



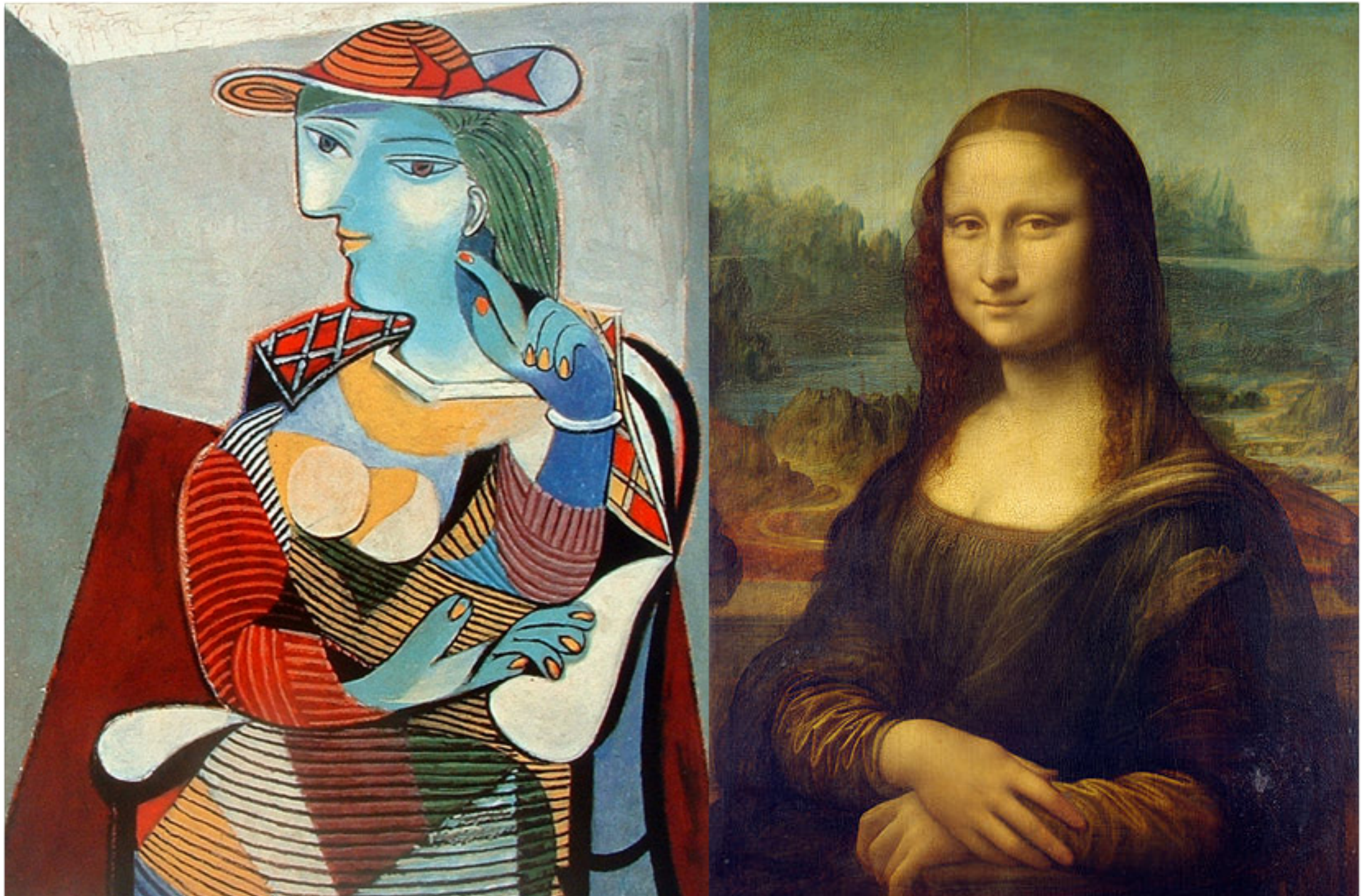
CARMINE-EMANUELE CELLA

PLAYING THE WORLD

AN INTRODUCTION TO PHYSICAL MODELLING FOR AUGMENTED REALITY

UC BERKELEY - MUSIC 159 - GUEST LECTURE #4

KATHARSIS AND MIMESIS



FROM PHYSICAL MODELLING TO PHYSICALLY-INSPIRED

**Physical modelling
synthesis**

Accurate

Real sounds (almost)



**Physically-inspired
synthesis**

Expressive

Plausible sounds



PHYSICAL MODELLING

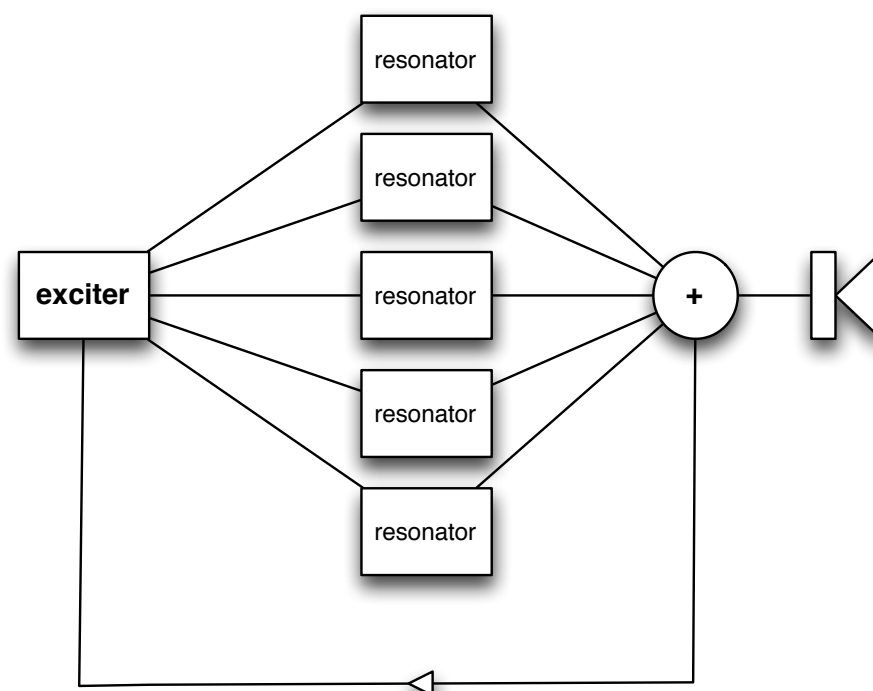
- Physical modelling synthesis generates sounds by copying the **mechanical system under vibration** and not by copying the sound itself

PHYSICAL MODELLING

- Physical modelling synthesis generates sounds by copying the **mechanical system under vibration** and not by copying the sound itself
- It is based on the solutions of wave equation: $\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$.

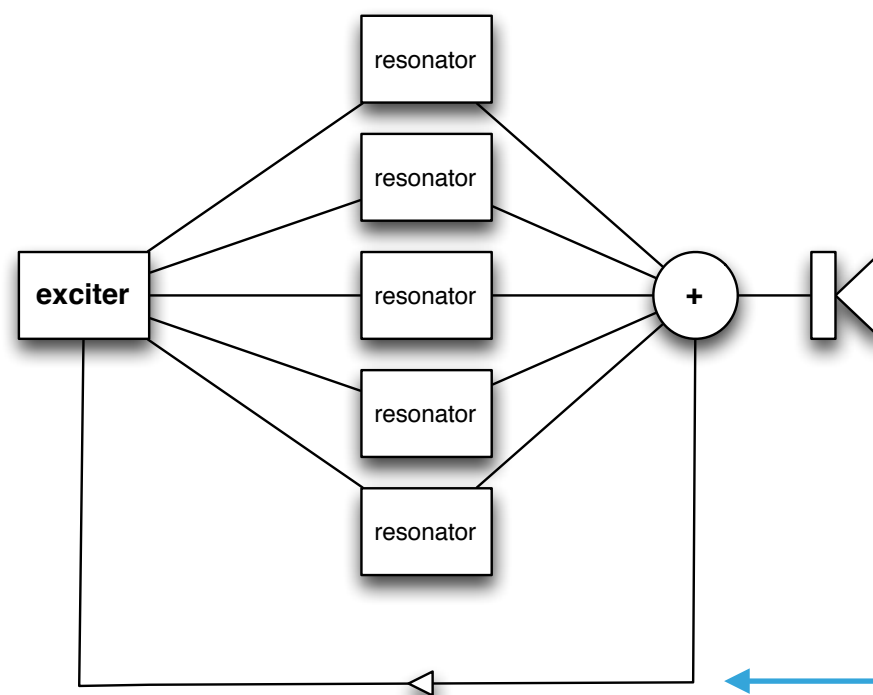
PHYSICAL MODELLING

- Physical modelling synthesis generates sounds by copying the **mechanical system under vibration** and not by copying the sound itself
- It is based on the solutions of wave equation: $\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$.
- A simplification is represented by the system **exciter-resonators**



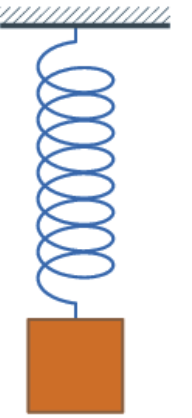
PHYSICAL MODELLING

- Physical modelling synthesis generates sounds by copying the **mechanical system under vibration** and not by copying the sound itself
- It is based on the solutions of wave equation: $\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$.
- A simplification is represented by the system **exciter-resonators**



HISTORICAL PERSPECTIVE

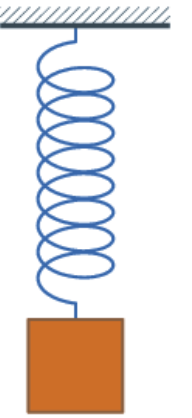
- Karplus-Strong (1983): delay-line + lowpass filter
- Smith-Karplus-Strong (1983): delay-line + lowpass filter + allpass filter
- Waveguides (1990/2000, Smith): two delay lines with taps and various filters
- **Modal synthesis** (1990/2010, Adrien): resonant filters and modal weights



MODES OF VIBRATION

- A vibrating object can be described by the *harmonic oscillator*, that can be represented by the spring-mass system:

$$x = e^{-\alpha t} A \cos(\omega_d t + \phi) \quad (1)$$

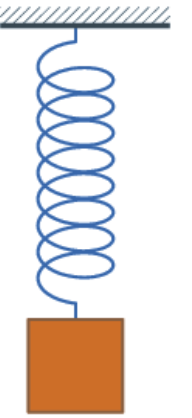


MODES OF VIBRATION

- A vibrating object can be described by the *harmonic oscillator*, that can be represented by the spring-mass system:

$$x = e^{-\alpha t} A \cos(\omega_d t + \phi) \quad (1)$$

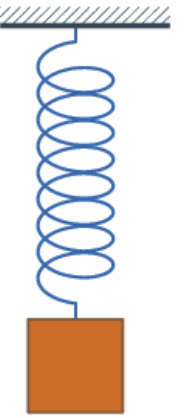
MODES OF VIBRATION



- A vibrating object can be described by the *harmonic oscillator*, that can be represented by the spring-mass system:

$$x = e^{-\alpha t} A \cos(\omega_d t + \phi) \quad (1)$$

- α is the decay constant of the system and depends on the mass and on the stiffness of the spring (dissipation)

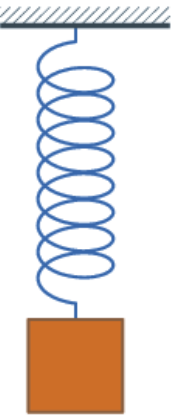


MODES OF VIBRATION

- A vibrating object can be described by the *harmonic oscillator*, that can be represented by the spring-mass system:

$$x = e^{-\alpha t} A \cos(\omega_d t + \phi) \quad (1)$$

- α is the decay constant of the system and depends on the mass and on the stiffness of the spring (dissipation)
- ω_d is the natural angular frequency



MODES OF VIBRATION

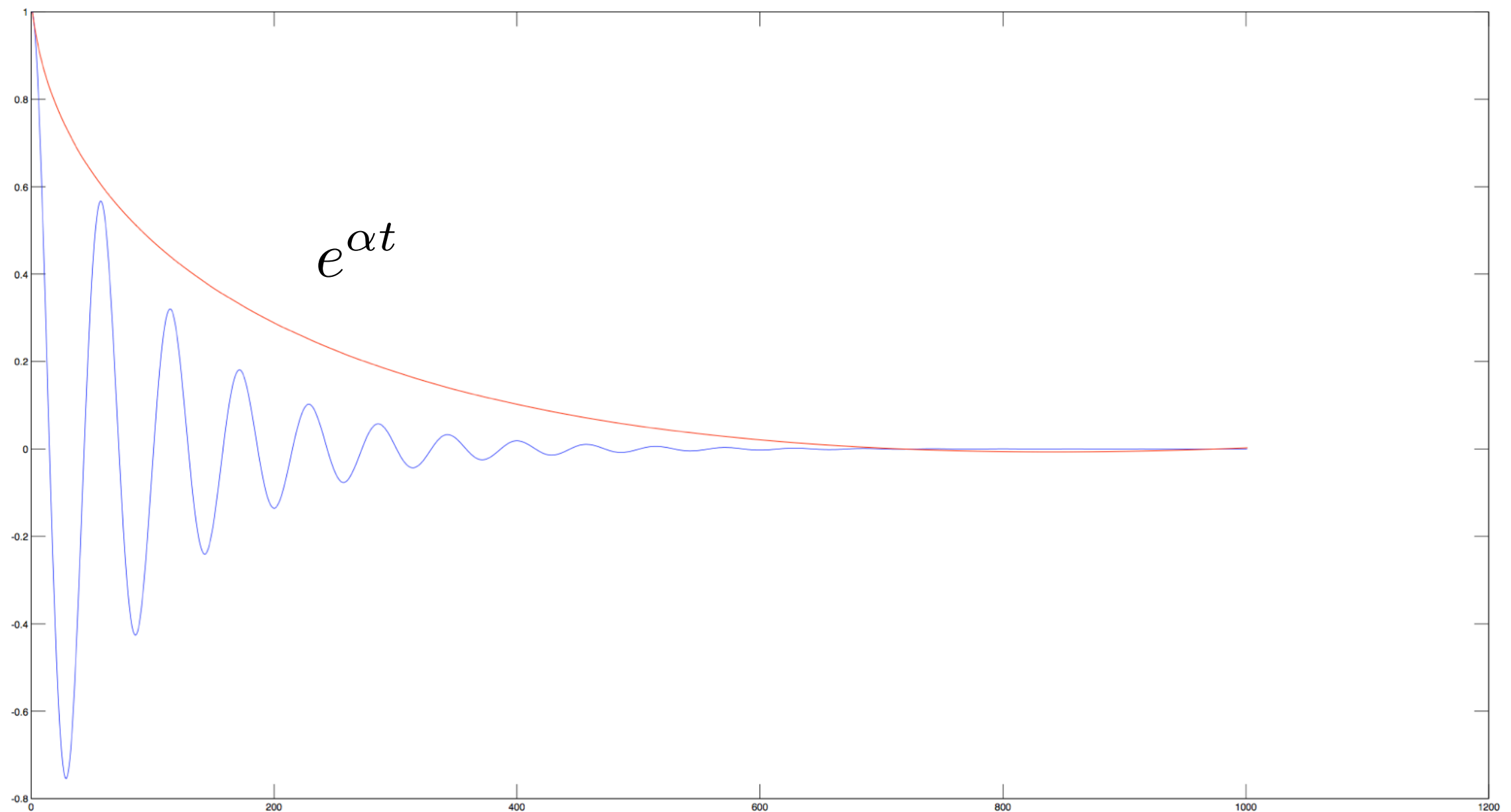
- A vibrating object can be described by the *harmonic oscillator*, that can be represented by the spring-mass system:

$$x = e^{-\alpha t} A \cos(\omega_d t + \phi) \quad (1)$$

- α is the decay constant of the system and depends on the mass and on the stiffness of the spring (dissipation)
- ω_d is the natural angular frequency
- A and ϕ are, respectively, the amplitude and the phase of the vibration and are determined by initial displacement and velocity

MODES OF VIBRATION

A natural mode of vibration, as described by equation 1

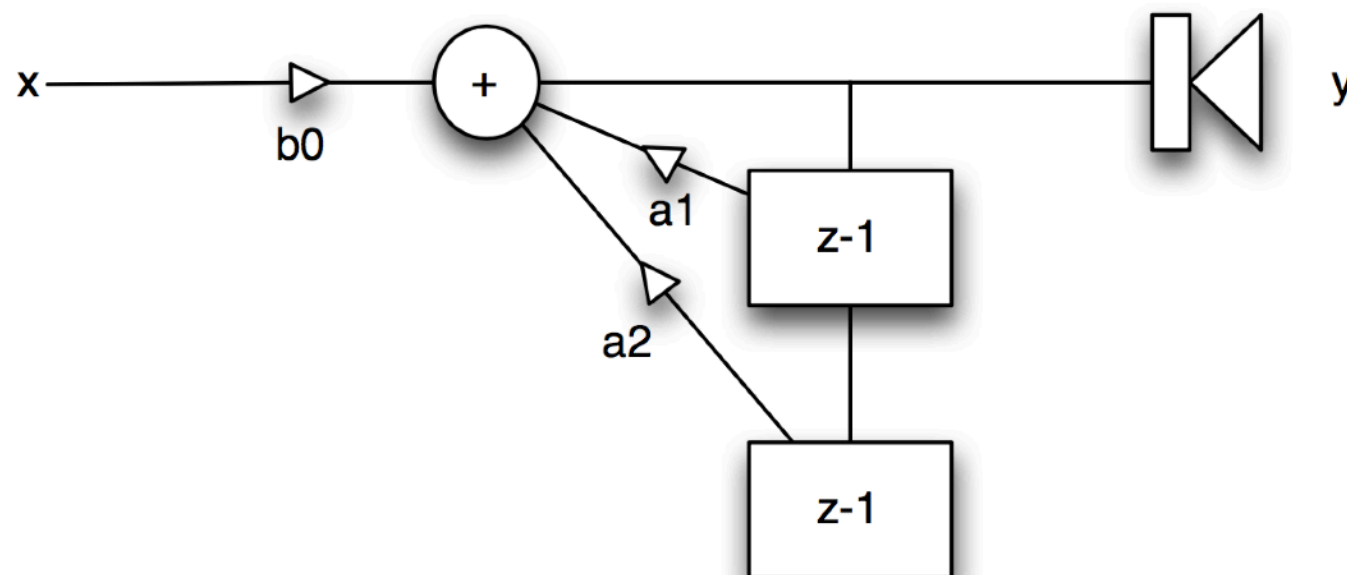


MODES AND FILTERS

In digital domain, equation 1 can be reproduced by the following second-order differential equation (two-poles):

$$y = x \cdot b_0 - y \cdot z^{-1} \cdot a_1 - y \cdot z^{-2} \cdot a_2 \quad (2)$$

where z^{-n} is the delay of n digital samples, b_0 , a_1 and a_2 are *coefficients* and x is the input signal

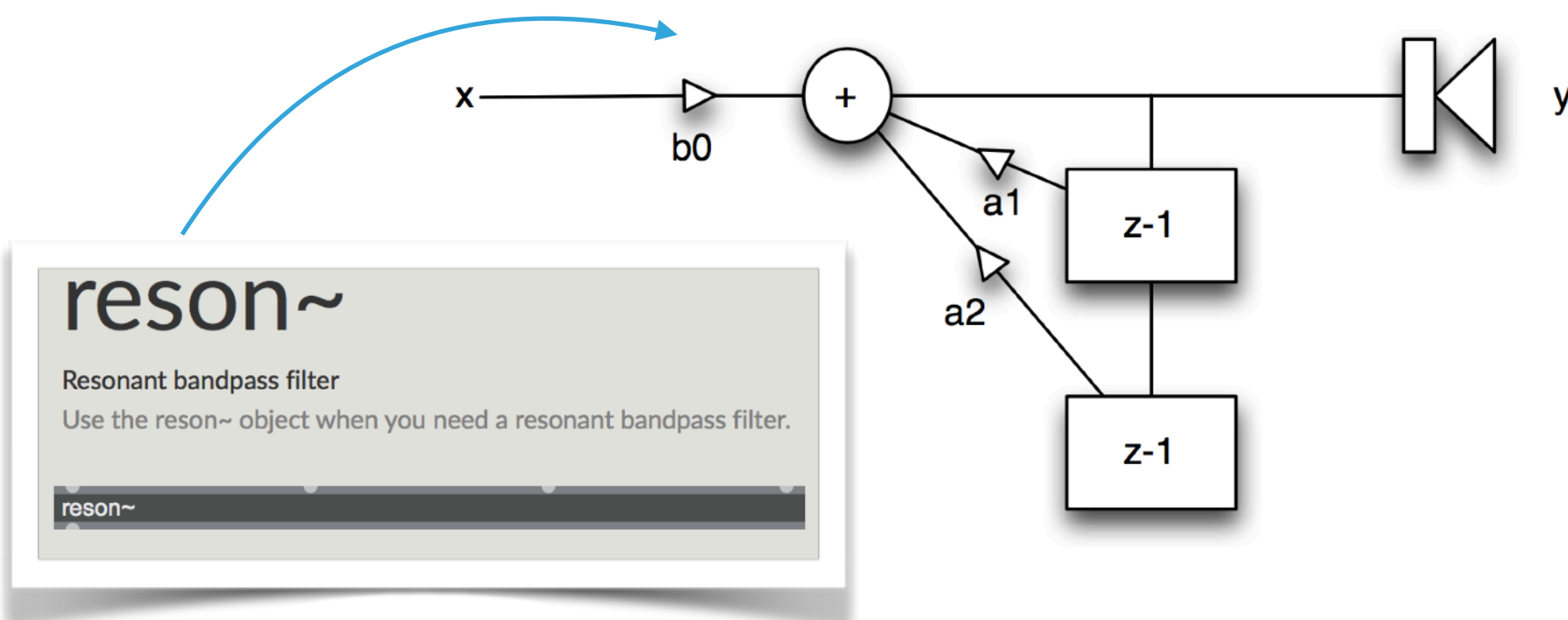


MODES AND FILTERS

In digital domain, equation 1 can be reproduced by the following second-order differential equation (two-poles):

$$y = x \cdot b_0 - y \cdot z^{-1} \cdot a_1 - y \cdot z^{-2} \cdot a_2 \quad (2)$$

where z^{-n} is the delay of n digital samples, b_0 , a_1 and a_2 are *coefficients* and x is the input signal



PROPERTIES OF MODAL SYNTHESIS

- The estimation of the parameters for resonators is based of *experimental* measurements

PROPERTIES OF MODAL SYNTHESIS

- The estimation of the parameters for resonators is based of *experimental* measurements
- Frequencies and the decays are based on physical properties (such as inharmonicity), amplitudes are usually determined by the **feedback** interaction between the resonators and the exciter

PROPERTIES OF MODAL SYNTHESIS

- The estimation of the parameters for resonators is based of *experimental* measurements
- Frequencies and the decays are based on physical properties (such as inharmonicity), amplitudes are usually determined by the **feedback** interaction between the resonators and the exciter
- Injecting a digital impulse into the resonators, will equally excite all resonators; with a feedback, the excitation signal will exhibits a **temporal smearing** and a **frequency equalisation**

PROPERTIES OF MODAL SYNTHESIS

- The estimation of the parameters for resonators is based of *experimental* measurements
- Frequencies and the decays are based on physical properties (such as inharmonicity), amplitudes are usually determined by the **feedback** interaction between the resonators and the exciter
- Injecting a digital impulse into the resonators, will equally excite all resonators; with a feedback, the excitation signal will exhibits a **temporal smearing** and a **frequency equalisation**



Feedback = timbre!!

A CREATIVE APPROACH

- The simulation of a real vibrating object by means of modal synthesis (for example a musical instrument) can be a difficult task

A CREATIVE APPROACH

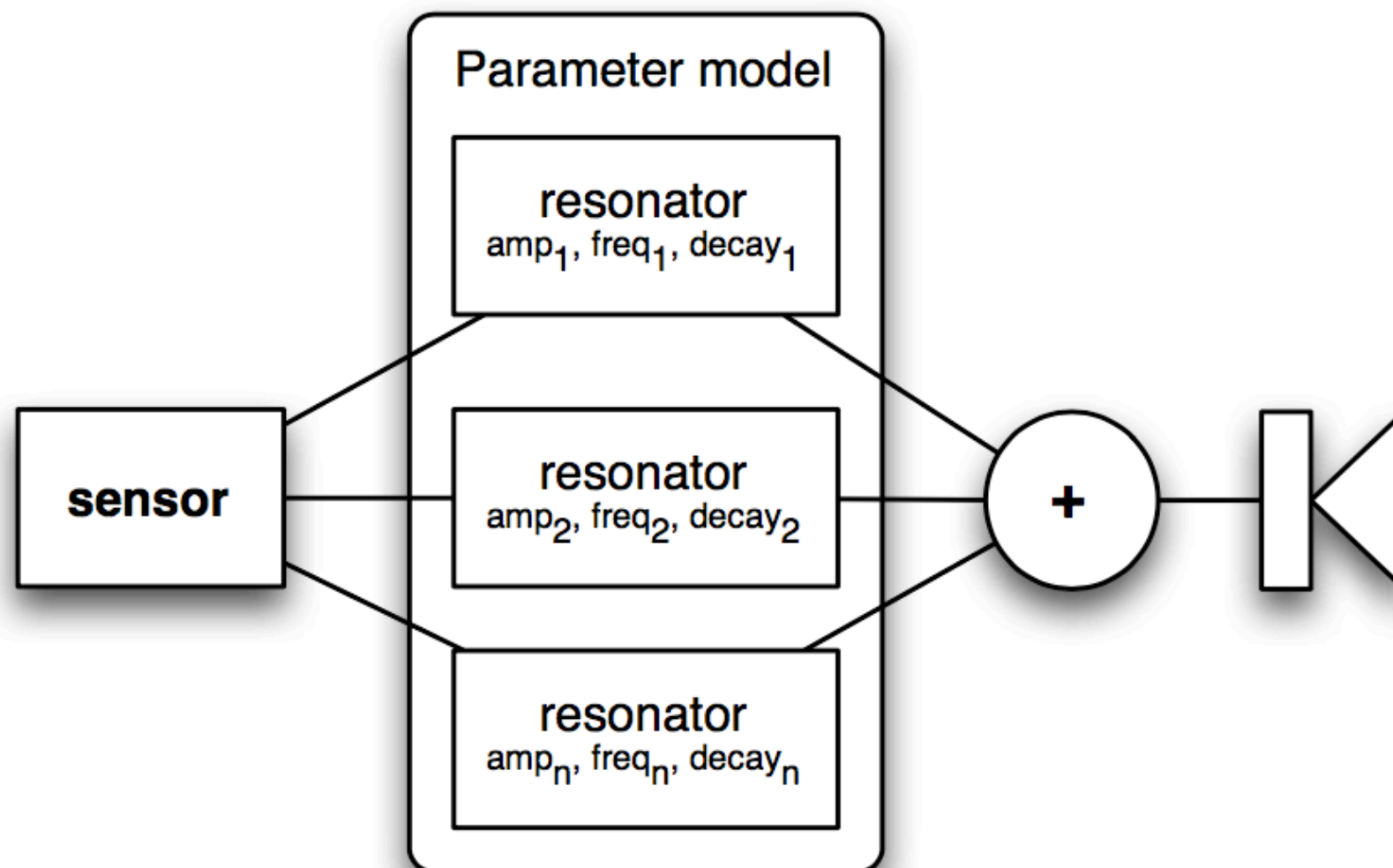
- The simulation of a real vibrating object by means of modal synthesis (for example a musical instrument) can be a difficult task
- The simulation of *quasi*-physical instruments can be an interesting creative activity

A CREATIVE APPROACH

- The simulation of a real vibrating object by means of modal synthesis (for example a musical instrument) can be a difficult task
- The simulation of *quasi*-physical instruments can be an interesting creative activity
- **Physically-inspired** synthesis is variant of modal synthesis that generates sounds with special *physical* characteristics without modelling real vibrating objects

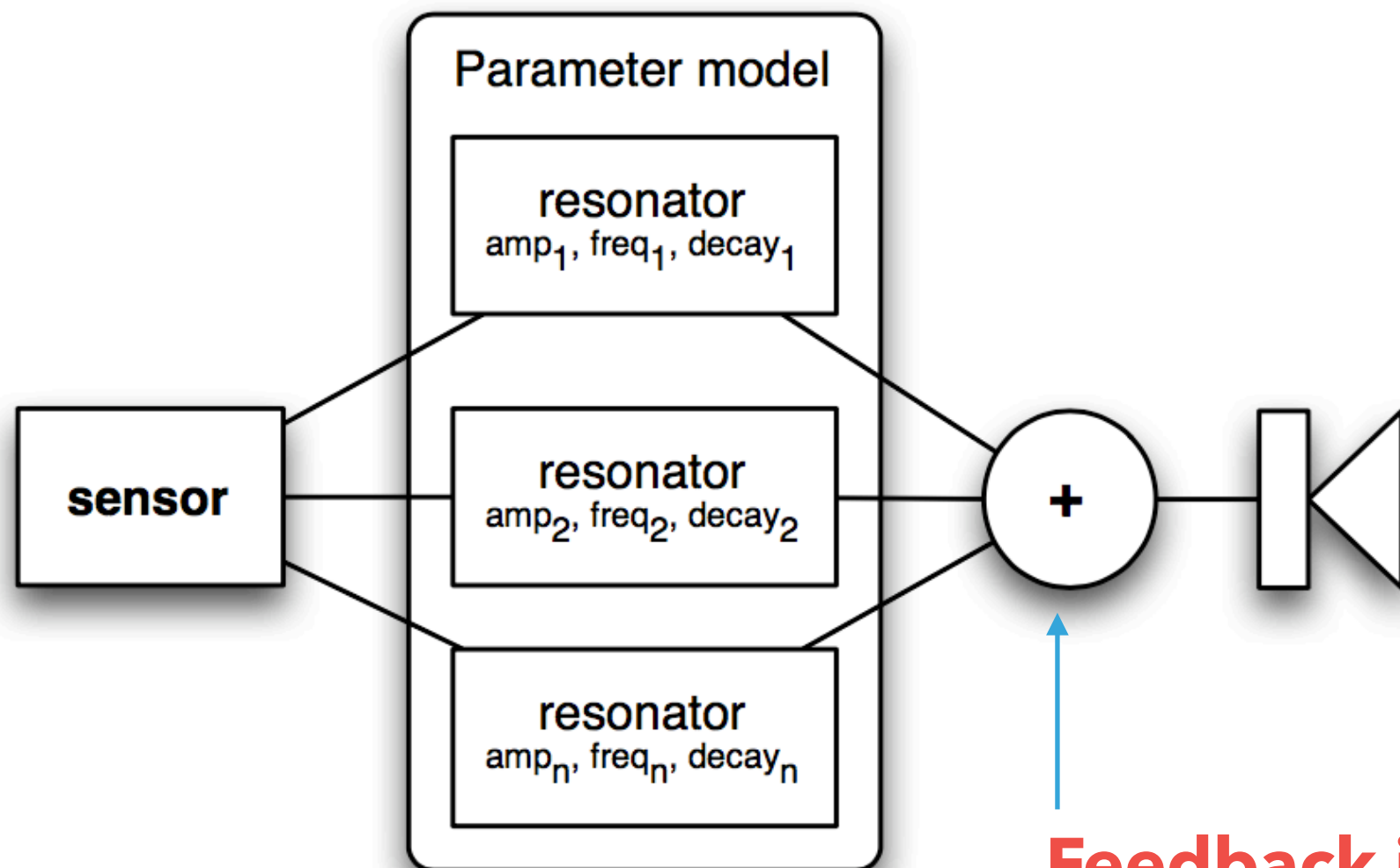
PARAMETER MODELS

In physically-inspired synthesis, the feedback between the exciter and the resonators is replaced by a **parameter model** and the excitation is provided by a **sensor**



PARAMETER MODELS

In physically-inspired synthesis, the feedback between the exciter and the resonators is replaced by a **parameter model** and the excitation is provided by a **sensor**



Feedback is gone!

GENERALISED SPECTRAL MODELING

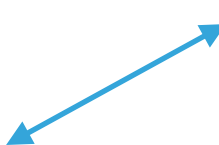
Our model will use a generalised series (harmonic + geometric) for the parameters of each mode, where each variable is connected to a physical property:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha} \cdot \beta^n + \gamma}$$

GENERALISED SPECTRAL MODELING

Our model will use a generalised series (harmonic + geometric) for the parameters of each mode, where each variable is connected to a physical property:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha} \cdot \beta^n + \gamma}$$

mode number 

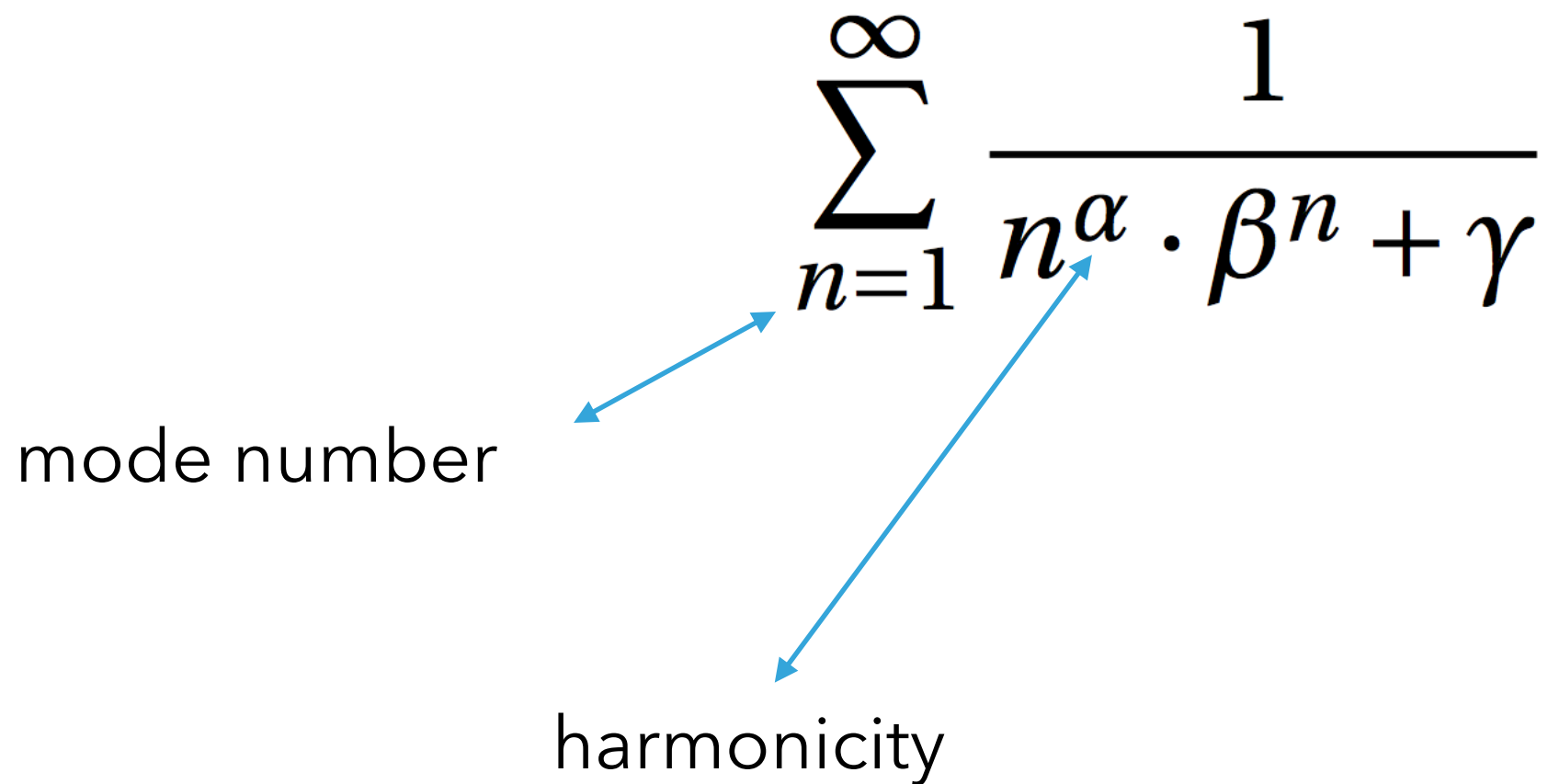
GENERALISED SPECTRAL MODELING

Our model will use a generalised series (harmonic + geometric) for the parameters of each mode, where each variable is connected to a physical property:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha} \cdot \beta^n + \gamma}$$

mode number

harmonicity



GENERALISED SPECTRAL MODELING

Our model will use a generalised series (harmonic + geometric) for the parameters of each mode, where each variable is connected to a physical property:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha} \cdot \beta^n + \gamma}$$

The diagram illustrates the physical properties associated with the variables in the equation. Three blue arrows point from the text labels to the corresponding parts of the equation: one from 'mode number' to the summation index n , one from 'harmonicity' to the exponent α , and one from 'deformation' to the base β .

mode number

harmonicity

deformation

GENERALISED SPECTRAL MODELING

Our model will use a generalised series (harmonic + geometric) for the parameters of each mode, where each variable is connected to a physical property:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha} \cdot \beta^n + \gamma}$$

mode number

harmonicity

deformation

size

CALCULATION OF PARAMETERS

We will split previous series in two parts; one will be used for frequencies and the other for decays:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha}}$$

$$\sum_{n=1}^{\infty} \frac{1}{\beta^n}$$

CALCULATION OF PARAMETERS

We will split previous series in two parts; one will be used for frequencies and the other for decays:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha}}$$



$$f_n = f_0 \cdot n^{\alpha}$$

$$\sum_{n=1}^{\infty} \frac{1}{\beta^n}$$

CALCULATION OF PARAMETERS

We will split previous series in two parts; one will be used for frequencies and the other for decays:

$$\sum_{n=1}^{\infty} \frac{1}{n^{\alpha}}$$

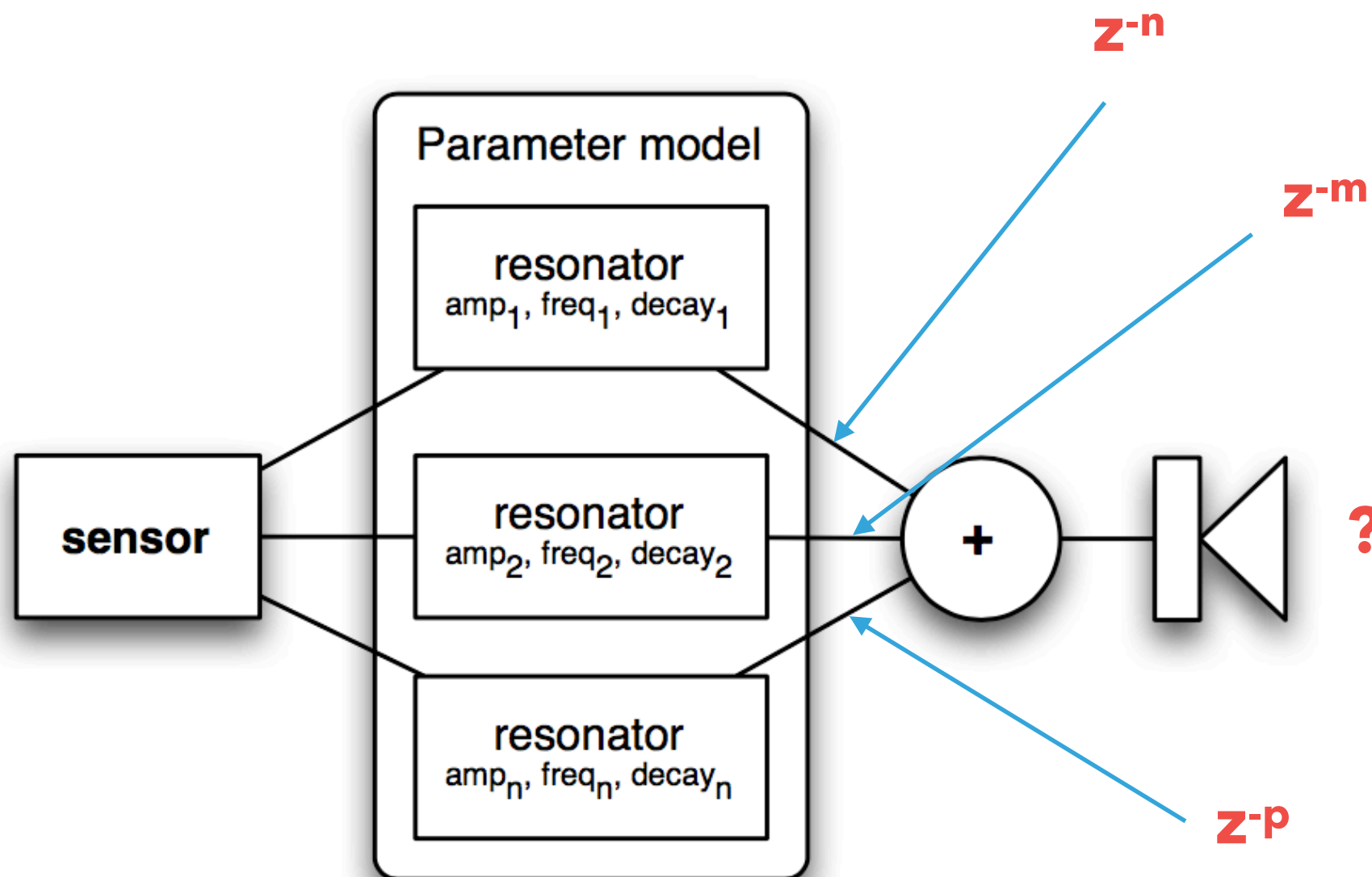
$$f_n = f_0 \cdot n^{\alpha}$$

$$\sum_{n=1}^{\infty} \frac{1}{\beta^n}$$

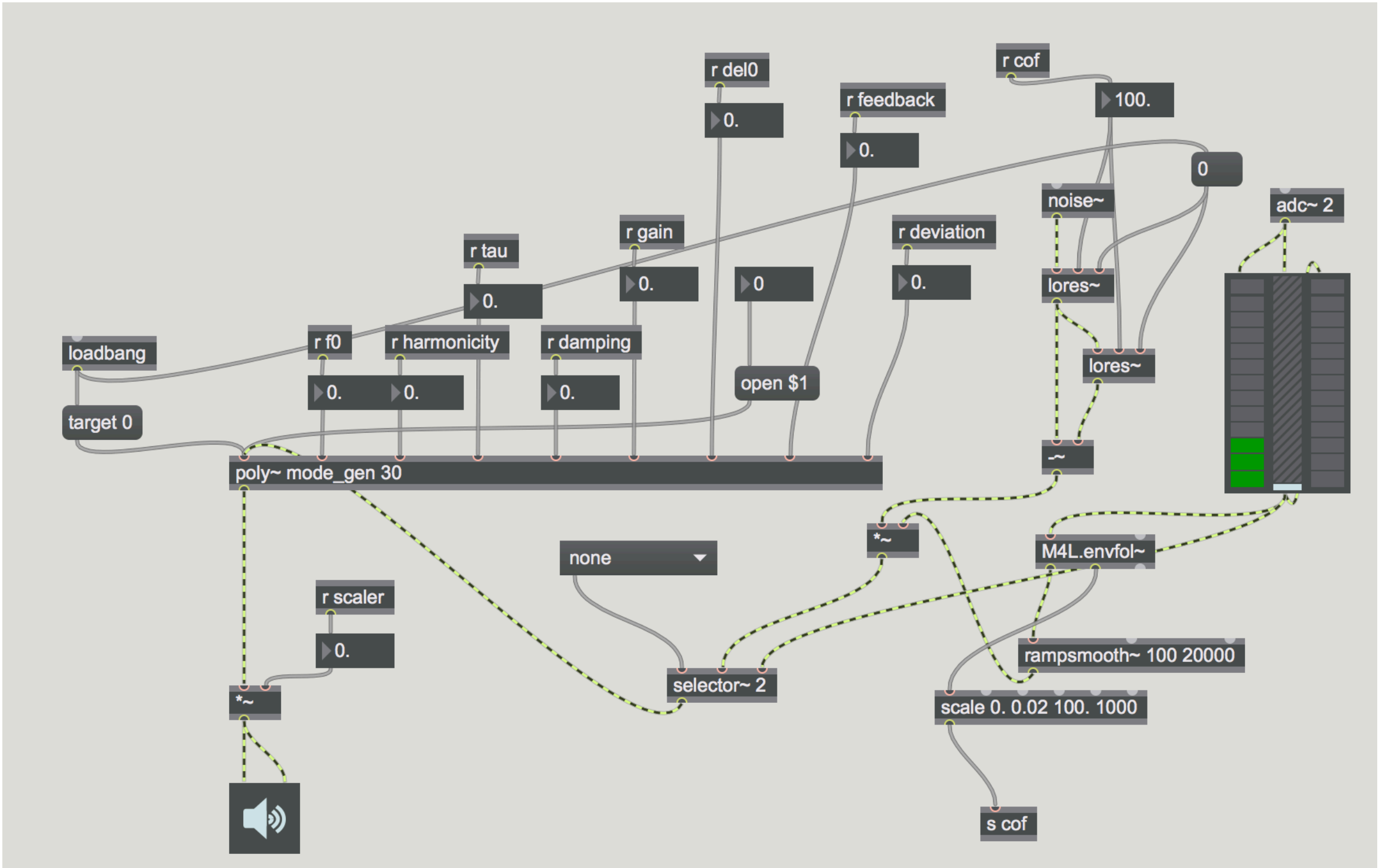
$$\tau_n = \tau_0 / \beta^n$$

QUESTION

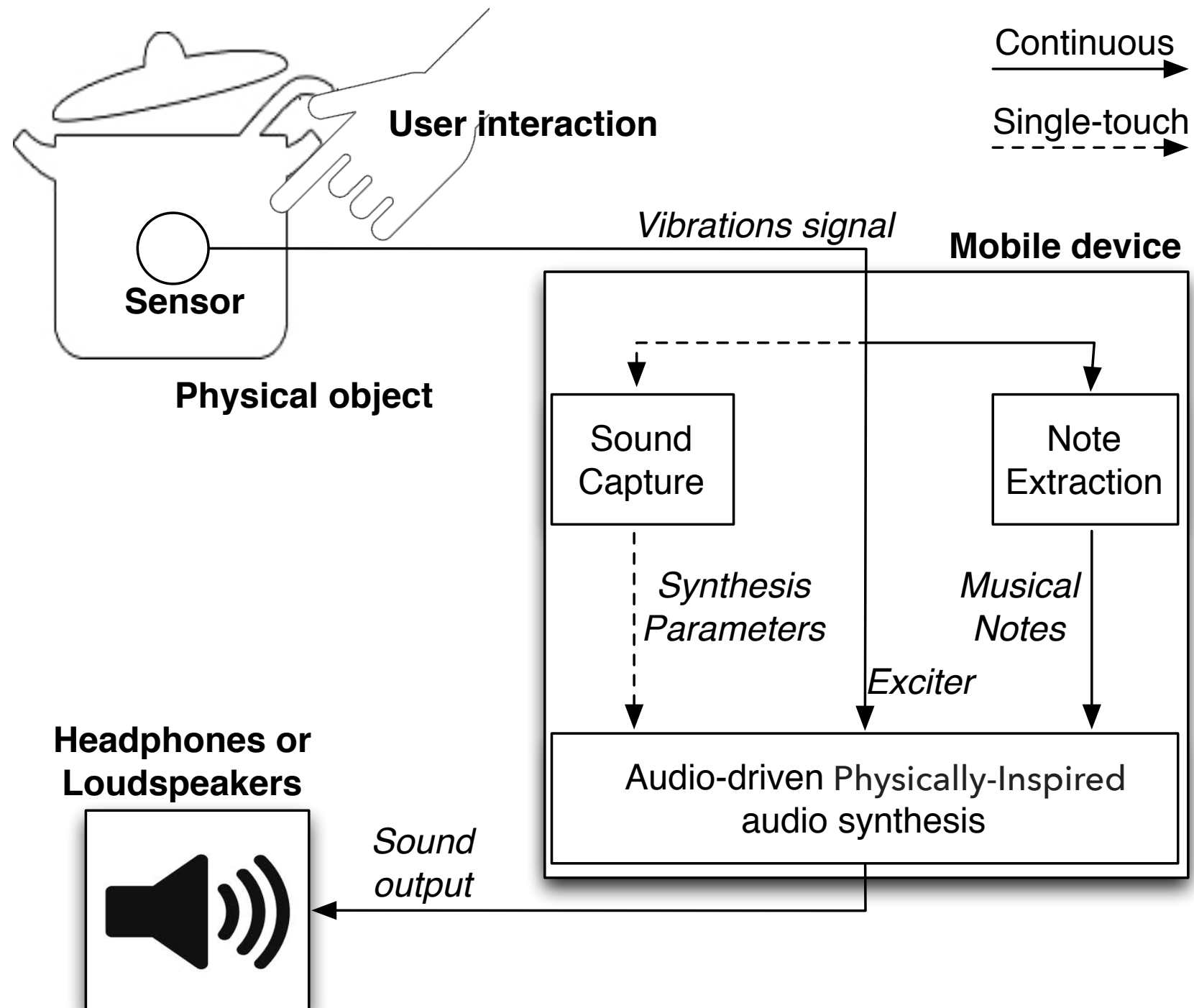
What happens if we sum the modes after delaying them independently?



LET'S GO LIVE!



CAN WE SONIFY THE WORLD?

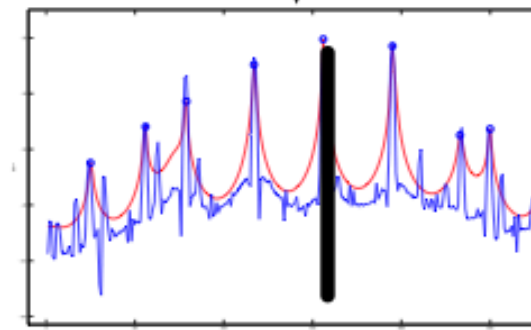
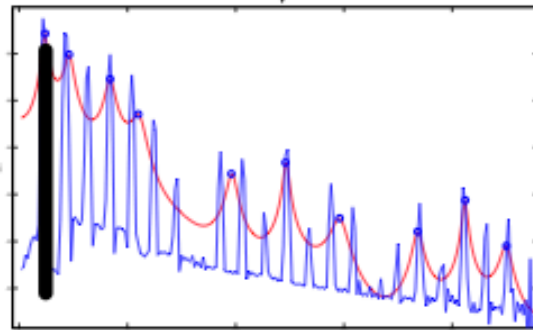


GESTURE MAPPING

low-frequency gesture



high-frequency gesture

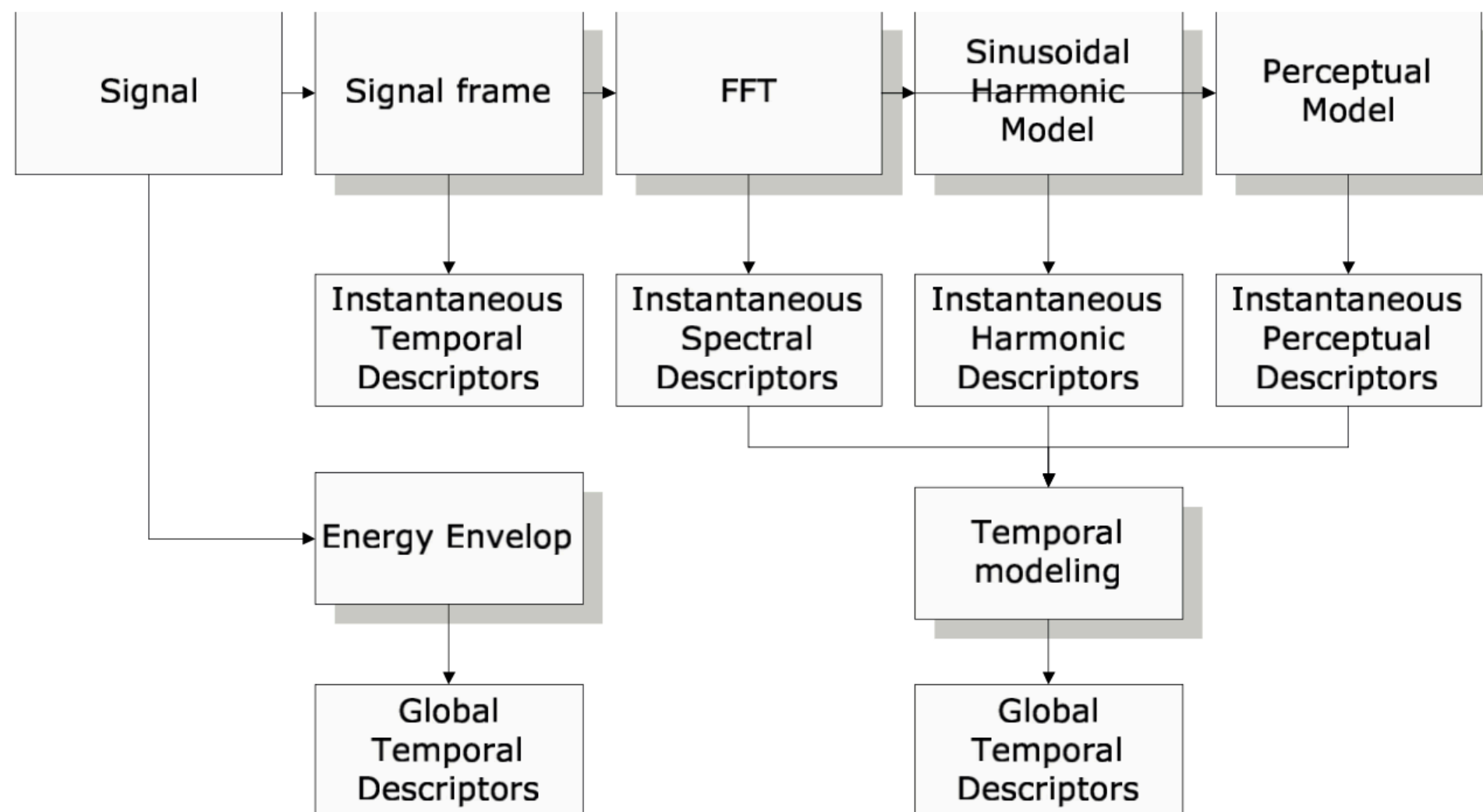


Mapping



LOW-LEVEL FEATURES FOR GESTURES

Numerical values describing the contents of a signal according to different kinds of inspection: *temporal*, *spectral*, *perceptual*, etc.



SPECTRAL FEATURES

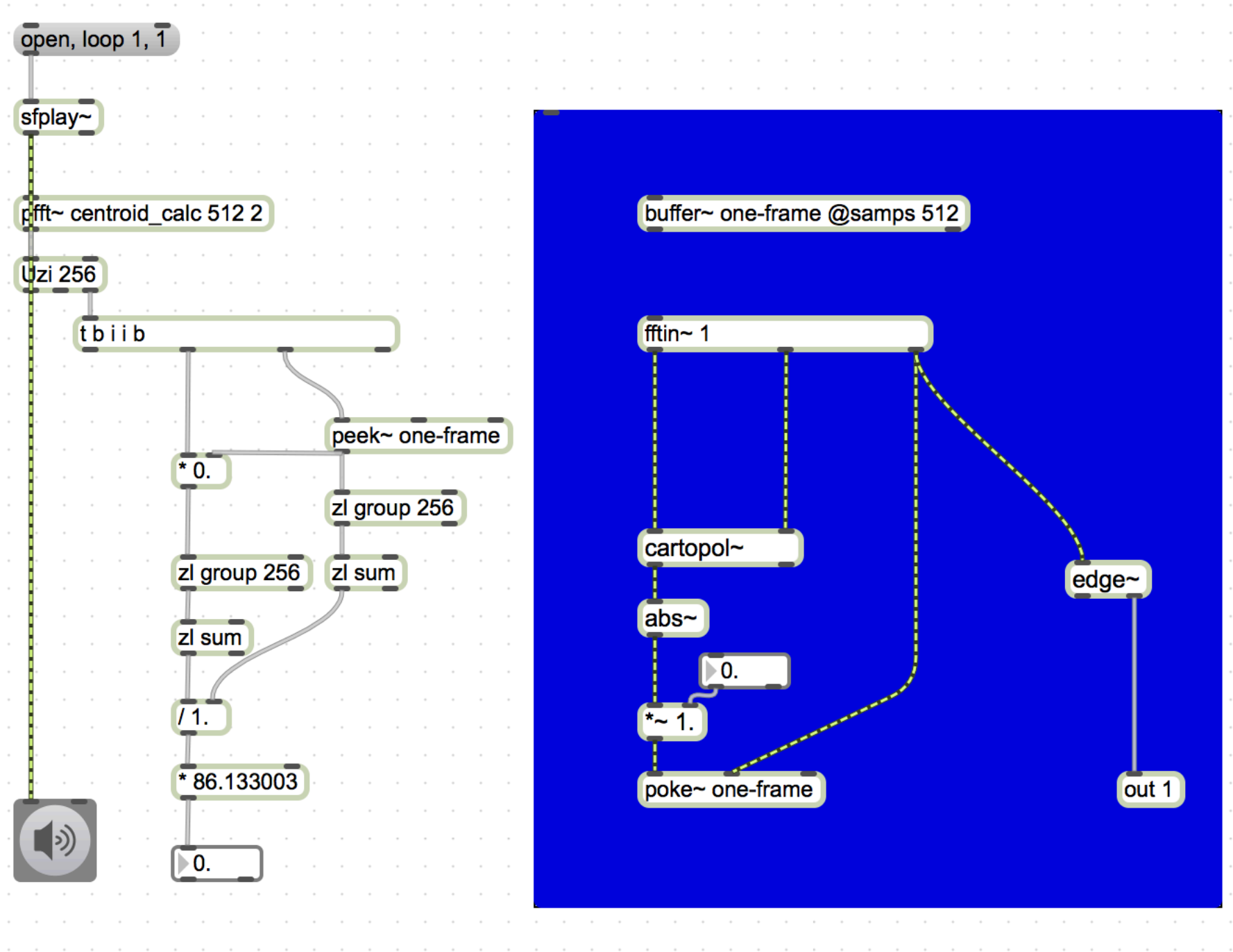
Spectral centroid (brightness) and spectral spread (bandwidth) are important features:

$$\mu = \int x \cdot p(x) dx.$$

$$\sigma^2 = \int (x - \mu)^2 \cdot p(x) dx.$$

Where x are the frequencies of the spectrum and $p(x)$ are the respective amplitudes; the spectral centroid is the *weighted average*

LET'S GO LIVE AGAIN!



MOGEES

"Mogees' software makes music magic!"

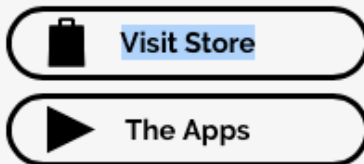
**USA
TODAY**



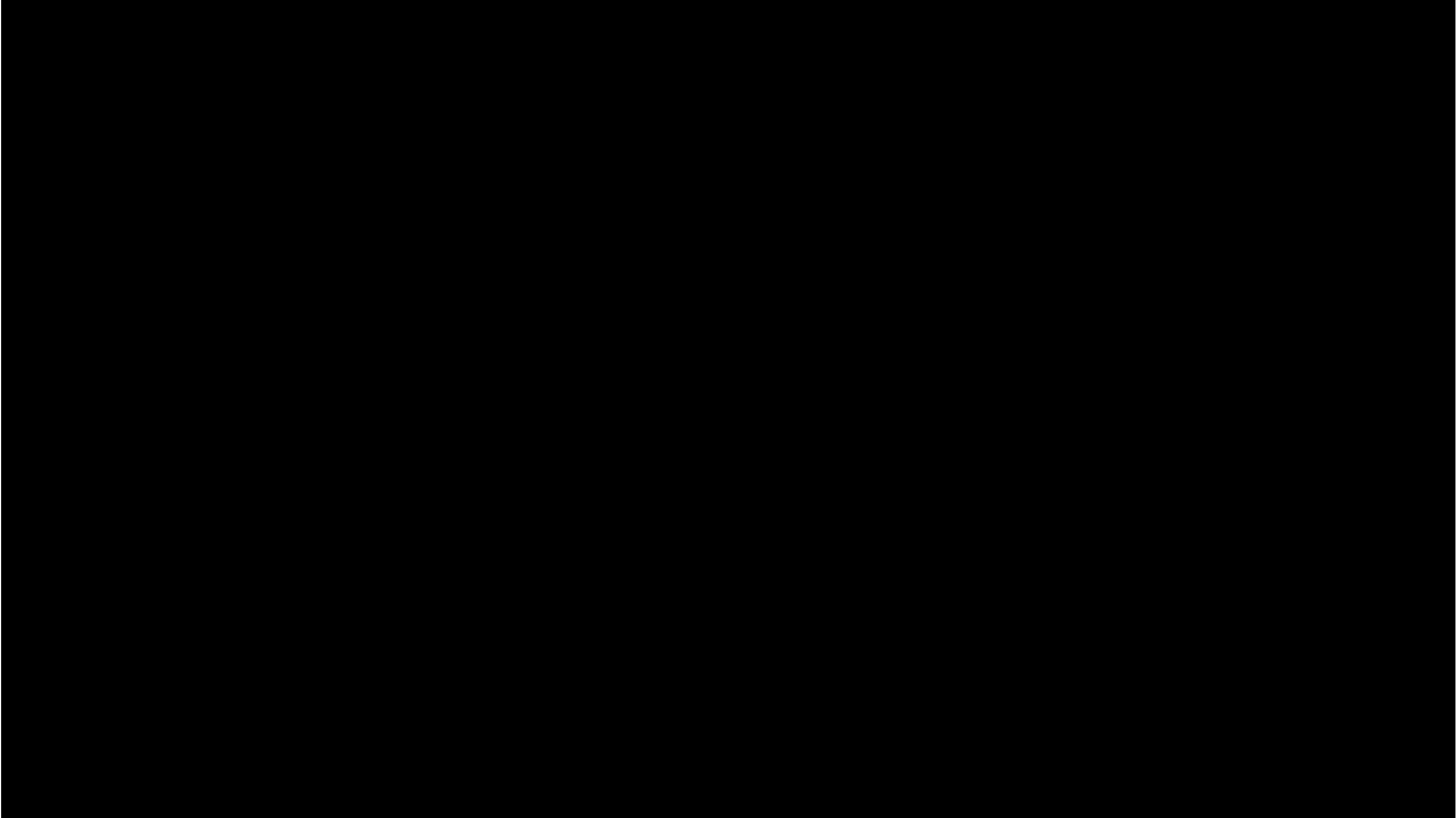
MOGEESPRO

Turn a tree into a harp.
Turn a table into a drumkit.
Turn a chair into a MIDI controller.

Mogees Pro gives you an entire world
of new creative possibilities.



MOGEES

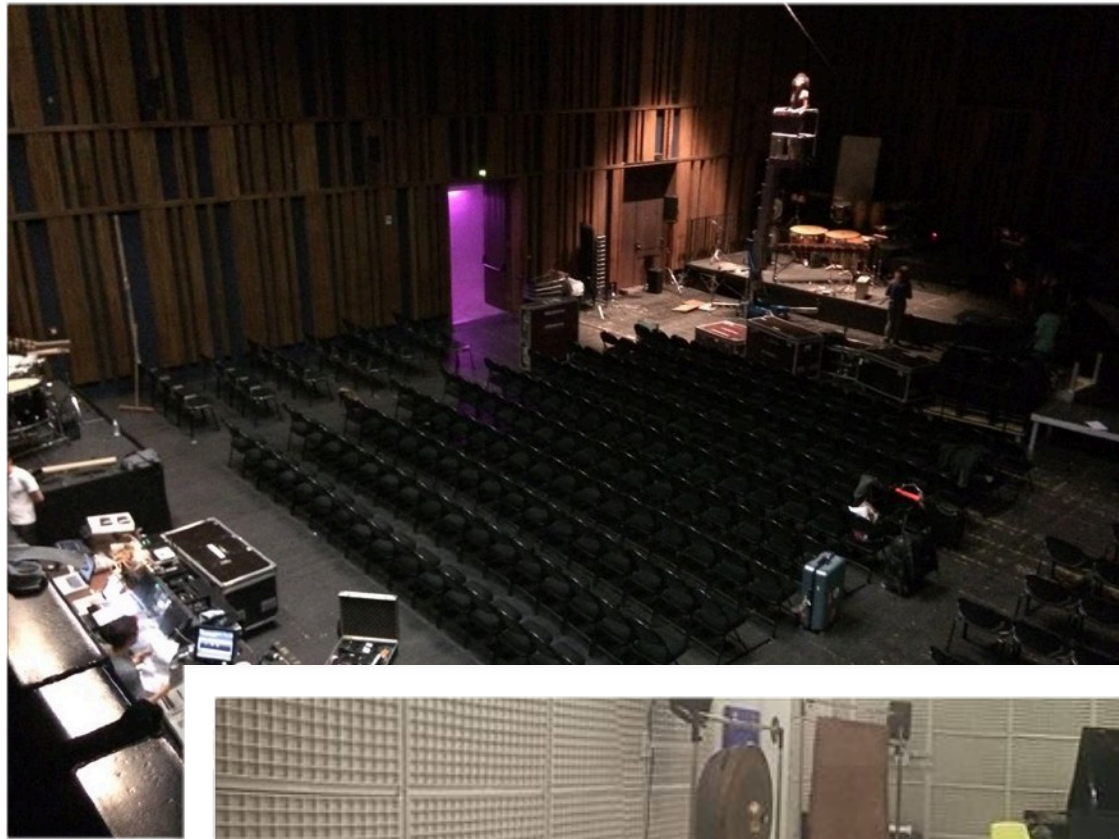


INSIDE-OUT

for smart percussions (2017)

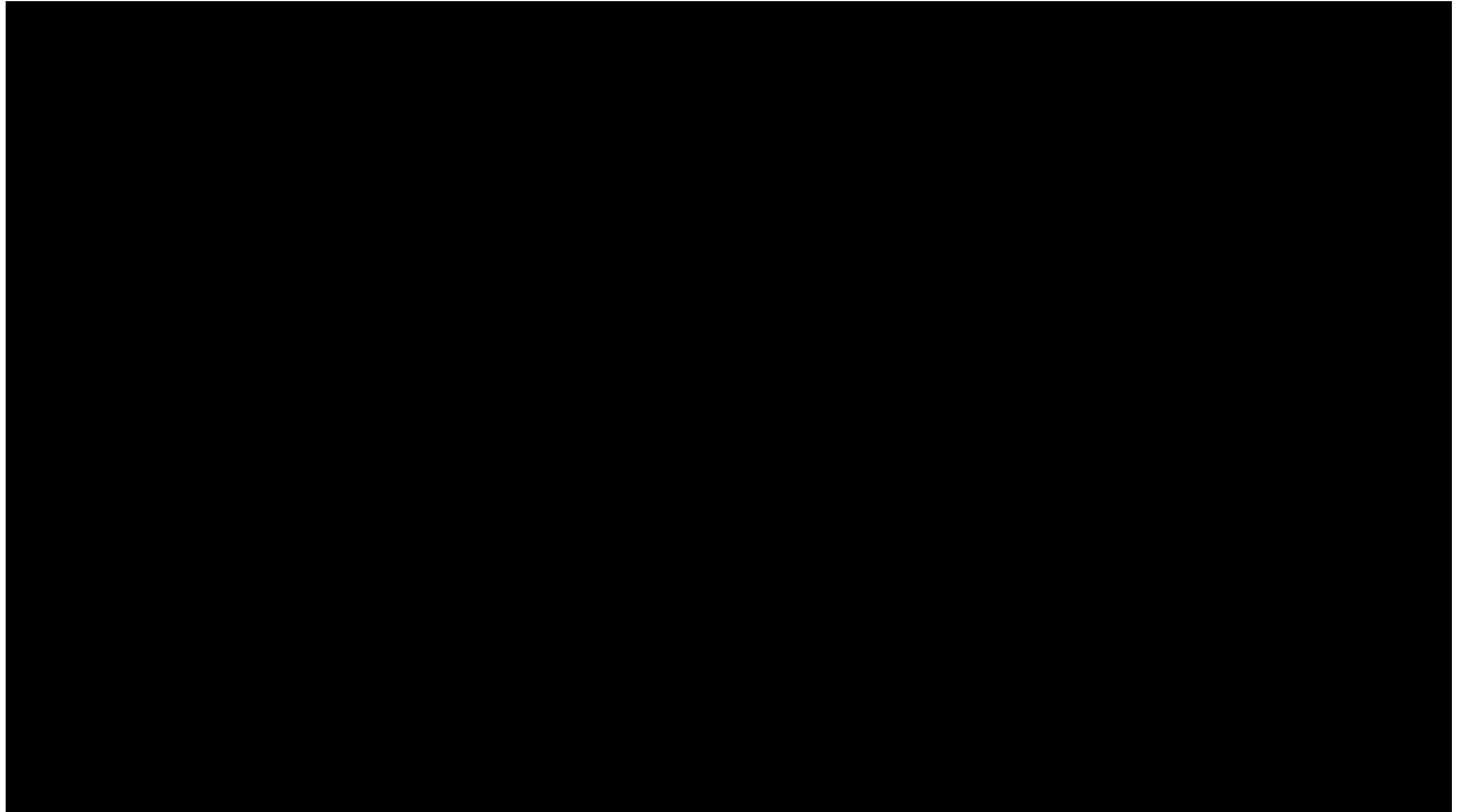
commissioned by Ircam and Percussions de Strasbourg

first performance: june 2017, Paris



INSIDE-OUT

for smart percussions (2017)



SUMMARY

- Modelling reality means choosing an *abstraction* level (mimesis and katharsis)

SUMMARY

- Modelling reality means choosing an *abstraction* level (mimesis and katharsis)
- Physical modelling synthesis is a flexible framework to model the acoustic behaviours of physical objects

SUMMARY

- Modelling reality means choosing an *abstraction* level (mimesis and katharsis)
- Physical modelling synthesis is a flexible framework to model the acoustic behaviours of physical objects
- Physically-inspired synthesis expands this possibility by creating *plausible sounds* by means of sensors and parameter models

SUMMARY

- Modelling reality means choosing an *abstraction* level (mimesis and katharsis)
- Physical modelling synthesis is a flexible framework to model the acoustic behaviours of physical objects
- Physically-inspired synthesis expands this possibility by creating *plausible sounds* by means of sensors and parameter models
- Gesture recognition, by means of low-level features, is the key step to create a system for **augmented reality**

GITHUB REPOSITORY OF THIS LECTURE

<https://github.com/CarmineCella/Berkeley2018>

SELECTED REFERENCES

- C. E. Cella, Generalized series for spectral design, 2013
- C. E. Cella, On physically-inspired synthesis of sound, 2012
- Rossing - Fletcher, The physics of musical instruments, 2002
- J. Smith, Physical audio signal processing, 2006
- M. Puckette, The theory and techniques of electronic music, 2006

ANY QUESTIONS?



carmine.emanuele.cella@gmail.com