CMPE 352
Signal Processing & Algorithms
Spring 2019

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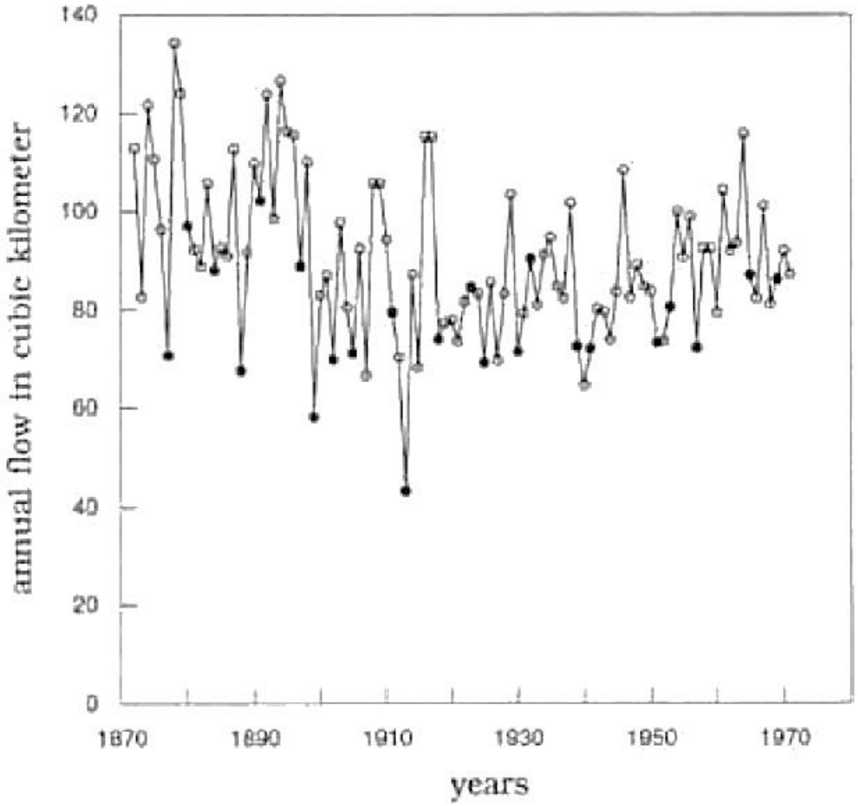
Some Simple Questions

- What is a signal?
- What can different signal forms be?
- What is an analog or a digital signal?
- What could the distinguishing characteristics of a signal be?
- What is a spectrum?
- What distinguishes a YouTube video-streaming signal from a Whatsapp message signal?
- What is an algorithm?
- How can an algorithm be physically realized/implemented?

Signal Representation under the Pyramids

approx. 2500 BC
(Palermo Stone)



modern recording

Representations of flood data for the River Nile

The Hellenic Shift to Analog Processing

- “Digital” representations of the world such as those depicted by the Palermo Stone are adequate for an environment in which quantitative problems are simple: counting animals, counting days and so on. As soon as the interaction with the world becomes more complex, so necessarily do the models used to interpret the world itself. Geometry, for instance, is born of the necessity of measuring and subdividing land property.
- In the 6th century BC, Pythagoras realized that the side and the diagonal of a square are incommensurable, i.e., that $\sqrt{2}$ is not a simple fraction. The discovery of what we now call “irrational numbers“ set the ground for an abstract model of the world that had already appeared in early geometric treatises and which today is called the “continuum.”
- Heavily rooted in its geometric origins (i.e., in the infinity of points in a segment), the continuum model postulates that time and space are an uninterrupted flow which can be divided arbitrarily many times into arbitrarily (and *infinitely*) small pieces. In signal processing terms, this is known as the “analog” world model.
- Zeno’s (490-430 BC) paradox points out to the extreme trickery of a model of the world which had not yet formally defined the concept of infinity.

Analog versus Digital Processing

- One of the fundamental problems in signal processing is to obtain a permanent record of the signal itself. E.g., measuring the ambient temperature $\theta(t)$: our measuring machine, however fast, will never be able to take an infinite amount of samples in a finite time interval. So how should we compute the average temperature:

$$\bar{\theta} = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \theta(t)dt$$

- Now consider the case in which all we have is a set of daily measurements θ_1, θ_2, $\cdots \theta_D$, : the "average" temperature of our measurements over *D* days is simply:

$$\hat{\theta} = \frac{1}{D} \sum_{i=1}^{D} \theta_i$$

This is an elementary sum of *D* terms which anyone can carry out by hand and which does not depend on how the measurements have been obtained: extremely simple!

Analog versus Digital Processing (cntd)

- So, obviously, the question is: “How different (if at all) is $\hat{\theta}$ from $\bar{\theta}$? In order to find out we can remark that if we accept the existence of a temperature function $\theta(t)$, then the measured values θ_i are *samples* of the function taken one day apart:

$$\theta_i = \theta(iT_s) \qquad \text{where } T_s \text{ is the duration of a day.}$$

- In this light, the sum to compute $\hat{\theta}$ is just the Riemann approximation to the integral used to compute $\bar{\theta}$ and the question becomes an assessment on how good an approximation that is.

- The answer, which we will study in detail later, is that in fact the continuous-time function and the set of samples *are perfectly equivalent representations* – provided that the underlying physical phenomenon “doesn’t change too fast”.

- Hence under this condition the analog and the digital worlds can perfectly coexist. We actually possess a *constructive* way to move between worlds: what we will call the *sampling theorem*.

Analog versus Digital Processing (cntd)

- The equivalence between the discrete and continuous representations only holds for signals which are sufficiently “slow” with respect to how fast we sample them.

- This makes a lot of sense: we need to make sure that the signal does not do “crazy” things between successive samples; only if it is smooth and well behaved can we afford to have such sampling gaps.

- Quantitatively, the sampling theorem links the speed at which we need to repeatedly measure the signal to the maximum frequency contained in its spectrum.

What is a Signal? What is a System?

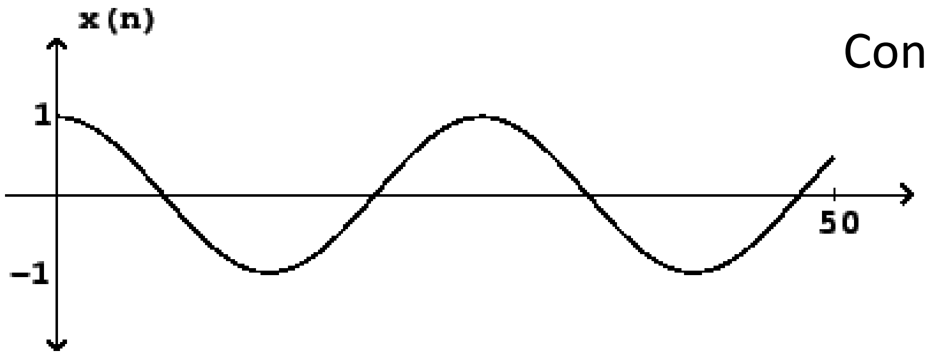
The physical nature of signals and systems found in various fields may be drastically different but they all share two basic features:

Signal: a function of one or more independent variables containing information about the behavior or nature of some phenomenon (*)

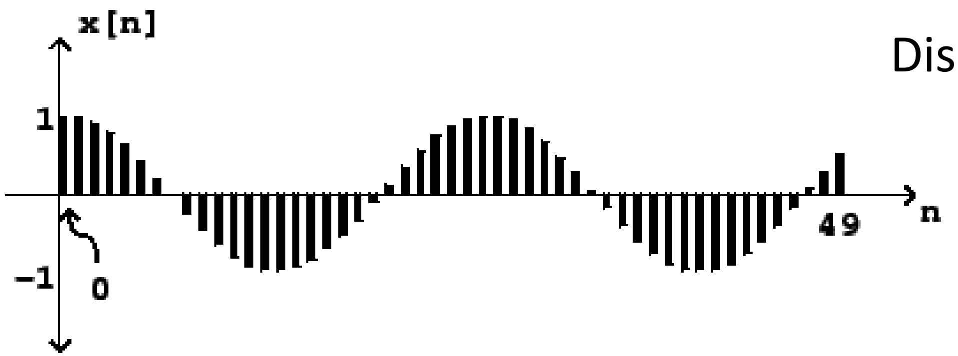
System: an “object” that responds to particular signals by producing other signals or some desired/observed behavior

(*) in this course, we will deal with signals that are functions of time

Continuous-Time & Discrete-Time Signals

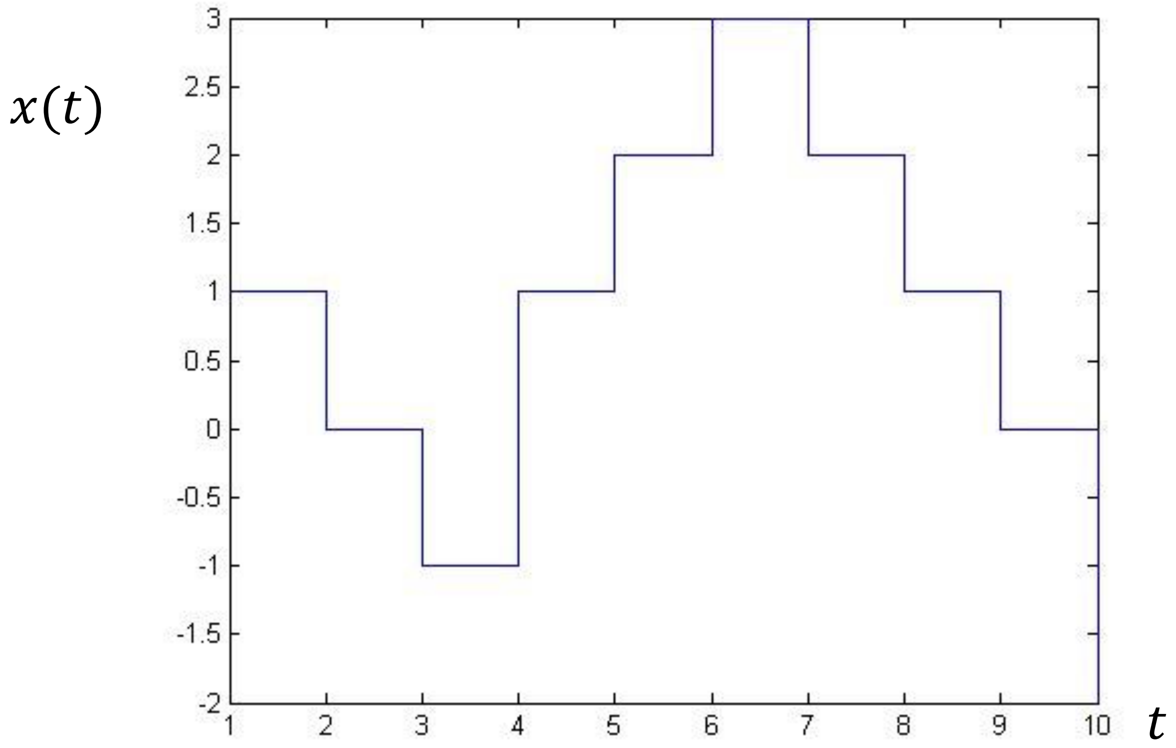


Continuous time



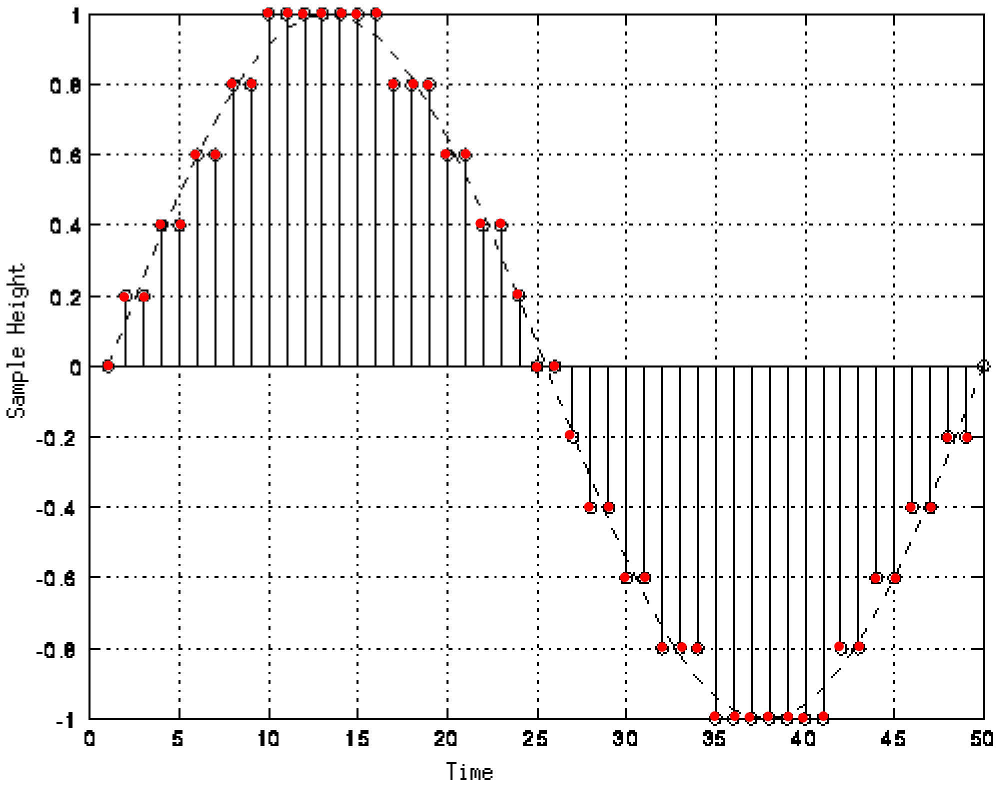
Discrete time

Discrete Amplitude



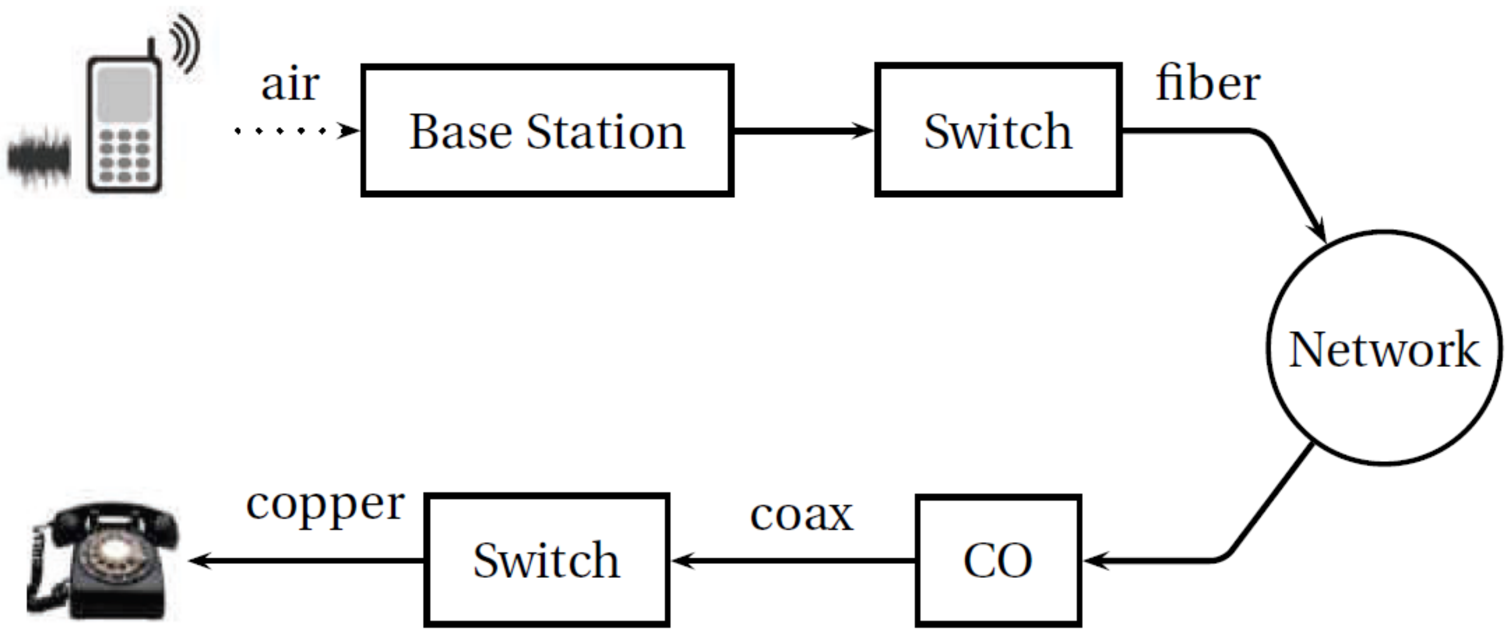
Discrete Time & Discrete Amplitude

$x[n]$

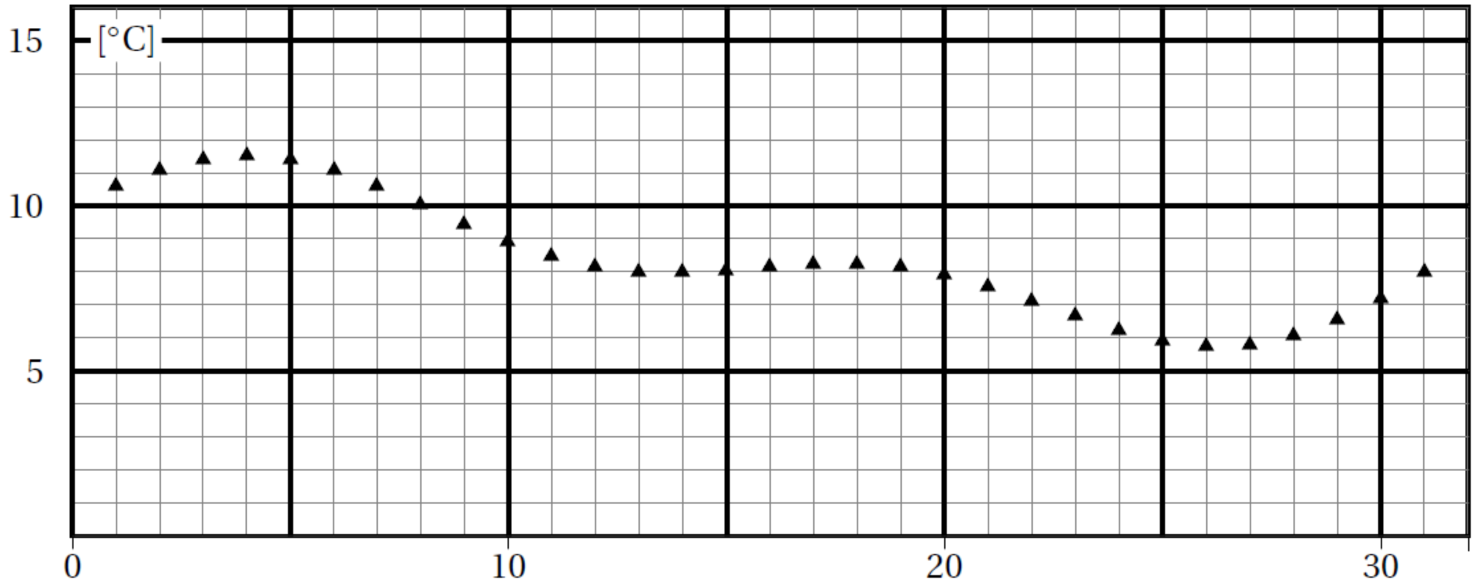


$[n]$

Example: Communication Systems



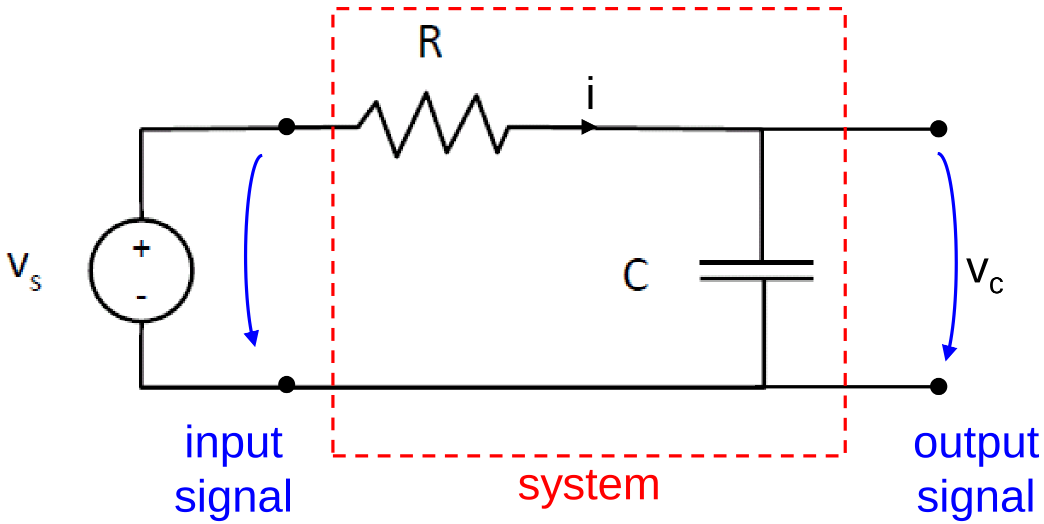
Examples of Signals (1)

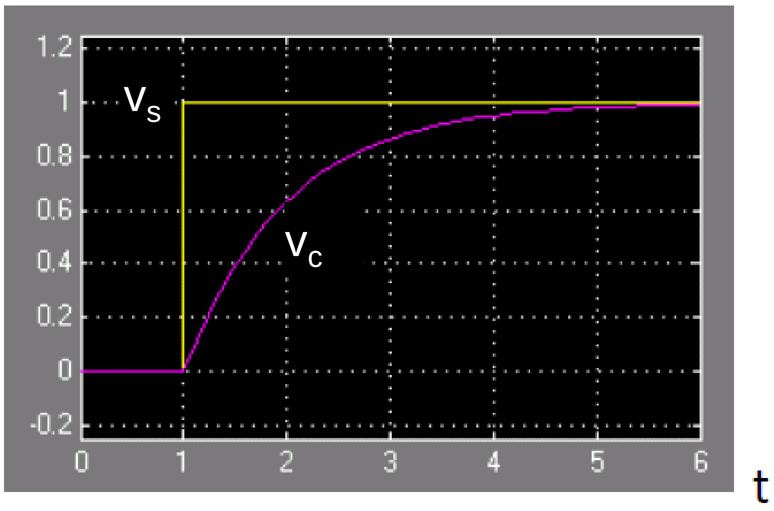


Temperature measurements over a month

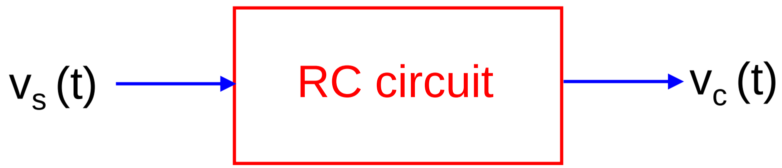
Examples of Signals (2)

Example: Electric Circuit

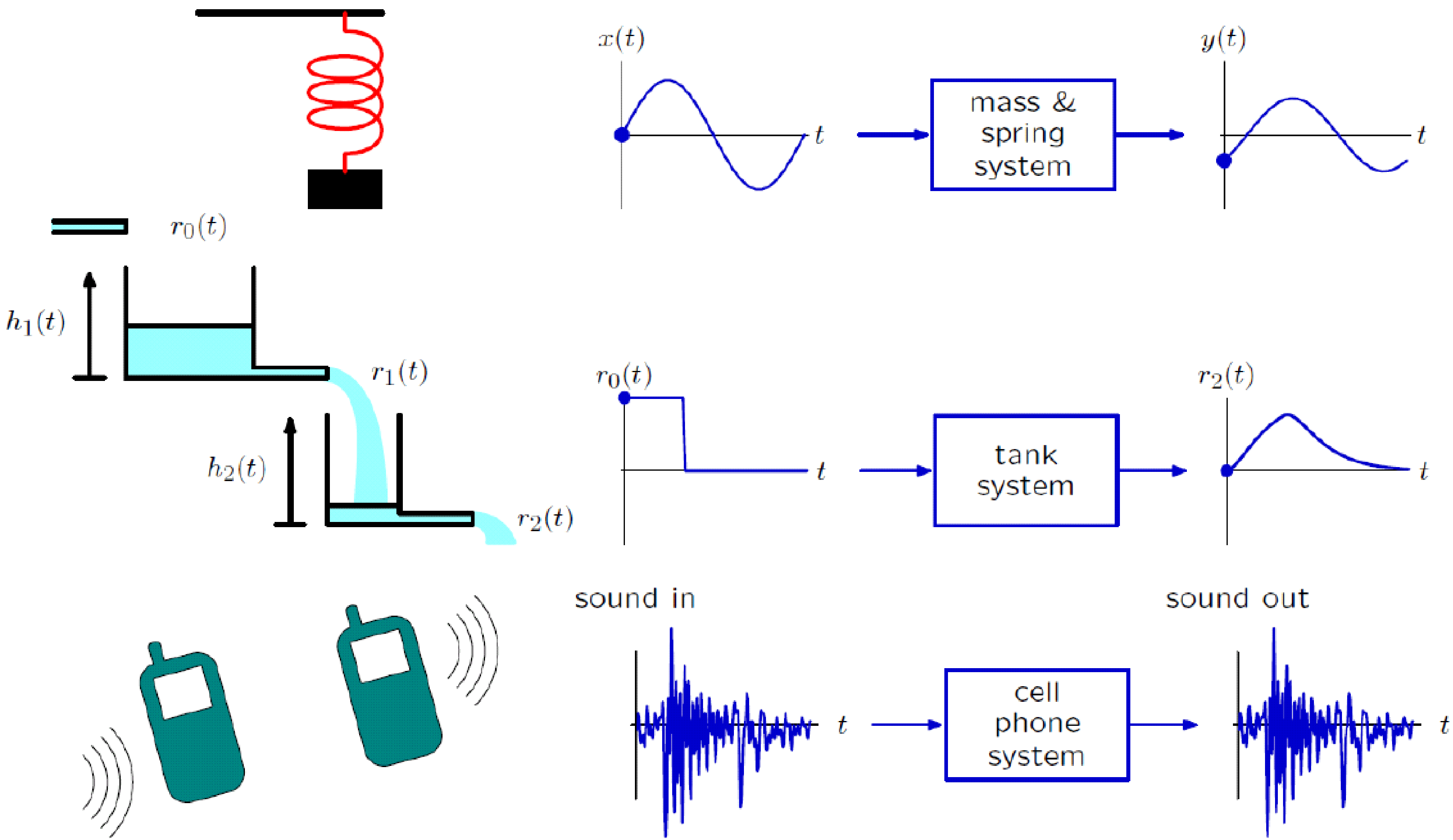




- Input and output voltages v_s and v_c are "signals"
- The electric circuit "responds" to the input signal and produces an output signal
- Note that the current i or the voltage across R are also signals
- More abstractly, this RC circuit can be represented as



Examples of Signals (3)



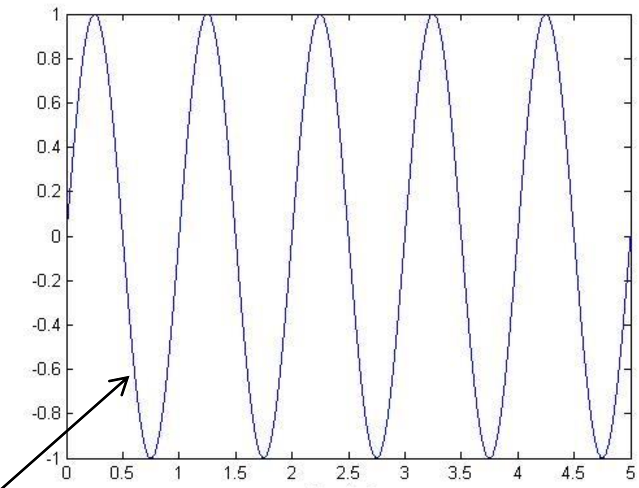
Examples of Signals (4)

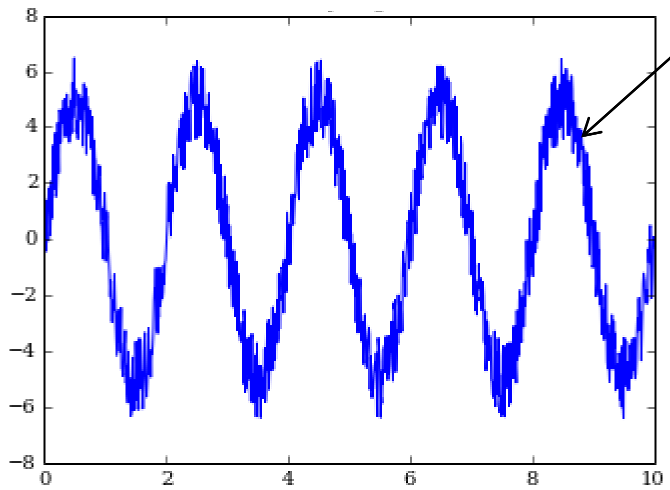
- Signals are found in a wide variety of fields, such as

Computing systems	Communications	Control systems
Biology	Chemical processes	Acoustics
Aeronautics	Seismology	Speech processing
Etc.		

Is Noise a Signal?

noisy signal

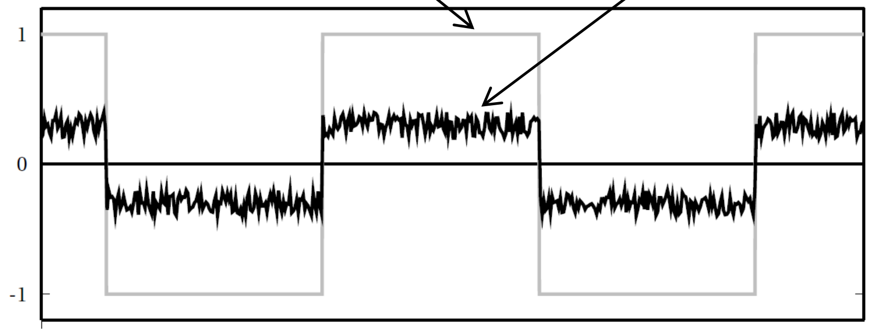




Clean, noiseless signal

Transmitted signal

Received signal



Signals and Algorithms: Why Are We Interested?

- Embedded systems: An embedded system is a computer system with a dedicated function within a larger (mechanical, electrical, chemical, biological,...) system, often with real-time computing constraints. It is embedded as part of a complete device often including hardware and other (mechanical, electrical, etc.) parts. Embedded systems control many devices in common use today. 98% of all microprocessors being manufactured are used in embedded systems.

- Modern embedded systems are often based on microcontrollers (i.e., CPUs with integrated memory or peripheral interfaces), but ordinary microprocessors (using external chips for memory and peripheral interface circuits) are also common. In either case, the processor(s) used may be types ranging from general purpose to those specialized in certain class of computations, or even custom designed for the application at hand. A common standard class of dedicated processors is the digital signal processor (DSP).

Signals and Algorithms: Why Are We Interested?

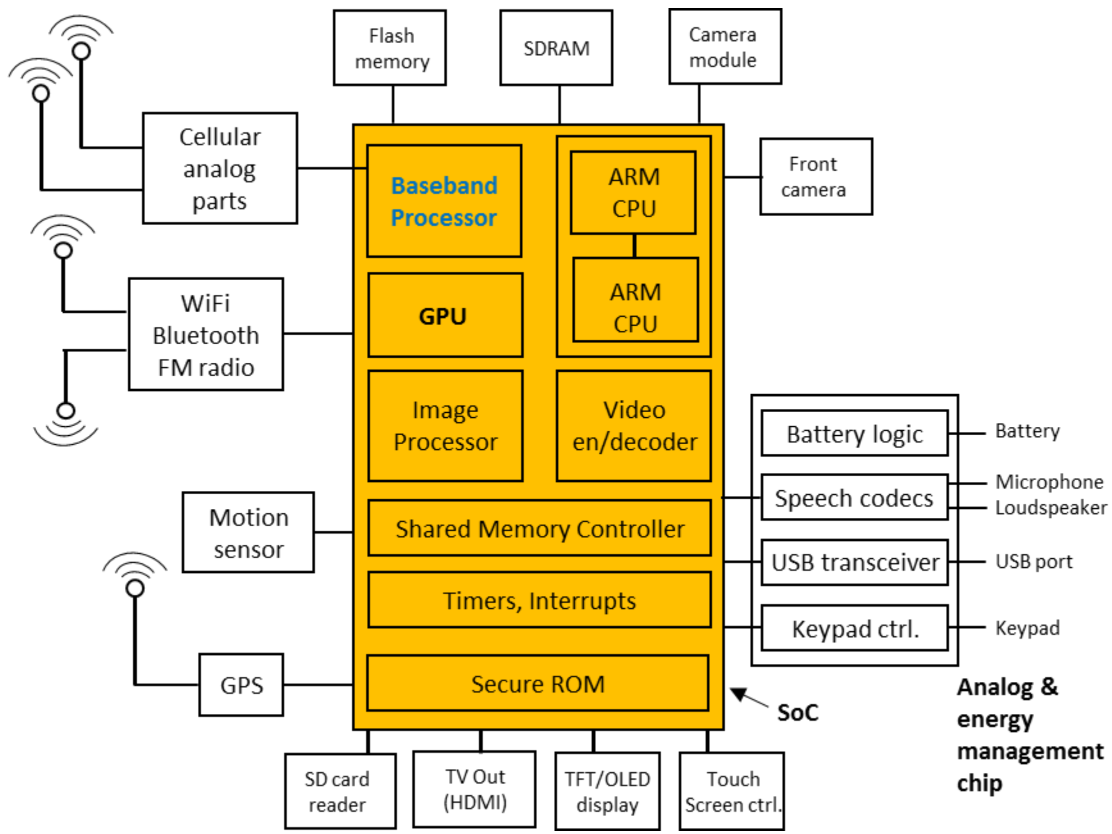
- Where are embedded systems used? MP3 players, mobile phones, videogame consoles, digital cameras, GPS receivers, printers, household appliances such as microwave ovens, washing machines and dishwashers, automobiles, etc. include embedded systems to provide flexibility, efficiency and features.

- Arduino is an application product of embedded systems, i.e., a microcontroller board, with a specifically designed API and software which makes programming it very easy.

- Hardware-software optimizations in the design of embedded systems requires a good understand of signals, their processing and algorithms.
- Embedded systems are key for the Internet-of-Things and for Industry 4.0

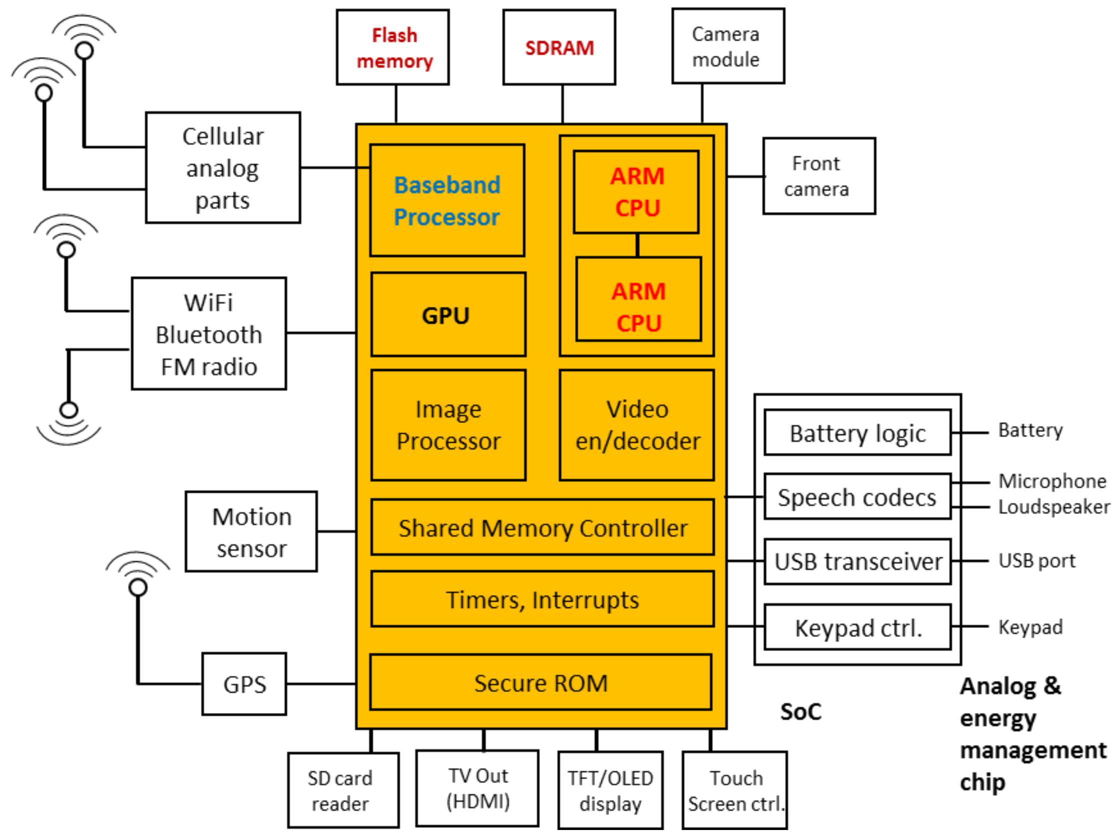
Example: Architecture of a Smartphone

- Simple GSM phones usually have one processor that handles both the modem functionality and the operating system for the user interface
- In smartphones, these tasks are performed by independent processors. This has become necessary as each function has become much more complex over time. In addition, smartphones include many new functionalities that require significant and specialized processing capabilities
- Most or even all of the functions are included in a single chip: such a combination is often referred to as a **System on a Chip (SoC)**
- The **baseband processor** is responsible for communication with the mobile network and does not only support GSM but also UMTS (3G) and LTE (4G/4.5G)
- A few analog components cannot be included in the SoC because of their size and function and are thus implemented separately



Example: Architecture of a Smartphone (cntd)

- The operating system for the user interface, such as Android or iOS, is executed on the application processor that usually consists of one or more **ARM processor cores**
- These ARM CPUs have an instruction set similar to that of the ARM processors of the voice-centric GSM phones. Due to their higher complexity and higher clock rates, their power consumption is much higher
- Baseband processor and application processor operate independently of each other and communicate over a fast serial interface with each other
- **Memory chips** are usually physically separate from the SoC



Signals and Systems: Why are We interested?

- In general, computer engineers are interested in the digital processing of signals for applications such as sensor processing, digital image processing, digital signal processing for telecommunications, control systems, computer architecture, data storage, biomedical engineering, robotics and artificial intelligence, seismology, etc.
- Some more specific examples are
  - Encoding music in MP3 format
  - Compression of picture in JPEG format
  - Adobe Photoshop relies heavily on digital signal processing
  - Voice recognition, face recognition (e.g., tag faces in Facebook)
  - SIRI, Instagram
  - ...
- Engineers usually study digital signals in one of the following two domains: <u>time domain and frequency domain</u>.