ADVANCED DATABASE SYSTEMS

Data Formats & Encoding II

03

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LAST CLASS

Storage Models (NSM, DSM, PAX)

Open-Source Data File Formats
→ File Meta-Data
→ Format Layout
→ Type System
→ Encoding Schemes
→ Block Compression
→ Zone Maps + Bloom Filters
→ Nested Data (Shredding vs. Presence)

NESTED DATA

Nếu lưu 1 json documents trong 1 row, chúng ta có thể dùng các hàm json để extract các value, nhưng sẽ mất hết đi những ưu điểm của Column store và PAX file và vectorized execution

Real-world data sets often contain semi-structured objects (e.g., JSON, Protobufs).

A file format will want to encode the contents of these objects as if they were regular columns.

Apache Dremio

Approach #1: Record Shredding

Approach #2: Length+Presence Encoding

DREMEL: A DECADE OF INTERACTIVE SQL ANALYSIS AT WEB SCALE
VLDB 2020

NESTED DATA: SHREDDING

Ducument.proto
khi dung `protoc`,
ne se tu gen ra class cho object do
tuy theo minh dung ngon ngu gi

Store paths in nested structure as separate columns with additional meta-data about paths.

Hỗ trợ các trường có thể NULL

optional || repeated

Definition Level: How many optional elements are defined in the path to an attribute.

Hỗ trợ các trường có thể repeated

Repetition Level: How many times a structure has been repeated.

Ví dụ: group "Name" , "Language" repeat bao nhiêu lần

This is protocol buffers - cross-platform data format , to serialize data from Google
https://github.com/protocolbuffers/protobuf

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

required: exactly one occurrence
optional: 0 or 1 occurrence
repeated: 0 or more occurrences

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
   Code: 'en-gb'
   Country: 'gb'
```

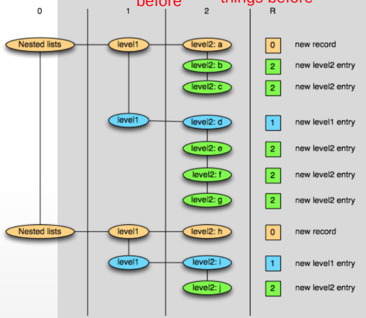
Shredded Columns

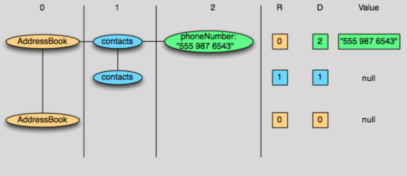
DocID Khi document trên được load vào database, nó sẽ:

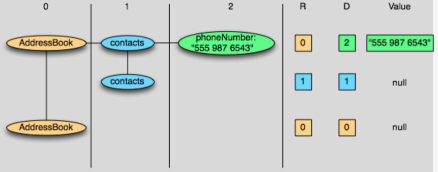
value	r	d
10	0	0

no repate before

no other things before







Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

Scan tiếp xuống

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Language.Code

value	r	d
en-us	0	$\boxed{2}$
	first group we saw in this level	level 2

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Language.Code

value	r	d
en-us	0	2

Name + Language là optional

Name.Language.Country

value	r	d
us	0	3

nhìn thấy lần đầu

Name + Language + Country

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

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Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Language.Code

value	r	d
en-us	0	2
en	1	2

structure Language repate lần nữa

Name.Language.Country

value	r	d
us	0	3

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
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  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Language.Code

value	r	d
en-us	0	2
en	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2

structure
này giống trên

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
   Code: 'en-gb'
   Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Url

value	r	d
http://A	0	2

Name.Language.Code

value	r	d
en-us	0	2
en	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2

NAME + Language

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2

Name + URL

Name.Language.Code

value	r	d
en-us	0	2
en	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2

Name.Language.Code

value	r	d	
en-us	0	2	
en	1	2	
NULL	1	1	Name

Name.Language.Country

value	r	d	
us	0	3	
NULL	1	2	
NULL	1	1	Name

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
   Code: 'en-gb'
   Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2

Name.Language.Code

value	r	d
en-us	0	2
en	1	2
NULL	1	1
en-gb	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2
NULL	1	1

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
   Code: 'en-gb'
   Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2

Name.Language.Code

value	r	d
en-us	0	2
en	1	2
NULL	1	1
en-gb	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2
NULL	1	1
gb	1	3

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
    Code: 'en-gb'
    Country: 'gb'
```

Shredded Columns

DocID

value	r	d
10	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2
NULL	1	1

Do có Name.Url table này trước đó nên scan tiếp sau khi Country: 'gb'

Name.Language.Code

value	r	d
en-us	0	2
en	1	2
NULL	1	1
en-gb	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2
NULL	1	1
gb	1	3

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 20
Name:
  Url: 'http://C'
```

Khi có doc mới

new record

Shredded Columns

DocID

value	r	d
10	0	0
20	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2
NULL	1	1

Name.Language.Code

value	r	d
en-us	0	2
en	1	2
NULL	1	1
en-gb	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2
NULL	1	1
gb	1	3

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 20
Name:
  Url: 'http://C'
```

Shredded Columns

DocID

value	r	d
10	0	0
20	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2
NULL	1	1
http://C	0	2

Name.Language.Code

value	r	d
en-us	0	2
en	1	2
NULL	1	1
en-gb	1	2

Name.Language.Country

value	r	d
us	0	3
NULL	1	2
NULL	1	1
gb	1	3

Source: Sergey Melnik

NESTED DATA: SHREDDING

Store paths in nested structure as separate columns with additional meta-data about paths.

Definition Level: How many optional elements are defined in the path to an attribute.

Repetition Level: How many times a structure has been repeated.

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 20
Name:
  Url: 'http://C'
```

Shredded Columns

Từ đây, khi select * from table where code = 'en-us'
Thì chỉ cần nhìn vào bảng đó, ra r và d và đọc trong document

DocID

value	r	d
10	0	0
20	0	0

Name.Url

value	r	d
http://A	0	2
http://B	1	2
NULL	1	1
http://C	0	2

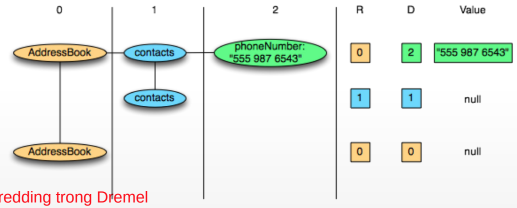
Bảng này sai
r: the number of time this group is repeated
Đọc ở bài Dremel

Name.Language.Code

value	r	d
en-us	0	2
en	1	2
NULL	1	1
en-gb	1	2
NULL	0	1

Name.Language.Country

value	r	d
us	0	3
NULL	1	2
NULL	1	1
gb	1	3
NULL	0	1



Hiểu thêm về Shredding trong Dremel
https://blog.twitter.com/engineering/en_us/a/2013/dremel-made-simple-with-parquet

Source: Sergey Melnik

NESTED DATA: LENGTH+PRESENCE

Store paths in nested structure as separate columns but maintain additional columns to track the number of entries at each path level (***length***) and whether a key exists at that level for a record (***presence***).

```
message Document {
  required int64 DocId;
  repeated group Name {
    repeated group Language {
      required string Code;
      optional string Country;
    }
    optional string Url;
  }
}
```

```
DocId: 10
Name:
  Language:
    Code: 'en-us'
    Country: 'us'
  Language:
    Code: 'en'
  Url: 'http://A'
Name:
  Url: 'http://B'
Name:
  Language:
   Code: 'en-gb'
   Country: 'gb'
```

```
DocId: 20
Name:
  Url: 'http://C'
```

DocId

value	p
10	true
20	true

Name

len
3
1

3 names trong DocID:10

Name.Url

value	p
http://A	true
http://B	true
	false
http://C	true

Name.Language

len
2
0
1
0

Name.Language.Code

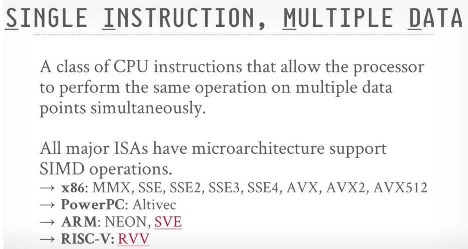
value	p
en-us	true
en	true
en-gb	true

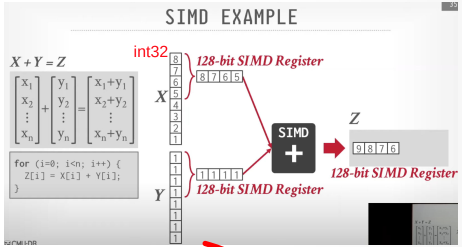
Name.Language.Country

value	p
us	true
	false
gb	true

đánh giá
k.ri tiss

CRITIQUES OF EXISTING FORMATS





int32

Variable-sized Runs

→ Not SIMD friendly.

Những thanh register này luôn cố định 128,256,512
-> data , ta luôn cần chọn size như nhau và put nó vào lane

Eager Decompression

→ No random access if using block compression. ví dụ: snappy, zlib

khi thực hiện tiếp với 4 gía trị sau

Dependencies Between Adjacent Values

→ Examples: Delta Encoding, RLE

sự phụ thuộc những giá trị liền kề trong column chunk:
- ko dùng được SIMD: ko có cách nào để pass data from 1 element to other element nếu nó ở cùng register

Vectorization Portability

→ ISAs (versions, vendor) have different SIMD capabilities.

Source: Azim Afroozeh

TODAY'S AGENDA

BtrBlocks (TUM)

FastLanes (CWI) FastLanes sẽ giải quyết các vấn đề ở trên

BitWeaving (Wisconsin)

BTRBLOCKS

PAX-based file format with more aggressive ***nested encoding schemes*** than Parquet / ORC.

Parquet chỉ dùng dict encode
for string

tham lam

Uses a greedy algorithm to select the best encoding for a column chunk (based on sample) and then recursively tries to encode outputs of that encoding.
→ No naïve block compression (Snappy, zstd)

Store a file's meta-data separately from the data.

Họ muốn để meta cho Manager sys quản lý
Nhưng nó sẽ trade off với tính di động

BTRBLOCKS: EFFICIENT COLUMNAR COMPRESSION FOR DATA LAKES
SIGMOD 2023

BTRBLOCKS: ENCODING SCHEMES

RLE / One Value

Frequency Encoding

Từ IBM, tìm most common value, store it, và có bitmap để biết bao nhiêu lần nó xuất hiện ở cột.
Những giá trị mà ít xuất hiện, thì store uncompressed

frame of reference

FOR + Bitpacking

~ Delta encoding

Dictionary Encoding

Pseudodecimals

convert floating point numbers into int

Fast Static Symbol Table (FSST)

duckdb
https: 1
www: 2
...

data: http://www...
lưu thành 1 2

Roaring Bitmaps for NULLs + Exceptions

ko delta endoing ở đây là nó ko phù hợp vs SIMD --> nhưng FastLane ở phần sau sẽ fix

BTRBLOCKS: ENCODING SELECTION

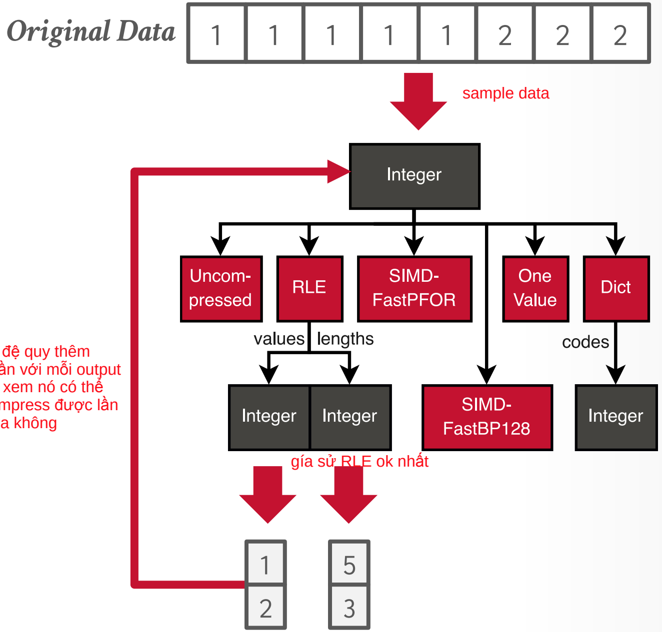
khi load data vào database
nó sẽ chọn encoding
- thử hết

Collect a sample from the data and then try out all viable encoding schemes. Repeat for three rounds.

Instead of sampling individual values, BtrBlocks selects multiple small runs from non-overlapping random positions.

→ For 64k values, it uses 10 runs of 64 values (1% sample size).

sẽ đệ quy thêm
3 lần với mỗi output
để xem nó có thể
compress được lần
nữa không



Source: Maximilian Kuschewski

BTRBLOCKS: ENCODING SELECTION

Collect a sample from the data and then try out all viable encoding schemes. Repeat for three rounds.

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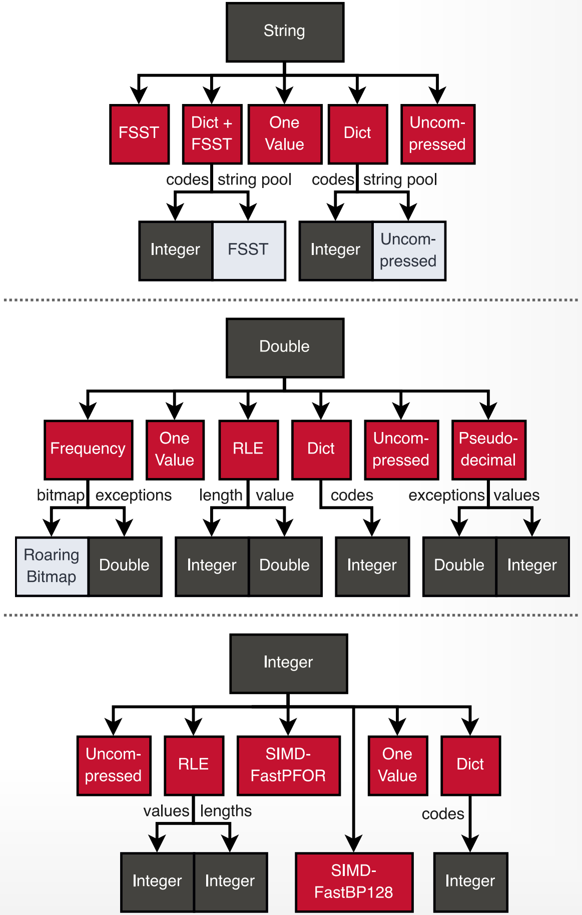


Source: Maximilian Kuschewski

BTRBLOCKS: ENCODING SCHEMES

RLE / One Value

Frequency Encoding

FOR + Bitpacking

Dictionary Encoding

Pseudodecimals

Fast Static Symbol Table (FSST)

Roaring Bitmaps for NULLs + Exceptions

FSST

String encoding scheme that supports random access without decompressing previous entries.

Replace frequently occurring substrings (up to 8 bytes) with 1-byte codes.

Uses a "perfect" hash table scheme for fast look-up of symbols without conditionals / loops.

→ Construct table using evolutionary algorithm that simply replaces entries if occupied.

FSST: FAST RANDOM ACCESS STRING COMPRESSION
VLDB 2020

ROARING BITMAPS

Bitmap index that switches which data structure to use for a range of values based local density of bits.
→ Dense chunks are stored using uncompressed bitmaps.
→ Sparse chunks use bitpacked arrays of 16-bit integers.

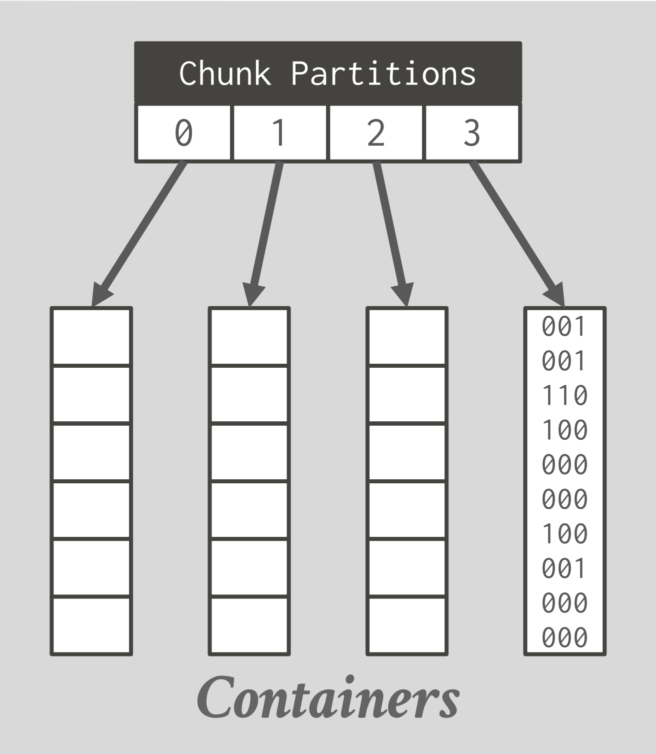
Dense chunks can be further compressed with RLE.

There are many open-source implementations that are widely used in different DBMSs.

ClickHouse influxdb Apache Spark Apache Lucene
SirixDB Weaviate Hive pilosa pinot

BETTER BITMAP PERFORMANCE WITH ROARING BITMAPS
SOFTWARE: PRACTICE AND EXPERIENCE 2015

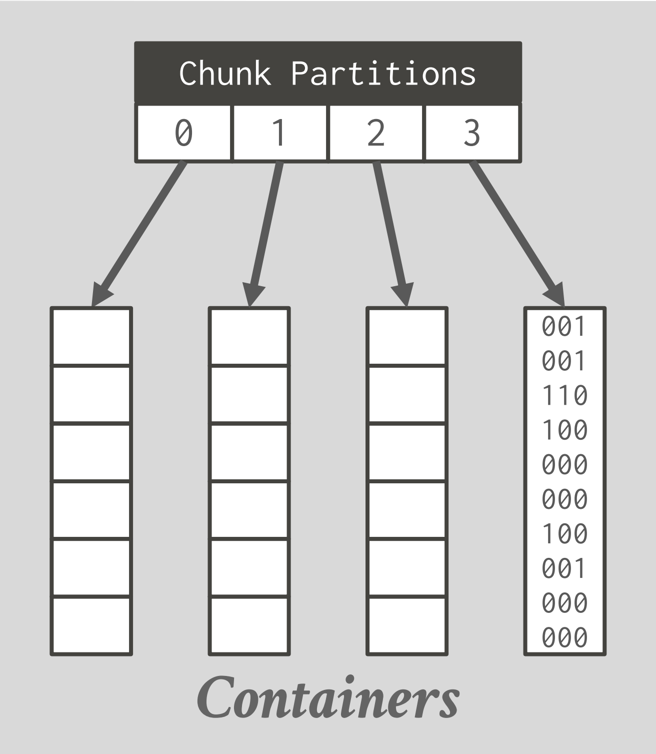
ROARING BITMAPS



For each value **k**, assign it to a chunk based on **$k/2^{16}$**.

→ Store **k** in the chunk's container.

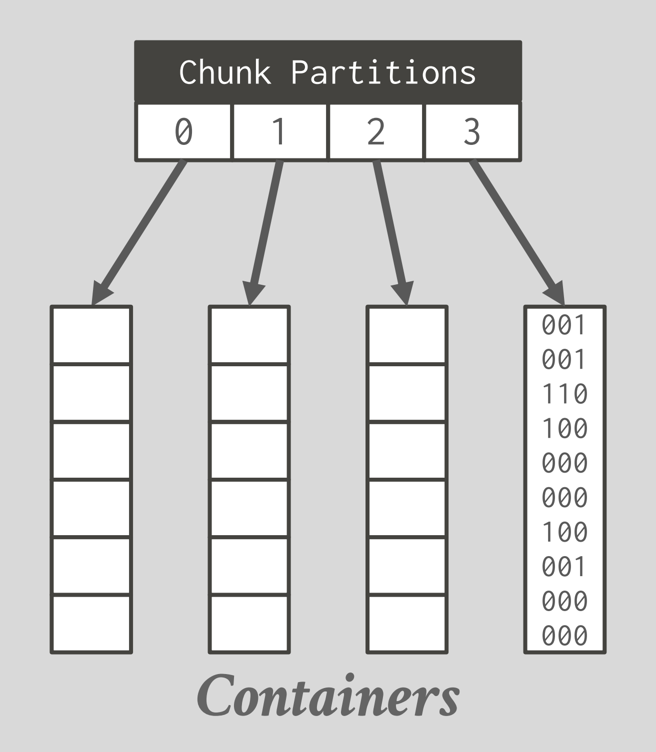
ROARING BITMAPS



For each value **k**, assign it to a chunk based on $\mathbf{k/2^{16}}$.

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

ROARING BITMAPS

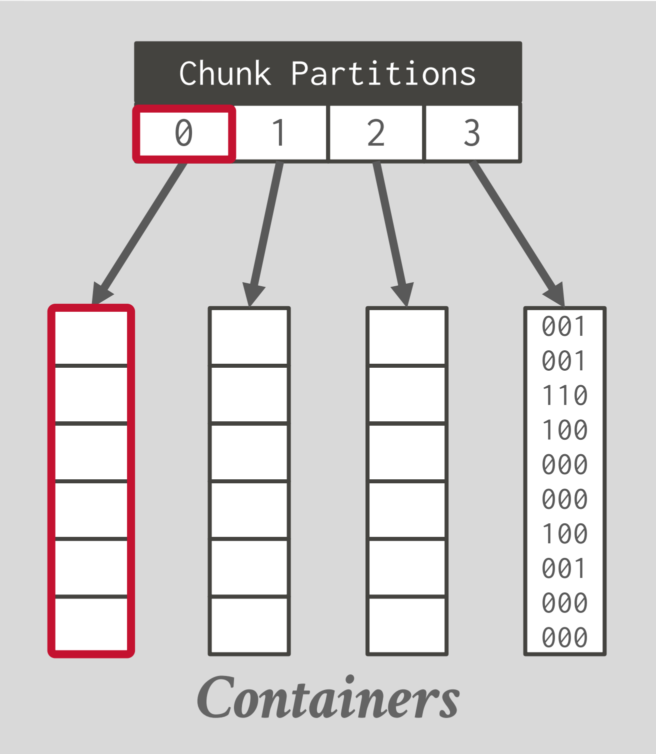


For each value **k**, assign it to a chunk based on **$k/2^{16}$**.

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

k=1000

ROARING BITMAPS



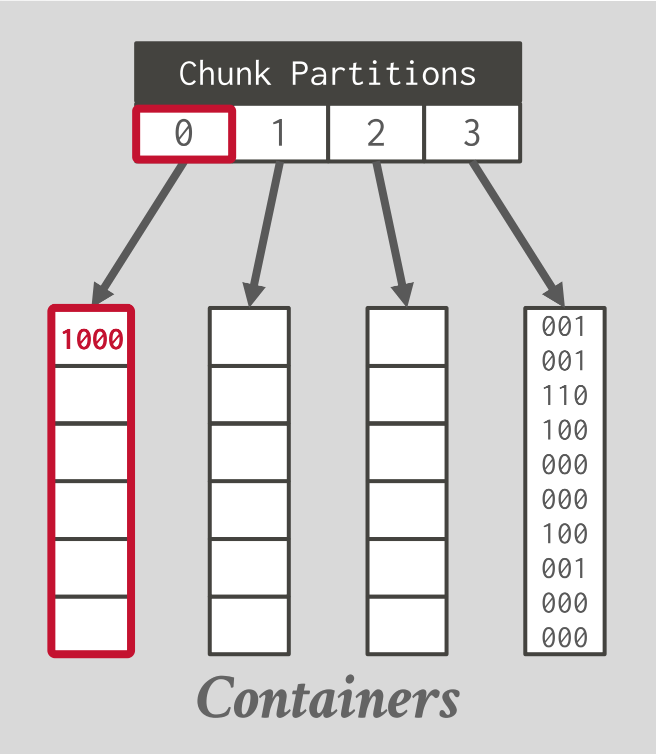
For each value **k**, assign it to a chunk based on **$k/2^{16}$**.

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

k=1000

$1000/2^{16}=0$

ROARING BITMAPS



For each value **k**, assign it to a chunk based on **$k/2^{16}$**.

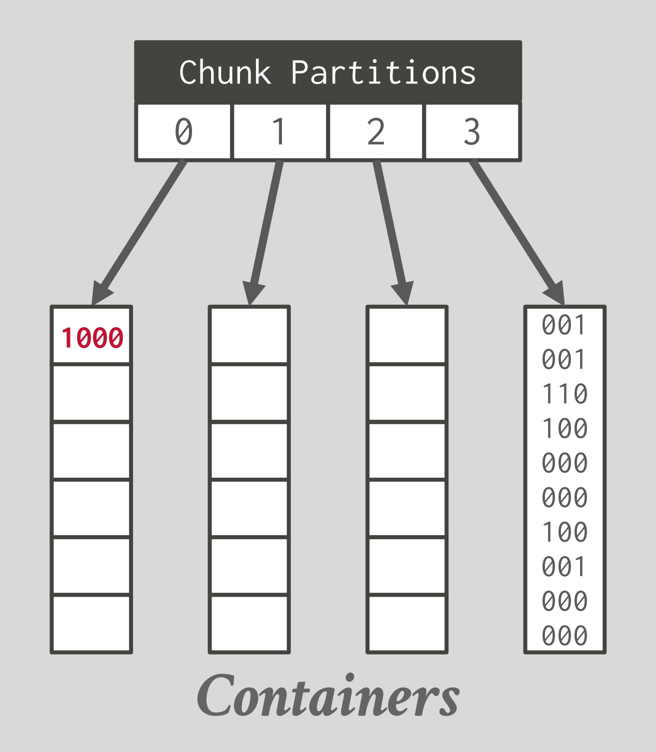
If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

$k=1000$

$1000/2^{16}=0$

$1000\%2^{16}=1000$

ROARING BITMAPS



For each value **k**, assign it to a chunk based on $\mathbf{k/2^{16}}$.

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

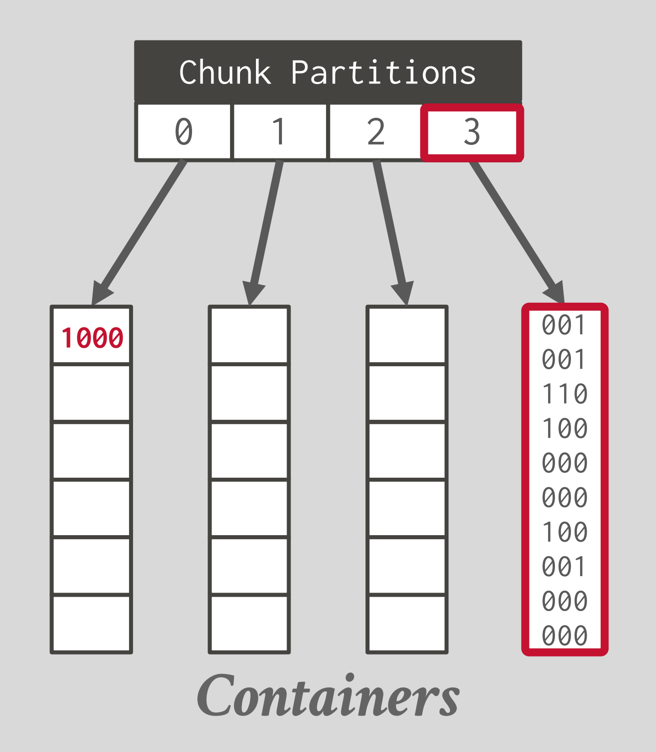
k=1000

k=199658

$\mathbf{1000/2^{16}=0}$

$\mathbf{1000\%2^{16}=1000}$

ROARING BITMAPS



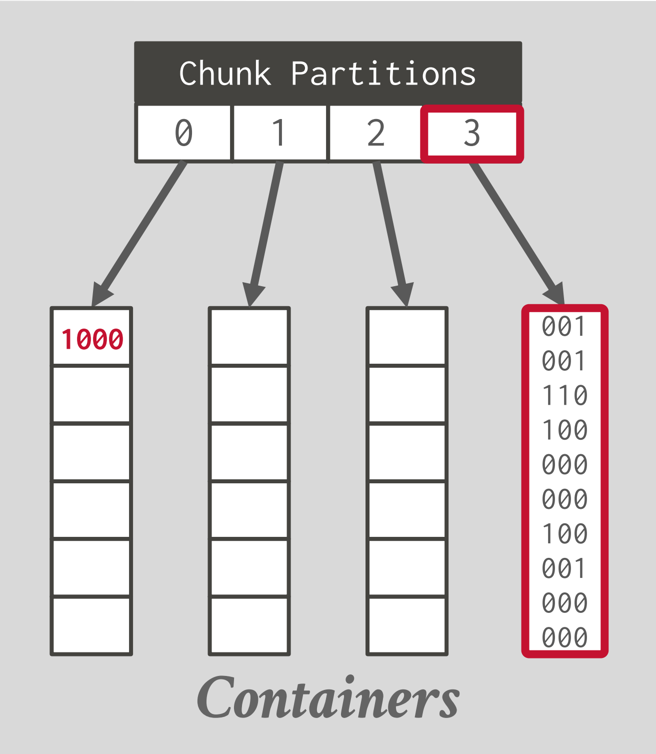
For each value **k**, assign it to a chunk based on $\mathbf{k/2^{16}}$.

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

k=1000
$\mathbf{1000/2^{16}=0}$
$\mathbf{1000\%2^{16}=1000}$

k=199658
$\mathbf{199658/2^{16}=3}$

ROARING BITMAPS



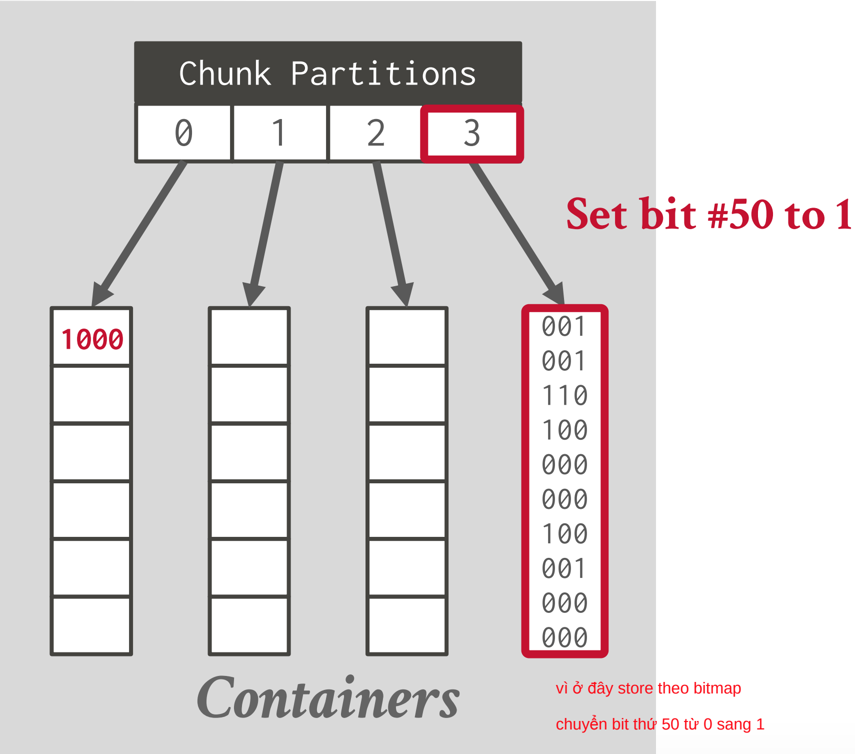
For each value **k**, assign it to a chunk based on **$k/2^{16}$**.

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

k=1000
$1000/2^{16}=0$
$1000\%2^{16}=1000$

k=199658
$199658/2^{16}=3$
$199658\%2^{16}=50$

ROARING BITMAPS



For each value **k**, assign it to a chunk based on **$k/2^{16}$**.

số dư

If # of values in container is less than 4096, store as array. Otherwise, store as Bitmap.

k=1000 lưu ở partition 0

$1000/2^{16}=0$

$1000\%2^{16}=1000$

1000 < 4096
lưu array

k=199658 lưu ở partition 3

$199658/2^{16}=3$

$199658\%2^{16}=50$

OBSERVATION

BtrBlocks + Parquet + ORC generate variable-length runs of values.

→ This wastes cycles during decoding for both scalar + vectorized operations.

Parquet + ORC use Delta encoding where each tuple's value depends on the preceding tuple's value.

→ This is impractical to process with SIMD because you cannot pass data between lanes in the same register.

VD: Nếu chỉ có 12 values, nó vẫn cho hết vào SIMD 16 values, 4 cái cuối coi là rác và sẽ clean sau

FASTLANES

Suite of encoding schemes that achieve better data parallelism thorough clever reordering of tuples to maximize useful work in SIMD operations.

Similar nested encoding as BtrBlocks:
→ Dictionary
→ FOR
→ Delta
→ RLE

To future proof format, they define a "virtual" ISA with 1024-bit SIMD registers.

M1

Will define all the Operations on virtual ISA - and show how can map that to exsting SIMD or other SIMD

For doing that, they use UNIFIED TRANSPOSED LAYOUT

THE FASTLANES COMPRESSION LAYOUT: DECODING > 100 BILLION INTEGERS PER SECOND WITH SCALAR CODE
VLDB 2023

UNIFIED TRANSPOSED LAYOUT

Reorder values in a column in a manner that improves the DBMS's ability to process them in an efficient, vectorized manner via SIMD.

Independent btw physical layer and logical layer
- relational model is based on unordered sets -> tự chọn ra cách store data tốt nhất để process data. Và để query engine bên trên tự tìm ra cách để đọc

→ Relational algebra is based on unordered sets, so users should not expect data to be ordered.

Algorithms defined in FastLanes' virtual 1024-bit SIMD ISA that can be emulated on AVX512 or scalar instructions.

mô phỏng

UNIFIED TRANSPOSED LAYOUT

Original Data

B	B	C	C	C	C	B	B	B	A	A	A	A	A	A	A
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Run-Length Encoding

B	C	B	A
3	2	1	0

Run Values

Run Lengths

2	4	3	7
3	2	1	0

Delta Encoding

Run Values

B	C	B	A
3	2	1	0

3	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Index Vector

1 khi giá trị thay đổi

0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

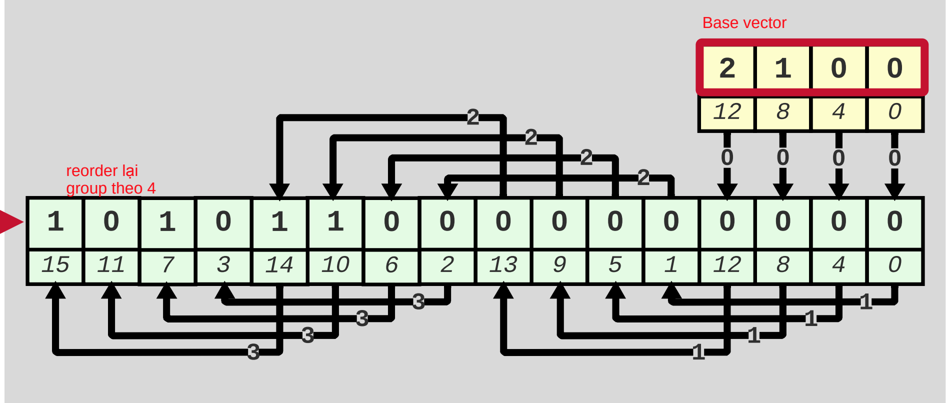
0

0
0

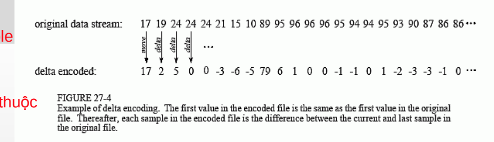
Delta Encoded Vector

delta (Δ) is used to denote the change in a variable

FastLanes RLE



Decoded Index Vector


original data stream: 17 19 24 24 24 21 15 10 89 95 96 96 96 95 94 94 95 93 90 87 86 86 ...

delta encoded: 17 2 5 0 0 -3 -6 -5 79 6 1 0 0 -1 -1 0 1 -2 -3 -3 -1 0 ...

FIGURE 27-4
Example of delta encoding. The first value in the encoded file is the same as the first value in the original file. Thereafter, each sample in the encoded file is the difference between the current and last sample in the original file.

phần nói về các giá trị phụ thuộc
ở slide 6 là do đây

Source: Azim Afroozeh

UNIFIED TRANSPOSED LAYOUT

Original Data

B	B	C	C	C	C	B	B	B	A	A	A	A	A	A	A
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

Run-Length Encoding

Run Values

B	C	B	A
3	*2*	*1*	*0*

Run Lengths

2	4	3	7
3	*2*	*1*	*0*

Delta Encoding

Run Values

B	C	B	A
3	*2*	*1*	*0*

3	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

Index Vector

0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

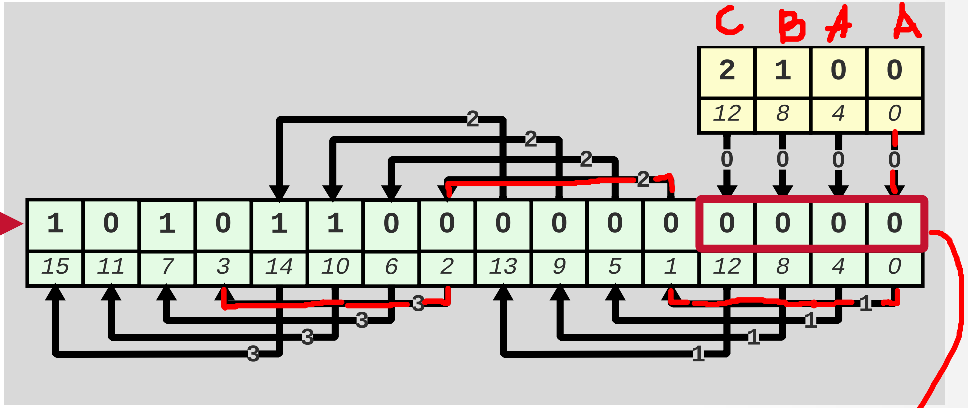
0
0

Delta Encoded Vector

FastLanes RLE

Note
1 SIMD ở đây 1 lane coi = 4 int
4x32=128 bit

khi muốn decode vector
như dưới



dùng phép cộng SIMD
2 0
1 0
0 +0
0 0
để ra output ở dưới, ghi 4 giá trị ở 4 locaion memory khác nhau
vì nó lq tới vị trí nó tồn tại ở original index

Decoded Index Vector

2	1	0	0
12	*8*	*4*	*0*

UNIFIED TRANSPOSED LAYOUT

Original Data

B	B	C	C	C	C	B	B	B	A	A	A	A	A	A	A
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

Run-Length Encoding

Run Values

B	C	B	A
3	*2*	*1*	*0*

Run Lengths

2	4	3	7
3	*2*	*1*	*0*

Delta Encoding

Run Values

B	C	B	A
3	*2*	*1*	*0*

3	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

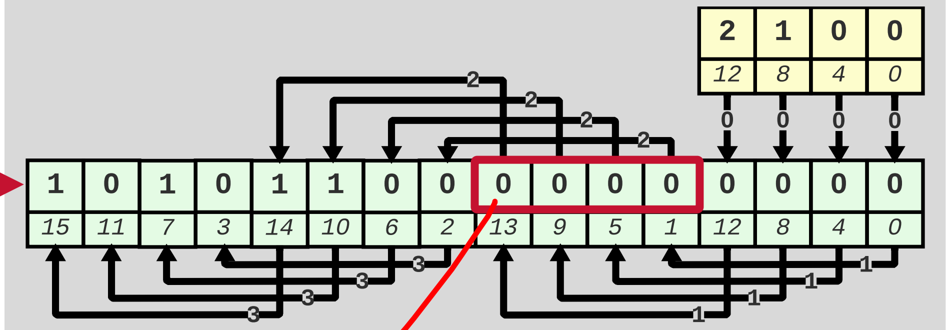
Index Vector

0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

0
0

Delta Encoded Vector

FastLanes RLE



Decoded Index Vector

2=2+0

2	2
13	*12*

1+0=1

1	1
9	*8*

0	0
5	*4*

0	0
1	*0*

UNIFIED TRANSPOSED LAYOUT

Original Data

B	B	C	C	C	C	B	B	B	A	A	A	A	A	A	A
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

Run-Length Encoding

Run Values

B	C	B	A
3	*2*	*1*	*0*

Run Lengths

2	4	3	7
3	*2*	*1*	*0*

Delta Encoding

Run Values

B	C	B	A
3	*2*	*1*	*0*

3	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

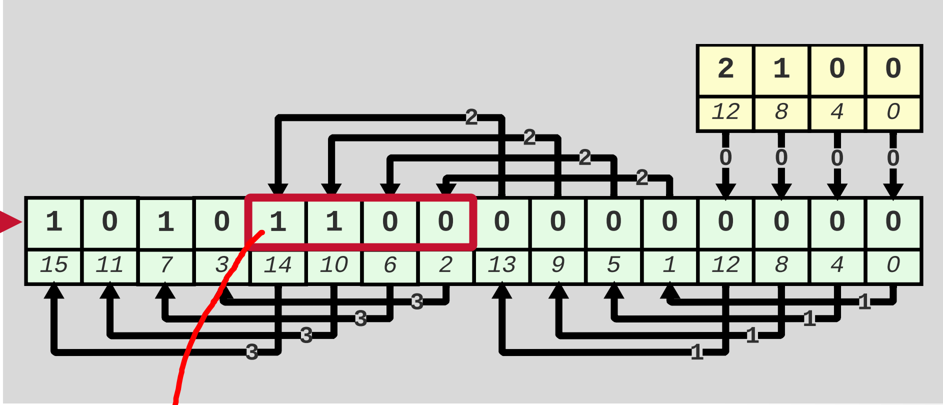
Index Vector

0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

0
0

Delta Encoded Vector

FastLanes RLE



Decoded Index Vector

3=2+1

3	2	2
14	*13*	*12*

2	1	1
10	*9*	*8*

0	0	0
6	*5*	*4*

0	0	0
2	*1*	*0*

Source: Azim Afroozeh

UNIFIED TRANSPOSED LAYOUT

Original Data

B	B	C	C	C	C	B	B	B	A	A	A	A	A	A	A
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Run-Length Encoding

Run Values

B	C	B	A
3	2	1	0

Run Lengths

2	4	3	7
3	2	1	0

Ta ko thể decode cái này
với SIMD hiệu quả
Vì ta cần thêm hàm Loop
Nhìn vào Run Lengths = 7
-> Loop 7

Delta Encoding

Run Values

B	C	B	A
3	2	1	0

3	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Index Vector

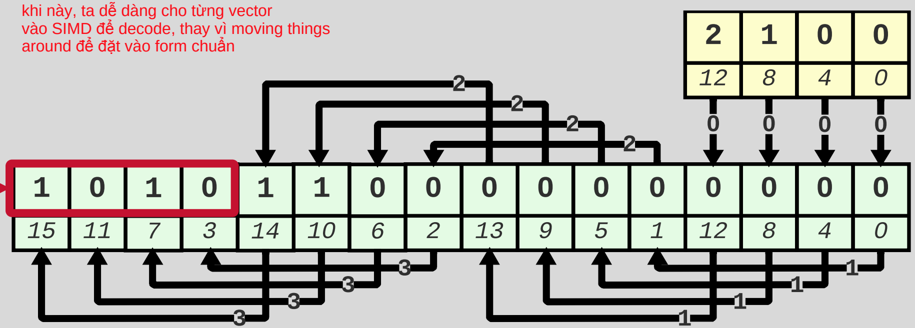
0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

0
0

Delta Encoded Vector

FastLanes RLE

khi này, ta dễ dàng cho từng vector
vào SIMD để decode, thay vì moving things
around để đặt vào form chuẩn



Decoded Index Vector

3	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Source: Azim Afroozeh

OBSERVATION

tất cả những scheme ta nói từ trước tới giờ: Parquet, ORC, BTRBlock, FastLane
It is all about scan a column, look at the entire value for each tuple, entirely every single time

The previous encoding schemes scan data by examining the entire value of each attribute (i.e., all the bits at the same time).

ngắt mạch

ko thể ngắt khi nhận ra câu WHERE ko match

→ The DBMS cannot "short-circuit" comparisons integer types because CPU instructions operate on entire words.

OBSERVATION

The previous encoding schemes scan data by examining the entire value of each attribute (i.e., all the bits at the same time).

→ The DBMS cannot "short-circuit" comparisons integer types because CPU instructions operate on entire words.

What if a DBMS could scan a **subset** of each value's bits and then only check the rest bits if needed?

BIT-SLICED ENCODING

Original Data

id	zipcode
1	21042
2	15217
3	02903
4	90220
6	14623
7	53703

Bit-Slices

null	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0																	

Thay vì store the actual int trên các bit liên tục

bin(21042)→ 00101001000110010

32 bit int
nhưng slide ngắn

ví dụ là 16 bit

BIT-SLICED ENCODING

Original Data

id	zipcode
1	21042
2	15217
3	02903
4	90220
6	14623
7	53703

Bit-Slices

null	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	1	0	1	0	0	1	0	0	0	1	1	0	0	1	0

bin(21042)→ 00101001000110010

Source: Jignesh Patel

BIT-SLICED ENCODING

Original Data

id	zipcode
1	21042
2	15217
3	02903
4	90220
6	14623
7	53703

Bit-Slices

null	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	1	0	1	0	0	1	0	0	0	1	1	0	0	1	0
0	0	0	0	1	1	1	0	1	1	0	1	1	1	0	0	0	1
0	0	0	0	0	0	1	0	1	1	0	1	0	1	0	1	1	1
0	1	0	1	1	0	0	0	0	0	0	1	1	0	1	1	0	0
0	0	0	0	1	1	1	0	0	1	0	0	0	1	1	1	1	1
0	0	1	1	0	1	0	0	0	1	1	1	0	0	0	1	1	1

Source: Jignesh Patel

BIT-SLICED ENCODING

Original Data

id	zipcode
1	21042
2	15217
3	02903
4	90220
6	14623
7	53703

Bit-Slices

null	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	1	0	1	0	0	1	0	0	0	1	1	0	0	1	0
0	0	0	0	1	1	1	0	1	1	0	1	1	1	0	0	0	1
0	0	0	0	0	0	1	0	1	1	0	1	0	1	0	1	1	1
0	1	0	1	1	0	0	0	0	0	0	1	1	0	1	1	0	0
0	0	0	0	1	1	1	0	0	1	0	0	0	1	1	1	1	1
0	0	1	1	0	1	0	0	0	1	1	1	0	0	0	1	1	1

```
SELECT * FROM customer_dim
 WHERE zipcode < 15217
```

Walk each slice and construct a result bitmap.

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

3 cái sau là 111 , chỉ cần nhìn vào từng khoảng giá trị 0 liền kề để tìm ra zipcode < 15217

BIT-SLICED ENCODING

Original Data

id	zipcode
1	21042
2	15217
3	02903
4	90220
6	14623
7	53703

Bit-Slices

	null	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
skip	0	0	0	1	0	1	0	0	1	0	0	0	1	1	0	0	1	0
	0	0	0	0	1	1	1	0	1	1	0	1	1	1	0	0	0	1
	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0	1	1	1
skip	0	1	0	1	1	0	0	0	0	0	0	1	1	0	1	1	0	0
	0	0	0	0	1	1	1	0	0	1	0	0	0	1	1	1	1	1
skip	0	0	1	1	0	1	0	0	0	1	1	1	0	0	0	1	1	1

```
SELECT * FROM customer_dim
 WHERE zipcode < 15217
```

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

Walk each slice and construct a result bitmap.

Skip entries that have **1** in first 3 slices (16, 15, 14)

Source: Jignesh Patel

BIT-SLICED ENCODING

Bit-slices can also be used for efficient aggregate computations.

Example: **SUM(attr)** using Hamming Weight

→ First, count the number of **1**s in **slice**$_{17}$ and multiply the count by 2^{17}

→ Then, count the number of **1**s in **slice**$_{16}$ and multiply the count by 2^{16}

→ Repeat for the rest of slices…

Use the **POPCNT** instruction to efficiently count the number of bits set to **1** in a register.

BITWEAVING

Alternative encoding scheme for columnar databases that supports efficient predicate evaluation on compressed data using SIMD.

→ Order-preserving dictionary encoding.
→ Bit-level parallelization.
→ Only require common instructions (no scatter/gather)

Implemented in Wisconsin's QuickStep engine.

→ Became an Apache Incubator project in 2016 but then died in 2018.

BITWEAVING: FAST SCANS FOR MAIN MEMORY DATA PROCESSING
SIGMOD 2013

BITWEAVING STORAGE LAYOUTS

Approach #1: Horizontal

→ Row-oriented storage at the bit-level

Approach #2: Vertical

→ Column-oriented storage at the bit-level.

→ Similar to Bit-Slicing but with SIMD support.

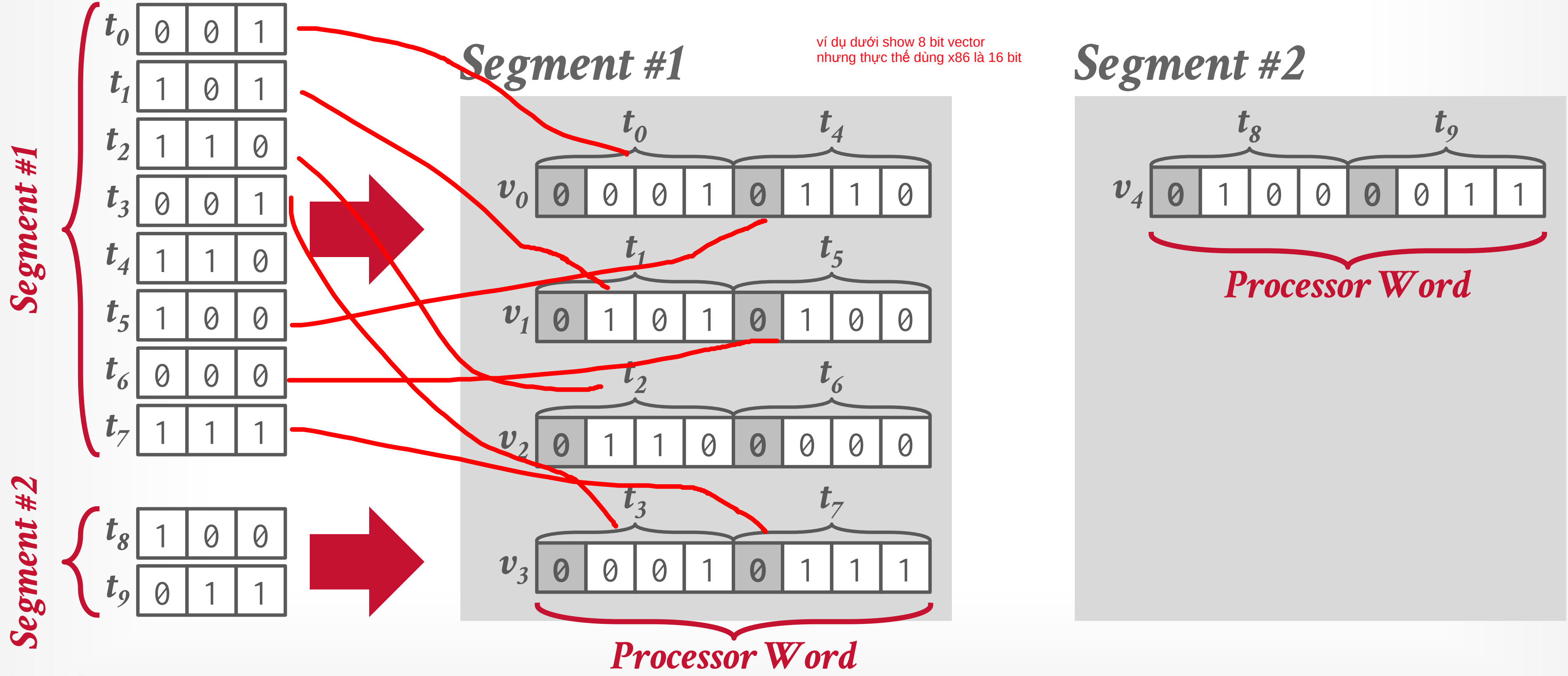
HORIZONTAL STORAGE

2 tuple we want to store
ở dạng bit value

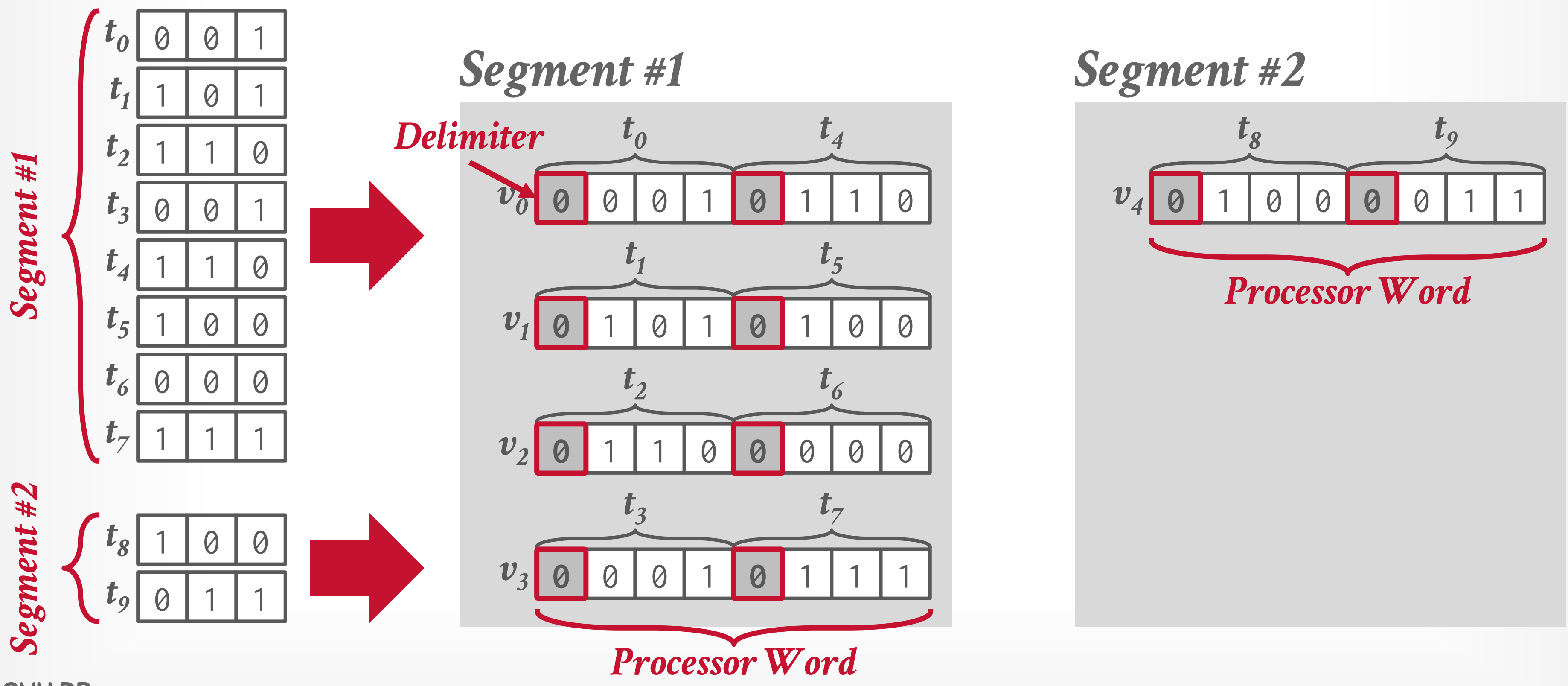
Segment
có thể think
nó như
RowGroup in
data file

Segment	Tuple				Value
Segment #1	t_0	0	0	1	=1
Segment #1	t_1	1	0	1	=5
Segment #1	t_2	1	1	0	=6
Segment #1	t_3	0	0	1	=1
Segment #1	t_4	1	1	0	=6
Segment #1	t_5	1	0	0	=4
Segment #1	t_6	0	0	0	=0
Segment #1	t_7	1	1	1	=7
Segment #2	t_8	1	0	0	=4
Segment #2	t_9	0	1	1	=3

HORIZONTAL STORAGE



HORIZONTAL STORAGE



BITWEAVING/H: EXAMPLE

```
SELECT * FROM table
 WHERE val < 5
```

1 0 1

1 6

$$X = \underbrace{0\,0\,0\,1}_{t_0}\;\underbrace{0\,1\,1\,0}_{t_4}$$

$$Y = \underbrace{0\,1\,0\,1}_{5}\;\underbrace{0\,1\,0\,1}_{5}$$

định nghĩa dấu "<"

$$mask = 0\,1\,1\,1\;0\,1\,1\,1$$

1: true (1 <5)

$$(Y+(X\oplus mask))\land\neg mask = \underbrace{1\,0\,0\,0\;0\,0\,0\,0}_{\textit{Selection Vector}}$$

Source: Jignesh Patel

BITWEAVING/H: EXAMPLE

```
SELECT * FROM table
 WHERE val < 5
```

1	0	1

$$X = \underbrace{\overbrace{0\,0\,0\,1}^{t_0}}_{5}\ \underbrace{\overbrace{0\,1\,1\,0}^{t_4}}_{5}$$

$$Y = \overbrace{0\,1\,0\,1}\ \overbrace{0\,1\,0\,1}$$

$$mask = 0\,1\,1\,1\ 0\,1\,1\,1$$

$$(Y+(X \oplus mask)) \wedge \neg mask = \underbrace{\boxed{1}}_{1<5}\,0\,0\,0\ \underbrace{\boxed{0}}_{5<6}\,0\,0\,0$$

BITWEAVING/H: EXAMPLE

```
SELECT * FROM table
 WHERE val < 5
```

1	0	1

	t_0				t_4			
$X =$	0	0	0	1	0	1	1	0
	5				5			
$Y =$	0	1	0	1	0	1	0	1
$mask =$	0	1	1	1	0	1	1	1
$(Y+(X \oplus mask)) \wedge \neg mask =$	$\boxed{1}$	0	0	0	$\boxed{0}$	0	0	0
	$1 < 5$				$5 < 6$			

Only requires three instructions to evaluate a single word.

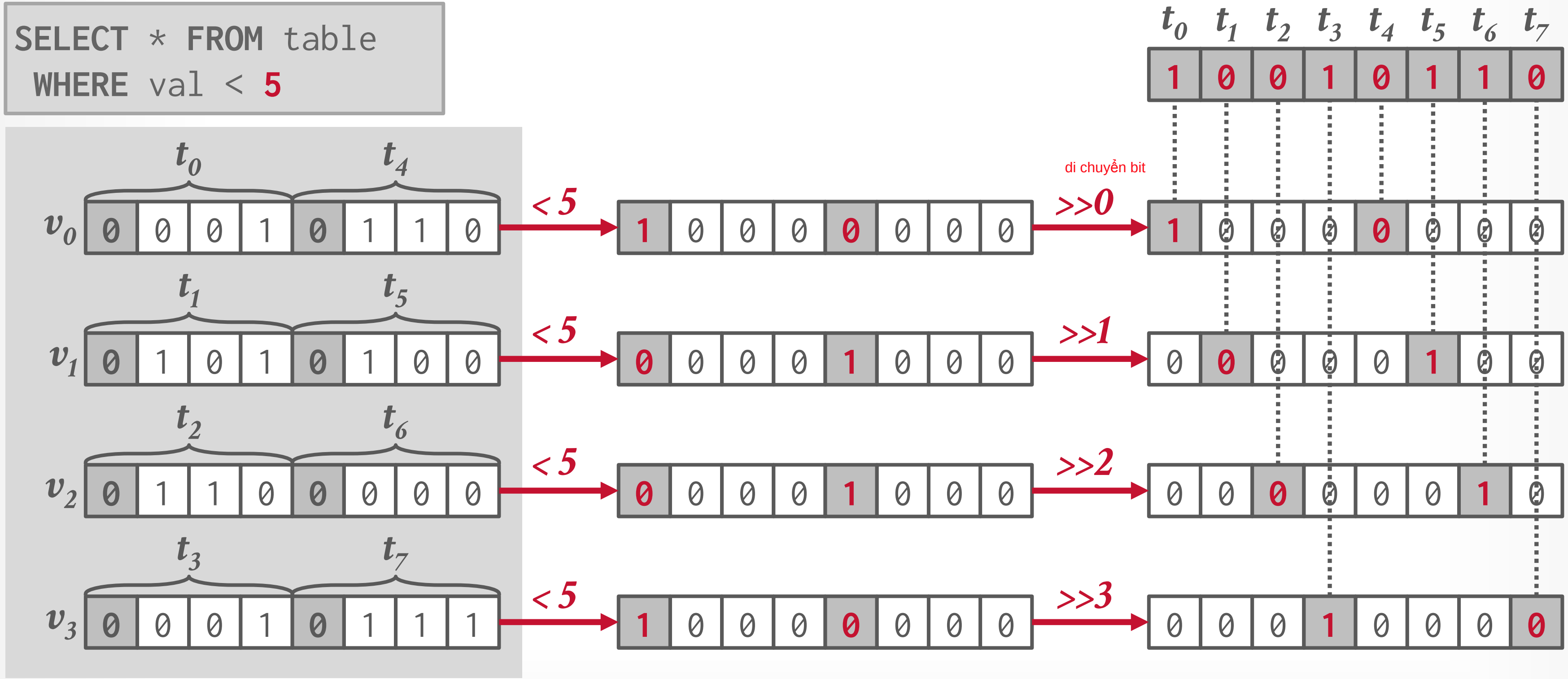
Works on any word size and encoding length.

Paper contains algorithms for other operators.

Source: Jignesh Patel

BITWEAVING/H: EXAMPLE

```
SELECT * FROM table
 WHERE val < 5
```



Source: Jignesh Patel

SELECTION VECTOR

SIMD comparison operators produce a bit mask that specifies which tuples satisfy a predicate.

→ DBMS must convert it into column offsets.

Approach #1: Iteration

Approach #2: Pre-computed Positions Table

thoả mãn val < 5 ở ví dụ trước

Selection Vector

t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7
1	0	0	1	0	1	1	0

```
tuples = [ ]
for (i=0; i<n; i++) {
  if sv[i] == 1
    tuples.add(i);
}
```

ko tốt, vì nó là for loop

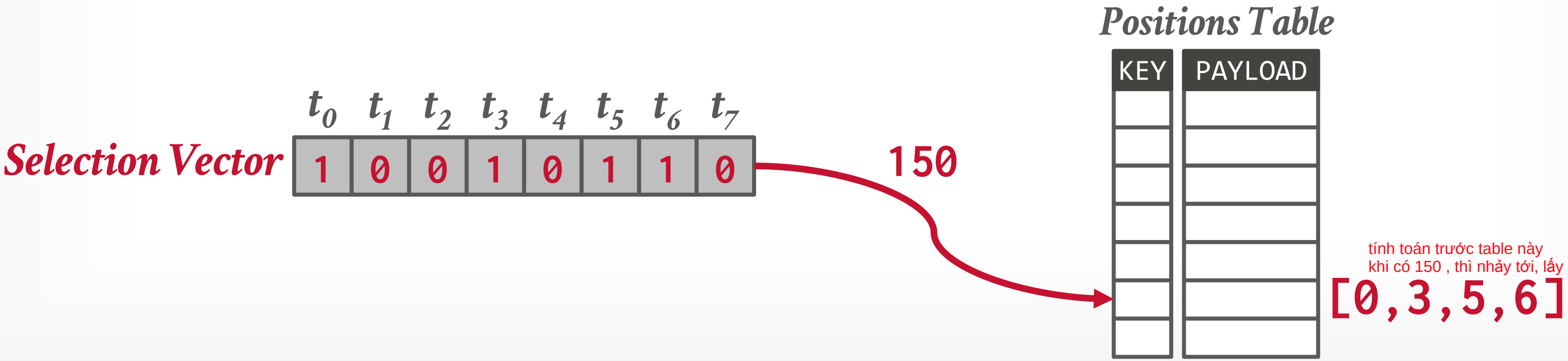
SELECTION VECTOR

SIMD comparison operators produce a bit mask that specifies which tuples satisfy a predicate.

→ DBMS must convert it into column offsets.

Approach #1: Iteration

Approach #2: Pre-computed Positions Table



tính toán trước table này
khi có 150 , thì nhảy tới, lấy ra giá trị dưới

VERTICAL STORAGE

Segment #1	t_0	0	0	1
	t_1	1	0	1
	t_2	1	1	0
	t_3	0	0	1
	t_4	1	1	0
	t_5	1	0	0
	t_6	0	0	0
	t_7	1	1	1
Segment #2	t_8	1	0	0
	t_9	0	1	1

VERTICAL STORAGE

Segment #1

t_0	0	0	1
t_1	1	0	1
t_2	1	1	0
t_3	0	0	1
t_4	1	1	0
t_5	1	0	0
t_6	0	0	0
t_7	1	1	1

Segment #2

t_8	1	0	0
t_9	0	1	1

Segment #1

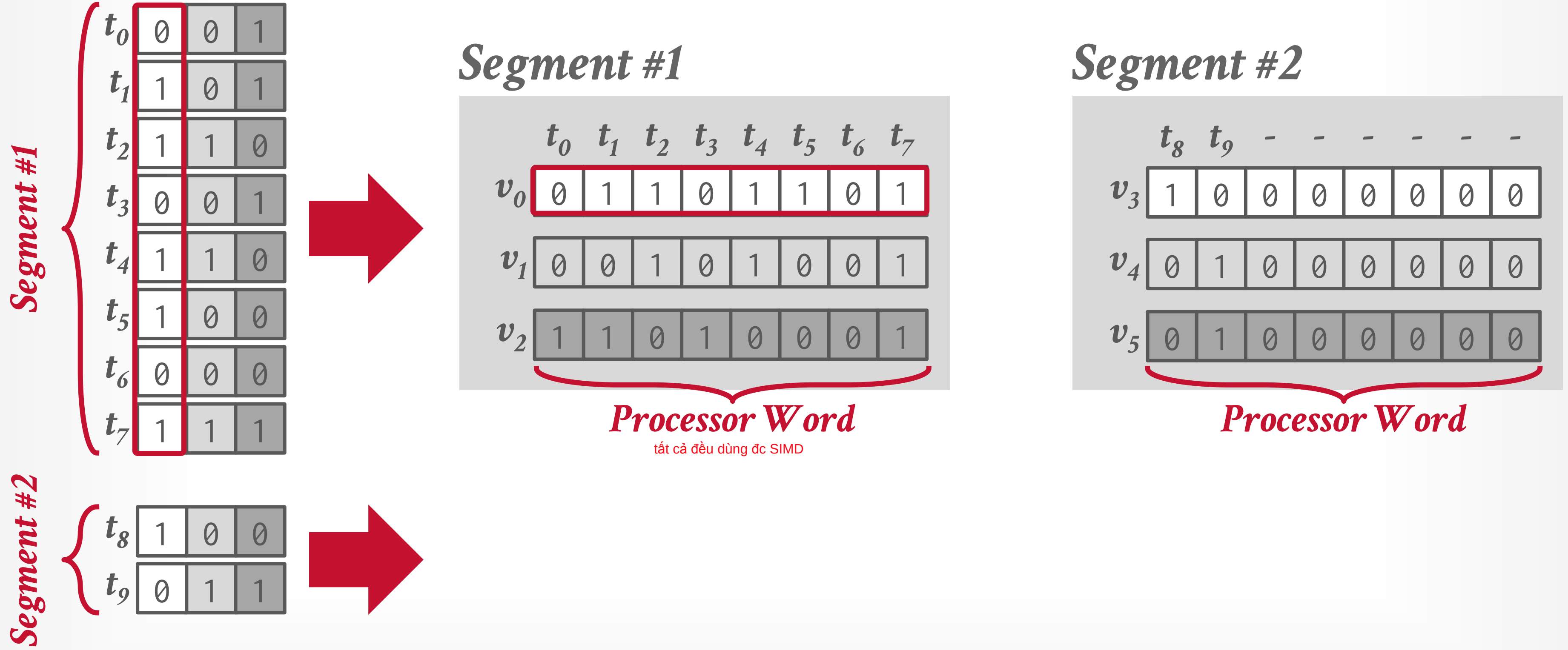
	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7
v_0	0	1	1	0	1	1	0	1
v_1	0	0	1	0	1	0	0	1
v_2	1	1	0	1	0	0	0	1

Segment #2

waste space
nhưng dễ dàng hơn khi tính toán
với cách tiếp cận này

	t_8	t_9	-	-	-	-	-	-
v_3	1	0	0	0	0	0	0	0
v_4	0	1	0	0	0	0	0	0
v_5	0	1	0	0	0	0	0	0

VERTICAL STORAGE



tất cả đều dùng đc SIMD

BITWEAVING/V: EXAMPLE

```
SELECT * FROM table
 WHERE val = 2
```

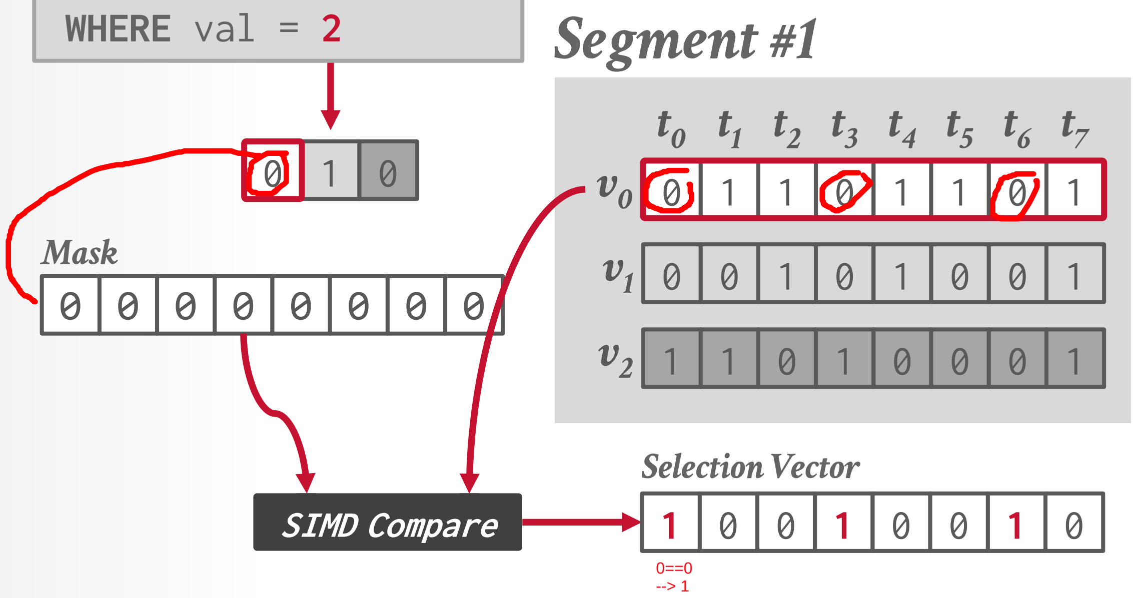
0	1	0

Segment #1

	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7
v_0	0	1	1	0	1	1	0	1
v_1	0	0	1	0	1	0	0	1
v_2	1	1	0	1	0	0	0	1

BITWEAVING/V: EXAMPLE

```
SELECT * FROM table
 WHERE val = 2
```



BITWEAVING/V: EXAMPLE

```
SELECT * FROM table
 WHERE val = 2
```

0	1	0

Segment #1

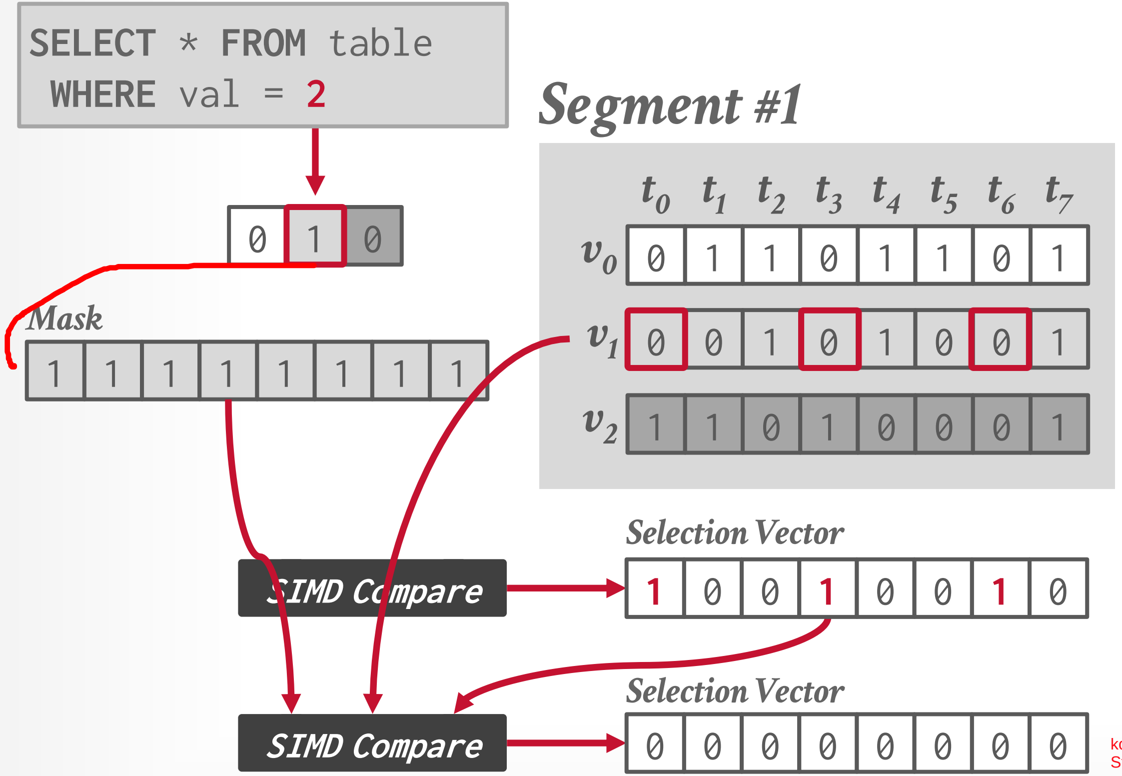
	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7
v_0	0	1	1	0	1	1	0	1
v_1	0	0	1	0	1	0	0	1
v_2	1	1	0	1	0	0	0	1

SIMD Compare

Selection Vector

1	0	0	1	0	0	1	0

BITWEAVING/V: EXAMPLE



ko có cái nào match
Stop

3 vector được cho vô đây

DBMS can perform early pruning like Bit-Slicing.

S

kip the last vector because all bits in previous comparison are zero.

PARTING THOUGHTS

Kết lại
- Tách biệt logical và physical là rất quan trọng

The last two lectures show why ***logical-physical data independence*** is one of the best parts of the relational model.

- → There are many strategies for representing data with unique compute-vs-storage trade-offs.
- → Applications can remain (mostly) oblivious to the low-details.

ứng dụng có thể (hầu hết) không biết đến các chi tiết thấp

Data parallelism via SIMD is going be an important tool for us the entire semester.

NEXT CLASS

Project Proposals (5 minutes)

→ The two groups for each project topic will present one after the other.
→ The liaisons for each project topic should also present the proposed API separately.

Email me PDF of your slides + proposal documents before class.