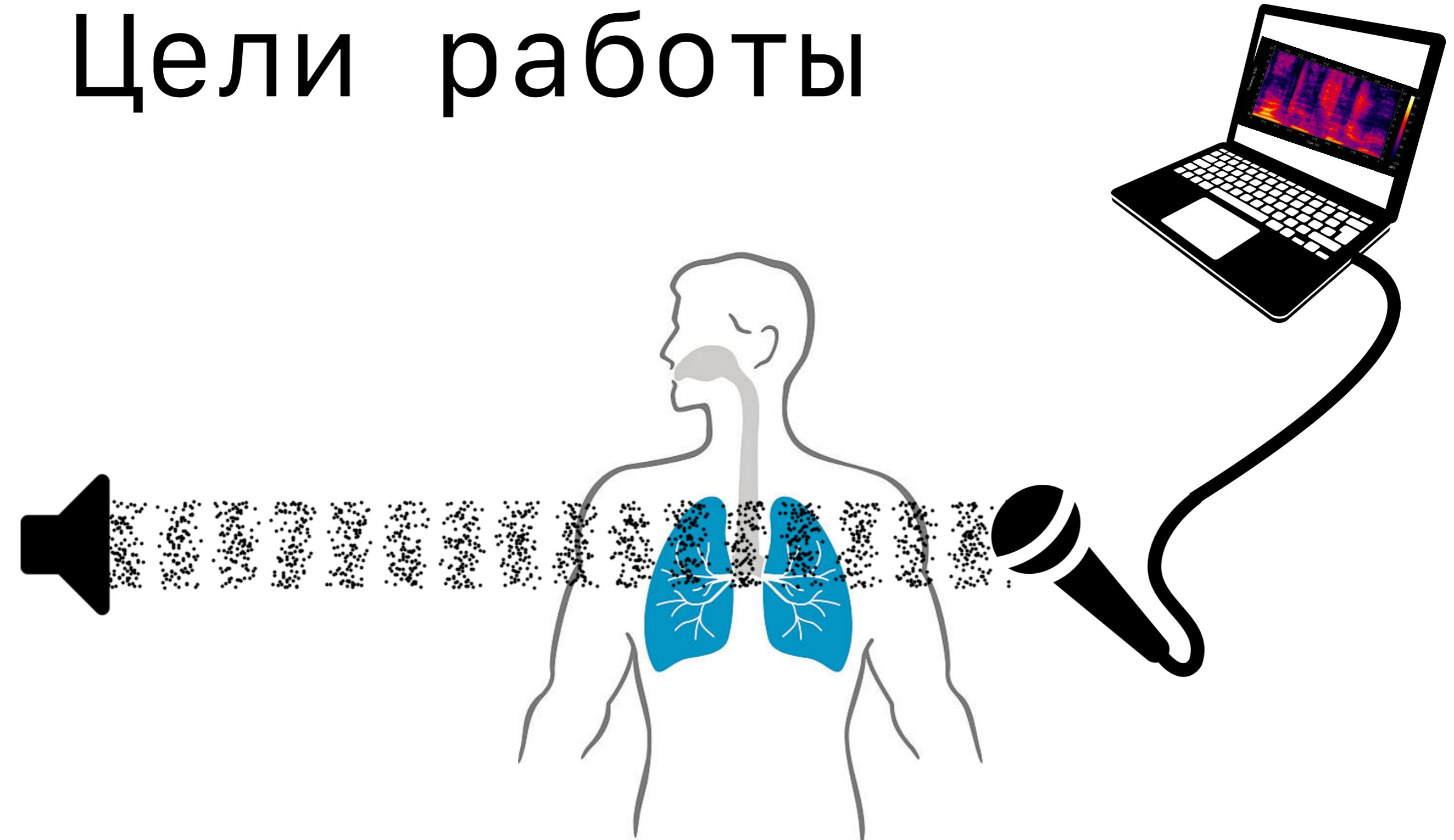


Цифровая акустическая система оценки состояния лёгких

МКН | Александр Родионов
Руководитель | Я.А. Туровский

вГУ | июнь 2019

Цели работы



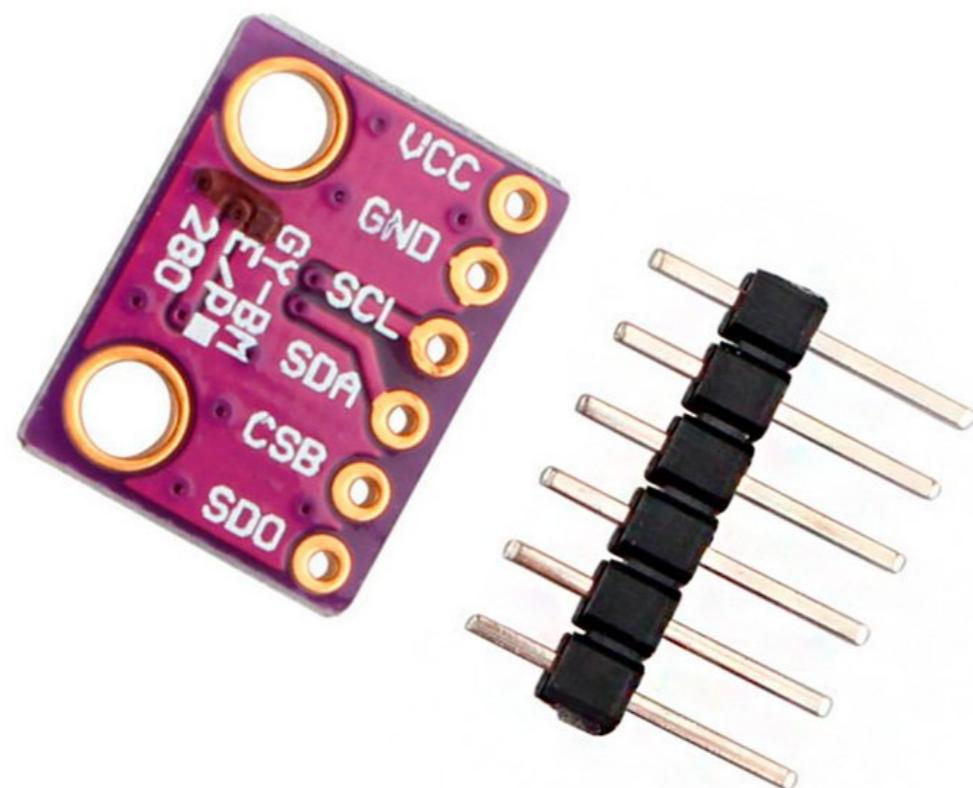
Цели работы

- устройство для оценки состояния легких
- ПО для этого устройство
- компьютерная модель легких

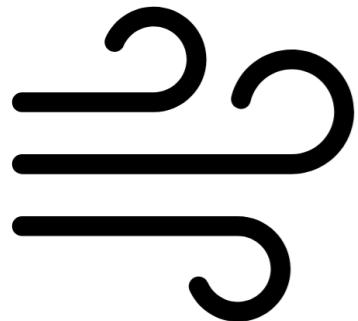
Устройство

- микроконтроллер Arduino Due
- Микрофон + Усилитель
- динамики
- трубка с 2 датчиками давления

Датчики давления Bosch BMP280



Автоматическая запись во время вдохов и выдохов



Програмное обеспечение

- по для Arduino
- по для компьютера

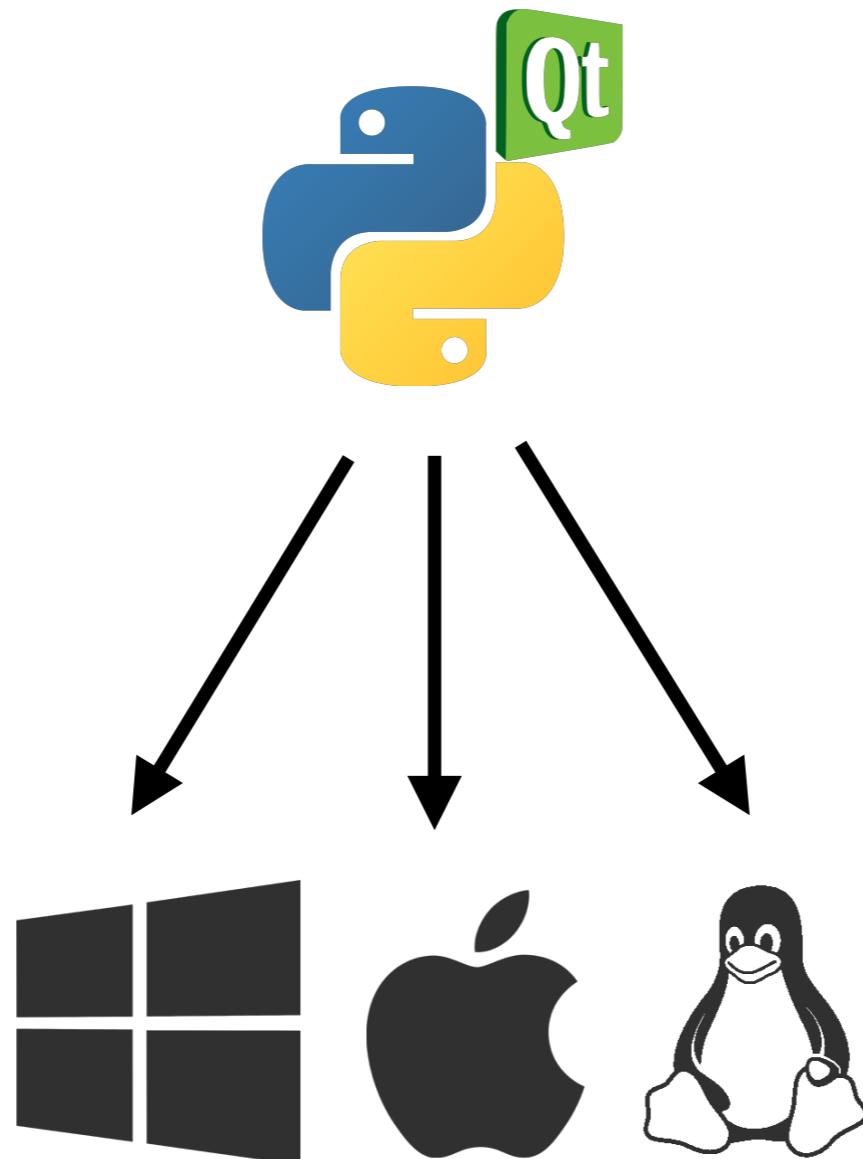
Программа для Arduino

- прием сигнала с датчиков давления
- прием сигнала с микрофона
- генерация звука
- передача данных на компьютер
- паралельное выполнение с использованием библиотеки DueTimer

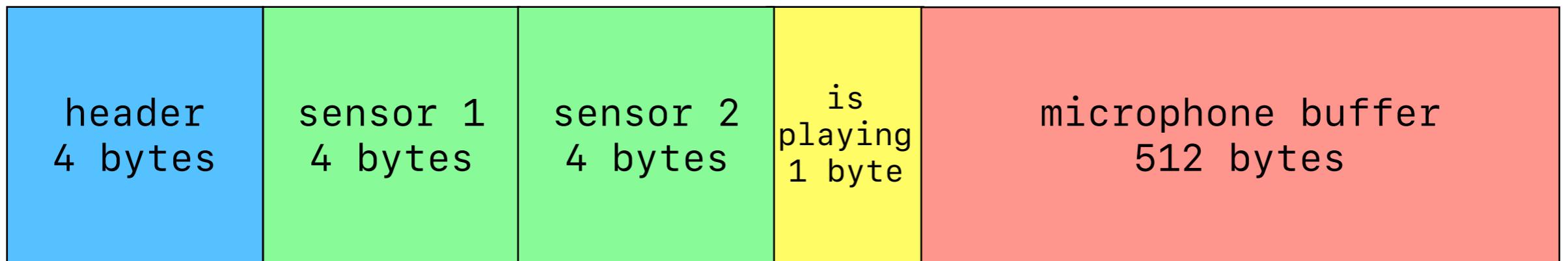
Программа для компьютера

- прием сигнала с компьютера
- графики + сигнал, спектр, спектrogramma
- запись по нажатию кнопки
- автозапись по вдоху/выдоху

Кросплатформенное desktop-приложение



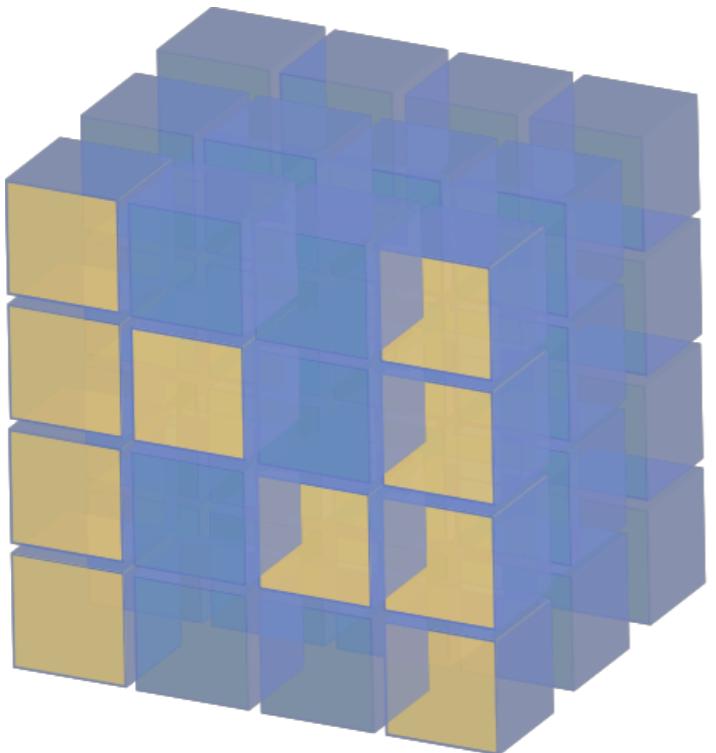
структура пакета данных



Qt Signals and Slots IPC



Работа с числовыми массивами



NumPy

FFT, работа с .wav файлами



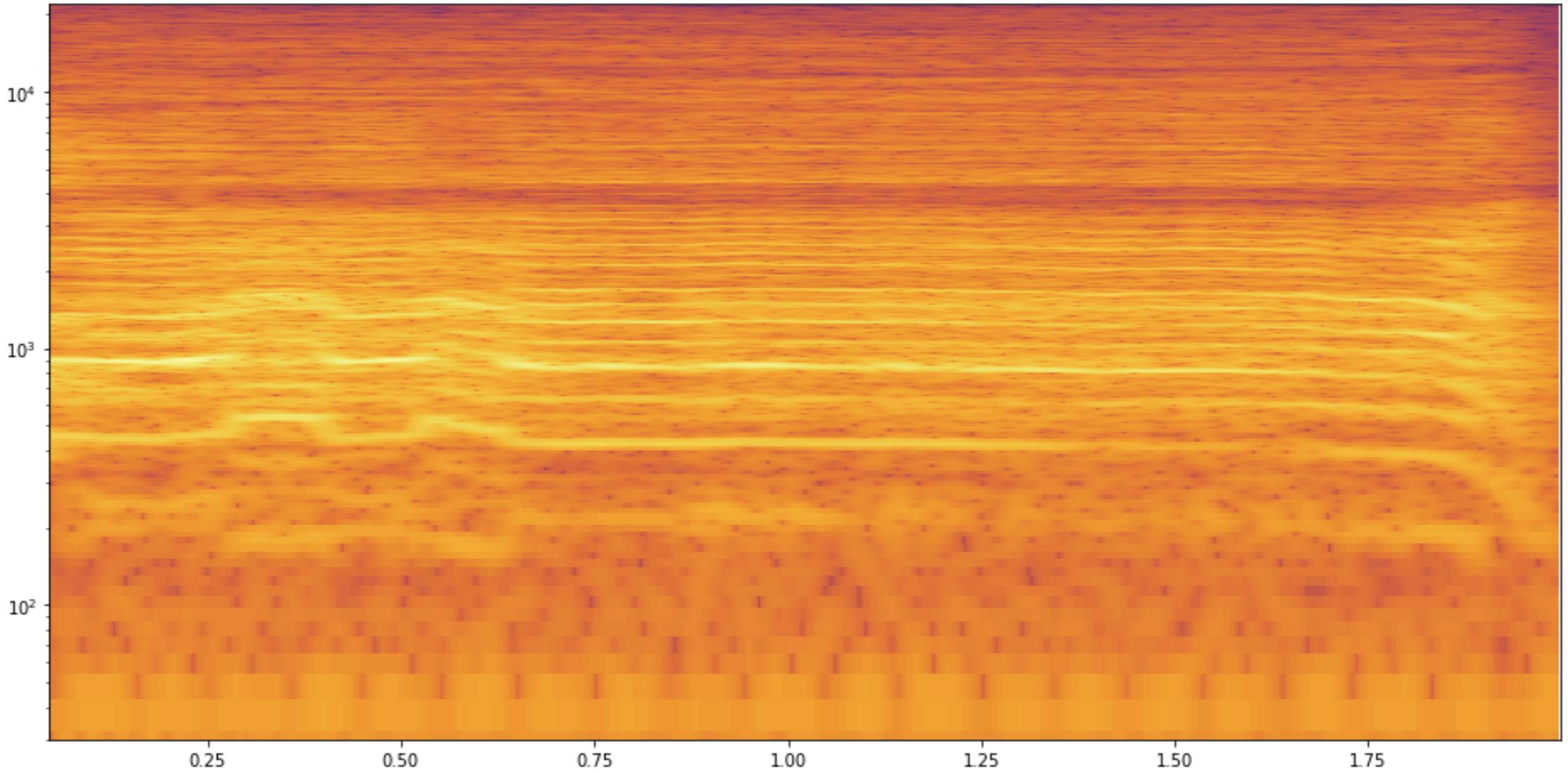
Чтение данных с USB



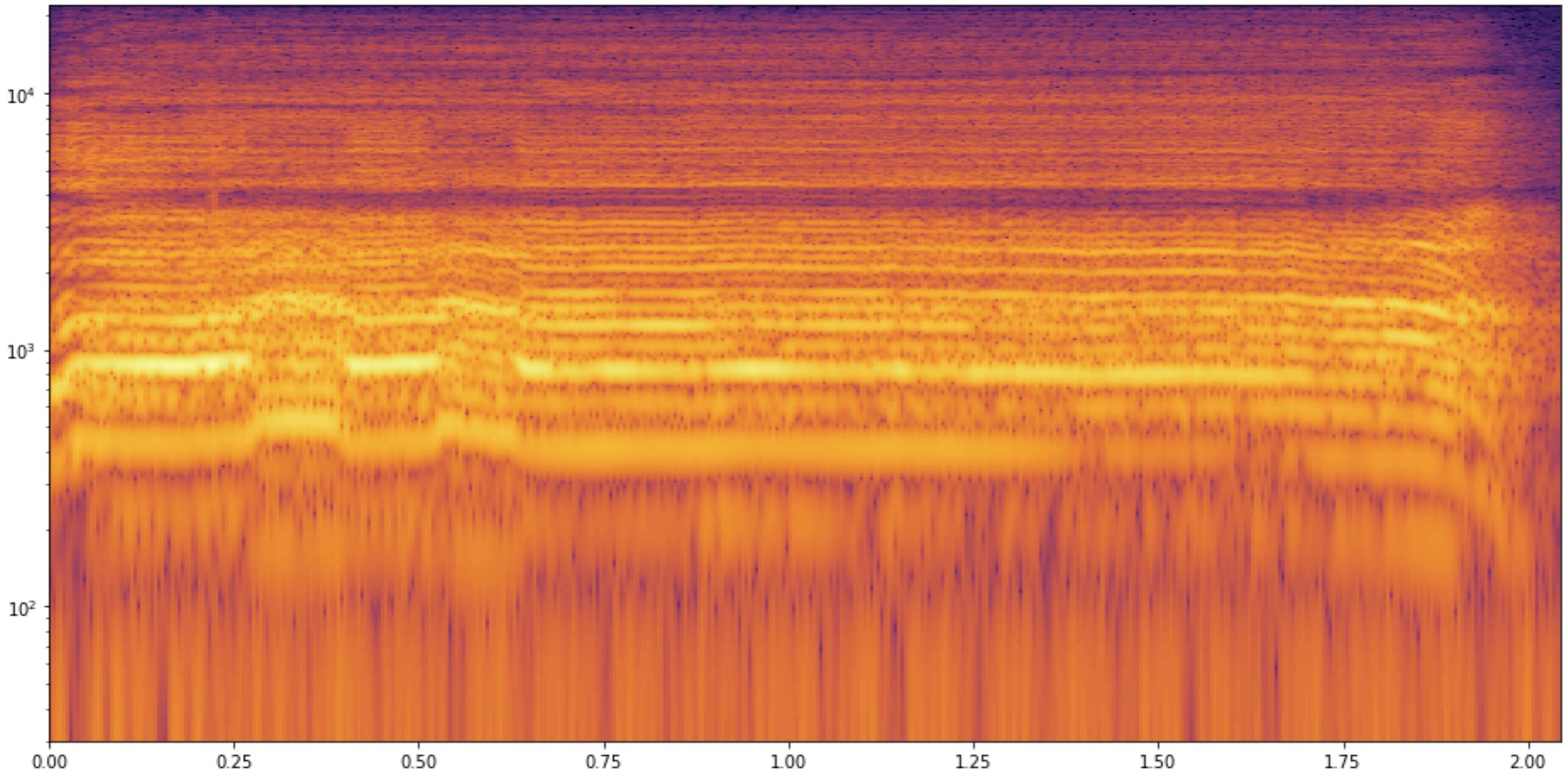
Быстрая отрисовка графиков

PyQtGraph

Повышение качества спектрограмм



Повышение качества спектрограмм



modes of cross correlation

full

		1	2	3	
5	6	7	8	9	9
5	6	7	8	9	26
5	6	7	8	9	50
5	6	7	8	9	44
5	6	7	8	9	38
5	6	7	8	9	28
5	6	7	8	9	15

same

		1	2	3	
5	6	7	8	9	9
5	6	7	8	9	26
5	6	7	8	9	50
5	6	7	8	9	44
5	6	7	8	9	38
5	6	7	8	9	28
5	6	7	8	9	28
5	6	7	8	9	28

valid

		1	2	3	
5	6	7	8	9	9
5	6	7	8	9	26
5	6	7	8	9	50
5	6	7	8	9	44
5	6	7	8	9	38
5	6	7	8	9	38
5	6	7	8	9	38
5	6	7	8	9	38

full *

				1	2	3
5	6	7	8	9		
5	6	7		8	9	
5	6		7	8	9	
	5	6	7	8	9	
	5	6	7		8	9
	5	6		7	8	9
		5	6	7	8	9

$$a = [1, 2, 3]$$

$$b = [5, 6, 7, 8, 9]$$

$$a * b = [9, 26, 50, 44, 38, 28, 15]$$

full *

					1	2	3	
5	6	7	8	9				9
5	6	7	8	9				
5	6	7	8	9				
5	6	7	8	9				
5	6	7	8	9				
5	6	7	8	9				
5	6	7	8	9				
5	6	7	8	9				

```
a      = [1,    2,    3]
b      = [5,    6,    7,    8,    9]
a * b = [9,   26,   50,   44,   38,   28,   15]
```

full *

			1	2	3		
5	6	7	8	9			9
5	6	7	8	9			26
5	6	7	8	9			
5	6	7	8	9			
5	6	7	8	9			
5	6	7	8	9			
5	6	7	8	9			

```
a      = [1,    2,    3]
b      = [5,    6,    7,    8,    9]
a * b = [9,   26,   50,   44,   38,   28,   15]
```

full *

	1	2	3		
5	9				9
5	8	9			26
5	7	8	9		50
	5	6	7	8	9
	5	6	7	8	9
	5	6	7	8	9
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	1	2	3		
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5	8	9			26
5	7	8	9		50
5	6	7	8	9	44
	5	6	7	8	9
	5	6	7	8	9
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full *

					1	2	3	
5	6	7	8	9				9
5	6	7	8	9				26
5	6	7	8	9				50
	5	6	7	8	9			44
	5	6	7	8	9			38
	5	6	7	8	9			28
		5	6	7	8	9		15

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same *

	1	2	3			
5	6	7	8	9		
5	6	7	8	9		26
5	6	7	8	9		50
5	6	7	8	9		44
5	6	7	8	9		38
5	6	7	8	9		28
	5	6	7	8	9	

$$a = [1, 2, 3]$$

$$\mathbf{b} = [5, 6, 7, 8, 9]$$

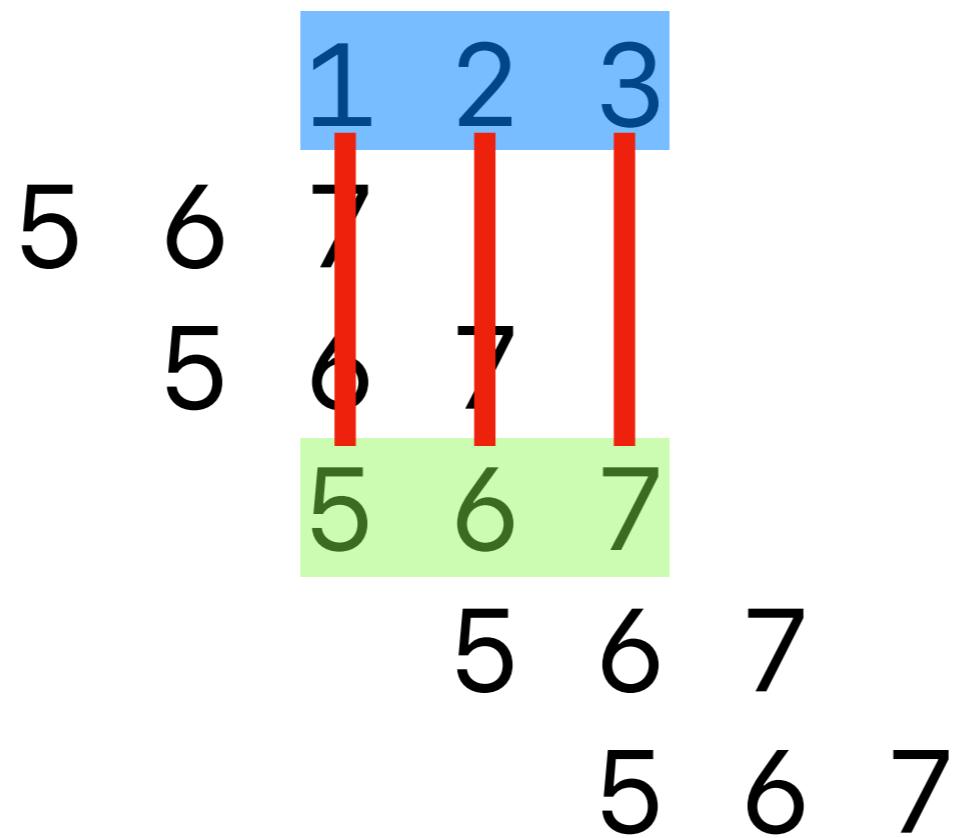
$$a * b = [9, 26, 50, 44, 38, 28, 15]$$

valid *

		1	2	3	
5	6	7	8	9	
5	6	7	8	9	
5	6	7	8	9	50
5	6	7	8	9	44
5	6	7	8	9	38
	5	6	7	8	9
	5	6	7	8	9

```
a      = [1,    2,    3]
b      = [5,    6,    7,    8,    9]
a * b = [9,   26,   50,   44,   38,   28,   15]
```

valid *



dot product

DFT

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-i2\pi kn/N}$$

$k = 0..N-1$



$$\begin{aligned}e^{-i\theta} &= \cos \theta - i \sin \theta \\ \theta &= 2\pi kn/N\end{aligned}$$

$$X(k) = \boxed{\sum_{n=0}^{N-1} x(n) \cos \left(\frac{2\pi kn}{N} \right)} - i \boxed{\sum_{n=0}^{N-1} x(n) \sin \left(\frac{2\pi kn}{N} \right)}$$

$$X(k) = \boxed{\sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi kn}{N}\right)} - i \boxed{\sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi kn}{N}\right)}$$

k = 0..N-1

$$f \cdot t(n) = \frac{k}{T} \cdot \frac{n}{f_s} \quad N = T \cdot f_s \quad A \sin(2\pi f t + \varphi)$$

$$X[k] = \sum x[n] \cdot \cos\left(2\pi \frac{k}{T} \cdot \frac{n}{f_s}\right)$$

$$- i \sum x[n] \cdot \sin\left(2\pi \frac{k}{T} \cdot \frac{n}{f_s}\right)$$

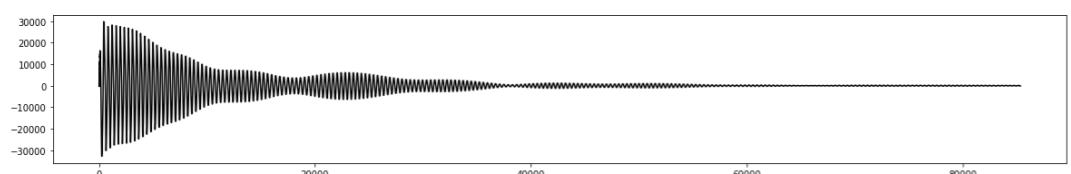
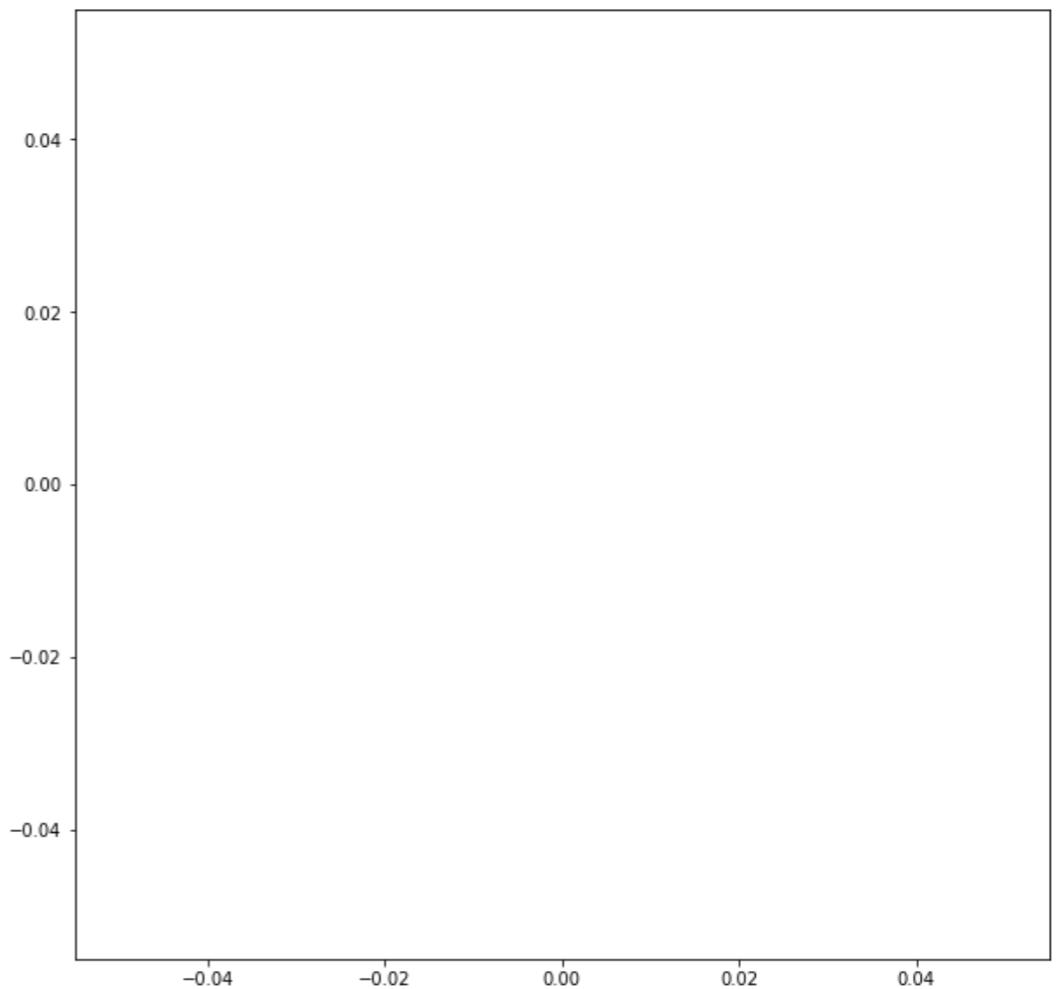
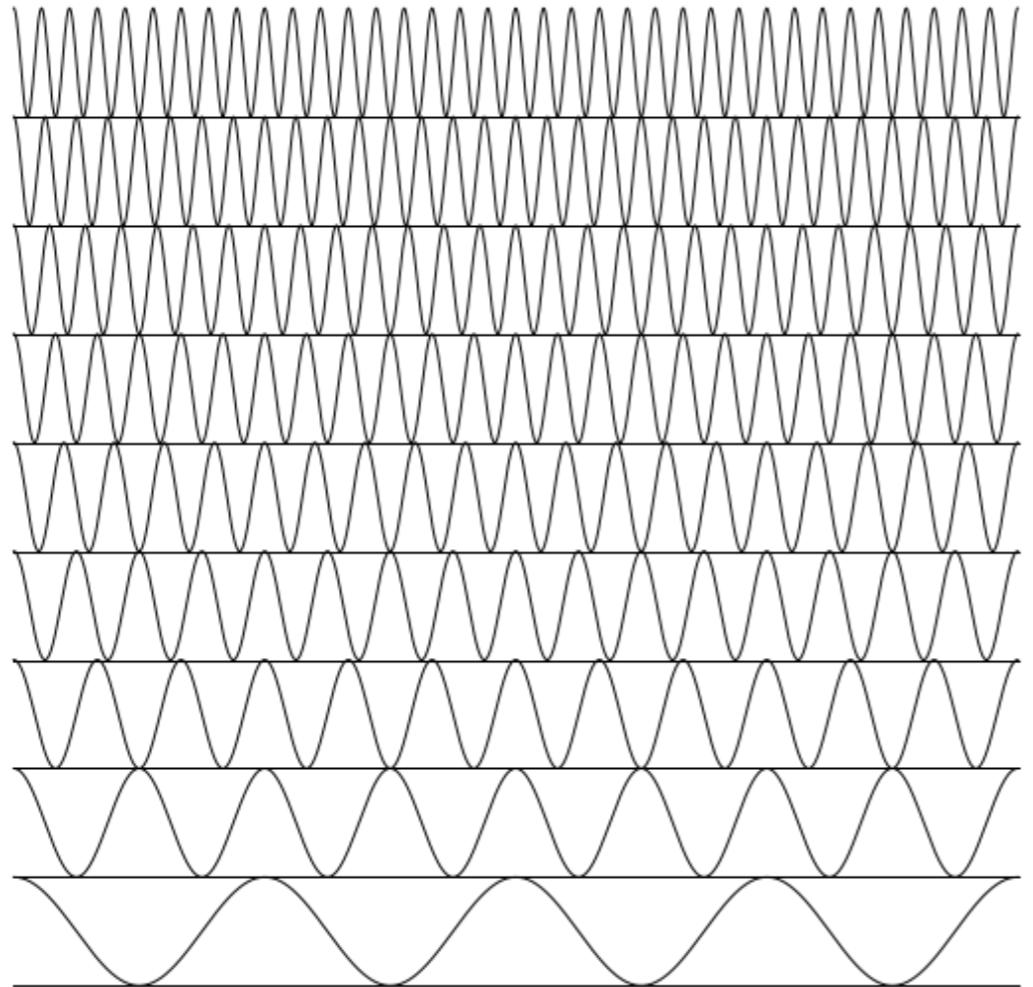
$$X(k) = \boxed{\sum_{n=0}^{N-1} x(n) \cos \left(\frac{2\pi kn}{N} \right)} - i \boxed{\sum_{n=0}^{N-1} x(n) \sin \left(\frac{2\pi kn}{N} \right)}$$

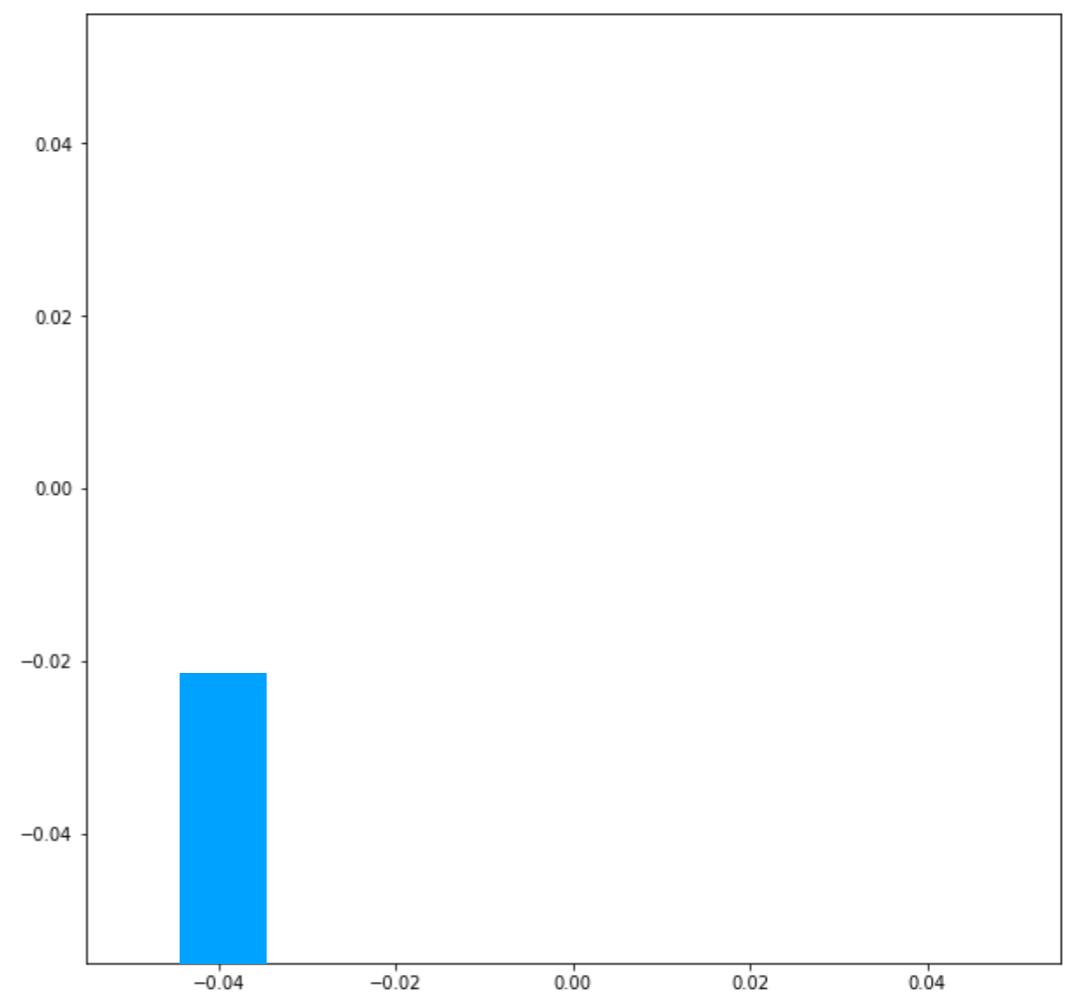
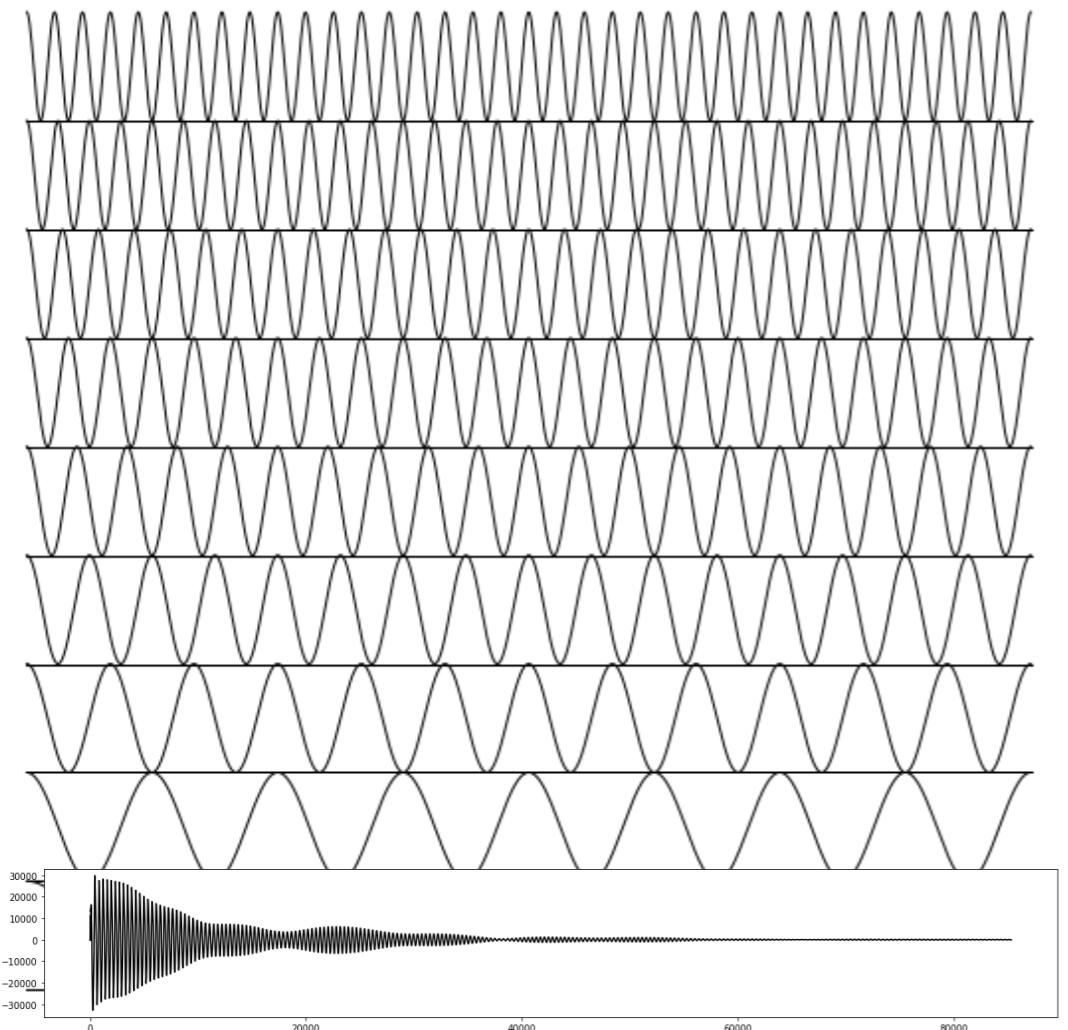
k = 0..N-1

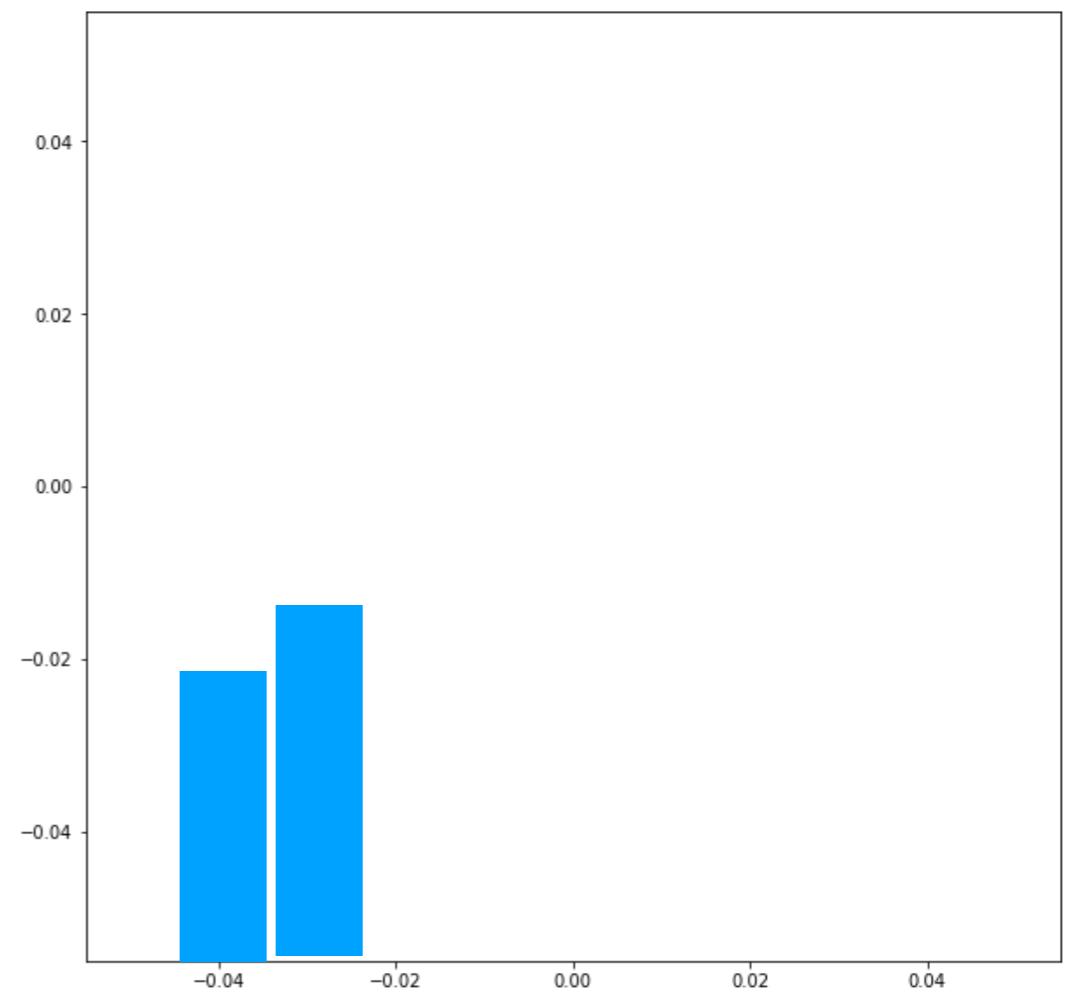
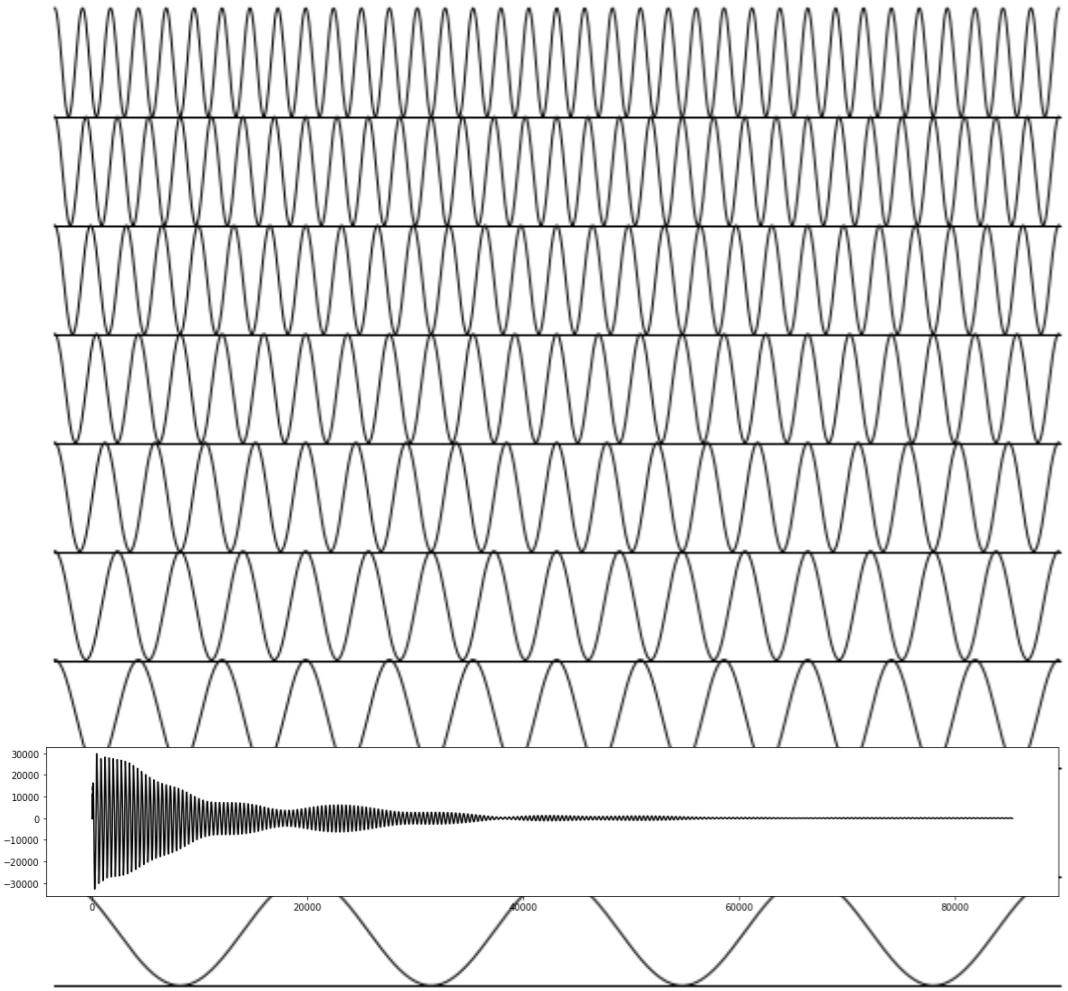
$$f \cdot t(n) = \frac{k}{T} \cdot \frac{n}{f_s} \quad N = T \cdot f_s \quad A \sin(2\pi \cancel{f}t + \varphi)$$

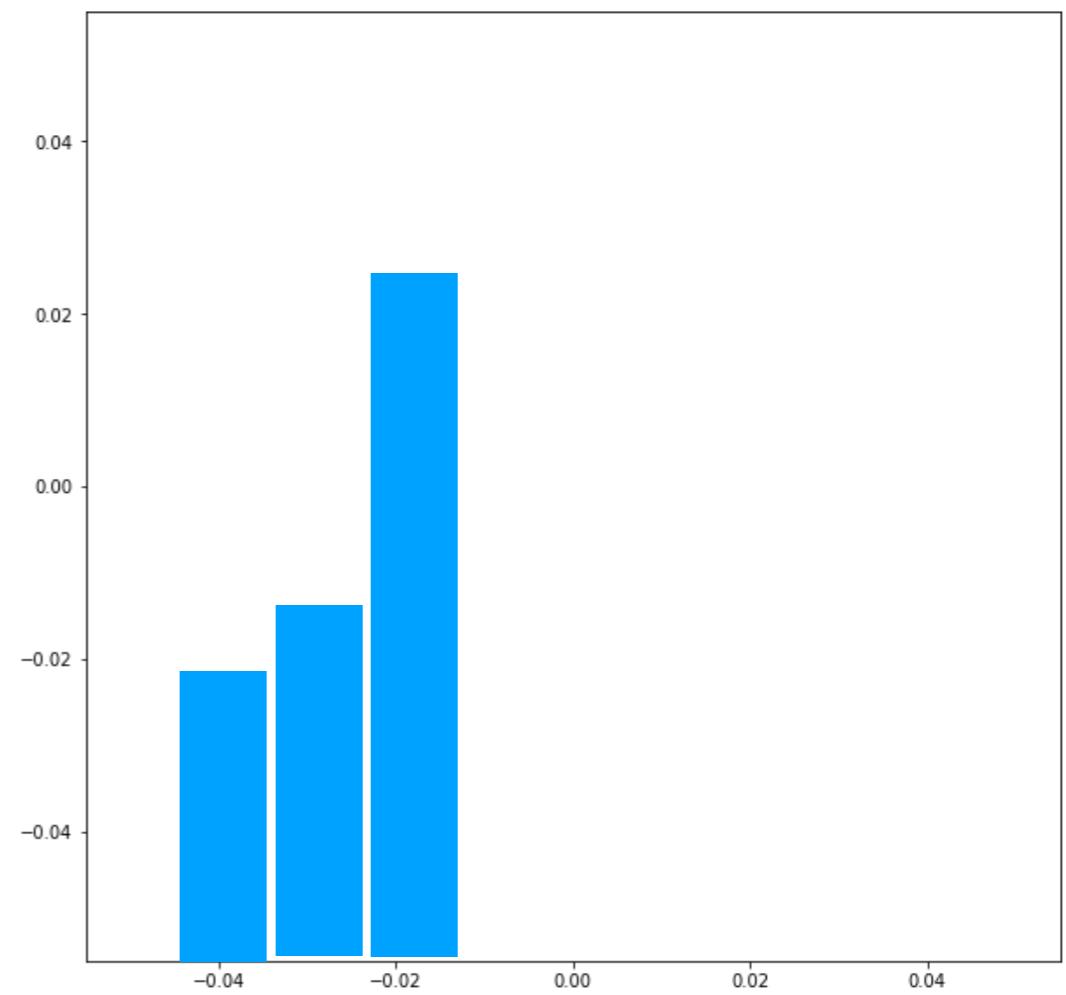
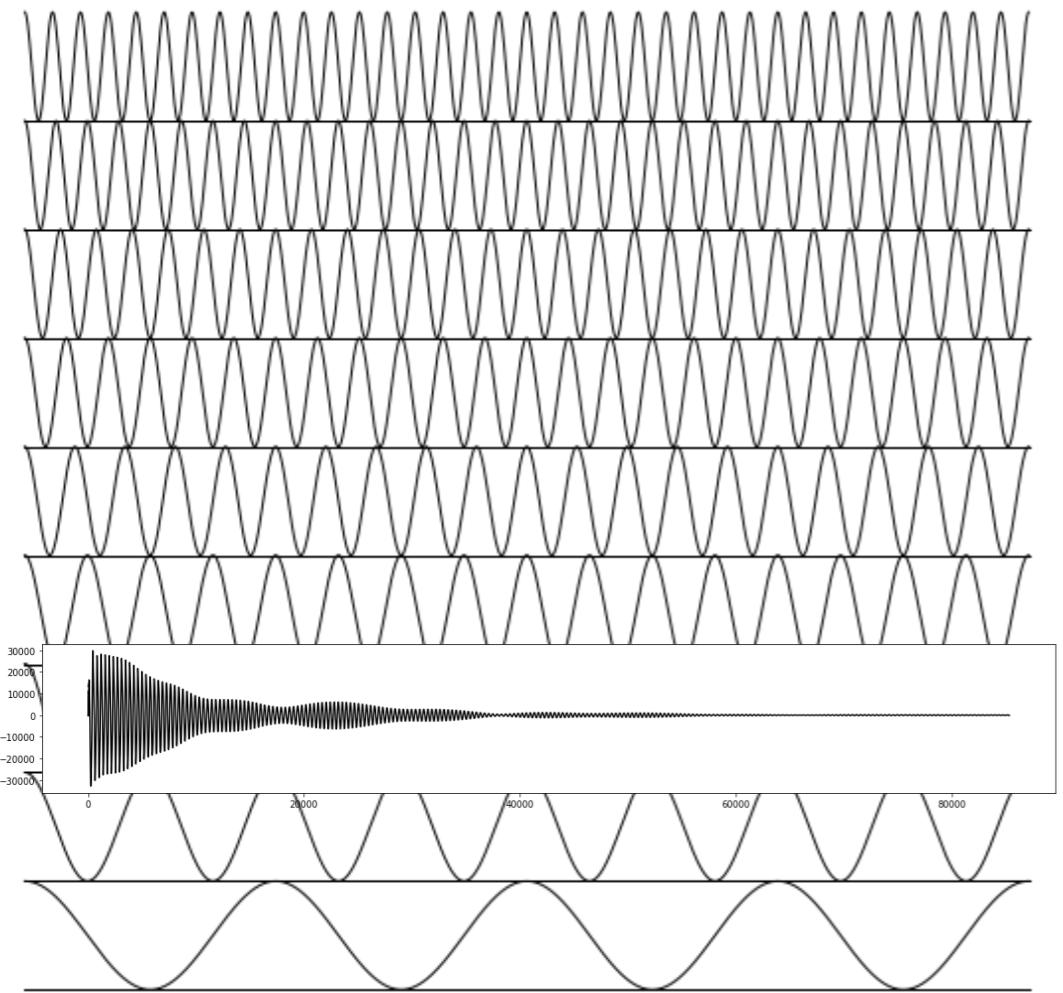
$$X[k] = \sum x[n] \cdot \cos(2\pi \frac{k}{T} \cdot \frac{n}{f_s})$$

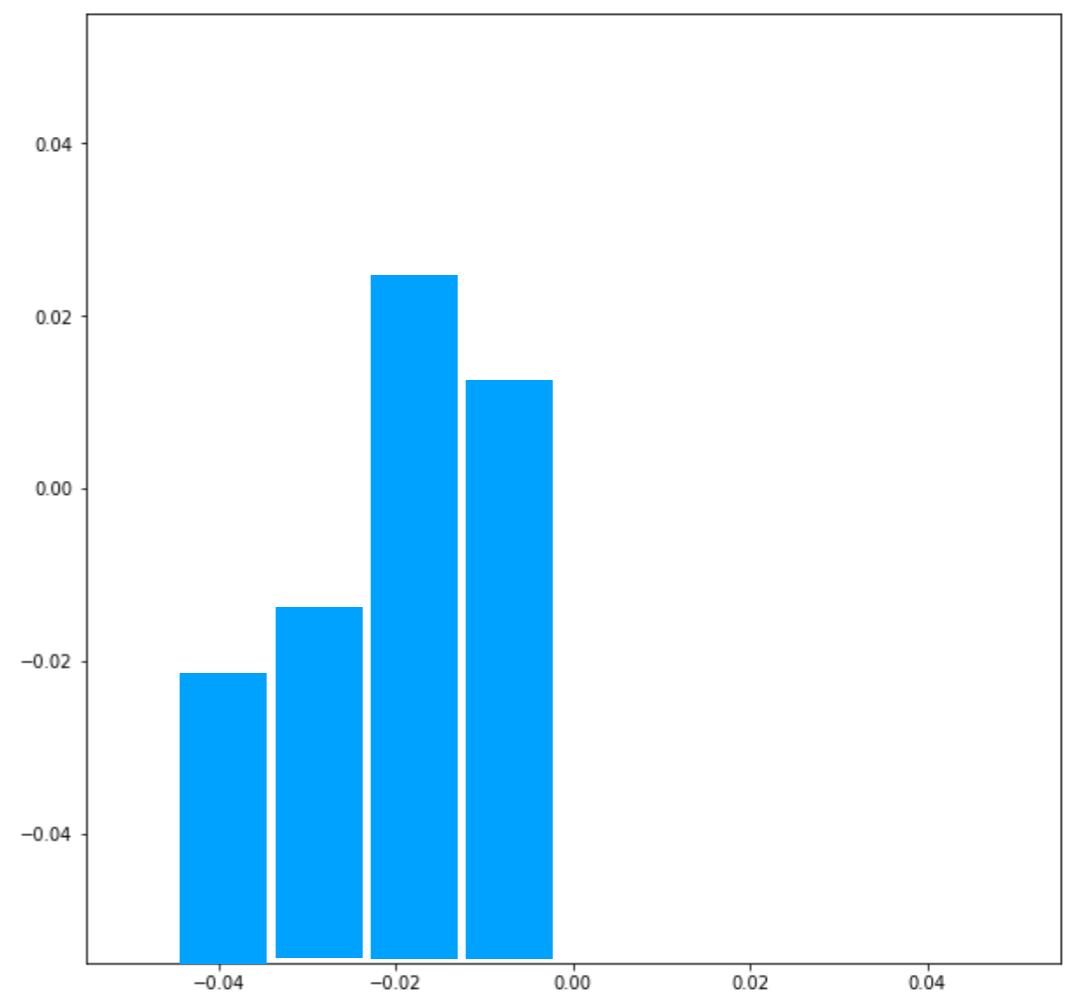
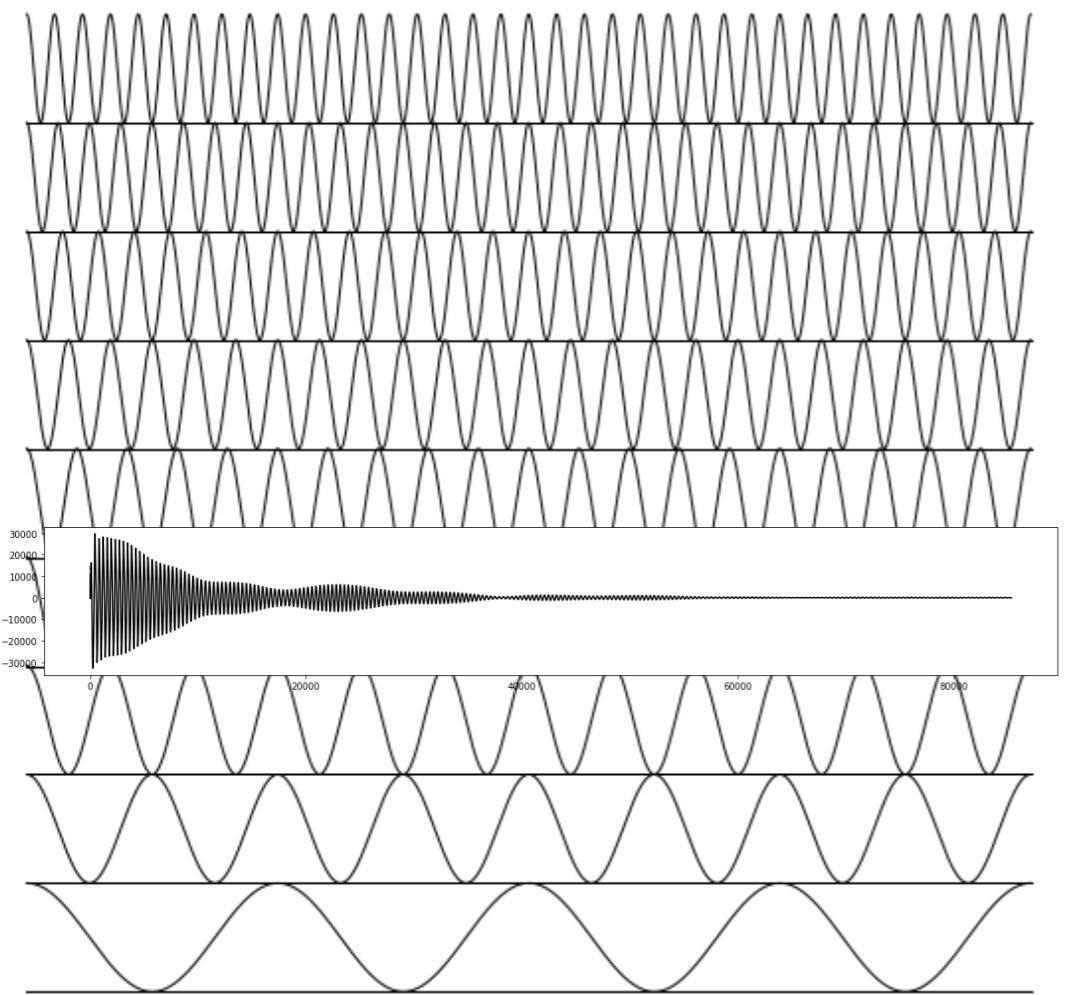
$$-i \sum x[n] \cdot \sin(2\pi \frac{k}{T} \cdot \frac{n}{f_s})$$

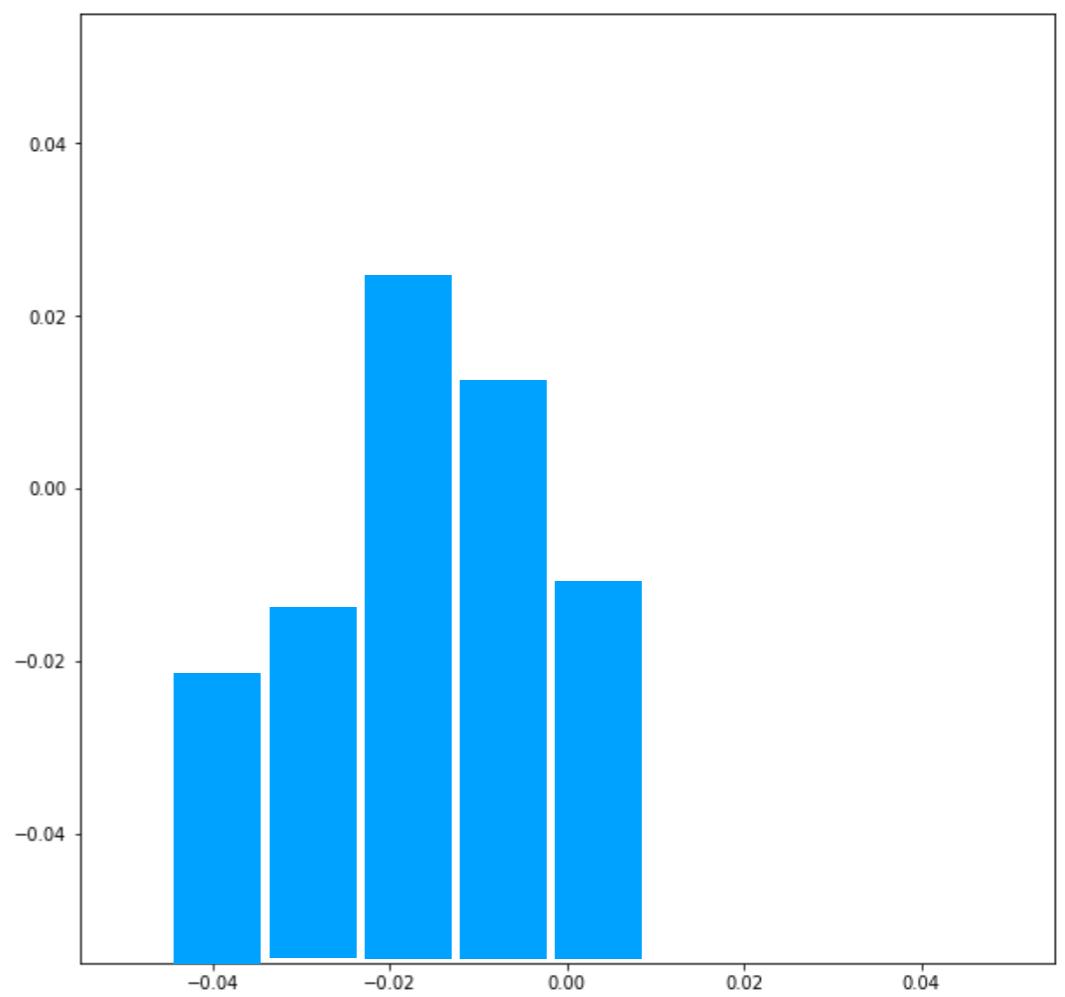
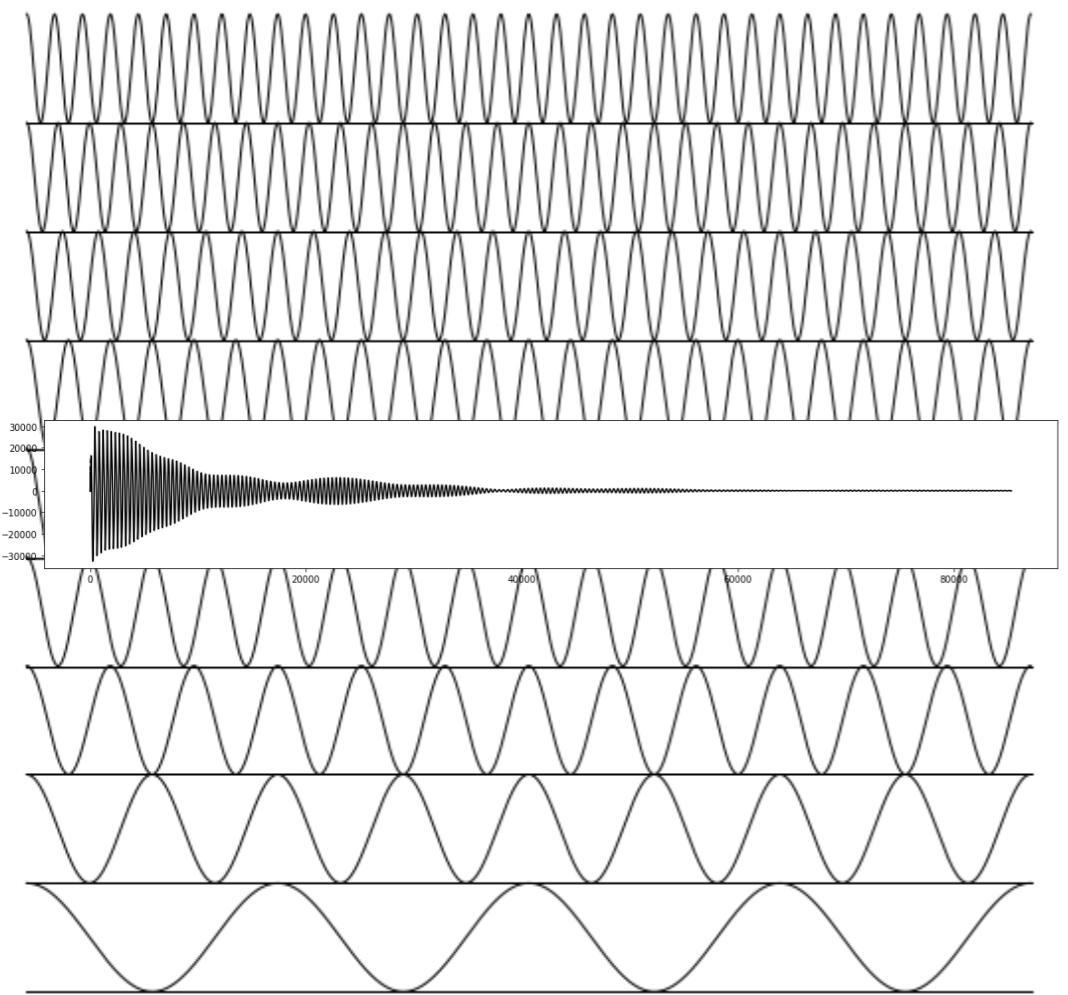


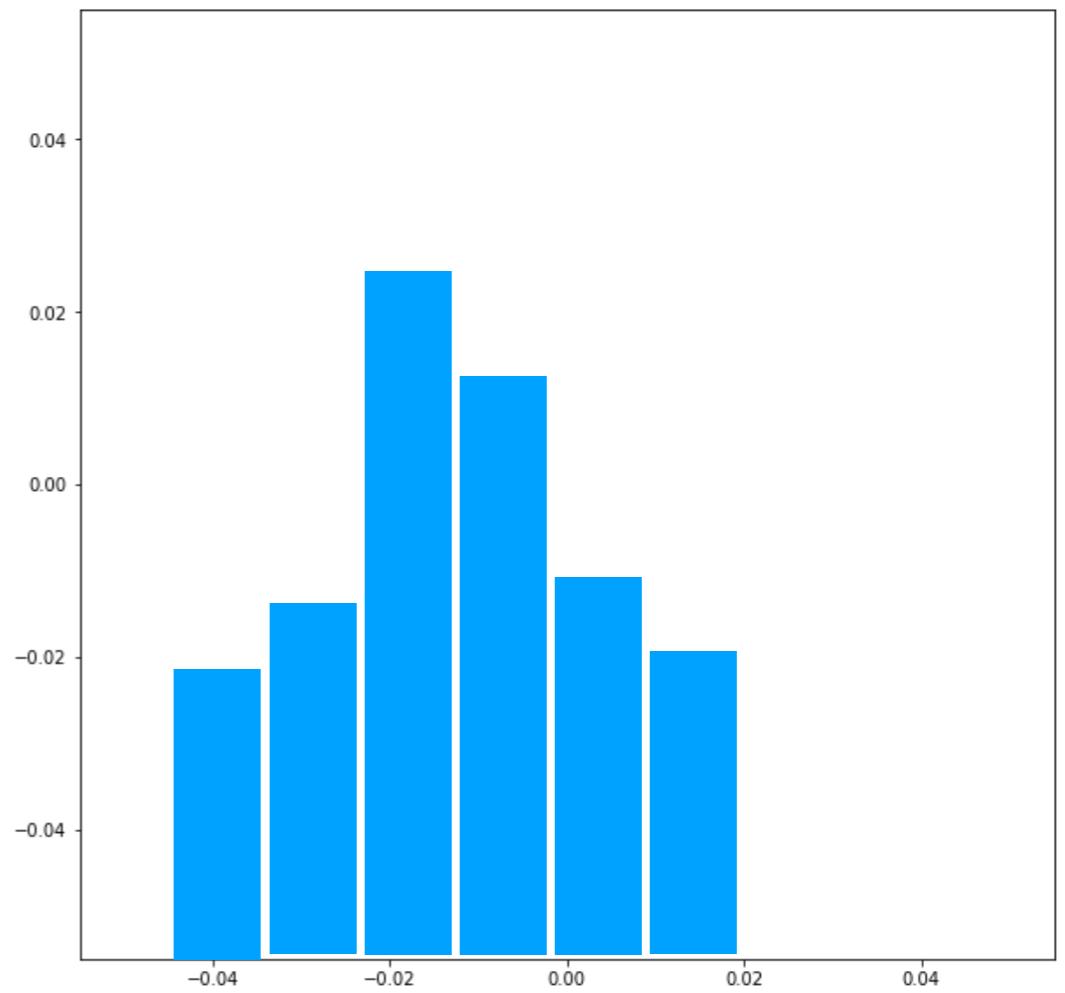
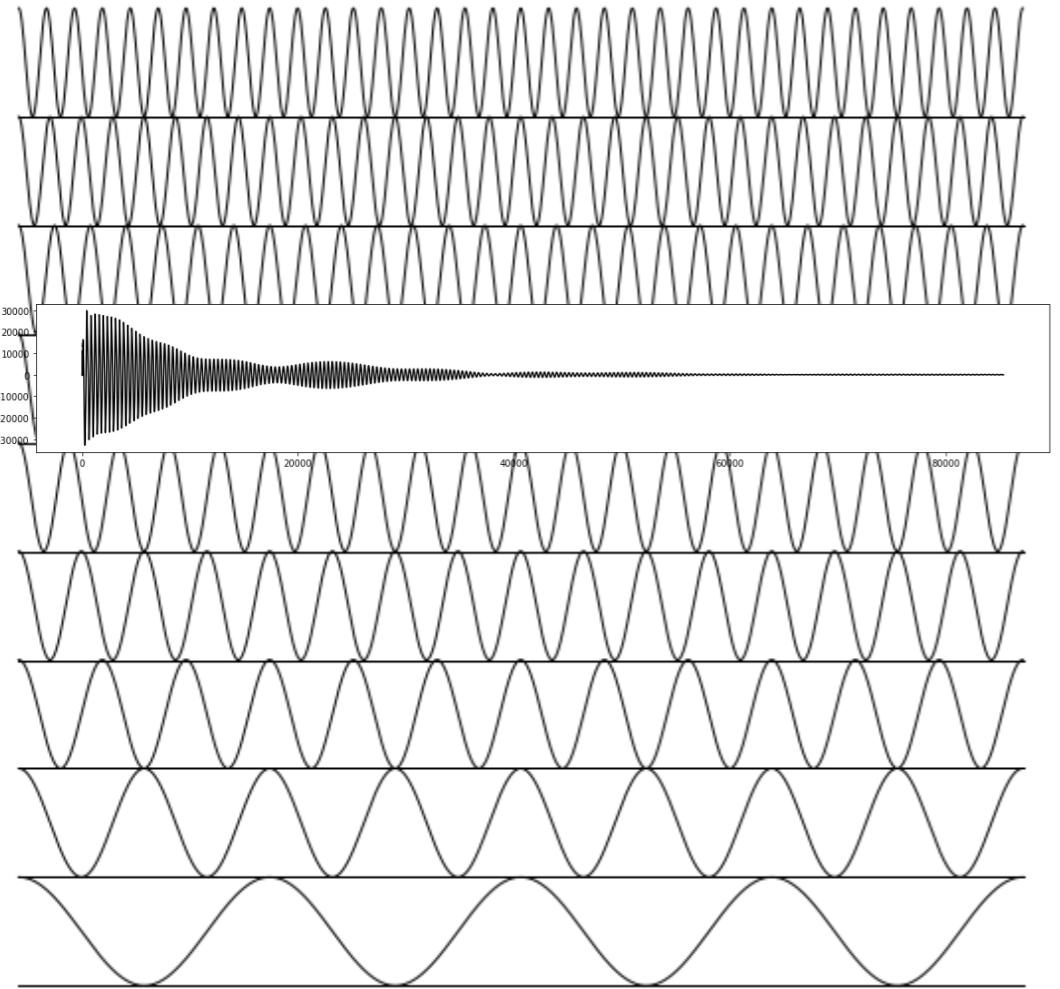


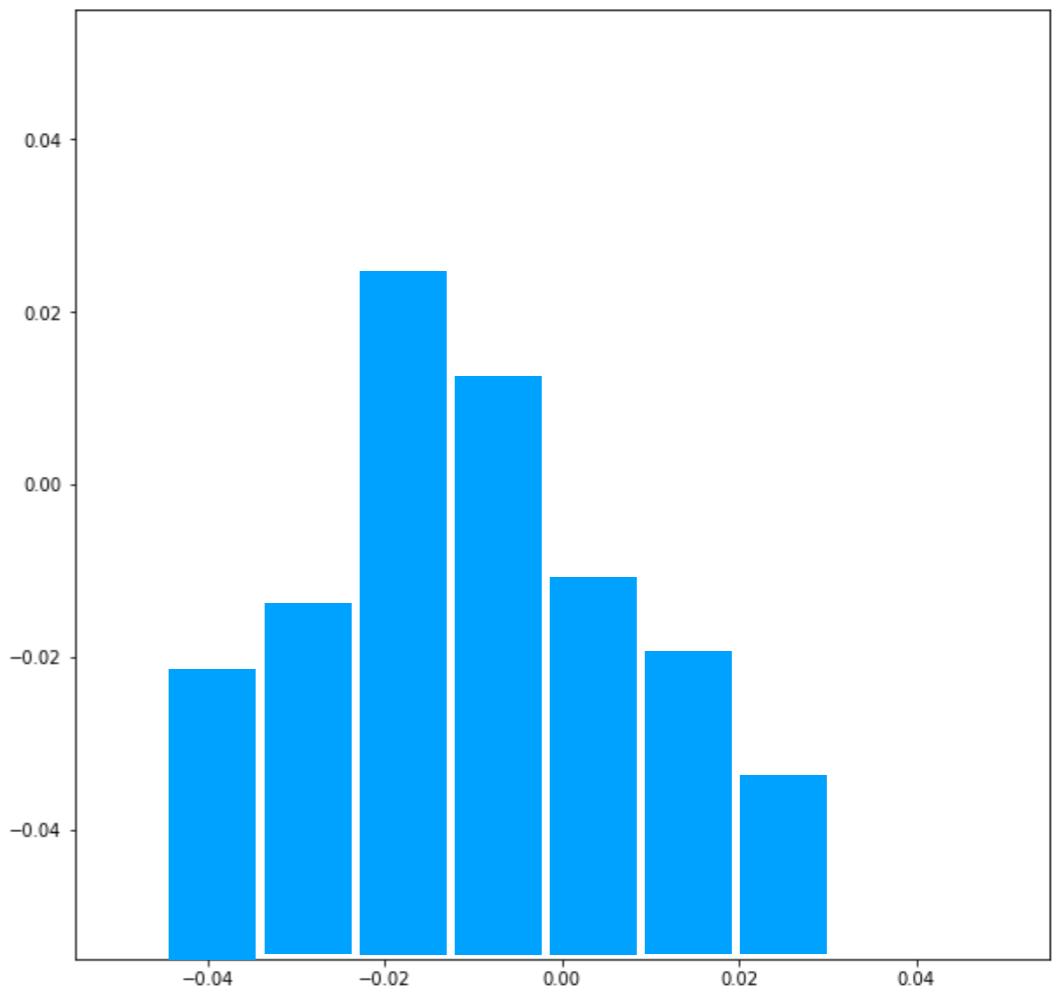
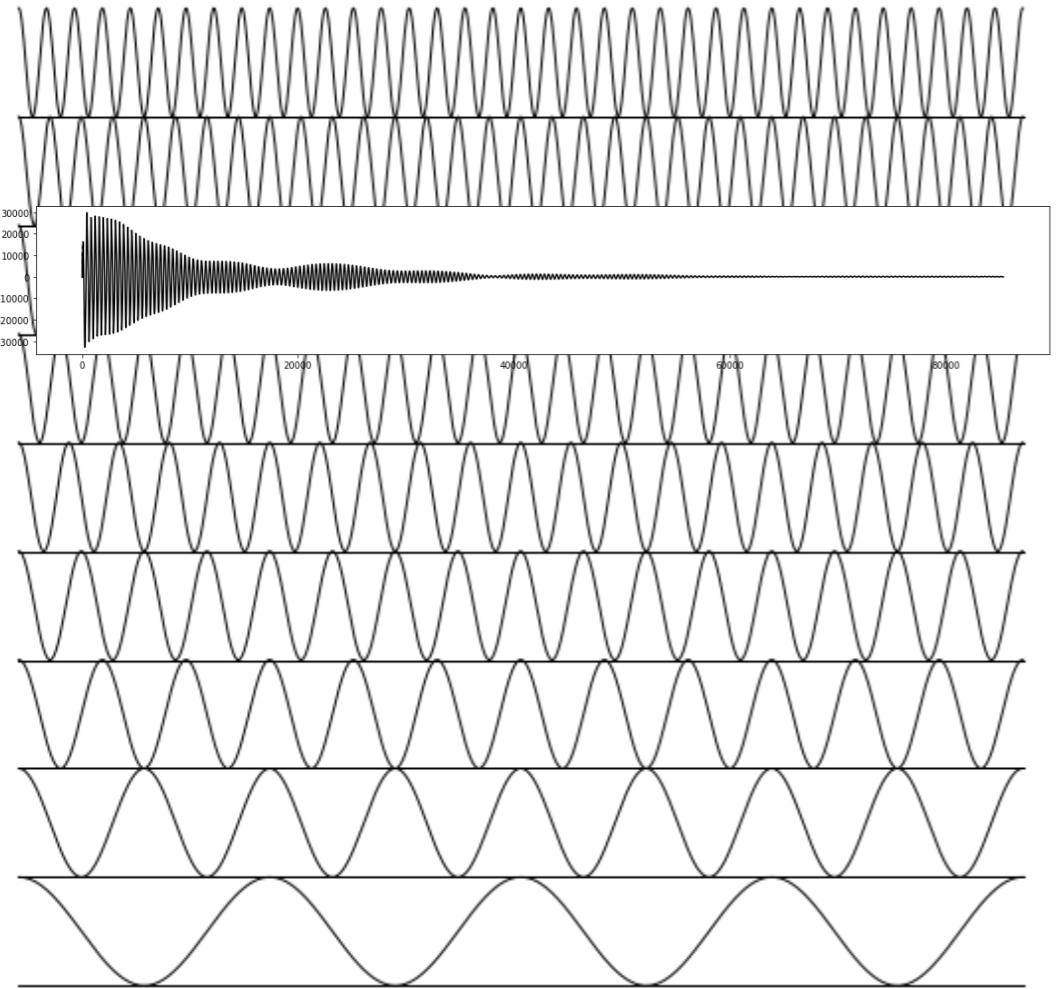


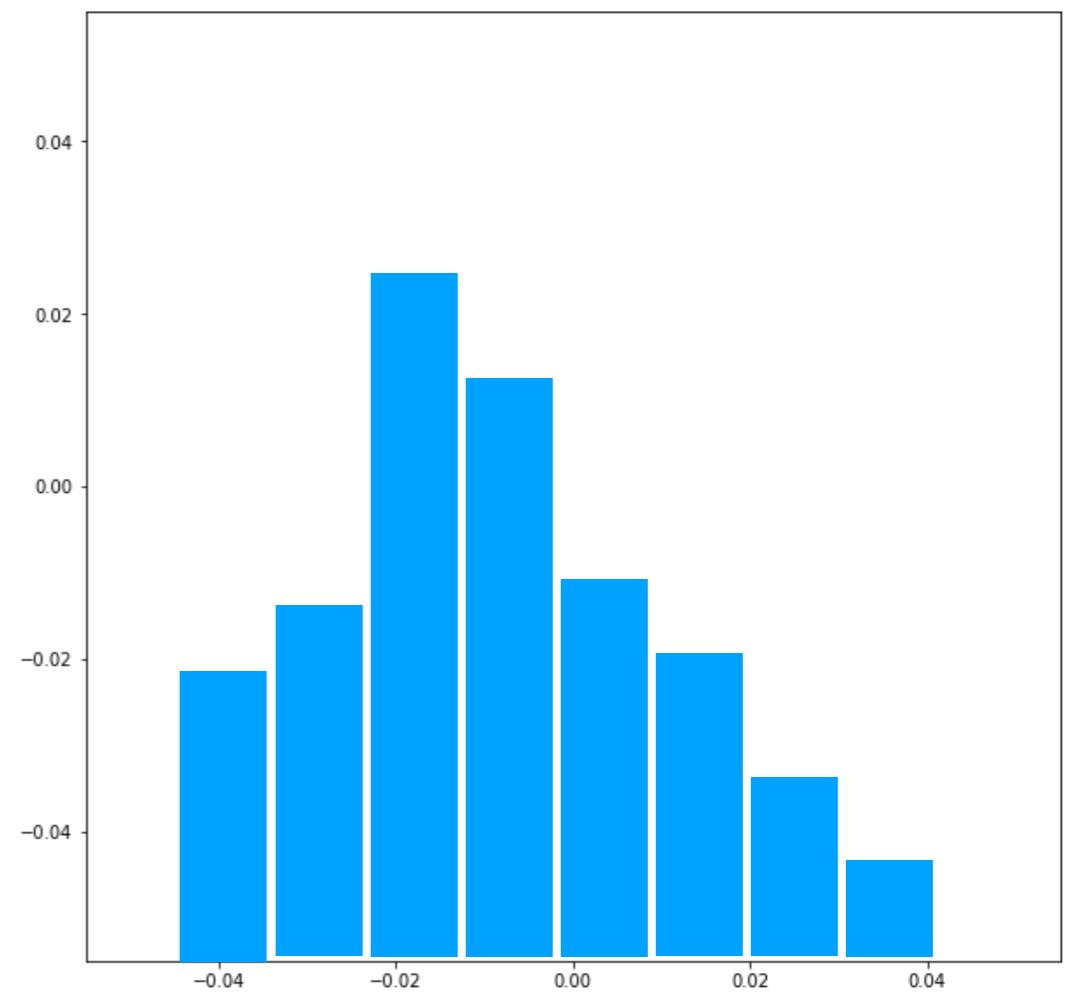
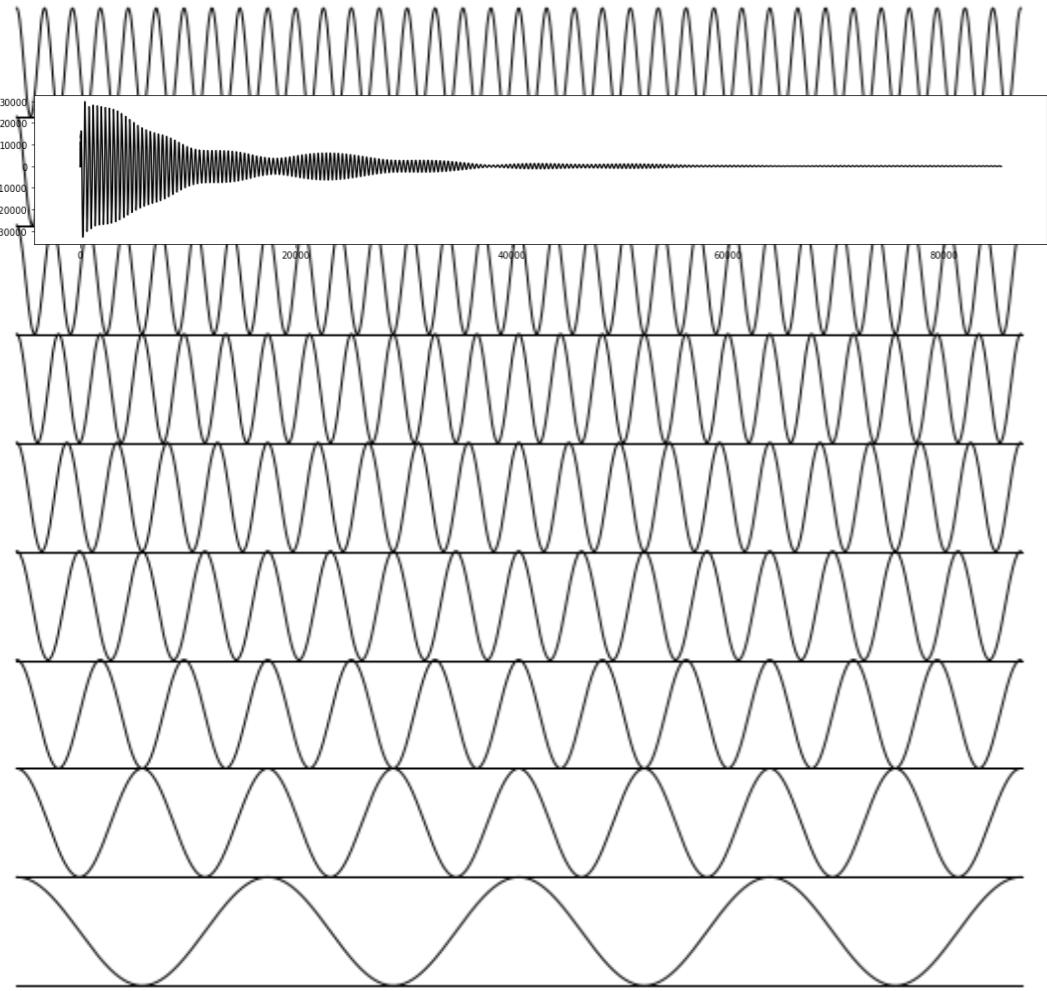


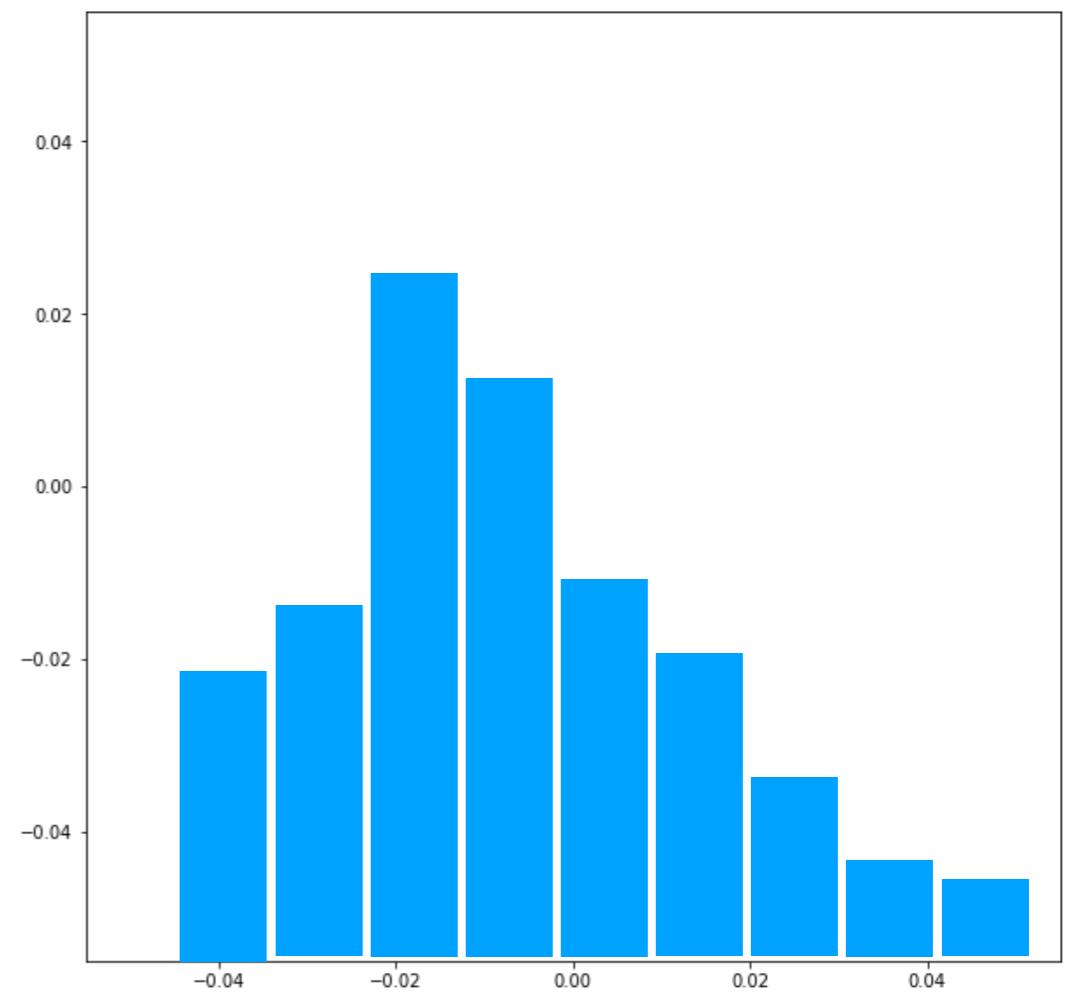
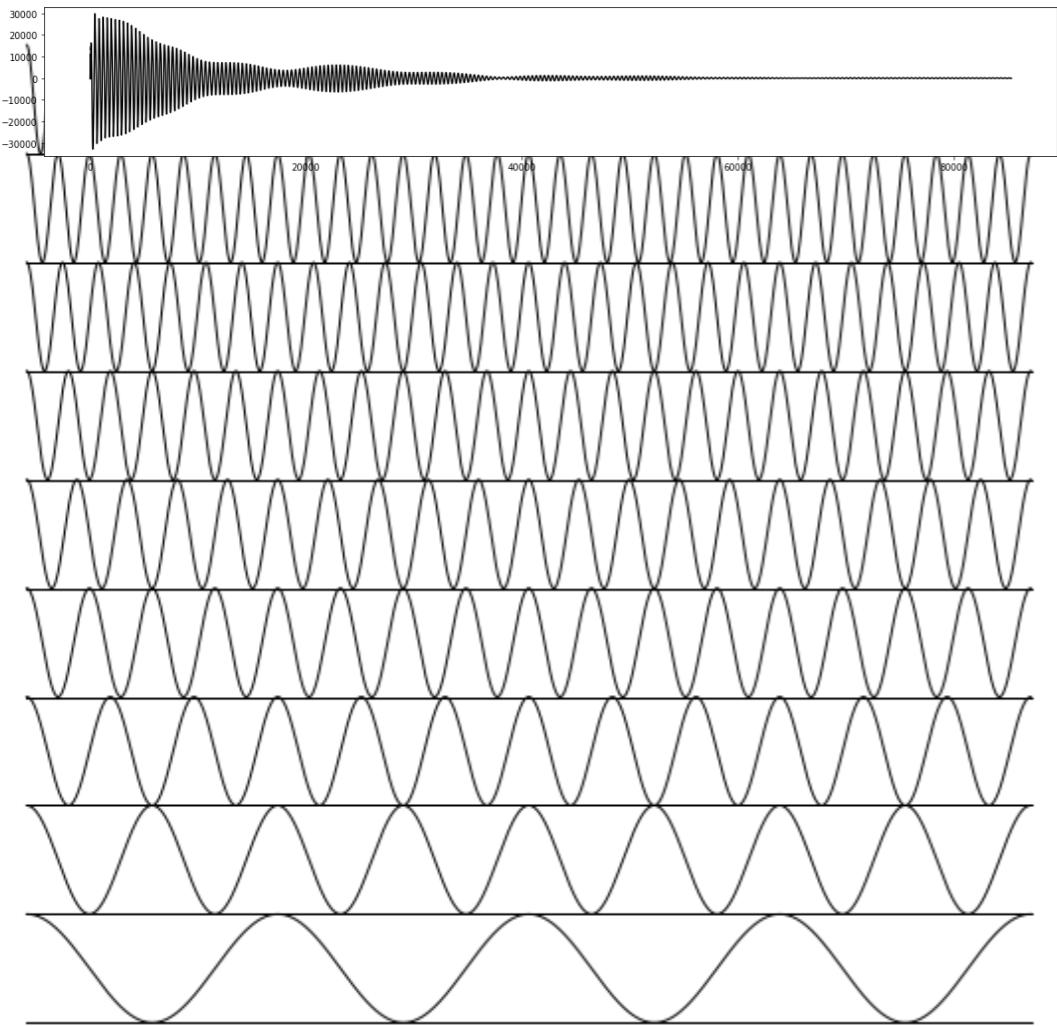


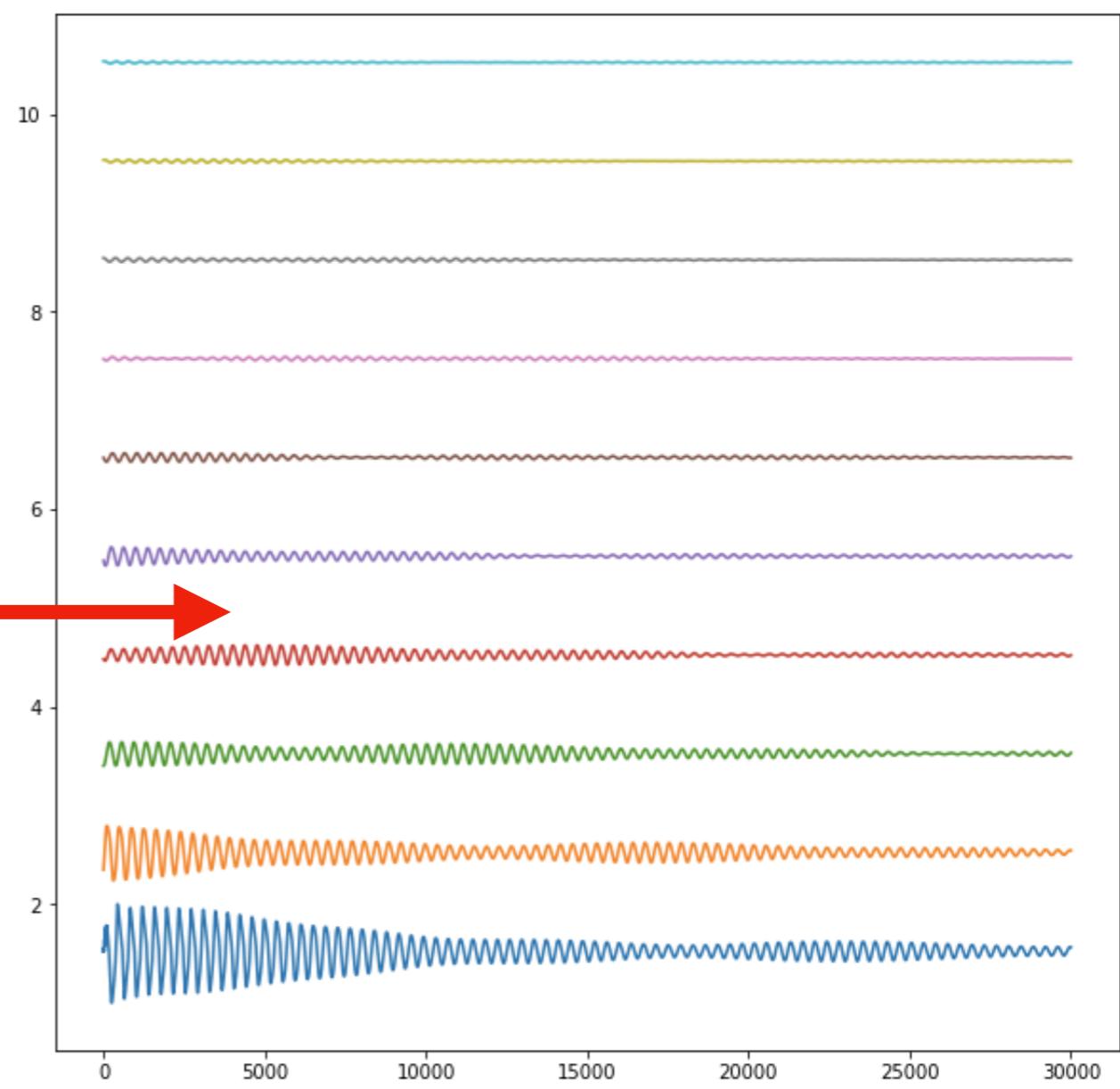
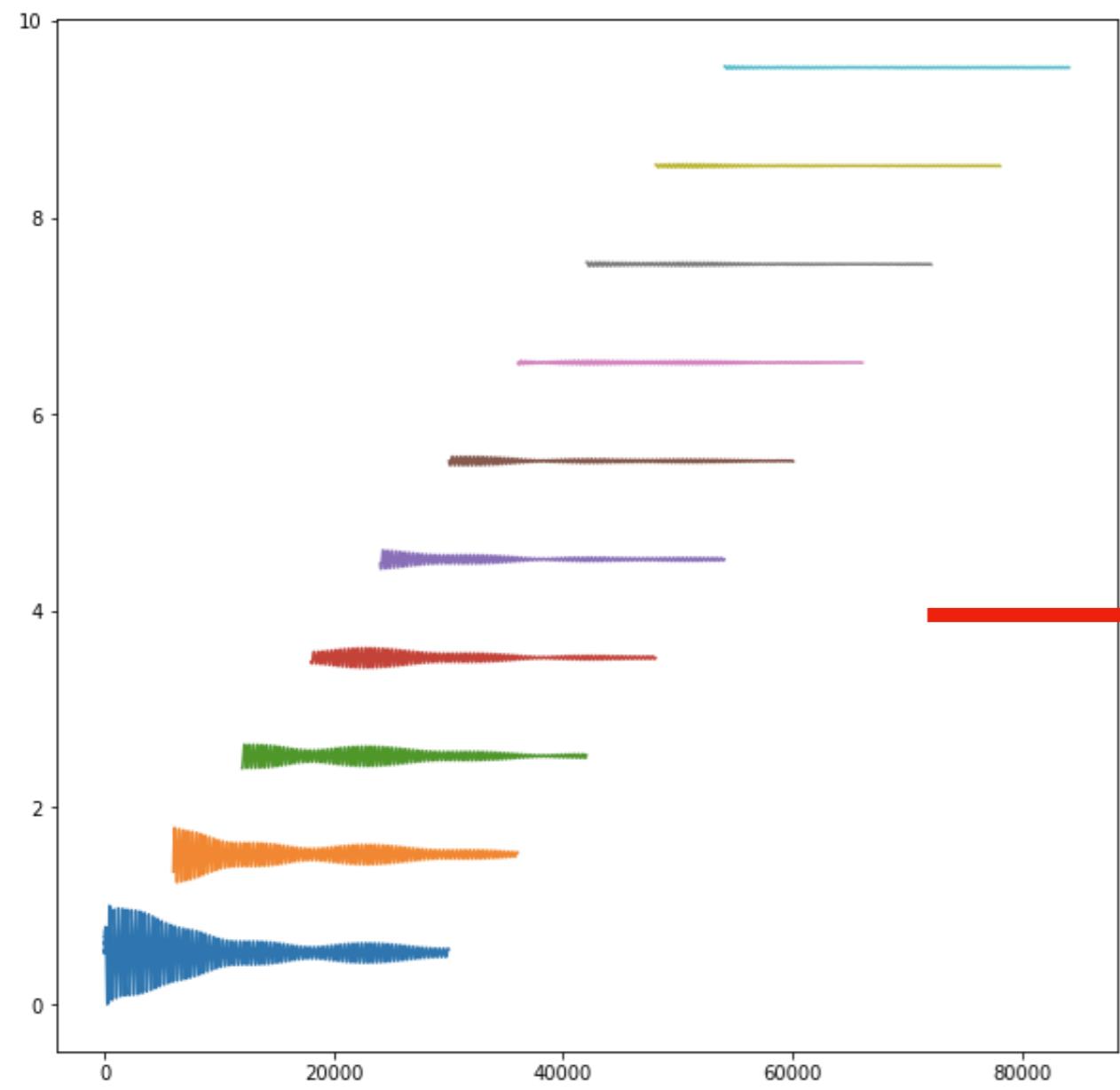
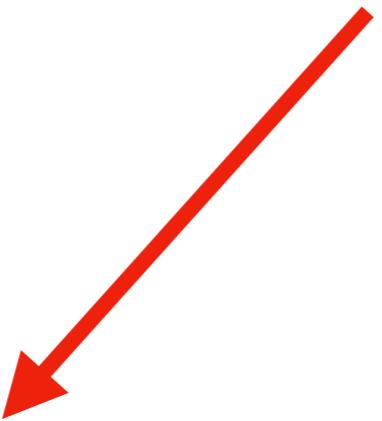
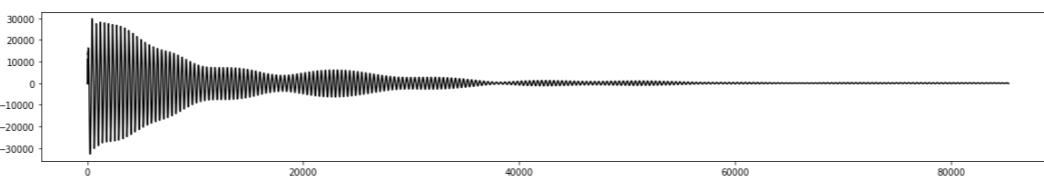


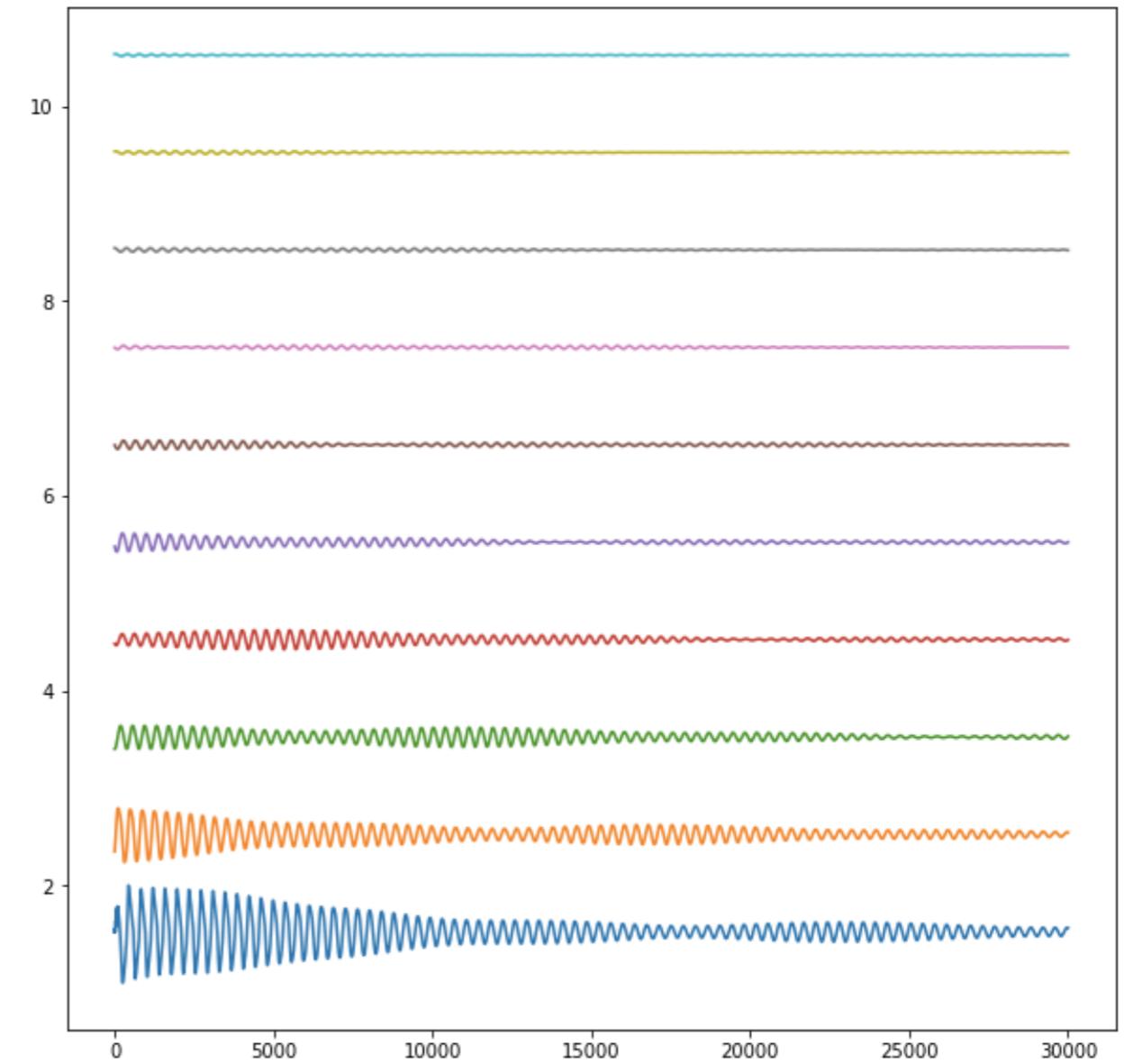
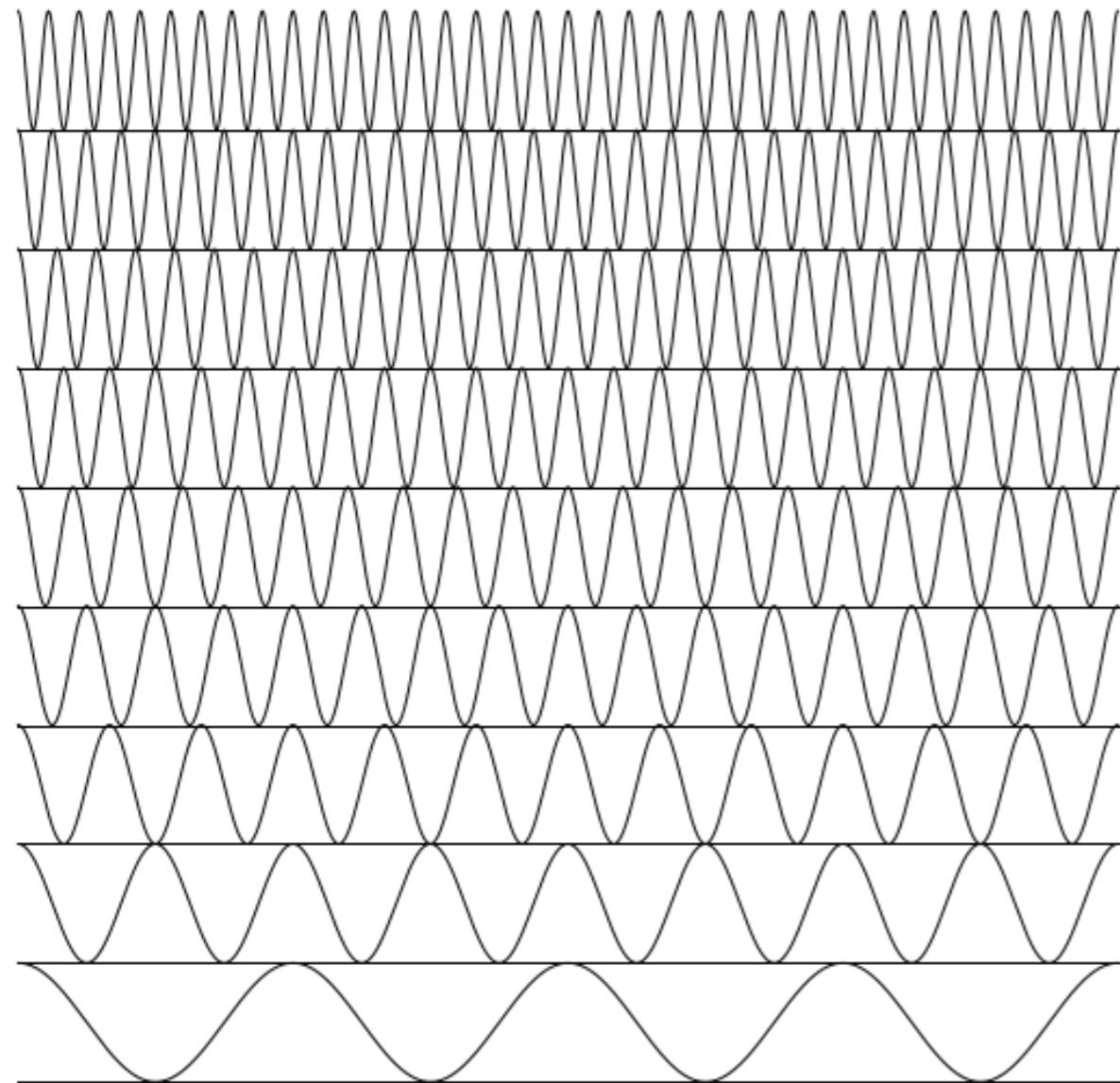




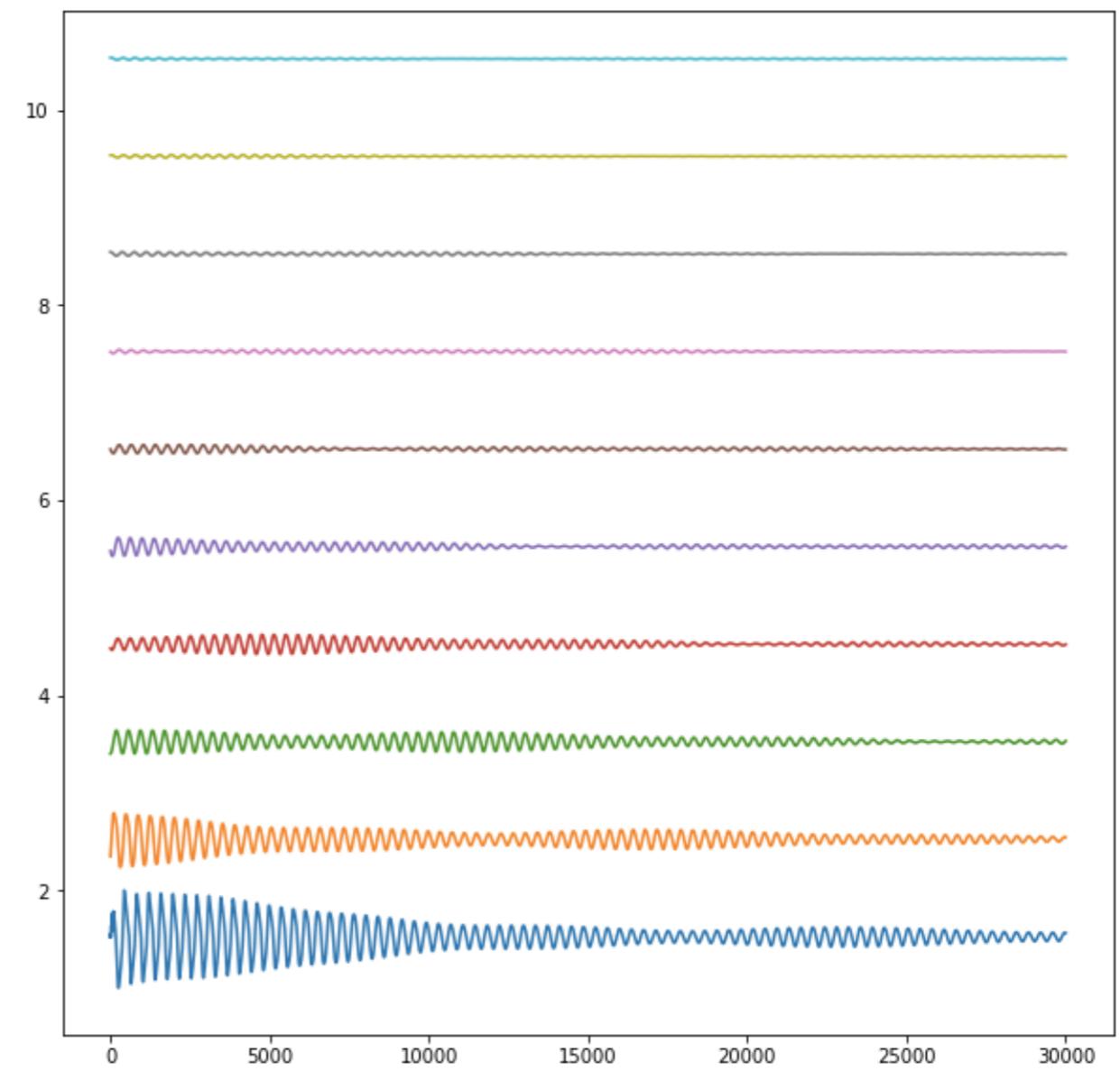
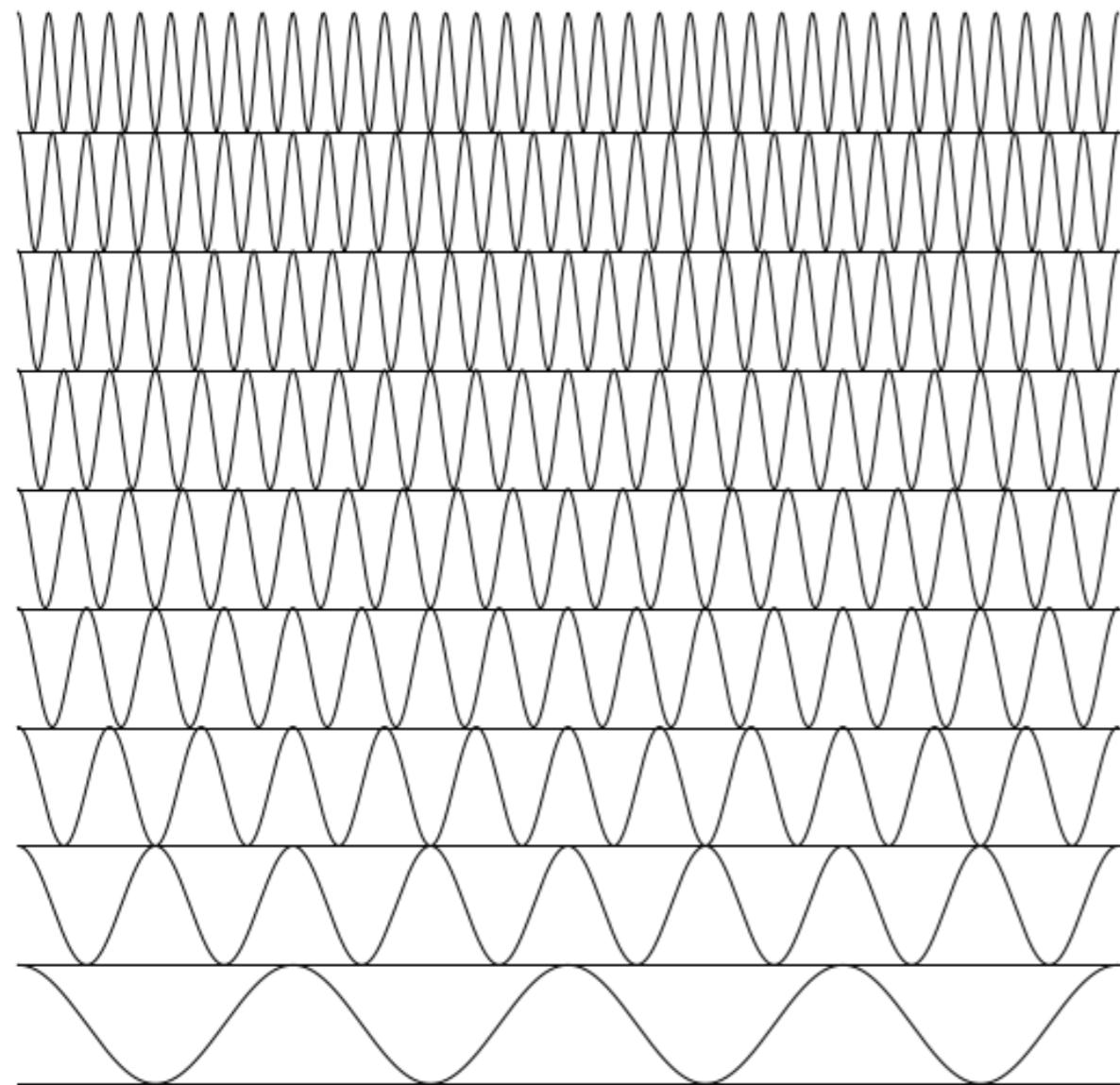


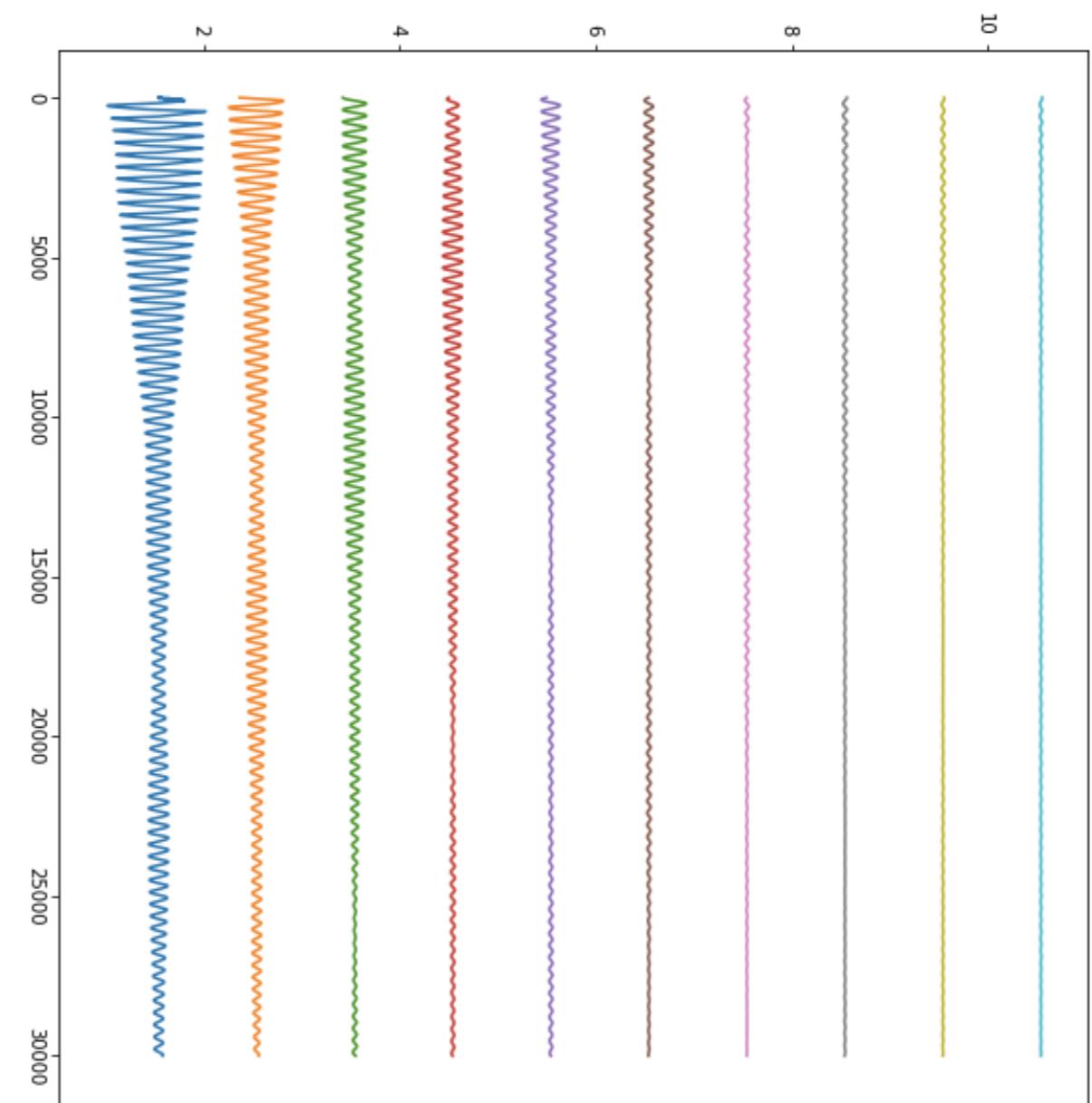
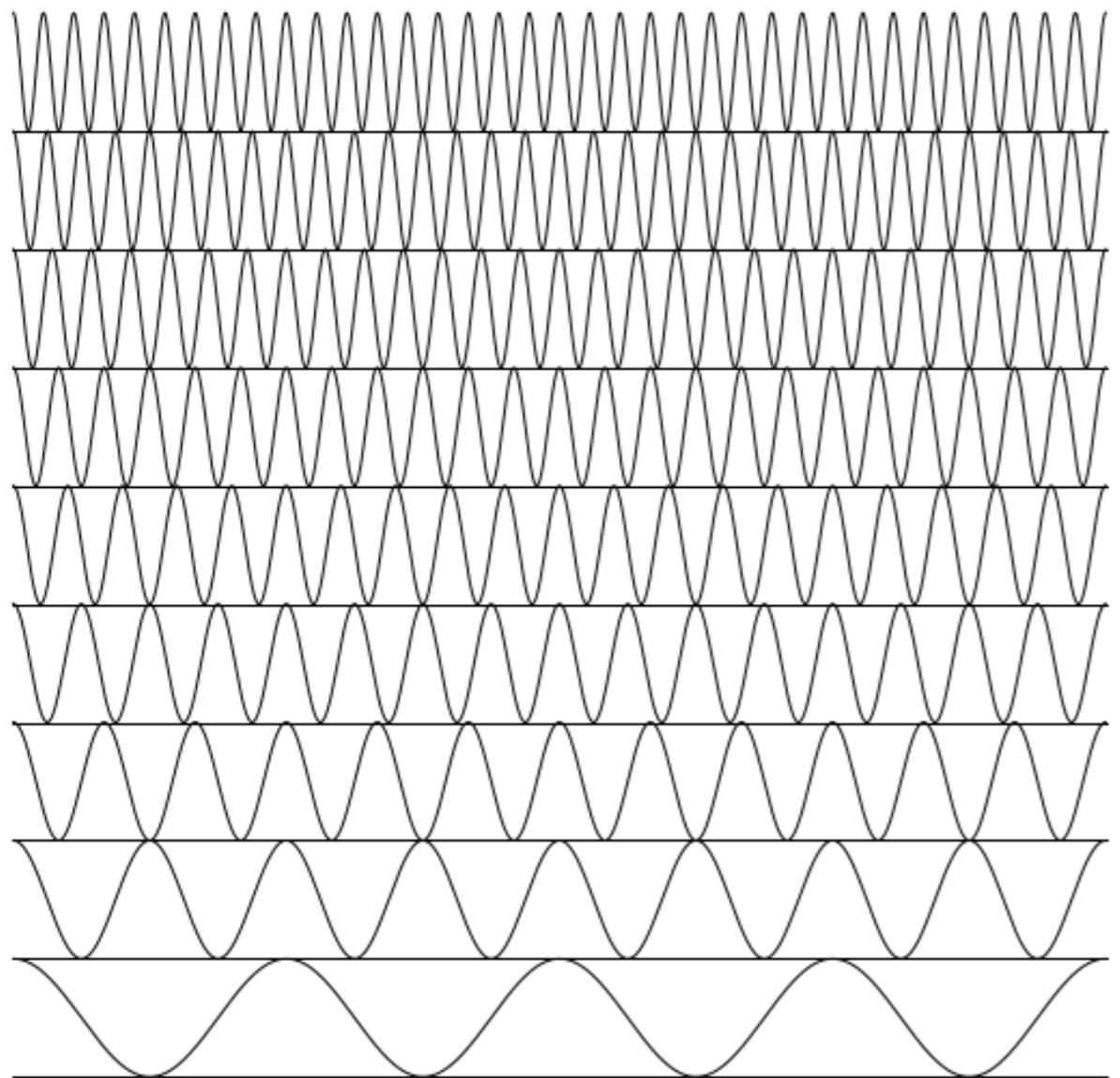




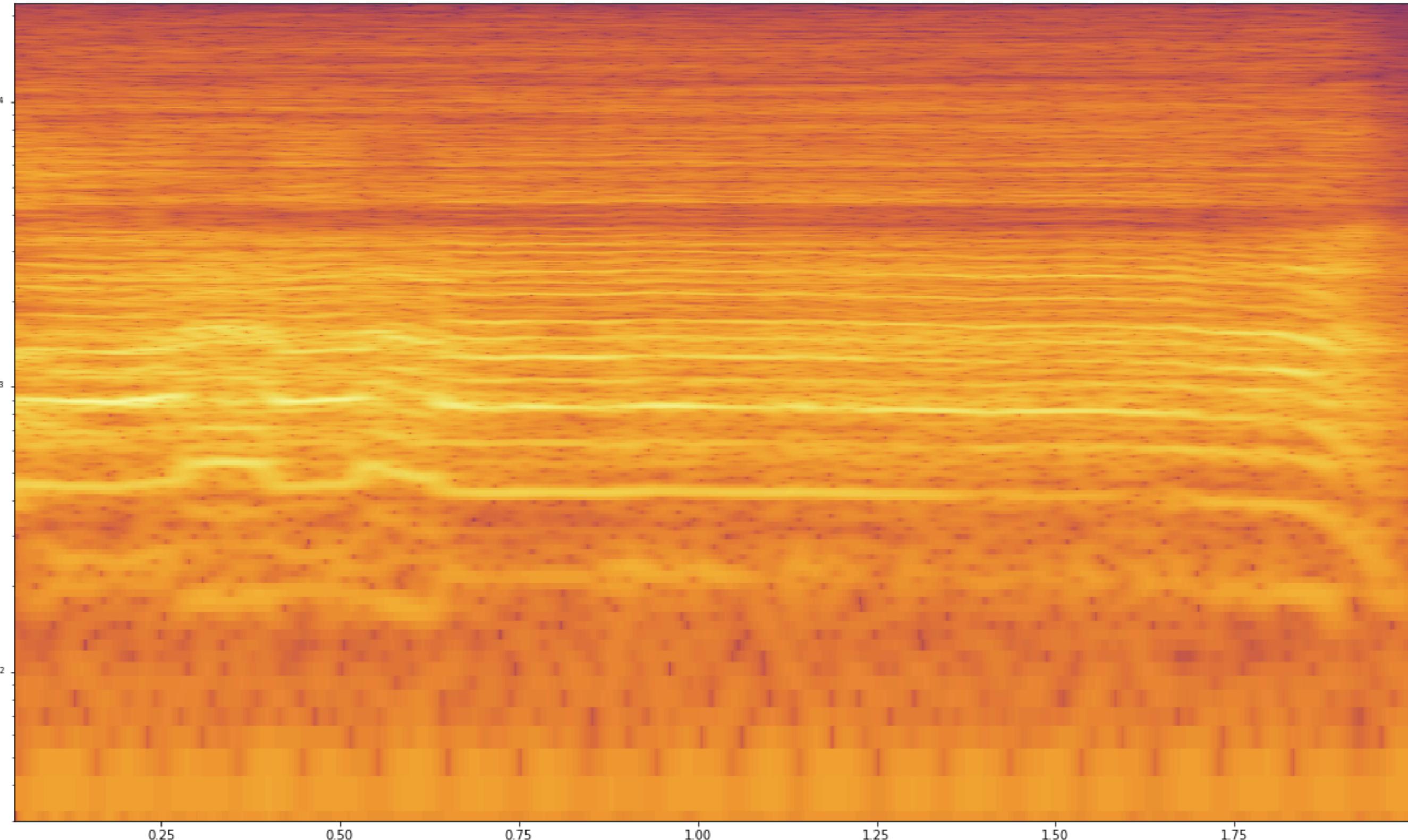


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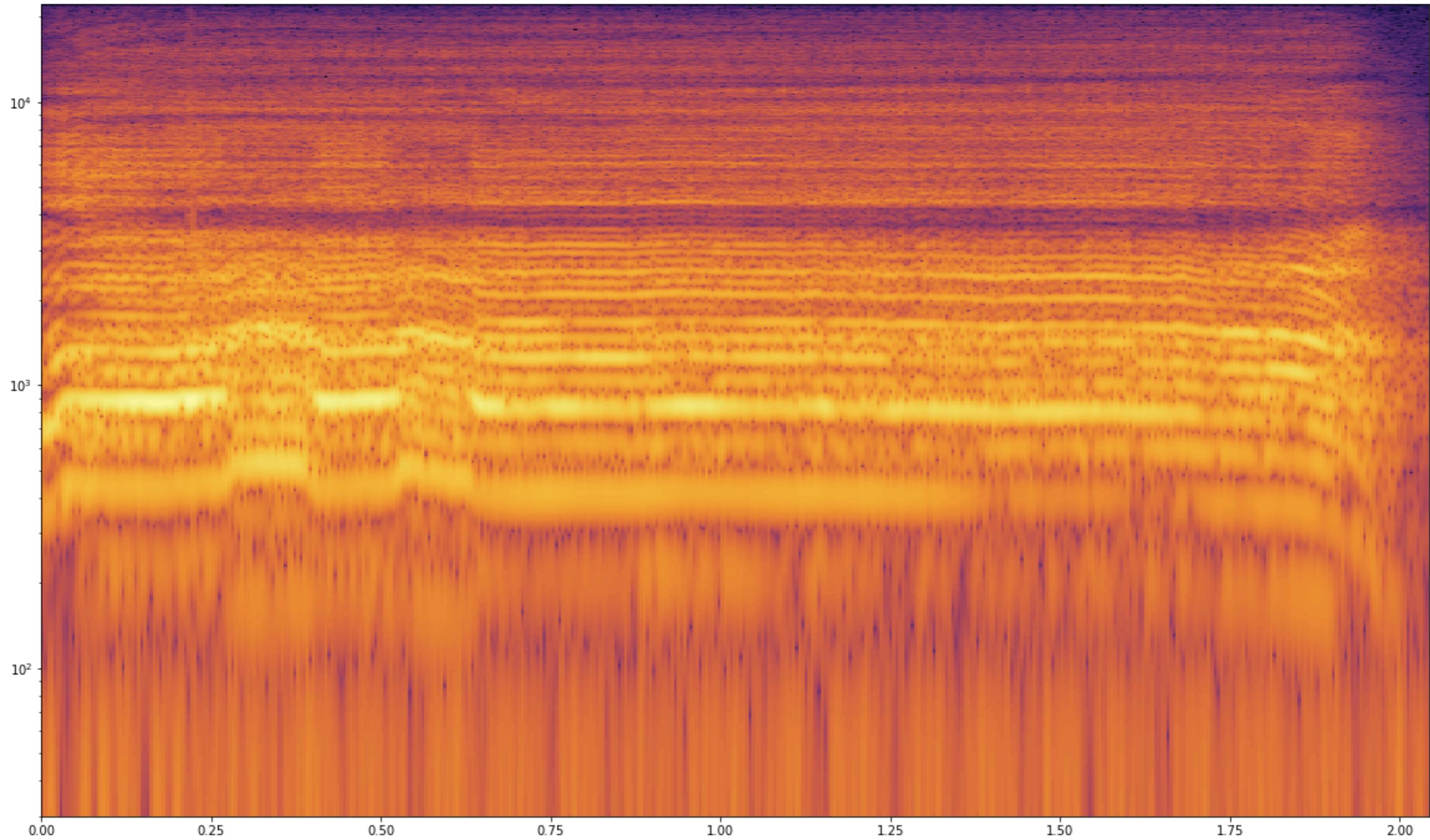




Повышение качества спектрограмм



Повышение качества спектрограмм

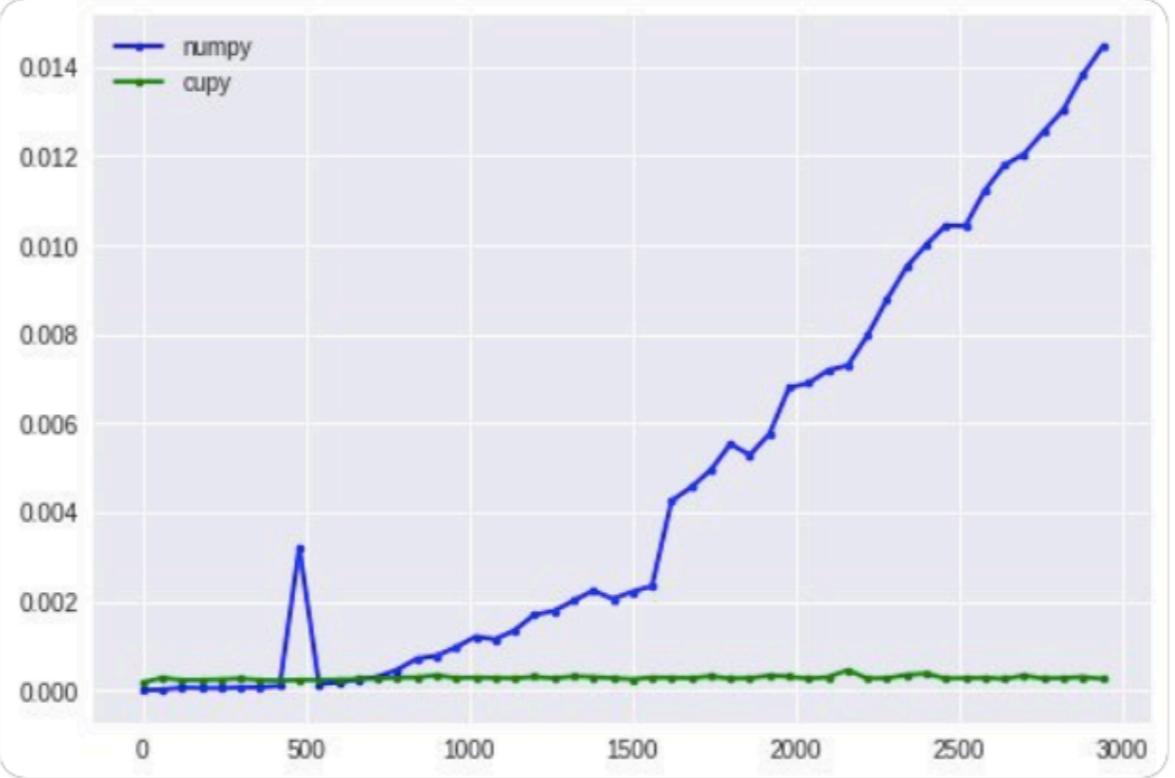


cupy on NVIDIA GPU

Alexander Rodionov
@tandavaya

numpy.dot() vs cupy.dot() benchmark
colab.research.google.com/drive/1ViOTV7_

...

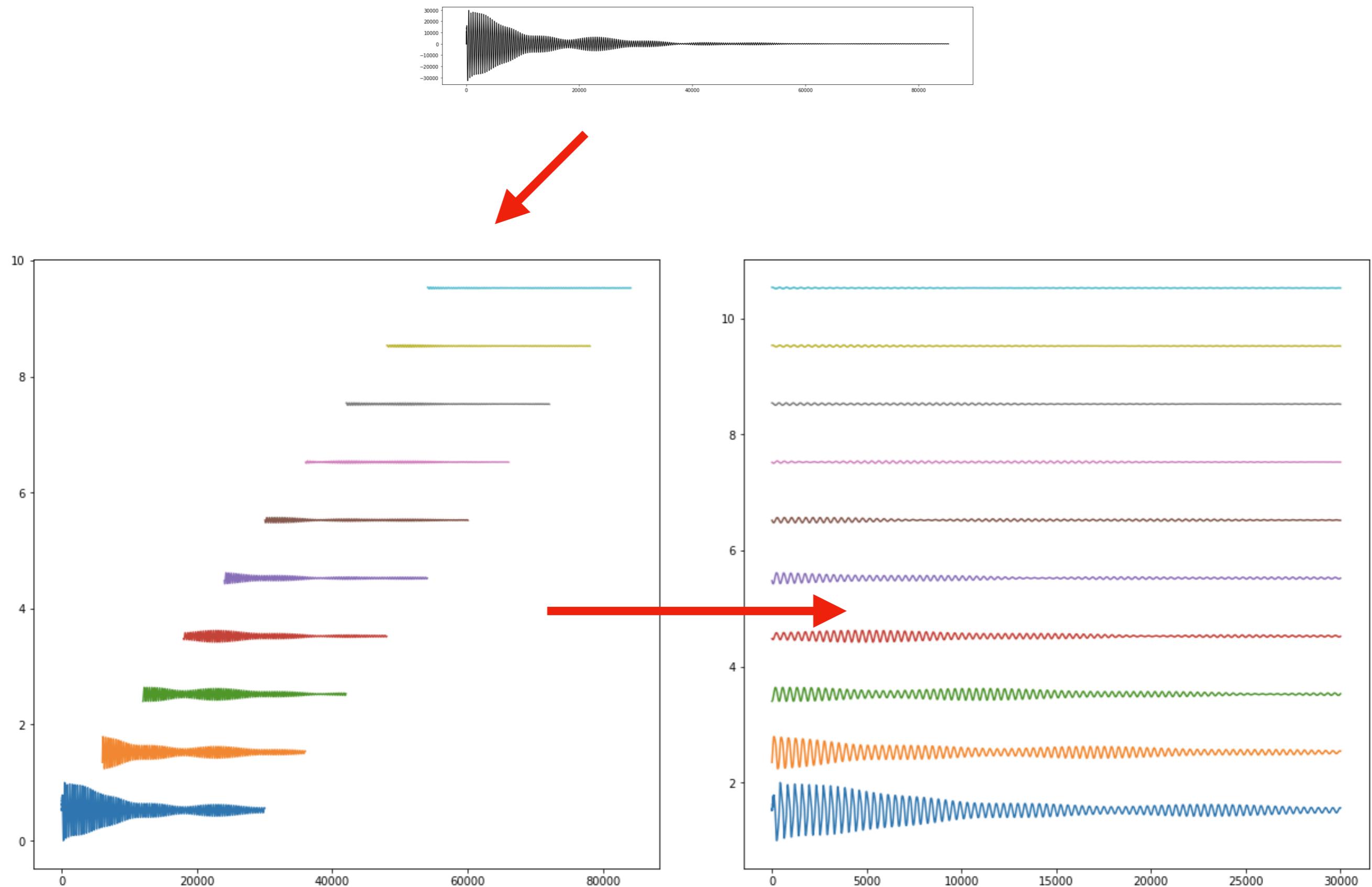


Size	numpy (s)	cupy (s)
0	0.0002	0.0002
500	0.0035	0.0002
1000	0.0012	0.0002
1500	0.0022	0.0002
2000	0.0068	0.0002
2500	0.0105	0.0002
3000	0.0140	0.0002

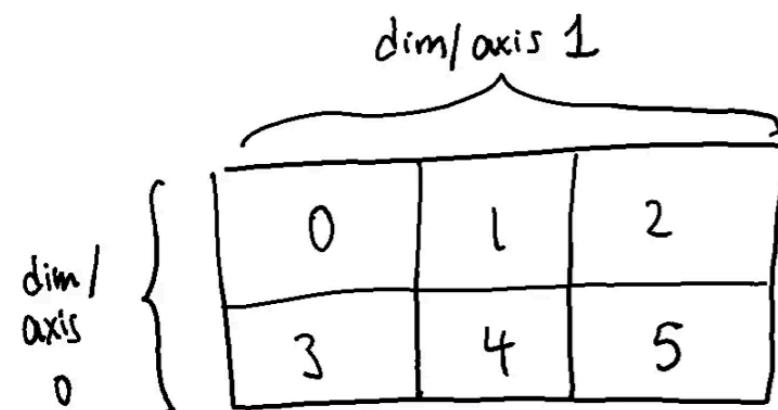
7:03 PM - 31 Jul 2018

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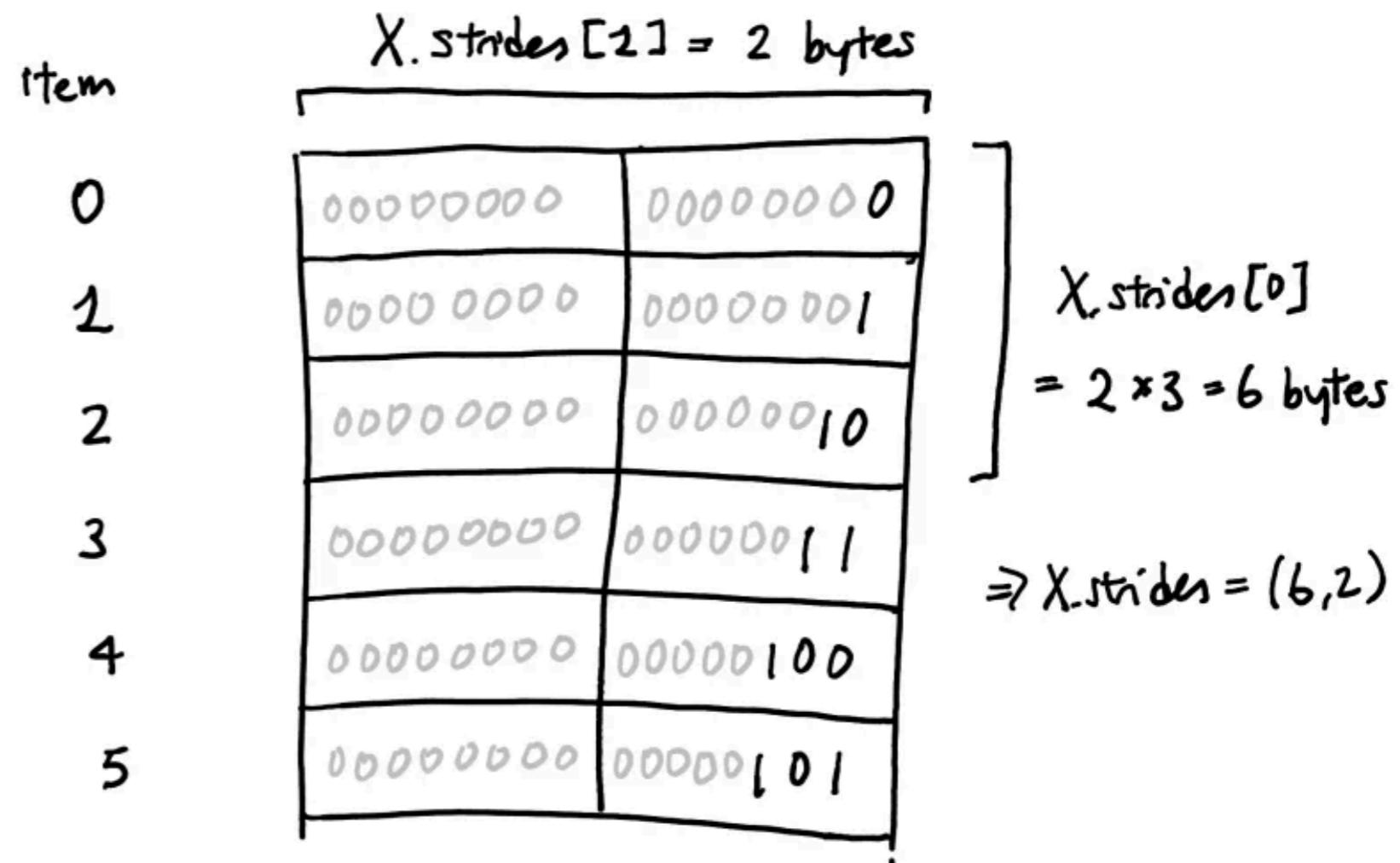
numpy.lib.stride_tricks.as_strided



numpy.lib.stride_tricks.as_strided



int16 (2 bytes)



(For $X = \text{array}([[0, 1, 2], [3, 4, 5]], \text{dtype=int16})$)

```
x = np.arange(12, dtype=np.uint8)
x
```

```
array([ 0,  1,  2,  3,  4,  5,  6,  7,  8,  9, 10, 11], dtype=uint8)
```

```
nperseg = 5
```

```
step     = 2
```

```
noverlap = nperseg - step
```

```
x_rolled = np.lib.stride_tricks.as_strided(
    x,
    shape  = ((x.shape[0] - noverlap) // step, nperseg),
    strides = (step * x.strides[-1], x.strides[-1])
)
```

```
x_rolled
```

```
array([[ 0,  1,  2,  3,  4],
       [ 2,  3,  4,  5,  6],
       [ 4,  5,  6,  7,  8],
       [ 6,  7,  8,  9, 10]], dtype=uint8)
```

Компьютерная модель распространения звука в легких



ELSEVIER

Computers in Biology and Medicine 34 (2004) 177–192

Computers in Biology
and Medicine

www.elsevierhealth.com/locate/comppbiomed

A high resolution computer model for sound propagation in
the human thorax based on the Visible Human data set

C. Narasimhan^a, Richard Ward^b, Kara L. Kruse^b, Murthy Guddati^c,
G. Mahinthakumar^{c,*}

^aUniversity of Tennessee, Knoxville, TN, USA

^bOak Ridge National Laboratory, Oak Ridge, TN, USA

^cNorth Carolina State University, Raleigh, NC, USA

Received 25 October 2002; accepted 29 April 2003

Математическая модель

Предположения

- среда ведет себя как жидкость (80% of body)
- среда неподвижна
- полное отражение на границах

Математическая модель

Волновое уравнение для неоднородной среды

$$\frac{1}{c^2(\mathbf{x})} \frac{\partial^2 p(\mathbf{x}, t)}{\partial t^2} = \rho(\mathbf{x}) \nabla \cdot \left(\frac{1}{\rho(\mathbf{x})} \nabla p(\mathbf{x}, t) \right),$$

$p(x, t)$ – pressure, давление воздуха
 $\rho(x)$ – плотность ткани / мышц
 $c(x)$ – скорость звука

$x = [x, y, z]$ | точка пространства

Математическая модель

Начальные условия

$$p(x, t=0) = 0 \text{ for all } x$$

$$\frac{\partial p(x, t)}{\partial t} \Big|_{t=0} = 0$$

Математическая модель

Начальные условия

$$p(x, t=0) = 0 \text{ for all } x$$

$$\frac{\partial p(x, t)}{\partial t} \Big|_{t=0} = 0$$

Границные условия (отражения + границы пространства)

$$p(x, t) = 0 \text{ if } \rho(x) < 0.1 \text{ g/cc}$$

Математическая модель

Начальные условия

$$p(x, t=0) = 0 \text{ for all } x$$

$$\frac{\partial p(x, t)}{\partial t} \Big|_{t=0} = 0$$

Границные условия (отражения + границы пространства)

$$p(x, t) = 0 \text{ if } \rho(x) < 0.1 \text{ g/cc}$$

Источник звука

$$p(a, b, c, t) = \sin(2\pi ft)$$

(a, b, c) – положение источника

Математическая модель

Численное приближ. решение

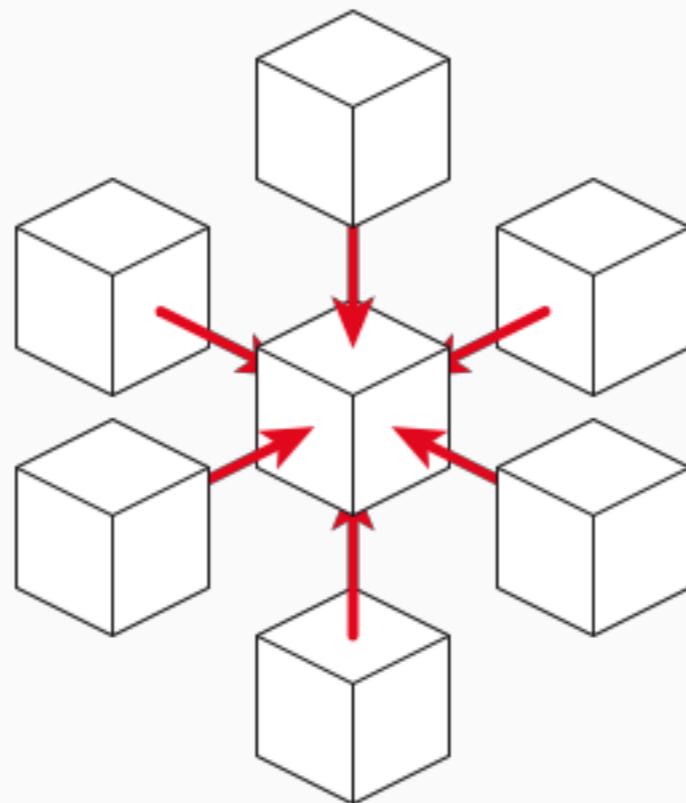
$$\begin{aligned} P_{i,j,k}^{m+1} = & (2 - 7.5\kappa_{i,j,k}^2)P_{i,j,k}^m - P_{i,j,k}^{m-1} \\ & + \frac{4\kappa_{i,j,k}^2}{3}[P_{i+1,j,k}^m + P_{i-1,j,k}^m + P_{i,j+1,k}^m + P_{i,j-1,k}^m + P_{i,j,k+1}^m + P_{i,j,k-1}^m] \\ & - \frac{\kappa_{i,j,k}^2}{12}[P_{i+2,j,k}^m + P_{i-2,j,k}^m + P_{i,j+2,k}^m + P_{i,j-2,k}^m + P_{i,j,k+2}^m + P_{i,j,k-2}^m] \\ & - \frac{\kappa_{i,j,k}^2}{3\rho_{i,j,k}}[(P_{i+1,j,k}^m - P_{i-1,j,k}^m) - (P_{i+2,j,k}^m + P_{i-2,j,k}^m)/8](\rho_{i+1,j,k} - \rho_{i-1,j,k}) \\ & - \frac{\kappa_{i,j,k}^2}{3\rho_{i,j,k}}[(P_{i,j+1,k}^m - P_{i,j-1,k}^m) - (P_{i,j+2,k}^m + P_{i,j-2,k}^m)/8](\rho_{i,j+1,k} - \rho_{i,j-1,k}) \\ & - \frac{\kappa_{i,j,k}^2}{3\rho_{i,j,k}}[(P_{i,j,k+1}^m - P_{i,j,k-1}^m) - (P_{i,j,k+2}^m + P_{i,j,k-2}^m)/8](\rho_{i,j,k+1} - \rho_{i,j,k-1}) \end{aligned}$$

$$\kappa_{i,j,k} = (l/h)c_{i,j,k} \quad l = \Delta t \quad h = \Delta x = \Delta y = \Delta z$$

Метод конечных разностей, 7-point stencil
производные заменяются разностями

FDTD: Finite Difference Time Domain method

7-point stencil



$$\kappa_{i,j,k} = (l/h)c_{i,j,k}$$

$$l = \Delta t$$

$$h = \Delta x = \Delta y = \Delta z$$

Численное приближ. решение.
Метод конечных разностей
производные заменяются разностями

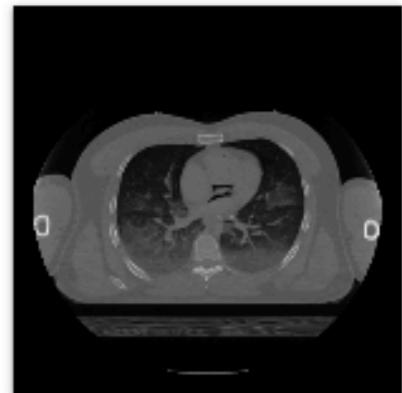
Numba : A Python Compiler



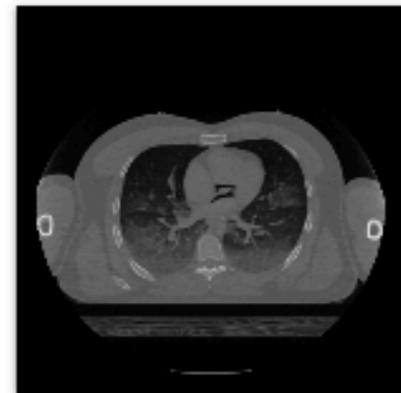
```
@numba.jit(nopython=True, parallel=True, fastmath = True, nogil=True)
def fresh(P_pp, P_p, P, ro):
|
    S = P_p.shape[0]
    N = P_p.shape[1]
    P[2:-2, 2:-2, 2:-2] = (2 - 7.5 * K2[2:-2, 2:-2, 2:-2]) * P_p[2:-2, 2:-2, 2:-2]

    # numba.prange
    for i in range(2, S - 2):
        for j in range(2, N - 2):
            for k in range(2, N - 2):
                if ro[i, j, k] < 0.1:
                    P[i, j, k] = 0
                else:
                    P[i, j, k] += K2[i, j, k] * 4/3 * (
                        P_p[i + 1, j      , k      ] +
                        P_p[i - 1, j      , k      ] +
                        P_p[i      , j + 1, k      ] +
                        P_p[i      , j - 1, k      ] +
                        P_p[i      , j      , k + 1] +
                        P_p[i      , j      , k - 1] +
                        P_p[i + 1, j + 1, k      ] +
                        P_p[i + 1, j - 1, k      ] +
                        P_p[i - 1, j + 1, k      ] +
                        P_p[i - 1, j - 1, k      ] +
                        P_p[i      , j + 2, k      ] +
                        P_p[i      , j - 2, k      ] +
                        P_p[i + 2, j      , k      ] +
                        P_p[i - 2, j      , k      ])
```

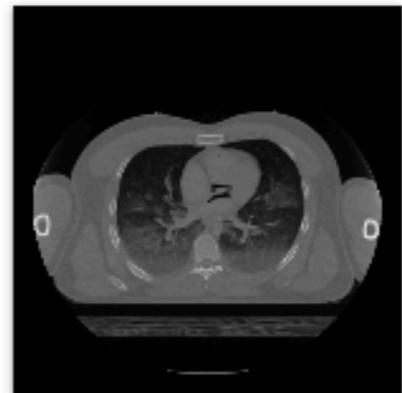
Human Visible Project Dataset



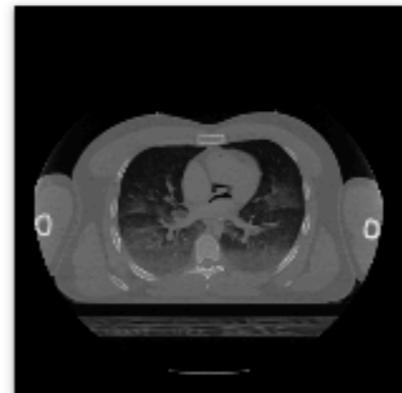
vhm.830.dcm.png



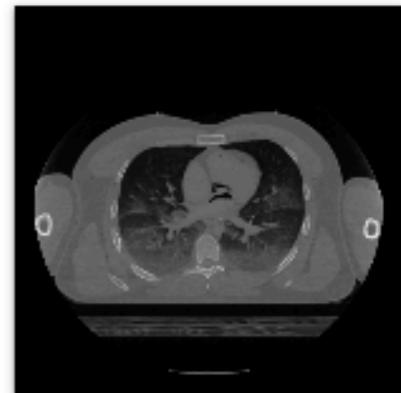
vhm.831.dcm.png



vhm.832.dcm.png



vhm.833.dcm.png



vhm.834.dcm.png



vhm.837.dcm.png



vhm.838.dcm.png



vhm.839.dcm.png



vhm.840.dcm.png



vhm.841.dcm.png



vhm.844.dcm.png



vhm.845.dcm.png



vhm.846.dcm.png

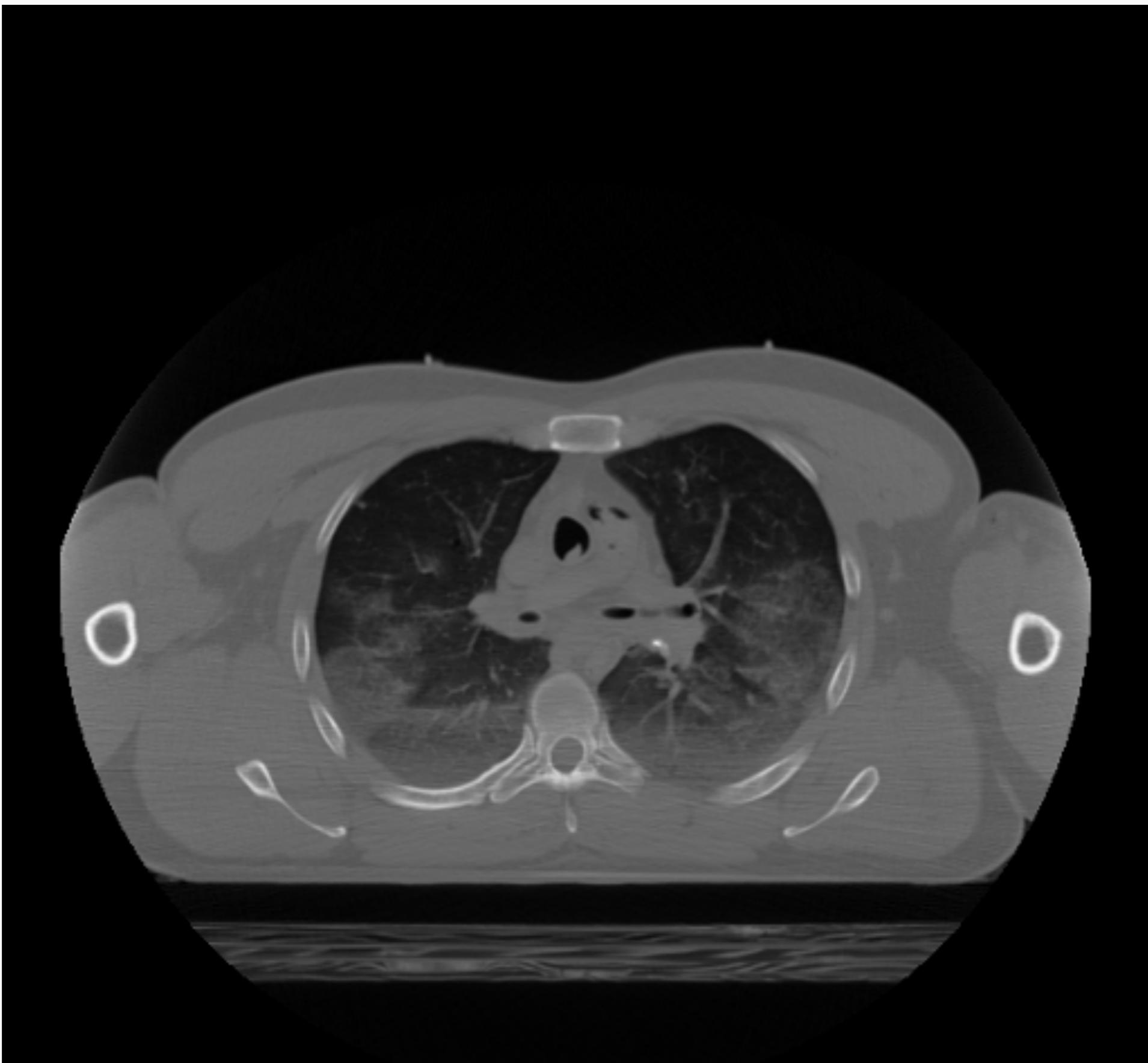


vhm.847.dcm.png



vhm.848.dcm.png

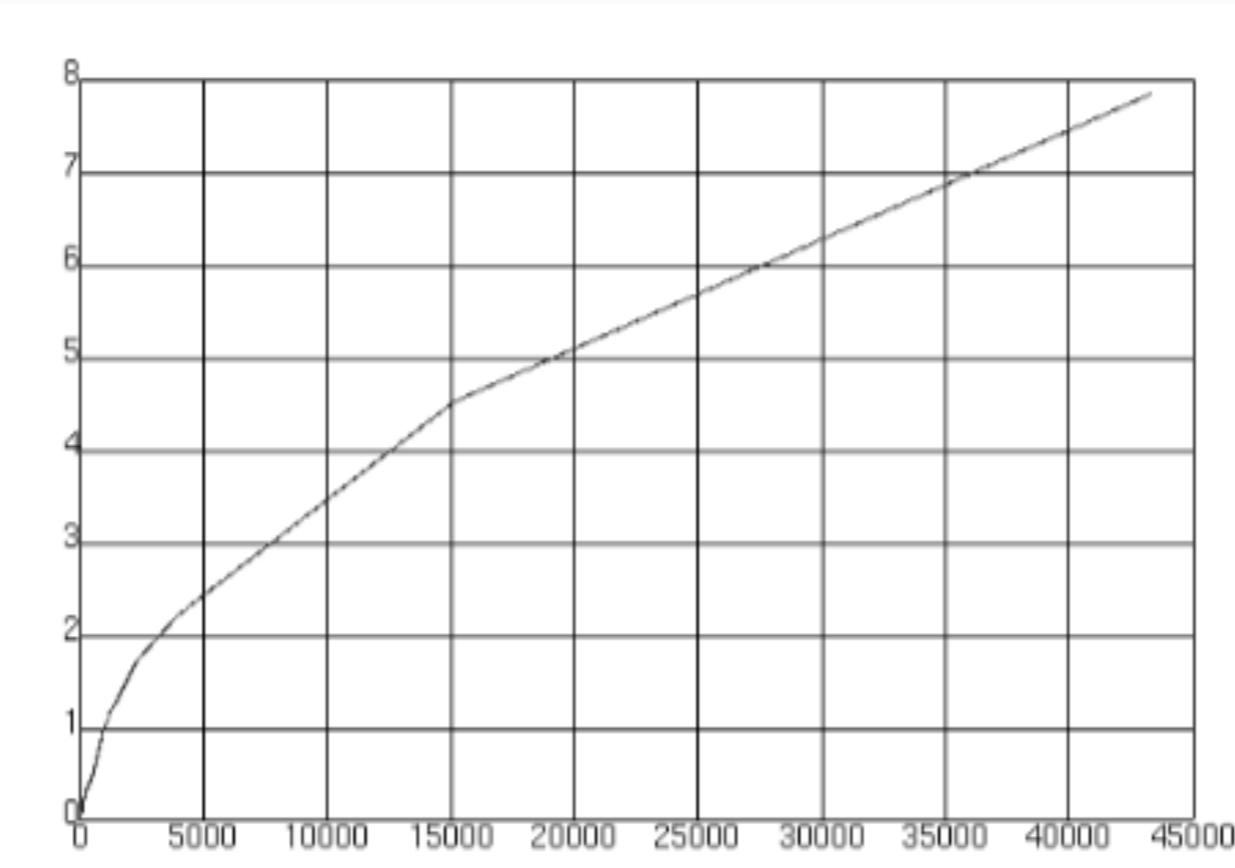
Human Visible Project Dataset



Human Visible Project Dataset



Human Visible Project Dataset



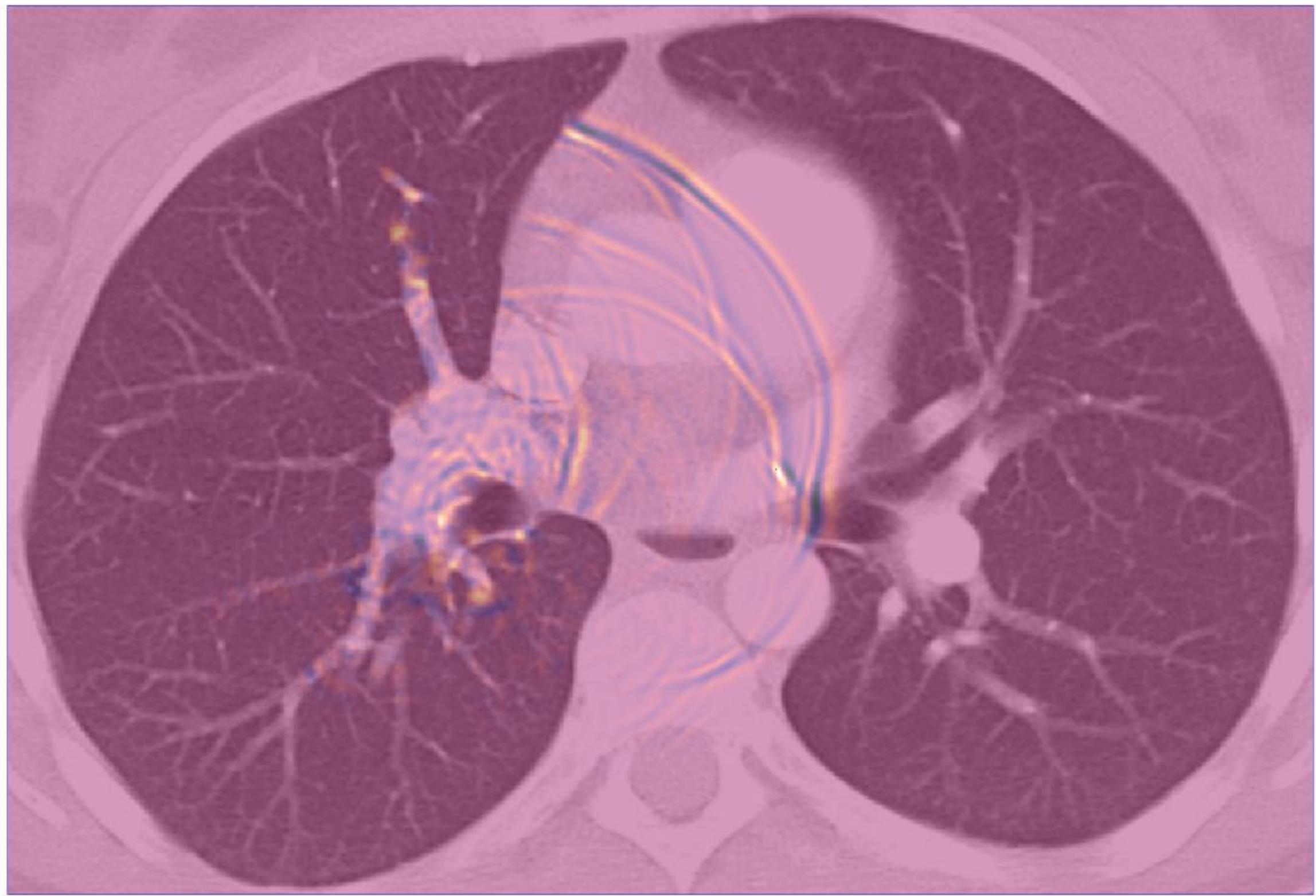
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0	0.000
20	0.001
254	0.292
444	0.438
944	0.895
957	0.945
986	0.980
1024	1.000
1139	1.116
1211	1.142
1504	1.285
1884	1.473
2307	1.707
4000	2.213
15160	4.510
43410	7.850



●

○

●



Red

Grey

Green



Red
Grey
Green



●

○

●



Red
Grey
Green





Red
Grey
Green



Red
Grey
Green



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○

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○

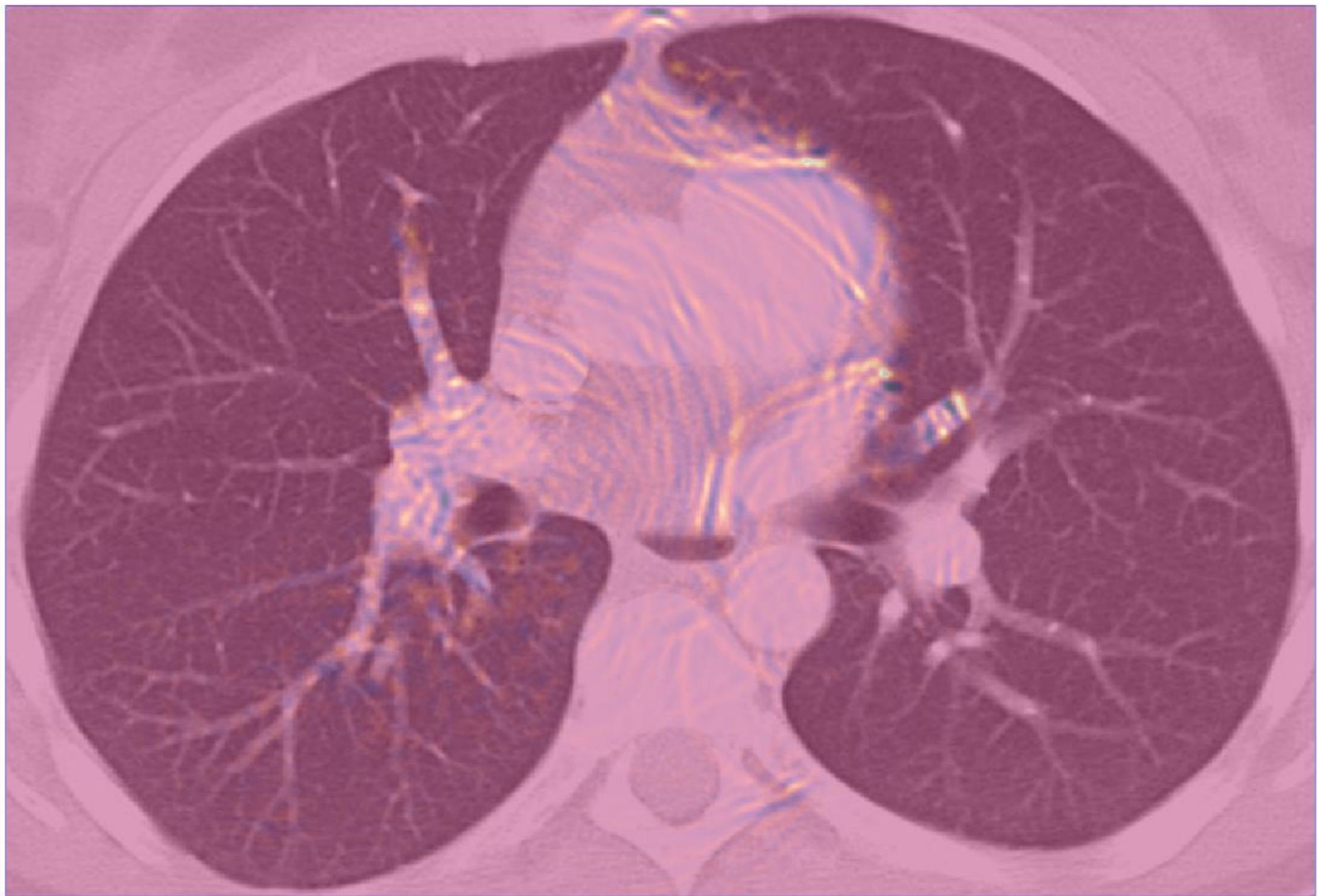
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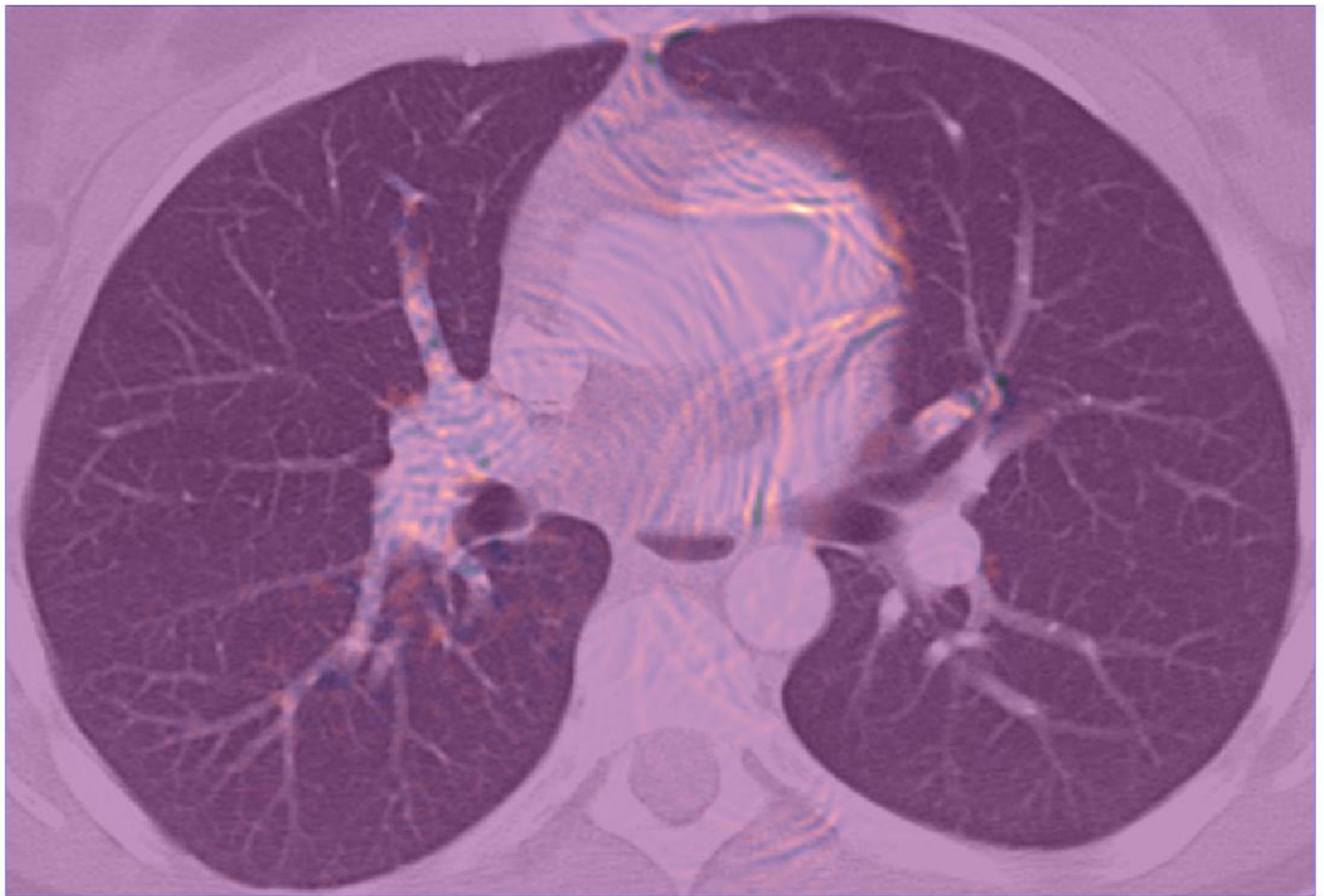
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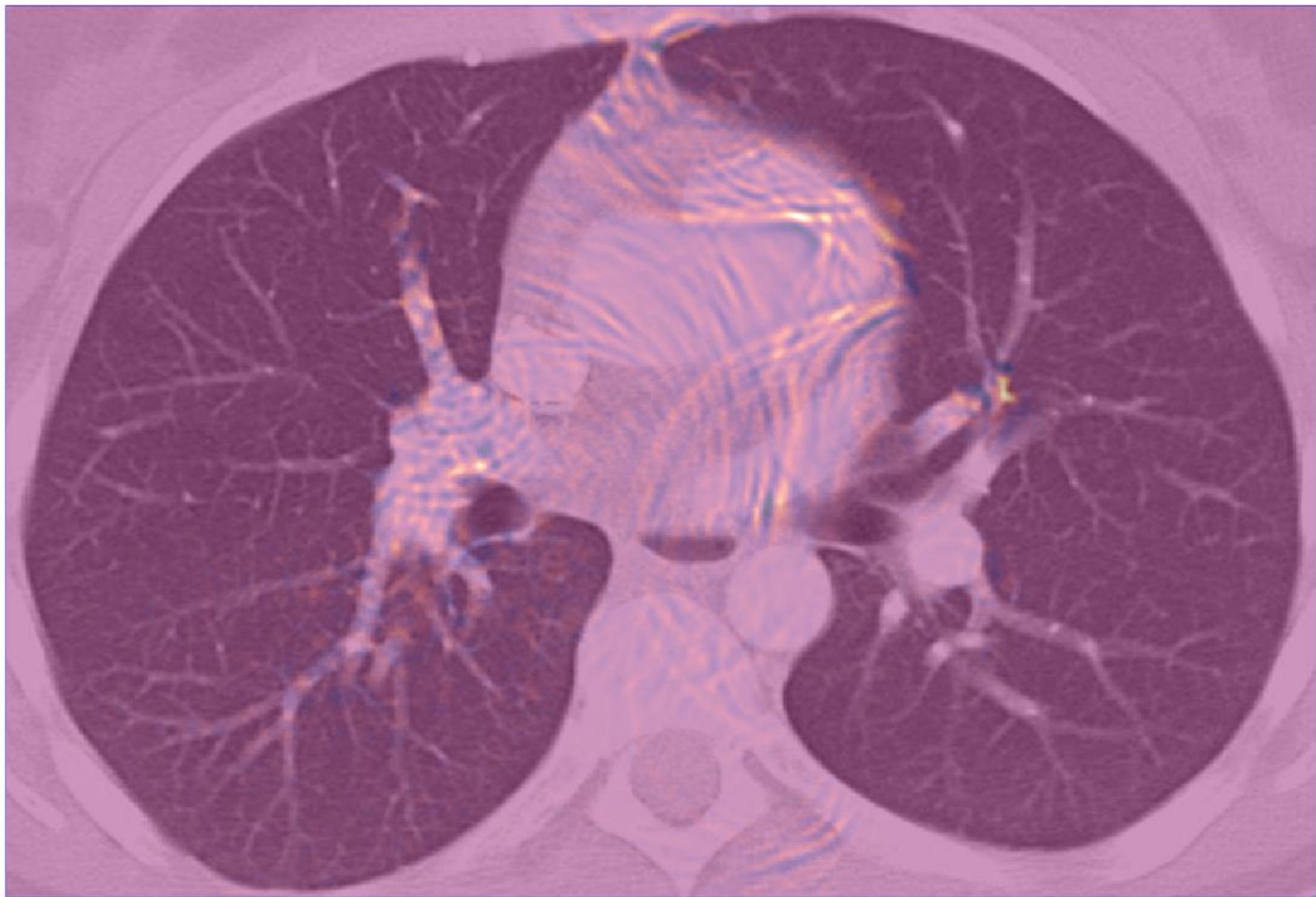
Red circle
Grey circle
Green circle



●

○

●





Red

Grey

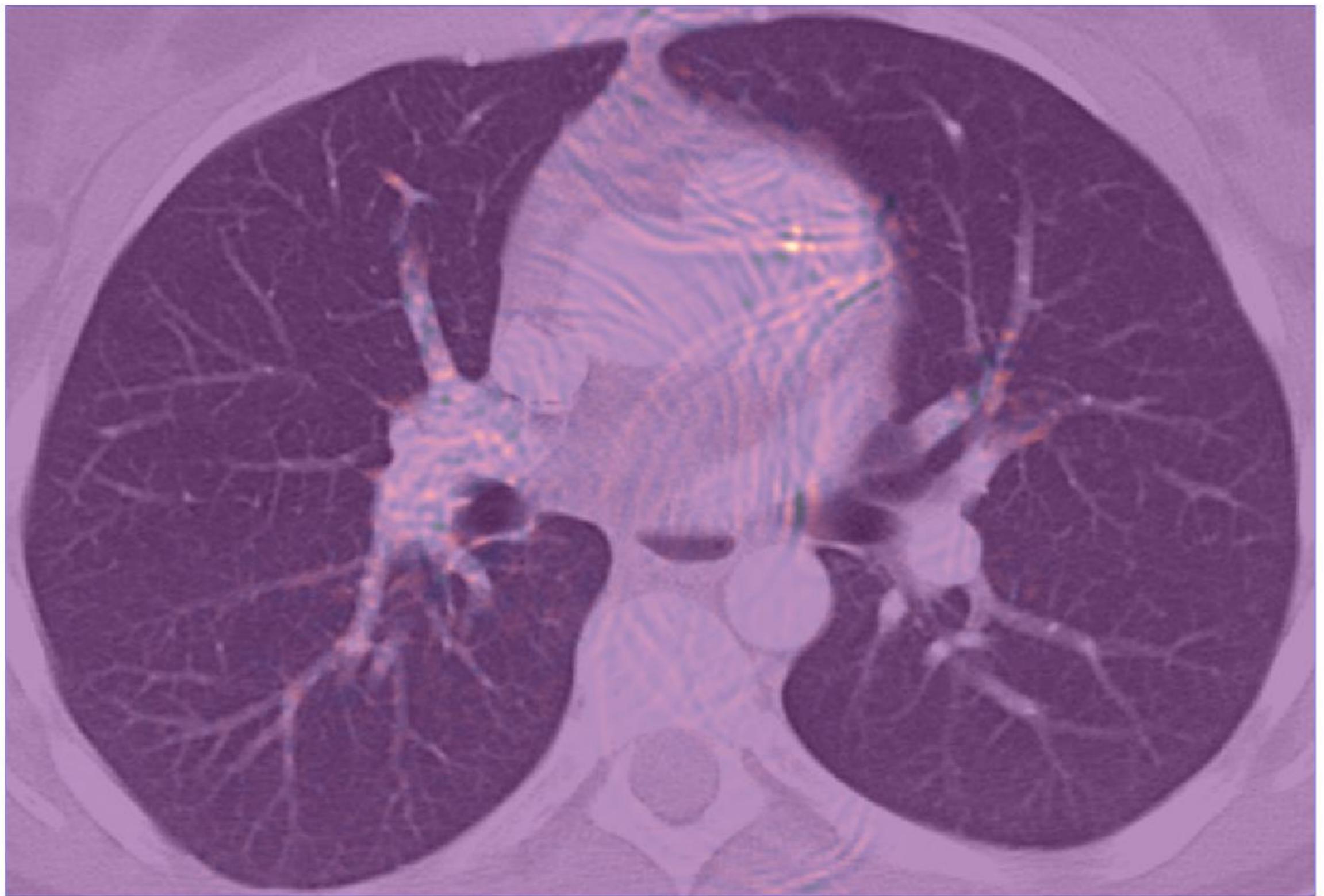
Green



Red

Grey

Green



Red

Grey

Green



●

○

●



●

○

●



Red

Grey

Green



Red

Grey

Green



●

○

●



●

○

●



●

○

●



500

400

300

200

100

0

0

100

200

300

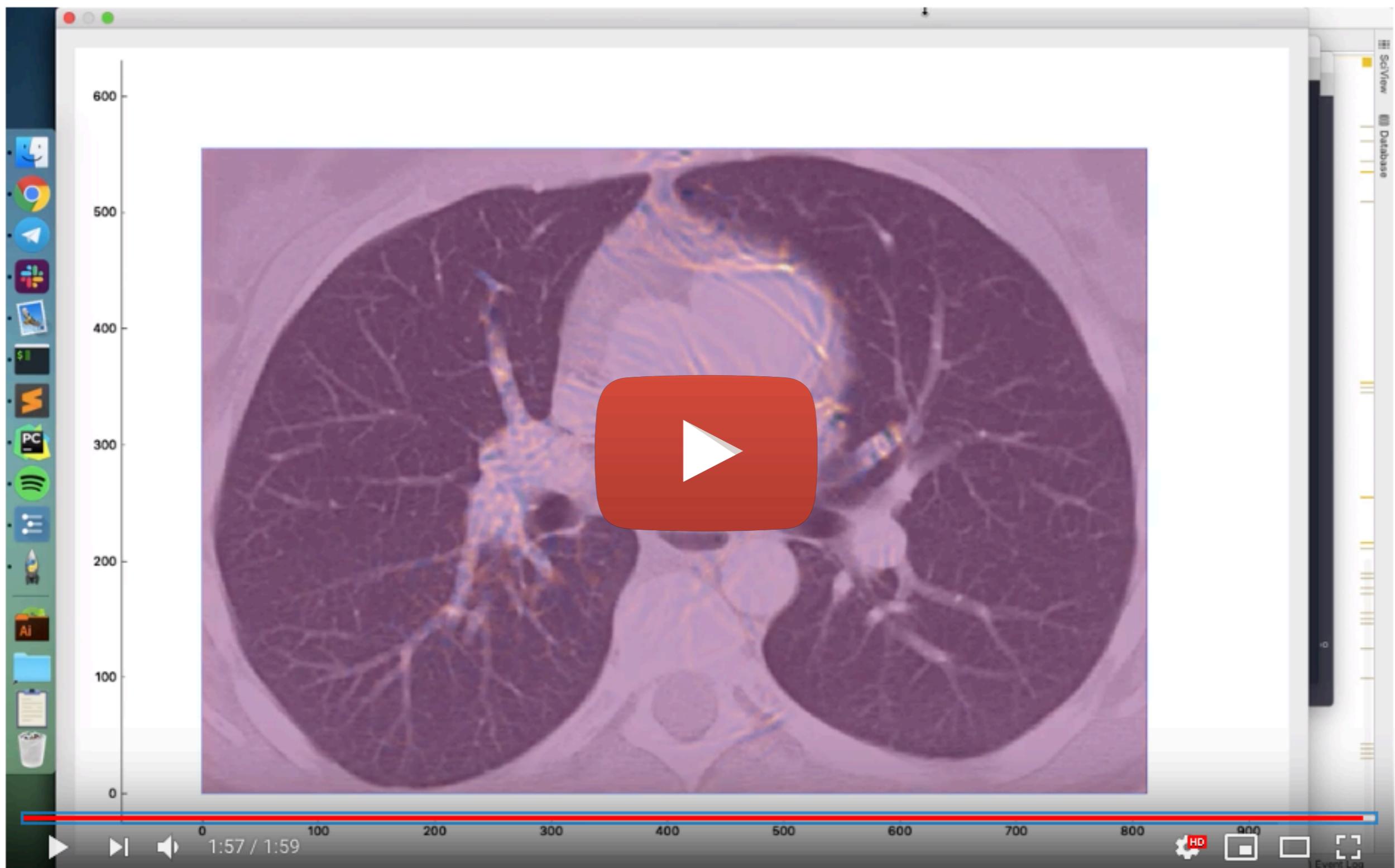
400

500

600

700

800



Sound Propagation in Lungs (acoustic FDTD simulation)

21 views

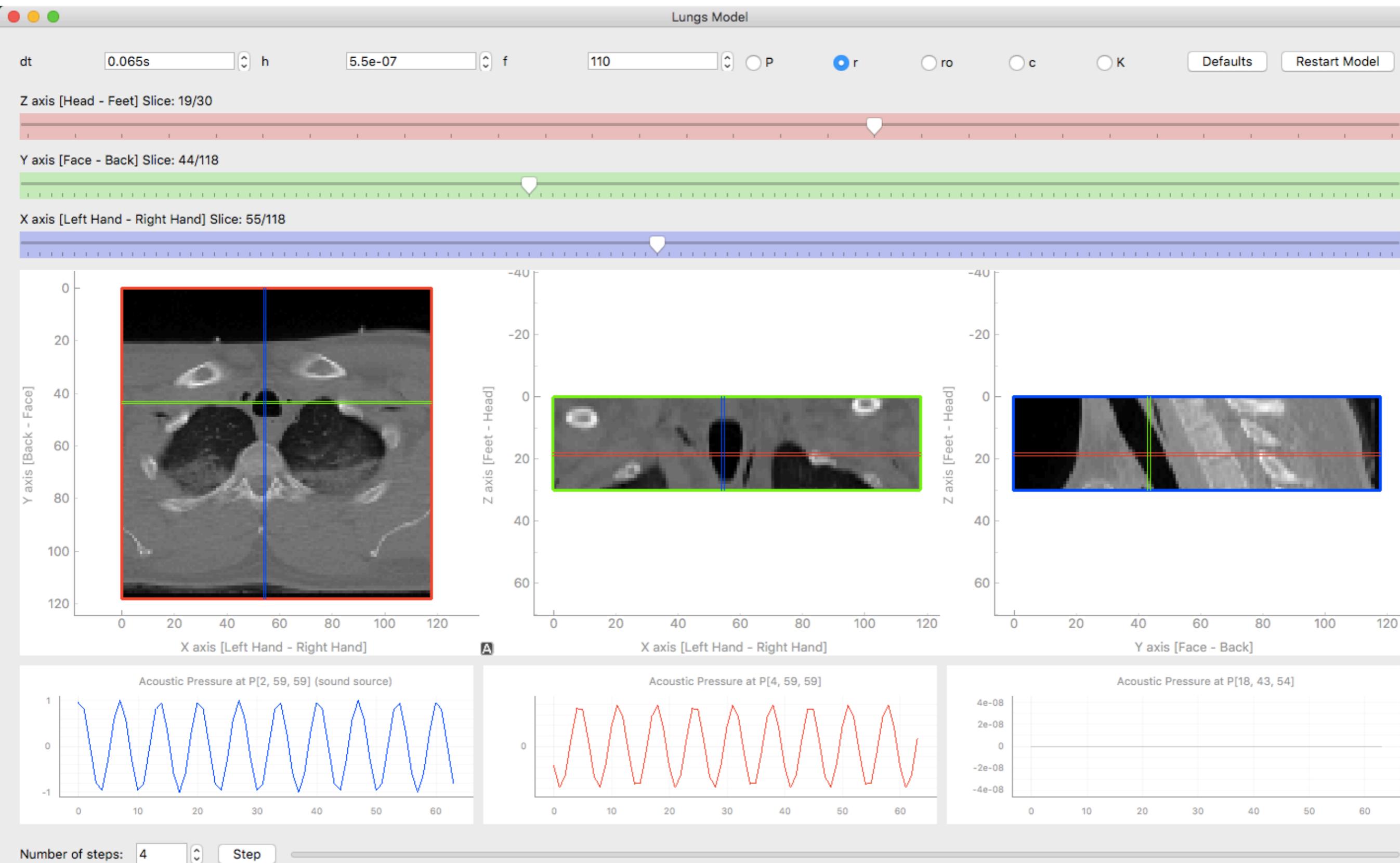
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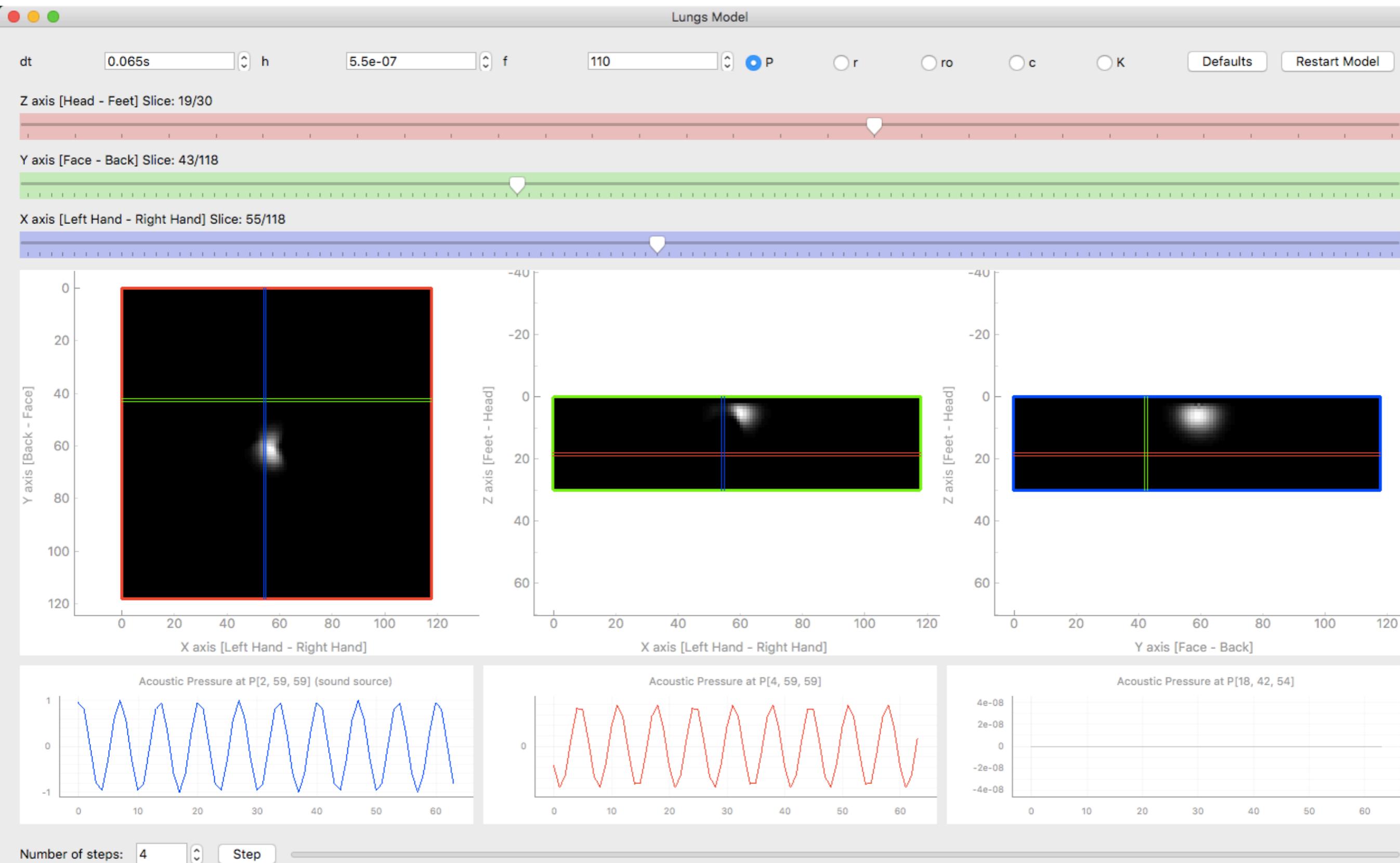
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