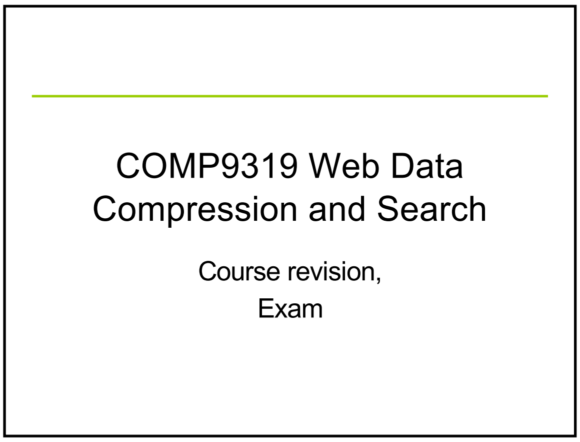
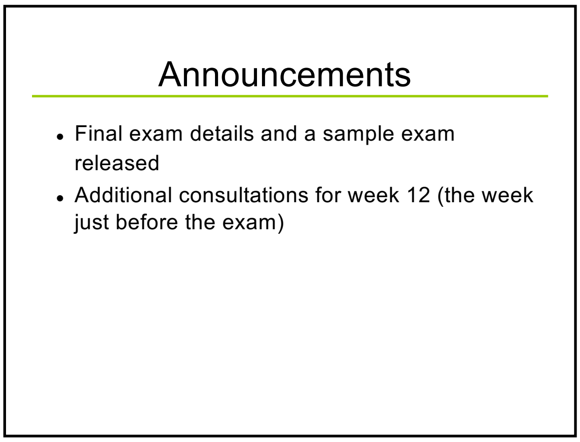


COMP9319 Web Data Compression and Search

Course revision,
Exam

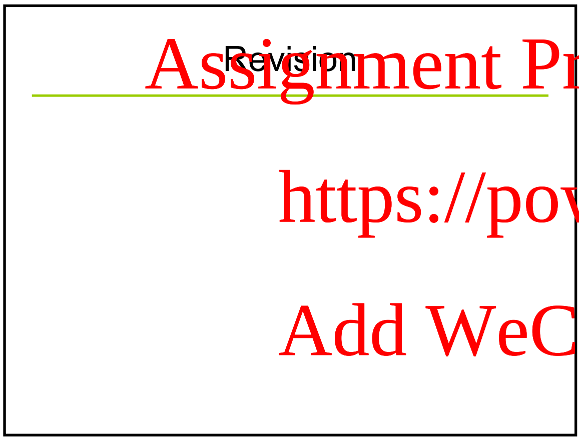
1



Announcements

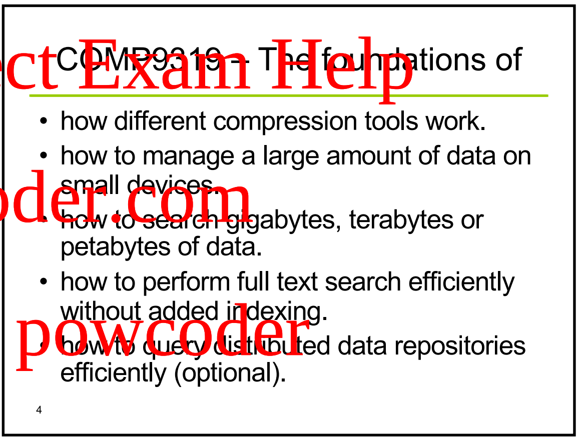
- Final exam details and a sample exam released
- Additional consultations for week 12 (the week just before the exam)

2



Revision

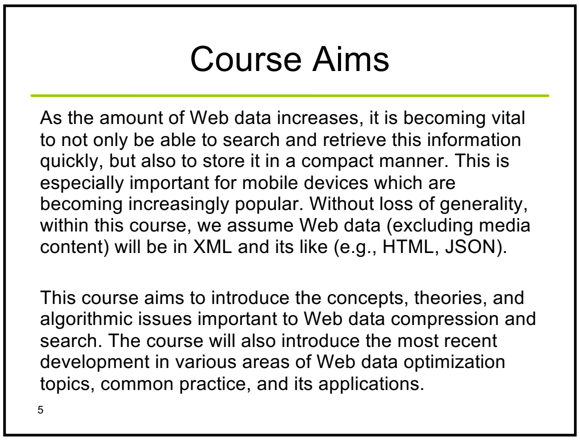
3



COMP9319 – The foundations of

- how different compression tools work.
- how to manage a large amount of data on small devices.
- how to search gigabytes, terabytes or petabytes of data.
- how to perform full text search efficiently without added indexing.
- how to query distributed data repositories efficiently (optional).

4



Course Aims

As the amount of Web data increases, it is becoming vital to not only be able to search and retrieve this information quickly, but also to store it in a compact manner. This is especially important for mobile devices which are becoming increasingly popular. Without loss of generality, within this course, we assume Web data (excluding media content) will be in XML and its like (e.g., HTML, JSON).

This course aims to introduce the concepts, theories, and algorithmic issues important to Web data compression and search. The course will also introduce the most recent development in various areas of Web data optimization topics, common practice, and its applications.

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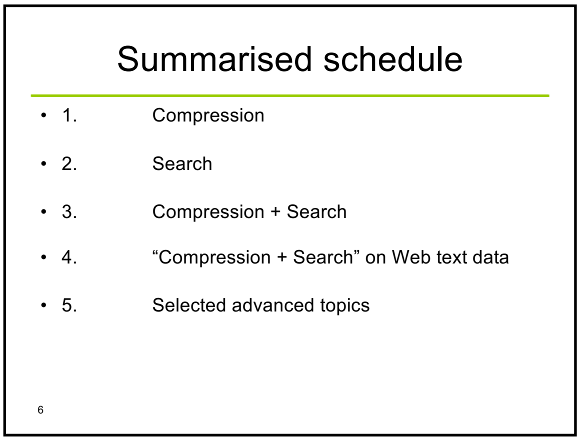

Summarised schedule

- 1. Compression
- 2. Search
- 3. Compression + Search
- 4. “Compression + Search” on Web text data
- 5. Selected advanced topics

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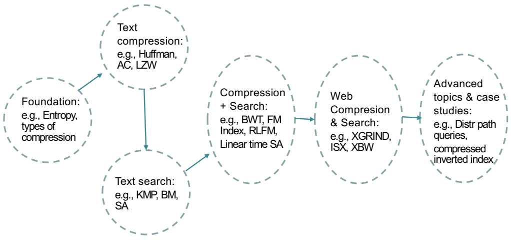
Topics



Foundation:
e.g., Entropy, types of compression

Text compression:
e.g., Huffman, AC, LZW

Text search:
e.g., KMP, BM, SA

Compression + Search:
e.g., BWT, FM Index, RLFM, Linear time SA

Web Compresion & Search:
e.g., XGRIND, ISX, XBW

Advanced topics & case studies:
e.g., Distr path queries, compressed inverted index

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Topic Snapshots

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Questions to discuss (www)

- What (is data compression)
- Why (data compression)
- Where

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Compression

- Minimize amount of information to be stored / transmitted
- Transform a sequence of characters into a new bit sequence
  - same information content (for lossless)
  - as short as possible

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Terminology (Types)

- 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

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Run-length coding

- Run-length coding (encoding) is a very widely used and simple compression technique
  - does not assume a memoryless source
  - replace runs of symbols (possibly of length one) with pairs of (symbol, *run-length*)

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Entropy

- What is the minimum number of bits per symbol?
- Answer: Shannon's result – theoretical minimum average number of bits per code work is known as Entropy (H)

$$\sum_{i=1}^{n} - p(s_i)\log_2 p(s_i)$$

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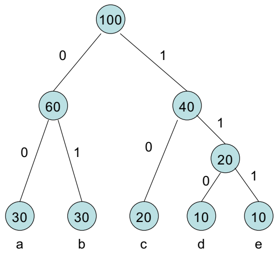
Huffman coding

S	Freq	Huffman
a	30	00
b	30	01
c	20	10
d	10	110
e	10	111



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Arithmetic coding (encode)

New Character	Low value	High Value
	0.0	1.0
B	0.2	0.3
I	0.25	0.26
L	0.256	0.258
L	0.2572	0.2576
SPACE	0.25720	0.25724
G	0.257216	0.257220
A	0.2572164	0.2572168
T	0.25721676	0.2572168
E	0.257216772	0.257216776
S	0.2572167752	0.2572167756

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Arithmetic coding (decode)

Encoded Number	Output Symbol	Low	High	Range
0.2572167752	B	0.2	0.3	0.1
0.572167752	I	0.5	0.6	0.1
0.72167752	L	0.6	0.8	0.2
0.6083876	L	0.6	0.8	0.2
0.041938	SPACE	0.0	0.1	0.1
0.41938	G	0.4	0.5	0.1
0.1938	A	0.2	0.3	0.1
0.938	T	0.9	1.0	0.1
0.38	E	0.3	0.4	0.1
0.8	S	0.8	0.9	0.1
0.0				

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LZW Compression

```
w = NIL;
 while ( read a character k )
   {
    if wk exists in the dictionary
     w = wk;
    else
      add wk to the dictionary;
      output the code for w;
      w = k;
   }
```

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LZW Decompression

```
read a character k;
 output k;
 w = k;
 while ( read a character/code k )
    {
      entry = dictionary entry for k;
      output entry;
      add w + entry[0] to dictionary;
      w = entry;
    }
```

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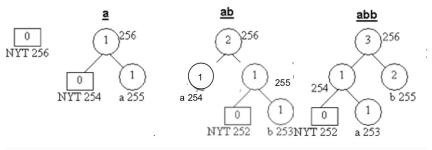
Adaptive Huffman

abbbbba: 0110000101100010011000100110001001100010011000100110001001100001

abbbbba: 01100001001100010111110 1



a: 01100001
b: 01100010

Modified from Wikipedia

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BWT(S)

```
function BWT (string s)
   create a table, rows are all possible
      rotations of s
   sort rows alphabetically
   return (last column of the table)
```

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InverseBWT(S)

```
function inverseBWT (string s)
   create empty table

   repeat length(s) times
      insert s as a column of table before first
            column of the table   // first insert creates
            first column
      sort rows of the table alphabetically
   return (row that ends with the 'EOF' character)
```

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Other ways to reverse BWT

Consider L=BWT(S) is composed of the symbols $V_0 \ldots V_{N-1}$, the transformed string may be parsed to obtain:

- The number of symbols in the substring $V_0 \ldots V_{i-1}$ that are identical to V_i. (i.e., Occ[ ])
- For each unique symbol, V_i, in L, the number of symbols that are lexicographically less than that symbol. (i.e., C[ ])

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Move to Front (MTF)

- Reduce entropy based on local frequency correlation
- Usually used for BWT before an entropy-encoding step
- Author and detail:
  - Original paper at cs9319/Papers
  - http://www.arturocampos.com/ac_mtf.html

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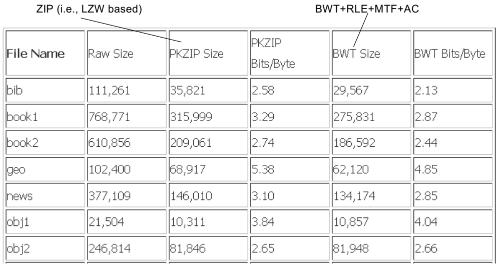
BWT compressor vs ZIP

ZIP (i.e., LZW based)

BWT+RLE+MTF+AC



File Name	Raw Size	PKZIP Size	PKZIP Bits/Byte	BWT Size	BWT Bits/Byte
bib	111,261	35,821	2.58	29,567	2.13
book1	768,771	315,999	3.29	275,831	2.87
book2	610,856	209,061	2.74	186,592	2.44
geo	102,400	68,917	5.38	62,120	4.85
news	377,109	146,010	3.10	134,174	2.85
obj1	21,504	10,311	3.84	10,857	4.04
obj2	246,814	81,846	2.65	81,948	2.66

From http://marknelson.us/1996/09/01/bwt/

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Pattern Matching

- Brute Force
- Boyer Moore
- KMP

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Regular expressions

- $L(\mathbf{001}) = \{001\}$
- $L(\mathbf{0+10}^*) = \{ 0, 1, 10, 100, 1000, 10000, \ldots \}$
- $L(\mathbf{0^*10}^*) = \{1, 01, 10, 010, 0010, \ldots\}$ i.e. $\{w \mid w$ has exactly a single $1\}$
- $L(\Sigma\Sigma)^* = \{w \mid w$ is a string of even length$\}$
- $L((\mathbf{0(0+1}))^*) = \{ \varepsilon, 00, 01, 0000, 0001, 0100, 0101, \ldots\}$
- $L((\mathbf{0+\varepsilon)(1+ \varepsilon})) = \{\varepsilon, 0, 1, 01\}$
- $L(1\varnothing) = \varnothing$; concatenating the empty set to any set yields the empty set.
- $R\varepsilon = R$
- $R+\varnothing = R$

- Note that $R+\varepsilon$ may or may not equal R (we are adding ε to the language)
- Note that $R\varnothing$ will only equal R if R itself is the empty set.

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Theory of DFAs and REs

- RE. Concise way to describe a set of strings.
- DFA. Machine to recognize whether a given string is in a given set.
- **Duality**: for any DFA, there exists a regular expression to describe the same set of strings; for any regular expression, there exists a DFA that recognizes the same set.

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DFA to RE: State Elimination

- Eliminates states of the automaton and replaces the edges with regular expressions that includes the behavior of the eliminated states.
- Eventually we get down to the situation with just a start and final node, and this is easy to express as a RE

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Signature files

- Definition
  - Word-oriented index structure based on hashing.
  - Use liner search.
  - Suitable for not very large texts.
- Structure
  - Based on a Hash function that maps words to bit masks.
  - The text is divided in blocks.
    - **Bit mask of block is obtained by bitwise ORing the signatures of all the words in the text block.**
    - **Word not found, if no match between all 1 bits in the query mask and the block mask.**

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Suffix tree

Given a string s a suffix tree of s is a compressed trie of all suffixes of s

To make these suffixes prefix-free we add a special character, say $, at the end of s

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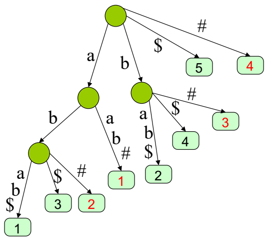
Generalized suffix tree (Example)

Let s_1=abab and s_2=aab here is a generalized suffix tree for s_1 and s_2

{	
\$	#
b\$	b#
ab\$	ab#
bab\$	aab#
abab\$	
}	



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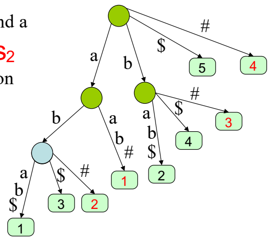
Longest common substring (of two strings)

Every node with a leaf descendant from string S_1 and a leaf descendant from string S_2 represents a maximal common substring and vice versa.

Find such node with largest “string depth”



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Suffix array

- We loose some of the functionality but we save space.

Let s = abab

Sort the suffixes lexicographically:
ab, abab, b, bab

The suffix array gives the indices of the suffixes in sorted order

3	1	4	2

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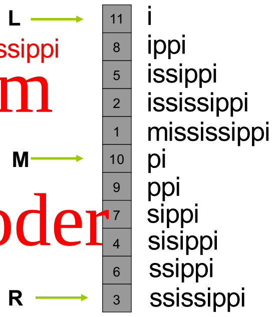
Example

Let S = mississippi

Let P = issa



11	i
8	ippi
5	issippi
2	ississippi
1	mississippi
10	pi
9	ppi
7	sippi
4	sisippi
6	ssippi
3	ssissippi

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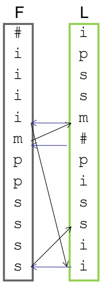
BURROWS-WHEELER TRANSFORM

Reminder: Recovering T from L

1. Find F by sorting L
2. First char of T? m
3. Find m in L
4. L[i] precedes F[i] in T. Therefore we get
   mi
5. How do we choose the correct i in L?
   - The i’s are in the same order in L and F
   - As are the rest of the char’s
6. i is followed by s: mis
7. And so on….



F	L
#	i
i	p
i	s
i	s
i	m
m	#
p	p
p	i
s	s
s	s
s	i
s	i

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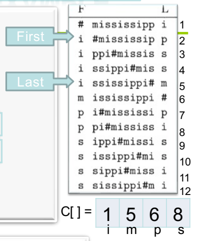
BACKWARD-SEARCH EXAMPLE

- P = pssi
  - i = 3
  - c = ‘s’
  - First = C[‘s’] + Occ(‘s’,1) +1 = 8+0+1 = 9
  - Last = C[‘s’] + Occ(‘s’,5) = 8+2 = 10
  - (Last – First + 1) = 2



F		L	
#	mississipp	i	1
i	#mississip	p	2
i	ppi#missis	s	3
i	ssippi#mis	s	4
i	ssissippi#	m	5
m	ississippi	#	6
p	i#mississi	p	7
p	pi#mississ	i	8
s	ippi#missi	s	9
s	issippi#mi	s	10
s	sippi#miss	i	11
s	sissippi#m	i	12

C[ ] =

1	5	6	8
i	m	p	s

```
Algorithm backward_search($P[1,p]$)
$i \leftarrow p$, $c \leftarrow P[p]$, First $\leftarrow C[c]+1$, Last $\leftarrow C[c+1]$;
while ((First $\leq$ Last) and ($i \geq 2$)) do
    $c \leftarrow P[i-1]$;
    First $\leftarrow C[c]$ + Occ($c$, First $-1$) $+1$;
    Last $\leftarrow C[c]$ + Occ($c$, Last);
    $i \leftarrow i-1$;
if (Last < First) then return “no rows prefixed by $P[1,p]$” else return ⟨First, Last⟩
```

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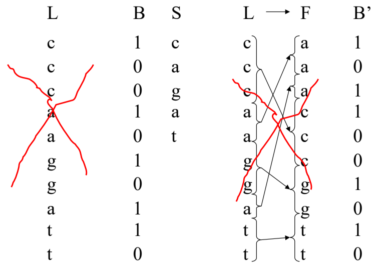
Compressed SA: Run-Length FM-index...



L	B	S	L	F	B’
c	1	c	c	a	1
c	0	a	c	a	0
c	0	g	c	a	1
a	1	a	a	c	1
a	0	t	a	c	0
g	1		g	c	0
g	0		g	g	1
a	1		a	g	0
t	1		t	t	1
t	0		t	t	0

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Changes to formulas

- Recall that we need to compute $C_T[c]+rank_c(L,i)$ in the backward search.
- **Theorem:** $C[c]+rank_c(L,i)$ is equivalent to $select_1(B’,C_S[c]+1+rank_c(S,rank_1(B,i)))-1$, when $L[i] \neq c$, and otherwise to $select_1(B’,C_S[c]+rank_c(S,rank_1(B,i)))+ i-select_1(B,i))$.

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Linear time suffix array construction

- Consider the popular example string S:
- **`bananainpajamas$`**

1. Construct the suffix array of S using the linear time algorithm
2. Then compute the BWT(S)
3. What’s the relationship between the suffix array and BWT ? (e.g., SA -> BWT vs BWT -> SA)

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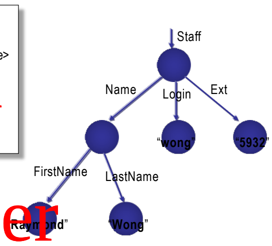
Semistructured Data: Tree/HTML/XML/JSON/RDF...

```
<Staff>
  <Name>
    <FirstName> Raymond </FirstName>
    <LastName> Wong </LastName>
  </Name>
  <Login> wong </Login>
  <Ext> 5932 </Ext>
</Staff>
```



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XPath for XML

/bib/book[@price < “60”]

/bib/book[author/@age < “25”]

/bib/book[author/text()]

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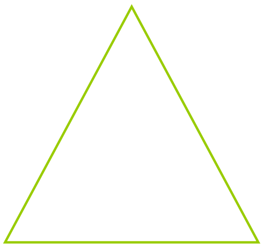
Path query evaluation

Top-down

Bottom-up

Hybrid



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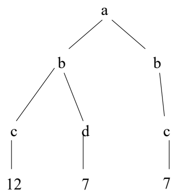
XPath evaluation

<a><b><c>12</c><d>7</d></b><b><c>7</c></b></a>

/ a / b [c = “12”]



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Path indexing

- Traversing graph/tree almost = query processing for semistructured / XML data
- Normally, it requires to traverse the data from the root and return all nodes X reachable by a path matching the given regular path expression
- Motivation: allows the system to answer regular path expressions without traversing the whole graph/tree

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Two techniques

- Based on the idea of language-equivalence
- Data Guide

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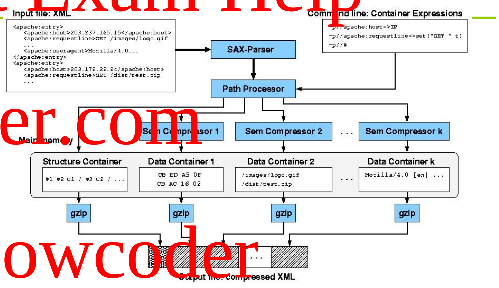
XMill



```
<apache:entry>
   <apache:host>203.237.165.15</apache:host>
   <apache:requestline>GET /images/logo.gif
   ...
   <apache:useragent>Mozilla/4.0...
</apache:entry>
<apache:entry>
   <apache:host>203.172.22.2</apache:host>
   <apache:requestline>GET /dist/test.zip
   ...
```

```
-p//apache:host=>IP
-p//apache:requestline=>set("GET " t)
-p//#
```

```
#1 #2 C1 / #3 C2 / ...
```

```
CB ED A5 0F
CB AC 16 02
```

```
/images/logo.gif
/dist/test.zip
```

```
Mozilla/4.0 [en] ...
```

Figure 4: Architecture of the Compressor

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XGRIND

Original Fragment:

<student name=“Alice“>
    <a1>78</a1>
    <a2>86</a2>

  <midterm>91</midterm>
    <project>87</project>
</student>

Compressed Fragment:

T0 A0 nahuff(Alice)
  T1 nahuff(78) /
  T2 nahuff(86) /
  T3 nahuff(91) /
  T4 nahuff(87) /
/

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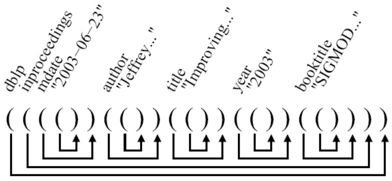
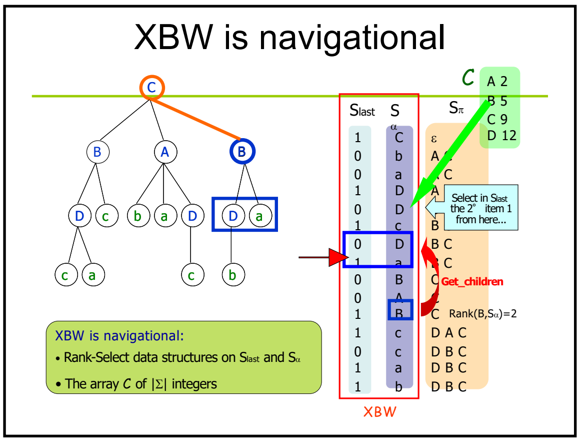
ISX: Balanced Parenthesis Encoding



0 0 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 1 1

48



XBW is navigational

XBW is navigational:

- Rank-Select data structures on S_{last} and S_α
- The array C of $|\Sigma|$ integers

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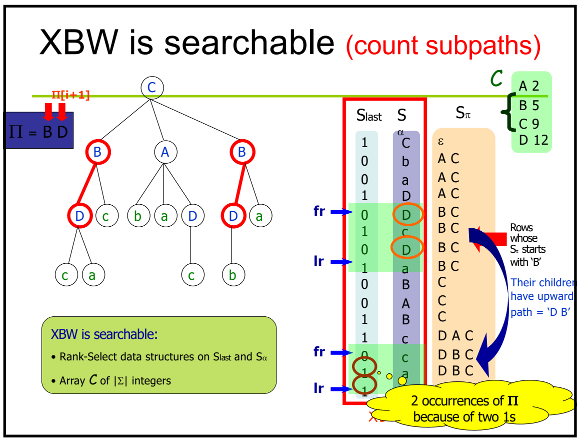


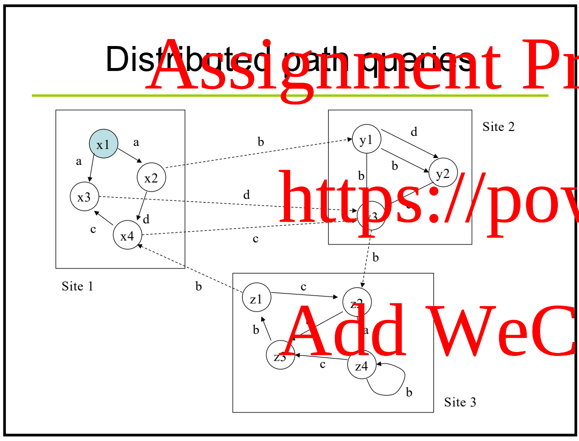
XBW is searchable (count subpaths)

Π[i+1]
Π = B D
C
B
A
B
D
c
b
a
D
D
a
c
a
c
b
S_{last}
S
S_π
C
A 2
B 5
C 9
D 12
fr
lr
fr
lr
Rows whose S_π starts with 'B'
Their children have upward path = 'D B'
2 occurrences of Π because of two 1s

XBW is searchable:

- Rank-Select data structures on S_{last} and S_α
- Array C of $|\Sigma|$ integers

50



Distributed path queries

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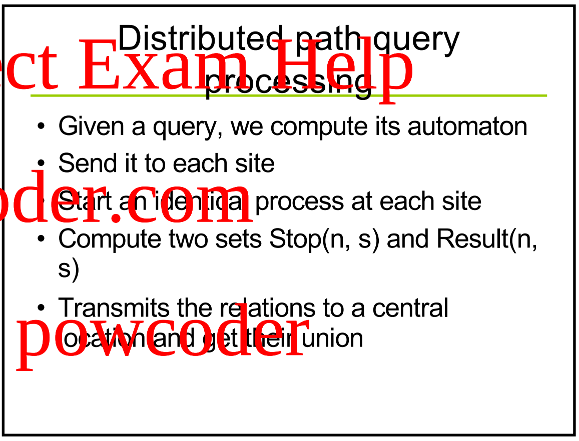

Distributed path query processing

- Given a query, we compute its automaton
- Send it to each site
- Start an identical process at each site
- Compute two sets Stop(n, s) and Result(n, s)
- Transmits the relations to a central location and get their union

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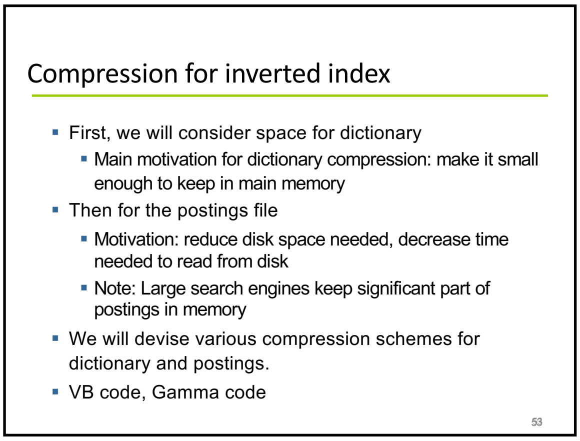

Compression for inverted index

- First, we will consider space for dictionary
  - Main motivation for dictionary compression: make it small enough to keep in main memory
- Then for the postings file
  - Motivation: reduce disk space needed, decrease time needed to read from disk
  - Note: Large search engines keep significant part of postings in memory
- We will devise various compression schemes for dictionary and postings.
- VB code, Gamma code

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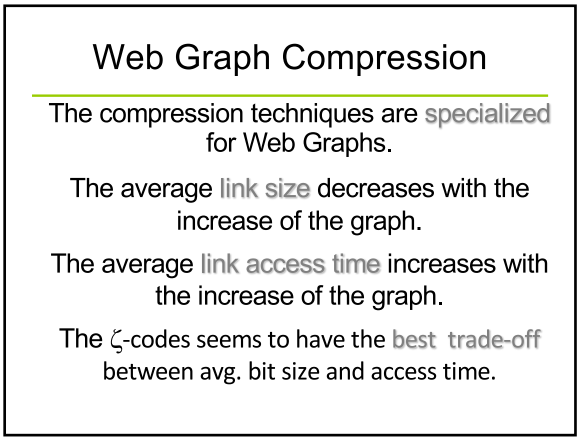

Web Graph Compression

The compression techniques are specialized for Web Graphs.

The average link size decreases with the increase of the graph.

The average link access time increases with the increase of the graph.

The ζ-codes seems to have the best trade-off between avg. bit size and access time.

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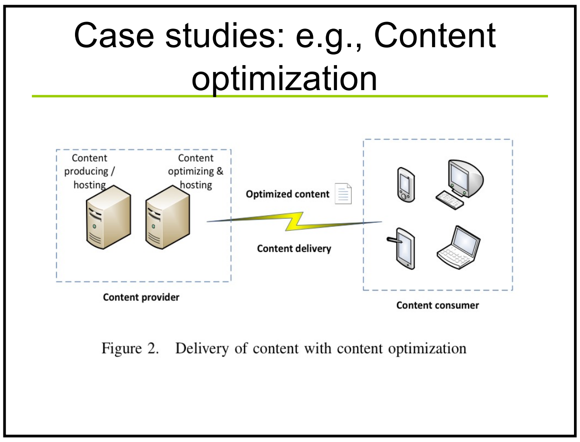

Case studies: e.g., Content optimization

Figure 2. Delivery of content with content optimization

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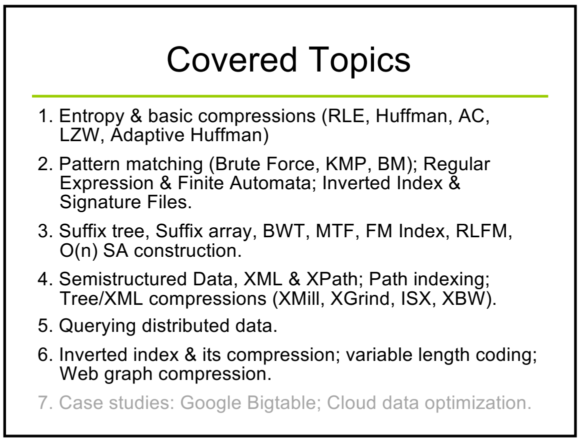

Covered Topics

1. Entropy & basic compressions (RLE, Huffman, AC, LZW, Adaptive Huffman)
2. Pattern matching (Brute Force, KMP, BM); Regular Expression & Finite Automata; Inverted Index & Signature Files.
3. Suffix tree, Suffix array, BWT, MTF, FM Index, RLFM, O(n) SA construction.
4. Semistructured Data, XML & XPath; Path indexing; Tree/XML compressions (XMill, XGrind, ISX, XBW).
5. Querying distributed data.
6. Inverted index & its compression; variable length coding; Web graph compression.
7. Case studies: Google Bigtable; Cloud data optimization.

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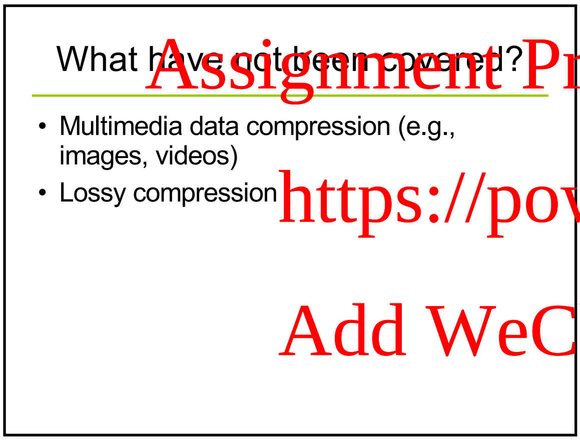

What have not been covered?

- Multimedia data compression (e.g., images, videos)
- Lossy compression

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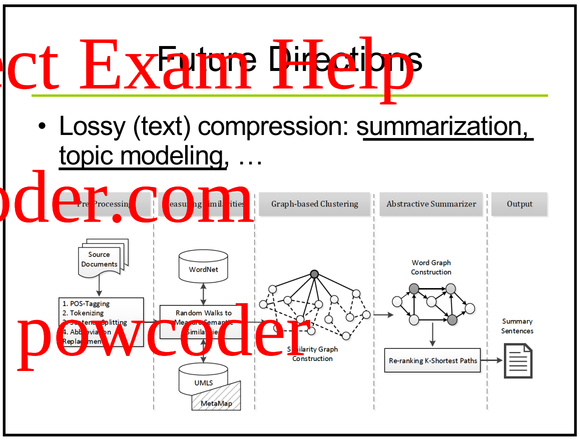

Future Directions

- Lossy (text) compression: summarization, topic modeling, …

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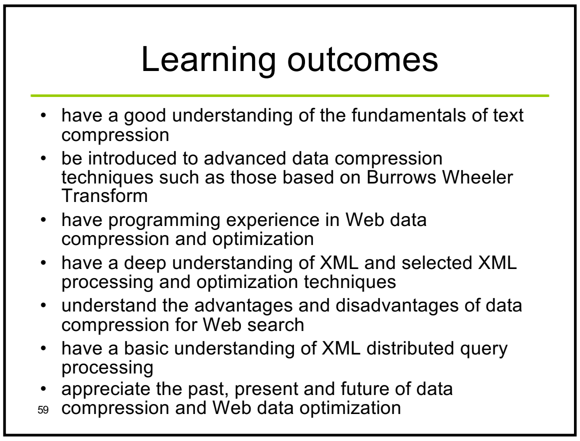

Learning outcomes

- have a good understanding of the fundamentals of text compression
- be introduced to advanced data compression techniques such as those based on Burrows Wheeler Transform
- have programming experience in Web data compression and optimization
- have a deep understanding of XML and selected XML processing and optimization techniques
- understand the advantages and disadvantages of data compression for Web search
- have a basic understanding of XML distributed query processing
- appreciate the past, present and future of data compression and Web data optimization

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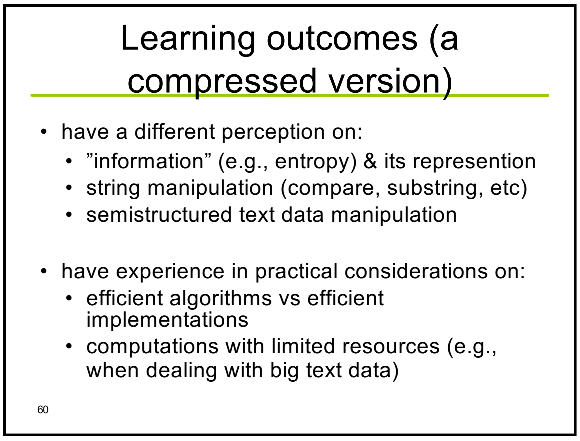

Learning outcomes (a compressed version)

- have a different perception on:
  - ”information” (e.g., entropy) & its represention
  - string manipulation (compare, substring, etc)
  - semistructured text data manipulation
- have experience in practical considerations on:
  - efficient algorithms vs efficient implementations
  - computations with limited resources (e.g., when dealing with big text data)

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Assignment 2

- We are still waiting for submissions with special considerations this week
- Marking script and test cases to be released next week (week 11)
- Aim to finish marking and release results in/by week 12 – before your exam in week 13

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Assignment 2 (BWT specific)

- Understand deeply how BWT backward search & decoding work
- Understand the relationship between L and F columns
- C[ ] for F column
- How Occ[ ] and C[ ] work

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Assignment 2 (general)

- What index structures to build
- Time & space to build index
- Size to keep the data + index
- Storage, memory, CPU, time considerations & trade-offs
- “Feel” the practical implementation bottlenecks vs algorithmic complexity

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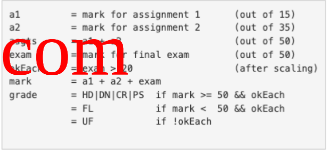
Assessment



```
a1          = mark for assignment 1      (out of 15)
a2          = mark for assignment 2      (out of 35)
assts       = a1 + a2                    (out of 50)
exam        = mark for final exam        (out of 50)
okEach      = exam > 20                  (after scaling)
mark        = a1 + a2 + exam
grade       = HD|DN|CR|PS  if mark >= 50 && okEach
            = FL           if mark <  50 && okEach
            = UF           if !okEach
```

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The final exam

- One final exam (50 pts).
- If you are ill on the day of the exam, do not attend the exam – c.f. fit-to-site policy. Apply for special consideration asap.
- It’s a 2.5 hr online exam (13:30-16:00 Aug 24, 2022 AEST).
- Read the sample exam to get familiar.
- Supp exam covers the same scope & CLOs but may be of a different format, e.g., an oral exam.

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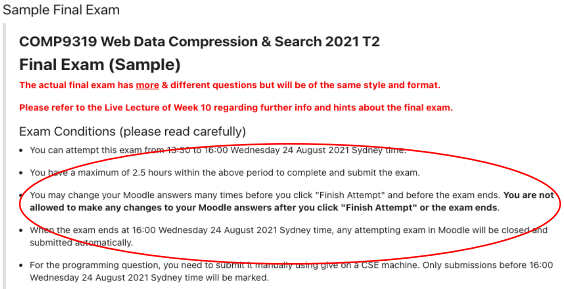
One attempt only! (for the Moodle Qns)



Sample Final Exam

COMP9319 Web Data Compression & Search 2021 T2

Final Exam (Sample)

The actual final exam has <u>more</u> & different questions but will be of the same style and format.

Please refer to the Live Lecture of Week 10 regarding further info and hints about the final exam.

Exam Conditions (please read carefully)

- You can attempt this exam from 13:30 to 16:00 Wednesday 24 August 2021 Sydney time.
- You have a maximum of 2.5 hours within the above period to complete and submit the exam.
- You may change your Moodle answers many times before you click "Finish Attempt" and before the exam ends. **You are not allowed to make any changes to your Moodle answers after you click "Finish Attempt" or the exam ends.**
- When the exam ends at 16:00 Wednesday 24 August 2021 Sydney time, any attempting exam in Moodle will be closed and submitted automatically.
- For the programming question, you need to submit it manually using give on a CSE machine. Only submissions before 16:00 Wednesday 24 August 2021 Sydney time will be marked.

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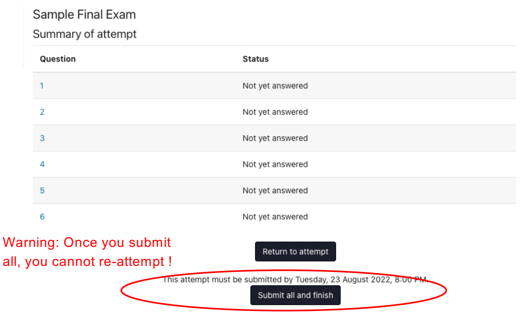
One attempt only! (for the Moodle Qns)



Sample Final Exam

Summary of attempt

Question	Status
1	Not yet answered
2	Not yet answered
3	Not yet answered
4	Not yet answered
5	Not yet answered
6	Not yet answered

This attempt must be submitted by Tuesday, 23 August 2022, 8:00 PM.

Warning: Once you submit all, you cannot re-attempt !

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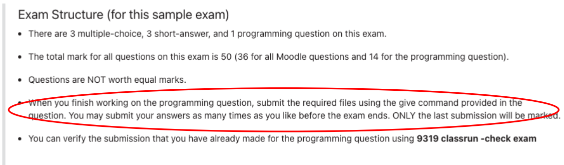
Multiple “give”



Exam Structure (for this sample exam)

- There are 3 multiple-choice, 3 short-answer, and 1 programming question on this exam.
- The total mark for all questions on this exam is 50 (36 for all Moodle questions and 14 for the programming question).
- Questions are NOT worth equal marks.
- When you finish working on the programming question, submit the required files using the give command provided in the question. You may submit your answers as many times as you like before the exam ends. ONLY the last submission will be marked.
- You can verify the submission that you have already made for the programming question using **9319 classrun -check exam**

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Hints

- Total 50 pts:
  - 20 M.C. (20 pts)
  - 10 short-answer questions (20 pts)
  - 1 short programming question (10 pts)

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Hints (con’t)

- M.C. and short-answer questions:
  - Some easy / conceptual qns (avg 2min), some need workout (avg 5min)
  - May need a calculator (make sure you have one next to you)
  - They are randomly selected fr a qn bank, so if you have qns during the exam, please copy&paste your exam qn in your email.

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Hints (con’t)

- M.C. and short-answer questions:
  - Should take approx 1.5 hr to complete.
  - You will run out of time if you try to study or “search for an answer”.
  - So make sure you study lectures and practise the exercises before hand.
  - Go to the wk10/wk11/wk12 consultations if you have qns

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Hints (con’t)

- Same as normal exam papers, this exam has been checked by at least one other staff member. We rarely got questions during the previous exams, and if we did, the answer would usually be " *the question is as it is written* ". We're not expecting it to be any different in this exam.

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Hints (con't)

- The programming question:
  - In C or C++, you need to provide a makefile
  - Test on CSE machines
  - No specific performance requirements
  - Will manually check code for some partial marks (if your program doesn't work & your code is readable)

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Hints (con't)

- The programming question:
  - A short program, should be able to finish and test it in 30-60mins.
  - Test cases will be small and you don't have to use dynamic memory management such as pointers.

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Hints (con't)

- Overall, the exam questions are:
  - Direct & straightforward (i.e., not tricky)
  - Most Moodle questions are similar to exercises' style
- Exam preparation:
  - Study the lectures (slides & recordings)
  - Exercises
  - **Come to the consultations if any questions**

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Finally

MyExperience: due very soon

Please give some constructive feedback, **thank you** !

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The End – *my last exercise for you* ☺

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kuo$cdogl

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