Query Processing on Dynamic Networks with Customizable Contraction Hierarchies on Neo4j

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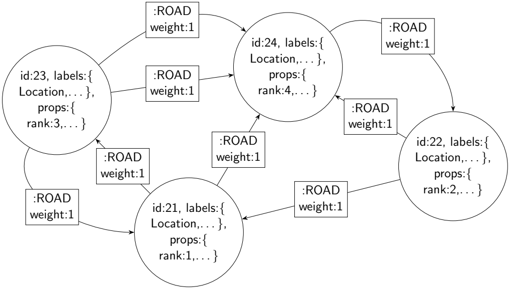
Motivation and Context

- Graph Databases ⇛ External memory
- Accelerate Shortest Path Queries in Databases
- Why Customizable Contraction Hierarchies?
  - fast for main memory applications
  - reasonable preprocessing time
  - It is updatable
- Test Data ⇛ Road Networks

Obstacles

Property Graph:



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Obstacles

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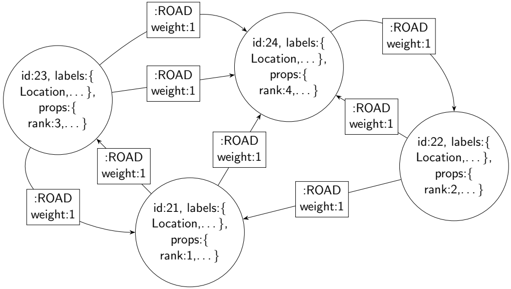
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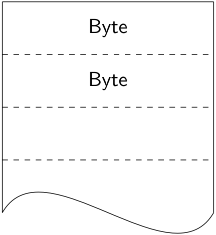
id:21, labels:{ Location,…}, props:{ rank:1,…}

File:



Obstacles

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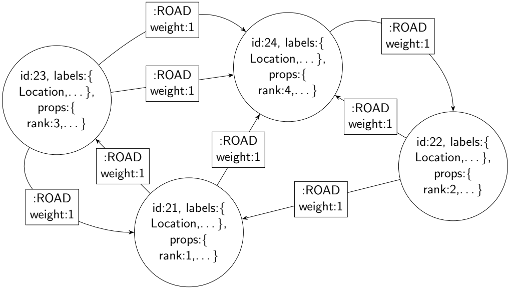
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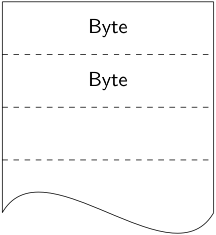

- transformation to data structure with a single dimension

Obstacles

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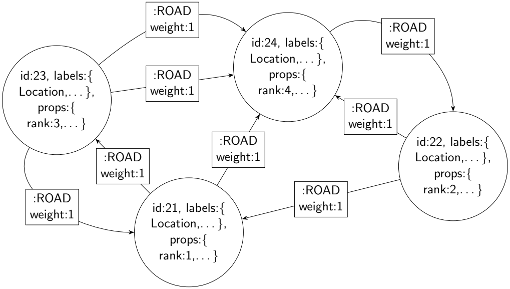
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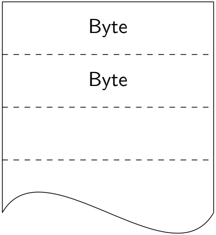
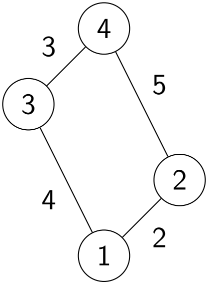


- transformation to data structure with a single dimension
- Databases use HDDs ⇛ slow random access

Contraction Hierarchies Example



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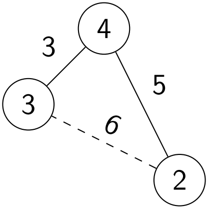
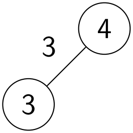


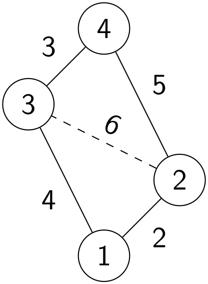
Contraction Hierarchies Example



Contraction Hierarchies Example

Contraction Hierarchies Example

Let's go from v_2 to v_3



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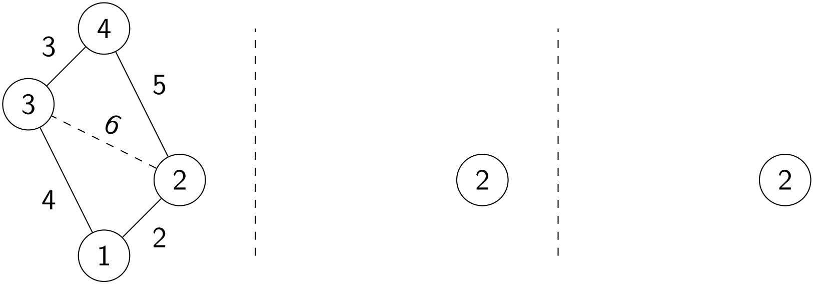

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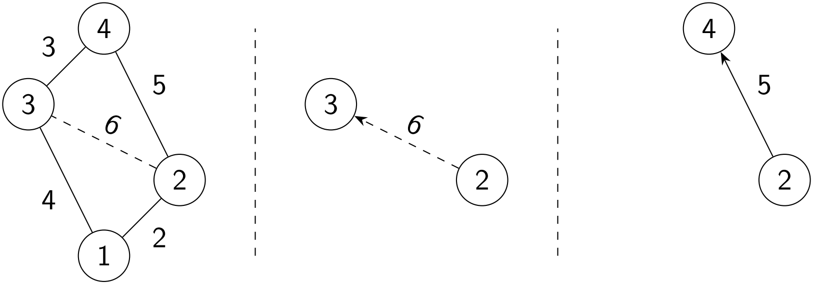

Contraction Hierarchies Example

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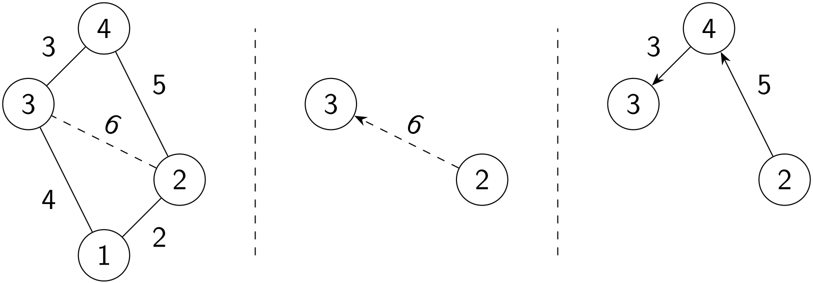
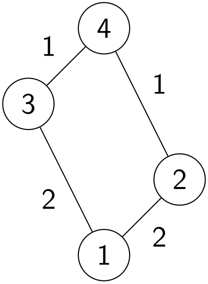
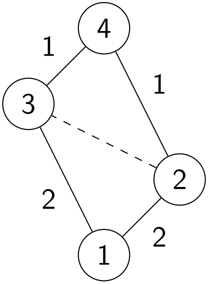


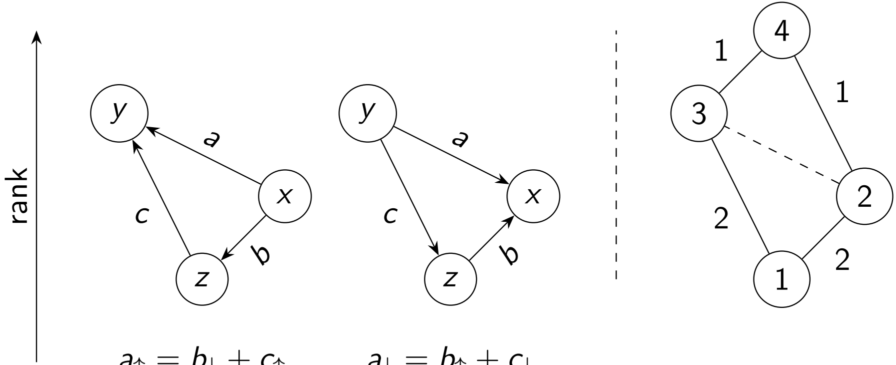
Customizable Contraction Hierarchies

- CH insert shortcut if shortest path property is violated
- CCH insert shortcut if there is no direct connection



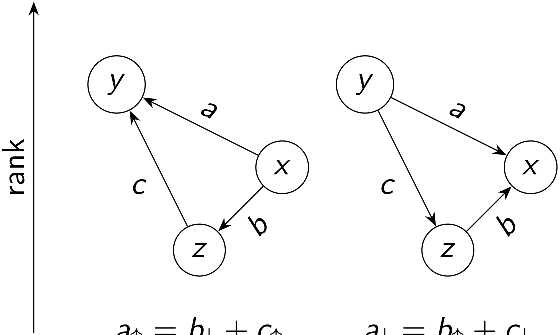


CCH Weights — Lower Triangles

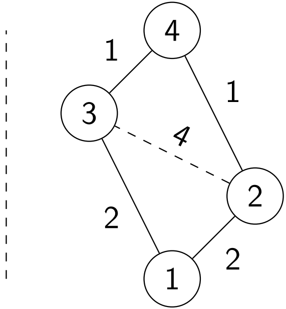


$$a_\uparrow = b_\downarrow + c_\uparrow \qquad a_\downarrow = b_\uparrow + c_\downarrow$$

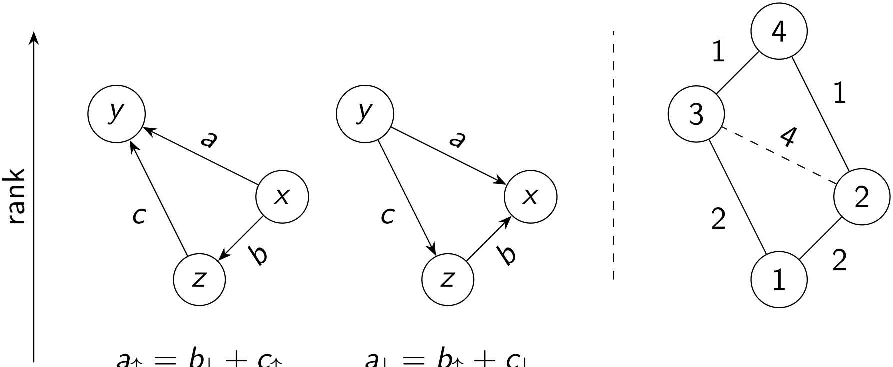
CCH Weights — Lower Triangles



$a_{\uparrow} = b_{\downarrow} + c_{\uparrow}$ $\qquad$ $a_{\downarrow} = b_{\uparrow} + c_{\downarrow}$



CCH Weights — Lower Triangles

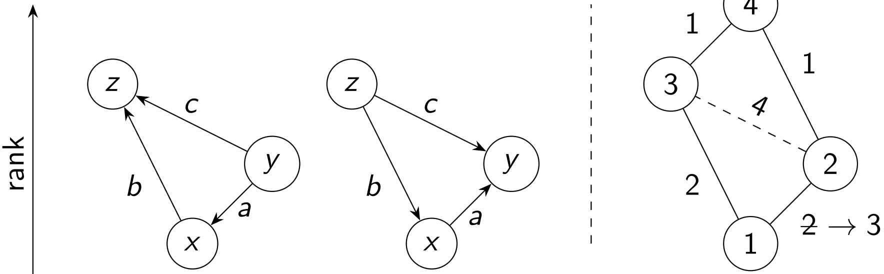


$$a_{\uparrow} = b_{\downarrow} + c_{\uparrow} \qquad a_{\downarrow} = b_{\uparrow} + c_{\downarrow}$$

Bottom up for every arc! Also original arcs

CCH Update — Upper Triangle

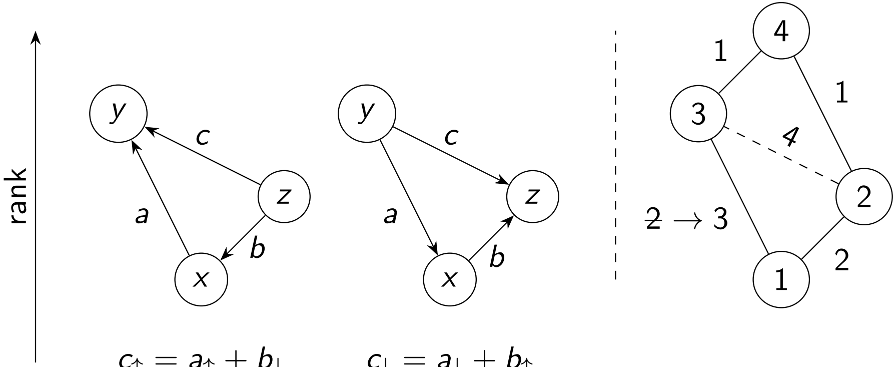
- Check if edge(y,z) could rely in edge(x,y)
- If yes ⇛ redo lower triangles for e(y,z)



$$c_\uparrow = a_\downarrow + b_\uparrow \qquad c_\downarrow = a_\uparrow + b_\downarrow$$

CCH Update — Intermediate Triangle

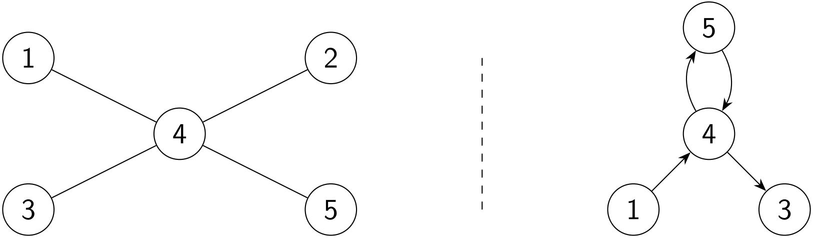
- Check if edge(y,z) could rely in edge(x,y)
- If yes ⇛ redo lower triangles for e(y,z)



$c_{\uparrow} = a_{\uparrow} + b_{\downarrow}$ $c_{\downarrow} = a_{\downarrow} + b_{\uparrow}$

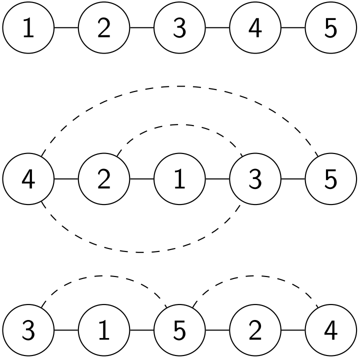
Important vertex not contraced Last

- Contracted Using Edge Difference
- Go from v(1) to v(3)
- Forward and Backward search are deeper that the should be
- Switch contraction order of v(4) and v(5)



Linear Contraction

1. linear contraction
   - No Shortcuts
   - Could happen with ED
   - four vertices to expand
2. middle vertex first
   - Three Shortcuts
   - four vertices to expand
3. good contraction order
   - Three Shortcuts
   - four vertices to expand



Importance Calculation

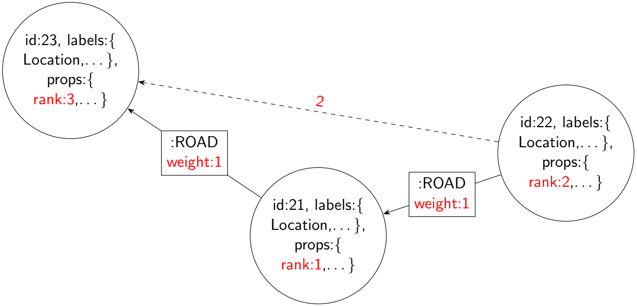
- add a level $l(v) = 0$ to each node
- if contracting v: $l(v) = max\{l(v) + 1, l(w)\} \forall w \epsilon N(v)$
- $A(v)$ set of added arcs
- $D(v)$ set of deleted arcs
- $h(a)$ hops an arc represents if unpacked

$$i(v) = l(v) + \frac{|A(v)|}{|D(v)|} + \frac{\sum_{a \epsilon A(v)} h(a)}{\sum_{a \epsilon D(v)} h(a)}$$

Important theorem

more shortcuts inserted but improves query time!

Persistance Objectives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2
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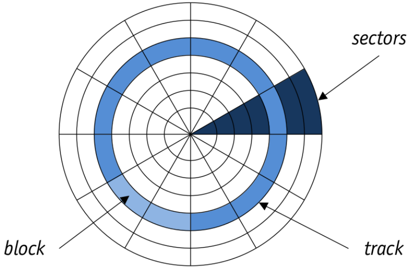
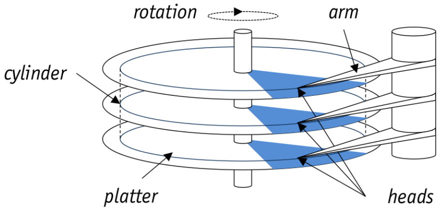
id:21, labels:{ Location,...}, props:{ rank:1,...}

- keep only necessary data
    - rank → to do the mapping to the input graph
    - arc weight
- Store edges that are likely to be request together spacial close
- Use as few space as possible → the less you write the less you read

Magnetic Disks





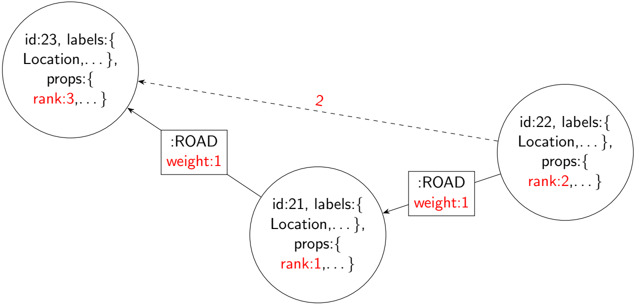
- Data is arranged in concentric rings (tracks) on platters
- Tracks are divided into arc-shaped sectors

One by One

Data is read from and written to disk one **block** at a time

Transformation to a Table

- Depth-First-Search starting at highest rank
- retrieve only arcs. vertices will be reconstructed form arcs
- remember middle node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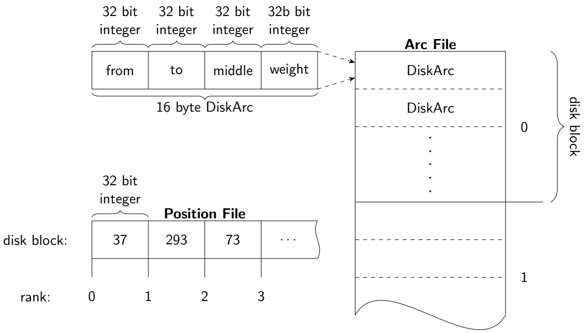
id:21, labels:{ Location,...}, props:{ rank:1,...}

start rank	end rank	middle rank	weight
1	3	-1	1
2	3	1	2

Store Example



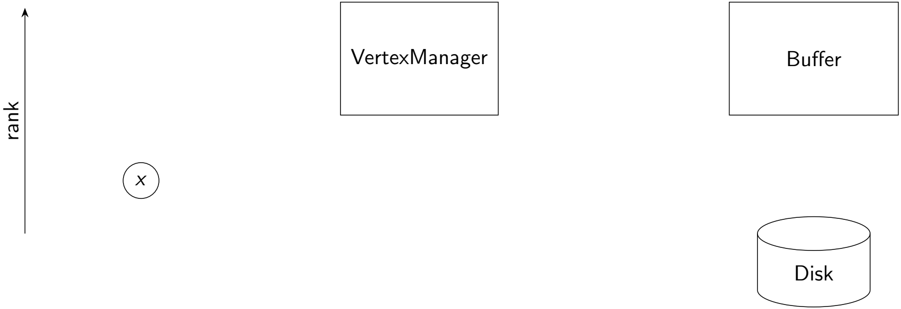
- fill all arcs of a vertex into a block
- add block number of rank to position file. $G_\uparrow$ use *from* ; $G_\downarrow$ use *to*
- if next vertex' arcs don't fit anymore → flush block and take next

Min Block Size

$$max(d_{\uparrow max}(v), d_{\downarrow max}(v)) \leqslant \frac{diskBlockSize}{16}$$

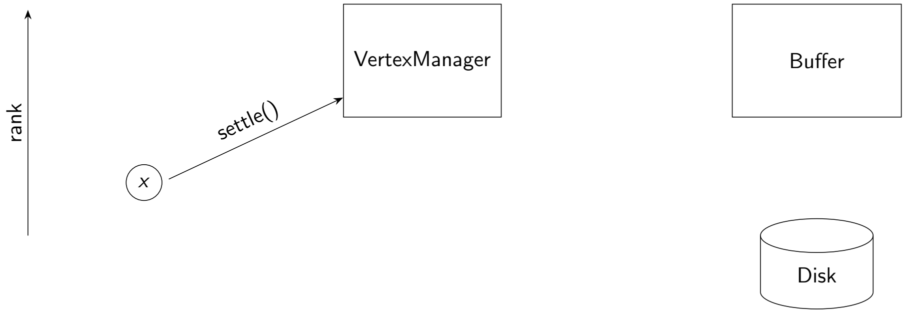
CCH Disk Search (upwards graph example)

1. lazy load vertices ⇒ only start node is loaded without arcs



CCH Disk Search (upwards graph example)

1. lazy load vertices ⇒ only start node is loaded without arcs
2. settle vertex (right before expanding it)



CCH Disk Search (upwards graph example)

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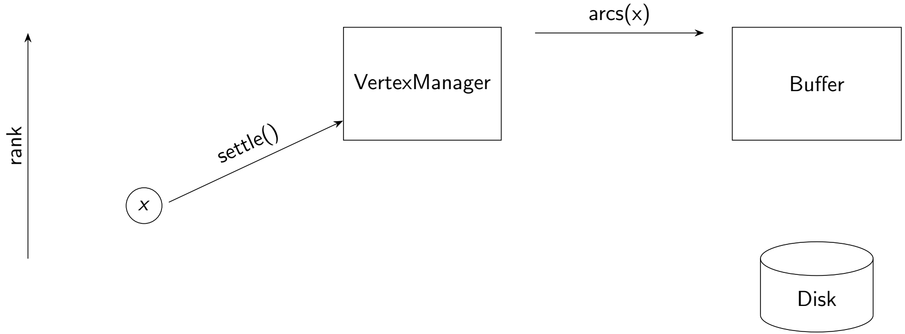
    - VertexManager requests arc of v(x) from buffer



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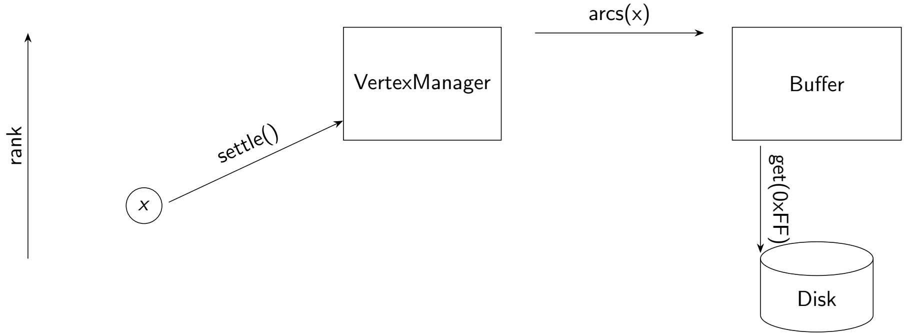

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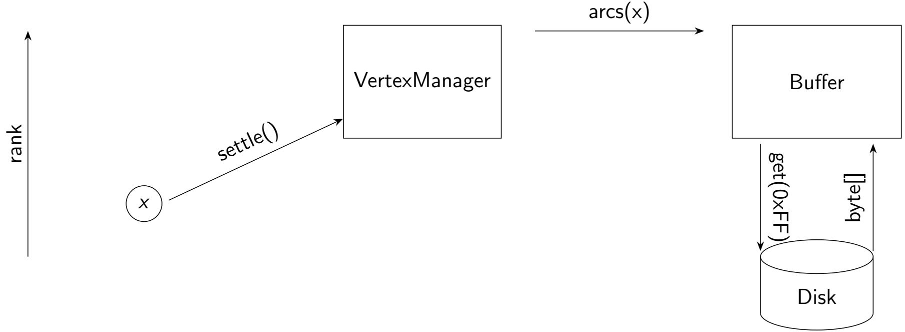

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   - VertexManager requests arc of v(x) from buffer
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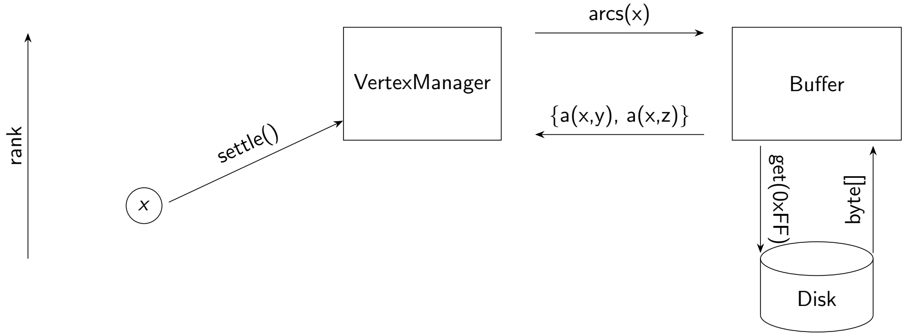
   - Buffer returns arcs



CCH Disk Search (upwards graph example)

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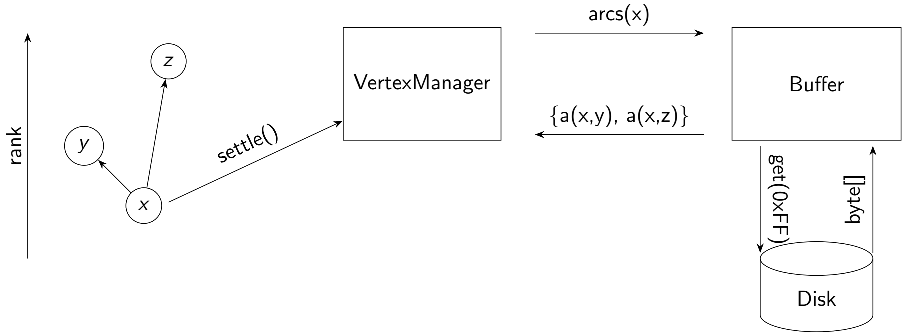
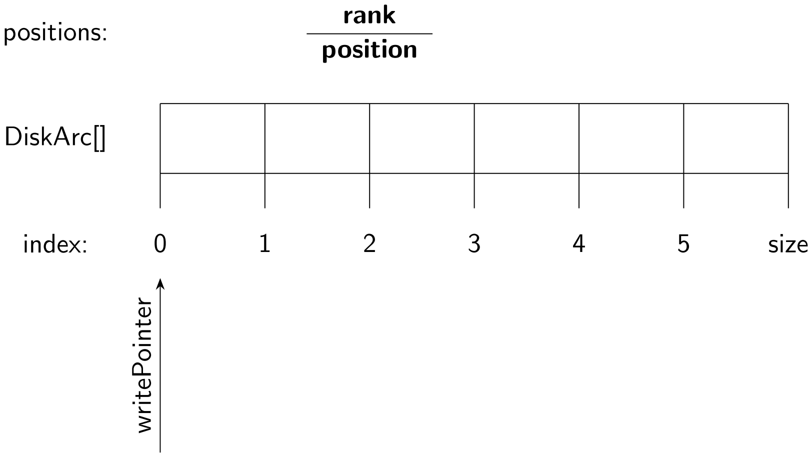
2. settle vertex (right before expanding it)
   - VertexManager requests arc of v(x) from buffer
   - Buffer requests arcs from disk if not cached yet
   - Buffer returns arcs
   - VertexManager attaches arcs to v(x)



Circular Buffer



positions:

rank

position

DiskArc[]

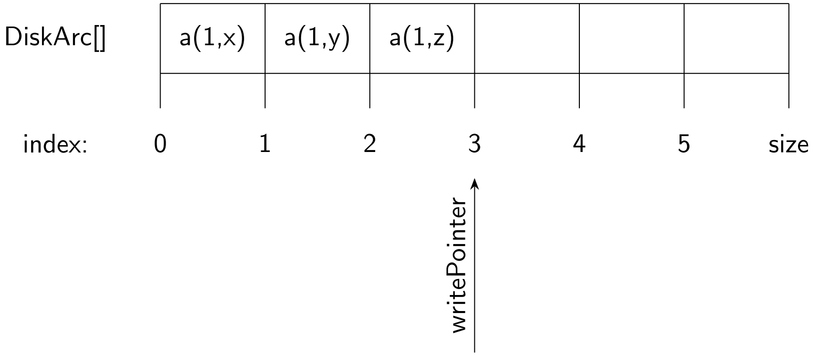
index: 0 1 2 3 4 5 size

writePointer

Circular Buffer

positions:

rank	1
position	2



DiskArc[]

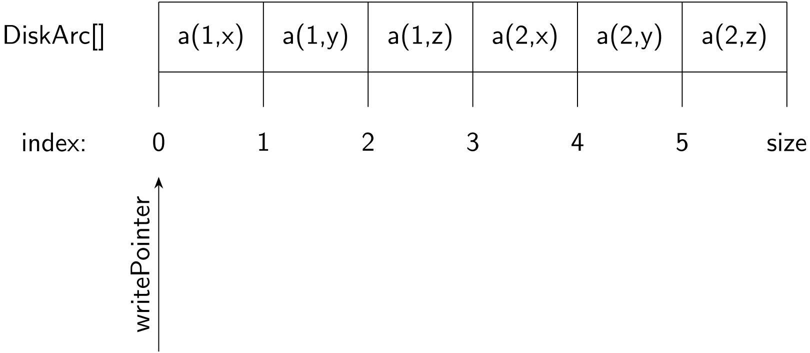
a(1,x)	a(1,y)	a(1,z)			

index: 0 1 2 3 4 5 size

Circular Buffer

positions:

rank	1	2
position	2	5



DiskArc[]

a(1,x)	a(1,y)	a(1,z)	a(2,x)	a(2,y)	a(2,z)

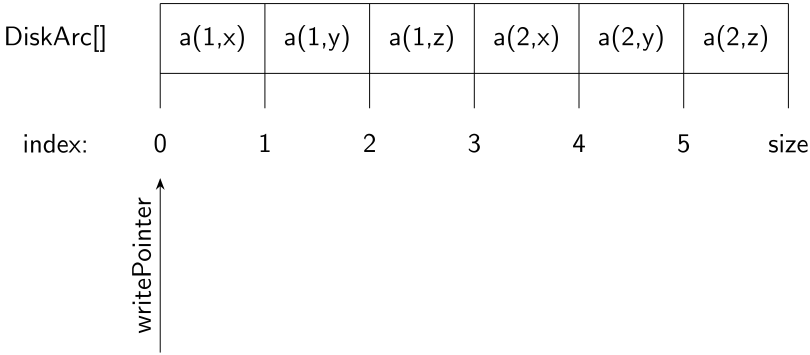
index: 0 1 2 3 4 5 size

writePointer

Circular Buffer

positions:

rank	1	2	max(rank)
position	2	5	-1



DiskArc[]

a(1,x)	a(1,y)	a(1,z)	a(2,x)	a(2,y)	a(2,z)

index: 0 1 2 3 4 5 size

Circular Buffer

positions:

rank	1	2	3	max(rank)
position	2	5	3	-1

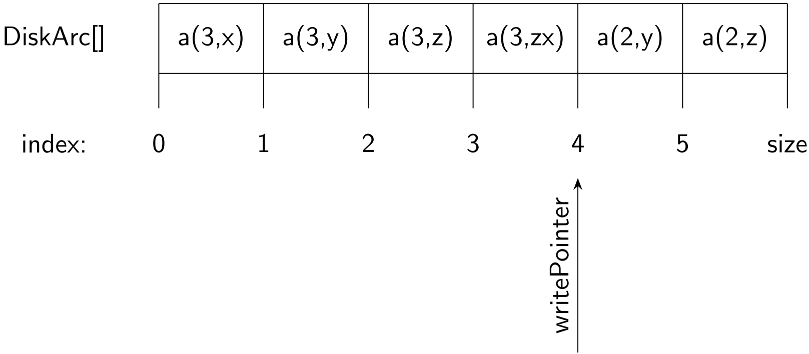
DiskArc[]	a(3,x)	a(3,y)	a(3,z)	a(3,zx)	a(2,y)	a(2,z)	
index:	0	1	2	3	4	5	size
					writePointer		

remove incomplete edge set from position

Circular Buffer

positions:

rank	1	3	max(rank)
position	2	3	-1



DiskArc[]	a(3,x)	a(3,y)	a(3,z)	a(3,zx)	a(2,y)	a(2,z)	
index:	0	1	2	3	4	5	size

writePointer

Circular Buffer

positions:

rank	1	3	max(rank)
position	2	3	-1

DiskArc[]	a(3,x)	a(3,y)	a(3,z)	a(3,zx)	a(2,y)	a(2,z)

index: 0 1 2 3 4 5 size

- Retrieve Arcs ⇛ iterate backwards from position until start vertex differs
- If arc is doesn't start with requested rank ⇛ remove position and refetch

General Results

	New York	Colorado	Florida	California +Nevada	Great Lakes	Eastern USA
$\lvert V \rvert$	264,346	435,666	1,070,376	1,890,815	2,758,119	3,598,623
$\lvert A \rvert$	730,100	1,042,400	2,687,902	4,630,444	6,794,808	8,708,058
$\lvert S \rvert$	2,153,002	1,680,290	4,397,804	8,598,552	17,833,050	17,712,722
$\frac{\lvert S \rvert}{\lvert A \rvert}$	2.93	1.59	1.62	1.85	2.62	2.03
$t_{contraction}$	545 s	233 s	579 s	4,384 s	25.29 h	23.29 h
$max(d(v))$	1,150	629	785	1,252	2,433	2,391
$\lvert \bigcirc A_{\uparrow} \rvert$	23.1 MB	21.9 MB	56.9 MB	107 MB	201 MB	215 MB
pos-file$_{\uparrow}$	1.1 MB	1.8 MB	1.3MB	7.6 MB	11.1 MB	14.4 MB
$t_{dijkstra}$	0.816 s	0.549 s	2.630 s	4.858 s	5.425 s	5.387 s
t_{cch}^{640kB}	0.140 s	0.122 s	0.147 s	0.289 s	0.732 s	0.727 s
I/O^{640kB}	574	437	500	899	1671	1572
t_{update}	90 s	51 s	142 s	444 s	1827s	1557s
$t_{cch-updated}^{640kB}$	0.147 s	0.129 s	0.150 s	0.302 s	0.783 s	0.855 s
$I/O_{cch-upd.}^{640kB}$	569	457	516	924	2779	2716
$t_{cch-updated}^{20\%}$	0.136 s	0.130 s	0.092 s	0.183 s	0.660 s	0.680 s
$I/O_{cch-upd.}^{20\%}$	315	307	226	283	804	680
$t_{cch-updated}^{100\%}$	0.062 s	0.038 s	0.039 s	0.099 s	0.438 s	0.479 s

New York — Colorado — Florida

	New York	Colorado	Florida
$\|V\|$	264,346	435,666	1,070,376
$\|A\|$	730,100	1,042,400	2,687,902
$\|S\|$	2,153,002	1,680,290	4,397,804
$\frac{\|S\|}{\|A\|}$	2.93	1.59	1.62
$t_{contraction}$	545 s	233 s	579 s
$max(d(v))$	1,150	629	785
$\|\bigcirc A_{\uparrow}\|$	23.1 MB	21.9 MB	56.9 MB
pos-file$_{\uparrow}$	1.1 MB	1.8 MB	1.3MB
t_{update}	90 s	51 s	142 s

New York — Colorado — Florida

	New York	Colorado	Florida
$t_{dijkstra}$	0.816 s	0.549 s	2.630 s
t_{cch}^{640kB}	0.140 s	0.122 s	0.147 s
$t_{cch-updated}^{640kB}$	0.147 s	0.129 s	0.150 s
$t_{cch-updated}^{20\%}$	0.136 s	0.130 s	0.092 s
$t_{cch-updated}^{100\%}$	0.062 s	0.038 s	0.039 s

New York — Colorado — Florida

	New York	**Colorado**	**Florida**
I/O^{640kB}	574	437	500
$I/O^{640kB}_{cch-upd.}$	569	457	516
$I/O^{20\%}_{cch-upd.}$	315	307	226

Colorado — Florida — California and Nevada

	Colorado	**Florida**	**California +Nevada**
$\lvert V\rvert$	435,666	1,070,376	1,890,815
$\lvert A\rvert$	1,042,400	2,687,902	4,630,444
$\lvert S\rvert$	1,680,290	4,397,804	8,598,552
$t_{contraction}$	233 s	579 s	4,384 s
t_{update}	51 s	142 s	444 s

Colorado — Florida — California and Nevada

	Colorado	**Florida**	**California +Nevada**
$\frac{\lvert S\rvert}{\lvert A\rvert}$	1.59	1.62	1.85
$max(d(v))$	629	785	1,252
$t_{dijkstra}$	0.549 s	2.630 s	4.858 s
t_{cch}^{640kB}	0.122 s	0.147 s	0.289 s
$t_{cch-updated}^{640kB}$	0.129 s	0.150 s	0.302 s
$t_{cch-updated}^{20\%}$	0.130 s	0.092 s	0.183 s
$t_{cch-updated}^{100\%}$	0.038 s	0.039 s	0.099 s

Colorado — Florida — California and Nevada

	Colorado	**Florida**	**California +Nevada**
I/O^{640kB}	437	500	899
$I/O^{640kB}_{cch-upd.}$	457	516	924
$I/O^{20\%}_{cch-upd.}$	307	226	283

California — Great Lakes — Estern USA

	California +Nevada	**Great Lakes**	**Eastern USA**
$\|V\|$	1,890,815	2,758,119	3,598,623
$\|A\|$	4,630,444	6,794,808	8,708,058
$\|S\|$	8,598,552	17,833,050	17,712,722
$\frac{\|S\|}{\|A\|}$	1.85	2.62	2.03
$t_{contraction}$	4,384 s	25.29 h	23.29 h
$max(d(v))$	1,252	2,433	2,391
$\|\bigcirc A_{\uparrow}\|$	107 MB	201 MB	215 MB
pos-file$_{\uparrow}$	7.6 MB	11.1 MB	14.4 MB
t_{update}	444 s	1827s	1557s

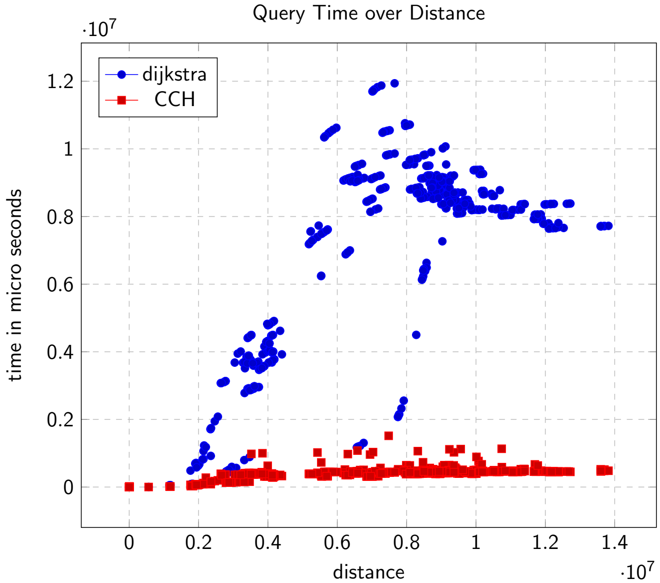
California — Great Lakes — Estern USA

	California +Nevada	**Great Lakes**	**Eastern USA**
$t_{dijkstra}$	4.858 s	5.425 s	5.387 s
t_{cch}^{640kB}	0.289 s	0.732 s	0.727 s
$t_{cch-updated}^{640kB}$	0.302 s	0.783 s	0.855 s
$t_{cch-updated}^{20\%}$	0.183 s	0.660 s	0.680 s
$t_{cch-updated}^{100\%}$	0.099 s	0.438 s	0.479 s

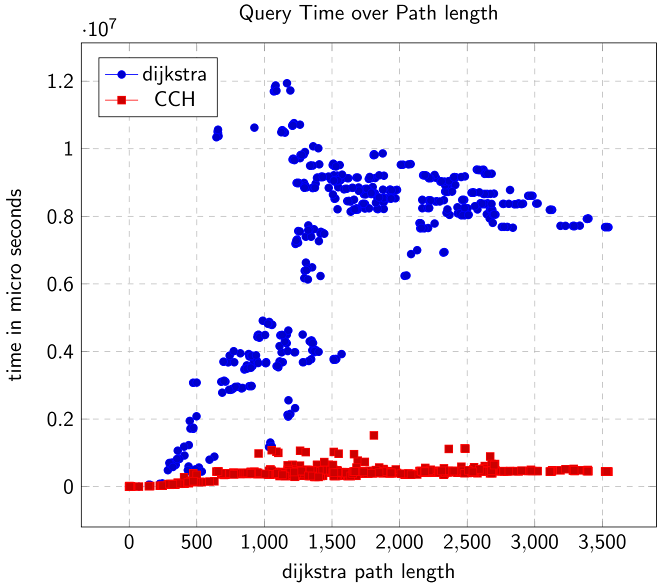
California — Great Lakes — Estern USA

	California +Nevada	**Great Lakes**	**Eastern USA**
I/O^{640kB}	899	1671	1572
$I/O^{640kB}_{cch-upd.}$	924	2779	2716
$I/O^{20\%}_{cch-upd.}$	283	804	680

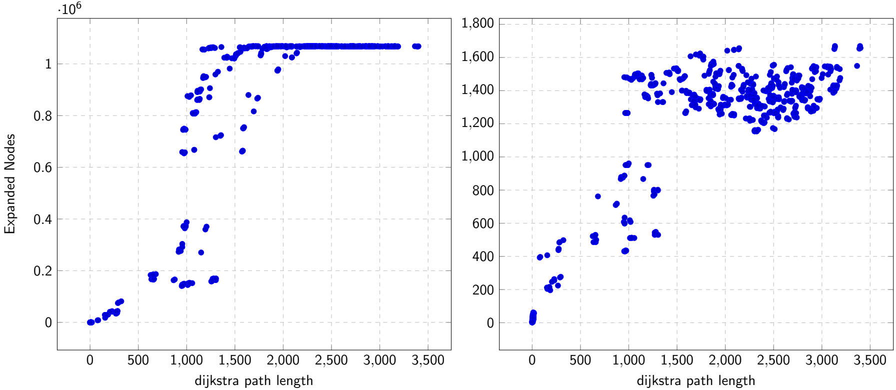
Dijkstra vs. CCH — Query Time



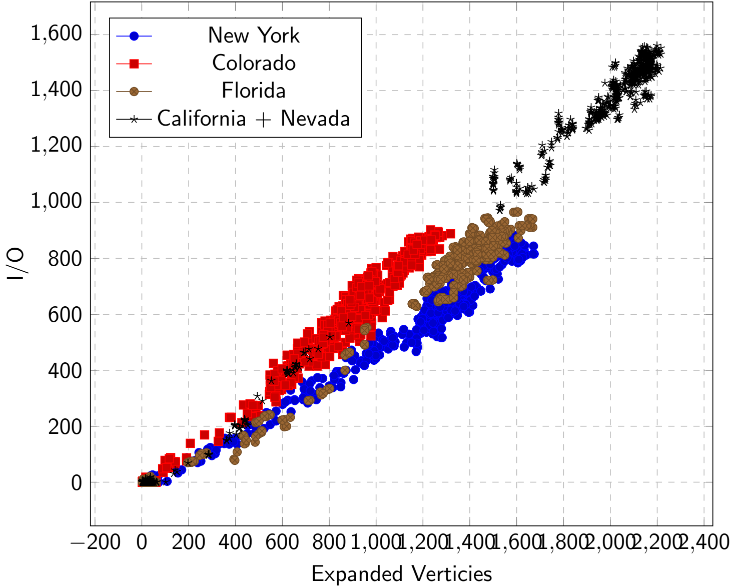
Dijkstra vs. CCH — Query Time



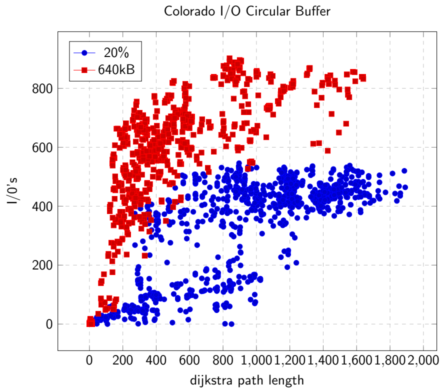
Expanded Vertices

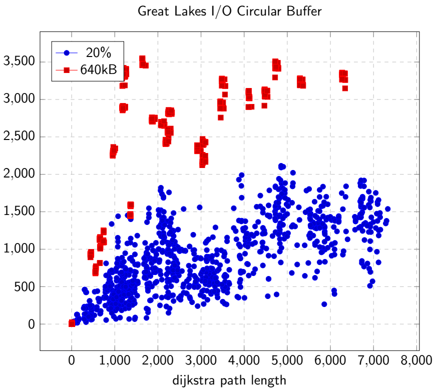


Buffer 640 kB



Buffer 20% Arc Count





Conclusion

- We can accelerate Graph Databases with CCH
- The major problem is to flatten the graph
- Try it with a Relational Database