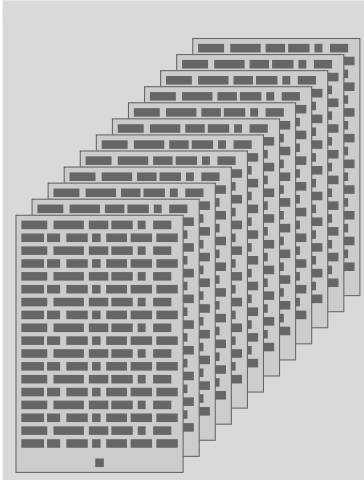
Karlsruhe Institute of Technology

Massive Text Indices

Final Meeting SPP Big Data

Florian Kurpicz

Motivation



- texts are everywhere
- collection of texts
- scanning not feasible

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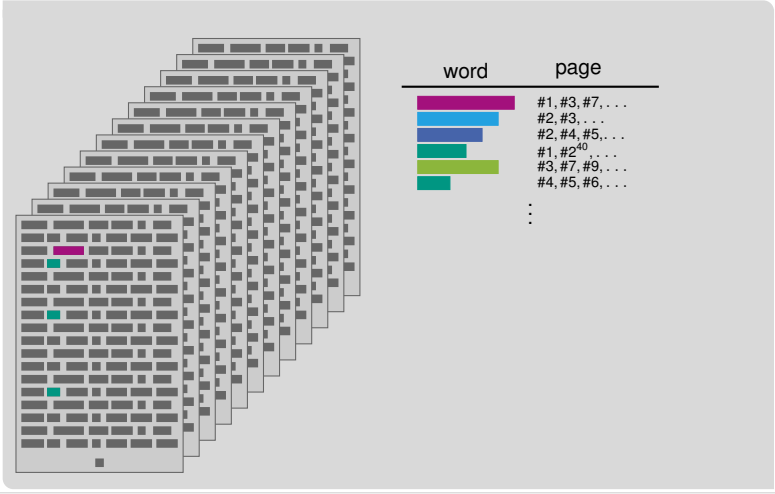

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- inverted index (word based)

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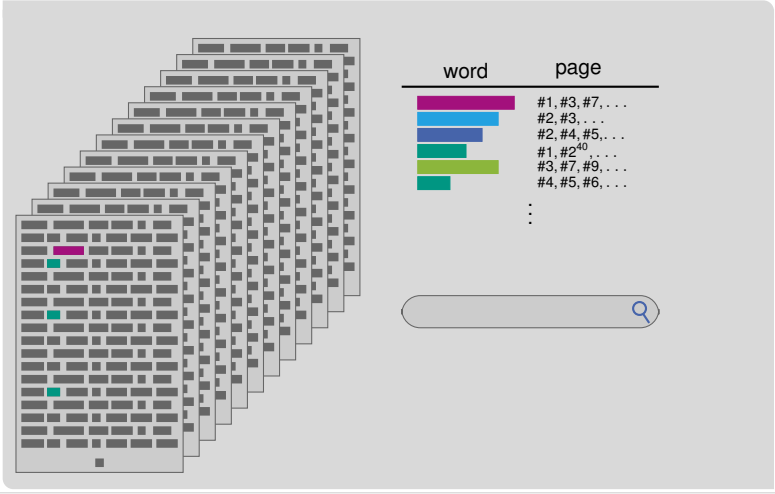

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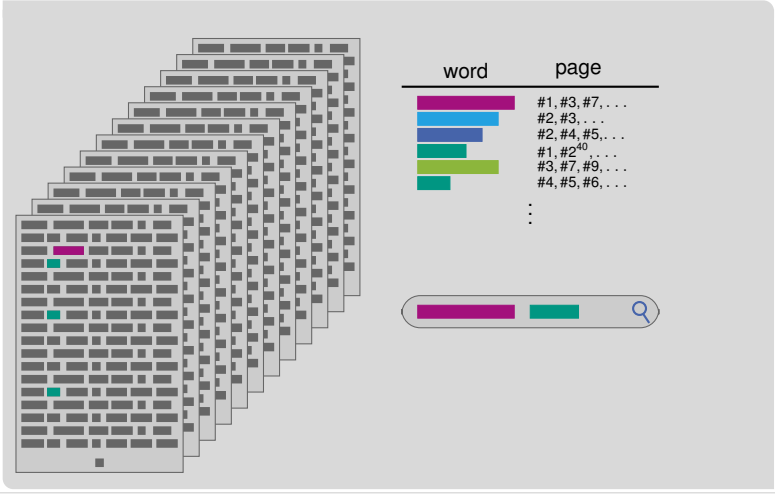

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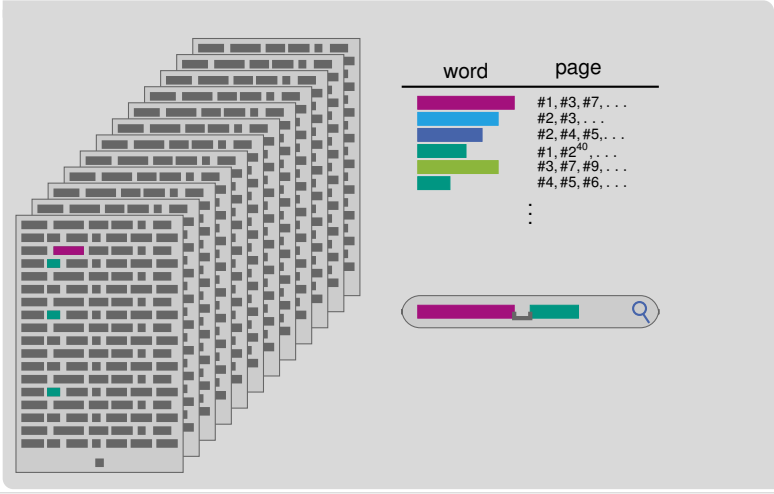

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- scanning not feasible
- inverted index (word based)
- phrase search

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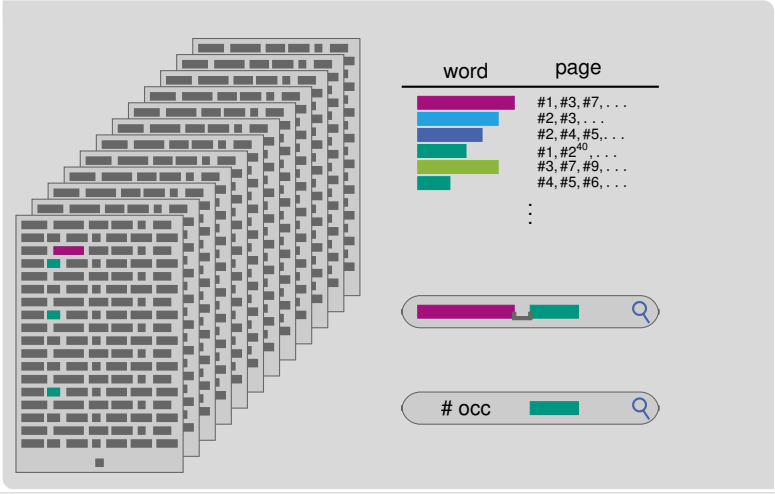

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- collection of texts
- scanning not feasible
- inverted index (word based)
- phrase search
- counting queries

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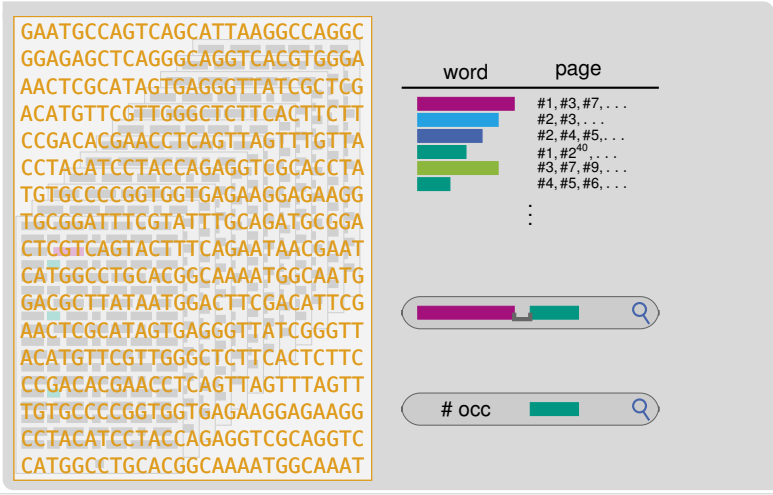

- texts are everywhere
- collection of texts
- scanning not feasible
- inverted index (word based)
- phrase search
- counting queries
- what if there are no “words”

Overview: Text Indices and Main Results

Suffix Tree
1973

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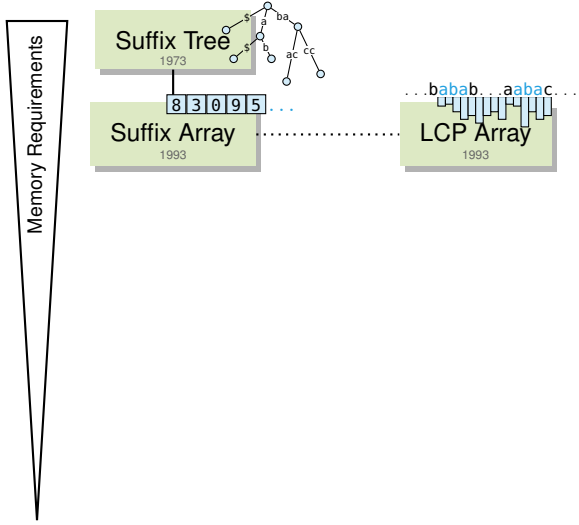

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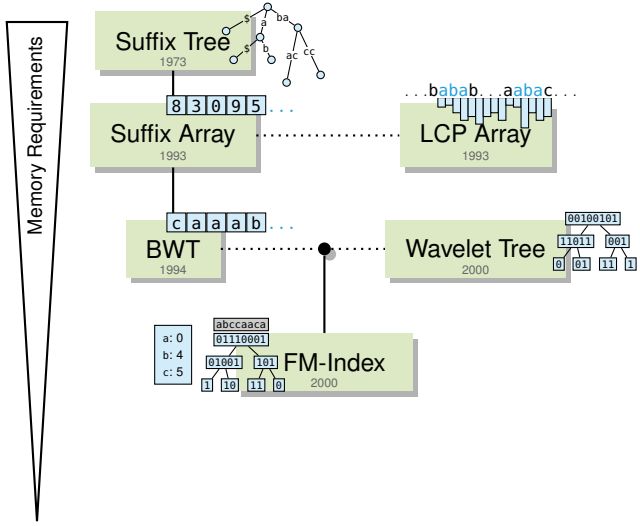

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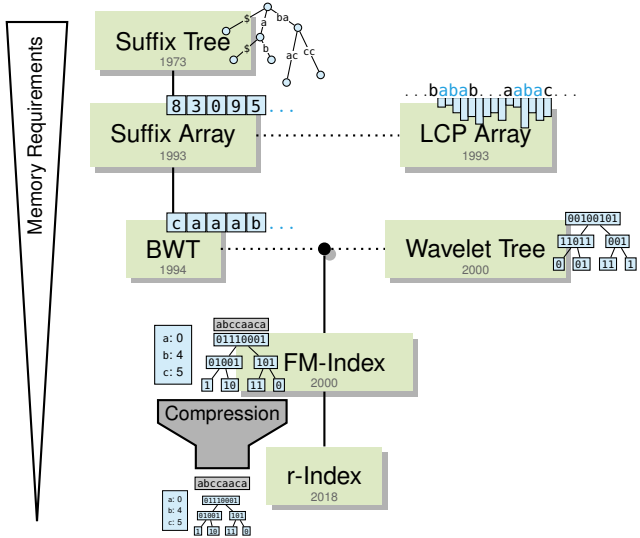

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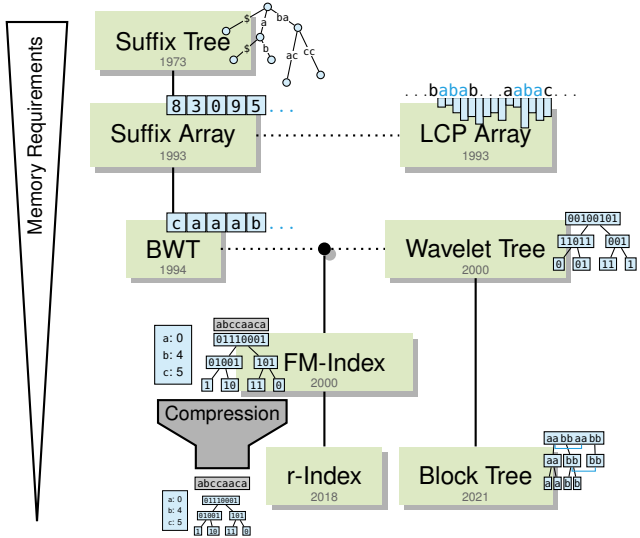

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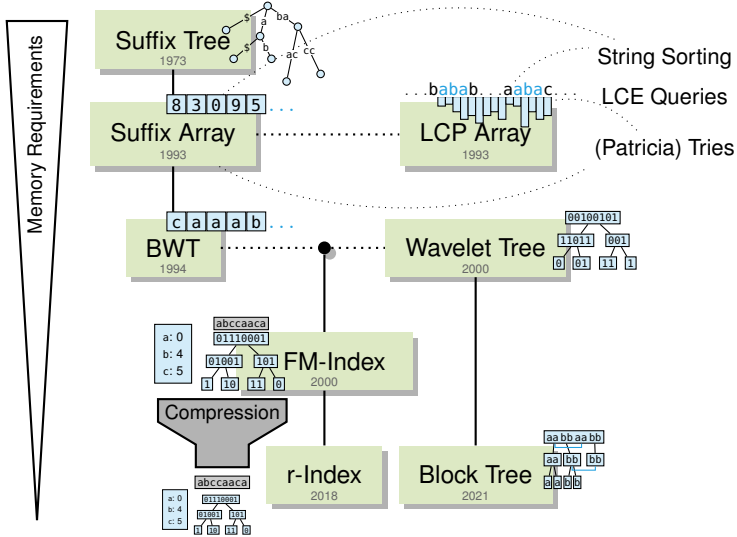

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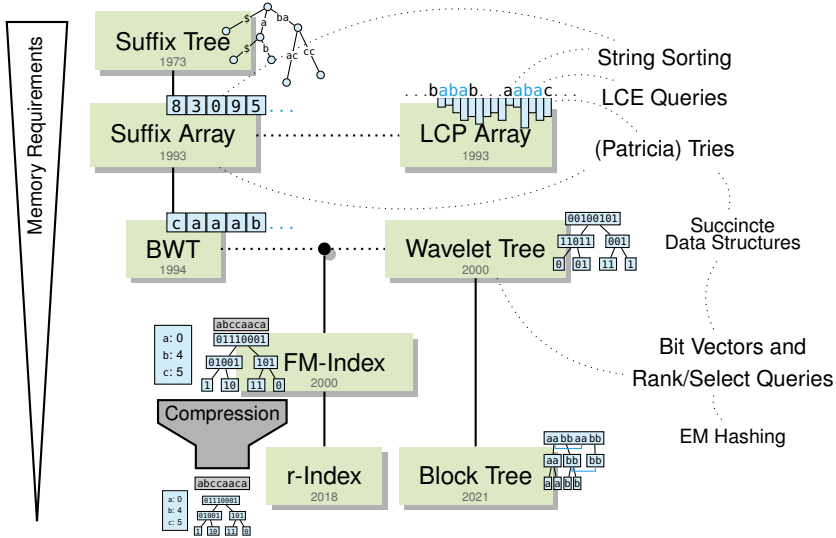

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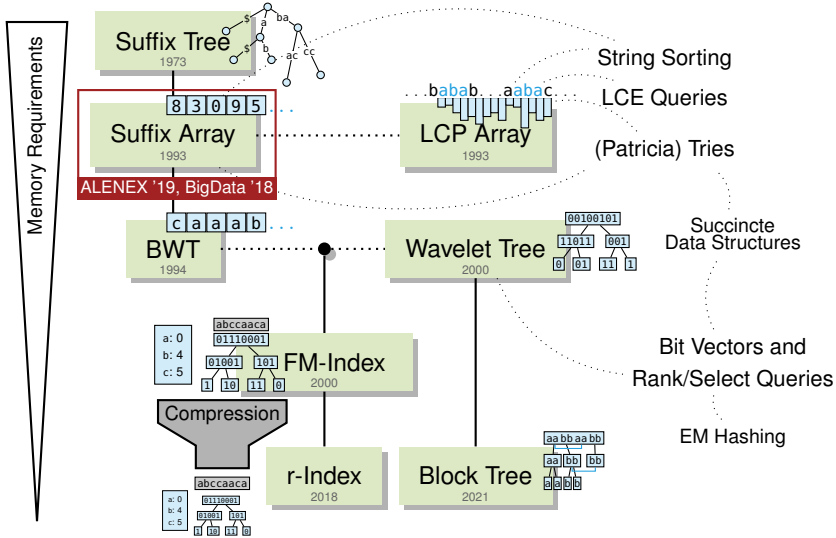
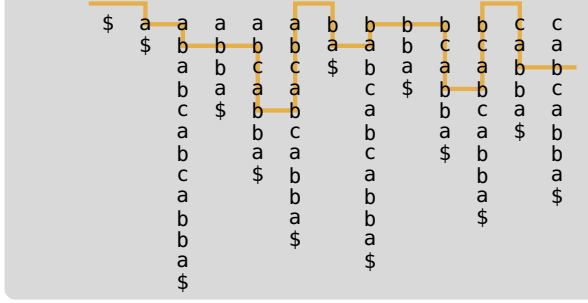
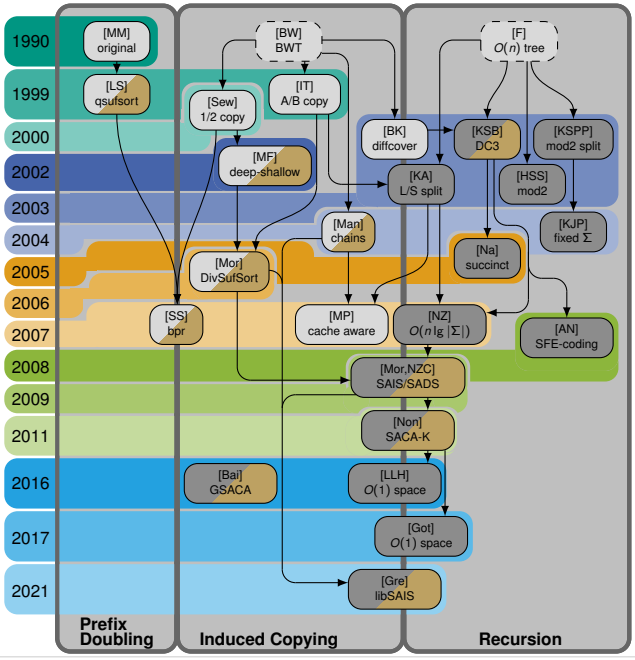


Suffix Array and Longest Common Prefix Array

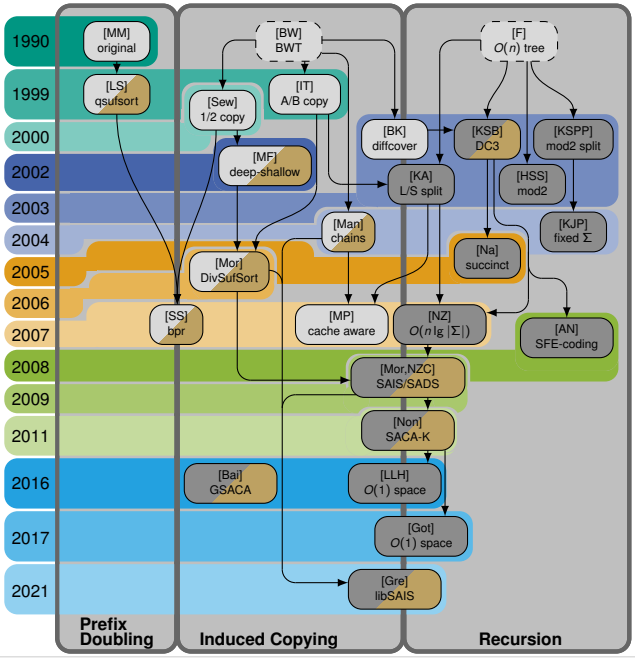
	1	2	3	4	5	6	7	8	9	10	11	12	13
T	a	b	a	b	c	a	b	c	a	b	b	a	$
SA	13	12	1	9	6	3	11	2	10	7	4	8	5
LCP	0	0	1	2	2	5	0	2	1	1	4	0	3





Timeline Sequential Suffix Sorting

- **darker grey**: linear running time
- **brown**: available implementation



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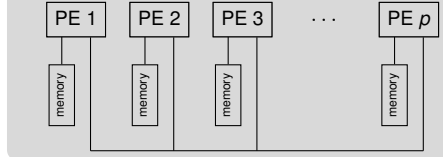
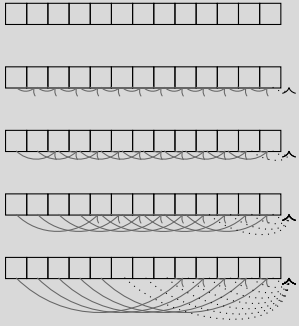
Distributed Memory



- not whole text available on every PE

Suffix Sorting Techniques

Prefix Doubling



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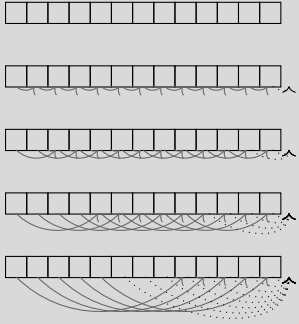
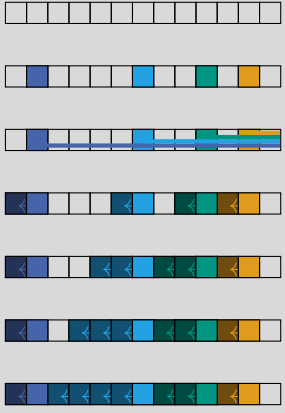


Induced Copying



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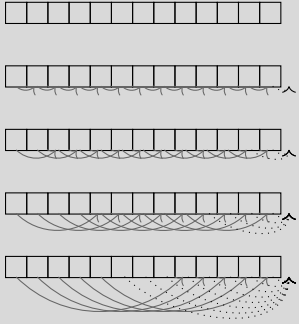

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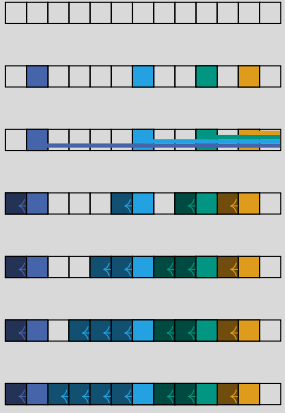
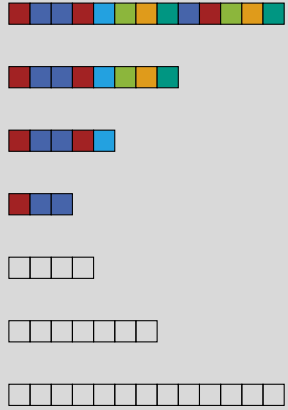
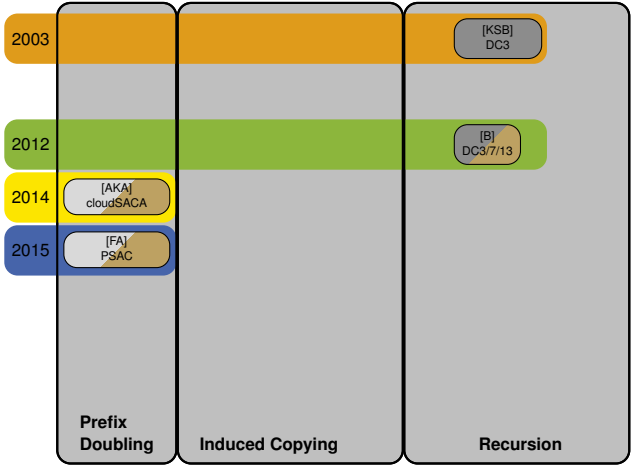


Recursion



Distributed Memory Suffix Sorting



- suffix sorting using Thrill
- suffix sorting using MPI

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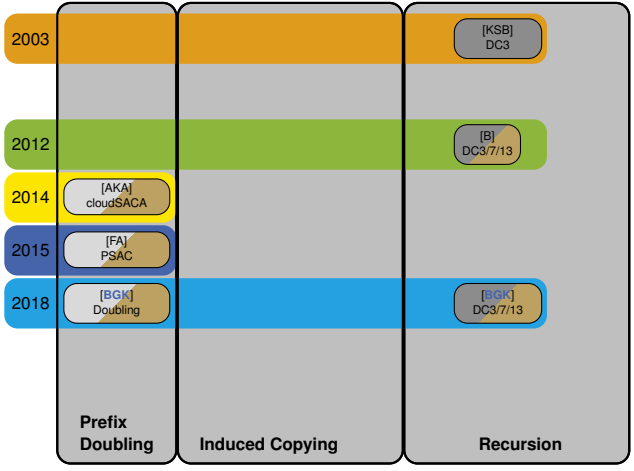

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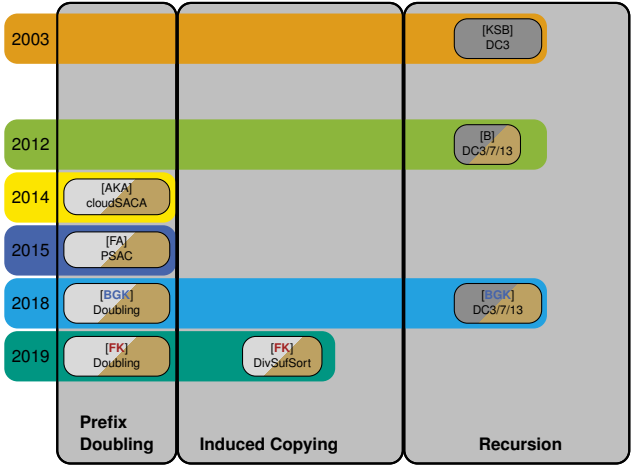

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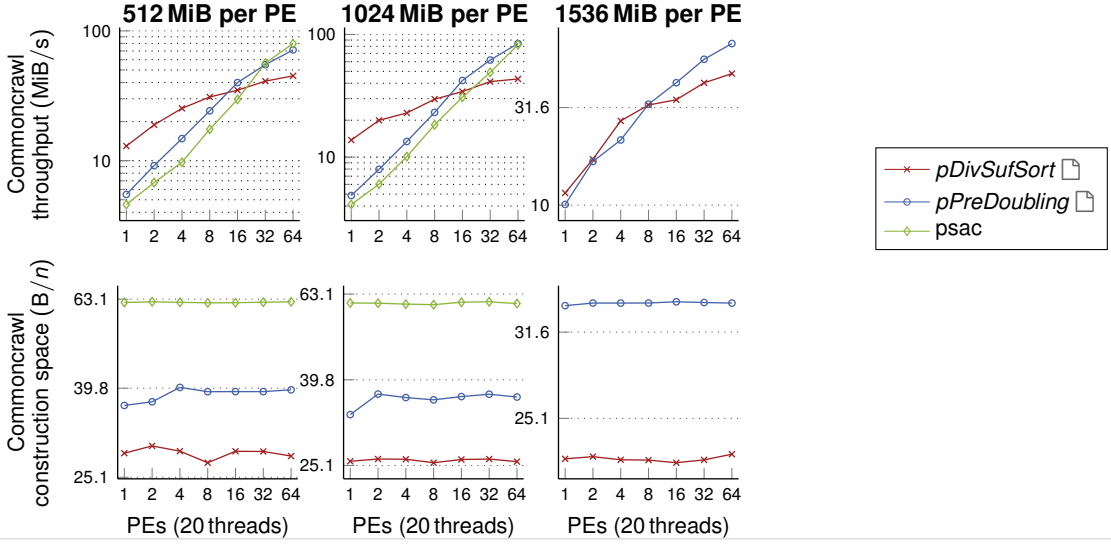
Distributed Memory Suffix Sorting: Experiments (MPI)



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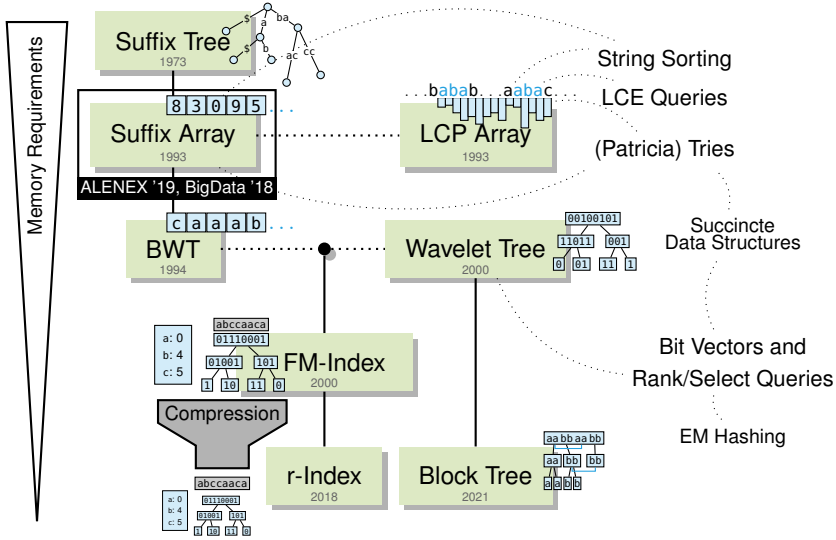

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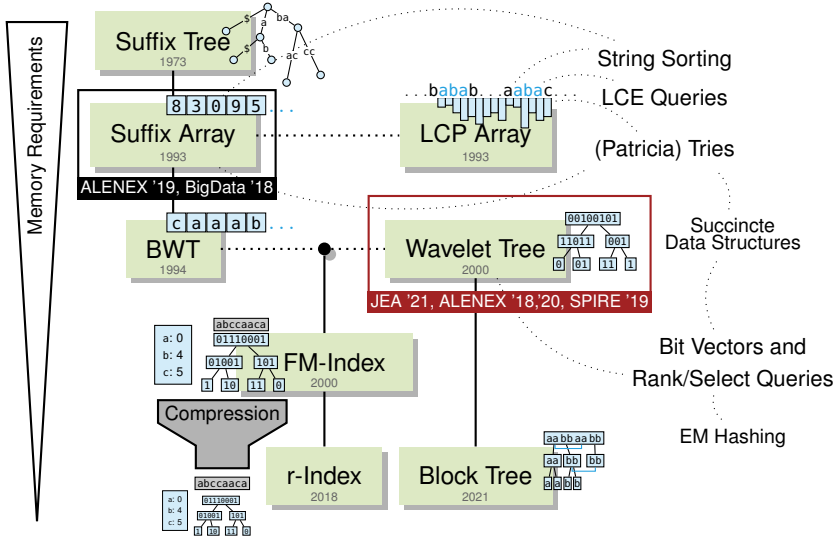
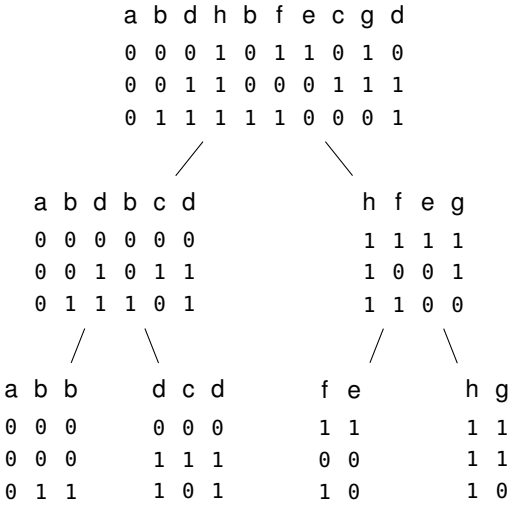


The Wavelet Tree Bottom-Up



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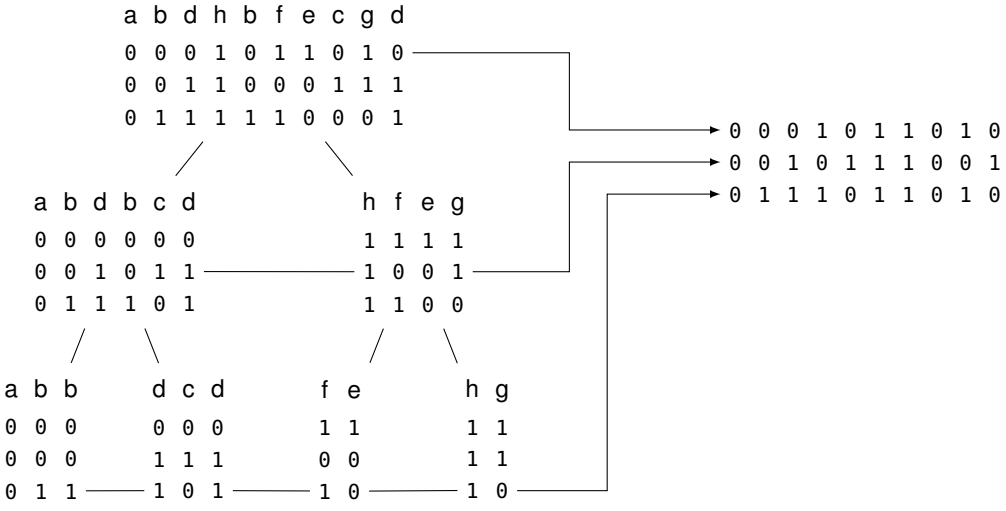

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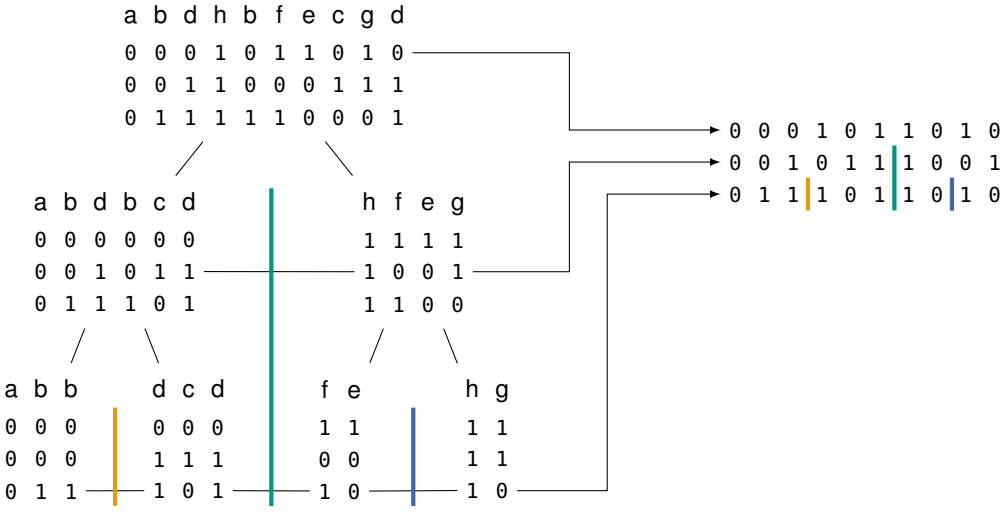

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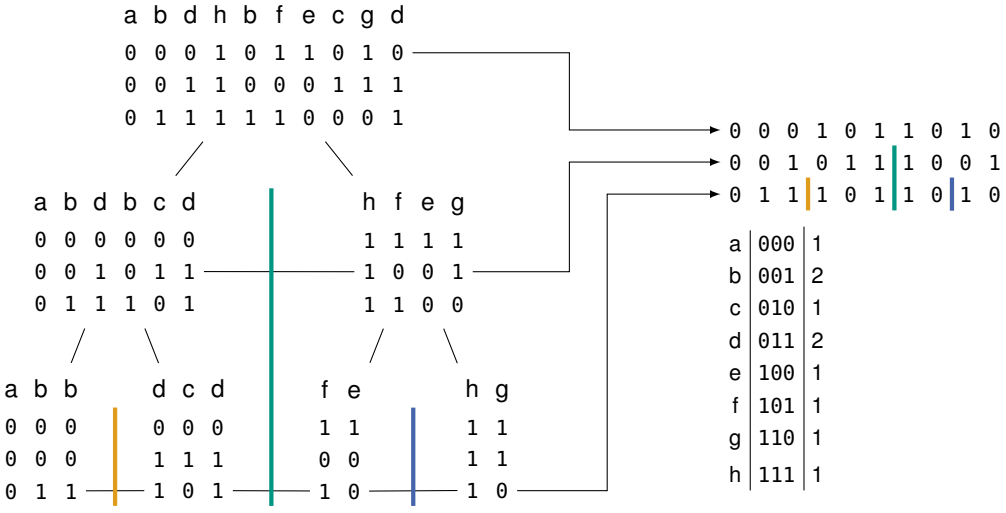

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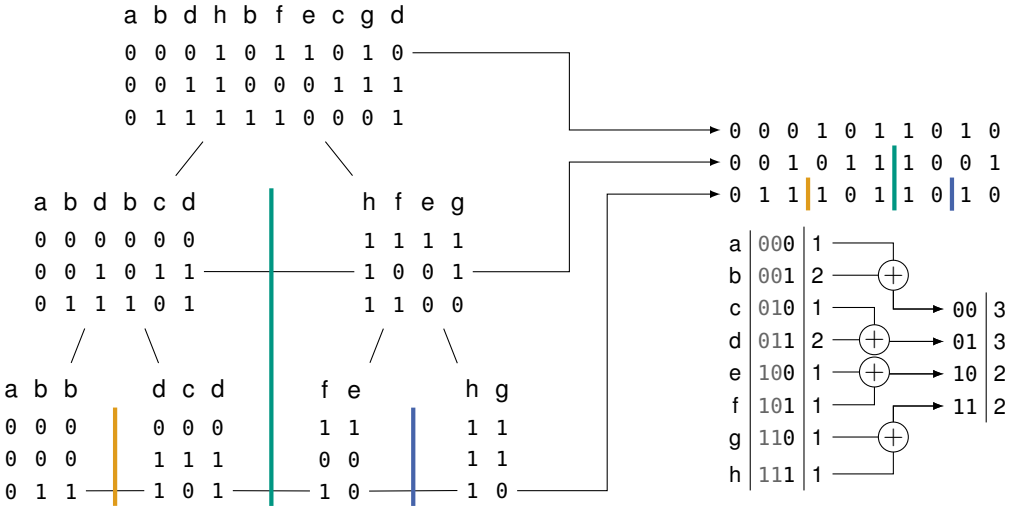

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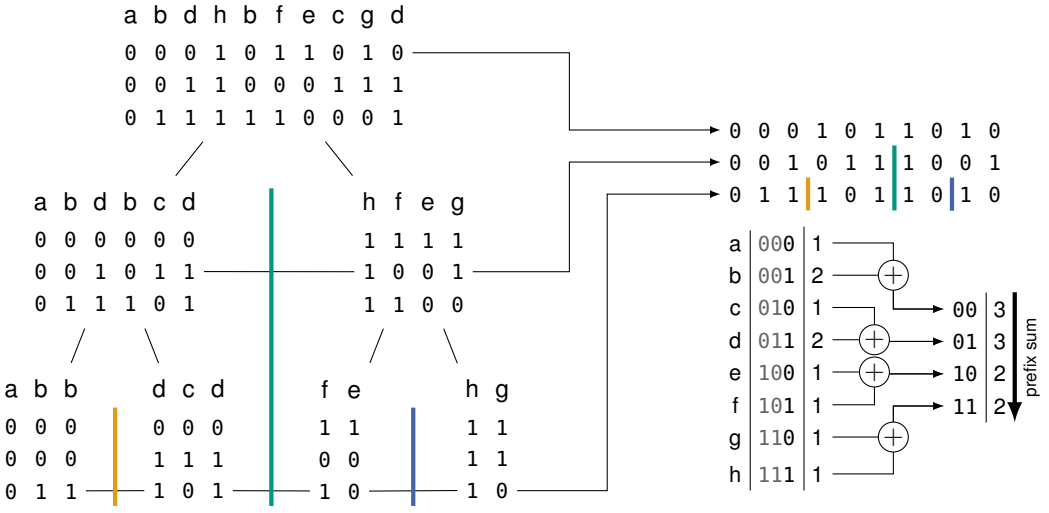

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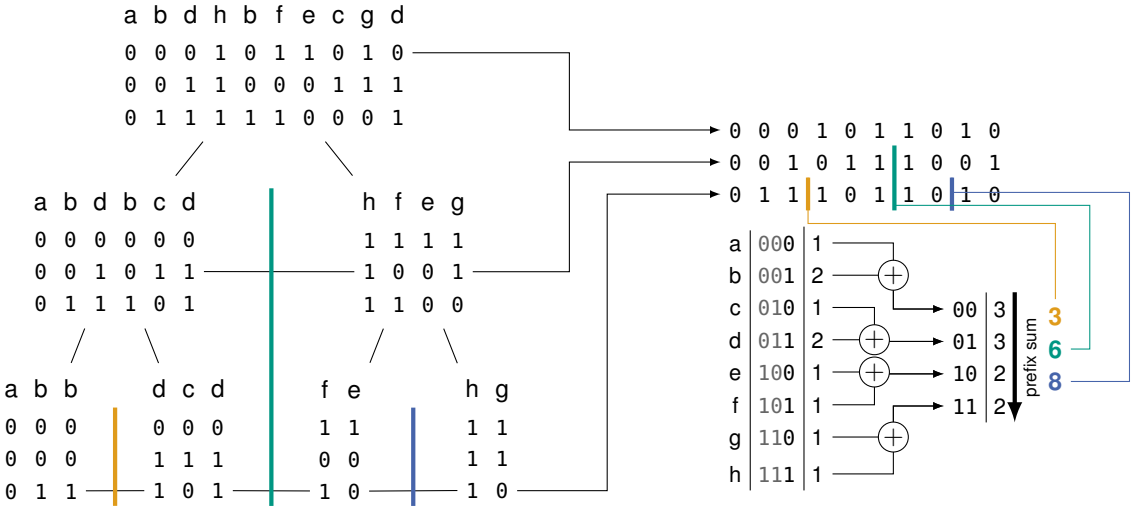


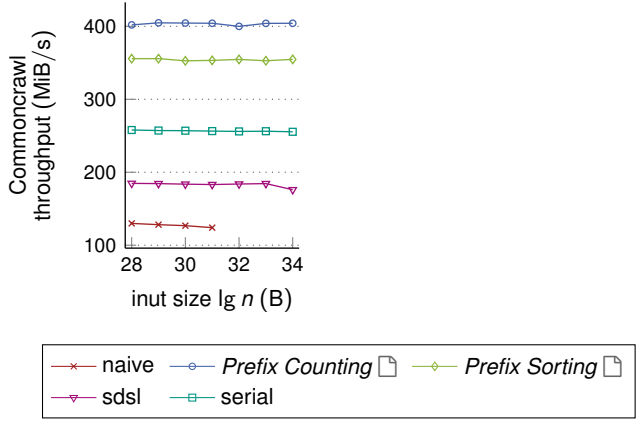
Sequential Wavelet Tree Construction

Prefix Counting

- insert bits based on borders

Prefix Sorting

- sort text based on borders
- insert bits from left to right



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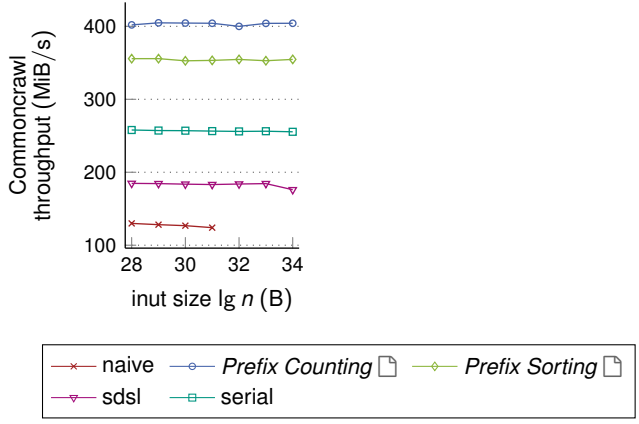

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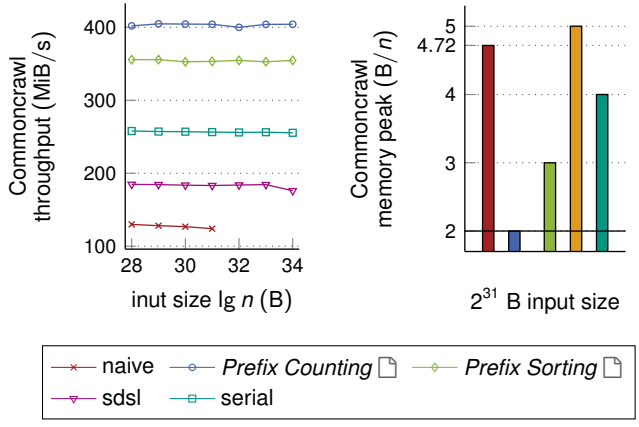

Parallel Wavelet Tree Construction

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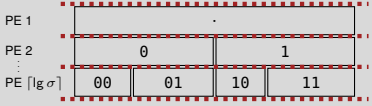

- at most $\lceil \lg \sigma \rceil$ PEs

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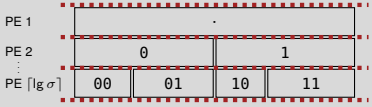

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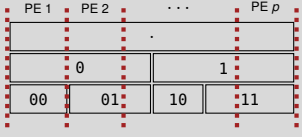
Parallel Prefix Sorting



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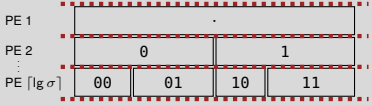

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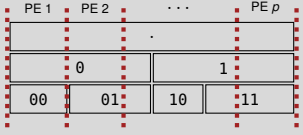
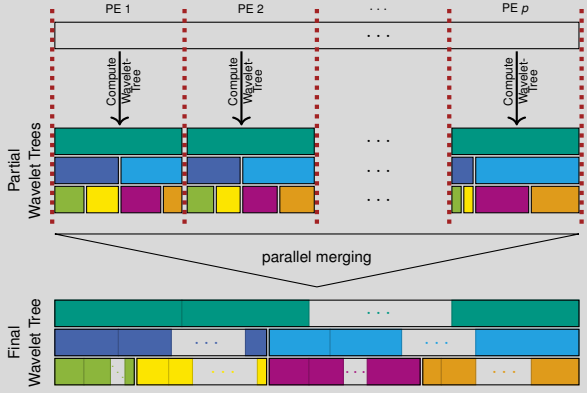


Domain Decomposition



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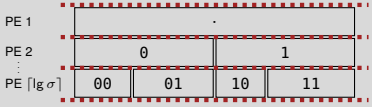

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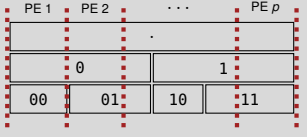

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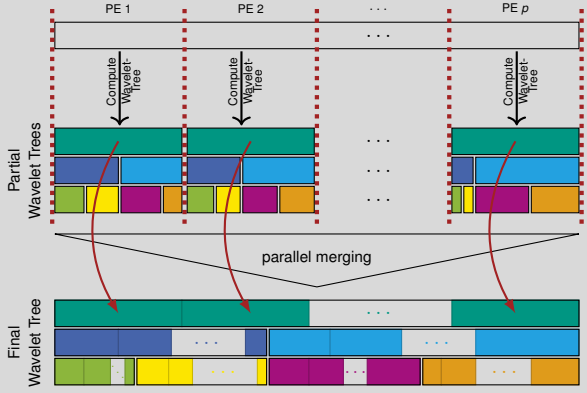

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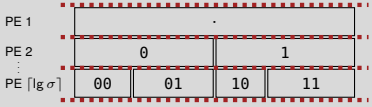

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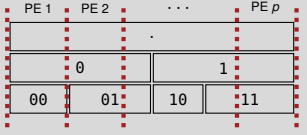

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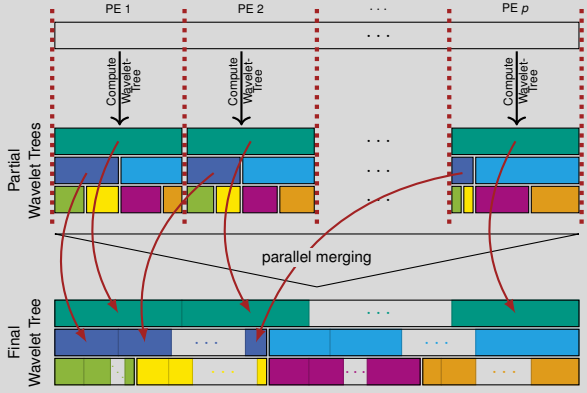

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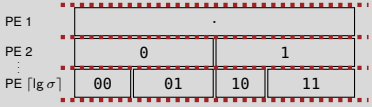

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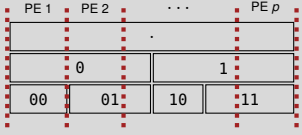
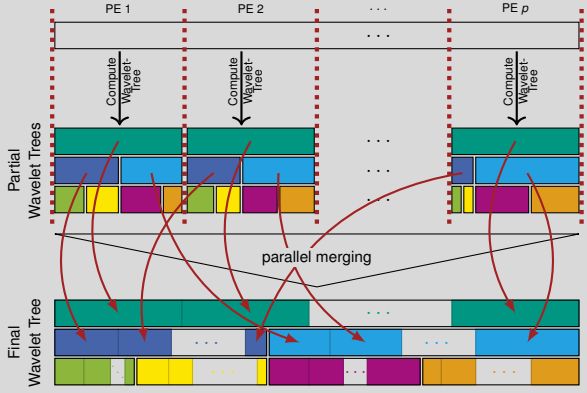
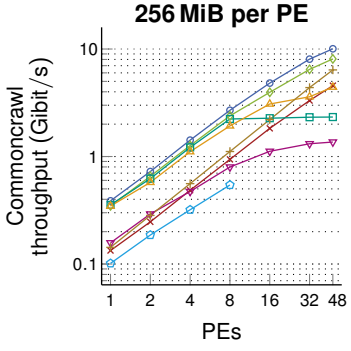
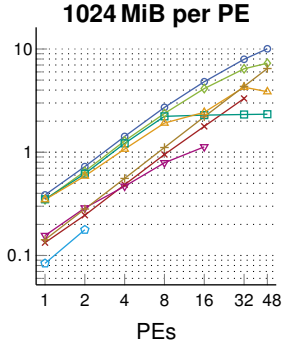


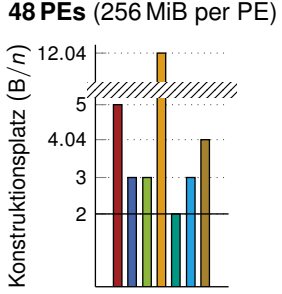
Domain Decomposition

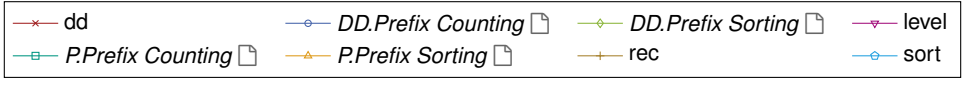


Parallel Wavelet Tree Construction: Experimental Evaluation









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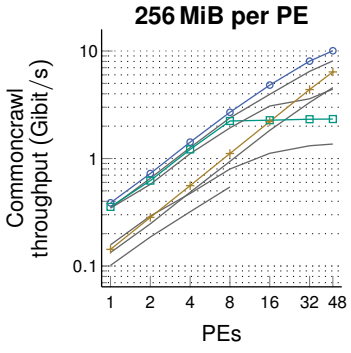
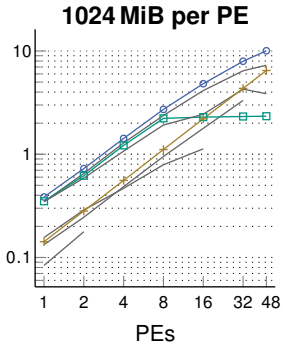
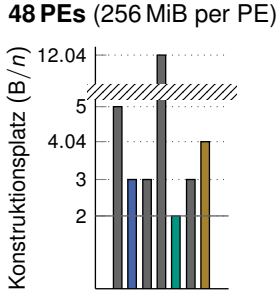
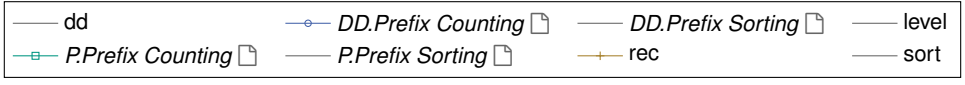
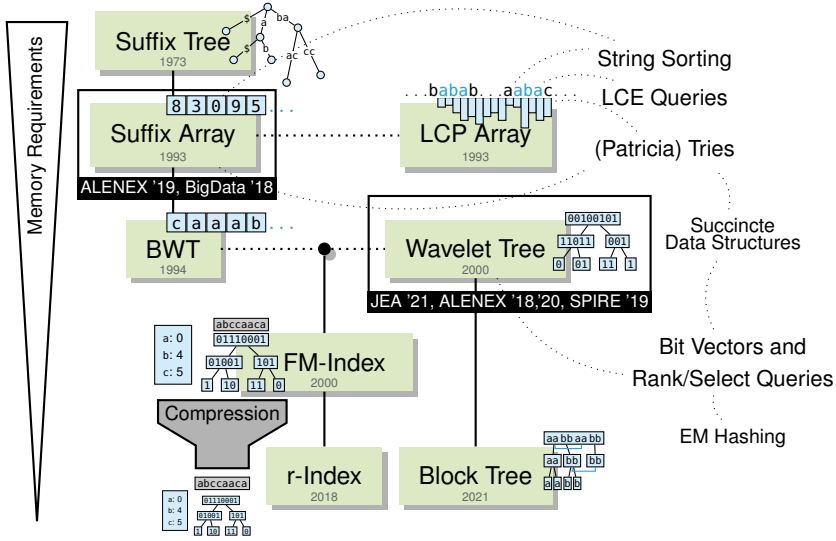








Overview: Text Indices and Main Results



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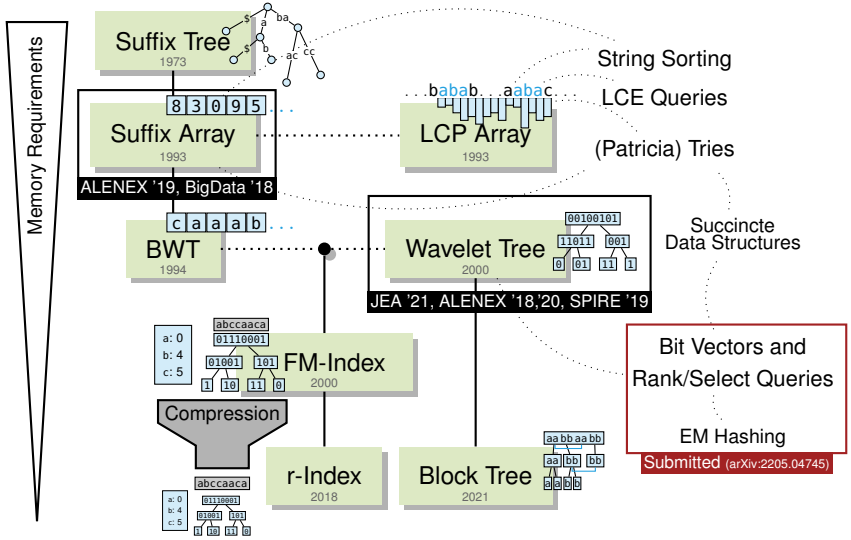

Rank Queries in Bit Vectors

$\text{rank}_\alpha(i)$ # of αs before i

$\text{select}_\alpha(j)$ position of j-th α

0	1	2	3	4	5	6	7	8	9
0	1	1	0	1	1	0	1	0	0

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$\text{rank}_0(5)$

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0	1	1	0	1	1	0	1	0	0

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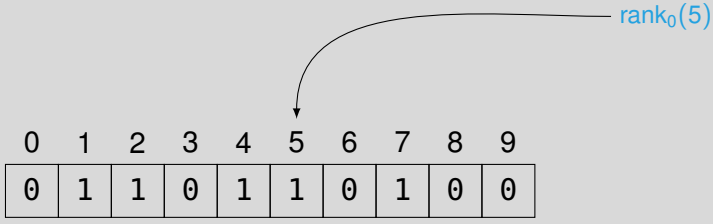

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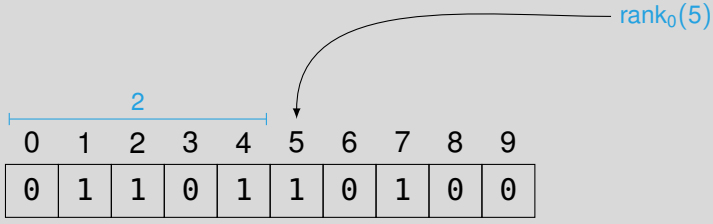

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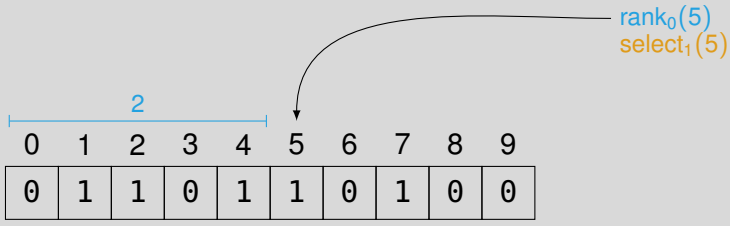

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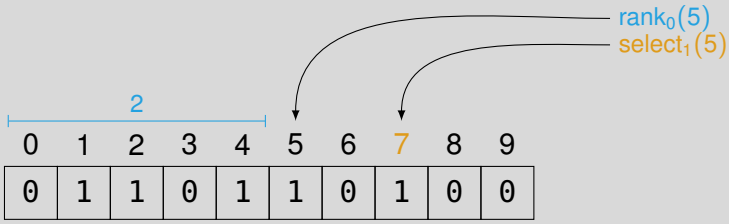

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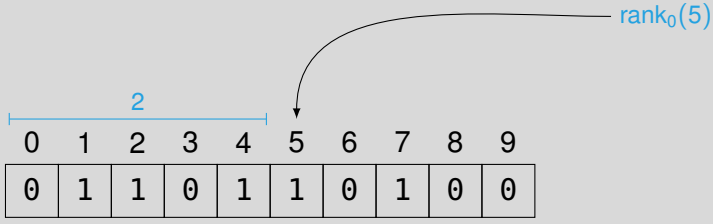

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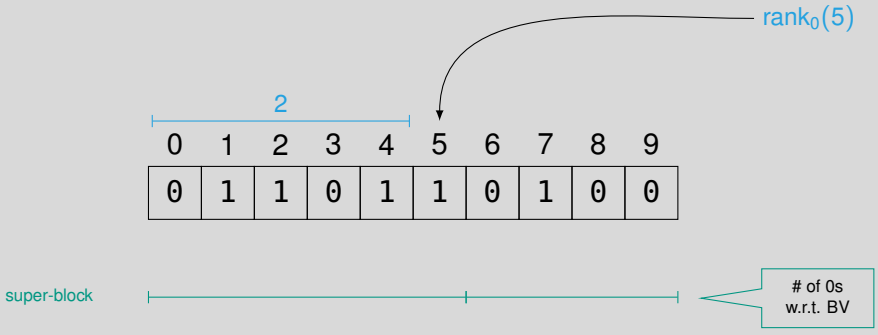

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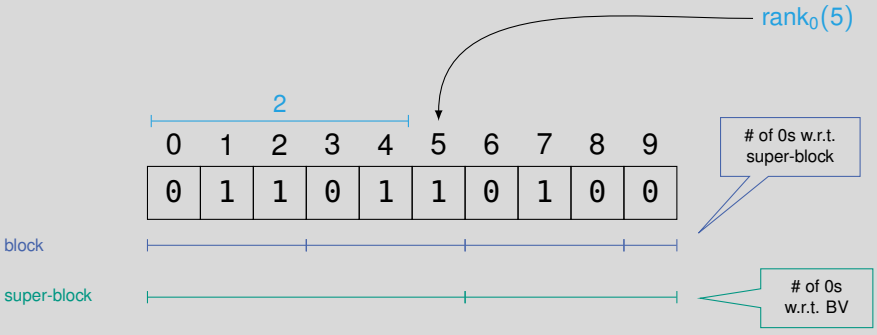

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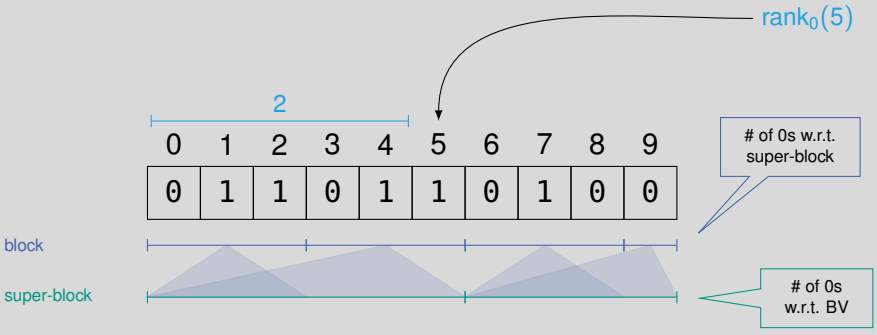

Bit Vectors with Rank and Select Support

cs-poppy

- Blocks (L2): 512 bits
- Super-Blocks (L1): 2048 bits
- Super-Super-Blocks (L0): 2^{31} bits
- 3.51 % space overhead

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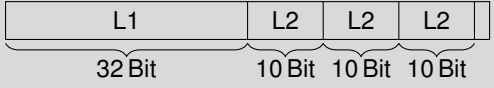
L1+L2 Together in 64 Bits



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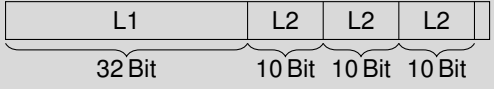
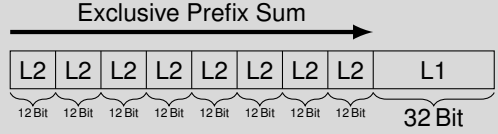


New: L1+L2 Together in 128 Bits



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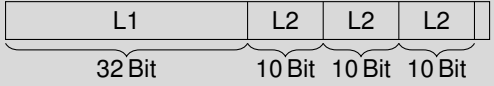

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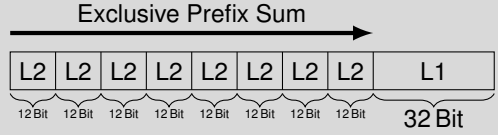


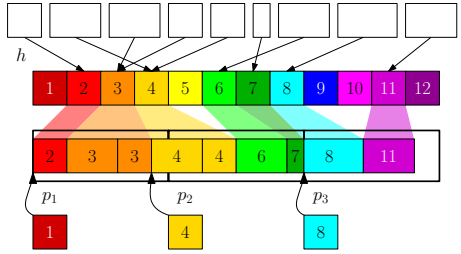
SIMD Access

- 3 consecutive bytes contain two 12 bit entries
- shuffle and shifte entries in seven 16 bit blocks
- search all entries at the same time
- 8 %–16 % faster than cs-poppy

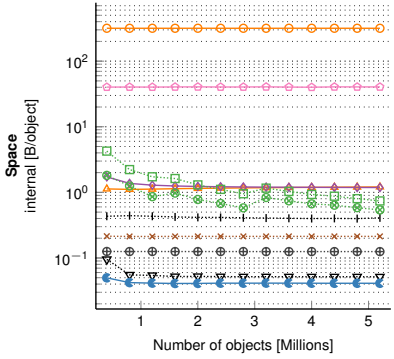
EM Hashing: PaCHash

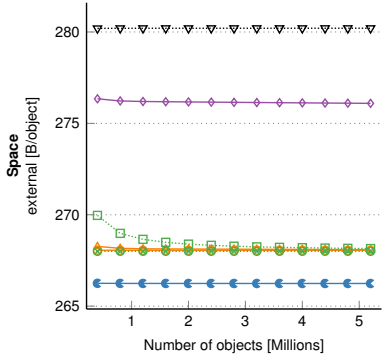
General Idea

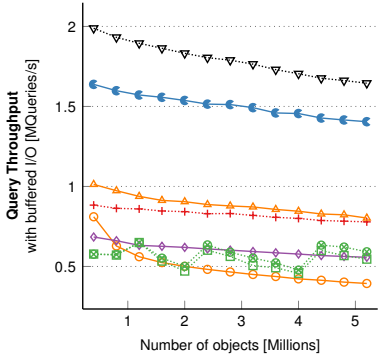
- small internal memory index
- Elias-Fano representataion
- $2 + \log a + o(1)$ bits per EM block
- $1.4427 + \log(a + 1) + o(1)$ theoretically possible
- variable size objects contiguously in EM
- retrieving x loads $\leq 1 + |x|/B + 1/a$ blocks in expectation

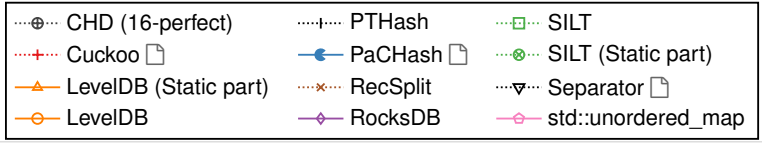


PaCHash Experiments (Fixed Size Objects)

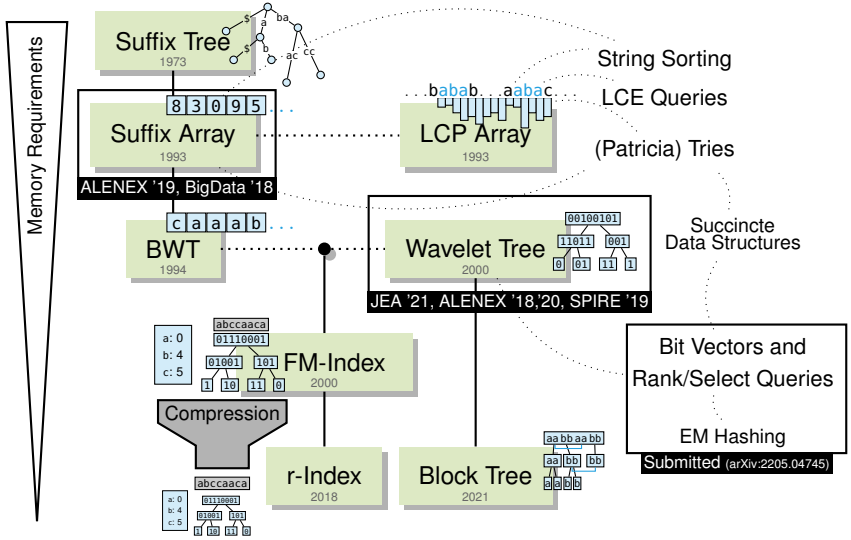








Thank You!


Memory Requirements
Suffix Tree
1973
Suffix Array
1993
ALENEX '19, BigData '18
BWT
1994
LCP Array
1993
Wavelet Tree
2000
JEA '21, ALENEX '18,'20, SPIRE '19
FM-Index
2000
Compression
r-Index
2018
Block Tree
2021
String Sorting
LCE Queries
(Patricia) Tries
Succincte
Data Structures
Bit Vectors and
Rank/Select Queries
EM Hashing
Submitted (arXiv:2205.04745)