Between physics and perception

signal models for high level audio processing

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Overview

- Introduction
- High level control of signal transformation algorithms
- Signal transformation – a short review
  - Sinusoidal model
  - Source-filter model
- Current State
- Research directions

Introduction

Transformation of sound signals

- Signal transformation
  - Change **perceived** signal characteristic: **Volume, duration, pitch, timbre**, etc.
- General objectives :
  - **Simple control.**
  - **High quality, no artefacts.**
  - **Robust operation.**
- **ALL** perceptual qualities leave us with an ambiguous description of the desired transformation.
  - "Duration" merely describes "length in seconds".
  - Exact specification of how to achieve the desired duration is left to the algorithm.

Introduction
Transformation of sound signals

- Simple Control?
- Desired signal modifications need to be:
  - Easy to achieve and to control.
- Many users do not understand signal processing concepts.
- Algorithms should be controlled **intuitively.**
- Important especially for **timbre transformation.**

Introduction

Intuition and high-level control

- Intuitive control:
  - control parameters should relate directly with our experience in the physical world.
  - Categories related to physical and signal domain: **pitch and duration**.
  - Categories related to physical domain: **description of the physical source, playing style, age and gender of speaker**, **instrument type**, etc.
- High level control:
  - Use categories related to the physical domain to control signal transformations
  - Can be obtained most easily if algorithms have a **direct link with the physical sound objects** that we know in our every day life.

High-level control

- What do we want to control:
  - instrument type, remix instruments, playing style and ornamentation, voice type, speaker characteristics, etc.
- Required
  - Mapping between the physical properties and the timbre.
  - Very complex and often nonlinear.

High-level control

- Physical models
  - Best candidate, but still requires extensive research to achieve high quality models.
  - Difficult to learn automatically from data.
  - Models are often very specific, general approach not yet available
- Signal models
  - Design a model that covers perceptually relevant properties of physical sound sources.

High-level control
Signal models

- 2 signal models are especially successful in establishing a link to the **physical world**.
- Source-Filter Model:
  - Independent representation of **excitation source** and **resonator (body) structure**.
- Sinusoidal Model:
  - Representation of the **individual vibration modes** of the **excitation source**.

Sinusoidal and source-filter model

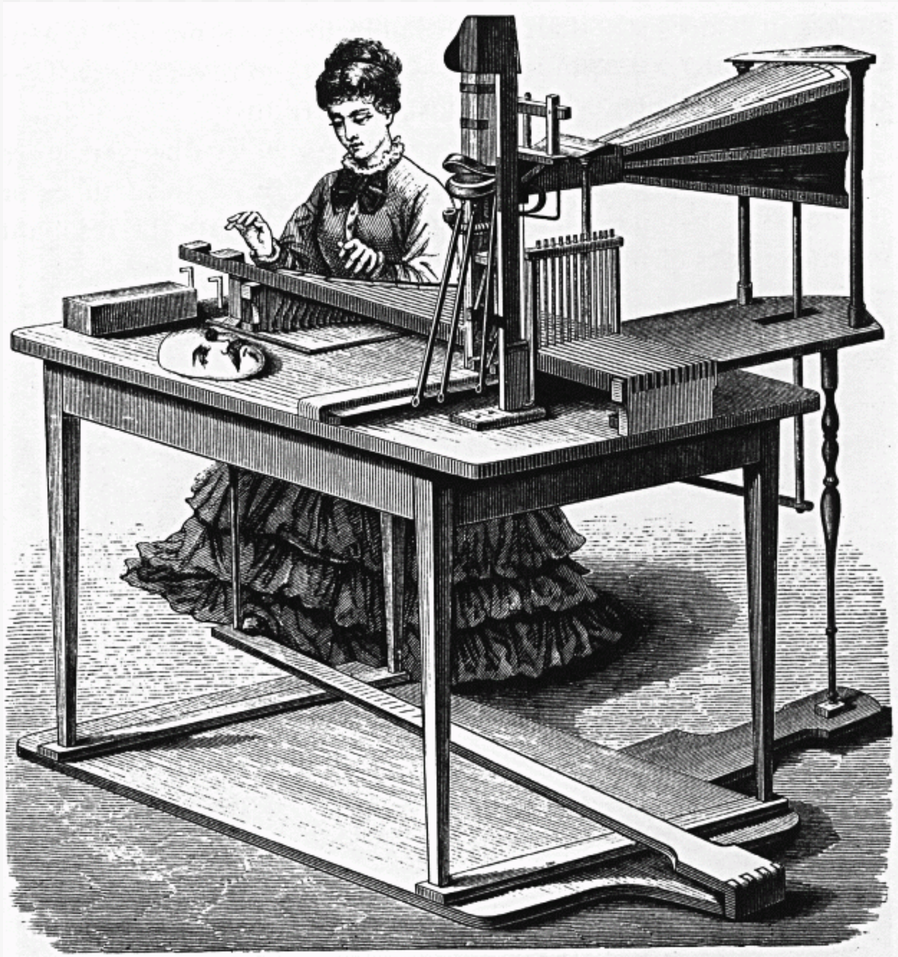
A short history

- Mechanical speech models
  - Wolfgang von Kempelen, Speaking machine [1773]: using periodic excitation and a resonator filter

Sinusoidal and source-filter model

A short history

- Joseph Faber's "Euphonia », shown in London [1846] : periodic and noise input source

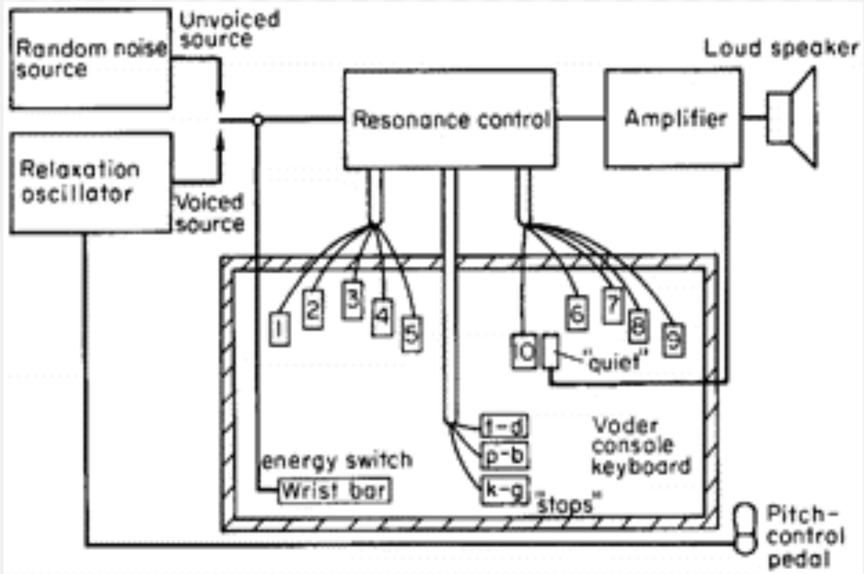


Sinusoidal and source-filter model

A short history

- Channel vocoder Homer Dudley [1939].
- First complete analysis/synthesize of speech,
- First electrical device.
  - Excitation switched between periodic pulse train (pitch controlled from analysis) and noise.
  - Energy distribution measured and controlled in ten 300Hz channels.
  - Manual control of channel energy.

Sinusoidal and Source-Filter model
A short history



28 Operators trained for 1 year

Voder greeting

Voder singing

Sinusoidal and Source-Filter Model

A short history

- Some important steps
  - Dudley [1939]: monolithic periodic excitation signal,
  - Flanagan/Golden [1966]: amplitude/frequency representation of a DFT spectrum phase vocoder, time stretching, in-harmonic signals, (Ex)
  - Moorer [1978]: phase vocoder+ LPC for transposition with timbre preservation, (Ex)
  - McAulay/Quatiery [1986]: Sinusoidal representation of source, independent analysis of vibrating modes, noise modelled as collection of sinusoids,
  - Smith/Serra [1990]: Distinct analysis/treatment of sinusoidal and noise components,
  - Quatiery/McAulay [1992]: Shape invariant speech model,
  - Laroche/Dolson [1999]: Phase vocoder with intra sinusoidal phase synchronization (Ex).

Sinusoidal and Source-Filter Model

Current state (IRCAM)

- Phase vocoder often used as efficient implementation of the sinusoidal model.
- Preservation of transients sufficient for time stretching, slightly worse for transposition. (Röbel DAFx 2003)
- Sinusoidal and noise components can be separated and modified independently (Zivanovic/Röbel/Rodet DAFx 2004 and 2007).
- Independent source and filter transformation allows high level control of age and gender for speech (Röbel/ Rodet DAFx 2005, Röbel DAFx 2010).

Outlook

Extension of high-level control:

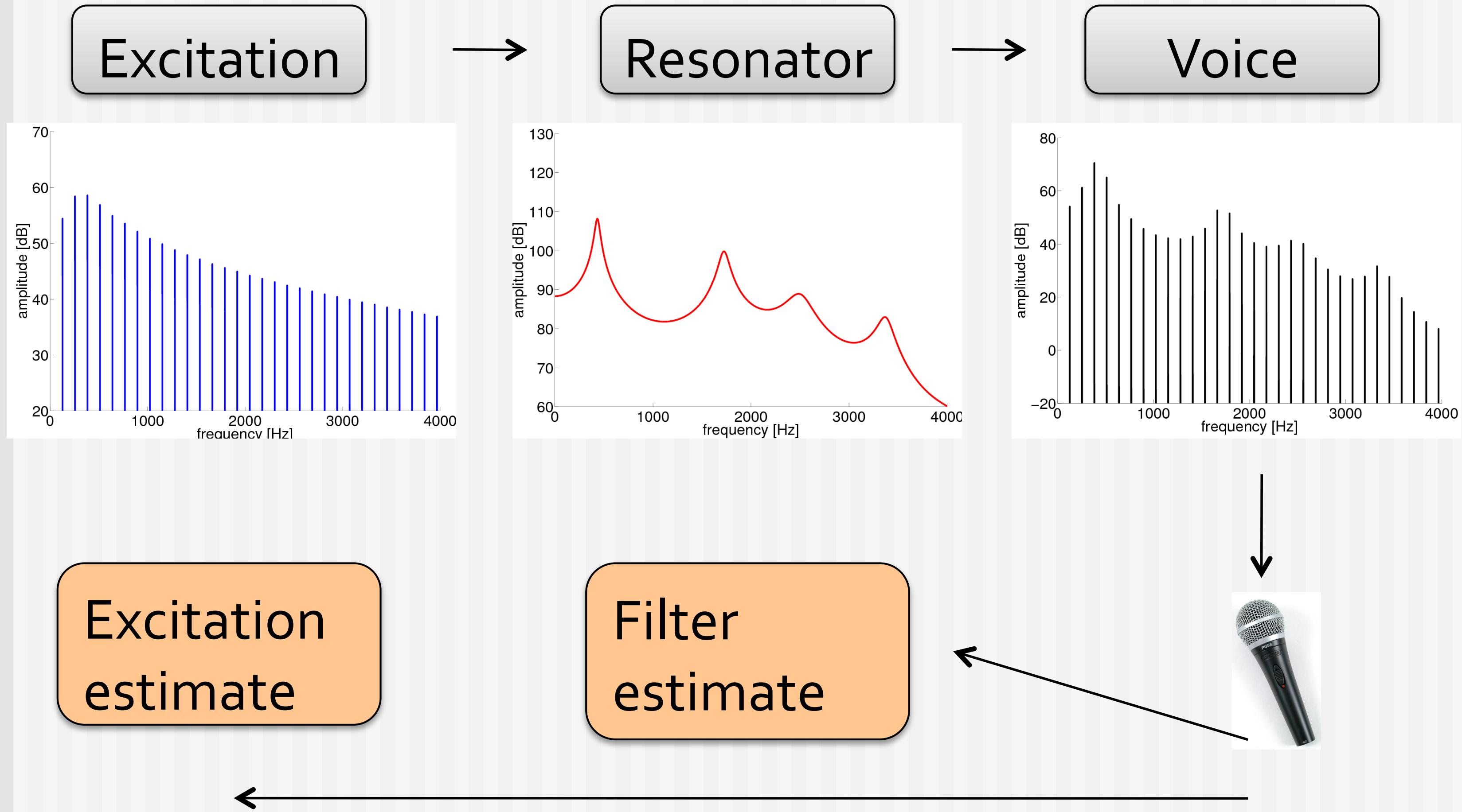
- Voice Conversion (convert between given speaker identities)
- Source-Filter model using non white source signals
- Source separation and polyphonic signal modification
- Expressive signal manipulation (Voice and instrument)

Outlook
Source-Filter Model

- Source and filter component separation is aiming to separate excitation oscillator and resonator filter.
- Physically reasonable excitation signal is not white!
- Coherent excitation signal estimates will:
  - improve perceptual relevance of controls, and
  - add new controls.
- Recent research:
  - Voice: ..., Fu and Murphy [2006], ..., Degottex [2009, 2010]... .
  - Music: Klapuri [2007], Hahn [2010] (DAFx), Sample Orchestrator 2...

Source-Filter Model

Estimate LF glottal excitation signals (G. Degottex)

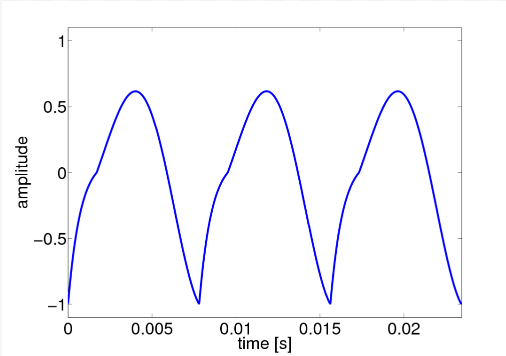


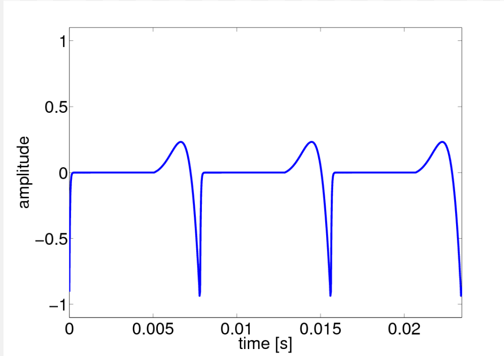
Source-Filter Model

Estimate glottal excitation signals (G. Degottex)

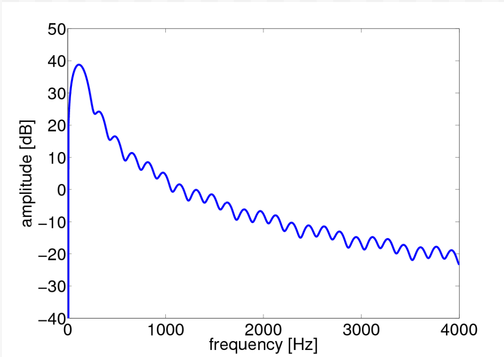
Liljencrants-Fant glottic source model + radiation

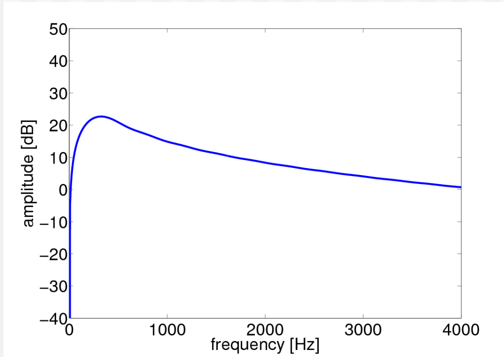
Time signal





Spectrum





Relaxed voice

Tense voice

Source-Filter Model

Estimate glottal excitation signals (G. Degottex)

Examples:

Transformation of glottic source parameters

Original voice:

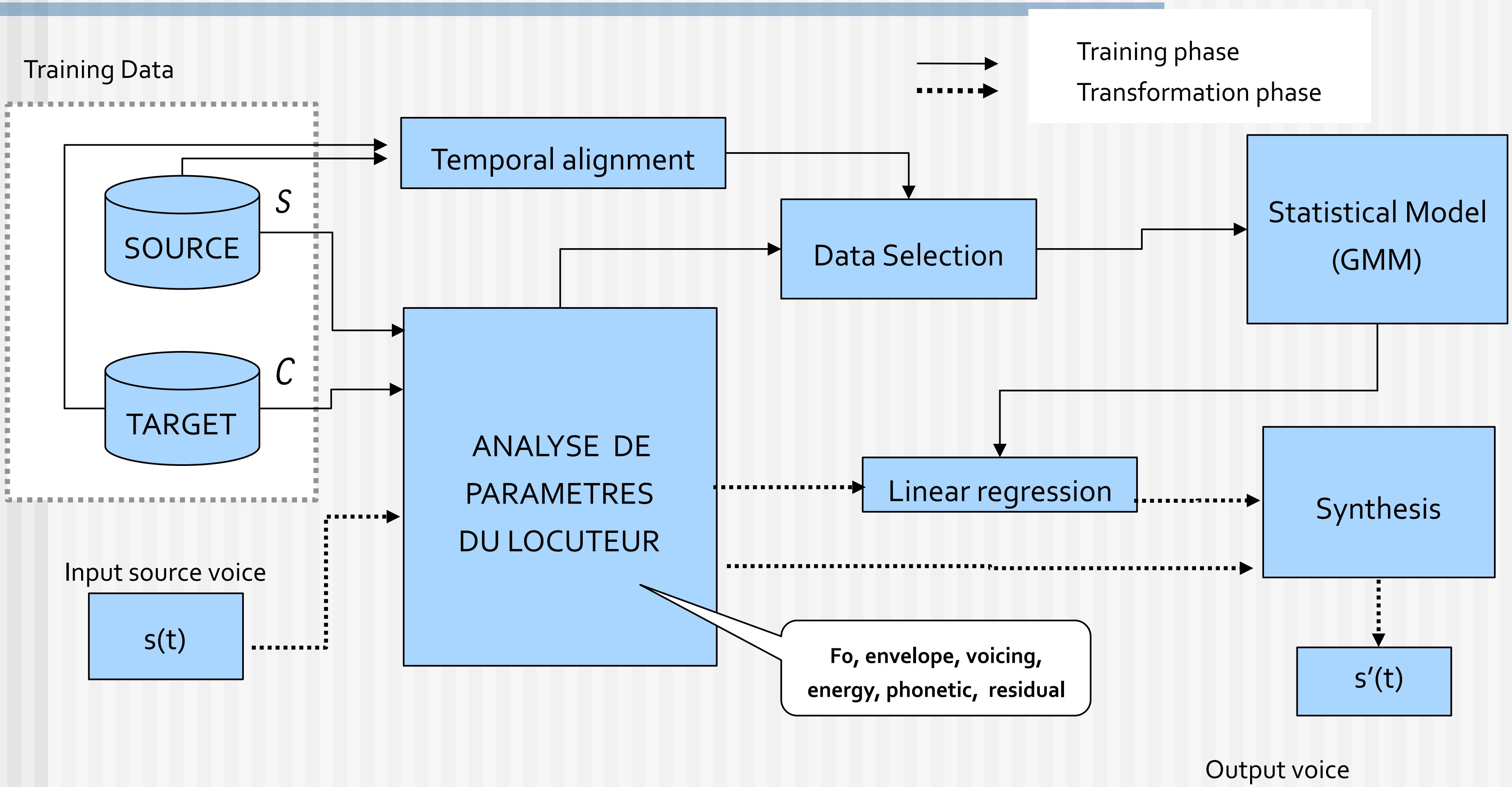
Transform into relaxed:

Transform into tense:

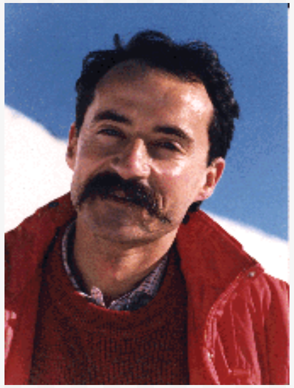
Voice Conversion (P. Lanchantin)

- High-level control of speaker identity
- Transform a given source speaker into a given target speaker
- Context aware transformation has to be learned from data.
- Current approaches limit the transformation to the vocal tract (filter part).
- To be addressed:
  - Prosodic information
  - Voiced/unvoiced balance
  - Glottic source parameters

Voice Conversion (P. Lanchantin)



Voice Conversion (P. Lanchantin)



Input Voice:

Transformed Voice:

Target Voice:

Transformation of Expressivity

Speech (C. Veaux)

- Text-to-Speech synthesis generally produces neutral speech.
- Expressive and emotional aspects are missing
- Intended high-level control: expressive state (anger, sadness, happiness, fear)

Transformation of Expressivity

Speech (C. Veaux)

Expressive transforms must address the five components of prosody [**Pfitzinger, H.R.,** *Speech Prosody 2006*]

Components	Features	Transforms
Intonation	Pitch	Dynamic transposition
Intensity	Loudness	Dynamic scaling
Speech Rate	Syllabic duration	Time stretch
Vocal Quality	Open quotient, Roughness and Fry, Breathiness	Rd modification, Glottal pulse jitter and shimmer
Articulation	Relative position of formants	Envelope Warping

After a stylization process (Legendre polynomial fitting), the reduced representations of these features are clustered for each expressivity (modelization step)

Transformation of Expressivity

Speech (C. Veaux)

Examples:

- Original, neutral expression
- Angry
- Happy
- Sad

Transformation of ornamentation

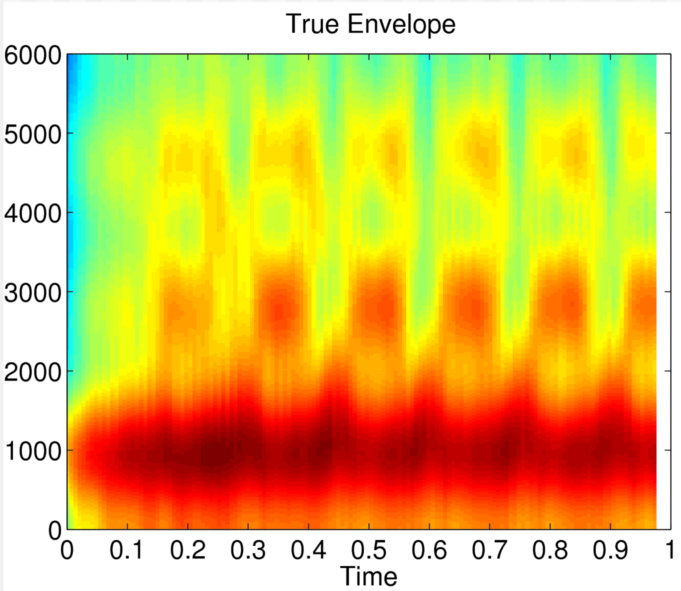
Vibrato/Tremolo/Note Transitions

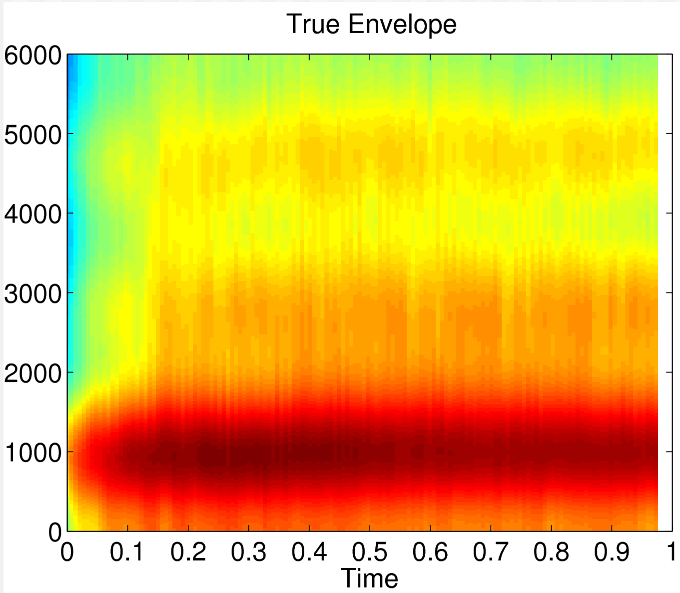
- Objective: independent manipulation of ornamentation and expressive playing style and pitch and duration.
- Recent versions of music samplers and other music software starts to integrate basic notion of expressivity transformation

Transformation of Ornamentation

Vibrato/Tremolo/Note Transitions

Example: Vibrato removal





Original Pitch correction Induced tremolo correction

Source Separation/Acoustic Scene Analysis

- Source separation and acoustic scene analysis are active research topics.
- Algorithms may use sparsity constraints or signal models.
- Applications: Polyphonic signal remixing and editing, signal restoration, automatic transcription, etc.
- First commercially available algorithm (Melodyne DNA) uses sinusoidal signal model.

Music Scene Analysis

- Integration of multiple signal analysis':
  - Beat markers (G. Peeters)
  - Polyphonic fundamental frequency (C. Yeh)
  - Adaptive instrument models (R. Houzet)
  - Onsets (A. Röbel)
- Followed by an adaptive filtering and stream forming phase

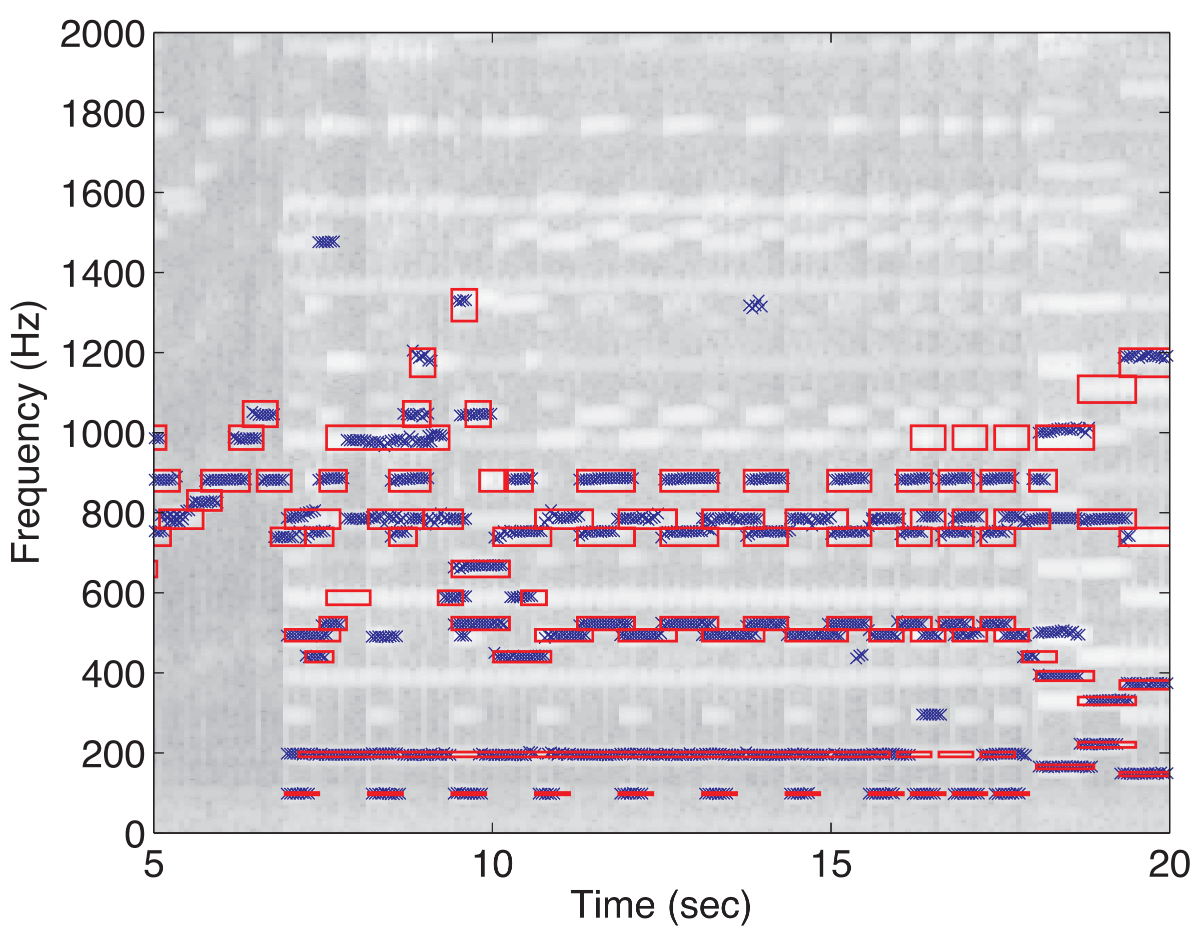
Music Scene Analysis

Audio to note (C. Yeh)

Example:

Multi Pitch

Analysis



Polyphonic Audio Transformation
(C. Yeh)

- High-level controls: Pitch and duration of individual notes of the polyphonic Music.
- Examples:

  Spanish guitar (original)

  Spanish guitar (some notes transposed)

  Jazz trumpet (original)

  Jazz trumpet (some notes transposed)

SUMMARY

- The desire and need to use every day concepts to intuitively control sound transformation is one of the driving forces of the evolution of sound transformation algorithms
- The underlying signal model concepts (sinusoidal and source-filter model) have hardly moved within the last 50 years.
- The high–level control concepts are becoming increasingly more complex.
- Many interesting questions are waiting to be solved.

Thanks for listening