black hat USA 2021

DBREACH

Database Reconnaissance and Exfiltration via Adaptive Compression Heuristics

Mathew Hogan	Saba Eskandarian	Yan Michalevsky
Stanford University	UNC Chapel Hill	Anjuna Security

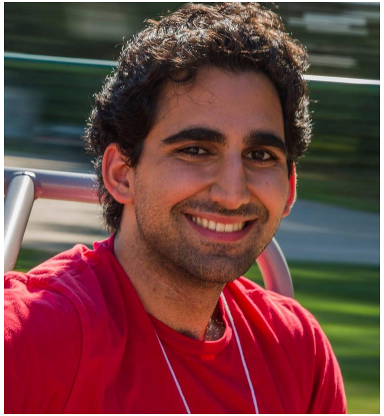
Who We Are

Mathew Hogan

- MS Candidate in CS at Stanford, Security track
- BS in CS from Stanford, Systems track

Yan Michalevsky

- CTO and co-founder at Anjuna.io
- PhD in Security and Crypto from Stanford



Saba Eskandarian

- Assistant Prof. at UNC Chapel Hill
- PhD in Crypto and Security from Stanford

Outline

1. Background
2. Our Attack
3. Roadblocks & Optimizations
4. Analysis
5. Mitigations
6. Conclusion

Background

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Key idea: use compression to reveal information about the original content

John Kelsey. "Compression and Information Leakage of Plaintext," FSE 2002.

CRIME/BREACH (2012/13)

Secret included in encrypted and compressed messages between client and server

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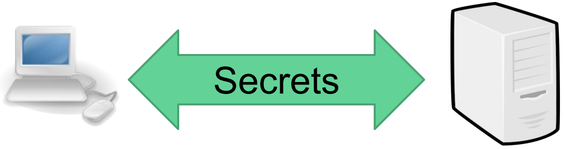

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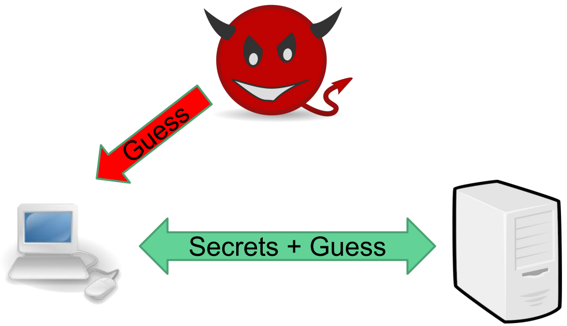

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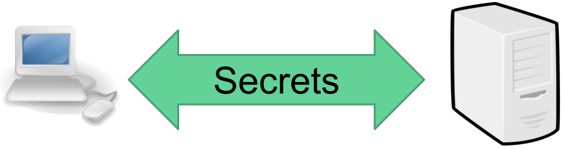

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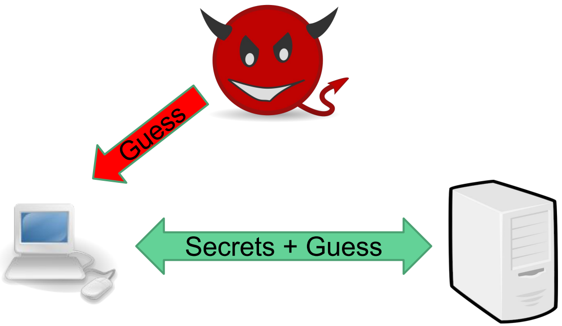

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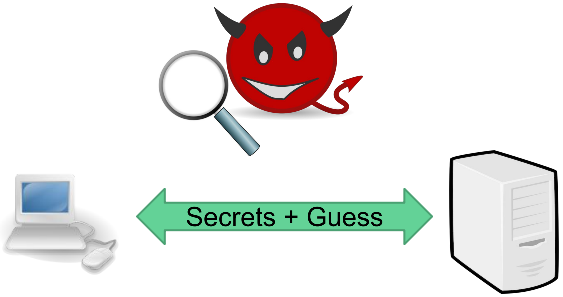

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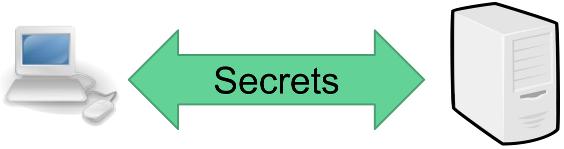

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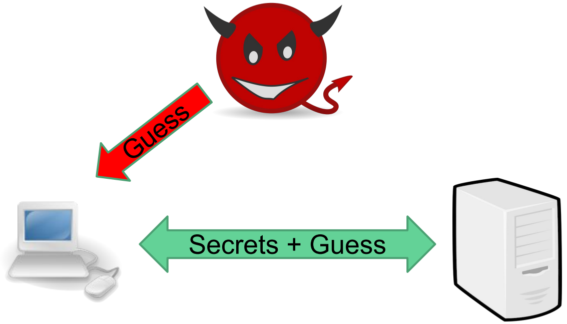

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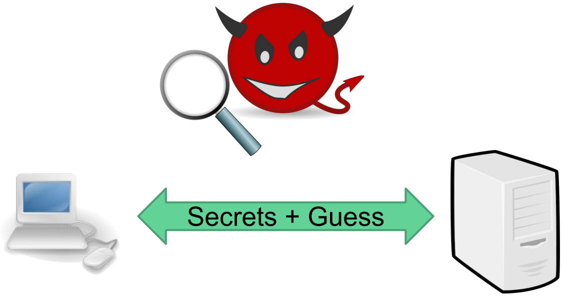

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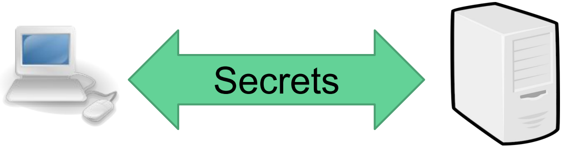

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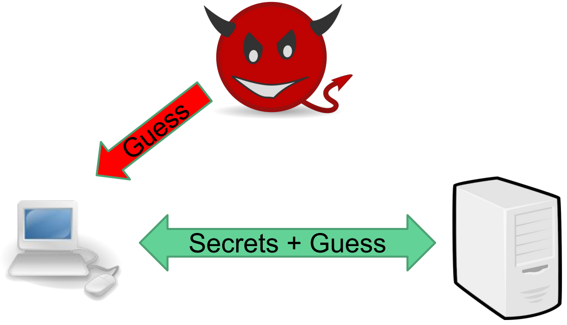

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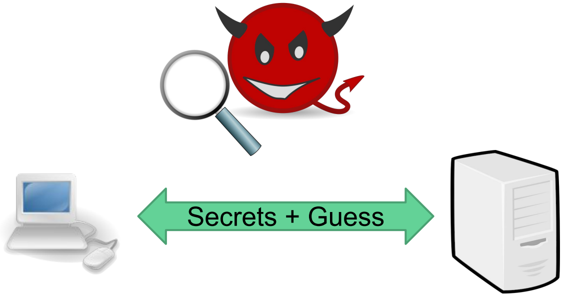

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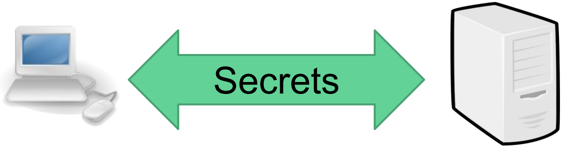

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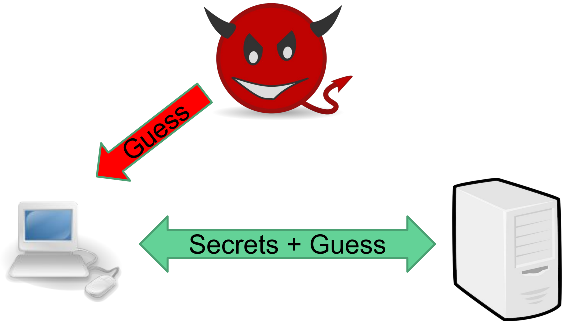

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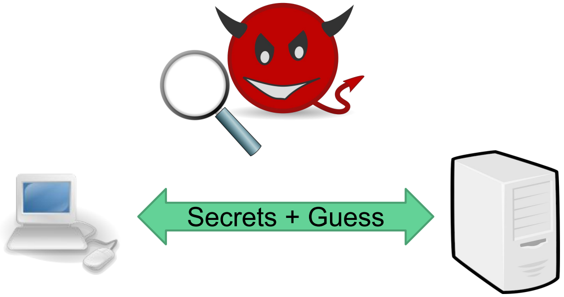

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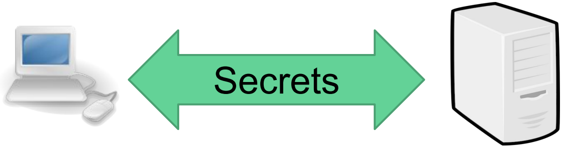

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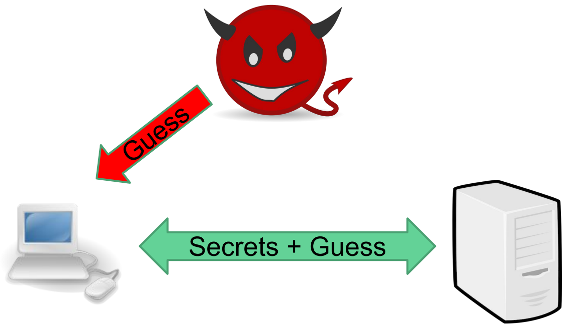

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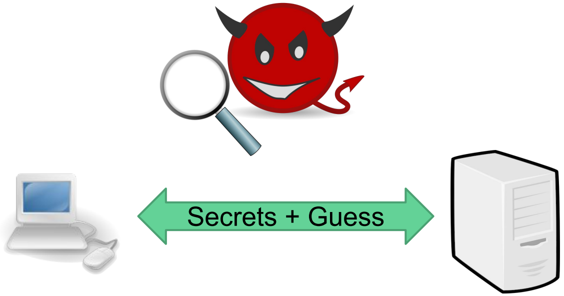

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Attack requirement 3:
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Where else do all these factors come together?

DBREACH in a Nutshell

Compression side-channel attack against databases

Attacker recovers other users’ encrypted content

Extends techniques from CRIME/BREACH beyond TLS to database context

MariaDB/InnoDB Encryption and Compression

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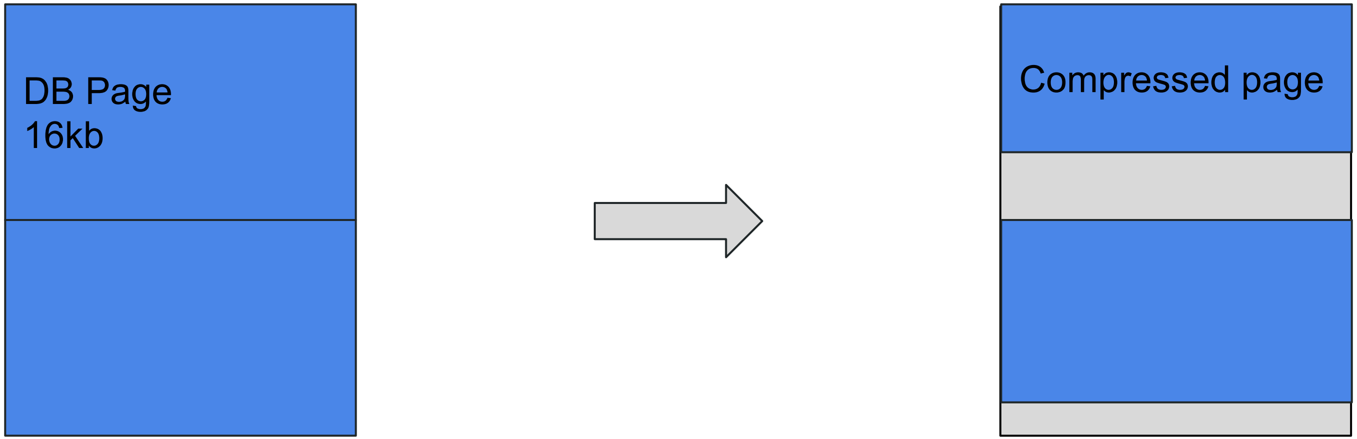

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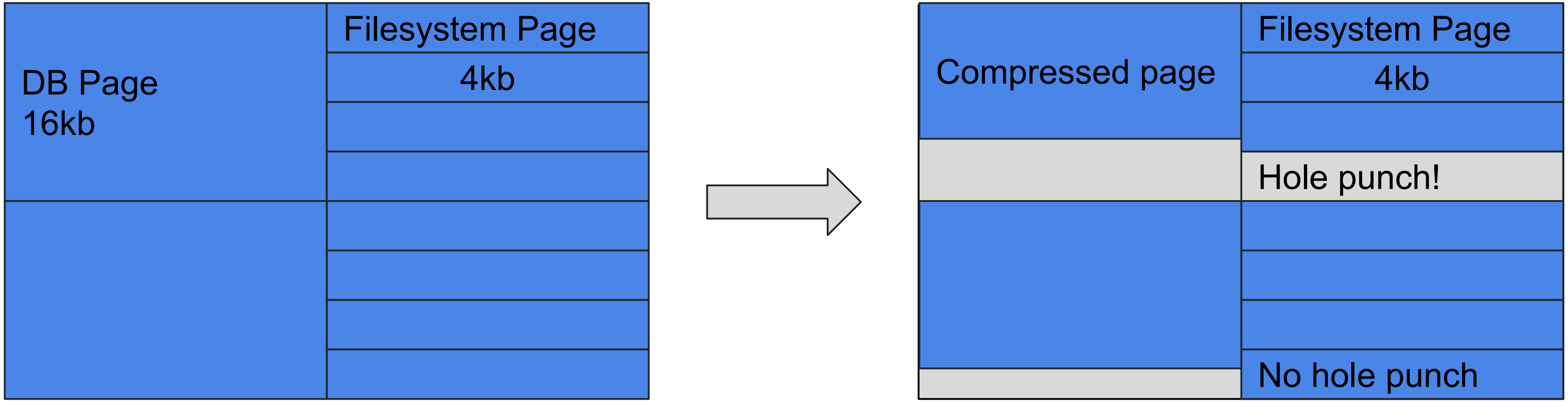

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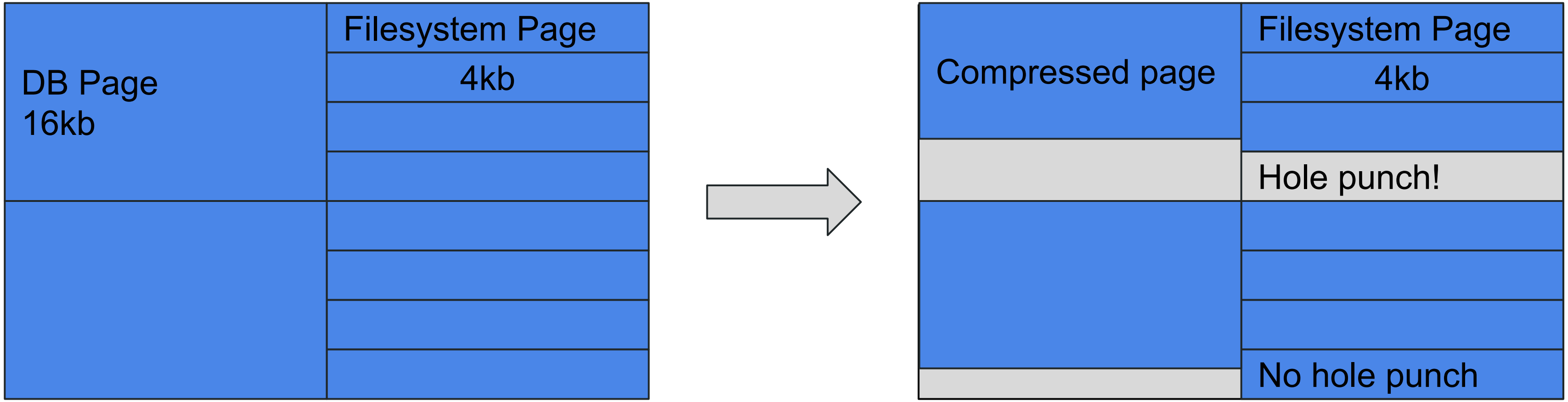
Uses *hole punching* to save space, only helps when there is enough compression to remove a whole filesystem page



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zlib additionally has a Huffman Coding step

Our Attack

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If UPDATE permissions can’t be achieved, an attacker with write access can force an update by rolling back the table file and inserting.

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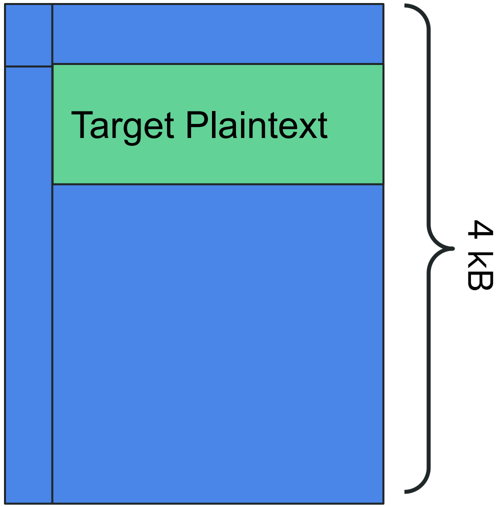

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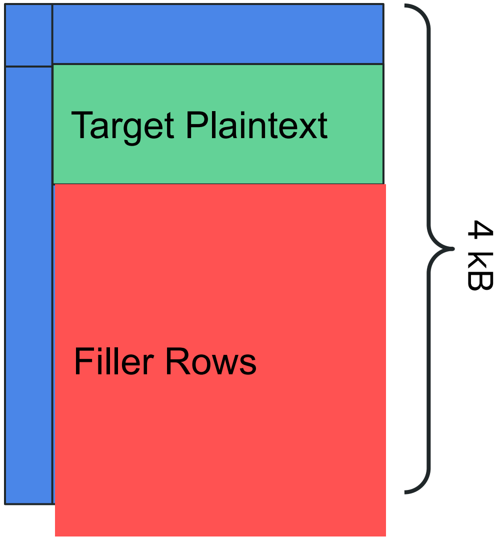

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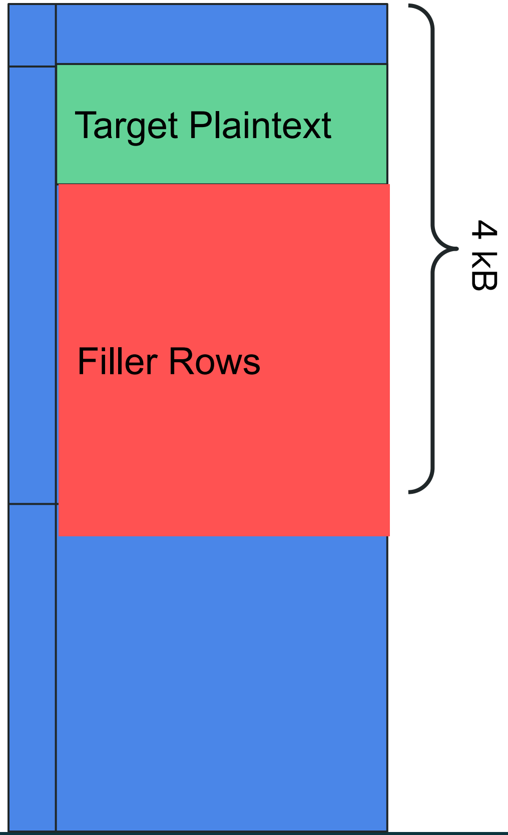

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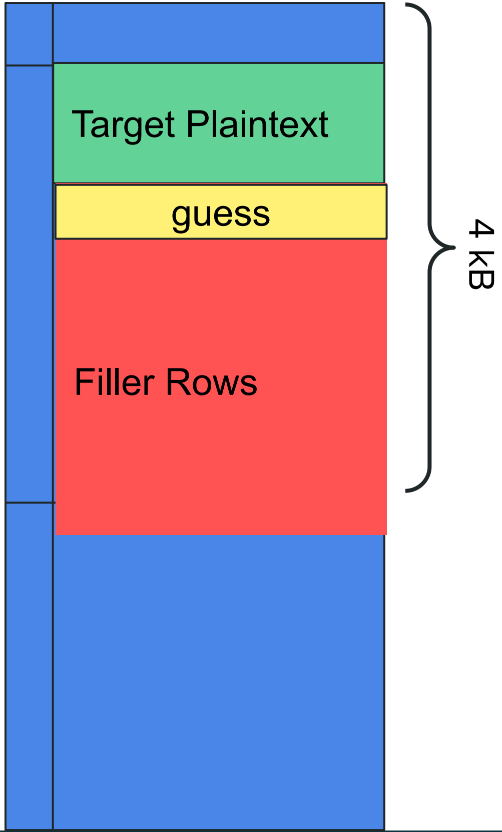

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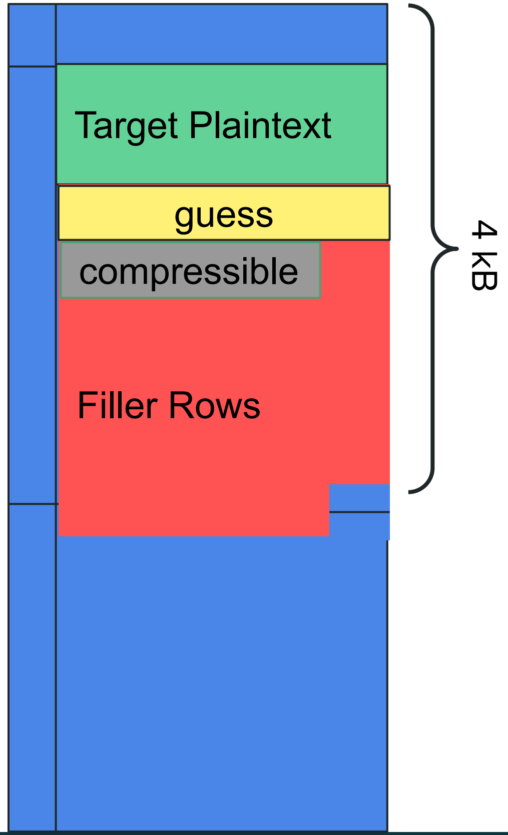

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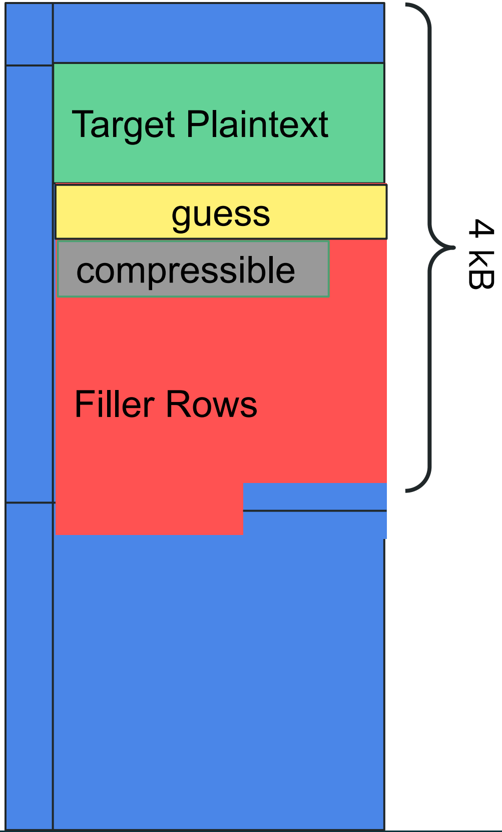

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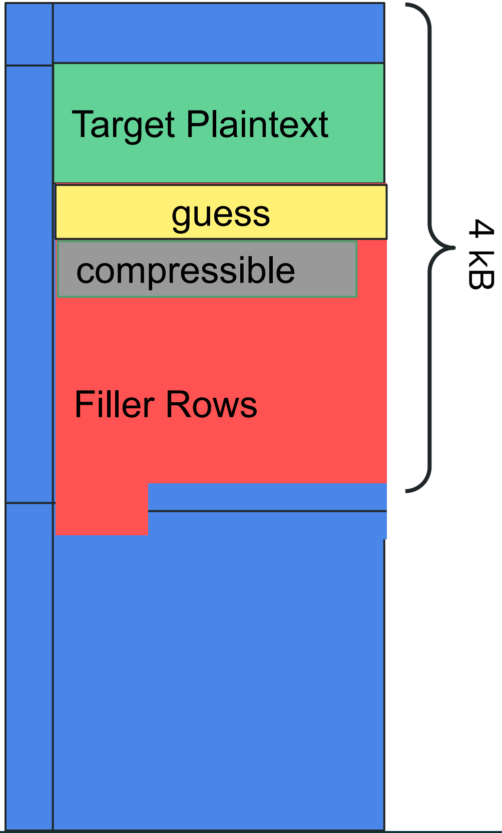

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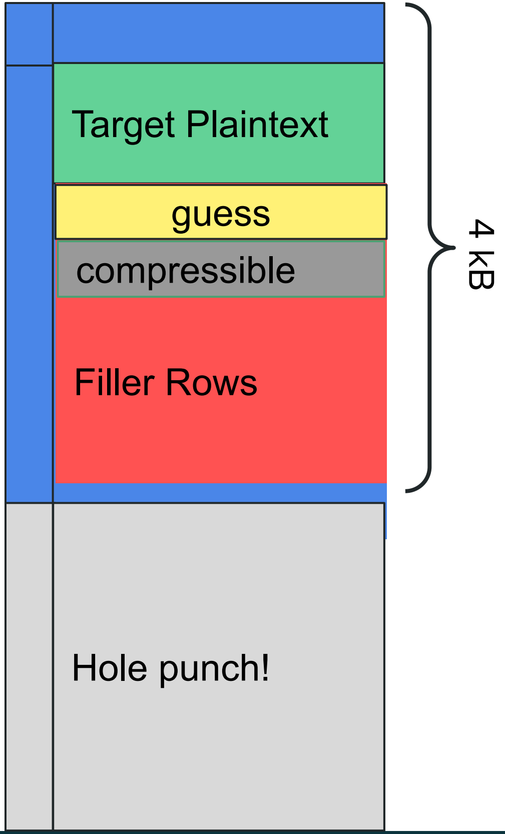

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   a. The number of bytes until the table shrinks determines this guess's "compressibility score"

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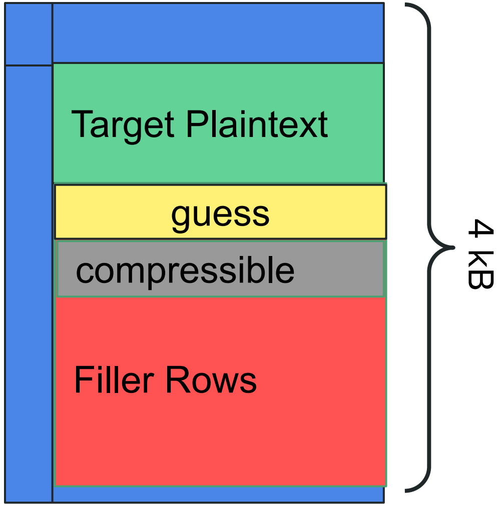

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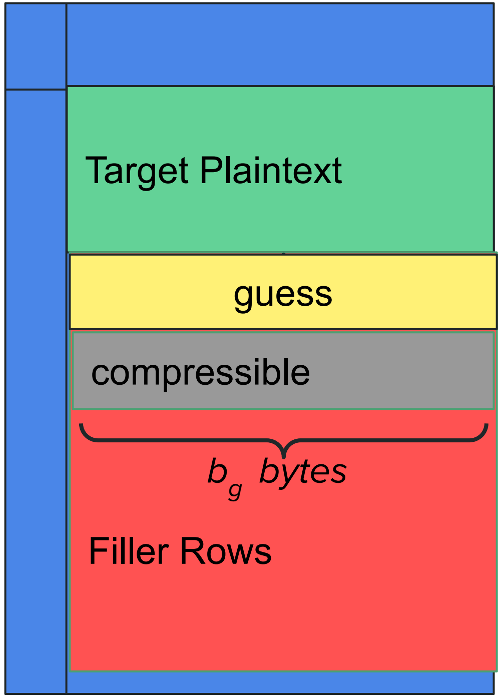

Compressibility Scores

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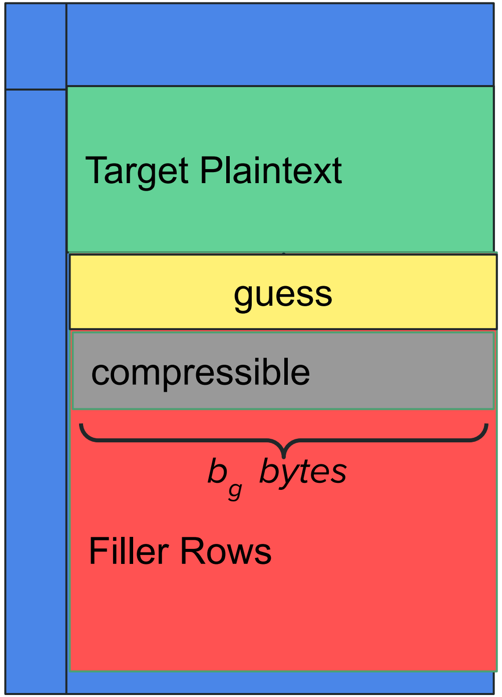
The compressibility score c_g is calculated as follows:

$$\boldsymbol{c_g = 1 / b_g}$$



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  - More complicated
  - We need a reference point for compressibility scores

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To gain reference points, we calculate scores $\boldsymbol{s}_{\boldsymbol{yes}}$ and $\boldsymbol{s}_{\boldsymbol{no}}$ for strings we know to be in and not in the table, respectively.

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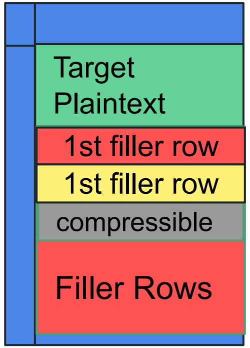

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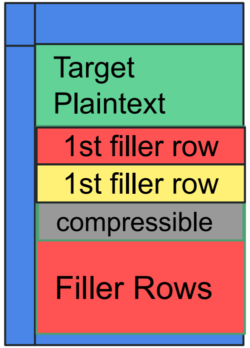

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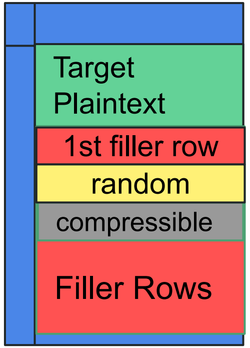

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If a guess's score is within some threshold of $\boldsymbol{s}_{\boldsymbol{yes}}$, answer "yes"

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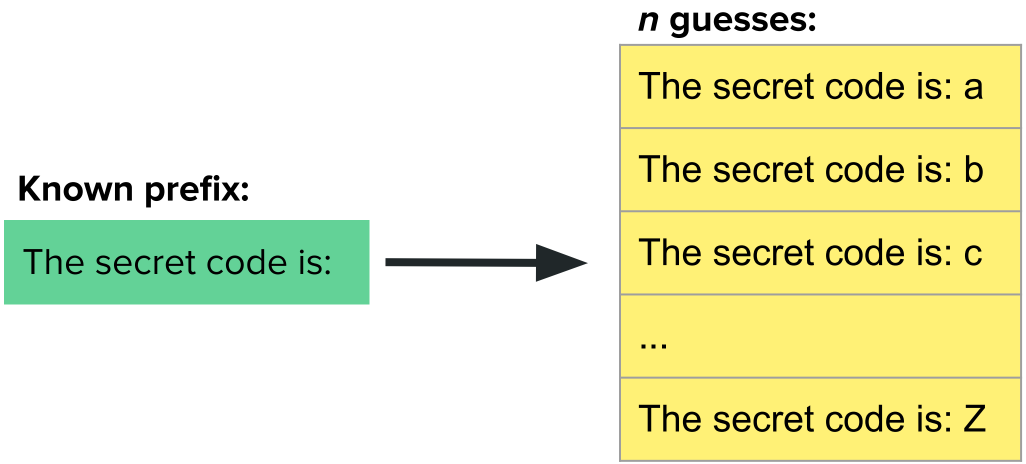

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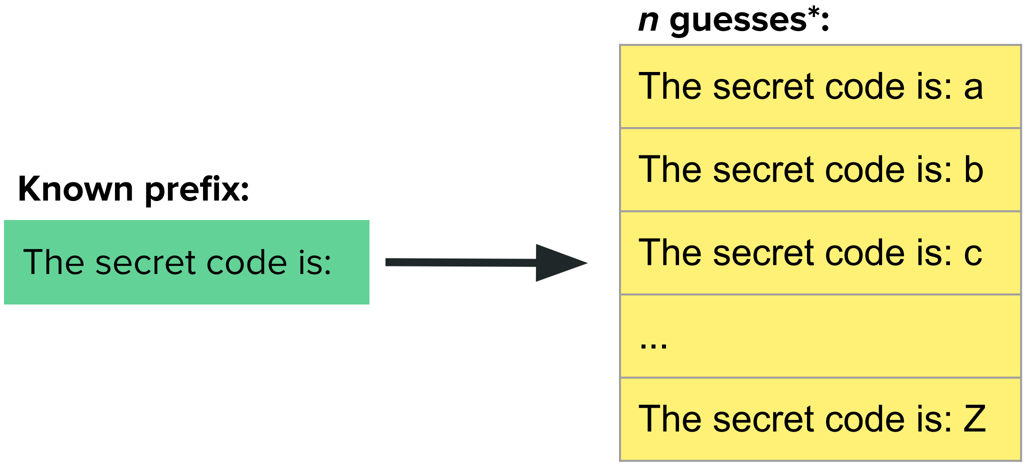

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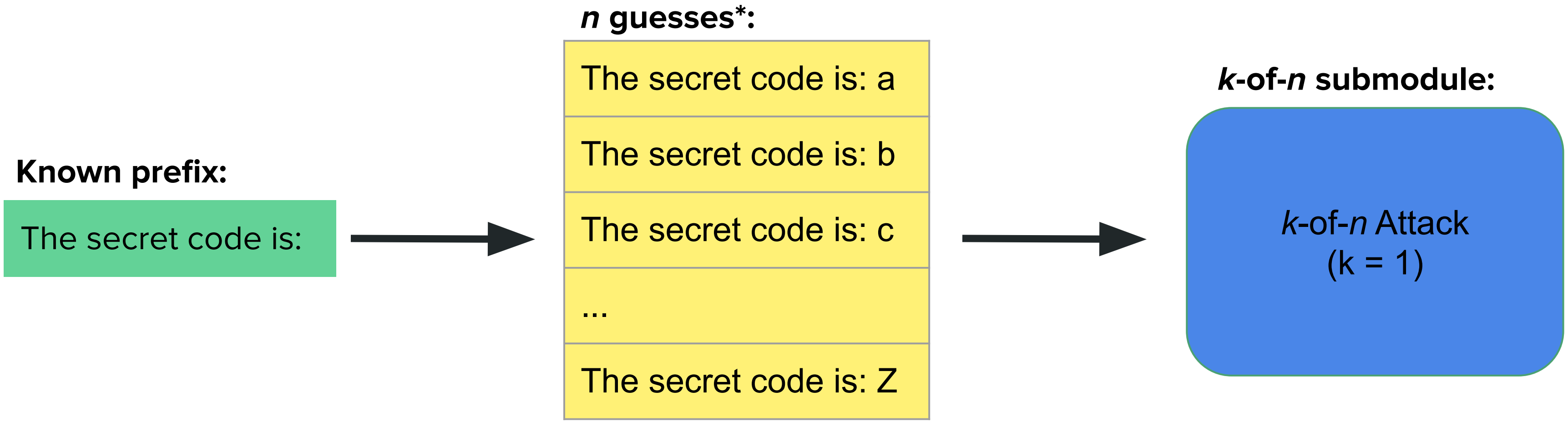

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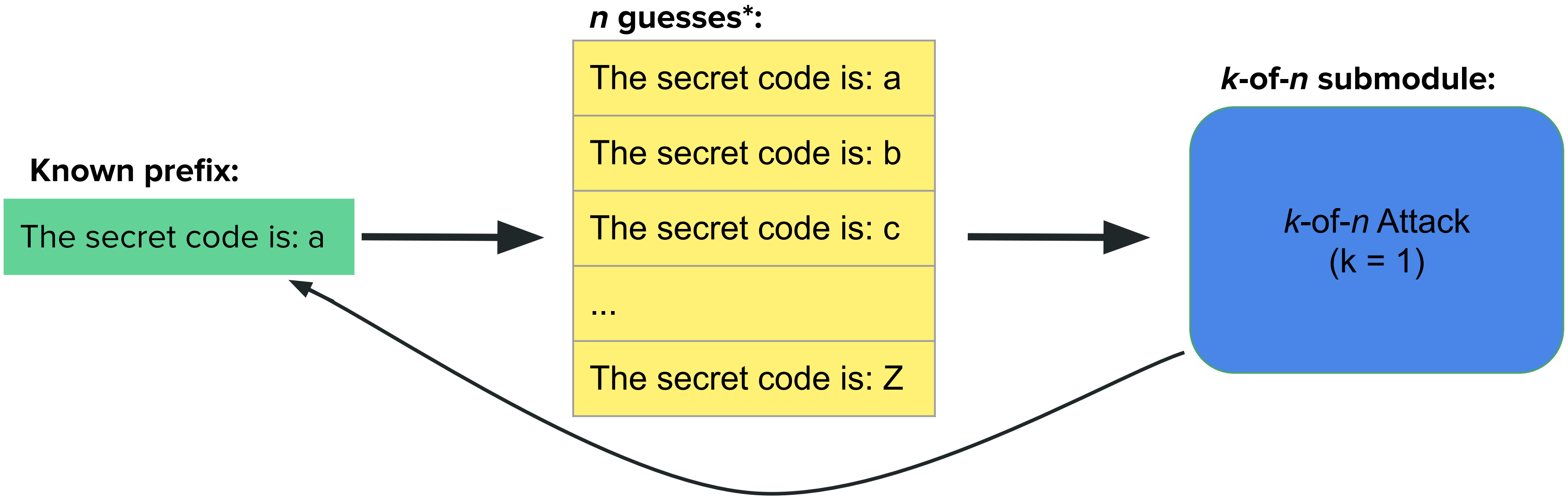

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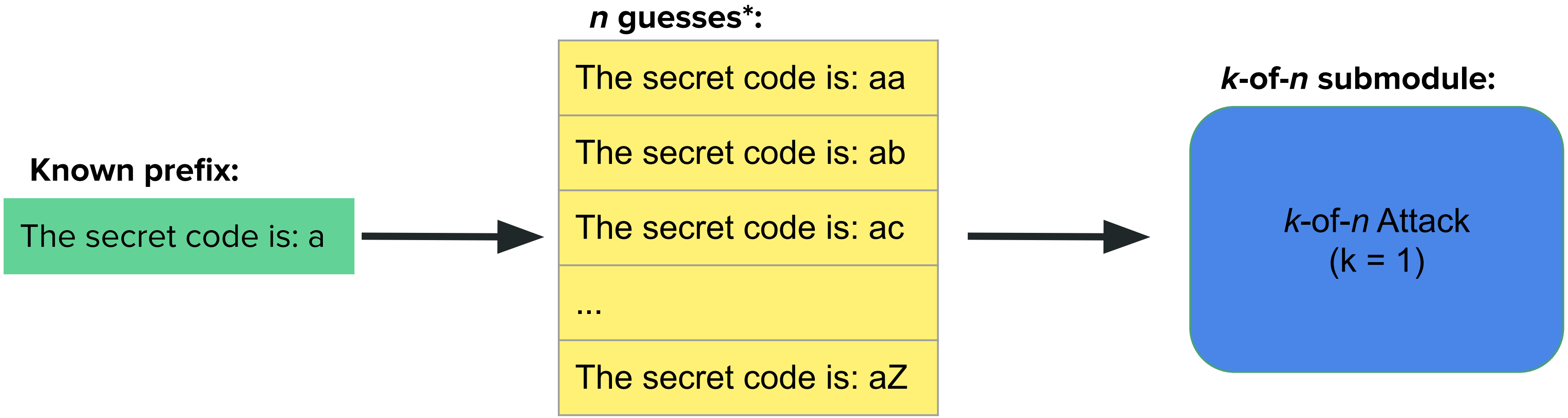

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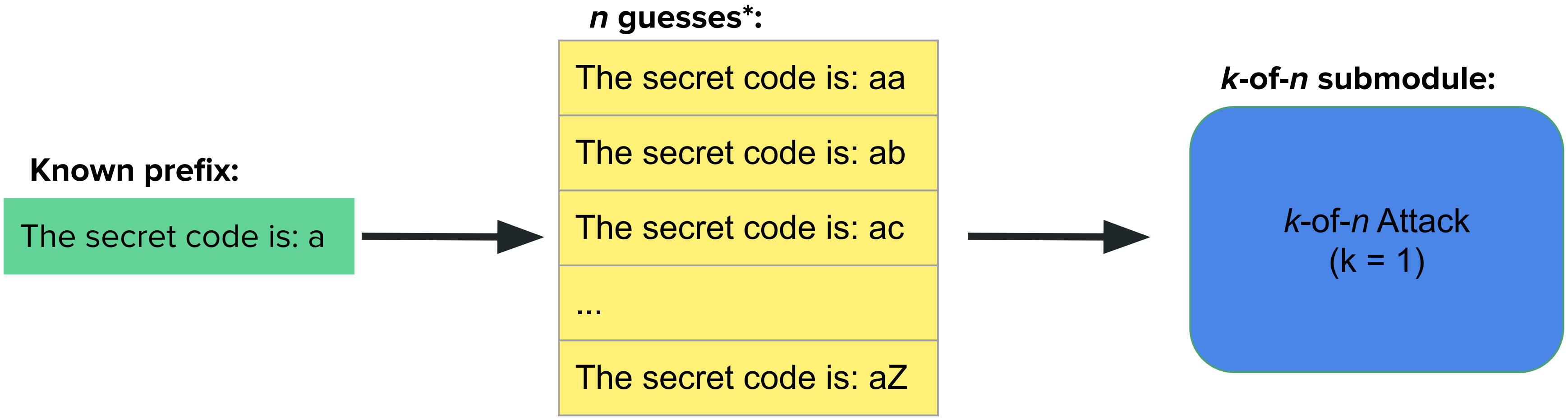

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...

The secret code is: aZ

***k*-of-*n* submodule:**

k-of-*n* Attack
(k = 1)

**n* = |Σ|, where Σ is the alphabet of all possible characters

Roadblocks & Optimizations

Substring/Superstring Problem

Might get false positives if guess is a:

- **Substring**: A guess is a substring of what is in the table

- **Superstring**: What is in the table is a substring of the guess

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Still vulnerable to false positives if the superstring is not much longer than the ground truth (recall that we only have to be close to $\boldsymbol{s_{yes}}$ and not precisely match it).

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Filler Row

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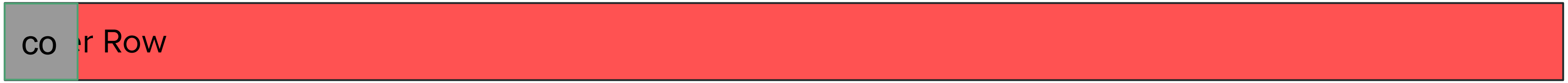

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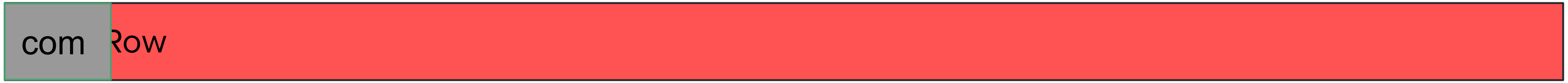

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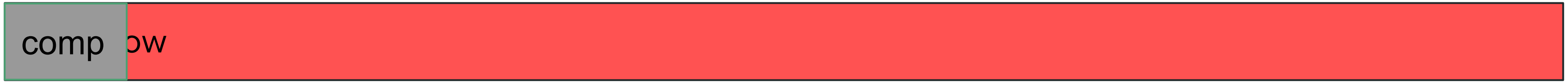

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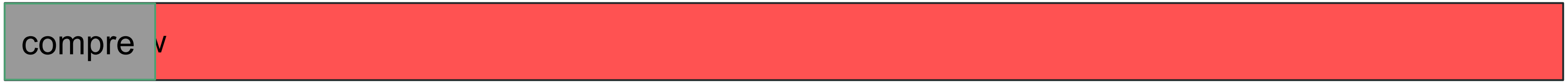

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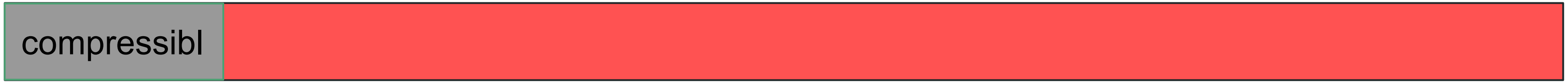

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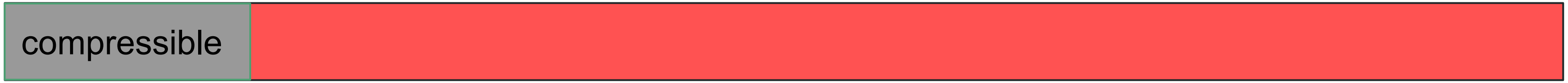

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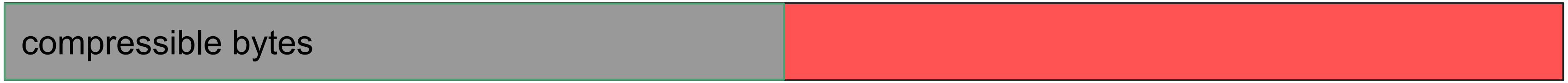

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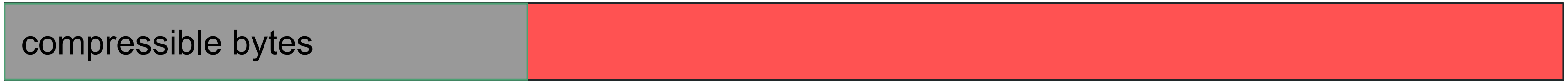

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Analysis

Efficiency & Speed

After our binary search optimization, the attack becomes very efficient:

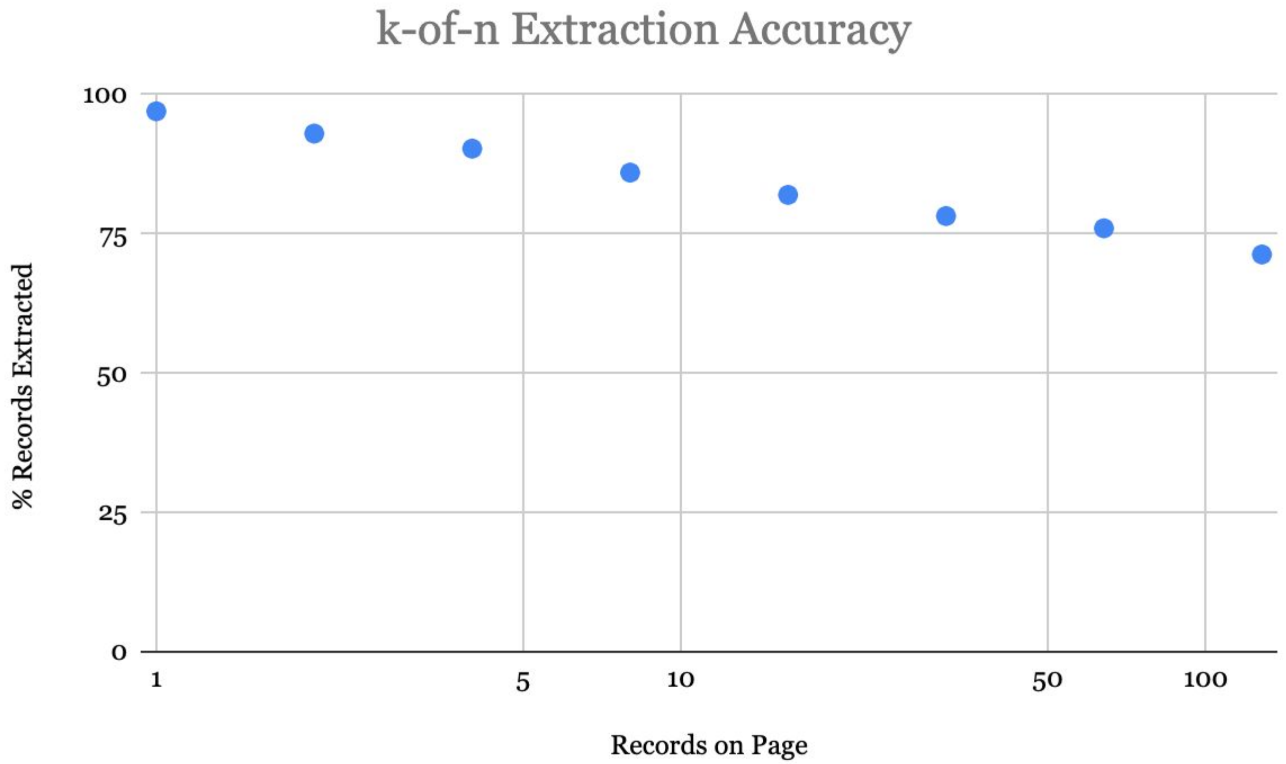
Let *R* be the maximum size of a row

- Insertion of filler rows
  - We must initially insert at most *page_size / R* rows to fill up the page
  - In practice, with an empty page and *R = 200*, this takes about 30 insertions
- Updates per guess
  - $\log_2 R$ updates per guess

Thus, for *n* guesses we perform $O(R + n \log R)$ database actions.

In practice, with *R = 200*, a single guess took 0.2-0.4 seconds.

Accuracy


k-of-n Extraction Accuracy
100
75
50
25
0
% Records Extracted
1
5
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50
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Records on Page

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We believe that other RDBMSs and storage engines are vulnerable to the same attack. MySQL is especially likely to be vulnerable.

Mitigations

Prevention

Recommendations for database administrators & developers using databases:

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Only foolproof solution: **Turn off compression.**

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- Compress only within rows
- Or, compress only within rows inserted by the same user / user group

Demo!

DBREACH

- Attack on compression & encryption in databases
- Simple threat model
- **Efficient** and **accurate**

Contact

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