Wavetable Synthesis

Wavetables

- A single sound sample can be resampled to change its pitch
- Wavetable synthesis uses resampling to construct an “instrument” from a small number of sound samples
- Resampling using a large scale factor produces unnatural sounds
  - Multiple samples may be used
  - The samples may be modified on the fly

Sample articulation (1)

- *Articulation:* a musical note may be long or short in duration, and may be loud or soft
- The raw sample used to play the note can be modified according to the note articulation
- The dynamics of a sample can be controlled by an envelope
  - Exponential envelope
  - Exponential-sine envelope
  - ADSR envelope

Sample articulation (2)

- To produce a sustained note, two loop points within the raw sample may be chosen
  - The raw sample is played normally until the second loop point is reached
  - As long as the note is held, the portion of the raw sample between the two loop points is then repeated

Exponential Envelope

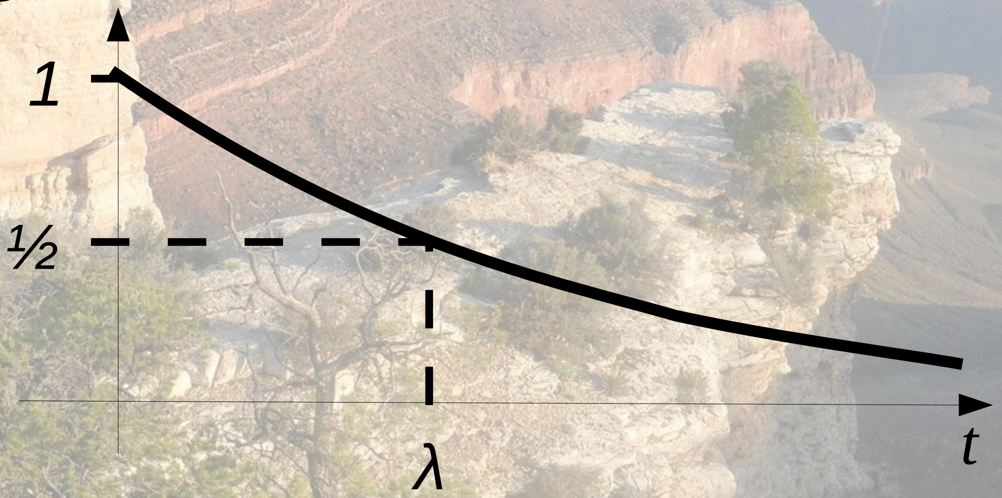
- Governed by the **decay rate** *k*

$$y(t) = e^{-kt}$$

- Used for piano or guitar type sounds

Exponentials in practice (1)

- It is common to use the **half-life** of an exponential: the time interval after which the amplitude falls to half its original value



$$\frac{1}{2} = e^{-k\lambda} \quad \Rightarrow \quad k = \frac{\ln 2}{\lambda}$$

Exponentials in practice (2)

- Theoretically, an exponential decay function will never have zero amplitude.
- In practice, since we represent output values by *b* bit integers, the amplitude has a value of zero for all times $t \geq \tau$, where

$$2^{b-1} e^{-k\tau} = \frac{1}{2} \;\Rightarrow\; \tau = \frac{b \ln 2}{k}$$

In the case $b = 16$, $\tau = (16 \ln 2)/k$, which gives a decrease in amplitude of $\approx -96\ dB$

Exponential Example (1)

- Suppose that the half-life an exponential decay envelope is $\lambda = 0.3\ s$. Find the decay constant.

$$k = \frac{\ln 2}{\lambda} = \frac{\ln 2}{0.3} \approx 2.31\, s^{-1}$$

- At what time after the envelope starts does it have the value of *-10 dB?*

$$g = 10^{-10/20} \approx 0.3162$$

$$e^{-kt} = g \;\Rightarrow\; t = -\frac{\ln(g)}{k} \approx 0.498\, s$$

Exponential Example (2)

- If an exponential envelope takes *7.42 s* to reach -*96 dB* (the effective zero for 16 bit sampling), what is the decay constant?

$$\tau = \frac{16 \ln 2}{k} \quad \Rightarrow \quad k = \frac{16 \ln 2}{\tau} = \frac{16 \ln 2}{7.42} \approx 1.49\, s^{-1}$$

- How long does it take the envelope to go from a gain of *0.8* to a gain of *0.3*?

$$0.8\, e^{-kt} = 0.3$$

$$\Rightarrow \quad t = -\frac{\ln(0.3/0.8)}{k} \approx 0.656\, s$$

Incremental Update

- Exponential function is computationally expensive
- More efficient to compute incrementally

$$y(t) = e^{-kt}$$

$$y\left(t + \frac{1}{R}\right) = y(t)\, e^{-k/R}$$

That is, successive values are computed by multiplying by the exponential factor

$$e^{-k/R}$$

Incremental Update Example

- Suppose an exponential decay envelope has decay rate $k = 0.8$, and the sampling rate is $R = 5\ Hz$
- Exponential factor is

$$e^{-k/R} = e^{-0.8/5} = e^{-0.16} \approx 0.8521$$

- First 4 envelope values are

$$y(0) = 1$$
$$y\left(\tfrac{1}{5}\right) = e^{-1.6} \approx 0.851$$
$$y\left(\tfrac{2}{5}\right) = y\left(\tfrac{1}{5}\right)e^{-1.6} \approx 0.7261$$
$$y\left(\tfrac{3}{5}\right) = y\left(\tfrac{2}{5}\right)e^{-1.6} \approx 0.6188$$

Exponential-Sine Envelope

- Exponential multiplied by a sine function
  - Additional parameter: LFO frequency *f*

$$y(t)=e^{-kt}\sin(2\pi ft)$$

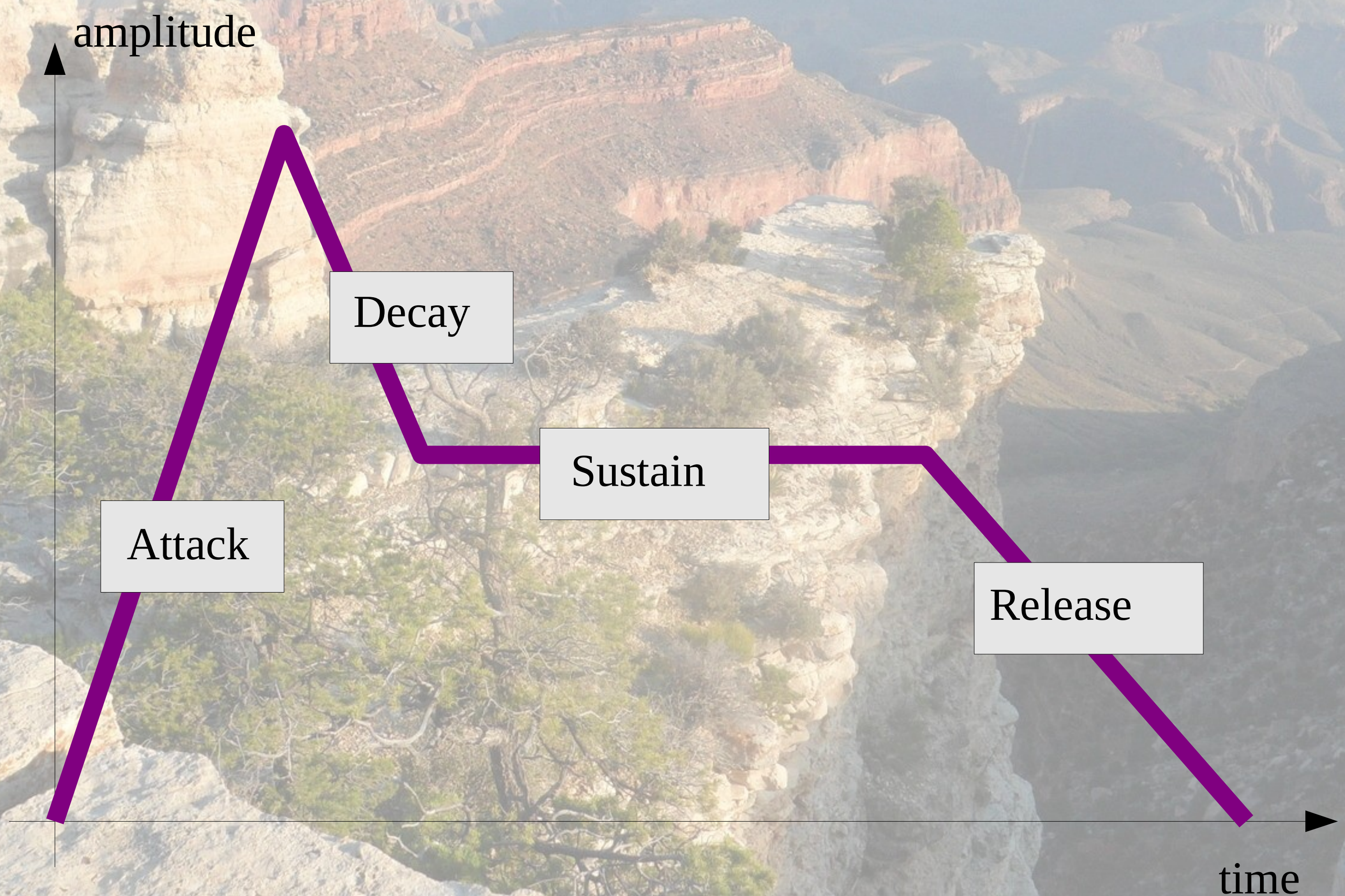
- Used to model bell-like sounds

ADSR Envelope (1)

- ADSR envelopes are common in audio
  - **Attack Phase** – gain increases from 0 to 1
  - **Decay Phase** – gain decreases from 1 to sustain level
  - **Sustain Phase** – constant gain
  - **Release Phase** – gain decreases from sustain level to 0
- In real-time applications, the sustain phase has indefinite duration. E.g., until the user releases a pressed key on a MIDI keyboard

ADSR Envelope (2)

- ADSR envelope diagram



ADSR Envelope (3)

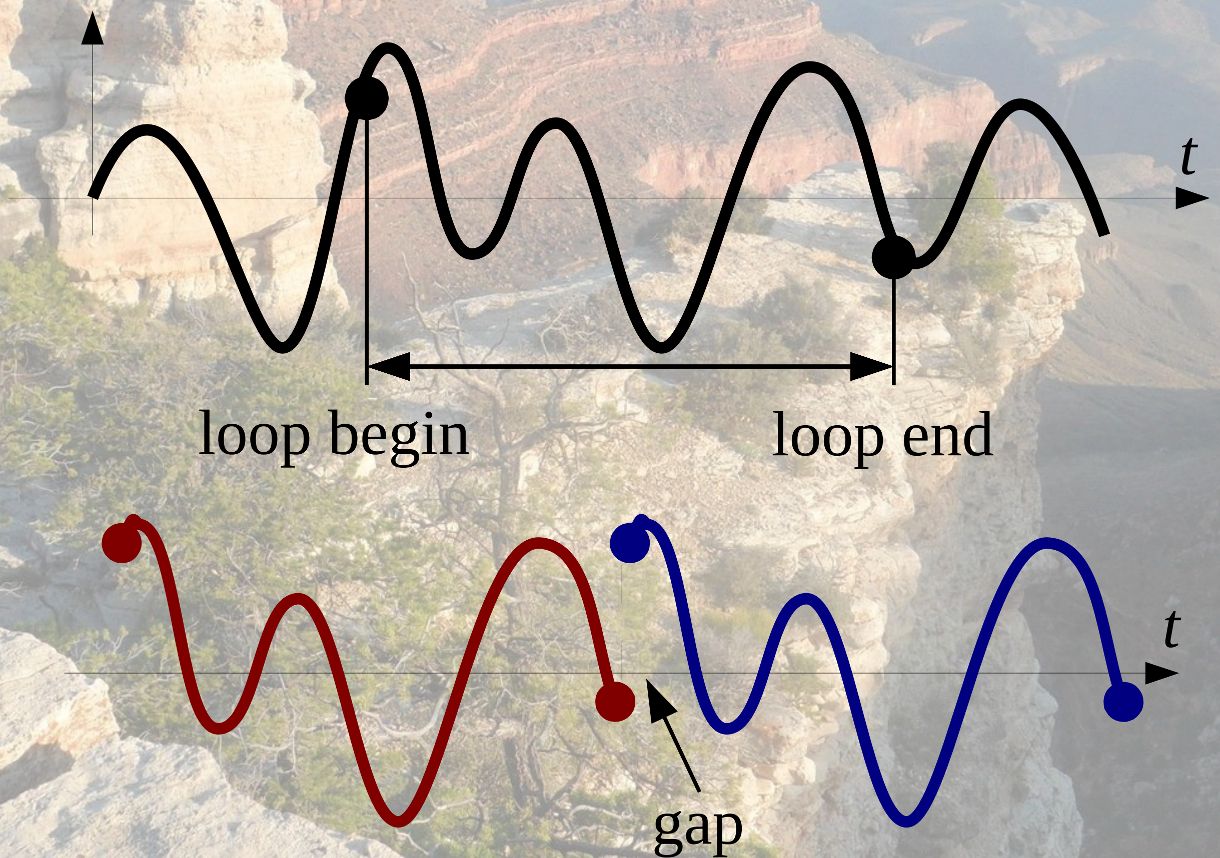
- The attack, decay, and release ramps may be
  - Linear
  - Exponential (linear on a logarithmic scale)
  - A mixture of linear and exponential

Incremental ADSR Envelope

- An ADSR envelope can be computed incrementally
  - Initialize envelope value to 0 (1 if attack time is 0)
  - Attack phase: increment envelope value until 1 is reached
  - Decay phase: decrement envelope value until sustain level is reached
  - Sustain phase: envelope value stays at sustain level until release phase is triggered
  - Release phase: decrement envelope value until (effective) 0 level is reached

Choosing Loop Points (1)

- If loop points are chosen poorly, there is an audible click with each loop iteration



Choosing Loop Points (2)

- Loop points are often chosen at points where the signal crosses the *t*-axis ("zero crossings")