Historical Queries on Graphs

Issues and Challenges

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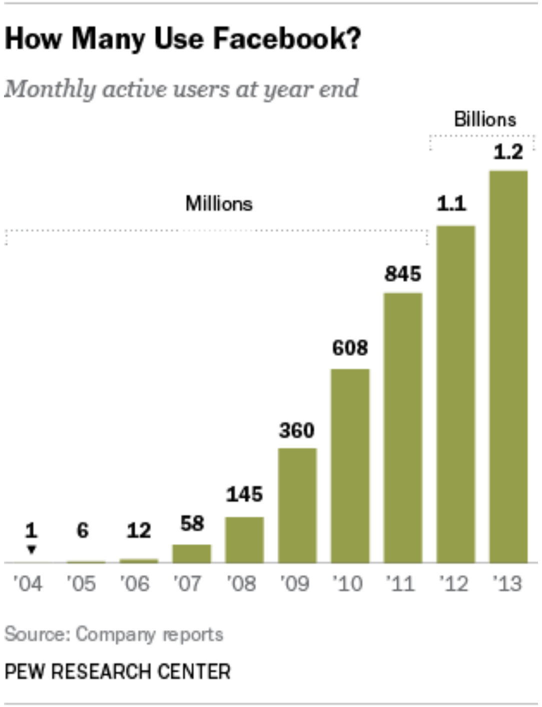
Why?

(Almost) all real-life graphs evolve over time (social networks included)

Both

- *Structure* (nodes, edges)
- *Content* (node and edge properties/content)



How Many Use Facebook?

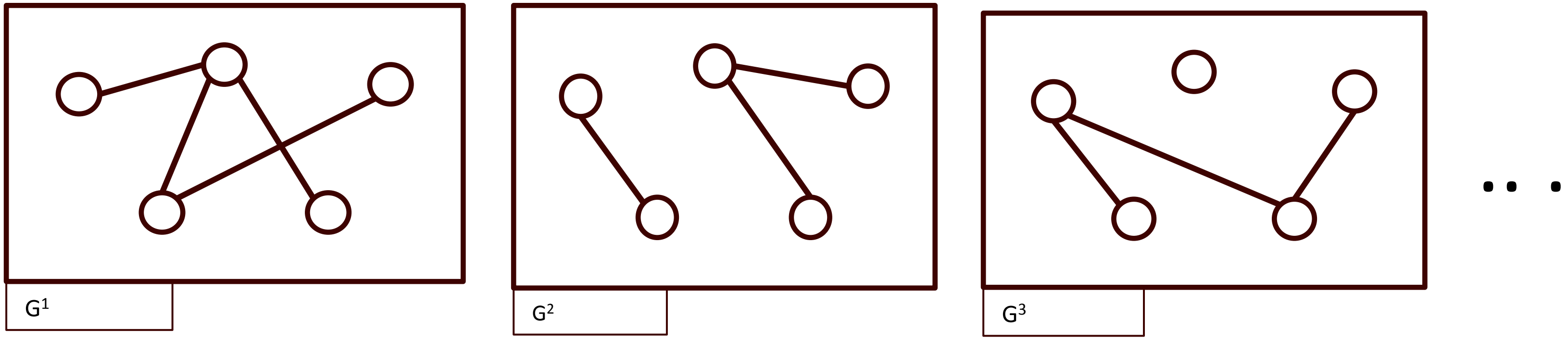
Monthly active users at year end

Source: Company reports

PEW RESEARCH CENTER

Challenge

Evolving graph: A sequence of graph snapshots G^t at time instance *t*



Store and process an evolving graph

Both

- Analytical processing and graph mining (community evolution, PageRank, diameter, betweeness, etc)
- *Online* query processing

Query types

Historical queries: queries that refer to the past

as opposed to queries that refer to a single (the current) snapshot of the graph)

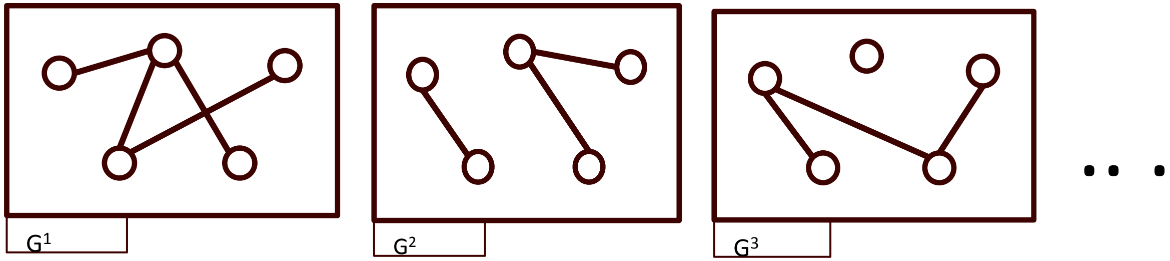
All types of graph queries

- Reachability, Shortest path
- Regular expressions, Graph patterns

- Single snapshot
- Multiple snapshots – *interval* [t_1, t_2]

semantics [SLP14]: conjunctive (in all), disjunctive (in at least one), at least-*k* semantics

e.g., is *v* reachable from *u*? degree of *v*?



Query types

Queries about *the evolution itself*

New range of graph queries

E.g.,

- What is the *first time* that *X* happened
- The *maximum time interval* for *X*
- *How many times X* happened
- *What/how* much *X* changed

Historical queries different than queries on *dynamic graphs* and *graph streams*

Some issues

What type of queries?

How to store?

How to process queries?

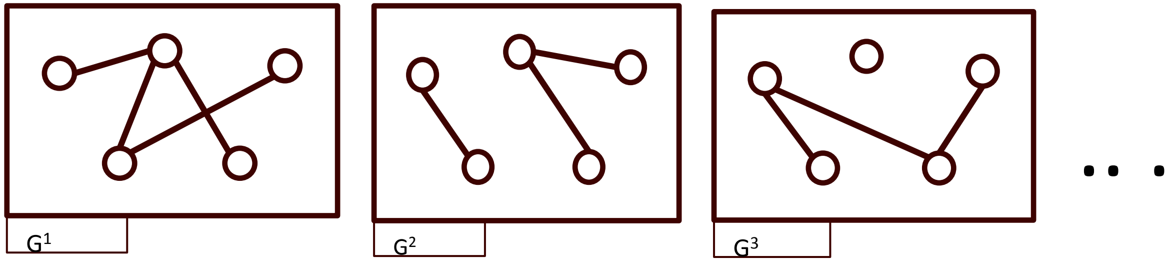
How to index?

Storage

Two fundamental approaches [KSP12]

1. Use of *deltas* [KD13]

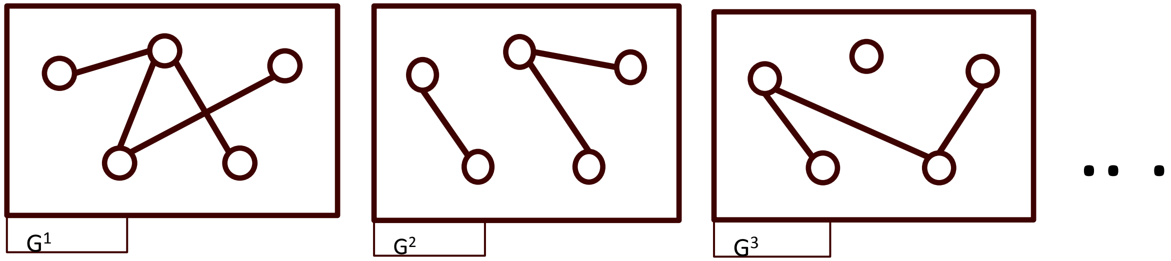
- Store (on disk)
  selected graph snapshots +
  operational deltas (logs) Δ (list of operations, e.g., add-edge, delete-edge, etc) G^1 *Δ = add(1, 2), delete(2, 4) etc*
- To create any snapshot G_t
  apply deltas on materialized snapshots

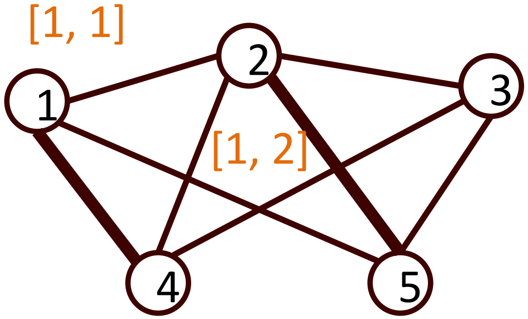


Storage

2. Versioning

Annotate the graph (edges, nodes, properties) with validity intervals





A note on partitioning (in memory, parallelism)[HKL+14, LBO+14]:

Two levels of locality:

- Temporal
- Structural

Query-dependent

Query execution plan

Simple 2-Level Strategy

1. Construct the required snapshots (e.g., apply the deltas, or use a time-index)
2. Use known algorithms

Find-Verify-and-Fix [VLDB11 paper]

Preprocessing

cluster similar snapshots

extract two representatives from each cluster ($G_\cap$ and $G_\cup$)

1. Apply query to each representative
2. For each graph snapshot G^t, *verify* the solution
3. If not verified, apply query on G^t

Partial Reconstruction [KP13]

Egocentric queries:

Restrict snapshots' reconstruction around a specific node

Index

To avoid online traversal, indexes for specialized graph queries (reachability, shortest-path, patterns)

Example:

For each node u in G, a *2 hop-code or label* (Lin(u), Lout(u)) such that for each pair of nodes u, v in G, v is *reachable from* u, if and only if,

$$\mathrm{Lin}(u) \cap \mathrm{Lout}(v) \neq \varnothing$$

L landmarks $w_1, w_2, \ldots, w_L$, such that for each pair *u*, *v* at least one w_i belongs to their shortest path

For each node *u*, a label $(d(u, w_1), d(u, w_2)\ldots d(u, w_L))$

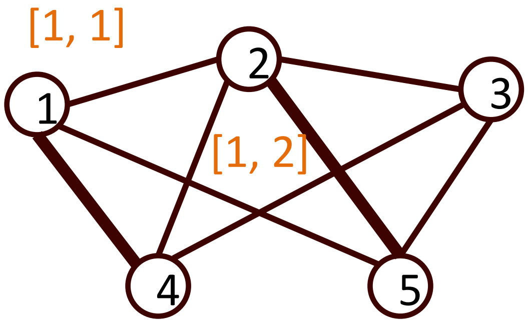
$$d(u, v) = \min_i(d(u, w_i) + d(v, w_i))$$

Index

- Single (current) snapshot
- Can we extend them for evolving graphs?
- What is their minimum size?

Shortest-path [HT14, AIY14 (insert only)]

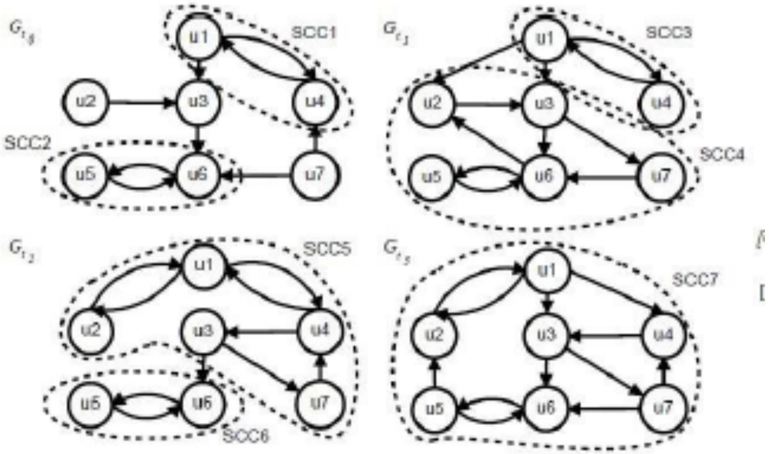
Our work on historical reachability queries (TimeReach)

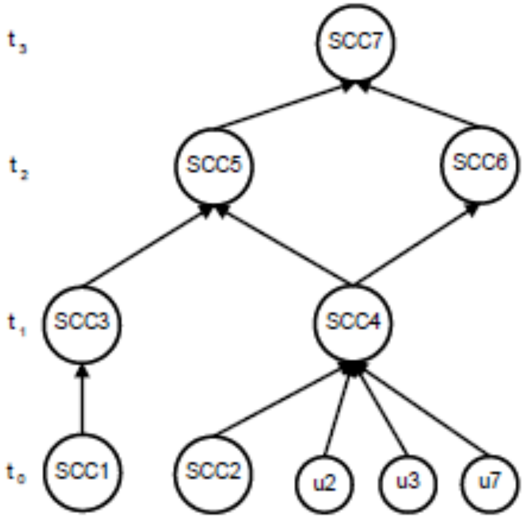


- Edge labels are interval sets
- Interval representation using bit vectors

  [2, 3] -> 0110000
- Efficient bit-wise operations for online traversal (time-interval joins)

Our work on historical reachability queries (TimeReach)

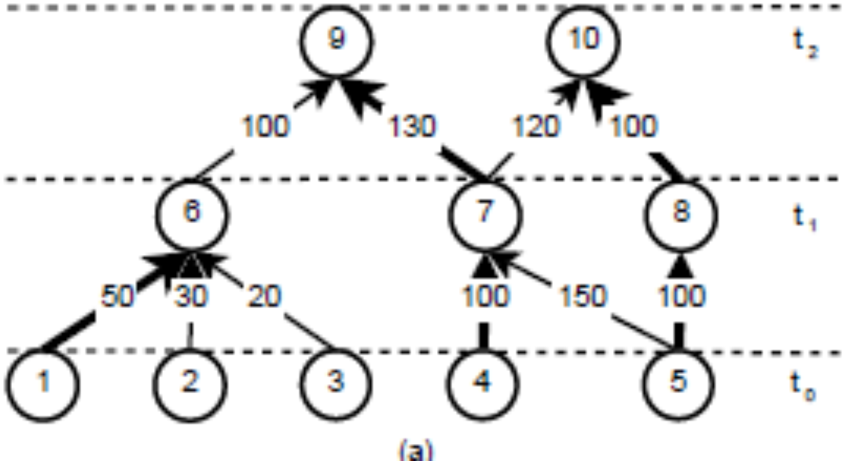




- Mapping SCCs across snapshots
- Maintain historical 2HOP for components

Our work on historical reachability queries (TimeReach)

Goal: minimum number of components



Show equivalence with bipartite mapping

Conclusions

There is more than the current snapshot

It is important to look into the type of queries that involve the whole sequence and how to process them

Related work (partial list)

[AIY14] T. Akiba, Y. Iwata, Y. Yoshida, *Dynamic and historical shortest-path distance queries on large evolving networks by pruned landmark labeling*, WWW 2014

[HKL+14] W. Han, Y. Miao, K. Li, M. Wu, F. Yang, L. Zhou, V. Prabhakaran, W. Chen, E. Chen, Chronos: A Graph Engine for Temporal Graph Analysis, EuroSys 2014

[HT14] W. Huo, V. Tsotras, *Efficient temporal shortest path queries on evolving social graphs*, SSDBM 2014

[KD13] U. Khurana, A. Deshpande, *Efficient snapshot retrieval over historical graph data*, ICDE 2013

[KSP12] G. Koloniari, D. Souravlias, E. Pitoura, *On Graph Deltas for Historical Queries*, WOSS 2012, VLDB workshop

[KP13] G. Koloniari, E. Pitoura, *Partial view selection for Evolving Social Graphs*, GRADES 2013

[LBO+] A. G. Labouseur, J. Birnbaum, P. Olsen Jr., Sean R. Spillane, J. Vijayan, W. Han, J. Hwang, *The G* Graph Database: Efficiently Managing Large Distributed Dynamic Graphs*, DAPD, (2014).

[RLK+11] C. Ren, E. Lo, B. Kao, X. Zhu, R. Cheng: *On Querying Historical Evolving Graph Sequences*. VLDB 2011

[SLP14] K. Semertzidis, K. Lillis, E. Pitoura: *TimeReach: Indexing for Historical Reachability Queries*, under submission

Thank you! Questions?

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