COMP9319 Web Data Compression and Search

LZW,
Adaptive Huffman

1

1

Dictionary coding

- Patterns: correlations between part of the data
- Idea: replace recurring patterns with references to dictionary
- LZ algorithms are adaptive:
  - Universal coding (the prob. distr. of a symbol is unknown)
  - Single pass (dictionary created on the fly)
  - No need to transmit/store dictionary

2

2

LZ77 & LZ78

- LZ77: referring to previously processed data as dictionary
- LZ78: use an explic

3

3

Lempel-Ziv-Welch (LZW) Algorithm

- Most popular modification to LZ78

., Unix compress, TIFF, etc)

regarding its patents

s (12bit 4096

reached

4

4

Patent issues again

From Wikipedia: "In 1993–94, and again in 1999, Unisys Corporation received widespread condemnation when it attempted to enforce licensing fees for LZW in GIF images. The 1993–1994 Unisys-Compuserve (Compuserve being the creator of the GIF format) controversy engendered a Usenet comp.graphics discussion *Thoughts on a GIF-replacement file format*, which in turn fostered an email exchange that eventually culminated in the creation of the patent-unencumbered Portable Network Graphics (PNG) file format in 1995. Unisys's US patent on the LZW algorithm expired on June 20, 2003 ..."

5

5

LZW Compression

```
p = nil;    // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

6

6

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

7

7

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			
^	W	^	256	^W

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

8

8

Example

Input: ^WED^WE^WEE^WEB^WET

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

9

9

Example

Input: ^WED^WE^WEE^WEB^WET

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

10

10

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			
^	W	^	256	^W
W	E	W	257	WE
E	D	E	258	ED
D	^	D	259	D^
^	W			
^W	E	256	260	^WE

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

11

11

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			
^	W	^	256	^W
W	E	W	257	WE
E	D	E	258	ED
D	^	D	259	D^
^	W			
^W	E	256	260	^WE
E	^	E	261	E^

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

12

12

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			
^	W	^	256	^W
W	E	W	257	WE
E	D	E	258	ED
D	^	D	259	D^
^	W			
^W	E	256	260	^WE
E	^	E	261	E^
^	W			

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

13

13

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			
^	W	^	256	^W
W	E	W	257	WE
E	D	E	258	ED
D	^	D	259	D^
^	W			
^W	E	256	260	^WE
E	^	E	261	E^
^	W			
^W	E			

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

14

14

Example

Input: ^WED^WE^WEE^WEB^WET

p c

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

15

15

Example

Input: ^WED^WE^WEE^WEB^WET

p c

Dict [index]

16

16

Example

Input: ^WED^WE^WEE^WEB^WET

p	c	output	index	symbol
NIL	^			
^	W	^	256	^W
W	E	W	257	WE
E	D	E	258	ED
D	^	D	259	D^
^	W			
^W	E	256	260	^WE
E	^	E	261	E^
^	W			
^W	E			
^WE	E	260	262	^WEE
E	^			
E^	W	261	263	E^W
W	E			
WE	B	257	264	WEB
B	^	B	265	B^
^	W			
^W	E			
^WE	T	260	266	^WET
T	EOF	T		

Dict [index]

```
p = nil;   // p for prev char
while read(c):
    if pc ∈ Dict:
        p = pc;
    else:
        add pc to Dict;
        output code(p);
        p = c;
```

17

17

LZW Compression

- Original LZW used dictionary with 4K entries, first 256 (0-255) are ASCII codes.
- In the above example, a 19 symbols reduced to 7 symbols & 5 code. Each code/symbol will need 8+ bits, say 9 bits.
- Reference: Terry A. Welch, "A Technique for High Performance Data Compression", IEEE Computer, Vol. 17, No. 6, 1984, pp. 8-19.

18

18

LZW Decompression

```
read(c);   // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict;
    p = Dict[c];
```

19

19

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
read(c);   // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

Dict [index]

p	c	output	index	symbol
	^	^		

20

20

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
read(c);   // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

p c

21

21

Example

Input: ^WED<256>E<260><261><257>B<260>T

Dict [index]

22

22

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
read(c);   // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

Dict [index]

p	c	output	index	symbol
	^	^		
^	W	W	256	^W
W	E	E	257	WE
E	D	D	258	ED

23

23

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
read(c);   // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

Dict [index]

p	c	output	index	symbol
	^	^		
^	W	W	256	^W
W	E	E	257	WE
E	D	D	258	ED
D	<256>	^W	259	D^

24

24

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
Read(c),  // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

p	c	output	Dict [index] index	symbol
	^	^		
^	W	W	256	^W
W	E	E	257	WE
E	D	D	258	ED
D	<256>	^W	259	D^
<256>	E	E	260	^WE

25

25

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
Read(c),  // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

p	c	output	Dict [index] index	symbol
	^	^		
^	W	W	256	^W
W	E	E	257	WE
E	D	D	258	ED
D	<256>	^W	259	D^
<256>	E	E	260	^WE
E	<260>	^WE	261	E^

26

26

Example

Input: ^WED<256>E<260><261><257>B<260>T

```
Read(c),  // c is likely to be > 8 bits
output c;
p = c;
while read(c):
    output Dict[c];
    add p + Dict[c][0] to Dict
    p = Dict[c];
```

p	c

27

27

Example

Input: ^WED<256>E<260><261><257>B<260>T

Dict [index]

28

28

Note: LZW decoding

- There is one special case that the LZW decoding pseudocode presented is unable to handle.
- This is your exercise to find out in what situation that happens, and how to deal with it.
- I'll go through this at the live lecture.

29

29

LZW implementation

- Parsing fixed number of bits from input is easy
- Fast and efficient

30

30

Types (revision)

- Block-block
  - source message and codeword: fixed length
  - e.g., ASCII
- Block-variable
  - source message: fixed; codeword: variable
  - e.g., Huffman coding
- Variable-block
  - source message: variable; codeword: fixed
  - e.g., LZW
- Variable-variable
  - source message and codeword: variable
  - e.g., Arithmetic coding

31

31

So far

We have covered:

- Course overview
- Background
- RLE
- Entropy
- Huffman code
- Arithmetic code
- LZW

32

32

More coding readings

http://www.ics.uci.edu/~dan/pubs/DC-Sec1.html

http://marknelson.us/1991/02/01/arithmetic-co

33

33

Lossless compression revisited

- Run-length coding
- Dictionary methods

daptive (LZW)

34

34

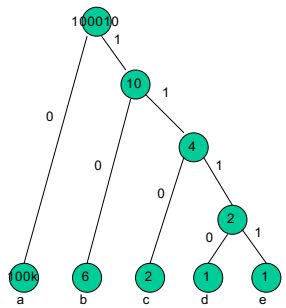
Huffman Coding (revisit) and then Adaptive Huffman

35

35

Huffman coding

S	Freq	Huffman
a	100000	0
b	6	10
c	2	110
d	1	1110
e	1	1111



36

36

Huffman not optimal

H = 0.9999 log 1.0001 + 0.00006 log 16668.333 + … + 1/100010 log 100010
≈ 0.00

L = (100000*1 + …)/100010
≈ 1

37

37

Problems of Huffman coding

Huffman codes have an integral # of bits.

E.g., log (3) = 1.585 while Huffman may need 2 bits

Noticeable non-optimality when prob of a symbol is high.

=> Arithmetic coding

38

38

Problems of Huffman coding

Need statistics & static: e.g., single pass over the data just to unchanged during

To decode, the stat ta transmitted. Table for small msg.

=> Adaptive compression e.g., adaptive huffman

39

39

Adaptive compression

Encoder

Update the model

Decoder
Initialize the model
Repeat for each input char
(
Decode char
Update the model
)

me Initialize & update model

40

40

Adaptive Huffman Coding (dummy)

Encoder
Reset the stat
Repeat for each input char
(
Encode char
Update the stat
Rebuild huffman tree
)

Decoder
Reset the stat
Repeat for each input char
(
Decode char
Update the stat
Rebuild huffman tree
)

41

41

Adaptive Huffman Coding (dummy)

Encoder
Reset the stat
Repeat for each input char
(
Encode char
Update the stat
Rebuild huffman tree
)

Decoder
Reset the stat
Repeat for each input char
(
Decode char
Update the stat
Rebuild huffman tree
)

This works but too slow!

42

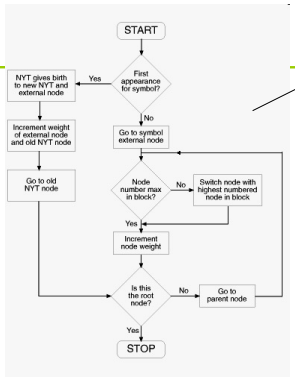
42

Adaptive Huffman (Algorithm outline)

1. If current symbol is NYT, add two child nodes to NYT node. One will be a new NYT node the other is a leaf node for our symbol. Increase weight for the new leaf node and the old NYT and go to step 4. If not, go to symbol's leaf node.
2. If this node does not have the highest number in a block, swap it with the node having the highest number
3. Increase weight for current node
4. If this is not the root node go to parent node then go to step 2. If this is the root, end.

43

43



The update procedure from Introduction to Data Compression by by Sayood Khalid

44

44

Adaptive Huffman

abbbba: 0110000101100010011000100110001001100010011000100110000 1

abbbba: 011000010011000100111 10

a: 01100001
b: 01100010

From an old Wikipedia page

45

Adaptive Huffman

abbbba: 0110000101100010011000100110001001100010011000100110000 1

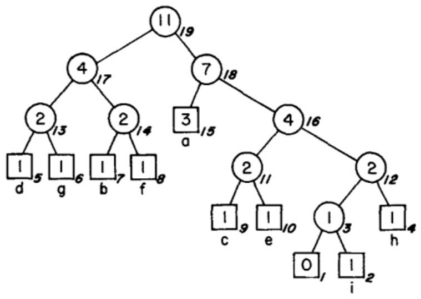
101

a: 01100001
b: 01100010

From an old Wikipedia page

46

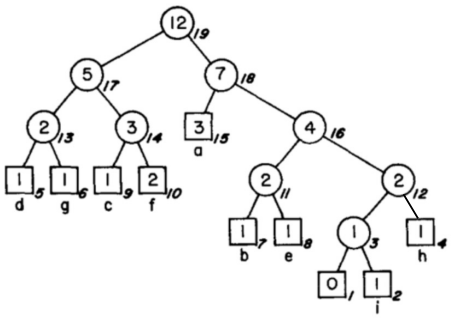
Adaptive Huffman (FGK)



47

47

Adaptive Huffman (FGK): when f is inserted



48

48

Adaptive Huffman (FGK vs Vitter)

1.
FGK: (Explicit) node numbering
Vitter: Implicit numbering

2.
Vitter's Invariant:

(•) For each weight w, all leaves of weight w precede (in the implicit numbering) all internal nodes of weight w.

49

49

Adaptive Huffman (Vitter'87)

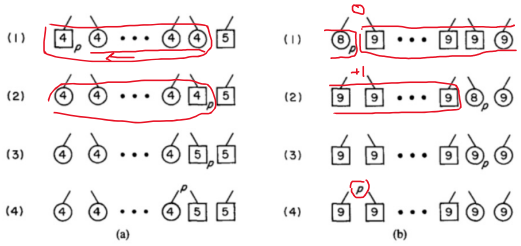


FIG. 6. Algorithm A's *SlideAndIncrement* operation. All the nodes in a given block shift to the left one spot to make room for node p, which slides over the block to the right. (a) Node p is a leaf of weight 4. The internal nodes of weight 4 shift to the left. (b) Node p is an internal node of weight 8. The leaves of weight 9 shift to the left.

50

50

Adaptive Huffman: Vitter's Invariant

⇨

51

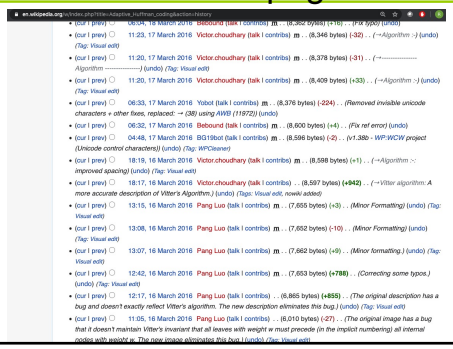
51

Issues with Wikipedia

52

52

COMP9319 students correcting lots of Wiki pages



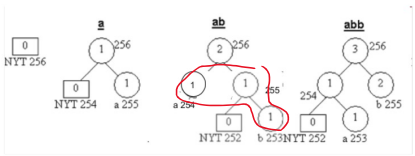
53

53

Adaptive Huffman (Vitter's)

abbbba: 0110000101100010011000100110001001100010011000100110000 1

abbbba: 0110000100110001011111 01



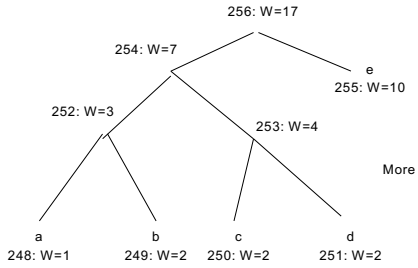
a: 01100001
b: 01100010

Corrected fr Wikipedia

54

54

More example on Vitter's

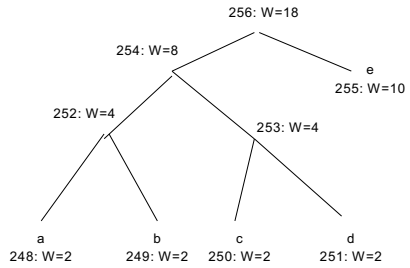


More aaaa.... coming

55

55

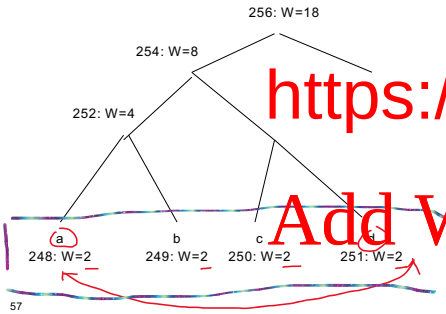
More example



56

56

More example



57

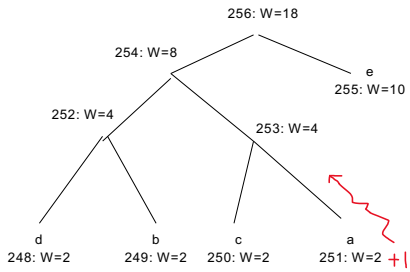
57

The Vitter's algo: swaps then slides

58

58

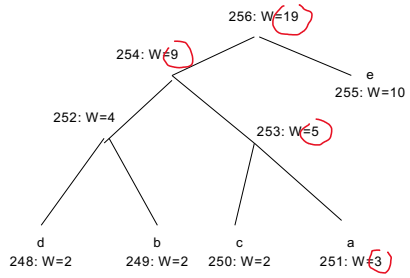
More example



59

59

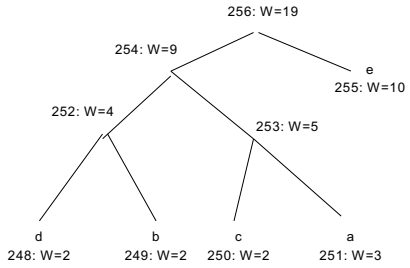
More example



60

60

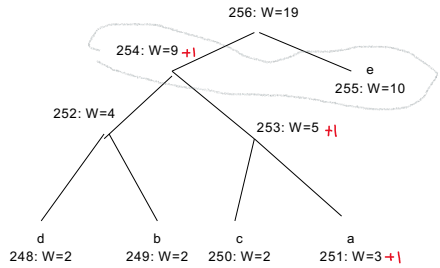
More example



61

61

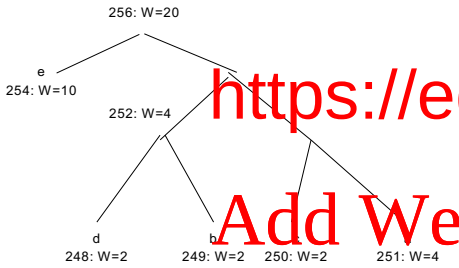
More example



62

62

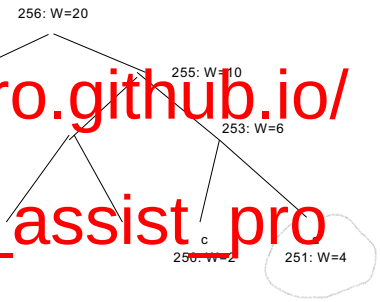
More example



63

63

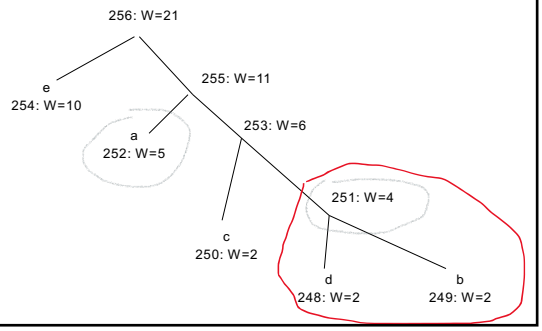
More example



64

64

More example



65

65

Adaptive Huffman

Question: Adaptive Huffman vs Static Huffman

66

66

Compared with Static Huffman

Dynamic and can offer better compression (cf. Vitter's experiments next)

Works when prior stat is unavailable

Saves symbol table overhead (cf. Vitter's expt next)

67

67

Vitter's experiments

Include overheads such as symbol tables / leaf node code etc.

t	k	S_t	b/l	D_t^Δ	b/l
100	96	664	13.1	569	10.2
500	96	3320	7.9	3225	7.4
960	96	6400	7.1	6305	6.8

Exclude overheads such as symbol tables / leaf node code etc.

95 ASCII chars + <end-of-line>

From Vitter's paper. You know where it is. ☺

68

68

More experiments

69

69