LING 490 - SPECIAL TOPICS IN LINGUISTICS

Fundamentals of Digital Signal Processing

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Week 6

Last week…

- Sound level: intensity I and pressure p
  - $I = \frac{p^2}{\rho \cdot c}$
- Sound intensity level (SIL) and sound pressure level (SPL)
  - Definition of decibel
  - $decibels = 10 \cdot log_{10} \frac{I}{I_{ref}} = 10 \cdot log_{10} (\frac{p}{p_{ref}})^2 = 20 \cdot log_{10} (\frac{p}{p_{ref}})$
- Theoretical vs practical SPL
- Loudness
  - Subjective perception vs objective measurement

Intro to linear time-invariant system

Definition of system

- What is system?
  - Something which performs some operations on, or transformation of, an ***input*** signal to produce an ***output*** signal
  - Signal processing (SP): a component or pipeline which processes signals to create other signals

- Can you think of any examples in audio SP?
  - Amplifier, filters, artificial reverberation generator, etc

Some examples of systems

- Telephone network
- VoIP, e.g. Skype
- An analogue or digital filter
- A guitar effects pedal
- Radar
- An image processing algorithm
- The economy
- A car steering system
- etc……..

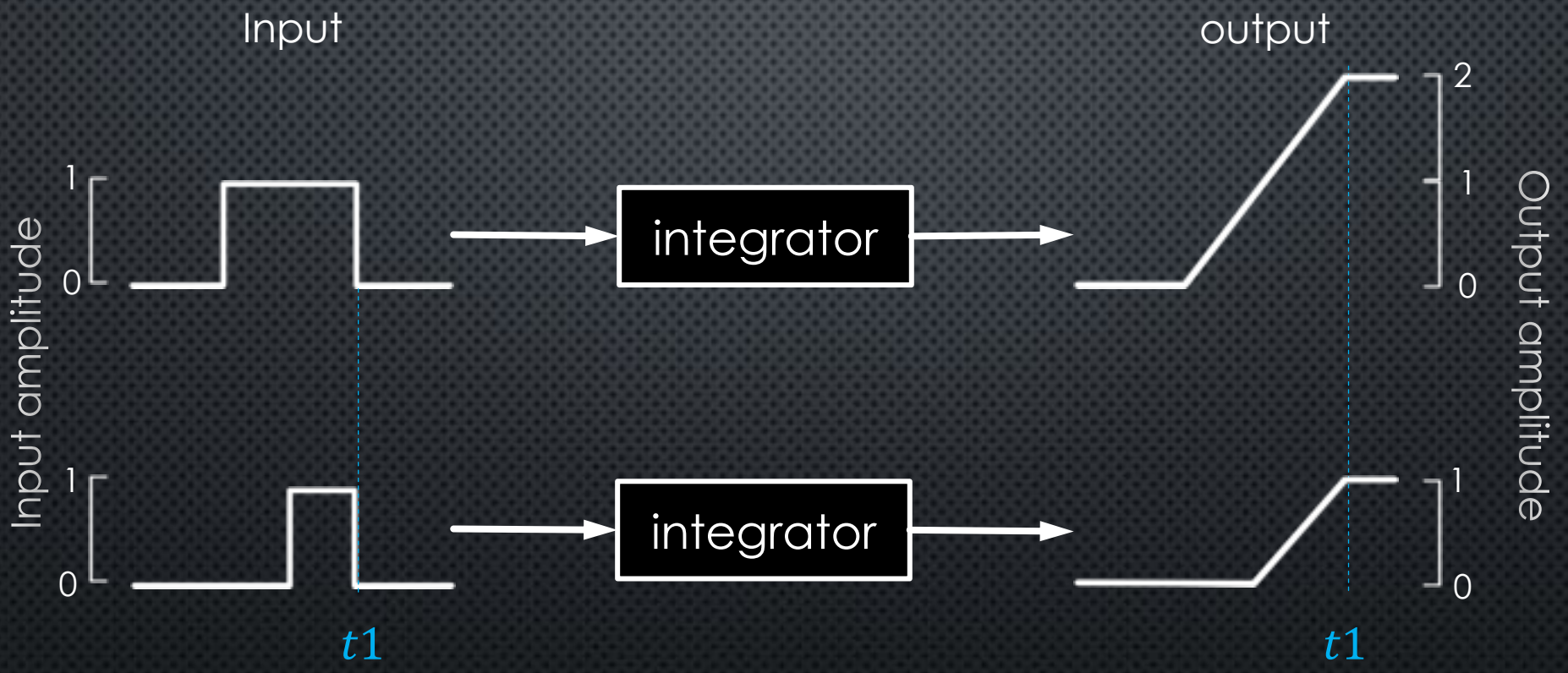
System diagrams

- A system operating on a signal can be presented as,

- Example: an amplifier

$$output(t) = 3 \times input(t)$$

A system with "memory"



Another example in discrete time: $output(t) = input(t) + output(t-1)$

Most of systems in DSP have "memory"!

"memory" of a system

- If a system has no "memory"
  - It only needs to know its input at one time, t, to produce the corresponding output for t
  - Doesn't not store any other information
  - E.g. chain and parallel systems
- A system with "memory"
  - Its output at t depends on the input signal at more than one time moment in past
  - $t, t-1, t-2$ and $t-n, n$ is positive integer
  - E.g. Feedback loop.

Causality of a system

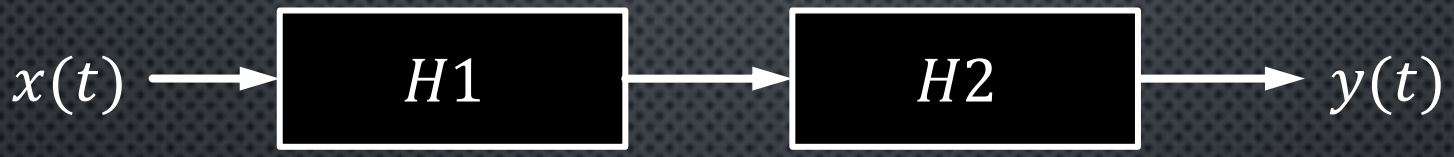
- What if the output of a system depends on the *future* of the input? i.e. $t+1, t+2$ and $t+n, n$ is positive integer
  - This system is not causal

- A system is *causal* if the output at time n only depends on the input or output up to time n

- Is every real world system casual?

Connecting systems

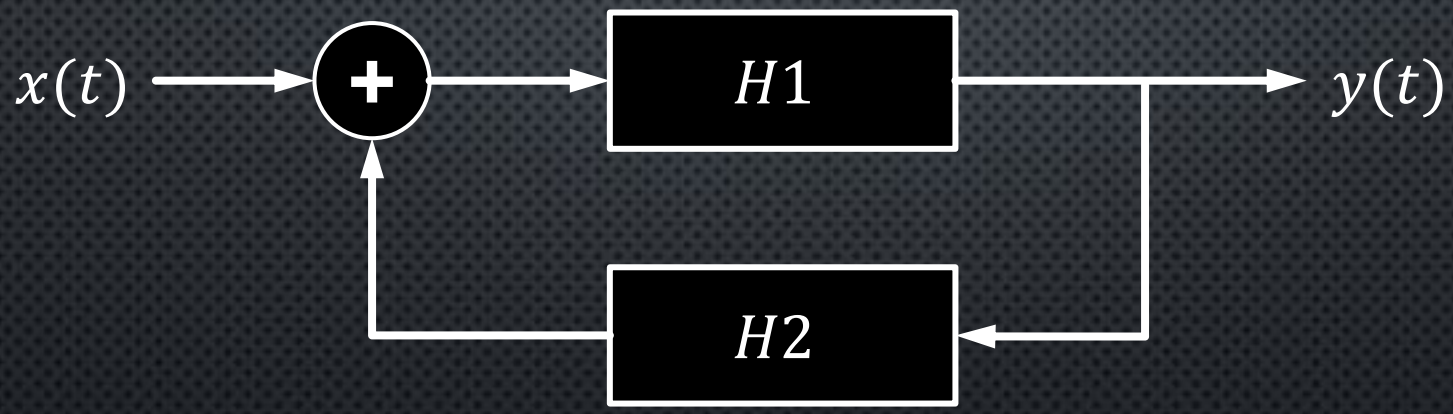
- Chain systems:



- Parallel system:

Connecting systems

- Feedback loop:



Linear time-invariant (LTI) system

- In DSP, we are concerned with systems that transform one digital signal into another, in particular with those that perform a ***linear*** processing that does not change with time (is ***time-invariant***)

- Linearity means that we can understand the output of a system in **response to a complex input** (like speech) in terms of the **sum of simpler components**

Properties of LTI system

- The properties of LTI system:
  - **Linearity** = *homogeneity + additivity*
  - **Time invariance**

Linearity: homogeneity

Homogeneity implies a proportionality between the level of the input and the level of the output

Is the following system homogenous?

- $y(t) = x(t) + 3x(t-1)$

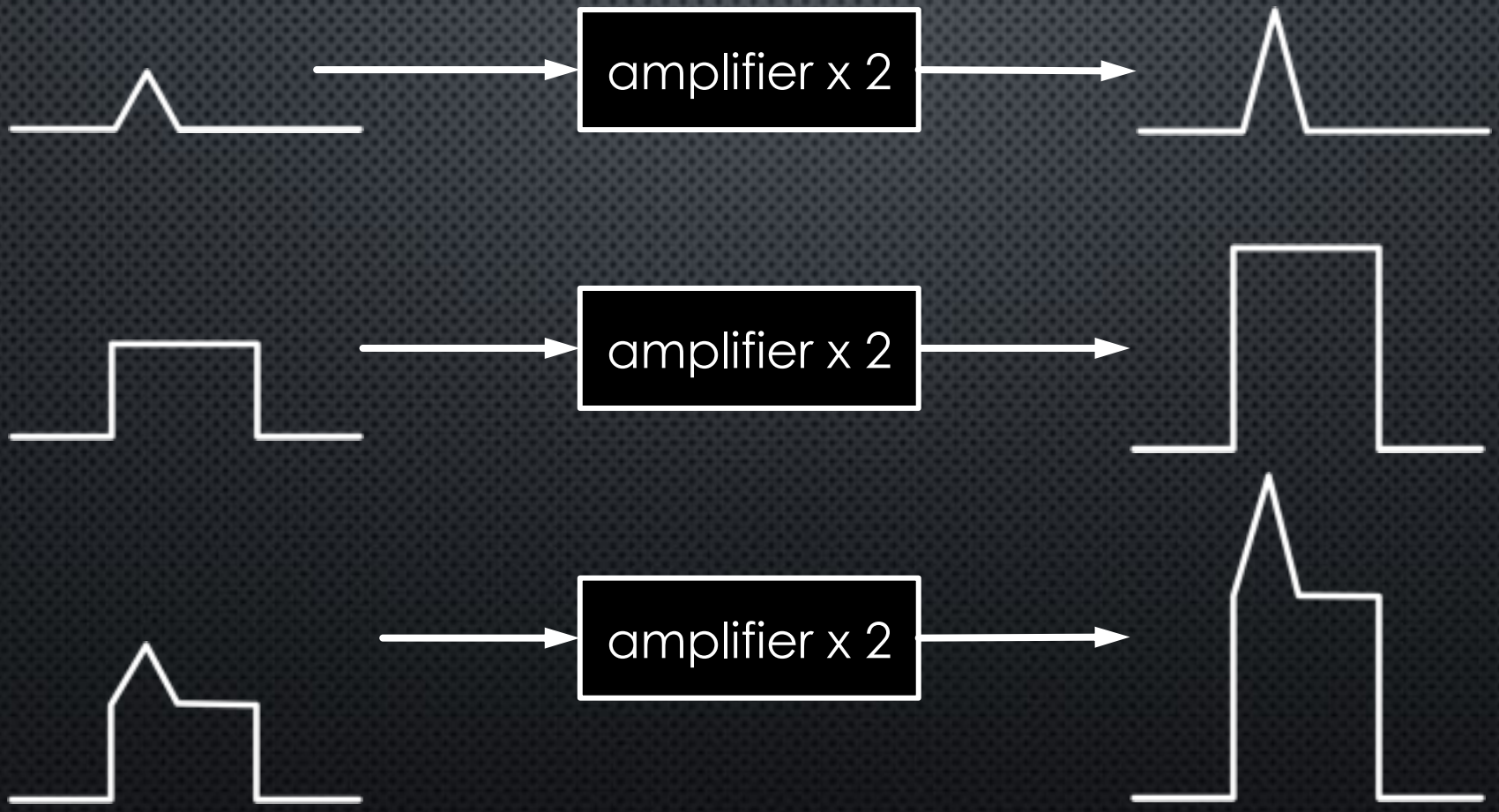
Linearity: additivity

Given the output to each individual input, if the system is additive, the output to the sum of all the inputs is the sum of the separate outputs

Is the following system additive?

- $y(t) = x(t) + 3x(t-1)$

Linearity: additivity



Question

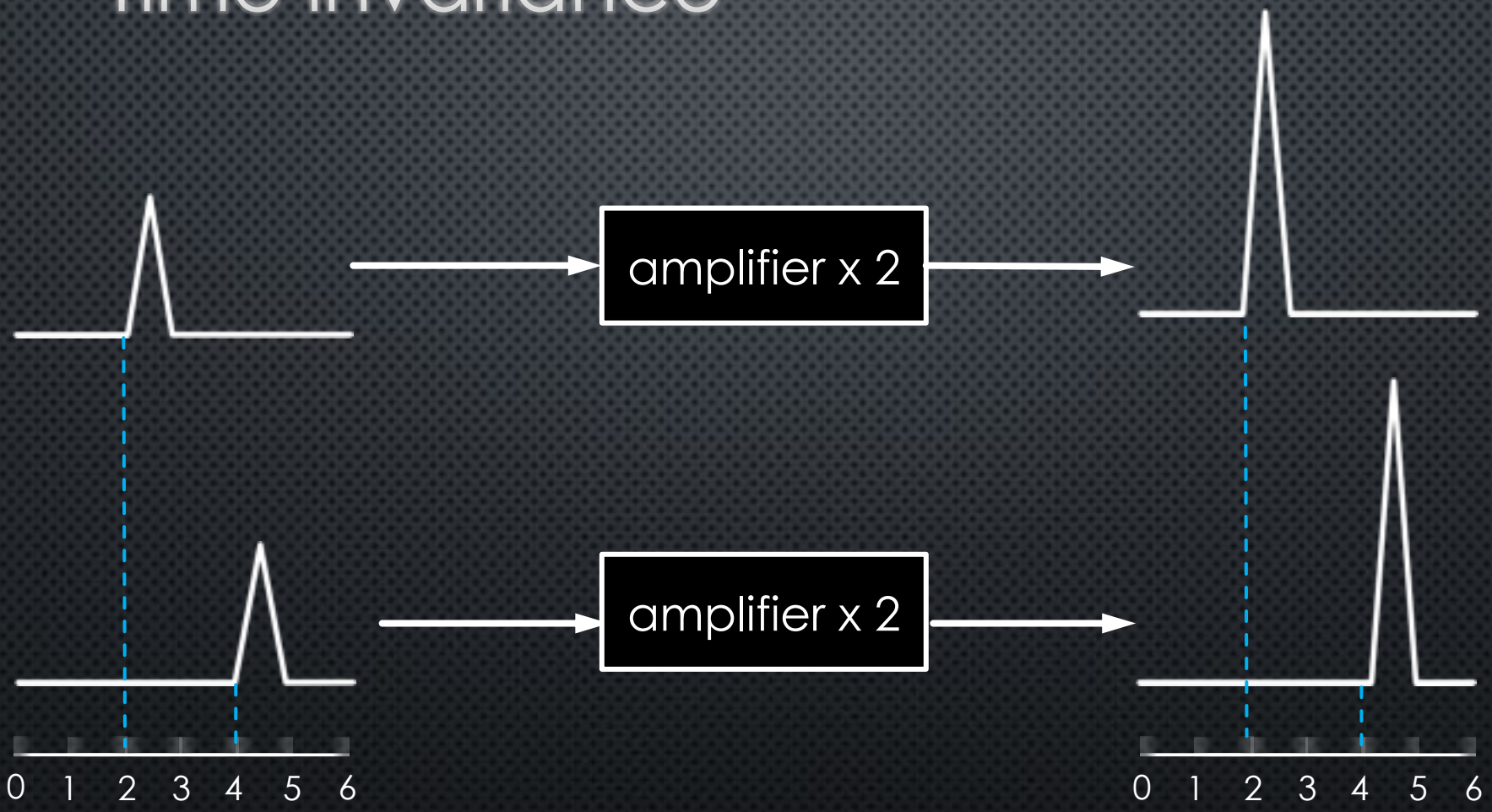
- Is this system linear or non-linear?

$$y(t) = 3x(t) + 5$$

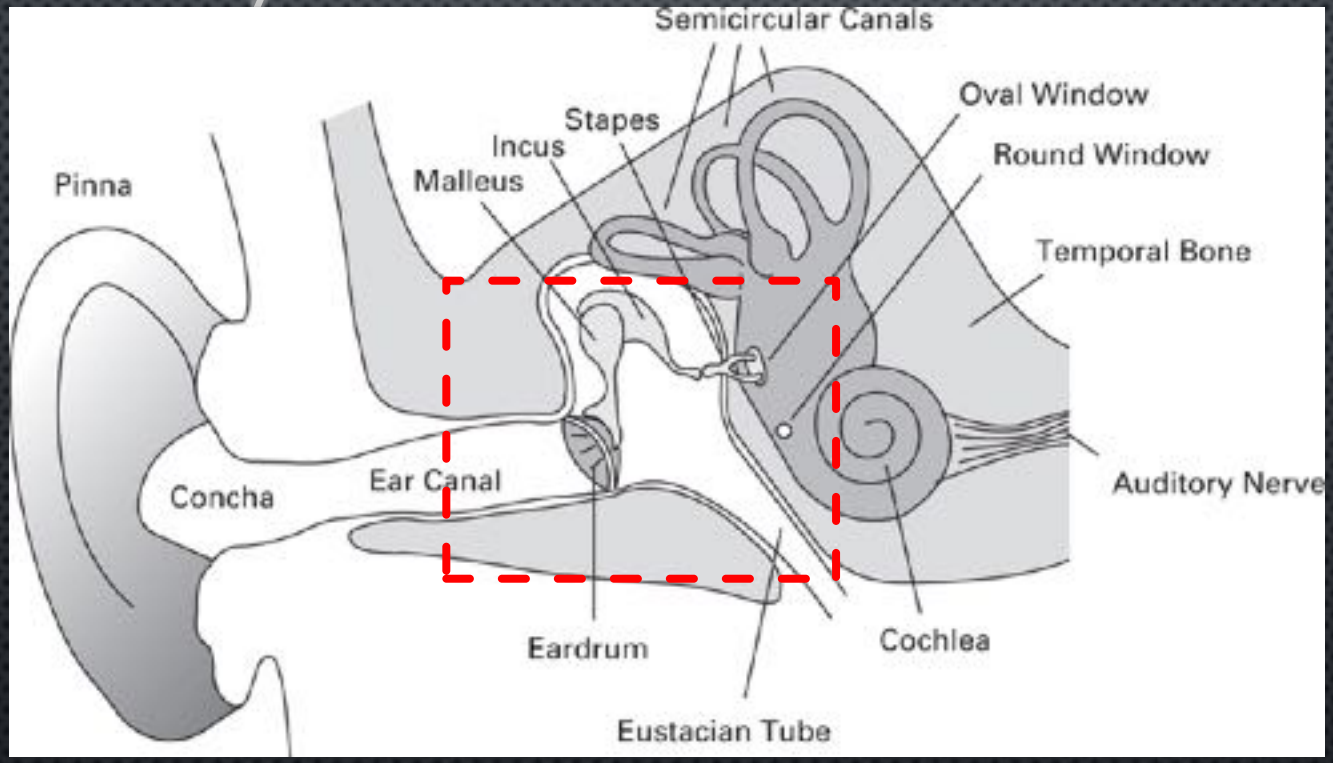
Time invariance

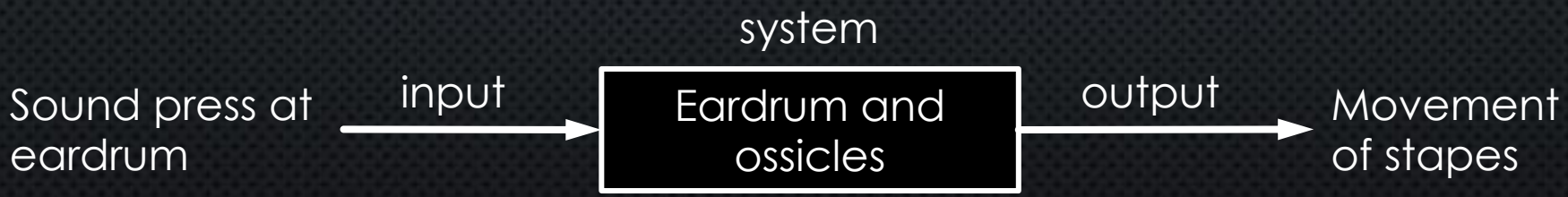
The system behaves the same way, regardless of when the input is applied

Time invariance

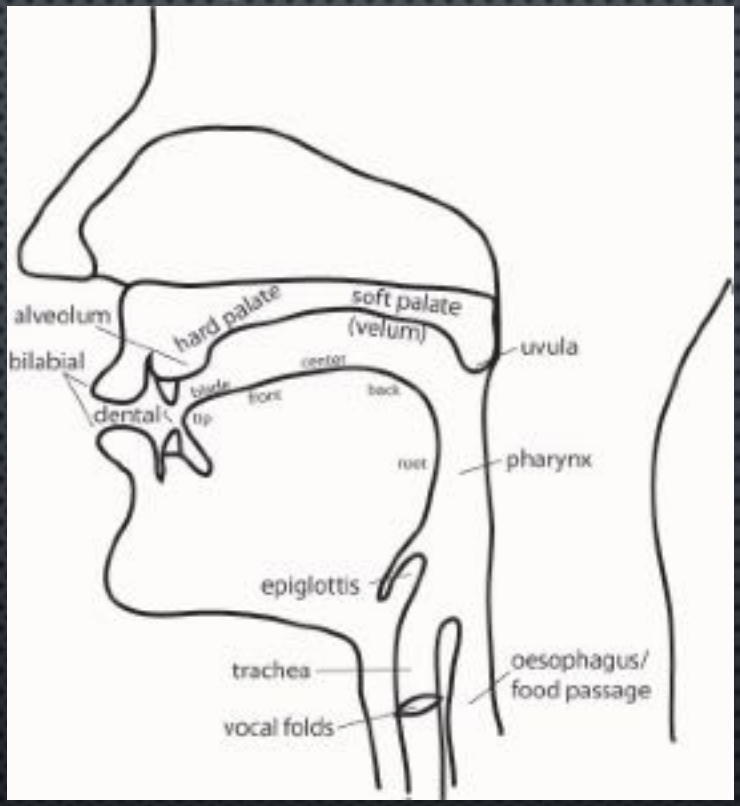


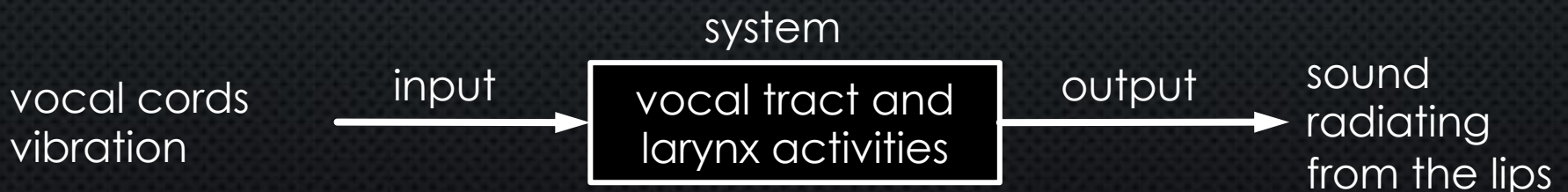
Linear system in real world



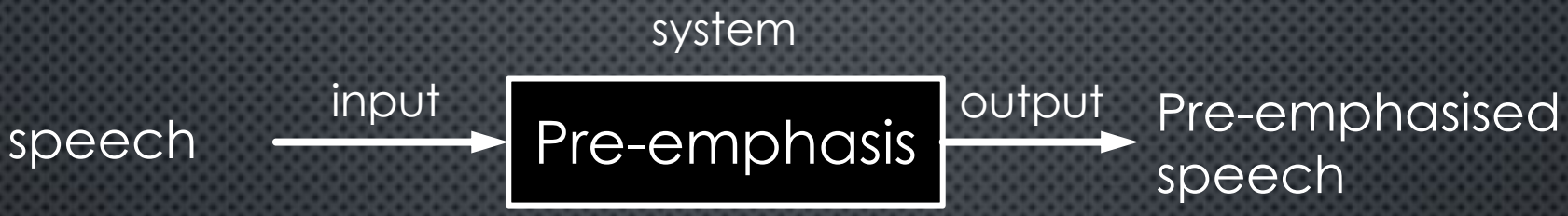


Time-variant system in real world





LTI in DSP: pre-emphasis



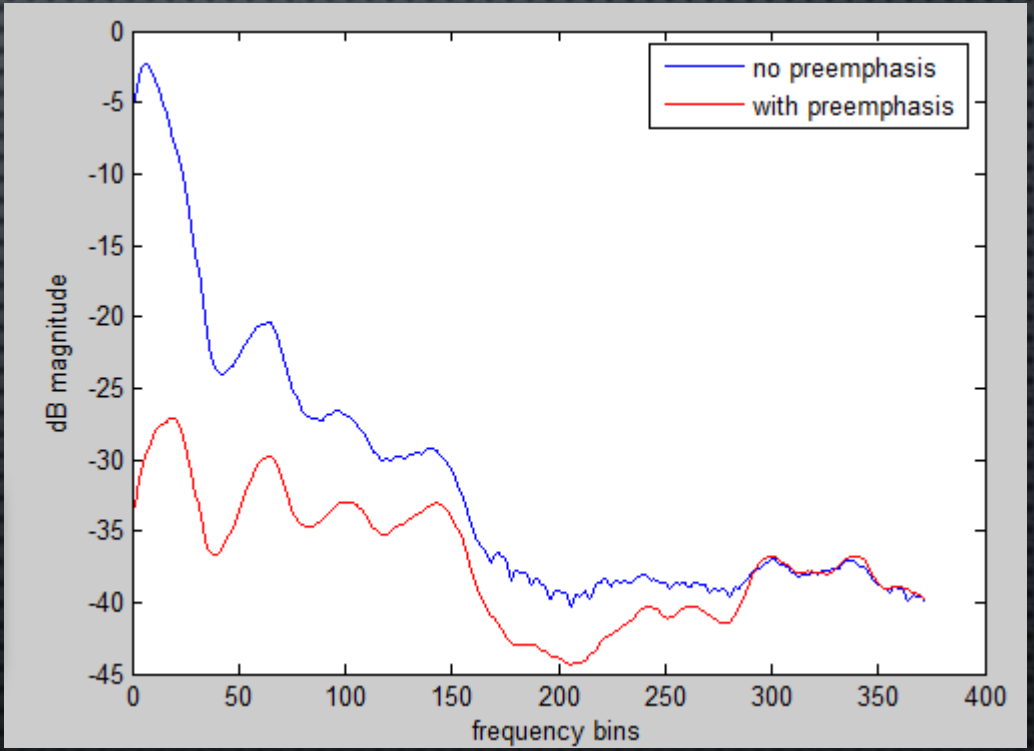
$$y(t) = x(t) - \alpha * x(t-1)$$

i.e. output y at time t is formed by taking the current input $x(t)$ and subtracting 'α' times the previous input, $x(t-1)$

```
x=[1 2 5 4 7];
preemphasis(x,0.98)
    1.0000    1.0200    3.0400   -0.9000    3.0800
```

What does pre-emphasis do?

- The effect of changing spectral tilt to boost the high frequencies in the spectrum
- Pre-emphasis is an example of a **filter**



Relationship between linear and non-linear systems

- LTI system is an ideal model of a subset of systems; it is an approximation to real situation
- Techniques developed for linear system can help understanding non-linear system, e.g. filter
- A linear system may only be *linear* over a limited range of input, e.g. auditory system
- Some parts of non-linear system can be analysed and modelled as LTI system, e.g. vocal tract
- A time-variant system may be treated as a TI system in a short period of time