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Speeding up compressed matching with SBNDM2

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Introduction

- Compressed matching problem: string matching in a compressed text without decompression
- Aim: faster searching

Introduction

- Several efficient methods are based on byte pair encoding (BPE).
- We achieved faster searching with encoding of different type.
- Earlier, we have presented a search algorithm based on Boyer-Moore-Horspool.
- Now, we present a search algorithm based on SBNDM2.

Byte pair encoding (BPE)

- BPE (Gage 94) replaces recursively the most common byte pair by an unused character code.

  abcabc... ⇒ d=ab|dcdc... ⇒ e=dc,d=ab|ee...

- Manber's BPE: bytes are classified either a start or end byte of a pair to ensure locally unambiguous decoding.
- BPE achieves moderate compression ratios on text: 45-75% (best methods achieve 20-30%)
- BPX (Maruyama et al. 08) is a modification of BPE with better comression ratio.

Our encoding method

- Codeword for a character is a variable-length sequence of k-bit base symbols.

```
 a  b  r  a   c     a   d     a  b  r  a
00 01 10 00 11 00 00 11 01 00 01 10 00
```

  - Related to Huffman encoding
  - de Moura et al. (00) use 8-bit symbols to encode words

- The coding method is called **S**topper **E**ncoding and denoted by SE_k for k-bit base symbols.

Our encoding method (cont.)

- Encoding and decoding are very fast.
- Search algorithm:
  - variation of SBNDM2 (new)
  - variation of Boyer-More-Horspool (presented earlier)
- Comparable compression ratio with fast BPE but searching is faster

Semi-static coding scheme

- Codewords are based on frequencies of characters in the text.
- Two passes
  1. The frequencies of characters are gathered
  2. Actual coding
- The code table is a part of the compressed file.

Stoppers and continuers

- Because the length of a codeword varies and SBNDM2 jumps forward, we need a mechanism to recognize where is a border of subsequent codewords.

Stoppers and continuers (cont.)

- Two classes of base symbols:
  - The last base symbol of a codeword is a stopper.
  - Other base symbols are continuers.

Example: $u_1u_2u_3u_4u_5$

continuers stopper

Stoppers and continuers (example)

codewords: 00, 01 00, 01 01 00

text: ...00 01 00...

Number of stoppers

- The optimal number depends on the number of different characters and their frequencies.
- Computation is straightforward.
- Example: 14 is optimal for the English Bible with 16 (4-bit) base symbols.

Searching

- The pattern is encoded in the same way as the text.
- Search is based on bytes.
- An occurrence of the pattern does not necessarily start at the beginning of a byte. To avoid bit manipulation, several patterns are searched at the same time.

SBNDM

Simple Backward Nondeterministic DAWG Matching

- SBNDM is a simplification of BNDM. Both are bit-parallel algorithms, which recognize factors of the pattern.
- Text $T = t_1 \ldots t_n$, pattern $P = p_1 \ldots p_m$.
- At an alignment of P: $t_i \ldots t_{i+m-1}$, scan T from right to left until the suffix $t_k \ldots t_{i+m-1}$ is not a factor of P or an occurrence of P is found ($k = i$).
- Next alignment starts at t_{k+1}.

SBNDM, example

P = **banana**, T = **antanabadbanana...**

alignment: **antana**badbanana

a

na

ana

not a factor: **tana**

next alignment: ant**anabad**banana

not a factor: **d**

next alignment: antanabad**banana**

SBNDM2 (modified)

- SBNDM can be made faster by reading two text characters instead of one before checking anything.
- Occurrence vectors are precomputed for all 2-grams.
- If the encoded pattern is 618e0 (in hexadecimal), we search for both 61-8e and 18-e0 simultaneously by searching the pattern 61-8e-18-e0.

Code splitting

- The high bits of base symbols are concatenated to one file and the low bits to another file:

  1110 0110 0011 = 110100 101011

- Motivation:
  dense accessing is faster than sparse accessing

Code splitting

- Low bits of the pattern are searched in the low bits of the text
- For matches found in low bits
  - verify with high bits
  - check that the preceding base symbol is a stopper

Combining code splitting with stopper encoding

- $SE_{k,h}$: stopper encoding with k-bit base symbols and with division to h high bits and $k-h$ low bits
- SE_k: stopper encoding without code splitting
- $SE_{8,h}$: plain code splitting without compression
- We consider here two versions: SE_4, $SE_{8,4}$

Test data

- Part of the fruitfly DNA (5 MB)
- English Bible (extended to 5 MB)
- Finnish Bible (extended to 5 MB)

Compression ratios

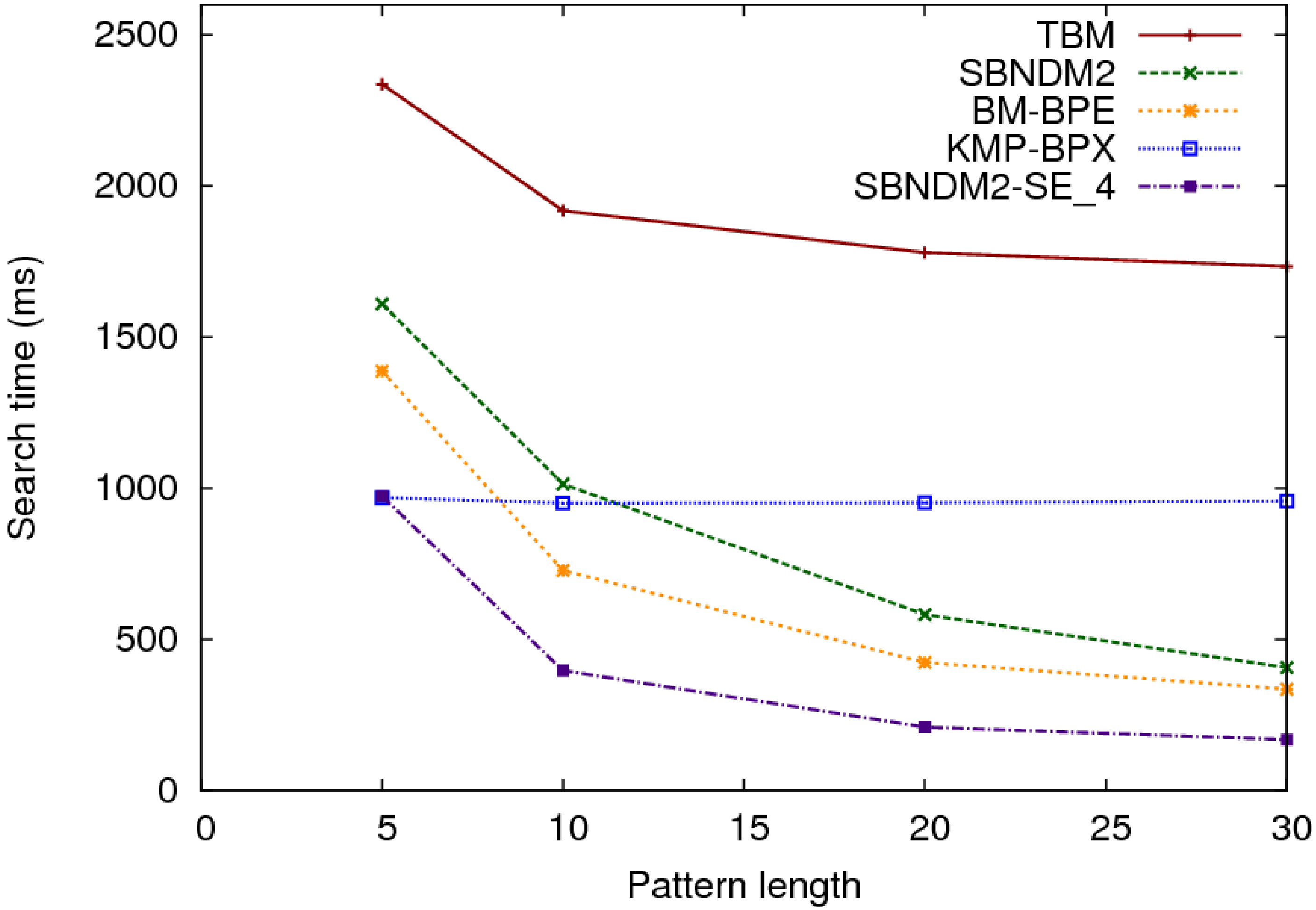
	English Bible	Finnish Bible	DNA
BPX	28,0 %	32,6 %	27,8 %
BPE	51,0 %	52,1 %	34,0 %
SE_4	58,8 %	58,2 %	50,0 %

- Compression ratio = compressed size / original size

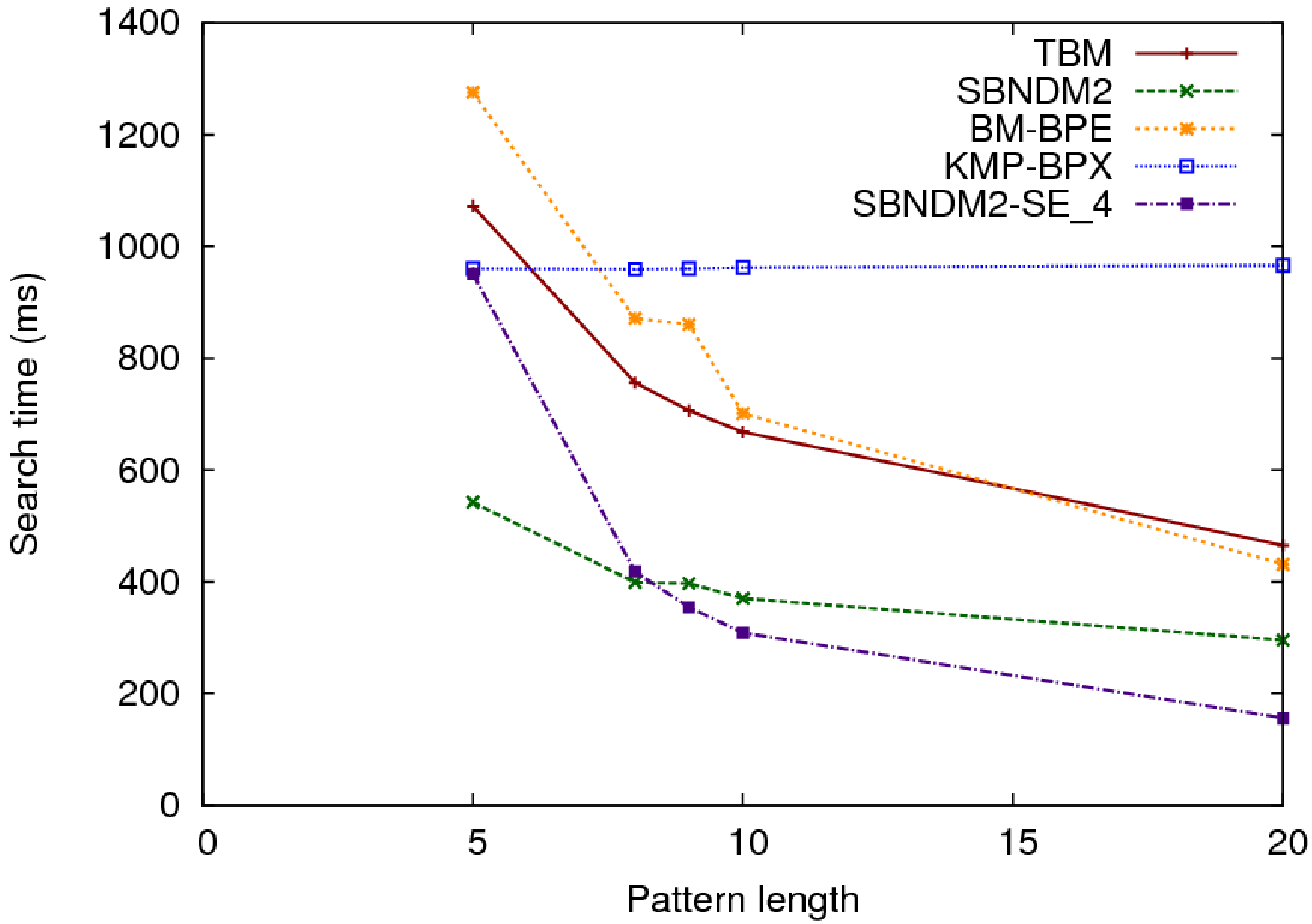
Tested search algorithms

- TBM: Tuned Boyer-Moore for uncompressed texts
- SBNDM2: for uncompressed texts
- BM-BPE: texts compressed by BPE by Shibata et al. (00)
- KMP-BPX: texts compr. by rec. pairing by Maruyama et al. (08)
- SBNDM2-SE_4: SBNDM2 for SE_4 encoded texts
- SBNDM2-$SE_{8,4}$: SBNDM2 for $SE_{8,4}$ encoded texts (code splitting, no compression)
- BM-SE_4: Boyer-Moore for SE_4 encoded texts
- BM-$SE_{8,4}$: Boyer-Moore for $SE_{8,4}$ encoded texts (cs, nc)

Results: DNA


TBM
SBNDM2
BM-BPE
KMP-BPX
SBNDM2-SE_4
Search time (ms)
Pattern length
0
500
1000
1500
2000
2500
0
5
10
15
20
25
30

Results: English text



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Concluding remarks

- Practical solutions for the compressed matching problem
- SBNDM2-SE_4 is faster than other tested methods of compressed matching in English and DNA texts for pattern lengths > 5.
- SBNDM2-SE_4 is faster than SBNDM2 for pattern lengths ≥ 9 in English text, but slower for shorter patterns.
- SE_4 has similar compression ratio to the fast BPE.