces what sound.

Read

Read about synthesis techniques.

This can give you new ideas to try.

- Then try them!
  Reading without trying = waste of time.

Excellent resource: **Synth Secrets** series.

- *Sound on Sound* magazine.
- All online, all free!
  (But, in English.)

`http://www.soundonsound.com/sos/allsynthsecrets.htm`

Modulation and effects

Don't forget about modulation!

- Basics of synthesis techniques: Not so complex.
- Creative *modulation* of the inputs creates unique sounds.

Know your studio effects.

- Synthesis doesn't do everything.
- The sound directly from the plug-in might be flat and dry.
- Delay, chorus, distortion, reverb can give it more life.

Keep a list of favorite techniques

When you find a sound you like, remember it and use it.

This becomes part of *your sound*.

In SuperCollider, I often come back to these tricks:

- Gapped spectra: Wavetables with some harmonics removed, or artificially boosted.
- FM synthesis with wavetables.
- Wavetable filled with noise, then filtered.
  A repeating wavetable produces pitch, even if it's noisy.
- Modal synthesis; formant filtering.

Patience

Above all, **be patient.**

- I started with very basic FM synthesis in my teens.
- I learned a little bit at a time.
- Now—after a couple of decades—I know a lot.
- I did **not** learn it all at once.
- I wasn't very good at it in the beginning.

You can't become an expert in a day or a week.

What you **can** do:

- Keep trying. Keep playing with it.
- Try something a little bit different every time.

Do this, and a year later, you'll be surprised what you can do.