English project
Final presentation
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TheremiNet Project

Online Java based Theremin

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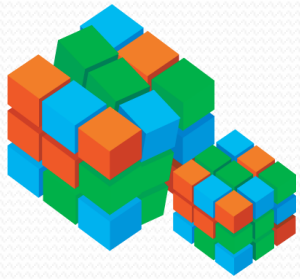
Project presentation

Challenge

- Create a virtual Theremin with a computer
- Make a small application for children, in order to allow them to play with sounds and colours
- Target a large audience by using an easy to deploy software system, such as a Java applet
- Modify a common input device to make it a bit more adapted to our project

Working units

- Colour system: José GUTIERREZ
- Sound system: Eric SIGOILLOT
- Input device: Jonathan BROSSARD



The Theremin

Source of inspiration

The Theremin

- The Theremin is an electronic musical instrument that is played without touching it
- It is composed of two radio frequency oscillators and two metal loop antennas that generate electric signals
- These signals are amplified and sent to a loudspeaker
- To play the Theremin, we move the hands around the two metal antennas

The Theremin

A Theremin played by his inventor

The Theremin: History

- Invented in 1919 by Leon Theremin (Russia), the Theremin was brought to America in the 1920s fascinating some audiences. Unfortunately, it did not have commercial success

- In the 1950s the Theremin fell into disuse because newer electronic instruments, easier to be play, were invented

- In the 1990s it started to be used again because of its unique sound.

The Theremin: Principle

- The musician controls two variables of the sound: the frequency and the volume
- These variables are controlled by the distance of the hands to the antennas
- Frequency: two oscillators, one fixed and one variable. The variable frequency oscillator is a variable capacitor that sees a ground in the hand. The difference between the two oscillators generates a signal in the audio frequency

The Theremin: Principle

- Volume: The hand is again the ground for a variable capacitor that acts as a variable resistance. This resistance controls the volume
- Typically the right hand controls the frequency and the left hand the volume
- Easy to play, but difficult to master

The Theremin: Use

- The Theremin is used in art music, popular music, TV, movies and movie soundtracks

- Ex: Jazz, Led Zeppelin (band's guitarist), Mars Attacks, Hellboy, Bugs Bunny cartoon, the Simpsons

What is an applet?

Applets: global definition

- A small application, designed to accomplish a specific task on the client side
  - Opposed to servlets, on client and server sides
- Encapsulated in a more general application, usually a web browser, but a complete web component
- Restricted abilities: an applet cannot leave its container with the limitations applied

Java applets

- Java applets: an applet written in Java, designed to be run in a web browser
- Concept created in 1995, with the first version of Java
- Offer a complete graphical user interface (AWT or Swing) to be easily manipulated
- Executed in a *sandbox*
  - Cannot access client local data unless authorized

Pros and cons

- Advantages
  - Platform independent: Windows, Linux, MacOS, … If there is a Java Virtual Machine for your system, it can use applets
  - A complete application, with large scale abilities
  - Only needs a browser
- Disadvantages
  - Requires a virtual machine, which is rather slow, at least while loading
  - Some web browser cannot use them, like text-based ones (Lynx, …)

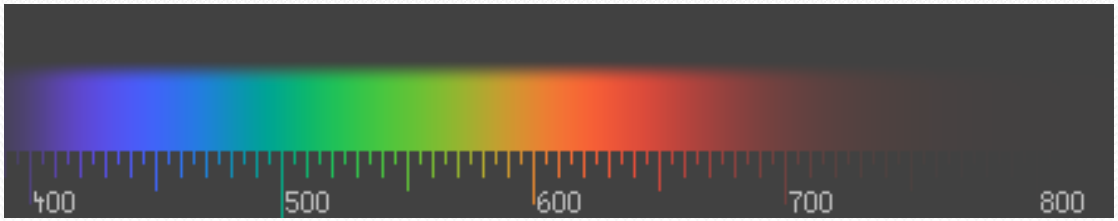
So why an applet?

- For a large audience
- Which can be used by anyone, on any computer with just a mouse and a sound card
- Which is fast and easy to develop and test
- As a challenge since making sound inside a web browser is not always an easy task

Colours representation

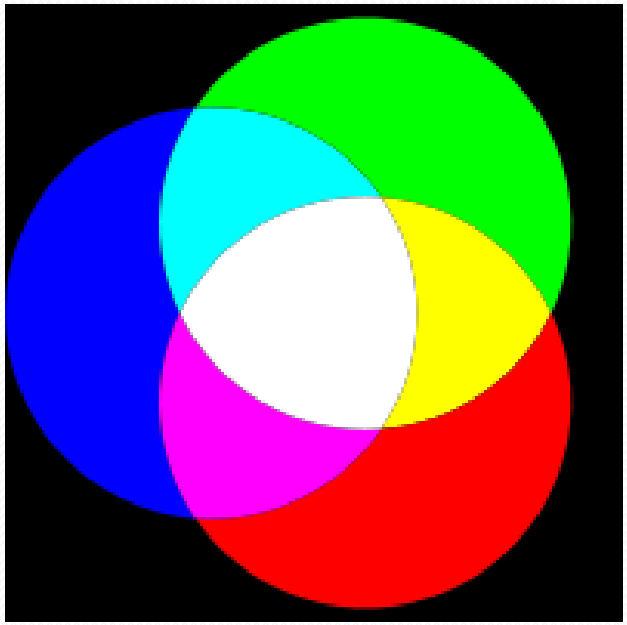
Colour representation

- The colour is the visual perception of the spectrum of light
- The human eye can perceive the light between 405 THz and 790 THz (wavelengths 740nm – 380nm)
- The human eye has 3 colour receptors that respond to red, blue and green respectively



Colour representation

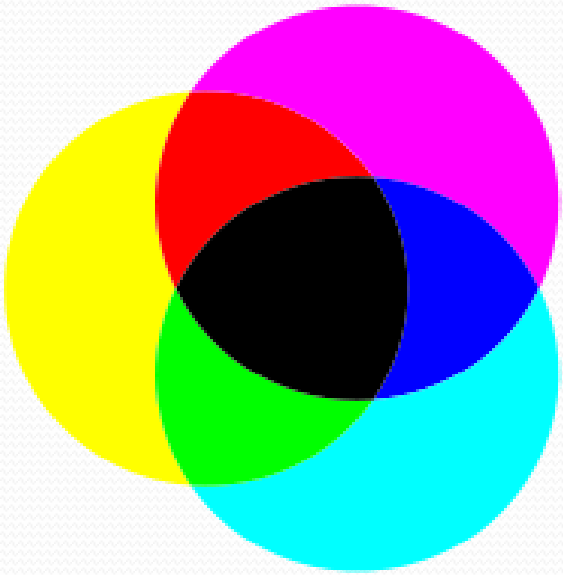
- RGB Model: Uses the colours red, green and blue, in an additive way, to generate a large range of the colours that the human eye can perceive



Additive colours

Colour representation

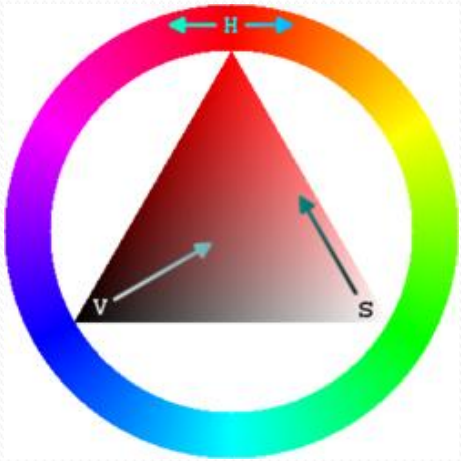
- CMY Model: Use the colours cyan, magenta and yellow, in an subtractive way, to generate a large range of the colours that the human eye can perceive

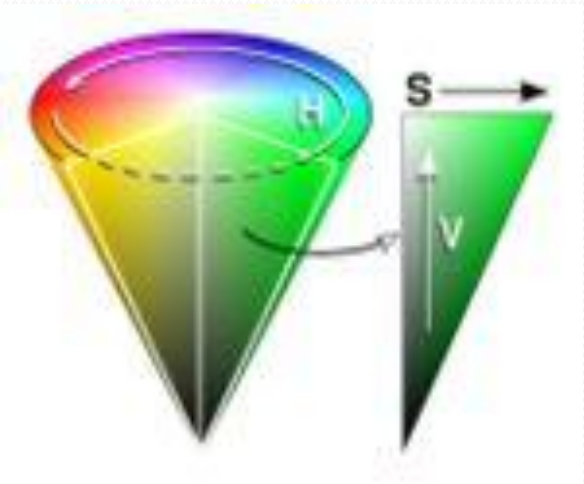


Subtractive colours

Colour representation

- HSV Model: Stands for Hue, Saturation and Value
  - Hue: Colour type (0°-360°)
  - Saturation: vibrancy of the colour (0-100%)
  - Value: brightness of the colour (0-100%)

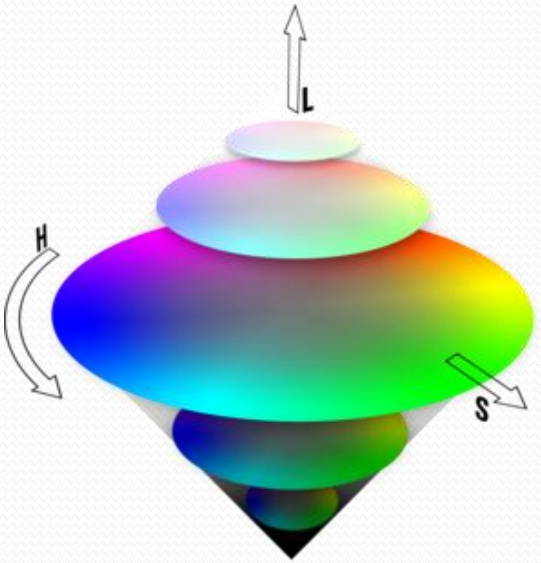




Colour representation

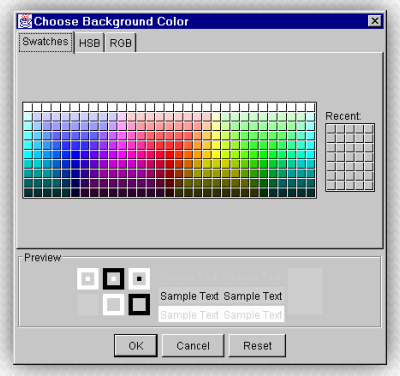
- HLS Model: Stands for Hue, Saturation and Lightness
  - Hue: same as HSV

  - Saturation: same as HSV
  - Lightness: luminance or intensity (0-100%).



Colour: Java implementation

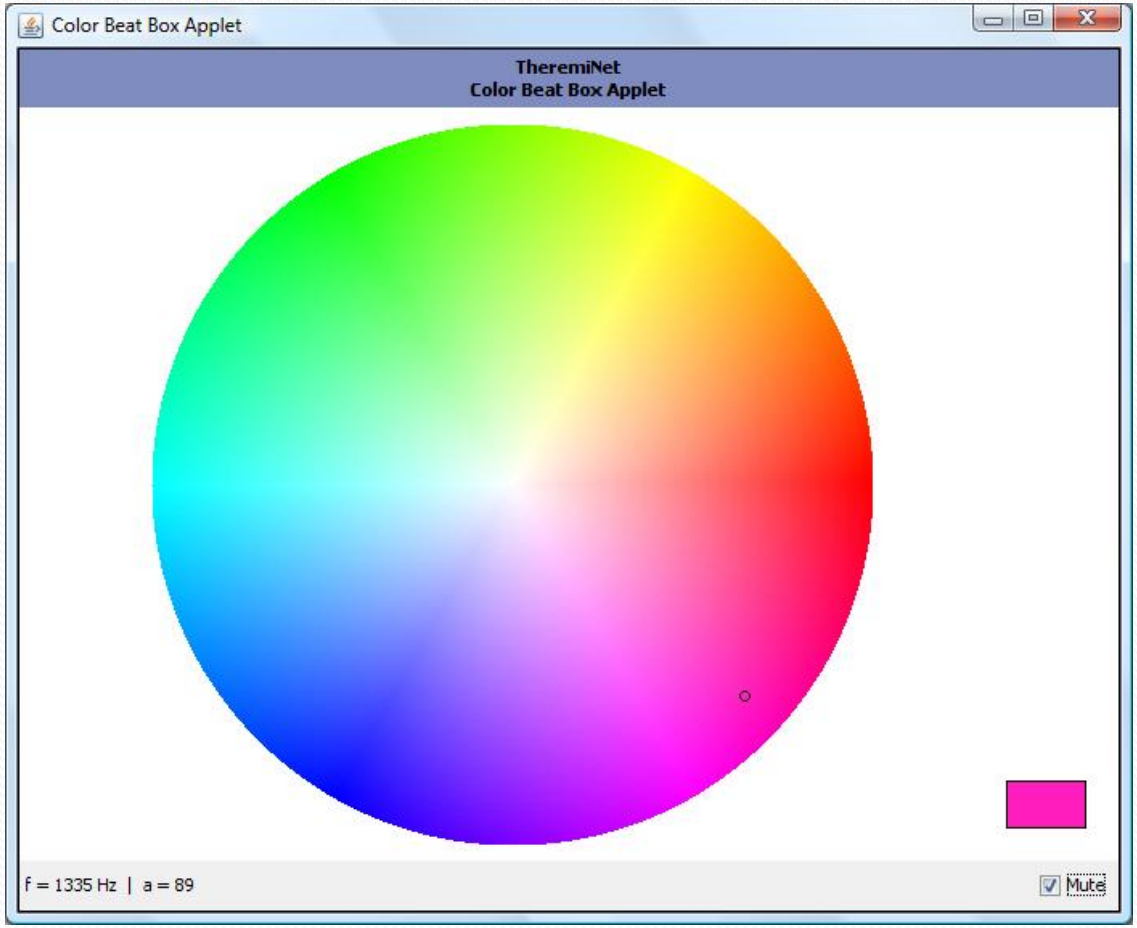
- Colour model chosen: HSL
- Java include the functionalities to manage different models like RGB and HSL (called HSB in Java)
- Rather easy to manipulate the colours



Colour: Java implementation

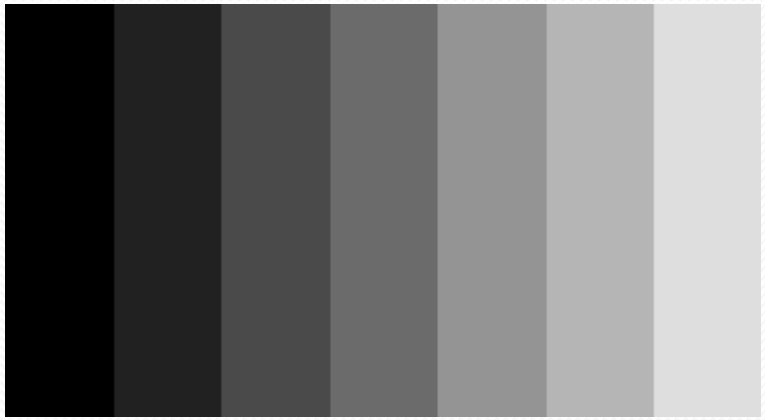
- Function used to draw the colours: `fillArc()`
- `fillArc()` draws an elliptical arc (in this case a circle arc) with the colour chosen
- Loop for the radius between 0 and 100 (Saturation parameter). For each step, a new circle is draw changing the initial angle from 0 to 360 in little steps (Hue parameter)

Colour: Java results



Colour: Java results

- We can see some kinds of lines (6) that seem to exist in the circle
- This is the result of an optical illusion called Mach Bands
- The human eye tries to adjust the intensity of the colour if we are next to a brighter colour



From colour to sound

- To make the sound, like the Theremin, we need a frequency and a volume

- Each time the mouse is moved inside the colour circle, we get the information of the colour pointed by the mouse (hue, saturation and luminance)

- *frequency = MIN_HZ + (MAX_HZ - MIN_HZ) * Hue*

- *level = MIN_LEVEL + (MAX_LEVEL - MIN_LEVEL) * Saturation*

Making sound

What is ‘sound’?

- Sound is energy, which propagates through matter as a wave – no matter, no sound
- As a wave, it has different properties:

The sound and our ear

- When considering a simple sound, the number of parameters can be reduced to 2:
  - Frequency (in Hz)
  - Amplitude (in dB)

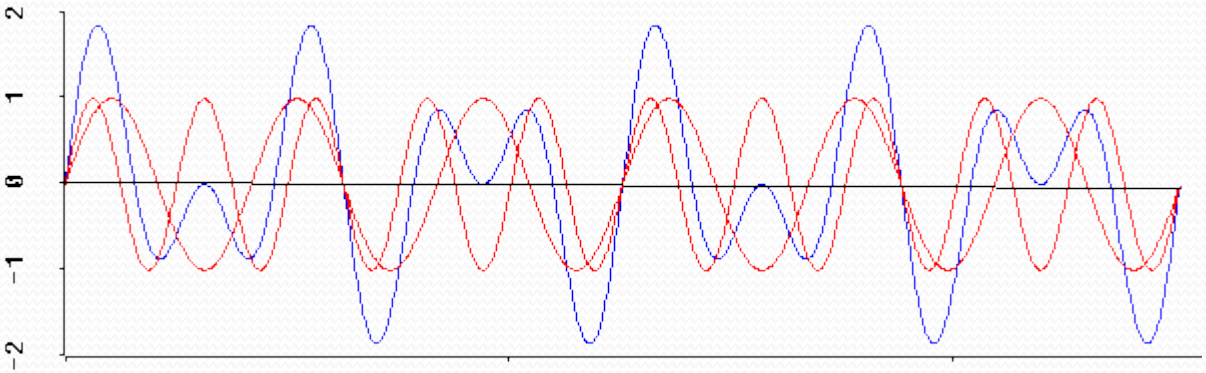
- For a human ear, these parameters are translated:
  - The **frequency** represents how **high** or **low** a sound may be, that is to say the **pitch** of the sound

  - The **amplitude** represents how **loud** a sound may be, in other words, the **level** of the sound

Complex sounds

- As Fourier has proved it: any wave can be represented with the infinite sum of sinusoidal waves

"Any complex wave can be treated as a combination of simple sine waves"



Notes of music (1)

- Notes of music are sounds, but specific sounds
  - Each note has a predefined frequency
  - Only one frequency has been chosen, all the others depend on it
- The only absolute frequency is given by a tuning fork

- This frequency – 440Hz - corresponds to the A4 note

Notes of music (2)

- The span of notes between one pitch and another that is twice its frequency is called an octave

- There are 12 notes per octave, which can be represented on a numerical scale like this one:

C	C#	D	D#	E	F	F#	G	G#	A	A#	B
-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2

- Eleven octaves has been defined, representing the notes from C_{-1} to B_9. Considering that f_{A4}=440Hz, the frequency of another note is given by the following formula:

$$f_n = f_{octave} \cdot 2^{n/12}$$

Theremin and music

- The sound produced by a Theremin is rather basic
  - Only one sound wave
  - Two parameters: the frequency and the pitch

- Based on the sine function:

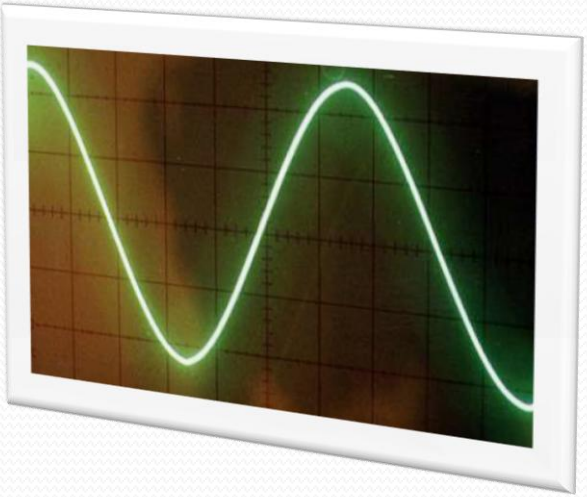
$$s(t) = a \sin(2\pi f t)$$

With: f frequency of the sound wave
a amplitude of the sound wave

- There is no place for predefined notes: all has to be done "manually"

The sine function

- The function is 2π-periodic
  - When you add or subtract 2π to its argument, the value remains unchanged
  - $\sin(A+2\pi) = \sin(A)$

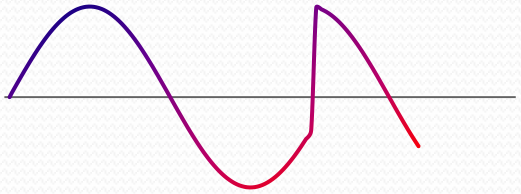


- It has some remarkable values:
  - $\sin(0) = \sin(\pi) = \sin(2\pi) = 0$
  - $\sin(\pi/2) = 1$
  - $\sin(3\pi/2) = -1$
- It has some mathematical properties:
  - $\sin(-x) = -\sin(x)$
  - $\sin(x+\pi) = -\sin(x)$

Sampling and soundcards

- Two worlds are opposing themselves:
  - Analogical – The sound
  - Digital – The computer and its soundcard
- We need a bridge to convert from analogical to digital
- Sampling is the reduction of a continuous signal to a discrete signal
  - We calculate the value of the sound function at fixed interval
  - We send those values to the soundcard at a specific rate

Sampling limitations



- The digitalized signal is not perfect
  - A total reconstruction would need an infinite number of sampled points
- However, our ear can be cheated if the number of points is sufficient
  - Nyquist-Shannon theorem: the sampling rate must be at least twice the maximum frequency of the original signal
  - For instance: a sine signal with a 440Hz frequency must be digitalized with a sampling rate of at least 880Hz, *ie* 880 points per second.
- Continuity between samples must be assured

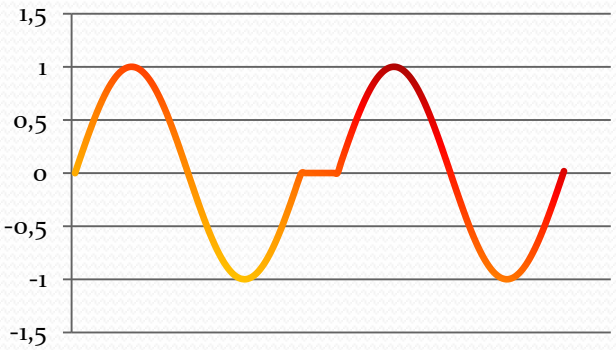
Sound in Java

- Two different approaches:
  - "*Old school*": AudioPlayer and one-time buffer – JDK 1.0
  - Java Sound System: mixer and audio lines – JDK 1.3

- Two different goals:
  - Compatible with as many browsers as possible, but low quality
  - High quality, but only compatible with modern browsers

Sun AudioPlayer – JDK 1.0

- Very limited player:
  - Only one audio format: µLaw 8kHz
  - Different channels, but one fixed buffer per channel
- Major problem:
  - A modification in the buffer is not directly taken into account
  - Three steps are needed:
    - Stop sound rendering
    - Set new buffer
    - Restart sound rendering
  - This leads to a sound discontinuation



Sun AudioPlayer – Code

- Sound playback

```
byte buffer[] = new byte[SAMPLE_LEN];
feedBuffer(buffer);
InputStream stream = new AudioDataStream(new AudioData(buffer));
AudioPlayer.player.start(stream);
...
AudioPlayer.player.stop(stream);
```

- Buffer feeding

```
double delta = SAMPLE_DURATION / SAMPLE_LEN;
double t = 0.0;
double w = (2.0*Math.PI)*(int)freq;
for (int i = 0; i < SAMPLE_LEN; i++) {
        t = (double)i*delta;
        buffer[i] = uLaw((int)(level*Math.sin(w*t)));
}
```

Java Sound System – JDK 1.3

- Major evolution in Java sound management:
  - Use of a global mixer
  - Use of different sound lines with multiple formats
  - Use of live buffers filled in real time
  - Able to play and record sounds
  - Sampled and MIDI sounds
  - User defined sound data or audio clips (sound files)
- Available through the `javax.sound` packages

The javax.sound.sampled API

- A few steps to make some noise:
  - Create an audio format (sample rate, bits per sample, …)
  - Request a mixer (optional)
  - Request a data line according to your needs
    - `SourceDataLine` to write sound data
    - `TargetDataLine` to read sound data (from the microphone for instance)
  - Obtain and open the requested line
  - Start the line
  - Get ready, write some data and… listen!

Some javax.sound.sampled code

- Getting a sound data line

```
AudioFormat af = new AudioFormat((float)SAMPLE_RATE, 8, 1, true, true);
DataLine.Info info = new DataLine.Info(SourceDataLine.class, af);
SourceDataLine  audioLine = (SourceDataLine)AudioSystem.getLine(info);
audioLine.open(af);
```

- Writing some audio data

```
audioLine.start();
audioLine.write(sample, 0, sampleLen);
```

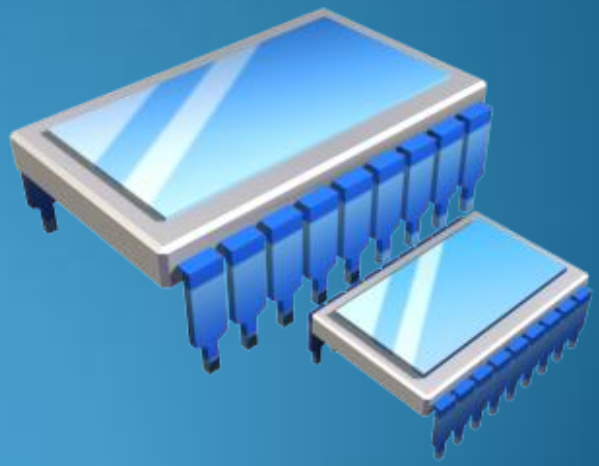
- Closing audio playback

```
audioLine.flush();
audioLine.stop();
```

Having a live sound

- A static sound is not funny!
  - The sound wave frequency is to be updated various times per second
  - The sound level may change according to user's mood
- The sound buffer has to be updated. How?
  - Maintain a timer that will fill the buffer with the expected data
  - Take into account the continuity problem
    - Each value lies at least between -128 and 127
    - The sine function lies between -1.0 and 1.0
    - A small error is immediately detected by our own human "sound system"
    - Use a buffer with a variable length and remove inappropriate data

Implementation and results



Colour driven Theremin

- An original combination between colours and sound
  - A new approach:
    - A colour can be represented with its hue, saturation and luminance components
    - A “note” can be represented with its frequency and its amplitude
  - Three components, but only two parameters
    - The luminance is arbitrary set to 1.0 to have brilliant colours
- A two dimensional interface to obtain two dimensional sounds

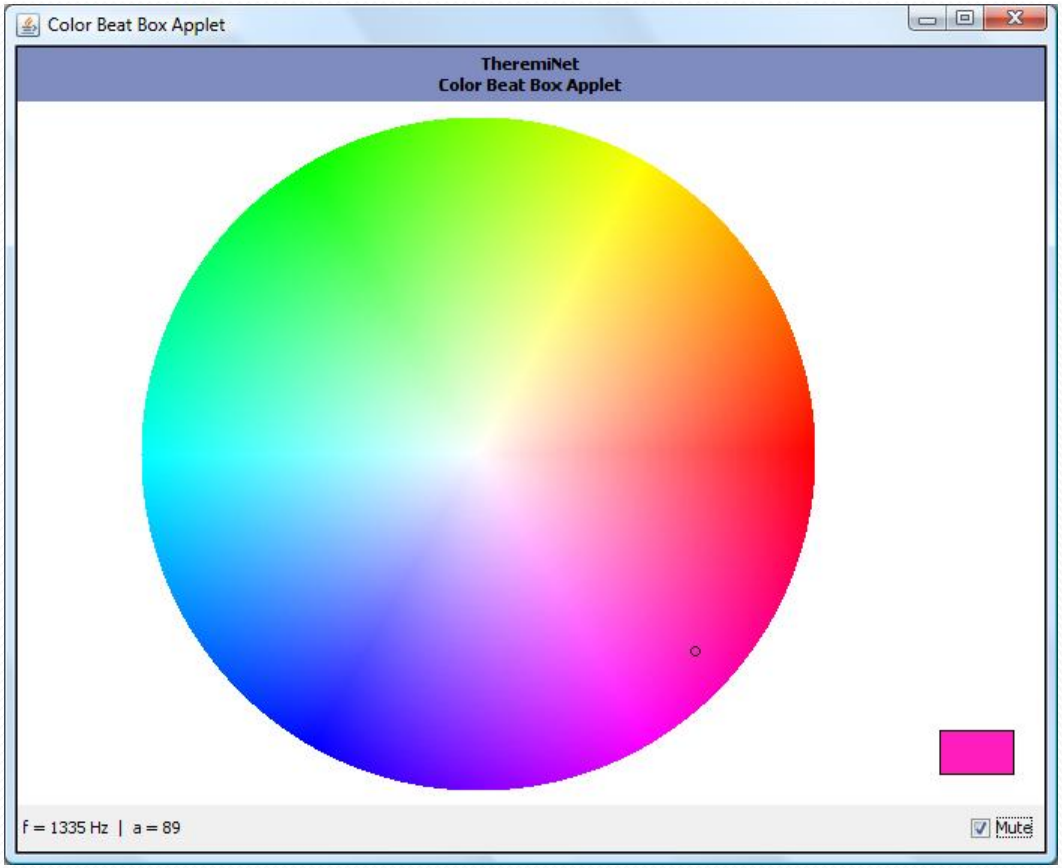
Mouse driven interface

- Only one input device: a mouse
  - Who does not have one (except geeks)?
  - Easy to handle, even for a child
  - Fast movements
  - Quite natural in a web browser
- Some limitations
  - Only two buttons to be compatible with a large audience
  - No mouse wheel due to applets/web browsers limitations

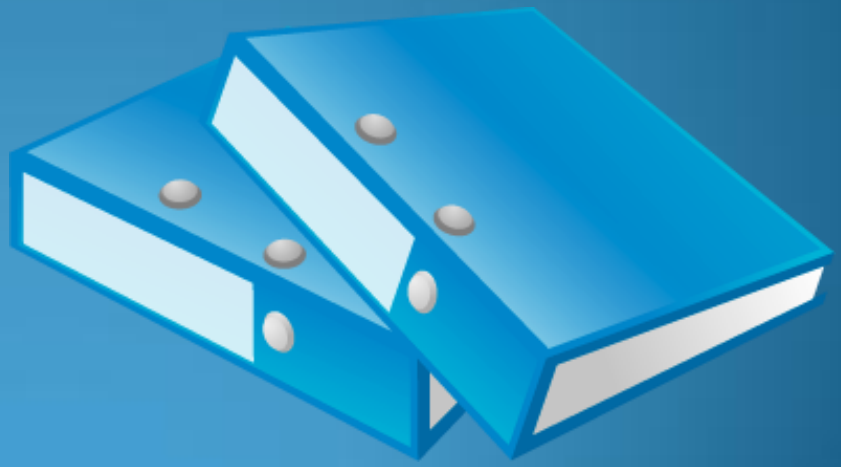
Problems to solve

- Still some discontinuities in sound rendering
- Rather poor interface
- No sound effects due to a lack of digital signal processing
- No special input device to link with the application

Demonstration



Conclusion



Conclusion

- Color and sound are sensations that we can represent in an analogical way
- For a human it is difficult to describe them, so we have to create models to represent them
- The computers help us to treat them in a digital way. To the common human eye and ear there is no difference

Conclusion

- We can use those signals to make applications we can enjoy
- In our case we can create sounds based on color sensations.
- It is a really simple application that can be used by everybody, just for fun!