Question of the Day

Your roommate is in the hospital after breaking his arm. Like the good friend that you are, you go check on him every 24 hours, at the same time.

Every time you're there, he's dead asleep.

What's wrong with him?

Time Series, Digitization & Sampling

Lecture 3
July 3, 2019

Course Outline: Road Map

Electrophysiological Data Analyses

"Field Potentials" (Time-Series)

"Spikes" (Point Process)

L **Math**

- Linear Algebra
- Complex Numbers

L **Coding**

Git & Python
numpy
scipy

Communication

- Reading Scientific Papers
- Visualization & Writing

Time-Series Analyses (3-11)

- 3 Sampling
- 4 Time-locked Analysis
- 5 Convolution
- 6 Fourier Analysis
- 7 Time-Frequency Analysis
- 8 Filtering
- 9-10 Hilbert
- 11 Nonlinear Techniques

2* **Brain Physiology**

Spike Analyses (12-14)

- 12 Spike-LFP Analysis
- 13 Spike-Train Models
- 14 Population Coding Models

15-16 **Other Modalities & Techniques**

- (f)MRI
- Single-cell Imaging

Goals for Today

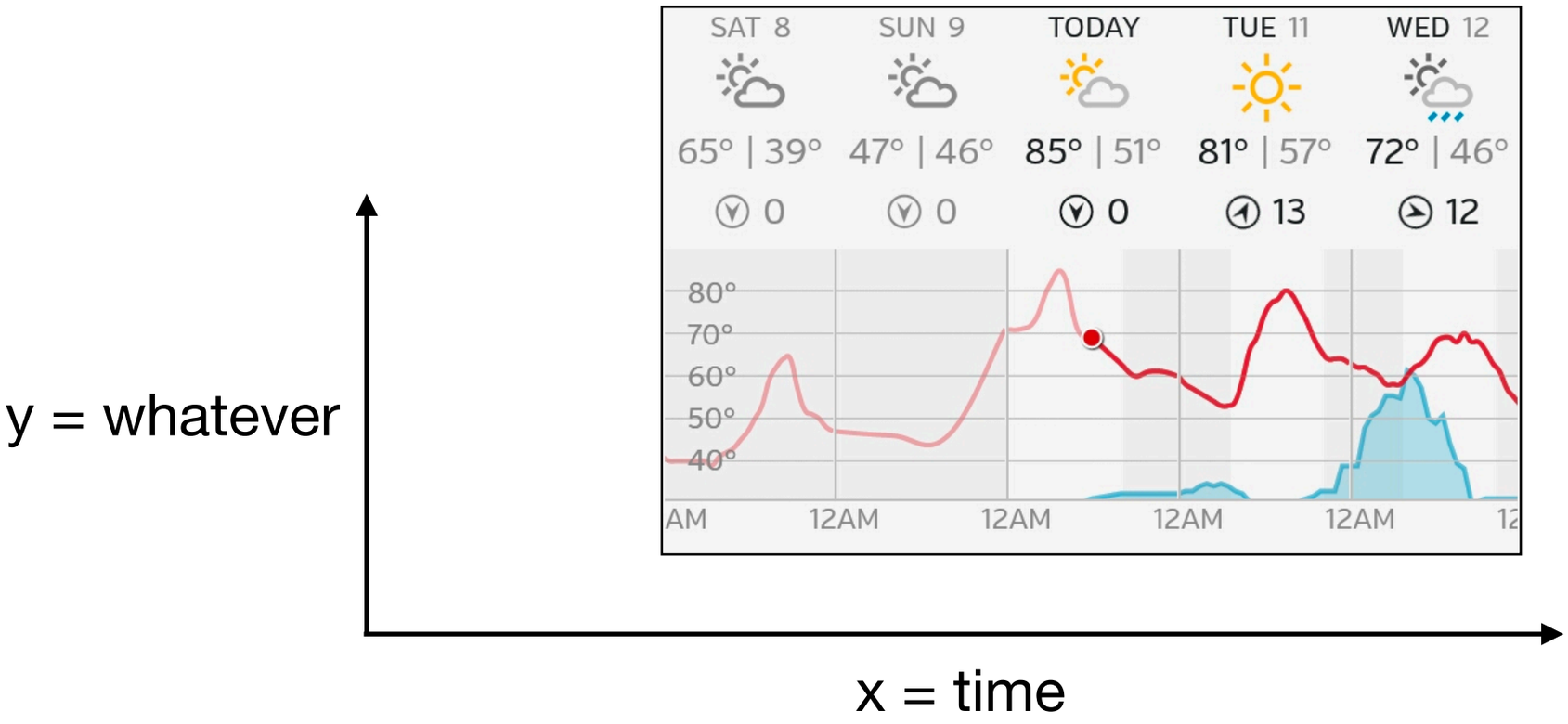
1. Conceptualize time series

2. Analog-to-digital conversion: understand digitization & sampling

3. Motivate Nyquist sampling theorem

Time Series

Time Series: measurements recorded over time.



Get into your groups…

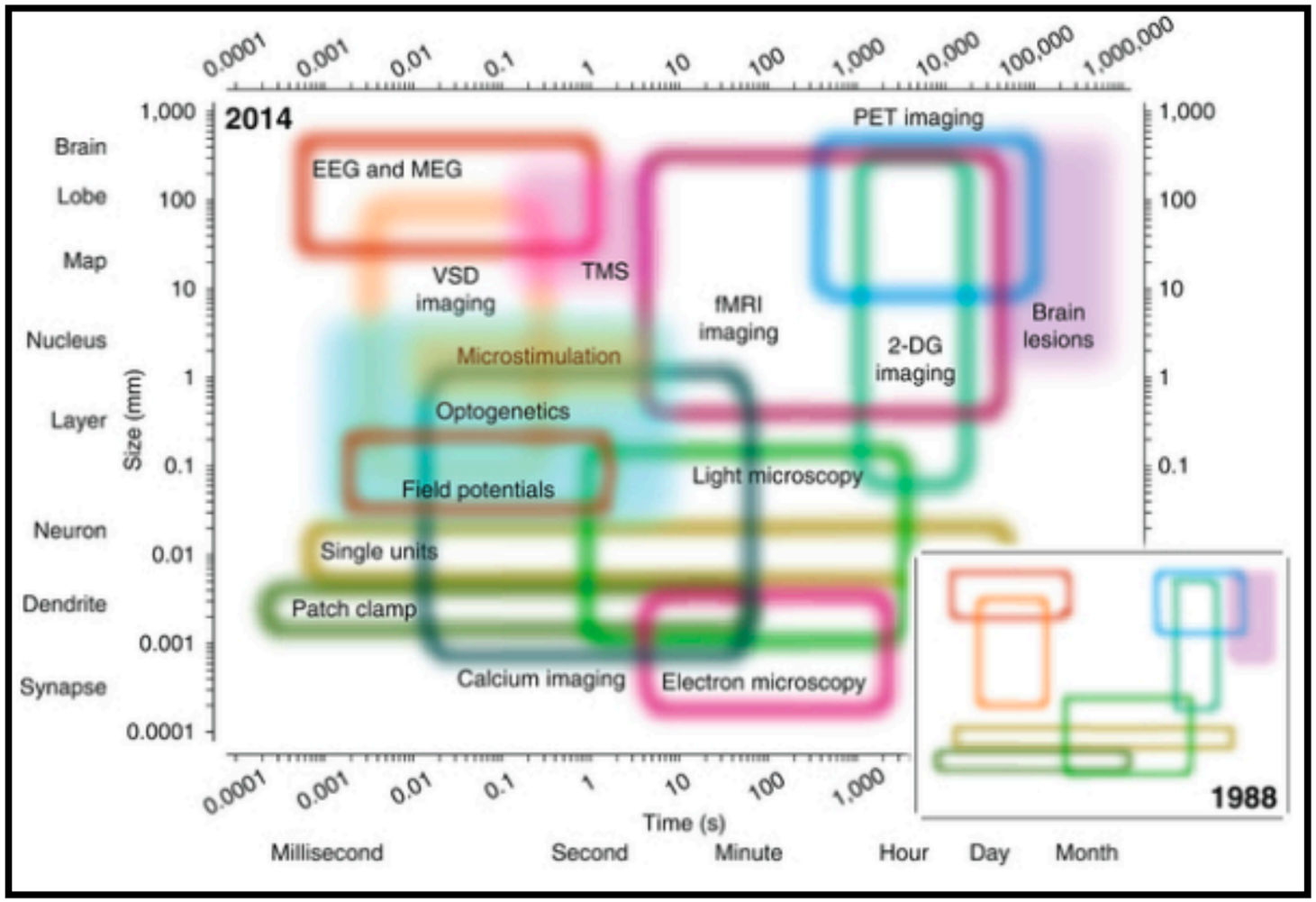
In 1 minute, write down as many time series measurements as you can think of.

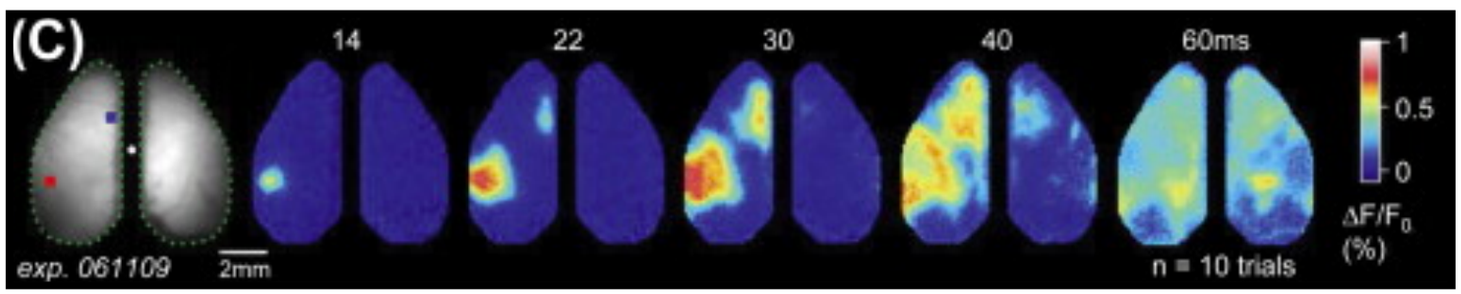
Time Series

Time Series: measurements recorded over time.

Examples:

Neural Time Series





Electrophysiology:
> voltage [V(t)]
> currents (ion exchange)
> **MEG**: magnetic fields

Optical Imaging: (luminance)
Concentration of something
> Calcium
> Non-specific charges (voltage sensitive dye)

Medical Imaging:
> fMRI: magnetic spin
> PET: radiation (positron)

Know what physical quantity each modality is measuring.

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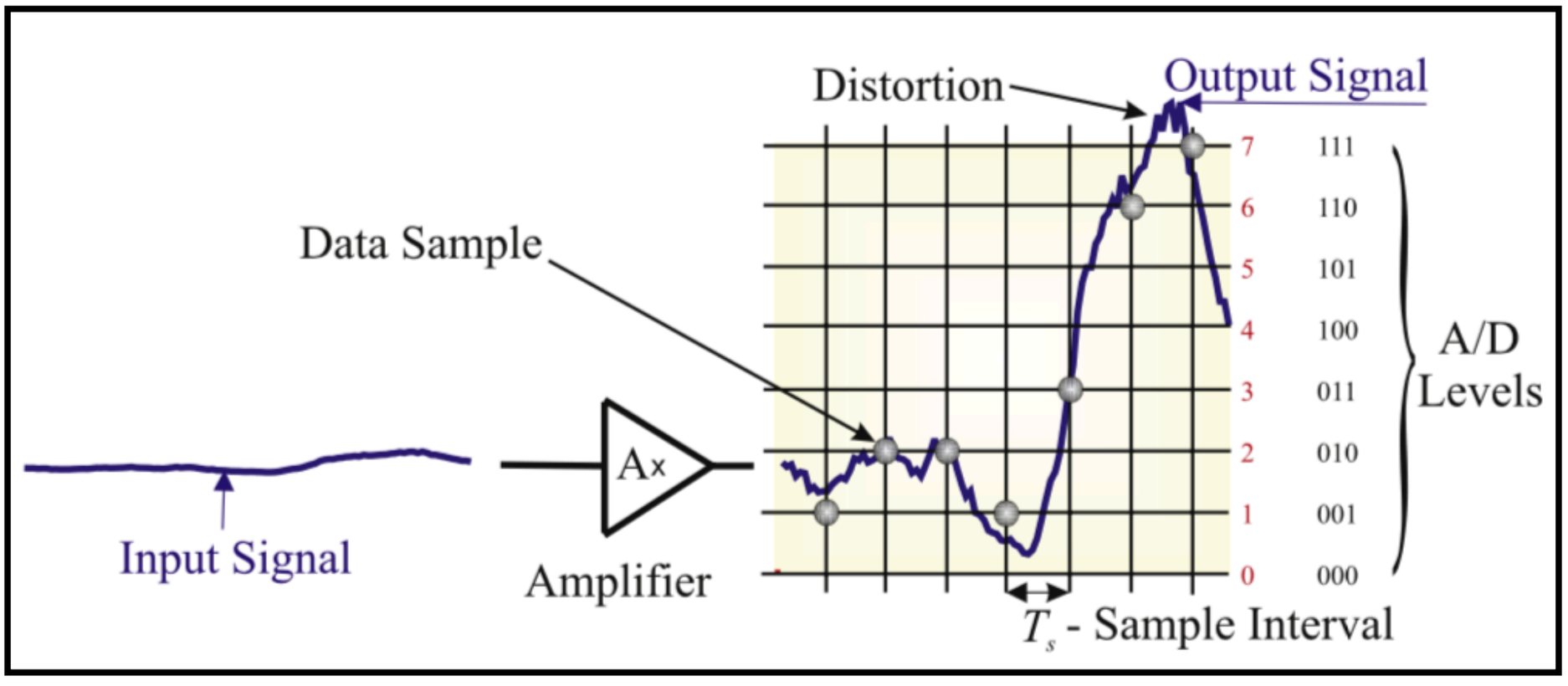
Analog to Digital Conversion

ADC: converting continuous (analog) signals to digital (discrete) signals…

in both value (**digitization / quantization**) and time (**sampling**).



Like drawing a grid over a continuous line (WvD Fig 1.6)

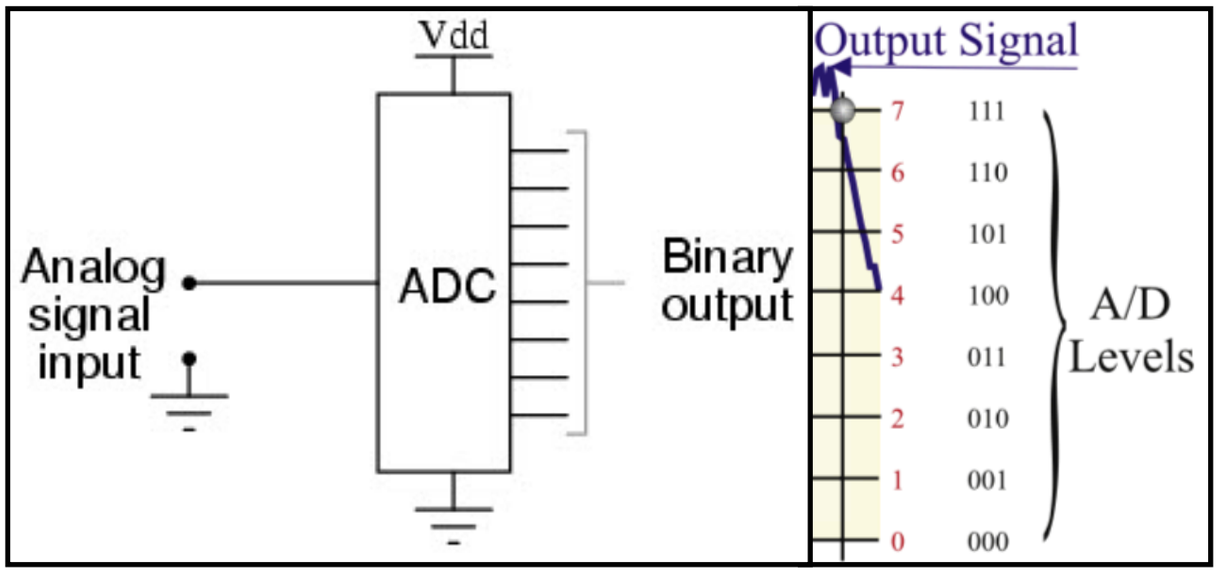
Digitization: Levels & Range

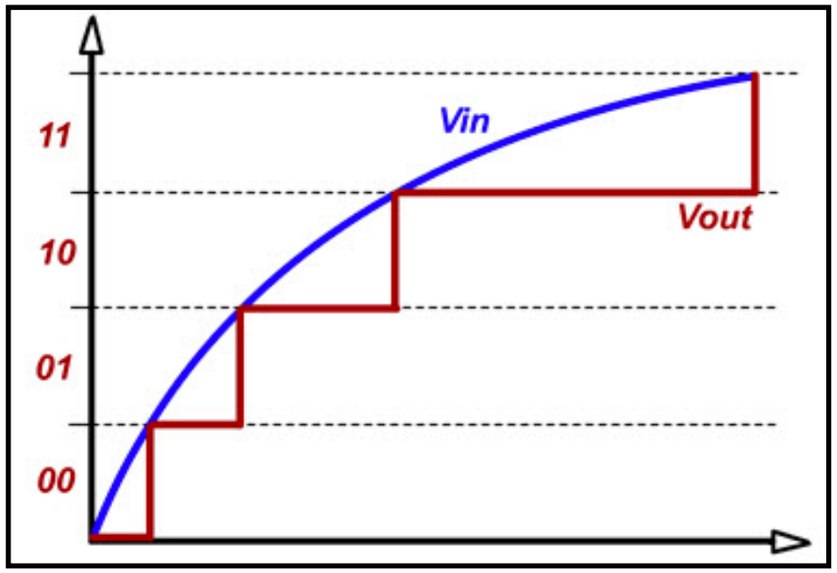
Digitization is essentially rounding (or sifting), and you need to know 2 things:

- **# of levels (and bits)**
- **range of your device**

Digitization: Bits

All modern computers operate with binary transistors.





8-bits = 8 binary slots
[0 0 0 1 0 1 0 1 0]

How many values can an 8-bit number represent?

2^8 = 256 (2 to the 8th power)

In general:
# of levels for n-bit ADC = 2^n

Digitization: Range & Resolution

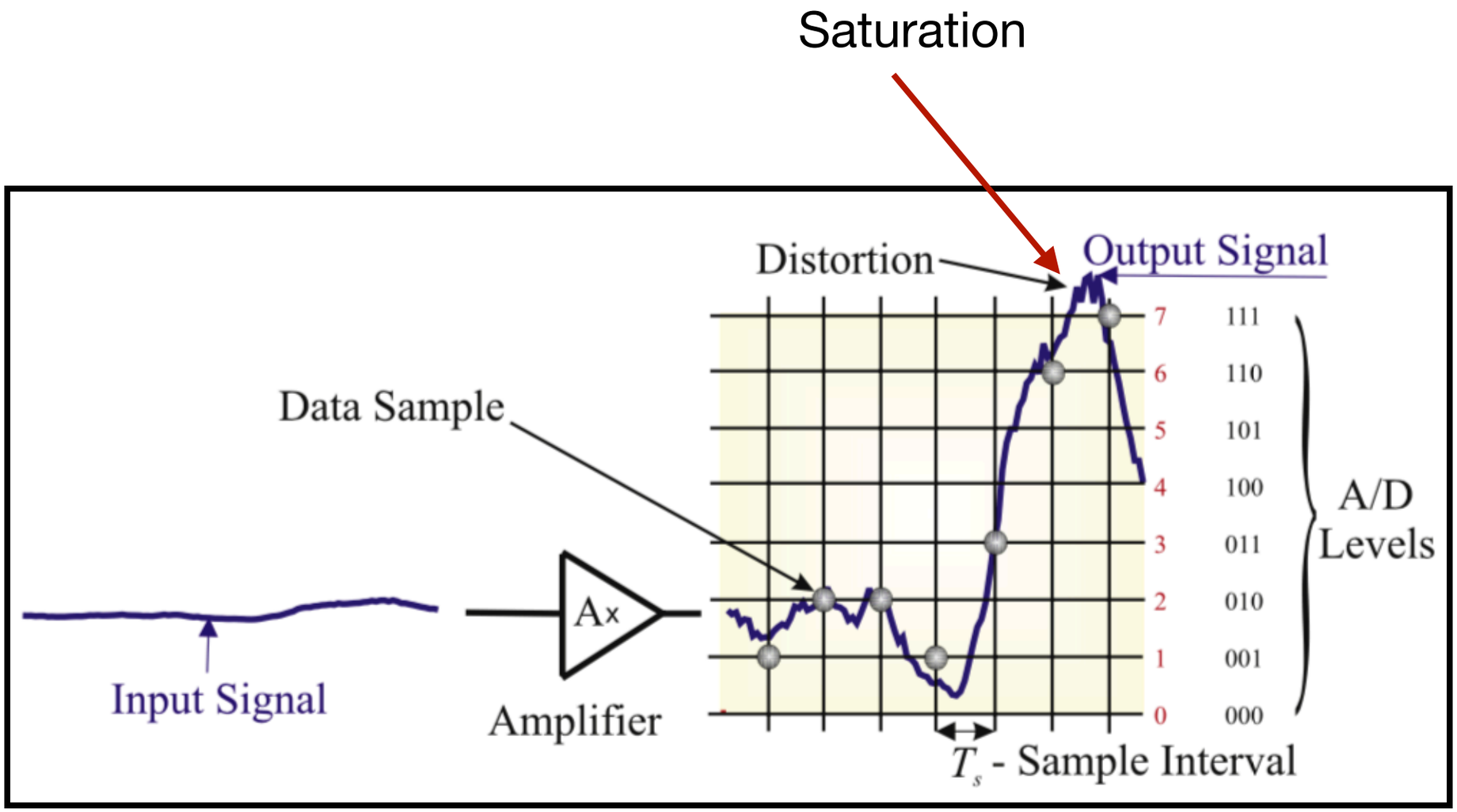
How should we best divide our levels?

	0,0,0,0	**0,0,0,1**	**0,0,1,0**
Use 4 bits to represent 0 to 1V	0	0.0625	0.125
Use 4 bits to represent 0 to 4V	0	0.25	0.5
Use 4 bits to represent 0 to 16V	0	1	2

Resolution

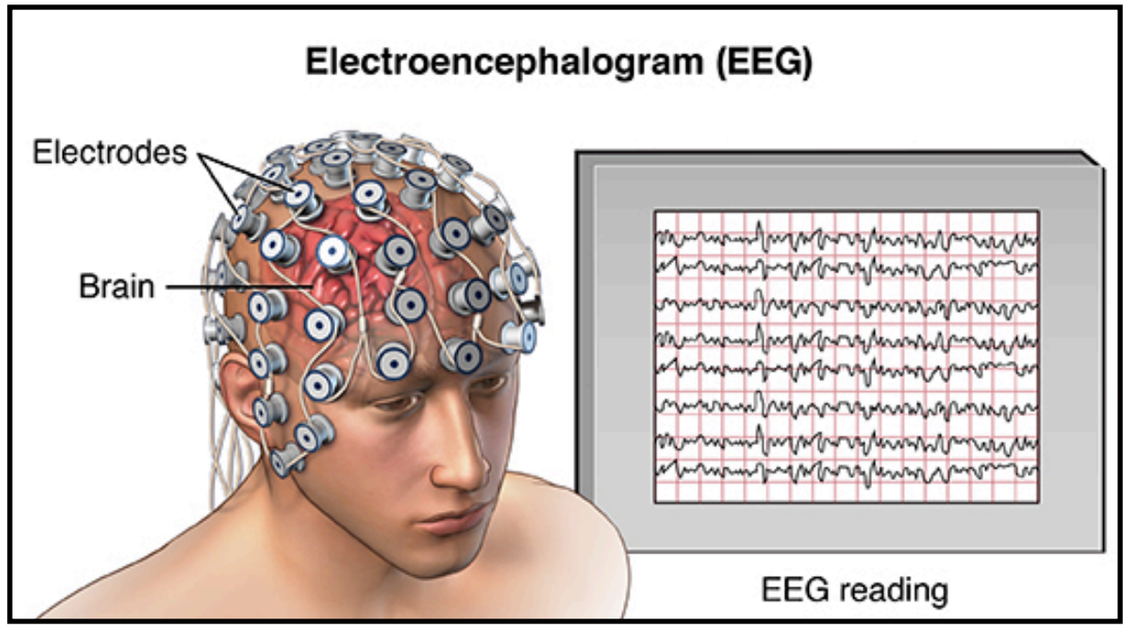
$$\text{Resolution} = \frac{range}{2^{\#\ of\ bits}}$$

Digitization: Saturation



This is **bad**: anything outside the range will flatline; so we need to readjust our “gain” or resolution.

Digitization: Example Question



Your lab wants to record human EEG.

You have an 8-bit ADC, and want to capture fluctuations on the order 0.1 of microvolts (uV).

What is the range of signal you can capture?

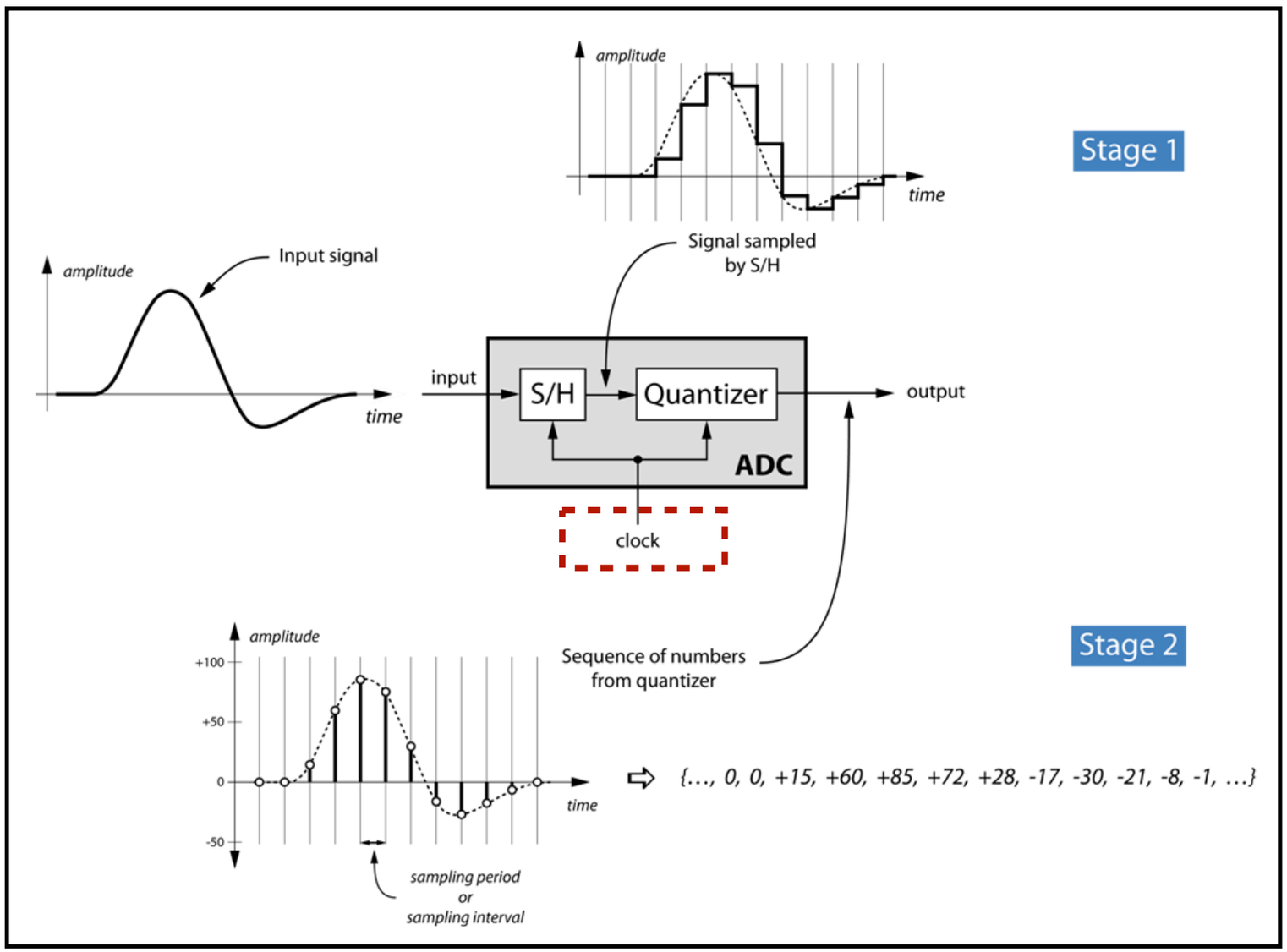
Is this good enough?

Digitization Diversion: 8-bit Music

Digital Audio: the real meaning of 8-bit music

Harmonia Acústica Follow
Jun 26, 2018 · 5 min read

Sampling (in Time)



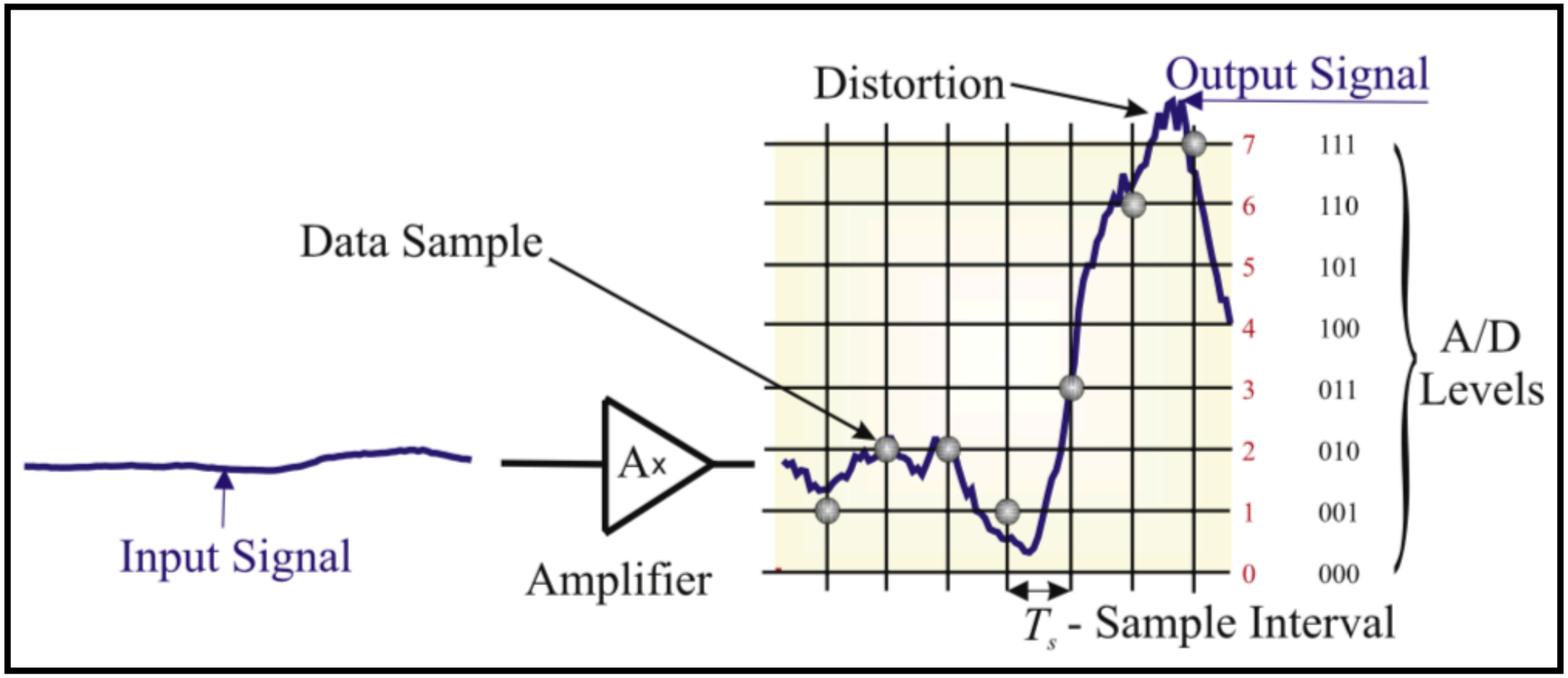
Similar to digitization, though you can sample forever:

no range restriction

only resolution considerations.

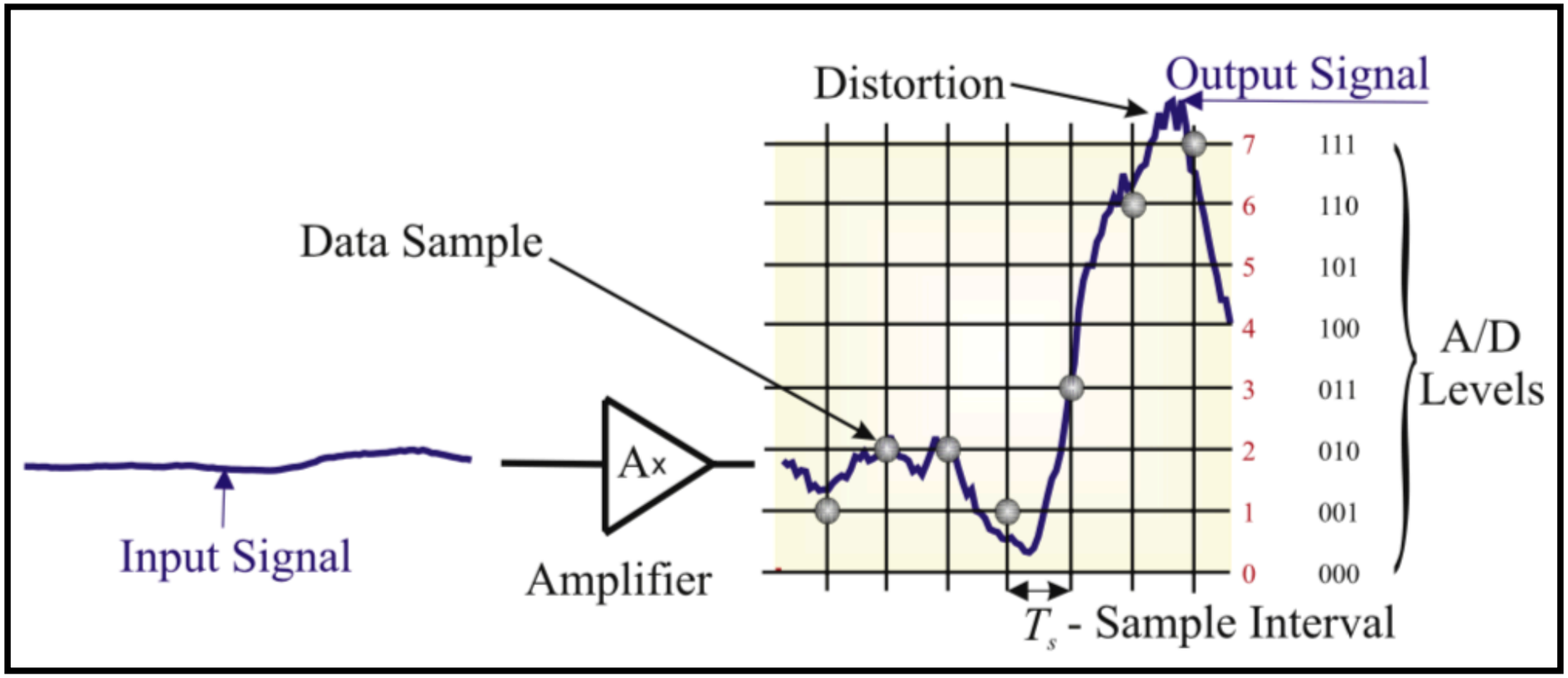
ADC Clock: imagine a metronome clicking.
Every time it clicks, you jot down the value of the signal.

Sampling Frequency (Rate)



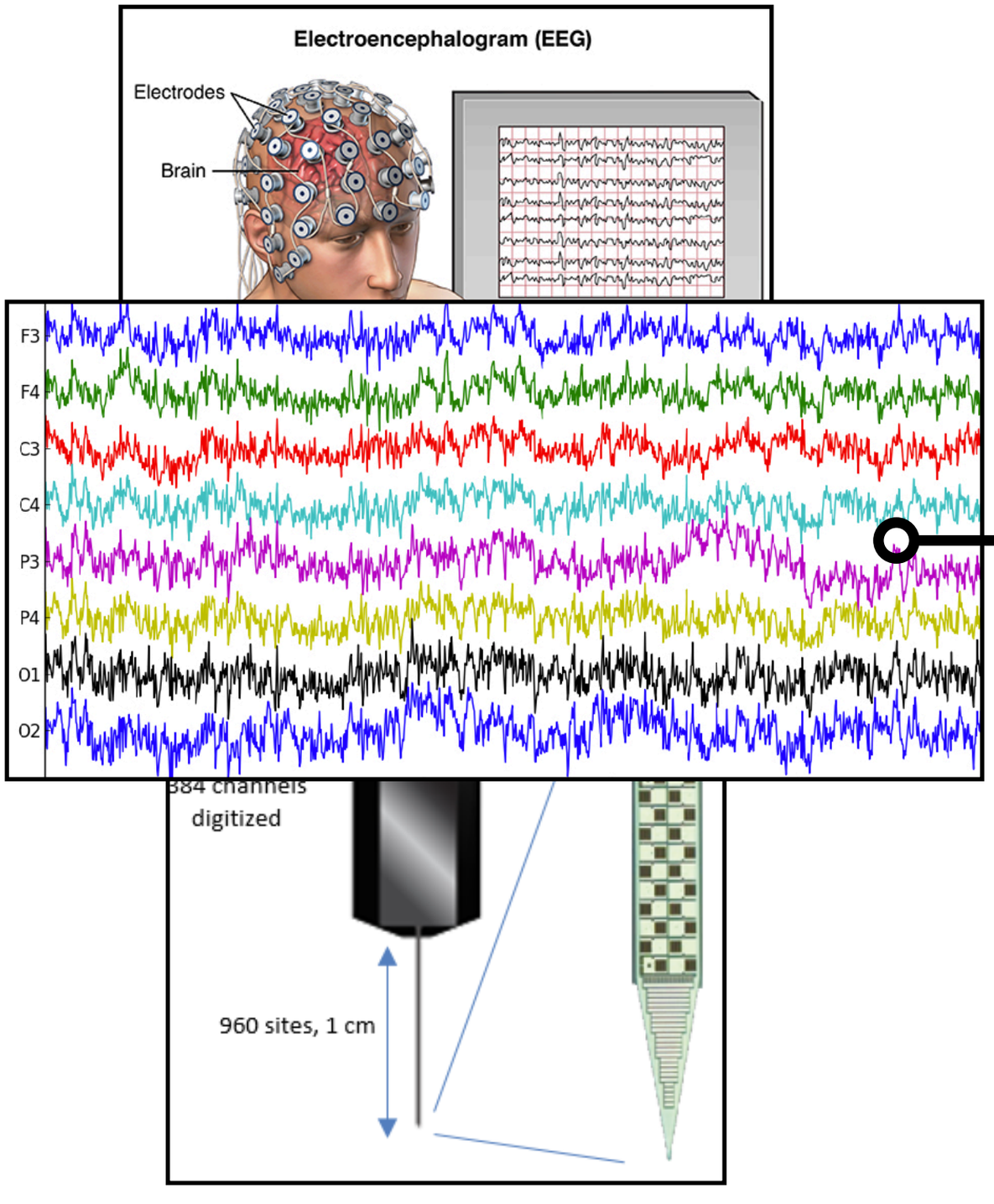
Sampling Frequency/Rate (f_s): number of times per second a signal is recorded, measured in Hz (=1/second).

Sampling Frequency (Rate)



What is the relationship between **sampling rate** (unit in Hz) and **sampling period (or interval**, unit in seconds**)**?

Digitized Multi-Channel Data: Matrix



time

channel

$$\begin{bmatrix} a_{1,1} & a_{1,2} & \dots \\ a_{2,1} & a_{2,2} & \\ a_{3,1} & a_{3,2} & \\ \dots & & \end{bmatrix}$$

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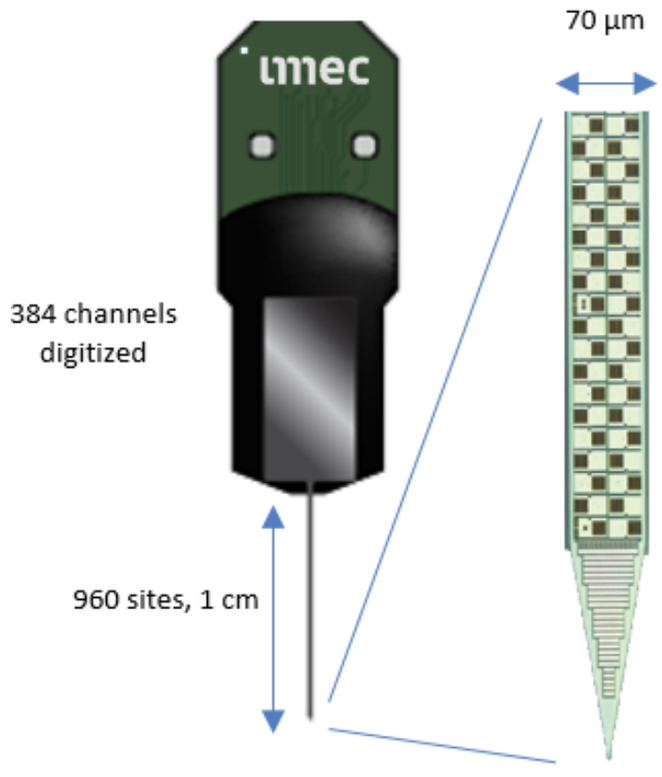
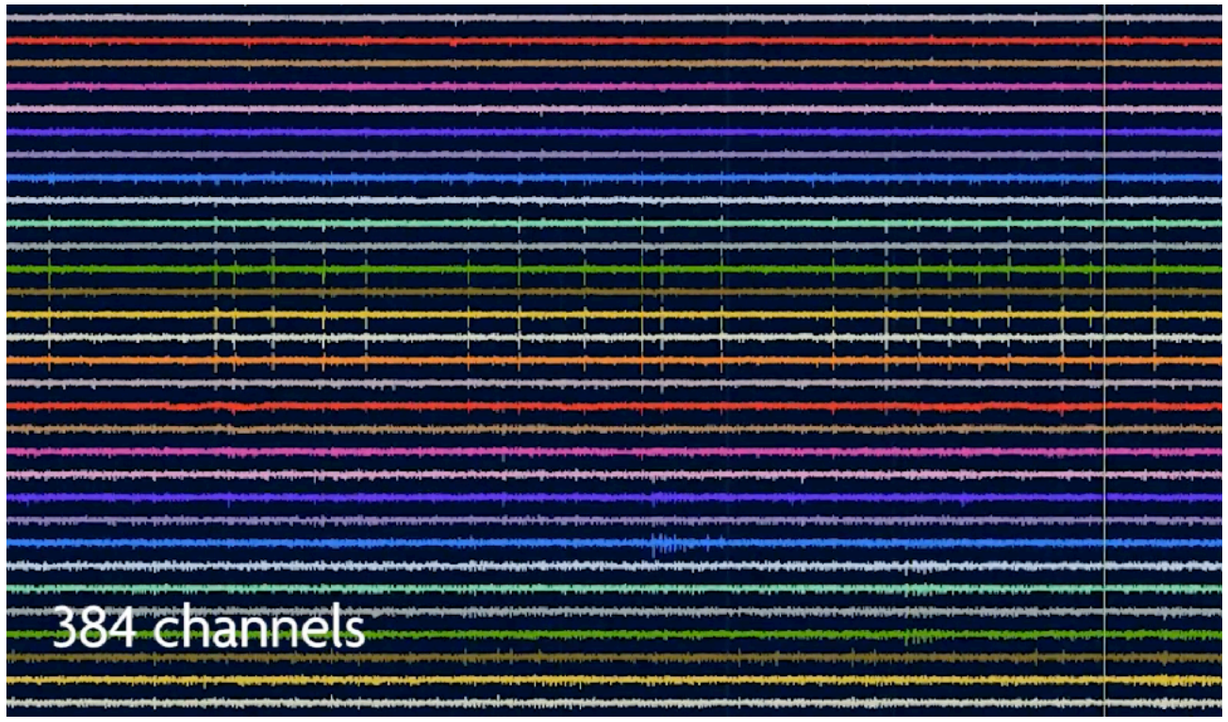
Real Life Neuroscience Example

"Neuropixel Probe"
for animal experiments





Let's do the math:

1 **"double-precision float"** sample = 64 bits

384 simultaneous channels

10,000Hz sampling rate

10 minute experiment

How big is your data file (in GBs)?

How Fast Should We Sample?

As fast as possible … but as cheaply as possible.

i.e., as **efficiently** as possible.

Fast sampling = better signal fidelity

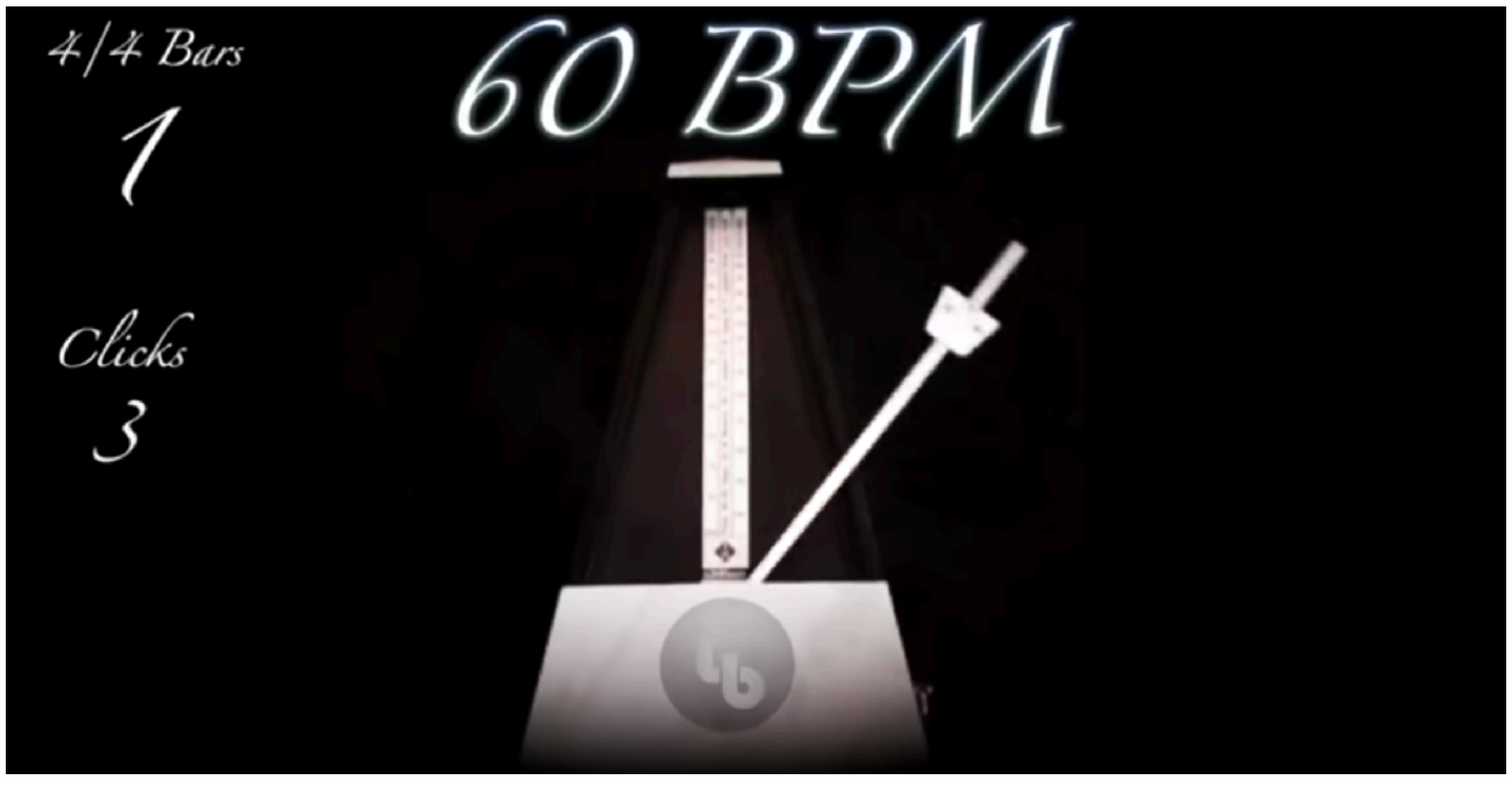
Slow sampling = less data storage

→ ???

1 & 5 min (TPS): Discuss with your partner an optimal strategy for this decision.
What are the important factors to consider?
Useful to think of real life examples.

How Fast Should We Sample?

Answer: it depends on your data / the process you're trying to measure.



Intuition: close your eyes, open and close them really quickly when it clicks.

How Fast Should We Sample?

Squig Rattlehead 4 years ago

That's because it's russia. In soviet russia, rotors don't spin. The pilot does.

189 REPLY

View 9 replies

How Fast Should We Sample?

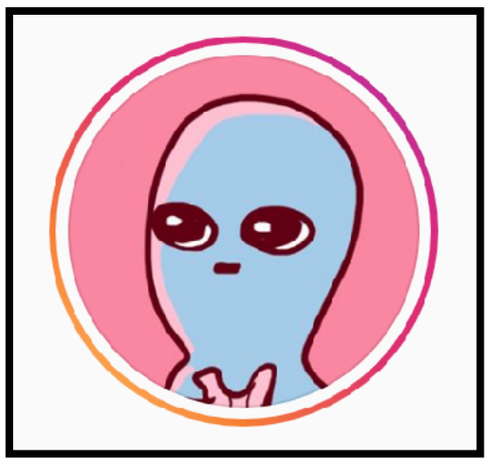
The helicopter blades spin at a certain frequency, and the video camera samples images at another frequency.

Under what condition(s) would this happen?

How Fast Should We Sample?

Answer: it depends on your data / the process you're trying to measure.

If the **periodic** process you're trying to measure changes really fast, you have to measure faster for a "accurate representation" of the phenomenon.



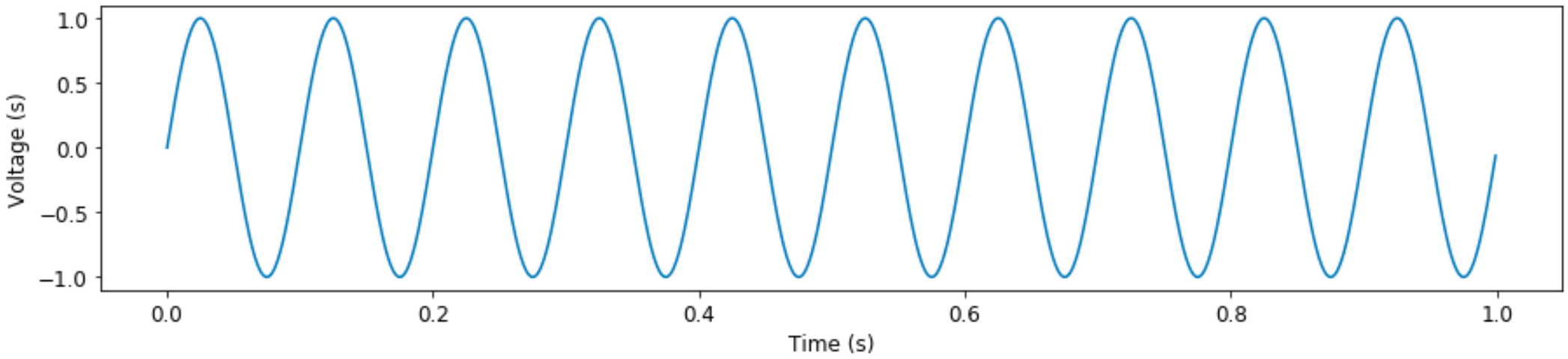
Let's say you are an alien on Earth, you can't "see" light, and want to measure the daily light cycle (sunrise to sunset).

What should be your **minimum** sampling rate (or sample interval)?

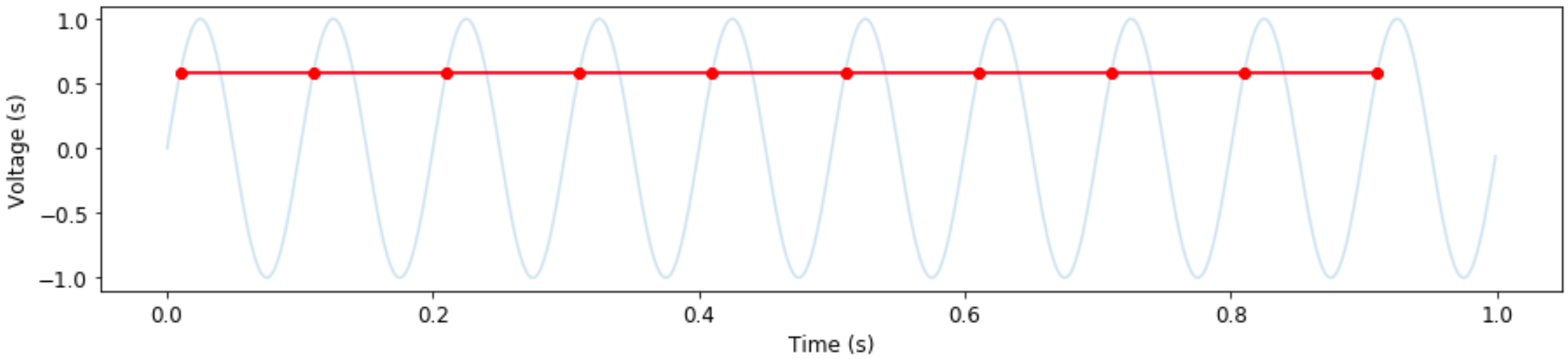
Answer: **at least** twice per day / once every 12 hours.

Nyquist Sampling Theorem

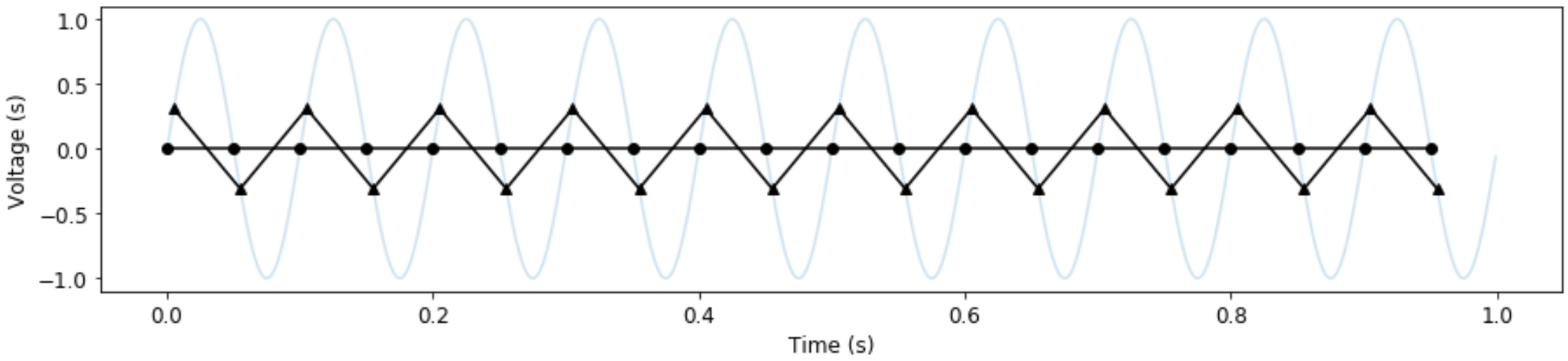
True Signal 10Hz



Sampled @ 10Hz



Sampled @ 20Hz



Nyquist Sampling Theorem

To accurately represent a periodic signal/process with an intrinsic frequency B, you have to sample **at least** twice as fast,

i.e., fs > 2B

This sampling rate is known as the **Nyquist rate**.

But what about non-periodic processes?

Teaser: all signals can be represented as periodic signals.

Summary

1. Conceptualize time series
2. Analog-to-digital conversion: understand digitization & sampling
3. Motivate Nyquist sampling theorem

https://tinyurl.com/cogs118c-att