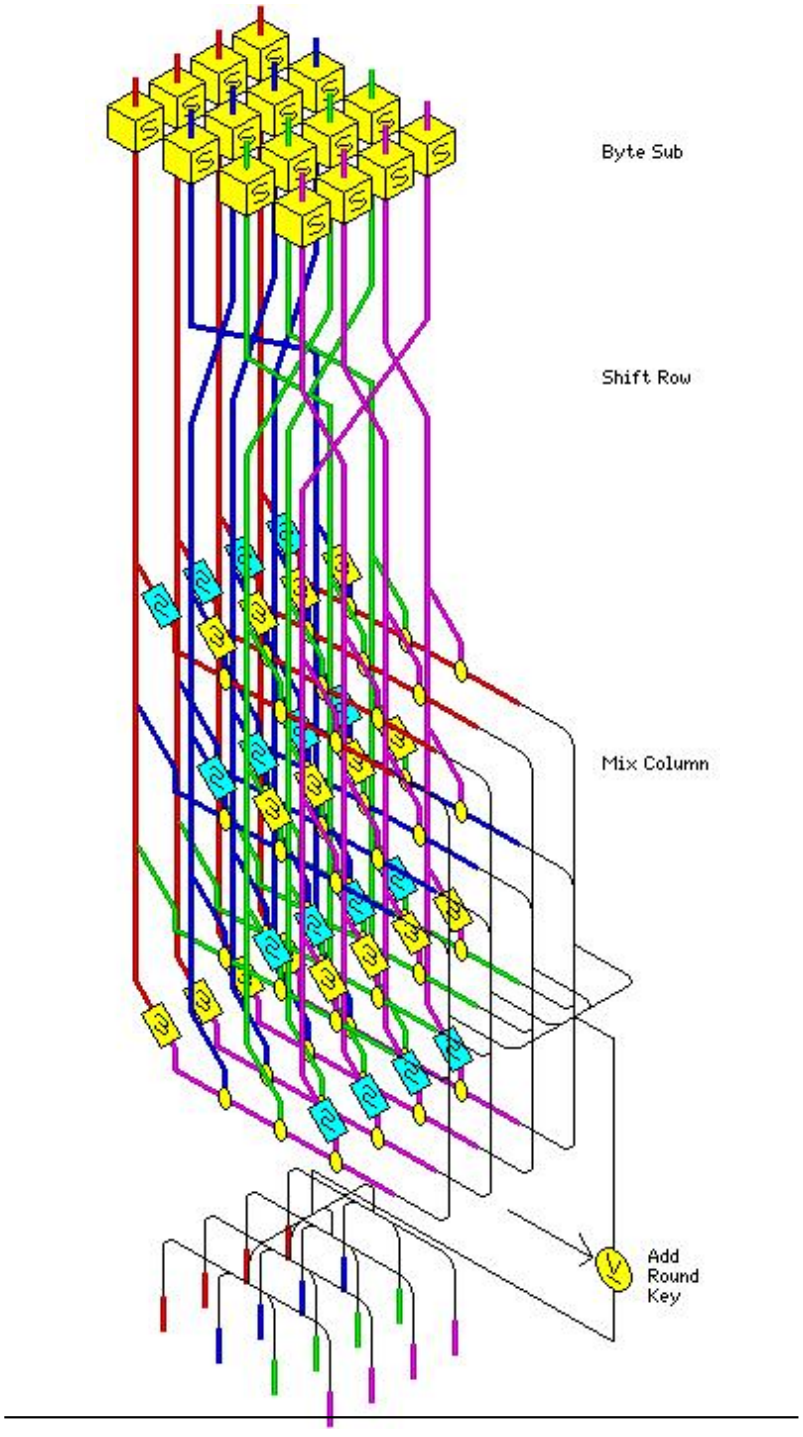


Image Source: Google

CS 553

CRYPTOGRAPHY

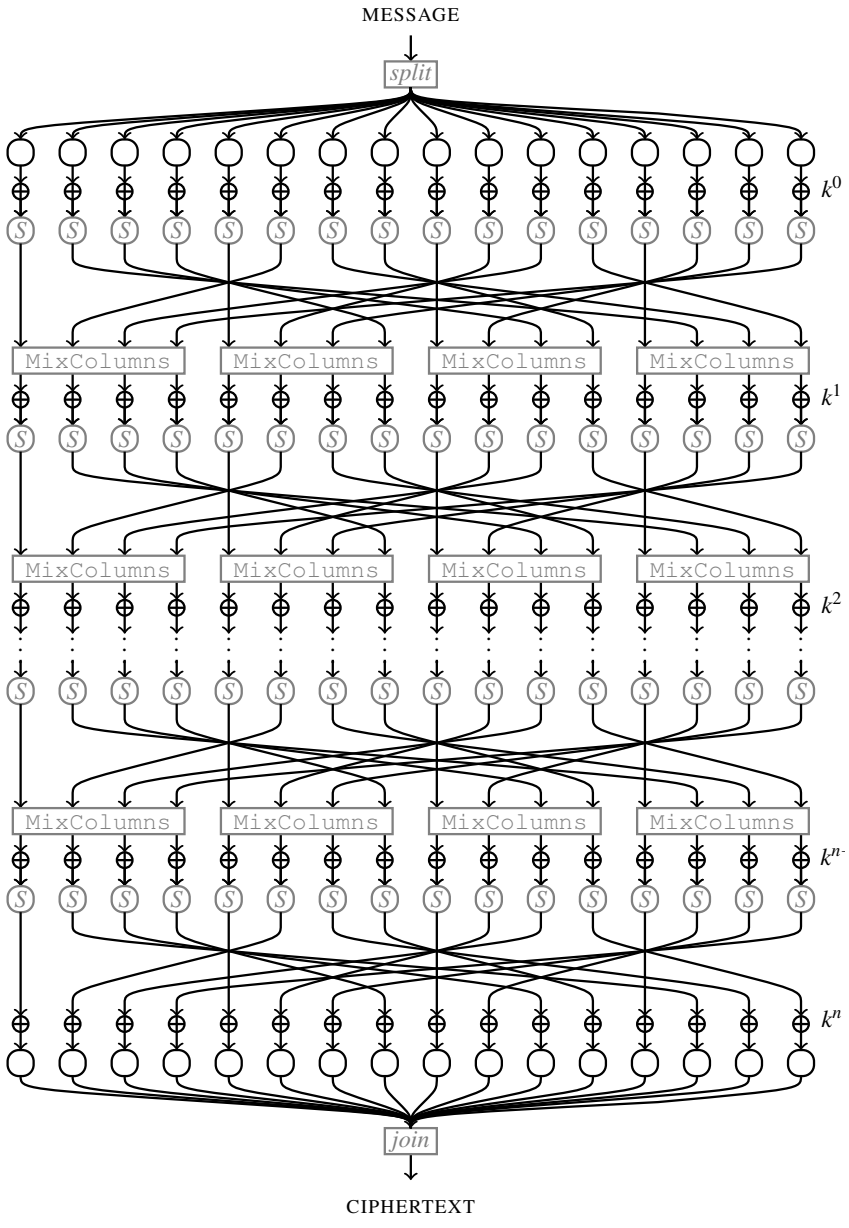
Lecture 11

The Story of AES

Instructor

Dr. Dhiman Saha

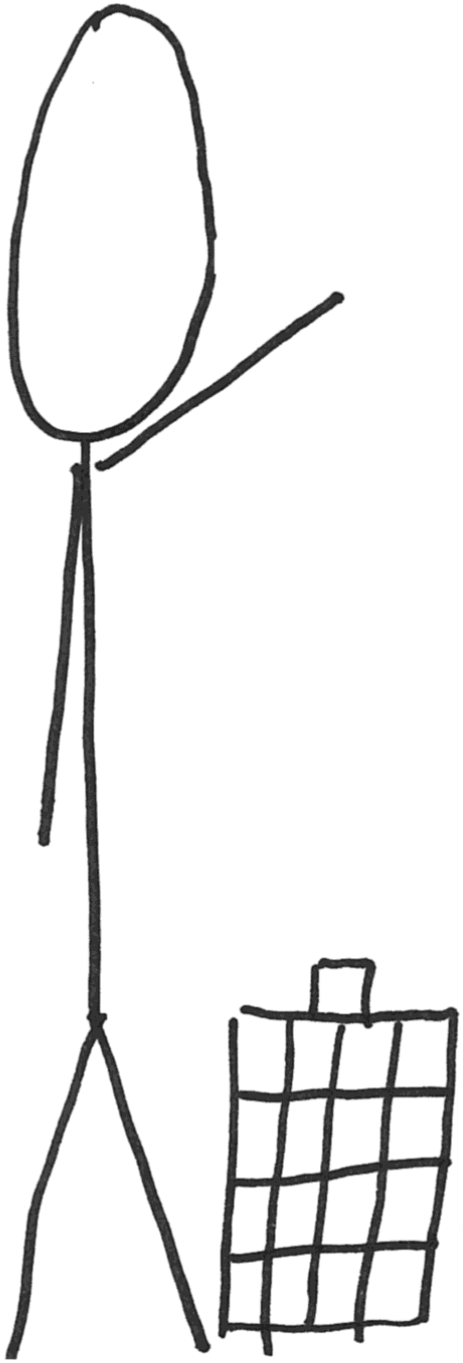
AES — The Advanced Encryption Standard



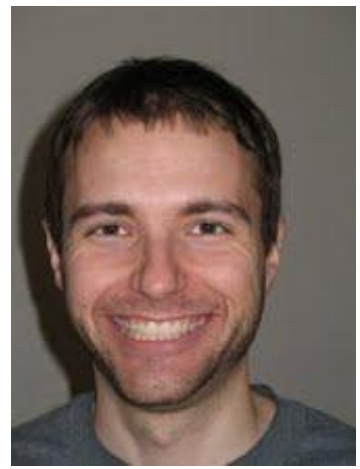
- Winner of AES competition: Rijndael - SPN Design
- Designed by Vincent Rijmen & John Daemen
- One of the most widely studied cryptographic algorithms
- Used almost everywhere
- With microprocessor-level instruction support

Probably the best intro to AES

Slides from Jeff Moser



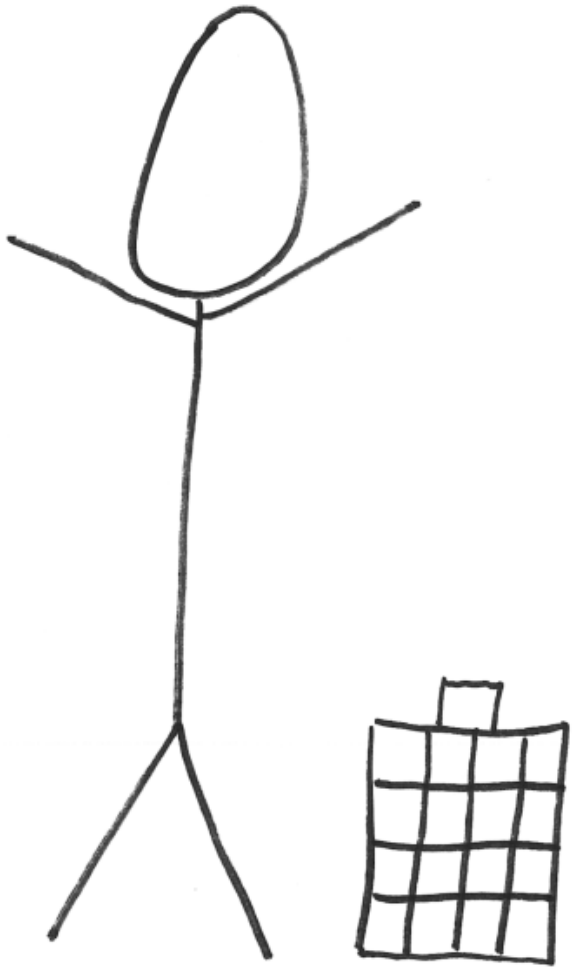
A Stick Figure Guide to the Advanced Encryption Standard (AES)



http://www.moserware.com/

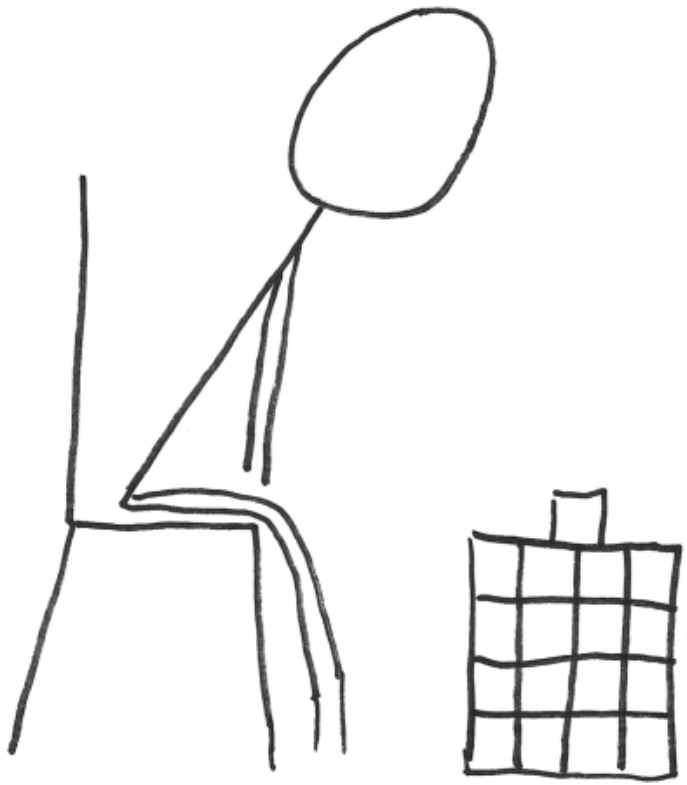
Act 1: Once Upon a Time…

I handle petabytes* of data every day. From encrypting juicy Top Secret intelligence to boring packets bound for your WiFi router, I do it all!

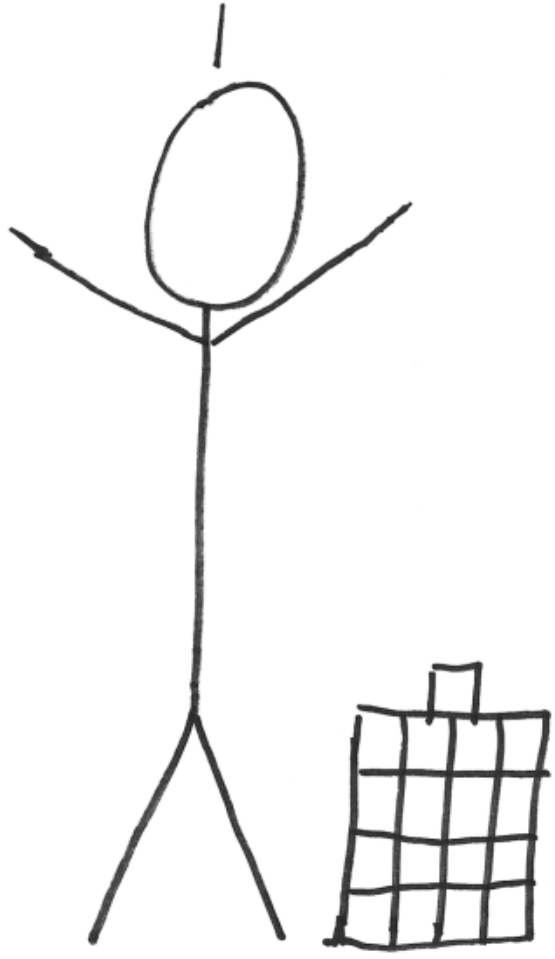


* 1 petabyte ≈ a lot

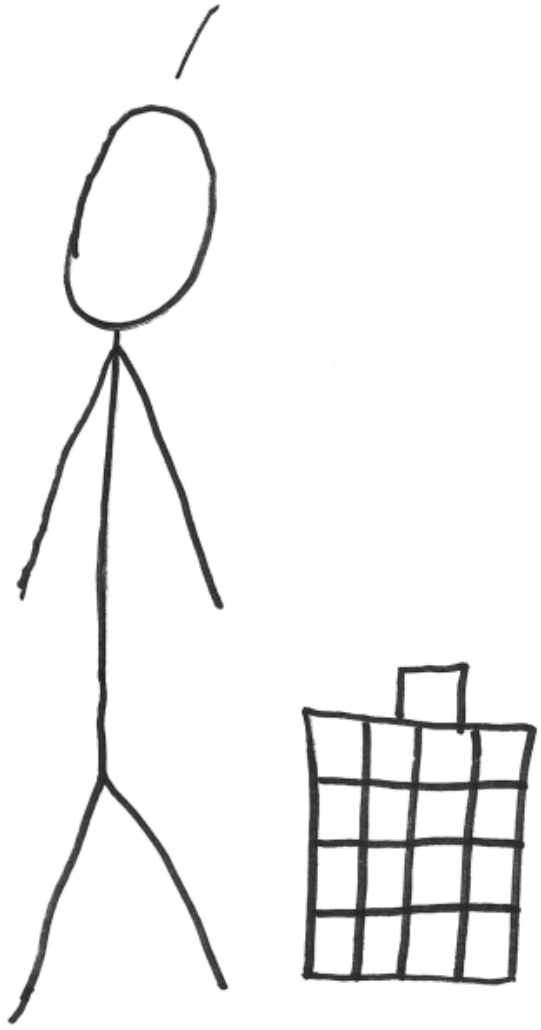
... and still no one seems to care about me or my story.



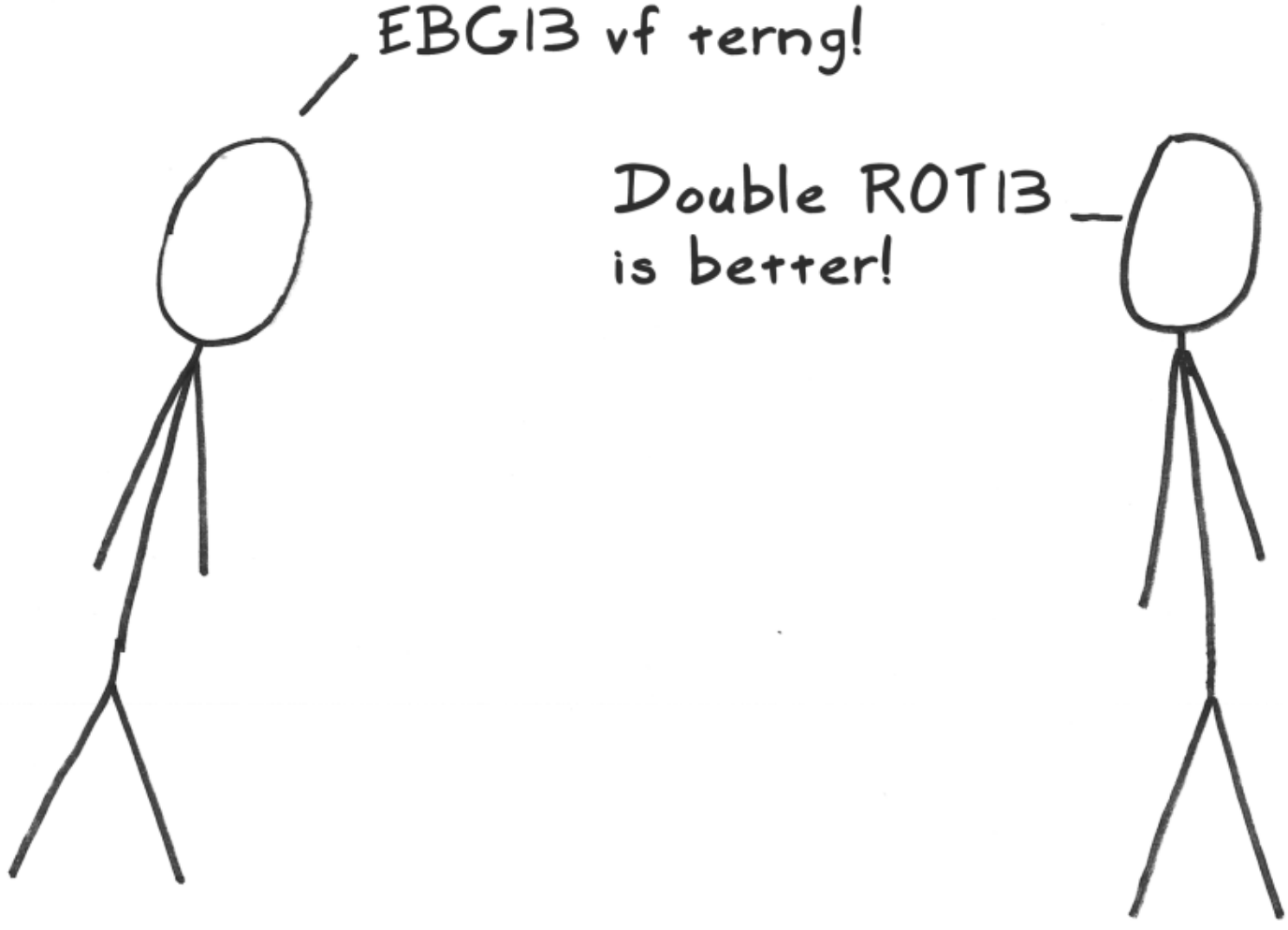
I've got a better-than-Cinderella story as I made my way to become king of the block cipher world.



Whoa! You're still there. You want to hear it? Well let's get started...



Once upon a time,* there was no good way for people outside secret agencies to judge good crypto.

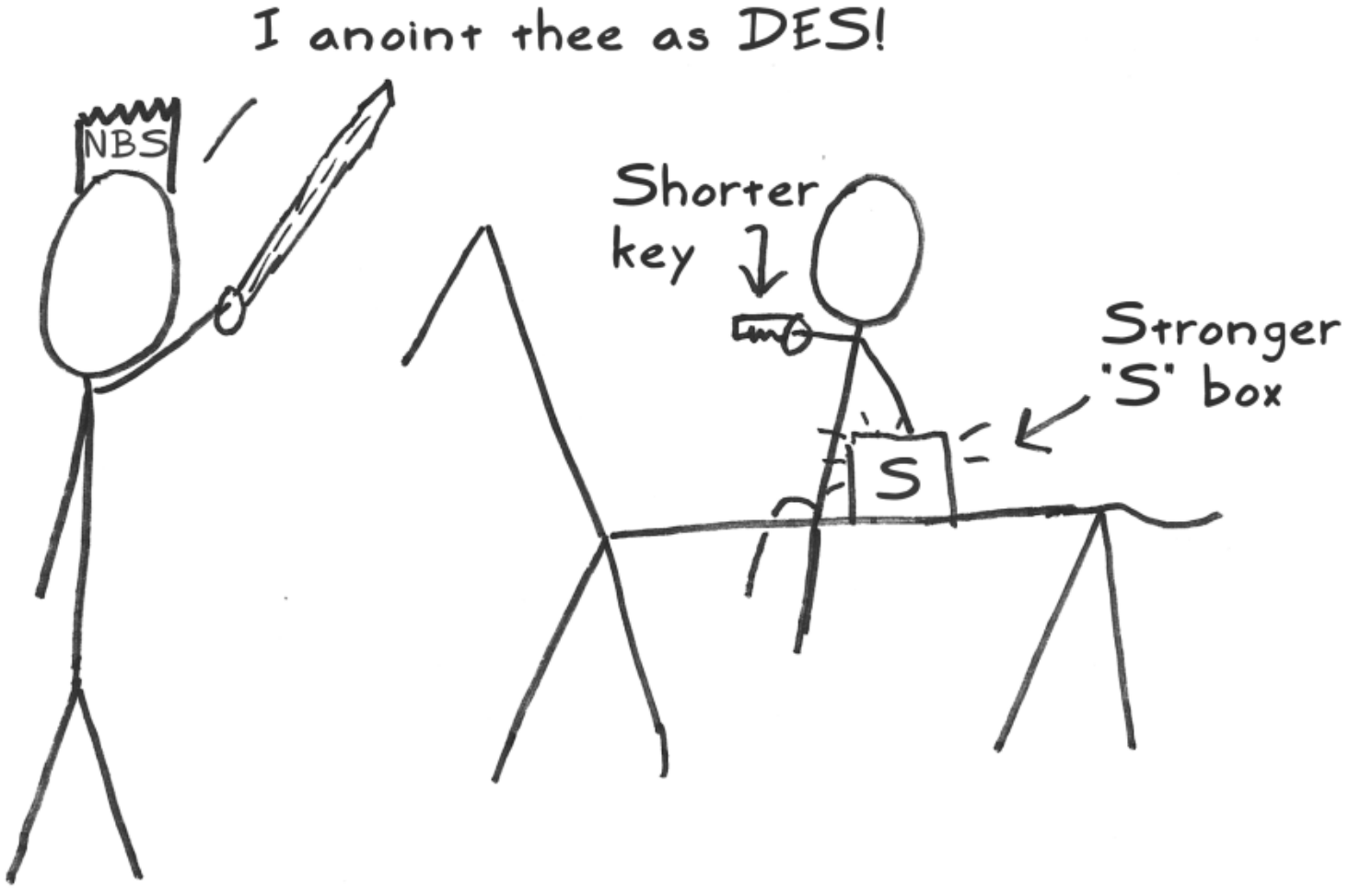


* ~ pre-1975 for the general public

A decree went throughout the land to find a good, secure, algorithm.

One worthy competitor named Lucifer came forward.

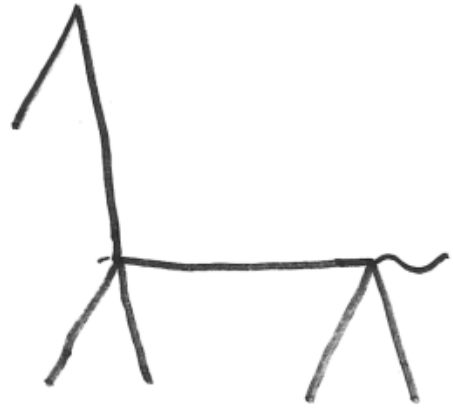
After being modified by the National Security Agency (NSA), he was anointed as the Data Encryption Standard (DES).



DES ruled in the land for over 20 years. Academics studied him intently. For the first time, there was something specific to look at. The modern field of cryptography was born.

"... to the best of our knowledge, DES is free from any statistical or mathematical weakness."

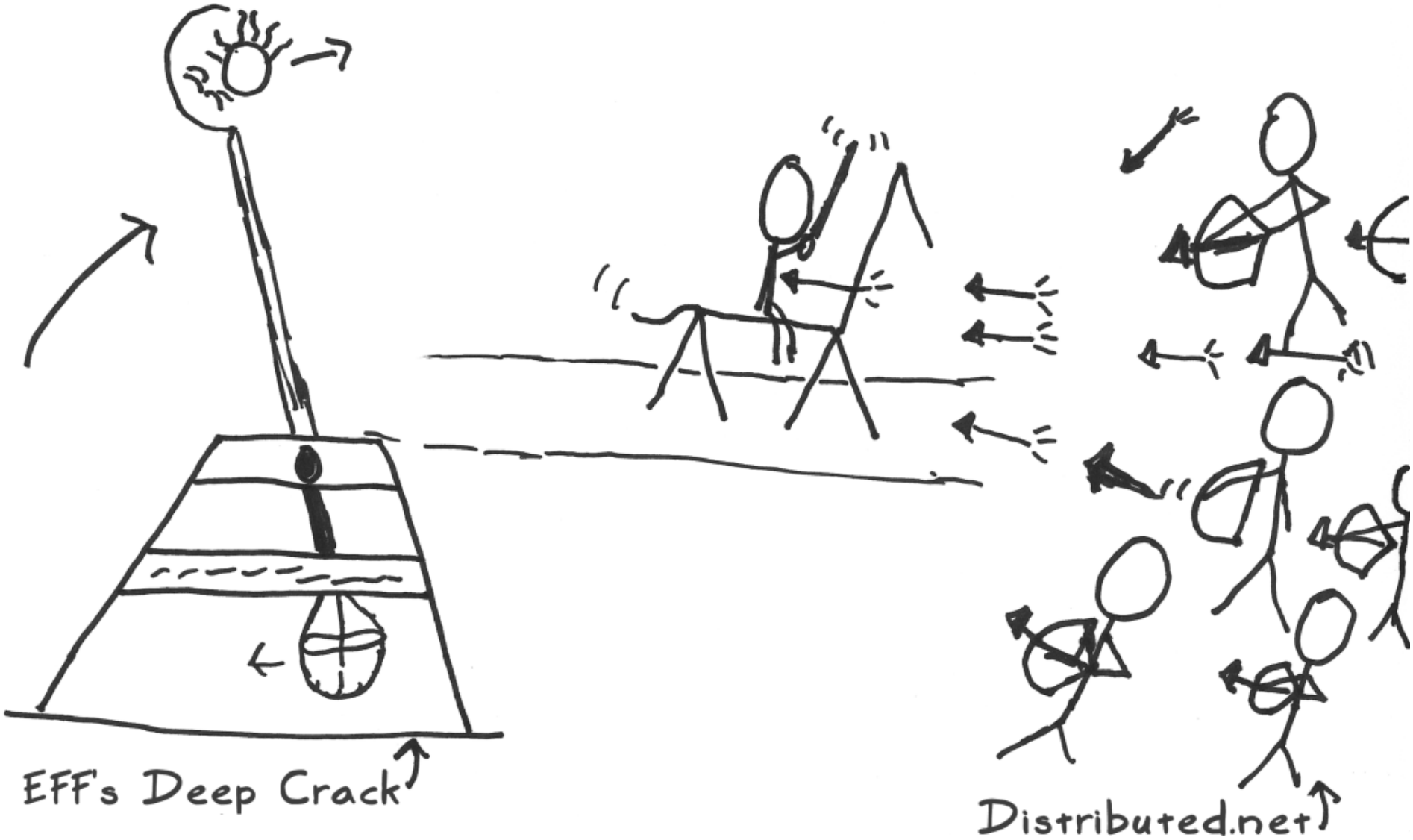
NSA



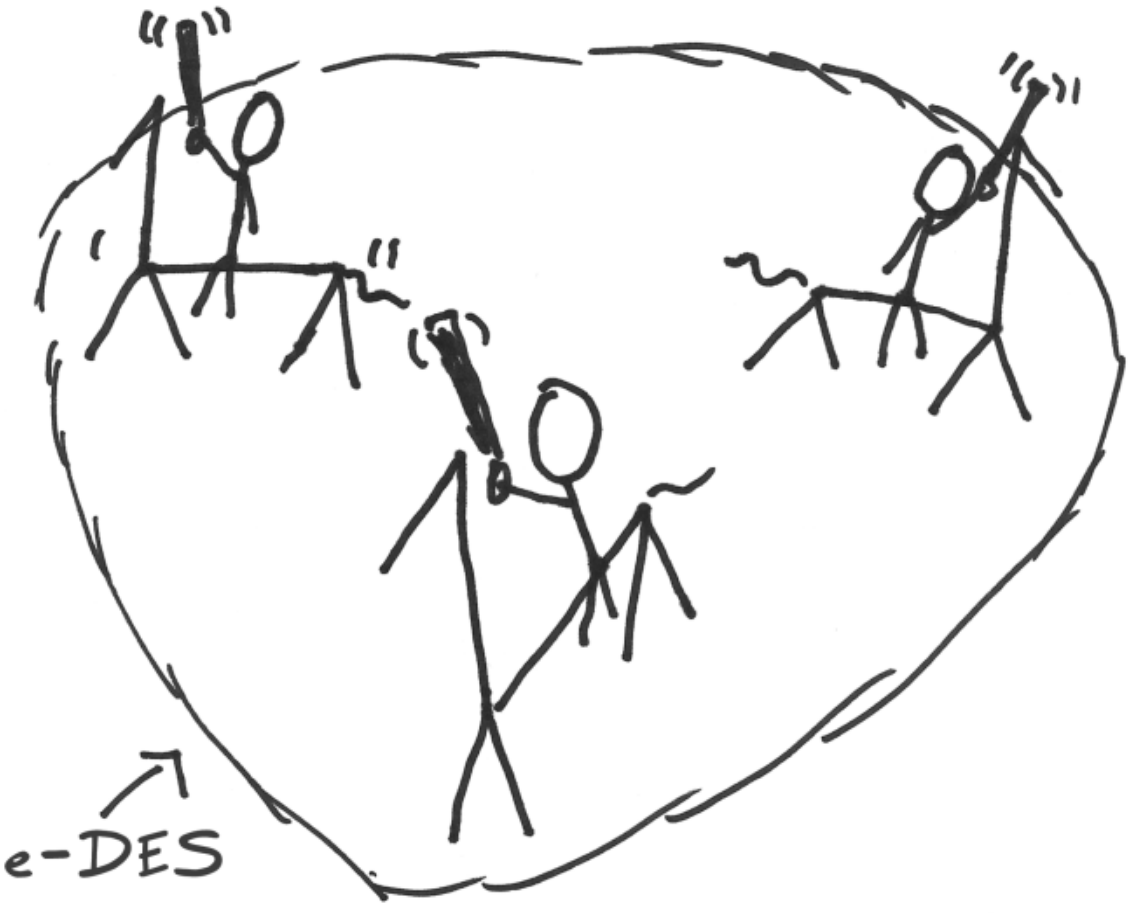
Check out that Feistel network!

Zzzz

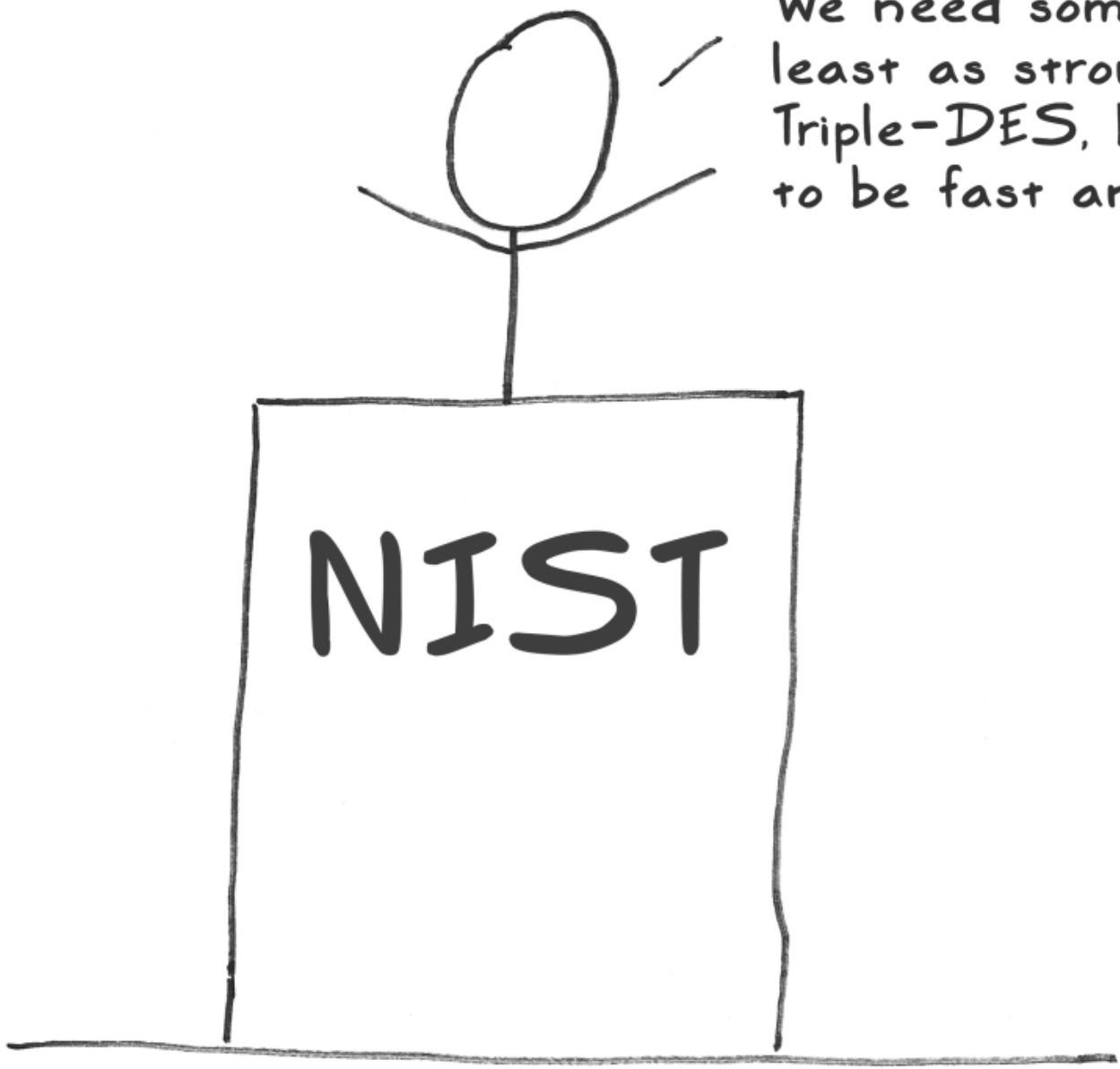
Over the years, many attackers challenged DES. He was defeated in several battles.



The only way to stop the attacks was to use DES 3 times in row to form 'Triple-DES. This worked, but it was awfully slow

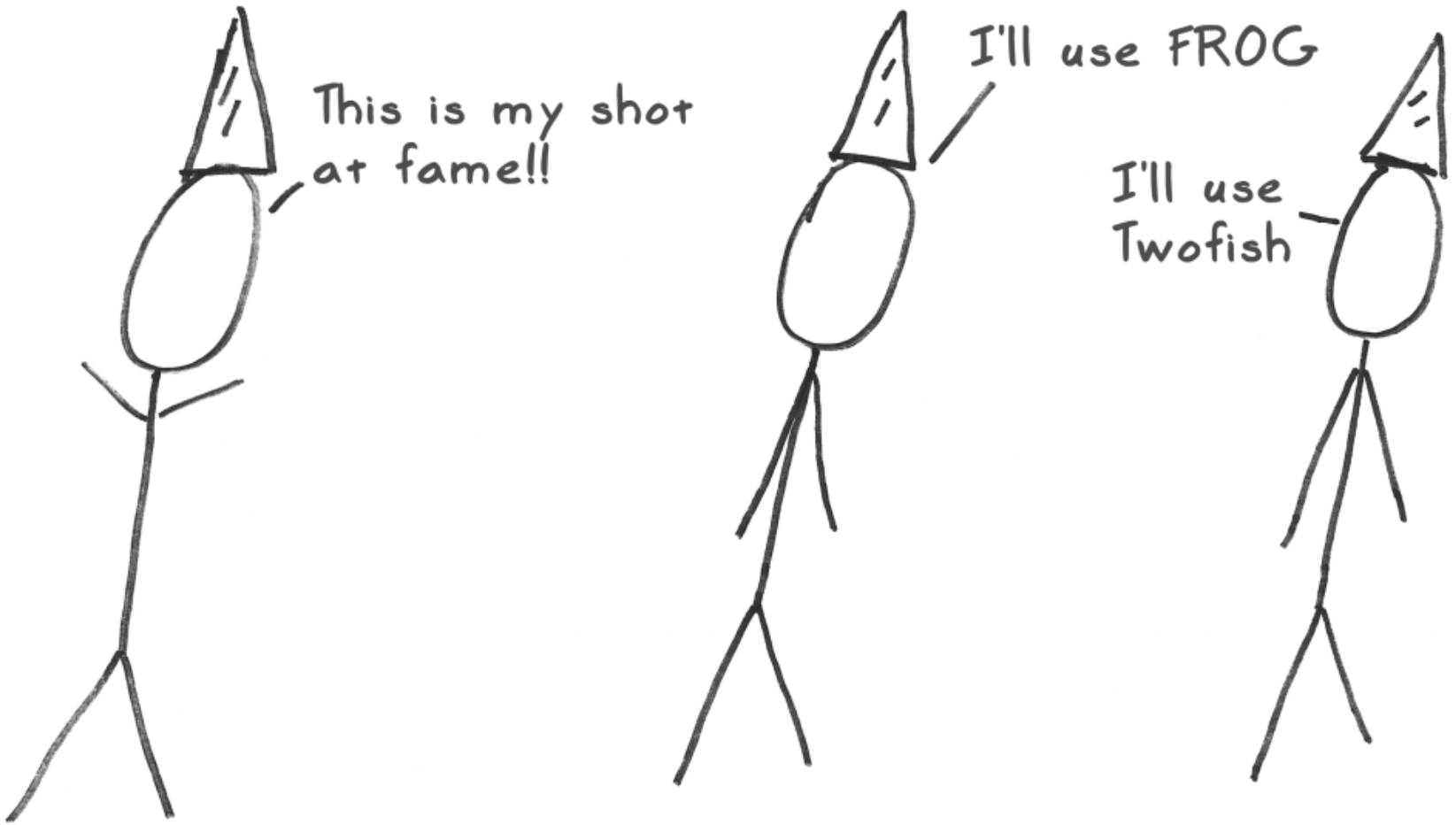


Another decree went out*...

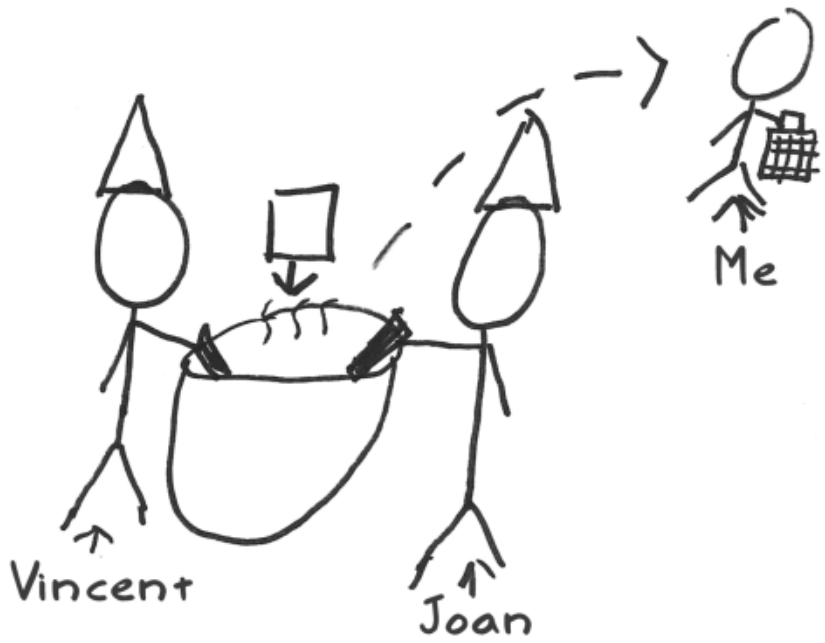


* ~ early 1997

This call rallied the crypto wizards to develop something better.

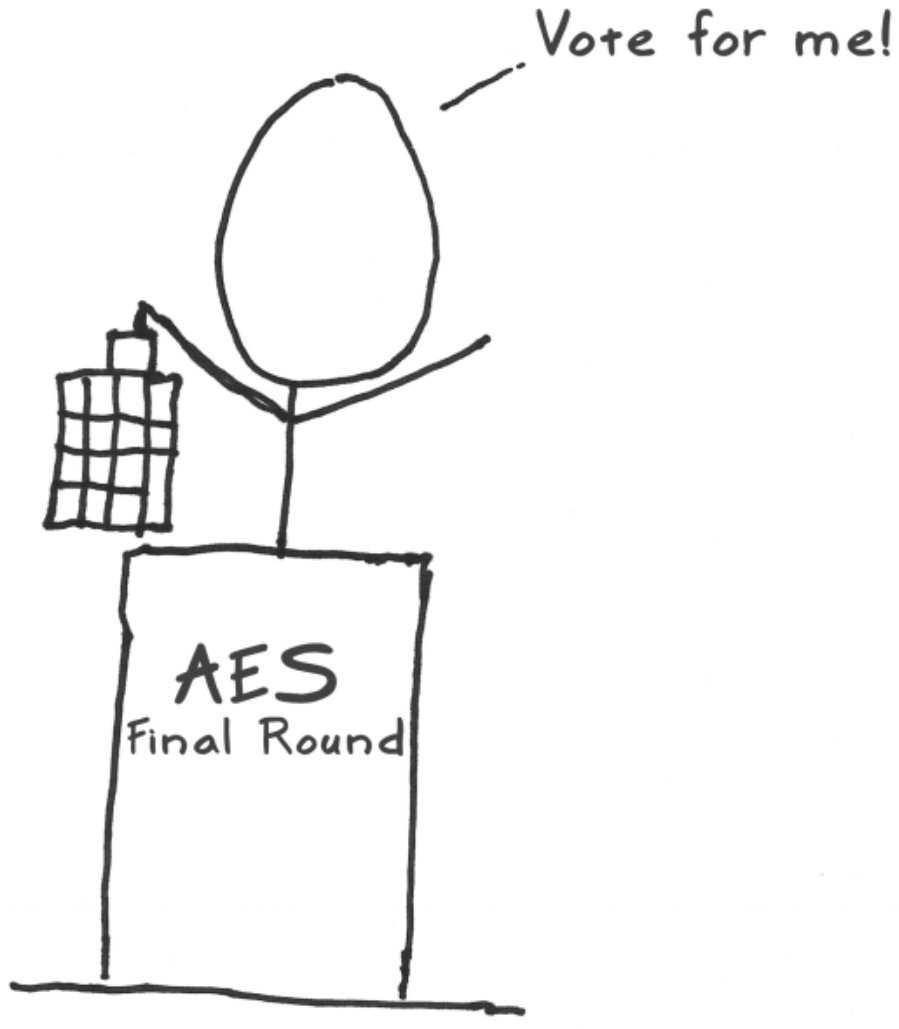


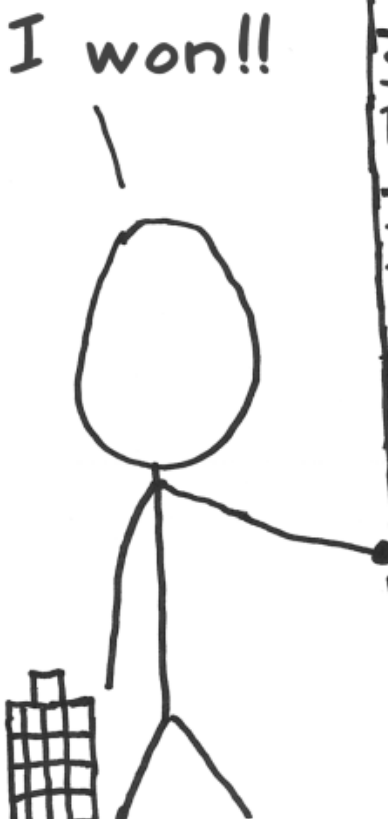
My creators, Vincent Rijmen and Joan Daemen, were among these crypto wizards. They combined their last names to give me my birth name: Rijndael.*



* That's pronounced "Rhine Dahl" for the non-Belgians out there.

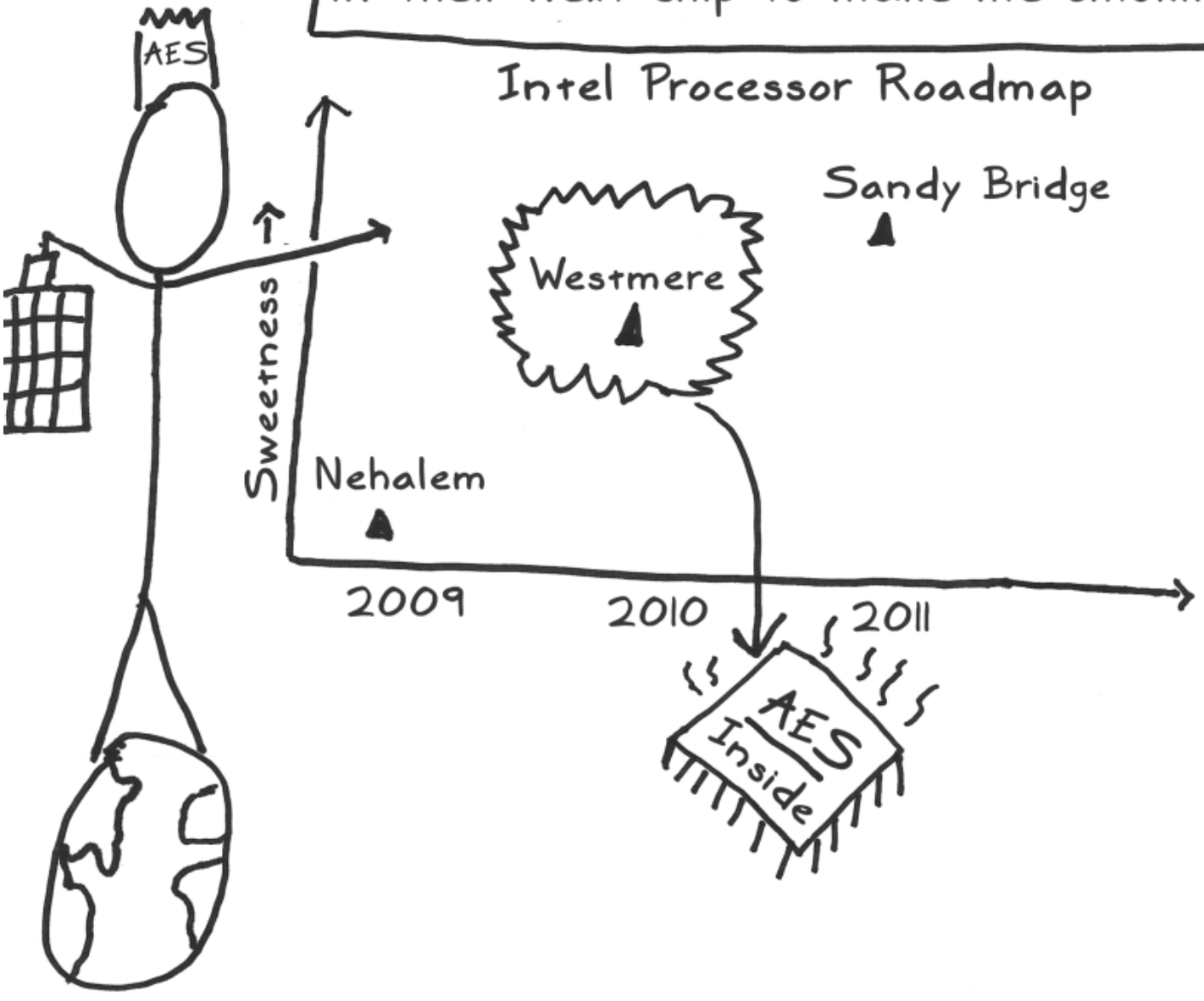
Everyone got together to vote and...

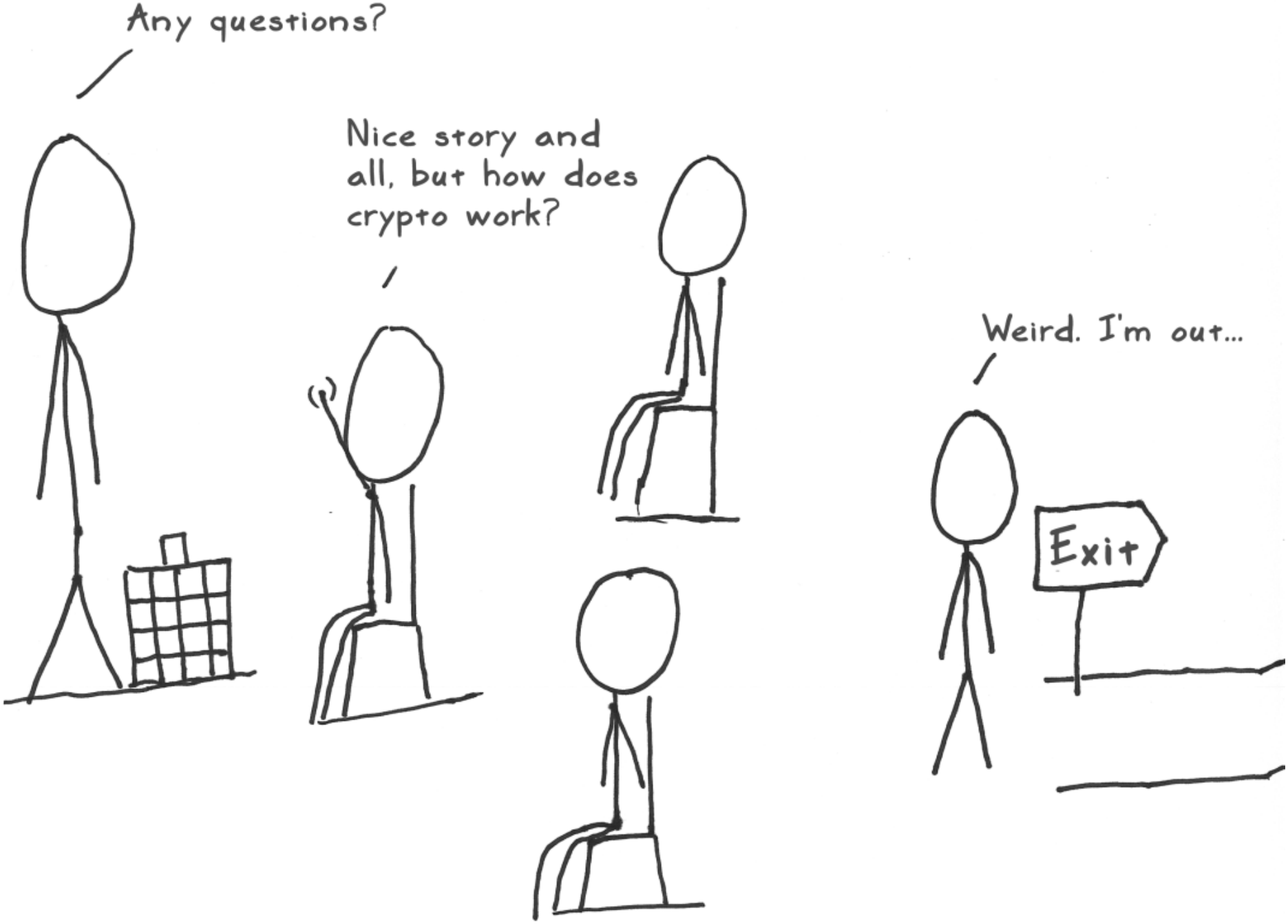




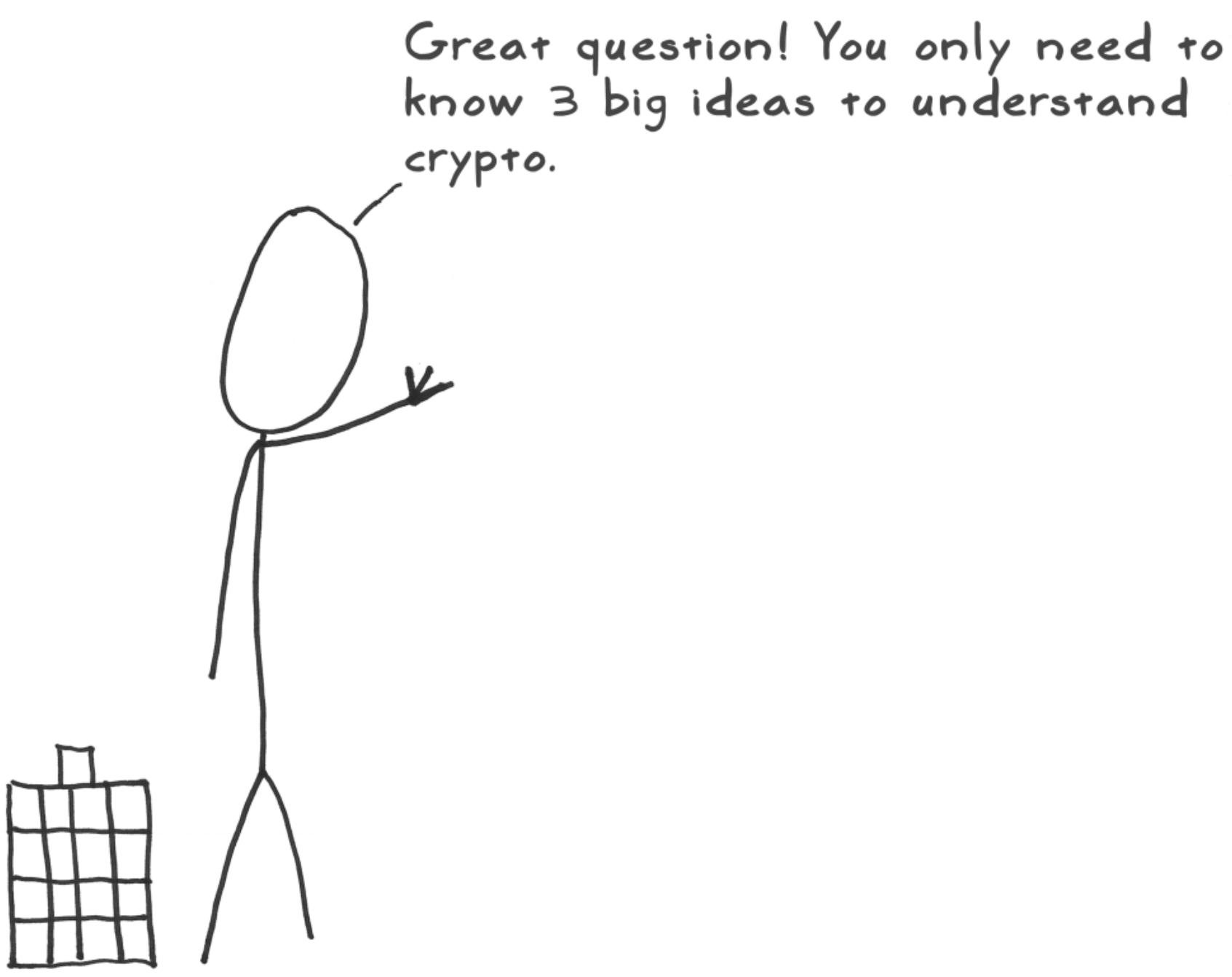
	Rijndael	Serpent	Twofish	MARS	RC6
General Security	2	3	3	3	2
Implementation Difficulty	3	3	2	1	1
Software Performance	3	1	1	2	2
Smart Card Performance	3	3	2	1	1
Hardware Performance	3	3	2	1	2
Design Features	2	1	3	2	1
~~Total~~ ε,	16	14	13	10	9

...and now I'm the new king of the crypto world. You can find me everywhere. Intel is even putting native instructions for me in their next chip to make me smokin' fast!



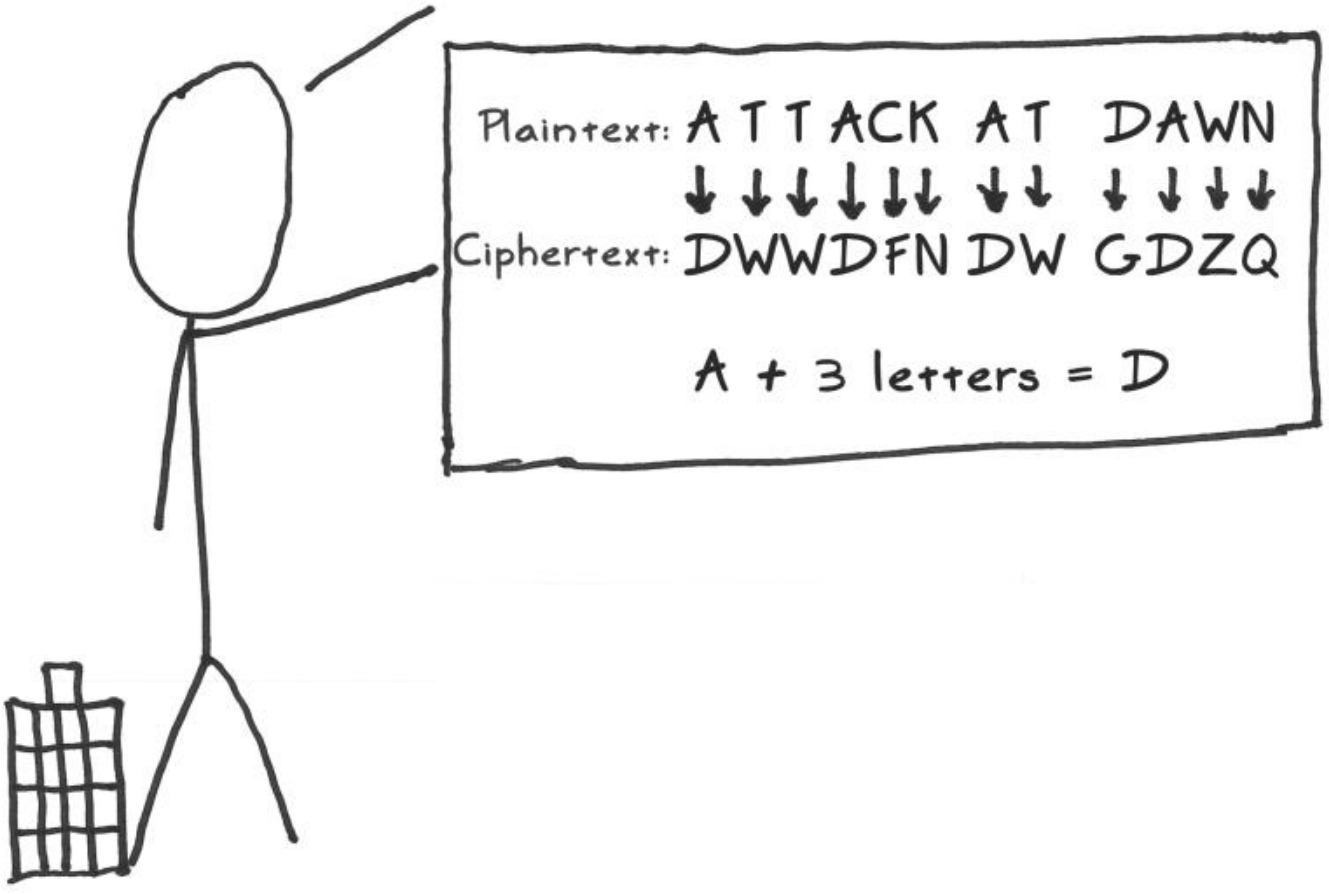

Any questions?
Nice story and all, but how does crypto work?
Weird. I'm out...
Exit

Act 2: Crypto Basics


Great question! You only need to know 3 big ideas to understand crypto.

Big Idea #1: Confusion

It's a good idea to obscure the relationship between your real message and your "encrypted" message. An example of this "confusion" is the trusty ol' Caesar Cipher:



Plaintext: ATTACK AT DAWN

Ciphertext: DWWDFN DW GDZQ

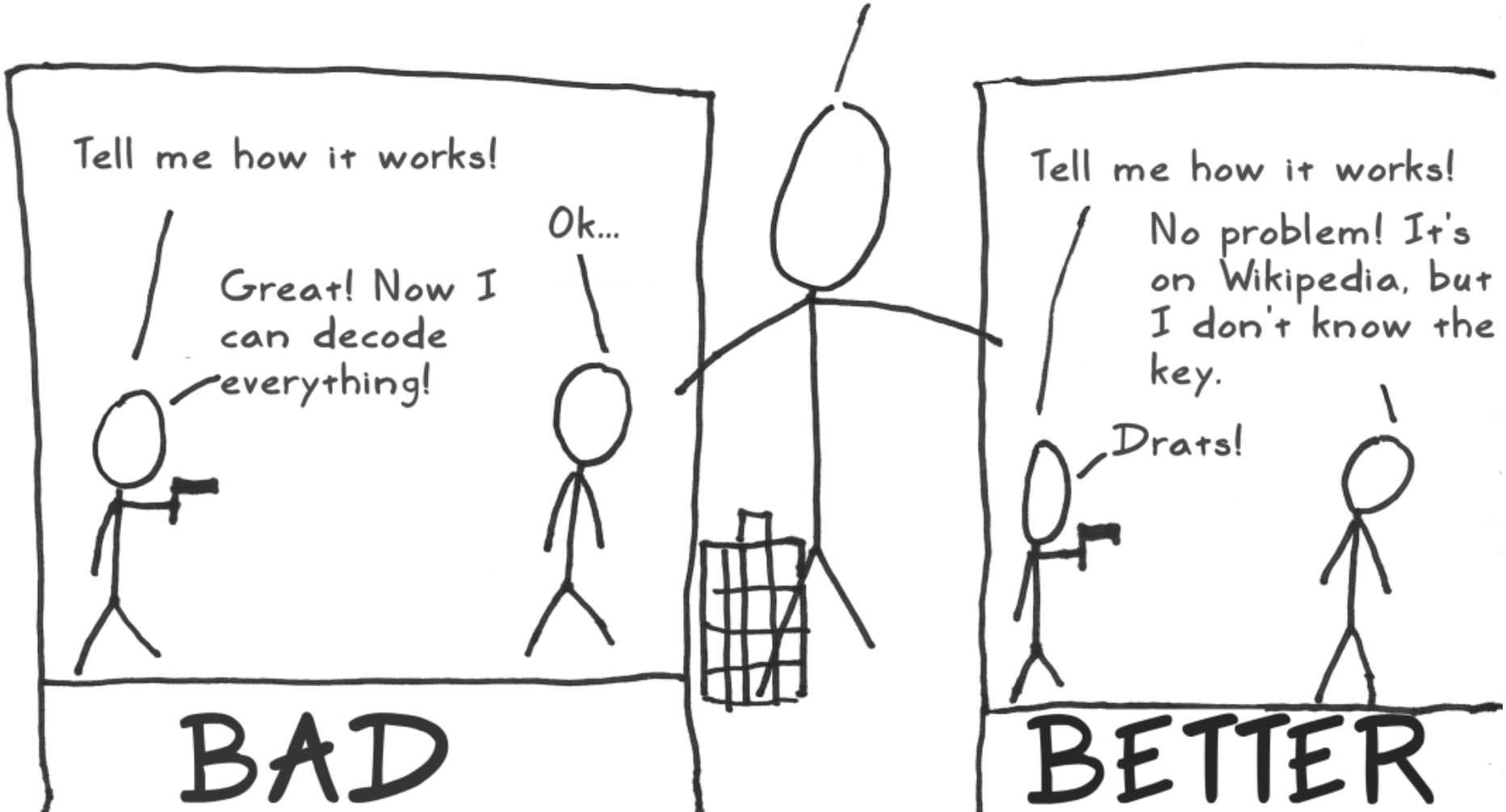
A + 3 letters = D

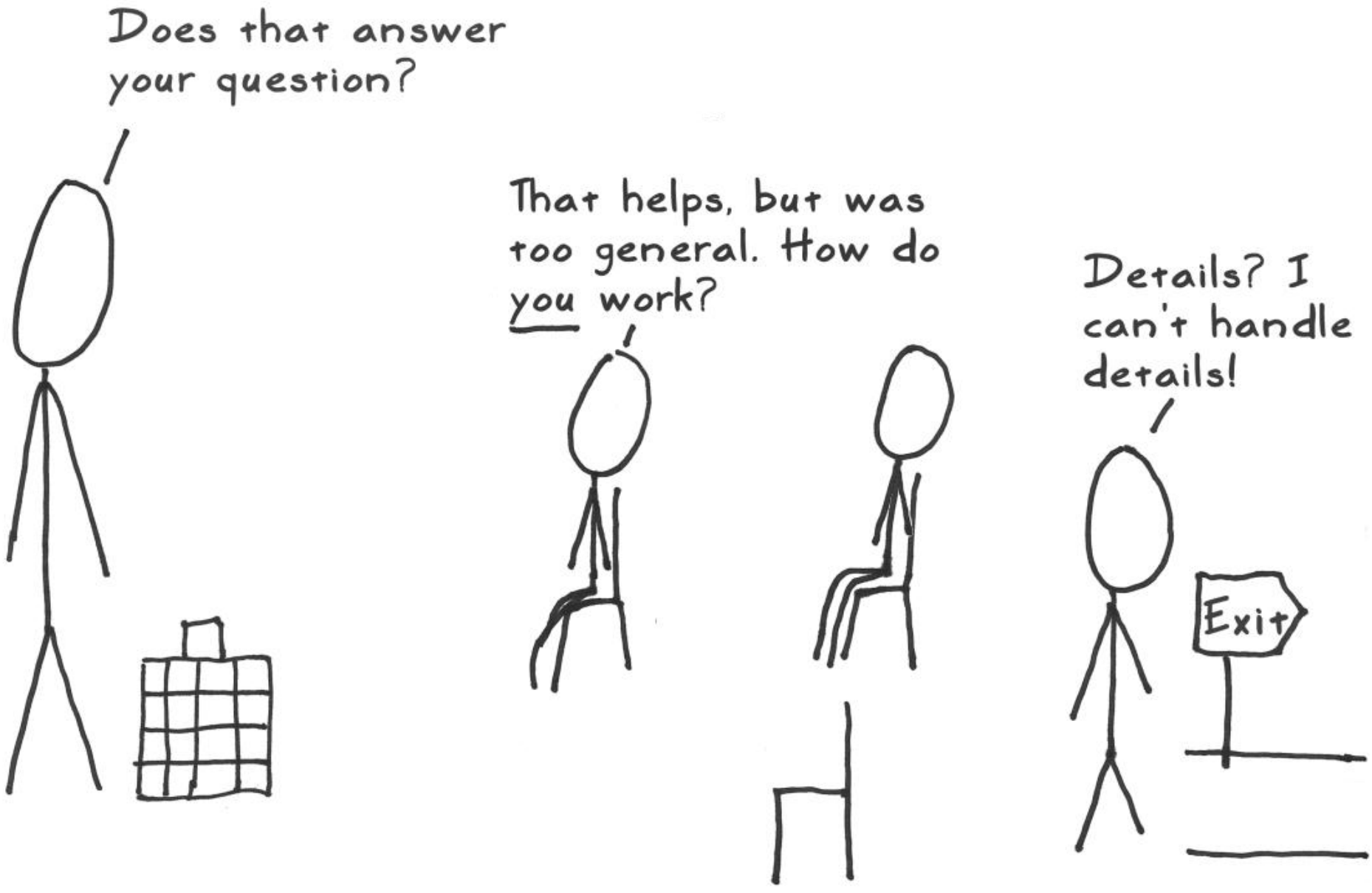
Big Idea #2: Diffusion

It's also a good idea to spread out the message. An example of this "diffusion" is a simple column transposition:

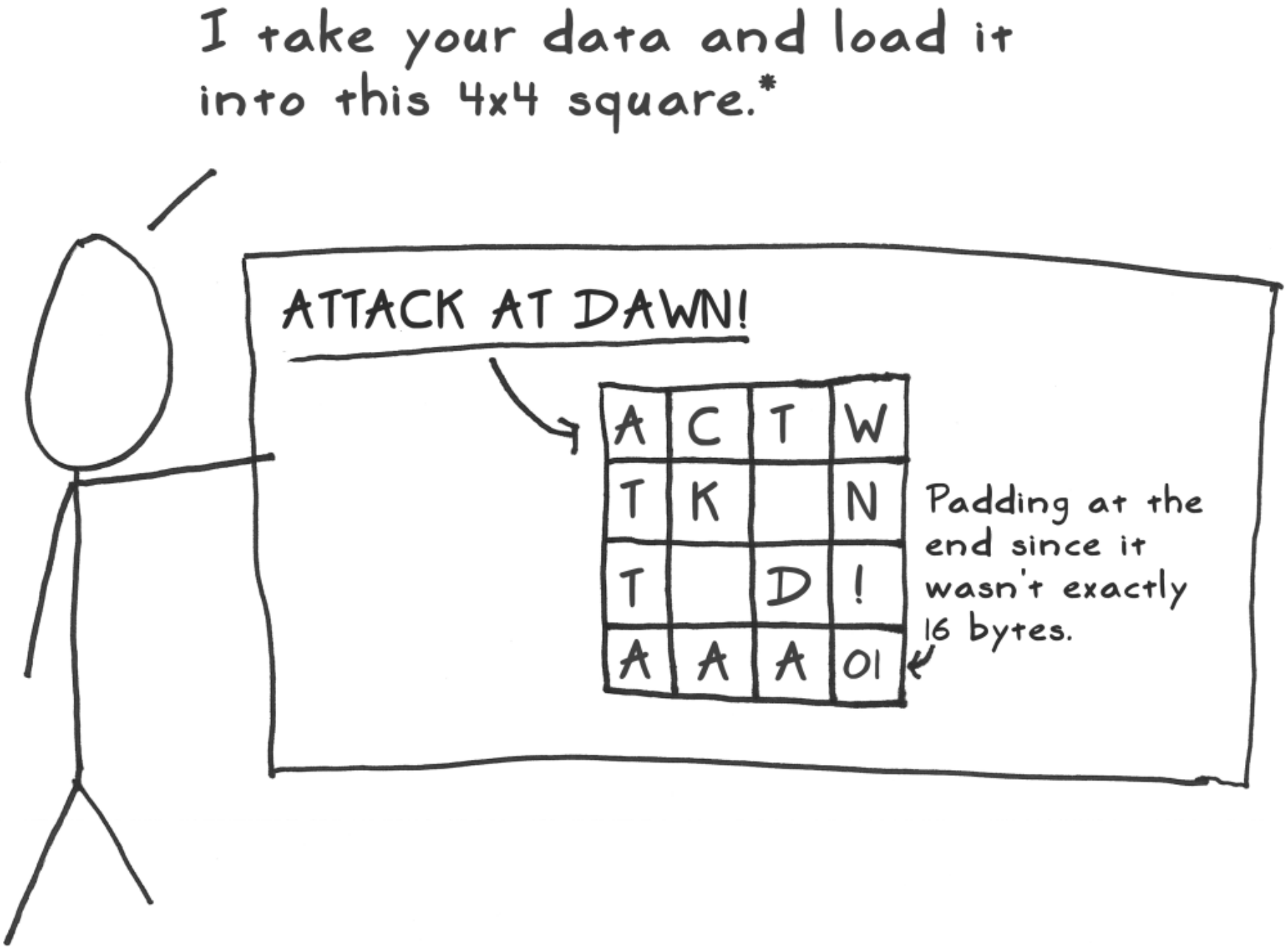
Big Idea #3: Secrecy Only in the Key

After thousands of years, we learned that it's a bad idea to assume that no one knows how your method works. Someone will eventually find that out.



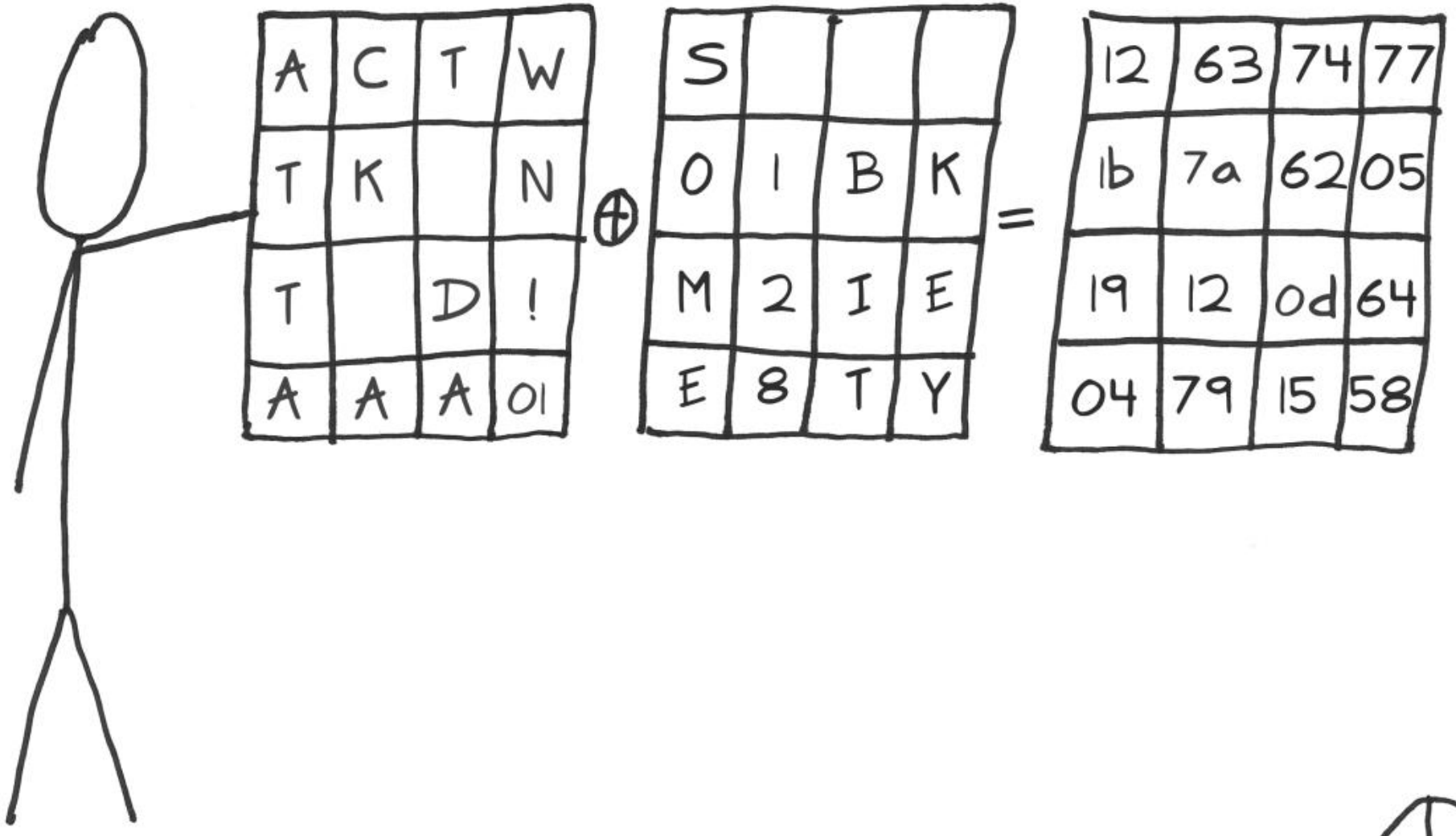

Does that answer your question?
That helps, but was too general. How do you work?
Details? I can't handle details!
Exit

Act 3: Details



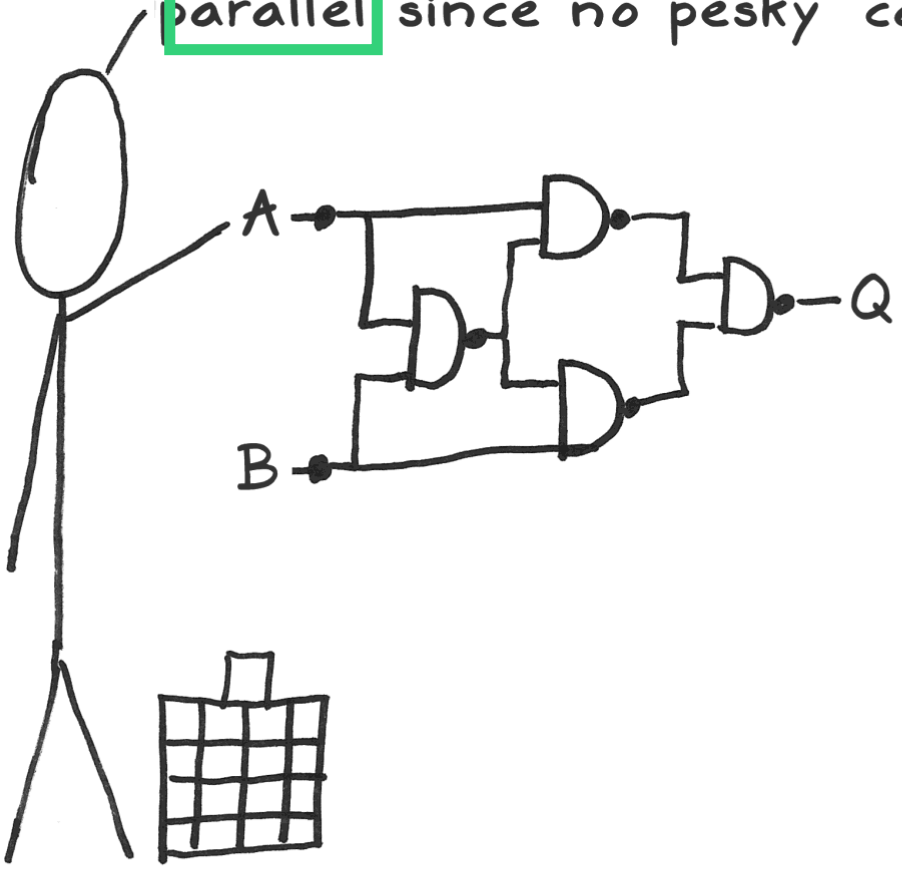
* This is the "state matrix" that I carry with me at all times.

The initial round has me xor each input byte with the corresponding byte of the first round key.



A Tribute to XOR

There's a simple reason why I use xor to apply the key and in other spots: it's fast and cheap - a quick bit flipper. It uses minimal hardware and can be done in parallel since no pesky "carry" bits are needed.



AES ♡ ⊕

Key Expansion: Part 1

I need lots of keys for use in later rounds. I derive all of them from the initial key using a simple mixing technique that's really fast. Despite its critics,* it's good enough.

S			
O	I	B	K
M	2	I	E
E	8	T	Y

Initial Key

el	cl	el	cl
21	10	52	19
86	b4	fd	b8
f2	ca	9e	c7

#1

...

ae	a6	a0	d4
97	d8	a6	c5
4d	7d	7a	d9
ef	ed	05	06

#9

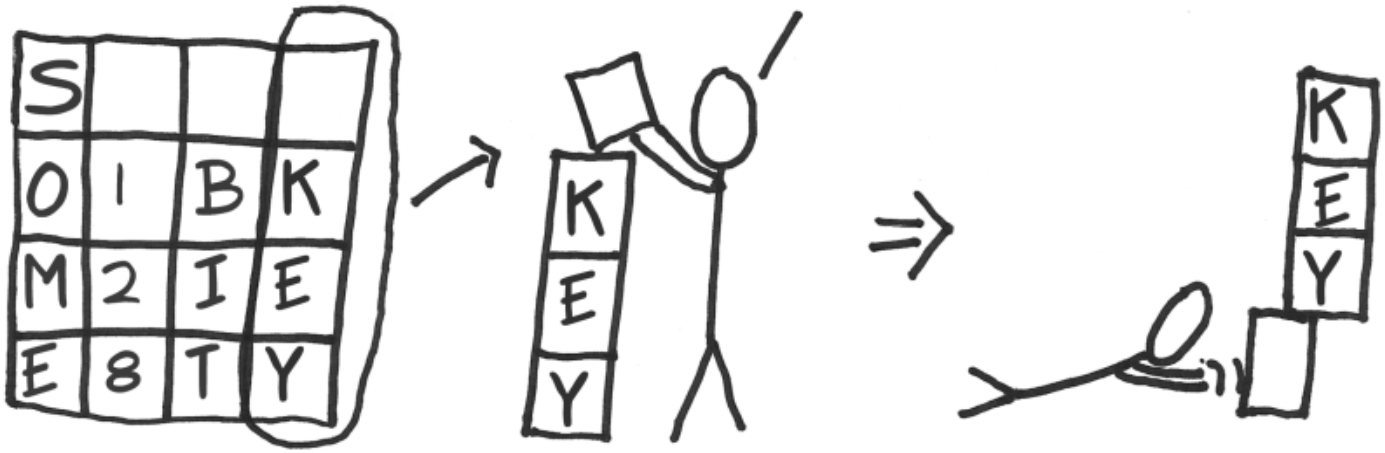
3e	98	38	ec
a2	7a	dc	19
22	5f	25	fc
a7	4a	4f	49

#10

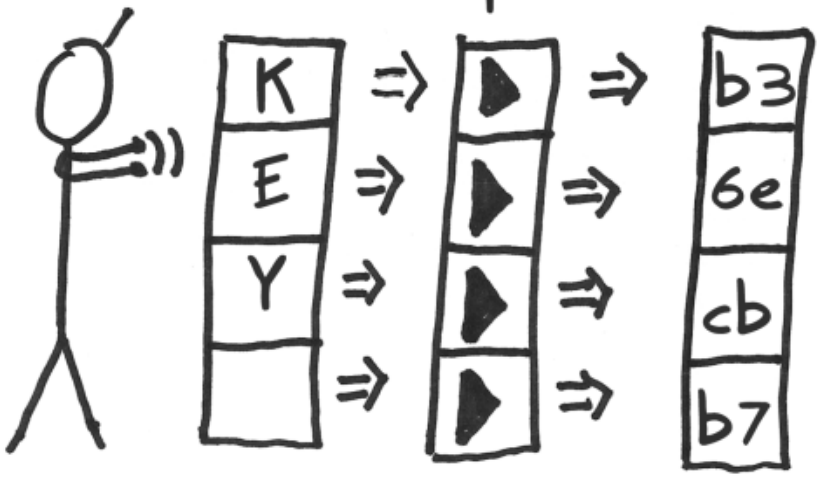
* By far, most complaints against AES's design focus on this simplicity.

Key Expansion: Part 2a

(1) I take the last column of the previous round key and move the top byte to the bottom:

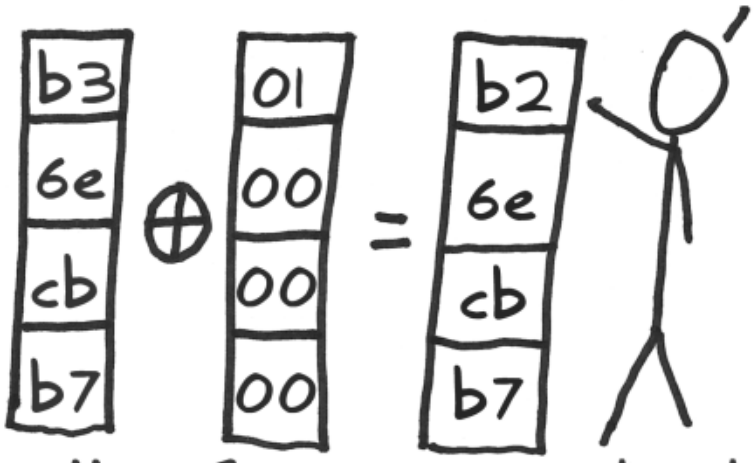


(2) Next, I run each byte through a substitution box that will map it to something else:

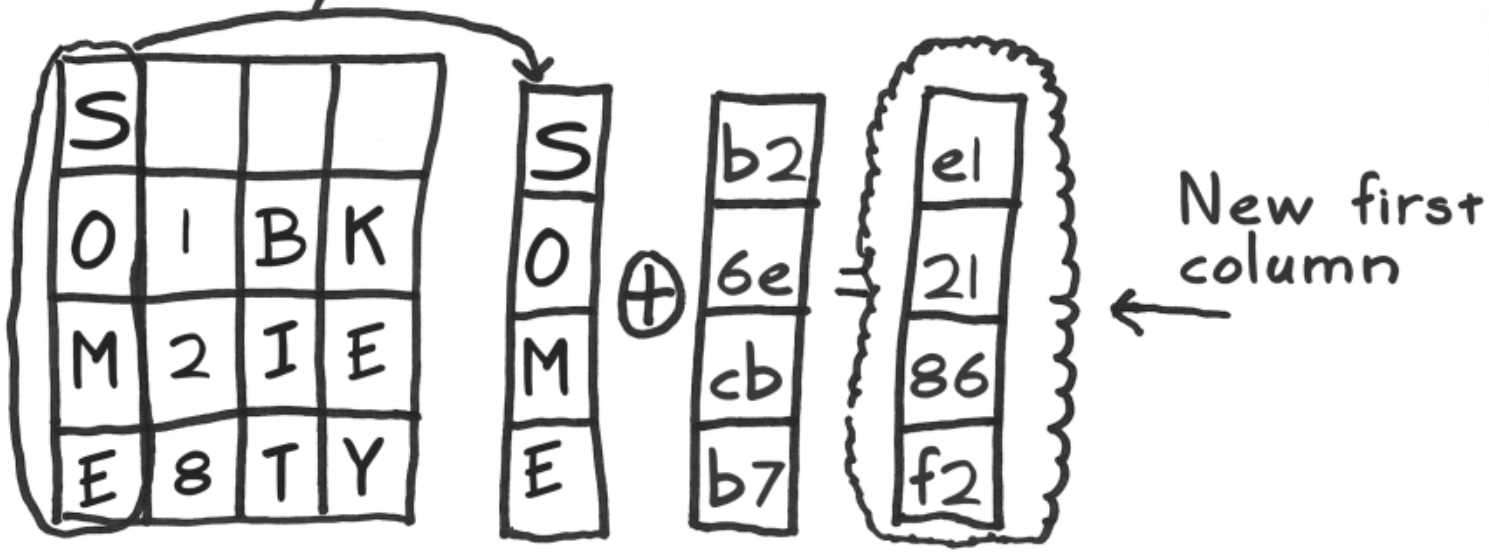


Key Expansion: Part 2b

(3) I then xor the column with a "round constant" that is different for each round.

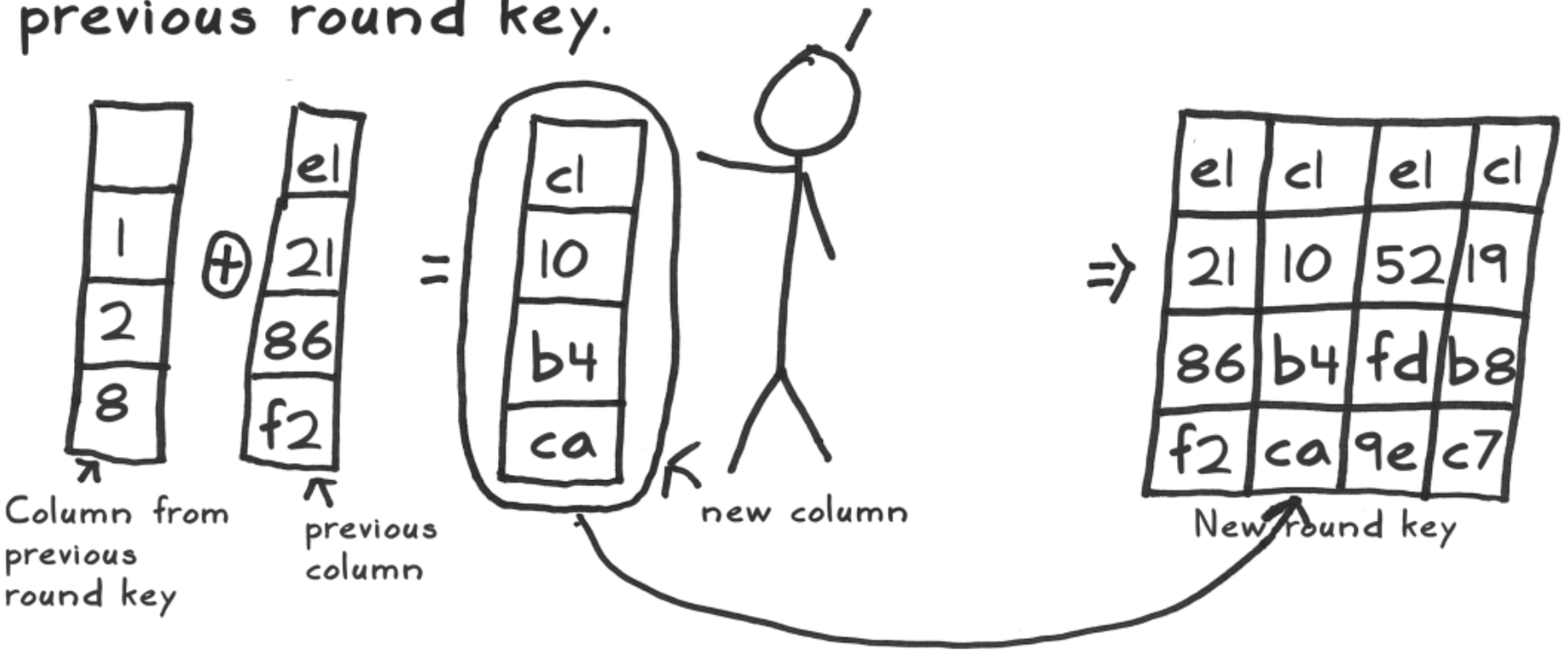


(4) Finally, I xor it with the first column of the previous round key:



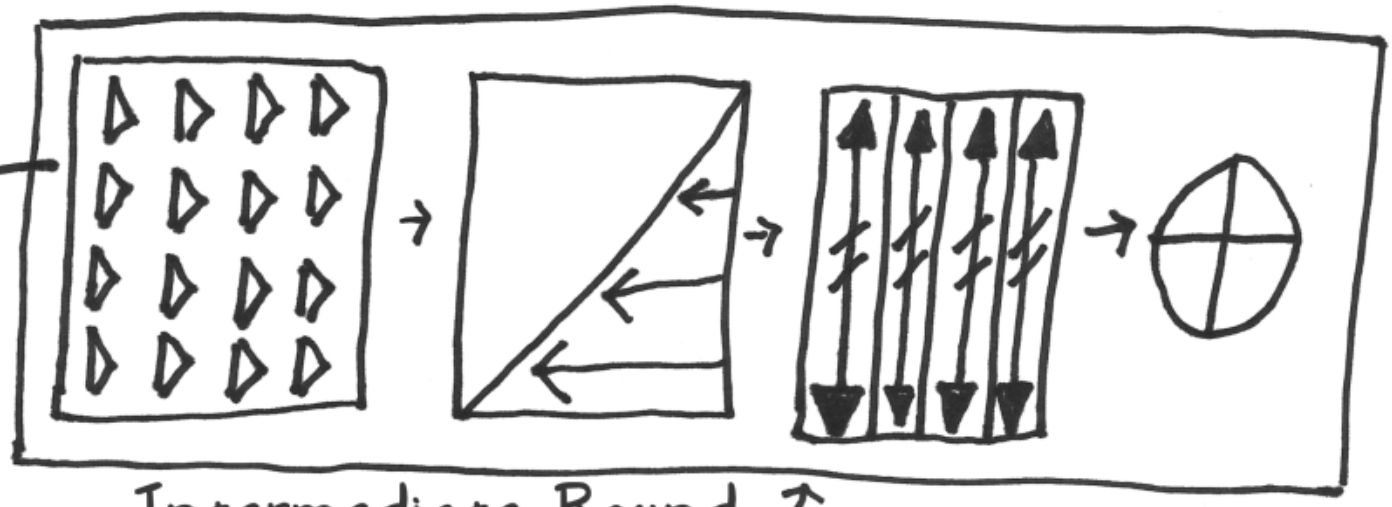
Key Expansion: Part 3

The other columns are super-easy,* I just xor the previous column with the same column of the previous round key.

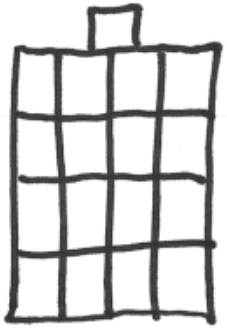


* Note that 256 bit keys are slightly more complicated.

Next, I start the intermediate rounds. A round is just a series of steps I repeat several times. The number of repetitions depends on the size of the key.



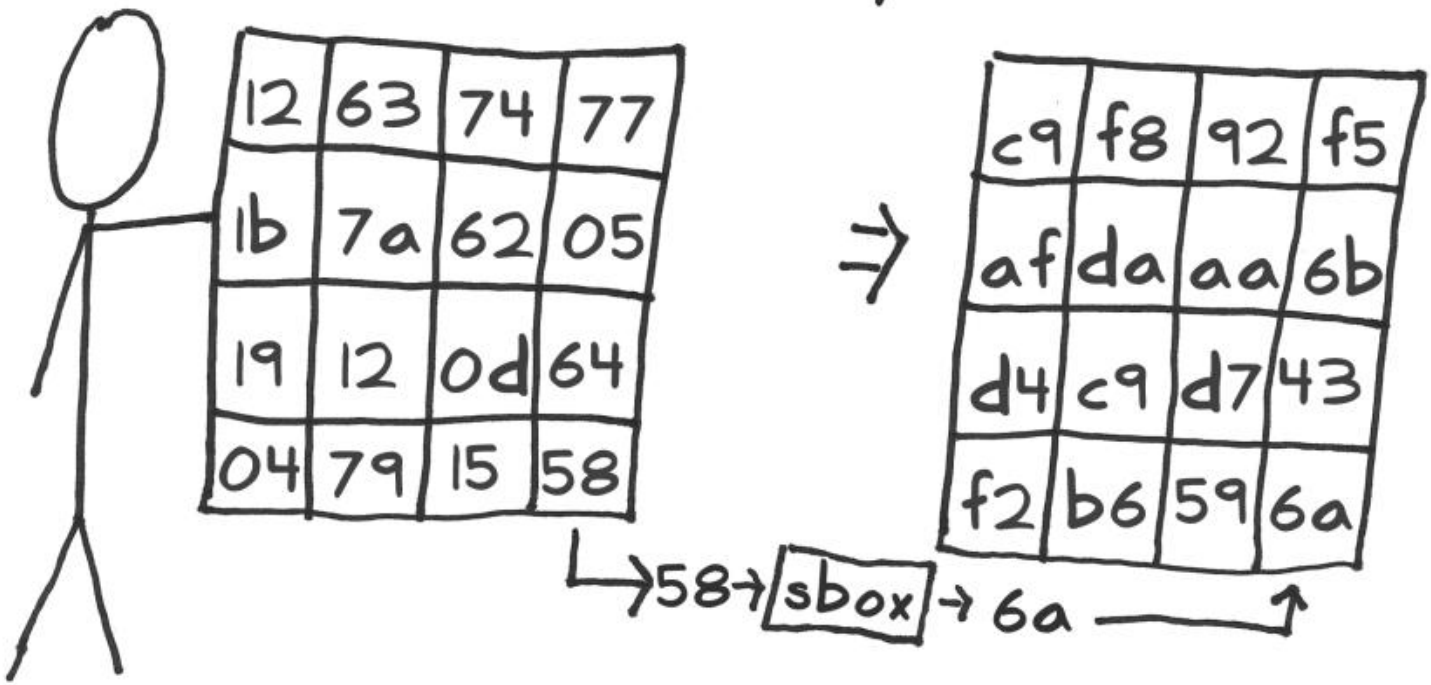
Intermediate Round ↗

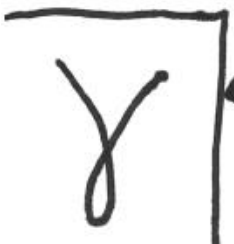


Round Repetitions	Key Size
9	128
11	192
13	256

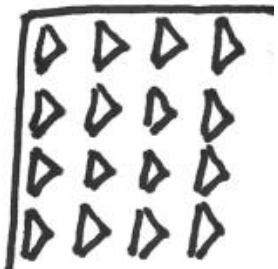
Applying Confusion: Substitute Bytes

I use confusion (Big Idea #1) to obscure the relationship of each byte. I put each byte into a substitution box (sbox), which will map it to a different byte:

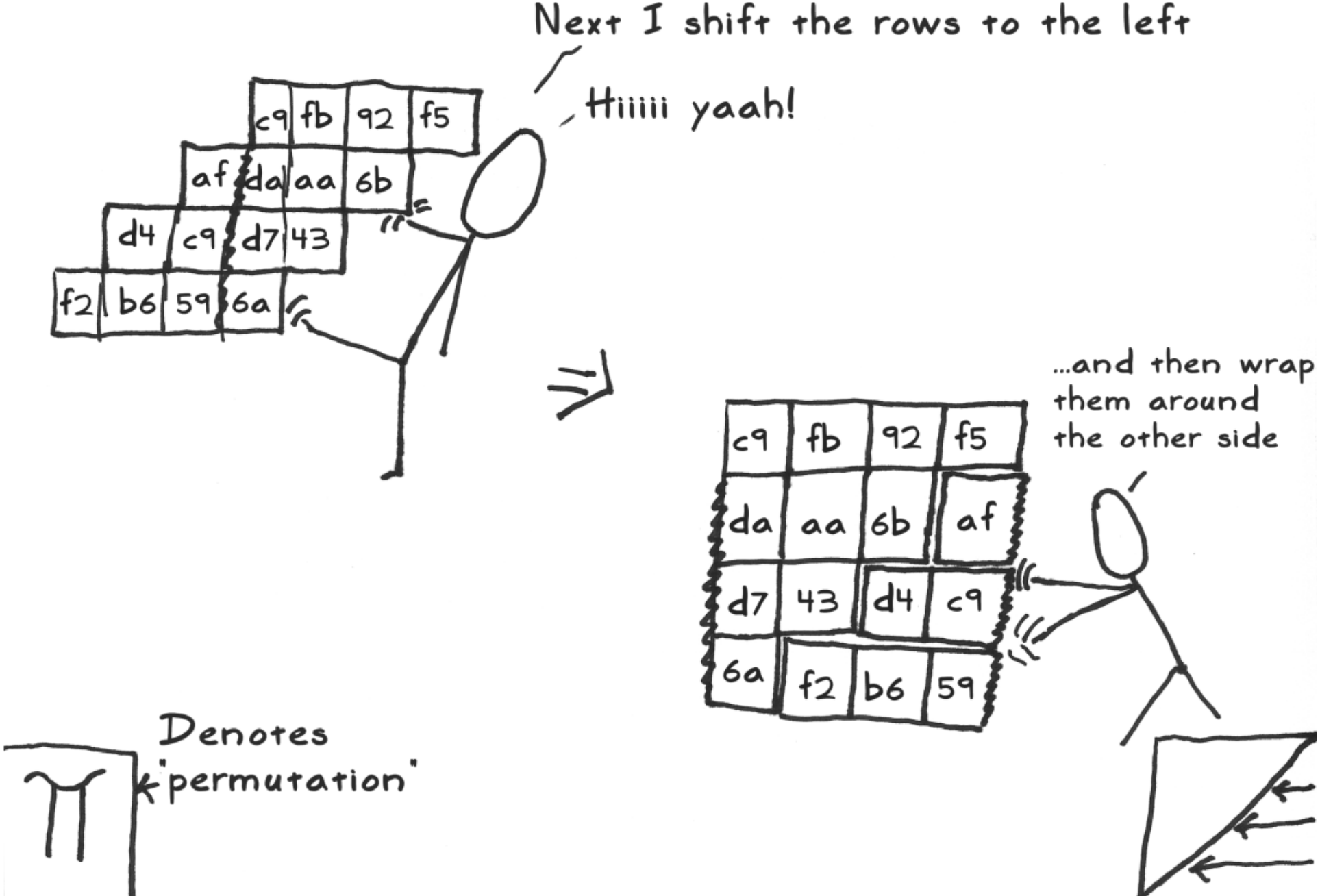




Denotes "confusion"



Applying Diffusion, Part 1: Shift Rows

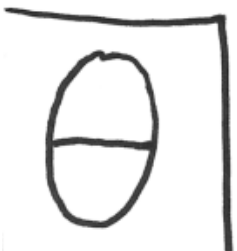


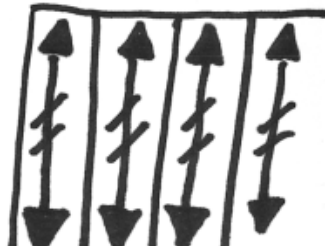
Applying Diffusion, Part 2: Mix Columns

c9	fb	92	f5
da	aa	6b	af
d7	43	d4	c9
6a	f2	b6	59

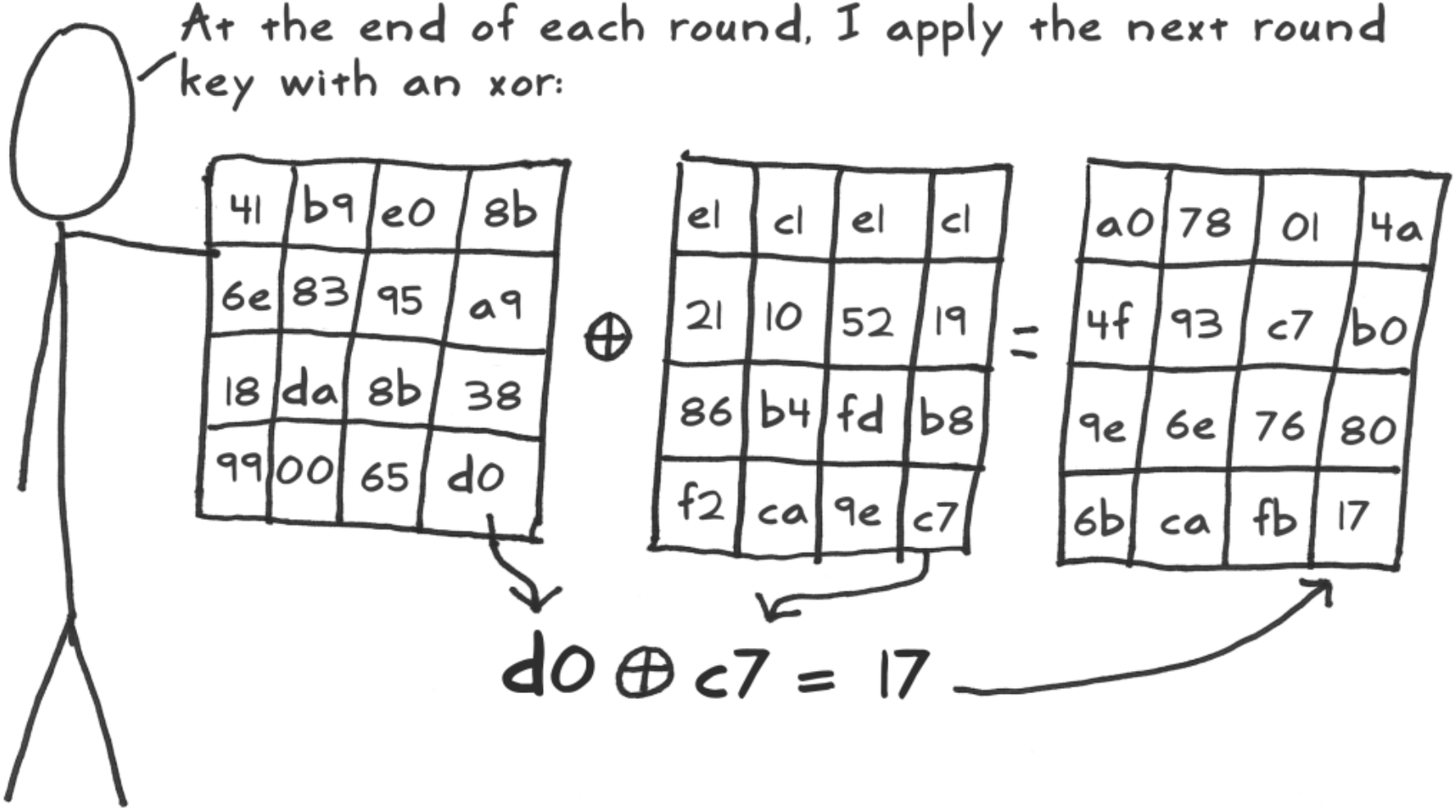
I take each column and mix up the bits in it.

41	b9	e0	8b
6e	83	95	a9
18	da	8b	38
99	00	65	d0

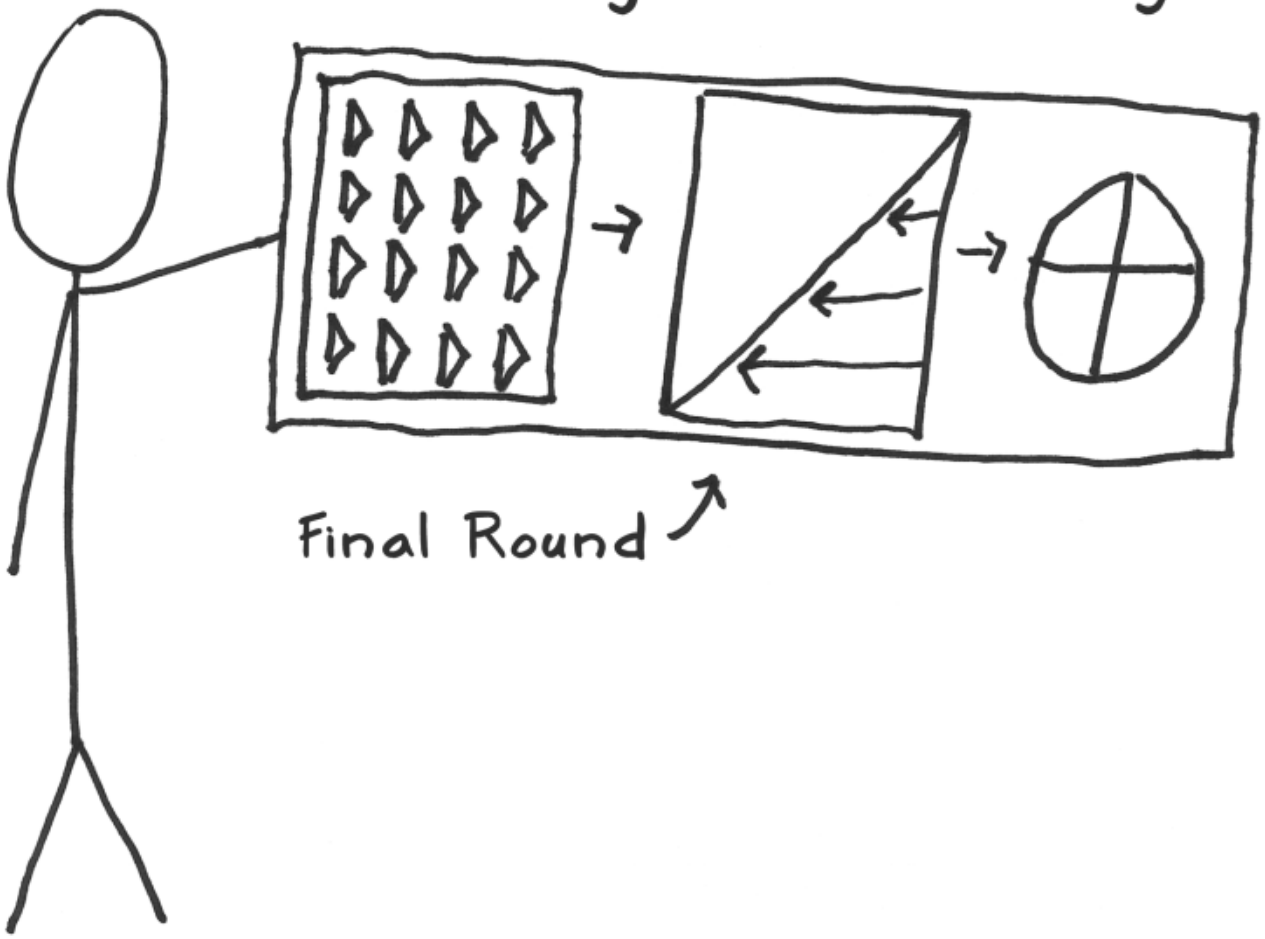




Applying Key Secrecy: Add Round Key

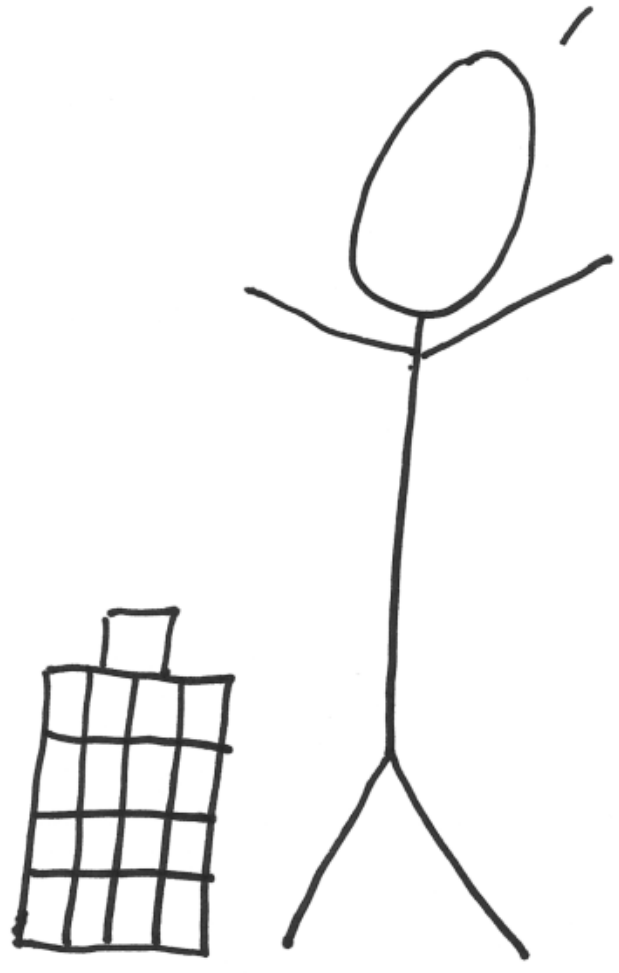


In the final round, I skip the "Mix Columns" step since it wouldn't increase security* and would just slow things down:

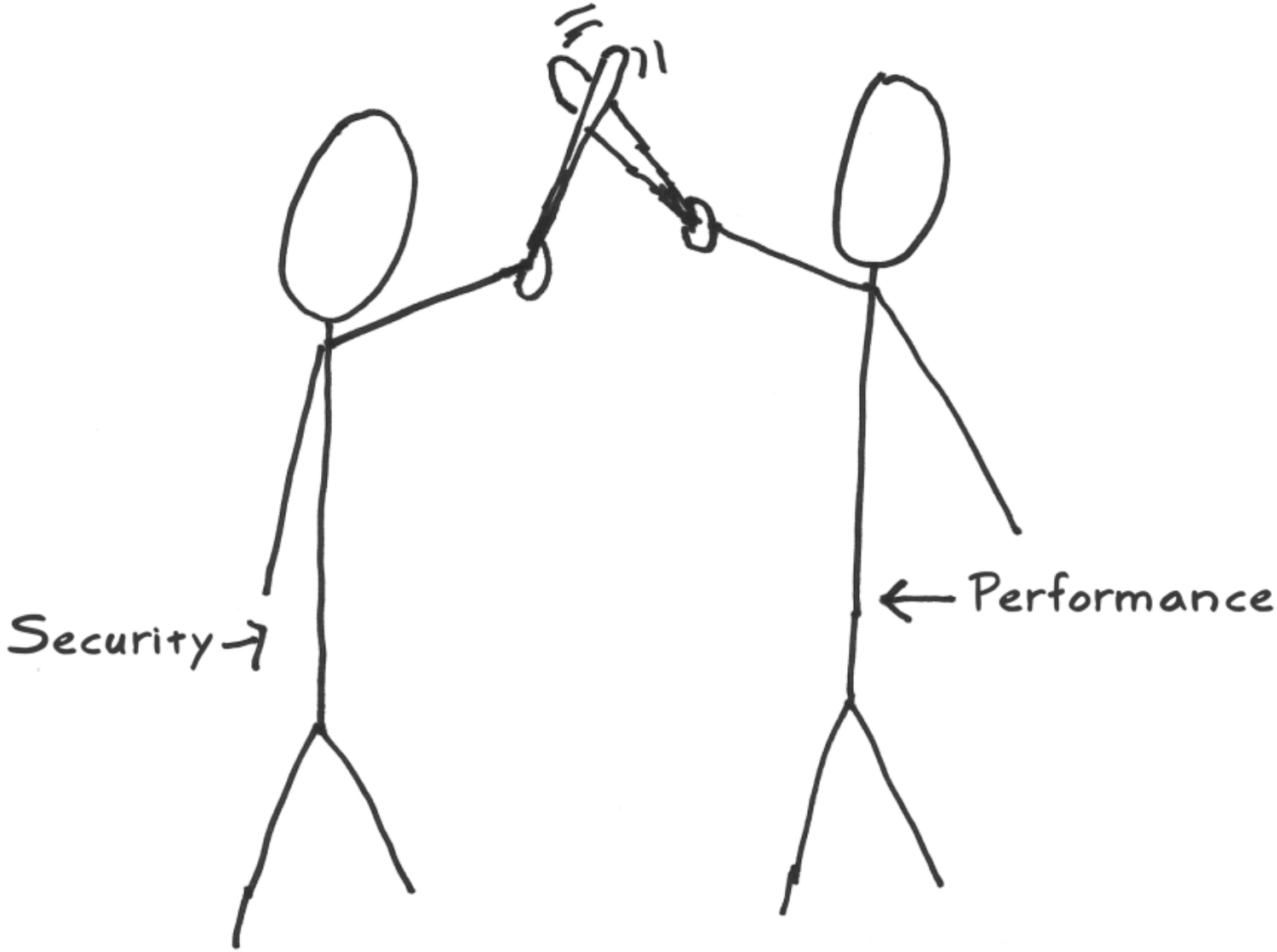


*The diffusion it would provide wouldn't go to the next round.

...and that's it. Each round I do makes the bits more confused and diffused. It also has the key impact them. The more rounds, the merrier!

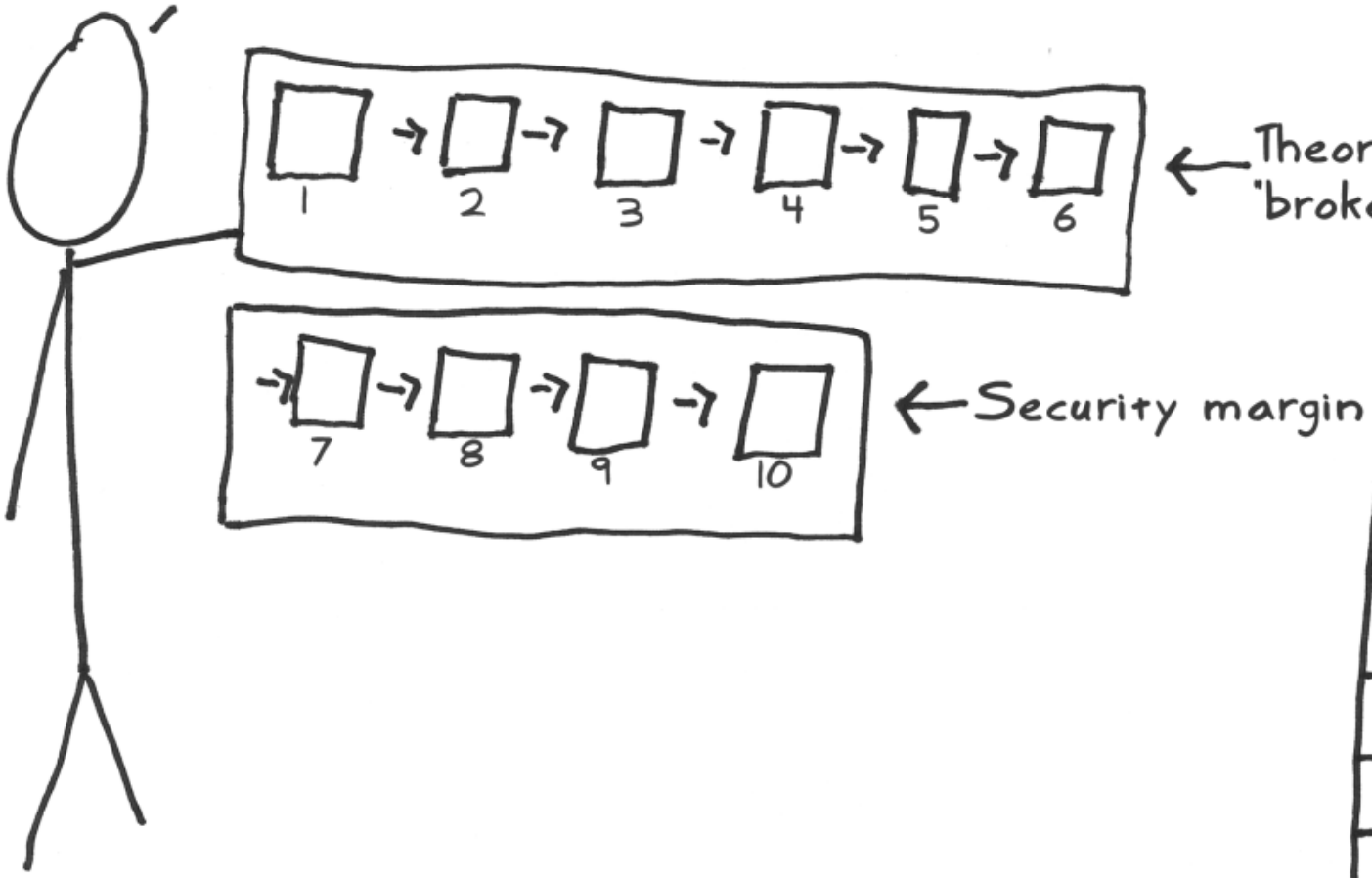


Determining the number of rounds always involves several tradeoffs.



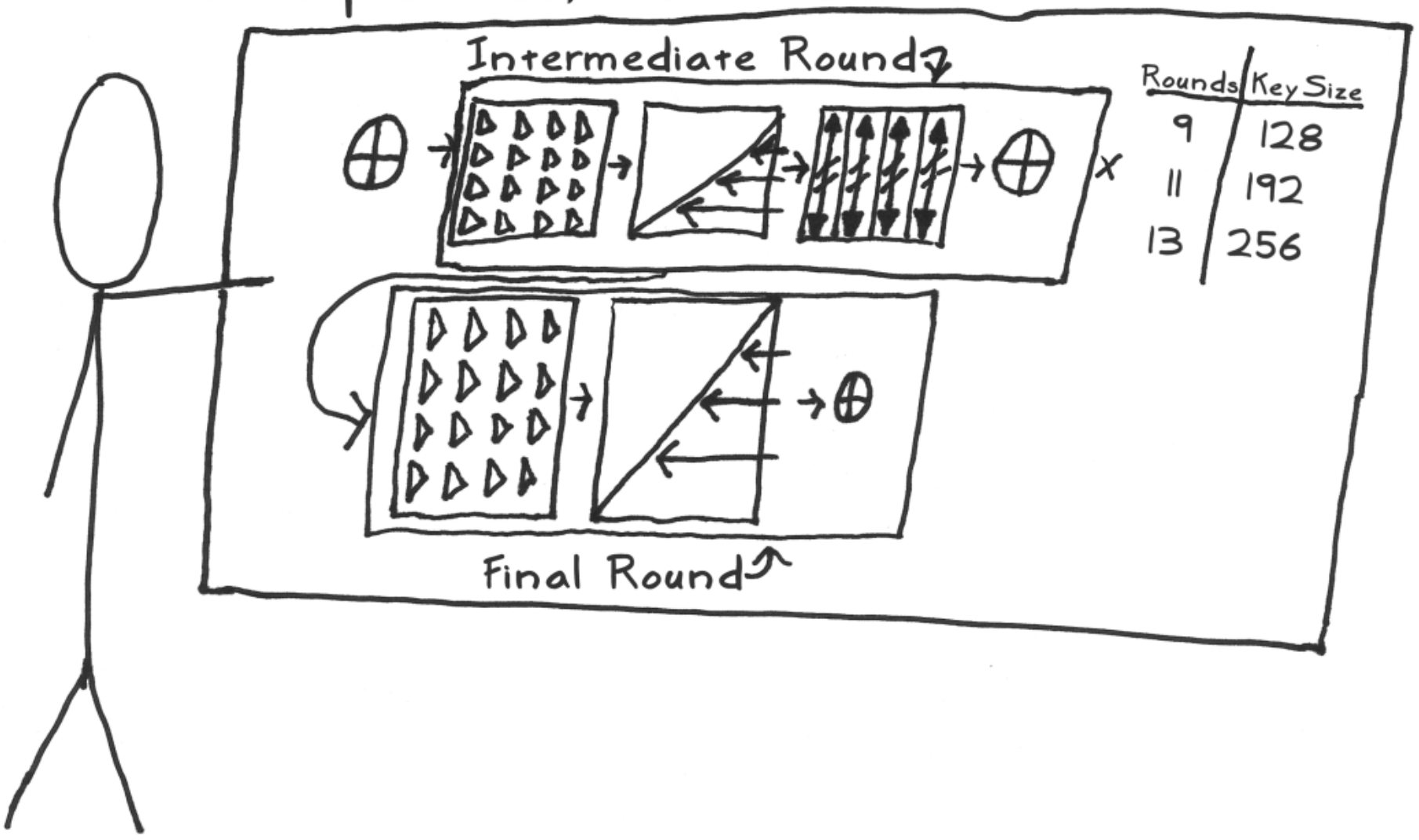
'Security always comes at a cost to performance' - Vincent Rijmen

When I was being developed, a clever guy was able to find a shortcut path through 6 rounds. That's not good! If you look carefully, you'll see that each bit of a round's output depends on every bit from two rounds ago. To increase this diffusion "avalanche," I added 4 extra rounds. This is my "security margin."



FIPS 197 Spec	
Key Size	Rounds
128	10
192	12
256	14

So in pictures, we have this:



The Story of AES Continues in Next Class...

Check out AES with Python Crypto Library or openssl