Ripal Pate

System Classification and properties System Classification

Memory vs. Memoryless

Linear vs.

Time-invarian

vs.

Stable Vs Non-stable

Non-stable

Time domain representation

Linear time-invariant systems (LTI systems) Impulse Response

## Signals and Systems UNIT 2

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Memory vs. Memoryless

Non-caus

Linear vs Nonlinea

I ime-invarian vs. —.

Stable Ve

Invertibilit

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum A continuous-time (discrete-time) system H is an operator that transfer the input x(t) (x[n]) into the output y(t) (y[n]). We denote the process by

$$x(t) \Longrightarrow \left[ \begin{array}{c} H \end{array} \right] \Longrightarrow y(t)$$

$$x(n) \Longrightarrow \left[ H \right] \Longrightarrow y(n)$$

$$y(t) = H[x(t)]$$

Example: y(t) = x(t) + 1

$$y(n) = H[x(n)]$$

Example: 
$$y(n) = x(n)^2$$

Memory vs. Memoryless

Non-caus

\_inear vs Vonlinea

Time-invarian

Time-varian

Stable Vs Non-stable

Invertibility

Time domain representation of LTI System

Linear time-invariant systems (LTI systems) • A system H is memoryless if the value  $y(t_0)$  (i.e.,  $y(t=t_0)$ ) only depends on the value  $x(t_0)$  for any  $t_0$ .

Memory vs. Memoryless

Non-caus

Linear vs Nonlinea

Time-invariant

Time-variant

Stable Vs Non-stable

Time domain representation

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • A system H is memoryless if the value  $y(t_0)$  (i.e.,  $y(t = t_0)$ ) only depends on the value  $x(t_0)$  for any  $t_0$ .

• Current time t:

Current input: x(t)

Past input: x(t-1), x(t-2),...x(t-k)

Future input: x(t+1), x(t+2),...x(t+k)

Memory vs. Memoryless

Non-caus

Nonlinea

vs. Time-variant

Stable Vs

Invertibility

Time domain representatio of LTI Syster

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • A system H is memoryless if the value  $y(t_0)$  (i.e.,  $y(t = t_0)$ ) only depends on the value  $x(t_0)$  for any  $t_0$ .

• Current time t:

Current input: x(t)

Past input: x(t-1), x(t-2),...x(t-k)

Future input: x(t+1), x(t+2),...x(t+k)

• Example:  $y(t) = x^2(t)$  is memoryless since  $y(t_0) = x^2(t_0)$  for  $t_0$ .

Memory vs. Memoryless

Non-caus Linear vs

Time-invariant

Time-variant

Non-stable

Invertibilit

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum • A system H is memoryless if the value  $y(t_0)$  (i.e.,  $y(t = t_0)$ ) only depends on the value  $x(t_0)$  for any  $t_0$ .

• Current time t:

Current input: x(t)

Past input: x(t-1), x(t-2),...x(t-k)

Future input: x(t+1), x(t+2),...x(t+k)

- Example:  $y(t) = x^2(t)$  is memoryless since  $y(t_0) = x^2(t_0)$  for  $t_0$ .
- Example: y(t) = x(t-1) is a system with memory since  $y(t_0) = x(t_01)$ , e.g., y(0) = x(1).  $y(t_0)$  depends on x(t) at  $t = t_01$ , not at  $t_0$ .

Memory vs. Memoryless

Non-caus Linear vs

Time-invarian

vs. Time-variant

Stable Vs

Invertibilit

Time domain representation of LTI System

Linear time-invariar systems (LTI systems) mpulse Response Convolution Sum • A system H is memoryless if the value  $y(t_0)$  (i.e.,  $y(t = t_0)$ ) only depends on the value  $x(t_0)$  for any  $t_0$ .

• Current time t:

Current input: x(t)

Past input: x(t-1), x(t-2),...x(t-k)

Future input: x(t+1), x(t+2),...x(t+k)

- Example:  $y(t) = x^2(t)$  is memoryless since  $y(t_0) = x^2(t_0)$  for  $t_0$ .
- Example: y(t) = x(t-1) is a system with memory since  $y(t_0) = x(t_01)$ , e.g., y(0) = x(1).  $y(t_0)$  depends on x(t) at  $t = t_01$ , not at  $t_0$ .
- In other words, output y(t) at current time  $t=t_0$  is only affected by input x(t) at current time  $t=t_0$

## Memory vs. Memoryless EXAMPLES

Ripal Pate

System
Classification
and properties

Memory vs. Memoryless

Causal vs. Non-causa

Nonlinear

vs. Time-variant

Stable Vs

. ....

Time domain representation of LTI System

Linear time-invariant systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

## Memory vs. Memoryless EXAMPLES

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System
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and properties
System Classification

Memory vs. Memoryless

Causal vs. Non-causa

Nonlinear

VS.

I ime-varian

Non-stable

Time domain representation

Linear time-invariant systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

Answer: Memoryless

## Memory vs. Memoryless EXAMPLES

Ripal Pate

System
Classification
and properties
System Classification

Memory vs. Memoryless

Causal vs. Non-causa

Linear vs

Time-invariar vs. —

Stable Vs

Non-stable

Time domain representation

Linear time-invariant systems (LTI systems) mpulse Response • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Memory vs. Memoryless

Causal vs. Non-causa

Linear vs Nonlinea

Time-invarian

Time-variant

Non-stable

Time domain representation

Linear time-invariar systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

Memory vs. Memoryless

Causal vs Non-caus

Linear vs Nonlinea

Time-invariant

Time-variant

Stable Vs Non-stable

Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

• Problem: y(t) = x(2 - t)

Causal vs. Non-caus

Linear vs Nonlinea

Time-invarian

Time-variant

Non-stable

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) mpulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

• Problem: y(t) = x(2 - t)

Answer: Memory

Memory vs. Memoryless

Causal vs. Non-causal

Linear vs Nonlinea

Time-invaria

vs. Time-variant

Stable Vs

Invertibilit

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

• Problem: y(t) = x(2-t)

Answer: Memory

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Causal vs Non-caus

Nonlinea

Time-invarian
vs.

Time-variant

Stable Vs

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Time domain representation of LTI System

Linear time-invariai systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

• Problem: y(t) = x(2-t)

• Answer: Memory

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Answer: Memory

Causal vs Non-caus

Linear vs Nonlinea

Time-invarian

Time-variant

Stable Vs

nvertibilit

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

• Problem: y(t) = x(2-t)

• Answer: Memory

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Answer: Memory

• Problem:  $y(t) = \frac{d}{dt}x(t)$ 

Non-caus

Nonlinea

Time-invarian

Time-variant

Stable Vs

vertibility

Time domain representation of LTI System

Linear time-invariar systems (LTI systems) mpulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Memoryless

• Problem: y(n) = x(n)x(n-1)

Answer: Memory

• Problem: y(t) = x(2-t)

• Answer: Memory

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Answer: Memory

• Problem:  $y(t) = \frac{d}{dt}x(t)$ 

• Answer: Memory

## System Classification and properties

Memory vs Memoryles

Causal vs. Non-causal

Linear vs Nonlinea

Time-invariar
vs.
Time-variant

Stable Vs

Invertibilit

Time domain representatio of LTI System

systems (LTI systems) Impulse Response Convolution Sum

- A system H is causal if the value  $y(t_0)$  only depends on  $x(t): t \leq t_0$ .
- I.e., current output y(t) is produce by current input x(t) and past input x(t-1), x(t-2), ... x(t-k), not future input x(t+1), x(t+2), ... x(t+k).
- The system y[n] = x[n-1] is causal (y[0] = x[-1])
- The system y[n] = x[n+1] is non-causal (y[0] = x[1])
- The system y(t) = x(t + a) is causal if  $a \le 0$  and is non-causal if a > 0

Causal vs. Non-causal

Linear vs. Nonlinear

Time-invariar vs.

Time-varian

Stable Vs Non-stable

Invertibility

Time domain representation of LTI System

of LTI System

Linear time-invariant systems (LTI systems)

Impulse Response

• Problem: y(n) = nx(n)

#### System Classification and properties

Memory vs.

Causal vs.

Non-causal Linear vs.

Time-invaria

Time-varian

Stable Vs Non-stable

Invertibility

Time domain representation

Linear time-invariant systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

Answer: Causal

Memory vs.

#### Causal vs. Non-causal

Linear vs

Time-invariar

Time-varian

Stable Vs Non-stable

Time domain representation

Linear time-invariant systems (LTI systems) mpulse Response • Problem: y(n) = nx(n)

Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Memoryless Causal vs.

Non-causal

Nonlinea

I ime-invariant vs. T:---

Stable Vs

Invertibility

Time domain representation of LTI Systen

Linear time-invarian systems (LTI systems) mpulse Response Convolution Sum • Problem: y(n) = nx(n)

Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Answer: Causal

Memory vs Memoryless

#### Causal vs. Non-causal

Linear vs Nonlinea

Time-invariant

Time-variant

Stable Vs Non-stable

Time domain representation

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Causal

• Problem: y(n) = x(n)x(n-1)

• Answer: Causal

• Problem: y(t) = x(2 - t)

Memoryles

Causal vs. Non-causal

Linear vs Nonlinea

Time-invariant

Time-variant

Non-stable

Time domain

Linear time-invari systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

• Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Answer: Causal

• Problem: y(t) = x(2 - t)

Answer: Non-causal

Memory vs Memoryles

Causal vs. Non-causal

Nonlinea

Time-invarian

Time-variant

Stable Vs

Invertibilit

Time domain

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Answer: Causal

• Problem: y(t) = x(2 - t)

Answer: Non-causal

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Memory vs Memoryles

Causal vs. Non-causal

Linear vs Nonlinea

Time-invarian

Time-variant

Stable Vs

Invertibilit

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Answer: Causal

• Problem: y(t) = x(2 - t)

Answer: Non-causal

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Answer: Causal

Memory vs Memoryles

Causal vs. Non-causal

Linear vs Nonlinea

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nvertibilit

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Answer: Causal

• Problem: y(t) = x(2 - t)

Answer: Non-causal

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

• Answer: Causal

• Problem:  $y(t) = \frac{d}{dt}x(t)$ 

Memory vs Memoryles

Causal vs. Non-causal

Linear vs Nonlinea

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Invertibility

Time domain representation of LTI System

.inear time-invaria ystems (LTI ystems) mpulse Response Convolution Sum • Problem: y(n) = nx(n)

Answer: Causal

• Problem: y(n) = x(n)x(n-1)

Answer: Causal

• Problem: y(t) = x(2 - t)

Answer: Non-causal

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

• Answer: Causal

• Problem:  $y(t) = \frac{d}{dt}x(t)$ 

• Answer: Causal

Memory vs Memoryles

Causal vs. Non-causa

Linear vs. Nonlinear

vs.

Carble Ma

Invertibilit

Time domain representation of LTL System

systems (LTI systems) Impulse Response Convolution Sum • H is called linear if H has the superposition property:

$$H[a_1x_1(t) + a_2x_2(t)] = a_1H[x_1(t)] + a_2H[x_2(t)]$$

where, 
$$y_1(t) = H[x_1(t)]$$
 and  $y_2(t) = H[x_2(t)]$ 

• The response of a weighted sum of input signals is equal to the same as weighted sum of output signals.

$$\frac{\chi_{(t)}}{H} \rightarrow \psi_{(t)}$$

$$\Rightarrow \frac{G\chi_{(t)} + G\chi_{(t)}}{H} \rightarrow \psi_{(t)} + G\psi_{(t)}$$

Ripal Pate

System Classification and properties System Classificatio

Causal vs.

Linear vs. Nonlinear

Time-invarian

Carle V/a

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum y(n)=x(n-3)

• Two output signals

$$y_1(n) = H[x_1(n)] = x_1(n-3)$$

$$y_2(n) = H[x_2(n)] = x_2(n-3)$$

•

$$H[a_1x_1(n) + a_2x_2(n)] = a_1x_1(n-3) + a_2x_2(n-3)$$

$$= a_1H[x_1(n)] + a_2H[x_2(n)]$$

$$= a_1y_1(n) + a_2y_2(n)$$

Hence, system is LINEAR.

Linear vs. Nonlinear

$$y(t) = x^2(t)$$

Two output signals

$$y_1(n) = H[x_1(t)] = x_1^2(t)$$

$$y_2(n) = H[x_2(t)] = x_2^2(t)$$

I HS:

$$H[a_1x_1(t) + a_2x_2(t)] = [a_1x_1(t) + a_2x_2(t)]^2$$

RHS:

$$a_1H[x_1(t)] + a_2H[x_2(t)] = a_1x_1^2(t) + a_2x_2^2(t)$$

LHS  $\neq$  RHS. Hence, system is NON-LINEAR.



Memory vs Memoryless

Causal vs. Non-causa

Linear vs. Nonlinear

Time-invarian

Time-varian

Time domain representation of LTI System

.inear time-invarian ystems (LTI ystems) mpulse Response Convolution Sum y(n) = nx(n)

$$y_1(n) = H[x_1(n)] = nx_1(n)$$

$$y_2(n) = H[x_2(n)] = nx_2(n)$$

$$H[a_1x_1(n) + a_2x_2(n)] = a_1nx_1(n) + a_2nx_2(n)$$

$$= a_1H[x_1(n)] + a_2H[x_2(n)]$$

$$a_1y_1(n) + a_2y_2(n)$$

Hence, system is LINEAR.

Ripal Pate

System Classification and properties System Classification

Memoryle Causal vs

Linear vs.

Time-invarian vs.

Time-varian

Invortibilit

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum

Two output signals

$$y_1(n) = H[x_1(n)] = x_1(n)x_1(n-1)$$

y(n) = x(n)x(n-1)

$$y_2(n) = H[x_2(n)] = x_2(n)x_2(n-1)$$

•

$$H[a_1x_1(n) + a_2x_2(n)] = a_1x_1(n)x_1(n-1) + a_2x_2(n)x_2(n-1)$$

$$= a_1H[x_1(n)] + a_2H[x_2(n)]$$

$$a_1y_1(n) + a_2y_2(n)$$

Hence, system is LINEAR.

Linear vs.

Nonlinear

## $y(t) = \frac{d}{dt}x(t)$

Two output signals

$$y_1(n) = H[x_1(t)] = \frac{d}{dt}x_1(t)$$
  
 $y_2(n) = H[x_2(t)] = \frac{d}{dt}x_2(t)$ 

I HS:

$$H[a_1x_1(t) + a_2x_2(t)] = \frac{d}{dt}[a_1x_1(t) + a_2x_2(t)]$$
  
=  $a_1\frac{d}{dt}x_1(t) + a_2\frac{d}{dt}x_2(t)$ 

RHS:

$$a_1H[x_1(t)] + a_2H[x_2(t)] = a_1\frac{d}{dt}x_1(t) + a_2\frac{d}{dt}x_2(t)$$

Memoryles

Non-caus

Time-invariant

Time-variant

. .....

Time domain representation of LTL System

systems (LTI systems) Impulse Response Convolution Sum • H is called time-invariant if the following is true:

$$H[x(t)] = y(t) \Longrightarrow H[x(t-t_0)] = y(t-t_0)$$

• I.e., a time-shift to in the input x(t) results in an identical time-shift to in the output.

$$\frac{\mathsf{Y}(t)}{\mathsf{H}} \Rightarrow \frac{\mathsf{Y}(t-t_0)}{\mathsf{H}} \Rightarrow \frac{\mathsf{Y}(t-t_0)}{\mathsf{H}}$$

Time-invariant

Time-variant

$$y(t)=e^{x(t)}$$

$$y(t) = e^{x(t)}$$

$$H(x(t - t_0) = e^{x(t - t_0)})$$
  
 $y(t - t_0) = e^{x(t - t_0)}$ 

Memoryle: Causal vs.

Linear vs.

Time-invariant

vs.

Time-variant

Non-stable

Time domain representation

Linear time-invaria systems (LTI systems)  $y(t) = e^{x(t)}$ 

$$H(x(t-t_0) = e^{x(t-t_0)})$$
  
 $y(t-t_0) = e^{x(t-t_0)}$ 

$$y(t) = g(t)x(t)$$

Time-variant

## Time-invariant vs. Time-variant EXAMPLE

$$y(t) = g(t)x(t)$$

$$H(x(t - t_0) = g(t)x(t - t_0))$$
$$y(t - t_0) = g(t - t_0)x(t - t_0)$$

Time-variant

$$y(t) = g(t)x(t)$$

$$H(x(t-t_0) = g(t)x(t-t_0))$$
  
 $y(t-t_0) = g(t-t_0)x(t-t_0)$ 

$$y(n)=x(n-k)$$

$$y(n)=x(n-k)$$

$$H(x(n-k-n_0)) = x(n-k-n_0)$$
$$y(n-k-n_0) = x(n-k-n_0)$$

Memoryle Causal vs.

Linear vs

Time-invariant

Time-variant

Stable Vs Non-stable

Time domain representation

of LTI Systen
Linear time-invarial
systems (LTI
systems)
Impulse Response

$$y(n) = x(n-k)$$

•

$$H(x(n-k-n_0)) = x(n-k-n_0)$$
$$y(n-k-n_0) = x(n-k-n_0)$$

System Classification and properties

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Stable Vs

Time domain representation

Linear time-invarian systems (LTI

Impulse Respons

y(t) = x(2t)

System
Classification
and properties
System Classification

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vs. Time-variant

Culle Me

Non-stable

invertibility

Time domain representation of LTI System

Linear time-invarian systems (LTI systems) Impulse Response

$$y(t) = x(2t)$$

$$H(x(t-t_0) = x(2t-t_0))$$
$$y(t-t_0) = x(2(t-t_0))$$

Time-variant

$$y(t) = x(2t)$$

$$H(x(t - t_0) = x(2t - t_0))$$
$$y(t - t_0) = x(2(t - t_0))$$

$$y(t) = \sin[x(t)]$$

System
Classification
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Time domain representation of LTL System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum

$$y(t) = \sin[x(t)]$$

$$H(x(t - t_0) = \sin[x(t - t_0)]$$
$$y(t - t_0) = \sin[x(t - t_0)]$$

Time-variant

$$y(t) = \sin[x(t)]$$

 $H(x(t-t_0) = \sin[x(t-t_0)]$  $y(t-t_0) = \sin[x(t-t_0)]$ 

Memory

Causal vs.

Linear vs.

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vs. Time-variant

Stable Vs

Time domain representation

Linear time-invarian systems (LTI

Impulse Respons

 $y(t) = x[\cos t]$ 

$$y(t) = x[\cos t]$$

$$H(x(t - t_0) = x[\cos t - t_0]$$
  
 $y(t - t_0) = x[\cos(t - t_0)]$ 

Time-variant

$$y(t) = x[\cos t]$$

 $H(x(t-t_0)=x[\cos t-t_0]$  $y(t-t_0) = x[\cos(t-t_0)]$ 

$$y(t) = \cos t.x(t)$$

$$y(t) = \cos t.x(t)$$

$$H(x(t - t_0) = \cos t.x(t - t_0))$$
$$y(t - t_0) = \cos(t - t_0).x(t - t_0)$$

System
Classification
and properties
System Classification

Memoryle Causal vs

Linear vs

Time-invariant

Time-variant

Stable Vs Non-stable

Time domain representation

Linear time-invariar systems (LTI systems) Impulse Response

ess .

$$y(t) = \cos t.x(t)$$

•

$$H(x(t - t_0) = \cos t.x(t - t_0))$$
$$y(t - t_0) = \cos(t - t_0).x(t - t_0)$$

vs. Time-variant

Stable Vs Non-stable

Time domain representation

of LTI System
Linear time-invariant
systems (LTI
systems)
Impulse Response

• Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

Memoryles

Causal vs. Non-causa

Nonlinea

Time-invariant

Time-variant

Stable Vs Non-stable

Time domain representation

Linear time-invariant systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

$$y_d(t) = \int_{-\infty}^{t/2} x(\tau - d)d\tau$$
$$= \int_{-\infty}^{t/2-d} x(s)ds$$
$$= \int_{-\infty}^{(t-2d)/2} x(s)ds$$
$$= y(t-2d).$$

Memory vs Memoryles

Causal vs. Non-caus

Linear vs Nonlinea

Time-invariant

Time-variant

Stable Vs Non-stable

Invertibility

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = \int_{-\infty}^{t/2} x(\tau) d\tau$ 

$$y_d(t) = \int_{-\infty}^{t/2} x(\tau - d)d\tau$$
$$= \int_{-\infty}^{t/2 - d} x(s)ds$$
$$= \int_{-\infty}^{(t - 2d)/2} x(s)ds$$
$$= y(t - 2d).$$

 Time-variant: Therefore, it does not obey the time-invariance condition. System
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Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response • Problem:  $y(t) = \int_{-\infty}^{t} x(\tau) d\tau$ 

Memoryle Causal vs.

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Time domain representation

Linear time-invariar systems (LTI systems) Impulse Response • Problem:  $y(t) = \int_{-\infty}^{t} x(\tau) d\tau$ 

The integrator system is also a time-invariant system. To prove this, we replace  $x(\tau)$  in (9.30) by  $x(\tau - t_0)$  obtaining the output w(t)

$$w(t) = \int_{-\infty}^{t} x(\tau - t_0)d\tau \tag{9.35}$$

Now, to prove time-invariance, we must manipulate the integral in (9.35) into a form that is recognizable in terms of the original output y(t). This is done by changing the "dummy variable" of integration to  $\sigma = \tau - t_0$ . In this substitution,  $d\tau$  is replaced by  $d\sigma$ , the lower limit  $\tau = -\infty$  becomes  $\sigma = -\infty$ , and the upper limit  $\tau = t$  becomes  $\sigma = t - t_0$ . Therefore (9.35) becomes

$$w(t) = \int_{-\infty}^{t-t_0} x(\sigma) d\sigma$$

and it is now clear that  $w(t) = y(t - t_0)$ , so the integrator system is seen to be time-invariant.

Time-variant

• Problem:  $y(t) = \frac{d}{dt}x(t)$ 

Memoryles

Linear vs.

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Time domain

Linear time-invariant systems (LTI systems) Impulse Response • Problem:  $y(t) = \frac{d}{dt}x(t)$ 

• The derivative of a time-shifted signal is

$$y_d(t) = \frac{d}{dt}[x(t-d)] = \frac{dx}{dt}(t-d)\frac{d}{dt}(t-d) = \frac{dx}{dt}(t-d) = y(t-d).$$

Time-variant

- Problem:  $y(t) = \frac{d}{dt}x(t)$
- The derivative of a time-shifted signal is

$$y_d(t) = \frac{d}{dt}[x(t-d)] = \frac{dx}{dt}(t-d)\frac{d}{dt}(t-d) = \frac{dx}{dt}(t-d) = y(t-d).$$

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems) mpulse Response • Problem: y(n) = 2x(n)u(n)

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Time domain

Linear time-invari systems (LTI systems) Impulse Response Convolution Sum

- Problem: y(n) = 2x(n)u(n)
- Not Time Invariant. The time-invariance condition does not hold, because the signal that is being multiplied by x(n) varies with time.

## Time-invariant vs. Time-variant EXAMPLE

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems) mpulse Response • Problem: y(t) = x(2 - t)

• Problem: 
$$y(t) = x(2 - t)$$

$$H(x(t-t_0) = x(2-t-t_0))$$
$$y(t-t_0) = x(2-(t-t_0)) = x(2-t+t_0)$$

Memoryle Causal vs.

Linear vs.

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nvertibility

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(t) = x(2 - t)

 $H(x(t-t_0) = x(2-t-t_0))$ 

$$y(t-t_0) = x(2-(t-t_0)) = x(2-t+t_0)$$

Time-variant

• Problem: y(n) = nx(n)

System
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Time domain representation

Linear time-invarian systems (LTI systems) • Problem: y(n) = nx(n)

Answer: Time-variant

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Time domain representation

Linear time-invariant systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Time-variant

• Problem: y(n) = x(n)x(n-1)

Memoryles

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Linear time-invaria systems (LTI systems) Impulse Response • Problem: y(n) = nx(n)

Answer: Time-variant

• Problem: y(n) = x(n)x(n-1)

Answer: Time-invariant

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Time domain representatio of LTI System

Linear time-invari systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Time-variant

• Problem: y(n) = x(n)x(n-1)

• Answer: Time-invariant

• Problem: y(t) = x(2 - t)

Causal vs.

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Time domain representation of LTI System

Linear time-invarii systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = nx(n)

• Answer: Time-variant

• Problem: y(n) = x(n)x(n-1)

• Answer: Time-invariant

• Problem: y(t) = x(2 - t)

• Answer: Time-variant

Memoryle

Linear vs Nonlinea

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Non-stable

Time domain representation

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum

- A system is said to be Bounded Input Bounded Output (BIBO) stable if and only if every bounded input results in bounded output.
- System H is BIBO stable if  $|x(t)| \le M_x < \infty$  then  $|y(t)| \le M_y < \infty$  for all t

Stable Vs Non-stable

• Problem:  $y(t) = x(t - t_0)$ 

Memoryles

Linear vs.

Time-invarian

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Stable Vs

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Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response • Problem:  $y(t) = x(t - t_0)$ 

• Bounded Input

$$|x(t)| \leq M_x < \infty$$

Memoryle:

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Stable Vs

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Time domain

Linear time-invarian systems (LTI systems) Impulse Response • Problem:  $y(t) = x(t - t_0)$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|x(t-t_0)| \leq M_x < \infty$$

Causal vs.

Linear vs Nonlinea

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Time domain representation of LTI System

Linear time-invarii systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = x(t - t_0)$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|x(t-t_0)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)| = |x(t - t_0)| \le M_x < \infty$$

Memoryles

Linear vs Nonlinea

Time-invarian vs.
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Stable Vs

Non-stable Invertibility

Time domain representation of LTI System

inear time-invariar ystems (LTI ystems) mpulse Response Convolution Sum • Problem:  $y(t) = x(t - t_0)$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|x(t-t_0)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)|=|x(t-t_0)|\leq M_x<\infty$$

• BIBO condition satisfied. Hence, stable.

Stable Vs Non-stable

• Problem: y(n) = x(-n)

Memory vs. Memoryless

Causal vs.

Linear vs. Nonlinear

Time-invariar vs.

Time-varian

Stable Vs

Non-stable

Time domain representation

Linear time-invariant systems (LTI systems) • Problem: y(n) = x(-n)

Bounded Input

$$|x(n)| \leq M_x < \infty$$

Memoryle Causal vs.

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Stable Vs

Non-stable

Time domain representatio of LTI System

Linear time-invarii systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = x(-n)

Bounded Input

$$|x(n)| \leq M_x < \infty$$

• By time reversing input x(n) by

$$|x(-n)| \leq M_x < \infty$$

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Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = x(-n)

Bounded Input

$$|x(n)| \leq M_x < \infty$$

• By time reversing input x(n) by

$$|x(-n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |x(-n)| \le M_x < \infty$$

Memoryle Causal vs.

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Time domain representation of LTI System

.inear time-invarial ystems (LTI ystems) mpulse Response Convolution Sum • Problem: y(n) = x(-n)

Bounded Input

$$|x(n)| \leq M_x < \infty$$

• By time reversing input x(n) by

$$|x(-n)| \leq M_x < \infty$$

Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |x(-n)| \le M_x < \infty$$

• BIBO condition satisfied. Hence, stable.

Memory vs. Memoryless

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems)

mpulse Response

• Problem:  $y(t) = [\sin 6t]x(t)$ 

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Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response • Problem:  $y(t) = [\sin 6t]x(t)$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

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Memoryle:

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Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = [\sin 6t]x(t)$ 

• Bounded Input

$$|x(t)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)| = |\sin 6t||x(t)|$$

Now,

$$|\sin 6t| \leq 1$$

$$|x(t)| \leq M_x < \infty$$

y(t) is also bounded.

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Time domain representation of LTI System

Linear time-invarian systems (LTI systems) mpulse Response Convolution Sum • Problem:  $y(t) = [\sin 6t]x(t)$ 

• Bounded Input

$$|x(t)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)| = |\sin 6t||x(t)|$$

Now,

$$|\sin 6t| \leq 1$$

$$|x(t)| \leq M_x < \infty$$

y(t) is also bounded.

• BIBO condition satisfied. Hence, stable.

Memory vs Memoryles

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems)

Impulse Response Convolution Sum • Problem: y(n) = x(n) + n

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Causal vs.

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Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response • Problem: y(n) = x(n) + n

Bounded Input

$$|x(n)| \leq M_x < \infty$$

Memoryles

Linear vs Nonlinea

Time-invarian vs.
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Stable Vs

Non-stable

Time domain representation of LTI System

Linear time-invari systems (LTI systems) Impulse Response Convolution Sum • Problem: y(n) = x(n) + n

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |x(n) + n| = |x(n)| + |n|$$

As  $n \to \infty$ ,  $y(n) \to \infty$  means output is not bounded.

Memory vs Memoryles

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Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum

• Problem: 
$$y(n) = x(n) + n$$

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |x(n) + n| = |x(n)| + |n|$$

As  $n \to \infty$ ,  $y(n) \to \infty$  means output is not bounded.

BIBO condition not-satisfied. Hence, Unstable.

System Classification and properties

Memory vs. Memoryless

Ivon-caus Linear vs.

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Time domain representation of LTI System

of LTI System Linear time-invariant systems (LTI systems)

Impulse Respons

• Problem:  $y(t) = x(\frac{t}{2})$ 

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Impulse Response

• Problem:  $y(t) = x(\frac{t}{2})$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

Memoryles

Linear vs

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Time-varian

Stable Vs Non-stable

Invertibilit

Time domain representation of LTI System

Linear time-invarian systems (LTI systems) Impulse Response • Problem:  $y(t) = x(\frac{t}{2})$ 

Bounded Input

$$|x(t)| \leq M_{x} < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|x(\frac{t}{2})| \le M_x < \infty$$

Memoryles

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Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = x(\frac{t}{2})$ 

• Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|x(\frac{t}{2})| \le M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)|=|x(\frac{t}{2})|\leq M_x<\infty$$

Memoryles Causal vs.

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Time domain representation of LTI System

Linear time-invarian systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = x(\frac{t}{2})$ 

• Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|x(\frac{t}{2})| \le M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)|=|x(\frac{t}{2})|\leq M_x<\infty$$

• BIBO condition satisfied. Hence, stable.

Stable Vs Non-stable

• Problem:  $y(t) = e^{x(t)}$ 

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Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response • Problem:  $y(t) = e^{x(t)}$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

Memory vs. Memoryless

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Time domain representatio

Linear time-invarian systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = e^{x(t)}$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|e^{x(t)}| \le M_x < \infty$$

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Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(t) = e^{x(t)}$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|e^{x(t)}| \le M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)| = |e^{x(t)}| \le M_x < \infty$$

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Time domain representation of LTI System

inear time-invarian ystems (LTI ystems) mpulse Response Convolution Sum • Problem:  $y(t) = e^{x(t)}$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

• By shifting input x(t) by  $t_0$ 

$$|e^{x(t)}| \le M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)|=|e^{x(t)}|\leq M_x<\infty$$

• BIBO condition satisfied. Hence, stable.

Stable Vs Non-stable

• Problem:  $y(n) = \cos[x(n)]$ 

Memoryles
Causal vs.

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems) Impulse Response • Problem:  $y(n) = \cos[x(n)]$ 

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

Ripal Pate

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Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(n) = \cos[x(n)]$ 

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |\cos[x(n)]|$$

As  $|\cos[x(n)| \le 1$ ,  $y(n) \to \infty$  means output is bounded.

Causal vs.

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Time domain representation of LTI System

Linear time-invariai systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(n) = \cos[x(n)]$ 

Bounded Input

$$|x(n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |\cos[x(n)]|$$

As  $|\cos[x(n)| \le 1$ ,  $y(n) \to \infty$  means output is bounded.

BIBO condition satisfied. Hence, stable.

System Classification and properties

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• Problem:  $y(n) = x(n)^2$ 

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Time domain representation

of LTI System Linear time-invariant systems (LTI systems) Impulse Response • Problem:  $y(n) = x(n)^2$ 

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

Memory vs Memoryless

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Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum • Problem:  $y(n) = x(n)^2$ 

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |x(n)^2|$$

As  $|x(n)^2| \le M_x^2 \le \infty$  means output is bounded.

# System Classification and properties

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Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum

## • Problem: $y(n) = x(n)^2$

• Bounded Input

$$|x(n)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(n)| = |x(n)^2|$$

As  $|x(n)^2| \le M_x^2 \le \infty$  means output is bounded.

• BIBO condition satisfied. Hence, stable.

Memory vs. Memoryless

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inear time-invariant systems (LTI systems)

Impulse Respons

• Problem:  $y(t) = \int_{-\infty}^{t} x(\tau) d\tau$ 

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Time domain representation

Linear time-invariant systems (LTI systems) Impulse Response • Problem:  $y(t) = \int_{-\infty}^{t} x(\tau) d\tau$ 

• Bounded Input

$$|x(t)| \leq M_x < \infty$$

Memory vs Memoryless

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> Linear time-invaria systems (LTI systems) mpulse Response Convolution Sum

• Problem:  $y(t) = \int_{-\infty}^{t} x(\tau) d\tau$ 

Bounded Input

$$|x(t)| \leq M_x < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)| = |\int_{-\infty}^{t} x(\tau)d\tau|$$

let's take x(t) = u(t)

$$|u(t)|=1$$

$$|y(t)| = |\int_{-\infty}^t x(\tau)d\tau| = |\int_{-\infty}^t 1d\tau| = [\tau]_{-\infty}^t = t + \infty$$

if 
$$t \to \infty$$
 then  $|y(t)| \to \infty$ 

Memory vs. Memoryless

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Time domain representation of LTI Syster

Linear time-invaria systems (LTI systems) mpulse Response Convolution Sum • Problem:  $y(t) = \int_{-\infty}^{t} x(\tau) d\tau$ 

Bounded Input

$$|x(t)| \leq M_{x} < \infty$$

 Taking magnitude on both sides of input-output relationship,

$$|y(t)| = |\int_{-\infty}^{t} x(\tau)d\tau|$$

let's take x(t) = u(t)

$$|u(t)|=1$$

$$|y(t)| = |\int_{-\infty}^{t} x(\tau)d\tau| = |\int_{-\infty}^{t} 1d\tau| = [\tau]_{-\infty}^{t} = t + \infty$$

if  $t \to \infty$  then  $|y(t)| \to \infty$ 

• BIBO condition not satisfied. Hence, Unstable.

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Non-stable Invertibility

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Linear time-invariant systems (LTI systems) Impulse Response  A system is said to be invertible if the input to the system may be uniquely determined from the output.

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems) Impulse Response

- A system is said to be invertible if the input to the system may be uniquely determined from the output.
- Distinct inputs produce distinct outputs

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Time domain representation of LTI System

Linear time-invari systems (LTI systems) Impulse Response Convolution Sum

- A system is said to be invertible if the input to the system may be uniquely determined from the output.
- Distinct inputs produce distinct outputs
- A system is said to be invertible, if the inverse of that system exists.

$$y(t) = T[x(t)] \Rightarrow x(t) = T_i[y(t)]$$
$$y(t) = T[x(t)] = 10x(t) \Rightarrow x(t) = T_i[y(t)] = 0.1y(t)$$

System Classification and properties

Memory vs Memoryles

Linear vs

Time-invarian

vs. Time-variant

Non-stable

Invertibility

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum To test for invertibilty, we use two different techniques:

 We may show that a system is invertible by designing an inverse system that uniquely recovers the input from output.

Memoryles

Linear vs

Time-invariar

vs. Time-variant

Invertibility

Time domain representation of LTL System

Linear time-invari systems (LTI systems) Impulse Response Convolution Sum To test for invertibilty, we use two different techniques:

- We may show that a system is invertible by designing an inverse system that uniquely recovers the input from output.
- We may show that system is not invertible by finding two different inputs that produce the same output.

System Classification and properties

Memoryle

Linear vs.

Time-invaria

VS.

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Stable Vs

#### Invertibility

Time domain representation of LTI System

Linear time-invarian systems (LTI

Impulse Respons

y[n] = 2x[n]

Ripal Pate

System
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Time-variant

Non-stable

Invertibility

Time domain representation of LTI System

Linear time-invarian systems (LTI systems) Impulse Response •

$$y[n] = 2x[n]$$

• For given output y[n], we may recover the input using

$$x[n] = \frac{1}{2}y[n]$$

Ripal Pate

ystem
Classification
Ind properties
System Classification

Memoryle Causal vs.

Linear vs Nonlinea

Time-invariant vs.

Stable Vs

Invertibility

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum

oryless

$$y[n] = 2x[n]$$

• For given output y[n], we may recover the input using

$$x[n] = \frac{1}{2}y[n]$$

• Hence, system is invertible.

Ripal Patel

System Classification and properties

Memory v

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Linear vs.

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Time domain representation of LTL System

Linear time-invarian systems (LTI systems)

Impulse Respons

y(n) = Re[x(n)]

Ripal Pate

System
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Time-varian

Stable Vs

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems) Impulse Response Convolution Sum v(n

$$y(n) = Re[x(n)]$$

Two different inputs can produce same output.

$$y(n) = Re[x(n)] = Re[2 - j2] = 2$$

$$y(n) = Re[x(n)] = Re[2 + j2] = 2$$

Ripal Pate

System
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Time-variant

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Time domain representation of LTI System

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Hence, system is not-invertible.

Ripal Patel

System Classification and properties

Memory v

Causal vs.

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Time domain representation of LTI System

Linear time-invariant systems (LTI systems)

Impulse Respons

 $y(t) = \cos[x(t)]$ 

Memoryles
Causal vs.

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Time-invariant

Time-variant

Stable Vs

Invertibility

Time domain representation of LTL System

Linear time-invariat systems (LTI systems) Impulse Response Convolution Sum •

$$y(t) = \cos[x(t)]$$

• Two different inputs can produce same output.

$$y(t) = \cos[x(t)] = \cos[0] = 1$$

$$y(t) = \cos[x(t)] = \cos[2\pi] = 1$$

Ripal Pate

System
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Time-invariant vs.

Time-variant

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Time domain representation of LTI System

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#### Invertibility

$$y(n) = x[n] + 0.5x[n-1]$$

Causal vs

Linear vs Nonlinea

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vs.
Time-variant

Stable Vs

Invertibility

Time domain representatio of LTI System

Linear time-invariant systems (LTI systems) Impulse Response Convolution Sum

$$y(n) = x[n] + 0.5x[n-1]$$

• For the given system the inverse of the system is possible,

$$x(n) = y[n] - 0.5x[n-1]$$

Invertibility

$$y(n) = x[n] + 0.5x[n-1]$$

For the given system the inverse of the system is possible,

$$x(n) = y[n] - 0.5x[n-1]$$

Hence, system is Invertible.

#### Invertibility

$$y(n) = x^2[n]$$

Ripal Pate

System
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Time domain representation of LTL System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum •

$$y(n) = x^2[n]$$

• Two different inputs can produce same output.

$$y(n) = x^2[n] = (-2)^2 = 4$$

$$y(n) = x^2[n] = (2)^2 = 4$$

Ripal Pate

System Classification and properties System Classificatio

Causal vs.

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Time-invariant vs. ---

Time-varian

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Time domain representation of LTI System

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Memory vs.

Non-caus Linear vs.

Nonlinear

Time-invarian vs.

Time-varian

Stable Vs

#### Invertibility

Time domain representation of LTI System

Linear time-invaria systems (LTI

Impulse Resp

Convolution Su

$$y(t) = 2^{-x(t)}$$

Memory vs Memoryles

Linear vs Nonlinea

Time-invariant

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Invertibility
Time domai

representation of LTI System

Linear time-invariar systems (LTI systems) Impulse Response •

$$y(t) = 2^{-x(t)}$$

For the given system, input can be find out using

$$x(t) = \log_2 y(t)$$

Ripal Pate

System
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Time domain representation

systems (LTI systems) Impulse Response

d properties

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Invertibility

$$y[n] = x[n] - x[n-1]$$

Invertibility

$$y[n] = x[n] - x[n-1]$$

Two different inputs can produce same output.

$$y[n] = x[n] - x[n-1] = 5 - 3 = 2$$

$$y[n] = x[n] - x[n-1] = 9 - 7 = 2$$

Invertibility

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#### Invertibility

 $y(t) = x^4(t)$ 

#### Invertibility

 $y(t) = x^4(t)$ 

$$y(t) = x^4(t)$$

Not-invertible

Invertibility

$$y(t)=x^4(t)$$

Not-invertible

$$y(t) = Ax(t)$$

Ripal Patel

System
Classification
and properties
System Classification

Memory vs Memoryless

Linear vs

Time-invariant vs.

Time-variant

Non-stable Invertibility

Time domain representation

Linear time-invariar systems (LTI systems) Impulse Response •

$$y(t) = x^4(t)$$

Not-invertible

$$y(t) = Ax(t)$$

Memoryles
Causal vs.

Linear vs

Time-invariant vs.

Time-variant

Non-stable Invertibility

Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response •

$$y(t) = x^4(t)$$

Not-invertible

.

$$y(t) = Ax(t)$$

Invertible

•

$$y(t) = Ax(t) + B$$

Ripal Patel

System
Classification
and properties
System Classification

Memoryles
Causal vs.

Linear vs

Time-invariant vs.

Stable Ve

Invertibility

Time domain

Linear time-invaria systems (LTI systems) Impulse Response •

$$y(t)=x^4(t)$$

Not-invertible

-

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Invertible

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Ripal Patel

System Classification and properties System Classification

Memoryles
Causal vs.

Linear vs

Time-invariant vs. ---

Time-varian

Invertibility

Time domain representation

systems (LTI systems) Impulse Response •

$$y(t) = x^4(t)$$

Not-invertible

$$y(t) = Ax(t)$$

Invertible

•

$$y(t) = Ax(t) + B$$

Invertible

•

$$y(n) = x(-n)$$

Ripal Pate

System Classification and properties System Classification

Memoryles
Causal vs.

Linear vs Nonlinea

Time-invariant vs. T:---

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Invertibility

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) impulse Response Convolution Sum •

$$y(t) = x^4(t)$$

Not-invertible

9

$$y(t) = Ax(t)$$

Invertible

•

$$y(t) = Ax(t) + B$$

Invertible

•

$$y(n) = x(-n)$$

Invertibility

Not-invertible

$$y(t) = Ax(t)$$

Invertible

Invertible

$$y(n) = x(-n)$$

y(t) = Ax(t) + B

 $y(t) = x^{4}(t)$ 

$$y(t) = e^{3x(t)}$$

Ripal Pate

#### System Classification and properties System Classification

Memoryles

Linear vs

Time-invariant

Time-variant

Stable Vs

#### Invertibility

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum •

$$y(t)=x^4(t)$$

Not-invertible

.

$$y(t) = Ax(t)$$

Invertible

•

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Invertible

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$$y(n) = x(-n)$$

Invertible

•

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Memory vs. Memoryless

Linear vs.

Time-invariant

Time-varian

Invertibility

Time domain

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum A continuous-time system is described by the following input-output relationship:

$$y(t) = [\sin 6t]x(t)$$

Determine whether this system is Memoryless, Time invariant, Linear, Causal and Stable?

Memoryless?

Memory vs. Memoryless

Linear vs.

Time-invariant

Stable Vs

Invertibility

Time domain representation

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- Memoryless?
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Memory vs. Memoryless

Linear vs.

Time-invarian

Time-variant

Invertibility

Time domain representation

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- Memoryless?
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- Time invariant?

Memory vs. Memoryless

Linear vs. Nonlinear

Time-invarian

I ime-varian

Invertibility

Time domain representation of LTI System

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Memory vs. Memoryless

Linear vs.

Time-invariant

Non-stable Invertibility

Time domai

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Memory vs. Memoryless

Linear vs.

Time-invarian vs.
Time-variant

Invertibility

Time domain representation of LTI Systen

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Memory vs. Memoryless

Linear vs.

Time-invarian vs. Time-variant

Invertibility

Time domain representation of LTI Systen

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- Stable?

Memory vs. Memoryless

Linear vs

Time-invariant

Stable Vs

Invertibility

Time domain representation of LTI System

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- Memoryless?
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Memory vs. Memoryless

Linear vs.

Time-invariant

Time-varian

Invertibility

Time domain representation

Linear time-invari systems (LTI systems) Impulse Response Convolution Sum A Discrete-time system is described by the following input-output relationship:

$$y(n) = x(n) + n$$

Determine whether this system is Memoryless, Time invariant, Linear, Causal and Stable?

• Memoryless?

Memory vs. Memoryless

Linear vs.

Time-invariant vs.

Stable Vs

Invertibility

Time domain representation of LTI System

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- Memoryless?
- Yes

Memory vs. Memoryless

Linear vs. Nonlinear

Time-invariant

Stable Vs

Invertibility

Time domain representation of LTI System

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- Memoryless?
- Yes
- Time invariant?

Memory vs. Memoryless

Linear vs. Nonlinear

Time-invariant

Stable Vs Non-stable

Invertibility

Time domain representation of LTI System

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Memory vs. Memoryless

Linear vs.

Time-invarian vs.

I ime-varian

Invertibility

Time domain representatio of LTI Syster

systems (LTI systems) Impulse Response Convolution Sum A Discrete-time system is described by the following input-output relationship:

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Memory vs. Memoryless

Linear vs.

Time-invarian vs. Time-variant

Invertibility

Time domain representation of LTI Systen

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Memory vs. Memoryless

Linear vs.

Time-invariant

Stable Vs

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Time domain representation of LTI System

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Memory vs. Memoryless

Linear vs.

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Time domain representation of LTI Systen

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Memory vs. Memoryless

Linear vs. Nonlinear

Time-invarian vs. Time-variant

Non-stabl

Invertibility

Time domain representatio of LTI Syster

Linear time-invarial systems (LTI systems) Impulse Response Convolution Sum A Discrete-time system is described by the following input-output relationship:

$$y(n) = x(n) + n$$

- Memoryless?
- Yes
- Time invariant?
- No
- Linear?
- No
- Causal?
- Yes
- Stable?
- No



System Classification and properties

Memoryle

Linear vs

Nonlinear ---

VS.

I ime-varian

Stable Vs Non-stable

Invertibility

representation of LTI System

Linear time-invarian systems (LTI systems)

mpulse Respons

 A class of systems used in signals and systems that are both linear and time-invariant

Memory vs Memoryles

Linear vs

Time-invarian vs.

Stable Vs

Non-stable

Time domain representation of LTI System

Linear time-invariant systems (LTI systems) Impulse Response

- A class of systems used in signals and systems that are both linear and time-invariant
- Linear systems are systems whose outputs for a linear combination of inputs are the same as a linear combination of individual responses to those inputs.

Memory vs. Memoryless

Linear vs

Time-invarian

vs. Time-variant

Invertibilit

Time domain representation of LTI System

Linear time-invarian systems (LTI systems) Impulse Response Convolution Sum

- A class of systems used in signals and systems that are both linear and time-invariant
- Linear systems are systems whose outputs for a linear combination of inputs are the same as a linear combination of individual responses to those inputs.
- Time-invariant systems are systems where the output does not depend on when an input was applied. These properties make LTI systems easy to represent and understand graphically.

System
Classification
and properties

Memory vs Memoryless

Linear vs

Time-invarian

vs. Time-variant

Invertibilit

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum

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- Used to predict long-term behavior in a system

System
Classification
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Memory vs Memoryless

Linear v

vs. Time-variant

Stable Vs

Invertibilit

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum

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- Time-invariant systems are systems where the output does not depend on when an input was applied. These properties make LTI systems easy to represent and understand graphically.
- Used to predict long-term behavior in a system
- The behavior of an LTI system is completely defined by its impulse response

Memory vs Memoryles

Causal vs. Non-causa

Linear vs Nonlinea

Time-invarian vs.

Time-variant

Non-stable

Time domain representation

Linear time-invari

Impulse Response Convolution Sum The discrete version of impulse function is defined by

$$\delta(n) = \begin{cases} 1, & n = 0 \\ 0, & n \neq 0 \end{cases}$$

The continuous time version of impulse function,

$$\delta(t) = \begin{cases} 1, & t = 0 \\ 0, & t \neq 0 \end{cases}$$

Memory v Memoryle

Causal vs Non-caus

Linear vs Nonlinea

Time-invariant

Time-varian

Stable Vs Non-stable

Time domain

Linear time-invaria systems (LTI

Impulse Response Convolution Sum • The impulse response" of a system, h[n], is the output that it produces in response to an impulse input. Definition: if and only if  $x[n] = \delta[n]$  then y[n] = h[n]

System
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vs. Time-variant

Time-variant

Invertibility

Time domain representation of LTI System

Linear time-inva

Impulse Response Convolution Sum

- The impulse response" of a system, h[n], is the output that it produces in response to an impulse input. Definition: if and only if  $x[n] = \delta[n]$  then y[n] = h[n]
- Given the system equation, the impulse response can be found out just by feeding  $x[n] = \delta[n]$  into the system.

System
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Memoryle

Linear vs

Time-invariant

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Invertibilit

Time domain representation of LTI System

systems (LTI systems)

Impulse Response

• Consider the system

$$y[n] = \frac{1}{2}(x[n] + x[n-1])$$

• Suppose we insert an impulse:

$$x[n] = \delta[n]$$

 Then whatever we get at the output, by Definition, is the impulse response. In this case it is

$$h[n] = \frac{1}{2}(\delta[n] + \delta[n-1]) = \left\{ egin{array}{ll} 0.5, & n=0,1 \ 0, & otherwise \end{array} 
ight.$$

System Classification and properties

Memoryle

Linear vs

Time-invariant

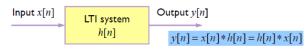
vs. Time-variant

Stable Va

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Time domain representation

Linear time-invarian systems (LTI systems) Impulse Response Convolution Sum



where, h[n]=impulse response of LTI system x[n]=Input Signal

System Classification and properties System Classification

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Linear vs

Time-invariant

VS.

Time-variant

Non-stable

Invertibility

Time domain representation of LTI System

Linear time-invariat systems (LTI systems) Impulse Response Convolution Sum



where, h[n]=impulse response of LTI system x[n]=Input Signal

$$y[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k]$$

System
Classification
and properties
System Classification

Memory vs Memoryles

Non-caus

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Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum



where, h[n]=impulse response of LTI system x[n]=Input Signal

$$y[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k]$$

input-excitation output-response

System Classification and properties System Classification

Memory vs Memoryles

Linear v

Time-invariant

Time-variant

Stable Vs Non-stable

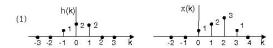
Invertibility

Time domain representation

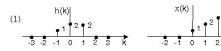
Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum Find the response y[n] of following LTI system.

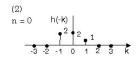
$$x(n)=[0,1,2,3,1,0]$$
 and  $h(n)=[0,1,2,2,0]$ 

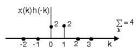
Convolution Sum



Convolution Sum







System
Classification
and properties

Memory vs Memoryles

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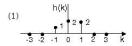
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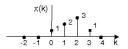
.....

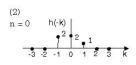
Time domain representation

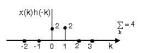
Linear time-invarian systems (LTI systems)

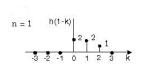
Impulse Response

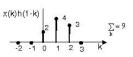












System
Classification
and properties

Memory vs Memoryles

Causal vs. Non-causa

Linear vs Nonlinea

Time-invariant

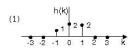
Time-variant

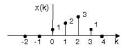
Stable Vs

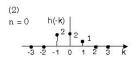
Invertibili:

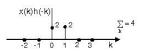
Time domain representation

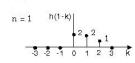
systems (LTI systems) Impulse Response

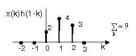


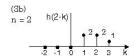


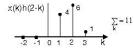












System
Classification
and properties

Memory v Memoryles

Causal vs. Non-causa

Linear vs Nonlinea

Time-invarian

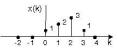
Time-varian

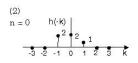
Stable Vs

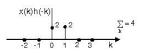
nvertibilit

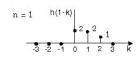
Time domain representation of LTI System

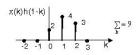
systems (LTI systems) Impulse Response Convolution Sum (1) h(k) 2 1 2 1 2 3 k

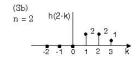


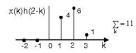












• 
$$y(n) = [...0, 1, 4, 9, 11, 8, 2, 0, ...]$$

Convolution Sum

• Size of x(n)=A=4, Size of h(n)=B=3Length of y(n)=A+B-1=4+3-1=6

Convolution Sum

# Convolution Sum (Analytical method)

- Size of x(n)=A=4, Size of h(n)=B=3Length of y(n)=A+B-1=4+3-1=6
- x(n) is starting from 0 index  $n_1=0$ h(n) is starting from -1 index  $n_2=-1$  $n_1 + n_2 = -1$ , range of n=-1 to 4

System
Classification
and properties

System Classification

Memoryles
Causal vs.

Linear vs Nonlinea

Time-invarian

Stable Vs Non-stable

Time domair

Linear time-invariant systems (LTI systems) Impulse Response Convolution Sum

- Size of x(n)=A=4, Size of h(n)=B=3Length of y(n)=A+B-1=4+3-1=6
- x(n) is starting from 0 index  $n_1=0$ h(n) is starting from -1 index  $n_2=-1$  $n_1 + n_2 = -1$ , range of n=-1 to 4
- For n=-1

$$y[-1] = \sum_{k=0}^{3} x[k]h[-1-k] = x[0]h[-1] + x[1]h[-2] = (1x1) + (2x0) = 1$$

System
Classification
and properties

Memoryles
Causal vs.

Linear vs Nonlinea

Time-invarian vs.
Time-variant

Stable Vs

Invertibility

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum Size of x(n)=A=4, Size of h(n)=B=3
 Length of y(n)=A+B-1=4+3-1=6

- x(n) is starting from 0 index  $n_1=0$ h(n) is starting from -1 index  $n_2=-1$  $n_1 + n_2 = -1$ , range of n=-1 to 4
- For n=-1

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• For n=0

For n=0
$$y[0] = \sum_{k=0}^{3} x[k]h[0-k] = x[0]h[0]+x[1]h[-1]+x[2]h[-2] = (1x2)+(2x1)+(3x0) = 4$$

System
Classification
and properties

Memory vs Memoryles

Linear vs.

Nonlinear

vs. Time-variant

Stable Vs

Invertibility

Time domain representation of LTI System

Linear time-invaria systems (LTI systems) Impulse Response Convolution Sum

- Size of x(n)=A=4, Size of h(n)=B=3
   Length of y(n)=A+B-1=4+3-1=6
- x(n) is starting from 0 index  $n_1=0$ h(n) is starting from -1 index  $n_2=-1$  $n_1 + n_2 = -1$ , range of n=-1 to 4
- For n=-1

$$y[-1] = \sum_{k=0}^{3} x[k]h[-1-k] = x[0]h[-1] + x[1]h[-2] = (1x1) + (2x0) = 1$$

• For n=0

$$y[0] = \sum_{k=0}^{3} x[k]h[0-k] =$$

$$x[0]h[0]+x[1]h[-1]+x[2]h[-2] = (1x2)+(2x1)+(3x0) = 4$$

• Likewise for all the values of n y(n) = [...0, 1, 4, 9, 11, 8, 2, 0, ...]

System Classification and properties

Memoryle

Linear vs

Time-invarian

vs. Time-variant

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Time domain representation

of LTI System

Linear time-invarian
systems (LTI
systems)

Impulse Response

Convolution Sum

$$x_1(n) = \begin{bmatrix} 1, 2, 3 \end{bmatrix}$$

$$x_2(n) = \begin{bmatrix} 2, 1, 4 \end{bmatrix}$$

$$y[n] = \sum_{k=-\infty}^{\infty} x_1[k]x_2[n-k]$$

• Size of  $x_1(n)$ =A=3, Size of  $x_2(n)$ =B=3 Length of y(n)=A+B-1=3+3-1=5

System
Classification
and properties

Memoryle

Linear vs

Time-invari

VS.

i ime-varian

Stable Vs

Invertibilit

Time domain representation of LTI System

systems (LTI systems) Impulse Response Convolution Sum

$$x_1(n) = \begin{bmatrix} 1, 2, 3 \end{bmatrix}$$

$$x_2(n) = \begin{bmatrix} 2, 1, 4 \end{bmatrix}$$

$$y[n] = \sum_{k=-\infty}^{\infty} x_1[k]x_2[n-k]$$

- Size of  $x_1(n)=A=3$ , Size of  $x_2(n)=B=3$ Length of y(n)=A+B-1=3+3-1=5
- $x_1(n)$  is starting from 0 index  $n_1=0$   $x_2(n)$  is starting from 0 index  $n_2=0$  $n_1 + n_2 = 0$ , range of n=0 to 4

Memoryles
Causal vs.

Linear vs

Time-invarian vs.

Stable Vs Non-stable

Invertibilit

Time domain representation of LTI System

Linear time-invariar systems (LTI systems) Impulse Response Convolution Sum • For n=0

$$y[0] = \sum_{k=0}^{2} x_1[k]x_2[-k] =$$

$$x[0]x_2[0] + x_1[1]x_2[-1] + x_1[2]x_2[-2]$$

$$= (1x2) + (2x0) + (3x0) = 2$$

System Classification and properties

Memoryle Causal vs.

Linear vs

Time-invarian vs.

Time-varian

Time domain representation of LTI System

Linear time-invariai systems (LTI systems) Impulse Response Convolution Sum • For n=0

$$y[0] = \sum_{k=0}^{2} x_1[k]x_2[-k] =$$

$$x[0]x_2[0] + x_1[1]x_2[-1] + x_1[2]x_2[-2]$$

$$= (1x2) + (2x0) + (3x0) = 2$$

• Likewise for all the values of n  $y(n) = \begin{bmatrix} 2, 5, 12, 11, 12 \end{bmatrix}$ 

#### System Classification

Contract Characteristics

Memory vs

Causal vs.

Linear vs.

Time-invarian

Time-varian

Stable Vs

Invertibility

Time domain representation of LTI System

Linear time-inv systems (LTI

Immulae Des

Convolution Sum

# The End