Lecture 2: Signals and Systems: What, why and where we're going

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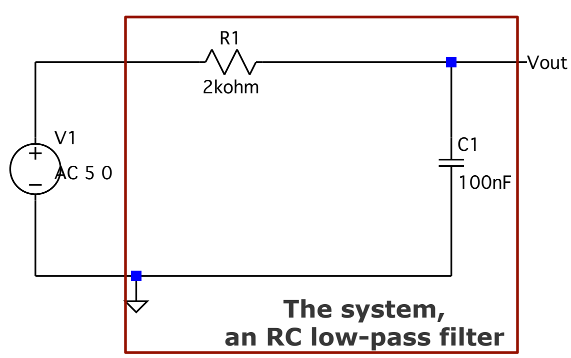
What's it all about?

- A *signal* is a waveform or measurement that represents some physical quantity
- A *system* is a set of operations that transforms *input* signals to *output* signals
- We've seen this kind of thing already in circuits (CMPE306)

The input signal, an analog voltage
V_1



The output signal, an analog voltage
V_{OUT}

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Signals and Systems

- We're interested in the characteristics of the signals and systems themselves…
- …generally not in the internal details

- Our task is to provide a model of the signal(s) and the system and their relationships
- The *language* we use to build the model is mathematics…
- …the framework we use is based on science!

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Continuous time (analog) vs. Discrete time

- We generally describe signals and systems as function of time, $s(t), s(t_1), s[n]$, etc …
- …but it's perfectly acceptable to use position, temperature, barometric pressure, etc. as the independent variable
- As computer engineers, we're generally interested in functions of time, so that's what we'll use.
- Don't forget that other independent variables are possible!

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Continuous time (analog) vs. Discrete time

- If the signal is defined for all values of time within a given range, $t_1 \le t \le t_2 = \left[t_1, t_2\right]$, we call the signal "continuous"
- If the signal is defined at only a set of times within a given range, $t_1 < t_2 < t_3 \ldots < t_n = \left\{t_1, t_2 \ldots, t_n\right\}$ we call the signal "discrete" or "discrete time
- "Continuous" and "discrete" refer to the *time axis*

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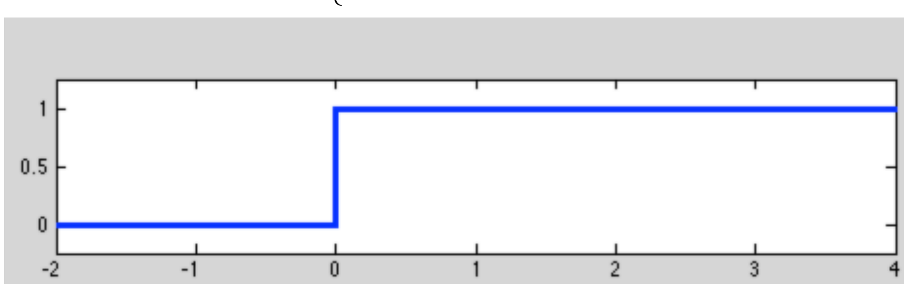
Continuous vs. Discrete (continued)

- Systems may also be continuous or discrete, where the terms are used in the same way
- Saying "continuous time" does not mean "continuous amplitude" in the sense we learned in Calc I/II!
- Example: The unit step function (remember from 306!)

$$u(t) = \begin{cases} 1 & t > 0 \\ 0 & t < 0 \end{cases}$$



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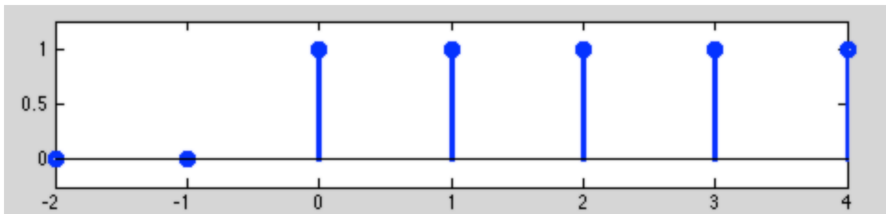
Continuous vs. Discrete (continued)

- **And the discrete version (which we *haven't* officially seen yet)**

$$u[n] = \begin{cases} 1 & n \geq 0 \\ 0 & < 0 \end{cases}$$



- **We'll (eventually) get to a little bit of discrete signals and systems, but our emphases is on *analog signals and systems.***
- **CMPE422 covers discrete signals and systems in great detail**

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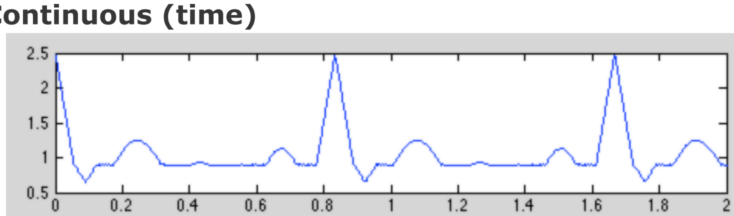
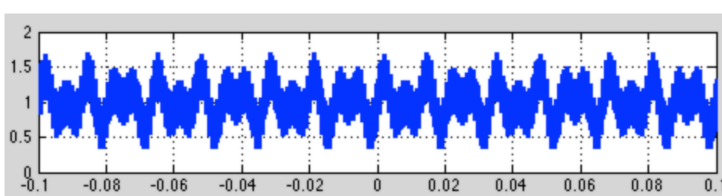
Examples

- **Continuous (time)**



(Simulated) Electrocardiogram (EKG)



(Simulated) 3-tone Double Sideband AM (DSB-AM) envelope

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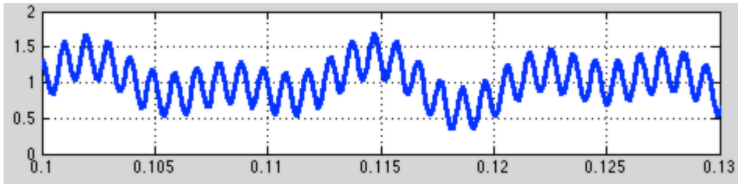
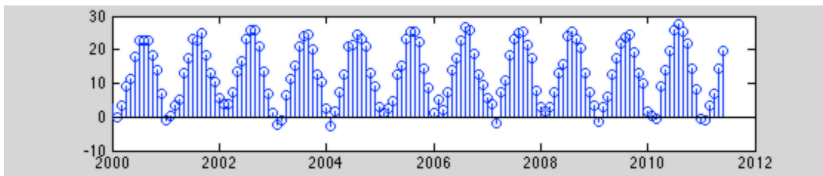
Examples



(Simulated) 3-tone Double Sideband AM (DSB-AM) envelope
Expanded scale



Average monthly temperature (C°) in Baltimore

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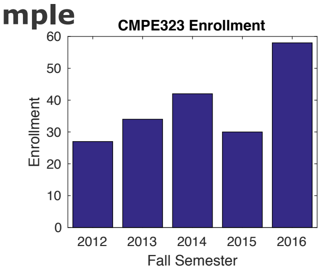
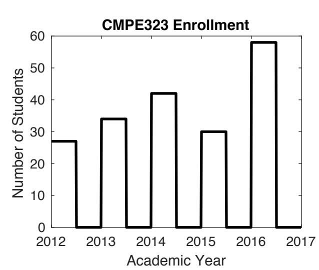
Analog vs. Digital

- **In the *amplitude* dimension we can also be “continuous” or “piecewise continuous” in the Calc I/II sense**
- **Or we can be discrete, as in the output of logic gates…**
- **…or the output of an A/D converter**
- **Example**





Discrete/Digital **Continuous/Digital**

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Random vs. Deterministic

- **In a deterministic waveform, if you know the value(s) at a single instant in time, you should be able to predict the value(s) at all future (and past?) times.**
- **In a random waveform, all you can do is predict the statistical properties (e.g. mean, variance, correlation, etc.)**
- **More on random waveforms in CMPE320…**
- **…we'll generally skip them.**

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Your turn

- **Within a small group of neighbors, choose or describe an examples of a signal, a system that might use that signal, and what the output signal might be.**
- **Is your signal analog (continuous time) or discrete time? Does your signal have a continuous (in the Calculus sense) amplitude or not?**
- **If you can, suggest a mathematical model of your input and output signals.**

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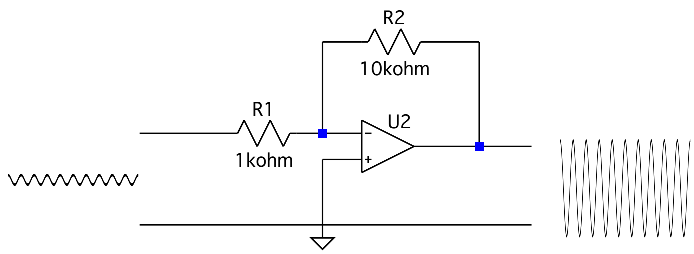
Systems vs. signals

- A system is some device or process that takes one signal and turns it into another



- It might be linear, or not…
- It might vary with time, or not…
- It might induce a delay, or not…
- It might change the shape of the waveform, or not

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Why bother?

- The major thing we want to do is to predict the ***output*** of a system to a given ***input*** signal…
- …without actually building the system.
- It's almost always cheaper to do by analysis!
- Analysis permits us to consider alternatives
  - Consider the ***feasibility*** of the system before building it.
  - Stress the system with inputs that might be impossible or dangerous to create in practice.
  - Efficiently perform tradeoffs between different systems or different implementations of the same system.

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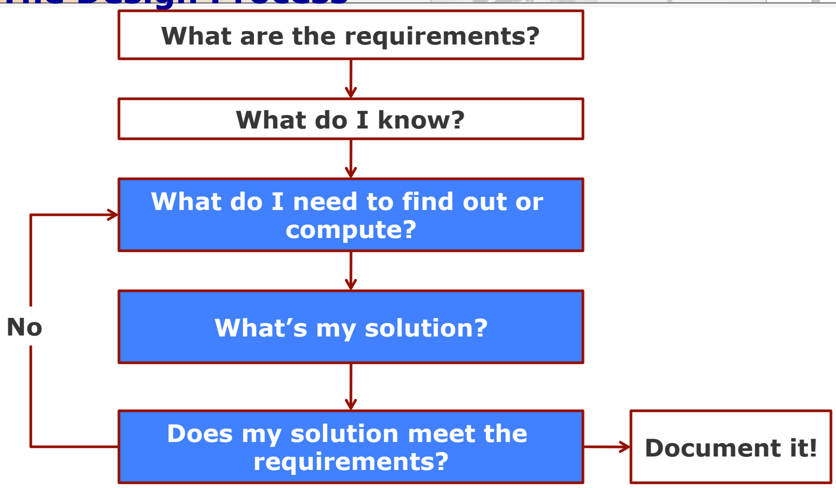
The Design Process



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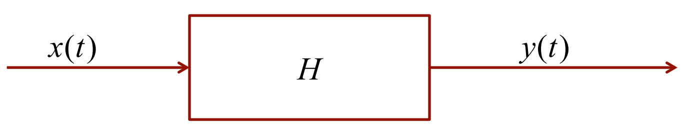
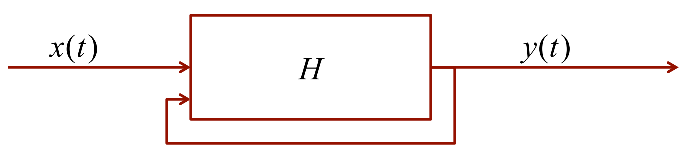
Mathematical Models for Systems

- We will usually have $x(t)$ or $s(t)$ as our system input and $y(t)$ as our output…
- …and we'll call our system H for reasons that will be obvious later.



- Some systems use "feedback" (like an op amp!)



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We are looking for a model

- We're trying to model the output $y(t)$ as some mathematical function of the input
- Examples

$$y(t) = ax(t)$$

$$y(t) = b_n \frac{d^n}{dt^n} x(t) + b_{n-1} \frac{d^{n-1}}{dt^{n-1}} x(t) + ... + b_0 x(t)$$

$$y(t) = \cos(2\pi f_0 t + \beta x(t))$$

$$y(t) = \cos(2\pi f_0 t + \beta \int_{-\infty}^{t} x(t))$$

$$y(t) = x(t)\cos\left(2\pi f_0 t\right)$$

$$y(t) = b_n \frac{d^n}{dt^n} x(t) + b_{n-1} \frac{d^{n-1}}{dt^{n-1}} x(t) + ... + b_0 x(t) + a_n \frac{d^n}{dt^n} y(t) + a_{n-1} \frac{d^{n-1}}{dt^{n-1}} y(t) + ... a_1 \frac{d}{dt} y(t)$$

$$y(t) = x^n(t), \ n > 1$$

$$y(t) = e^{-\lambda x(t)}; \ x(t) > 0 \quad \text{(What would a useful } x(t) \text{ be?)}$$

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Your turn

- Working in your table groups and using your common experience, see if you can come up with a system that is modeled by each of the previous candidates

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Some matters of notation

- $x(t), y(t), s(t)$ represent signals where the valid range of t is defined
- If the range is not give, we assume $-\infty < t < \infty$
- $x(t), y(t), s(t)$ also represent the VALUE of the signal at time t, $x(t) = 10 \text{ for } t = 1 \text{ sec}, \quad \text{i.e. } x(1) = 10.$
- To keep things straight, we usually use a particular time, and write $x(t_0) = 10, \text{ or } x(1) = 10.$
- If we say $x(t) = 10$, we (usually) mean "the function x has a constant value for all time t"
- Pay attention! Both notations are used and you need to know which is right in a given situation
- For example $\frac{d}{dt}x(t) = 10, t > 0$ is a time varying signal,

while $\frac{d}{dt}x(t_1) = 10$ is (probably) a value at time = t_1.

Your turn

- Working in your table groups, identify the input signal, the output signal an appropriate math model for the following systems, and draw a simple input/output diagram. Identify any elements as continuous or discrete time and digital or continuous amplitude

1. The fuel gauge on you car.
2. The GPS output of your smartphone.
3. A simple power meter that measures the power produced in a resistor.
4. A thermocouple that measures temperature.
5. A Geiger counter
6. A simulation of the growth of a bacteria population.
7. An automatic temperature measurement and recording system.