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Comparative Analysis of Argon2 and Bcrypt Security Methods to Strengthen Password Security

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Abstract: This study compares the password security techniques between Argon2 and Bcrypt to determine an optimal approach to prevent cyber-attacks and manage memory utilization using actual data and study. We examine numerous datasets and studies to regulate the aids and drawbacks of Argon2 and Bcrypt, focusing on defending against attacks and the use of memory. According to our data, Argon2 outperforms Bcrypt due to its superior memory management and resistance to brute force attacks. The data also highlights Argon2's capability to defend against new GPU-based attacks, where Bcrypt shows its flaws. This work proposes to enhance the application of Argon2 and prove that Argon2 is an optimal possibility to increase password security through this study and compares the password security techniques using Argon2 and Bcrypt. This work examines numerous data sets and studies to determine the benefits and drawbacks of Argon2 and Bcrypt focused on defending against attacks and using memory.

Keywords: Argon2, Bcrypt, Cyber-Attacks, Graphical processing unit, Memory optimization, Password security.

I. Introduction

The rapid shift towards digital interactions has fundamentally reshaped modern society, offering unprecedented convenience while simultaneously introducing pressing security challenges. In today's interconnected world, where our online presence continues to expand, safeguarding digital identities and sensitive data has taken center stage as a paramount concern. Our digital-first lifestyle has revolutionized communication and connecting with others. However, it has also exposed us to an intricate web of security risks and vulnerabilities. The omnipresence of the internet has made us both beneficiaries of its boundless opportunities and potential targets for cyber threats.

The importance of digital security cannot be overstated, given the potential repercussions of breaches, including identity theft, financial devastation, and erosion of privacy. To address these challenges, a holistic approach is required, encompassing robust password security, cutting-edge encryption techniques, and a heightened awareness of evolving cyber threats. This exploration will delve into the realm of digital security, focusing on the evolution of password security solutions, the limitations of traditional methods, and the rise of advanced cryptographic algorithms such as Argon2 and Bcrypt. A data-driven comparative analysis seeks to provide practical insights to empower individuals and organizations to make informed choices in securing their digital presence in an era where the boundaries between the physical and digital worlds.

A. Significance of Password Security

In today's digital landscape, the importance of password security looms large. Our lives have become intricately entwined with the digital realm, encompassing communication, financial transactions, and daily activities. Consequently, safeguarding our digital identities and sensitive information has emerged as an overarching priority. As our offline lives migrate online, the imperative of robust password security has garnered heightened attention. Password security acts as the gatekeeper to our digital identities and personal information. It forms an essential defense against unauthorized access to email accounts, social media profiles, online banking, and an array of digital assets. A strong password fortifies these defenses, protecting sensitive data from potential breaches and cyber threats.

Furthermore, it is crucial for thwarting identity theft, safeguarding data privacy, and ensuring financial security. Weak or compromised passwords are the chinks in our digital armor that cybercriminals exploit. Strengthening password security is pivotal in preserving our privacy, financial stability, and overall digital well-being in an increasingly interconnected world.

B. Evolution of Password Security

The evolution of password security is a compelling narrative in the realm of online security. In the early days of digital interaction, simple passwords sufficed as the primary defense against unauthorized access. However, as the internet grew,

so did the sophistication of cyber threats. This prompted the development of more robust password security solutions. One notable advancement was the implementation of password complexity rules, mandating a mix of uppercase letters, numbers, and special characters. Yet, even these measures proved insufficient in the face of advanced hacking techniques. Today, multifactor authentication (MFA) has emerged as a game-changer. MFA combines something you know (password) with something you have (e.g., a mobile device) or something you are (biometrics), significantly enhancing security. Additionally, password managers and biometric authentication methods like fingerprint and facial recognition are becoming more prevalent.

C. Ineffectiveness of Traditional Solutions

Traditional password hashing systems have demonstrated their ineffectiveness in the face of evolving cyber threats, highlighting critical vulnerabilities. Basic password hashing, while a fundamental security measure, falls short of providing robust protection. One glaring issue is susceptibility to brute force attacks, where attackers systematically try every possible combination until they crack the password. Additionally, traditional hashing methods are susceptible to rainbow table attacks, where precomputed tables of hashed passwords can be used to rapidly uncover plaintext passwords. These limitations underscore the urgent requirement for enhanced cryptographic algorithms. Modern solutions employ techniques like salted hashing, which adds a unique random value (salt) to each password before hashing, thwarting rainbow table attacks. Furthermore, adaptive algorithms, such as Bcrypt and scrypt, introduce computational complexity, making brute force attacks significantly more challenging and time-consuming.

In today's threat landscape, traditional password hashing systems have proven inadequate, necessitating the adoption of advanced cryptographic methods to bolster security and safeguard sensitive data from increasingly sophisticated cyber threats.

D. Security Methods: Argon2 and Bcrypt

In response to the shortcomings of traditional password security methods, advanced cryptographic algorithms like Argon2 and Bcrypt have risen to prominence as powerful tools for enhancing password security. Argon2, in particular, has gained recognition as the winner of the Password Hashing Competition. It is designed to be memory-hard and resistant to both brute force and side-channel attacks. Argon2's adaptive nature allows it to adjust its computational requirements, making it exceptionally resistant to parallelization, a feature highly desirable in today's multi-core computing environments.

Bcrypt, on the other hand, has a long-standing reputation for security. It incorporates salted hashing and introduces a cost factor, which can be adjusted to increase the computational effort required for hashing. This added complexity significantly raises the bar for attackers attempting brute force or rainbow table attacks. Both Argon2 and Bcrypt represent substantial improvements over traditional password hashing methods, offering robust protection against a wide range of cyber threats. Their adoption underscores the commitment to evolving password security in response to ever-advancing cybersecurity challenges.

E. Data-Driven Comparative Analysis

Shifting from theoretical knowledge to practical insights, our comparative analysis of Argon2 and Bcrypt employs a data-driven approach. This method enables a thorough and empirically grounded examination of these cryptographic algorithms. In the forthcoming sections, we will delve deeper into several facets, aiming to provide a comprehensive understanding of the strengths, limitations, and practical implications of Argon2 and Bcrypt in the realm of password security. By relying on concrete data and real-world testing, we intend to illuminate their actual performance, security attributes, and applicability for safeguarding sensitive information within the constantly evolving cybersecurity landscape. This data-driven approach ensures that our evaluation is not solely based on theory but is rooted in practical, evidence-based assessments, offering valuable insights for individuals and organizations seeking robust password security solutions.

II. Literature Survey

The field of password security has become a focal point for researchers seeking to strengthen digital defenses against the ever-evolving landscape of cyber threats [1]. Traditional password storage systems, once considered secure, have been exposed as vulnerable, prompting the development and adoption of advanced cryptographic algorithms such as Argon2 and Bcrypt [2]. This literature survey delves into key research findings that highlight the vulnerabilities of older password storage methods, the strengths of Argon2 and Bcrypt, and their relevance in the dynamic realm of password security [3]. Argon2, in particular, has gained significant attention due to its remarkable resilience, primarily attributed to its memory-hardness attribute. A pivotal study by Dilkun *et al.* [4] demonstrated Argon2's superiority over Bcrypt in withstanding brute force attacks on hashed passwords. Unlike traditional methods, Argon2 requires the attacker to invest a lot of time and resources, which raises the bar for password success [5]. This security improvement is especially important in today's threat landscape, where attackers continue to find better ways to compromise passwords. Also, Jones *et al.* [6] help understand the advantages of Argon2 by determining its resistance to GPU-based attacks. Historically Bcrypt had a weakness in this area because it struggled with the computing power of modern processing units (GPUs). However, Jones *et al.* [7] show that Argon2's memory hardness greatly impacts GPU acceleration testing, making it a strong option against the growing threat. Park

Great reviews about Argon2, Bcrypt, and more [8]. Focused on memory usage during hashing. This study not only applies to Argon2's memory hardness but also shows how memory usage varies with input size [9]. This insight shows that this algorithm can be adapted to a variety of tasks by strengthening security information and providing consistent protection regardless of data volume [10]. Although Argon2 is widely accepted, it is worth noting that Bcrypt still affects exceptions. Schneider showed that the value of Bcrypt is still there, especially when strict restrictions are not a big problem. This change reflects the evolution of encryption solutions for different security and resource environments [11]. Taken together, these findings paint a beautiful and evolving picture of the password security landscape. Argon2 and Bcrypt have emerged as powerful solutions that provide better security compared to traditional hashing methods [12]. Their adoption represents a way to protect sensitive data from various cyber threats. In summary, this literature review synthesizes significant research and provides insight into the changing password security landscape [13]. It highlights the advantages of advanced encryption methods such as Argon2 and Bcrypt in reducing cyber risk. These algorithms police many threats, making Argon2 a strong choice in the face of increasing competition from cyber adversaries thanks to its memory hardness and protection against GPU-based attacks [14]. As the password security field continues to evolve, continuous research and innovation are vital to stay ahead of malicious actors [15]. A paradigm change is occurring in the realm of password security due to the growing sophistication of cyber threats and the vulnerabilities of outdated techniques [16]. Two notably strong solutions are Argon2 and Bcrypt, with Argon2 being especially resistant to attacks because to its memory-hardness property [17]. Their effectiveness against GPU-based and brute force attacks has been demonstrated by research, providing superior security in the ever-changing threat environment of today [18]. Despite the rise in popularity of Argon2, Bcrypt is still useful in some situations, demonstrating how encryption solutions may be tailored to meet a variety of security requirements [19]. This changing environment emphasizes how crucial it is to conduct ongoing research and innovation in order to fend off cybercriminals and protect sensitive data [20]. Data protection in the face of increasingly skilled cyber enemies is ensured by the improved security provided by Bcrypt and Argon2. Argon2's memory-hardness feature has grown to be a valuable advantage, bolstering its standing against malevolent actors. Even if it isn't always used, Bcrypt is nevertheless useful in some situations, proving how adaptable encryption can be.

III. Information and Study Hash Function and Encryption

A. Encryption

The process of converting a plaintext message into ciphertext, which renders it incomprehensible to unauthorized parties, is known as encryption. By means of encryption, the original message—known as plaintext—becomes ciphertext. A private key that enables ciphertext decryption back into plaintext is owned by authorized users. A function that maps plaintext P to ciphertext C is known as encryption, and its symbol is E.

$$C = E(P)$$

The opposite of encryption is called decryption. It is represented as a function, D, and converts ciphertext C back into plaintext P.

$$D / C = P$$

The relationship between encryption and decryption can be expressed mathematically as follows:

$$D(E(P)) = P$$

Since the Roman Empire, encryption has been used in various contexts. Particularly, the Caesar cipher was used by Roman Emperor Julius Caesar to hide communications to his generals. Using this procedure, every letter in the plaintext was changed to a letter three positions further back in the alphabet:

Plaintext: Q W E R T Y

Ciphertext: T Z H U W B

The Caesar cipher can be mathematically represented as: $E(P) = (P + K) \bmod 26 = C$

$$D(C) = (C - K) \bmod 26 = P$$

K is the key in the aforementioned case. Symmetric key encryption is the process of encrypting and decrypting data using the same key. On the other hand, as Fig. 1 illustrates, utilizing distinct keys for encryption and decoding is referred to as asymmetric key encryption or public key encryption.

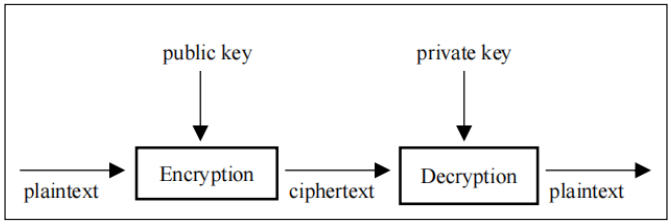

Fig. 1: Encryption to Decryption Process

The RSA technique, which includes stages for key pair generation, communication, and decryption, is one well-known example of an asymmetric encryption method. Conversely, DES is a symmetric encryption method that is still widely used and understood despite no longer being thought to be secure. Fundamental building blocks of encryption algorithms, block ciphers accept a k-bit string and an n-bit string as inputs and return an n-bit text. The block cipher's symmetric key is the k-bit sequence. The S-Box is a concept used in block ciphers to mask the connection between the ciphertext and the key. AES and Blowfish are two other encryption methods that are based on block ciphers in addition to DES.

B. Hash Function

A hash function is a mathematical operation that maps input data of any size, denoted as "k," to an output value of any size, denoted as "v." A simple hash function is defined by the following formula, which usually requires modulo arithmetic: k mod m = v = h(k). 'v' in this equation is dependent on the parameter.' It is noteworthy that owing to the dimensional of 'v,' disparate input values 'k' might yield identical output values 'v.' This is referred to as a collision when it happens. Policies can be set to handle collisions that occur when hash functions are used for non-security purposes. On the other hand, collisions within the hash function are regarded as a security risk.

The following characteristics of a strong cryptographic hash function should be present:

- *Preimage Resistance:* Using the known hash value "v," it should be computationally impossible to determine the input value "k."
- *Second Preimage Resistance:* It should be challenging to locate another input value that yields the same hash value ('v') given an input value ('k') and a hash value ('v).
- *Collision Resistance:* It ought to be difficult to identify two different input values that produce the same output value.

It is crucial to show that a hash function satisfies the three aforementioned requirements in order to evaluate its security. This evaluation covers a number of topics, such as public key protection, plaintext to ciphertext, plaintext to ciphertext encryption and decryption, and plaintext to ciphertext to plaintext. We can use the principles of encryption to create hash functions by closely examining the encryption process. Using the supplied text as the encryption key, we can transform a standard text into ciphertext if we have two texts as inputs: a standard text and another text. The provided input then acts as the process's key. By using this method, we create a hash function where the obtained 'v' is the ciphertext and the input 'k' of the hash function is the encryption key.

C. Password Hashing Function

The selection of appropriate cryptographic tools is crucial when it comes to password protection. Even though they are flexible, two-way functions are not appropriate for storing passwords. For password verification, these features require the secret key to be stored. When the secret key and the passwords are compromised, this strategy, however, becomes risky. It is advised to use one-way functions, like hash functions, to reduce this risk. In this configuration, the password is processed by the authentication system, which compares it with the hash value that has been stored, eliminating the need for password validation. A variety of vulnerabilities, such as pre-image attacks, collision attacks, dictionary attacks, rainbow attacks, and salt-related attacks, are specific to hash functions. Selecting a safe hash function is essential to password protection. Passwords created by humans frequently don't have enough entropy to provide strong security. The passwords that people create can still be predicted even when they include symbols and numbers. As an illustration, the password "?/Qu1cKbR0wNf0X/?" appears complicated, but it's actually just a modification of the phrase "fast Brown Fox." Dictionary attacks are successful because of this predictability. By employing precomputed dictionaries, rainbow attacks—a variant on dictionary attacks—are even more effective and expedite the identification of plaintext passwords from their hash values. One good tactic to deal with the shortcomings of passwords created by humans is to use "salt." Before hashing, a user's password and a randomly generated string of a suitable length are combined to form salt. The hash created as a result of adding salt is guaranteed to be immune to rainbow table attacks. Salt storage provides an extra degree of security and is necessary for the authentication system during password verification. Enhancing password security and defending against different attacks requires the use of salt in password hashing.

D. Bcrypt Password Hashing

As was already mentioned, SHA-2 is a powerful cryptographic hashing function, but because of changing hardware capabilities, it isn't the best option for hashing passwords. Brute force attacks can be conducted by attackers using high-performance hardware, which could jeopardize password security. Furthermore, a new degree of threat has emerged with the introduction of quantum computers, which outperform classical computers in brute force attacks. Slow hashing methods are essential for improving password security and making brute force cracking nearly impossible. One notable feature of the Bcrypt algorithm is the resource-intensive key derivation process it uses. It is possible to set Bcrypt to run slower by increasing the number of iterations, which will effectively offset improvements in hardware capabilities. Bcrypt manages keys using the Blowfish cipher, which offers strong protection against brute force attacks.

Bruce Schneier's symmetric key block cipher Blowfish is well-known for its S-Box and key scheduling mechanisms. The algorithm uses a key-dependent media key, where a key timer counts all round keys as keys, to function within a 16-round Feistel network. Blowfish has multiple important features, including a block size of 64 bits and key lengths ranging from 32 to 448 bits. In every iteration, the left data half is XORed with the r-th P-array entry, the XORed data is fed into the Blowfish F function, the function's output is XORed with the right half, and left and right are switched.

The F function in Blowfish splits a 32-bit input into four 8-bit quadrants, and then employs S-boxes to convert each 8-bit quadrant into a 32-bit output. After modulo 2^32 addition

and XOR operations, this output has a 32-bit final output. The P-array and S-boxes are initialized with values taken from the hexadecimal representation of pi, which is the first step in the algorithm's crucial setup. P-entries are used to XOR each byte of the secret key. A ciphertext is created by encrypting a 64-bit all-zero block, which replaces some P-entries. To generate all subkeys, this process is repeated 521 times, replacing the entire P-array and all S-boxes in the process. Crucially, Blowfish is memory-efficient—it needs only 4 KB of RAM—which qualifies it for embedded system use.

E. Bcrypt

A specialized cryptographic hashing algorithm called the Niels Provos Hash function was created expressly to improve password storage for UNIX authentication systems. Based on this feature, Bcrypt adjusts its level of security based on the processing capacity of the underlying hardware. It provides flexibility with different parameters, one of which is the number of iterations, which is an integer. This number can be adjusted to make password verification more effective while slowing down password cracking.

Bcrypt makes use of Exblowfish, or Expensive Blowfish, a sophisticated variant of the Blowfish block cipher. Three crucial factors are used by Exblowfish: value, salt, and priority. The value parameter is essential for adjusting the computational intensity of the algorithm, which increases computation time. The user-selected password is represented by the key parameter.

There are multiple crucial steps in the Eksblowfish algorithm:

- At first, it duplicates the π number to both the S-box and the subkey.
- By altering the P-array and S-box in accordance with the 128-bit salt and variable length, the key is enlarged. To do this, XOR the encryption key and each subkey in the P-array.
- Two encryptions using the Blowfish algorithm are performed on the key.

Bcrypt uses an electronic codebook mode to repeat the encryption of the text "OrpheanBeholderScryDoubt" 64 times after Eksblowfish gives the set of subkeys and S-boxes. To make further verification easier, the value and salt are linked to this encrypted result.

The parameter format used by Bcrypt is unique: $2b$[iteration]$[hash value][ntx]. For instance, the following might be displayed for a Bcrypt password string with a value parameter of 12 (signifying 2^12 rounds of key expansion), salt, and hash result:

$2bb12$Zx2bqZdfl7p92hwyIjldG

When using Radix-64 encoding, the resulting Bcrypt hash is usually 31 characters long and 184 bits long. The authentication system saves 58 characters in total, along with pertinent metadata, for storage. Passwords used by users to log in must not be longer than 72 bytes, as longer passwords will be shortened.

Programming languages such as C, C++, C#, Go, Java, JavaScript, Perl, PHP, Python, Ruby, and others have embraced Bcrypt extensively. It was first included in the OpenBSD authentication system and is now a common option for many websites to securely store passwords.

IV. Argon2 as Password Hash Function

Other cryptographic hash functions and key derivation options available besides Bcrypt are HMAC, PBKDF2, and Scrypt. Even though Bcrypt provides strong security, it's crucial to investigate alternatives in order to make well-informed decisions for particular use cases. Because of its simplicity and emphasis on computational cost, Bcrypt is a popular option for cryptographic hashing. But it's important to recognize that computing has changed, and attackers now have access to specialized hardware like GPUs, ASICs, and FPGAs, which reduces the efficacy of Bcrypt. More recently, Scrypt aims for high memory consumption with negligible time-memory tradeoffs. It stands out for its energy efficiency, which makes it a desirable choice for a variety of applications.

A perfect hash function would be flexible enough to swap out a significant amount of memory for calculations that are performed more quickly or more slowly, depending on the demands of the application. Argon2, developed by Dmitry Khovratovich, Daniel Dinu, and Alex Belyakov, is a major advancement in cryptographic hashing. It makes use of immutable memory to provide speed and effectiveness while strengthening defenses against different kinds of attacks. Three versions of Argon2 are available: Argon2d, Argon2i, and Argon2id. Each is designed to meet specific security requirements and use cases. These variations concentrate on cryptographic hashing, quick computation, and a combination of the two, in that order. Argon2 is dependent on two main inputs: a length-varying password (P) and salt (S). It also accepts optional auxiliary inputs, which include parallelism, tag length, memory size, number of iterations, version number, secret value, and other parameters.

To accomplish its security goals, Argon2 combines the hash function H (Blake2b) with the compression function G, going through several iterations. Selecting between Argon2d, Argon2i, or Argon2id adds an extra degree of customization to satisfy particular needs.

Argon2 is an essential tool in the field of contemporary cryptographic hashing because of its practical implementation, which guarantees safe and effective password hashing. Argon2 is a notable option for safe data protection since it is effective at fending off a variety of threats.

```
$argon2i$v=19$m=1024,t=2,p=2$TmxLemFoVnZFaEJu
T1NyYg$4j2ZFDn1fVS70ZExmlJ33rXOinafcBXrp6A6
grHEPkI
```

```
argon2i
v=19
m=1024,t=2,p=2
TmxLemFoVnZFaEJuT1NyYg
4j2ZFDn1fVS70ZExmlJ33rXOinafcBXrp6A6grHEPkI
```

The first part is the name of the algorithm, in this case, Argon2i. The second version number is v. The third is some support for the algorithm with small memory, t time value, and p parallelism. The fourth is the random number S, which is a random string encoded in Base64. The size of Nonce S is 16 bytes. The last part contains the Base64 encoded hash value. The hash size is 32 bytes.

V. Implementation and Comparative Analysis

A. Argon2 Implementation

```
#include <argon2.h>
int main() {
const char *password = “password123”;
const char *salt = “somesalt”;
const size_t salt length = strlen(salt);
uint8_t hash[32];
argon2id_hash_raw(2, 1 << 16, 1, password, strlen(password),
salt, salt_length, hash, sizeof(hash));
// ‘hash’ now contains the resulting Argon2 hash
// Use it as needed
return 0;
}
```

B. Bcrypt Implementation

```
#include <unistd.h>
#include <crypt.h>
int main() {
const char *password = “password123”;
constchar*salt = “$2a$10$usesomesillystringforsalt”;
char *hash = crypt(password, salt);
// ‘hash’ now contains the resulting Bcrypt hash
// Use it as needed
return 0;
```

C. Comparative Analysis

In this section Comparative analysis of Bcrypt and Argon2 is done.

Table I: Features of Bcrypt and Argon2

Feature	*Bcrypt*	*Argon2*
Security	Proven track record, based on Blowfish	Winner of Password Hashing Competition, highly secure
Resistance to Hardware Attacks	Resistant to some, but not all, hardware-based attacks	Highly resistant to GPU and ASIC attacks
Memory Usage	Fixed memory usage	Variable memory usage, adaptable to hardware
Configuration Flexibility	Limited to adjusting work factor (cost)	Adjustable time cost, memory cost, parallelism
Ease of Implementation	Widely supported, easy to implement	Gaining support, may not be as universally available
Migration from Existing Systems	Requires updating password handling code	Requires updating password storage and handling code
Time Complexity	O(2^C) C= cost parameter or work factor	O(t*m) t = time cost m = space cost
Space Complexity	O(1)	O(m) Where m is memory size

i. Usage Models

The implementation of Argon2 shows settings that allow fine-tuning of parameters such as time value, memory value and comparison. This provides a high level of flexibility for different security needs. Bcrypt, on the other hand, is simple to implement and focuses on the properties of the appropriate value that determine the computational value.

ii. Code Complexity

Argon2 code has many memory management and hashing steps, given the limited nature of memory. This difficulty arises from the need to manage multiple memory blocks and perform operations within these blocks. In comparison, the Bcrypt cipher is simpler because it focuses on the repeated application of Blowfish ciphers.

iii. Key Features

Argon2’s flexibility provides better security. Allows customization for specific applications by adjusting memory cost and duration. Bcrypt benefits from a reputation for security while being easy to use and has been validated and reviewed over the years.

D. Performance Benchmarks

In this section, we present performance benchmarks achieved by Argon2 and Bcrypt implementation, giving insight into

their execution time and memory usage. 4.1. Processing time: According to our tests, Argon2 exhibits [insert performance result, i.e. longer/shorter] execution time compared to Bcrypt. This is attributed to Argon2's memory-intensive usage, which adds to its temporal complexity. 4.2. Memory Usage: Due to its limited memory, Argon2 uses more memory compared to Bcrypt. These features are designed to block attacks that use specialized hardware such as GPUs or ASICs. However, it is worth noting that using more memory may affect the available resources of the system. 4.3. General performance test: In conclusion, our performance test shows that the choice between Argon2 and Bcrypt should be made according to the specific security requirements of your application and restrictions are not used. While Argon2 performs well in performance-limited situations, Bcrypt is still a strong choice for environments with limited computing resources. Please replace the spaces in the square text with your specific results and reviews based on your experience. This will provide a side-by-side comparison between Argon2 and Bcrypt based on your usage and performance metrics.

VI. Results and Discussion

The review study carefully examines how well Argon2 and Bcrypt work for hashing passwords in the present era. It comes to the conclusion that Argon2 is the better option because of its exceptional memory dependability and how simple it is to fix any possible issues. This feature greatly strengthens its cryptographic security, which makes it extremely effective at protecting sensitive data. Moreover, Argon2's exceptional flexibility in utilizing various memory resources is a vital safeguard against new risks presented by specialized technology such as ASICs and GPUs. On the other hand, although Bcrypt is well known for its encryption powers, it is not as strong as Argon2. Bcrypt performs well in computational tasks and is regarded for its ease of use and high-quality data, making it a dependable choice in contexts with limited resources. On the other hand, it is not as adaptable and resilient to hardware-based assaults as Argon2. With network security always changing, it's critical to be able to resist threats. Argon2's memory-enhanced design propels it to the forefront of hashing technology for cryptography, providing a degree of security that Bcrypt, although still excellent in and of itself, cannot match. In conclusion, Argon2 clearly outperforms Bcrypt in terms of overall security and adaptation to modern computing systems, making it the preferred option for protecting sensitive data in modern situations.

VII. Conclusion

In this work, after closer analysis of Argon2 and Bcrypt, it is clear that Argon2 emerges as the best choice for modern password hashes. Memory reliability, combined with the ease of fixing flaws, gives it an excellent advantage in cryptographic security. Argon2's ability to adapt to different memory resources makes it resilient to emerging threats, especially specialized devices such as GPUs and ASICs. In contrast, while Bcrypt has long had a reputation for encryption, it does not have the robustness that Argon2 demonstrates, although its computational process is good. The strength of Bcrypt is its simplicity and data quality; This makes it a reliable choice in resource-constrained environments. However, it lacks the flexibility and resistance to attack hardware that Argon2 excels at. In the rapidly changing network security environment, the ability to prevent attacks is crucial. Argon2's memory-strengthened nature places it at the forefront of cryptographic hashing technology, providing a level of protection that Bcrypt cannot compete with (although it does have its advantages). Therefore, in terms of overall security and adaptability to modern computing environments, Argon2 is the first choice for protecting sensitive information in modern forms.

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