Universität Konstanz

# Locality Optimization for traversal-based Queries on Graph Databases

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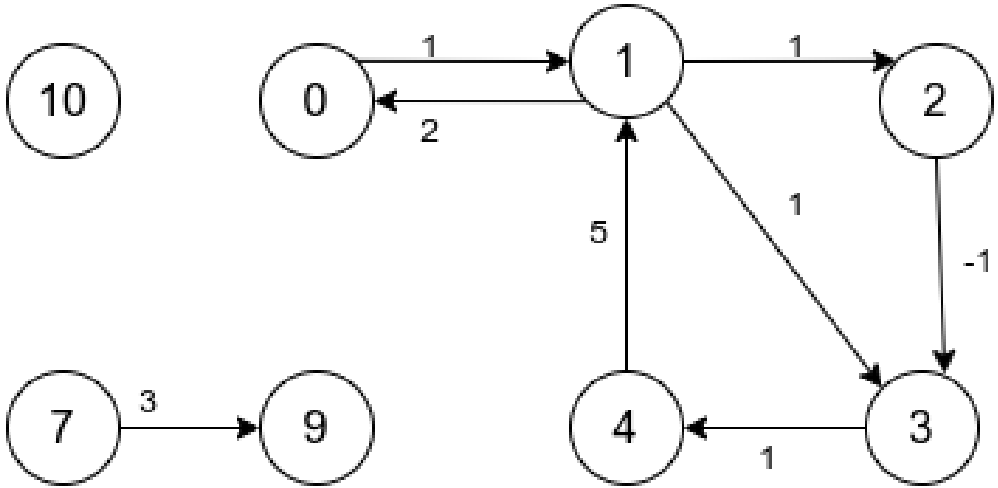
# Graphs



# Data Structures I

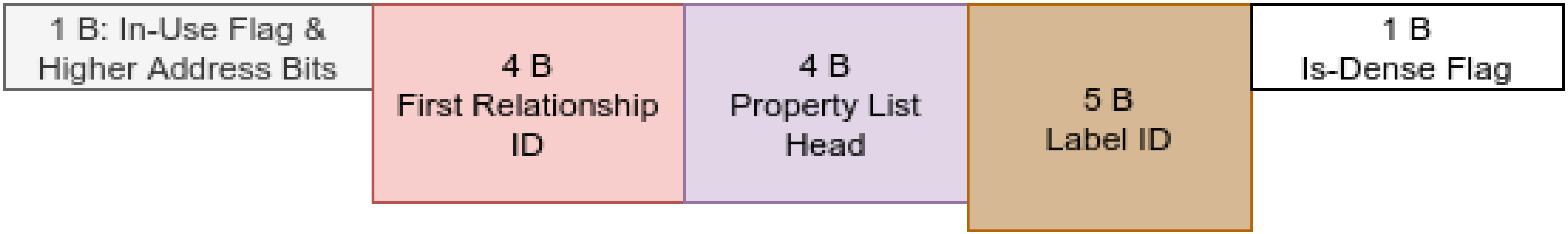
Two essential record structures:

1. Node records

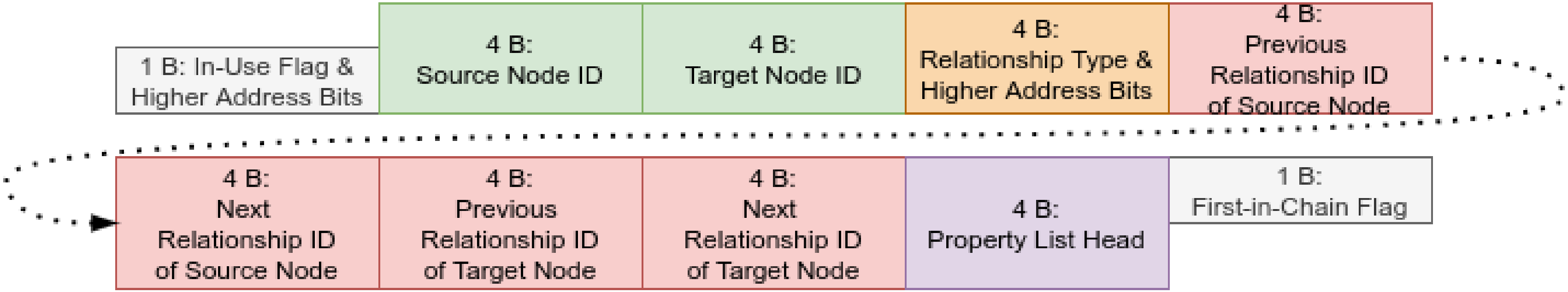
2. Relationship records

Inspired by Neo4J [1], [2].

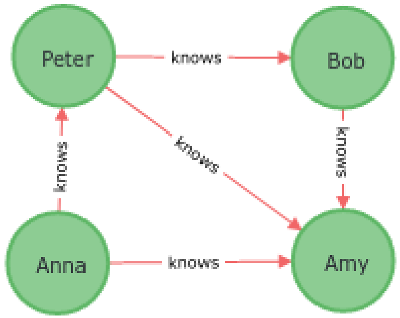
# Data Structures II

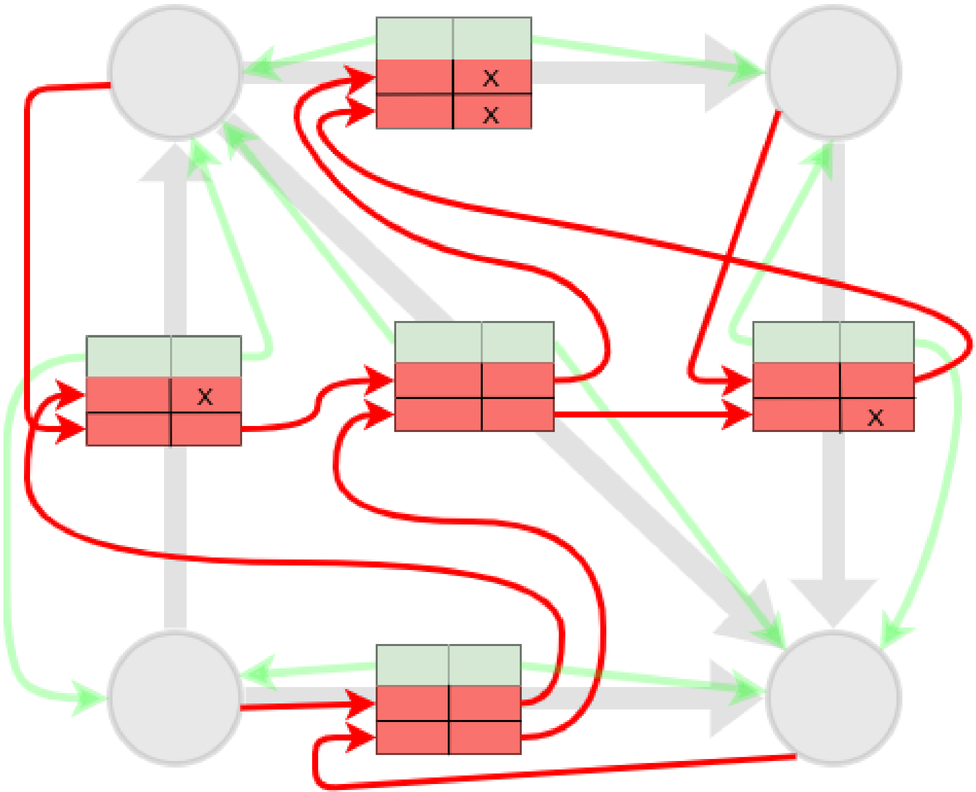


# Data Structures III



# Data Structures – Example




X
X
X
X

## Example Query

Show me all people that Bob knows:

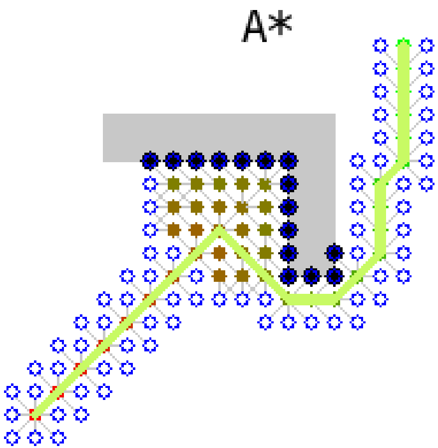
$$\uparrow_{x}^{y}$$

$$\sigma_{x.\text{name} = \text{'Bob'}}\ (\bigcirc\ x)$$

$\Rightarrow$ Scaning and filtering read sequential.

$\Rightarrow$ `Expand` does not necessarily.

# Traversal-based Query



# Motivation

- `Expand`'s access pattern depends on the query, record and incidence list order.

- When these factors are not considered, access is random.

  Potentially leads to

  $\Rightarrow$ hard-to-predict access patterns.
  $\Rightarrow$ cache & prefetch misses, thrashing and pollution.
  $\Rightarrow$ inadequate page eviction behavior.

Traversals rely primarily on `expand`!

# Locality I

- “memory references tend to be localized in time and space” [3].
- Tendency to access nearby memory locations based on previous accesses [4].

# Locality II

Temporal locality based on blocks

$$P(X_{t+\Delta} = B | X_t = B)$$

Spatial locality in the same sense

$$P(X_{t+\Delta} = B \pm \varepsilon | X_t = B)$$

with $\varepsilon = \lceil \frac{p}{b} \rceil$ [5].

$\Rightarrow$ The more localized the access, the less IO ops are necessary [5].

# Problem Definition

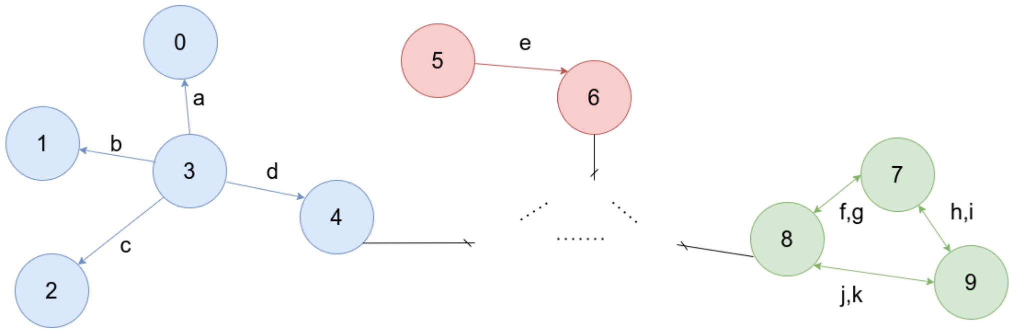
Given a graph $G$, logical block size $b$, page size $p$.

Desired is

1. A partition of $G$ into blocks of size $b$,
2. permutations $\pi_v, \pi_e$ of the blocks,

such that locality is as high as possible for traversal-based queries.

# Example: Block Formation and Order



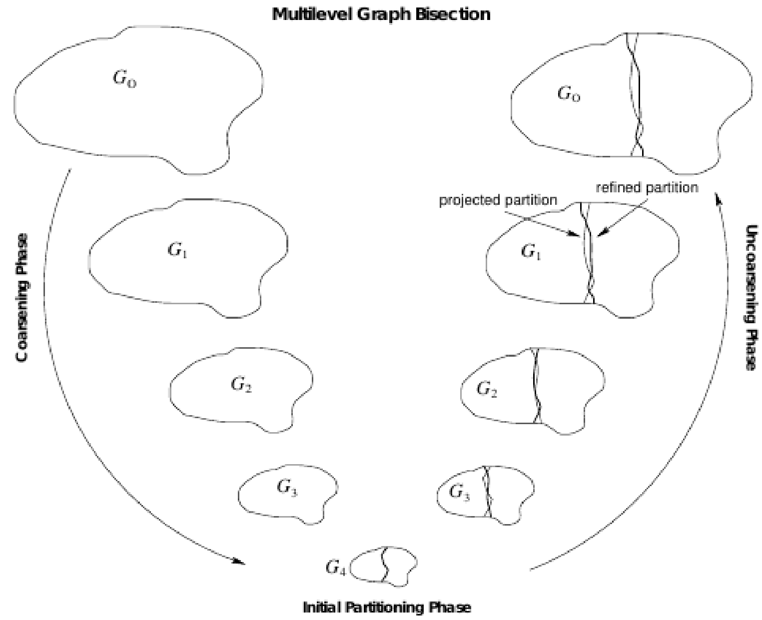

| | | | | | | |
|---|---|---|---|---|---|---|
| node.db | 0, 5, 7 | 1, 4, 9 | 2, 6, 8 | 3 | | |
| edge.db | a, f | b, g | c, h | d, i | e, j | k |

| | | | | | | |
|---|---|---|---|---|---|---|
| node.db | 7, 8, 9 | 0, 1, 3 | 2, 4, 5 | 6 | | |
| edge.db | f, h | g, k | i, j | a, b | c, d | e |

# Record Layout Methods: Overview

- Existing methods
  - G-Store [6]
  - ICBL [7]
- Our approach
  - Community detection — Louvain method [8].
  - Incidence list reordering

# G-Store I

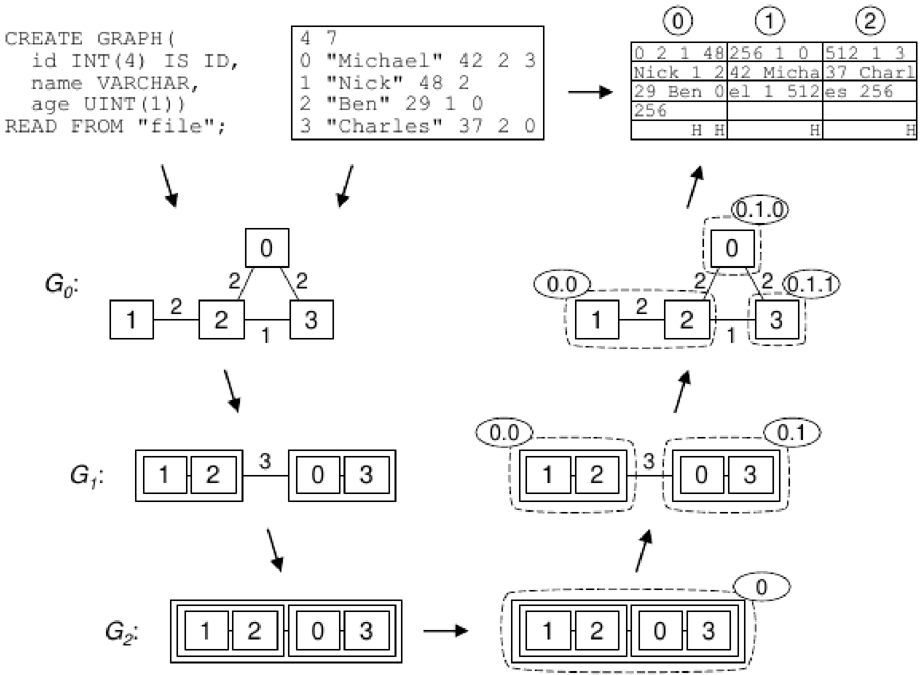

Multilevel Graph Bisection
$G_0$
$G_1$
$G_2$
$G_3$
$G_4$
$G_0$
$G_1$
$G_2$
$G_3$
projected partition
refined partition
Coarsening Phase
Uncoarsening Phase
Initial Partitioning Phase

# G-Store II

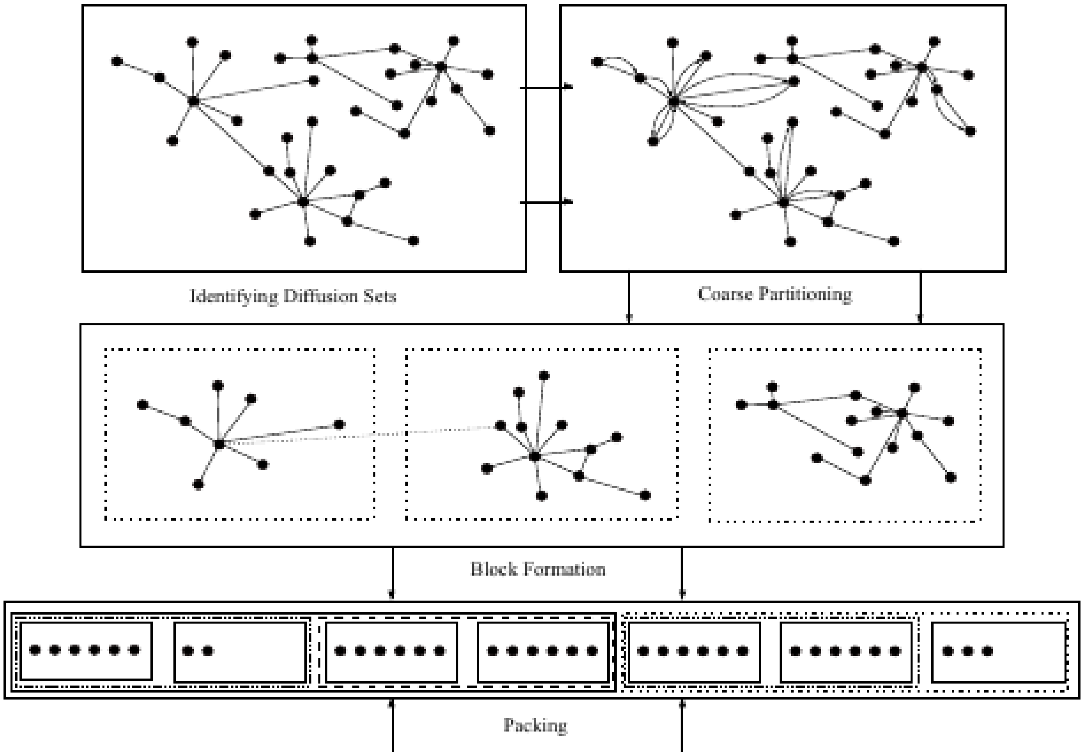
1. Coarsening: Heavy-Edge Matching [9]
2. Turn-around
3. Uncoarsening
   3.1 Project
   3.2 Reorder
   3.3 Refine

$$\min \sum_{(u,v)\in E} |\phi(u) - \phi(v)|$$

# G-Store III


CREATE GRAPH(
id INT(4) IS ID,
name VARCHAR,
age UINT(1))
READ FROM "file";
4 7
0 "Michael" 42 2 3
1 "Nick" 48 2
2 "Ben" 29 1 0
3 "Charles" 37 2 0
0 2 1 48
Nick 1 2
29 Ben 0
256
256 1 0
42 Micha
el 1 512
512 1 3
37 Charl
es 256
$G_0$:
$G_1$:
$G_2$:
0.0
0.1
0.1.0
0.1.1

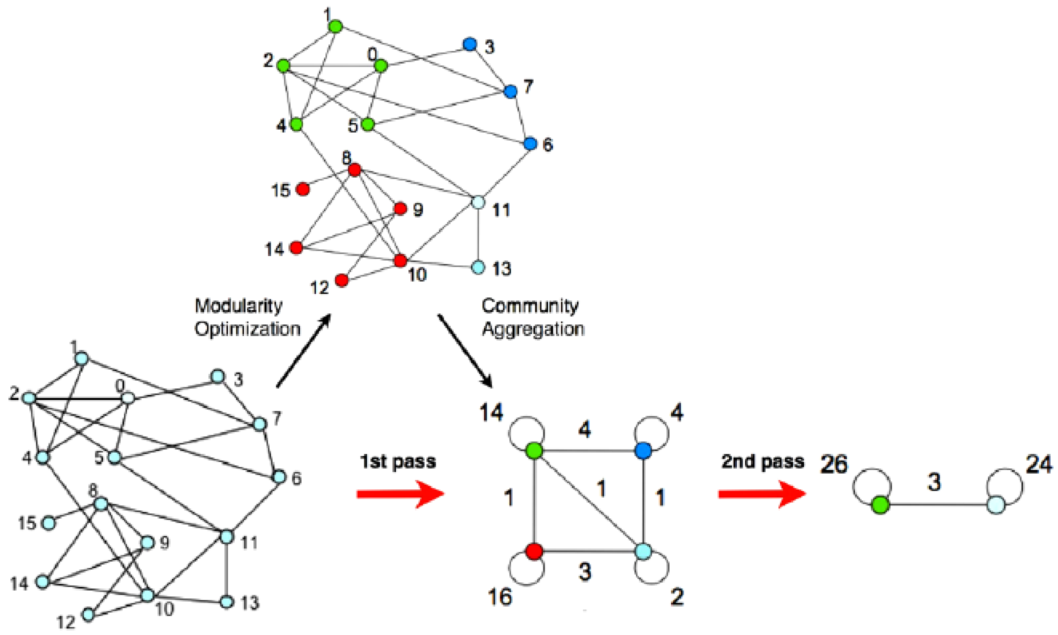
# ICBL I


Identifying Diffusion Sets
Coarse Partitioning
Block Formation
Packing

# ICBL II

- I Feature extraction: Do $t$ random walks [10] of length $l$.
- C Coarse clustering: Adapted K-Means [11].
- B Block Formation: Agglomerative hierarchical clustering [12].
- L Layout Blocks: Sort blocks and subgraphs

# Louvain Method I

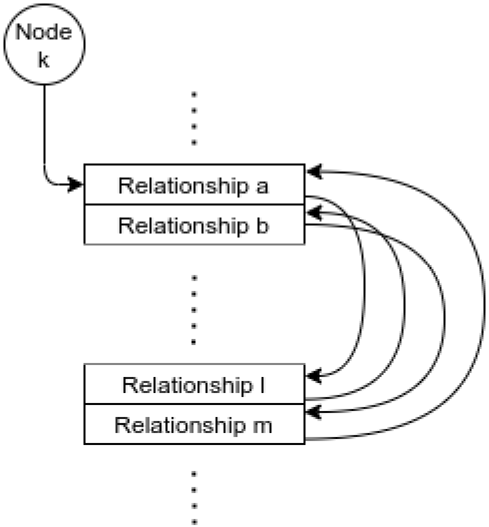


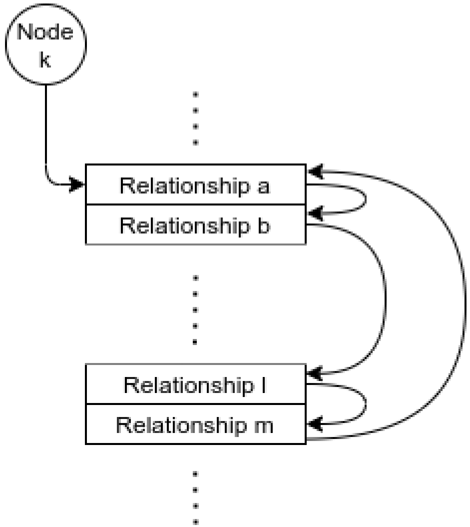
# Louvain Method II

1. Initialize all nodes in singleton community.
2. Merge community into a neighboring community where modularity gain is maximal, until modularity gain is below threshold.
3. Construct new graph from aggregated communities and go to 1.

$$\frac{1}{2m}\sum_{u,v\in V}\left(w_{(u,v)} - \frac{w_u w_v}{2m}\right)\cdot\delta(c_u, c_v)$$

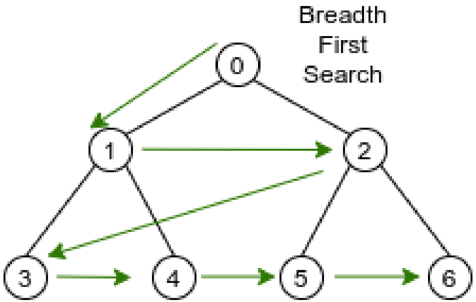
# Incidence List Rearrangement

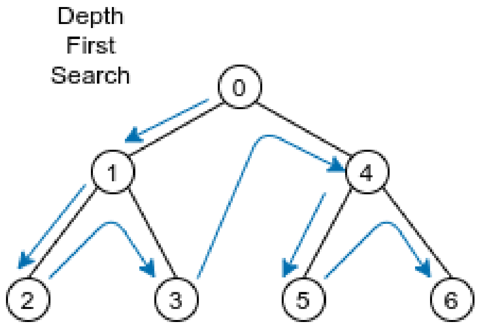


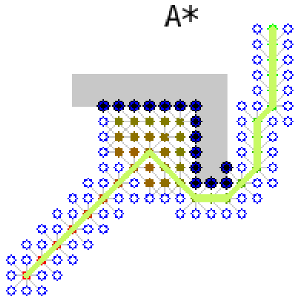



# Setup I

- Queries: BFS, DFS, Dijkstra, A*, ALT.



# Setup II

- Datasets: $[131, 1'134'890]$ nodes, $[764, 2'987'624]$ edges, average degree $[2.6, 25.5]$

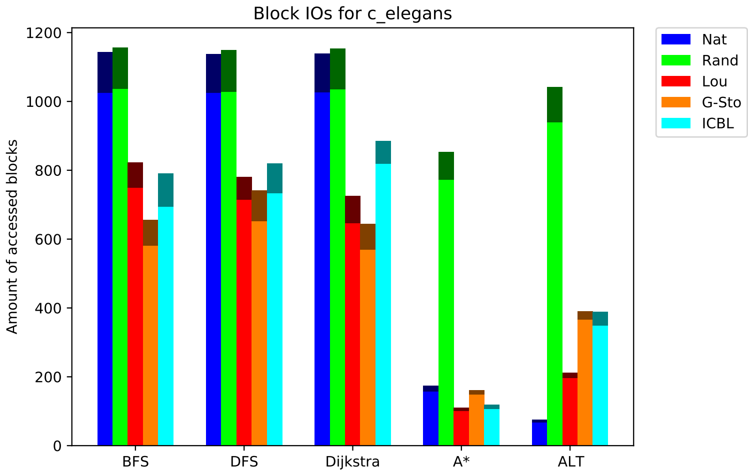
- Domains include biological neural net, e-mails, co-authors, frequent item sets, video channel subscriptions [13].

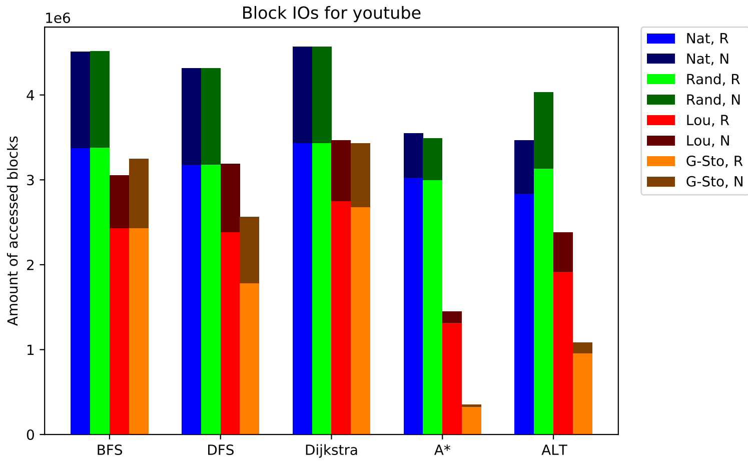
# Setup III

- Simulate IOs using in-memory access layer, queries and record IDs.
- Block no. $=$ record ID $\cdot$ `sizeof`(record struct) $/$ block size
- Buffer of 1 block. $b = 512$ B, $p = 4096$ B
- Consecutive accesses to same block require no additional IO op.
  All other accesses do.

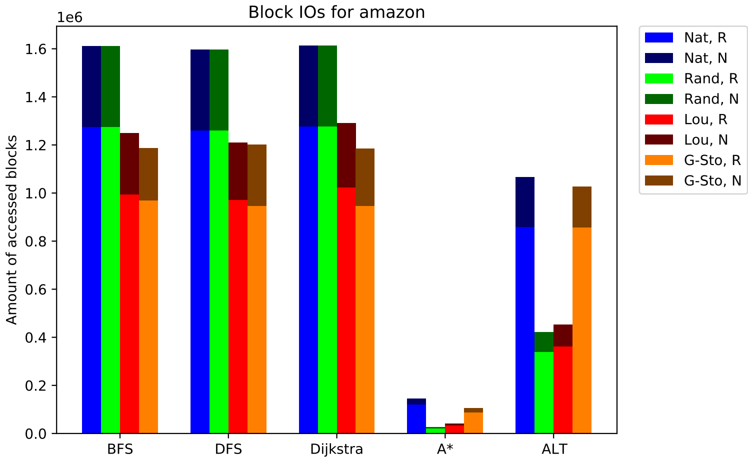
1. Import dataset.
2. Run query and log IDs of accessed nodes and relationships.
3. Calculate sequence of block no. from sequence of IDs.
4. Calculate sequence of page no. from sequence of block no.

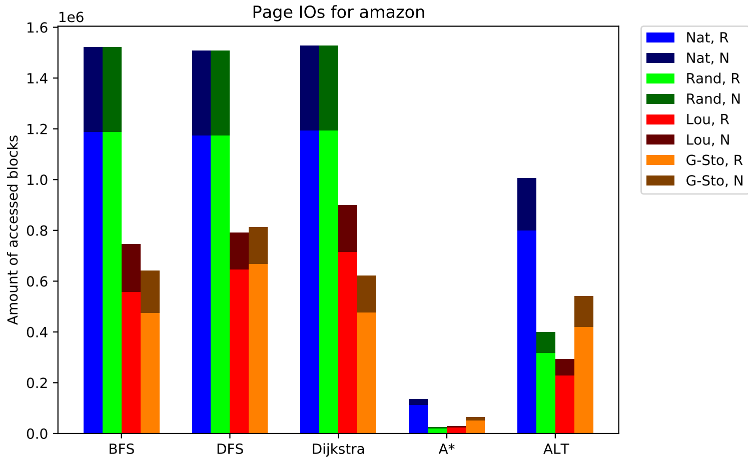
# Results I


Block IOs for c_elegans
Amount of accessed blocks
0
200
400
600
800
1000
1200
BFS
DFS
Dijkstra
A*
ALT
Nat
Rand
Lou
G-Sto
ICBL

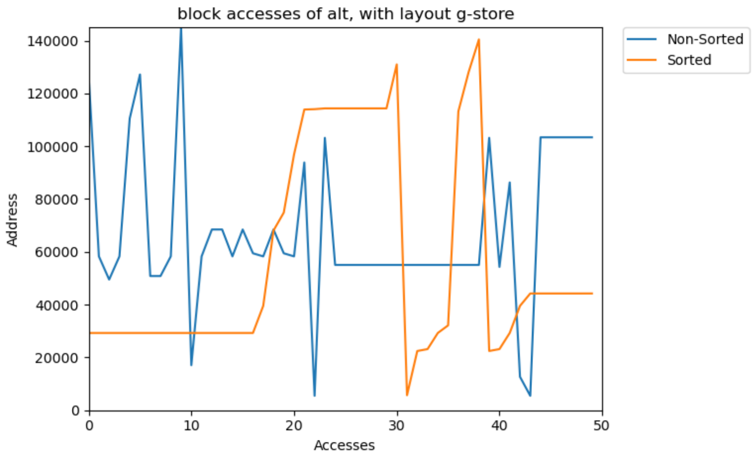

Block IOs for youtube
1e6
Amount of accessed blocks
0
1
2
3
4
BFS
DFS
Dijkstra
A*
ALT
Nat, R
Nat, N
Rand, R
Rand, N
Lou, R
Lou, N
G-Sto, R
G-Sto, N

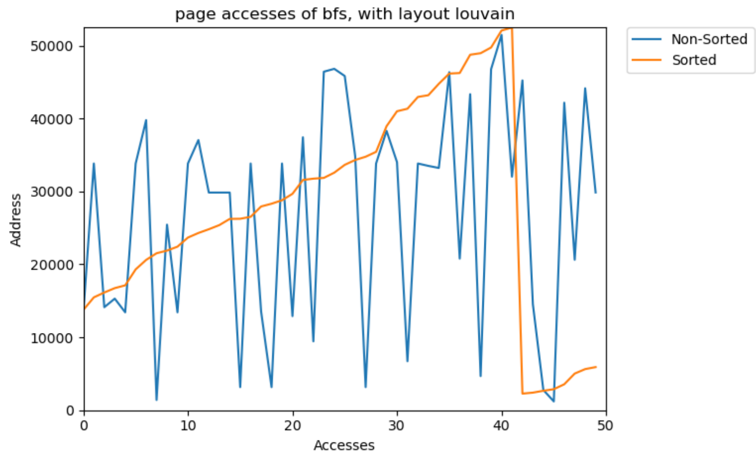
# Results II


Block IOs for amazon
1e6
Amount of accessed blocks
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
BFS
DFS
Dijkstra
A*
ALT
Nat, R
Nat, N
Rand, R
Rand, N
Lou, R
Lou, N
G-Sto, R
G-Sto, N

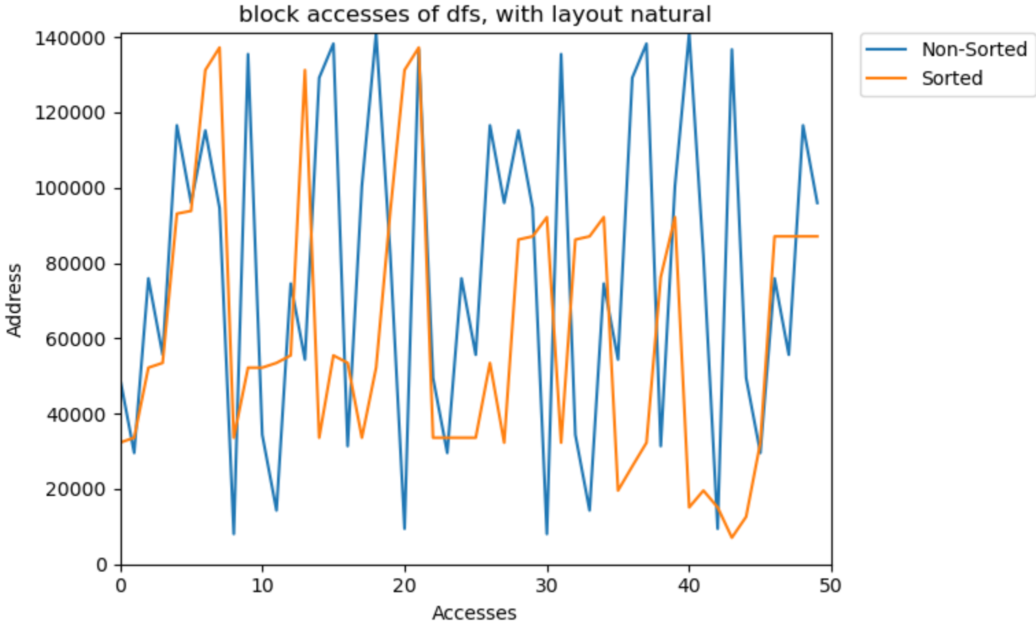

Page IOs for amazon
1e6
Amount of accessed blocks
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
BFS
DFS
Dijkstra
A*
ALT
Nat, R
Nat, N
Rand, R
Rand, N
Lou, R
Lou, N
G-Sto, R
G-Sto, N

# Results III


block accesses of alt, with layout g-store
Non-Sorted
Sorted
Address
Accesses
140000
120000
100000
80000
60000
40000
20000
0
0
10
20
30
40
50


page accesses of bfs, with layout louvain
Non-Sorted
Sorted
Address
Accesses
50000
40000
30000
20000
10000
0
0
10
20
30
40
50

# Results IV


block accesses of dfs, with layout natural
Address
Accesses
140000
120000
100000
80000
60000
40000
20000
0
0
10
20
30
40
50
Non-Sorted
Sorted

# Summary

- Static rearrangement methods increase locality.

  $\Rightarrow$ decrease number of block accesses

- Order of blocks determines spatial locality.

- Sorting the incidence lists leads to more sequential access sequences.

- Results differ between queries

# Future Work

- Leiden [14] instead of Louvain
- RCM-based [15] rearrangement
- Dynamic Rearrangement
  - Query-based
  - History-based

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