The Spectrum

- Jean Baptiste Fourier (1768-1830) discovered a fundamental tenet of wave theory
- All periodic waves are composed of a series of sinusoidal waves
- These waves are harmonics of the fundamental
- Each harmonic has its own amplitude and phase
- The decomposition of a complex wave into its harmonic components, its *spectrum*, is known as a Fourier analysis
The Spectrum

It is often more useful to represent complex waveforms with a spectral plot as opposed to a time domain plot.

- **time domain**: amplitude as a function of time
- **spectral domain**: amplitude as a function of frequency
Sound in Time

Our perception of sound and music events is determined by the behavior of frequency and loudness over time
Sound in Time

All instruments can be characterized by changes in amplitude over time (the envelope).

Changes in amplitude often correspond with changes in frequency content...
Sound in Time

- Most instrument’s sound begins with an initial *transient*, or *attack*, portion
- The transient is characterized by many high frequencies and noise
- Example: the scraping of a bow or the *chiff* of breath
- An instrument’s distinctiveness is determined primarily by the transient portion of its sound
Information Theory

According to Information Theory:
only information essential to understand must be transmitted

To compress signals for faster transmission, the predictable parts are removed, as they can be inferred by the receiver. The \textit{information} is the unpredictable part.

With a sound event, the transient is analogous to the information, the unpredictable part.
Sound in Time

- Following the transient, instruments usually produce a *steady-state*, or *sustained*, sound.
- The steady state is characterized by
  - Periodicity
  - Harmonic spectrum
The Spectrogram (or sonogram)

Most natural sounds (and musical instruments) do not have a stable spectrum. Rather, their frequency content changes with time.

The *spectrogram* is a three-dimensional plot:

![Vibraphone note at 293 Hz (middle D)]

1) time

2) frequency

3) power of a given frequency (darkness level)

The instrument’s sound is characterized by the fundamental at 293 Hz and the fourth harmonic at 1172 Hz. The attack also contains noise below 2 kHz, the tenth harmonic at 2930 Hz and the seventeenth harmonic at 4981 Hz. Once the steady state portion sets in, the highest harmonic fades first, followed by a fading of the fundamental.