SplitSFC: A database solution for massive point cloud data management

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- Introduction: Point Cloud
- Background: Space Filling Curve
- Methodology
- Results
- Conclusion

01

Point Cloud

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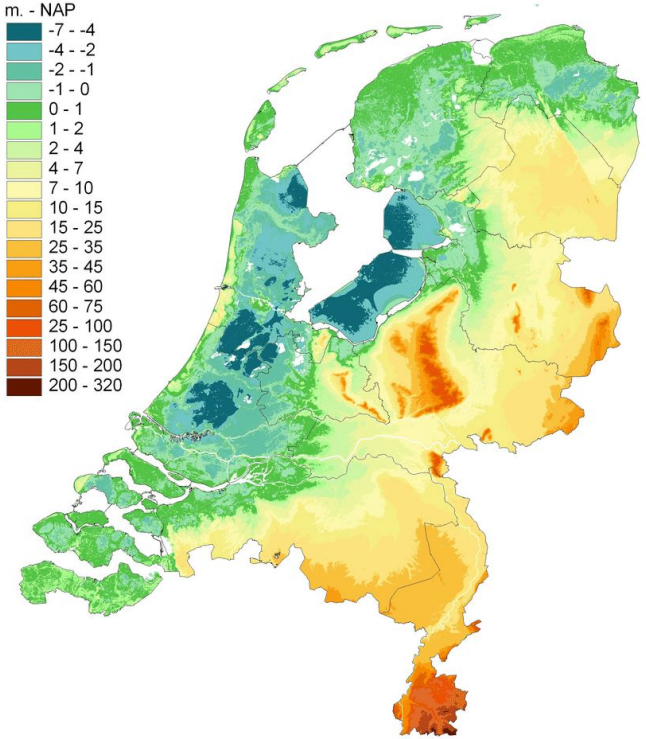
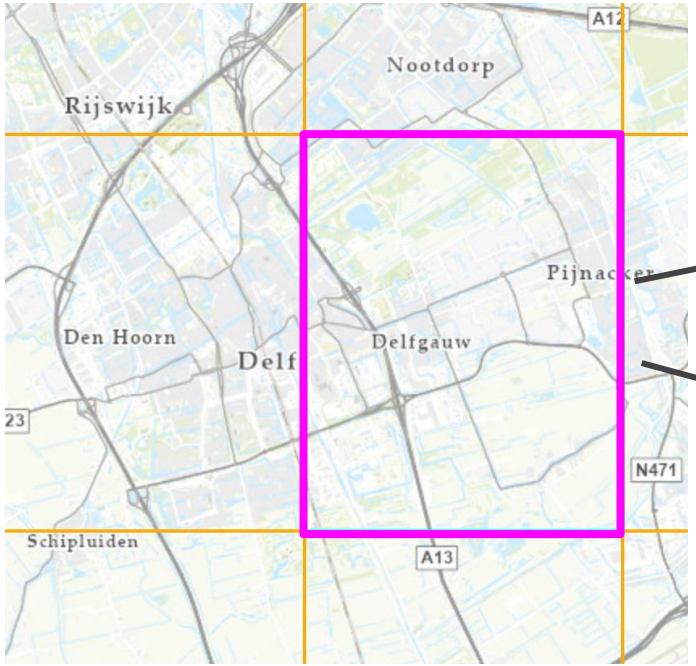
Example: Digital Surface Model



Elevation of the Netherlands

Downloading AHN3 from PDOK

Example: Digital Surface Model



0.5m Raster

Point Cloud

AHN3, Tile 37en2

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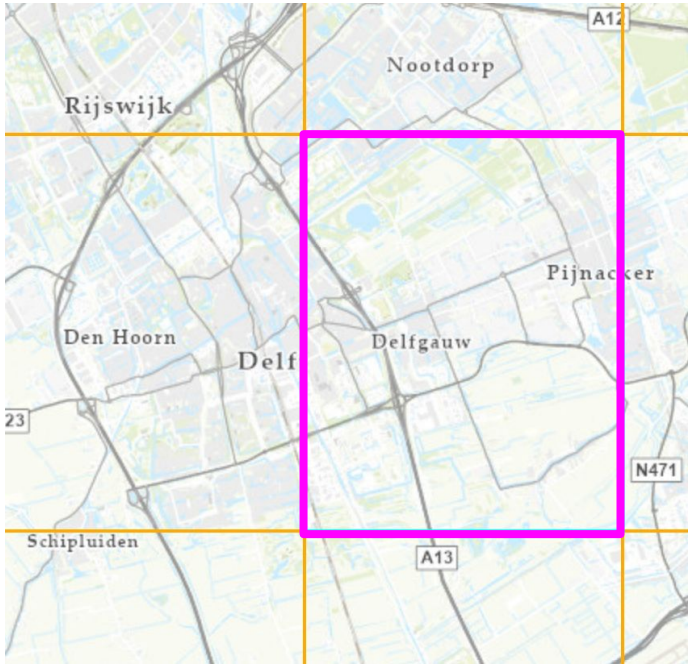
Example: Digital Surface Model



AHN3, Tile37en2

	Format	Size
0.5m Raster	TIF	0.49 GB
Point Cloud	LAZ	**2.47 GB**

Over **5 times** larger!

510 millions points in one tile!

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Example: Digital Surface Model

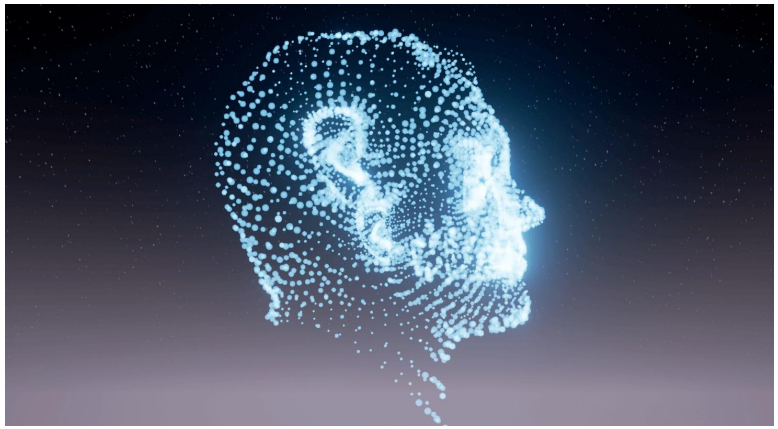
AHN3 from PDOK

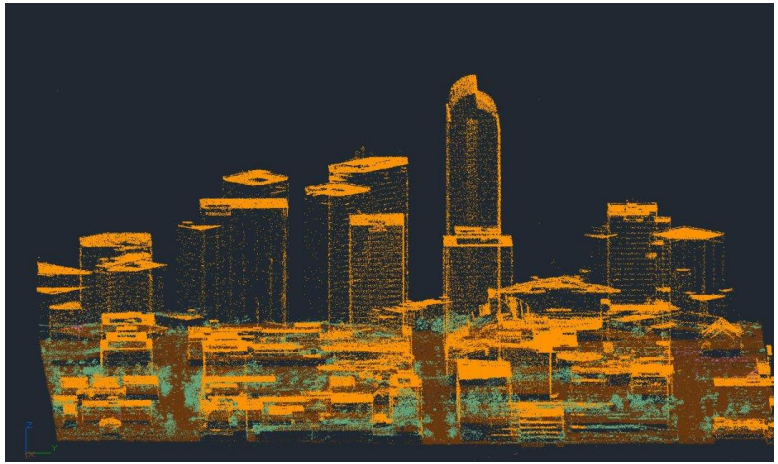
- **~640 billion points** in total!
- How about global DSM?

- How to store them?
- How to provide functionalities?

What is a point cloud?

- A set of points in 3D space
  - XYZ
  - Classification, RGB, GPS time, etc.
- A third representation of spatial data
  - vector, raster, PC
- Wide usage
  - 3D reconstruction
  - Autonomous driving
  - VR, AR, Gaming





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However, the data management is challenging!

However, the data management is challenging!

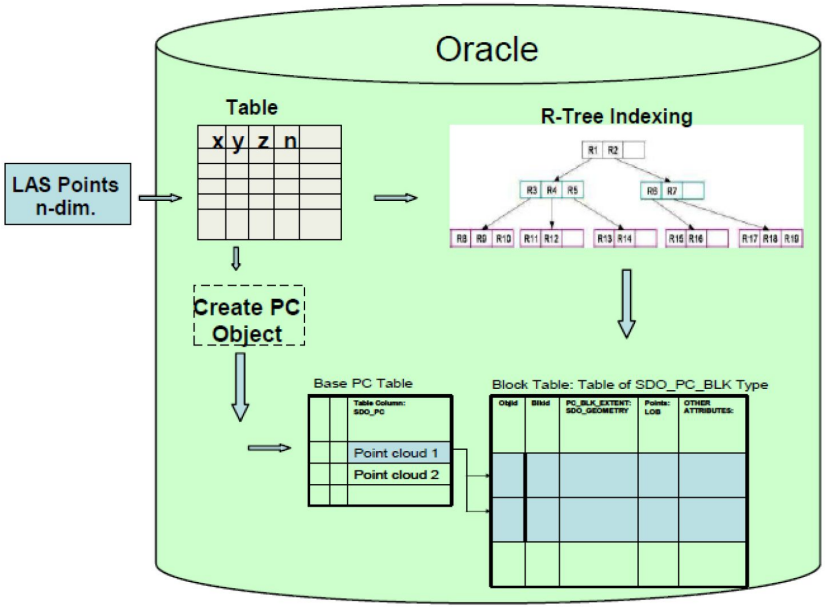
- Point clouds are a set of points, **massive** in size
- **File formats** like LAS are dominating
- But, **DBMS solutions** are also **crucial**
  - Functionalities
  - Optimised disk IO strategies
  - Auto parallelization in the query executions

Types of database storage

- Flat table
  - flexible, but large in size
  - suitable for small point cloud
- Block-based model
  - compact and scalable
  - suitable for massive point clouds

    Oracle SDO_PC

    pgPointCloud



Storage Model for Oracle SDO_PC type
Ravada et al., 2010

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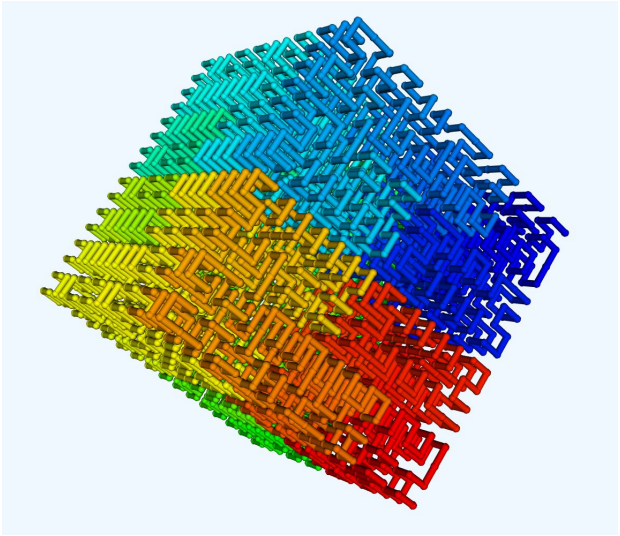
Spatial Access Methods

- Space Filling Curve
  - PlainSFC (van Oosterom, 2015)
  - DynamicSFC (Psomadaki, 2016)
  - HistSFC (Liu, 2020)

- But, PlainSFC uses a flat table
- A SFC-based block model is required!



3D Morton Curve
Source: https://www.hongheiniao.com

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Objective & Question

- Objective of the research
  - To investigate a database solution for massive points clouds
  - The storage model is block-based, and use SFC to organize points
  - Implement the prototype and test it

- Core question:
  - **Does employing the split Space Filling Curve approach constitute an effective strategy for managing massive point clouds in a relational database?**

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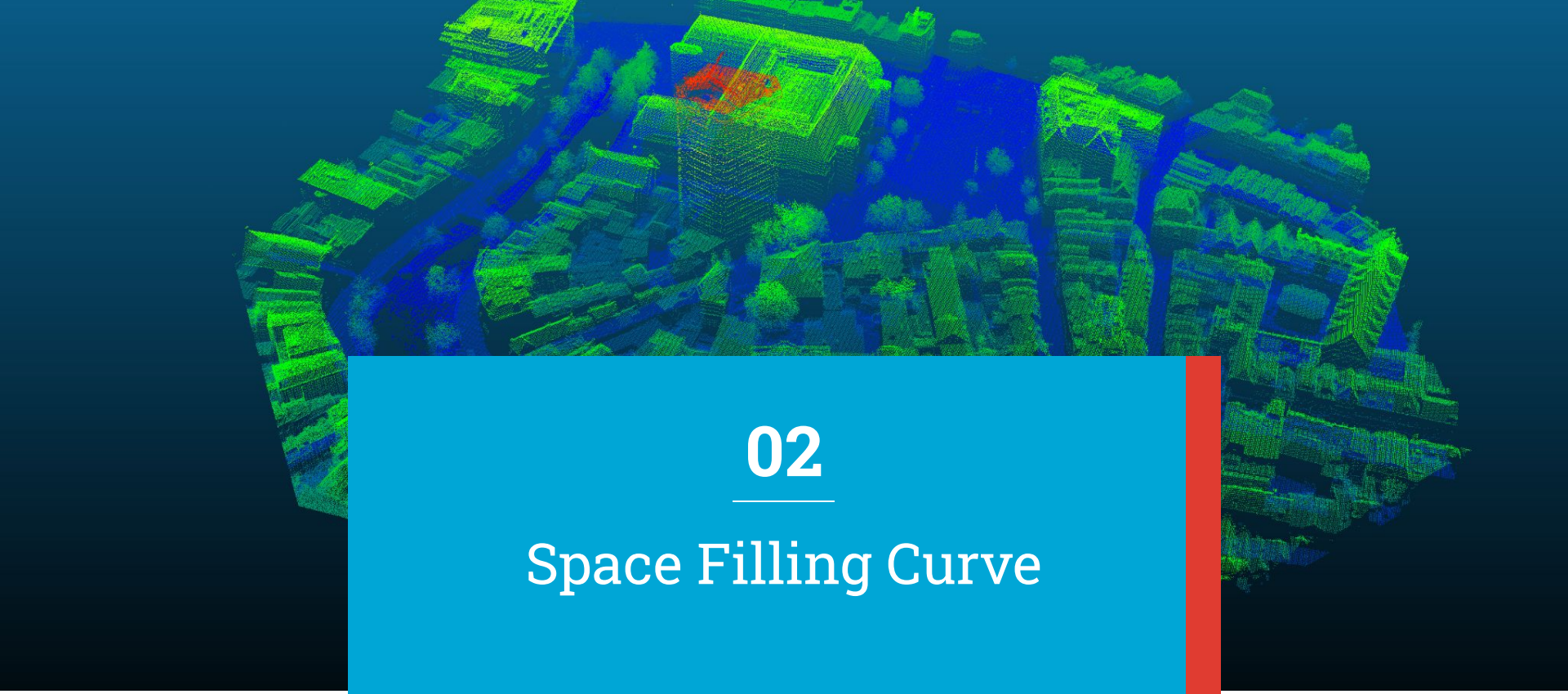

02

Space Filling Curve

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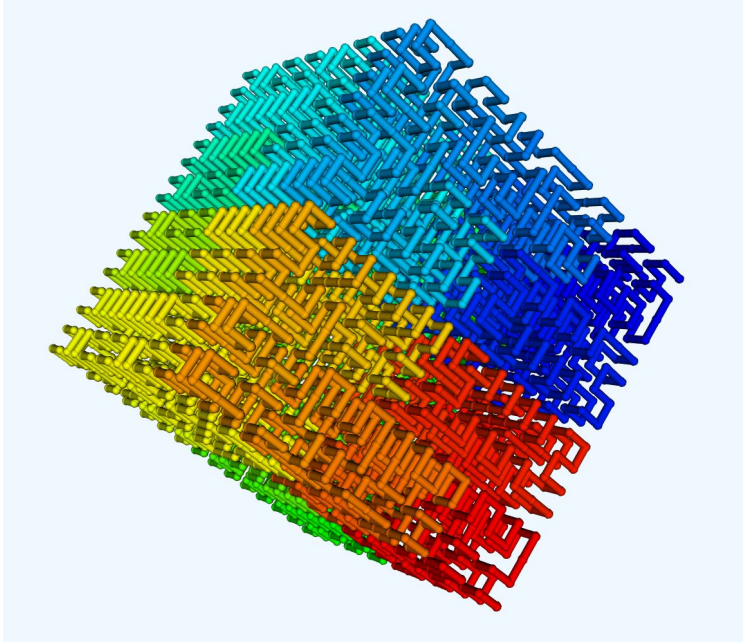
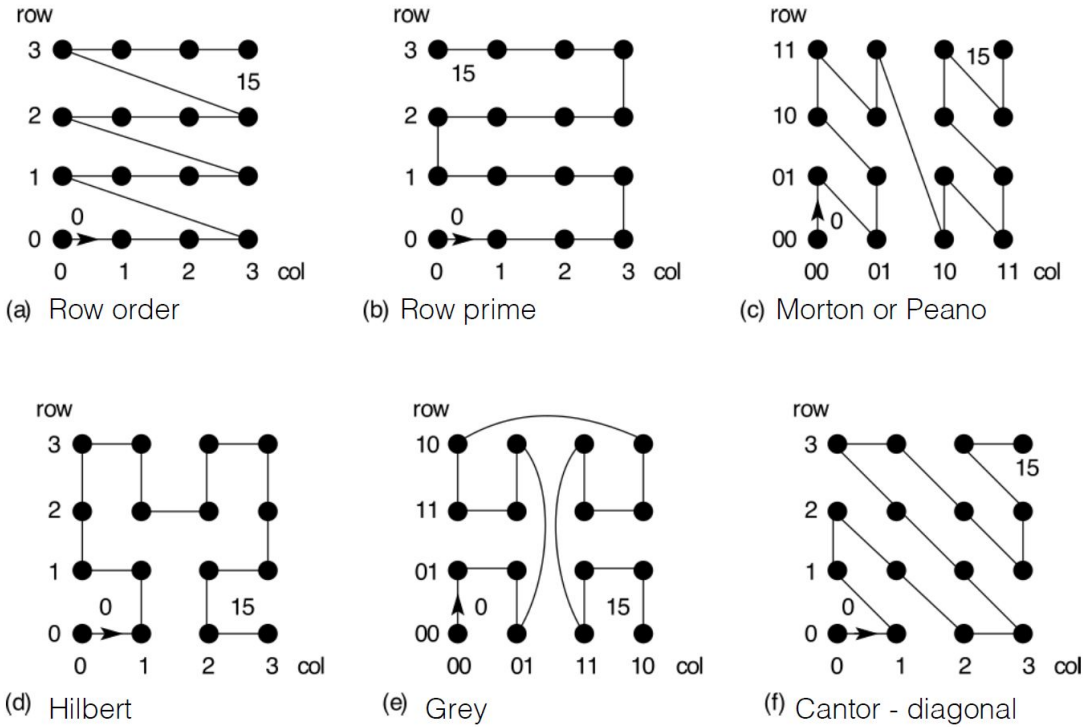
Space Filling Curve

- What is SFC?
  - **Applying a linear order to multi-dimensional data**
- Why SFC?
  - Dimensionality reduction (sorting, indexing)
  - Full resolution curve (compression)
  - Spatial clustering (physics storage)



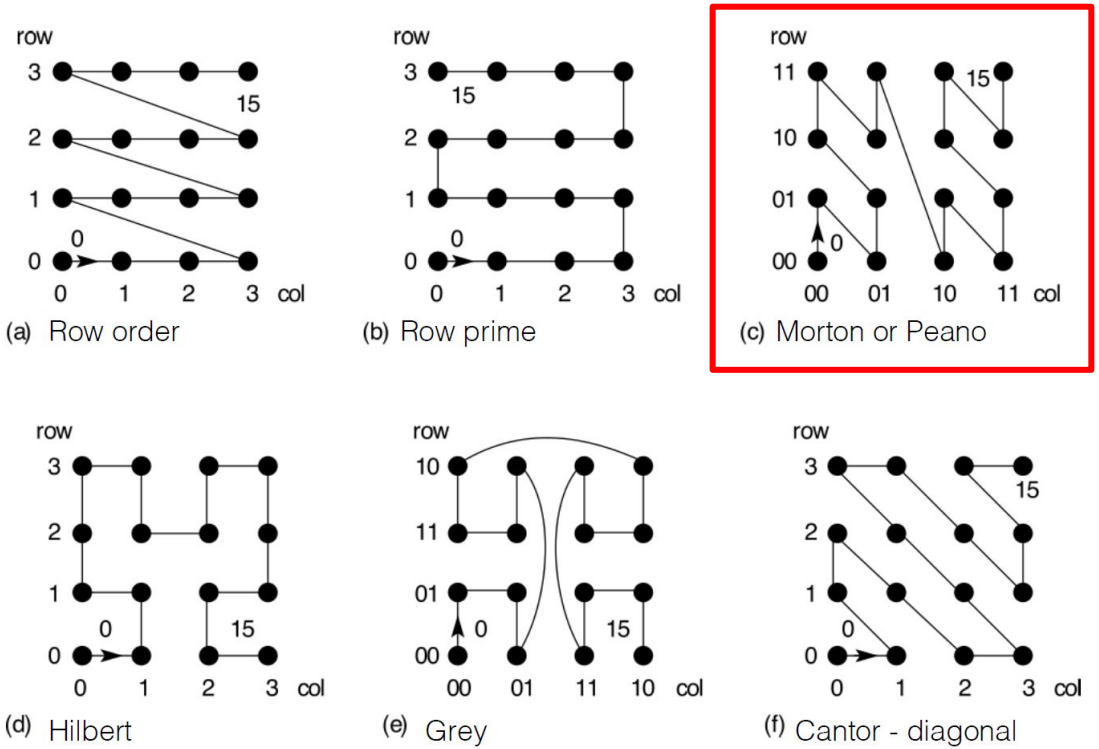
Source: https://www.hongheiniao.com

Space Filling Curve



Source: Van Oosterom, Spatial Access Methods, 1999

Space Filling Curve - We choose Morton!

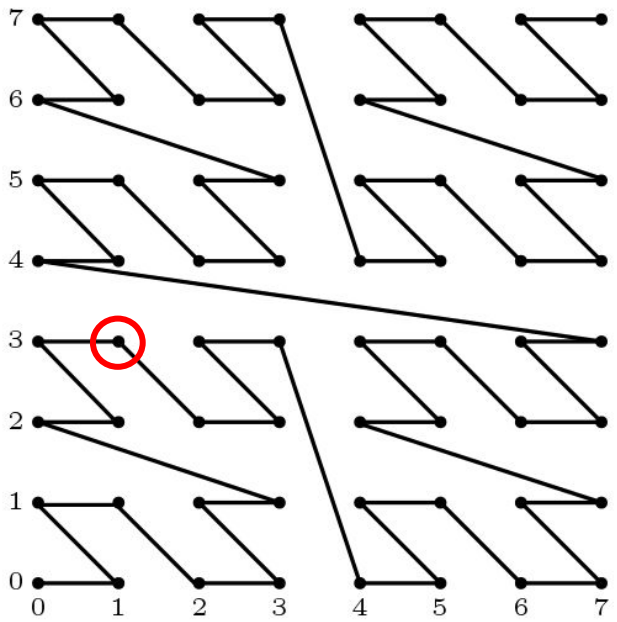


- Simplicity
- 2n-tree hierarchy

Source: Van Oosterom, Spatial Access Methods, 1999

Morton Encoding

- Bitwise interleaving
  - Point (1,3)
  - x= 1 or **001** in binary
  - y= 3 or **011** in binary
  - Morton = **000111**



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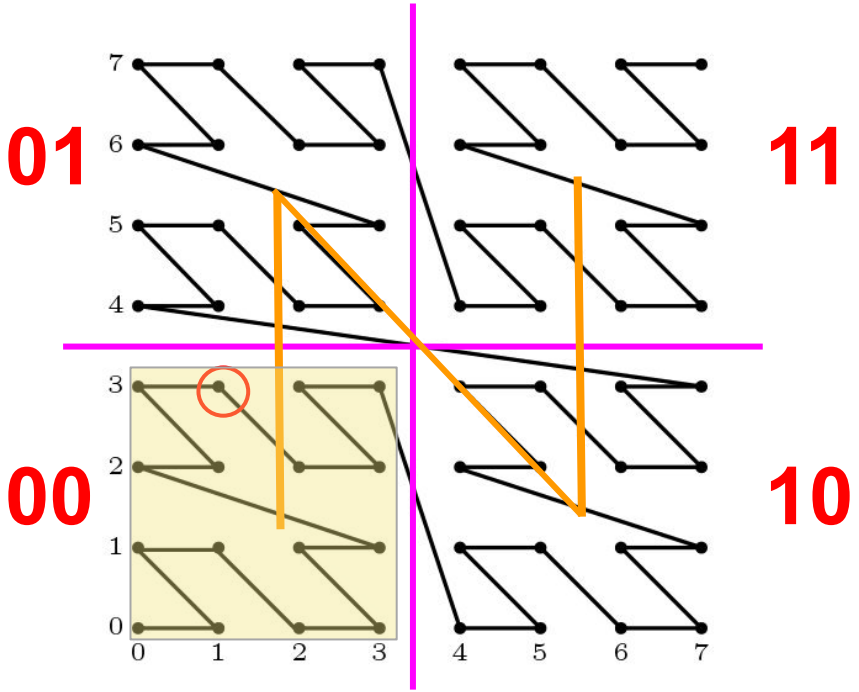
Quadtree structure in Morton keys

- Bitwise interleaving
  - Point (1, 3) / (**001**, **011**)
  - Morton = **000111**
- A hierarchy equivalent to a Quadtree
  - 00



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Quadtree structure in Morton keys

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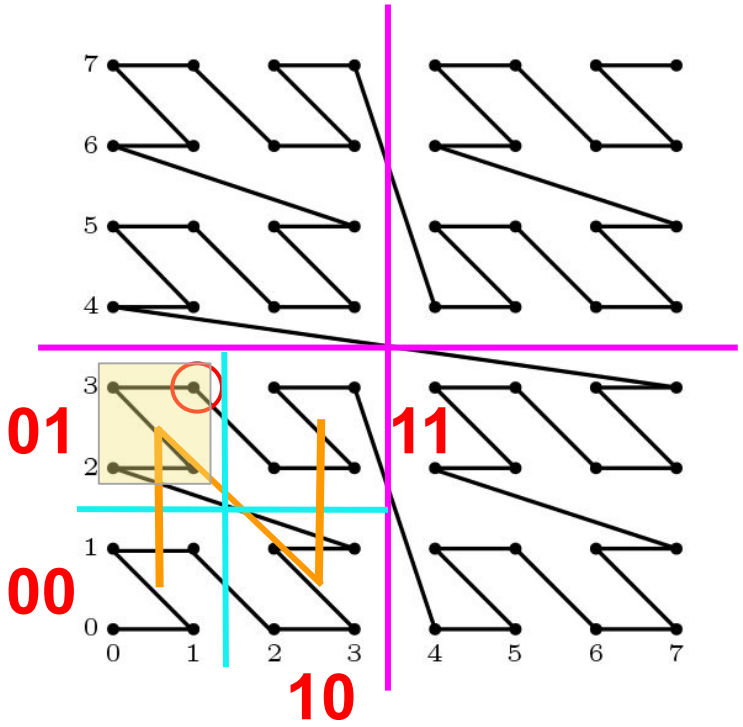
  - 00 01



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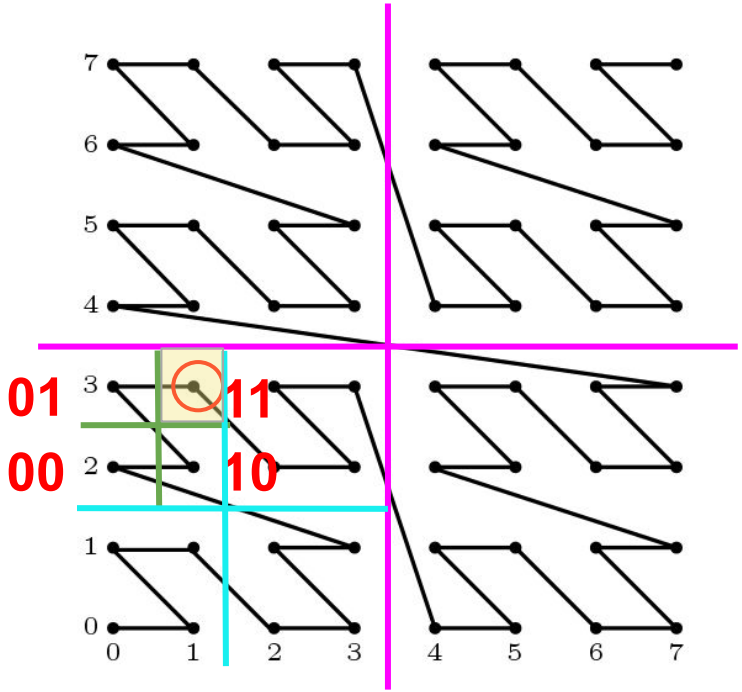

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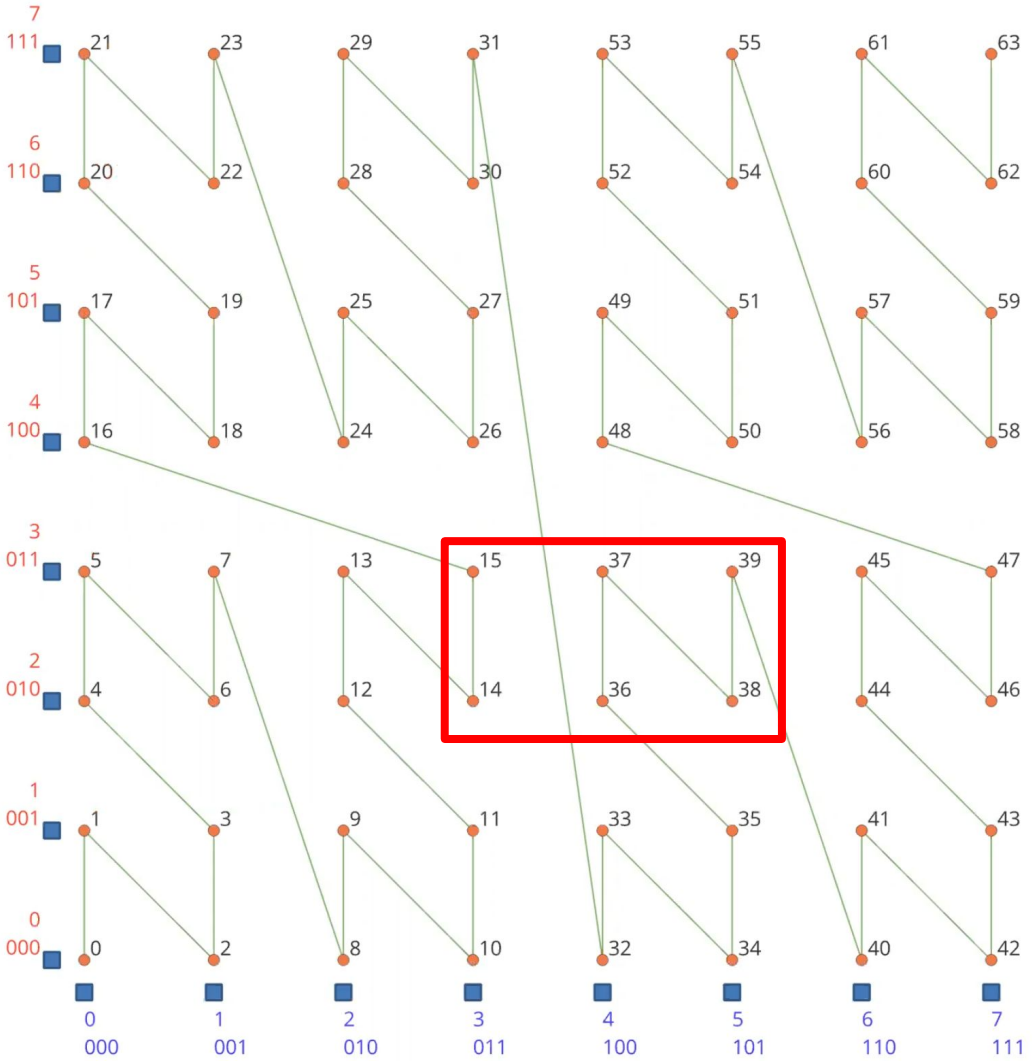
Query

Box ((3,2), (5,3))



Overlaps

No overlappings

Fully contained

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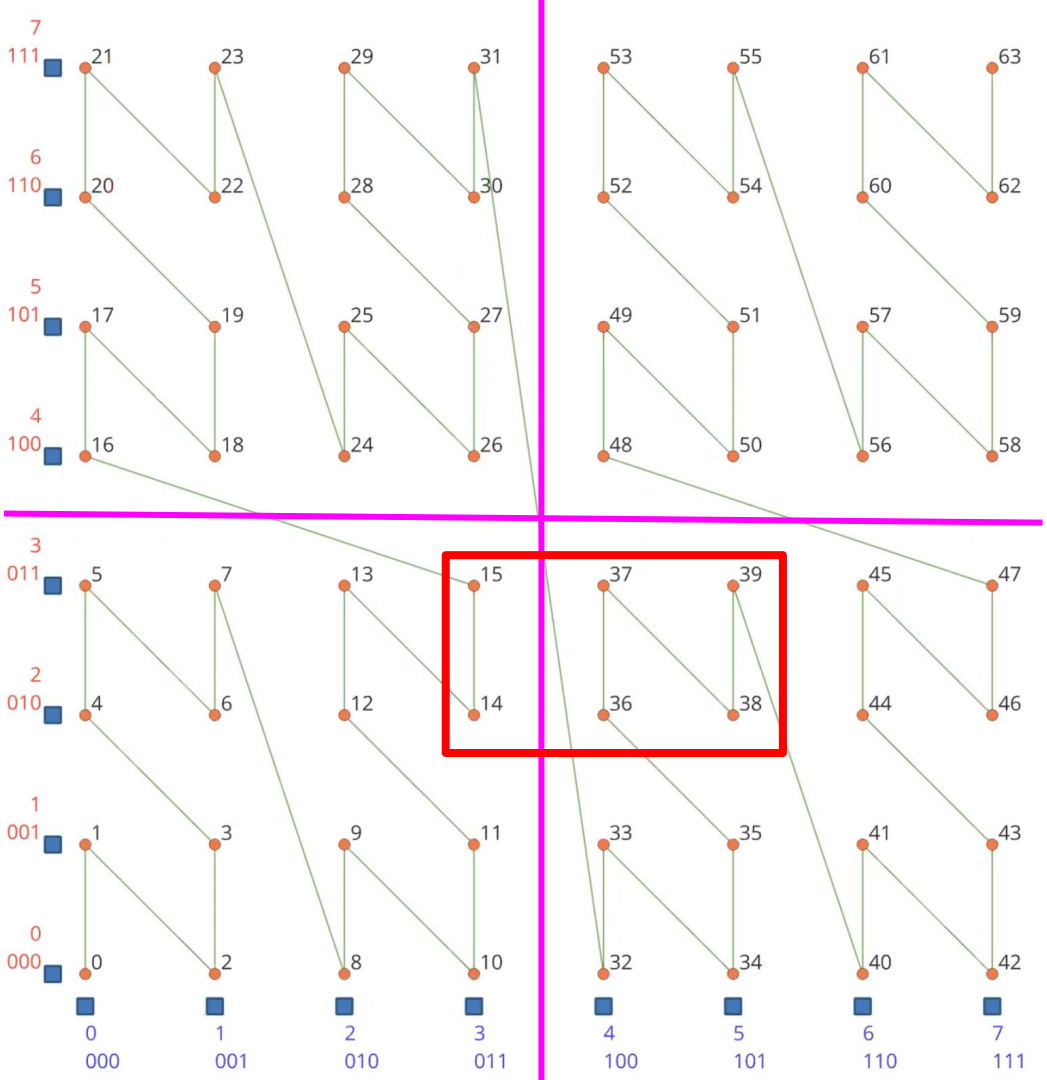
Query

Box ((3,2), (5,3))



Overlaps

No overlappings

Fully contained

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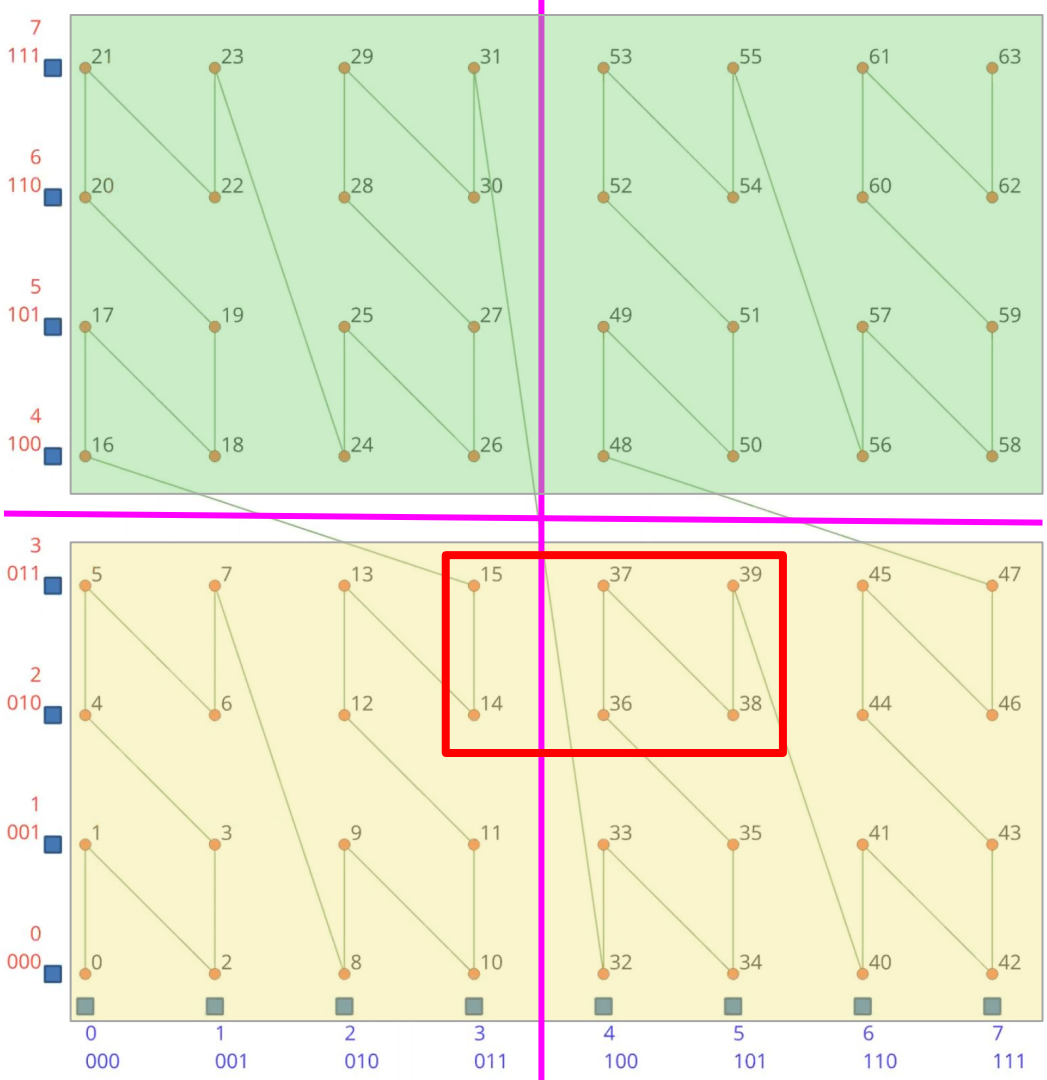
Query

Box ((3,2), (5,3))

Ranges

[0, 16)

[32, 47)



Overlaps

No overlappings

Fully contained

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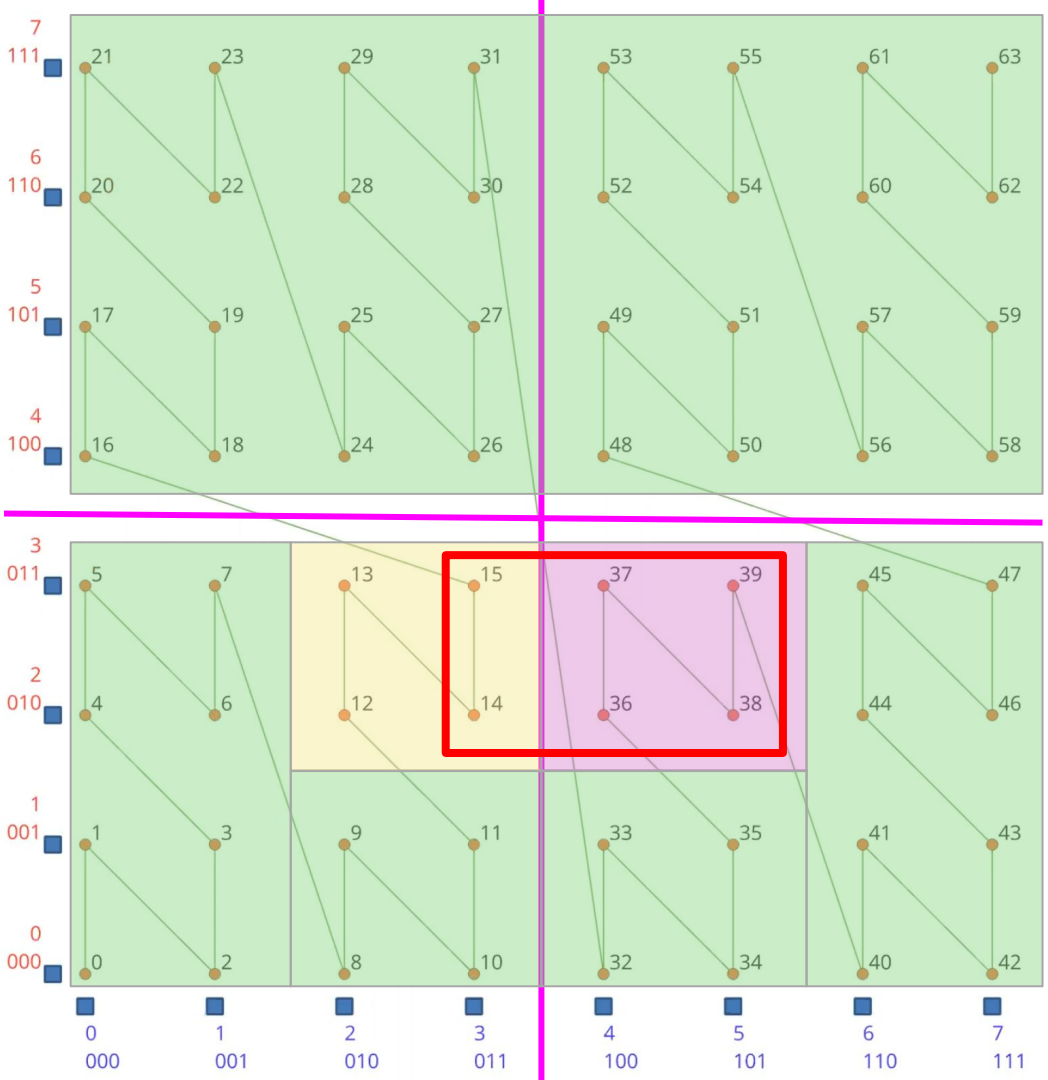
Query

Box ((3,2), (5,3))

Ranges

[12, 16)

[36, 40)



Overlaps

No overlappings

Fully contained

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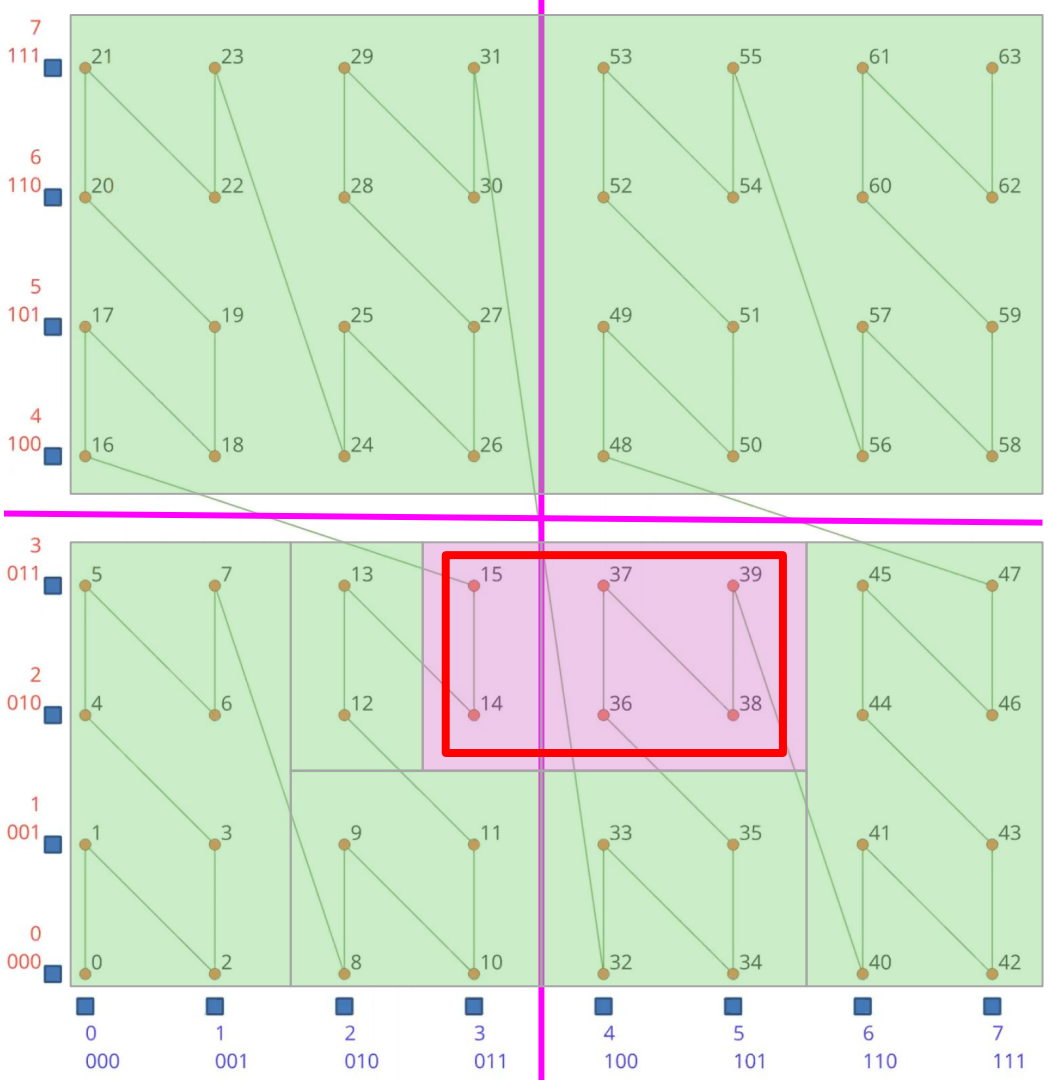
Query

Box ((3,2), (5,3))

Ranges

[14, 16)

[36, 40)



Overlaps

No overlappings

Fully contained

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Using SFC to organize points in flat table

X	Y	Z	...
1	1	3.5	...
0	3	0.4	...
1	5	10.8	...
3	4	5.9	...
6	4	2.7	...

Normal

Morton key	Z	...
00000011	3.5	...
00000101	0.4	
00010011	10.8	...
00011010	5.9	...
00111000	2.7	...

PlainSFC

Van Oosterom et al., 2015

- Point are clustered
- Query efficiency improved
- Still flat table

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The SplitSFC Method

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Numerical meaning of the split

Morton key	Z	...
00000011	3.5	...
00000101	0.4	
00010011	10.8	...
00011010	5.9	
00111000	2.7	...

Numerical meaning of the split

Morton key	Z	...
00000011	3.5	...
00000101	0.4	
00010011	10.8	...
00011010	5.9	
00111000	2.7	...

- Noticing same parts in Morton keys
- **Can we split the Morton key and make blocks out of it?**

Numerical meaning of the split

Morton key	Z	...
00000011	3.5	...
00000101	0.4	
00010011	10.8	...
00011010	5.9	
00111000	2.7	...

SFC head	SFC tile	Z	...
0000	[0000,0001, 0011,1000]	[3.5, 0.4, 2.9, 5.0]	...
0001	[0000,0001, 0011,1000]	[7.5, 1.6, 10.8, 4.3]	...
0011	[0000,0001, 0011,1000]	[12.4, 2.7, 0.2, 6.1]	...

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Numerical meaning of the split

- Storage
  - Block model, compact & compressed
  - SFC head stored once, shared with many
- Querying
  - The geometric meaning of the split?

SFC head	SFC tile	Z	…
0000	[0000,0001, 0011,1000]	[3.5, 0.4, 2.9, 5.0]	…
0001	[0000,0001, 0011,1000]	[7.5, 1.6, 10.8, 4.3]	…
0011	[0000,0001, 0011,1000]	[12.4, 2.7, 0.2, 6.1]	…

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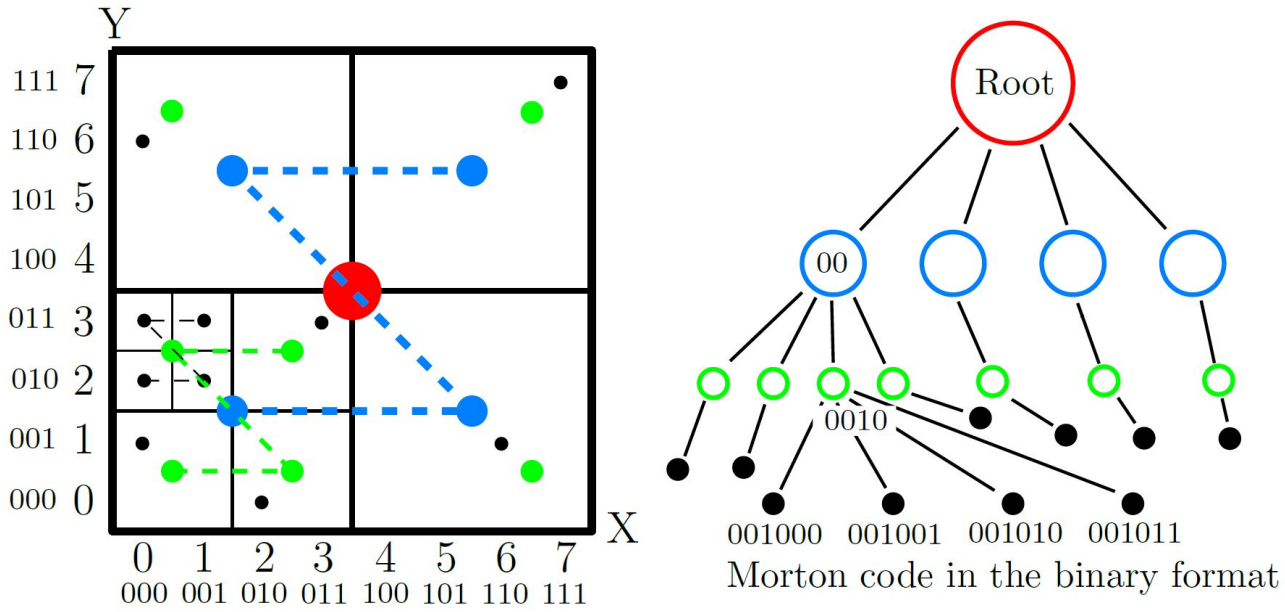
Geometric meaning of the split



Source: H Liu, 2022. nD-PointCloud Data Management.

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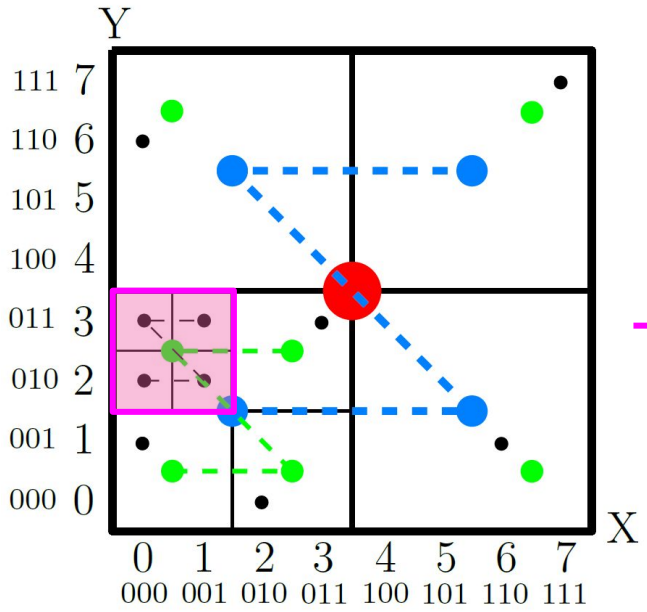
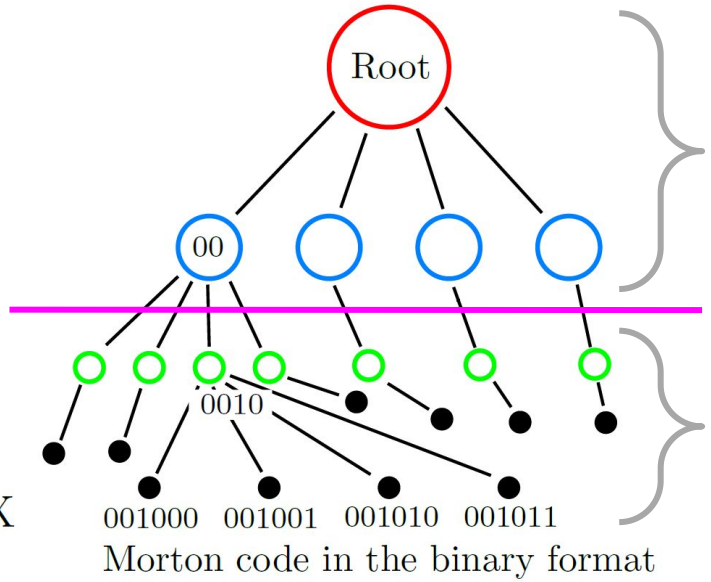
Geometric meaning of the split





SFC head:

Location of the quadrant

SFC tail:

Specific location of a point inside the quadrant

Source: H Liu, 2022. nD-PointCloud Data Management.

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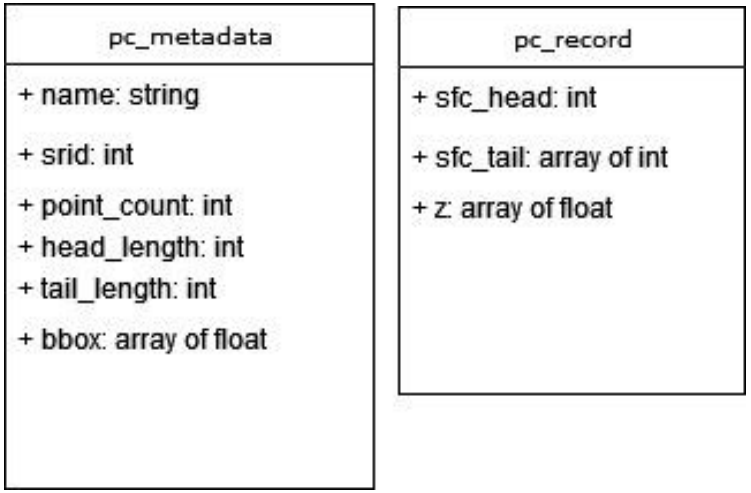
Storage Model



Points
- Organizing dimensions → SFC key (Morton)
  - SFC head
  - SFC tail
- Associate dimensions

A block
- Points with the same SFC head
- Sorted by SFC tail

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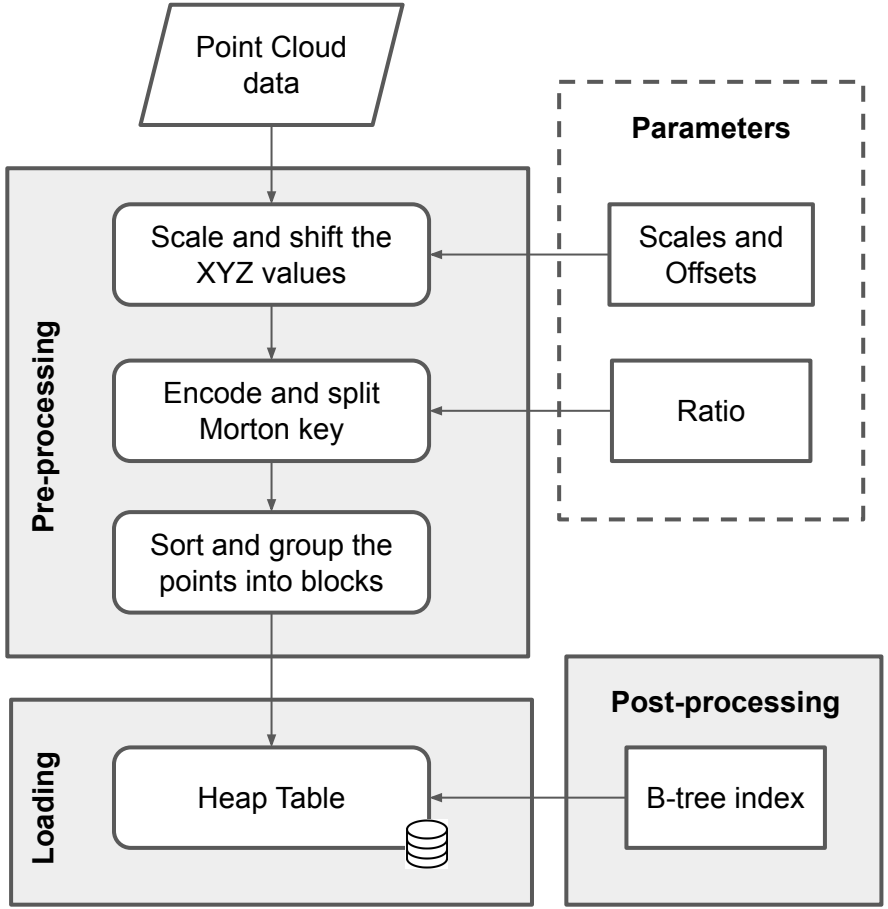
Storage Model

SFC head	SFC tile	Z	…
0000	[0000,0001,0011,1000]	[3.5, 0.4, 2.9, 5.0]	…
0001	[0000,0001,0011,1000]	[7.5, 1.6, 10.8, 4.3]	…
0011	[0000,0001,0011,1000]	[12.4, 2.7, 0.2, 6.1]	…

Loading Procedure



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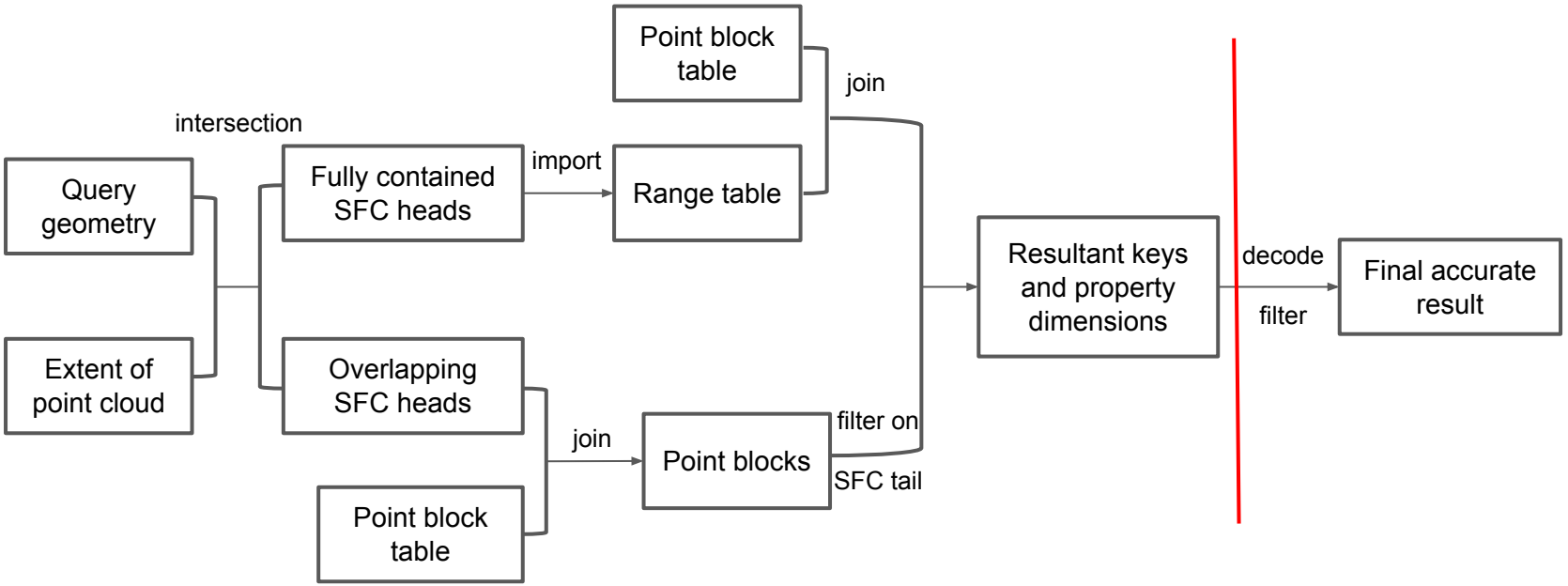
Query Procedure



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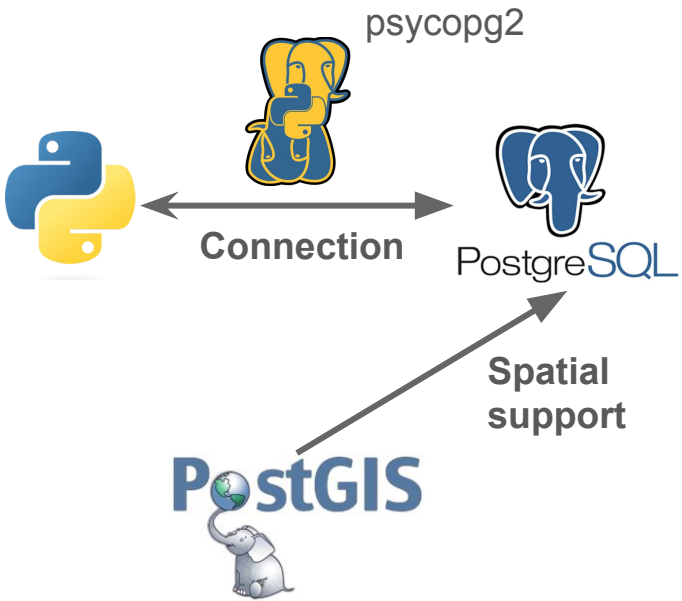
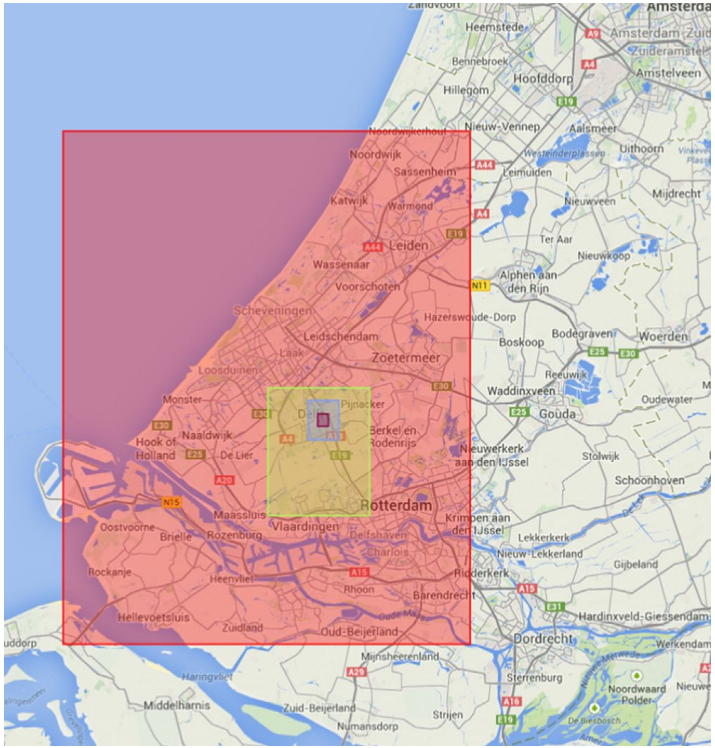
Implementation

- Hardware & software
  - PostgreSQL, PostGIS: DBMS
  - Python: complex algorithms
  - Pakhuis: the supercomputer of GIST Group
- Products
  - Importer (las2pg)
  - Querying tools
  - Exporter (pg2las)



Benchmark

- A scalable framework
  - AHN2
  - From Delft Campus to South Holland
  - Proposed by van Oosterom et al (2015)
- Why?
  - Reproductive, as AHN2 is open data
  - Well-designed and comprehensive
  - Easy to compare with other solutions

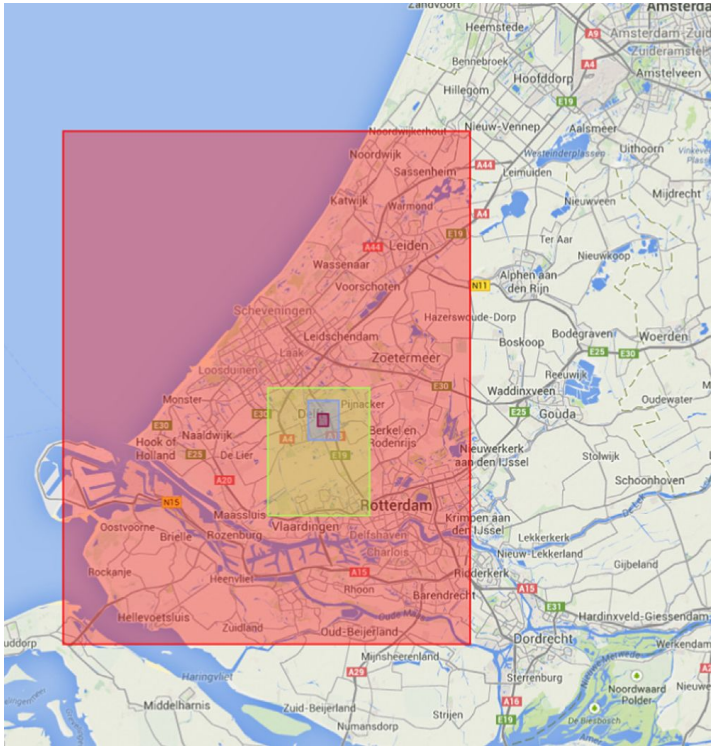


Source: van Oosterom et al., 2015. Massive point cloud data management: Design, implementation and execution of a point cloud benchmark.

Benchmark

- Measure performance
  - Importing time
  - Storage size
  - Query response time

Point	File	Size	Description
20M	1	0.4	TU Delft Campus (purple)
210M	1	4	Major of Delft city (cyan)
2201M	153	42	Delft city and surroundings (green)
23090M	1492	440	Major of South Holland (red)



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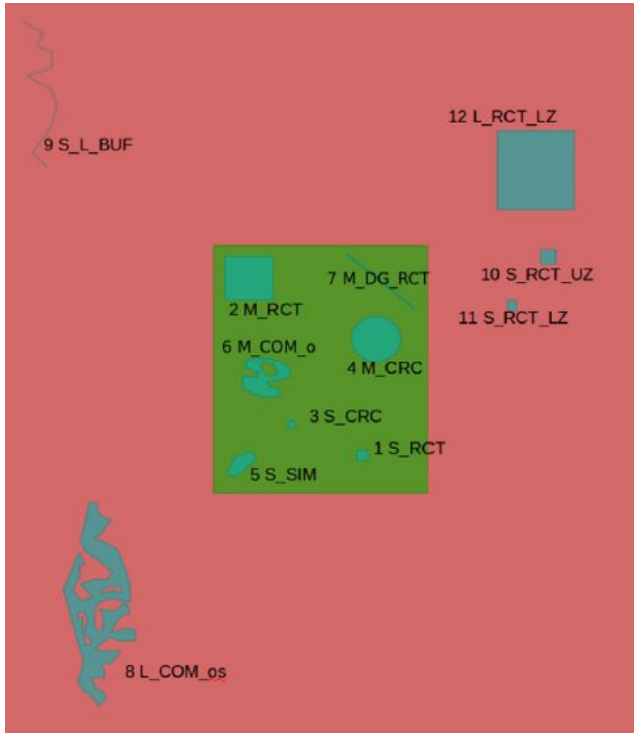
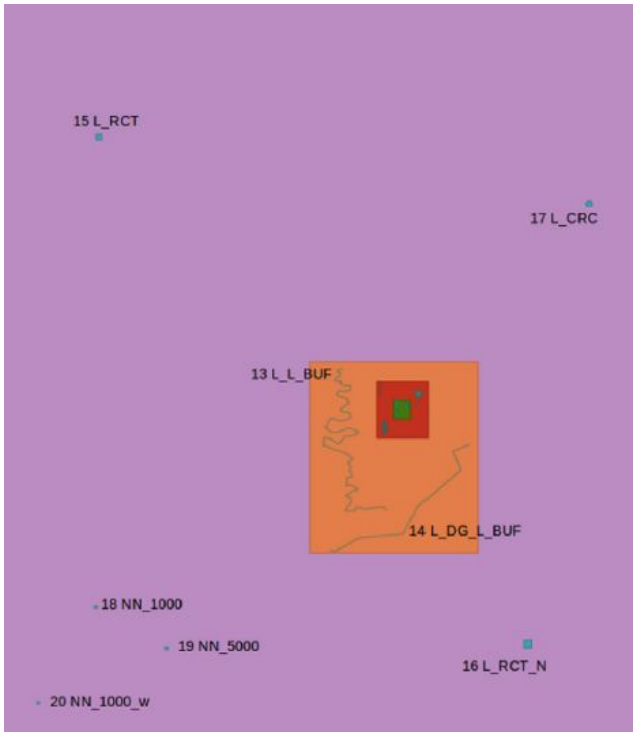
Benchmark





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Source: van Oosterom et al., 2015. Massive point cloud data management: Design, implementation and execution of a point cloud benchmark.

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Results

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Mini-benchmark

- To explore the effects of the parameters, including scales, offsets and ratios
- 20M, 210M dataset

	Explanation	Scales	Offsets
Solution 1	Default value	[0.01, 0.01]	[0, 0]
Solution 2	The points are shifted to the corner of their bounding box	[0.01, 0.01]	[min_x, min_y]
Solution 3	The resolution is reduced to 1m	[1, 1]	[0, 0]

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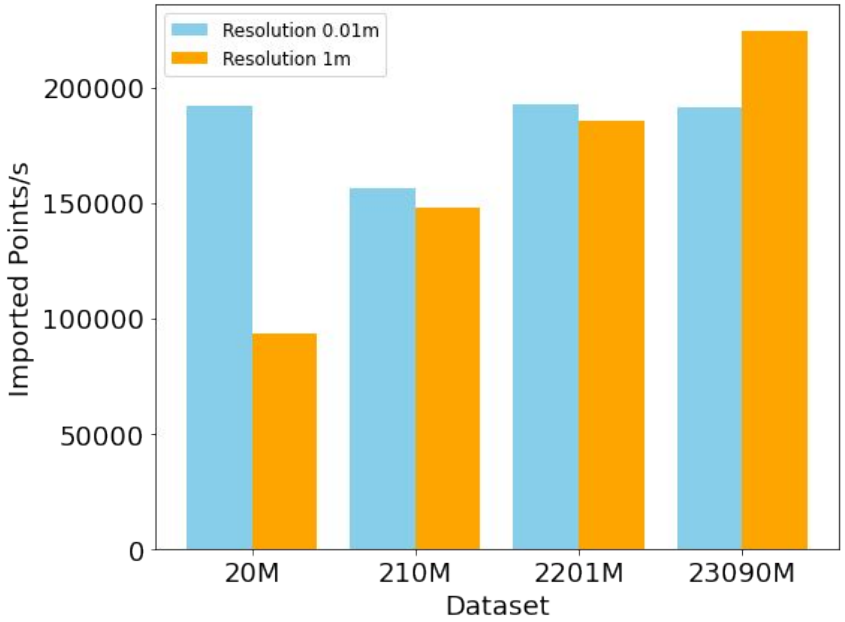
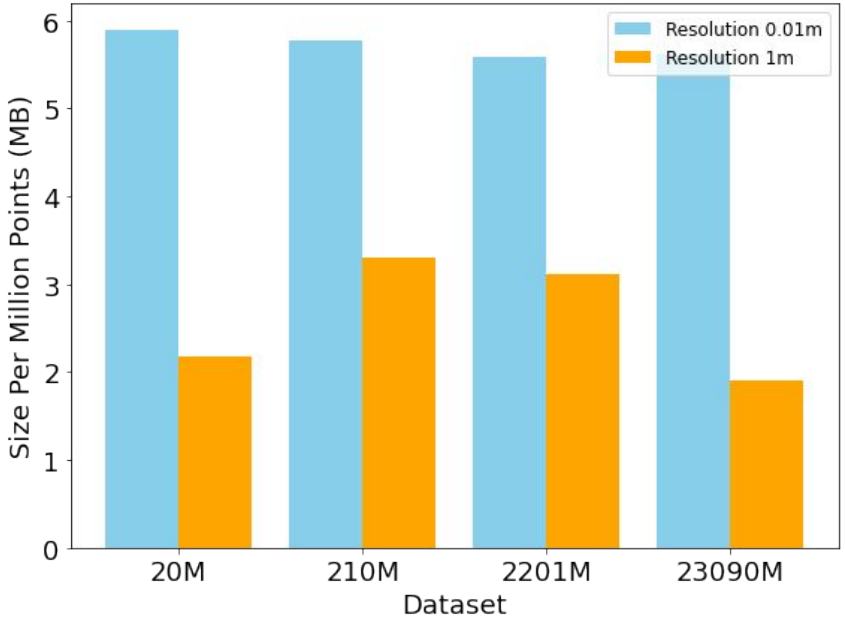
Scales





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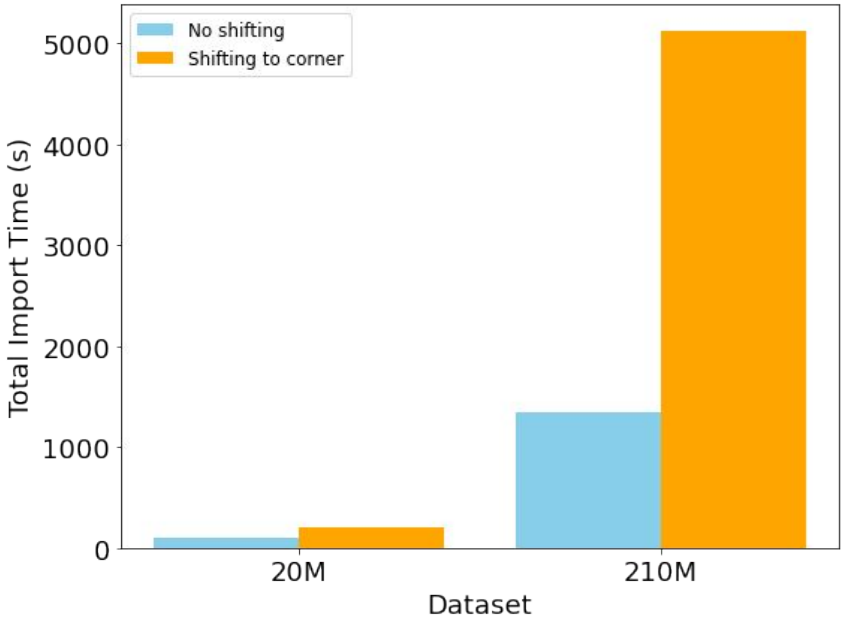
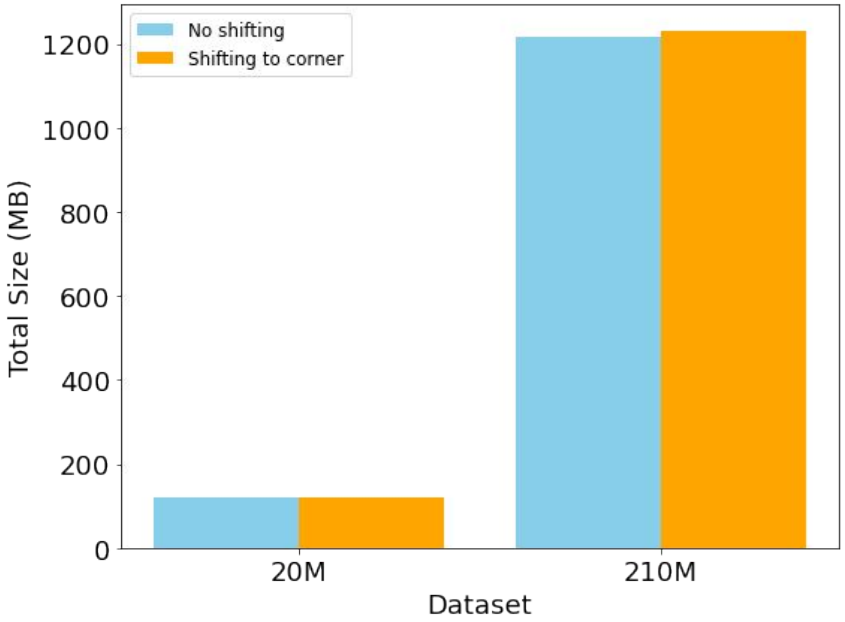
☺ Saves storage space

☹ Little help with importing time

Offsets





☹ No significant differences for the storage size

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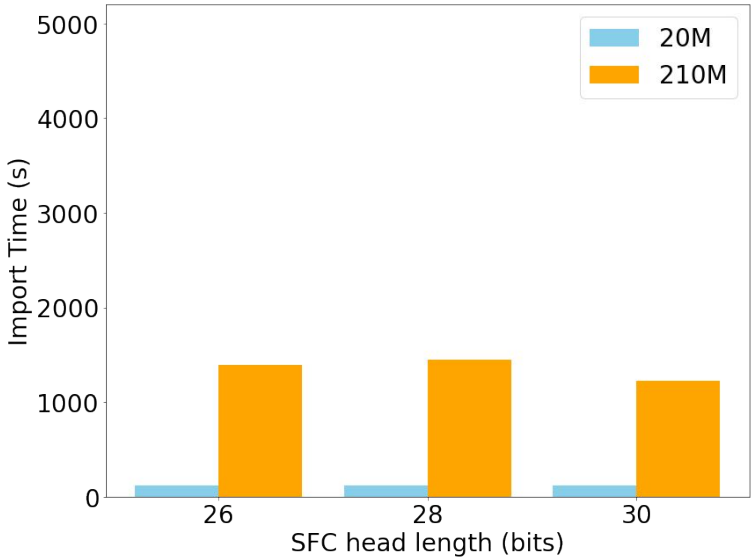
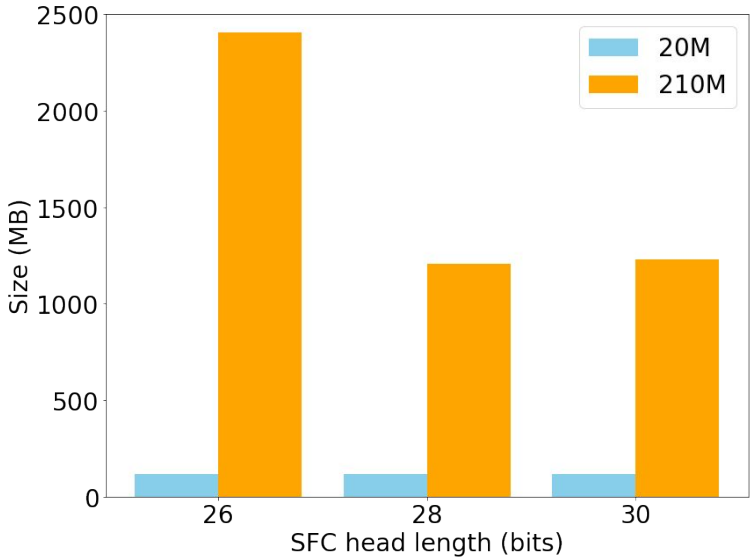
Ratios (default mode)





The ratio is dataset specific, and its tuning needs experiments.

The details effects are not clear yet, but the ratio of AHN2 can be 50%~60%.

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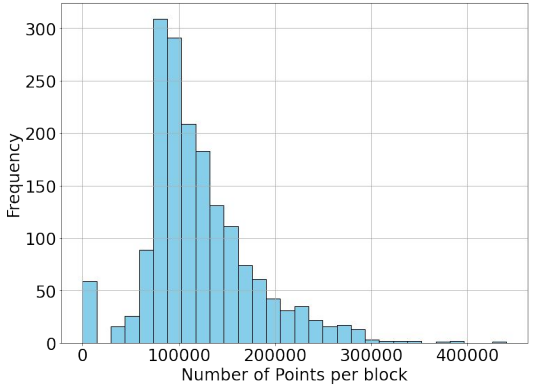
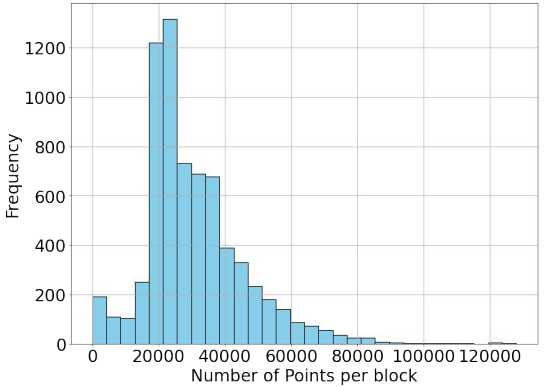
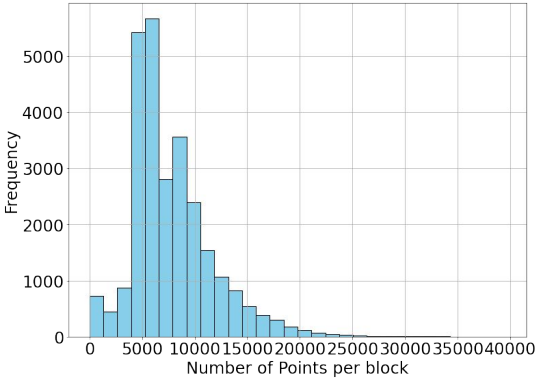
Point distribution (210M dataset)



50% split



55% split



60% split

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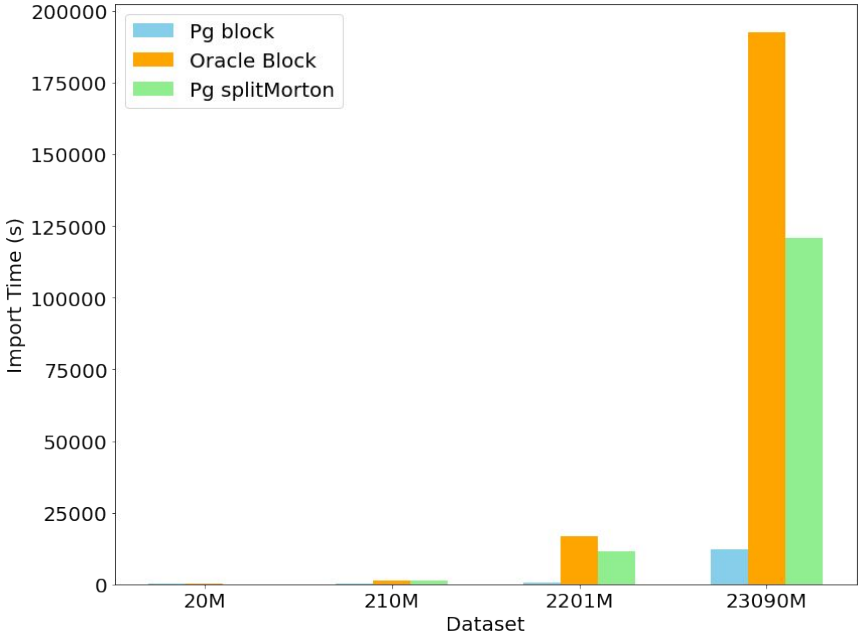
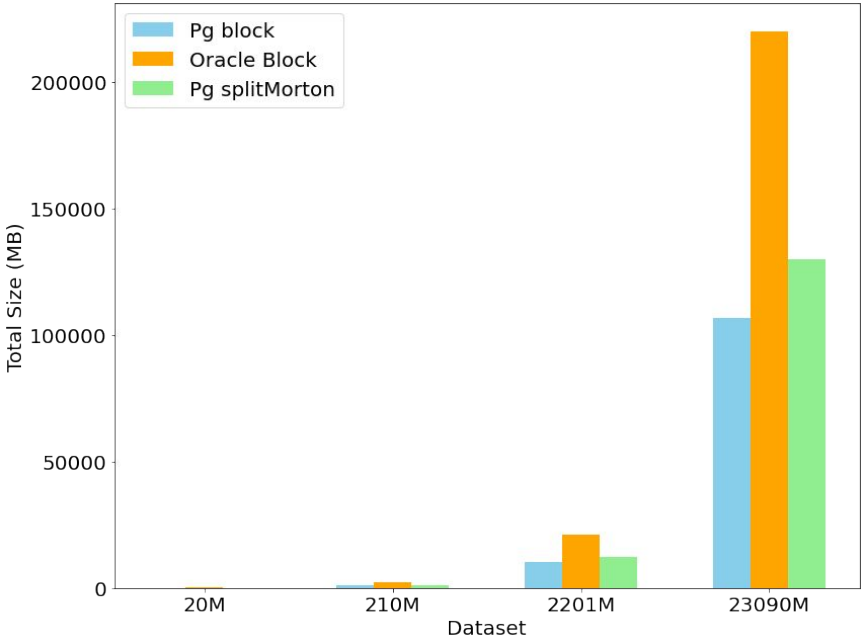
Medium-benchmark

- To explore the scaling behaviour
- To evaluate and compare the performance
  - SplitSFC
  - pgPointCloud
  - Oracle SDO_PC

Importing time & Storage Size





pgPointCloud > SplitSFC > Oracle SDO_PC

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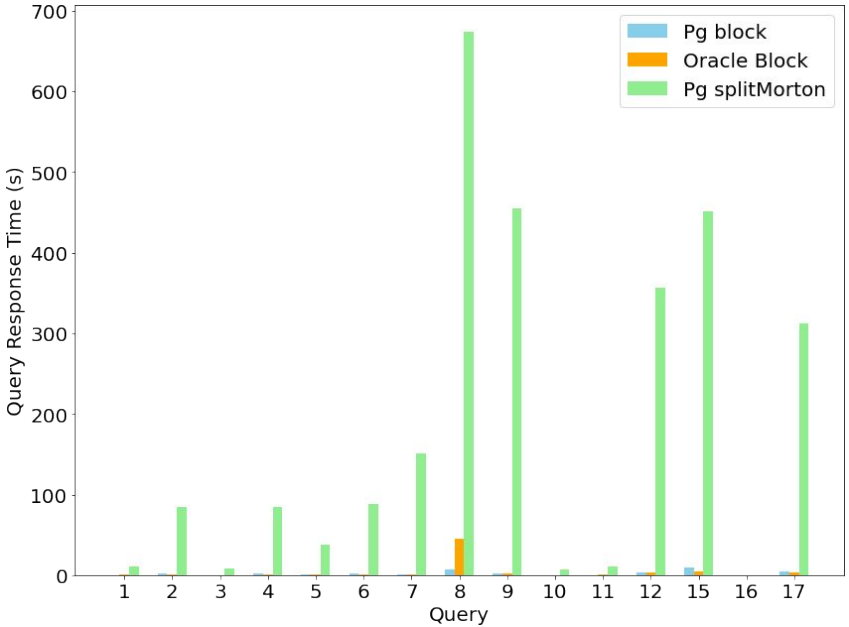
Data retrieval



pgPointCloud ~ Oracle SDO_PC >> SplitSFC

Possible cause: Morton decoding, Python implementation

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Medium-bench In Summary

- **Importing Time.** The SplitSFC approach takes longer time to import, because of the extra time in Morton key computation, sorting and grouping and the nature of Python implementation.
- **Storage size.** pgPointCloud and SplitSFC approach occupy comparable storage space, and the Oracle SDO_PC approach occupies more storage space. Notably, if the algorithm and the implementation are improved, there is a chance that SplitSFC can have a very good performance compared to other state-of-the-art DBMS solutions.
- **Querying response time.** SplitSFC is much slower in querying. However, this may also be due to the nature of Python implementation.

05

Conclusion & Discussion

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Conclusions

Does employing the split Space Filling Curve approach constitute an effective strategy for managing massive point clouds in a relational DBMS?

 SplitSFC approach has potential advantages for massive point clouds in DBMS

 The immediate implementation may not yield a definitive improvement

- Fixed-length SFC key splitting
- Interpreted nature of Python
- Parallel Loading

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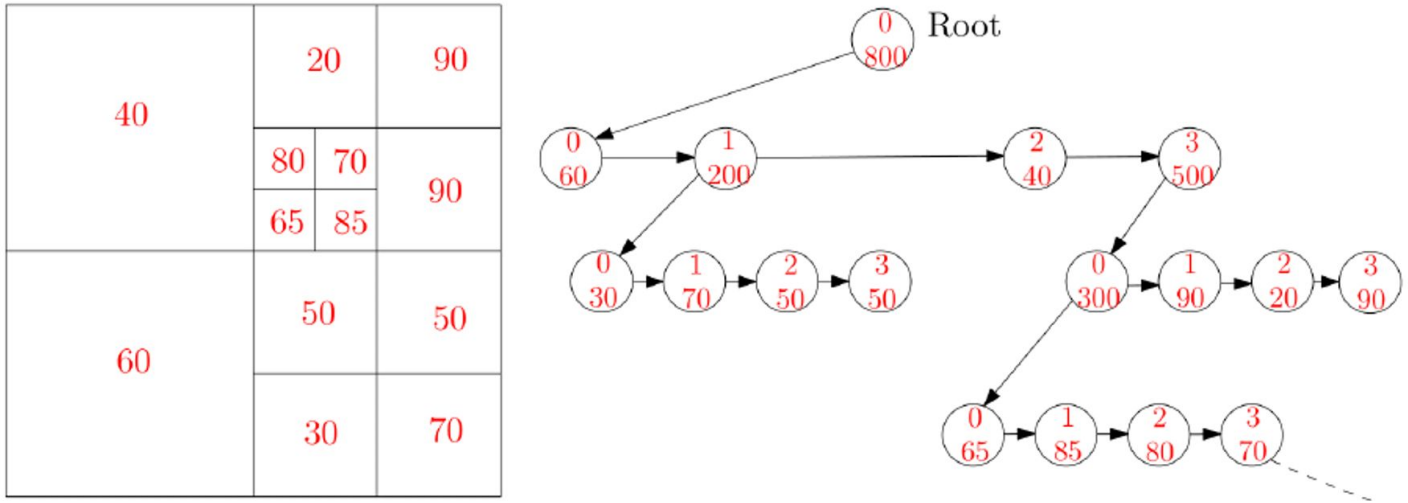
Future work

- Adaptive splitting algorithm
  - HistogramTree: the distribution of the points



Source: H Liu, 2022. nD-PointCloud Data Management.

Future work

- Adaptive splitting algorithm
  - HistogramTree: the distribution of the points
- 3D Morton key
  - How to encode the z dimension?
- Multi-split algorithm
  - i.e. head, body, tail
- Implementation with C++

Thank you for listening!