Методы обработки сигналов в телекоммуникационных системах

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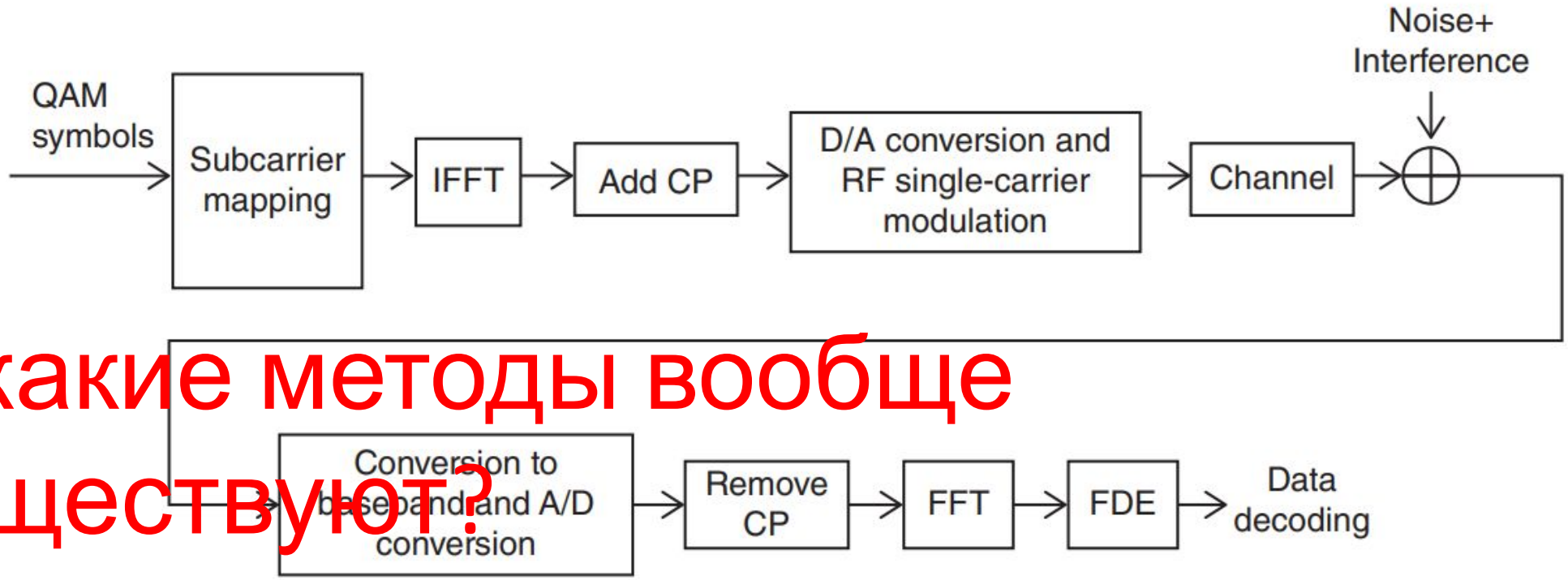
4226а

Некоторые слайды на английском языке

ТКС МИЭТ

Какие методы необходимо применять в предлагаемой схеме?



А какие методы вообще существуют?

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А какие методы вообще существуют?

- А какие сигналы мы обрабатываем?

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Analog signals	Digital signals
Infinite precision in amplitude	Finite precision in amplitude
Continuous signal	Only present at certain points
Continuous mathematics	Discrete mathematics

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Analog signals	Digital signals
восстановление	спектральный анализ
разделение информационных потоков	линейная фильтрация
подавление шумов	свертка традиционных типов
сжатие данных	частотно-временной анализ
фильтрация	нелинейная обработка
усиление сигналов	адаптивная фильтрация
	многоскоростная обработка
	секционная свертка

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Базовые операции

задержка сигналов

сложение сигналов

вычитание сигналов

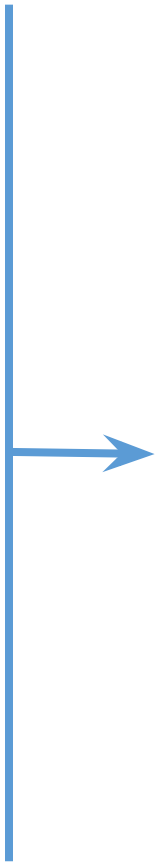
умножение сигналов

деление сигналов

интегрирование

дифференцирование

фильтрация



спектральный анализ

линейная фильтрация

свертка традиционных типов

частотно-временной анализ

нелинейная обработка

адаптивная фильтрация

многоскоростная обработка

секционная свертка

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Какие ещё виды обработки сигналов возможны?

- Статистическая обработка сигналов
- Обработка звука
  - Распознавание речи
- Обработка изображений
  - Обработка видео

- Обработка сигналов нужна для обработки информации
  - Включая экспериментальные данные

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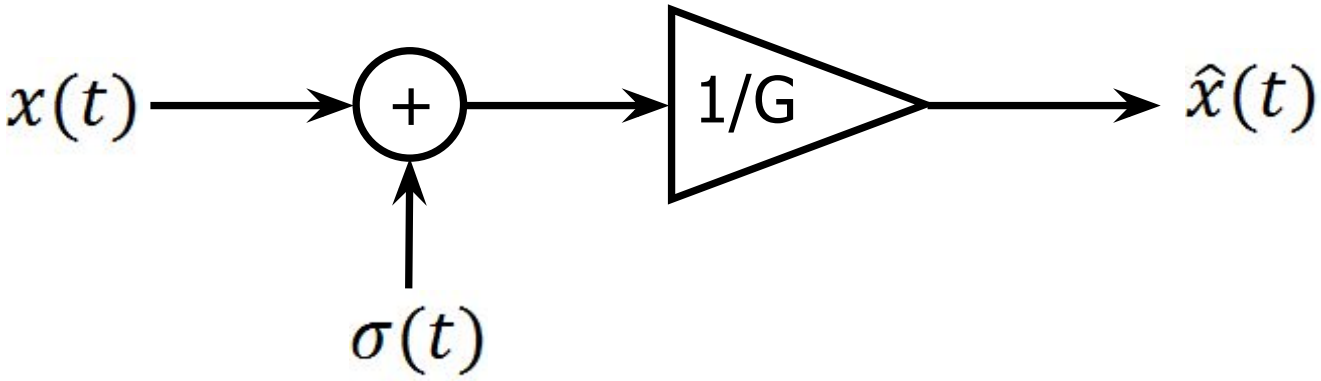
Signal processing methods

- Today:
- Part 1
  - Digital signals
- Part 2
  - Basic programming in Python
  - Data types (in Python)
  - Correct notations in coding
  - Visualizing your signals

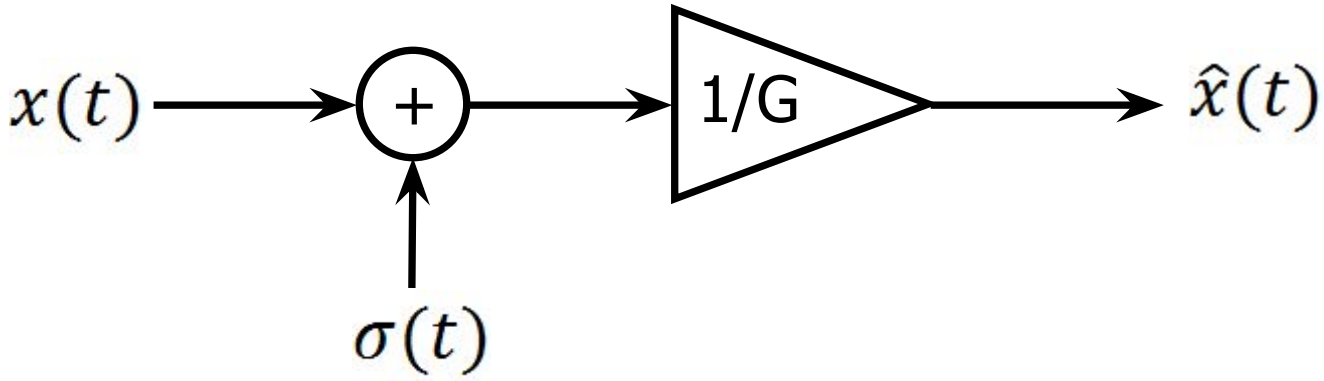
Why digital signals are useful?

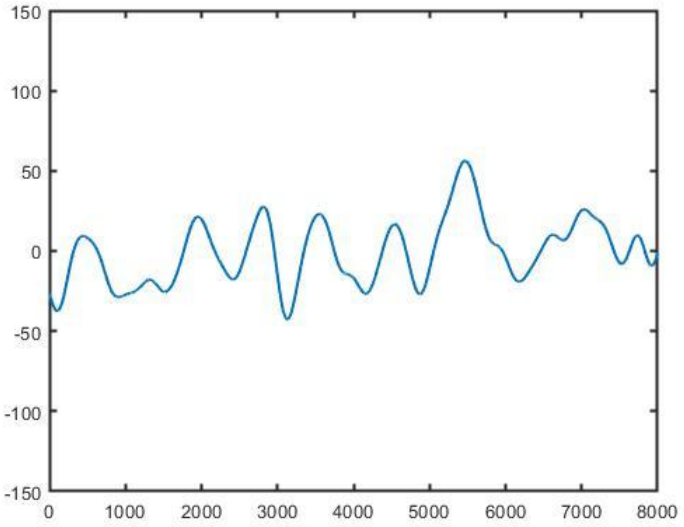
- Storage (generalized computer memory, compatibility)
- Processing (coding, no mechanical or physical interactions)
- Transmission(signal regeneration)

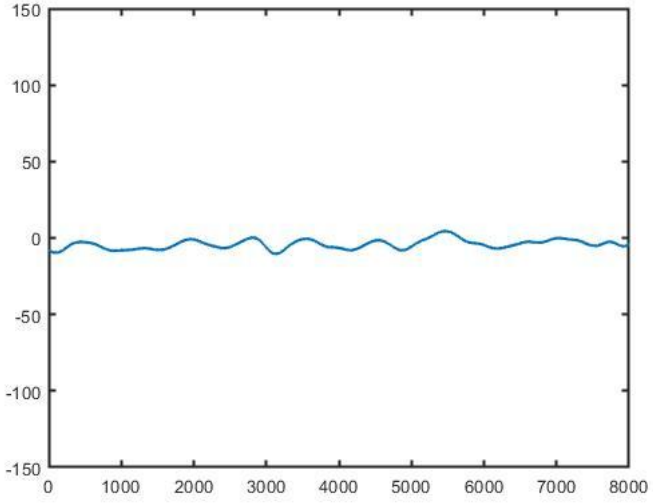
Transmission - signal regeneration

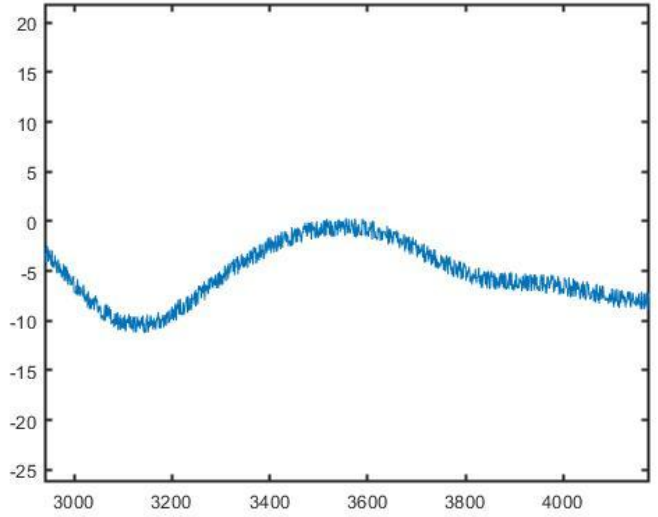


Transmission - signal regeneration

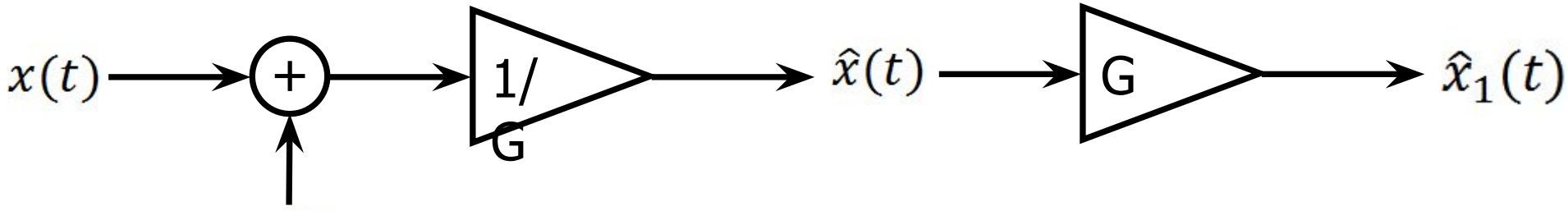


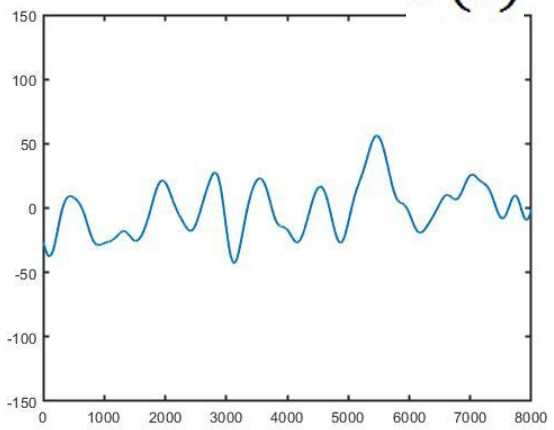




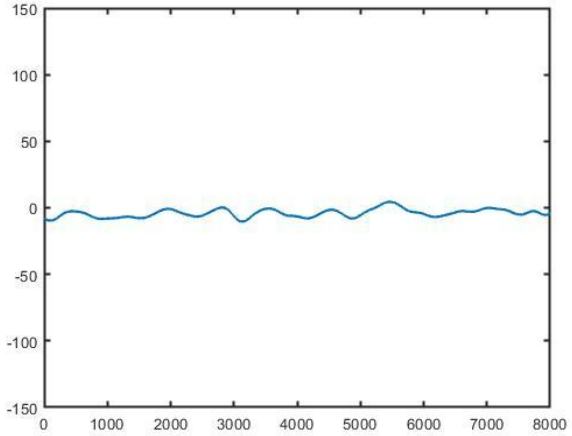


Transmission - signal regeneration

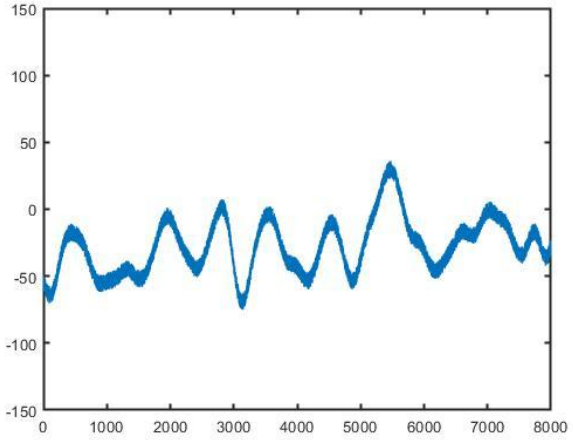




$x(t)$



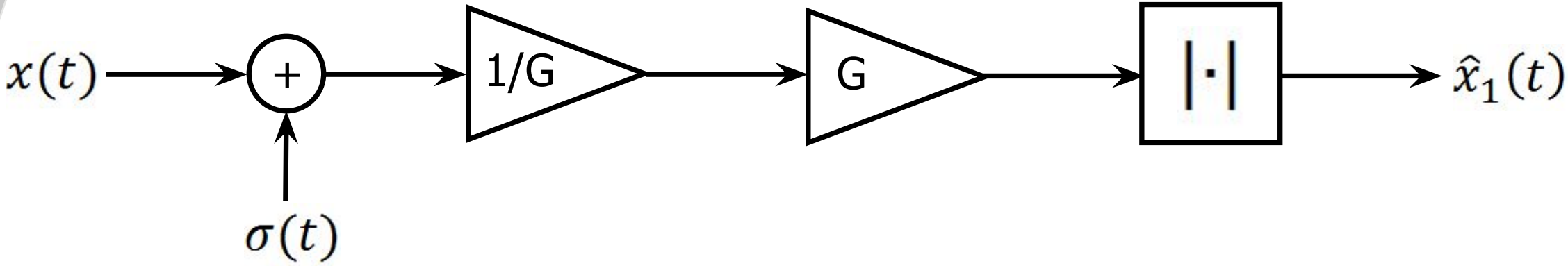
$\hat{x}(t) = x(t)/G + \sigma(t)$

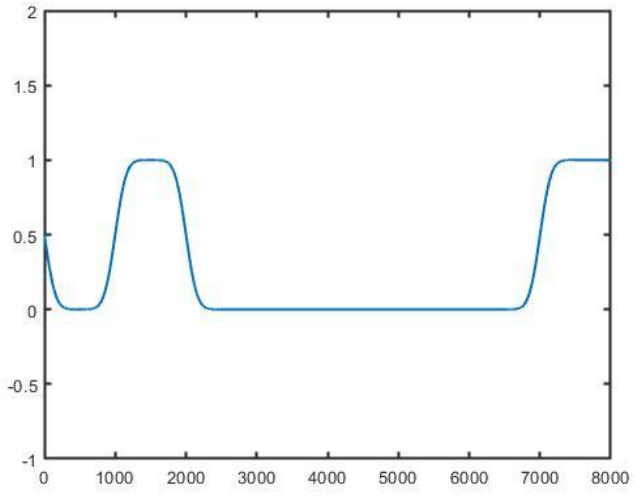


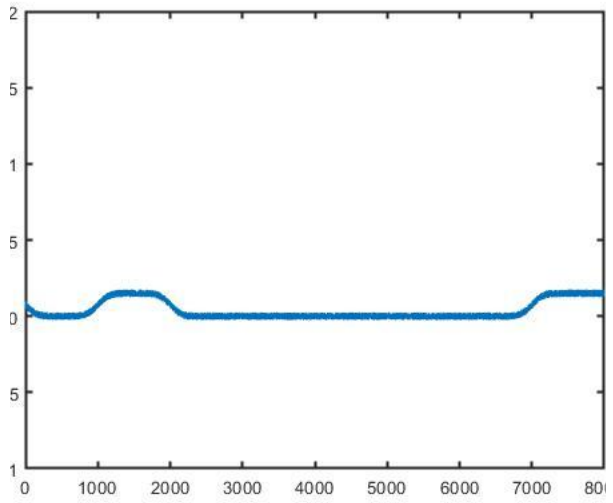
$\hat{x}_1(t) = [x(t)/G + \sigma(t)]G$

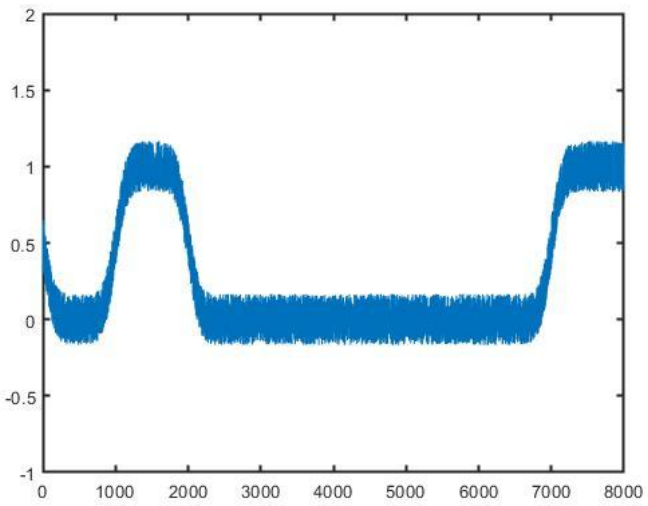
$\hat{x}_1(t) = x(t) + G\sigma(t)$

Transmission - signal regeneration

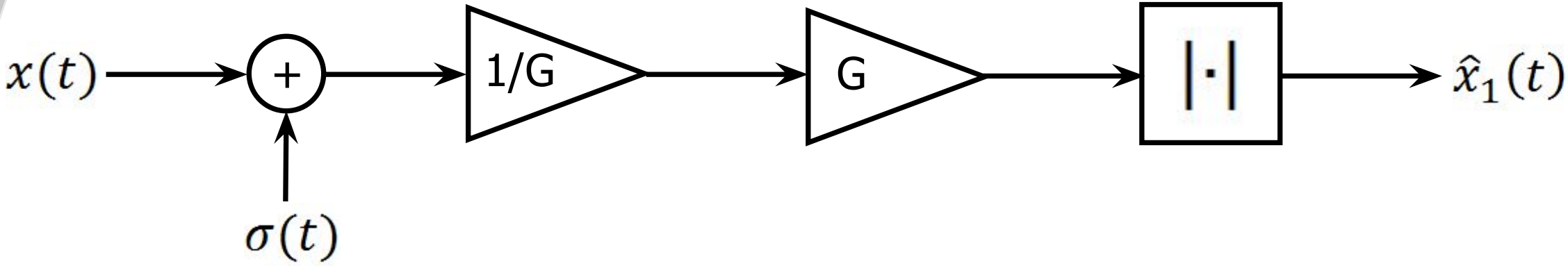


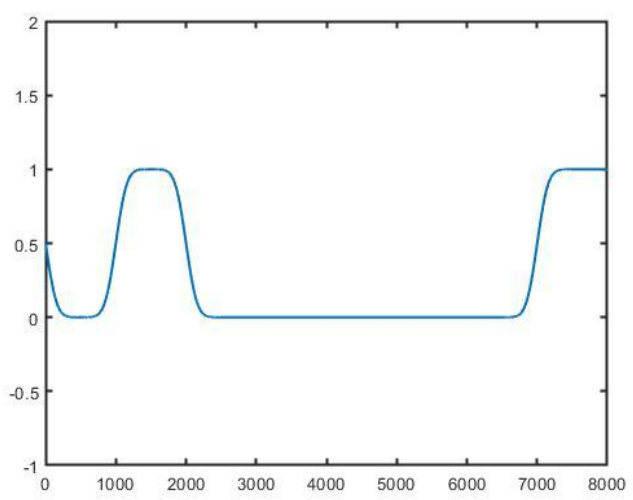


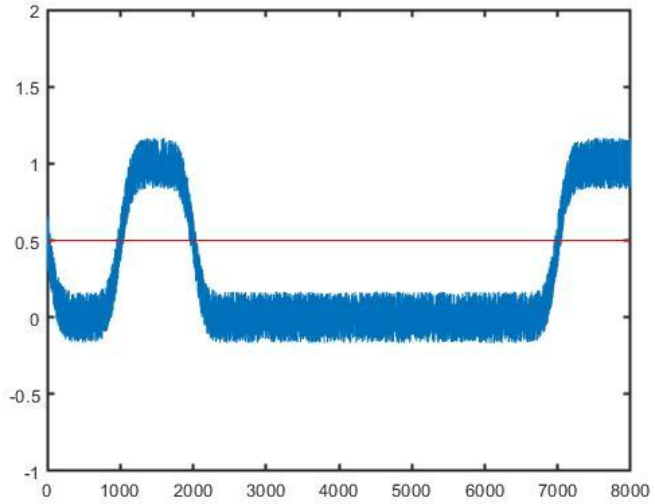


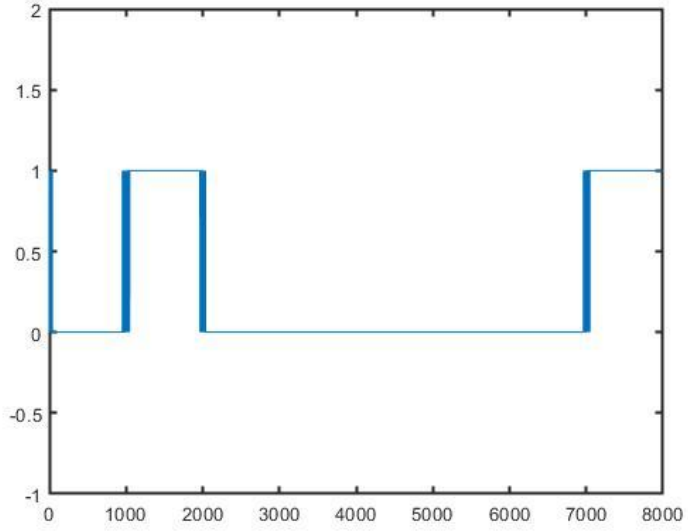


Transmission - signal regeneration









Why digital signals are useful?

- Storage (generalized computer memory, compatibility)
- Processing (coding, no mechanical or physical interactions)
- Transmission(signal regeneration)

Digital signals

- One dimensional (for now)
- Notation x[n] where «n» is an integer
- Two sides sequences x : ℤ □ ℂ
- n is a-dimensional

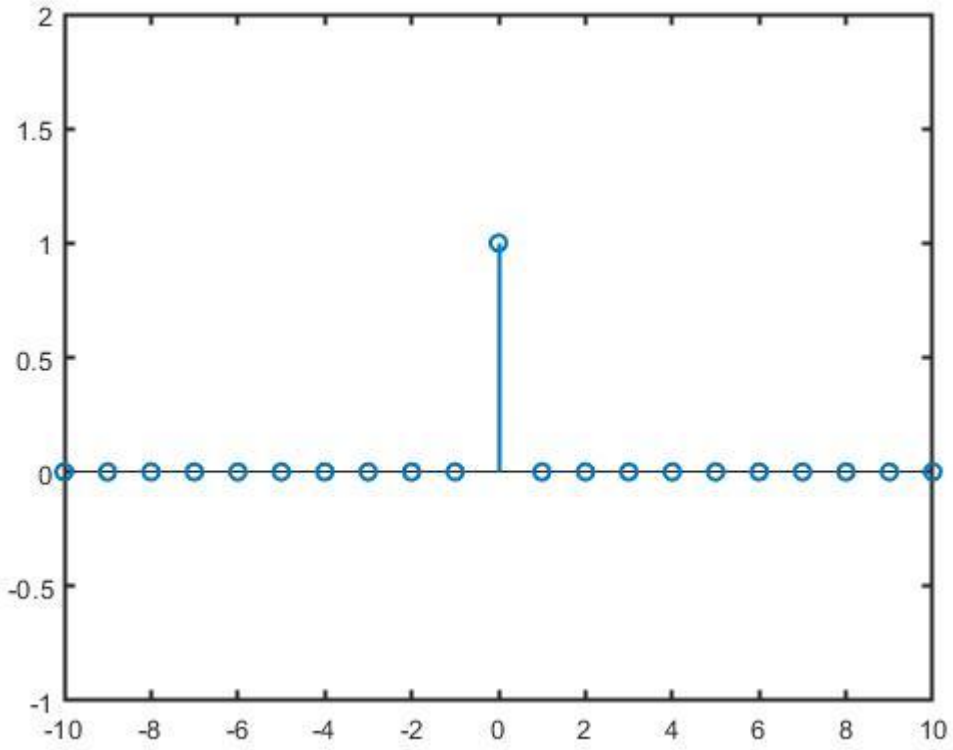
$\mathbb{Z}\ (set\ of\ integers)$
$\mathbb{C}\ (set\ of\ complex\ numbers)$

- Analysis (by taking periodic measurements
- Synthesis (program that generates a stream of samples)

Digital Signals – common signals

- Delta Dirac function
- Unit step function
- Exponential decay
- Sinusoidal signals

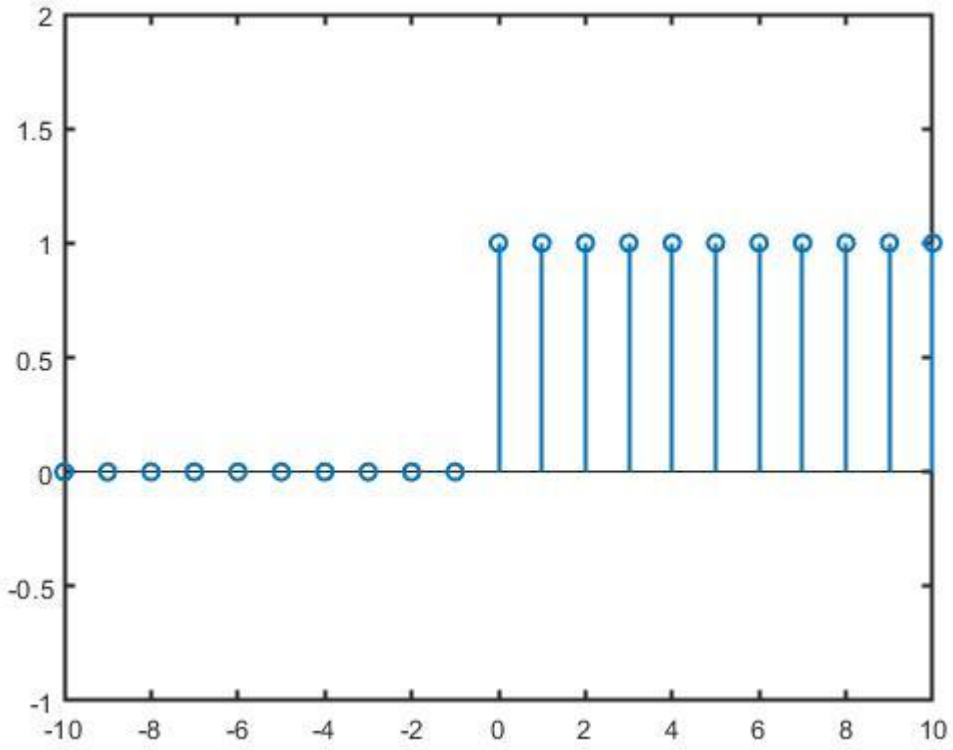
Delta signal



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

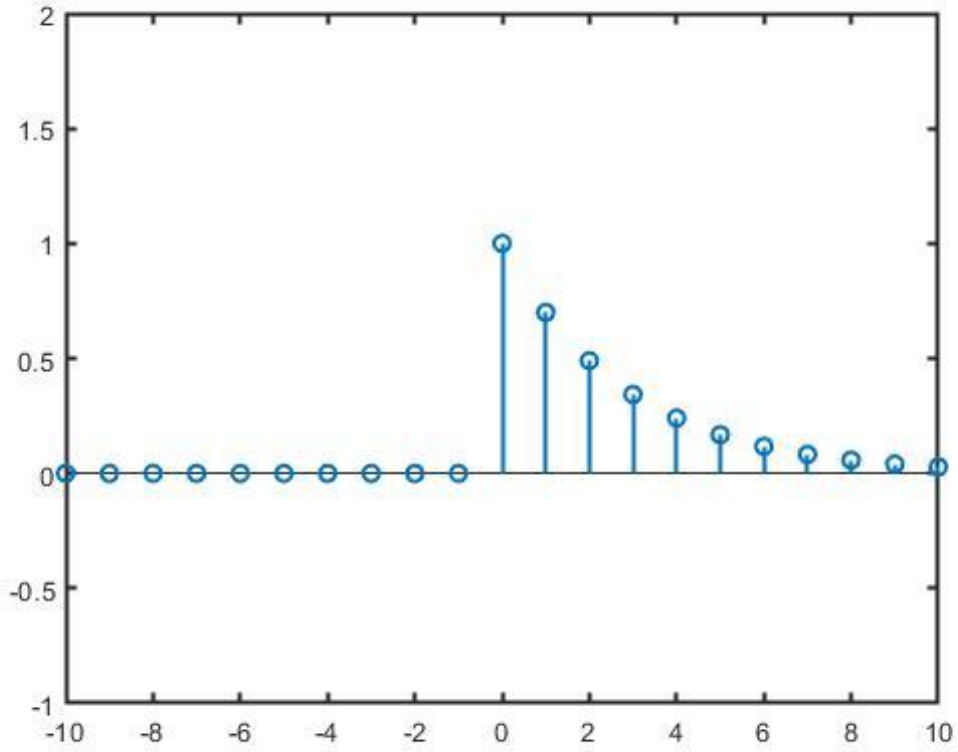
$$x[n] = \begin{cases} 0, & when\ n \neq 0 \\ 1, & when\ n = 0 \end{cases}$$

Unit Step function



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

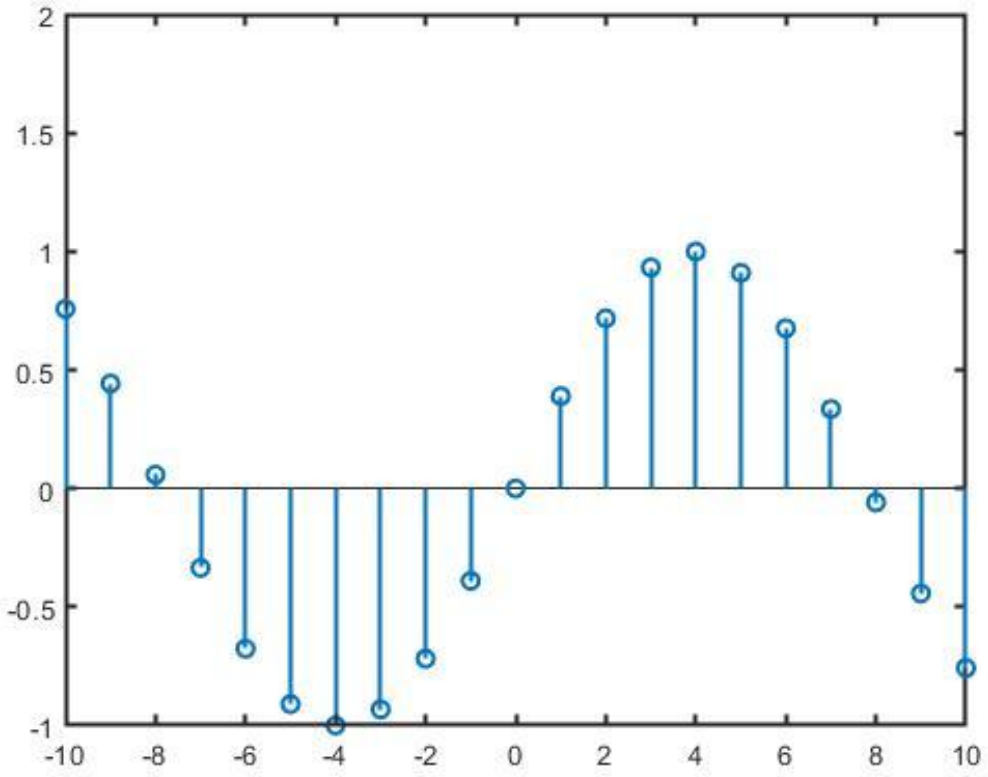
Exponential functions



$$x[n] = \begin{cases} 0, & when\ n < 0 \\ a^n, & when\ n \geq 0 \end{cases}$$

$$when\ a < 1\ converges\ to\ 0$$

Sinusoidal functions



$$x[n] = \sin(w_o n + \theta)$$

Signal classes

- Finite length x[n] for n = 0,1, … ,N-1
- Infinite length
- Periodic
- Finite-support

Finite length

- Sequence notation $x[n] = 0,1,\dots N-1$
- Vector notation $x = [x_0 \; x_1 \; \dots. \; x_{N-1}]^T$
- Easy to process in numerical packages (numPy)

Infinite length

- Sequence notation $x[n], n \in \mathbb{Z}$
- Good for theorems

Periodic

- N-periodic Sequence $\tilde{x}[n] = \tilde{x}[n + kN], \quad n, k, N \in \mathbb{Z}$
- The same information as finite signals with length N
- Useful as a bridge between finite and infinite signals

Finite support signals

$$x[n] = \begin{cases} x[n], & if\ 0 \le n < N \\ 0, & otherwise \end{cases} \qquad n \in \mathbb{Z}$$

- The same information as finite signals of length N
- Useful as a bridge between finite and infinite signals

Energy and Power

$$E_x = \sum_{n=-\infty}^{\infty} |x[n]|^2$$

$$P_x = \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{N} |x[n]|^2$$

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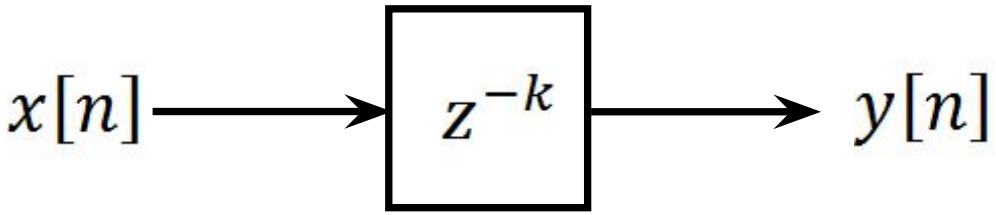
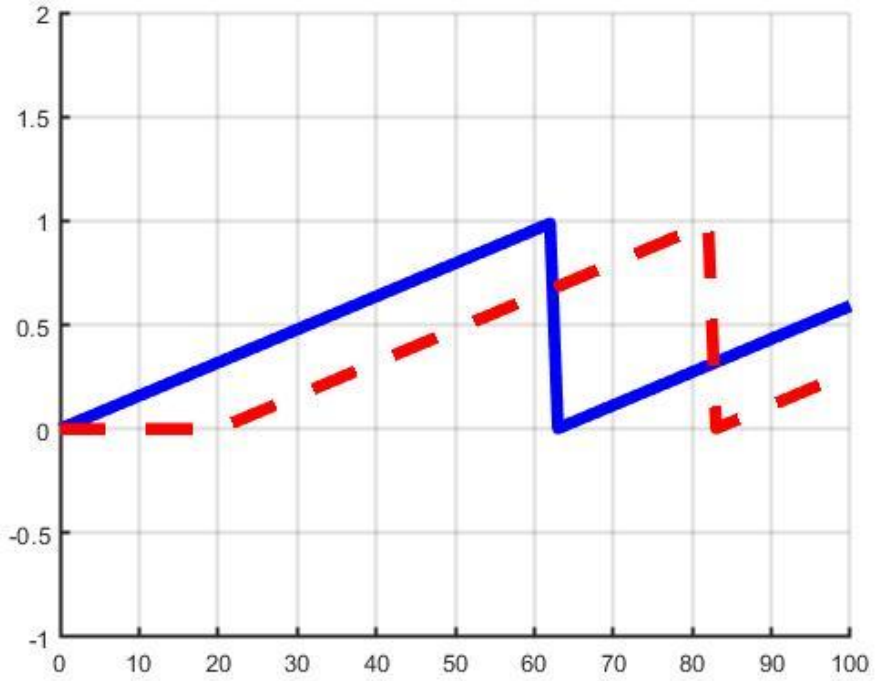
Elementary operators

- Delay $y[n] = x[n-k] \quad k \in \mathbb{Z}$
- Scaling $y[n] = ax[n]$
- Summation $y[n] = x[n] + f[n]$

Elementary operators

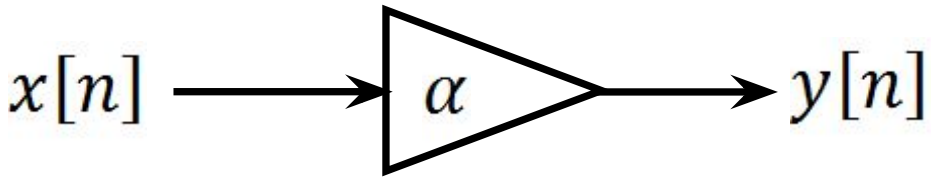
- Delay $y[n] = x[n-k] \quad k \in \mathbb{Z}$

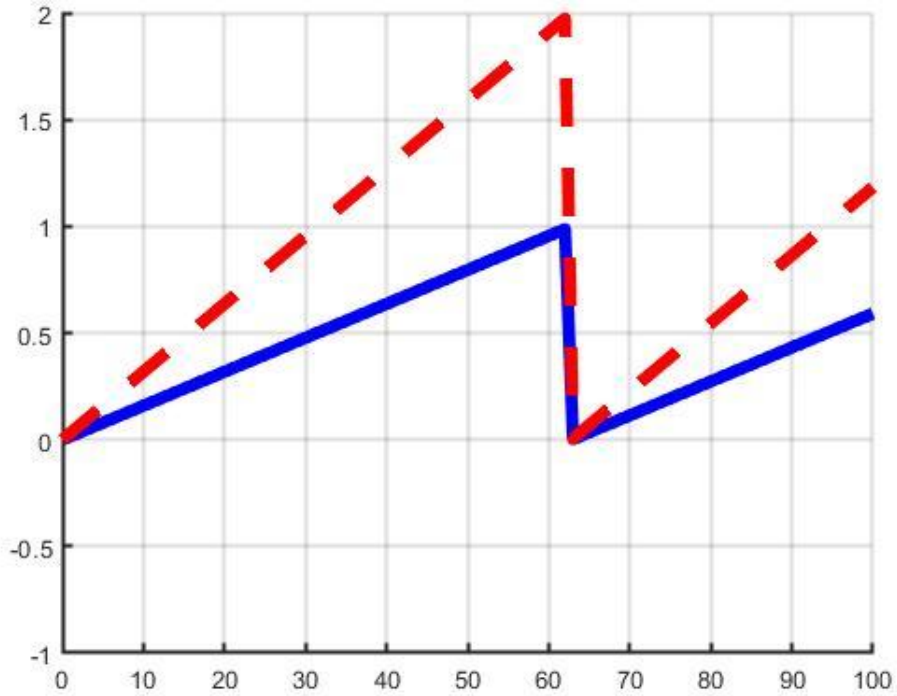




Elementary operators

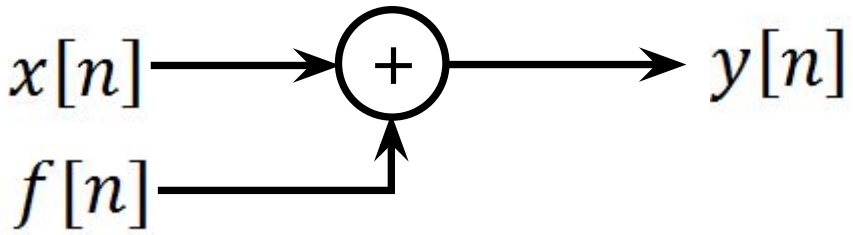
- Scaling $y[n] = ax[n]$

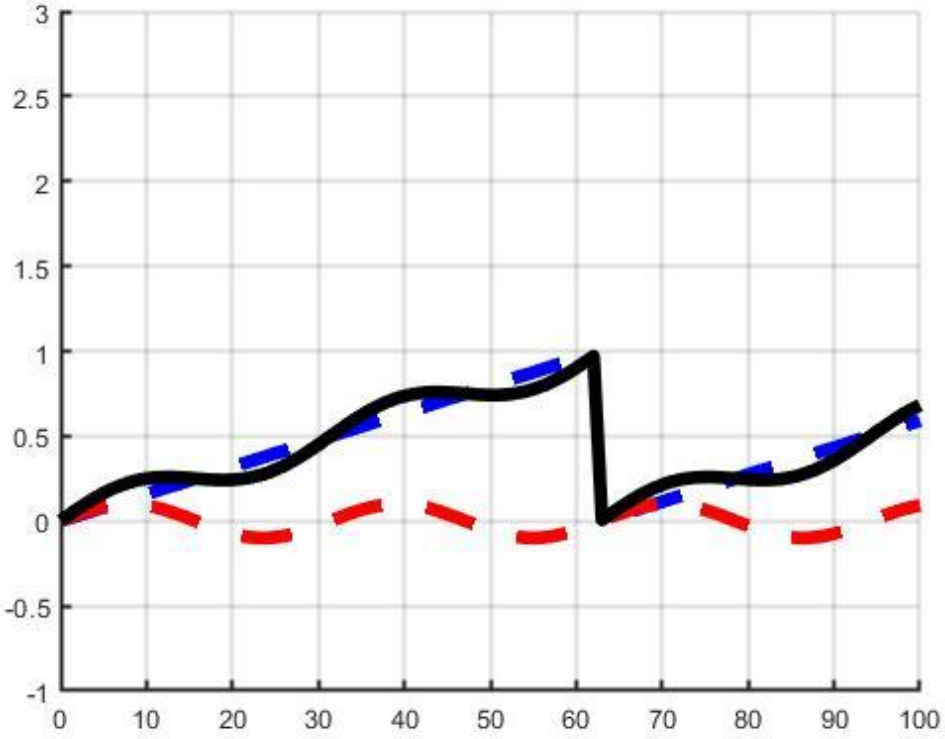




Elementary operators

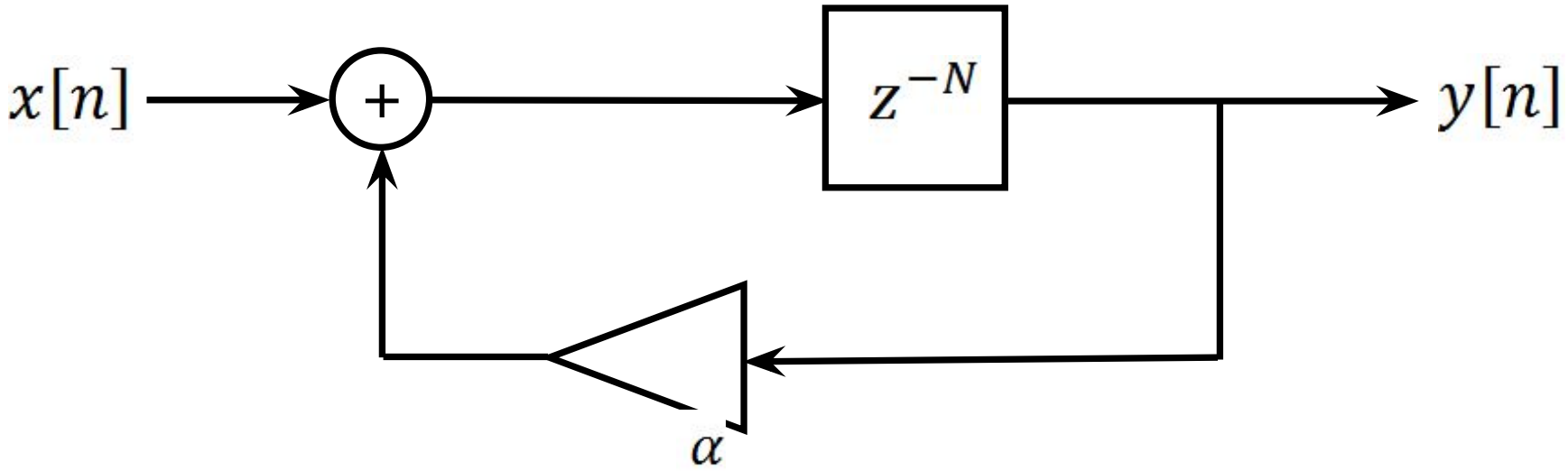
- Summation $y[n] = x[n] + f[n]$



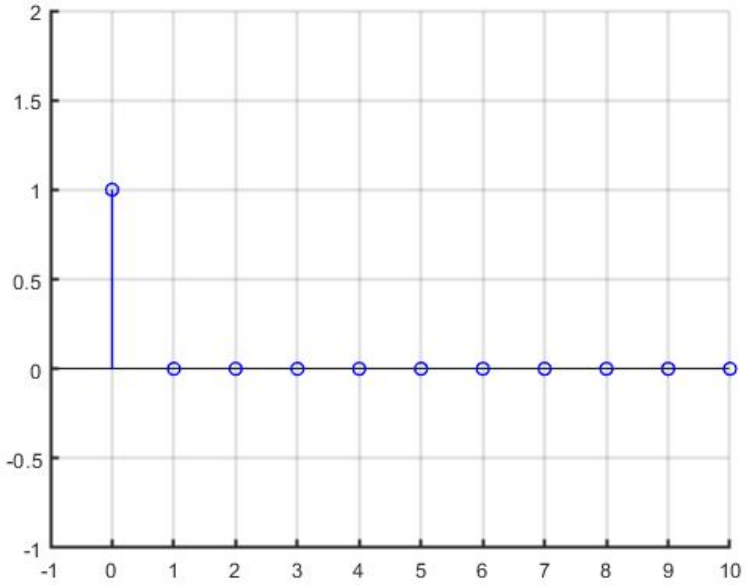


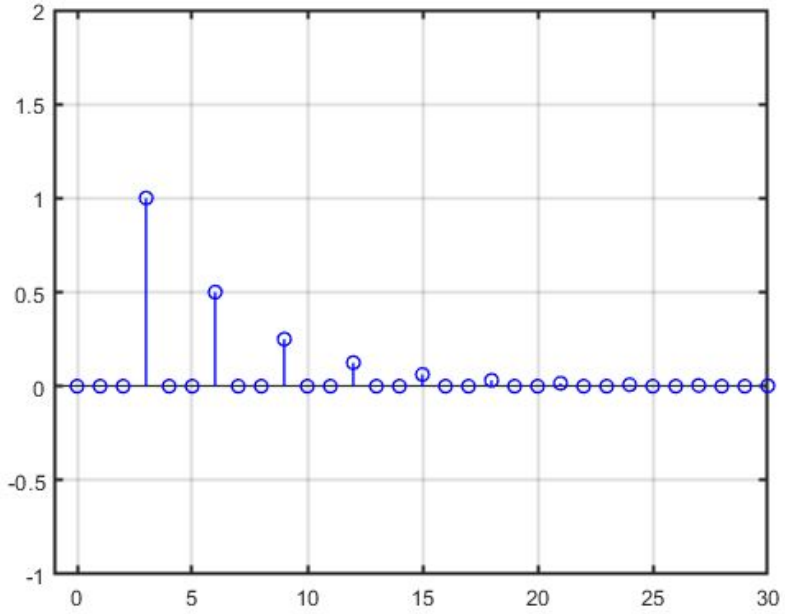
Karplus-Strong algorithm - simplified

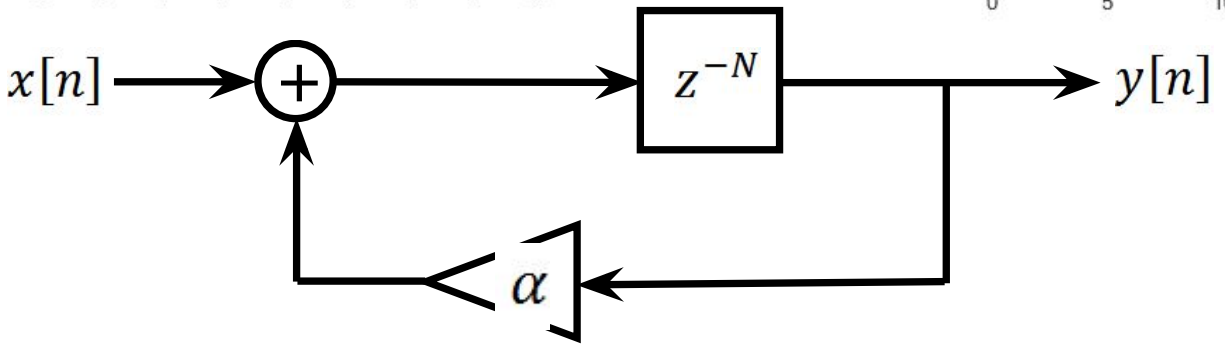
$$y[n] = x[n - N] + \alpha \cdot y[n - N]$$



Karplus-Strong algorithm - simplified





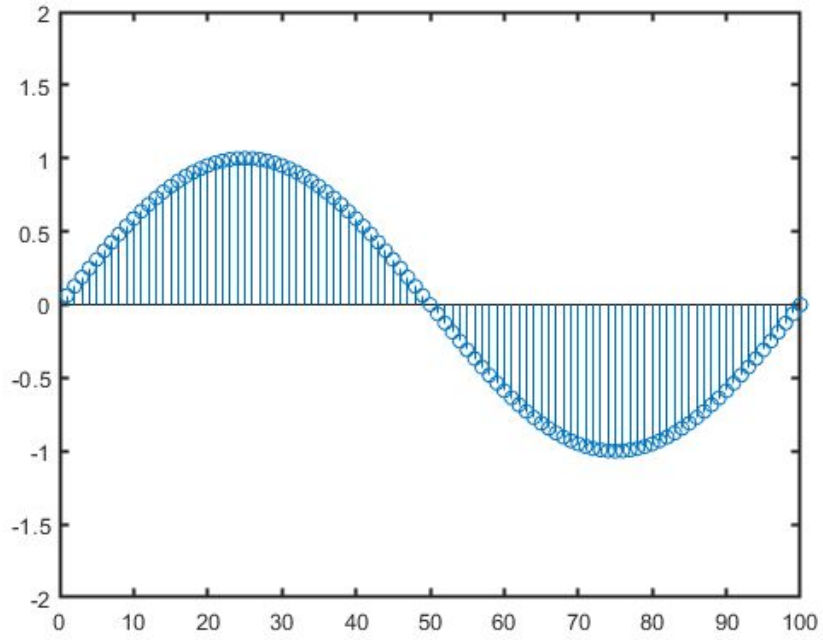


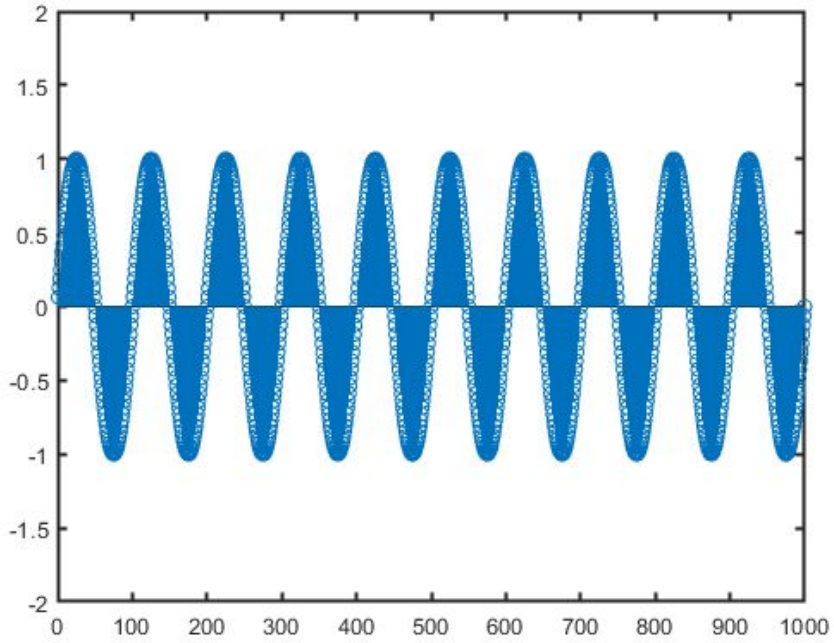
Karplus-Strong algorithm - simplified

$$y[n] = x[n-N] + \alpha \cdot y[n-N]$$

$$\bar{x}(n) = \sin\left(2\pi \frac{n}{100}\right)$$

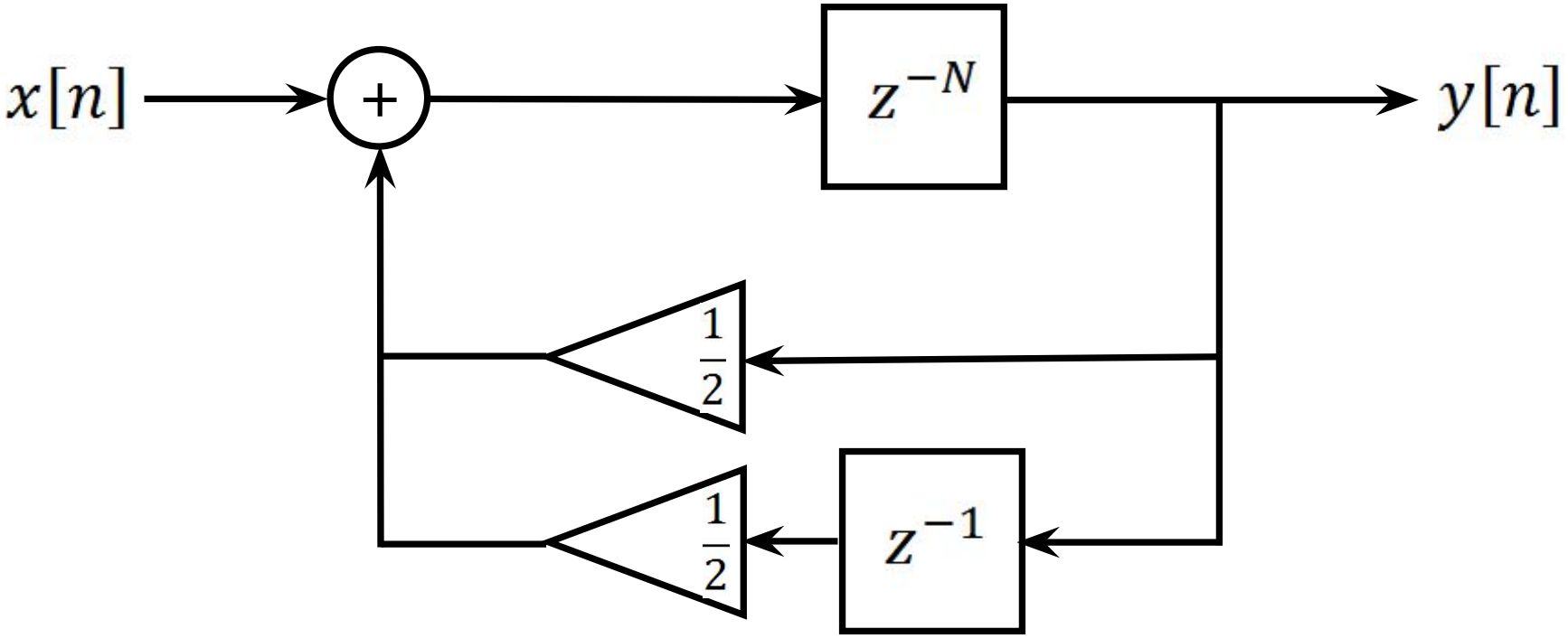
$N = 100$ $\alpha = 1$



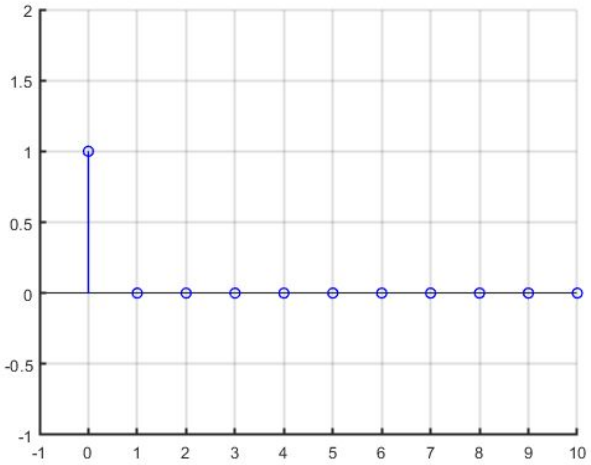


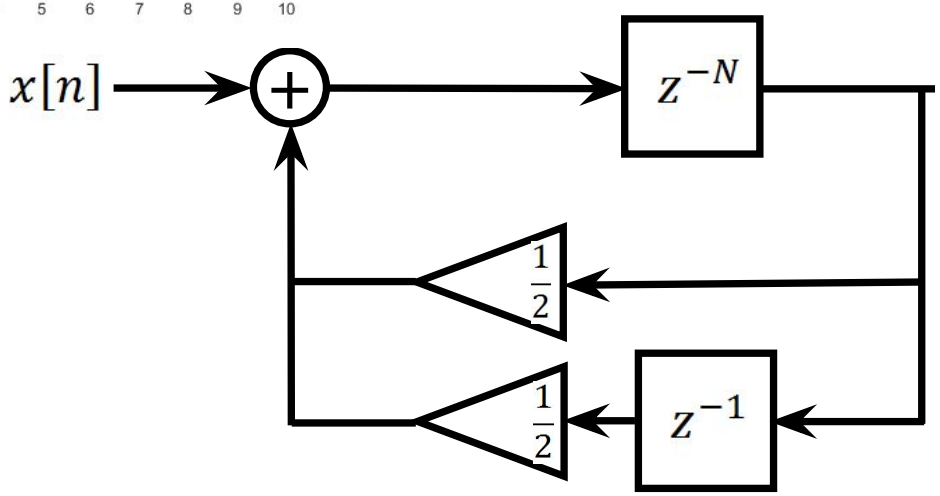
Karplus-Strong algorithm

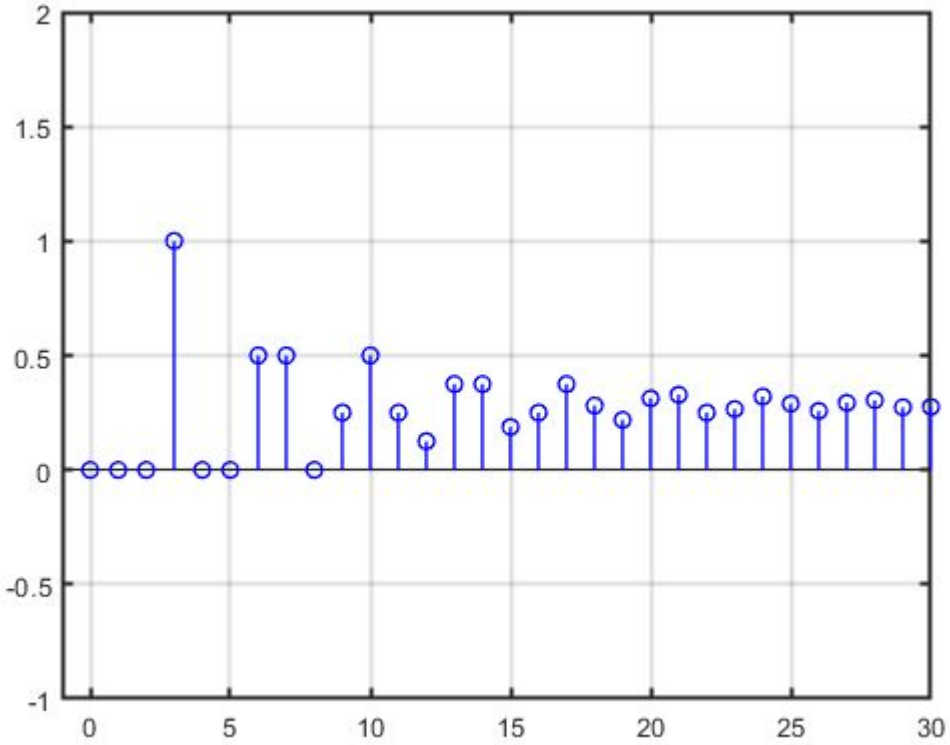
$$y[n] = x[n-N] + \frac{y[n-N] + y[n-(N+1)]}{2}$$



Karplus-Strong algorithm







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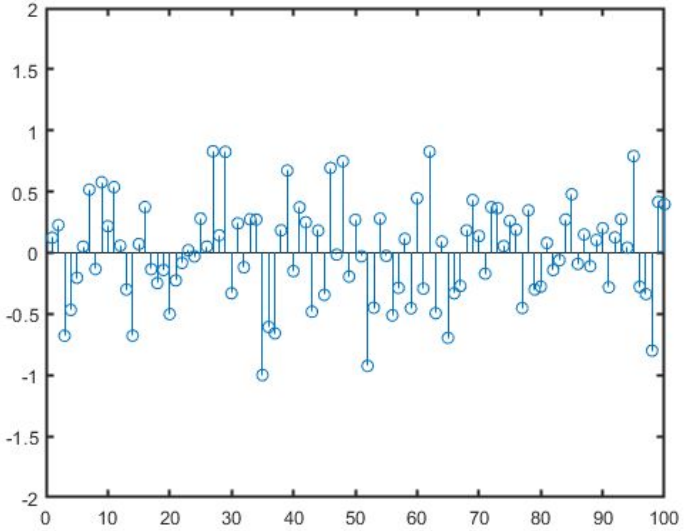
[Understanding the Karplus-Strong with Python (Synthetic Guitar Sounds Included) | Frolian's blog (flothesof.github.io)]

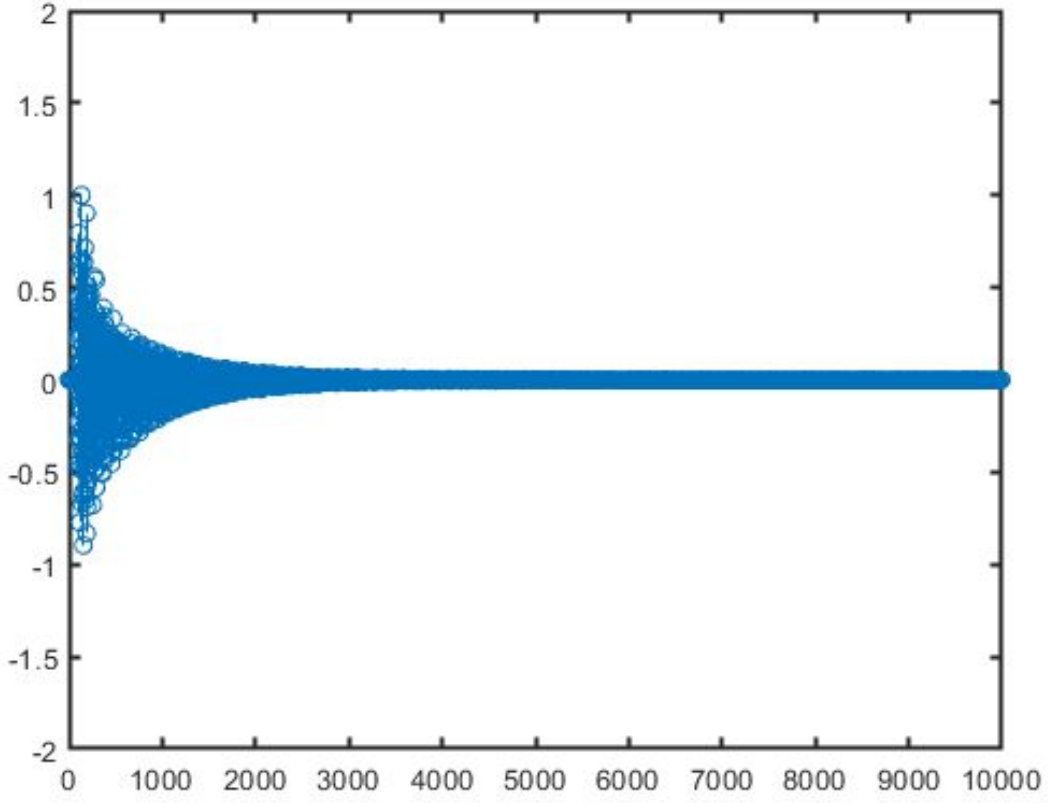
Karplus-Strong algorithm

N controls the frequency (pitch)

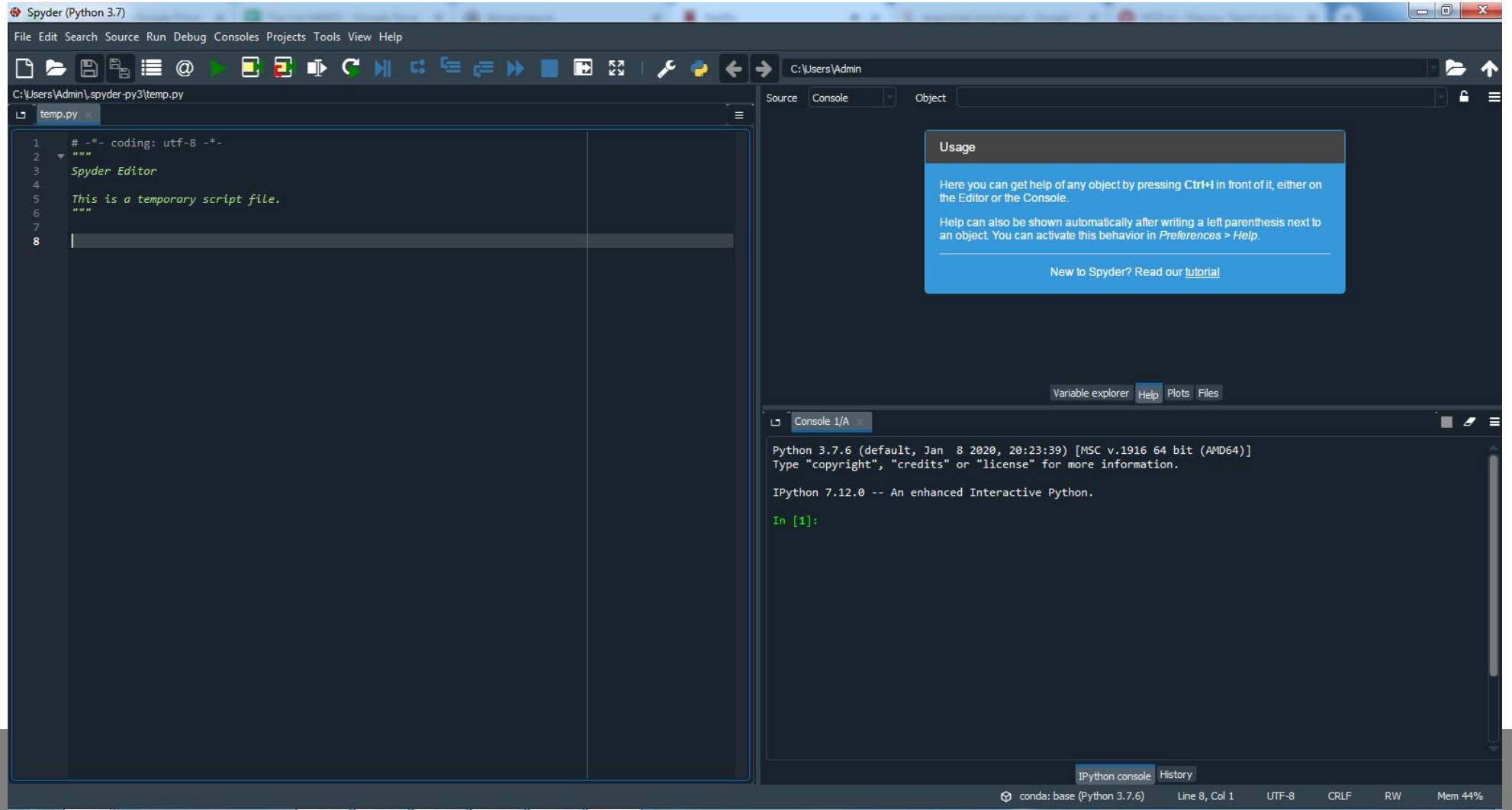
a controls the envelope (decay)

$\bar{x}(n)$ controls the color (Timbre)





Python 3 Anaconda - Spyder



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Data types

Text Type:	str
Numeric Types:	int, float, complex
Sequence Types:	list, tuple, range
Mapping Type:	dict
Set Types:	set, frozenset
Boolean Type:	bool
Binary Types:	bytes, bytearray, memoryview

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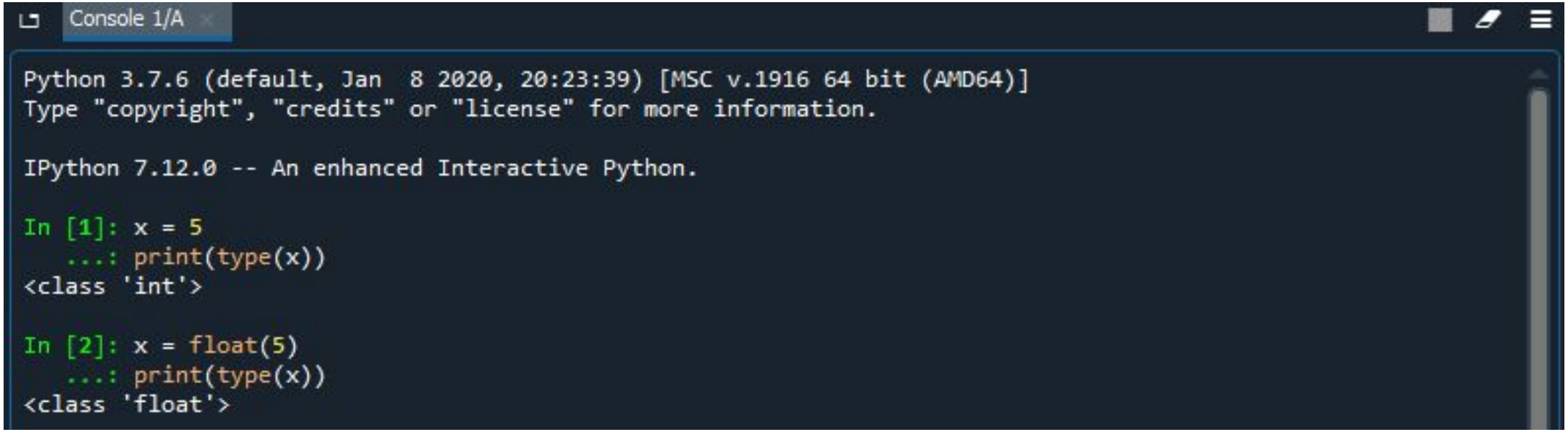
Data types

You can assign the datatype manually (like programming in C)

OR

You can assign the datatype automatically



Data types

Some data types can interact

Try assigning the INTEGER 5 to variable ‘x’

Try assigning the float 7 to variable ‘y’

Multiply ‘x’ and ‘y’ and assign the result to ‘z’ (you type ‘z=x*y’)

Determine the data type of ‘z’

```
In [8]: x=5

In [9]: y=float(7)

In [10]: z=x*y

In [11]: print(type(z))
```

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Importing libraries

- For example try to print the number **π**

```
In [1]: pi
Traceback (most recent call last):

  File "<ipython-input-1-f84ab820532c>", line 1, in <module>
    pi

NameError: name 'pi' is not defined


In [2]: math.pi
Traceback (most recent call last):

  File "<ipython-input-2-c49acc181da4>", line 1, in <module>
    math.pi

NameError: name 'math' is not defined
```

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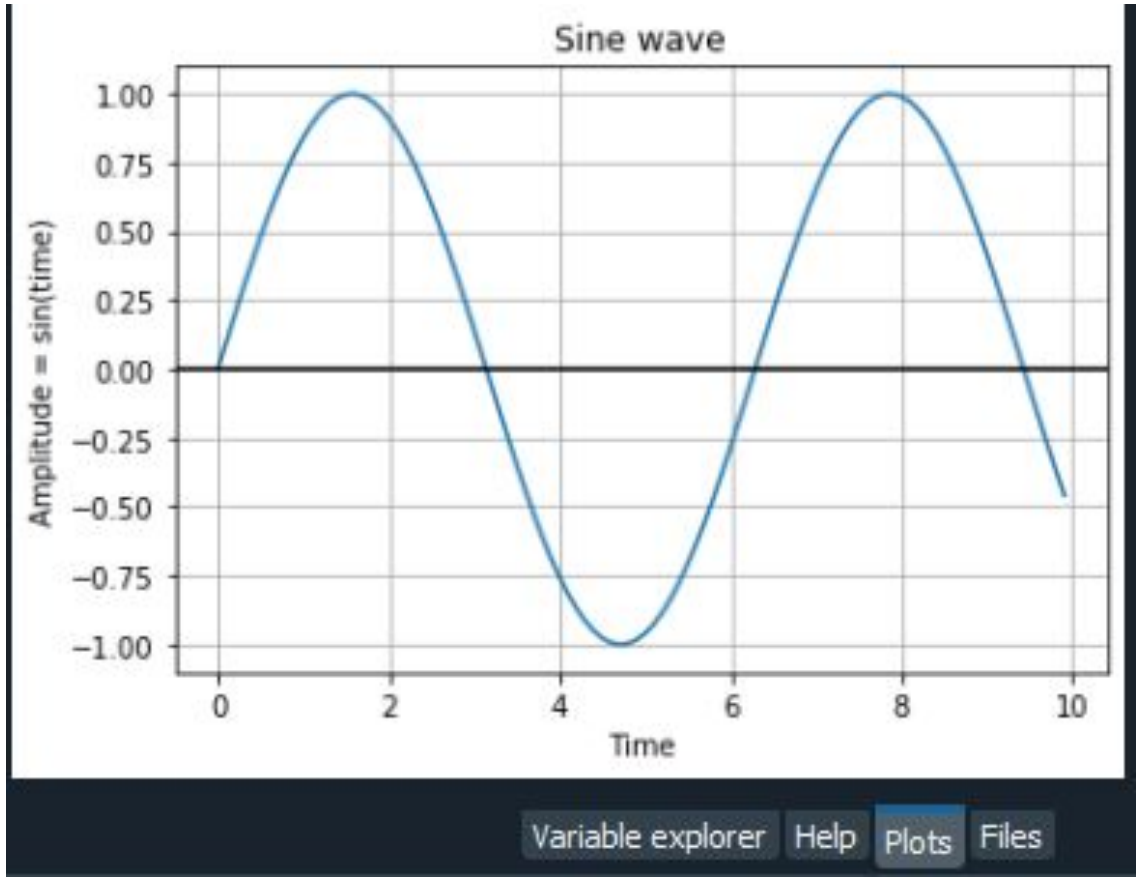
Importing functions

- For example try to print the number **π**

```
In [3]: import math
   ...: print(math.pi)
3.141592653589793
```

Visualizing numbers – plotting a sine wave

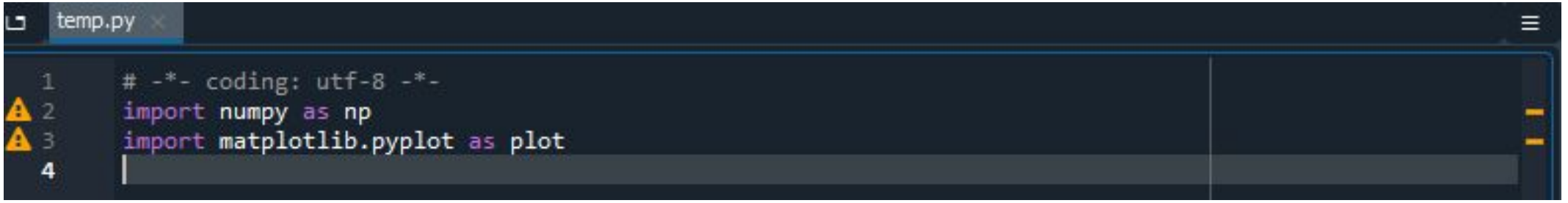


ТКС МИЭТ

Visualizing numbers – plotting a sine wave

Import module numpy

Import the function pyplot from the module matplotlib



Visualizing numbers – plotting a sine wave

Create time points for the x-axis

Numbers 0 until 10 with step size 0.01

(so you will get a range from [0 0.01 0.02 0.03 … 1])

```
# Get x values of the sine wave
time          = np.arange(0, 10, 0.1);
```

ТКС МИЭТ

Visualizing numbers – plotting a sine wave

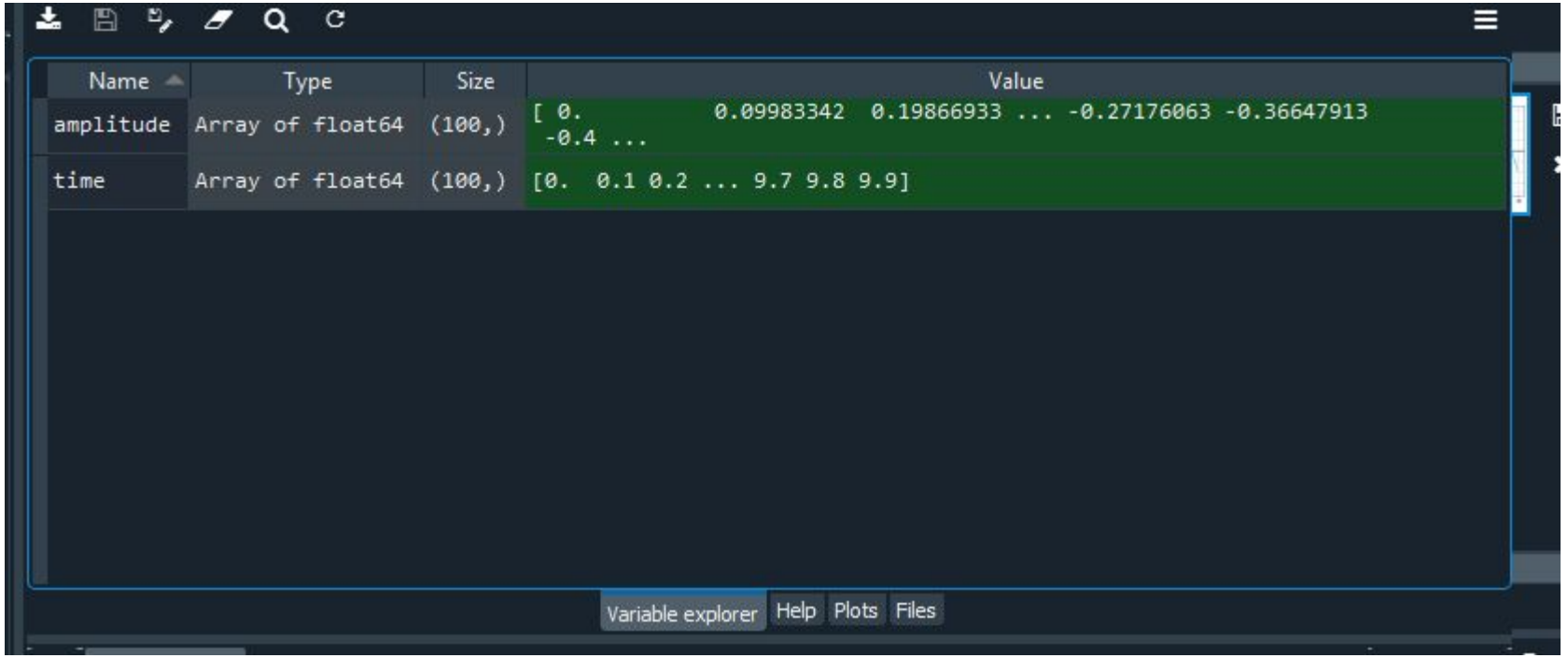
Create the amplitude points for each point in time

Use the sin function of the numpy module

(which you loaded and renamed as ‘np’

```
# Amplitude of the sine wave is sine of a variable like time
amplitude   = np.sin(time)
```

Visualizing numbers – plotting a sine wave



ТКС МИЭТ

Visualizing numbers – plotting a sine wave

Create the plot.

```
# Plot a sine wave using time and amplitude obtained for the sine wave
plot.plot(time, amplitude)
```

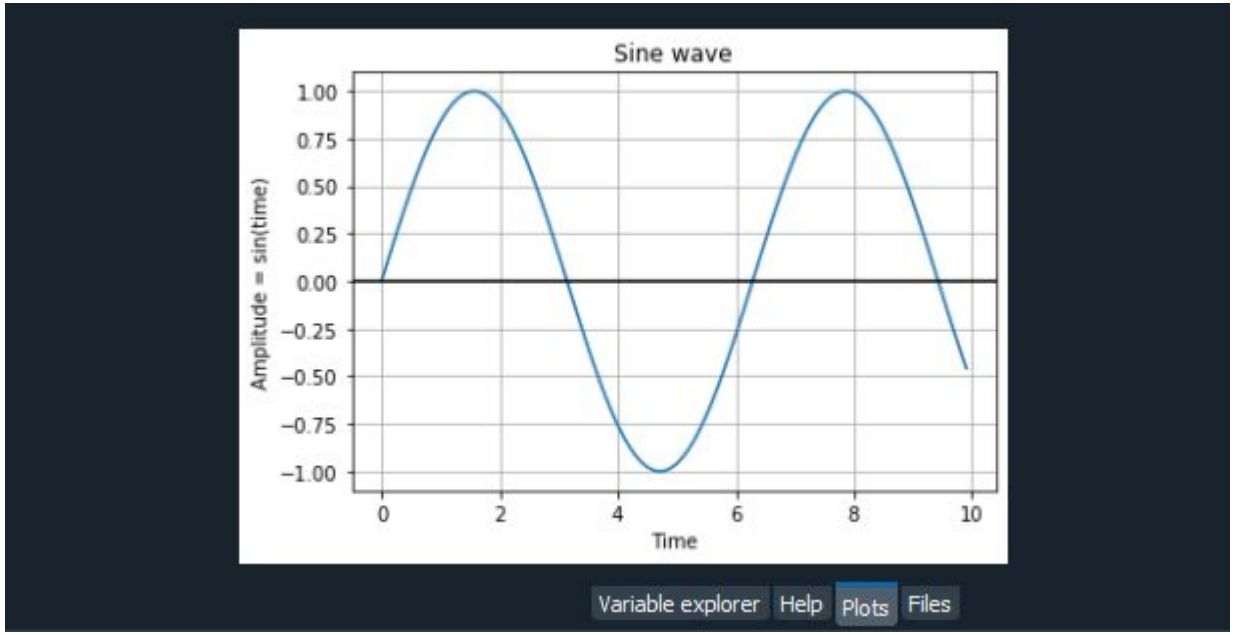
Create the mark up for the plot

```
# Give a title for the sine wave plot
plot.title('Sine wave')
# Give x axis label for the sine wave plot
plot.xlabel('Time')
# Give y axis label for the sine wave plot
plot.ylabel('Amplitude = sin(time)')
plot.grid(True, which='both')
plot.axhline(y=0, color='k')
```

Visualizing numbers – plotting a sine wave

Display the plot.

```
22
23  plot.show()
```



Python

Try to adhere to good practice!!

Code is written once, but read multiple times.

Find ground rules here:
https://www.python.org/dev/peps/pep-0008/

Digital signals - limitations

1 + 1e20 - 1e20 = ?

1 + (1e20 - 1e20) = ?

Why?

- $(1e20 \cdot 1e20) \cdot 1e\text{-}20 = ?$
- $1e20 \cdot (1e20 \cdot 1e\text{-}20) = ?$
- $1e20 \cdot (1e20\text{-}1e20) = ?$
- $1e20 \cdot 1e20 - 1e20 \cdot 1e20 = ?$

Data types - Integer (int)

```
In [16]: a = 100

In [17]: a.bit_length()
Out[17]: 7

In [25]: bin(100)
Out[25]: '0b1100100'

In [26]: bin(-4)
Out[26]: '-0b100'
```

```
In [38]: a=1

In [39]: b=1

In [40]: a is b
Out[40]: True

In [46]: a==b
Out[46]: True
```

```
In [41]: a=257

In [42]: b=257

In [43]: a is b
Out[43]: False
```

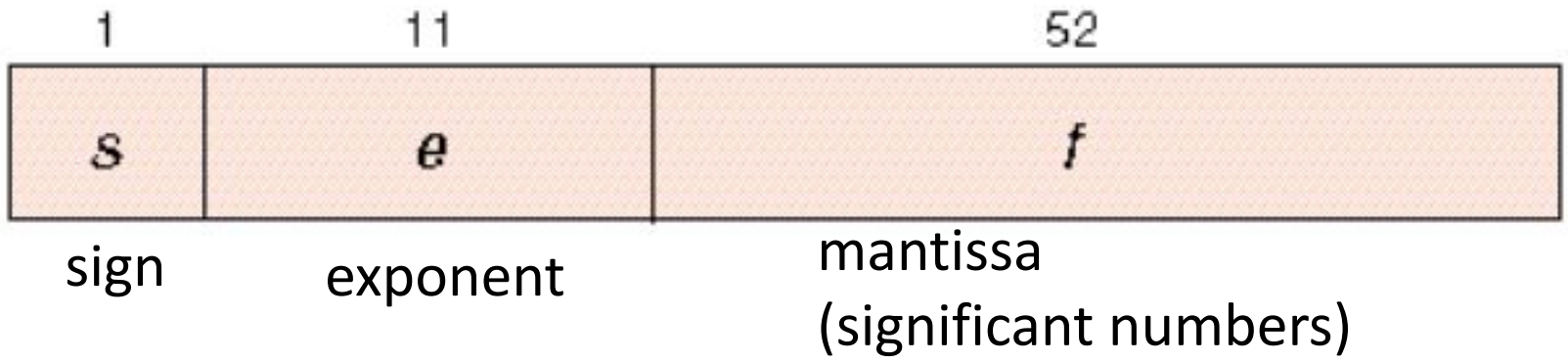
ТКС МИЭТ

Floating point - Single precision (single) / double precision (double)

double precision (64 bit) floating numbers

-123.4567890123 = -1.234567890123 e2

sign — mantissa (significant numbers) — exponent



Floating point - Single precision (single) / double precision (double)

double precision (64 bit) floating numbers

$$x = \pm (1 + f) \cdot 2^{e}$$

Giving the decimal interval for e as
$-1022 \leq e \leq 1023$
Using offset binary representation

With fraction f
$0 \leq f < 1$
In the interval where
$2^{52} \cdot f$ is an integer
$0 \leq 2^{52} \cdot f < 2^{52}$

Floating point - Single precision (single) / double precision (double)

double precision (64 bit) floating numbers

With exponent e as integer in the interval

$-1022 \leq e \leq 1023$

With fraction f

$0 \leq f < 1$

In the interval where $2^{52} \cdot f$ is an integer

$0 \leq 2^{52} \cdot f < 2^{52}$

$$x = \pm (1 + f) \cdot 2^{e}$$

```
In [11]: a = float(2) ** 1023

In [12]: a = float(2) ** 1024
Traceback (most recent call last):

  File "<ipython-input-12-a340186a386a>", line 1, in <module>
    a = float(2) ** 1024

OverflowError: (34, 'Result too large')
```

```
In [9]: a = float(10) ** 308

In [10]: a = float(10) ** 309
Traceback (most recent call last):

  File "<ipython-input-10-92873524ff56>", line 1, in <module>
    a = float(10) ** 309

OverflowError: (34, 'Result too large')
```

ТКС МИЭТ

Не сравнивайте числа с плавающей запятой

```
float f = 0.1;
while (f != 1.0) {
   f += 0.1;
}
```

```
f=0.2000000030
f=0.3000000119
f=0.4000000060
f=0.5000000000
f=0.6000000238
f=0.7000000477
f=0.8000000715
f=0.9000000954
f=1.0000001192
f=1.1000001431
f=1.2000001669
f=1.3000001907
f=1.4000002146
f=1.5000002384
f=1.6000002623
```

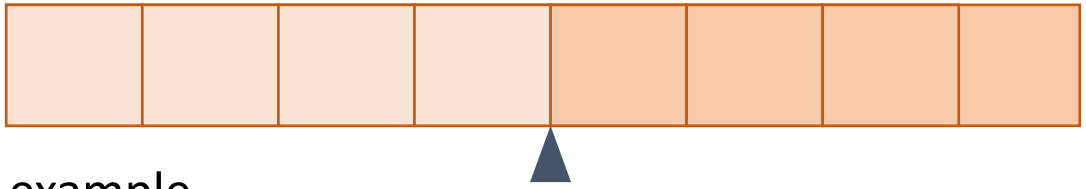
ТКС МИЭТ

Будьте аккуратны с числами с плавающей запятой

- Точность уменьшается по мере роста величины
- Ошибки переполнения и округления
  - Ракета-носитель «Ариан-5» 4 июня 1996 была подорвана на 34-й секунде полёта
    - Конвертация данных из 64-разрядного числа с плавающей запятой в 16-разрядное привела к зависанию компьютера
  - Точность ракет Patriot в 1991 (Война в Персидском заливе) была ограничена ошибкой округления

Data types - Fixed point

A fixed decimal point. Often used in low level devices.



example

10001011

$2^3 + 2^{-1} + 2^{-3} + 2^{-4} = 8.675$

```
>>> from decimal import *
>>> getcontext()
Context(prec=28, rounding=ROUND_HALF_EVEN, Emin=-999999999, Emax=999999999,
        capitals=1, flags=[], traps=[Overflow, DivisionByZero,
        InvalidOperation])

>>> getcontext().prec = 7       # Set a new precision
```

ТКС
МИЭТ

5 steps of a method/function in any language

- 1 Initialization
- 2 input
- 3 process
- 4 output
- 5 Termination

ТКС МИЭТ

1) Define a function

```
def myFirstFunction(input):
    print("This will be the output, %s" %(input))
```

myFirstScript.py

```
# -*- coding: utf-8 -*-
"""
Created on Sat Aug 29 18:53:26 2020
@author: Admin

Last Modified on Sat Aug 29 18:53:26 2020
@author: Admin


"""

def myFirstFunction(input):
    print("This will be the output,%s" %(input))
```

Name	Date Modified
__pycache__	29/8/2020 6:55
KarplusStrong.py	29/8/2020 6:53
myFirstScript.py	29/8/2020 6:56

ТКС
МИЭТ

Importing the function

```
In [53]: import myFirstScript
```

Calling the function

```
In [55]: myFirstScript.myFirstFunction( 'aaaa')
This will be the output,aaaa
```

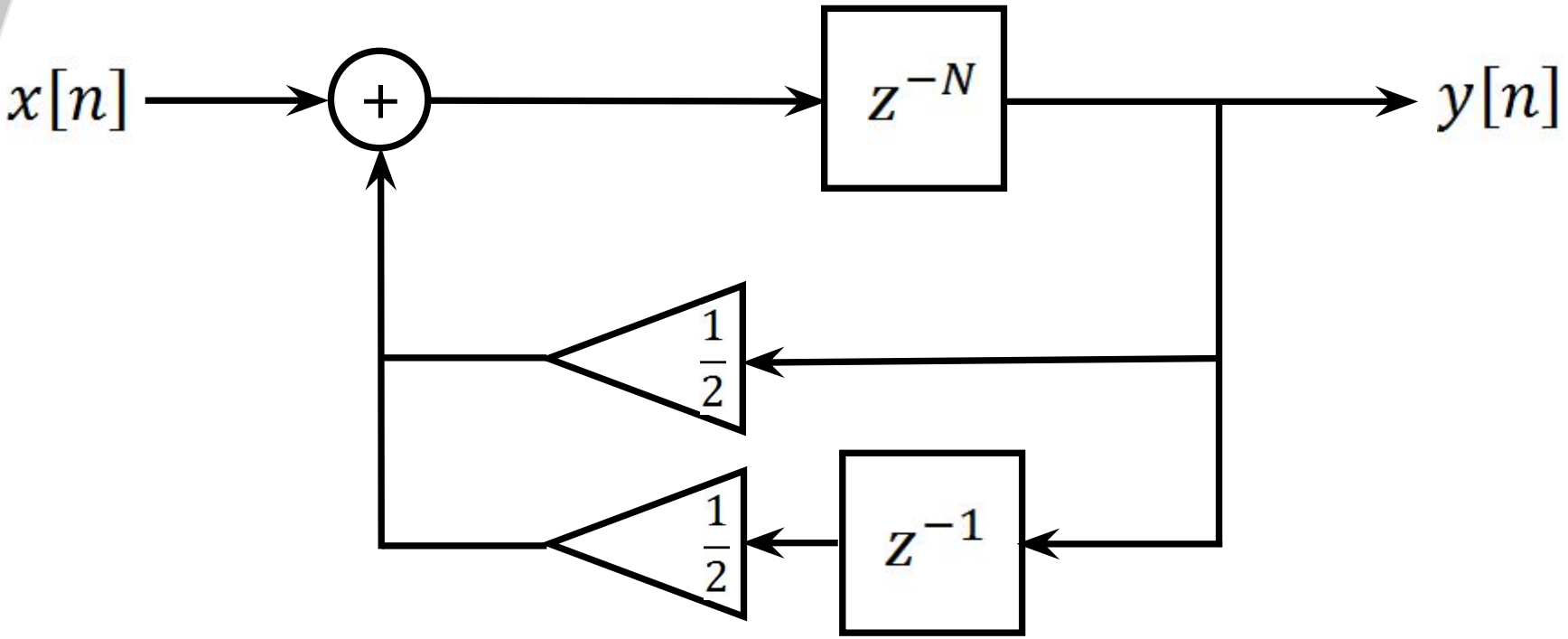
ТКС МИЭТ

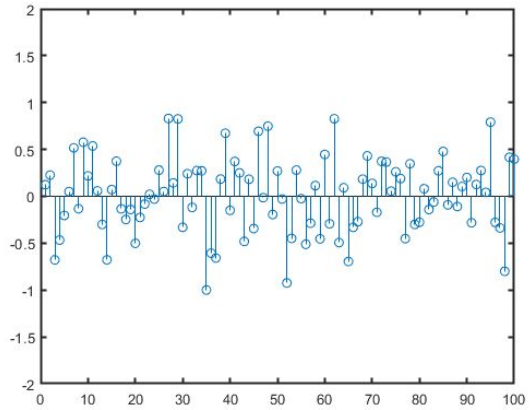
Data types

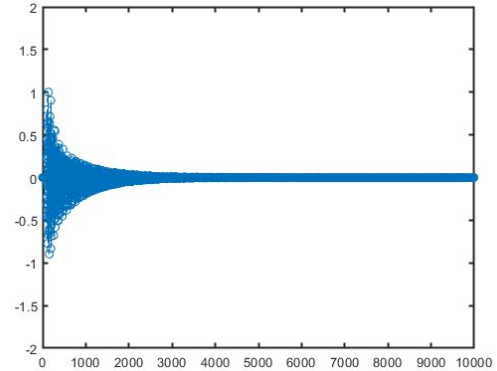
Text Type:	str
Numeric Types:	int, float, complex
Sequence Types:	list, tuple, range
Mapping Type:	dict
Set Types:	set, frozenset
Boolean Type:	bool
Binary Types:	bytes, bytearray, memoryview

Writing a Karplus-Strong algorithm in Python

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

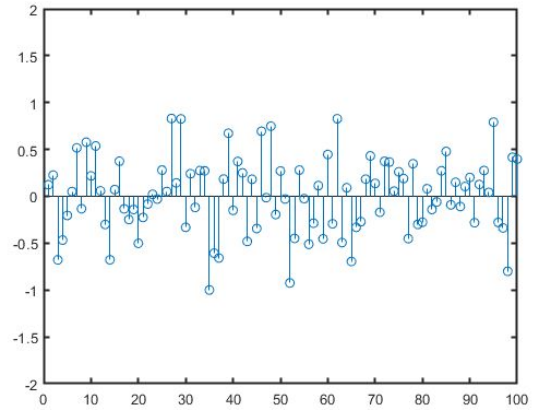


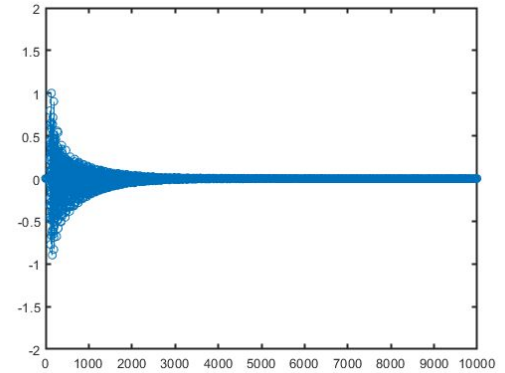




Writing a Karplus-Strong algorithm in Python

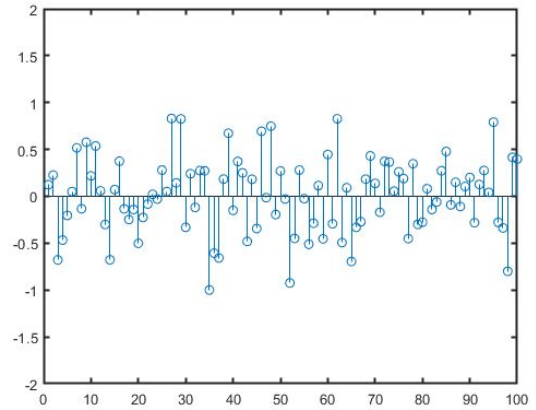
- Generate a random input
- Process the input using the algorithm
- Show the Result
- Save the result





Writing a Karplus-Strong algorithm in Python

- Generate a random input



[Understanding the Karplus-Strong with Python (Synthetic Guitar Sounds Included) | Frolian's blog (flothesof.github.io)]

ТКС МИЭТ

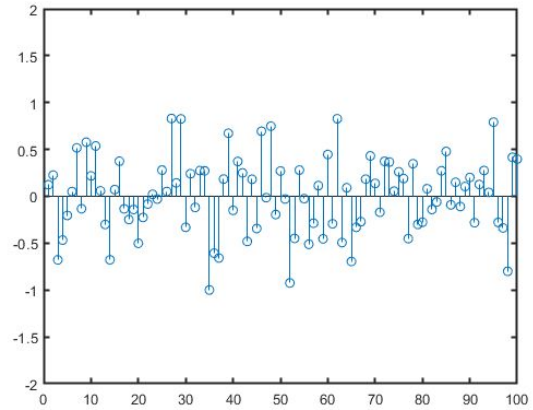
Data types

Text Type:	str
Numeric Types:	int, float, complex
Sequence Types:	list, tuple, range
Mapping Type:	dict
Set Types:	set, frozenset
Boolean Type:	bool
Binary Types:	bytes, bytearray, memoryview

Writing a Karplus-Strong algorithm in Python

- **Generate a random input**

  numpy.random.uniform



- **Syntax**

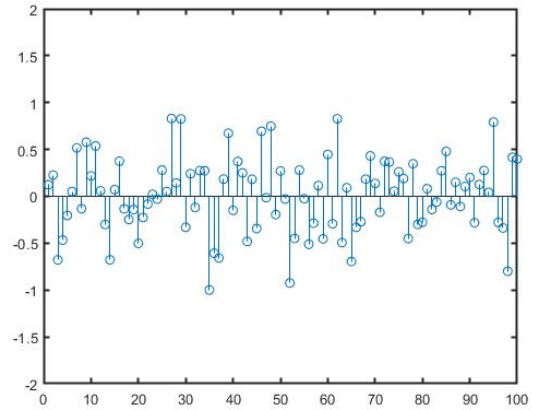
import numpy as np

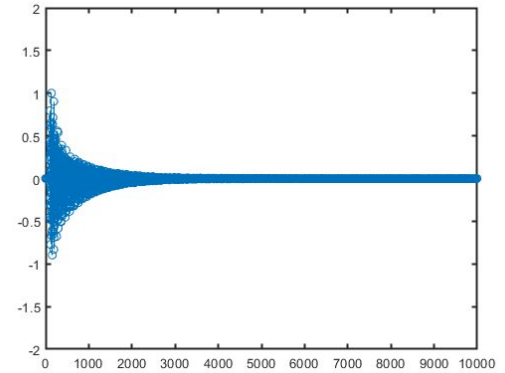
np.random.uniform**(***low=0.0***,** *high=1.0***,** *size=None***)**

np.random.uniform(-1,1,1000)

Writing a Karplus-Strong algorithm in Python

- ~~Generate a random input~~
- Process the input using the algorithm
- Show the Result
- Save the result





Writing a Karplus-Strong algorithm in Python

First solution

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

1) Create variable ***y*** as a copy of input ***x;***
   Append ***N*** zeros in front of ***y***

   OR

   Create ***y*** as zeros for a lenght of ***x*** plus N
   Replace the indexed values in ***y*** with values of ***x***

2) Write a for-loop, which goes through all indexes of ***y***
   Replace indexed values of ***y***, with a sum of the current value plus scaled previous values

ТКС МИЭТ

Writing a Karplus-Strong algorithm in Python

First solution

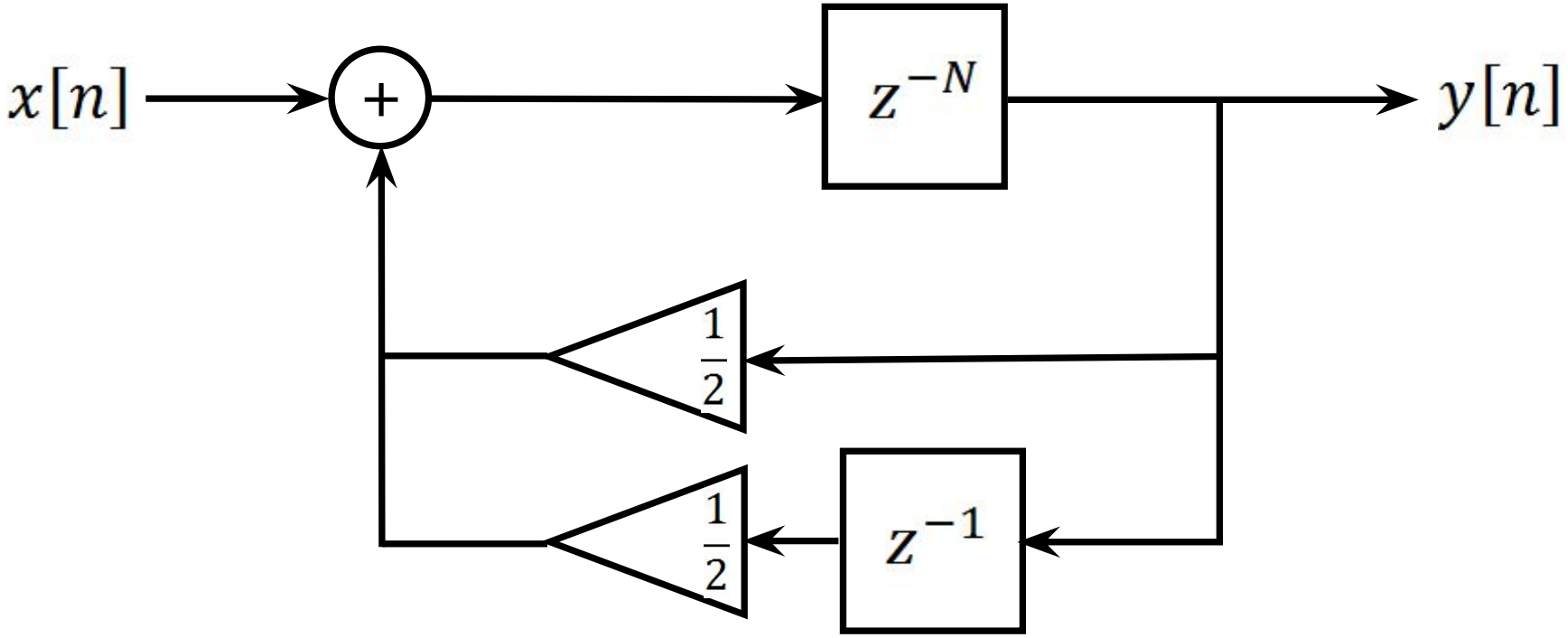
$$y[n] = x[n-N] + \frac{y[n-N] + y[n-(N+1)]}{2}$$

```
def KS1(signal,delayN,envelopeA,totalLength):
    import numpy as np
#    M = len(signal)
    y = np.zeros((delayN))
    y = np.append(y, signal)
    y = np.append(y, np.zeros(totalLength-len(y)))

    for index in range(delayN, totalLength):
        y[index] = y[index] + envelopeA/2 * ( y[index - delayN] + y[index - (delayN+1)] )
    return y
```

Writing a Karplus-Strong algorithm in Python

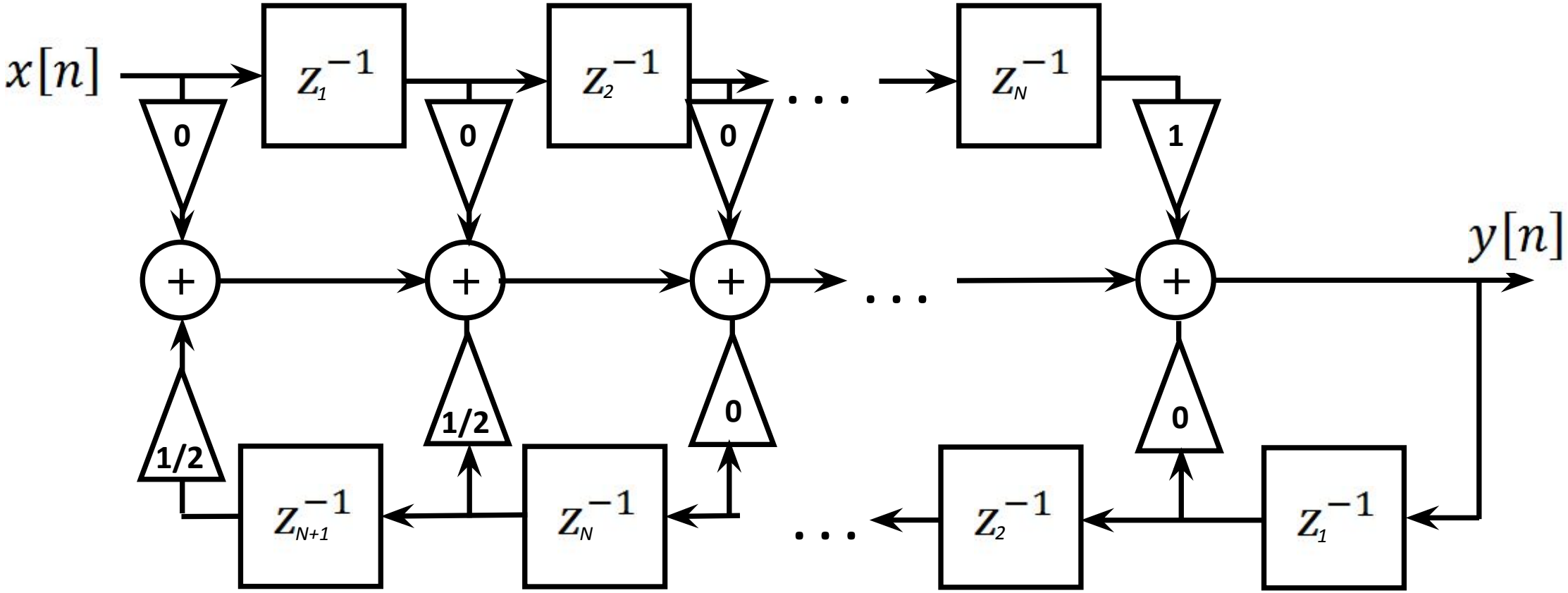
Second solution



ТКС МИЭТ

Writing a Karplus-Strong algorithm in Python

Second solution



Writing a Karplus-Strong algorithm in Python

Second solution:

IIR Filter

b-coefficients

$b_0, b_1, \ldots b_{N-1}$ are *0*

b_N is *1*

a-coefficients

a_0 is *1*

$a_1 .. a_{N-1}$ are *0*

a_N and a_{N+1} are *0.5*

Writing a Karplus-Strong algorithm in Python

```
#using a filter
randomInput=np.append(randomInput, np.zeros(totalLength-len(randomInput)))
b = np.append(np.zeros(delay), [1])
a = np.append([1], np.zeros(delay-1))
a = np.append(a, [-alpha/2, -alpha/2])
outputSignal = signal.lfilter(b, a, randomInput)
plot.plot(outputSignal)
plot.show()
```

ТКС МИЭТ

Save your output

```
fs = 44100  # 44100 samples per second
audio = outputSignal * (2**15 - 1) / np.max(np.abs(outputSignal))
audio = audio.astype(np.int16)
write('test.wav', 44100, audio)
```

ТКС МИЭТ

Homework Task 1

1) Write your own function and generate outputs (for example your own random number generator, a lookup table etc.)
2) Change the code to match «good practice»

   https://www.python.org/dev/peps/pep-0008/

3) Create a function that has multiple outputs, and optimize the memory usage and processing speed.
4) Retrieve the outputs from the function and display them (or plot them)

ТКС МИЭТ

Полезная литература

- Методы и техника обработки сигналов при физических измерениях (2 тома)
- Signal processing for 5G
- Multi-Carrier Communication Systems with Examples in MATLAB: A New Perspective
- An Image Processing Tour of College Mathematics Yevgeniy V. Galperin
- Fundamentals of IMAGE, AUDIO, and VIDEO PROCESSING Using MATLAB: With Applications To PATTERN RECOGNITION
- Introduction to Modeling and Simulation with MATLAB and Python
- PySDR: A Guide to SDR and DSP using Python
- Python documentation