COM303: Digital Signal Processing

Lecture 1: Introduction to Signal Processing

Module Overview:

- practical information
- signal processing: history and philosophy
- transoceanic signal transmission

Course webpage

http://com303.learndsp.org/

No paper handouts, go to the website for:

- syllabus
- weekly announcements
- weekly homework
- handouts, extra chapters, slides
- login with your SCIPER number, email me if access doesn't work

https://www.coursera.org/learn/dsp/

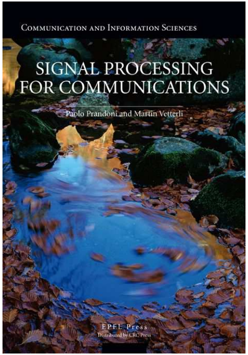
- all lectures available on video
- auto-graded exercises
- forum
- more than 120K students worldwide

2019 Schedule

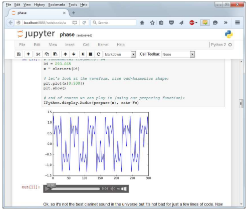
- lectures:
  - Mondays 2pm-4pm, INF1
  - Tuesdays 10am-12pm, CE2
- exercise sessions:
  - Thursdays 2pm-4pm, INM201
  - details on the website

Course Material

- Textbook: *Signal Processing for Communications*, EPFL Press, 2008, by P. Prandoni and M. Vetterli. Paper version available at PPUR, Amazon.
- Free PDF and HTML versions available online: `http://www.sp4comm.org/`
- Weekly homework sets
- Occasional handouts
- Jupyter notebooks in Python



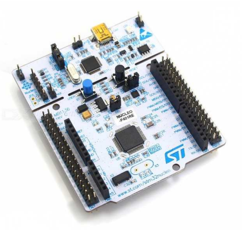
- It's important to implement what we learn to get a good feeling for what DSP can do
- We will be using Python:
  - real programming language
  - great numerical libraries (numpy, matplotlib)
  - **Jupyter notebooks!!**
- if in doubt: just download and install Anaconda



ANACONDA

Applied Signal Processing II: hardware lab

- five optional applied DSP labs
- get a feeling for what it's like to implement DSP algorithms on "real" hardware
- we will be using the ST Nucleo board
- Adrien Hoffet will be your guide



How to pass this class

- Lectures:
  - communication should be two-way
  - ask questions!
- Exercise sessions:
  - go to the exercise sessions but **do the exercises first!**
  - tell us what you want to see explained
  - come to office hours
- Exam:
  - exam is not necessarily hard but cannot be done with pattern matching
  - learn to “think” and solve problems like an engineer!

Grading

- final exam only (perfect final $= 6$)
- mock midterm on April 16
- homework is not graded

A Word to the Wise

- download the math self-test from the website
- do the test on your own and without the internet!
- review the topics in which you don't feel confident, you'll be happy you did

Questions?

(digital) signal processing for communications

Signal

Description of the evolution of a physical phenomenon

- temperature (weather)
- pressure (sound)
- magnetic deviation (recorded sound)
- gray level on paper (photograph)
- ...

Signal

Description of the evolution of a physical phenomenon

- temperature (weather)
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- gray level on paper (photograph)
- ...

Processing

Analysis: *understanding* the information carried by the signal

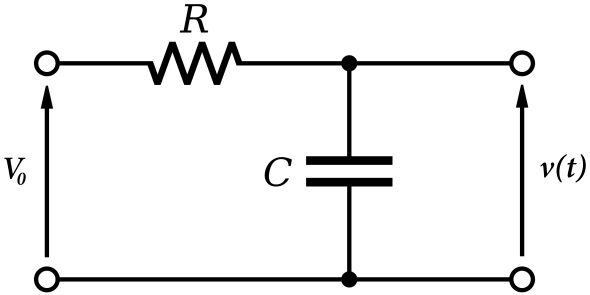
Synthesis: *creating* a signal to contain the given information

Reception: *analysis* of an incoming signal

Transmission: *syntesis* of an outgoing signal

Signal Models

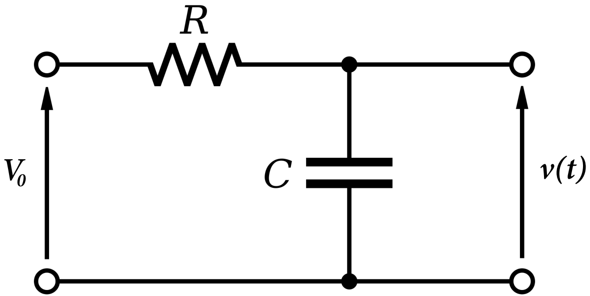
Description of the evolution of a physical phenomenon



$$v(t) = V_0(1 - e^{-\frac{t}{RC}})$$

Signal Models

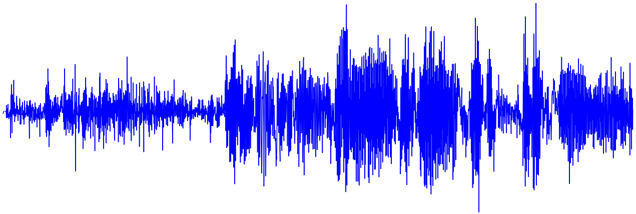
$$f : \mathbb{R} \to \mathbb{R}$$



$$v(t) = V_0(1 - e^{-\frac{t}{RC}})$$

only 2 degrees of freedom: R, C

What about "interesting" signals?



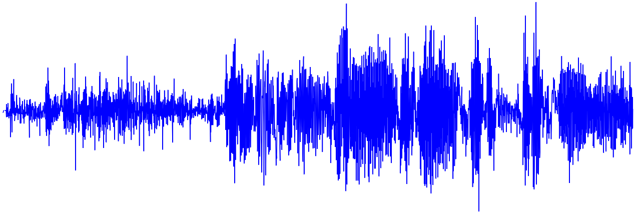
$$f(t) = ?$$

The Digital Model

Key ingredients:

- discrete time
- discrete amplitude

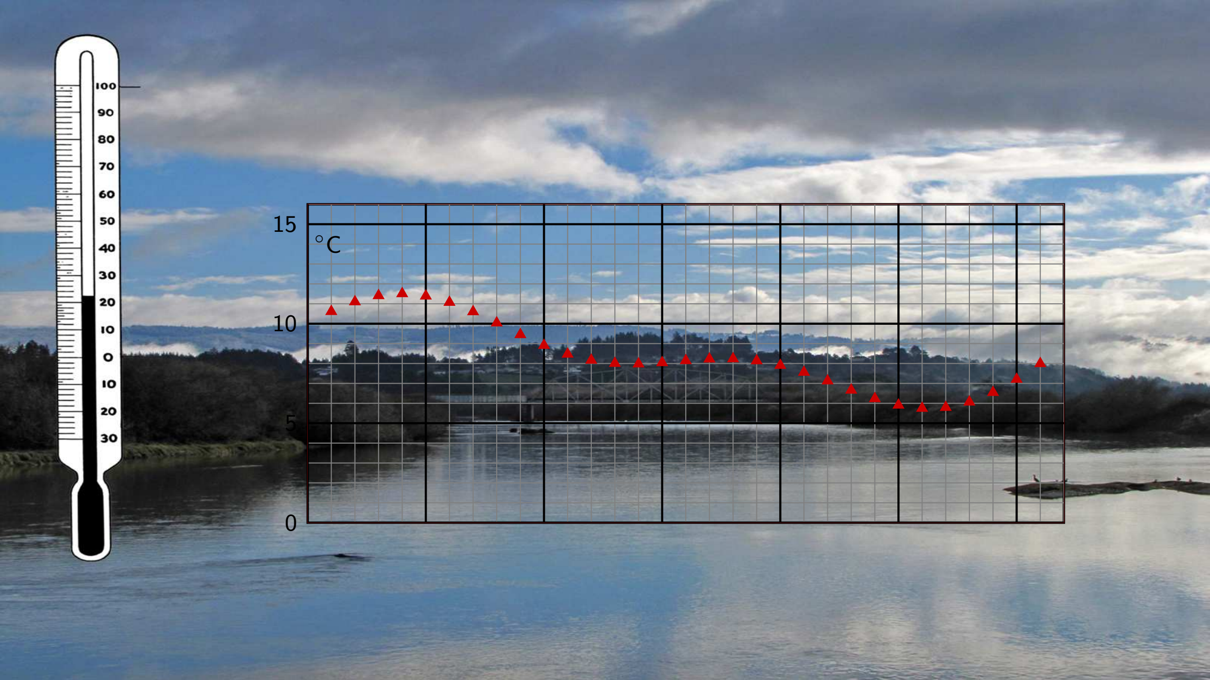
From analog...



... to digital

```
...  74 31 -66 9 -123 33 159 -26 102 148 86
-136 -179 70 72 -84 -113 -42 -88 88 8 -180 -7
-133 8 164 -4 108 35 -82 74 -49 52 32 -31 ...
```


100
90
80
70
60
50
40
30
20
10
0
10
20
30



100
90
80
70
60
50
40
30
20
10
0
10
20
30
15
10
5
0
°C

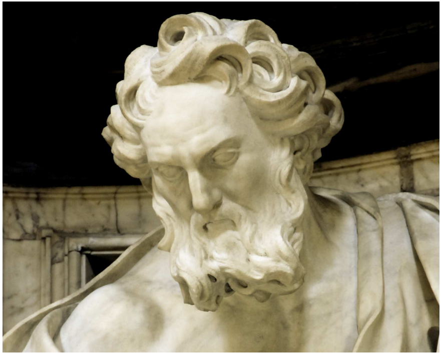
Discretizing Time

What is time?

What is time?

Immanuel Kant

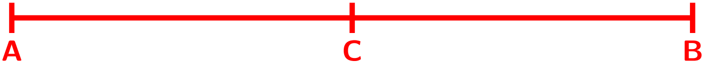
A very old phylosophical problem



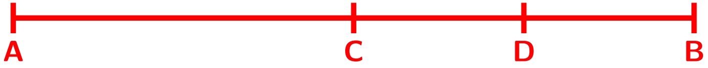
Zeno of Elea

The Dichotomy Paradox

The Dichotomy Paradox



The Dichotomy Paradox



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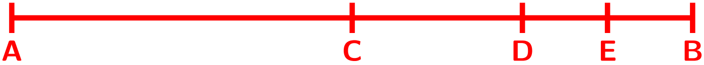
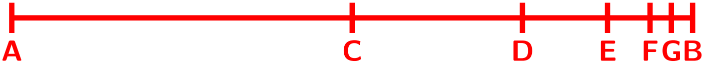
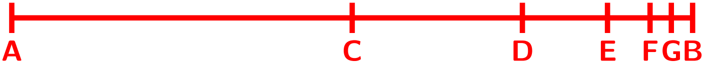


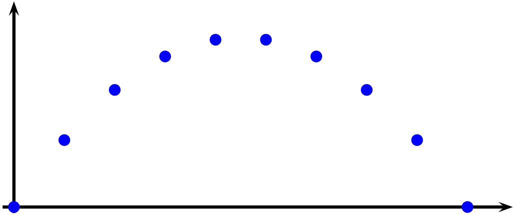
The Dichotomy Paradox



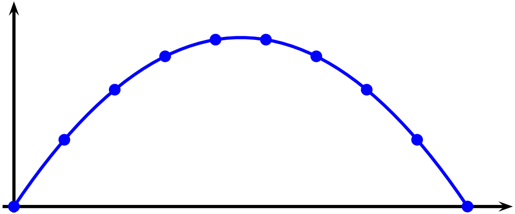
The Dichotomy Paradox



$$\sum_{n=1}^{\infty} \frac{1}{2^n} = 1$$



$$\vec{x}(t) = \vec{v}_0 t + (1/2)\vec{g}\, t^2$$



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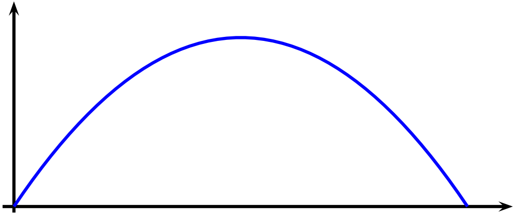


$$\vec{x}(t) = \vec{v}_0 t + (1/2)\vec{g}\, t^2$$

The Discrete-Time Model

$$x : \mathbb{R} \to \mathbb{V}$$

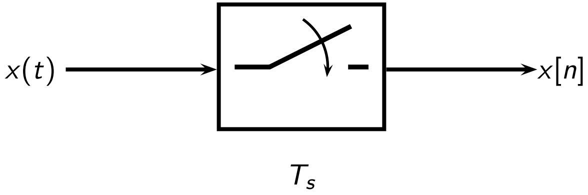
The Discrete-Time Model

$$\cancel{f : \mathbb{R} \to \mathbb{V}}$$

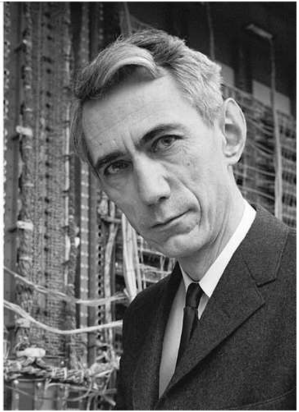
$$x : \mathbb{Z} \to \mathbb{V}$$

$$x[n] = \ldots, 1.2390, -0.7372, 0.8987, 0.1798, -1.1501, -0.2642 \ldots$$

Are we losing information?



Translating between languages: the founding fathers

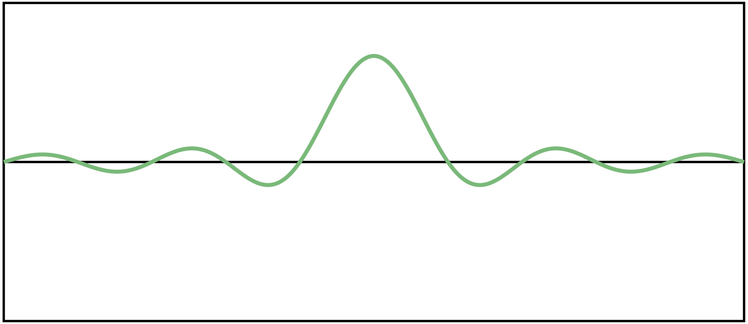


The Sampling Theorem (1920)

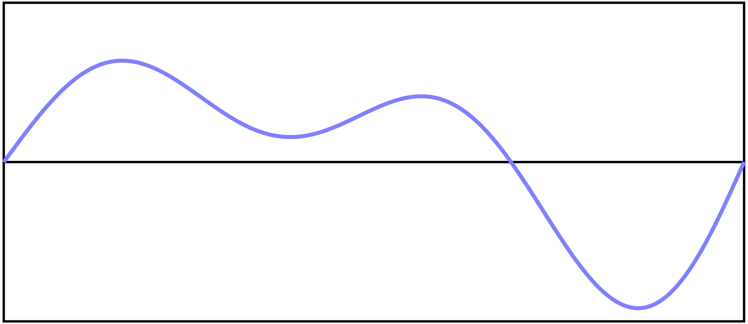
Under appropriate "slowness" conditions for $x(t)$ we have:

$$x(t) = \sum_{n=-\infty}^{\infty} x[n] \operatorname{sinc}\left(\frac{t - nT_s}{T_s}\right)$$

The sinc function

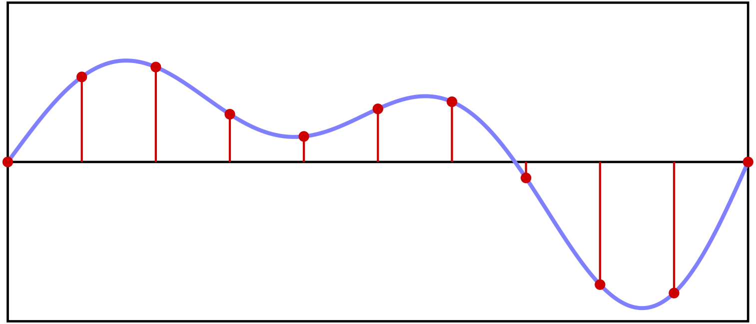


From continuous to discrete time and back!



$x(t)$

From continuous to discrete time and back!



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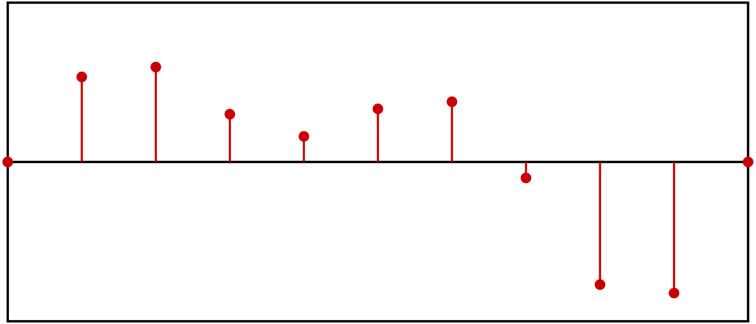
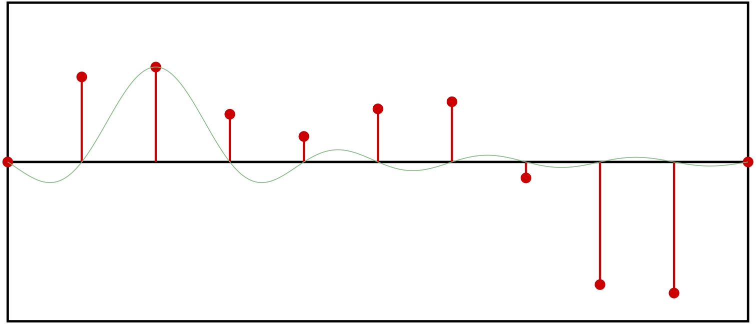


$x[n]$

From continuous to discrete time and back!



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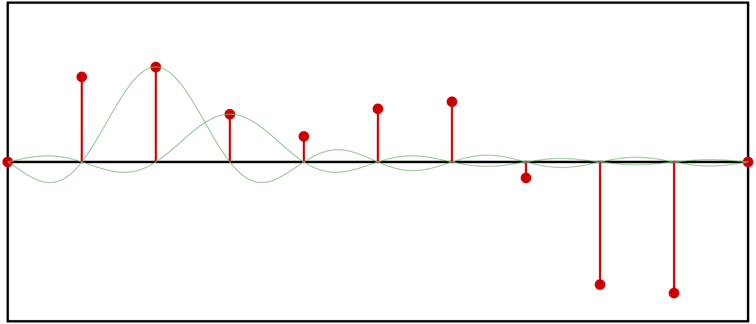

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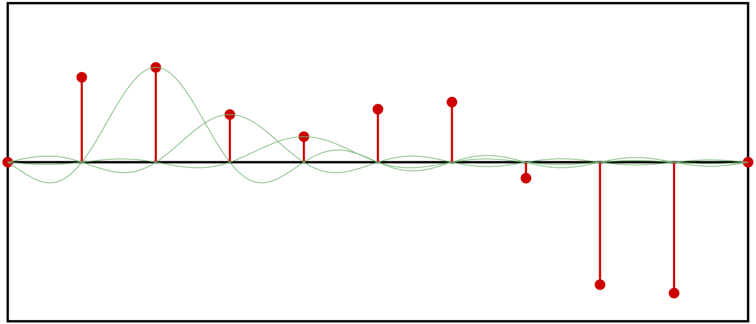

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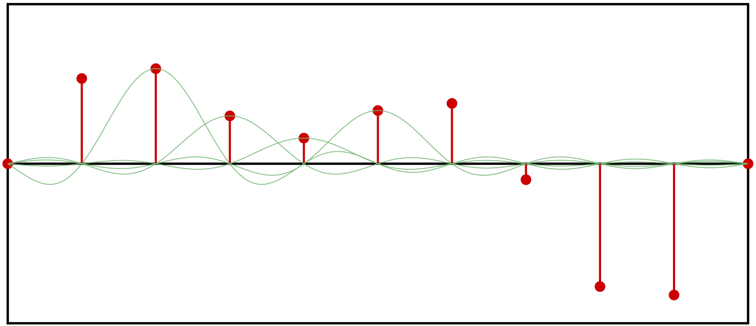

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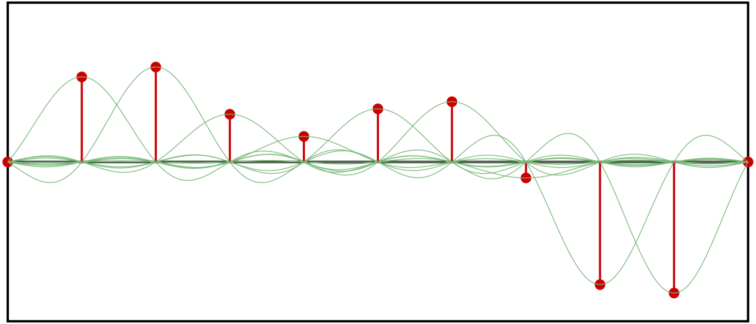

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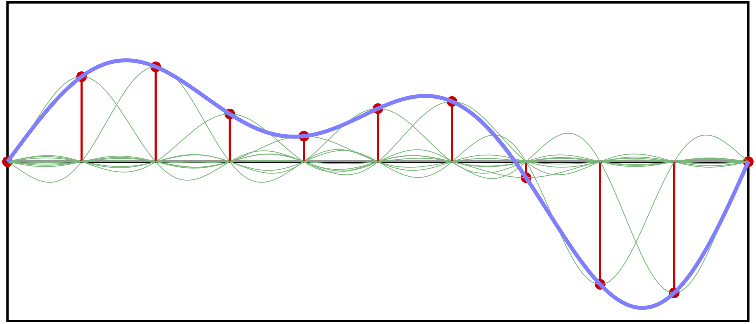
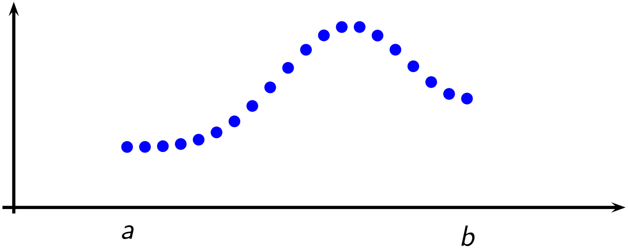


When can we do all this? Ask Fourier!

By the way, discrete time is easy!



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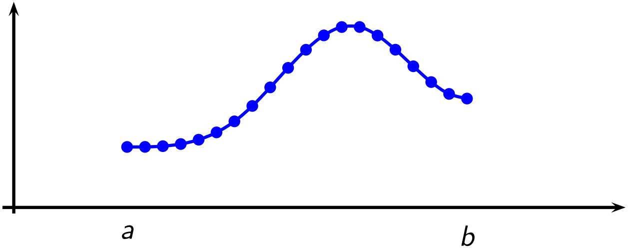

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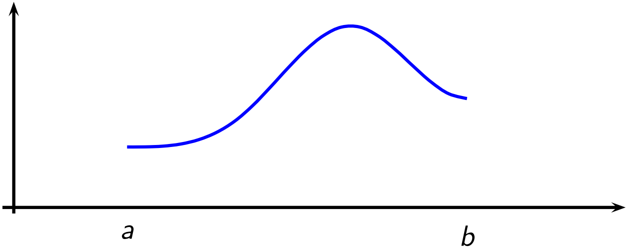

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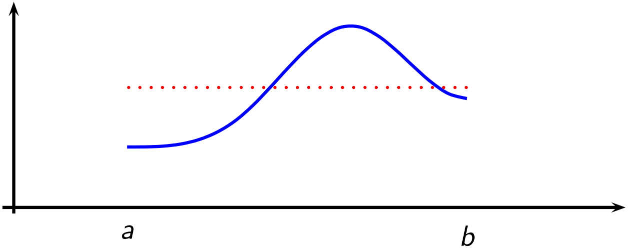
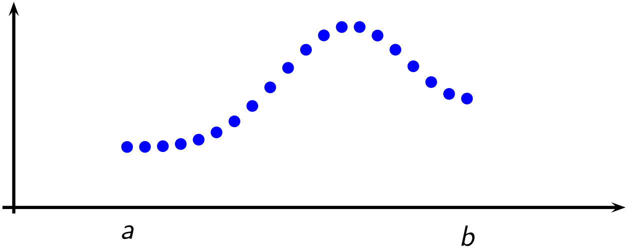


$$\bar{x} = \frac{1}{b-a}\int_a^b f(t)dt$$

By the way, discrete time is easy!



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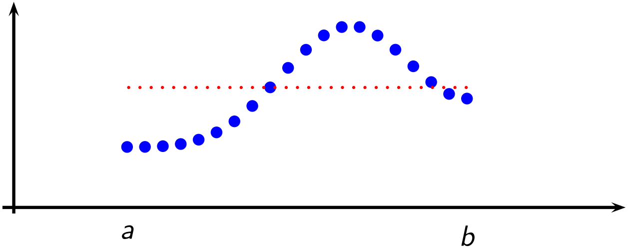


$$\bar{x} = \frac{1}{N}\sum_{n=0}^{N-1} x[n]$$

(digital) signal processing for communications

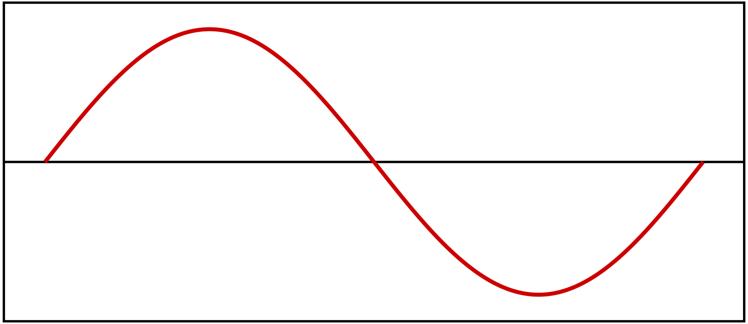
Key ingredients:

- discrete time
- **discrete amplitude**

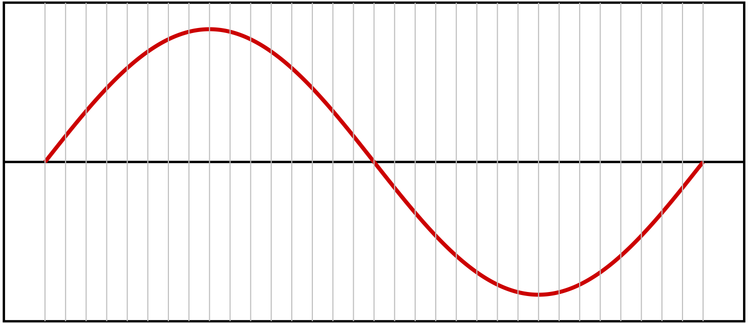
$$x : \mathbb{Z} \to \mathbb{Z}$$

$$x[n] = \ldots, 123, -73, 89, 17, -11, -26, \ldots$$

Digital Signals

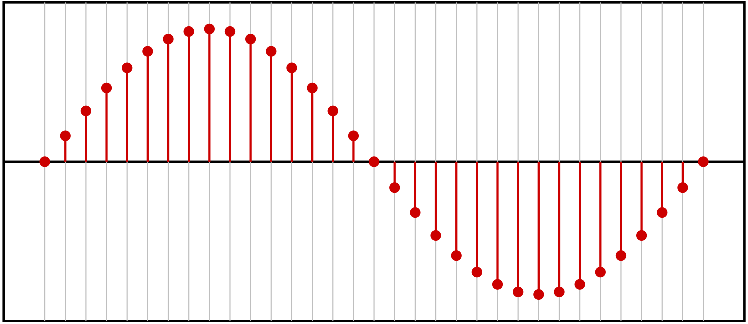


$x(t)$



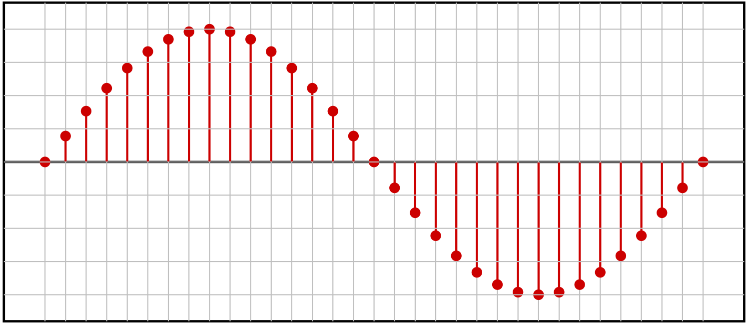
$x(t)$

Digital Signals



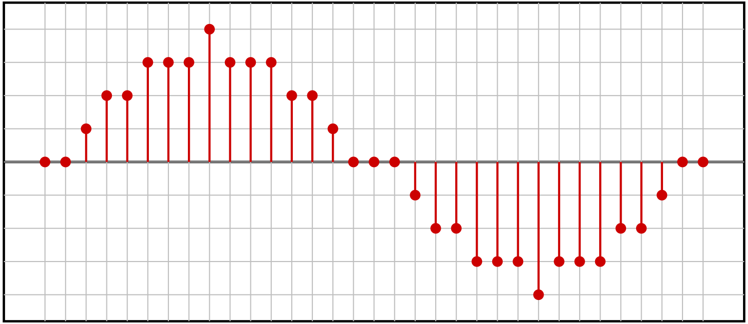
$x[n]$

Digital Signals



$x[n]$

Digital Signals



$\hat{x}[n]$

Digital amplitude

Why it is important:

- storage
- processing
- transmission

Data storage

Analog storage:

paper, wax cylinders, reel-to-reel, vinyl, compact cassette, VHS, Betamax, silver plates, Kodachrome, Super8, 8-Track, microfilm, ...

Digital storage:

$\{0, 1\}$

Analog storage:

paper, wax cylinders, reel-to-reel, vinyl, compact cassette, VHS, Betamax, silver plates, Kodachrome, Super8, 8-Track, microfilm, ...

Digital storage:

$$\{0, 1\}$$

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Digital storage:

$\{0, 1\}$

Analog storage:

paper, wax cylinders, reel-to-reel, vinyl, compact cassette, VHS, Betamax, silver plates, Kodachrome, Super8, 8-Track, microfilm, ...

Digital storage:

$$\{0, 1\}$$


Just one
MicroSD card
stores more than
the rest combined...
25 years
of storage

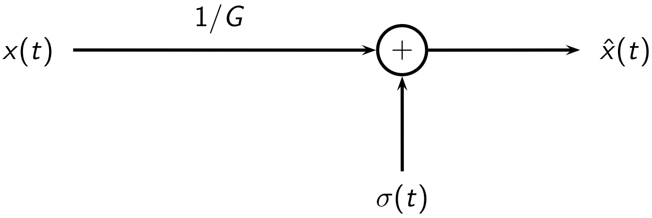
Processing

```
extern double a[N];      // The a's coefficients
extern double b[M];      // The b's coefficients

static double x[M];      // Delay line for x
static double y[N];      // Delay line for y

double GetOutput(double input)
{
  int k;

  // Shift delay line for x:
  for (k = N-1; k > 0; k--)
    x[k] = x[k-1];

  // new input value x[n]:
  x[0] = input;

  // Shift delay line for y:
  for (k = M-1; k > 0; k--)
    y[k] = y[k-1];

  double y = 0;
  for (k = 0; k < M; k++)
    y += b[k] * x[k];
  for (k = 1; k < M; k++)
    y -= a[k] * y[k];

  // New value for y[n]; store in delay line
  return (y[0] = y);
}
```

digital vs analog communications

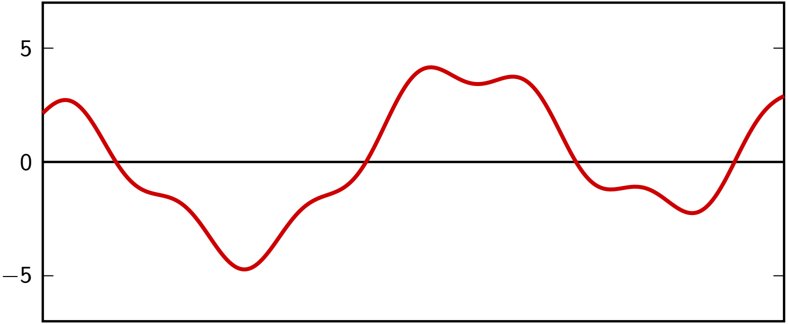
Data transmission

What happens to analog signals



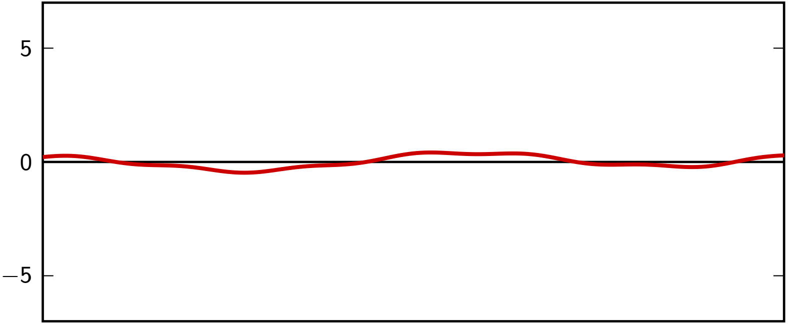
$$\hat{x}(t) = x(t)/G + \sigma(t)$$

What happens to analog signals



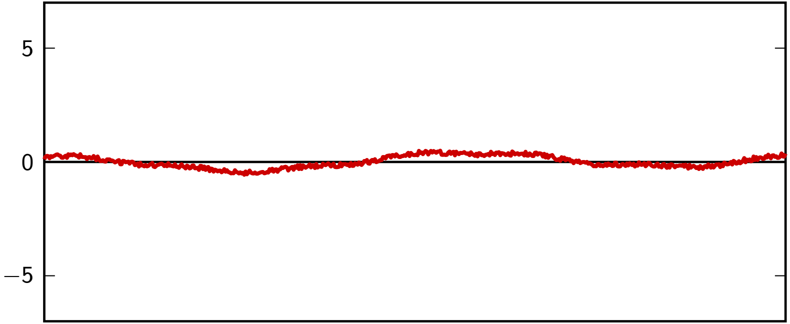
$x(t)$

What happens to analog signals



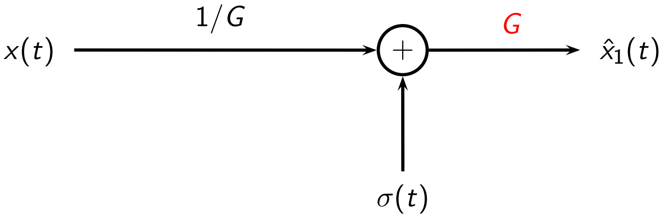
$x(t)/G$

What happens to analog signals



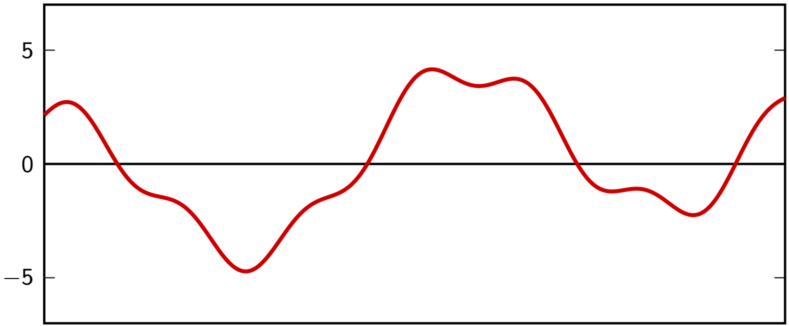
$$x(t)/G + \sigma(t)$$

We can amplify to compensate attenuation



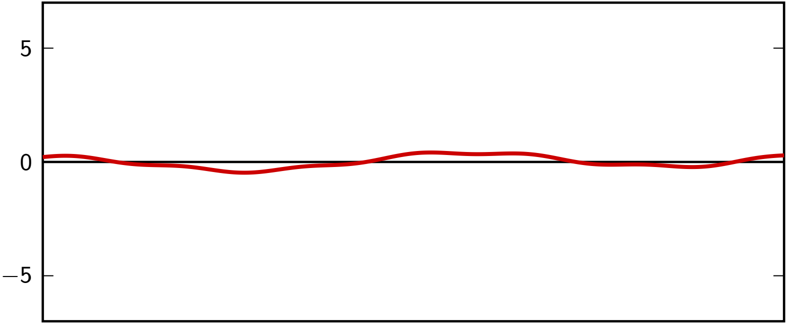
but: $\hat{x}_1(t) = x(t) + G\sigma(t)$

Transmission of analog signals

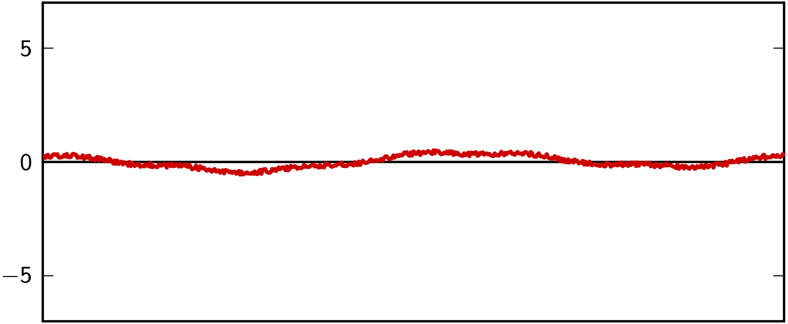


$x(t)$

Transmission of analog signals

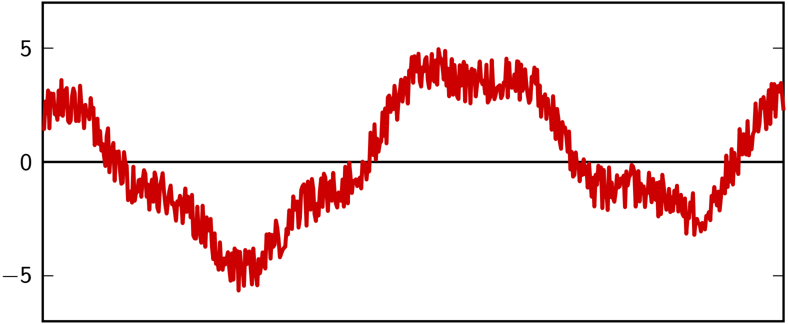


$x(t)/G$

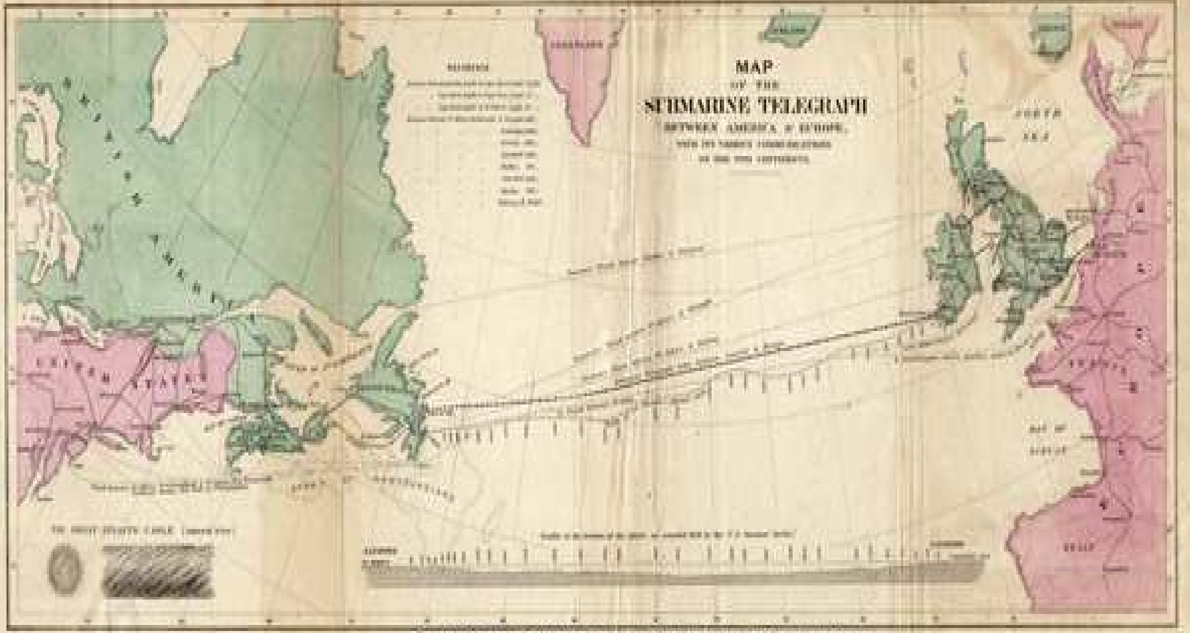


$$x(t)/G + \sigma(t)$$

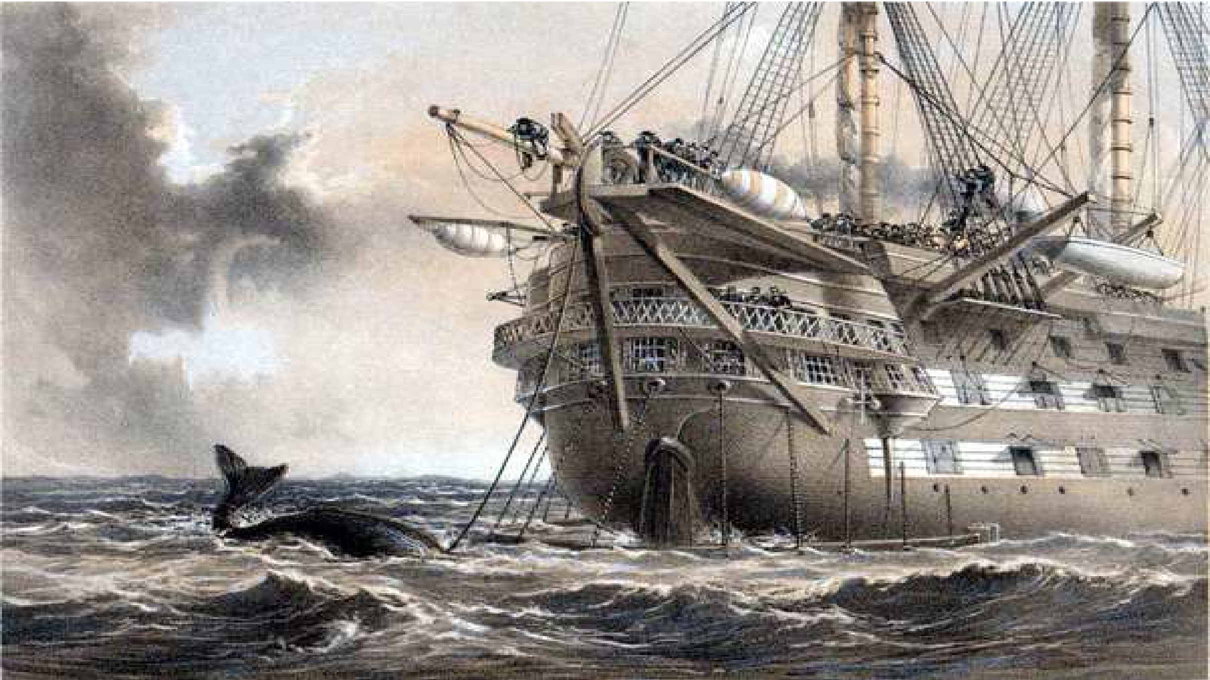
Transmission of analog signals



$$\hat{x}_1(t) = G[x(t)/G + \sigma(t)] = x(t) + G\sigma(t)$$

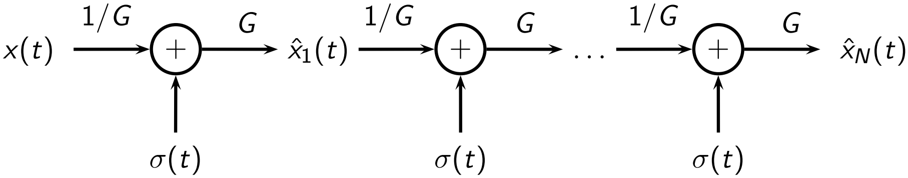


Printed for HOWE'S ADVENTURES & ACHIEVEMENTS OF AMERICANS



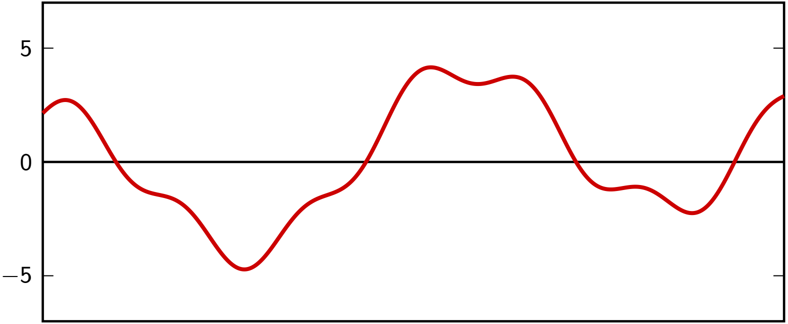
Transmitting a signal overseas

For a long, long channel we need repeaters



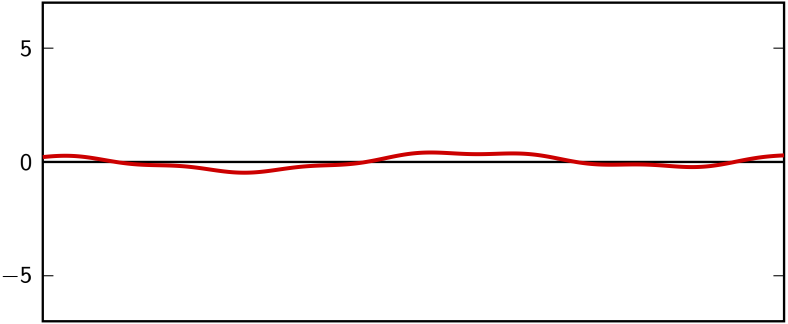
$$\hat{x}_N(t) = x(t) + NG\sigma(t)$$

Transmission of analog signals



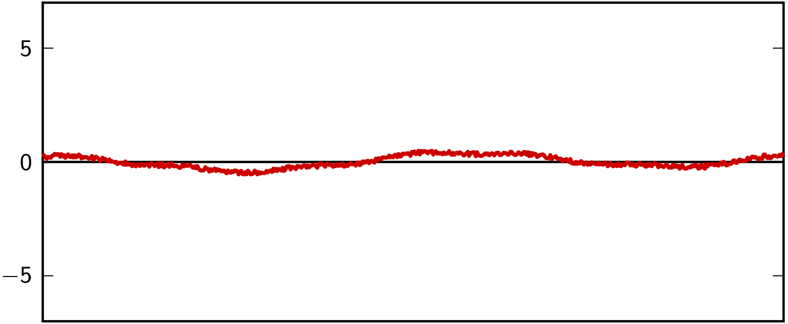
$x(t)$

Transmission of analog signals

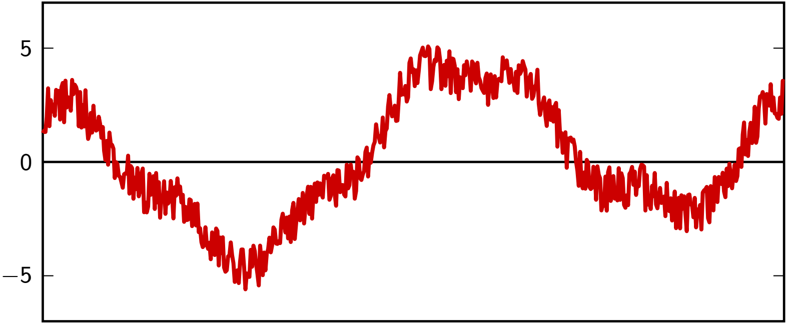


$x(t)/G$

Transmission of analog signals

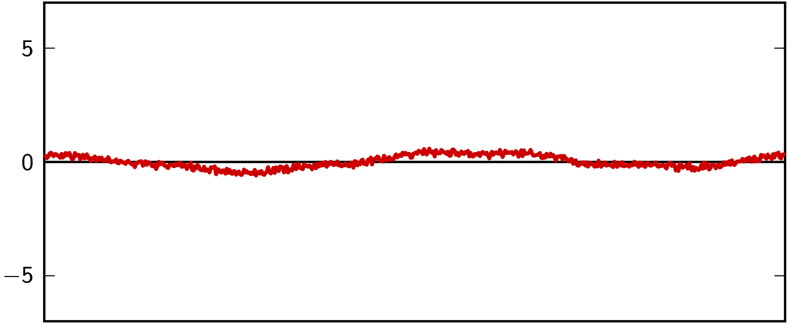


$$x(t)/G + \sigma(t)$$

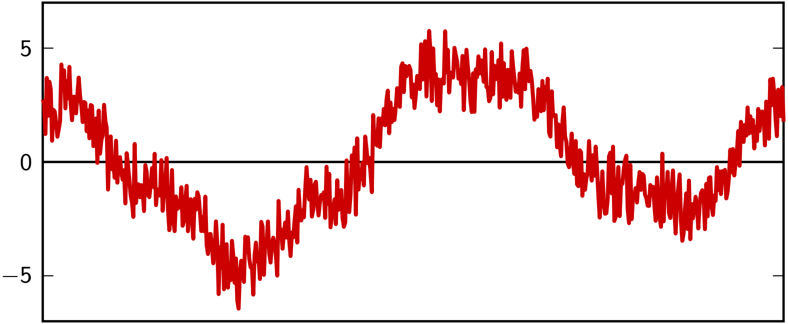


$$\hat{x}_1(t) = G[x(t)/G + \sigma(t)] = x(t) + G\sigma(t)$$

Transmission of analog signals

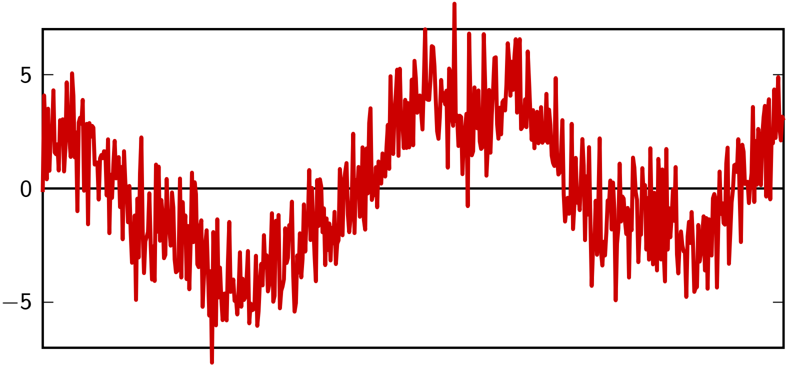


$$\hat{x}_1(t)/G + \sigma(t)$$



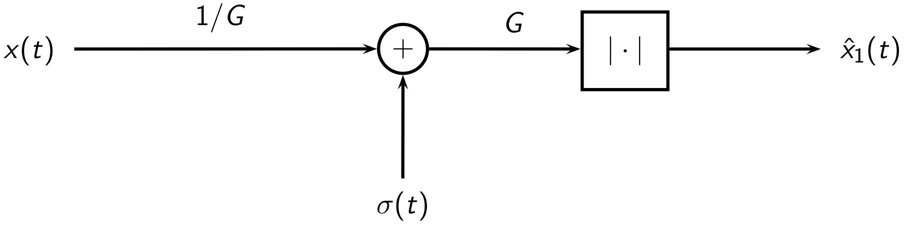
$$\hat{x}_2(t) = G[\hat{x}_1(t)/G + \sigma(t)] = x(t) + 2G\sigma(t)$$

Transmission of analog signals

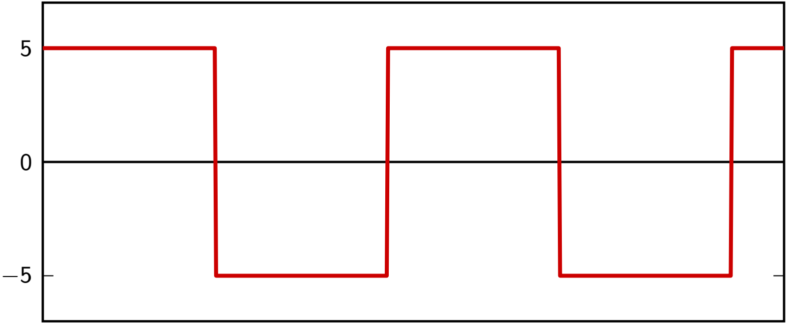


$$\hat{x}_N(t) = x(t) + NG\sigma(t)$$

In digital signals we can threshold

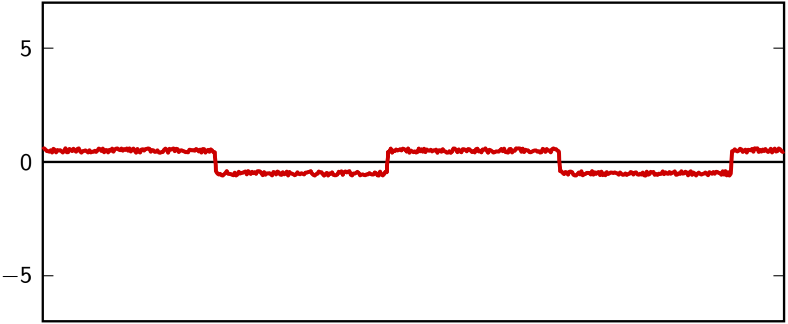


$$\hat{x}_1(t) = \mathrm{sgn}[x(t) + G\sigma(t)]$$



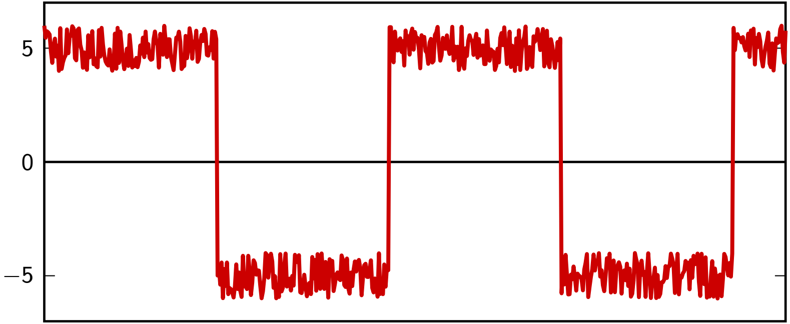
$x(t)$

Transmission of quantized signals



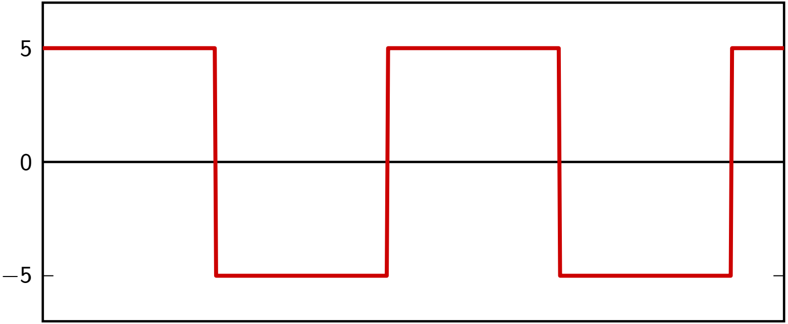
$x(t)/G + \sigma(t)$

Transmission of quantized signals



$$G[x(t)/G + \sigma(t)] = x(t) + G\sigma(t)$$

Transmission of quantized signals



$$\hat{x}_1(t) = G\,\mathrm{sgn}[x(t) + G\sigma(t)]$$

Digital data throughputs

- Transatlantic cable:
  - 1866: 8 words per minute ($\approx$5 bps)
  - 1956: AT&T, coax, 48 voice channels ($\approx$3Mbps)
  - 2005: Alcatel Tera10, fiber, 8.4 Tbps (8.4×10^{12} bps)
  - 2012: fiber, 60 Tbps
- Voiceband modems
  - 1950s: Bell 202, 1200 bps
  - 1990s: V90, 56Kbps
  - 2008: ADSL2+, 24Mbps

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numerical example