SC205
Discrete Mathematics Project

MUSIOTIC

Storing Digital Data Into DNA Sequences

INDEX

1 Digital Audio

1.1 What are Digital Audios?

Digital audio is a form of sound recorded or converted into a digital signal. Here an Analog Audio Signal is converted to Digital Audio Signal by the process in which amplitudes of an analog sound wave are captured at a specified sample rate and bit depth and converted into Binary form which can be understood by the computers.

The primary difference seen between sound and digital audio is that digital audio is a non-continuous signal where a series of amplitude values are used to reconstruct the original analog sound wave whereas as analog sound is a continuous electrical signal. Digital Audio Signal is basically like joining various small parts together and Analog Audio Signal is itself a complete continuous part.

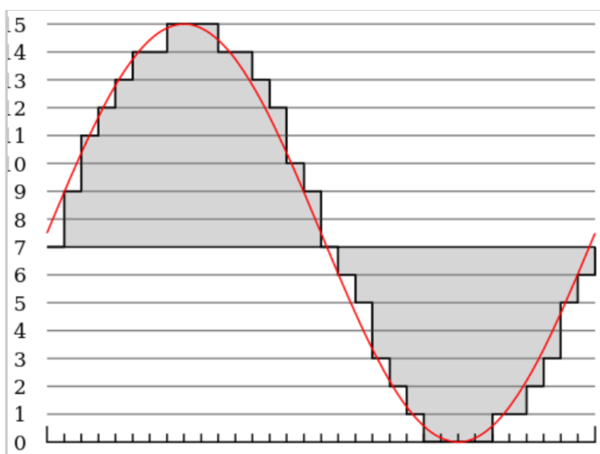

Figure 1: Analog and Digital Audio Signals

Here the continuous signal in red colour represent the Analog Audio Signal whereas the discontinuous one in black colour represents the Digital Audio Signal.In the coming sections, we will see how a Analog signal is converted to Digital Signal which a computer can understand.

1.2 Quantization: Analog-to-Digital conversion

The process of converting Analog Audio Signal to Digital Audio Signal is called quantization. In digital audio, an analog to digital converter captures thousands of audio samples per second at a specified sample rate and bit depth to recreate the original signal. The high the value of sample rate and bit depth, the higher is the audio quality.

1.2.1 Audio Sample Rate

Sample rate is the number of samples per second that are taken of a waveform to plot its discrete digital signal. The higher the sample rate, the more samples are collected of the audio signal. The value of audio sample rate is measured in **kilohertz (kHz)**. It determines the interval at which you take the samples.

For example, a sample rate of 44.1 kHz means that the every single second of the waveform is divided into 44,100 small parts and for each small part we calculate the amplitude of the waveform at that specific instance. After this a new digital signal is plotted by mapping this amplitude values against their respective small sample parts.

While working with music, like recording, mixing, etc, it's always advantageous to work at the highest possible sample rates and bit-depths, i.e. 48 kHz, 96, kHz, or even 192 kHz. This allows for better quality in all mixing and effects. It also gives us the flexibility of bouncing down to a sample rate suitable with our medium of distribution. The below figure shows how increasing the sample rate increases the quality of our digital signal.

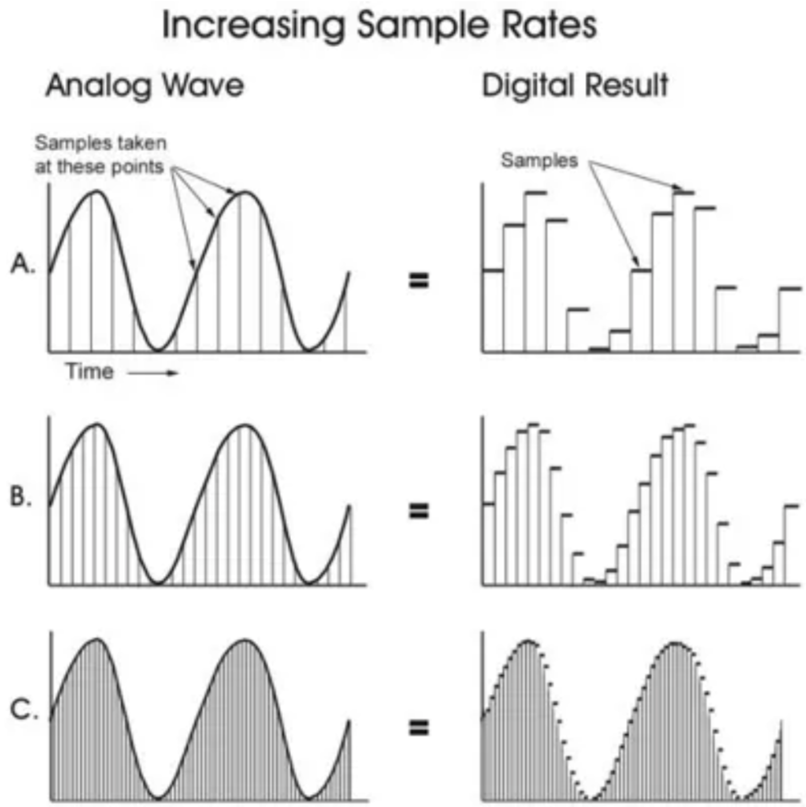

Figure 2: Quality of Audio Signal with respect to Sample Rate

1.2.2 Audio Bit Depth

The audio bit depth determines the number of possible amplitude values we can record for each audio sample. Basically it is the number of different amplitude levels to which we can measure the amplitude of the small sample part. The higher the bit depth, the more amplitude values per sample can be measured to recreate the original audio signal.

The most commonly used audio bit depths are **16-bit, 24-bit** and **32-bit.** Each is a binary term, representing a number of possible values.

- 16-bit : 65,536 values

- 24-bit : 16,777,216 values
- 32-bit : 4,294,967,296 values

Higher bit depths mean higher resolution audio. If the bit depth is too low, some information of the original audio signal is lost. With a higher audio bit depth and therefore a higher resolution, more amplitude values are available for us to record. As a result, the continuous analog wave's exact amplitude is closer to an available value when sampled.

For example, a bit depth of 16-bit means that for a small sample of our analog signal we have 65,536 different levels to plot the amplitude at that instance. And each amplitude value will be stored in binary form in memory using 16-bit representation. The below figure shows how increasing the bit depth increase the quality of our Digital Audio Signal. Also, increasing the sample rate and bit depth decreases the error in the conversion from Analog to Digital.

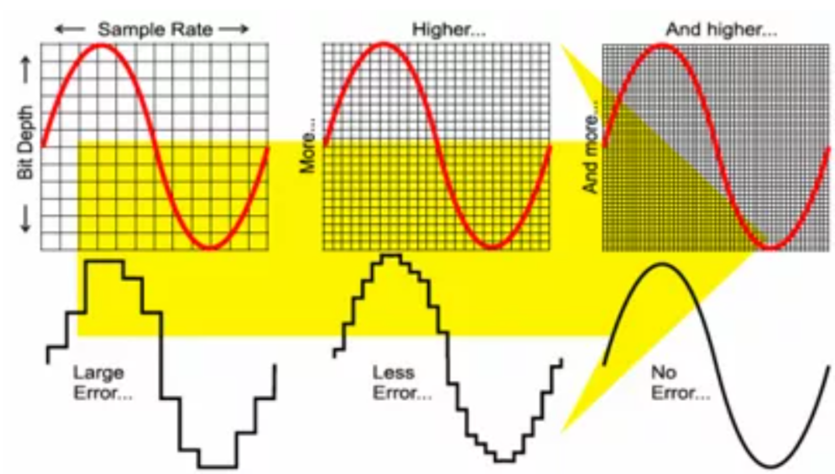

Figure 3: Quality of Audio Signal with respect to Bit Depth

1.3 Storing Digital Audio in Computer Memory

To store a Digital Audio in a computer memory we need the values of amplitude and the sampling rate. The sampling rate is fixed for a specific analog-to-digital converter. It is already predefined in the system of converter at what bit rate it has to take samples of a given wave form. Firstly, sampling of the wave form is done and for each small sample the amplitude value is measured. This amplitude values are in the form of voltages measured by a microphone or any sound recorder.

Now this amplitude values are converted into binary numbers and are stored as a single string in the computer memory. Let us understand this using a 4 bit depth system. For this we will be having 16 different amplitude values. This value range from **+7 to -8**. We want to store the Analog Audio Signal shown in the below figure in the computer memory.

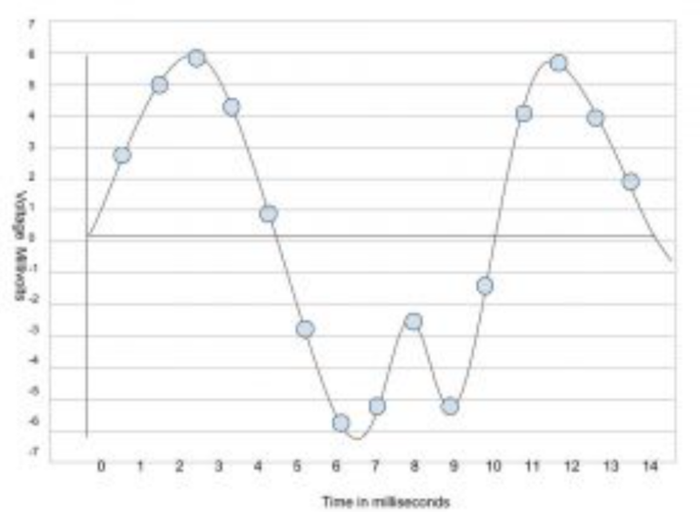

Figure 4: Analog Audio Signal

Here, the x-axis represent the sampling time in milliseconds and y-axis represents the amplitude values in terms of millivolts. It is in milliseconds because a sample rate of 44.1kHz will take sample at every $\boldsymbol{\frac{1}{44100}s;}$ which is equal to $\boldsymbol{0.022\ milliseconds.}$This means that the system will measure the value of amplitude at every 0.022 millisecond of the wave form.Here we have taken only 15 samples of the wave form. The measure values of the voltages(amplitudes) of the waveform are as below:

Readings(in mV))	Sign Bit(+/−)	Values(in mV)	Binary Form
3	0	011	0011
5	0	101	0101
6	0	110	0110
4	0	011	0011
1	0	001	0001
-3	1	011	1011
−6	1	011	0011
−6	1	110	1110
−3	1	011	1011
−6	1	110	1110
−2	1	010	1010
4	0	100	0100
6	0	110	0110
4	0	100	0100
2	0	010	0010

Now this signal will be stored in the computer memory as a binary string made up of all the binary values of the voltages(amplitudes) as shown below:

0011 1010 0110 0100 0001 1011 1110 1110 1011 1110 1010 0100 0110 0100 0010

Following is the final Digital Audio Signal stored in the memory.

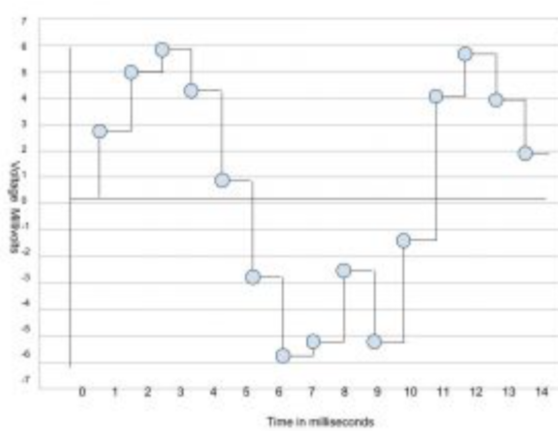

Figure 5: Digital Audio Signal

2 Digital Images

2.1 What are Digital Images?

A Digital Image is an image composed of finite number of digital picture elements known as **Pixels**. This pixels organise in a form of 2D-Array to represent a digital Image. Thus, a Digital Image is a Matrix representation of Pixels. The height of the image represents the number of rows of this matrix and width represents the number of columns.

This image matrix is defined over a coordinate system where every pixel has their own x and y coordinates. Here, the x coordinates increases in the direction of left to right and y coordinates in the direction of top to bottom. Here, the origin is the top-left corner of an image. As compare to our normal cartesian coordinate convention, the y-coordinates are being flipped.

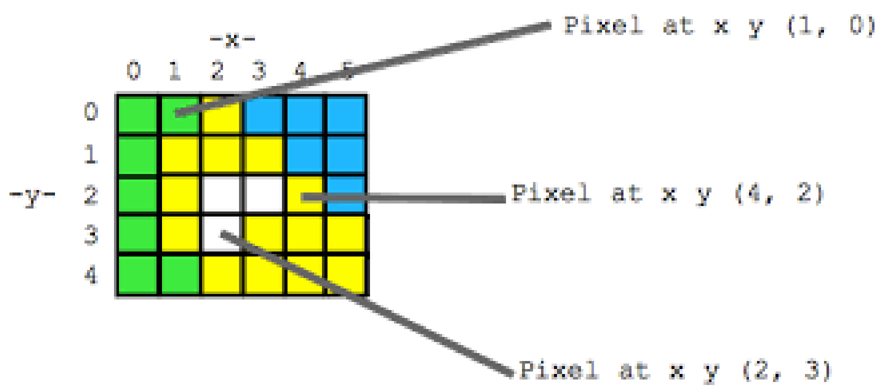

Figure 6: Coordinates System of Image Matrix

Along with this **Intensity** is the one more factor which defines the digital Images. Every pixels in this Matrix representation has their own intensity. An image of a uniform solid colour has all pixels with same intensity. Black and White images have the colour intensities varying from the darkest black to the lightest white in the shade of gray. Whereas colour images have the intensities varying from the darkest to the lightest of the mixture of the 3 colours : Red, Blue and Green.

All this together creates a Digital Image.

2.2 Storing Digital Images in Computer Memory

To store a Digital Image in a computer memory, firstly the image is broken into various pixels. The number of this pixels is calculated by the values of the height and width of an image. For example, an image with the dimensions of **200X300** has total of **60,000** pixels. Further each of these pixels are represented in the binary form based on the colour of the pixel. These binary forms are stored in the memory to store a Digital Image. Now, let us understand how these pixels are converted into binary numbers.

For each pixel, an average shade is found and a binary value is assigned to it based on that shade. A monochrome image, made of only 2 colours, requires only 1 bit to represent the 2 colours; 0 for white and 1 for black. For a colour image, each pixel is represented using set of bits. There is a unique set of bit corresponding to a unique shade of colour. In technical terms, the number of bits assigned to a shade is known as **bit depth** or **color depth**. Based on the color depth, the number of shades of the colour are defined as:

$$\boldsymbol{2^n}$$

where **n** is the value of color depth. For example,

- A value of **8**-bit color depth has $\mathbf{2^8\ (256)}$ shades of color.
- A value of **16**-bit color depth has $\mathbf{2^{16}\ (65,536)}$ shades of color.
- A value of **24**-bit color depth has $\mathbf{2^{24}\ (16.7\,\boldsymbol{million})}$ shades of color.

Now, let us understand this concept for a 2-bit color depth which means 2^2 (4) shades of colours. Here, each shade is represented by 2 bits. We want to store the following image in the computer memory.

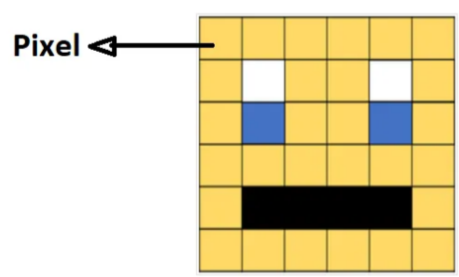

Figure 7: Actual Image to be Stored

Let us assign binary numbers to the colour shades.

- WHITE = 00
- YELLOW = 10
- BLACK = 01
- BLUE = 11

Now, the image is store in the memory in the form of binary representation as shown below.

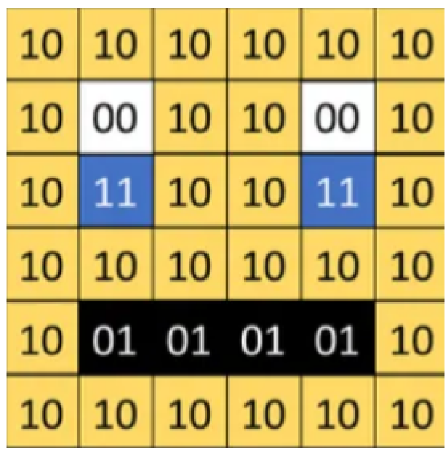

Figure 8: Image Stored in the Computer Memory

Thus, all the Digital Images are stored in the computer memory by representing the shade of a pixel in terms of a binary number.

3 Need For A New Data Storage Technique

Based on the study carried out by the Massachusetts Institute of Technology, our current techniques of storing the data will not be much feasible in the coming future. On Earth right now, about 11 trillion gigabytes of digital data exist and every day, humans keep on producing more and more data in form of text, emails, photos, videos, etc which is nearly 2.5 million gigabytes per day. A large amount of this data is stored in enormous facilities known as **Exabyte Data Centers** (an exabyte is 1 billion gigabytes). Each of this centers is equal to size of several football fields and cost around $1 billion to build and maintain.

Scientist have found out a new method to store data called **DNA Digital Data Storage Method**. Here, the data is stored in the strands of Artificial DNA which evolved to store massive quantities of information at very high density. **"A coffee mug full of DNA could theoretically store all of the world's data"**, says **Mark Bathe**, an MIT professor of biological engineering. Also, Artificial DNA has various other plus points which makes it a crucial data storage technique in the coming future.

On the basis of above discussion, it seems that the amount of storage available and being produced can't cope with the data we keep producing each day . Thus, there is a need for a new Data Storage Technique which can cope with the data we are producing today. And it seems that the DNA storage is one solution to this problem of data storage.

4 Data Storage Using DNA

4.1 What Is DNA Data Storage?

DNA stands for **Deoxyribonucleic Acid**. It is a complex organic molecule that carries the genetic information of a living thing. It is found in all living beings and stores information like skin color, eye color, height, and other physical and biological traits. Thus, the idea is to use this information storing property of DNA to store our Digital Data.

A DNA spiral has multiple and alternating pairs of four unique bases. They are adenine (A), guanine (G), cytosine (C), and thymine (T). These bases are attached to the DNA spiral in pairs, called base pairs. The two base pairs are Adenine-Thymine and Guanine-Cytosine. In DNA data storage, the four nucleotide bases (A, C, G, T) store and encode data. Information is stored in permutations of three nucleotide bases, called **codons**.

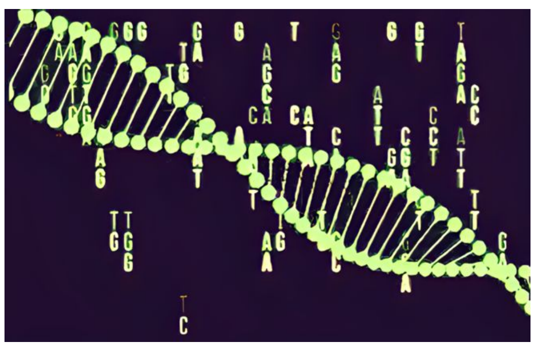

Figure 9: DNA along with 4-Bases

4.2 The Process Of Storing DATA Into DNA Form

Discrete Mathematics concepts like number systems, sampling theory, quantization and coding theory are essential for understanding and implementing the conversion of audio files into DNA sequences. DNA storage comprises of mainly of three processes:

1 Coding the data

2 Synthesizing the data into DNA

3 Storing the DNA sequences

We know that the data is stored in binary digits (1s and 0s) in computer memory. Therefore, the binary codes holding information are translated first into DNA codes or codons using an algorithm. Then they are deposited in a container in a cool and regulated environment. The DNA sequences carrying information can be frozen in solution, stored as droplets or stored on silicon chips. The below shown figure summarises the above discussed whole process.

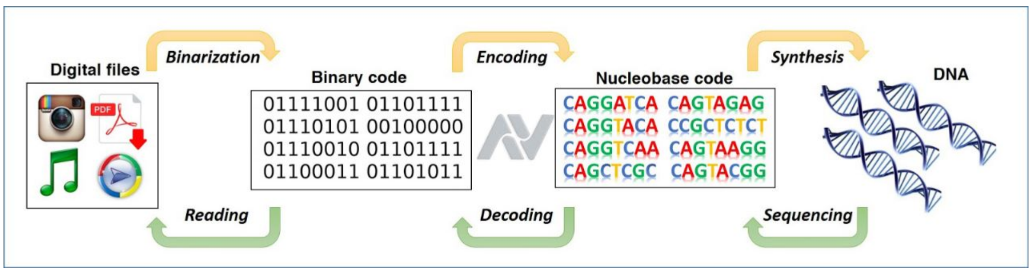

Figure 10: Conversion of Digital Files into DNA Sequences

Scientists are currently working on making the reading of DNA storage faster and less expensive. As of now, data stored in DNA has to be taken to the lab to be decoded into error-free binary information, and it takes a long time.

4.3 Storage Capacity Of DNA Data Storage

DNA Data Storage is a significant solution for the storage shortage problem because it can store a large amount of data in a very little space. One gram of DNA can store 215 petabytes of data. A petabyte is 1,024 terabytes. So, **one gram of DNA can store approximately 220,160 terabytes.**

Figure 11: Large Data Storage Capacity of DNA

Comparing this with current technology: a one-terabyte hard disk drive weighs approximately 400 grams. So, to store the amount of data that one gram of DNA can store, we need more than 88 million grams of hard drives. With this information, researchers say that all the data in the world right now can fit into a **Shoebox** using DNA Data Storage.

4.4 Advantages of DNA Data Storage

Using DNA storage over digital storage, as a storage medium comes has various benefits . It provides high data storage capacity, a considerably longer lifespan than other forms of storage, compactness, not dependent on electrical failures, replicability, etc.

4.4.1 Durability

The digital storage equipments available today are far from being durable. They are all subject to decay and degradation. Digital decay is the gradual decomposition of data stored on a computer. This affect millions of people every year.

The DNA has a half-life of 500 years. When stored in an optimum and regulated environment, data stored in DNA can be available for hundreds of years. The below image shows the durability of DNA in storage as compare to other mediums of data storage.

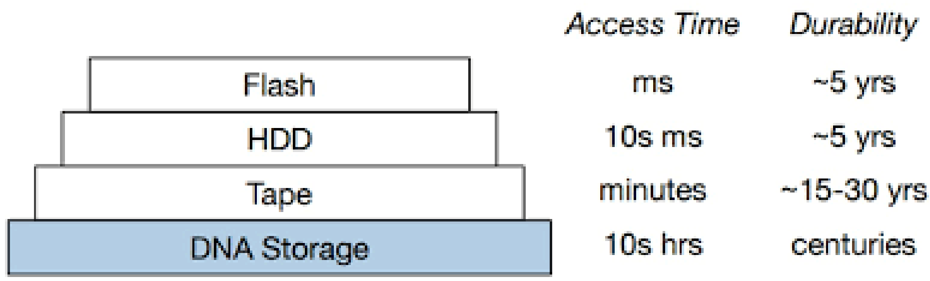

Figure 12: Durability of DNA vs Other Storage Mediums

4.4.2 Storage Density

The primary advantage of DNA storage over other storage mediums is its high storage density as compare to other mediums. Even though you store your data remotely on the cloud, they are still stored in big servers and data centers. These data centers are as large as football stadiums and cost billions of dollars to build and maintain. The following image shows the DATA Center of one of the Tech Giants **GOOGLE**:

Figure 13: Google's Data Storage Center

It is not the same with DNA data storage. DNA Data Storage allows you to store very large amounts of data in a very compact space. As mention above, even a small space allows us to store millions of gigabytes of digital data using DNA data storage. Hence, reducing the problems of space, maintenance expenses, and shortage of storage equipment.

4.4.3 Replicability

Because of the degradation of data, Digital Data in data centers have to be copied and transferred onto another hardware after a certain period of time to preserve the information stored. This process is frequently unwieldy due to heaviness and the bulk of data.

Data stored in DNA can easily be replicated. One method scientists have tested is to insert the DNA with stored information into a bacterium. This bacterium then reproduces, on its own, other generation of bacteria that possess the same information stored in the first DNA without any errors or loss.

4.5 The Future Of DNA Data Data Storage

Researchers have made significant progress in utilizing DNA as a medium for storing information. In 2012 and 2013, independent groups led by Church and Goldman successfully stored around a megabyte of data in DNA. In 2018, researchers scaled up the techniques and stored approximately 200 megabytes of data using DNA.

Despite these advancements, there are practical technological limitations to consider when designing a DNA based storage system. Writing data onto DNA and reading data from DNA have several challenges that must be overcome to make this a success.

"DNA has evolved to store massive quantities of information at very high density, and it's remarkably stable, too. The largest human chromosome carries up to 250 million base pairs of DNA. **If data could be stored on every base pair, all the data in the world could theoretically fit in a coffee mug**," says **Yingjin Yuan**, a professor of biochemical engineering at Tianjin University.

Figure 14: World's Digital Data in a Cup of Coffee ?

Yuan's team has successfully stored two pictures and a video in it, and the encoded data occupies more than 95% of the sequence. "Our work broke through the current DNA data storage limit of only a few thousand bases per genome, " says Yuan.

Thus, in the near future the DNA Data Storage method will emerge as a dominant data storage method and will significantly replace the current data storage mediums.

5 MUSIOTIC - A DNA Data Storage Approach

5.1 MUSIOTIC - The Beginning

Based on the above discussion in Section 3, it seems significant that we should look for new data storage techniques to store the world's digital data in the coming future. One of the possible ways is the DNA Data Storage Technique discussed in Section 4. Our project **MUSIOTIC** is a small contribution into the ongoing research in the field of DNA Data Storage. Now, let us discuss in detail about MUSIOTIC.

Figure 15: MUSIOTIC 1.0

5.2 Working of MUSIOTIC

As discussed in Section 4.2, that for storing the digital data in the form of DNA, we first need to convert the binary codes into DNA codes using an algorithm. Our project MUSIOTIC works in this step of the whole DNA Data Storage process.

Our approach here is that we take the digital data, i.e. Audios and Images in their respective file formats, and convert them into DNA Files which could further be used in the process of DNA Synthesising. Currently, MUSIOTIC is under the phase of development and till now it is capable in converting Audio files into DNA files. Let us look upon how this conversion is done in MUSIOTIC.

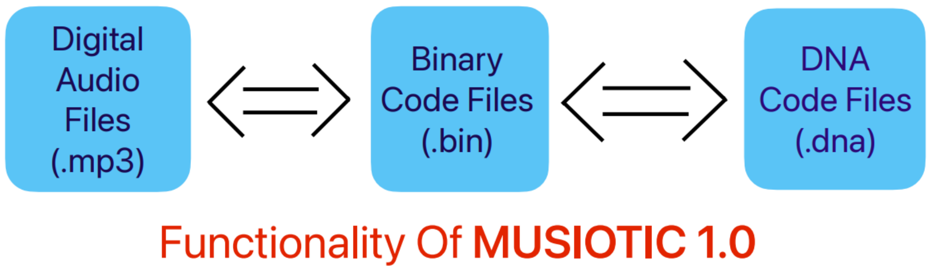

Figure 16: Current Working of MUSIOTIC 1.0

5.3 Converting Audio/Music Files into DNA Files

The main work of MUSIOTIC is to convert the Digital Audio Files into the DNA Files. As discussed above in Section 1.3, we know how these Digital Audio Files are stored in computer memory in Binary representation. So, we have used this Binary File in DNA conversion.

The first step in converting the Audio File (.mp3) into DNA file is to retrieve the Binary file of a given Audio file. Here, the **.mp3** file is first converted into the **.bin** file. This .bin file is the binary representation of the .mp3 Digital Audio file. Than using our Algorithm we convert this Binary file into DNA file, i.e. **.bin** to **.dna**.

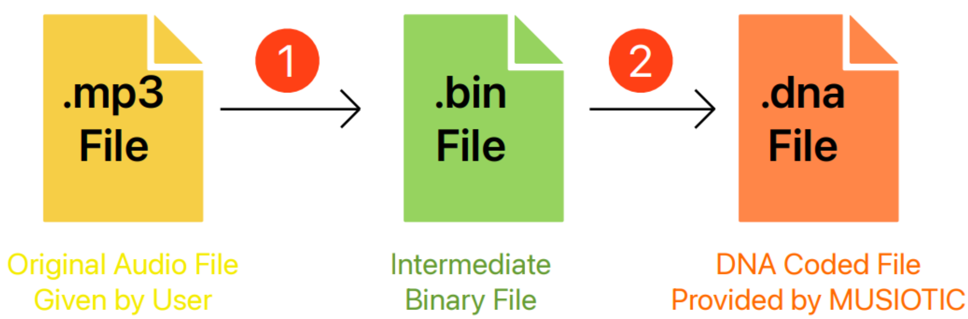

Figure 17: Steps Involved in Forming .dna File

5.3.1 Algorithm Used In converting .bin to .dna

We know that a DNA sequence consist of 4-Bases (A, T, G and C). So, in order to represent the Binary File into DNA File we need to do something such that we could map this 4-Bases with some Binary patterns.Thus, with this idea we came up with the following mapping scheme.

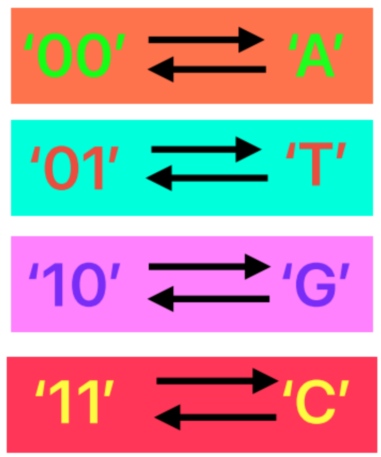

Figure 18: Mapping Scheme For Conversion Algorithm

We took the binary pattern of 2 binary digits. With this pattern scheme we made all 4 possible combinations of binary digits and map this 4 combinations with the 4 bases. Therefore, a pattern of **'00'** represents the first base **'A'**. Similarly the other bases are also represented in same manner as shown in figure 17. Now, let us understand this using the binary pattern we stored earlier in section 1.3.

0011 1010 0110 0100 0001 1011 1110 1110 1011 1110 1010 0100 0110 0100 0010

We want to store this pattern into DNA sequence using the mapping scheme discussed above. The DNA sequence representing this Binary pattern based on our mapping scheme is:

AC GG TG TA AT TC CG CG GC CG GG TA TG TA AG

Thus, in this way MUSIOTIC converts the binary pattern into a DNA sequence. Using the reverse mapping we can retrieve binary pattern back from a given DNA sequence.

MUSIOTIC does not simply convert binary file directly into DNA sequences. We have used the **RSA Encryption Algorithm** to encrypt the given binary file. The use of encryption algorithm makes the storage of data into DNA sequence more safer and prevents its misuse.

5.3.2 Role of RSA Encryption Algorithm in MUSIOTIC

Nowadays, Data Security is an important aspect of Data Storage. Data Security prevents the crucial data from being stolen, ending up in wrong hands, data breach, etc. It also protects the data from hacking . If our data is encrypted then there are very less chances that it will be misused. So, encryption of data is very important for the security of our data.

We have developed MUSIOTIC keeping in mind the Data Safety of the user. In order to encrypt the users' data while creating the DNA Files we have used RSA Encryption Algorithm. So, the .mp3 Digital Audio File given by the user is first converted into an encrypted .bin file using RSA Algorithm. After this, the encrypted .bin file is converted into .dna file and latter this encrypted .dna file is used in storing data in DNA sequence. Therefore, the data stored in the DNA sequence is not directly accessible without decrypting which makes it storage safe.

While retrieving back the .mp3 file from .dna file, the encrypted .dna file is first converted to an encrypted .bin file. This encrypted .bin file is than decrypted using decryption algorithm and then it is converted back to original .mp3 file. Thus, storing an encrypted DNA sequence protects the data in various aspects.

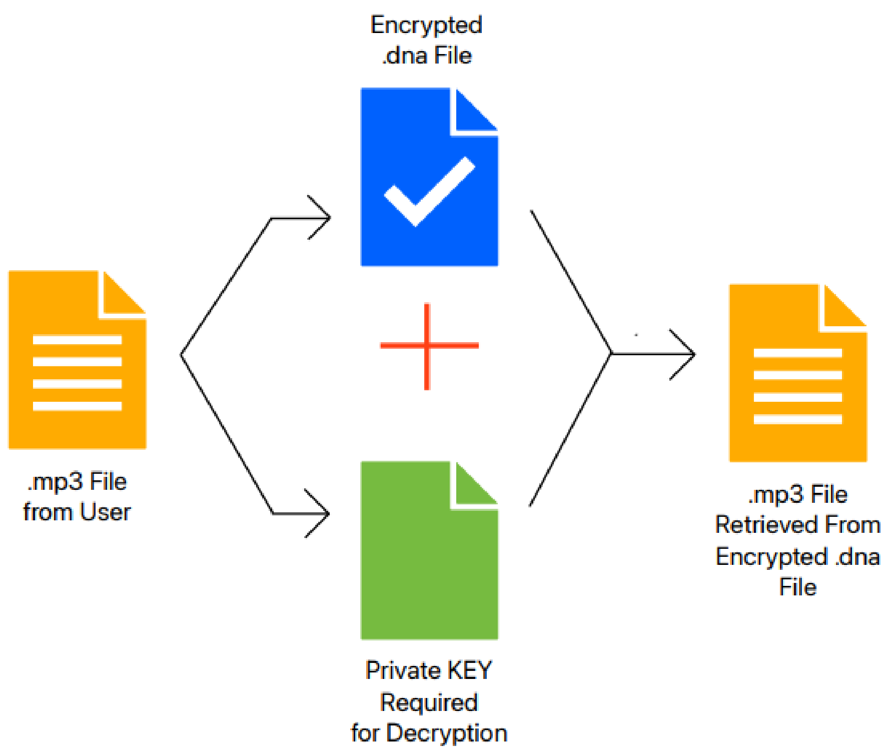

Figure 19: Working of MUSIOTIC Under RSA Encryption Algorithm

5.3.3 An Overview of RSA Encryption Algorithm

RSA Encryption Algorithm is one of the most widely used encryption algorithm in the field of Data Security. Here, we will have an overview of how the RSA Algorithm works. The process involved in encryption and decryption of a file using RSA Algorithm is show in below figure.

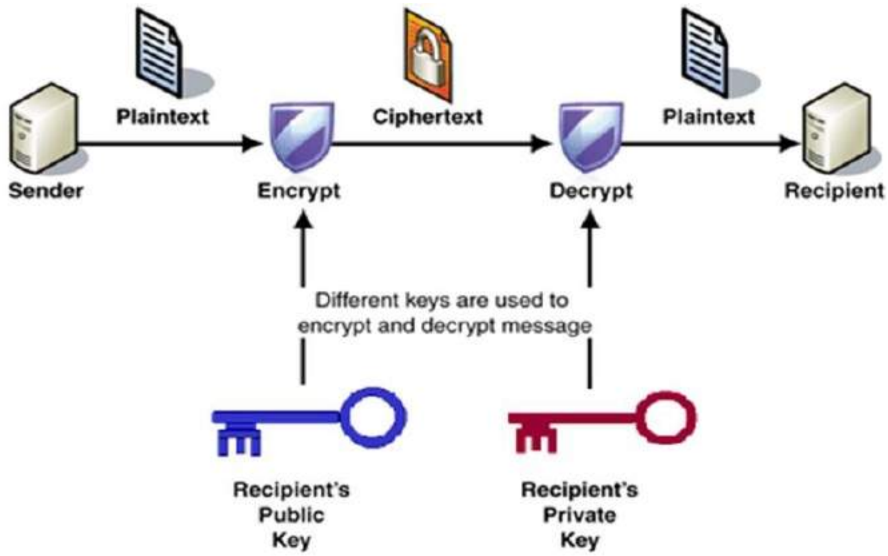

Figure 20: Steps Involved in RSA Algorithm

As shown, we have 2 type of keys in the process of RSA Algorithm, public key and private key. Both of these keys are generated by the receiver. The sender uses the public key of receiver to encrypt the data file and convert it to the encrypted data file. He then sends this encrypted data file to the receiver. Now, the receiver receives the encrypted data file and by using the private key he decrypts this encrypted data file into original data file.

In the complete process, once the file is decrypted and sent to the receiver, only the person having excess to the private key can decrypt it back to the original file. It is not possible for some to decrypt the file without knowing private key. Hence, making the file transfer safer.

While using MUSIOTIC, the final DNA File given to the user will be an encrypted file. Along with this encrypted file, the user is also provided with the private key which he need to use to decrypt the file. Thus, the user can send the file to anyone he wants to allow to access the file and no one other could misuse or hack the data of the file.

For more information about RSA Encryption Algorithm, its mathematical approach and code of RSA Encryption;
Click Here

5.4 Some Other Additional Features Of MUSIOTIC

Along with the one major feature of MUSIOTIC discussed broadly, we have developed some other features too. The other features are as below:

- **.mp3** to **.bin**
- **.bin** to **.mp3**
- **.bin** to (encrypted)**.dna**
- (encrypted)**.dna** to **.bin**
- **.dna** to **.jpeg**
- math function to **.wav**

5.4.1 Math Function to .wav Audio File

This is a very interesting feature of MUSIOTIC 1.0. Here, we have converted the actual Maths Functions into .wav Audio File. You can select the math function of your choice from the drop down menu or use any function from Python's Numpy Library. Along with selecting the function, you need to provide the values of its Frequency and Amplitude. The below figure shows .wav File generator in MUSIOTIC 1.0.

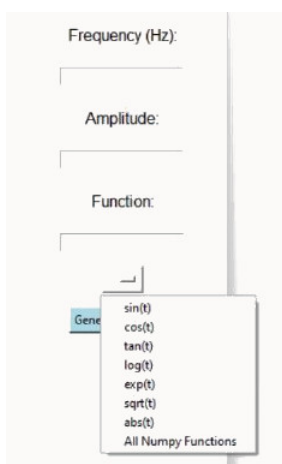

Figure 21: Maths Function to .wav File Generator

Let us understand this by taking an example. Consider that I want to convert a function $\mathbf{2\cos 5}\boldsymbol{t}$ into .wav file. We know that a math function is represented as $\boldsymbol{A}\,\mathbf{cos}\,\boldsymbol{\omega t}$ where **A** represents the **Amplitude** and $\boldsymbol{\omega}$ represents the **Frequency** of the function.

Therefore, to choose the function $\mathbf{2\cos 5}\boldsymbol{t}$, I need to input the value 5 in Frequency, 2 in Amplitude and then select $\cos t$ as my Function. The .wav File generated by MUSIOTIC will be the Audio representation of this function. Thus, in this way you can also work with other Math Functions.

5.5 Future And Commercialization OF MUSIOTIC 1.0

The 1.0 version of MUSIOTIC is capable of successfully running all the features discussed and mentioned till now. Currently, MUSIOTIC is capable of working only on .mp3(Audio/Music Files). Our plan is to develop MUSIOTIC so that it can also work for Image Files and Text Files. Thus, we are planning to make MUSIOTIC able to work on all different types of file formats.

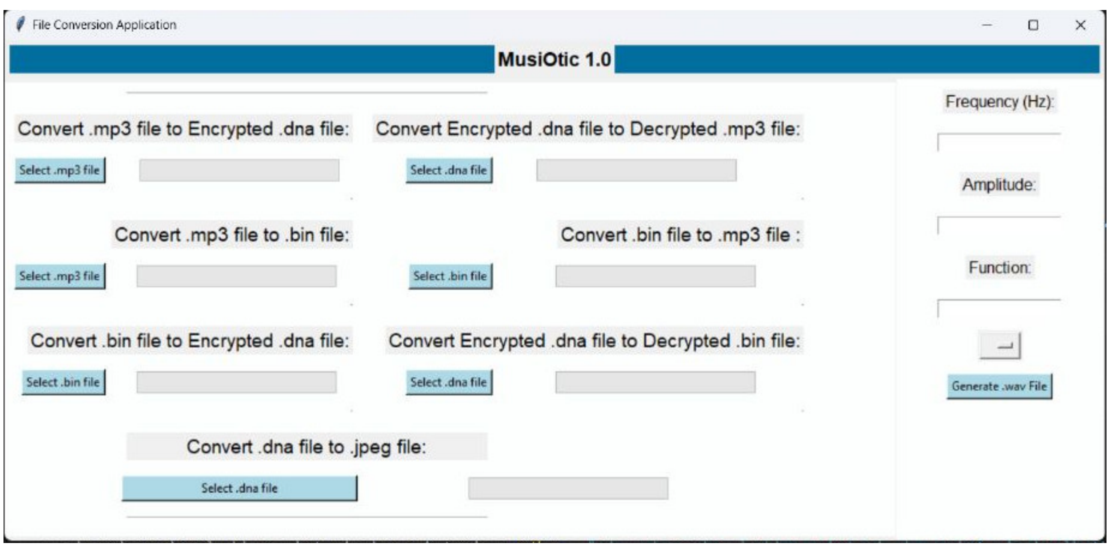

Figure 22: User Interface Of MUSIOTIC 1.0 Application

For now we are launching our app **MUSIOTIC 1.0.** The first version of MUSIOTIC 1.0 is a PC based application which means that you can install the app from its .exe file. This .exe file of MUSIOTIC 1.0 is available to download from our website. Our plan is to launch this app for the mobile users making it available to use on mobile phones too. Figure 22 shows the UI of MUSIOTIC 1.0 PC based application.

All the file conversion are also available on our website. So, users can carry out the file conversion online using our website. The below figure shows the Activities page of MUSIOTIC 1.0 website.

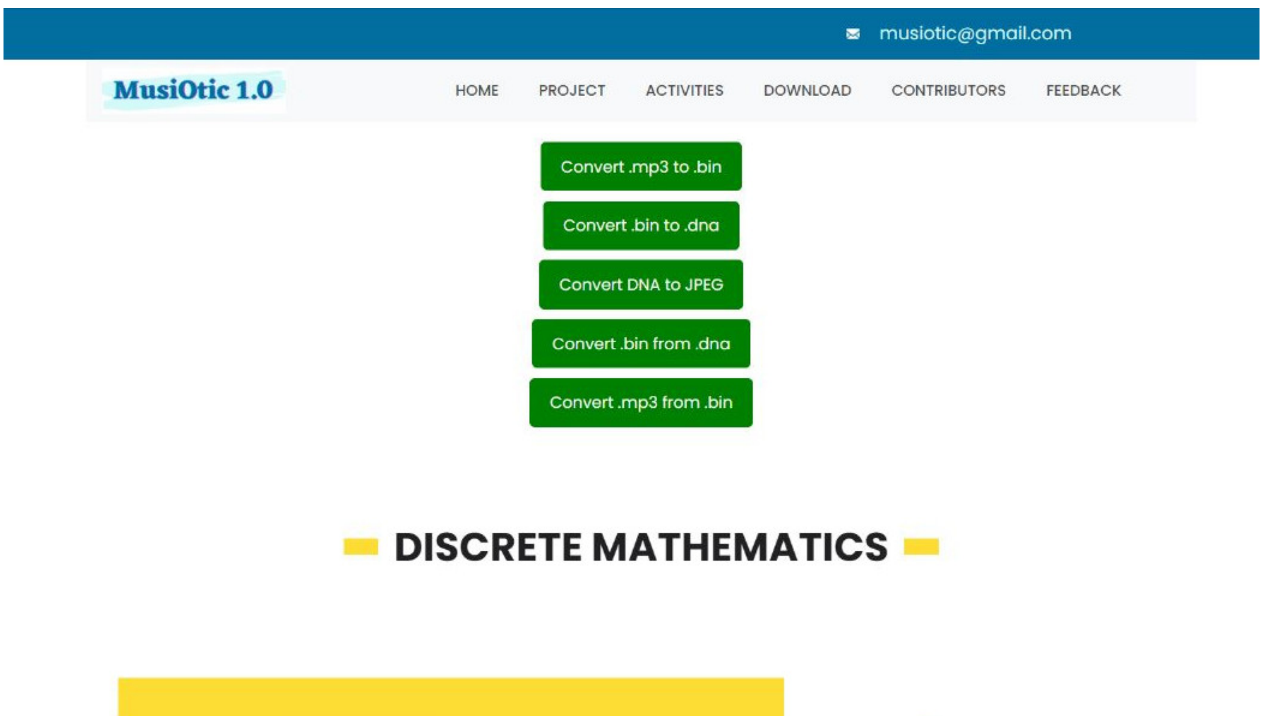

Figure 23: Activities Section of MUSIOTIC 1.0 Website

After the launch of one complete version of MUSIOTIC, we are going to monetize our app in different ways possible. We will also launch some special services for our premium users. Users will need to pay on the basis of monthly and yearly plans to be a premium user of MUSIOTIC.

We, Team MUSIOTIC are continuously developing our app and website by adding more features and making it more user friendly by taking feedbacks from the users and working upon drawbacks it currently have. We will try to the fullest to reach the needs of our every user and see to that they don't face any issues using our app or website.

We will be launching MUSIOTIC 2.0 in the near future. Till then we hope that you will be having great experience using MUSIOTIC 1.0

"We consider ourselves as the responsible engineers of society and we ought to work in the advancement and development of the society."

~ Team MUSIOTIC

6 Team MUSIOTIC

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