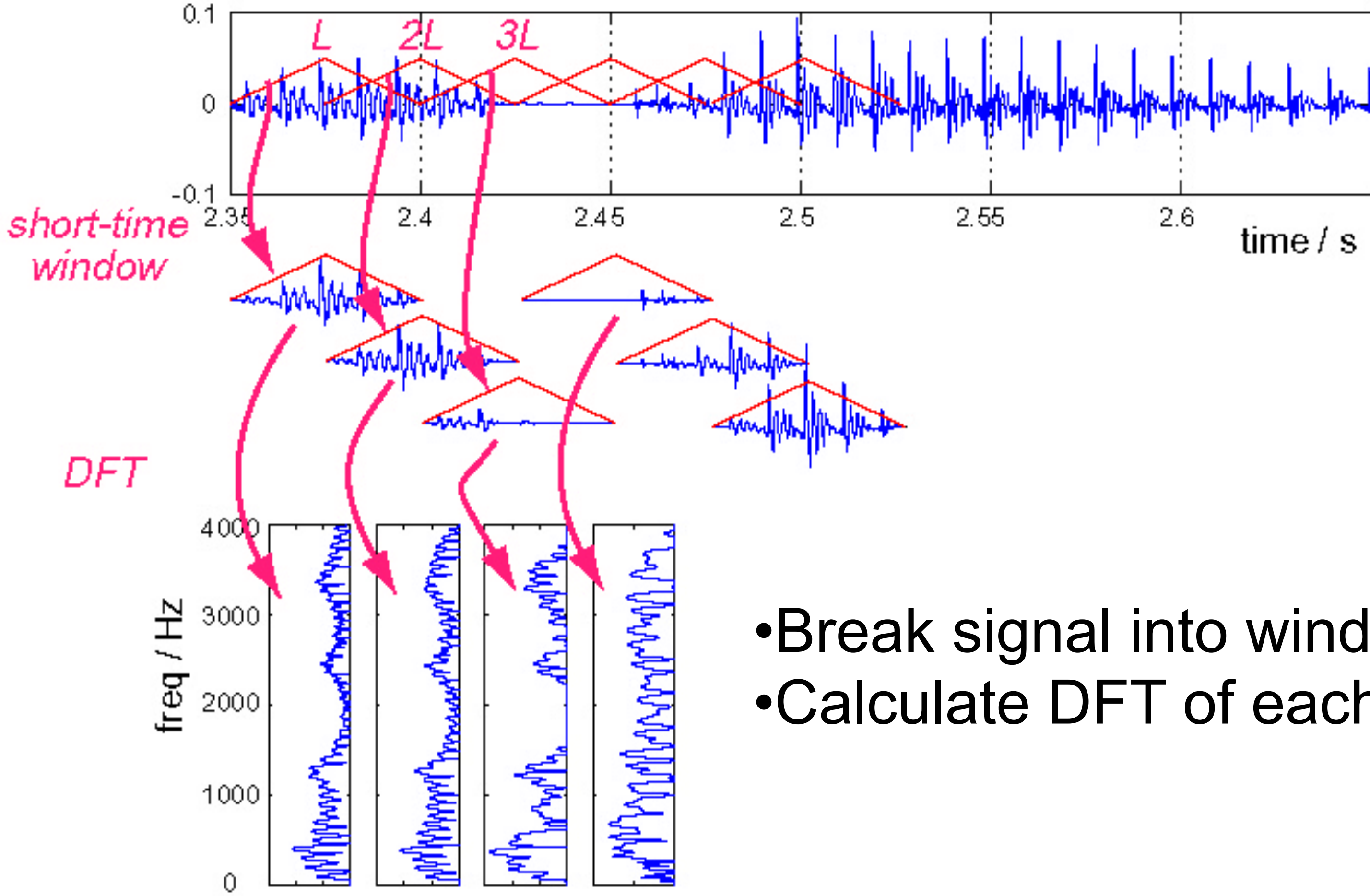
Topic

Spectrogram

Chromagram

Cesptrogram

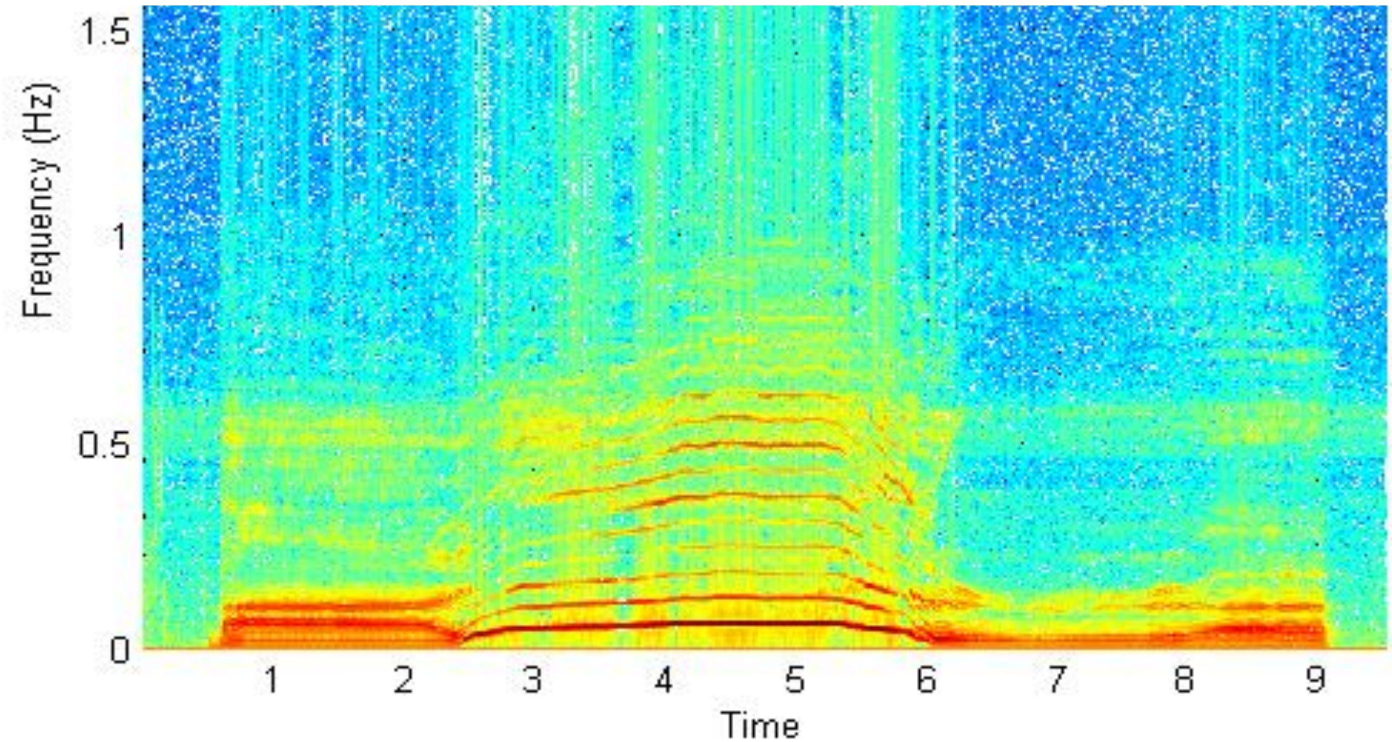
Short time Fourier Transform



- Break signal into windows
- Calculate DFT of each window

The Spectrogram

spectrogram(y,1024,512,1024,fs,'yaxis');



- A series of short term DFTs
- Typically just displays the magnitudes of **X** from 0 Hz to Nyquist rate

Equal Temperament

- Octave is a relationship by power of 2.
- There are 12 half-steps in an octave

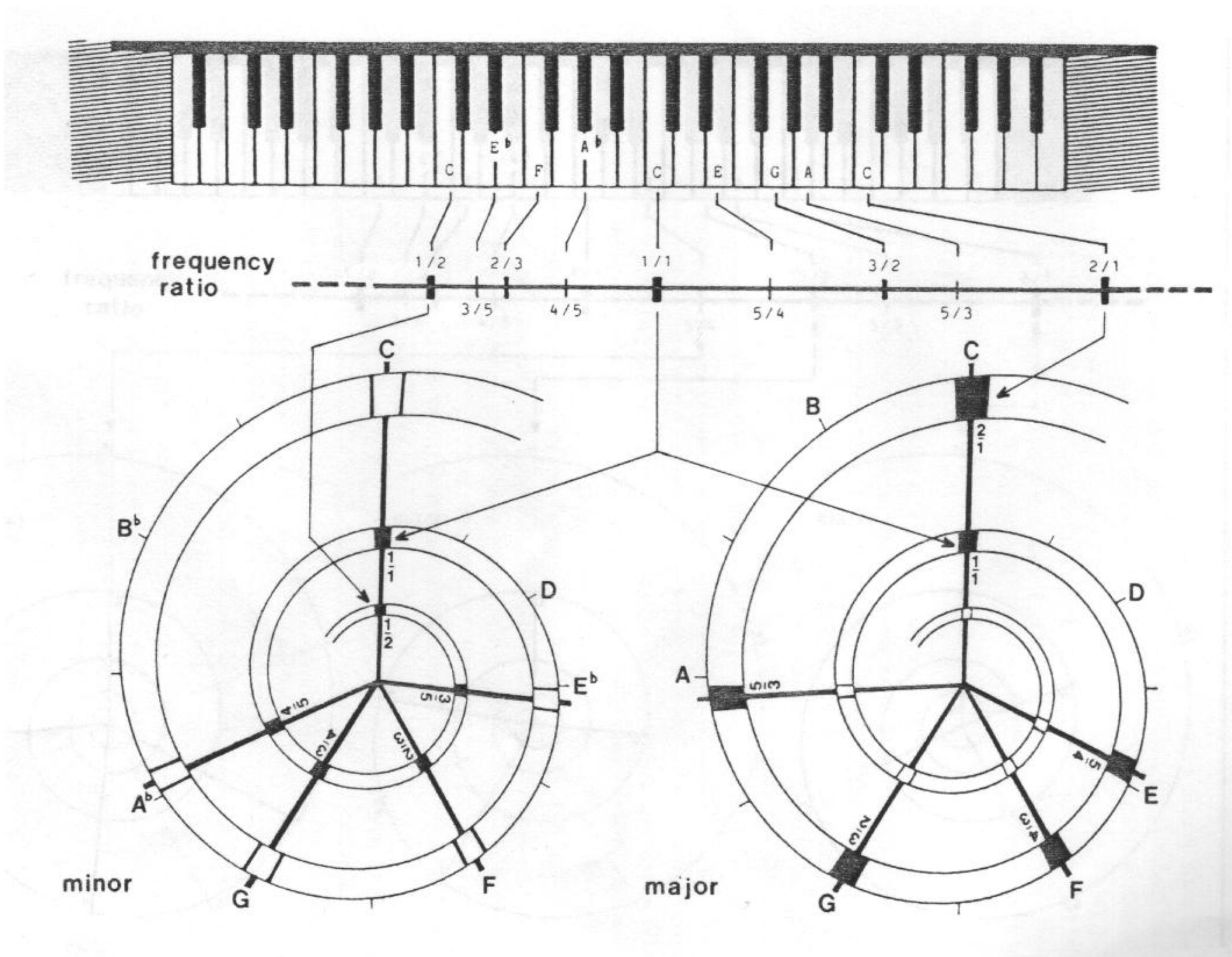
number of half-steps from the reference pitch

frequency of desired pitch

$$f = 2^{\frac{n}{12}} f_{ref}$$

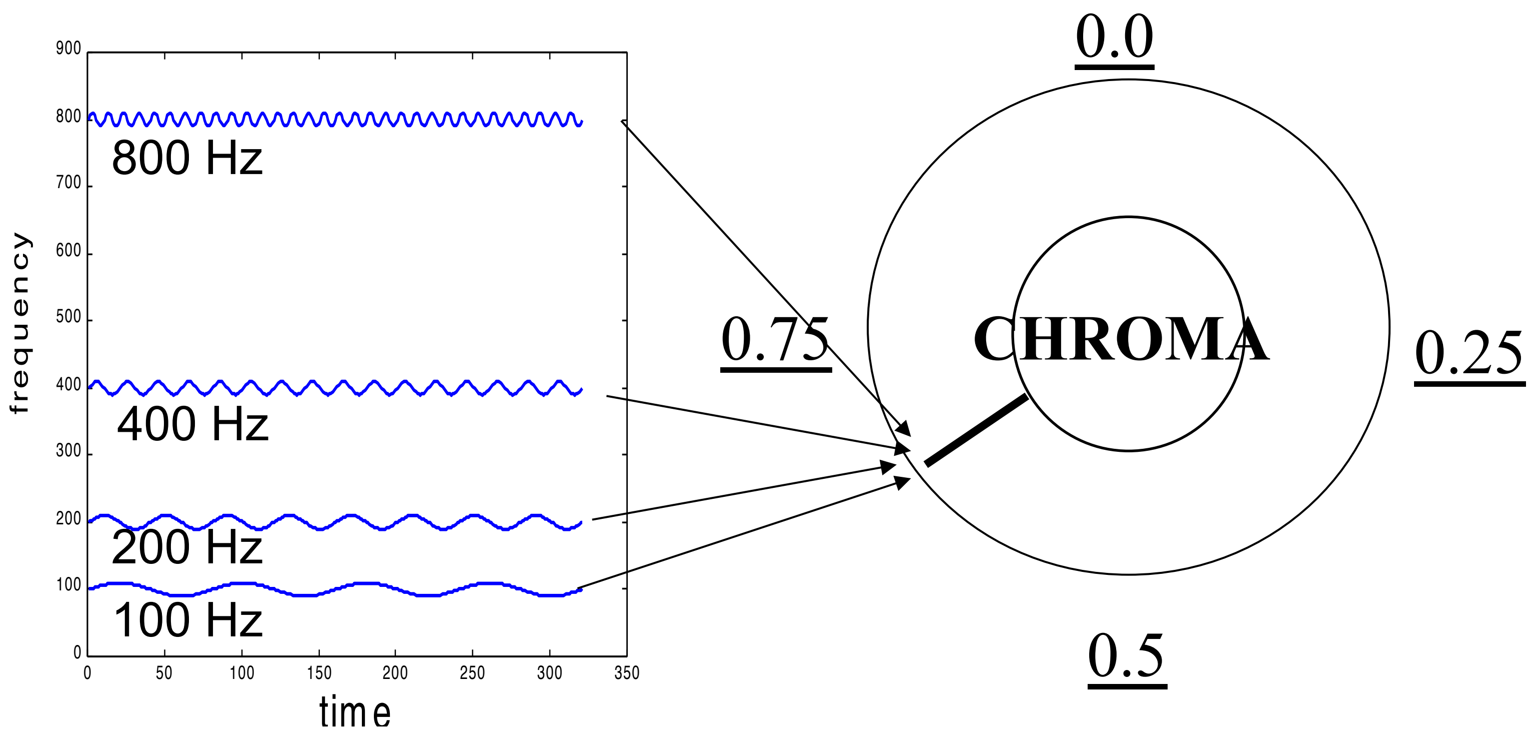
frequency of the reference pitch

Spiral Pitch representation



Chroma: Many to one

- Chroma = log2(freq) – floor(log2(freq))
- Chroma periodic in range 0 to (almost) 1
- Chroma map on to pitch classes

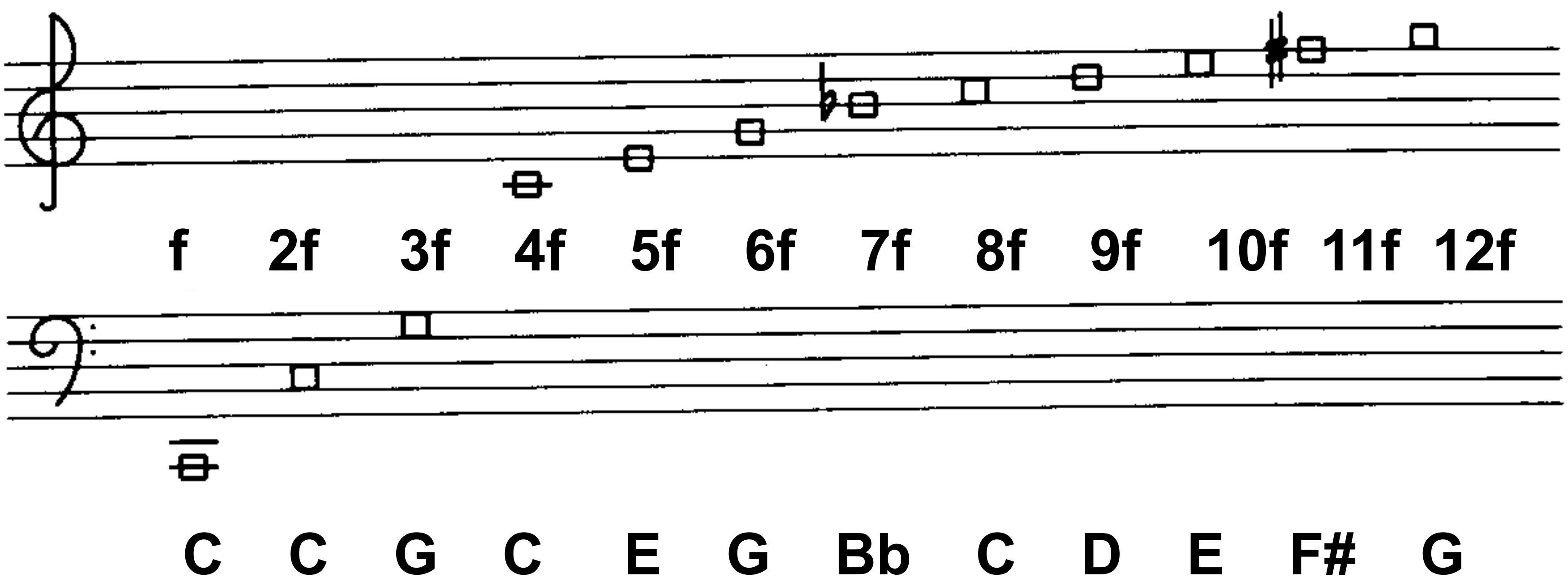


Making a Chromagram

- Decide how to quantize (bin) the chroma range.
  - 12 pitch classes? 120 bins? Equal temperment?
- Make a spectrogram
- For each time-step in the spectrogram
  - find the chroma for each frequency from 0 to N/2
  - Sum the amplitude of all frequencies with the same chroma bin
    - (Some chromagrams also add in the energy from the odd harmonics)
  - Place that value in the chroma bin

Overtone Series

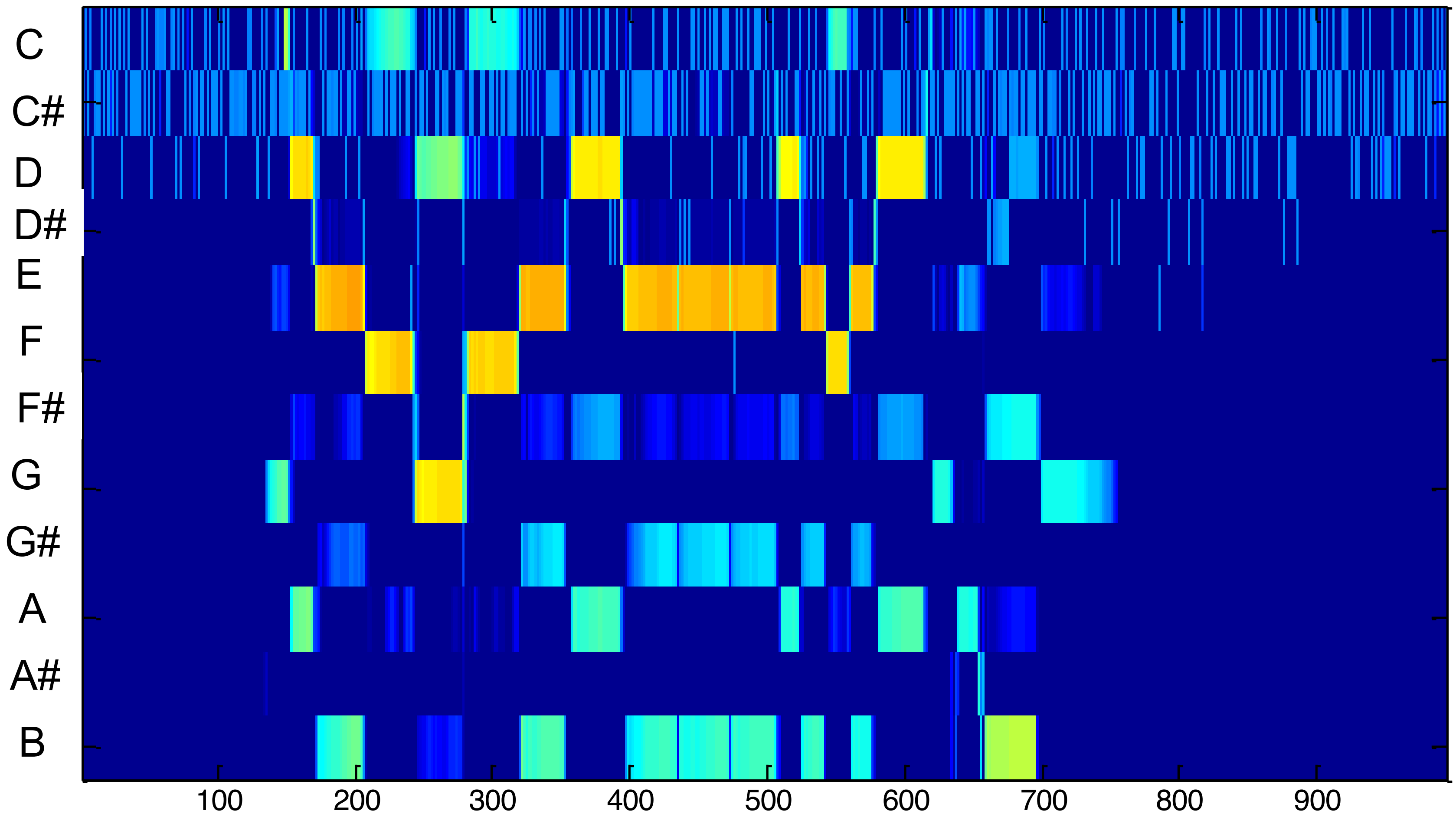
- Approximate notated pitch for the harmonics (overtones) of a frequency



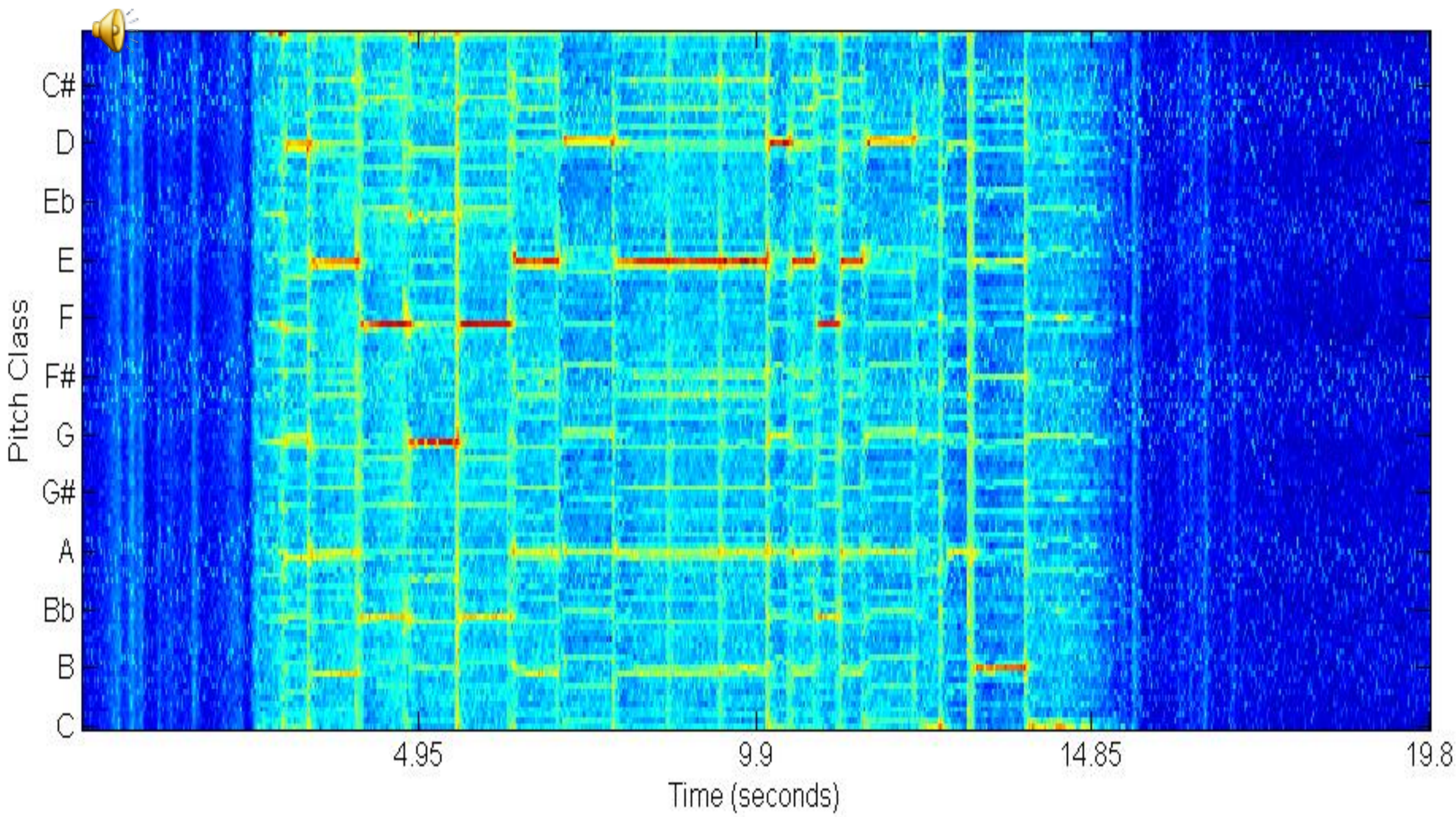
A fancier chromagram

- For complex sounds (like the bassoon example from class) you might want to consider adding up energy from more harmonics than just the octaves (1f, 2f, 4f…etc).
- Try taking the energy from the 3rd, 5th and 7th harmonics as well.

Chromagram of Clarinet

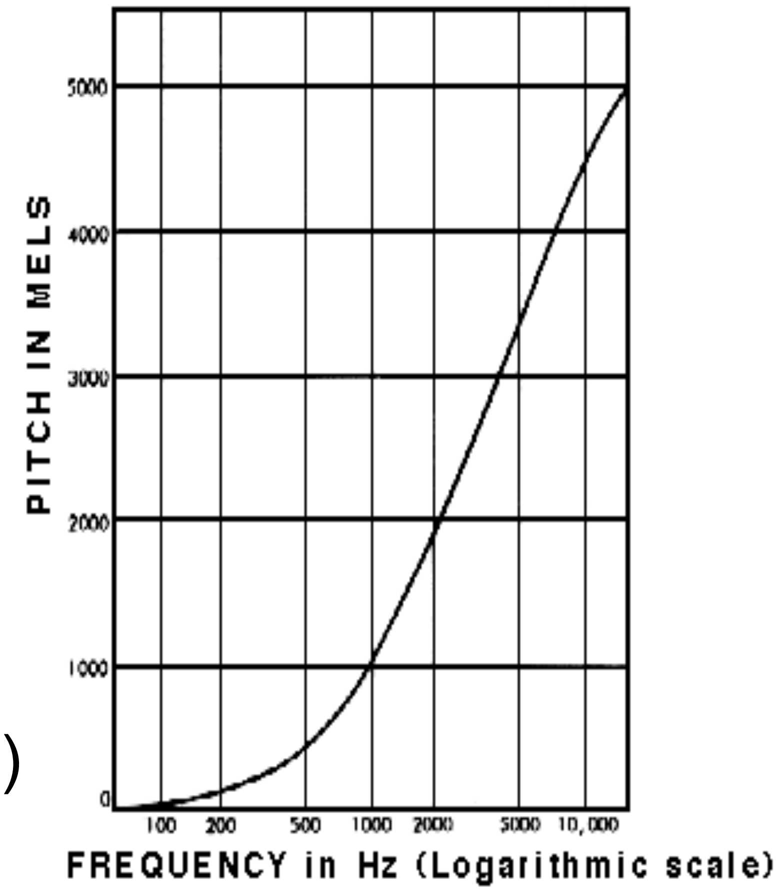


Chromagram of Clarinet



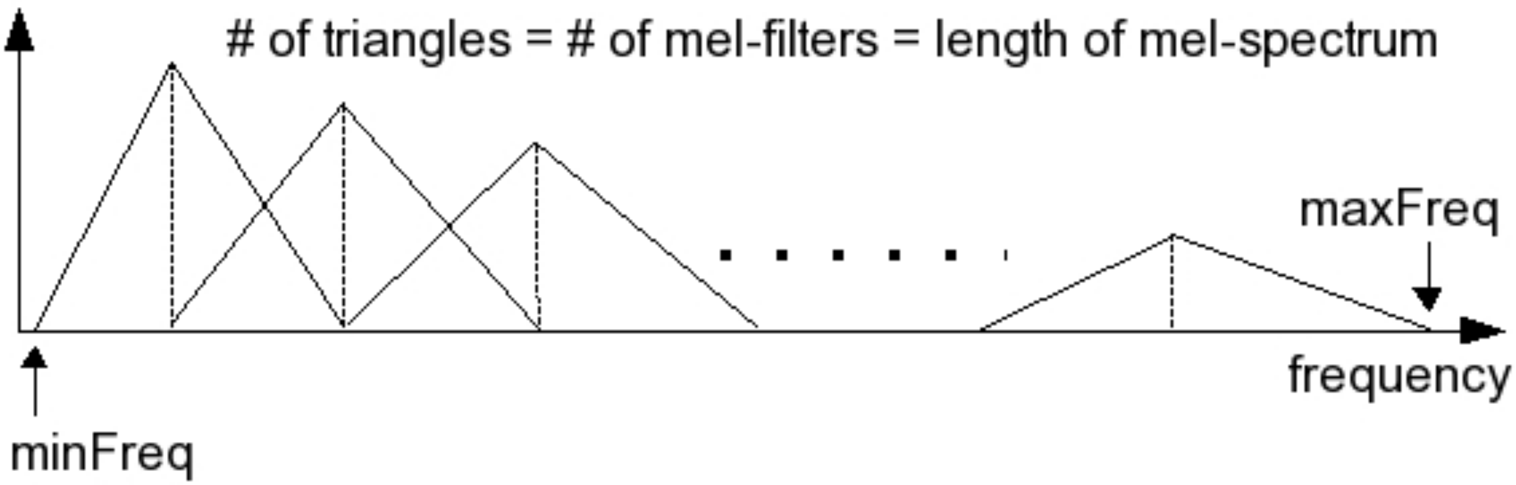
Mel Scale

- Stevens, Volkmann and Newmann (1937)
- A scale of pitches judged by listeners to be equidistant.
- The reference point:
  - 1000 mels = 1000 Hz at 40 dB SPL
- Below 500Hz mel ~= hertz
- Above 1000 Hz mel ~= log(hertz)



From: Appleton and Perera, eds., *The Development and Practice of Electronic Music,* Prentice-Hall, 1975, p. 56; after Stevens and Davis, *Hearing*

Mel Filter Bank



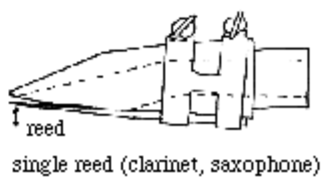
- Filters spaced equally in the log of the frequency.
- Mels are (more or less) related to frequency by…

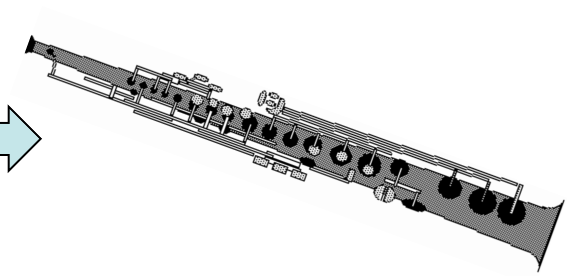
$$f_{mel} = 2595 \log_{10}\left(\frac{f}{700} + 1\right)$$

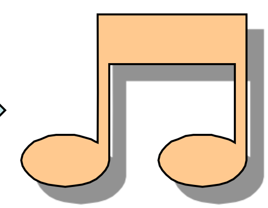
- Edge of each filter = center frequency of adjacent filter
- Typically, 40 filters are used

Source-Filter Model

Source Signal x(t)	→	Filter h(t)	→	Output Signal y(t)







$$x(t) * h(t) = y(t)$$

Convolution

The Cepstrum

- Filtering is
  - Convolution in the time domain
  - A product in the frequency domain
- What if we want to make it an addition operation?

$$Y[k] = X[k] \cdot H[k]$$

$$|Y[k]| = |X[k]| \cdot |H[k]|$$

$$\log(|Y[k]|) = \log(|X[k]|) + \log(|H[k]|)$$

The Cepstrum

- Filtering is
  - Convolution in the time domain
  - A product in the frequency domain
- What if we want to make it an addition operation?
- They do this by defining the ***cepstrum.***

$$Cep_x(q) = Z^{-1}(\log|X(z)|)$$

A frequency representation

Quefrency

The Inverse Z transform
(general case of the Inverse
Discrete Fourier Transform)

What is the Cepstrum for?

- Invented for finding echoes (aftershocks) in seismograph data.
- If something is useful for finding echoes, it is useful for finding impulse response functions
- …which makes it useful for finding filter coefficients.

Let’s look at an example…

Some terms

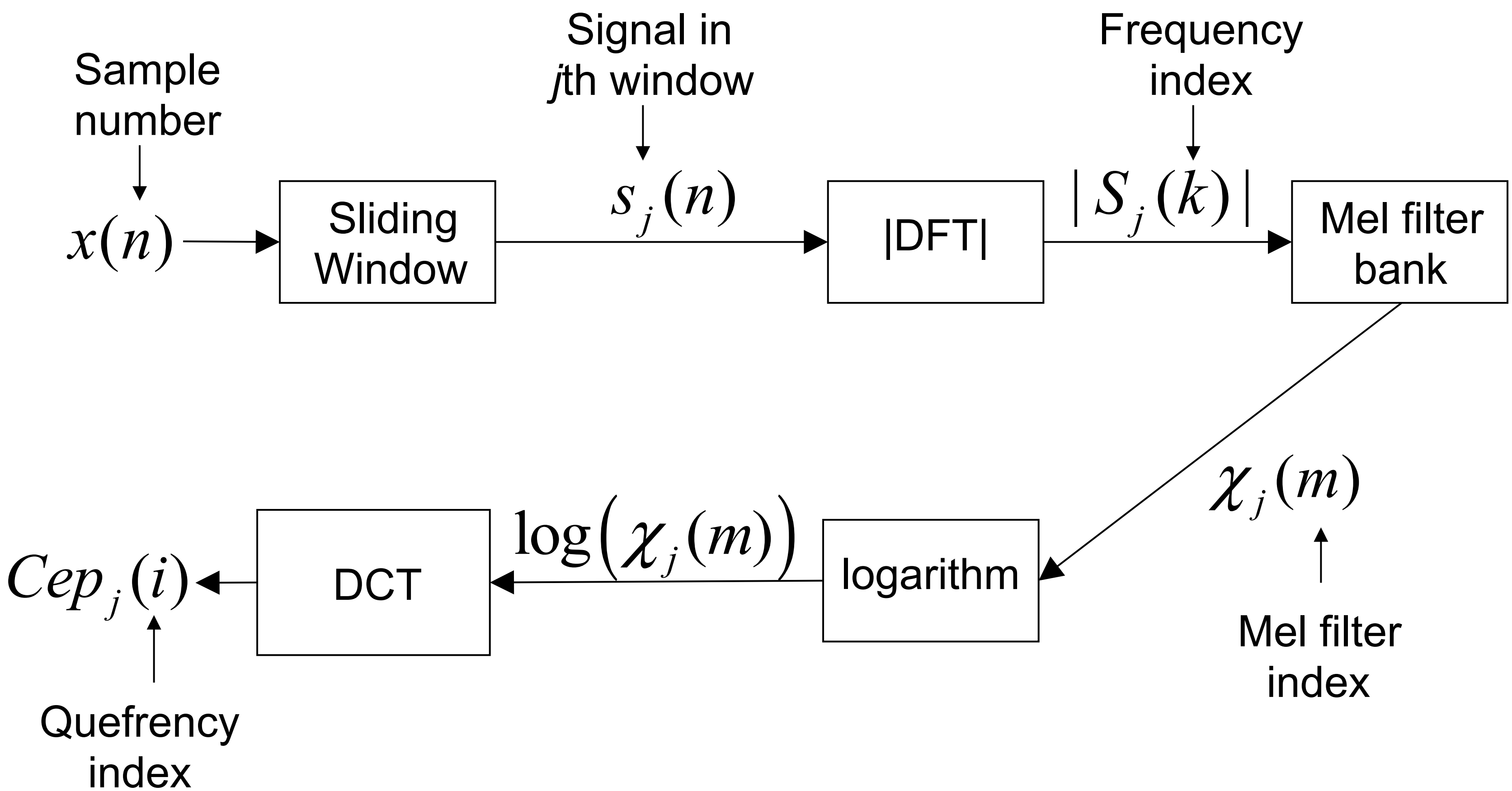
- Spectrum
- Spectrogram
- Frequency
- Filtering

- Cepstrum
- Cepstrogram
- Quefrency
- Liftering

The Cepstrum

- Gives information about rate of change in the different quefrency bands.
- Popular representation for speech and music
- Distinguishing FILTER from the SIGNAL
  – Some quefrencies represent the filter (what instrument), others represent the signal (what pitch)
- For these applications, the spectrum is usually first transformed to Mel Frequency bands.
- Result: **Mel Frequency Cepstral Coefficients (MFCC)**

Making a Mel Freq Cepstrogram



Here DCT = Discrete Cosine Transform

Let's have a look!

- (Go to bassoon/tuba demo)