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Project: Homomorphic Encryption Web-Based User Interface

Abstract

As cloud computing becomes more and more popular, ensuring its security becomes increasingly essential. Homomorphic encryption provides an efficient, secure way to perform operations on data without the need to decrypt and jeopardize its integrity. This paper is a compilation of my own work involving the development of a web-based user interface that portrays how different data types can be encrypted, have homomorphic operations done on shares created from the data, then be decrypted. For the creation of shares, Shamir's Secret Sharing Scheme was utilized because of its homomorphic properties. In this paper, the programs written to encrypt each data type are summarized. Java was the chosen language to implement the programs due to its ability to easily create graphical interfaces for practical usability. Furthermore, each program along with its necessary directories (if any) are packed into Java Archive files and/or ZIP files for quicker download times.

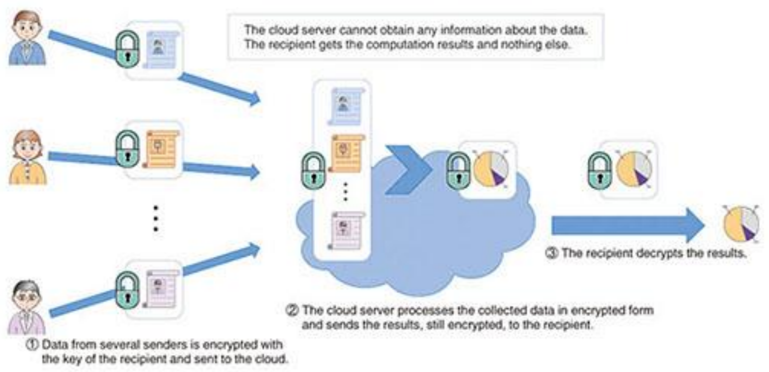
Overview and Background

Homomorphic encryption can be defined as "the conversion of data into ciphertext that can be analyzed and worked with as if it were still in its original form" (Rouse). This project is a web-based user interface in which several options for showing how homomorphic encryption manipulates data are available. Data type options for homomorphic encryption include numbers, text, and images. Each data input is used to create multiple shares using Shamir's Secret Sharing Scheme. Operations are then performed on these shares rather than the original data.

This project is an excellent introduction into homomorphic encryption. Homomorphic encryption is the modern way of encrypting and performing operations on cloud data to better protect the information than the traditional way. As stated in the scientific paper *Homomorphic Encryption for Data Security in Cloud Computing*:

> *Traditional standard encryption methods provide security to data in storage state and transmission state. But in processing state, performing operations on data require decryption of data. At this state data is available to cloud provider. Hence traditional encryption methods are not sufficient to secure data completely.* (Chauhan)

The following diagram portrays homomorphic encryption and processing on cloud data.


The cloud server cannot obtain any information about the data.
The recipient gets the computation results and nothing else.
① Data from several senders is encrypted with the key of the recipient and sent to the cloud.
② The cloud server processes the collected data in encrypted form and sends the results, still encrypted, to the recipient.
③ The recipient decrypts the results.

(Tibouchi)

In 1979, Shamir proposed a way to divide a secret into several shares that are then distributed to multiple individuals (Benaloh). Shamir's (k, n)-threshold scheme is one in which the secret is divided into n shares and can be reconstructed using any k or more shares (Lin, H.). In summary, a (k, n)-threshold scheme encrypts a secret value, s, using a polynomial equation, E, in the form:

$$E(x) = a_0 + a_1 x + a_2 x^2 + \cdots + a_{k-1} x^{k-1} \ (mod\ q)$$

… where $0 < k \leq n$, $a_0 = s$, $a_0 \ldots a_{k-1} < q$ and q is prime.

Shamir's Secret Sharing is a vital tool in the encryption world because "in certain application cases, it is a risk if a set of secret data is held by only one person without extra copies because the secret data set may be lost incidentally or modified intentionally…(or) it might be necessary for a group of persons to share a certain set of secret data" (Lin, C.). One such scenario might be ensuring the confidentiality of digitalized medical records. As stated in *Medical Image Security and EPR Hiding Using Shamir's Secret Sharing Scheme*, "Medical applications such as telediagnosis require information exchange over insecure networks" (Ulutas). This means that attackers may attempt to steal the sensitive data while it is in transit. The paper suggests using Shamir's Scheme to mitigate this risk.

Motivation
This website will serve as an interactive learning tool focused on the homomorphic properties of Shamir's Secret Sharing Scheme for future cryptography students. As stated in one paper studying the impact of interactive websites on learning, "Using features which promote…interactive learning activities encourages a deep approach to learning…and enhanced understanding of content" (Kember). The opportunity to develop such a tool, which may help others to understand secret sharing and homomorphic encryption, was one of the driving factors for pursuing this topic.

Scope
The scope of this project includes the use of three data types for demonstrating the homomorphic properties of Shamir's Scheme: numbers, text, and images. There exist two examples for number encryption (addition and subtraction), four examples for text encryption (addition, subtraction, concatenation, and searching), and two examples for image encryption (pixel addition and subtraction).

Limitations
To run the demonstration programs provided in the website, users must first download the necessary Java Archives and/or ZIP files. Programs that require the use of external files (i.e. text search, pixel subtraction, and pixel addition) are compressed into ZIP files that contain the necessary directories for saving and reading in files. In these cases, the user must download and extract the contents of the compressed file into the same parent directory for the program to function correctly. Otherwise, the user is only required to download a JAR file.

Certain browsers and anti-virus tools will warn of potential security risks or block the downloading of the site's files. The user will need to either confirm that they are aware of the risks or add a security exception to download the demonstration files. Users are also required to have Java installed on their machines.

Implementation

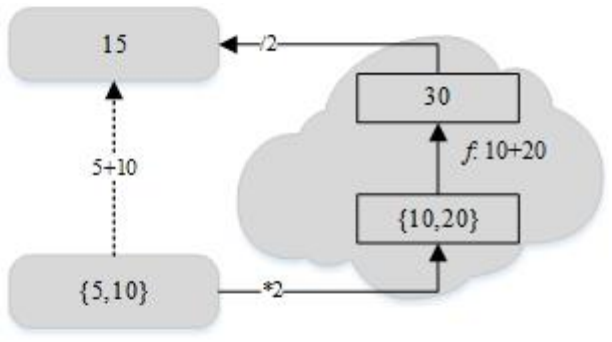
This section is segmented into descriptions of the homomorphic properties possessed by each data type used. Each of these sections are then separated further into detailed descriptions of each homomorphic encryption technique included in each of the corresponding data type webpages.

When a user runs one of the Java Archives, they will be presented with a GUI in which they can provide their own data to see the selected homomorphic encryption techniques performed on it. If the user is required to choose one or more files, they will be provided with a file explorer to search their computer for the desired file(s). Otherwise, inputs can be typed directly into the interface.

Numbers

In homomorphic number encryption, operations are performed on the encrypted versions of numbers rather than the original inputs. The following figure is an example of homomorphic encryption on two numbers, five and ten, whose sum can be resolved from the sum of their encrypted versions, ten and twenty.

*This is a naïve implementation of what is included in the website for homomorphic number encryption, which utilizes Shamir's Secret Sharing.

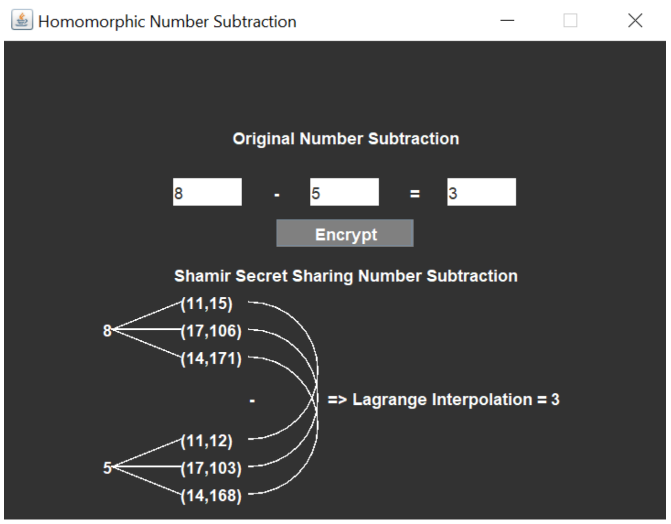


(*Fully Homomorphic Encryption Schemes*)

For the number encryption webpage, the user can choose between homomorphic number addition and homomorphic number subtraction. After downloading and running one of the demo programs, the user enters two integers in the form:

A +/- B = C

Where A and B are user inputs and C is the sum of those inputs, which is automatically generated after the user clicks the "Encrypt" button. Each user input is then divided into several encrypted shares. The shares of the second input are then added to or subtracted from the shares of the first input to produce shares of the secret. These shares are then passed through the reconstruction function, which utilizes Lagrange Interpolation, to produce the secret sum or difference of the user inputs. Below is a screenshot of the homomorphic number subtraction demo.


Homomorphic Number Subtraction
Original Number Subtraction
8
-
5
=
3
Encrypt
Shamir Secret Sharing Number Subtraction
8
(11,15)
(17,106)
(14,171)
-
=> Lagrange Interpolation = 3
5
(11,12)
(17,103)
(14,168)

In this scenario, the user inputs are eight and five. The original difference of three is displayed in the rightmost textbox. Below the encryption button, the shares that were generated from each user input can be seen in the format:

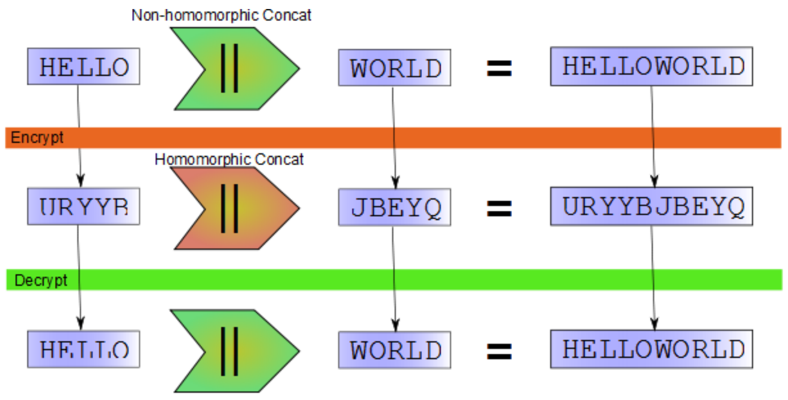
(x-value, y-value)

…where x=the value used to encrypt the number and y=the encrypted value.

The curved lines connecting the shares from the eight and the five represent the subtraction operation performed between the shares. Finally, through Lagrange Interpolation, these results are used to reconstruct the desired output of three, which matches the original outcome.

Text

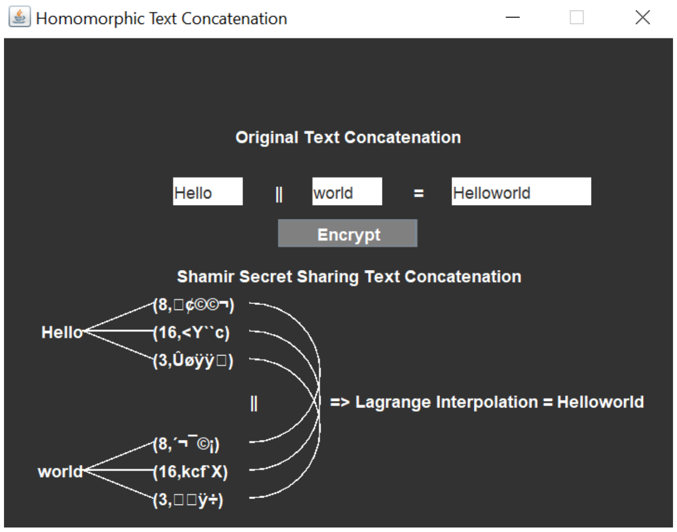
For text, there are several ways to show the homomorphic properties of Shamir's Scheme. One example of homomorphic text encryption is string concatenation, which is shown in the following figure.



(Stuntz)

*This is a naïve implementation of what is included in the website for homomorphic text encryption, which utilizes Shamir's Secret Sharing.

String concatenation is included in the text encryption webpage in addition to text addition, subtraction, and search. In homomorphic concatenation, the user provides two strings which are each divided into several encrypted shares. These shares are concatenated and the resulting strings are passed through the reconstruction function, which utilizes Lagrange Interpolation, to produce a string that is identical to the original string concatenation. Below is a screenshot from the homomorphic text concatenation demo.



Homomorphic Text Concatenation
Original Text Concatenation
Hello
||
world
=
Helloworld
Encrypt
Shamir Secret Sharing Text Concatenation
Hello
(8,□¢©©¬)
(16,<Y``c)
(3,Ûøÿÿ□)
||
=> Lagrange Interpolation = Helloworld
world
(8,´¬¯©¡)
(16,kcf`X)
(3,□□ÿ÷)

In this scenario, the user provided the strings “Hello” and “world” which concatenate to “Helloworld”. The shares generated from each string are shown in the same fashion as in the number subtraction demo. Users can verify that the program worked correctly by comparing the reconstructed concatenation with the original, which should be identical.

Homomorphic text addition and subtraction work in almost the same way as homomorphic number addition and subtraction, the only exception being that the text is read in and encrypted one character at a time to allow the program to operate on the ASCII number values.

Homomorphic text search reads in a user-supplied text file and a user-supplied string to search for in the file. Shares are created from both the text file and the string. Each string share is searched for in the corresponding (same x-value) file share. If the string is found in the file, it is replaced by asterisks (*) so the user can see all found locations more easily. The files generated from these searches are then used to reconstruct the original text file with all found matches replaced with asterisks. The user can view each file by clicking the corresponding buttons provided in the graphical user interface.

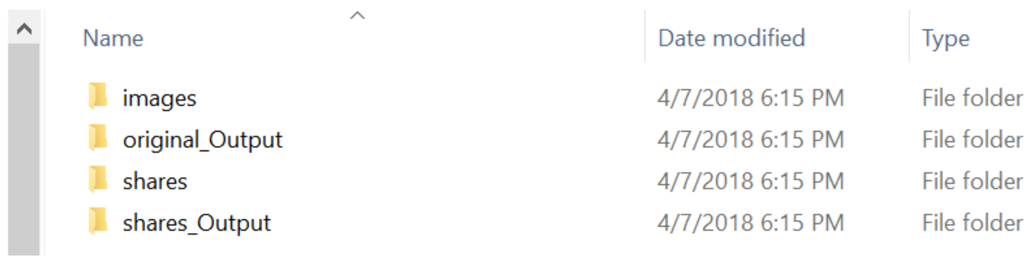
Images

For homomorphic image encryption, the user can either choose two images from their personal storage or two sample images from the provided directory, named “images”. Shares are created from these images on which a user-chosen homomorphic encryption method is used: addition or subtraction. The results from these share operations are then used to reconstruct the secret image, which is either the sum of the pixels from the image inputs or their difference. Users can view the images in larger format by navigating the provided directories. The file structure can be seen in the following images.

Parent directory

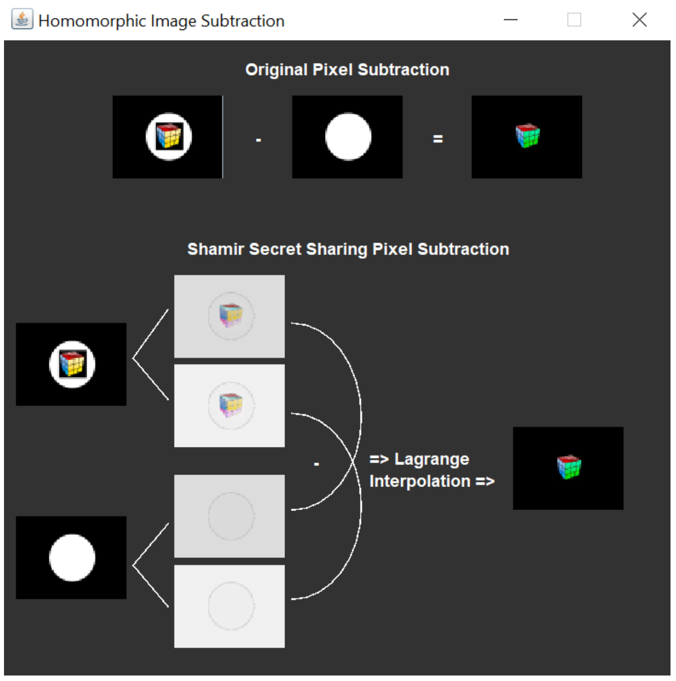
Name	Date modified	Type
dataset	4/7/2018 6:15 PM	File folder
SSS.jar	4/8/2018 3:03 PM	Executable Jar

Contents of "dataset"



Name	Date modified	Type
images	4/7/2018 6:15 PM	File folder
original_Output	4/7/2018 6:15 PM	File folder
shares	4/7/2018 6:15 PM	File folder
shares_Output	4/7/2018 6:15 PM	File folder

The directory "images" contains sample images that users can choose from, as previously stated. The directories "original_Output" and "shares_Output" contain the original image addition or subtraction output and the reconstructed output, respectively. Lastly, "shares" contain all image shares and share result images. The following screenshot is from the homomorphic pixel subtraction demo.


Homomorphic Image Subtraction
Original Pixel Subtraction
-
=
Shamir Secret Sharing Pixel Subtraction
-
=> Lagrange Interpolation =>

In this scenario, the user selected one image of a circle containing a cube and one of the same circle, but empty. Original pixel subtraction produced the image on the right side of the equal sign in the top portion of the GUI. Image shares were then generated and the subtraction operation was performed on each pair. Following reconstruction, the resulting image can be seen in the bottom righthand side of the interface. If the process worked correctly, the two result images should be identical.

Applications Used

Application	**Usage**
Notepad++	Webpage development
IntelliJ IDEA Community Edition	Encryption programs
GitHub.com	Website hosting

Conclusions

Throughout the development of this project, I found that the most difficult homomorphic encryption process to implement was for the image data type. This is not only due to the need for encrypting large quantities of pixel values but also the program's need to access and write to external files. With regards to execution time, image encryption also took the largest amount of time to complete out of the three data types described in this paper. This project serves as proof that Shamir's Secret Sharing Scheme possesses homomorphic properties that allow for operations to be performed on the encrypted versions of data without the need of decryption, preserving its integrity.

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