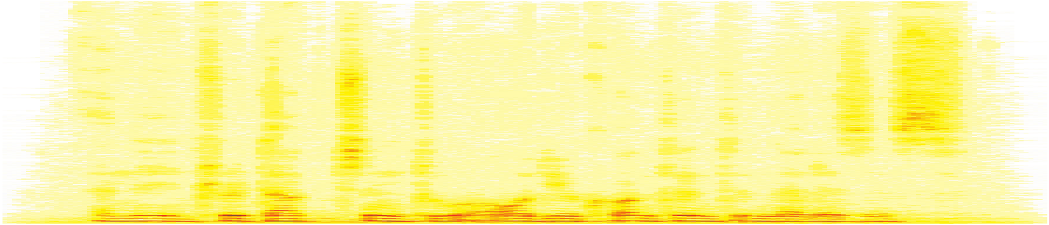
# Introduction to Audio Content Analysis

## Module 2.1: Fundamentals — Sampling

alexander lerch



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# introduction
## overview



**corresponding textbook section**

Chapter 2 — Fundamentals: pp. 9–11

- **lecture content**
  - discretization of signals in time
  - ambiguity and aliasing
  - sampling theorem
- **learning objectives**
  - summarize the principle of discretization
  - describe the implications of the sample theorem

# introduction

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# digital signals
## introduction

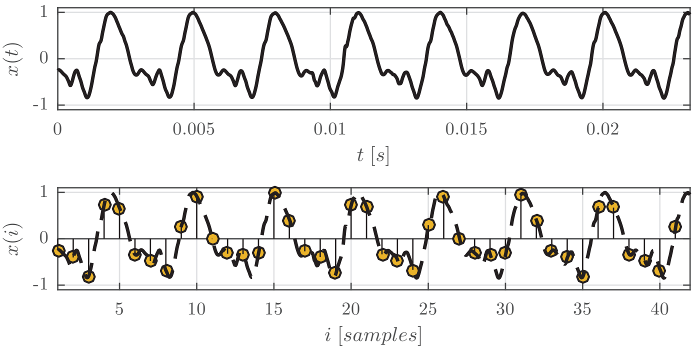
*digital* signals are represented with a limited number of values

$\Rightarrow$

1. **sampling**: time discretization
   continuous time $\mapsto$ discrete equidistant points in time
2. **quantization**: amplitude discretization
   continuous amplitude $\mapsto$ discrete, pre-defined, set of values

# sampling
## basic concept






matlab source: matlab/displaySampling01.m

- $f_S$ [Hz]: number of samples per second
- $T_S = {}^1/_{f_S}$ [s]: distance between two neighboring samples

# sampling
## sampling frequencies

**What are typical sample rates**

# sampling

## sampling frequencies



**What are typical sample rates**

- 8–16 kHz: speech (phone)
- 44.1–48 kHz: (consumer) audio/music
- $>$48 kHz: production audio

# sampling

## sampling frequencies



### What are typical sample rates

- 8–16 kHz: speech (phone)
- 44.1–48 kHz: (consumer) audio/music
- >48 kHz: production audio

| $f_S$ | 44.1 kHz | 32 kHz | 22.05 kHz | 16 kHz | 8 kHz | 6 kHz |
|---|---|---|---|---|---|---|

# sampling

## sampling ambiguity

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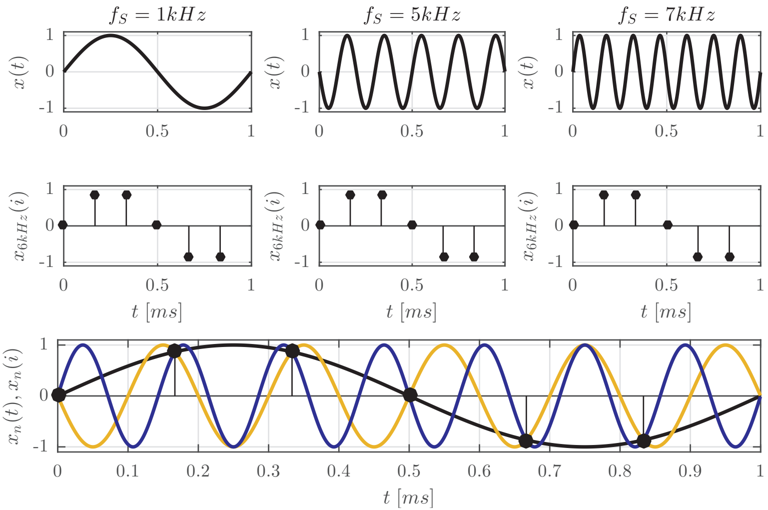
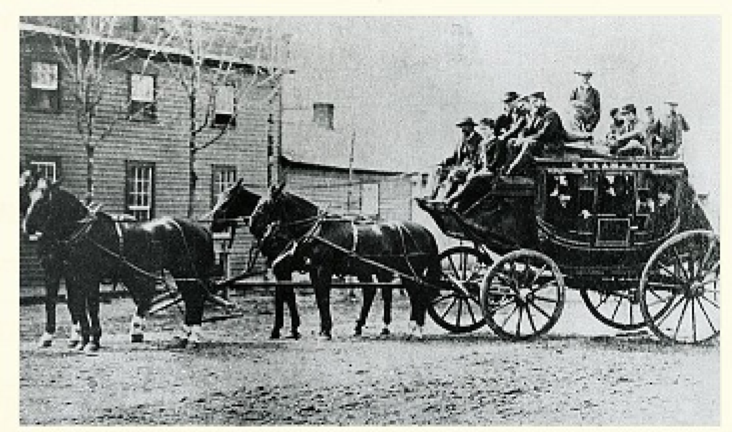



matlab source: matlab/displaySampling02.m

# sampling

## sampling ambiguity — wagon-wheel effect





flickr.com/photos/fotoguy49057/12209056184

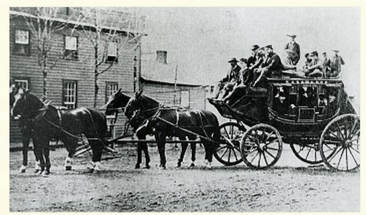
# sampling

## sampling ambiguity — wagon-wheel effect



compare speed of wheel (spokes) $f_{\mathrm{wheel}}$ between real world and video recording for an accelerating stage coach

1. $f_{\mathrm{wheel}} < \frac{f_S}{2}$
   speeding up
2. $\frac{f_S}{2} < f_{\mathrm{wheel}} < f_S$
   slowing down
3. $f_{\mathrm{wheel}} = f_S$:
   standing still
4. ...



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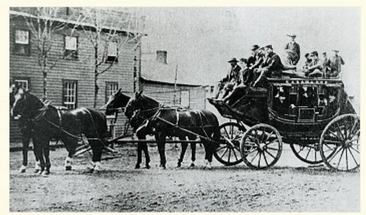

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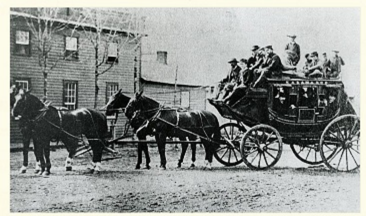

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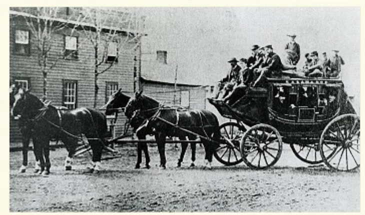

video example: youtu.be/QYYK4tICMIY

# digital signals

## sampling ambiguity — spectral domain

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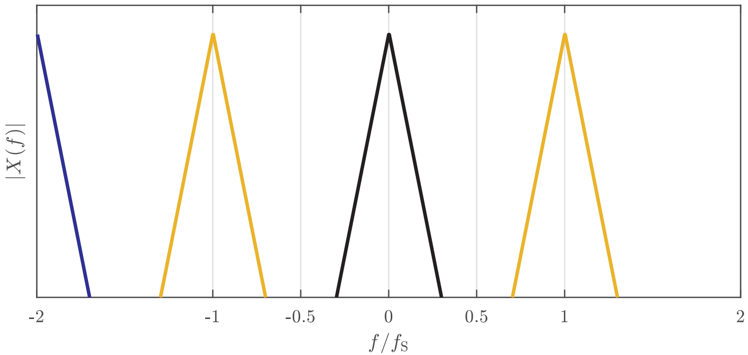


matlab source: matlab/animateSampling.m

# digital signals

## sampling theorem



### sampling theorem

A sampled signal can be reconstructed without loss of information if the sample rate $f_\mathrm{S}$ is higher than twice the bandwidth $f_\mathrm{max}$ of the original audio signal.

$$f_\mathrm{S} > 2 \cdot f_\mathrm{max}$$

$f_\mathrm{S}/2$ is also referred to as the *Nyquist*[1]-rate

[1] Harry Nyquist, 1889–1976

# summary

## lecture content

- a continuous signal is sampled to be **discrete in time**
  - number of samples per second is called sampling rate or sampling frequency
- **sampling theorem**
  - A sampled signal can be reconstructed without loss of information if the sample rate $f_S$ is higher than twice the bandwidth f max of the original audio signal.
  - if the sampling theorem is violated
    - reconstruction is ambiguous
    - aliasing occurs