ZIP file encryption weaknesses

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Security PWNing 2017

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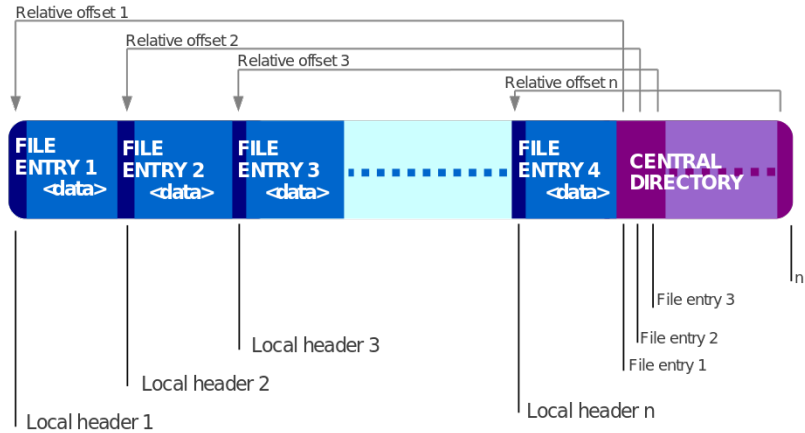
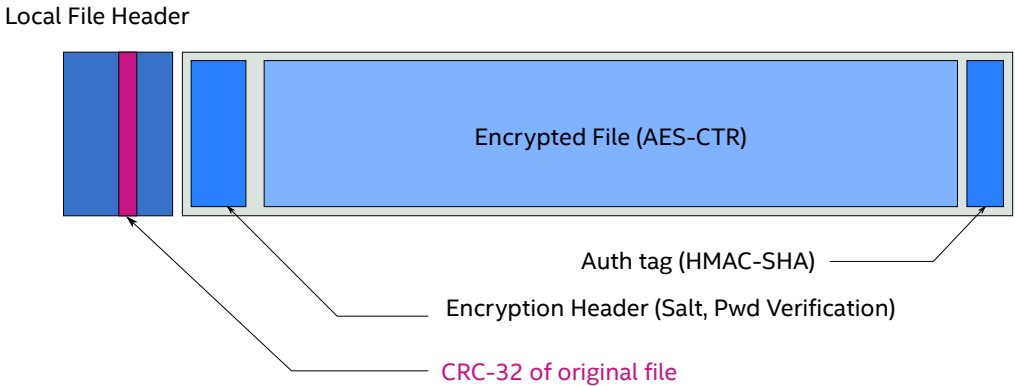
Structure of ZIP files



Structure of File Entry



Cyclic Redundancy Codes

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Step 1: Take data* bits $d_0, d_1, d_2, \ldots, d_{n-1}$ as coefficients of a polynomial over the binary field

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Step 2: Compute the remainder $C(x)$ of a polynomial division of $D(x)$ by a fixed reduction polynomial $R(x) = r_0 + r_1 x + \cdots + x^u$

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* almost: needs data padding, initial and final xors

Polynomial modulo reduction

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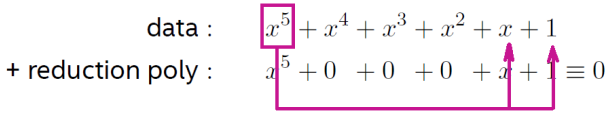
Consequence:

- Can iteratively reduce polynomial of any degree, replacing x^u according to (1)

Modulo reduction: example

$$
\begin{aligned}
\text{data :} \quad & x^5 + x^4 + x^3 + x^2 + x + 1 \\
\text{+ reduction poly :} \quad & x^5 + 0 \ + 0 \ + 0 \ + x + 1 \equiv 0 \\
\hline
\text{result :} \quad & 0 \ + x^4 + x^3 + x^2 + 0 + 0
\end{aligned}
$$

Linearity of CRC



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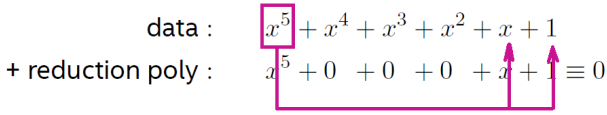


Example:

$$c = \mathsf{CRC32}(x), \qquad |x| = 32$$

Bits c_i can be represented as an affine function of 32 input bits x_i:

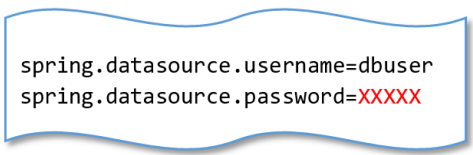
$$
\begin{aligned}
c_0 &= x_0 + x_1 + x_2 + x_3 + x_4 + x_6 + x_7 + x_8 + x_{16} + x_{20} + x_{22} + x_{23} + x_{26}, \\
c_1 &= x_1 + x_2 + x_3 + x_4 + x_5 + x_7 + x_8 + x_9 + x_{17} + x_{21} + x_{23} + x_{24} + x_{27}, \\
c_2 &= x_0 + x_2 + x_3 + x_4 + x_5 + x_6 + x_8 + x_9 + x_{10} + x_{18} + x_{22} + x_{24} + x_{25} + x_{28} + 1, \\
c_3 &= x_1 + x_3 + x_4 + x_5 + x_6 + x_7 + x_9 + x_{10} + x_{11} + x_{19} + x_{23} + x_{25} + x_{26} + x_{29} + 1, \\
&\vdots \\
c_{31} &= x_0 + x_1 + x_2 + x_3 + x_5 + x_6 + x_7 + x_{15} + x_{19} + x_{21} + x_{22} + x_{25} + x_{31}
\end{aligned}
$$

We like linearity

$$\begin{bmatrix} c_0 \\ c_1 \\ \vdots \\ c_{n-1} \end{bmatrix} = \begin{bmatrix} q_{0,0} & q_{0,1} & \cdots & \cdots & \cdots & q_{0,m-1} \\ q_{1,0} & q_{1,1} & \cdots & \cdots & \cdots & q_{1,m-1} \\ \vdots & \vdots & & & & \vdots \\ q_{n-1,0} & q_{n-1,1} & \cdots & \cdots & \cdots & q_{n-1,m-1} \end{bmatrix} \cdot \begin{bmatrix} d_0 \\ d_1 \\ \vdots \\ \vdots \\ \vdots \\ d_{m-1} \end{bmatrix} + \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_{n-1} \end{bmatrix}$$

Scenario 1

Extracting bits from mostly known file: basics



- We have 32 equations
- We can solve for unknown bits of the data
- Can recover up to 32 bits, depending on the rank of the matrix

Extracting bits from mostly known file: in general

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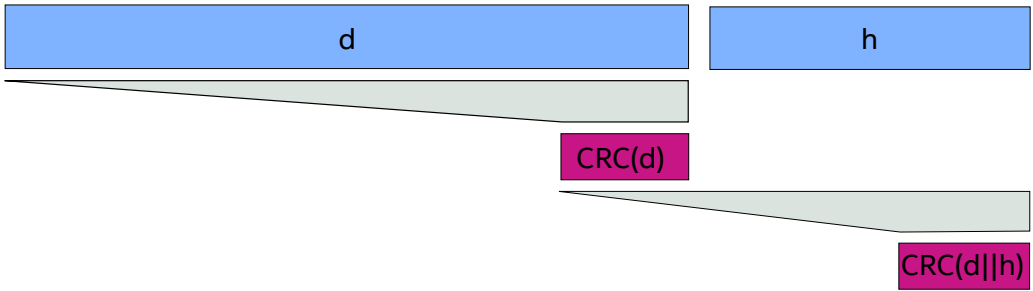
Example: If the only unknown part of the file is a password:

- we have a good chance of determining it uniquely if the entropy is ≤ 32 bits,
- we can sieve out vast majority of potential passwords from our wordlist.

Scenario 2

Incremental files

- CRC computation is “incremental”
- Easy to compute $c' = CRC(d||h)$ knowing $c = CRC(d)$ and h, without the knowledge of d



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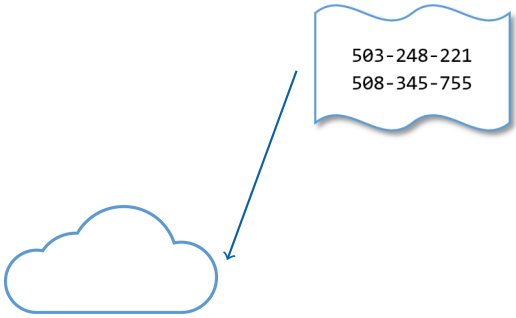

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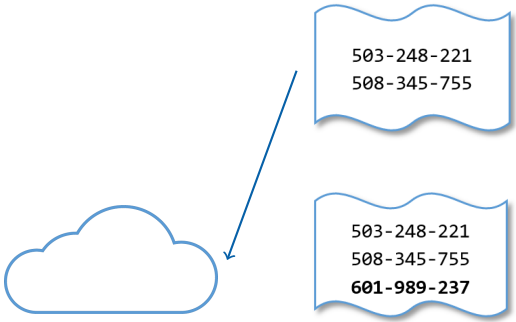

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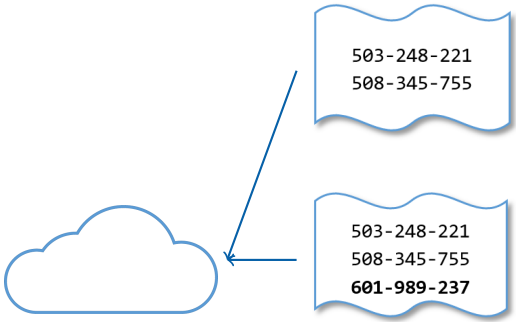

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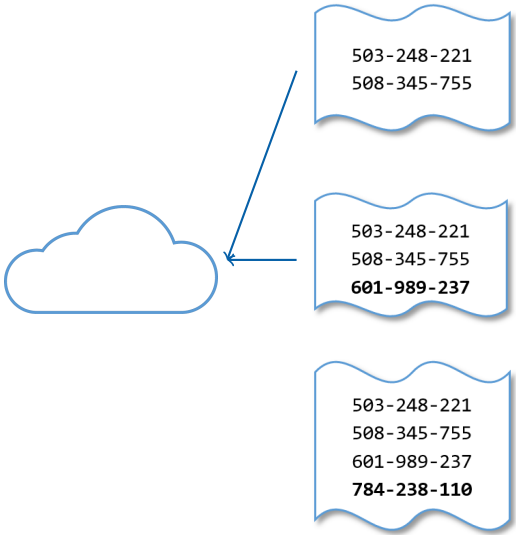

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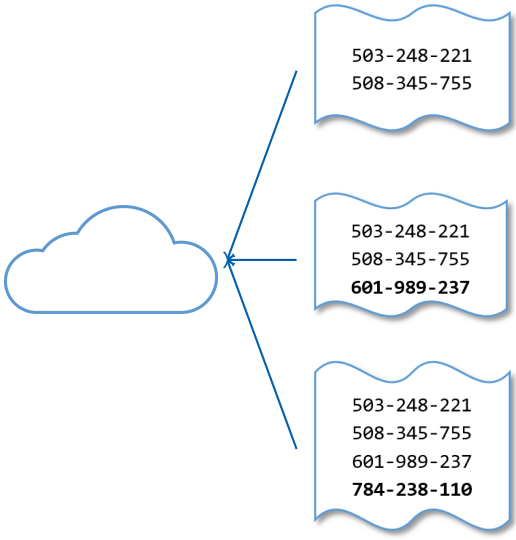

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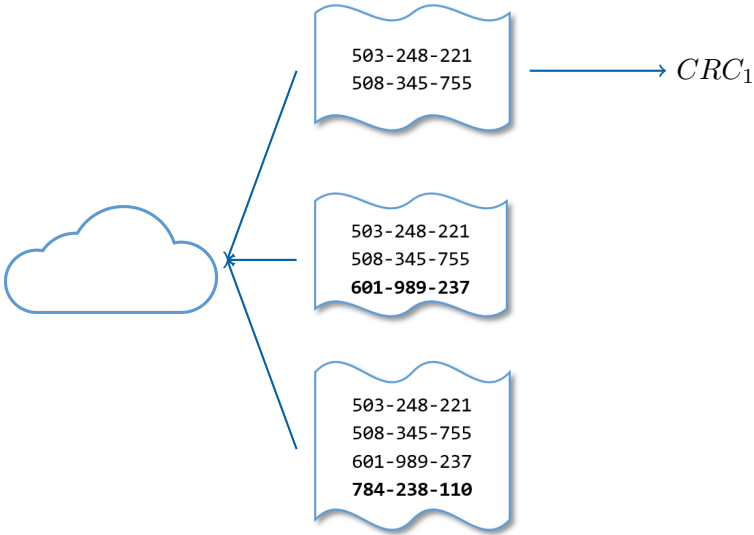

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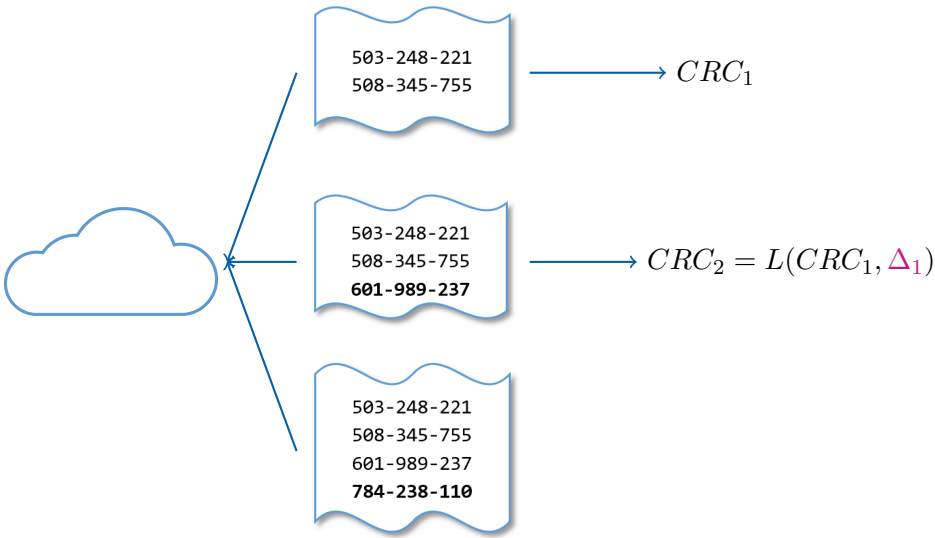

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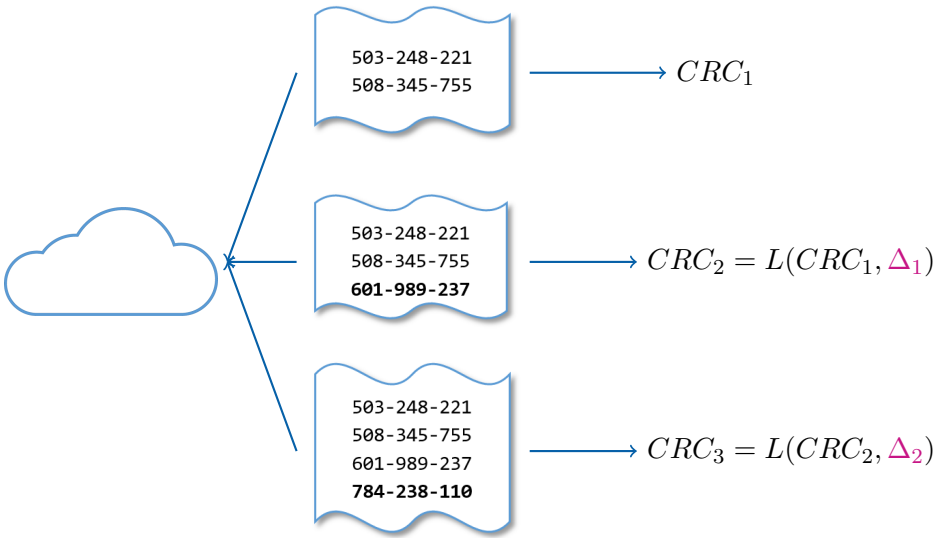

Recovering incremental files

- If data increment Δ is small (≤ 32 bits of entropy), we can find $\Delta_i = L_{\text{inv}}(CRC_{i-1}, CRC_i)$
- Recover the increments Δ_i and reconstruct file contents

Scenario 3

Information tagging

- CRC values of unencrypted data can be extracted from encrypted ZIP files

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Information tagging

- CRC values of unencrypted data can be extracted from encrypted ZIP files
- CRC values are $\approx$ uniformly distributed
- Probability of collision is 2^{-16} for CRC-32
- If your chance of being wrong is $1/65000$, would you get a warrant?

The Fix

- Easy to fix: don’t store CRC for encrypted files
- Reported our findings to WinZip (Corel), issue acknowledged
- “Fixed” in WinZip 22: registry setting to switch between AE-1 AE-2

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- CRC codes are linear!
- Linearity is always a friend of a cryptanalyst
- Potential improvements: uncompressed/compressed size available, go beyond 32 bits

Thank you!

Backup

CRC-32 Source code

```
uint32_t crc32(unsigned char * buffer, size_t len)
{
  const uint32_t INITXOR = 0xFFFFFFFFU;
  const uint32_t FINALXOR = 0xFFFFFFFFU;
  const uint32_t CRCPOLY = 0xEDB88320U;
  uint32_t crcreg = INITXOR;
  // for each byte of the buffer
  for (size_t j = 0; j < len; ++j) {
    unsigned char b = buffer[j];
    // for each bit of the current byte b
    for (size_t i = 0; i < CHAR_BIT; ++i) {
      unsigned int lastBit = (crcreg ^ b) & 1;
      crcreg = crcreg >> 1;
      crcreg ^= lastBit ? CRCPOLY : 0;
      b >>= 1;
    }
  }
  return crcreg ^ FINALXOR;
}
```