Design and Implementation of Plug-ins for JCrypTool

Visualization of the Merkle-Hellman Algorithm and of Hash Sensitivity
Diploma thesis by Ferit Dogan
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Declaration

I hereby declare that this Diploma thesis is my original work and it has been written by me in its entirety. I have acknowledged all the sources of information which have been used in the thesis.

Darmstadt, 10th March 2015

(Perit Dogan)
Conventions

For a better understanding, there are some typographical conventions that are followed in this Diploma thesis.

- **Courier** - Code examples, class, method and file names
- **Bold** - Name of the user interface elements such as menus, buttons, input boxes, window titles and plug-in names.
- **Italic** - Formulas and mathematical constructs.

This diploma thesis was written entirely in \LaTeX. For the external layout the corporate design of the Technical University of Darmstadt was chosen. Served for the internal structure of the thesis the following literature: [MG00], [Kop00] and [Kna04]. For the design of Eclipse plug-ins we used the books [EC09] and [DG03].

Abbreviations

- GUI = Graphical User Interface
- IDE = Integrated Development Environment
- JCT = JCrypTool
- OSGi = Open Service Gateway initiative
- RCP = Rich Client Platform
- UI = User Interface
Abstract

JCrypTool is the Java and Eclipse Rich-Client-Platform (RCP) based cryptography e-learning platform. Developed as an open-source project, it enables students, teachers, developers, and anyone else interested in cryptography to apply and analyze cryptographic algorithms in a modern, easy-to-use application. Its aim is to create a new form of e-learning by not just encouraging users to learn about cryptography and apply the algorithms themselves, but also to develop their own cryptographic plug-ins and extend the JCrypTool platform in new directions. JCrypTool already includes a wealth of cryptographic mechanisms including classic, symmetric, and asymmetric encryption, hash functions, analysis tools, visualizations, and crypto games.

This diploma thesis describes the design and the implementation of two plug-ins, Visualization of the Merkle-Hellman Algorithm and of Hash Sensitivity for the JCrypTool framework. The Merkle-Hellman algorithm is an asymmetric encryption scheme based on the knapsack problem, developed by Ralph Merkle and Martin Hellman in 1978. Hash Sensitivity considers some hash functions such as MDS, SHA etc. The aim of this thesis is to implement suitable visualizations for both topics.

1 https://www.cryptool.org/en/jcryptool-en
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1 Introduction

This diploma thesis describes the design and the implementation of two plug-ins, Merkle-Hellman and Hash Sensitivity, for the e-learning platform JCrypTool (JCT)¹. JCrypTool is a cryptographic e-learning platform, which offers visualizations of various cryptographic algorithms. It is used in schools and at universities by students, teachers and cryptography interested persons to understand the functionality of cryptographic algorithms. It is an open-source project that bases on Eclipse Rich-Client-Platform². JCrypTool also provides the opportunity to implement new plug-ins to add new functionalities to the JCrypTool platform. The head of this project is Prof. Bernhard Esslinger from the University of Siegen.

The goal of this diploma thesis is to implement two adequate visualizations of the above named algorithms for JCrypTool, so that the users are supported in understanding these cryptographic methods better, and can do self-studies and experiments with the according algorithms and their intentions. Both plug-ins and their online documentation are implemented in both English and German.

In this chapter we explain the functionality of RCP and show how you can create/develop a plug-in. In the chapters 2 - 3 the plug-ins are demonstrated and in chapter 4 we finish our thesis with an outlook.

1.1 The JCrypTool Project

With the help of JCrypTool users can get a better overview and faster understanding of cryptographic functions such as symmetric/asymmetric cryptographic systems, (public/private) key generation, encryption/decryption, hash functions, and cryptanalysis of systems. They even can implement their own games at this project. The goal of the JCrypTool project is to make users aware of how cryptography can help against network security threats and to explain the underlying concepts of cryptology. The software JCT is available in English and German. It runs on the operating systems Windows, Linux and MacOS.

The JCrypTool consists of two parts: JCrypTool Core³ and JCrypTool Crypto⁴. The Core project contains the editors (Hex and text), the views (Crypto-Explorer view and Action view), the logging, the help, cryptographic functions and crypto providers (FlexiProvider and Bouncy Castle). The Crypto project contains new cryptographic plug-ins in the categories algorithms, analyses, games, and visualizations.

1.2 Eclipse Rich Client Platform

Eclipse RCP is a platform for software developments, which was created in 2004 from the Eclipse IDE⁵ and additionally includes common ingredients. The components of the backbone include the workbench structure, user interface, extensible plug-in system, the aid component and the update manager. These modules enable developers to implement their own application functions in a simple way. Since June 26th, 2013 Eclipse is available in version 4.3 as Kepler release. For the implementation of the plug-ins for this diploma thesis the Kepler release was used, but as a target platform version 3.7 was used which serves as the basis for the current version JCrypTool. The creation of an RCP application consists of the following basic components:

- OSGi⁶ specifies a Java runtime environment that enables the execution of modules (so-called bundles or plug-ins). Eclipse implements this specification with Eclipse Equinox. Eclipse applications consist of a variety of plug-ins that run in Equinox.
- Eclipse Core Runtime provides the not UI⁷ related functionalities for Eclipse applications. Among others, the life cycle of Eclipse applications is managed so that it is responsible for the start and initialization of applications.
- Standard Widget Toolkit (SWT) is the UI toolkit developed by the Eclipse platform and provides the native UI widgets such as layouts and components (buttons, text entry fields, tables, ...) of the operating system for the construction of an application with a graphical user interface.

¹ JCT: JCrypTool – http://www.cryptool.org/de/jcryptool
³ https://github.com/jcryptool/core
⁴ https://github.com/jcryptool/crypto
⁵ IDE: integrated development environment
⁶ OSGi: Open Service Gateway initiative
⁷ UI: User Interface
• JFace provides the functionalities that are needed to fill the UI widgets that are provided by SWT with data from Java model objects.

1.3 Setting up the development environment

JCrypTool was originally hosted at Sourceforge\(^8\) as Subversion\(^9\) repository. Due to the increasing popularity of the version management program GIT\(^10\) it was decided to migrate to GIT. Thus, since August 11th, 2011 the source code of JCrypTool is available on GitHub\(^11\) as a GIT repository. GIT, in comparison to SVN, has the advantage that you can also check in your changes offline. In order to integrate JCrypTool into the development environment you have to check out both the Core and the Crypto project of JCrypTool. Because this diploma thesis deals with the visualization of algorithms you can check out the Core project as read-only. For the Crypto project you must have permission for this repository to check in your changes; this is in turn controlled by the JCrypTool team. To check out the source code from GitHub now you can go into Eclipse Git Repository Exploring perspective and select \textit{Clone a Git repository}. Now you can select the URL and switch with \textit{Next} to the next screen, where you can get your login information, as shown in Figure 1.1 and enter them to check out the Master branch of the repository.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{git.png}
\caption{Check out the Crypto project of JCrypTool}
\end{figure}

After the checkout is completed, you must still import the projects into the Eclipse workspace. For this, you click with the right mouse button on the repository and select \textit{Import Projects...}. With \textit{Import existing projects} you can integrate all existing projects of the repository into the workspace. In order to check in/out changes flexibly you should create a new branch with \textit{Switch To – New Branch...}. This allows for a simpler handling of the commits when you merge into the master branch later. The same procedure must be done for the JCrypTool Core project to set up all the necessary resources locally. In Conclusion you should still include the target platform, which is included in the project \texttt{org.jcryptool.product}, so that you can directly develop against it. For this you go into the Eclipse Preferences and change the target platform by selecting the file \texttt{jcryptool.target} and confirm with \textit{OK}. The file \texttt{jcryptool.product} which is in the project \texttt{org.jcryptool.product} can now be executed to start JCrypTool.

\begin{itemize}
\item \texttt{http://sourceforge.net}
\item Subversion (SVN) version control software – \texttt{http://subversion.apache.org/}
\item \texttt{http://git-scm.com}
\item GitHub is a web hosting service for software development projects.
\end{itemize}
2.1 Merkle-Hellman algorithm

As the Merkle-Hellman algorithm is based on the subset sum problem it is helpful to bring some definitions from the subset sum problem. For this problem first we define the term knapsack vector. A knapsack vector consists of a set $A$ which contains positive and pairwise different integers: $A = (a_1, a_2, ..., a_n), a_i \neq a_j$ if $i \neq j$. For our algorithm we need a superincreasing vector which requires that the set $A$ consists of positive and pairwise different integers.

In the following, we explain what the subset sum problem is: The subset sum problem is an important problem in cryptography which is also described as a special case of the knapsack problem. It is NP-complete this means there is no polynomial algorithm to solve it. We denote here two aspects for the following description: Known and Unknown.

**Known:** A knapsack vector $A = (a_1, a_2, ..., a_n)$ and the sum $s$ that is a positive integer.

**Unknown:** Is there a subset $A'$ of $A$ with $\sum a' \in A'(a') = s$, or equivalent: Does there exist a vector $X = (x_1, x_2, ..., x_n), x_i$ in $(0, 1)$, with $A*X = s$?

$A*X$ is defined as: $a_1 * x_1 + a_2 * x_2 + ... + a_n * x_n$

The problem described in Unknown is called decision problem. To get a solution the following task must be computed: $X = (x_1, x_2, ..., x_n), x_i$ in $(0, 1)$ such that $A*X = s$ The functional problem of a knapsack vector $A$ together with a sum $s$ is given as $(A, s)$.

Now we give a small example for the subset sum problem: $A$ is the set with the following elements $A = (8, 7, 20, 32, 13)$ and the sum $s$ is 40. A possible solution for $(A, 40)$ is illustrated by the vector $X = (1, 0, 0, 1, 0)$ then $A*X = a_1 + a_4 = 8 + 32 = 40$. The corresponding subset is $A' = (8, 32)$. This solution is not the only one for our example, there may be several solutions for $(A, 40)$ as $X = (0, 1, 1, 0, 1)$ with the subset $A' = (7, 20, 13)$.

### 2.1.1 Key generation

In general for the communication of this algorithm we need two keys, the public key only for encryption and the private key only for decryption. In Merkle-Hellman, the keys are two knapsack vectors. The public key is a hard knapsack $A$, and the private key is an easy, or superincreasing, knapsack $B$. At first we start to fix the elements of $A$ with the parameter $n$ which defines the size of the message to be encrypted. $B$ has the same length as $A$. Then we pick a superincreasing set $A = (a_1, ..., a_n)$. With the term superincreasing we mean that each element of the set is greater than the sum of all the elements before it. In next step the modulus $M$ gets chosen that is an integer with the property $M > \sum_{i=1}^{n} a_i$. Now the multiplier $W$ is chosen so that $\gcd(M, W) = 1$ and $1 \leq W < M$. $W$ effects the computation of the inverse element as $U := U*W = 1$ (mod M). Then the elements of the public key $B$ are calculated by the following formula: $B_i = (A_i * W) \mod M$ for $i = 1, ..., n$. At last we get the public key $B$ and the private key $(A, M, W)$ as a tuple.

### 2.1.2 Encryption

Before we can start to encrypt a message whose length is defined by the parameter $n$ it can be necessary that a large message $m$ must be divided into $n$-bit blocks. Now $m = (m_1, m_2, ..., m_n)$ is the binary message that we encrypt. We get the ciphertext $c$ by calculating as follows: $c = b_1 * m_1 + b_2 * m_2 + ... + b_n * m_n = m * B$. If the $i$-th bit of $m$ is 1 $c$ takes the $i$-th element of $B$. 

1976 Whitfield Diffie and Martin Hellman presented a new concept in cryptography, the so-called public-key cryptography. Two years later, 1978, Ralph Merkle and Martin Hellman released their cryptosystem: The Merkle-Hellman algorithm is an asymmetric cryptosystem which bases on the knapsack problem/subset sum problem [RM78]. It was also an alternative idea to RSA. 1983 Adi Shamir and Richard Zippel broke this cryptosystem [Sha84].
2.1.3 Decryption

For the decryption of the ciphertext $c$ two steps must be done. The first step is to compute the equation $c' = U \ast c \mod M = W^{-1} \ast c \mod M$. As next step $(A, c')$ is to solve. It is a required condition that $A$ must be a superincreasing set for the solution.

2.2 Mathematical description

Here, we go more into the details of the mathematical description. After that, we will present an example to understand the algorithm better.

2.2.1 Key generation

To encrypt $n$-bit messages, first we fix a knapsack vector $A$ which contains positive and pairwise different integers.

$$A = (a_1, a_2, ..., a_n)$$

Then a random integer $M$ is chosen as follows

$$M > \sum_{i=1}^{n} a_i,$$

A random integer $W$ is picked, such that $\gcd(W, M) = 1$ (i.e. $W$ and $M$ are coprime). This side condition is important because coprimeness guarantees the existence of $B$ that allows the decryption.

As next step we compute the sequence $B$

$$B = (b_1, b_2, ..., b_n)$$

where

$$B_i = W \ast a_i \mod M$$

The public key is $B$ and the private key is $(A, M, W)$.

2.2.2 Encryption

To encrypt an $n$-bit message $m$

$$m = (m_1, m_2, ..., m_n)$$

where $m_i$ is the $i$-th bit of the message and $m_i \in \{0, 1\}$, compute

$$c = \sum_{i=1}^{n} m_i b_i$$

The ciphertext is $c$. 
2.2.3 Decryption

To decrypt a ciphertext $c$, we firstly calculate $c'$ as follows:

$$c' = U \ast c \mod M = W^{-1} \ast c \mod M$$

Here we need the inverse element $U$ which is:

$$W \ast U = 1 \mod M$$

We use Extended Euclidean algorithm to get $U$.

After that we start to solve $(A, c')$:

$$c' = \sum_{i=1}^{n} m_i a_i \mod M$$

Now we pick the largest element of $A$ denoted by $a_l$. If $a_l > c'$ then $m = 0$, if $a_l \leq c'$ then $m = 1$. Then we subtract $lm_i$ from $c'$ till we get 0.

2.2.4 Example

To demonstrate the functionality of the Merkle-Hellman algorithm we need first a superincreasing sequence $A$ for the private key $(A, M, W)$. We choose the following sequence

$$A = \{24, 34, 65, 141, 308\}.$$  

Now we calculate the sum of the superincreasing sequence.

$$\sum A = 572$$

Then we choose a number $M$ that is greater than the sum.

$$M = 900$$

Next step is to pick a number $W$ that is in the range $[1, M)$ and is coprime to $M$.

$$W = 541$$

The private key contains the elements $M, A$ and $W$.

For the calculation of the public key we multiply each element in $A$ by $W \mod M$. So we get the following sequence

$$B = \{384, 394, 65, 681, 128\}$$

because of

$$b_1 := a_1 \ast W \mod M = 24 \ast 541 \mod 900 \equiv 384$$
$$b_2 := a_2 \ast W \mod M = 34 \ast 541 \mod 900 \equiv 394$$
$$b_3 := a_3 \ast W \mod M = 65 \ast 541 \mod 900 \equiv 65$$
$$b_4 := a_4 \ast W \mod M = 141 \ast 541 \mod 900 \equiv 681$$
$$b_5 := a_5 \ast W \mod M = 308 \ast 541 \mod 900 \equiv 128$$
Our public key is now the sequence \( B \).

For the encryption we choose the message \( m = 22 \) with the condition to be in the range \([1, 32)\). The open upper bound for \( m \) depends on \( A \) which is part of the private key. This upper bound \( UB \) is defined by the number of elements of \( A \): \( UB < 2^{|A|} \). In our example \( A \) has five elements, so \( m \) can be between 0 and 31. The binary representation of \( m \) is 10110.

Now we multiply each respective bit by the corresponding number in \( B \). If the bit is 1 then we add the previous value in the iteration otherwise not.

\[
\begin{align*}
    m_1 := 1 & \Rightarrow 1 \times 384 + 0 = 384 \\
    m_2 := 0 & \Rightarrow 0 \times 394 + 384 = 384 \\
    m_3 := 1 & \Rightarrow 1 \times 65 + 384 = 449 \\
    m_4 := 1 & \Rightarrow 1 \times 681 + 449 = 1130 \\
    m_5 := 0 & \Rightarrow 0 \times 128 + 1130 = 1130 \\
\end{align*}
\]

We get the cipher \( c = 1130 \) for the message \( m = 22 \).

To decrypt the cipher \( c = 1130 \) we first have to calculate \( c' = c \times W^{-1} \mod M \). We use the Extended Euclidean algorithm for the inverse of \( W \). In our example the inverse of \( W \) is 361. Now we can insert the values into the equation and get the following

\[
c' = c \times W^{-1} \mod M = 1130 \times 361 \mod 900 = 230
\]

For the decryption we use the private key \( A \). We decompose 230 by selecting the largest element in \( A \) which is less than or equal to 230. Then selecting the next largest element less than or equal to the difference, until the difference is 0. If it is not 0 then the text is trying to decrypt with a wrong key.

\[
230 := 230 - 141 - 64 - 24 = 0
\]

\[
\begin{array}{cccc}
1 & 0 & 1 & 1 \\
24 & 34 & 65 & 141 & 308 \\
24 & 0 & 65 & 141 & 0 \\
\hline
\text{sum: } & 230
\end{array}
\]

The elements which we select from our private key correspond to the 1 bits in the message 10110. When we convert from binary to decimal we get the plaintext 22.
2.3 The design of the plug-in

In this section we want to go into the design of the Merkle-Hellman plug-in. The user interface of the plug-in is created according to the GUI Guideline [JCT12] of JCrypTool. Thereby, the usability of the plug-in is important because it is our goal to guide the user through the algorithm and not simply to present the final result. To achieve our aim we select suitable presentation forms for the individual steps of the algorithm. The end result and the used lines of each table are highlighted. This action is helpful for a better overview.

For those who do not know the algorithm some sample values have been pre-assigned, so the users can start directly with the algorithm. The Merkle-Hellman plug-in and its components are schematically shown in figure 2.1. The numbers in this figure are related to the steps a user has to perform in the GUI. These numbers from the GUI and the according attributes are described in table 2.1 and 2.2:

- **Type**: The SWT-Widget element.
- **Initial state**: The initial state of the Widget (enabled or disabled).
- **Text**: The name of the used Widget.
- **Description**: Description of the Widget.

![Figure 2.1: Merkle-Hellman plug-in and the numbers of the behavioral description](image-url)
<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Initial state</th>
<th>Text</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>StyledText</td>
<td>disabled</td>
<td>see figure 2.1</td>
<td>Description of the algorithm (dynamic).</td>
</tr>
<tr>
<td>2</td>
<td>Group</td>
<td>enabled</td>
<td>Key generation</td>
<td>Includes entry fields for user input of private and public keys.</td>
</tr>
<tr>
<td>2.1</td>
<td>Combo</td>
<td>enabled</td>
<td>4</td>
<td>In this place the user can choose the number of elements (</td>
</tr>
<tr>
<td>2.2</td>
<td>Combo</td>
<td>enabled</td>
<td>32</td>
<td>In this place the user can choose the start value.</td>
</tr>
<tr>
<td>2.3</td>
<td>Button</td>
<td>enabled</td>
<td>Generate private key</td>
<td>To generate a private key. By clicking on the button, the generated values will be shown in the entry fields under the name Private key A.</td>
</tr>
<tr>
<td>2.4</td>
<td>Group</td>
<td>enabled</td>
<td>see figure 2.1</td>
<td>In this place the private key parts will be shown as entry fields. The values in the fields can be changed by the user. The number of elements of B is independent of the value in 2.1. By outsize the scroll bar appears.</td>
</tr>
<tr>
<td>2.5</td>
<td>Textfield</td>
<td>enabled</td>
<td>the value(M)</td>
<td>This value is either generated by clicking on the Generate private key button or can be entered by user. The condition is that M &gt; SUM(A(i)).</td>
</tr>
<tr>
<td>2.6</td>
<td>Textfield</td>
<td>disabled</td>
<td>the value of SUM(A(i))</td>
<td>This value will be calculated based on the private key parts in 2.4, and cannot be changed via user entry.</td>
</tr>
<tr>
<td>2.7</td>
<td>Textfield</td>
<td>enabled</td>
<td>W</td>
<td>This value is either generated by clicking on the Generate private key button or can be entered by user. The condition is that ( \text{ggT}(M, W) = 1 ) and ( 1 \leq W &lt; M ).</td>
</tr>
<tr>
<td>2.8</td>
<td>Textfield</td>
<td>disabled</td>
<td>the value of U</td>
<td>This value will be calculated based on the condition ( W \cdot U = 1 \mod M ) and cannot be changed via user entry.</td>
</tr>
<tr>
<td>2.9</td>
<td>Label</td>
<td>enabled</td>
<td></td>
<td>This shows the condition for the public key parts (B(i)) based on the value of the number of elements (</td>
</tr>
<tr>
<td>2.10</td>
<td>Button</td>
<td>enabled</td>
<td>Generate public key</td>
<td>To generate a public key. By clicking on the button, the generated values will be shown in the disabled entry fields under the name Public key B. The group Key generation will be disabled and Encryption enabled.</td>
</tr>
<tr>
<td>2.11</td>
<td>Group</td>
<td>disabled</td>
<td>see figure 2.1</td>
<td>In this field the public key parts will be shown as disabled entry fields. The number of the parts are independent of the value in 2.1. By outsize the scroll bar appears.</td>
</tr>
</tbody>
</table>

<p>| Table 2.1: The behavioral description of the Merkle-Hellman plug-in – part 1 |</p>
<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Initial state</th>
<th>Text</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Group</td>
<td>disabled</td>
<td>Encryption</td>
<td>Includes entry field and the table for the encryption iterations.</td>
</tr>
<tr>
<td>3.1</td>
<td>Textfield</td>
<td>disabled</td>
<td>empty</td>
<td>This field will be enabled by clicking on the <strong>Generate public key</strong> button. In this place the user enters the message ((m)). The condition is that the value is between 0 and (2^n) number of the elements (</td>
</tr>
<tr>
<td>3.2</td>
<td>Textfield</td>
<td>disabled</td>
<td>see figure 2.1</td>
<td>The value for the condition of the message. This will be calculated based on the number of elements (</td>
</tr>
<tr>
<td>3.3</td>
<td>Textfield</td>
<td>disabled</td>
<td>empty</td>
<td>This field visualizes the binary code of the message((m)) dynamically.</td>
</tr>
<tr>
<td>3.4</td>
<td>Table</td>
<td>disabled</td>
<td>empty</td>
<td>The table consists of 3 columns. They shows the Iterations, the (m(i))s and the equations of calculation of the ciphertext.</td>
</tr>
<tr>
<td>3.5</td>
<td>Textfield</td>
<td>disabled</td>
<td>empty</td>
<td>In this place the ciphertext will be shown after the calculation</td>
</tr>
<tr>
<td>3.6</td>
<td>Button</td>
<td>disabled</td>
<td>Encrypt</td>
<td>By clicking on the button the ciphertext will be calculated and the iterations of calculation will be shown in the table.</td>
</tr>
<tr>
<td>4</td>
<td>Group</td>
<td>disabled</td>
<td>Decryption</td>
<td>Includes entry field and the table for the decryption iterations.</td>
</tr>
<tr>
<td>4.1</td>
<td>Textfield</td>
<td>disabled</td>
<td>empty</td>
<td>This field will be enabled by clicking on the <strong>Encrypt</strong> button. The ciphertext will be taken in the field or user can enter a ciphertext.</td>
</tr>
<tr>
<td>4.2</td>
<td>Textfield</td>
<td>disabled</td>
<td>M</td>
<td>After the decryption of the message((m)), in this field M gets shown.</td>
</tr>
<tr>
<td>4.3</td>
<td>Textfield</td>
<td>disabled</td>
<td>empty</td>
<td>This field visualizes the binary code of the ciphertext((c)) dynamically.</td>
</tr>
<tr>
<td>4.4</td>
<td>Table</td>
<td>disabled</td>
<td>empty</td>
<td>The table consists of 2 columns. They shows the Iterations and the equations of calculation of the message.</td>
</tr>
<tr>
<td>4.5</td>
<td>Textfield</td>
<td>disabled</td>
<td>empty</td>
<td>In this field the message gets shown after the calculation</td>
</tr>
<tr>
<td>4.6</td>
<td>Button</td>
<td>disabled</td>
<td>Decrypt</td>
<td>By clicking on the button the message will be calculated and the iterations of calculation will be shown in the table.</td>
</tr>
<tr>
<td>5</td>
<td>Icon</td>
<td>enabled</td>
<td>see figure 2.1</td>
<td><strong>Restart</strong> icon: By clicking on this button, all user input and results will be deleted. The initial state of the plug-in will be restored. If you move the mouse over the icon, a tooltip <strong>Restart</strong> will be shown.</td>
</tr>
<tr>
<td>6</td>
<td>Icon</td>
<td>enabled</td>
<td>see figure 2.1</td>
<td><strong>Reset</strong> icon: By clicking on this button, the input fields for the private key will be enabled so that the user can enter new values for the private key. If you move the mouse over the icon, a tooltip <strong>Reset</strong> will be shown.</td>
</tr>
</tbody>
</table>

**Table 2.2:** The behavioral description of the **Merkle-Hellman** plug-in – part 2
2.4 The implementation of the plug-in

The plug-in is grouped in four packages:

- org.jcryptool.visual.merkleHellman
- org.jcryptool.visual.merkleHellman.algorithm
- org.jcryptool.visual.merkleHellman.handlers
- org.jcryptool.visual.merkleHellman.views

The package org.jcryptool.visual.merkleHellman contains the activator class MerkleHellmanPlugin which controls the whole lifecycle of the plug-in. This class is generated by the eclipse wizard. In the package org.jcryptool.visual.merkleHellman.handlers there are two classes RestartHandler and ResetHandler that implement the functionality in the menu bar. The class MerkleHellmanView is implemented in the package org.jcryptool.visual.merkleHellman.views which represents all the visualization of the plug-in. We would like first to describe the algorithm. The algorithm is implemented in the class MerkleHellman that is in the package org.jcryptool.visual.merkleHellman.algorithm. The class has the following attributes:

- int dim – number of the elements for the keys
- BigInteger[] privateKey – contains the private key elements
- BigInteger[] publicKey – contains the public key elements
- BigInteger M – modulus for the calculation
- BigInteger W – weight for the calculation
- BigInteger U – is the inverse of W mod M

The constructor of the class is shown in listing 2.1.

```java
public MerkleHellman(int n) {
    this.dim = n;
    this.privateKey = new BigInteger[n];
    this.publicKey = new BigInteger[n];

    for (int i = 0; i < this.dim; i++) {
        this,privateKey[i] = BigInteger.ZERO;
        this.publicKey[i] = BigInteger.ZERO;
    }
}
```

**Listing 2.1: Constructor of the class MerkleHellman**

As parameter you hand over the number of the elements for the private and public key. The private and public keys are an array of type BigInteger and they are initialized with zero. The class has a static method public static BigInteger randomNumber(BigInteger min, BigInteger max) which returns a random number in the range from min to max. The implementation of the method is shown in listing 2.2. First we check if the max value is smaller than the min value. If so we switch the max and min values. If both values are equal then we return the min value. We determine the bit length of the range and generate a BigInteger result of these length. If this value is out of the range so if the value of result is bigger then the bit length of the range then we generate a new value and assign it to result. At last we add the min value and return result.

```java
public static BigInteger randomNumber(BigInteger min, BigInteger max) {
    if (max.compareTo(min) < 0) {
        BigInteger tmp = min;
        min = max;
        max = tmp;
    }
    // Code to generate a BigInteger result
    // ...
    return result;
}
```

**Listing 2.2: Method randomNumber of class MerkleHellman**
To make the encryption and decryption work we need a superincreasing vector for the private key. To do that we use the method `public void getSuperInc(BigInteger start)` which generates us a superincreasing vector and store it in the class attribute array `privateKey`. The implementation of this method is shown in listing 2.3. It takes as parameter a `start` value which is only allowed for non negative `BigInteger` value. The start value is the first element of the sequence. First we determine the bit length of the `start` value. Then we shift left the number one by the bit length of the `start` value and store it in the variable `t`. For the other key elements we iterate over the number of the key elements, save the sum of the key elements in the variable `sum` and generate each key element using the method `randomNumber(min, max)` which we have explained before. As `min` parameter we use the maximum of the variable `t` and the `sum` of the previous key elements incremented by one. The `max` parameter is the bit length left shifted by one and substracted by one. In each iteration we shift left the variable `t` by one. So we guarantee that the private key elements are superincreasing.

```java
public void getSuperInc(BigInteger start) {
    if (start.compareTo(BigInteger.ZERO) <= 0)
        return;
    /* t is the bit length of start */
    BigInteger t = BigInteger.valueOf(start.bitLength());
    t = BigInteger.ONE.shiftLeft(t.intValue());
    this.privateKey[0] = start;
    BigInteger sum = getPrivateKeyElement(0);

    /* choose set[i] to be a (t+i)−bit number so that set[i] > sum */
    for (int i = 1; i < dim; i++) {
        this.privateKey[i] = randomNumber(sum.add(BigInteger.ONE).max(t),
            (t.shiftLeft(1).subtract(BigInteger.ONE)));
        sum = sum.add(this.getPrivateKeyElement(i));
        t = t.shiftLeft(1);
    }
}
```

Listing 2.3: Generation of a superincreasing vector

The method `public void setM()` which generates a modulus for a given private key is shown in listing 2.4. First, we determine the bit length of the last key element and store it in the variable `t`. Then we shift left a number one by this bit length to get the next bigger potency of two and store it in `t` again. This value we use to calculate the maximum of this value and the sum of the private key elements incremented by one as `min` parameter for the method `randomNumber`. As `max` parameter we shift left the value `t` substracted by one. So we guarantee that the modulus `M` is a random number and is bigger than the sum of the private key elements.

```java
public void setM() {
    /* t is the bit length of last element in super increasing sequence */
    BigInteger t = BigInteger.valueOf(this.privateKey[dim - 1].bitLength());
```
The method `public void setW()` is calculating the weight \( W \) and the variable \( U \) which we need for the decryption. First, we check if the modulus \( M \) is zero. If so then we have to generate a new modulus with `setM()`. After that we generate a random number \( w \) in the range from two to modulus \( M \) minus two. The greatest common divisor is calculated with \( d = w.gcd(this.M) \) and stored in \( d \). Now we iterate in a loop until the condition \( d.compareTo(BigInteger.ONE) != 0 \) becomes true. In the loop we divide \( w \) by \( d \) and calculate \( d \) again. Finally we determine the weight \( W \) by dividing \( w \) by the \( gcd(w,M) \) with the statement \( this.W = w.divide(w.gcd(this.M)) \). The variable \( U \) is at last the multiplicative inverse of \( W \) modulus \( M \) with the statement \( this.U = w.modInverse(this.M) \). The source code of the method is shown in listing 2.5.

### Listing 2.4: Generation of a modulus for a given private key

```java
int t = BigInteger.ONE.shiftLeft(t.intValue());
/* choose M to be a 2^t bit number with M > SUM(Ai) */
this.M = randomNumber(getSum().add(BigInteger.ONE).max(t),
    (t.shiftLeft(1).subtract(BigInteger.ONE)));
```

### Listing 2.5: Generation of the weight

```java
public void setW() {
    if (this.M.compareTo(BigInteger.ZERO) == 0)
        setM();
    
    BigInteger w = randomNumber(new BigInteger("2"), this.M.subtract(new BigInteger("2")));
    BigInteger d = w.gcd(this.M);
    
    while (d.compareTo(BigInteger.ONE) != 0) {
        w = w.divide(d);
        d = w.gcd(this.M);
    }
    
    this.W = w.divide(w.gcd(this.M));
    this.U = w.modInverse(this.M);
}
```

### Listing 2.6: Generation of the public key

The method `public void createPublicKeys()` is used to generate the public key. Each public key element is calculated in which each private key element is multiplied by the weight \( W \) modulus \( M \). The listing is shown in 2.6.

```java
public void createPublicKeys() {
    for (int i = 0; i < dim; i++) {
        setPublicKeyElement(i, this.W.multiply(this.privateKey[i]).mod(this.M));
    }
}
```

### Listing 2.7: Encryption

For the encryption we use the method `public BigInteger encrypt(BigInteger plain)` that is shown in listing 2.7. The method takes a plaintext of type `BigInteger` and returns the corresponding ciphertext `chiffre`. First, we initialize `chiffre` with zeros. We store the number of key elements in the variable \( n \). Then, we use another variable \( s \), initialize it with one and shift it left by the variable \( n \) to multiply it with \( n * 2 \).

Now we iterate in a loop to calculate for each bit in the plaintext to add the corresponding public key elements to the `chiffre` text. We add the public key element only if the bit in the plaintext is one otherwise we skip the addition. To determine if the bit in the plaintext is one we use the `add` method with the variable \( s \) which we shift right in every iteration.

```java
public BigInteger encrypt(BigInteger plain) {
    BigInteger chiffre = BigInteger.ZERO;
    int n = this.dim - 1;
    BigInteger s = BigInteger.ONE;
    ```
s = s.shiftLeft(n);

boolean b;
for (int i = 0; i < this.dim; i++) {
    b = false;
    if (plain.and(s).compareTo(BigInteger.ZERO) != 0)
        b = true;
    if (b) {
        chiffre = chiffre.add(this.getPublicKeyElement(i));
    }
    s = s.shiftRight(1);
}
return chiffre;

Listing 2.7: Encryption of a plaintext

In the package org.jcryptool.visual.merkleHellman.views we have the class MerkleHellmanView which describes all the graphical interface and the user interaction of the plug-in. There are two drop-down menus where you can choose the number of key elements and a start value as you can see in figure 2.1. When the plug-in is loaded by default a private key and all needed components to perform the algorithm are generated. For that the method private void generatePrivateKey(int numberOfElements, int startValue) is used that is shown in 2.8. As start value there will be a random number generated between $\left\lfloor \frac{\text{start}}{2} \right\rfloor$ and start value which can be chosen in the drop-down menu.

private void generatePrivateKey(int numberOfElements, int startValue) {
    BigInteger startVal = BigInteger.valueOf(startValue);
    privKey = new MerkleHellman(numberOfElements);
    privKey.createPrivateKeys(MerkleHellman.randomNumber(startVal.shiftRight(1), startVal));

    for (int i = 0; i < privateKeyFields.size(); i++) {
        privateKeyFields.get(i). setText(String.valueOf(privKey.getPrivateKeyElement(i)));
    }

    textM.setText(String.valueOf(privKey.getM()));
    textSumA.setText(String.valueOf(privKey.getSum()));
    textU.setText(String.valueOf(privKey.getU()));
    textW.setText(String.valueOf(privKey.getW()));
}

Listing 2.8: Generation of the sample private key

When you change the values of the Number of private key elements or the start drop-down menu new private keys are dynamically generated. You can also click on the button Generate private key to generate new private keys. If you use the automatically generated way all conditions are fulfilled and you can click the button Create public key. When you change some values - all changeable fields are enabled and editable - then all conditions for the algorithm have to be checked while you are clicking the button Create public key. The calculation is only executed when not all fields are empty. There are four conditions that have to be checked:

1. Private key values have been changed and $W$ or $M$ values have not been changed.
2. Private key values have not been changed and $W$ or $M$ values have been changed.
3. Private key values have been changed and $W$ or $M$ values have been changed.
4. No values have been changed.
In the first case only the private key values have to be updated. For that we use the method `public void updatePrivateKey(BigInteger[] keys)` of the class `MerkleHellman` which assigns the new entered key to the algorithm and calculates the attribute $M$ and $W$. The implementation is shown in listing 2.9. If the new entered private key values are not a superincreasing vector then a warning dialog appears. The user can accept the values by clicking the Ok button. In this case the algorithm might not work correctly because this condition is necessary for the uniqueness of the decryption.

```
public void updatePrivateKey(BigInteger[] keys) {
    this.privateKey = keys;
    this.setM();
    this.setW();
}
```

Listing 2.9: Update private key

In the second case only the values for $M$ or $W$ have been changed. In this case three things have to be checked. First, $M$ has to be bigger as the sum of the private keys. If not an error dialog is shown for the user. Secondly, $W$ has to be smaller than $M$. If not again an error dialog is shown. And at last the greatest common divisor of $M$ and $W$ has to be one. If none of these three cases are violated the new values for $M$ or $W$ are set for the algorithm.

In the third case both conditions private key and $M$ or $W$ are violated. Now we check if the private key is a superincreasing vector, if $M$ is bigger as the sum of the private key, $W$ is smaller then $M$ and if the the greatest common divisor of $M$ and $W$ has to be one. If none of these conditions are violated then we update the private key values and assign the new values for $M$ and $W$ for the algorithm.

In the fourth case no values are changed so no extra handling is needed. We create the public key by executing the method `public void createPublicKeys()` in class `MerkleHellman`. The implementation is shown in listing 2.6. The public key elements are created by multiplying the corresponding private key element with the weight $W$ modulus $M$.

Now that the private and public key are created, the user can enter a message into the corresponding field. While the user enters a value for the message the binary representation of the value is dynamically calculated and displayed below. For the input message there are only values between $0$ to $2^{number\ of\ key\ elements}$ allowed. To guarantee this we use a `ModifyListener` which is shown in listing 2.10. First we instanciate a `BigInteger` with `BigInteger a = new BigInteger(message.getText())` and store the binary representation in a variable `bitRepresentation` with `String bitRepresentation = a.toString(2)`.

Now we check if the length of `bitRepresentation` is smaller than `numberOfElements`. If so we have to add leading zeros to the bit representation. We determine the number of leading zeros with `int counter = numberOfElements - bitRepresentation.length()` and iterate over the variable `counter` to append the leading zeros with `sb.append("0")` to the resulting `StringBuilder sb`. Otherwise when the `bitRepresentation` is not smaller than `numberOfElements` we don’t need leading zeros and can append the `bitRepresentation` directly to the `StringBuilder sb`. When a valid message is entered the button Encrypt will be activated.

```
public void modifyText(ModifyEvent e) {
    if (e.getSource() instanceof Text) {
        Text message = (Text) e.getSource();
        if (message.getText().compareTo("") != 0) {
            int numberOfElements = Integer.parseInt(comboKeyElements.getText());
            BigInteger a = new BigInteger(message.getText());
            String bitRepresentation = a.toString(2);
            StringBuilder sb = new StringBuilder();

            if (bitRepresentation.length() <= numberOfElements) {
                int counter = numberOfElements - bitRepresentation.length();
                for (int i = 0; i < counter; i++) {
                    sb.append("0");
                }
            }
        }
    }
}
```

textM_encryption.addModifyListener(new ModifyListener() {
    @Override
    public void modifyText(ModifyEvent e) {
        if (e.getSource() instanceof Text) {
            Text message = (Text) e.getSource();
            if (message.getText().compareTo("") != 0) {
                int numberOfElements = Integer.parseInt(comboKeyElements.getText());
                BigInteger a = new BigInteger(message.getText());
                String bitRepresentation = a.toString(2);
                StringBuilder sb = new StringBuilder();

                if (bitRepresentation.length() <= numberOfElements) {
                    int counter = numberOfElements - bitRepresentation.length();
                    for (int i = 0; i < counter; i++) {
                        sb.append("0");
                    }
                }
            }
        }
    }
});
The user can start to encrypt by clicking the button Encryption. The implementation of the method is shown in listing 2.11. We iterate over the number of the key elements and add the calculation details into a table. The table consists of three columns. The first column represents the number of the iteration, the second column represents whether the bit of the message was used, and the third column represents the calculation details of the current iteration. The sum of all bits where the bit value is one is stored in the variable `String result` with the statement `String result = String.valueOf(privKey.encrypt(new BigInteger(textM_encryption.getText()))).` The encrypted message is also entered as input for the decryption. The private key elements, the value $M$ and $W$ are also editable for the decryption to have the possibility to perform the decryption with different keys.

```java
@Override
public void widgetSelected(SelectionEvent e) {
    int numberOfElement = Integer.parseInt(comboKeyElements.getText());
    String bitRepresentation = textBinaryM.getText();

    for (int i = 0; i < numberOfElement; i++) {
        StringBuilder sb = new StringBuilder();
        sb.append(String.valueOf(bitRepresentation.charAt(i)) + " * " + privKey.getPublicKeyElement(i) + " mod " + privKey.getM() + " = ");
        sb.append(new BigInteger(String.valueOf(bitRepresentation.charAt(i))).multiply(privKey.getPublicKeyElement(i)).mod(privKey.getM()));
        TableItem tmp = new TableItem(tableEncrypt, SWT.BORDER);
        tmp.setText(0, String.valueOf(i));
        tmp.setText(1, String.valueOf(bitRepresentation.charAt(i)));
        tmp.setText(2, sb.toString());
    }

    String result = String.valueOf(privKey.encrypt(new BigInteger(textM_encryption.getText())));
    tableEncrypt.setSelection(numberOfElement - 1);
    tableEncrypt.showSelection();

    textC_encryption.setText(result);
    textC_encryption.setEnabled(true);
    textC_decryption.setText(result);
    textC_decryption.setEnabled(true);
    textM_encryption.setEditable(false);
    btnEncrypt.setEnabled(false);
    btnDecrypt.setEnabled(true);

    styledTextDescription.setText(Messages.MerkleHellmanView_0000 + Messages.MerkleHellmanView_000);
```
The implementation of the decryption is shown in listing 2.12. Because the private key input fields are editable the same conditions as for the encryption must be checked. For the decryption we need to calculate $c' = c \times U \mod M$ and save the value in the variable $\text{BigInteger } cc$. Now we iterate over the number of the key elements starting from the last key element to the first. In the loop we compare the variable $cc$ with the private key element stored in variable $\text{tmpPrivateKeyElement}$. If $cc$ is equal or bigger than $\text{tmpPrivateKeyElement}$ then the private key value $\text{tmpPrivateKeyElement}$ is eligible for the calculation and we mark it in the table with a binary one. We subtract this value from $cc$ for the next iteration. Otherwise we mark the entry with a binary zero. No subtraction is needed. When we exit the loop we check if the binary string for encryption and decryption are equal. If so we color the field with the binary string green otherwise in red. After finishing the decryption it is possible for the user to enter another ciphertext and run the decryption again.

```java
@Override
public void widgetSelected(SelectionEvent e) {
    ...
    BigInteger c = new BigInteger(textC_decryption.getText());
    BigInteger U = privKey.getU();
    BigInteger M = privKey.getM();
    BigInteger cc = c.multiply(U).mod(M);
    textCC.setText(String.valueOf(cc));
    int numberOfElement = Integer.parseInt(comboKeyElements.getText());
    BigInteger tmpCC = cc;
    StringBuilder binResult = new StringBuilder();
    for (int i = numberOfElement - 1; i >= 0; i--) {
        StringBuilder sb = new StringBuilder();
        BigInteger tmpPrivateKeyElement = privKey.getPrivateKeyElement(i);
        if (tmpCC.compareTo(tmpPrivateKeyElement) >= 0) {
            sb.append("c' = " + tmpCC + " >= " + tmpPrivateKeyElement + " = A" + (i + 1) + ");
            sb.append(" ==> p(" + i + ") = 1. ");
            sb.append("c' = " + tmpCC + " - " + tmpPrivateKeyElement + " = " + (tmpCC - tmpCC.subtract(tmpPrivateKeyElement)));
            binResult.insert(0, "1");
        } else {
            sb.append("c' = " + tmpCC + " < " + tmpPrivateKeyElement + " = A" + (i + 1) + ");
            sb.append(" ==> p(" + i + ") = 0. ");
            sb.append("c' = " + tmpCC + " - 0" + " = " + (tmpCC = tmpCC.subtract(BigInteger.ZERO)));
            binResult.insert(0, "0");
        }
    }
    TableItem tmp = new TableItem(tableDecrypt, SWT.BORDER);
    tmp.setText(0, String.valueOf(i));
    tmp.setText(1, sb.toString());
}
```

Listing 2.11: Encryption of a message
The user can click on the button Restart or Reset in the menu bar at any time. The Restart button resets the view of the plug-in to the initial state so that the user can start from scratch. New private key values will be created. The Reset button resets the tables and the public keys, enables the input fields for the private key to give the user the possibility to change the values without generating new values.
2.5 The functionality of the plug-in

In this section we want to describe the functionality of the plug-in Merkle-Hellman. The plug-in can be started via the menu Visuals or via the crypto explorer tab Visuals.

![Merkle-Hellman plug-in](image)

The plug-in consists of a description field and three basic areas: Key generation, Encryption and Decryption. In the description field the corresponding statements about the algorithm are displayed dynamically, depending on which step of the algorithm the user is currently performing.

### 2.5.1 Key generation

This section summarizes the actions that are required to generate a private key and a public key. First of all the number of the elements for the private key and the initial start value must be selected from the drop-down boxes. By default, the number of elements for the private key is 4 and the start value is 32. The start value is needed for the generation of the first element of the private key $A(1)$. It will be used a random number in the range of $[\text{start value}/2 − \text{start value}]$. The number of the private key elements will be dynamically created depending on user selection.

![Key generation](image)
On this selection, the user can either use the automatically and randomly generated sample values for $A(i)$, $M$ and $W$, or he can manually enter new values, or he can generate new values for the private key by clicking the button Generate private key.

![Figure 2.4: Button Generate private key](image)

If the entered private key elements $A(i)$s are not a superincreasing vector and the user is clicking on the button Create public key, the user gets displayed the following note message:

![Figure 2.5: Button Create public key](image)

There is also a check for the parameters $M$ and $W$ when the user is clicking the button Create public key. Depending on which condition is violated different information dialogs pop up. For $M \leq \sum A(i)$ the following information is shown:

![Figure 2.7: Button Warning message for M](image)

For $g g T(M, W) \neq 1$ the following information is shown:

![Figure 2.8: Button Warning message for W](image)

Now all the conditions are fulfilled, the public key will be calculated and the elements $B(i)$s are shown in the Public key B area.
2.5.2 Encryption

After the keys have been generated, the user can enter a message $m$ in the corresponding field. As you type the message, the binary representation is dynamically calculated in addition and shown below in the field binary representation of $m$. The button Encrypt will be activated once a valid value $m$ is entered.

When you click on the button Encryption the message parts are calculated and the iteration of the calculations will be shown in the table below. The ciphertext is also calculated, displayed and entered for the decryption.

2.5.3 Decryption

For the decryption you can enter any values for $c$. The binary representation of the entered value is dynamically calculated and shown again.

By clicking the button Decryption the ciphertext will be decrypted and its iterations of the calculation will be shown in the table. After the decryption the user has the possibility to decrypt other messages with the same key.
In case that the decryption was successful the following message will be displayed and both the plaintext and the ciphertext will be colored green:

![Decryption successful](image)

**Figure 2.16: Decryption successful**

Otherwise, the plaintext and the ciphertext are highlighted in red color and the following message appears:

![Decryption failed](image)

**Figure 2.17: Decryption failed**

### 2.5.4 The menu bar

- A click on the icon **Restart** in the menu bar brings the plug-in back to its initial state, and you can start the algorithm from scratch.

- You can change the values of the private key by clicking on the icon **Reset** in the menu bar. Clicking this icon deletes all entries in the plug-in besides the private key.

![Button Restart](image)

**Figure 2.18: Button Restart**
Figure 2.19: Button Reset
3 Hash Sensitivity plug-in

Cryptographic hash functions play an important role in modern cryptography. They are used in data processing, digital signatures, message authentication codes (MACs), building of block ciphers etc.

In this chapter we go into the Hash Sensitivity. At first we describe what a cryptographic hash function is, as next step we illustrate and realize three hash function families which are Message Digest Algorithm (MD in the variant MD2, MD4 and MD5), Secure Hash Algorithm (SHA, in the variants SHA-1 and SHA-2), and RACE Integrity Primitives Evaluation Message Digest (RIPEMD, in the variant RIPEMD-160).

Under a cryptographic hash function we mean a mapping

\[ h : \Sigma^* \rightarrow \Sigma^n, \quad n \in \mathbb{N} \]  

That means that hash functions map strings of any size to strings of fixed size. They are never injective [Buc08].

Hash functions receive a message as input and give back an output as hash value called as message digest. In the following sections we want to deal with the topic hash Sensitivity. We present some popular hash functions only briefly because our goal is to realize them as plug-ins. For more details about these we recommend the literature to which we refer.

3.1 Message Digest (MD)

The family of the Message Digest (MD) algorithms contains MD2, MD4, and MD5. Ronald L. Rivest was the developer of these cryptographic hash functions. All these algorithms get a message of any length as input and return a 128-bit hash value as output called also message digest. These algorithms are structurally similar but they differ in construction. While MD2 is developed for 8-bit computers, MD4 and MD5 are designed for 32-bit computers. MD6 is the current version, but not offered in the Bouncy Castle library yet. Now we take a look at these three hash functions.

3.1.1 Message Digest2

The algorithm Message Digest2 (MD2) is the first cryptographic hash function of the series of the message digest group which was designed by Ronald L. Rivest in 1989 [RSA15]. MD2 was broken in 1995 [NR95]. The digest length is 128 bit (16 byte). MD2 was designed for 8-bit computers. Its specification is defined in RFC 1319. As a first step the message has to be extended that its block length is dividable by 16 byte (128 bit), then a checksum with 16 byte gets added to the message, and finally the hash value is calculated on the complete message.

3.1.2 Message Digest4

The algorithm Message Digest4 (MD4) is the successor version of MD2 and the predecessor of MD5. As in MD2 Ronald L. Rivest is also the developer of this hash function which is published in 1990 [Riv90]. MD4 is broken in 1995 [RSA15]. The hash value (output) is 128 bit long (16 byte). MD4 is designed for 32-bit computers. Its specification is described in RFC 1320. Hash functions such as MD5, SHA1 and SHA2 use the design principles of MD4. The message is extended with a leading 1, followed by 0s so that the length of the message is congruent to 448 modulo 512. Now, bits between 1 and 512 are appended to the message and finally the size of the original message is concatenated to the last 64 bit.

3.1.3 Message Digest5

The algorithm Message Digest5 (MD5) was designed by Ronald L. Rivest in 1991 [Riv92]. It is the successor of MD4 and MD2. MD6 is its successor. MD5 was broken in 1996 [Dob96]. This hash function returns also a 128-bit hash value as output as MD2 and MD4. MD5 is also designed for 32-bit computers. The specification of this algorithm is shown in RFC 1321. The following description of the MD5 algorithm is from [MD515].
Description of the MD5 algorithm

MD5 processes a variable-length message into a fixed-length output of 128 bit. The input message is broken up into chunks of 512-bit blocks (sixteen 32-bit words); the message is padded so that its length is divisible by 512. The padding works as follows: first a single bit, 1, is appended to the end of the message. This is followed by as many zeros as are required to bring the length of the message up to 64 bits fewer than a multiple of 512. The remaining bits are filled up with 64 bits representing the length of the original message, modulo $2^{64}$.

The main MD5 algorithm operates on a 128-bit state, divided into four 32-bit words, denoted A, B, C, and D. These are initialized to certain fixed constants. The main algorithm then uses each 512-bit message block in turn to modify the state. The processing of a message block consists of four similar stages, termed rounds; each round is composed of 16 similar operations based on a non-linear function $F$, modular addition, and left rotation. There are four possible functions $F$; a different one is used in each round:

- $F(B, C, D) = (B \land C) \lor (\neg B \land D)$ with $(0 \leq i \leq 15)$
- $G(B, C, D) = (B \land D) \lor (C \land \neg D)$ with $(16 \leq i \leq 31)$
- $H(B, C, D) = B \oplus C \oplus D$ with $(32 \leq i \leq 47)$
- $I(B, C, D) = C \oplus (B \lor \neg D)$ with $(48 \leq i \leq 63)$

$\oplus, \land, \lor, \neg$ denote the XOR, AND, OR and NOT operations respectively.

3.2 Secure Hash Algorithm (SHA)

The series of the Secure Hash Algorithm (SHA) are cryptographic hash functions including SHA-0, SHA-1, SHA-2, and lastly SHA-3. Beside SHA-3, all of these have been developed by the National Security Agency (NSA) and published by the National Institute of Standards and Technology NIST. The history of SHAs began in 1993. The SHA algorithms have different structures. Especially SHA-3 (Keccak) has a completely different design as SHA-0, SHA-1 and SHA-2. Keccak was nominated as SHA-3, but NIST didn’t publish SHA-3 as a final standard yet. The SHAs get a message as input and give back a hash value as output called message digest. The size of the message digests varies between 160 bit and 512 bit, based on the algorithm. They are used in digital signatures, in message authentication codes etc. Now we take a look at the SHA versions.

3.2.1 Secure Hash Algorithm SHA/SHA-0

The Secure Hash Algorithm SHA/SHA-0 is the original version of the SHA series which was developed by the NSA and published by NIST in 1993 [NI12] under the name SHA. It generates a 160-bit (20-byte) hash value as output. This algorithm was broken in 1998 [FC93]. A construction fault that was found after the publishing led to a correction of this algorithm, and 1995 this correction was renamed as SHA-1.

3.2.2 Secure Hash Algorithm SHA-1

SHA-1 is the improved version of SHA/SHA-0. SHA-1 was published by NIST in 1995 [NI12]. The SHA-1 algorithm was broken in 2005 [XW05]. It also generates a 160-bit (20-byte) hash value as its result. The hash value is a hexadecimal number with a length of 40 hex digits. SHA-1’s design is similar to MD5. SHA-1 is still the most popular of the SHA hash functions. The specification of this cryptographic hash function is described in RFC 3174. The difference between SHA-0 and SHA-1 lies in the left rotation of the compression function.
In the figure 3.1 above we see a typical iteration within SHA-1. In the following the notation of SHA-0/SHA-1 is shown.

- A, B, C, D and E are 32-bit words of the state;
- F is a nonlinear function that varies;
- $\ll_n$ denotes a left bit rotation by n places;
- $\gg_n$ denotes a right bit rotation by n places;
- n varies for each operation;
- $W_t$ is the expanded message word of round t;
- $K_t$ is the round constant of round t;
- $\oplus$ Addition denotes addition modulo $2^{32}$.

The following functions and constants are used in the SHA-1 [SHA01]:

A sequence of logical functions $f(0), f(1), \ldots, f(79)$ is used in SHA-1. Each $f(t)$, $0 \leq t \leq 79$, operates on three 32-bit words B, C, D and produces a 32-bit word as output. $f(t; B, C, D)$ is defined as follows: for words B, C, D,

- $f(t; B, C, D) = (B \land C) \lor ((\neg B) \land D) \ (0 \leq t \leq 19)$
- $f(t; B, C, D) = B \oplus C \oplus D \ (20 \leq t \leq 39)$
- $f(t; B, C, D) = (B \land C) \lor (B \land D) \lor (C \land D) \ (40 \leq t \leq 59)$
- $f(t; B, C, D) = B \oplus C \oplus D \ (60 \leq t \leq 79)$

A sequence of constant words $K(0), K(1), \ldots, K(79)$ is used in the SHA-1. In hex these are given by

- $K(t) = 5A827999 \ (0 \leq t \leq 19)$
- $K(t) = 6ED9EBA1 \ (20 \leq t \leq 39)$
- $K(t) = 8F1BBDC \ (40 \leq t \leq 59)$
- $K(t) = CA62C1D6 \ (60 \leq t \leq 79)$
3.2.3 Secure Hash Algorithm SHA-2

The Secure Hash Algorithm SHA-2 is the successor of SHA-1 and was published by NIST in 2001 [WP08]. SHA-2 contains four cryptographic hash functions named as 224, 256, 384 and 512. That means that each variant has different block sizes and messages digest lengths in bits. There is also a difference in word size: SHA-256 uses for example 32-bit words and SHA-512 uses 64-bit words. The structure of these hash functions is indeed equally but different numbers of shift, rounds and extra constants are used by them for their computation. The family of SHA-2 is still an interesting object of cryptanalysis research because until now this hash function is still unbroken. (NIST) nominated SHA-3 as an alternative cryptographic hash function as successor of SHA-2 if it eventually should be broken but it doesn’t mean that SHA-3 replaces SHA-2 today.

Now we take a brief look at the versions of SHA-2/256 and SHA-2/512, also called SHA-256 and SHA-512.

The Secure Hash Algorithm SHA-2/256 produces a 256-bit (32-byte) hash value as result. The block size is 512-bits long and this algorithm works with 32-bit words. This hash function uses six logical functions and 64 constant words each of 32-bit. The function definitions for SHA-2/256 are in [WP08]:

\[
W_i = \begin{cases} M_i, & \text{if } 0 \leq i \leq 15 \\ \sigma_1(W_{i-2}) + W_{i-7} + \sigma_0(W_{i-15}) + W_{i-16}, & \text{if } 16 \leq i \leq 63 \end{cases}
\]

including

- \(\Sigma_0(x) = 2 \oplus x \gg 13 \oplus x \gg 22\)
- \(\Sigma_1(x) = 6 \oplus x \gg 11 \oplus x \gg 25\)
- \(\sigma_0(x) = 7 \oplus x \gg 18 \oplus x \gg 3\)
- \(\sigma_1(x) = 17 \oplus x \gg 19 \oplus x \gg 20\)
- \(f_{ij}(b, c, d) = b \land c \oplus \neg b \land d\)
- \(f_{maj}(b, c, d) = b \land c \oplus b \land d \oplus c \land d\)

The Secure Hash Algorithm SHA-2/512 generates a 512-bit (64-byte) hash value as output. The block size is 1024-bits long and this algorithm works with 32-bit words. This algorithm also uses six logical functions and 80 constant words each of 32-bit. The function definitions for SHA-2/512 are in [SHA12]:

\[
W_i = \begin{cases} M_i, & \text{if } 0 \leq i \leq 15 \\ \sigma_1(W_{i-2}) + W_{i-7} + \sigma_0(W_{i-15}) + W_{i-16}, & \text{if } 16 \leq i \leq 79 \end{cases}
\]

including

- \(\Sigma_0(x) = 28 \oplus x \gg 34 \oplus x \gg 39\)
- \(\Sigma_1(x) = 14 \oplus x \gg 18 \oplus x \gg 41\)
- \(\sigma_0(x) = 1 \oplus x \gg 8 \oplus x \gg 7\)
- \(\sigma_1(x) = 19 \oplus x \gg 61 \oplus x \gg 6\)
- \(f_{ij}(b, c, d) = b \land c \oplus \neg b \land d\)
- \(f_{maj}(b, c, d) = b \land c \oplus b \land d \oplus c \land d\)

In figure 3.2 below a classical iteration within SHA-2 is depicted.
Here is the notation used in the SHA-2 descriptions.

- A, B, C, D, E, F, G and H are 32-bit/64-bit\(^1\) words of the state;
- F is a nonlinear function that varies;
- n varies for each operation;
- \(W_t\) is the expanded message word of round t;
- \(K_t\) is the round constant of round t;
- \(\oplus\) denotes addition modulo \(2^{32}/2^{64}\)\(^2\)
- \(\oplus\) denotes bitwise XOR
- \(\&\) denotes bitwise AND
- \(\lor\) denotes bitwise OR
- \(\neg\) denotes bitwise complement
- \(\gg _n\) denotes right shift by n bits
- \(\gg ^n\) denotes right rotation by n bits

### 3.3 RACE Integrity Primitives Evaluation Message Digest (RIPEMD-160)

The RIPEMD-160 cryptographic hash function was developed by Hans Dobbertin, Antoon Bosselaers and Bart Preneel [HD96] and published in 1996. It is the successor of the original version of RIPEMD. The family of the RIPEMD algorithms contains all in all four series with different bit sizes, namely RIPEMD-128, RIPEMD-160, RIPEMD-256, and finally RIPEMD-320. RIPEMD-160 is the most popular version of this series. RIPEMD-160 is optimized for 32-bit processors. This algorithm works 512-bit input message blocks and generates a 160-bit hash value as outcome. The design principles of MD4 are used in RIPEMD-160 and the performance of SHA-1 is similar to RIPEMD-160. That’s why RIPEMD-160 is seen as a subfamily of the MD-SHA family. RIPEMD-160 is also still unbroken like SHA-2.

A schematic overview of a RIPEMD-160 round is depicted in the figure 3.3.

\(^1\) It depends on the version, if SHA-256 then 32 bit, and if SHA-512 then 64 bit.
In the following the notation of RIPEMD-160 is given.

- A, B, C, D and E are 32-bit words of the state;
- F is a nonlinear function that varies;
- $\ll_n$ denotes a left bit rotation by n places;
- $\gg_n$ denotes a right bit rotation by n places;
- n varies for each operation;
- $W_n$ is the expanded message word of round t;
- $K_n$ is the round constant of round t;
- $\boxplus$ Addition denotes addition modulo $2^{32}$.
- $\oplus$ denotes bitwise XOR
- $\land$ denotes bitwise AND
- $\lor$ denotes bitwise OR
- $\neg$ denotes bitwise complement

The used boolean functions are:

$$f(j, x, y, z) = x \text{ XOR } y \text{ XOR } z \quad (0 \leq j \leq 15)$$
$$f(j, x, y, z) = (x \text{ AND } y) \text{ OR } (\text{NOT}(x) \text{ AND } z) \quad (16 \leq j \leq 31)$$
$$f(j, x, y, z) = (x \text{ OR } \text{NOT}(y)) \text{ XOR } z \quad (32 \leq j \leq 47)$$
$$f(j, x, y, z) = (x \text{ AND } z) \text{ OR } (y \text{ AND } \text{NOT}(z)) \quad (48 \leq j \leq 63)$$
$$f(j, x, y, z) = x \text{ XOR } (y \text{ OR } \text{NOT}(z)) \quad (64 \leq j \leq 79)$$

In this chapter we intentionally explained only three hash methods as examples. For clarity reasons listing 3.3 also only contains these three hash methods. In the plug-in all hash methods listed in table 3.1 under #2.1 are implemented.
3.4 The design of the plug-in

In this section we want to go into the design of our plug-in. Again, we use the GUI Guideline [JCT12] of JCrypTool to create the user interface.

The plug-in shows how sensitive the hash value is, when doing even minor changes to one of the inputs. For the visualization the hash values are observed as bit sequence (binary representation) and the comparison of two hash values results in a bit sequence as well. Within this sequence two different types of sub sequences occur: The so-called zero-runs only consist of zeros, whereas the so-called one-runs only consist of ones. A zero-run indicates a bit sequence being identical in both the first input and the second input. The longest zero-run together with its length and its zero-based offset is stated in the bottom line. The statistical analysis of the longest zero-run was the basic approach to the successful analysis of the MD-4 hash function.

The Hash Sensitivity plug-in is schematically shown in the figure 3.4. The user interface and its attributes are described in table 3.1 and table 3.2:

- **Type**: The SWT-Widget element.
- **Initial state**: The Initial state of the Widget (enabled or disabled).
- **Text**: The name of the used Widget.
- **Description**: The description of the Widget.
<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Initial state</th>
<th>Text</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>StyledText</td>
<td>disabled</td>
<td>see figure 3.4</td>
<td>Description of the plug-in.</td>
</tr>
<tr>
<td>2</td>
<td>Group</td>
<td>enabled</td>
<td>Select a hash function</td>
<td>Includes drop down menu for hash function selection.</td>
</tr>
<tr>
<td>2.1</td>
<td>Combo</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>In this place you can select the hash function. Currently available hash functions are:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• MD2 (128 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• MD4 (128 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• MD5 (128 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-1 (160 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-2 (256 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-2 (512 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-3 (224 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-3 (256 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-3 (384 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SHA-3 (512 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SKEIN-256 (256 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SKEIN-512 (512 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SKEIN-1024 (1024 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• SM3 (256 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• RIPEMD-160 (160 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• TIGER (192 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• GOST3411 (256 bit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• WHIRLPOOL (512 bit)</td>
</tr>
<tr>
<td>3</td>
<td>Group</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>Shows the representation of the hash values.</td>
</tr>
<tr>
<td>3.1</td>
<td>Button</td>
<td>enabled</td>
<td>hexadecimal</td>
<td>Switch to hexadecimal view of the hash values.</td>
</tr>
<tr>
<td>3.2</td>
<td>Button</td>
<td>enabled</td>
<td>decimal</td>
<td>Switch to decimal view of the hash values.</td>
</tr>
<tr>
<td>3.3</td>
<td>Button</td>
<td>enabled</td>
<td>binary</td>
<td>Switch to binary view of the hash values.</td>
</tr>
<tr>
<td>4</td>
<td>Textfield</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>In this field the user can enter the input 1 text for the hash value calculation. The JCrypTool example text is loaded by default when the plug-in is initially shown.</td>
</tr>
<tr>
<td>5</td>
<td>Textfield</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>In this field the user can enter the input 2 text for the hash value calculation. The JCrypTool example text is loaded by default when the plug-in is initially shown.</td>
</tr>
<tr>
<td>6</td>
<td>Textfield</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>Generates automatically the hash value for the input 1 text which was entered in the input 1 text field.</td>
</tr>
</tbody>
</table>

Table 3.1: The behavioral description of the **Hash Sensitivity** plug-in – part 1
<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Initial state</th>
<th>Text</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Textfield</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>Generates automatically the hash value for the input 2 text which was entered in the input 2 text field.</td>
</tr>
<tr>
<td>8</td>
<td>Textfield</td>
<td>enabled</td>
<td>differences of the hash values</td>
<td>In this field the differences of the hash values of input 1 and input 2 are shown. The bits which are different are highlighted in red.</td>
</tr>
<tr>
<td>9</td>
<td>Button</td>
<td>active</td>
<td>Underline longest unchanged bit sequences</td>
<td>By clicking on the button the longest unchanged bit sequence will be underlined.</td>
</tr>
<tr>
<td>10</td>
<td>Button</td>
<td>deactivated</td>
<td>Underline longest changed bit sequences</td>
<td>By clicking on the button the longest changed bit sequence will be underlined.</td>
</tr>
<tr>
<td>11</td>
<td>Icon</td>
<td>enabled</td>
<td>see figure 3.4</td>
<td>Restart icon: By clicking on the button the initial state of the plug-in will be opened. If you move the mouse over the icon, the tooltip Restart will be shown.</td>
</tr>
</tbody>
</table>

Table 3.2: The behavioral description of the Hash Sensitivity plug-in – part 2
3.5 The implementation of the plug-in

The plug-in is grouped in four packages:

- org.jcryptool.visual.hashing
- org.jcryptool.visual.hashing.algorithm
- org.jcryptool.visual.hashing.handlers
- org.jcryptool.visual.hashing.views

The activator class HashingPlugin of the plug-in is located in the package org.jcryptool.visual.hashing. The package org.jcryptool.visual.hashing.handlers contains the RestartHandler which implements the restart functionality of the plug-in. In the package org.jcryptool.visual.hashing.algorithm we implement an enumeration HashFunction which is shown in listing 3.1. The method getName(String name) returns the corresponding hash function for the given name and otherwise it returns null.

```java
public enum HashFunction {
    MD2("MD2 (128 bits)"), MD4("MD4 (128 bits)"), MD5("MD5 (128 bits)"),
    SHA1("SHA−1 (160 bits)"), SHA256("SHA−2 (256 bits)"), SHA512("SHA−2 (512 bits)"),
    RIPEMD160("RIPEMD−160 (160 bits)"),
    private final String hashFunctionName;
    private HashFunction(String name) {
        hashFunctionName = name;
    }
    public HashFunction getName(String name) {
        for (HashFunction h : values()) {
            if (h.hashFunctionName.compareToIgnoreCase(name) == 0) {
                HashFunction value = valueOf(h.name());
                return value;
            }
        }
        return null;
    }
}
```

Listing 3.1: Enumeration class HashFunction

The user interface is implemented in the class HashingView of the package org.jcryptool.visual.hashing.views. First we have the description field where the functionality is explained. For the selection of a hash function we use a Combo and add all the supported hash functions. It implements a SelectionListener which is shown in listing 3.2.

```java
public void widgetSelected(SelectionEvent e) {
    if (!textInput.getText().isEmpty()) {
        hashInputValueHex = computeHash(comboHash.getText(), textInput.getText(), textHashInput);
    }
    if (!textOutput.getText().isEmpty()) {
        hashOutputValueHex = computeHash(comboHash.getText(), textOutput.getText(), textHashOutput);
    }
    if (!textInput.getText().isEmpty() && !textOutput.getText().isEmpty()) {
        computeDifference();
    } else {
        textDifference.setText(" ");
    }
}
```

Listing 3.2: Selection of a hash function
The method checks if the texts from input 1 and input 2 are not empty. If so, the hash values of the two input fields will be calculated and are displayed in the field below. To calculate the hash value the method `private String computeHash(String hashName, String inputText, Text hashText, String hashHexValue)` will be used. Only if both text fields are not empty the differences of both hash values will be calculated with the method `computeDifference()`. The implementation of this method is shown in listing 3.3.

```java
private String computeHash(String hashName, String inputText, Text hashText) {
    hash = hash.getName(hashName);
    byte[] digest = null;
    switch (hash) {
        case MD2:
            MD2Digest md2 = new MD2Digest();
            digest = new byte[md2.getDigestSize()];
            md2.doFinal(digest, 0);
            break;
        case MD4:
            MD4Digest md4 = new MD4Digest();
            digest = new byte[md4.getDigestSize()];
            md4.doFinal(digest, 0);
            break;
        case MD5:
            MD5Digest md5 = new MD5Digest();
            digest = new byte[md5.getDigestSize()];
            md5.doFinal(digest, 0);
            break;
        case SHA1:
            SHA1Digest sha1 = new SHA1Digest();
            sha1.update(inputText.getBytes(), 0, inputText.getBytes().length);
            digest = new byte[sha1.getDigestSize()];
            sha1.doFinal(digest, 0);
            break;
        default:
            break;
    }
    String hashHexValue = new String(Hex.encode(digest));
    if (btnHexadecimal.getSelection()) {
        String hashValueOutput = hashHexValue.toUpperCase().replaceAll(".\{2\}", "$0 ");
        hashText.setText(hashValueOutput);
    } else if (btnDezimal.getSelection()) {
        String hashValue = hexToDecimal(hashHexValue);
        hashValue = hashValue.replaceAll(".\{3\}", "$0 ");
        hashText.setText(hashValue);
    } else if (btnBinary.getSelection()) {
        String hashValue = hexToBinary(hashHexValue);
        hashValue = hashValue.replaceAll(".\{8\}" , "$0# ");
        hashText.setText(hashValue);
    }
    return hashHexValue;
}
```

Listing 3.3: Implementation of the hash calculation
The method has three parameters, the name of the hash function, the text which has to be used for the calculation and the text field where we write the calculated hash value back and returns the calculated hash value. First we deliver by name the hash function and store it into our enumeration variable with hash = hash.getName(hashName). Then we use a switch statement for the hash function. To calculate the hash function we use the Bouncy Castle\(^2\) crypto library. We will demonstrate this for SHA256 here, the procedure differs only in the creation of the hash digest. We create a SHA256Digest with SHA256Digest sha256 = new SHA256Digest(). Then we use the update method to update it with the input text. For the result we create a byte array of the size of the SHA256Digest with digest = new byte[sha256.getDigestSize()] and finally we write the calculated hash value into the array with sha256.doFinal(digest, 0). We use a hex encoder to encode the byte array to a String with String hashHexValue = new String(Hex.encode(digest)). Before we return the hash value we first check which representation of the hash value is selected to transform the hash value to the correct representation.

To compute the difference in the bit sequences we use the method computeDifference() which is shown in listing 3.4. We store the input 1 and input 2 hex values into two variables input and output of type BigInteger as hexadecimal. Then we use the xor method to build the xor of them and save it into the variable result with String result = input.xor(output).toString(16). We convert the hexadecimal representation into binary to show the difference of the bits.

```java
private void computeDifference() {
    BigInteger input = new BigInteger(hashInputValueHex, 16);
    BigInteger output = new BigInteger(hashOutputValueHex, 16);
    String result = input.xor(output).toString(16);
    result = hexToBinary(result);

    if (!result.toString().equalsIgnoreCase("0")) {
        textDifference.setText((hexToBinary("0").replaceAll("(8)\", "$0#")));
    } else {
        int count = result.length();
        int zeroBits = result.length() - result.replaceAll("0", "").length();
        int oneBits = result.length() - result.replaceAll("1", "").length();
        double percent = ((double) oneBits / (double) count) * 100;
        int[] sequence = find(result);

        result = result.replaceAll("(8)\", "$0#");
        int lengthPrettyPrint = result.length();
        count = lengthPrettyPrint / OUTPUT_SEPARATOR;

        StringBuilder sb = new StringBuilder(result);
        for (int i = 0; i < count; i++) {
            sb.insert(((OUTPUT_SEPARATOR) + (i + 1) + i), "\n");
        }
        if (hash == HashFunction.RIPEMD160 || hash == HashFunction.SHA1) {
            sb.insert(sb.length(), "\n");
        }
        result = sb.toString();
        char[] bitArray = result.toCharArray();

        for (int i = 0; i < bitArray.length; i++) {
            if (bitArray[i] == '1') {
                StyleRange bits = new StyleRange();
                bits.start = i;
            }
```

\(^2\) https://www.bouncycastle.org/
Listing 3.4: Calculate the bit differences

If the texts of input 1 and input 2 are equal then there are no differences in the bits or their hash values, and we fill up the output with zeros. Otherwise, we count the bits which represent binary ones and binary zeros and the percentage of the different bits for the statistics. We also want to find the longest unchanged bit sequence and its offset. For that we use the method private int[] findLongestSequence(String s) shown in listing 3.5 which returns an int array with the longest sequence and its offset.

Listing 3.5: Finding longest sequence

We use a regular expression to find all sequences of zeros. Then we iterate all matching elements and search the longest element and its offset. The length of the sequence we store at index 0 and the offset at index 1 and return the result array. Finally we highlight the binary ones in red with a StyleRange.

The user can switch to any time the representation of the calculated hash values from hexadecimal to decimal to binary. The SelectionListener of the decimal button is shown in listing 3.6. The SelectionListener for the hexadecimal and binary conversion are equal. The conversion of the values will only be performed if the input 1 or the input 2 text are not empty.
It is easy to add new hash functions to the plug-in if they are supported by the Bouncy Castle crypto library. To add a new hash function you only have to add in the method computeHash shown in listing 3.3 an instance of the new hash function. The calculation of the hash function itself is very performant even if the hash values are longer than 512 bit. What the performance of the plug-in slows down a bit is the calculation of the statistics of the hash sensitivity when the hash function is bigger than 512 bits.

Listing 3.6: Decimal representation button

```java
7  }
8  if (!textOutput.getText().isEmpty()) {
9      hash = hexToDecimal(hashOutputValueHex);
10     hash = hash.replaceAll(".[3]", "$0 ");
11     textHashOutput.setText(hash);
12  }
13 }
```
3.6 The functionality of the plug-in

In this section we describe the functionality of the plug-in **Hash Sensitivity**. The plug-in can be started via the menu **Visuals** or via the crypto explorer tab **Visuals**.

![Hash Sensitivity plug-in](image)

The plug-in consists of a description field and four basic areas: **Hash function, Input 1 text, Input 2 text** and **Difference**. In the description field some statements about the algorithm are displayed.

In the hash function area you can select a hash function and the representation you want.

![Hash function selection](image)

There are the following hash functions available:

- MD2 (128 bit)
- MD4 (128 bit)
- MD5 (128 bit)
- SHA-1 (160 bit)
- SHA-2 (256 bit)
- SHA-2 (512 bit)
- SHA-3 (224 bit)
- SHA-3 (256 bit)
• SHA-3 (384 bit)
• SHA-3 (512 bit)
• SKEIN-256 (256 bit)
• SKEIN-512 (512 bit)
• SKEIN-1024 (1024 bit)
• SM3 (256 bit)
• RIPEMD-160 (160 bit)
• TIGER (192 bit)
• GOST3411 (256 bit)
• WHIRLPOOL (512 bit)

The hash function can be represented in hexadecimal, decimal or binary.

The hash value of input 1 and input 2 text will be calculated and displayed below in the corresponding representation.

Based on the entry of the input 1 and input 2 text the differences of the bits in the hash value will be displayed in the difference area. The different bits are highlighted in color red.
There are also some statistics displayed. You can change at any time the hash function and the representation of the hash value.

When you click the radio button **Underline longest unchanged bit sequences** the unchanged bit sequence will be underlined. The same is for the button **Underline longest changed bit sequences**.

When you click the **Restart** icon in the menu bar the default text will be loaded into the text areas of input 1 and input 2.

**Figure 3.11:** Difference between the hash values of input 1 and input 2

**Figure 3.12:** Underline longest unchanged and changed bit sequence

**Figure 3.13:** Restart functionality
4 Outlook

In this diploma thesis we designed, implemented and presented the two plug-ins Merkle-Hellman and Hash Sensitivity for the visualization category of the e-learning platform JCrypTool. A seamless integration in the existing open-source project and an interactive and easy usability of the plug-ins were the main purpose. The user group which includes students, teachers and any cryptography-interested person should get a clear overview and easy access to these cryptographic algorithms. In the bilingual online help (German and English), the user can read the description of the algorithms and the functionality of the plug-ins directly.

During the preparation of our thesis we learned a lot by participating in this open-source project: On the one hand we could use the content of our classes at the university by enhancing our own understanding of the theory and bring it into practice. On the other hand we learned how to participate and contribute to an active and distributed open-source project, to develop plug-ins with the Eclipse Framework, and especially how to design user-friendly GUIs.

We also took advantage by some students who tested the plug-ins and who gave feedback which led to improvements of the plugins. Overall, we received a very positive feedback for both plug-ins and their online help confirming they helped to better understand both the idea of the asymmetric cipher from Merkle-Hellman and the high sensitivity of cryptographic hash methods to any kind of change in the text inputs.

For the future we recommend interested students to visit the website of the JCrypTool wiki\(^1\) which proposes other projects which could be implemented to enhance the knowledge about cryptography and the awareness for IT security. Another resource of interesting algorithms for other projects is the book by Prof. Dr. Johannes Buchmann [Buc08].

\(^1\) https://github.com/jcryptool/core/wiki/project-Ideas
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