Security Aspects of Piecewise Hashing in Computer Forensics

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IMF, 2011-05-10

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2. Principal Investigator within Center for Advanced Security Research Darmstadt (CASED)
3. Establishment of forensic courses within Hochschule Darmstadt.
4. Current working fields:
   - Fuzzy Hashing (IT forensics, biometrics, malware detection).
   - Real-time and efficient detection of malware.
   - Anomaly detection in high-traffic environments.

Motivation

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Foundations of Hash Functions

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Piecewise Hashing

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Anti-Forensics on CTPH

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Summary

Motivation

Use Case: Prosecution

1. Police and prosecutors confronted with different storage media:
   - Hard disk drives, solid-state drives, USB sticks.
   - Mobile phones, SIM cards.
   - Digital cameras, digital camcorders, SD cards.
   - CDs, DVDs.
   - RAM (dumps).
   - ...
2. Amount of distrained data often exceeds 1 terabyte.

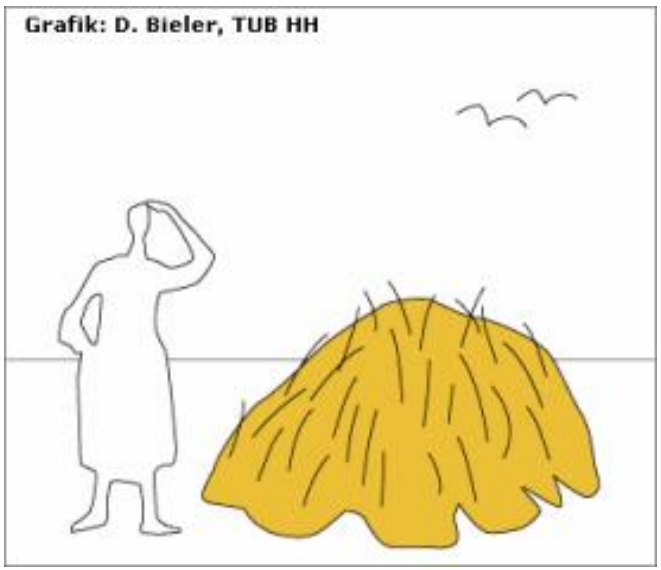
Different views of 1 terabyte (idea due to BKA)

1 terabyte of digital text is (approximately) equal to:

1. 1 trillion characters: 1 character = 1 byte.
2. 220 million pages: 1 page = 5000 characters.
3. 21 years of printing time: 20 sheets per minute.
4. 1 million kg of paper: onesided printed.
5. Paper stack of 22 km height: bulk of 0.1 mm.

Motivation

Finding relevant files resembles ...

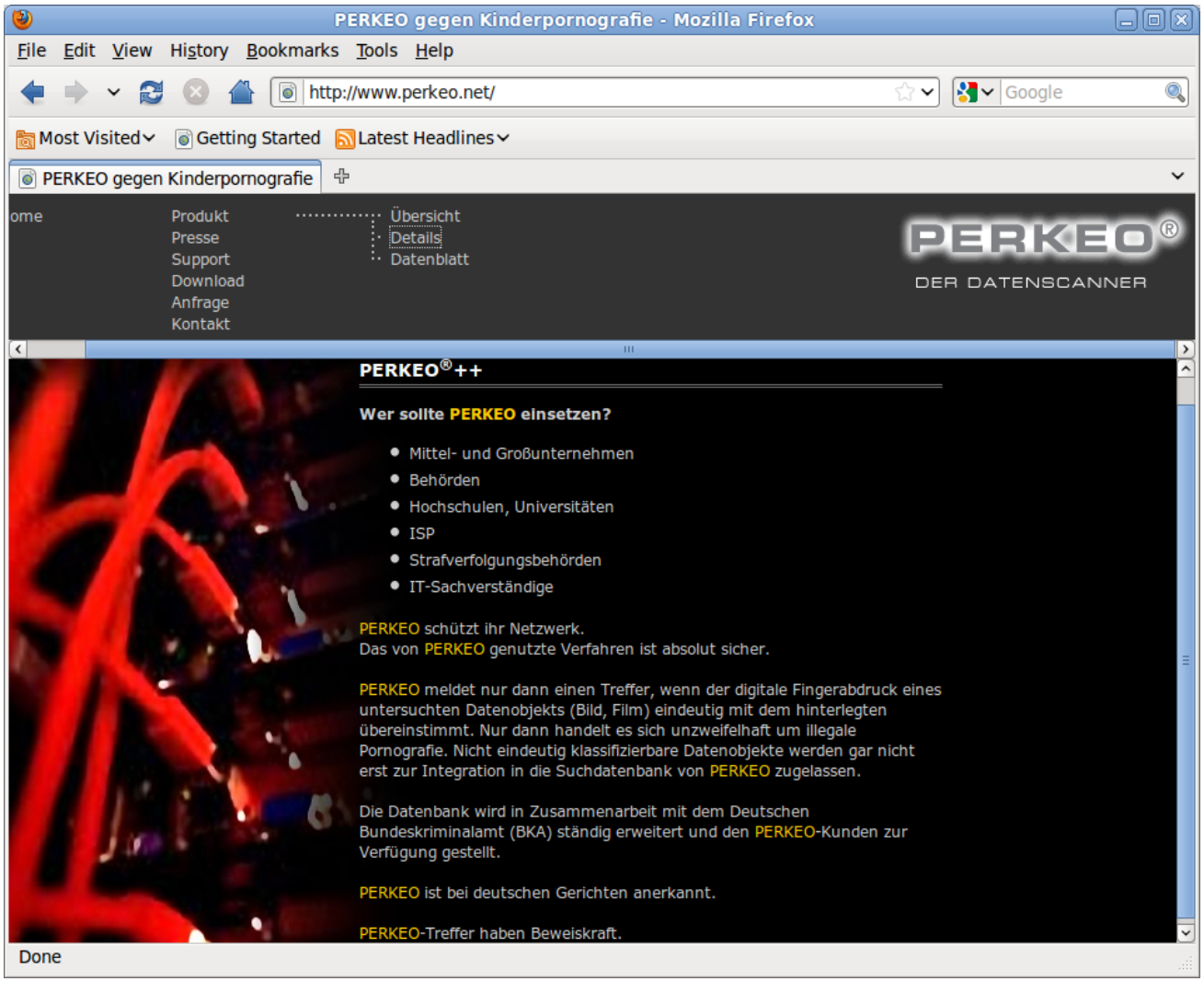


Source: tu-harburg.de

Source: beepworld.de

Motivation

... or is it solved for suspect files?



Aims of the Use of Hash Functions

Automated identification of known files.

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   - ... byte level.

Promise of piecewise hashing: Support automatic finding of files similar to known files on the byte level.

Foundations of Hash Functions

Definition and Security Applications

1. A hash function h is a function with two properties:
   - Compression: $h : \{0,1\}^* \longrightarrow \{0,1\}^n$.
   - Ease of computation: Computation of $h(m)$ is 'fast' in practice.
2. Notation:
   - m is a 'document' (e.g. a file, a device).
   - $h(m)$ its *hash value* or *digest*.

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3. Cryptographic hash functions follow the avalanche effect:
   - If m is replaced by m', $h(m')$ behaves pseudo randomly.
   - Every bit in $h(m')$ changes with probability 50%, independently of the number of different bits in m'.
   - No control over the output, if the input is changed.

Sample Cryptographic Hash Functions

Name	MD5	SHA-1	SHA-256	SHA-512	RIPEMD-160
n	128	160	256	512	160

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```
1  $ echo 'Dear Angela, I give you 1 million EUR. Wolfgang' | sha1sum
2  9bf13969f2c283cfe0ace585667fa22c7ab4f84a -
3
4  $ echo 'Dear Angela, I give you 1 billion EUR. Wolfgang' | sha1sum
5  60d0b09f8d18e75b3cd7ffb0406de84bbc459510 -
```

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Goals

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     - Suspect files similar to known to be bad files are not detected.
     - Fragments are not detected (due to deletion, fragmentation).

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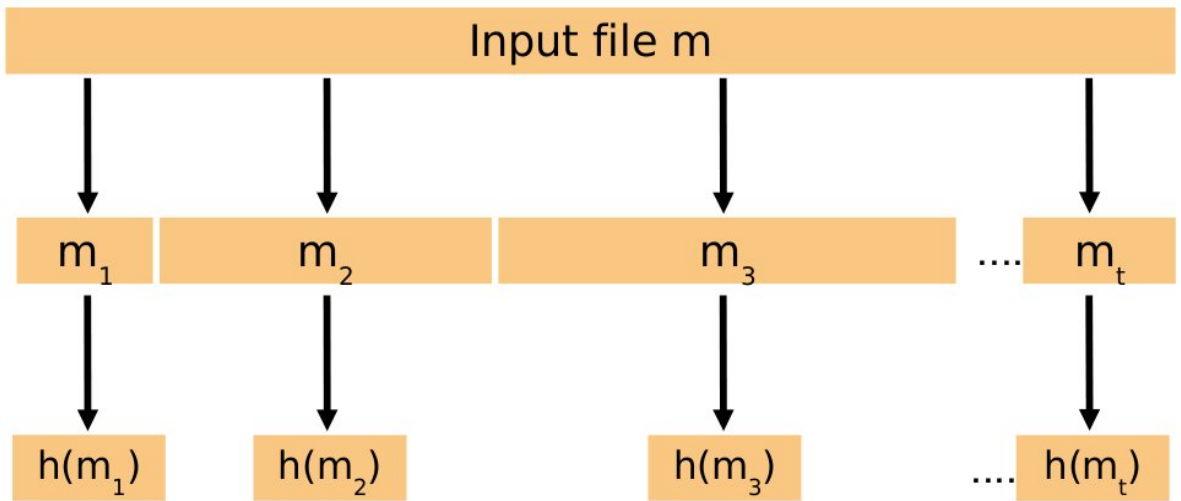
   - White-/Blacklisting:
     - Suspect files similar to known to be bad files are not detected.
     - Fragments are not detected (due to deletion, fragmentation).
3. Currently known approaches:
   - Segment hashes (also called block hashes).
   - Context-triggered piecewise hashes.

Piecewise Hashing

Context Triggered Piecewise Hashes



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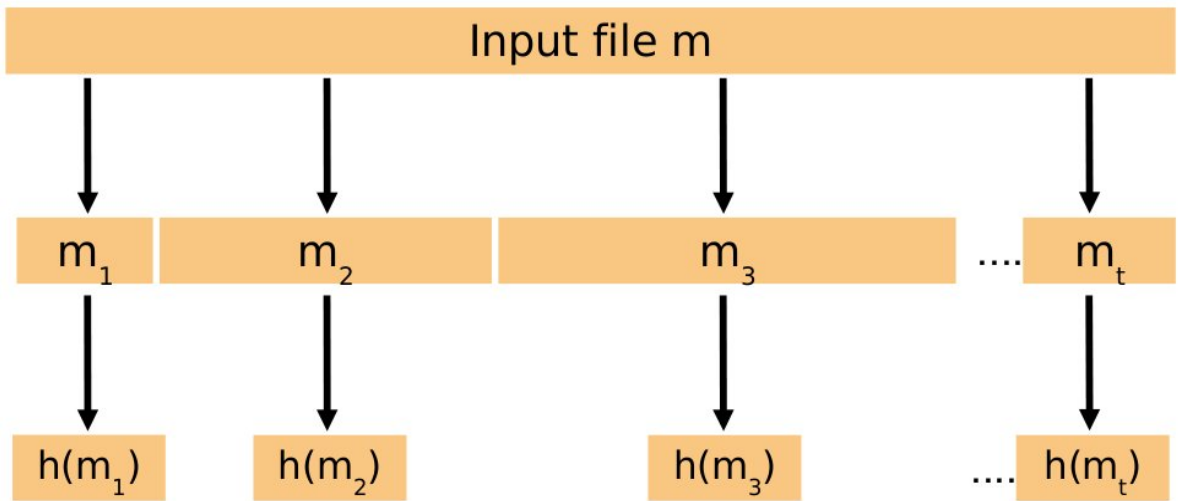
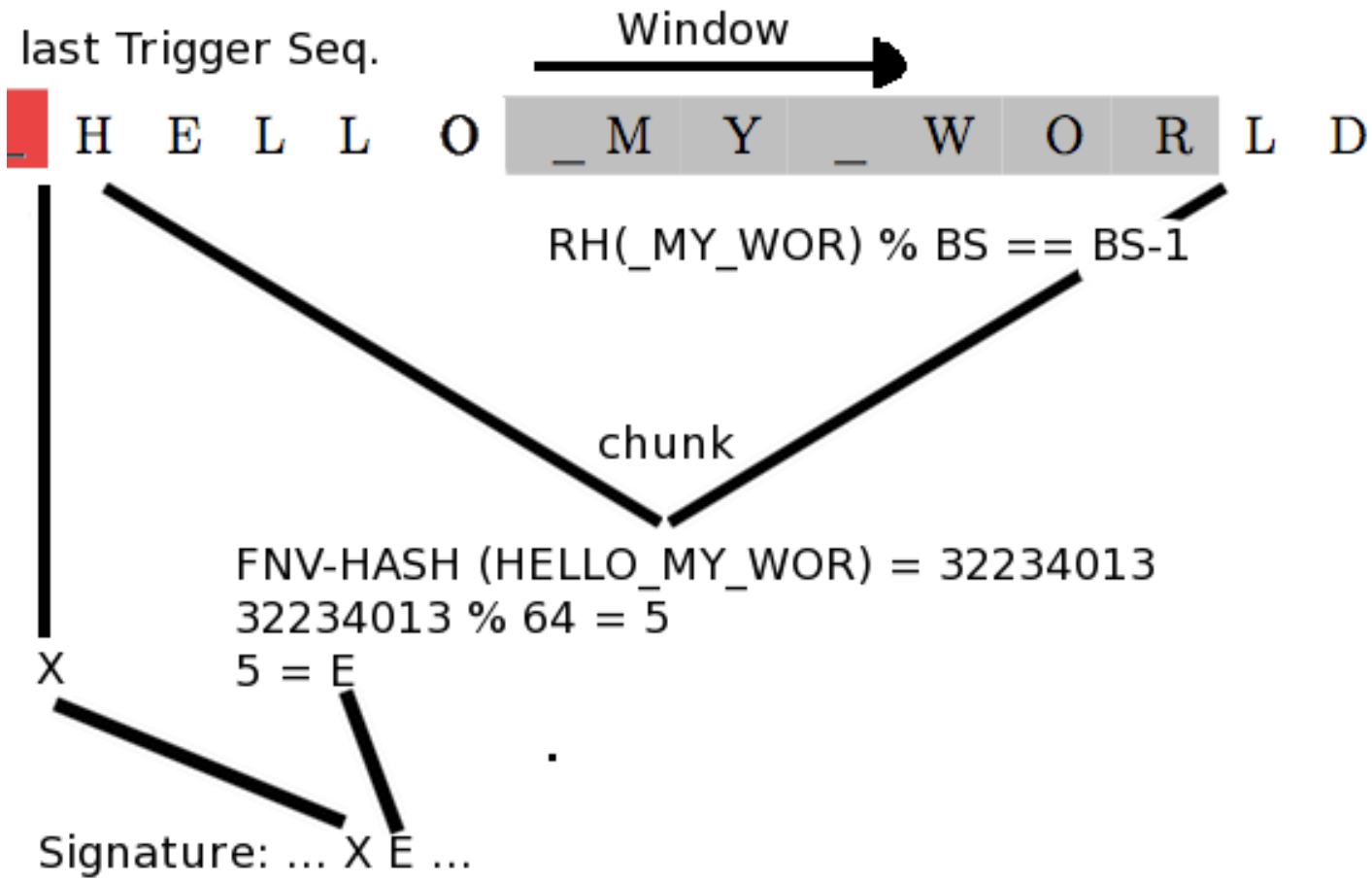


1. Originally proposed for spam detection (`spamsum` by Andrew Tridgell, 2002)
2. Ported to forensics by Jesse Kornblum, 2006: `ssdeep`.

Piecewise Hashing

CTPH: Workflow



Piecewise Hashes: The algorithm

Algorithm 1 CTPH(BS, PF, TV, h)

Input: A string of bytes BS of length N.
A pseudo random function $PF : \{0,1\}^{8w} \rightarrow \{0,1\}^{l}$.
A trigger value TV.
A hash function $h : \{0,1\}^{*} \rightarrow \{0,1\}^{n}$.

Output: The corresponding context triggered piecewise hash of the byte string BS.

$i \leftarrow 0; c \leftarrow 0;$
$CTPH \leftarrow$ ' '; // initialise CTPH as empty string
$B_{c-w+1} \leftarrow 0; B_{c-w+2} \leftarrow 0; \cdots; B_{c-1} \leftarrow 0;$ // initialise padding bytes
while $i < N$ **do**
  if $PF(B_{i-w+1}B_{i-w+2} \cdots B_i) = TV$ **then**
    $CTPH \leftarrow CTPH \parallel h(B_cB_{c+1} \cdots B_i);$
    $c \leftarrow i+1; B_{c-w+1} \leftarrow 0; B_{c-w+2} \leftarrow 0; \cdots; B_{c-1} \leftarrow 0;$
  $i \leftarrow i+1$
$CTPH \leftarrow CTPH \| h(B_c \| B_{c+1} \| \cdots \| B_{N-1});$
return $(CTPH);$

Kornblum's ssdeep tool

1. Window size: $w = 7$.
2. CTPH is a sequence of printable characters:
   - Least significant 6 bits (LS6B) of a segment hash.
   - LS6B are encoded Base64.

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3. Number of segments S: $32 \leq S \leq 64$.
4. Block size b: Used to trigger the rolling hash PF
   - $PF(B_{i-w+1}B_{i-w+2}\cdots B_i) \equiv b - 1 \bmod b$.
   - $b \approx \frac{N}{S}$ (medium segment size)
   - $b_{init} = b_{min} \cdot 2^{\lceil \log_2(\frac{N}{S \cdot b_{min}}) \rceil}$
   - If S is too small for b_{init}, set $b \leftarrow \frac{b}{2}$.

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5. ssdeep outputs CTPH for both, b and $2b$.

Piecewise Hashing

Sample ssdeep output


```
1  $ ls -l hacker-siedlung.jpg
2  -rw------- 1 baier baier 78831 2011-05-09 10:16 hacker-siedlung.jpg
3
4  $ ssdeep -l hacker-siedlung.jpg
5  ssdeep,1.0--blocksize:hash:hash,filename
6  1536:ZfICsORJt2PazD7Z2xqHmqL36uuXtrHTXkkknIKB+W2pDHviF4eYySb:
       ZfICNRf2CD7YwGqL36FXVTXQnIWgDvi2,"hacker-siedlung.jpg"
```

Comparing CTPH

- Based on the weighted edit distance of both letter sequences.
- Count the number of insertions, deletions, changes, swaps.
- $e(s_1, s_2) = i + d + 3c + 5s$.
- Edit distance is scaled to a similarity percentage match M, $0\% \leq M \leq 100\%$ (e.g. $e(s_1, s_2) = 0 \mapsto 100\%$)

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```
1  $ dd if=hacker-siedlung.jpg of=start bs=1 count=50000
2
3  $ ssdeep -l -p hacker-siedlung.jpg start
4  hacker-siedlung.jpg matches start (82)
5
6
7  $ dd if=hacker-siedlung.jpg of=tail bs=1 skip=40000
8
9  $ ssdeep -l -p hacker-siedlung.jpg tail
10 hacker-siedlung.jpg matches tail (72)
```

Anti-Forensics on CTPH

Characteristics of Kornblum's Implementation

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   - A successful match needs at least one common substring in the signature of length 7.
   - An `ssdeep` signature has at most 64 characters:
     - If 63 trigger points are already found, all further ones until `EOF` are ignored, i.e. the final trigger point is `EOF`.

Anti-Forensic Ideas for Anti-Blacklisting

1. Our anti-forensic aim is to circumvent a blacklist:
   - Modified incriminated files of the blacklist are not detected although perceptual identical to the original known-to-be-bad file.
   - Generate false negatives.

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   - Inflating a file.
   - Edit between trigger points.
   - Adding trigger sequences.

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   - Generate false negatives.
2. Ideas:
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   - Edit between trigger points.
   - Adding trigger sequences.
3. No semantic attacks like rotations, colour changes, ...

Inflating a File (1/2)

- Exploited property: *Only `ssdeep` signatures with the same block size or within a factor of 2 can be compared.*
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```
1  $ ls -l hacker-siedlung.jpg
2  -rw------- 1 baier baier 78831 2011-05-09 10:16 hacker-siedlung.jpg
3
4  $ dd if=/dev/urandom of=hacker-siedlung-inflated.jpg bs=1 count=300000
5
6  $ dd if=hacker-siedlung.jpg of=hacker-siedlung-inflated.jpg bs=1 conv=
       notrunc
7
8  $ ssdeep -l hacker-siedlung.jpg hacker-siedlung-inflated.jpg
9  ssdeep,1.0--blocksize:hash:hash,filename
10 1536:ZfICsORJt2PazD7Z2xqHmqL36uuXtrHTXkkknIKB+W2pDHviF4eYySb:
       ZfICNRf2CD7YwGqL36FXVTXQnIWgDvi2,"hacker-siedlung.jpg"
11 6144:ZACNp2CD7Yw3L3e4IWMmDJm29krRbUrfLjhf3zrfaiEj1dXJrgpiF57IjRdseF:
       VQC37jezmDg29kr1O3J3vfBiH77mX,"hacker-siedlung-inflated.jpg"
```

Inflating a File (2/2)

`hacker-siedlung.jpg`

`hacker-siedlung-inflated.jpg`

Edit between Trigger Points (1/4)

- Exploited property: *A successful match needs at least one common substring in the signature of length 7*.
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  - File size remains.
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- Typical consequences:
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  - No match is computed using `ssdeep`.
- Easily applicable to `txt` or `bmp` files.
- Approach for `bmp` files: $B \leftarrow B \oplus 01$.

Edit between Trigger Points (2/4)

```
$ ./anti-bl-ebtp hacker_siedlung.bmp h 7 hacker_siedlung-manipulated.bmp
block size: 12288
7 -> TS: ->|0E 0E 11 0F 0F 0F 0F | -> change: 10 to 11
   chunk-size: 244fc  modify character offset: 244f5
14 -> TS: ->|25 21 20 23 1E 1D 24 | -> change: 20 to 21
   chunk-size: 9245  modify character offset: 2d73a
21 -> TS: ->|7A 78 78 7D 78 79 7B | -> change: 78 to 79
   chunk-size: 28dbe  modify character offset: 564f8
28 -> TS: ->|9C 9F 8E 9A 9E 93 9F | -> change: 8D to 8C
   chunk-size: 188b0  modify character offset: 6eda8
35 -> TS: ->|1F 23 1E 1F 22 1D 1E | -> change: 1E to 1F
   chunk-size: 230cb  modify character offset: 91e73
42 -> TS: ->|24 24 32 30 30 46 41 | -> change: 26 to 27
   chunk-size: 18236  modify character offset: aa0a9
49 -> TS: ->|25 18 21 24 1A 1F 20 | -> change: 23 to 22
   chunk-size: 24232  modify character offset: ce2db
56 -> TS: ->|DC DF EA E8 CA D7 D5 | -> change: DF to DE
   chunk-size: 15d47  modify character offset: e4022
58 Trigger Sequences
done
```

Edit between Trigger Points (3/4)

```
1  $ ls -l hacker_siedlung.bmp hacker_siedlung-manipulated.bmp
2  -rw-r--r-- 1 baier baier 959754 2011-01-12 13:29 hacker_siedlung.bmp
3  -rw------- 1 baier baier 959754 2011-05-09 11:59 hacker_siedlung-
       manipulated.bmp
4
5  $ ssdeep -l hacker_siedlung.bmp hacker_siedlung-manipulated.bmp
6  ssdeep,1.0--blocksize:hash:hash,filename
7  12288:GrxpWErqprJp3415jQd+PS9Q5oCitcoMNaBpeEvNEB7cQ0c6ePmbLikD+Jd:23
       qZYLQd+PMQKlioXvNEVEiJJd,"hacker_siedlung.bmp"
8  12288:GrxpWEYqprJp3715jQd+wS9Q5oCttcoMNa6peEvNEO7cQ0c61PmbLik8+Jd:2
       kqZbLQd+wMQKaiowvNEY5icJd,"hacker_siedlung-manipulated.bmp"
9
10 $ ssdeep -p hacker_siedlung.bmp hacker_siedlung-manipulated.bmp
```

Edit between Trigger Points (4/4)

`hacker-siedlung.bmp`

`hacker-siedlung-manipulated.bmp`

Adding Trigger Points (1/4)

- Exploited property: *An `ssdeep` signature has at most* 64 *characters:*
- Attack idea: Insert 63 trigger sequences in the file header.
  - Trigger sequences may be pre-computed (even *global trigger sequences*).
  - Trigger sequences may be computed on the fly.

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  - Trigger sequences may be pre-computed (even *global trigger sequences*).
  - Trigger sequences may be computed on the fly.
- Easily applicable for `jpg`, `pdf`, `doc`.
  - Make use of dedicated software to insert trigger sequences.
  - E.g. `jhead` for `jpg` files.

Adding Trigger Points (2/4)

```
$ ./generateTriggerSeqForFile hacker-siedlung.jpg j
1. Read file and generate Blocksize
2. Process file..
Modified: fake.jpg

$ ls -l hacker-siedlung.jpg fake.jpg
-rw------- 1 baier baier 79241 2011-05-09 14:17 fake.jpg
-rw------- 1 baier baier 78831 2011-05-09 14:16 hacker-siedlung.jpg

$ ssdeep -l hacker-siedlung.jpg fake.jpg
ssdeep,1.0--blocksize:hash:hash,filename
1536:ZfICsORJt2PazD7Z2xqHmqL36uuXtrHTXkkknIKB+W2pDHviF4eYySb:
     ZfICNRf2CD7YwGqL36FXVTXQnIWgDvi2,"hacker-siedlung.jpg"
1536:FG+OGOmu1VIAET7HSBZJhMfLbuuVV1wssHaq66y6pwwk0o7HDGlddwrHr/SfICsv:FG
     +OGEVGHNVV1mHaq66yewLHDvCfICNS,"fake.jpg"

$ ssdeep -p hacker-siedlung.jpg fake.jpg
```

Adding Trigger Points (3/4)

```
$ xxd hacker-siedlung.jpg | less

0000000: ffd8 ffe0 0010 4a46 4946 0001 0102 001c ......JFIF......
0000010: 001c 0000 ffdb 0043 0003 0202 0202 0203 .......C........
0000020: 0202 0203 0303 0304 0604 0404 0404 0806 ................
0000030: 0605 0609 080a 0a09 0809 090a 0c0f 0c0a ................
0000040: 0b0e 0b09 090d 110d 0e0f 1010 1110 0a0c ................
0000050: 1213 1210 130f 1010 10ff db00 4301 0303 ............C...
0000060: 0304 0304 0804 0408 100b 090b 1010 1010 ................
0000070: 1010 1010 1010 1010 1010 1010 1010 1010 ................
0000080: 1010 1010 1010 1010 1010 1010 1010 1010 ................
0000090: 1010 1010 1010 1010 1010 1010 1010 ffc0 ................
00000a0: 0011 0801 c902 bc03 0122 0002 1101 0311 ........."......
```

Adding Trigger Points (4/4)

```
$ xxd fake.jpg | less

0000000: ffd8 ffe0 0010 4a46 4946 0001 0101 012c ......JFIF.....,
0000010: 012c 0000 ffdb 0043 0003 0202 0202 0203 .,.....C........
0000020: 0202 0203 0303 0304 0604 0404 0404 0806 ................
[REMOVED]
0000090: 1010 1010 1010 1010 1010 1010 1010 fffe ................
00000a0: 0198 4141 4141 4158 2b41 4141 4142 4b78 ..AAAAAX+AAAABKx
00000b0: 4141 4141 424d 5a41 4141 4142 504d 4141 AAAABMZAAAABPMAA
00000c0: 4141 4256 3341 4141 4142 706d 4141 4141 AABV3AAAABpmAAAA
00000d0: 4277 6441 4141 4142 7946 4141 4141 4366 BwdAAAAByFAAAACf
00000e0: 6d41 4141 4143 6f46 4141 4141 4473 7441 mAAAACoFAAAADstA
00000f0: 4141 4144 7556 4141 4141 4478 4941 4141 AAADuVAAAADxIAAA
[REMOVED]
0000210: 4141 5375 4c41 4141 4154 797a 4141 4141 AASuLAAAATyzAAAA
0000220: 5543 4e41 4141 4155 4641 4141 4141 556f UCNAAAAUFAAAAAUo
0000230: 7a41 4141 4155 744f ffc0 0011 0801 c902 zAAAAUtO........
0000240: bc03 0122 0002 1101 0311 01ff c400 1d00 ..."............
```

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Summary

- CTPH from Kornblum does not withstand an active adversary with respect to
  - blacklisting.
  - whitelisting.
- Doubtful if piecewise hashing can fulfill the expectations of fuzzy hashing:
  - Typically it is possible to flip one bit in each chunk.
- In order to create a viable new fuzzy hash function, it will be necessary to find different approaches.

Summary

Questions?

"Sorry about the odor. I have all my passwords tattooed between my toes."