Symmetric Cryptography

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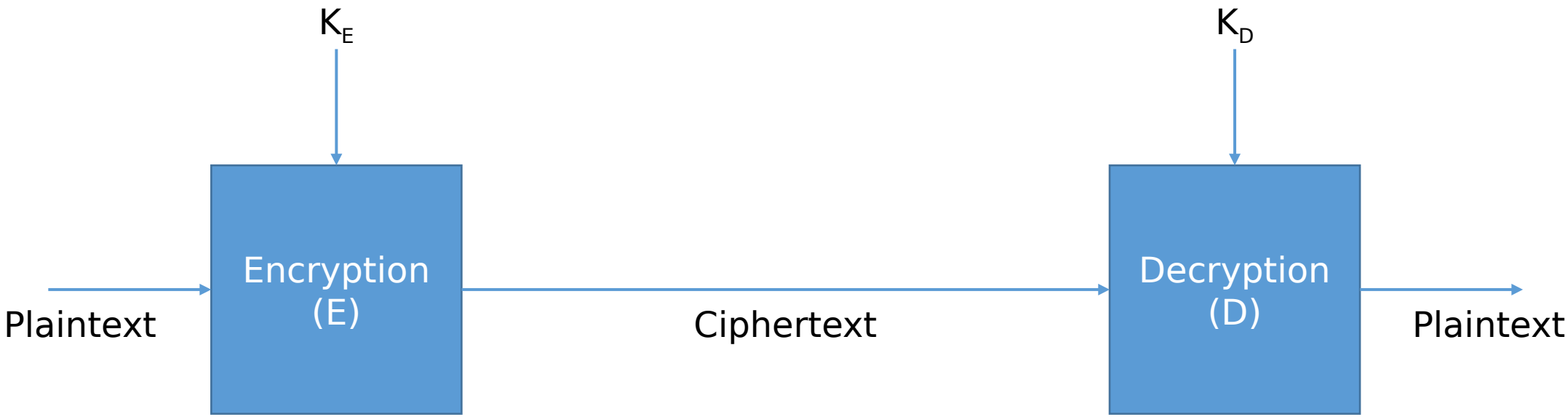
Basic Concept



Symmetric Encryption: $K_E = K_D$

Notes

- Despite the word “text” the data is normally arbitrary binary data
- The key K is a small (e. g., 128 bit) binary token
- The service provided by encryption is **confidentiality**
  - Adversary is not able (hopefully!) to decode the plaintext from the ciphertext
- Encryption adds overhead
  - Time: executing *E* and *D* require CPU effort
  - Space: memory required by *E* and *D*
  - Network Bandwidth: ciphertext might be larger (but probably not)
- Key must be secure
  - Analysis assumes adversary has no knowledge of key *K*
  - … but, as usual, analysis assumes adversary knows algorithms *E* and *D*

Problem with Symmetric Encryption

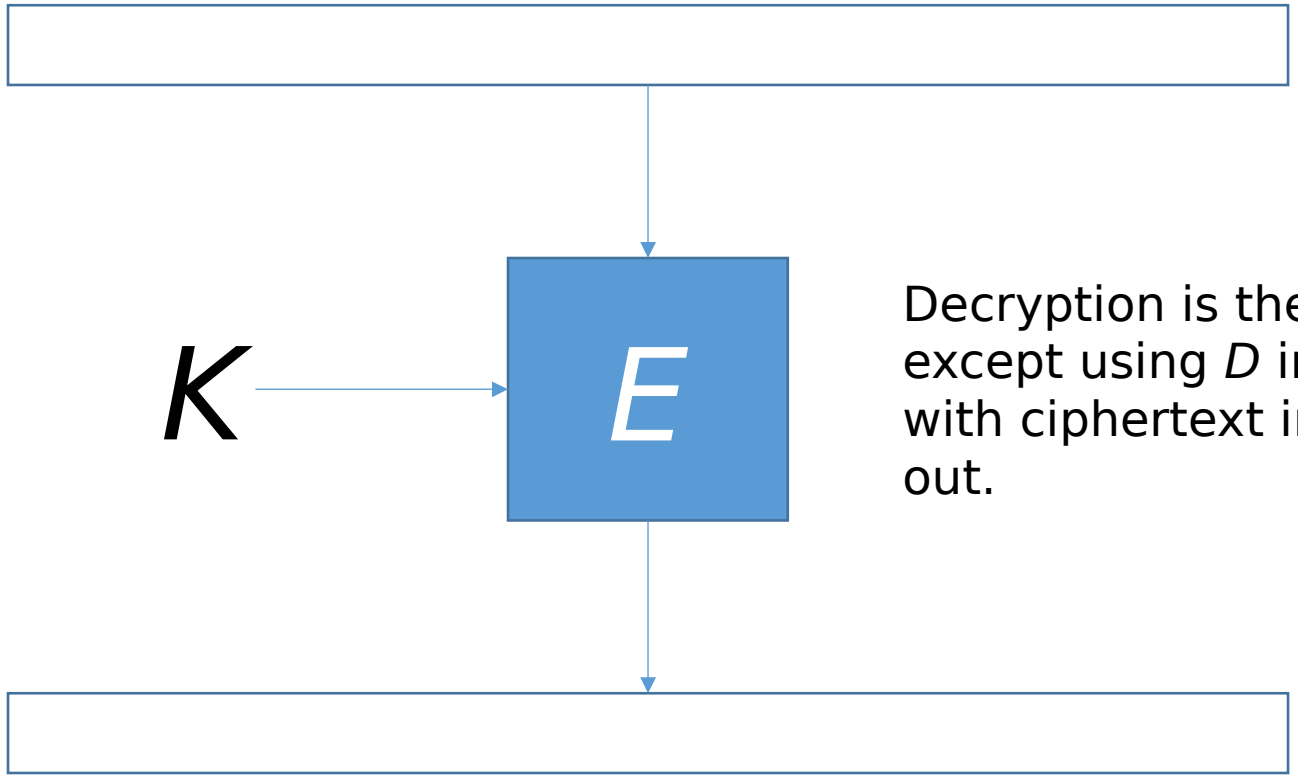
- How to get *K* from sender to receiver?
  - Sender and receiver might be the same entity (ciphertext stored in a file)
- Use a secure channel?
  - Alice and Bob meet in a café where Alice gives Bob the key
  - Alice sends Bob the key via trusted courier
  - Alice tells Bob the key over a secure phone line
- … but then *why not just send the message over the secure channel*?
  - Secure channel likely slow or intermittent (think about the café)
  - Message data might be huge
- We will return to this *key exchange problem* later

Two Approaches

- Block Ciphers…
  - … process the input in units called blocks
  - Block size varies by encryption algorithm. Typically 64 bits (8 bytes) or 128 bits (16 bytes).
  - Creates an issue of what to do if the last block is only partially filled.
- Stream Ciphers…
  - … process the input one byte (or even one bit) at a time.
  - No issue at the end of the input.

Block Cipher Diagram

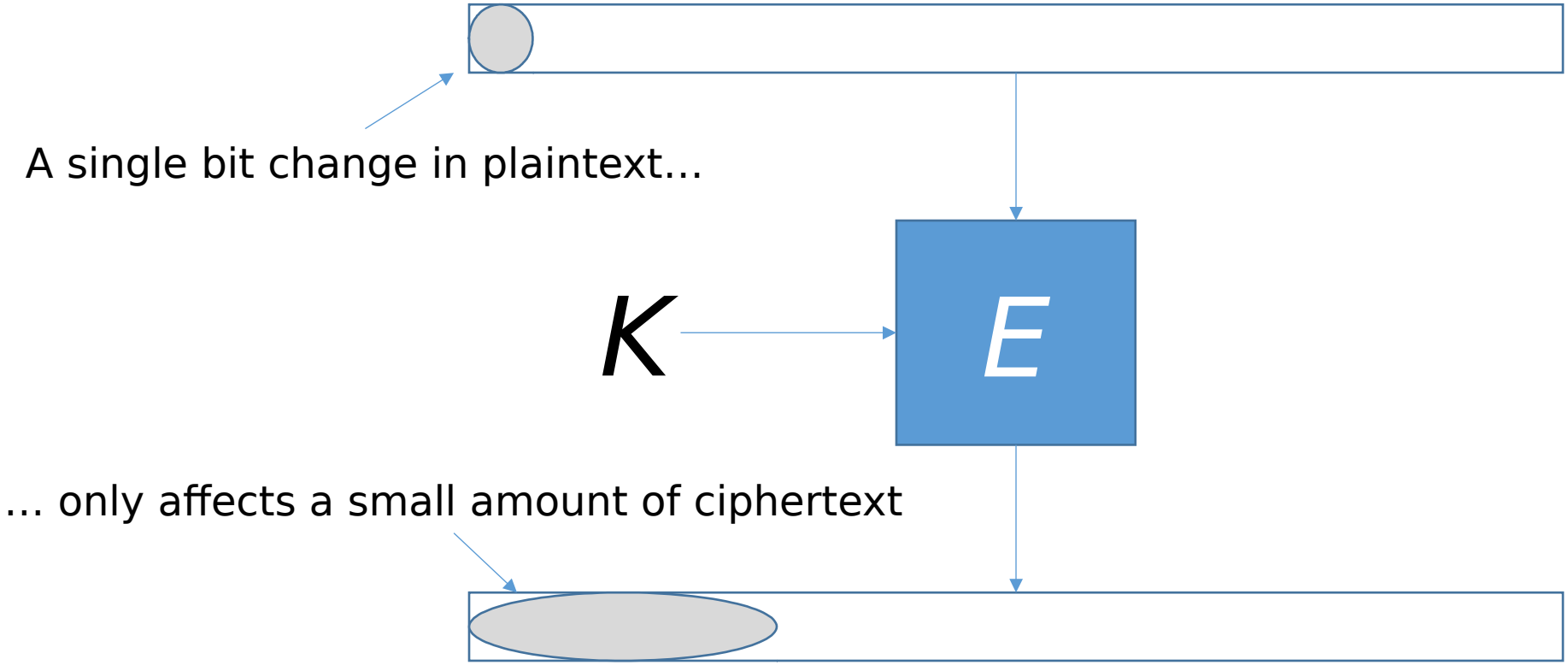
1 block of plaintext = (for example) 64 bits



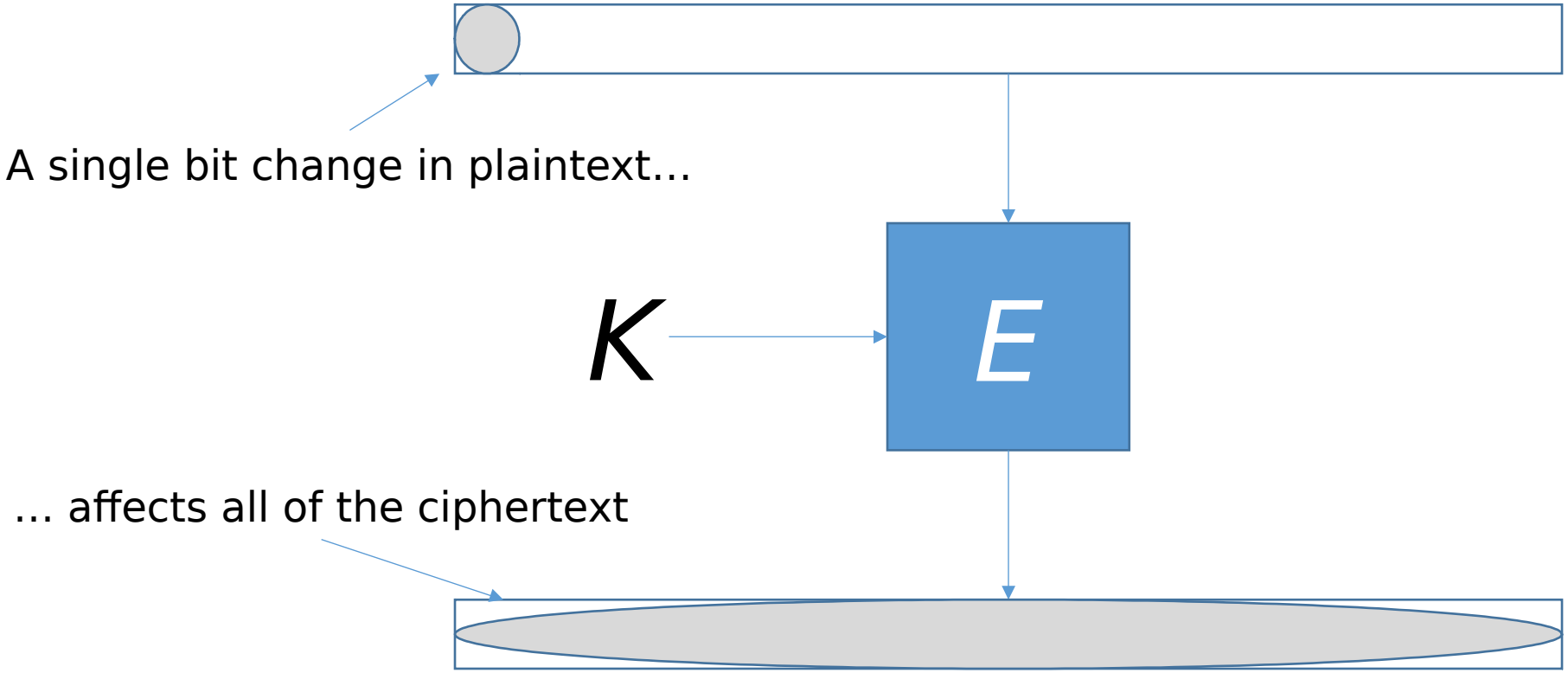
Decryption is the same picture except using *D* instead of *E*, and with ciphertext in and plaintext out.

1 block of ciphertext = (as above) 64 bits

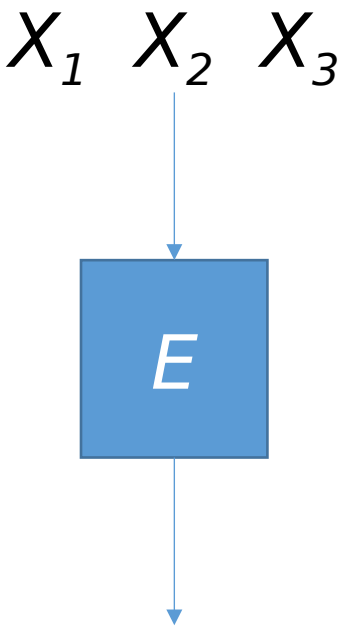
Diffusion (Example of Bad)



Diffusion (Example of Good)



Confusion



Is it possible to express ciphertext bits as a *linear combination* of plaintext?

$$Y_1 = A_{11} X_1 + A_{12} X_2 + A_{13} X_3$$

$$Y_2 = A_{21} X_1 + A_{22} X_2 + A_{23} X_3$$

$$Y_3 = A_{31} X_1 + A_{32} X_2 + A_{33} X_3$$

If so, inverting matrix *A* allows computing plaintext from ciphertext!
If not, the encryption algorithm is *non-linear* and said to have “confusion.”
There is a matter of degree: even an approximate result can be a problem.

Note: Matrix *A* is key dependent, but might be computable given a (plaintext, ciphertext) pair!

Key Size?

- What size should the key be?
  - Does not have to be the same as the block size (often isn’t)
  - Big keys generally take longer to process; increases overhead
  - Big keys are more secure
  - Some algorithms allow variable sized keys
- Small keys?
  - Keys less than 64 bits are not taken seriously in today’s world
  - Keys of 80 bits are probably okay
  - Keys of 128 bits are more like it
  - *Where did I come up with these numbers?*

Brute Force Attack!

- Very simple: Try every possible key
  - 64 bit key implies $2^{64} = 1.8447 \times 10^{19}$ keys
- Suppose…
  - Machine can execute 10^9 trial decryptions per second
  - $1.8447 \times 10^{19} / 10^9 = 1.8447 \times 10^{10}$ seconds to exhaust key space
  - … that's 584.55 years!
  - BUT… problem is easy to parallelize. Specialized hardware is very fast.
  - With today's technology you could probably go 100x faster
  - … reduces time scale to ~years… or maybe ~months or ~weeks!
  - Likely to find the key when about ½ the key space has been searched

Brute Force Attack?

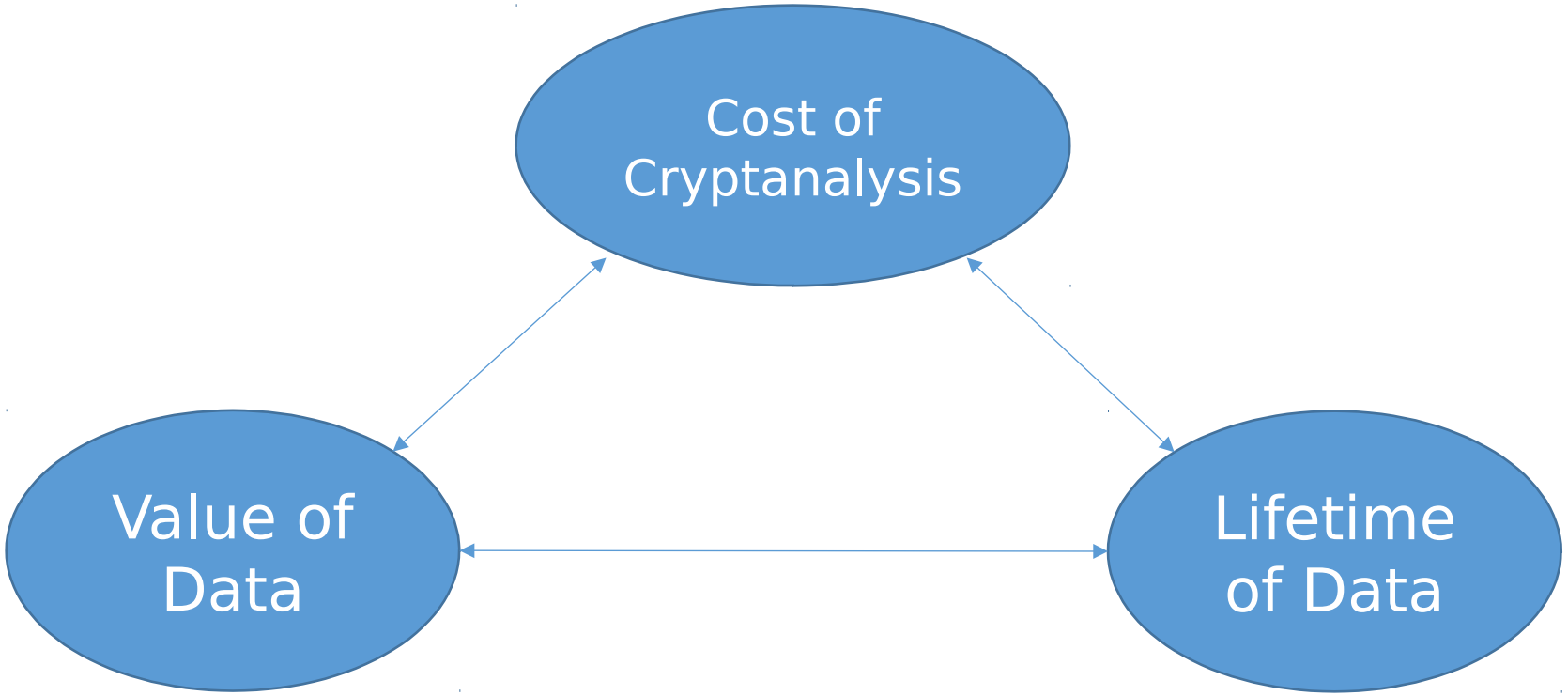
- Let’s use 128 bit keys
  - 128 bit key implies $2^{128} = 3.4028 \times 10^{38}$ keys
- Suppose…
  - Machine can execute 10^9 trial decryptions per ***nanosecond***!
  - $3.4028 \times 10^{38} / 10^{18} = 3.4028 \times 10^{20}$ seconds required to exhaust key space
  - That’s 1.0783×10^{13} years!
  - That’s 780 times longer than the age of the universe!
  - Conclusion: **Brute forcing a 128 bit key is out of reach by any foreseeable tech**.

Why Use 256 Bit Keys?

- Some algorithms allow for very long keys
  - … but long keys generally take more processing overhead. Why use them?
- Brute force effort is the threshold for cryptographic analysis
  - Algorithms are sometimes said to be “broken” if there exists a mathematical way to crack them that is more efficient than brute force.
  - … but that doesn’t necessarily mean it is easy!
  - Attacks on (a slightly weakened form of) AES have been found that are faster than brute force,† but still completely impractical to execute.
- Super large keys offer insurance against future developments in cryptanalysis

† *Improved Cryptanalysis of Rijndael* by Niels Ferguson, et. al.

Three Way Trade-Off



Three Way Trade-Off

- Cost
  - Super powerful computers are expensive
  - Some adversaries won’t have the money to buy them
- Value of Data
  - Some secrets just aren’t worth the cost
  - Adversaries are willing to spend money to learn important secrets
- Lifetime of Data
  - Daily battlefield orders useless tomorrow
  - Must be cracked quickly (which costs a lot) to be of any value

Fit Encryption Properly

- **Encryption adds overhead**
  - Don’t use more encryption than you actually need… ideally none!
- Dial up your encryption tech to match…
  - … the resources your adversary is likely to use against you
  - … the value of the data you are protecting
  - … the lifetime of the data you are protecting
- Q: What’s the ideal key size?
  - A: The smallest one you can get away with
  - … while making sure to protect your data for as long as needed against an adversary willing to spend an “appropriate” amount on discovering it