Lecture 8 - Signal and Image Processing

NENS 230: Analysis Techniques in Neuroscience

Fall 2015

Outline

1. **Introduction to concepts in signal processing**
2. **The Fourier transform**
3. **Sampling frequency**
4. **Filtering**
5. **Image Processing**
6. **Audio read / write**

What constitutes a ‘signal’ ?

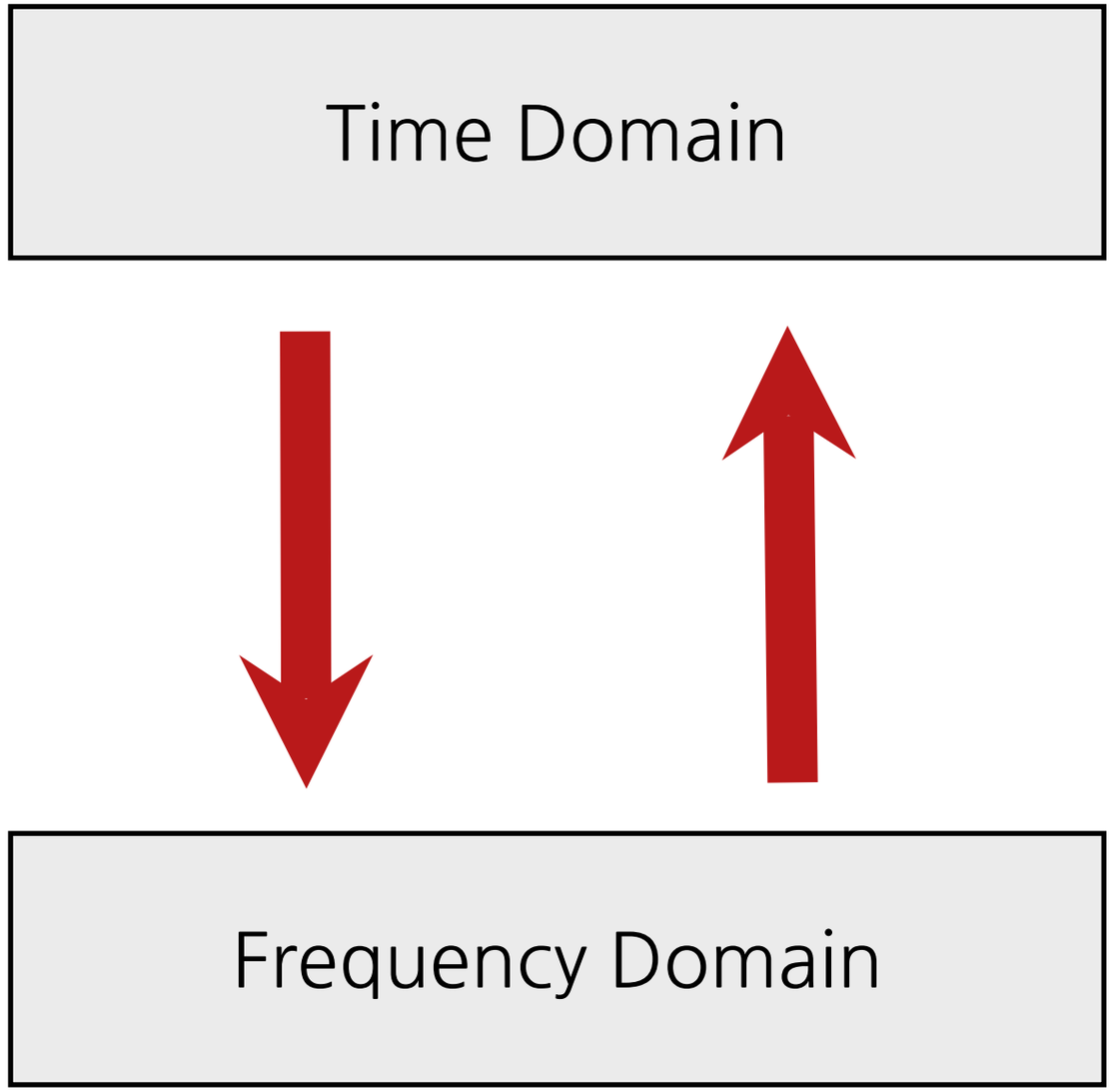
- Pretty much any measurement or piece of data…
- Most common: values that vary across either time or space
- Properties of signals:
    - dimensionality (1D, 2D, etc.)
    - sampling rate (samples per second)
    - range (max value - min value)
- Some examples
    - Audio waveform from a microphone

Fourier Analysis: A primer

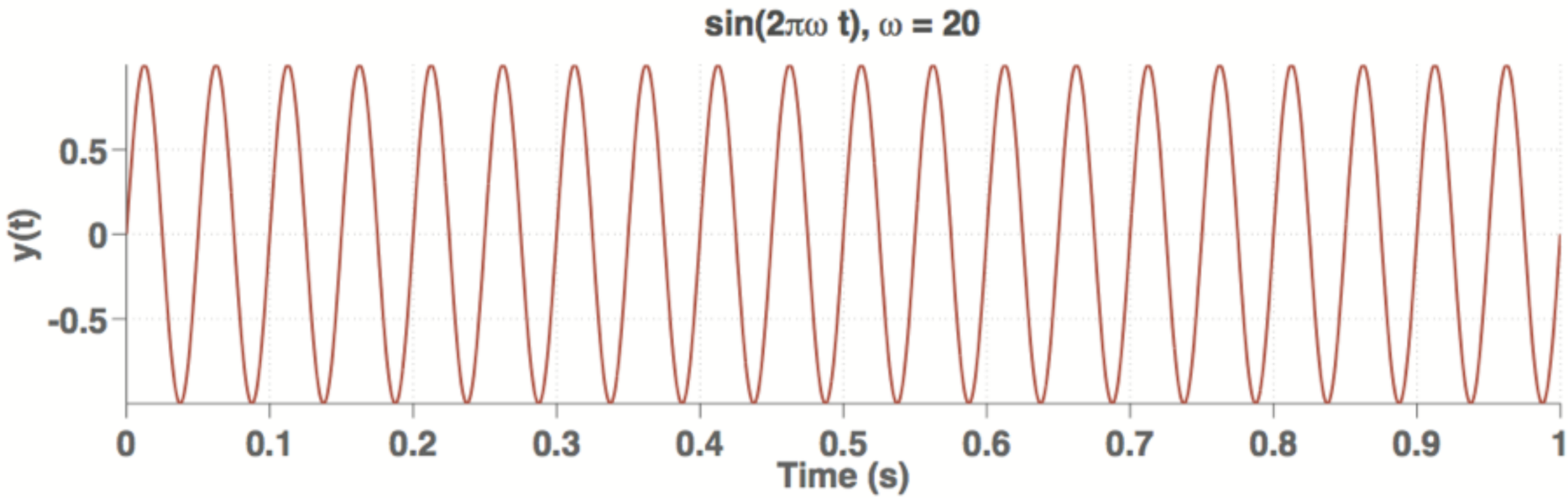
Useful for:

- Noise Reduction
- Period Estimation
- Anti-aliasing
- and much, much more ....

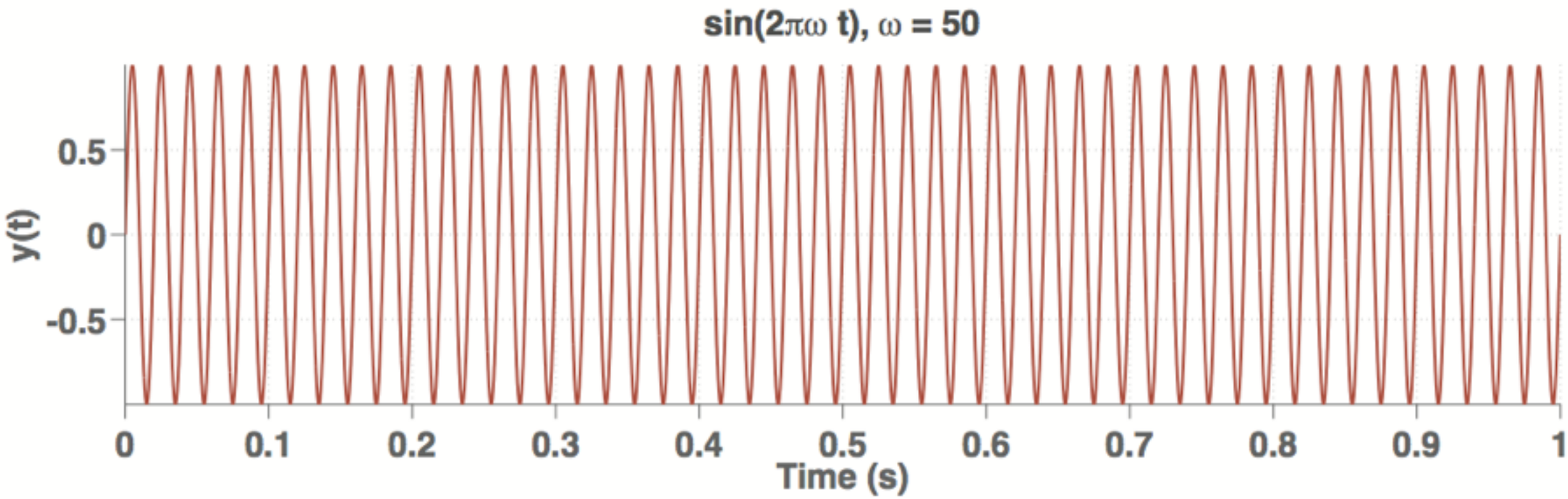
Fourier Analysis: A primer



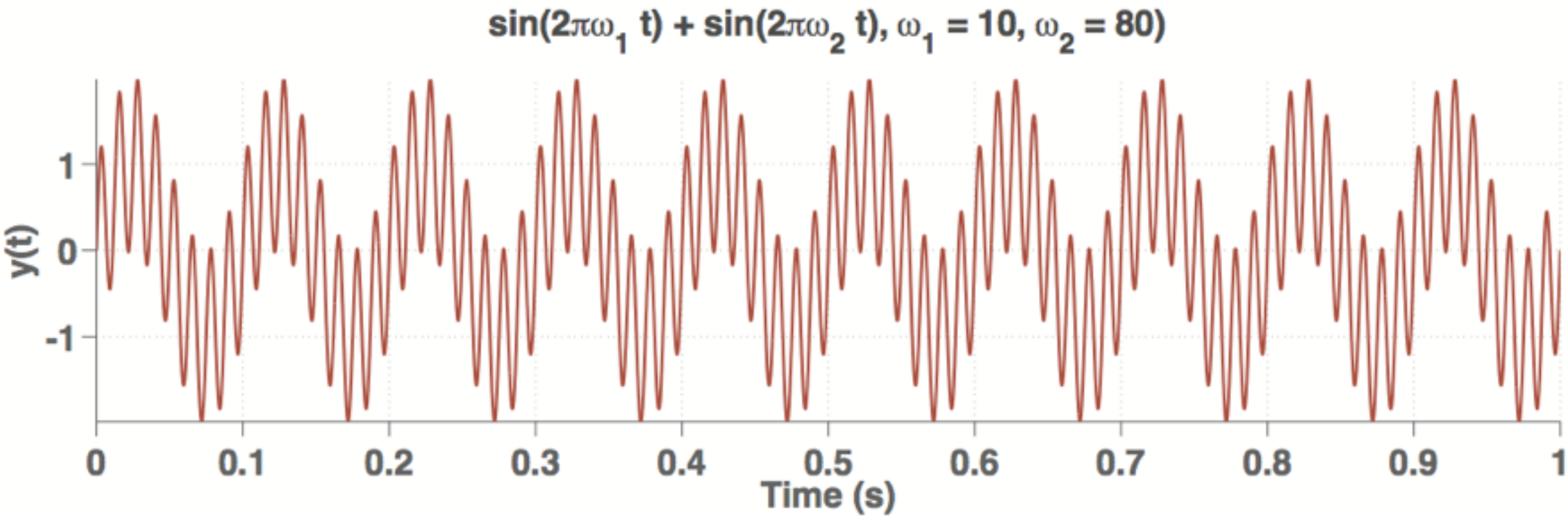
Simple Signals



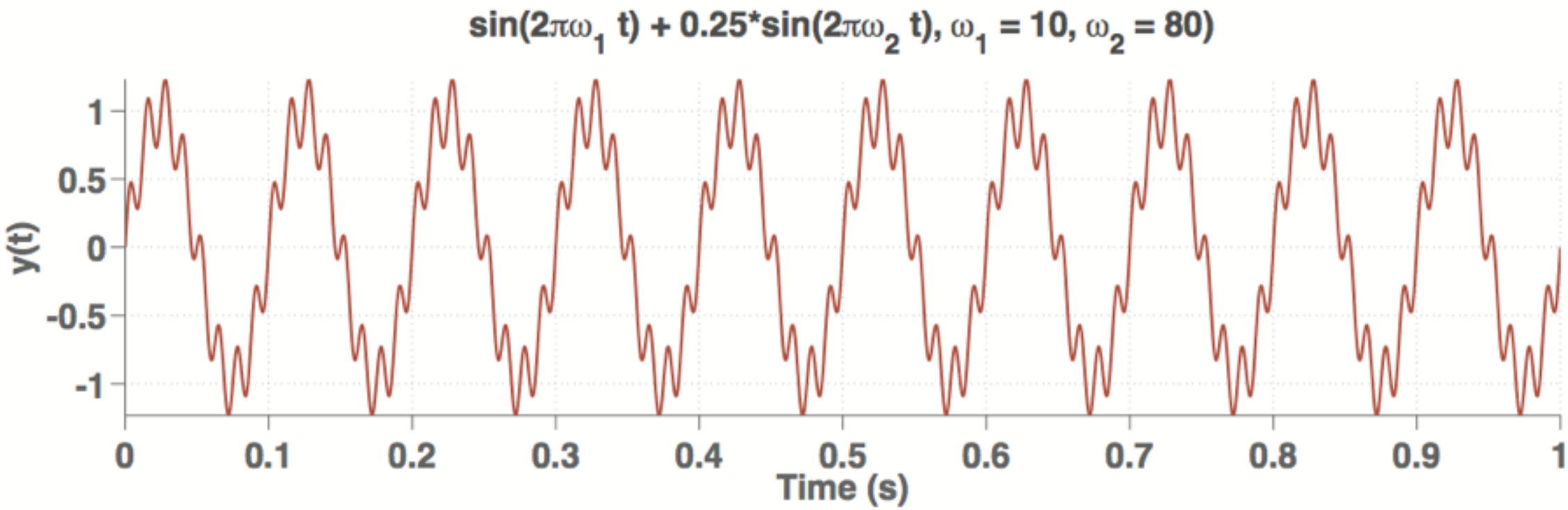
Simple Signals



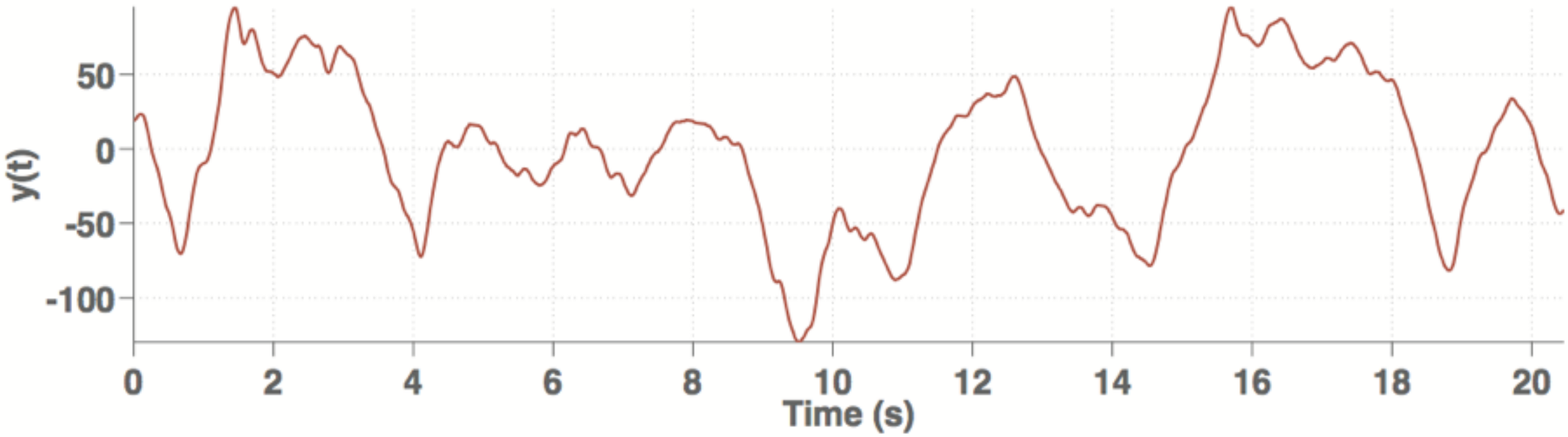
Linearity


sin(2πω1 t) + sin(2πω2 t), ω1 = 10, ω2 = 80)
y(t)
1
0
-1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (s)

Linearity

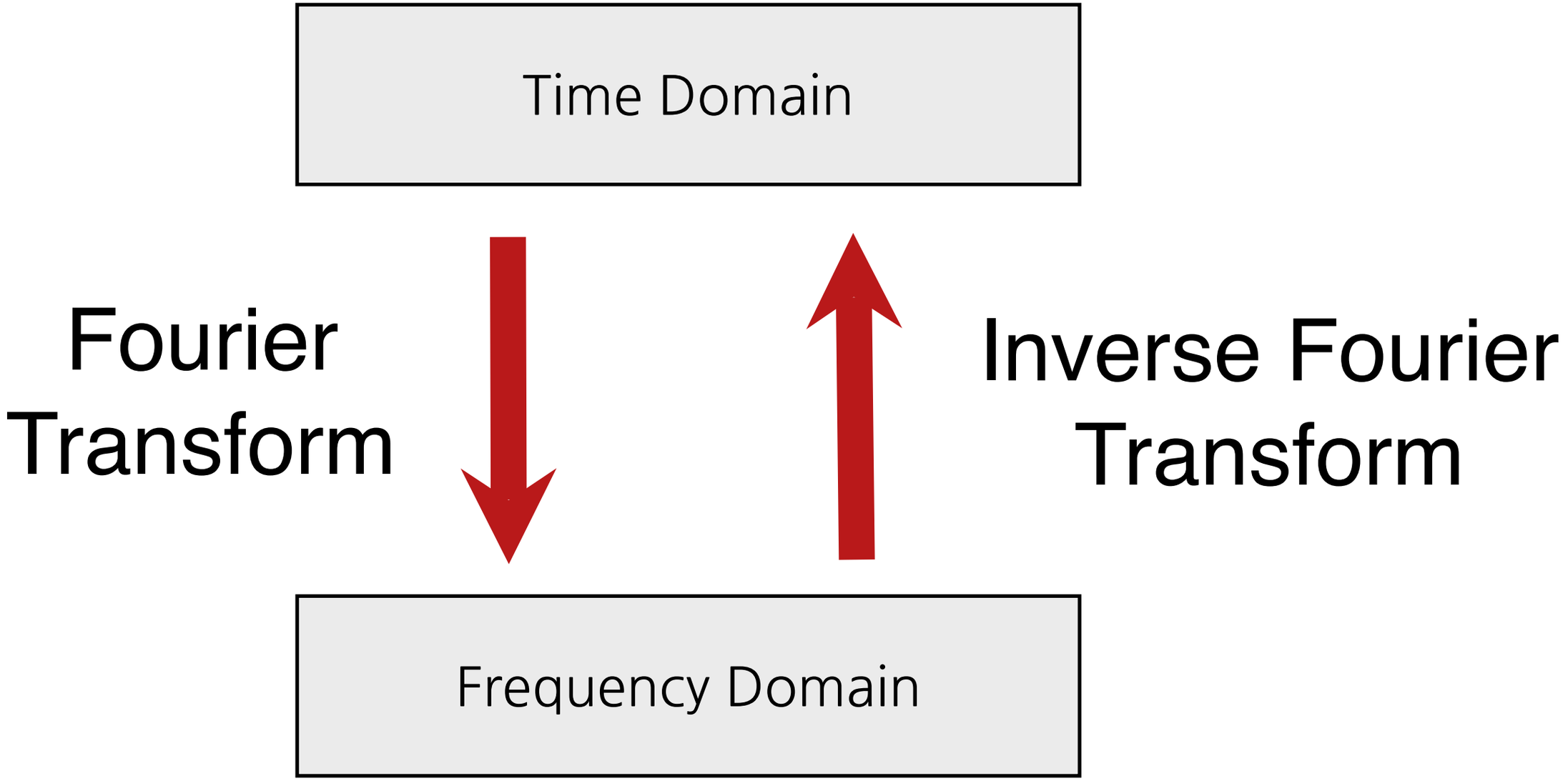

sin(2πω1 t) + 0.25*sin(2πω2 t), ω1 = 10, ω2 = 80)
y(t)
1
0.5
0
-0.5
-1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (s)

Complex Signals



Demo:
Fourier Series
representation of a square wave

Fourier Analysis: A primer



The Fourier Transform

- Decomposes a time series signal into a sum of sine and cosine signals of various amplitudes and frequencies.
- Can be used to identify the dominant frequencies in a signal
- Lots of mathematical depth we can't go into here (there's a whole Stanford course: EE261, The Fourier transform and its applications)

Fourier Analysis in Matlab

Given a signal y(t):

```
F = fft(y);
```

Computes the Fast Fourier Transform (FFT)

F is a vector the same size as y

Demo:

FFT on Audio Signal

Fourier Analysis in Matlab

Excellent toolbox for spectral analysis:

Chronux: www.chronux.org

Example uses:

1) LFP Analysis
2) Spike-spike coherence
3) spike-field coherence
4) etc.

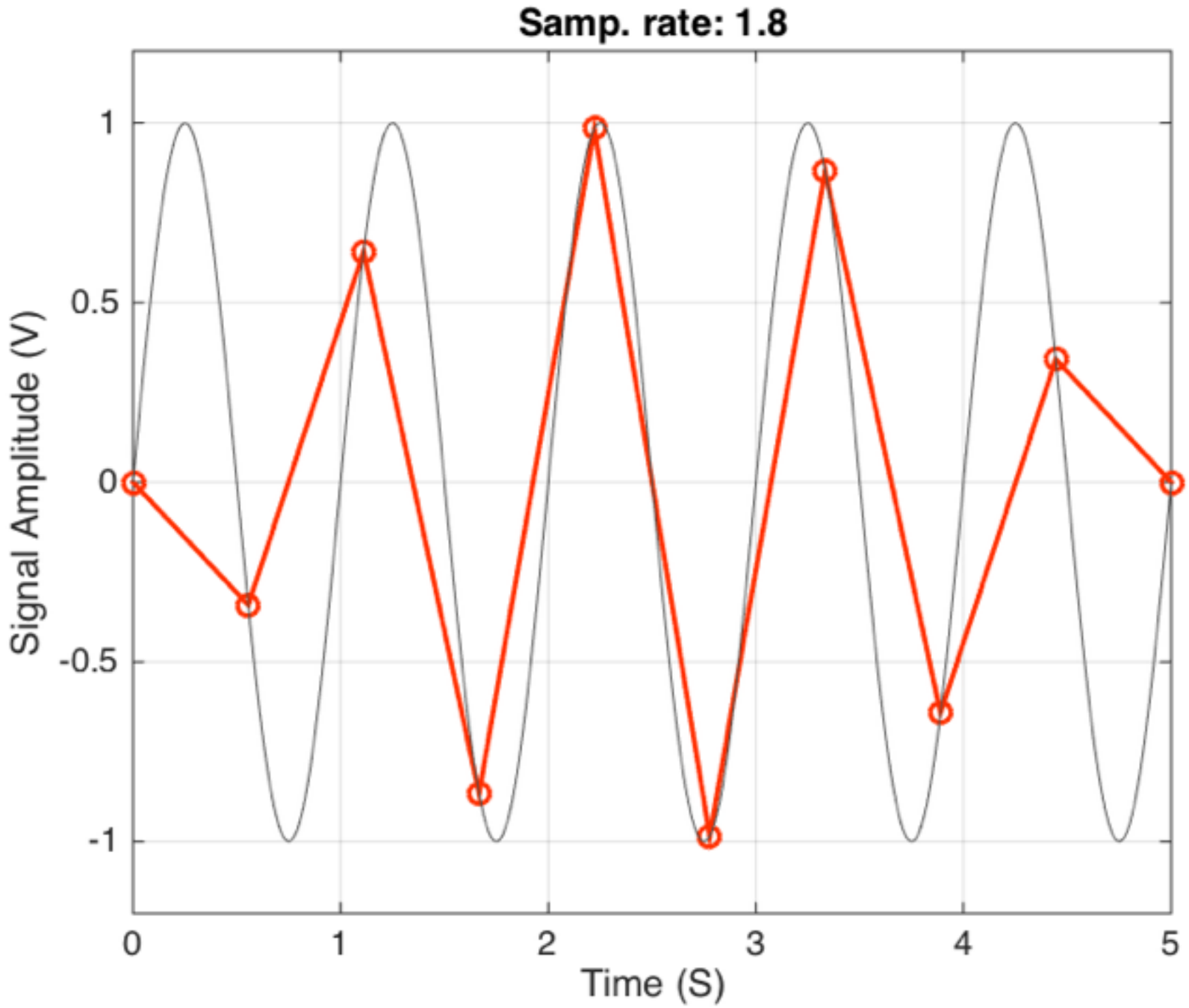
Nyquist limit

You can only resolve or estimate frequencies up to half of the sampling rate

- Note that rate can refer to:
    1. Time (e.g.: audio signal sampling rate)
    2. Space (e.g.: pixel resolution in microscopy image)

This has important implications for your data collection. You have to sample fast enough or with high enough spatial resolution to capture the signals of interest.

Sampling too slow



Demo: Sampling Frequency

Filtering

- What should you do if you only care about a signal within a certain frequency band?
- How to deal with noise?
- If you know what you're looking for (e.g.: neural spikes, LFP, some radio signal, bird chirp audio, etc) then you can filter out frequencies not contained in that signal
- Conceptually similar to fluorescence microscopy (want to keep only specific frequencies and remove the rest).

Filtering Example Uses

- Isolating neural spikes from LFP (or LFP from spikes)
- Removing 60 Hz “hum” from electrical recordings
- Removing background noise from audio recording
- Almost any application involving quantitative measurement

Designing filters in Matlab

- Again, there's a lot of depth we can't cover here, and whole courses designed around filtering math and theory.
- Matlab hides much of this complexity and makes filter design relatively simple

`fdatool`

- Filter Design and Analysis tool

Demo:

Filter Design

Signal Processing in Matlab

Other useful functions (see documentation for more info):

`filter` (apply a filter to a signal)

`conv` (convolution)

`xcorr` (cross correlation)

Peak Detection

Lots of different algorithms, we will use one on FileExchange:

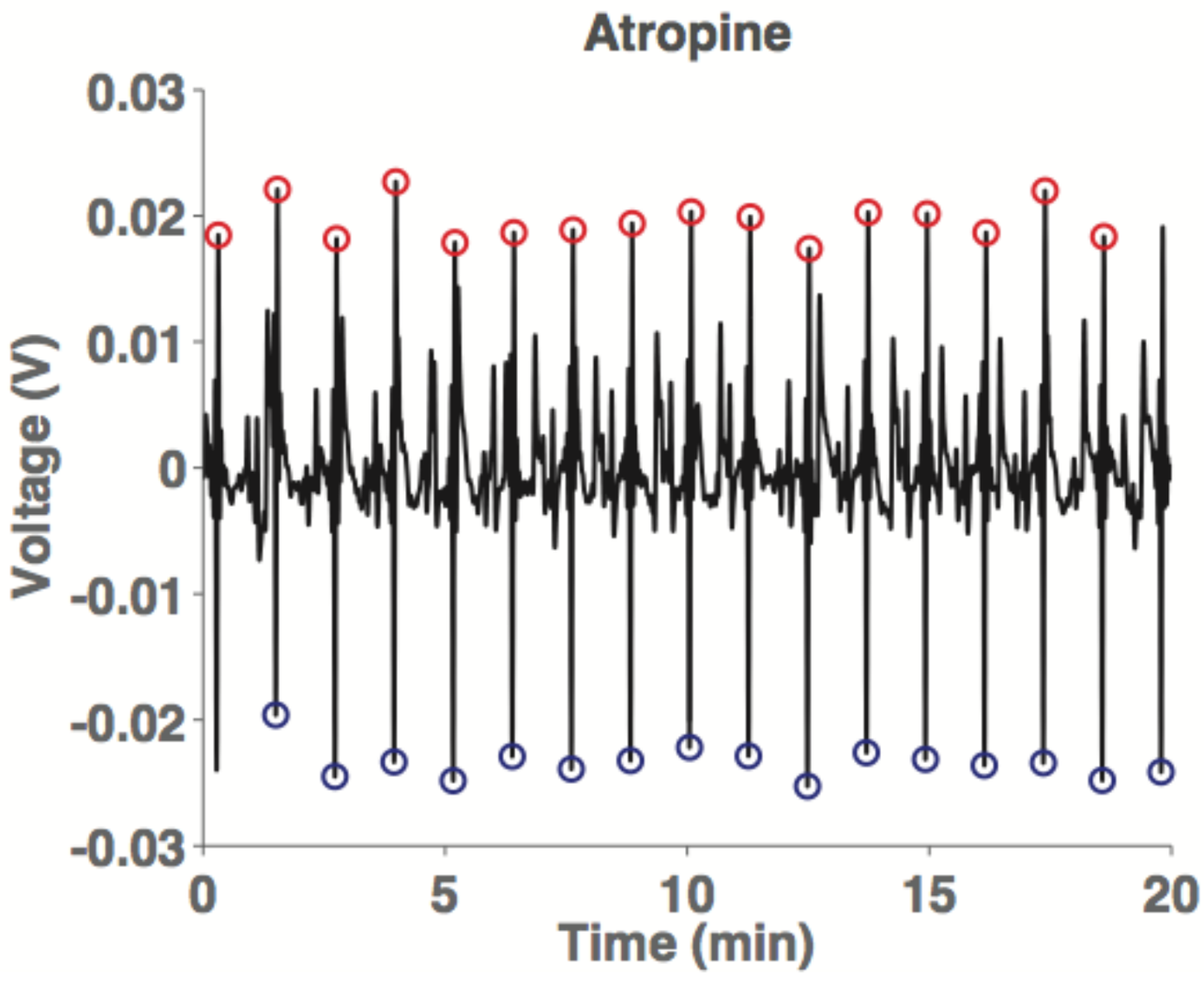


Image Processing

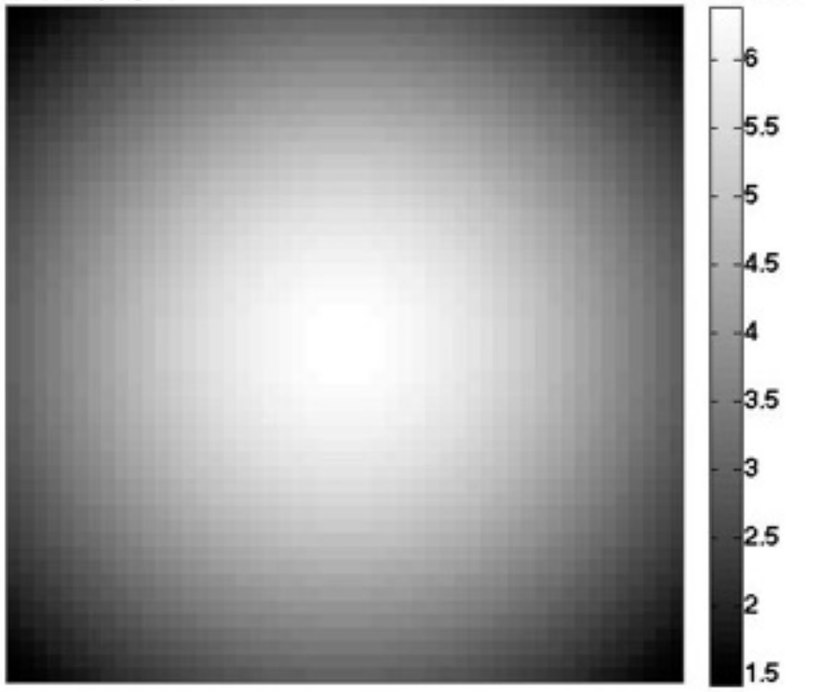
- Many image processing algorithms are 2D generalizations of signal processing algorithms
- Examples:
    1. (Gaussian blur = 2D convolution of filter coefficients with an image)
    2. Affine image registration - 2D cross correlation
- Play around with the NUMEROUS demos if you're interested in exploring image processing

Image Processing

image

*

filter



=

Image Processing

Loading/Displaying images:

`imread`

`imshow`

`rgb2gray`

Filtering images:

`imfilter`

`fspecial`

Demo:

Image Processing

Audio

Reading audio files:

```
[y, fs] = wavread('sound.wav');
% also see: audioread
% use wavwrite to save audio
```

Can import many other file types, like .mp3 using File Exchange importers.

Demo:

Audio