What Is AES Encryption and How Does It Work?

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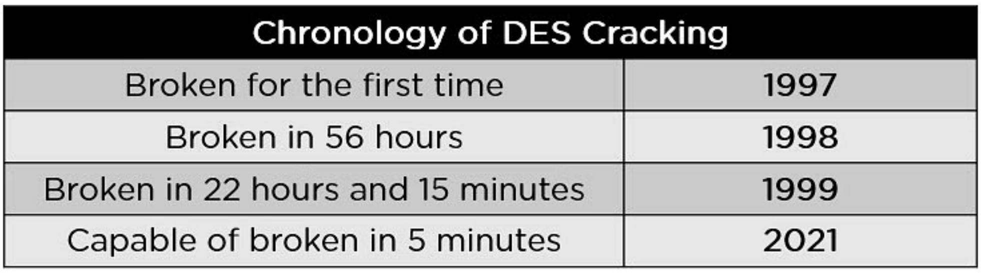
Encryption has found a place in today's digital world, by cultivating a culture of security and privacy. When the AES Encryption algorithm succeeded the Data Encryption Standard as the global standard for encryption algorithms in 2001, it fixed many shortcomings of its predecessor. It was seen as the future for encryption in daily life applications. So far, the Advanced Encryption Standard has achieved the targets placed during its inception. And it has a long way to grow.

Why Was the AES Encryption Algorithm necessary?

When the Data Encryption Standard algorithm, also known as the DES algorithm, was formed and standardized, it made sense for that generation of computers. Going by today's computational standards, breaking into the DES algorithm became easier and faster with every year, as seen in the image below.



Chronology of DES Cracking	
Broken for the first time	1997
Broken in 56 hours	1998
Broken in 22 hours and 15 minutes	1999
Capable of broken in 5 minutes	2021

Source: Wikipedia

A more robust algorithm was the need of the hour, with longer key sizes and stronger ciphers to break into. They created the triple DES to fix this problem, but it never became mainstream because of its relatively slower pace. Thus, the Advanced Encryption Standard came into existence to overcome this drawback.

What is the Advanced Encryption Standard?

The AES Encryption algorithm (also known as the Rijndael algorithm) is a symmetric block cipher algorithm with a block/chunk size of 128 bits. It converts these individual blocks using keys of 128, 192, and 256 bits. Once it encrypts these blocks, it joins them together to form the ciphertext.

It is based on a substitution-permutation network, also known as an SP network. It consists of a series of linked operations, including replacing inputs with specific outputs (substitutions) and others involving bit shuffling (permutations).

In this tutorial, you will go through some of the standout features that AES offers as a globally standardized encryption algorithm.

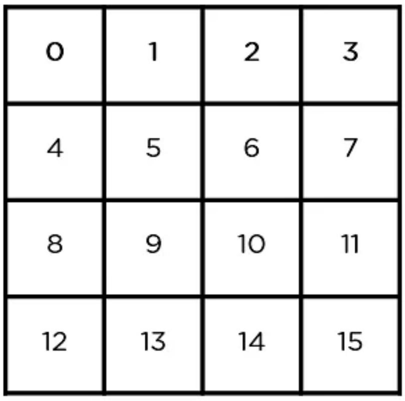
What are the Features of AES?

1. SP Network: It works on an SP network structure rather than a Feistel cipher structure, as seen in the case of the DES algorithm.
2. Key Expansion: It takes a single key up during the first stage, which is later expanded to multiple keys used in individual rounds.
3. Byte Data: The AES encryption algorithm does operations on byte data instead of bit data. So it treats the 128-bit block size as 16 bytes during the encryption procedure.
4. Key Length: The number of rounds to be carried out depends on the length of the key being used to encrypt data. The 128-bit key size has ten rounds, the 192-bit key size has 12 rounds, and the 256-bit key size has 14 rounds.

How Does AES Work?

To understand the way AES works, you first need to learn how it transmits information between multiple steps. Since a single block is 16 bytes, a

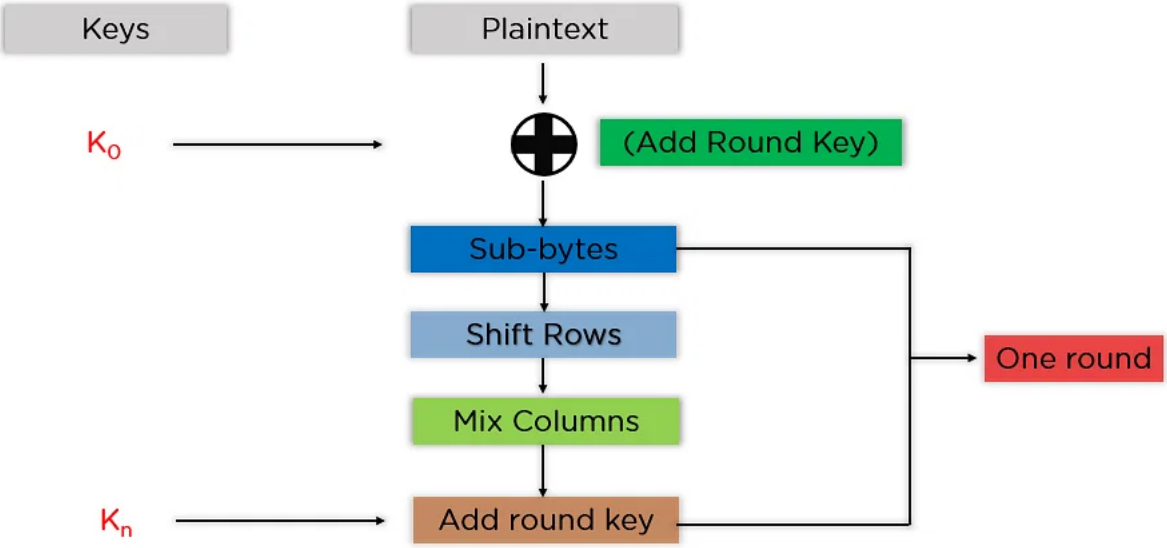
To understand the way AES works, you first need to learn how it transmits information between multiple steps. Since a single block is 16 bytes, a 4x4 matrix holds the data in a single block, with each cell holding a single byte of information.



0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

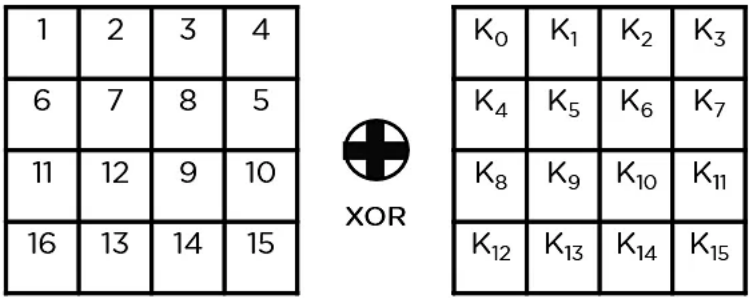
The matrix shown in the image above is known as a state array. Similarly, the key being used initially is expanded into (n+1) keys, with n being the number of rounds to be followed in the encryption process. So for a 128-bit key, the number of rounds is 16, with no. of keys to be generated being 10+1, which is a total of 11 keys.

Steps to be followed in AES



The mentioned steps are to be followed for every block sequentially. Upon successfully encrypting the individual blocks, it joins them together to form the final ciphertext. The steps are as follows:

- Add Round Key: You pass the block data stored in the state array through an XOR function with the first key generated (K0). It passes the resultant state array on as input to the next step.

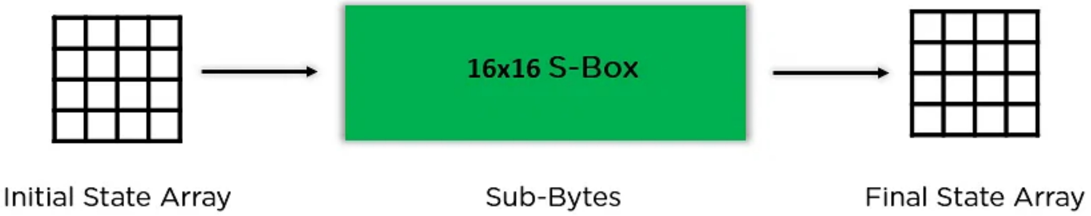


1	2	3	4
6	7	8	5
11	12	9	10
16	13	14	15

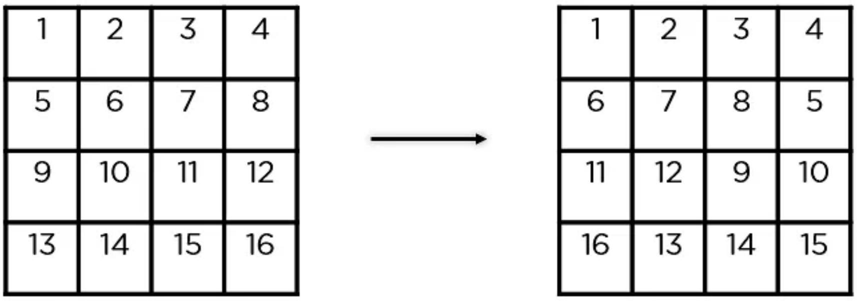
XOR

K_0	K_1	K_2	K_3
K_4	K_5	K_6	K_7
K_8	K_9	K_{10}	K_{11}
K_{12}	K_{13}	K_{14}	K_{15}

- Sub-Bytes: In this step, it converts each byte of the state array into hexadecimal, divided into two equal parts. These parts are the rows and columns, mapped with a substitution box (S-Box) to generate new values for the final state array.



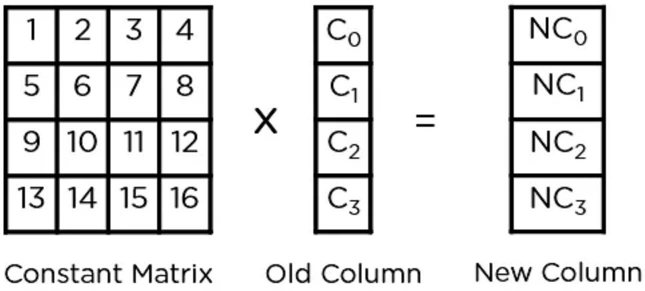
- Shift Rows: It swaps the row elements among each other. It skips the first row. It shifts the elements in the second row, one position to the left. It also shifts the elements from the third row two consecutive positions to the left, and it shifts the last row three positions to the left.



1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

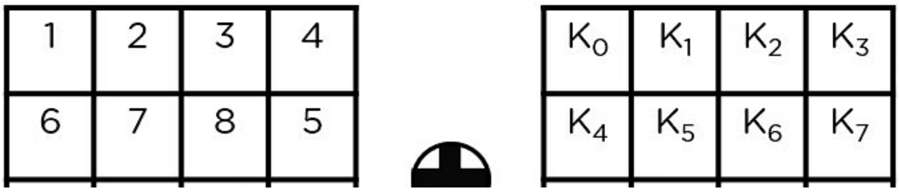
1	2	3	4
6	7	8	5
11	12	9	10
16	13	14	15

- Mix Columns: It multiplies a constant matrix with each column in the state array to get a new column for the subsequent state array. Once all the columns are multiplied with the same constant matrix, you get your state array for the next step. This particular step is not to be done in the last round.



$$\begin{bmatrix}1&2&3&4\\5&6&7&8\\9&10&11&12\\13&14&15&16\end{bmatrix} \times \begin{bmatrix}C_0\\C_1\\C_2\\C_3\end{bmatrix} = \begin{bmatrix}NC_0\\NC_1\\NC_2\\NC_3\end{bmatrix}$$

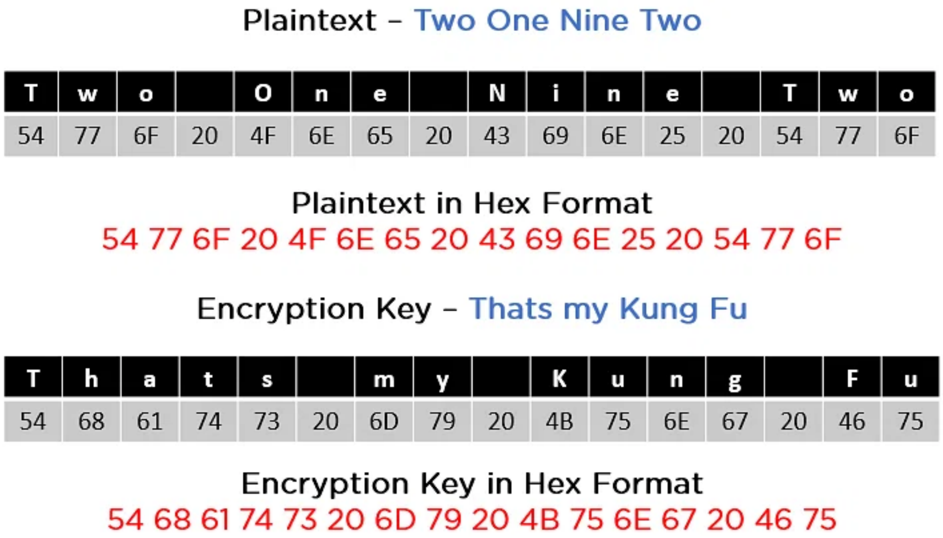
- Add Round Key: The respective key for the round is XOR'd with the state array is obtained in the previous step. If this is the last round, the resultant state array becomes the ciphertext for the specific block; else, it passes as the new state array input for the next round.



1	2	3	4
6	7	8	5

K_0	K_1	K_2	K_3
K_4	K_5	K_6	K_7

Now that you understand the basic steps needed to go through the encryption procedure, understand this example to follow along.



Plaintext – Two One Nine Two

T	w	o		O	n	e		N	i	n	e		T	w	o
54	77	6F	20	4F	6E	65	20	43	69	6E	25	20	54	77	6F

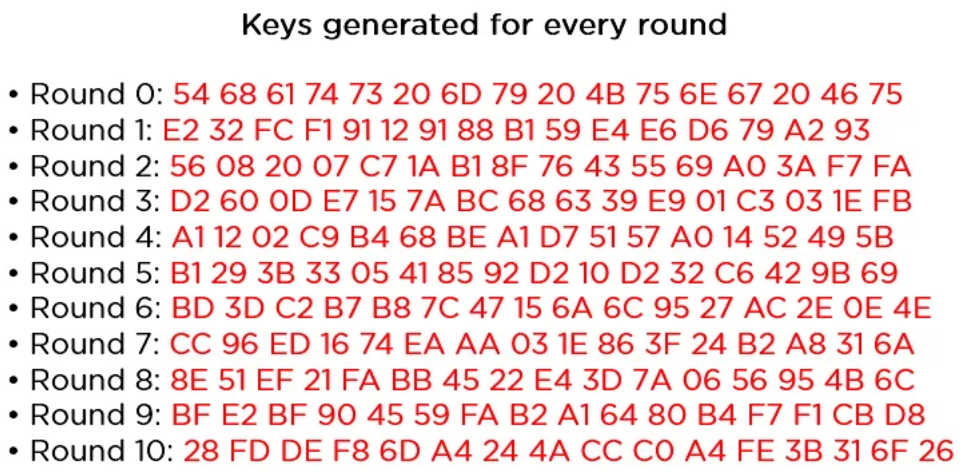
Plaintext in Hex Format
54 77 6F 20 4F 6E 65 20 43 69 6E 25 20 54 77 6F

Encryption Key – Thats my Kung Fu

T	h	a	t	s		m	y		K	u	n	g		F	u
54	68	61	74	73	20	6D	79	20	4B	75	6E	67	20	46	75

Encryption Key in Hex Format
54 68 61 74 73 20 6D 79 20 4B 75 6E 67 20 46 75

As you can see in the image above, the plaintext and encryption convert keys to hex format before the operations begin. Accordingly, you can generate the keys for the next ten rounds, as you can see below.

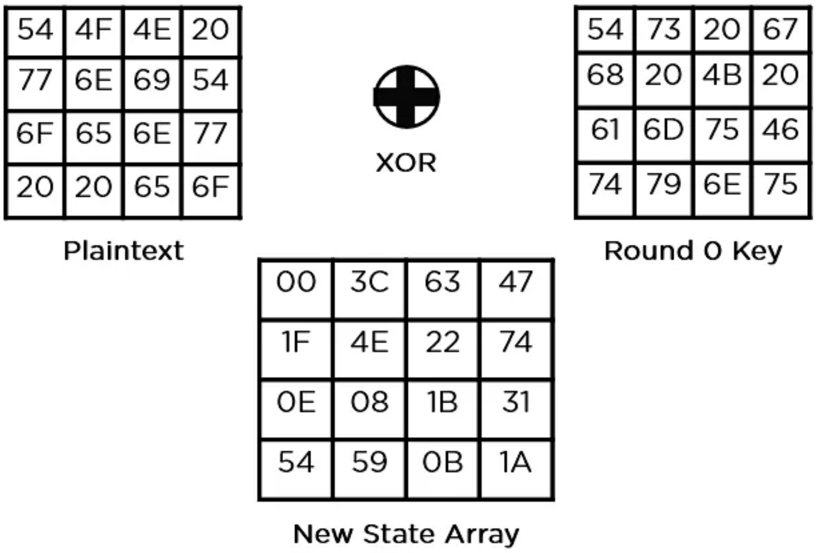


Keys generated for every round

- Round 0: 54 68 61 74 73 20 6D 79 20 4B 75 6E 67 20 46 75
- Round 1: E2 32 FC F1 91 12 91 88 B1 59 E4 E6 D6 79 A2 93
- Round 2: 56 08 20 07 C7 1A B1 8F 76 43 55 69 A0 3A F7 FA
- Round 3: D2 60 0D E7 15 7A BC 68 63 39 E9 01 C3 03 1E FB
- Round 4: A1 12 02 C9 B4 68 BE A1 D7 51 57 A0 14 52 49 5B
- Round 5: B1 29 3B 33 05 41 85 92 D2 10 D2 32 C6 42 9B 69
- Round 6: BD 3D C2 B7 B8 7C 47 15 6A 6C 95 27 AC 2E 0E 4E
- Round 7: CC 96 ED 16 74 EA AA 03 1E 86 3F 24 B2 A8 31 6A
- Round 8: 8E 51 EF 21 FA BB 45 22 E4 3D 7A 06 56 95 4B 6C
- Round 9: BF E2 BF 90 45 59 FA B2 A1 64 80 B4 F7 F1 CB D8
- Round 10: 28 FD DE F8 6D A4 24 4A CC C0 A4 FE 3B 31 6F 26

You need to follow the same steps explained above, sequentially extracting the state array and passing it off as input to the next round. The steps are as follows:

- Add Round Key:



54	4F	4E	20
77	6E	69	54
6F	65	6E	77
20	20	65	6F

Plaintext

54	73	20	67
68	20	4B	20
61	6D	75	46
74	79	6E	75

Round 0 Key

00	3C	63	47
1F	4E	22	74
0E	08	1B	31
54	59	0B	1A

New State Array

- Sub-Bytes: It passes the elements through a 16x16 S-Box to get a completely new state array.

- Shift Rows:

- Mix Columns:

- Add Round Key:

This state array is now the final ciphertext for this particular round. This becomes the input for the next round. Depending on the key length, you repeat the above steps until you complete round 10, after which you receive the final ciphertext.

Now that you understand how AES works, go through some of the applications of this encryption algorithm.

What Are the Applications of AES?

The applications of the AES Encryption algorithm are as follows:

1. Wireless Security: Wireless networks are secured using the Advanced Encryption Standard to authenticate routers and clients. WiFi networks have firmware software and complete security systems based on this algorithm and are now in everyday use.

2. Encrypted Browsing: AES plays a huge role in securing website server authentication from both client and server end. With both symmetric and asymmetric encryption being used, this algorithm helps in SSL/TLS encryption protocols to always browse with the utmost security and privacy.

3. General File Encryption: Apart from corporate necessities, AES is also used to transfer files between associates in an encrypted format. The encrypted information can extend to chat messages, family pictures, legal documents, etc.

4. Processor Security: Many processor manufacturers enable hardware-level encryption using the likes of AES encryption to bolster security and prevent meltdown failures, among other low-profile risks.

Now that you learned about the applications of AES encryption, take a look at its upgrades over its predecessor, the DES encryption algorithm.

Differences Between AES & DES

DES Algorithm	AES Algorithm
Key Length - 56 bits	Key Length - 128, 192, 256 bits
Block Size - 64 bits	Block size - 128 bits
Fixed no. of rounds	No. of rounds dependent on key length
Slower and less secure	Faster and more secure

FAQs

1. Is AES encryption secure?

AES encryption is secure; however, its security varies according to its variants. For example, using brute-force methods, the 256-bit is virtually impenetrable, while the 52-bit DES key can be cracked in less than a day.

2.Is AES the best encryption method?

Because of its key length options, AES encryption remains the best choice for securing communications. The time required to crack an encryption algorithm is directly related to the length of the key used, i.e., 128-bit, 192-bit, and 256-bit.

3. What is AES encryption used for?

AES is implemented in hardware and software worldwide to encrypt sensitive data. It is a symmetric block cipher essential for government computer security, electronic data protection, and cybersecurity.

4. Which is better: RSA or AES?

RSA is considerably slower and more computationally intensive than AES. RSA has to deal with large numbers and calculations, which makes it slower. AES is considered secure against analysis with quantum computers and is generally used by various organizations.

5. Is AES free to use?

AES is available for free, and anyone can use it. Though several countries apply export restrictions, it is an open standard that is free to use for any private, public, non-commercial, or commercial use.

6. What is AES?

Advanced Encryption Standard is a symmetric block cipher chosen by the US government. It converts the individual blocks using different keys. It is one of the best encryption protocols available, letting anyone enjoy their daily online activities without disruption.

How Can Simplilearn Help You?

With this, you have seen the impact AES Encryption has on the global stage, with many systems needing a secure channel of authentication as DES collapsed. With many bases to cover in cybersecurity, cryptography is one of the most crucial aspects, even though several other topics are essential to excel as a cybersecurity expert.

Simplilearn offers a "Cybersecurity Expert" course designed to equip you with all the skills necessary to start or promote your career in cybersecurity. It doesn't have any academic pre-requirements, and the introductory module will prepare beginners for the course ahead. Training for highly sought-after certifications like CompTIA Security+, CEH, CISM, and CISSP is at the forefront of this course, preparing you for the best jobs being offered in the industry.

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Conclusion

This tutorial explores the need for AES Encryption, its origin and process of encryption, all the way up to its applications, and a direct comparison with the DES algorithm. Hope this tutorial has been of value to you.

If you are looking to learn further on encryptions, cryptography and other fundamental concepts and skills in cybersecurity, Simplilearn's Advanced Executive Program In Cyber Security program should be a great fit for you. This program covers all the fundamental and advanced aspects of cybersecurity and provides you the right job-ready training you need to become a world-class cybersecurity expert today. Explore the program today.

Do you have any questions for us regarding this AES encryption tutorial? Please don't hesitate to mention them in the comment section of this tutorial, and we'd be happy to have our experts answer them for you.

About the Author

Baivab Kumar Jena

Baivab Kumar Jena is a computer science engineering graduate, he is well versed in multiple coding languages such as C/C++, Java, and Python.

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