Distributed Exact Subgraph Matching in Small Diameter Dynamic Graphs

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Outline

- Subgraph Matching
- Dynamic Graphs
- Exact Subgraph Matching in Dynamic Graphs
- Graph Pruning
- Evaluation
- Conclusion and Future Work

Subgraph Matching

Input: Data graph G (V, E, L), Query graph Q (V^q, E^q, L^q)

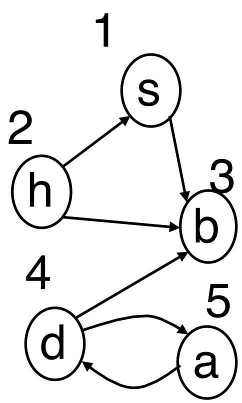
Output: All subgraphs in G that "match" Q

- Applications
  - Search in OSN, Knowledge graphs, plagiarism detection, …
- Matching Models
  - Subgraph Isomorphism
    - Exact matching
  - Graph Simulation
    - Relaxed matching

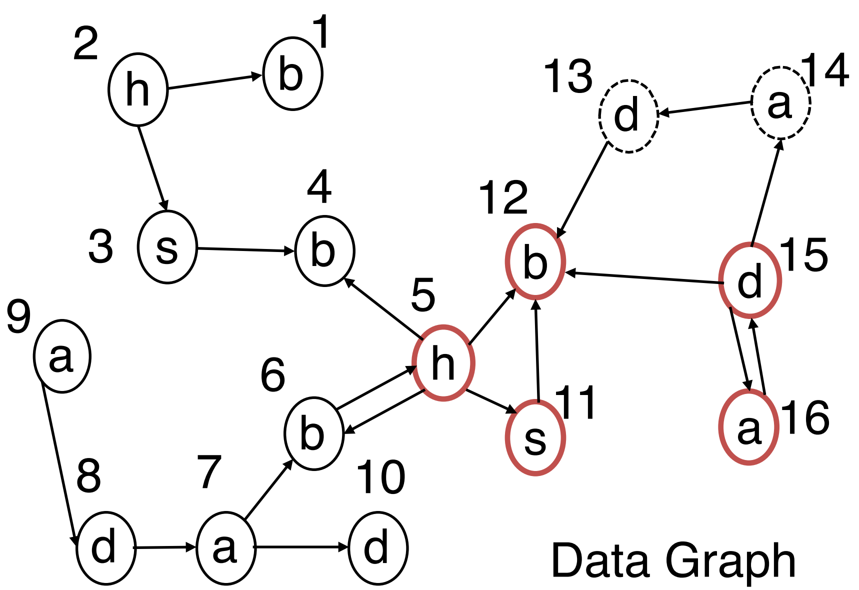
Subgraph Isomorphism

Q matches data graph G iff there exists subgraph $G^S \subseteq G$ and bijective function f: $V^Q \rightarrow V^S$ such that

- any node $v \in V^q$ and $f(v) \in V^S$ have the same label
- An edge $(v_i, v_j) \in E^q$ *exists iff* $\left(f(v_i), f(v_j)\right) \in E^S$



Query Graph



Data Graph

Graph Simulation

Subgraph Simulation:

- Q matches data graph G if a binary relation $R \subseteq V^q \times V$ exists such that
  - 1) if $(u, u') \in R$ then $l^q(u) = l(u')$;
  - 2) $\forall (u, v) \in E^q, \exists (u', v') \in E: (u, u') \in R$;
  - 3) $\forall u \in V^q, \exists u' \in V: (u, u') \in R$

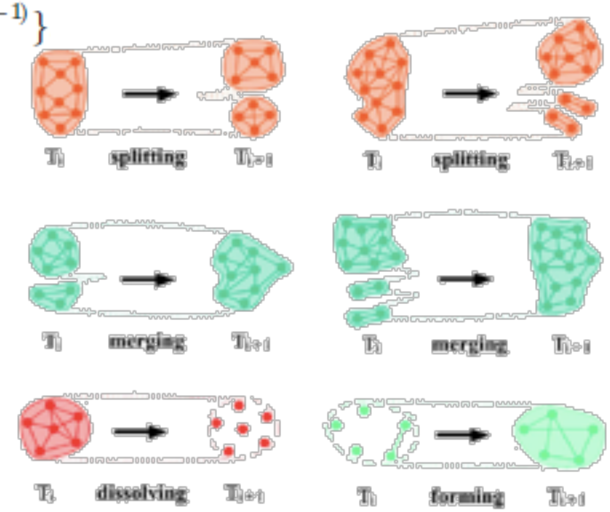
Subgraph Dual Simulation:

- Q matches data graph G if
  - 1) Q matches G via graph simulation under a match relation $R_D \subseteq V^q \times V$;
  - 2) $\forall (u, u') \in R_D \ [(w, u) \in E^q \Rightarrow \exists w' \in V: (w, w') \in R_D \wedge (w', u') \in E]$

Dynamic Graphs

- Graphs that change with time
  - Dynamic Network, e.g., $G=(V,E,W)$, $W = \{w_1, w_2, \ldots, w_T\}$
  - Evolving Graph, e.g., $G^t = (V^t,E^t)$
  - Temporal Graph, e.g., *graph sequence* $\{G_1, \ldots, G_t, \ldots, G_T\}$
  - Graph Stream, e.g., $\mathcal{G}^{(s)} := \{G^{(t_s)}, G^{(t_s+1)}, \ldots, G^{(t_{s+1}-1)}\}$
  - Networks Sequence, i.e., $\{G^t\}_{t=0,\cdots,T}$
  - Time-Series Graphs
- Usually, used for event detection

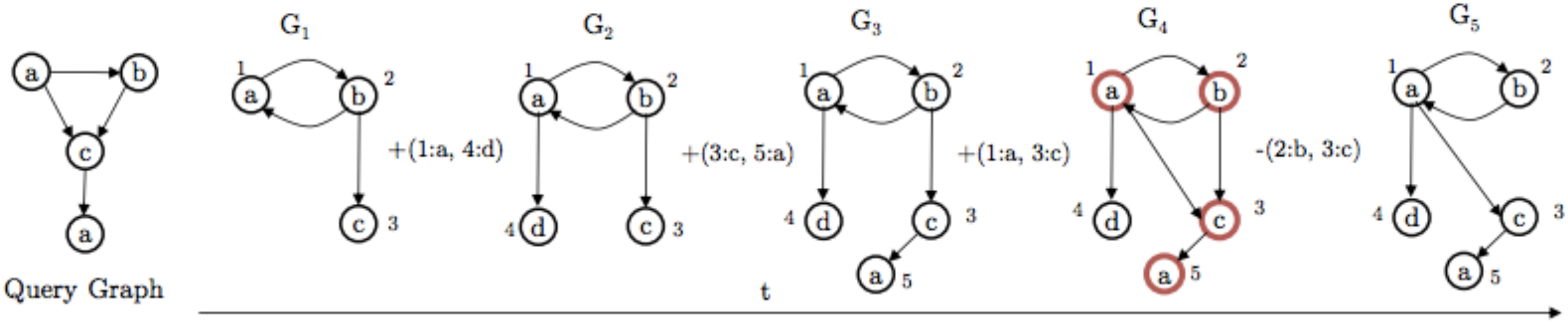
Source: NetSpot: Spotting Significant Anomalous Regions on Dynamic Networks



Source: GED: the method for group evolution discovery in social networks

Subgraph Matching in Dynamic Graphs

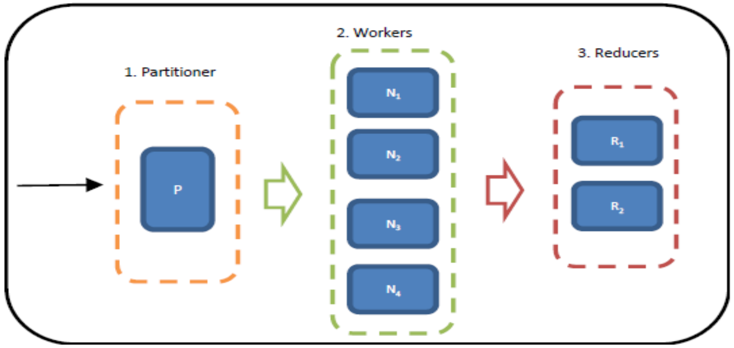
- **Focus**: How to maintain a set of subgraph matches in a dynamic graph?



  - Let M_t be the set of subgraphs in G_t that match query graph Q via subgraph isomorphism
  - An **incremental** subgraph matching algorithm takes G_t, Δe_u and M_t as input, to produce M_{t+1} for G_{t+1} by computing the **changes** ΔM to set M_t
- **Observation**:
  - The set of subgraphs that can be potentially affected by an edge update is within a **radius** from the edge update
  - This "neighborhood" is bounded by the query **diameter**
- **Assumption**: $D_Q << D_G$

A Distributed Incremental Algorithm

- Goal: leverage already computed results to minimize unnecessary re-computations
- Solution: framework that re-uses legacy SIM libraries developed for small static graphs
- Edge updates are processed in batches
- Practitioner assign edge updates to workers
- Each worker is responsible for maintaining a disjoint partition of G
- When an update arrives at a worker
  - Distributed depth limited BFS (may span to graph portions stored in other workers)
  - Affected subgraph is copied to worker
  - Matches are made on the affected subgraph
  - Matches are sent to the Reducer



Existing subgraph isomorphism libraries can be used to find matches

Parallelism at multiple levels

- Edge updates are processed in parallel
- Distributed subgraph construction for each edge update

Graph Pruning

- Performance can degrade with increasing query graph diameter
- Even more so in **small diameter** graphs
  - An edge update can affect subgraph matches in a major portion of the graph
  - The size of the subgraph constructed by the distributed depth limited BFS can grow fast with increasing D_Q
- Solution:
  - Distributed algorithm to maintain a pruned graph based on **dual simulation** in a dynamic graph and the notion of **safe edges**
  - Reduces the size of *G* to be searched for matches
  - Reduces communication overhead of subgraph construction
- Algorithm follows the BSP model
- Complexity
  - $O(E_{\{SCC\}})$ super-steps, where $E_{\{SCC\}}$ is the number of edges in the largest strongly connected component

Evaluation - Setup

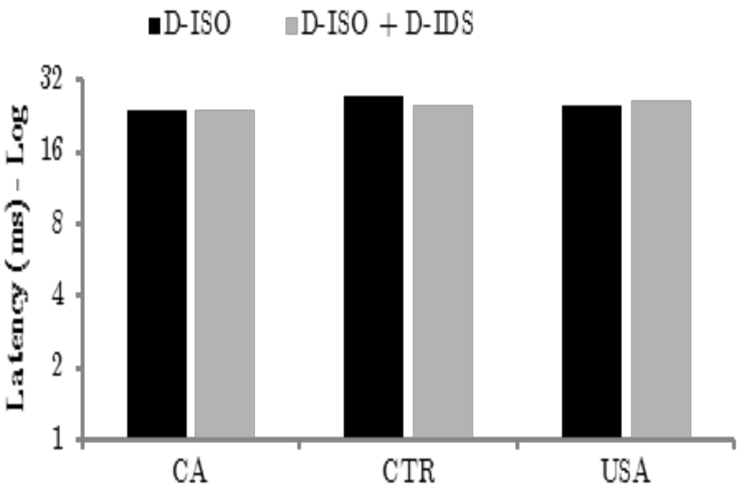
- Implementation
  - C++, MPI (MPICH2)
  - VF2 is used for subgraph matching within neighborhood subgraphs
  - Lemon graph library for efficient implementation of graph data structure
- Platform
  - Amazon EC2 – c3.2xlarge
  - 5 nodes
- Datasets

Dataset	$\|V\|$	$\|E\|$	Type
California R/N (CA)	1,965,206	2,766,607	Large diameter
Central USA R/N (CTR)	14,081,816	34,292,496	Large diameter
Full USA R/N (USA)	23,947,347	58,333,344	Large diameter
DBLP network (DBLP)	317,080	1,049,866	Small-diameter
YouTube (YT)	4,945,382	49,445,382	Small-diameter
Live Journal (LJ)	5,284,457	77,402,652	Small-diameter

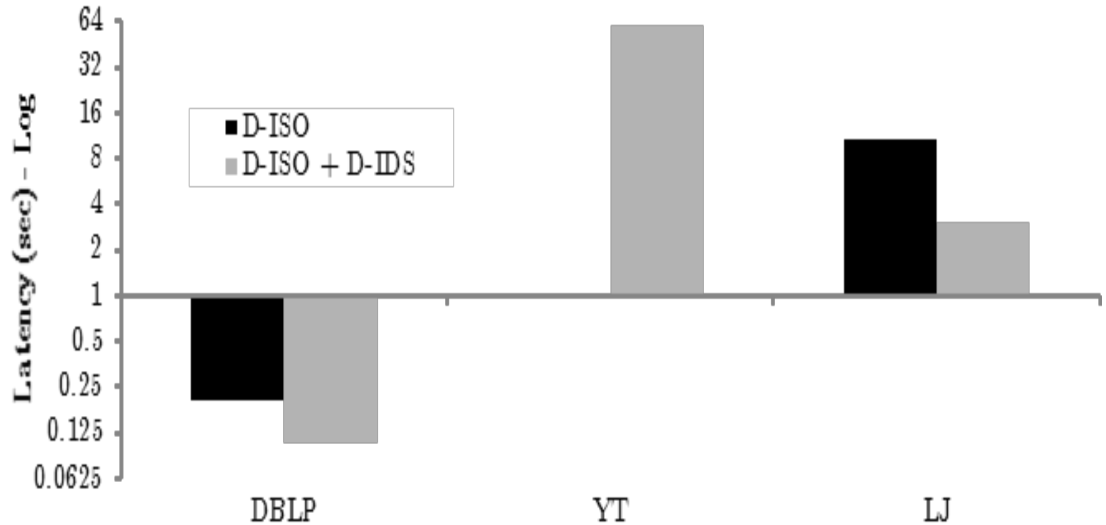
- Query graphs: D = 1,2,3 (|V|=5,12,17)

Evaluation Results (1)

- Latency comparison with/without graph pruning
- Baseline: **Sequential exact** subgraph isomorphism algorithm [TODS2013]



Road networks



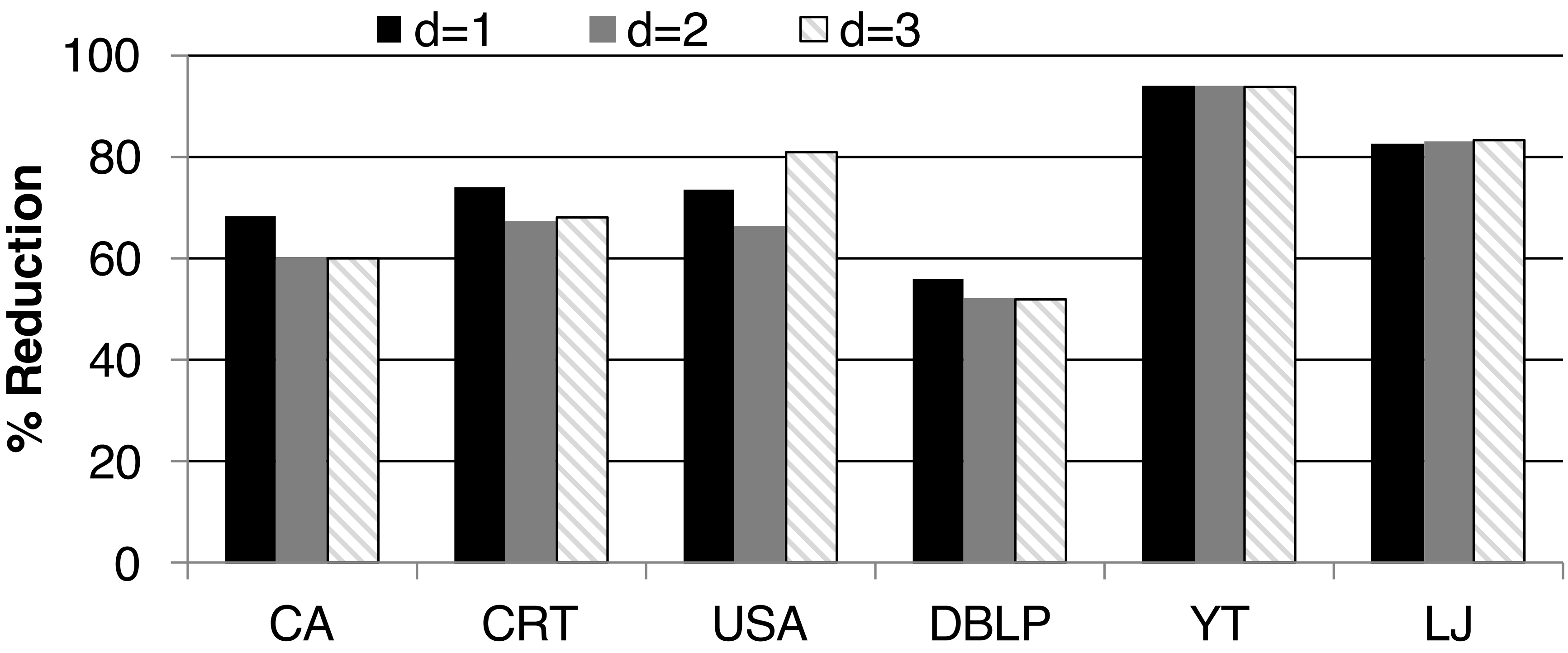
Social Graphs

Facilitated incremental exact matching on large diameter networks

Pruning **significantly improves** performance on small world networks

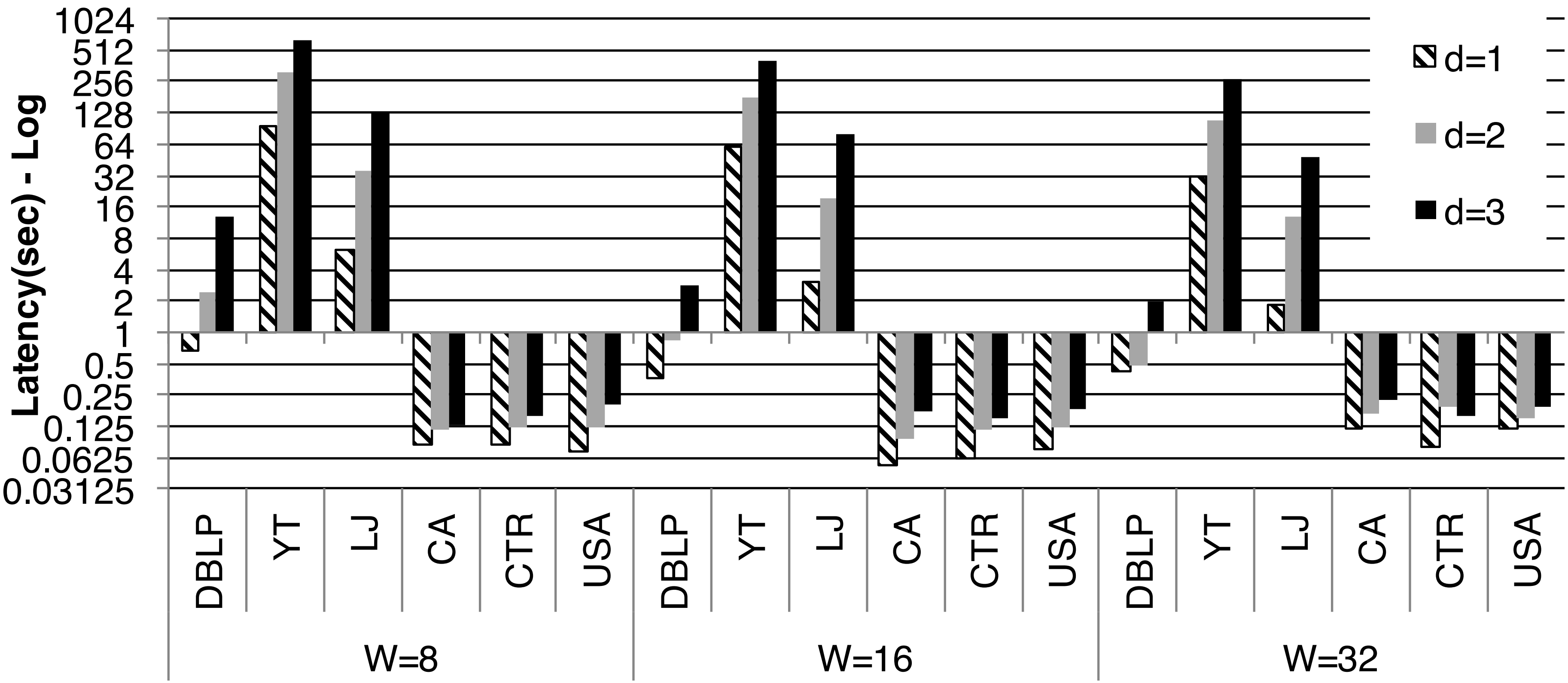
Evaluation Results (2)

- Average % reduction in graph size



Evaluation Results (3)

- Latency with increasing number of workers



Conclusion and Future Work

- Proposed a query preserving distributed graph pruning approach (D-IDS) to enable **exact subgraph matching** in **small diameter dynamic** graphs
- Graph pruning resulted in over 60% reduction in graph size in real-world networks
- Significantly improved the performance of neighborhood search based subgraph matching for small diameter graphs
- Future work
  - Examine impact of graph partitioning strategies
  - Study effect of update rate in a variety of dynamic settings

Questions?

- Thank you!