Error-Resilient LZW data compression

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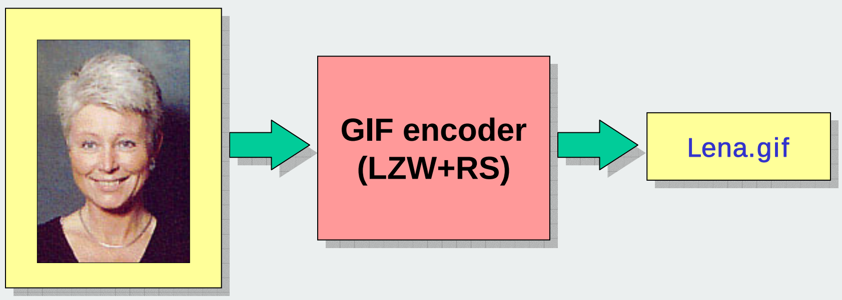
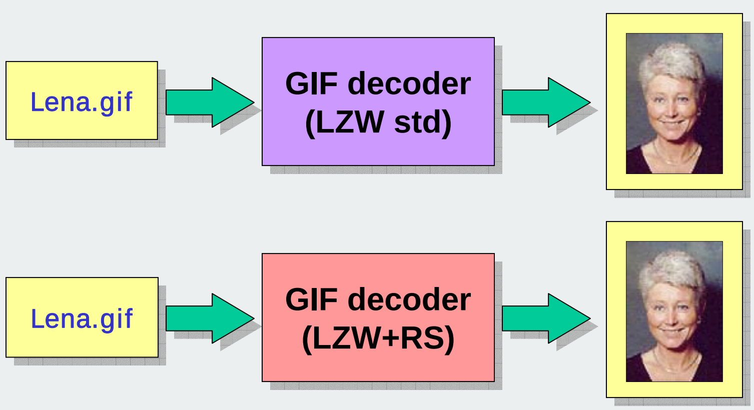
Problem definition

- How to achieve joint source and channel coding in LZW (i.e., by adding error resiliency)
  - by keeping backward-compatibility with the original LZW?
  - and without significantly degrading the compression performance

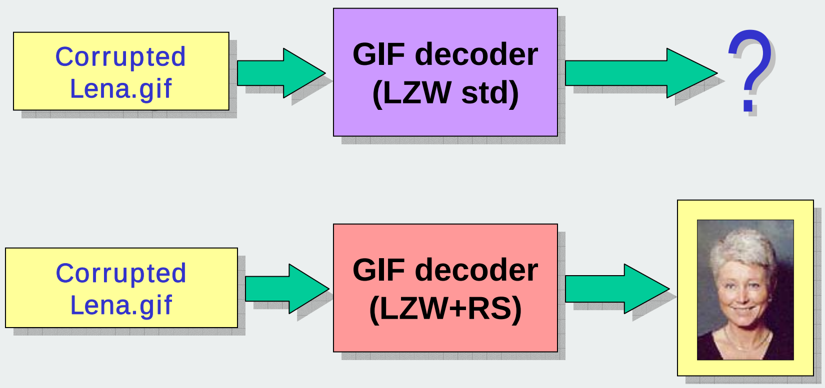
Encoding



Decoding (no errors)



Decoding (with errors)



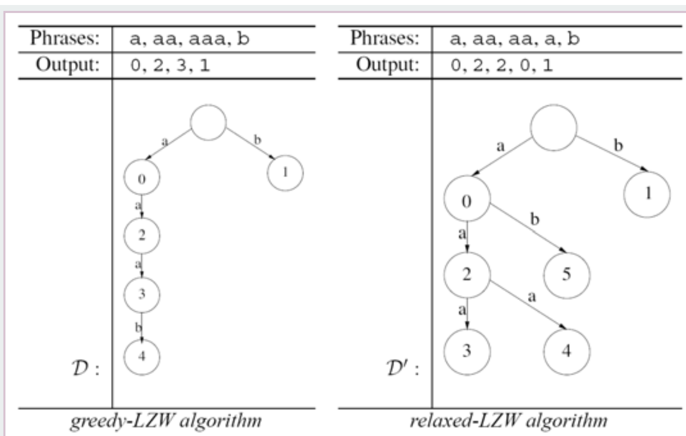
Roadmap

- We will show how to embed extra redundant bits in LZW
- We will show how to achieve error resiliency in LZW

Some related works

- Storer and Reif, “Error-resilient optimal data compression”, SICOMP, 1997
- Louchard, Szpankowski and Tang, “Average profile for the generalized digital search trees and the generalized Lempel-Ziv algorithm”, SICOMP, 1999
- Szpankowski and Knessl, “A note on the asymptotic behavior of the height in *b*-tries for *b* large”, Elect. J. of Combinatorics, 2000
- Lonardi and Szpankowski, “Joint source-channel LZ'77 coding”, DCC’03
- Shim, Ahn and Jeon, “DH-LZW: lossless data hiding in LZW compression”, ICIP’04

Greedy-LZW vs. relaxed-LZW



Is relaxed-LZW backward-compatible?

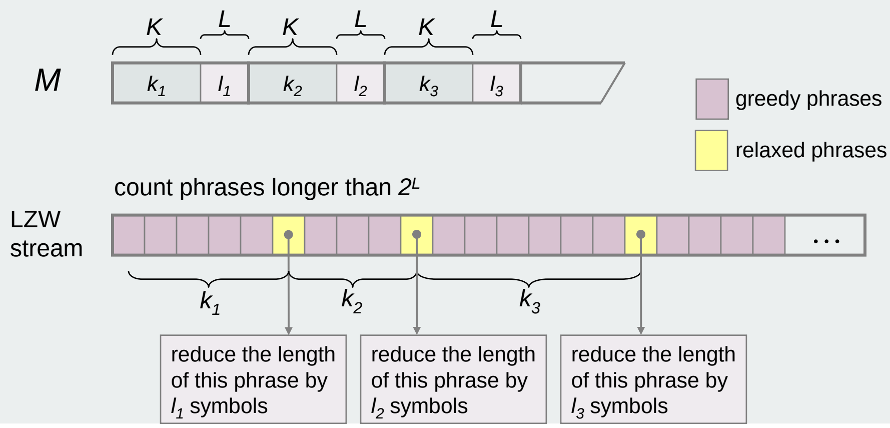
- We tested the decoding of non-greedy phrases
  - in the GIF format using MS paint, IE, and Mozilla
  - in the ZIP format using Winzip
  - in the .Z format using Unix Compress
- All LZW decoders we tested uses hash tables for the dictionary, so multiple identical entries in the dictionary do not cause any problem

Embedding extra bits in LZW

- Relax *some* of the phrases in the parsing (do not relax *too many* otherwise compression degrades)

- The pattern of occurrence of non-greedy phrases encodes for the extra information being embedded

Embedding extra bits in LZW



Selection of *K* and *L*

- *K* and *L* controls the capacity of the message-embedding channel
- Generally, compression ratio degrades as the channel capacity increases
- Need to determine the best trade-off, such that the channel capacity is sufficient for the parity bits, but not much more than that

Channel capacity estimation

- Want to estimate the capacity of the message-embedding channel, given *K, L, n*, and *H*, where *n* is the length of the text *T* to be compressed and *H* is the entropy of *T*
- To simplify the model, we assume
  - The length of the phrases are always greater than 2^L
  - The message *M* to be embedded is generated by an i.i.d. source with 0 and 1 having equal probabilities

Channel capacity estimation

- The text *T* can be logically decomposed into T_1 and T_2, where T_1 is encoded by the greedy phrases and T_2 is encoded by non-greedy phrases. Let $n_1=|T_1|$, $n_2=|T_2|$
- The average length of greedy phrases is equal to $\log n_1/H$
- Solving a set of equations for |*M*| gives the estimated channel capacity (next slide)
- Estimation is fairly accurate

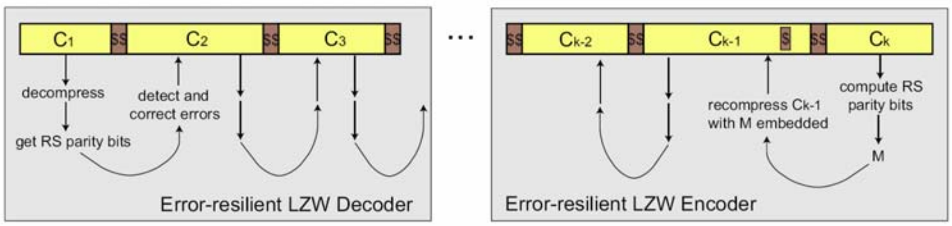
Channel capacity estimation

$$\hat{k} = \frac{2^K + 1}{2}, \hat{l} = \frac{2^L + 1}{2}$$
$$l_1 = \frac{\log n_1}{\mathcal{H}}, l_2 = l_1 - \hat{l}$$
$$B = \frac{n_1}{l_1 \hat{k}}, n_2 = B(l_1 - \hat{l})$$
$$n = n_1 + n_2 = ... = n_1 + \frac{n_1}{\hat{k}} - \frac{n_1 \mathcal{H} \hat{l}}{\hat{k} \log n_1}$$
$$m = B(K + L) = ... = \frac{n_1 \mathcal{H}}{\hat{k} \log n_1}(\hat{k} + \hat{l})$$

Towards error-resiliency

- Typical LZW implementation uses a fixed size dictionary (usually 4,096)
- As soon as the dictionary is full, it is flushed and refreshed, and a special EOD symbol is inserted into the LZW file
- Those EOD symbols logically break the text into self-contained *chunks*

Error-resilient encoding/decoding



$ denotes EOD

Implementation

- We are still working on a full implementation of the error-resilient LZW
- We have implemented a new GIF encoder that is capable of embedding the bits of another file
- The "augmented" GIF is decodable by any standard programs, but if given to our decoder the bits of the second file are recovered
- Available at http://www.cs.ucr.edu/~yonghui/

Experimental results (GIF)

size of the compressed image with *M* embedded

estimated message length

size of the compressed image

size of the message *M* embedded

	$\lvert T' \rvert$	l	$\lvert T'_M \rvert$	$\lvert M \rvert$	l_M	$\lvert T'_M \rvert - \lvert T' \rvert - \lvert M \rvert$	$\lvert M \rvert / \lvert T' \rvert$	estim. $\lvert M \rvert$
airplane	64908	5.77	66468	1706	5.63	-146	0.02628	1980
baboon	149414	2.49	151804	2169	2.45	221	0.01451	4678
couple	19604	4.88	20088	505	4.77	-21	0.02576	587
girl	23573	4.04	24127	566	3.94	-12	0.02401	712
lena	96373	3.87	98770	2396	3.78	1	0.02486	2973
peppers	105262	3.54	107792	2372	3.46	158	0.02253	3258

averag phrase length

average phrase length after embedding

$K = 5,\ L = 1$

Findings

- Method to recover extra redundant bits from LZW
- Extra bits allow to incorporate error-resiliency in LZW
  - backward-compatible (deployment without disrupting service)
  - compression degradation due to the extra bits is minimal