FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

CWI Centrum Wiskunde & Informatica

TUM

Tree-Encoded Bitmaps

Harald Lang
Alexander Beischl
Viktor Leis (Friedrich-Schiller Universität)
Peter Boncz (CWI)
Thomas Neumann
Alfons Kemper

PORTLAND

ACM SIGMOD + PODS 2020

ACM SIGMOD/PODS International Conference on Management of Data
June 14-19th, 2020

Portland, Oregon USA

Intro & Motivation

- Tree-Encoded Bitmaps: **Compression technique for bitmaps**
- Bitmap compression plays an important role in bitmap indexes.
    - Bitmap indexes allow for efficient evaluation of multi-dimensional predicates.
    - Bitmap indexes can become quite large
    - Thus, bitmap compression is commonly used to reduce space consumption
    - In fact, the term bitmap index typically refers to a *compressed* bitmap index.

Bitmap Compression Techniques

- Many bitmap compression techniques have been proposed
  - **Word-Aligned Hybrid** (WAH), and variants PLWAH, Concise, VAL-WAH, EWAH, SBH, etc.
    - based on run-length encoding
    - no efficient random access, all preceding bits need to be decompressed
  - **Roaring Bitmap**
    - uses integer arrays
    - efficient random access (binary search) => efficient evaluation of conjunctive predicates

- Tree-Encoded Bitmaps (TEBs):
  - up to 50% space savings compared to Roaring
  - without giving up efficient random access

TEB Ingredients

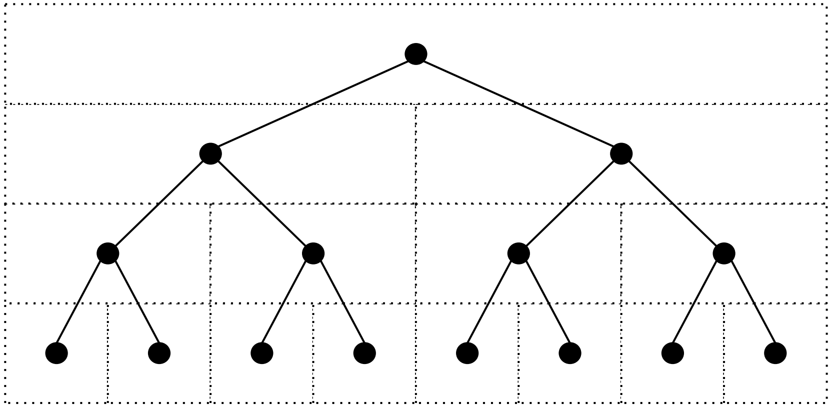
- Tree-based bitmap compression
- Tree encoding
- Additional space optimizations

Tree-Based Compression

Plain Bitmap:

1	1	0	1	0	0	0	0

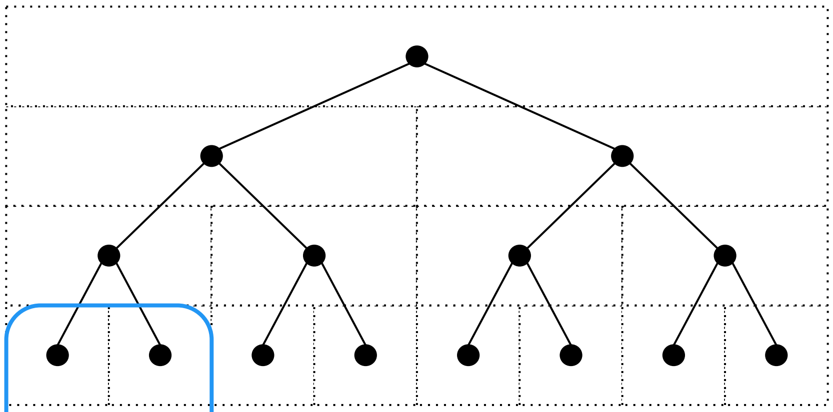
Tree-Based Compression



Plain Bitmap:								
	1	1	0	1	0	0	0	0

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA | CWI Centrum Wiskunde & Informatica | TUM

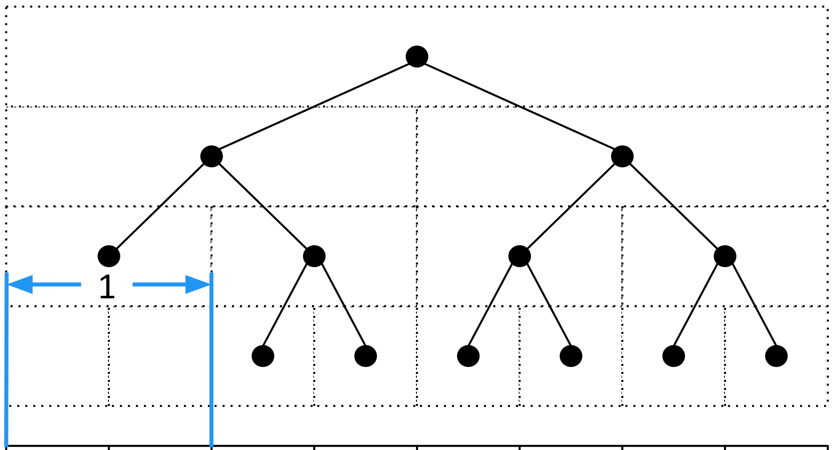
Tree-Based Compression



Plain Bitmap:

1	1	0	1	0	0	0	0

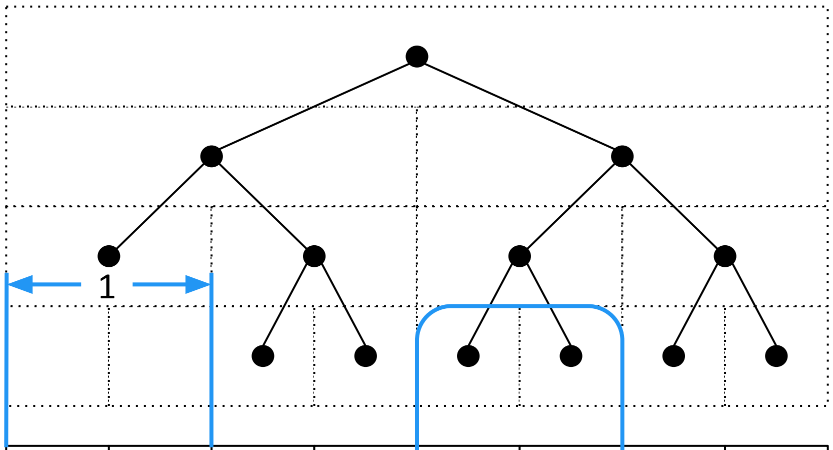
Tree-Based Compression



Plain Bitmap:

1	1	0	1	0	0	0	0

Tree-Based Compression

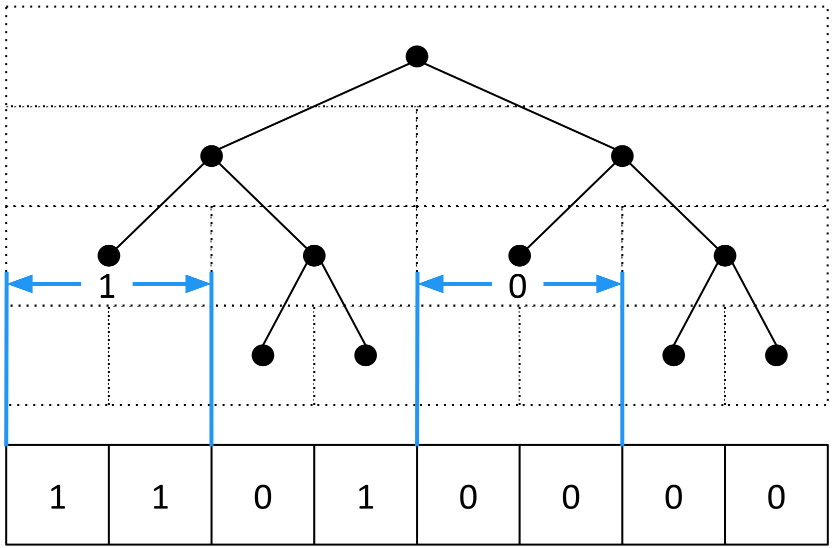


Plain Bitmap:

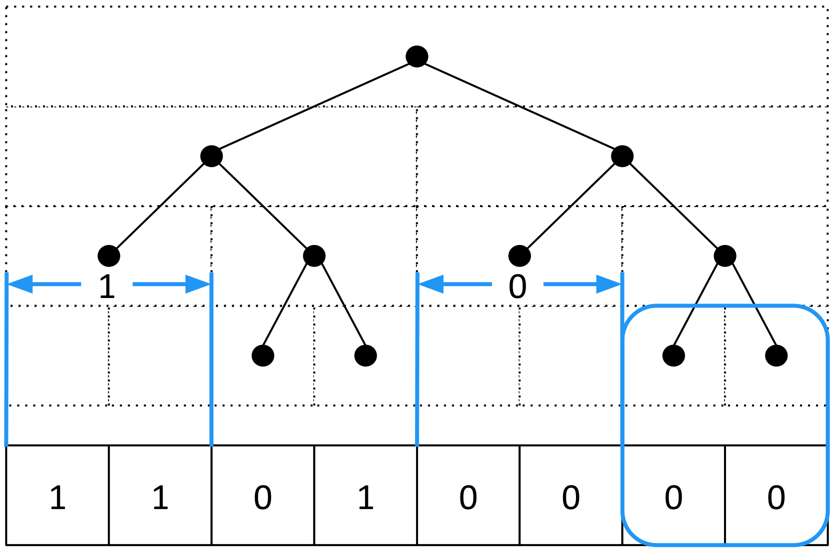
1	1	0	1	0	0	0	0

Tree-Based Compression

Plain Bitmap:

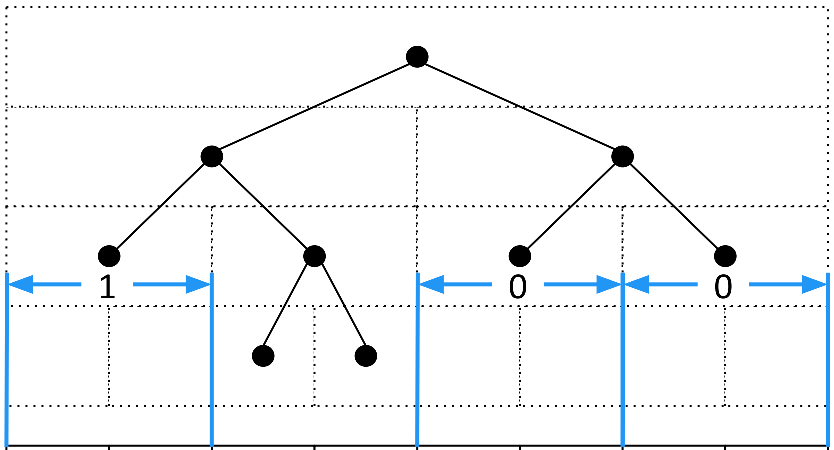


Tree-Based Compression



Plain Bitmap:

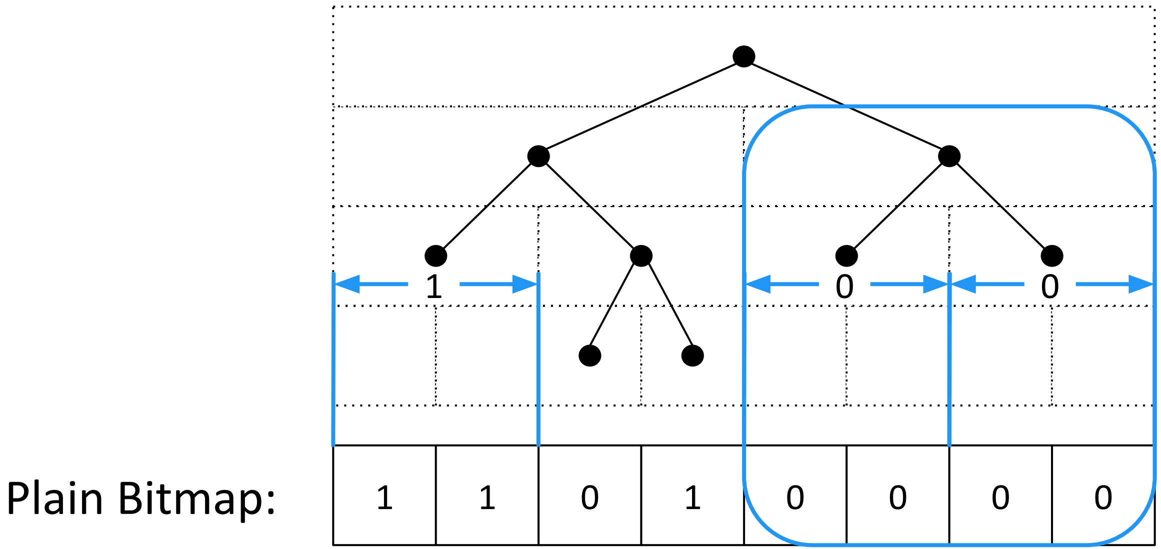
Tree-Based Compression



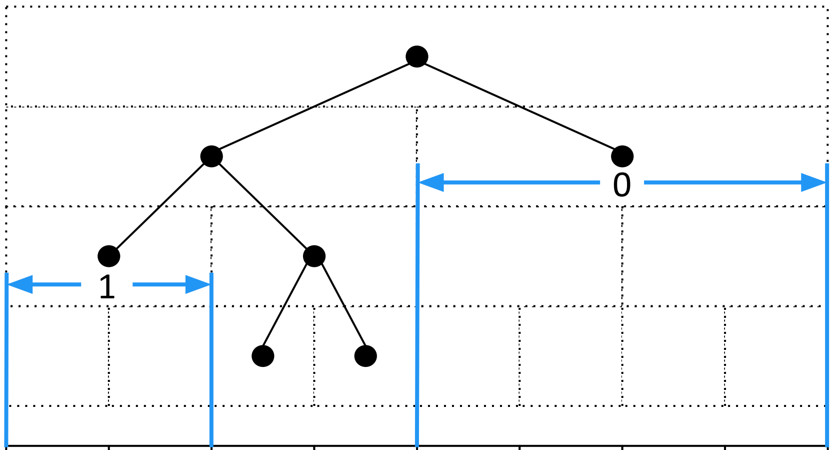
Plain Bitmap:

1	1	0	1	0	0	0	0

Tree-Based Compression



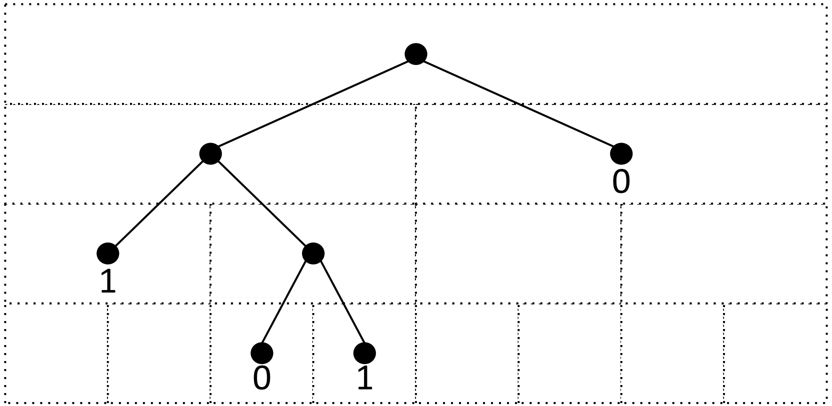
Tree-Based Compression



Plain Bitmap:

1	1	0	1	0	0	0	0

Tree Encoding

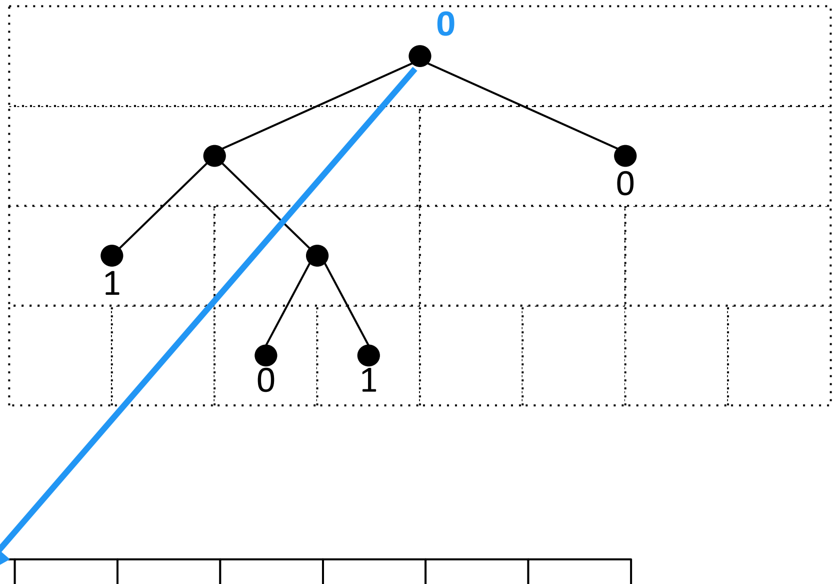


Level-order binary marked representation (G. Jacobson, 1989):

Tree Structure:

Labels:

Tree Encoding



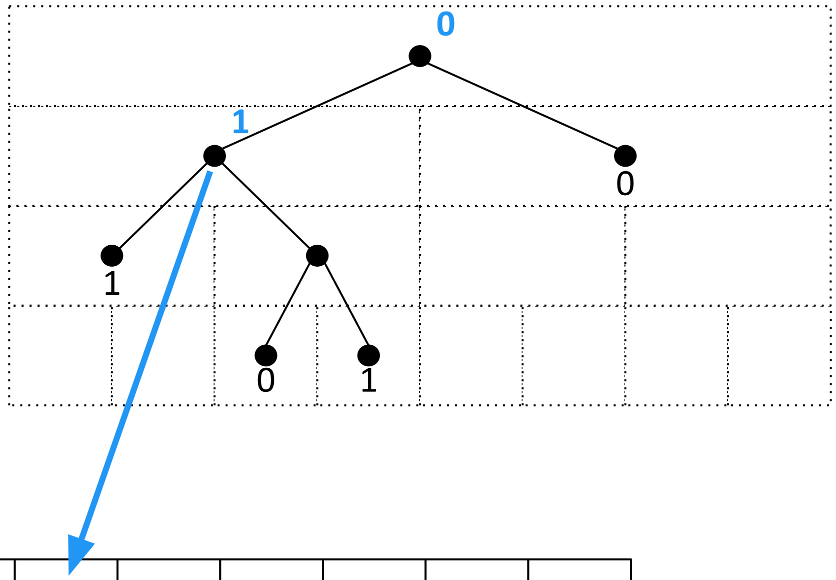
Tree Structure:

1						

0

Labels:

Tree Encoding

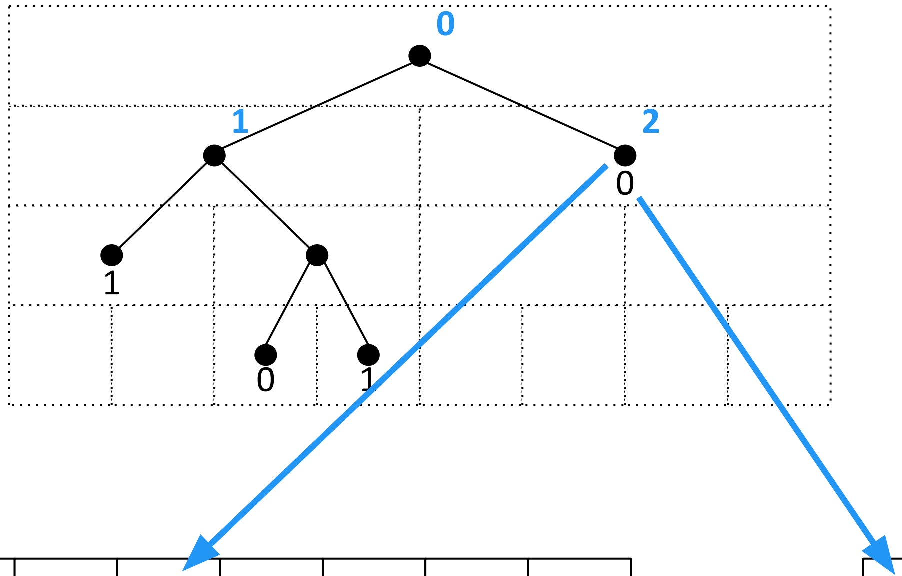


Tree Structure:

1	1					
0	1					

Labels:

Tree Encoding



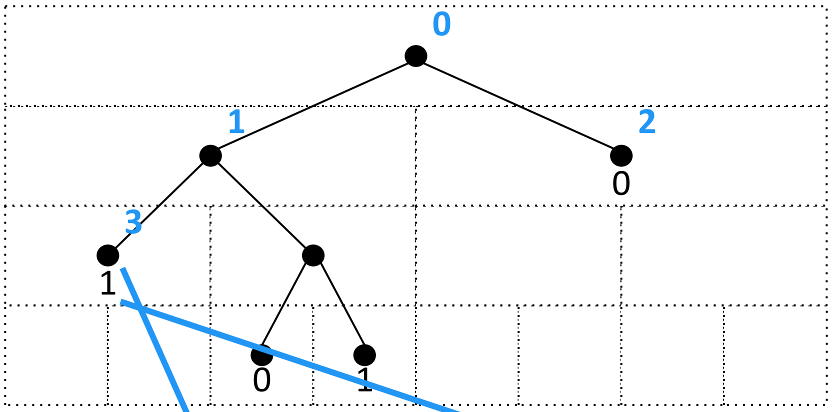
Tree Structure:

1	1	0				
0	1	2				

Labels:

0			
2			

Tree Encoding



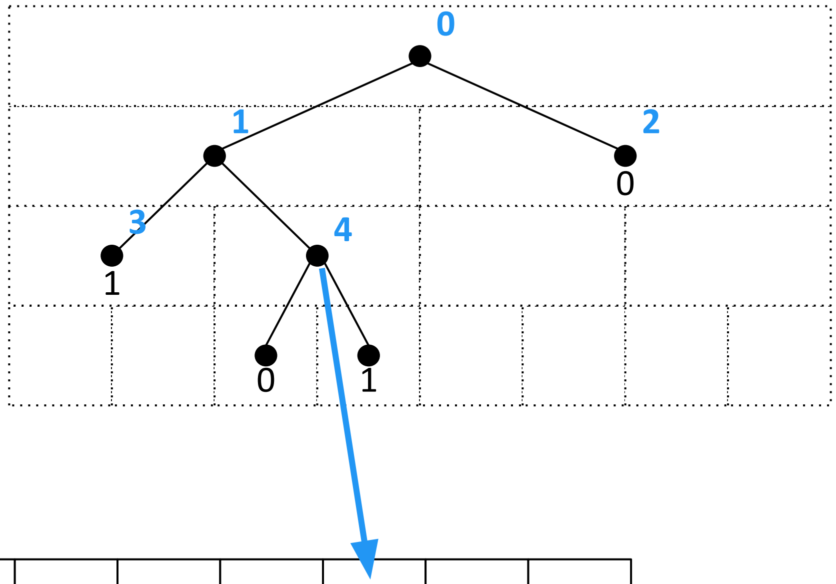
Tree Structure:

1	1	0	0			
0	1	2	3			

Labels:

0	1		
2	3		

Tree Encoding



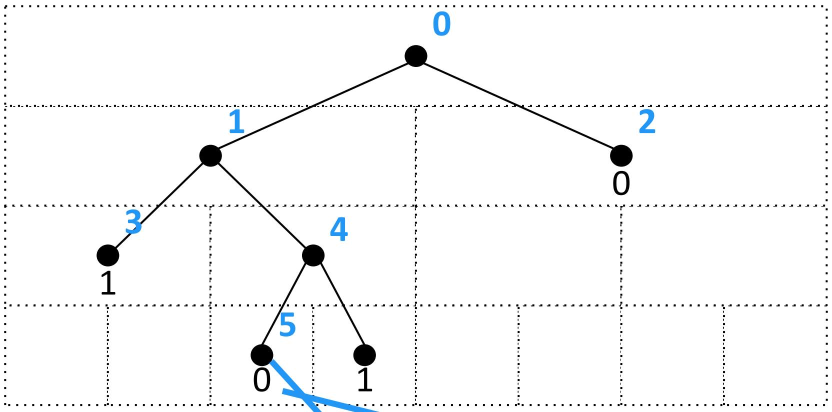
Tree Structure:

1	1	0	0	1		
0	1	2	3	4		

Labels:

0	1		
2	3		

Tree Encoding



Tree Structure:

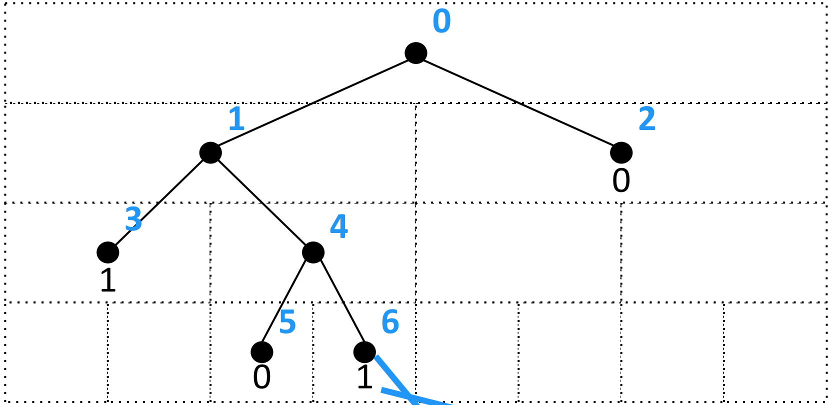
1	1	0	0	1	0	
0	1	2	3	4	5	

Labels:

0	1	0	
2	3	5	

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA | CWI Centrum Wiskunde & Informatica | TUM

Tree Encoding



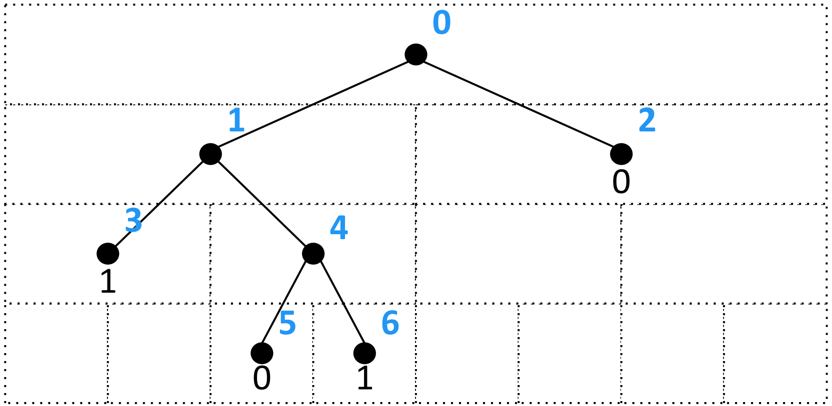
Tree Structure:

0	1	2	3	4	5	6
1	1	0	0	1	0	0

Labels:

2	3	5	6
0	1	0	1

Tree Encoding



Level-order binary marked representation (G. Jacobson, 1989):

Tree Structure:

0	1	2	3	4	5	6
1	1	0	0	1	0	0

Labels:

2	3	5	6
0	1	0	1

Tree-Encoding

- Beside the encoded tree structure and the labels, we maintain an additional data structure: a **rank lookup table**
- Additional space requirements: 0.0625 * size of the tree structure
- **Enables efficient navigation within the encoded tree**
  - Determining the left/right child of a tree node in O(1)

Space Optimizations

- So far: space requirements of a TEB could be ~3x of the original plain bitmap
- Thus, additional optimizations are required
- Worst case **w/ optimizations enabled**: plain bitmap size + small header

Experimental Results

- Space consumption:
  - TEB has the lowest space consumption in 7 (out of 8) real-world data sets
    - Up to **34% space savings** compared to Roaring
    - Up to **63% space savings** compared to WAH
- Performance (bitwise-AND, in-memory setting, bitmap size 2^20):
  - Plain bitmap shows the best performance
  - Roaring takes ~1.8x the time of plain bitmap intersection.
  - **TEB takes ~1.6x the time of Roaring**
  - WAH up to an order of magnitude slower, depending on bitmap characteristics

What else can be found in the paper

- More detailed evaluation
- Implementation details for modern hardware
- and a **link to the source code**

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

CWI Centrum Wiskunde & Informatica

TUM

Thank you, for watching.