# Authentication of LZ'77 compressed data

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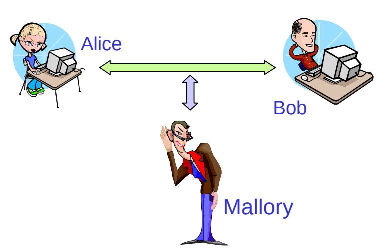
joint work with *M. J. Atallah (Purdue U.)*

## Problem

- Alice sends a document *T* to Bob
- She wants to make sure that what Bob receive is
  - Authentic
  - Integral




- Mallory monitors the communication and he will attempt to tamper with *T* and impersonate Alice

# Signatures

- Signature requirements
  - Authentic/Unforgeable
  - Not reusable
  - Cannot be repudiated
- The signed document should be unalterable *(integrity)*
- Typical solution involves PKC

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# Fragile watermarks

- An alternative way to authenticate a document and ensure that it reaches the destination in a integral state is to use a fragile watermark
- A *fragile watermark* is a watermark designed to break as soon as the content of the document is changed

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# Rationale

- Textual data is difficult to watermark
- Lossless compression is very common nowadays (compress, gzip, (win)zip, (win)rar, lzh, bzip2, etc.)
- Since we are sending the document over the network and it is likely that we are going to compress it anyway, why not watermark the compressed file?

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# Notations

- *T:* document
- *k:* secret key
- *W:* (fragile) watermark
- *T':* watermarked & compressed document

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## Specs

- *T=T'* (or semantically equivalent)
- Unless *k* is known
  - it is very hard to retrieve *W* from *T'*
  - it is very hard to add *W* to another text and pretend to be Alice
- The presence of *W* in *T'* shuld hold up in court (false positives are extremely rare)
- The security of the process should be based solely on the secrecy of the key *(Kerckhoffs' principle)*

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## Approach

- We propose a method that hides *W* (the digest of *T*) directly in the compressed file as a fragile watermark
- Advantages
  - transparency (and therefore backward compatibility)
  - does not require to send separately the signature (authentication is embedded)
- We also satisfy all the previous requirements

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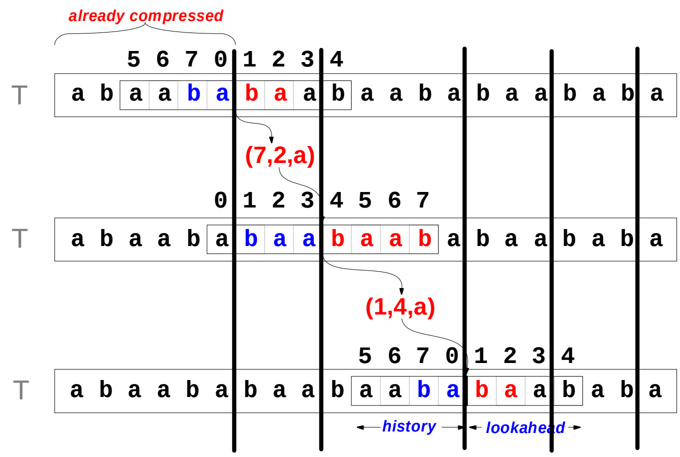
# Lempel-Ziv 77 (gzip)




The LZ processing induces a parsing of *T* into *phrases*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# Watermarking LZ'77


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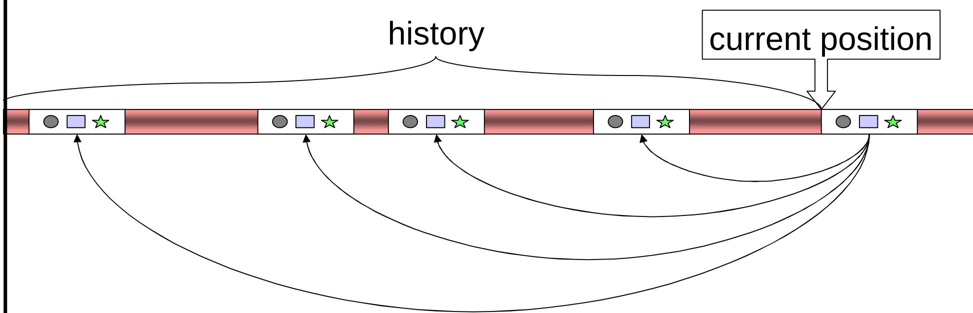
Which of these pointers do we choose?

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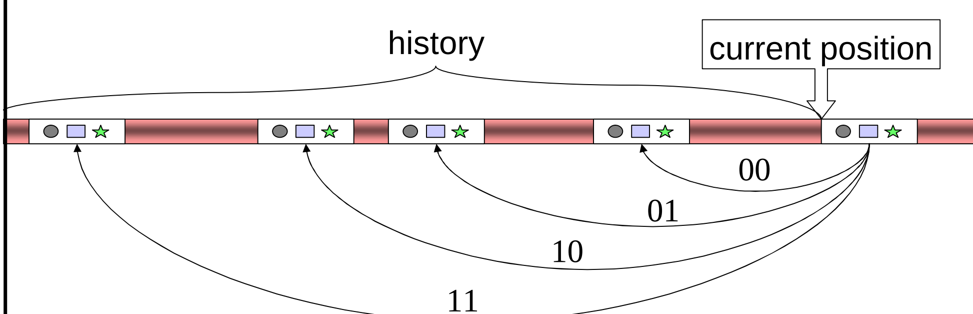
By choosing one of these pointers we are "hiding" two extra redundant bits. Note that we are not changing LZ'77

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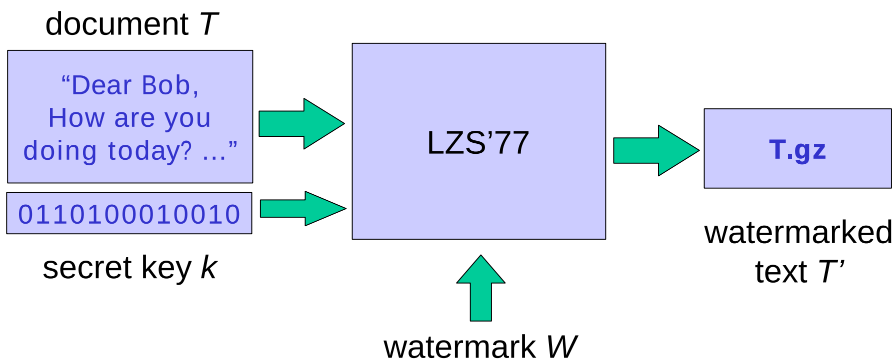


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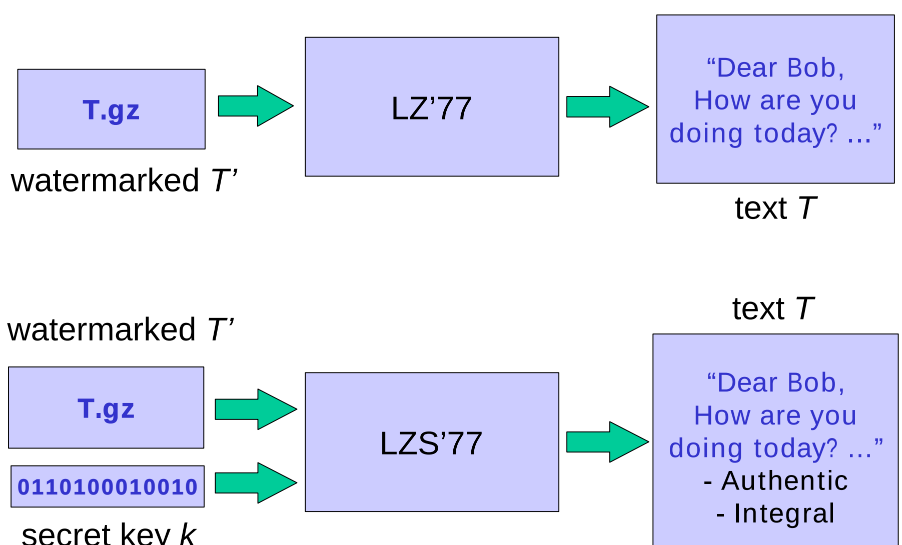


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# Method

# Multiplicity

- Definition: a position *i* in the text *T* has *multiplicity* *q* if there exists exactly *q* matches of the longest prefix of *T[i,n]*
- Given a position with multiplicity *q*, we denote by $p_0, p_1, \ldots, p_{q-1}$ the *q* choices for the pointer
- We can embed about $\lfloor \log_2 q \rfloor$ bits

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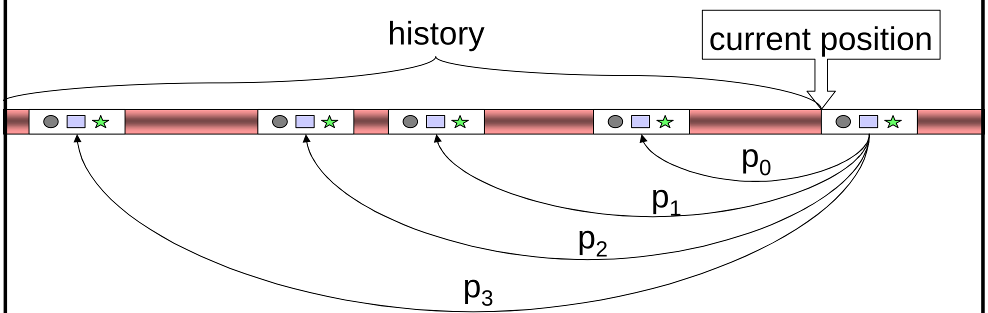
Multiplicity $q=4$





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# Encoding

- For each phrase $i$ with multiplicity $q>1$
  - Initialize the seed of a random number generator with $H(k,i,p_0,p_1,\ldots,p_{q-1})$
  - Generate a uniformly distributed random permutation $R$ of the set $\{0,1,\ldots,q-1\}$
  - Reorder the pointers based on $R$, *i.e.*, $p_{R[0]}, p_{R[1]}, \ldots, p_{R[q-1]}$
  - Assign each pointer $p_{R[i]}$ the binary code $i$
  - Choose the pointer which binary code matches with the next bits of $W$


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# Security

- Recovering the watermark is at least as hard as breaking the pseudo-random generator
- Finding the key requires to be able to invert a one-way hash function

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# Security

- Using some crypto-secure RNG, like BBS [Blum, Blum, Shub 86], the pseudo-random sequence *cannot* be reproduced in a reasonable amount of computing time without the knowledge of the seed $H(k,i,p_0,p_1,\ldots,p_{q-1})$

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# Experiments

# Prototype

- We implemented a suffix tree-based LZ'77
- We measured
  - the numbers of bits embedded vs. the length of the text
  - the multiplicity of pointers
  - the length of the phrases

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# Number of bits embedded

| *# of bits embedded* | *length of the prefix of* `paper2` |
|---|---|
| 128 | 1,149 |
| 256 | 1,692 |
| 1,024 | 4,778 |

| *# of bits embedded* | *length of the prefix of* `progc` |
|---|---|
| 128 | 863 |
| 256 | 1,729 |
| 1,024 | 4,401 |

| *# of bits embedded* | *length of the prefix of* `news` |
|---|---|
| 128 | 1,115 |
| 256 | 1,825 |
| 1,024 | 5,195 |

| *# of bits embedded* | *length of the prefix of* `mito` |
|---|---|
| 128 | 1,488 |
| 256 | 3,078 |
| 1,024 | 14,310 |

**Remark:** more bits can be embedded relaxing the greediness


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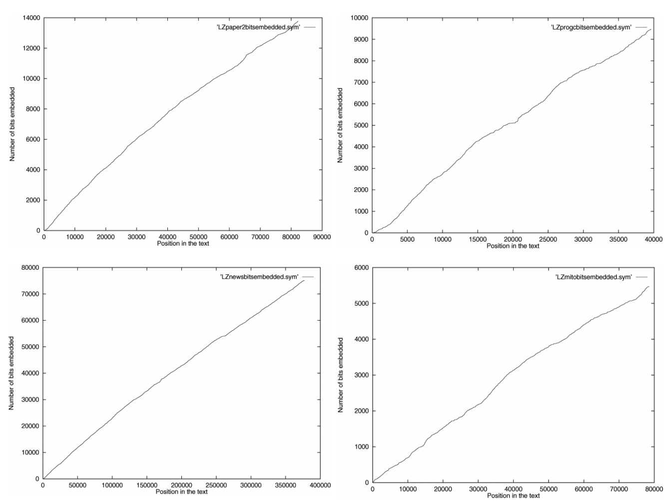
# Number of bits embedded





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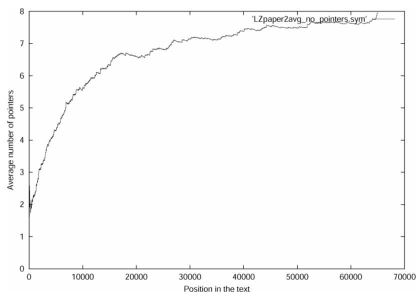
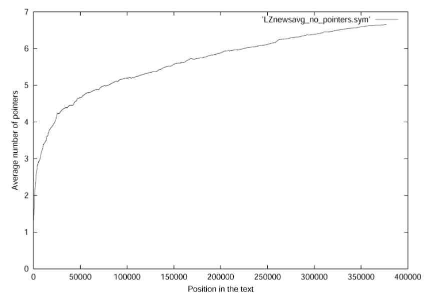
# Average multiplicity




Theorem: The average multiplicity ? *O(1)*, as *n? 8* (DCC'03)

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# gzip

- Open source implementation of LZ'77
- gzip issues pointers in a sliding window of 32KB (typically)
- The length of phrases is represented by 8 bits (3-258)
- Phrases smaller than 3 symbols are encoded as literals

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# gzip

- gzip always chooses the most recent occurrence of the phrase
- We modified gzip-1.2.4 to evaluate the potential degradation of compression performance due to changing the rule of choosing always the most recent occurrence
- As a preliminary experiment, we simply chose one pointer at random

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# gzip vs. gzipS

| *file size* | gzip | gzipS | *file* | *bytes embedded* |
|---|---|---|---|---|
| 111,261 | 39,473 | 39,511 | bib | 1,721 |
| 768,771 | 333,776 | 336,256 | book1 | 14,524 |
| 610,856 | 228,321 | 228,242 | book2 | 10,361 |
| 102,400 | 69,478 | 71,168 | geo | 4,101 |
| 377,109 | 155,290 | 156,150 | news | 5,956 |
| 21,504 | 10,584 | 10,783 | obj1 | 353 |
| 246,814 | 89,467 | 89,757 | obj2 | 3,628 |
| 53,161 | 20,110 | 20,204 | paper1 | 937 |
| 82,199 | 32,529 | 32,507 | paper2 | 1,551 |
| 46,526 | 19,450 | 19,567 | paper3 | 893 |
| 13,286 | 5,853 | 5,898 | paper4 | 249 |
| 11,954 | 5,252 | 5,294 | paper5 | 210 |
| 38,105 | 14,433 | 14,506 | paper6 | 738 |
| 513,216 | 62,357 | 61,259 | pic | 3,025 |
| 39,611 | 14,510 | 14,660 | progc | 736 |
| 71,646 | 18,310 | 18,407 | progl | 1,106 |
| 49,379 | 12,532 | 12,572 | progp | 741 |
| 93,695 | 22,178 | 22,098 | trans | 1,201 |

336,256-
333,776=
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2,480

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## Conclusions

- Authenticity and integrity for LZ'77 files can be obtained efficiently and elegantly
- The degradation of the compression due to the embedding is almost negligible (about 2% when re-shuffling randomly *all* pointers)

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## Some open problems

- About LZ'77
  - Can we design a steganography system for it?
  - Can we design a robust watermarking method for it?
- What about the other types of lossless compression?

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