Tesseract: Distributed, General Graph Pattern Mining on Evolving Graphs

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Graph Pattern Mining 101

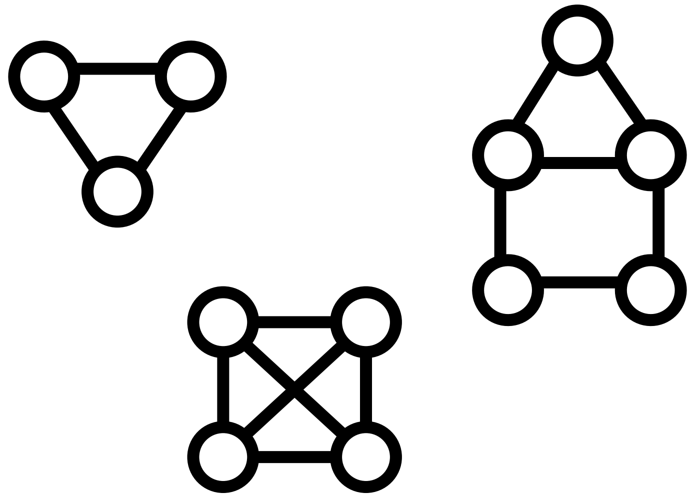
Find all instances of interesting subgraphs (patterns) in a graph

Each instance of a pattern is called a match

- Even small graphs can contain billions or trillions of matches

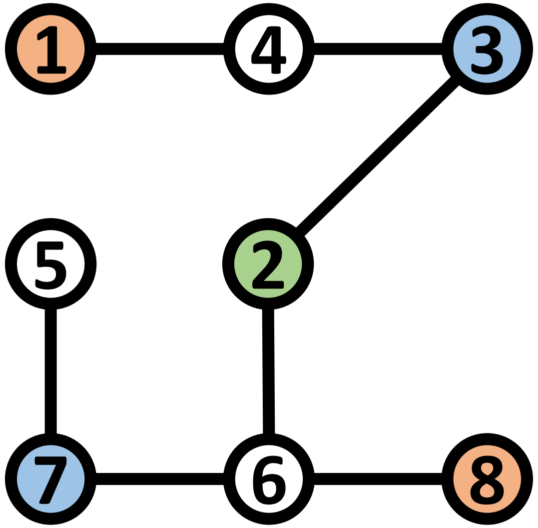
Graph Dataset

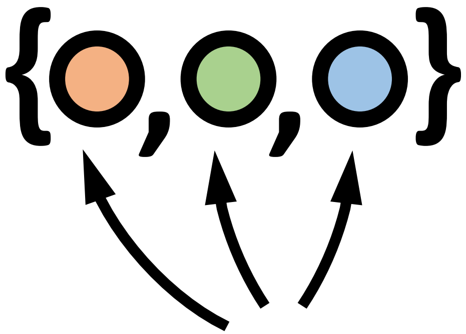
Patterns



Example – Graph Keyword Search

Input Graph

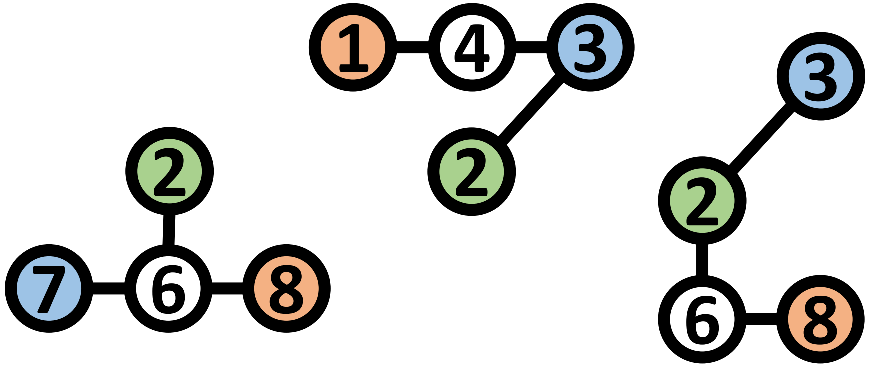


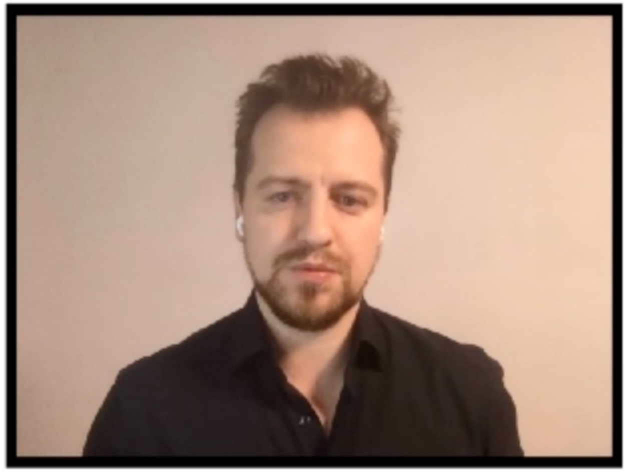


Pattern

Labels

Matches



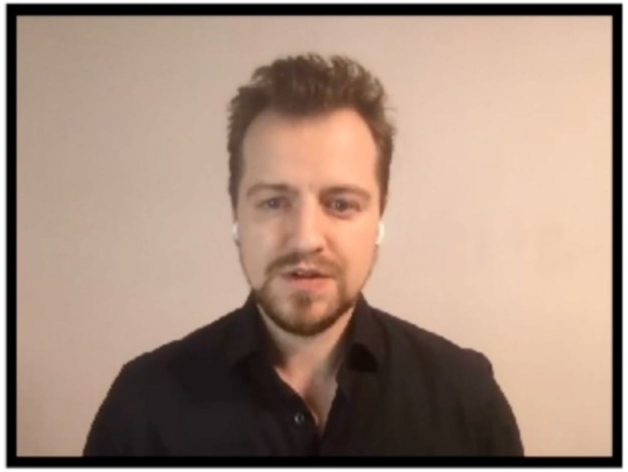


Graph Mining with Evolving Graphs

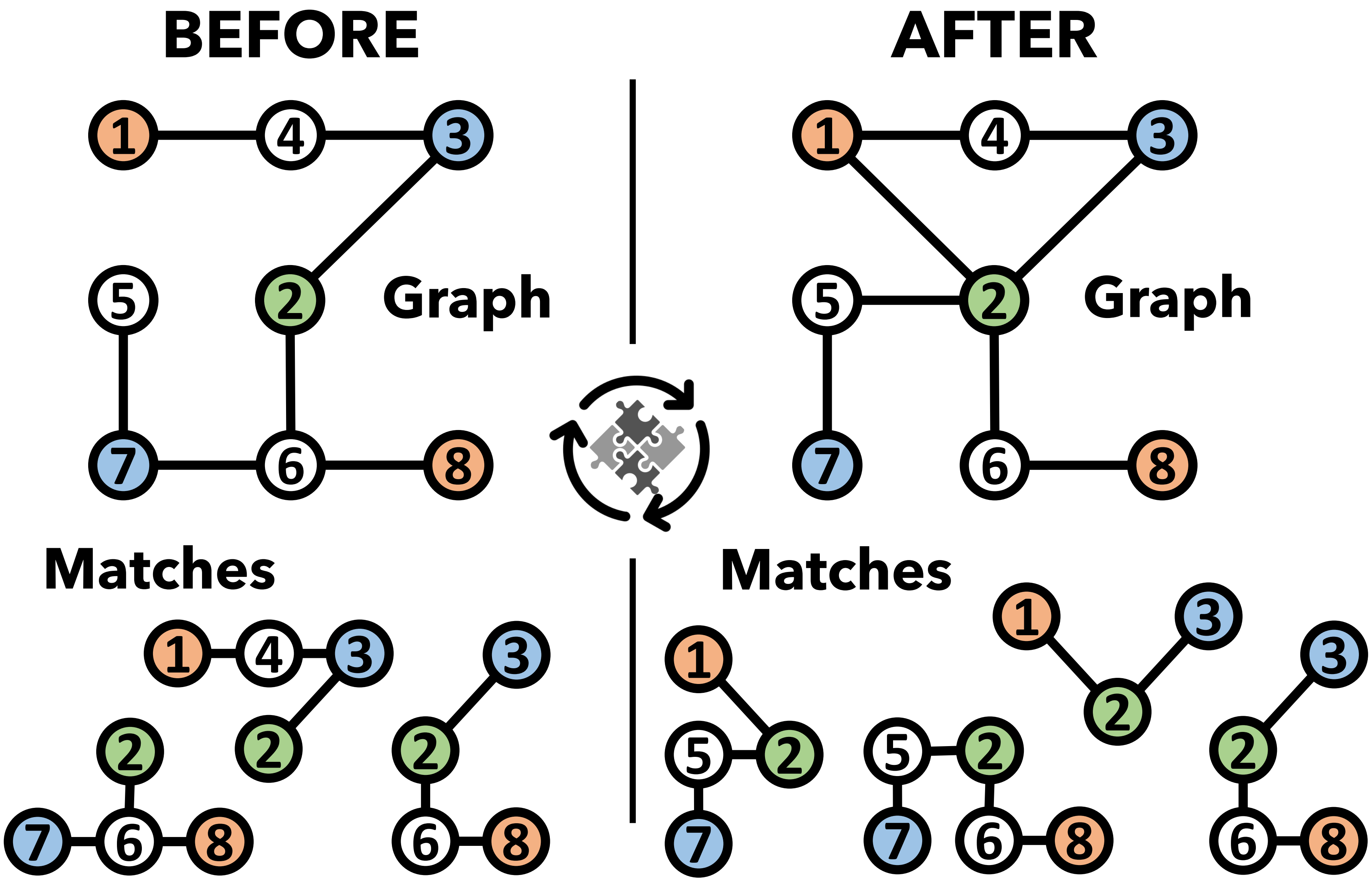
Find matches in a graph that receives a stream of updates
⇒ Incrementally maintain the match set so that it matches the input graph

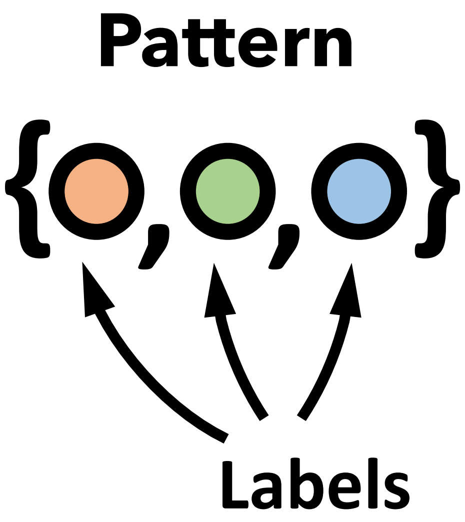
Challenges

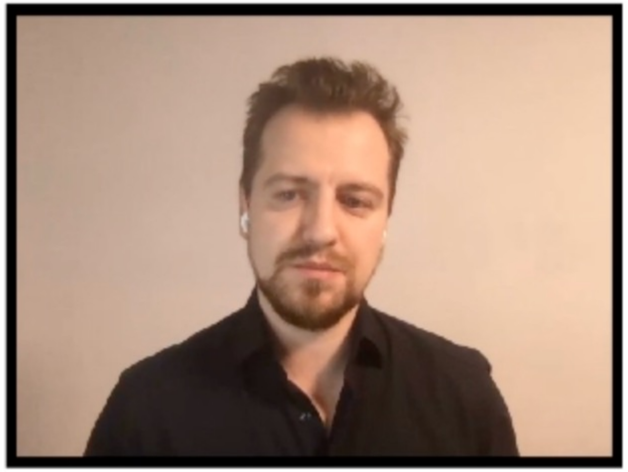
- Correctness
  - Matches in original graph + matches from updates = matches in new graph
  - Avoid exploring/outputting duplicate matches
- Efficiency
  - Expect millions of updates per second
  - Recomputation is out of the question
- Scale-out
  - Minimize data transfer between workers



Example – Incremental Graph Keyword Search







Tesseract: Evolving, Distributed, General

Tesseract incrementally mines **evolving** graphs

- Several thousands of times faster than naive complete computation

Tesseract supports **distributed** execution

Tesseract supports a **general** programming model

Tesseract is also faster for static graph mining

Key Ideas in Tesseract

Update-based exploration

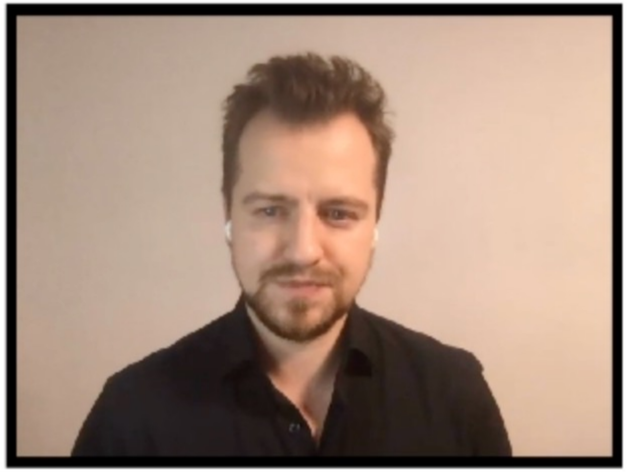
- Process one update at a time independently
- Find all corresponding changes to the match set using differential mining

Duplicate elimination

- Symmetry breaking
- Multiversioned graph store
- Snapshot-based exploration

⇒ No data exchange across workers required

⇒ No synchronization across workers required

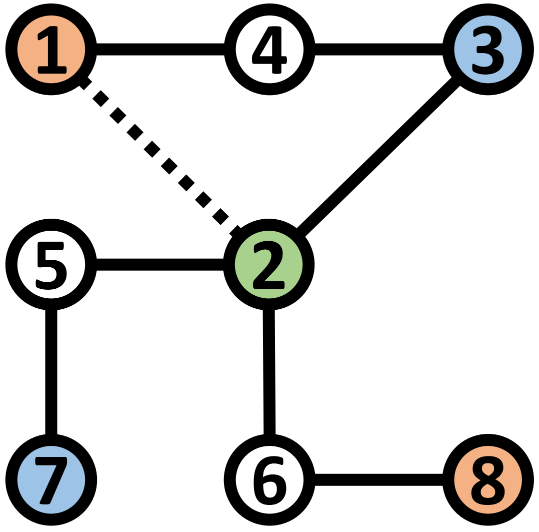


Update-Based Exploration

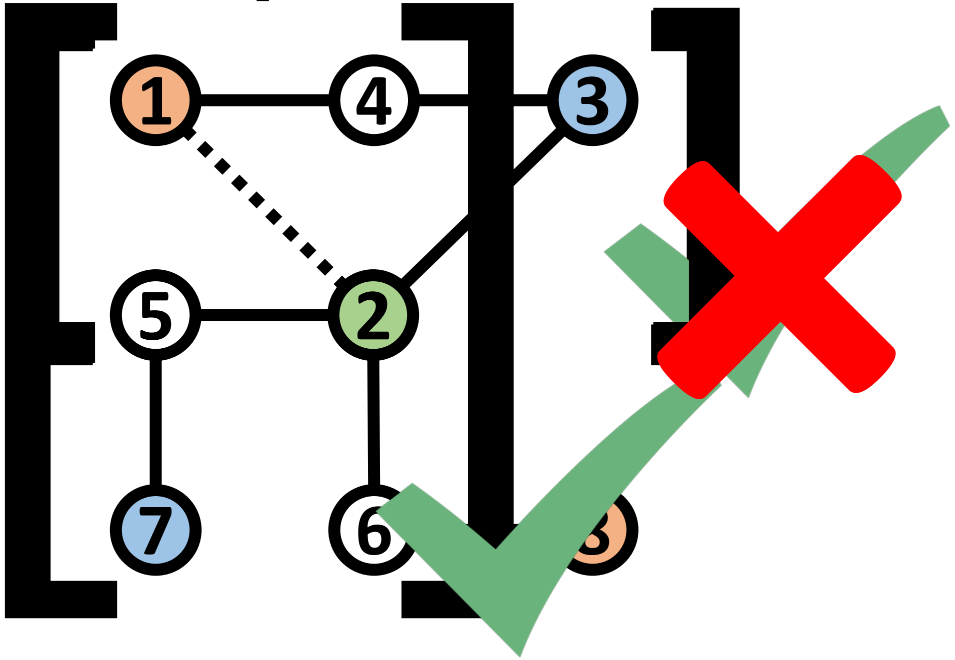
Each worker processes one update at a time

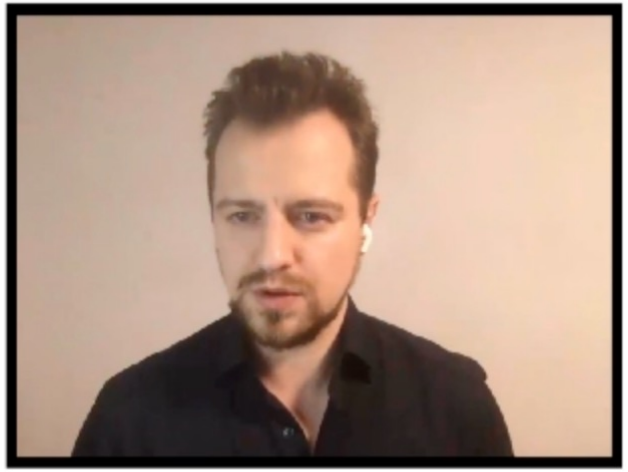
Exploration enumerates all subgraphs including the update

Input Graph



Exploration





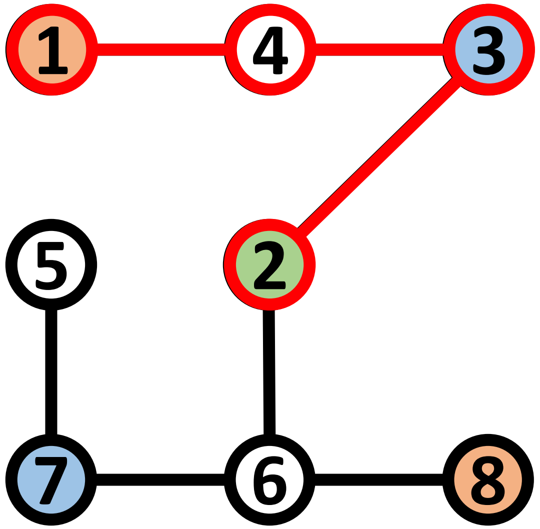
Differential Pattern Mining

Goal: find all changes involving the update being explored

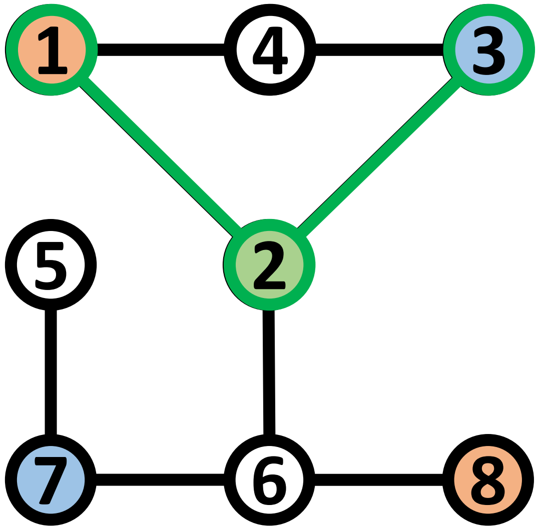
Solution: explore the pre-update and post-update graphs

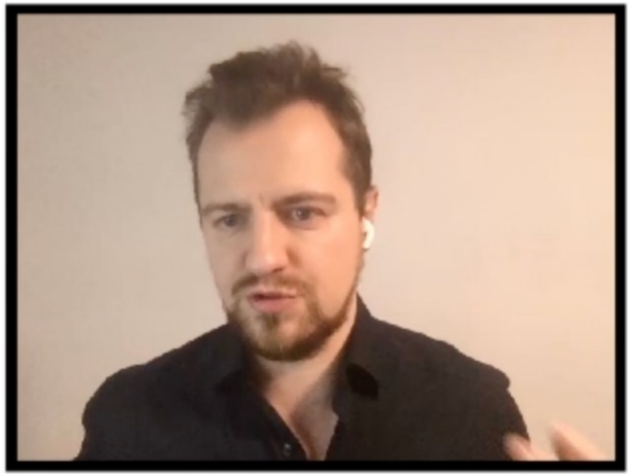
- Remove matches in pre-update graph
- Add matches in post-update graph

BEFORE UPDATE



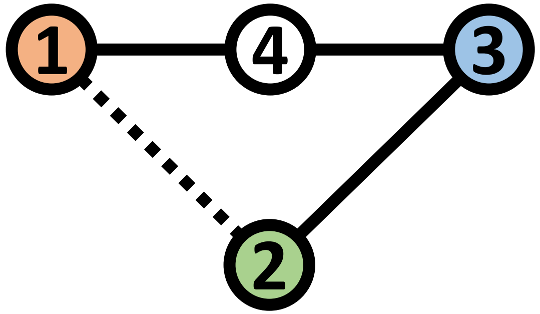
AFTER UPDATE



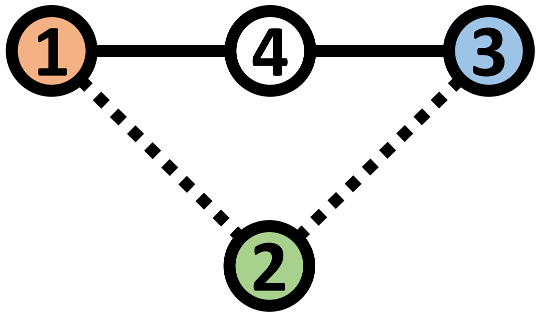


Exploration May Find Duplicates

Duplicates can occur from a single update or multiple updates



can be explored as (1, 2, 3, 4) or (1, 2, 4, 3)
⇒ duplicate match from a single update



can be found from (1, 2) and from (2, 3)
⇒ duplicate match from two updates

Avoiding Duplicates

Single update: use symmetry breaking

- Root exploration at update + enforce expansion order

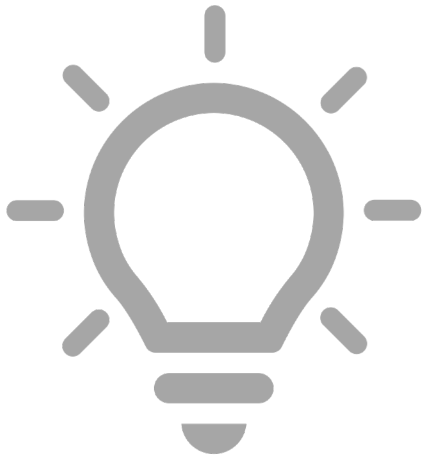
Multiple updates: leverage multiversioned graph store

- Explore each update at corresponding graph snapshot
- Total ordering based on update timestamps prevents “seeing the future”

Optimize exploration with snapshots containing multiple updates

- Decrease snapshot overhead
- Skip work for intermediate matches

Parallel Exploration Across Workers



No other changes necessary!

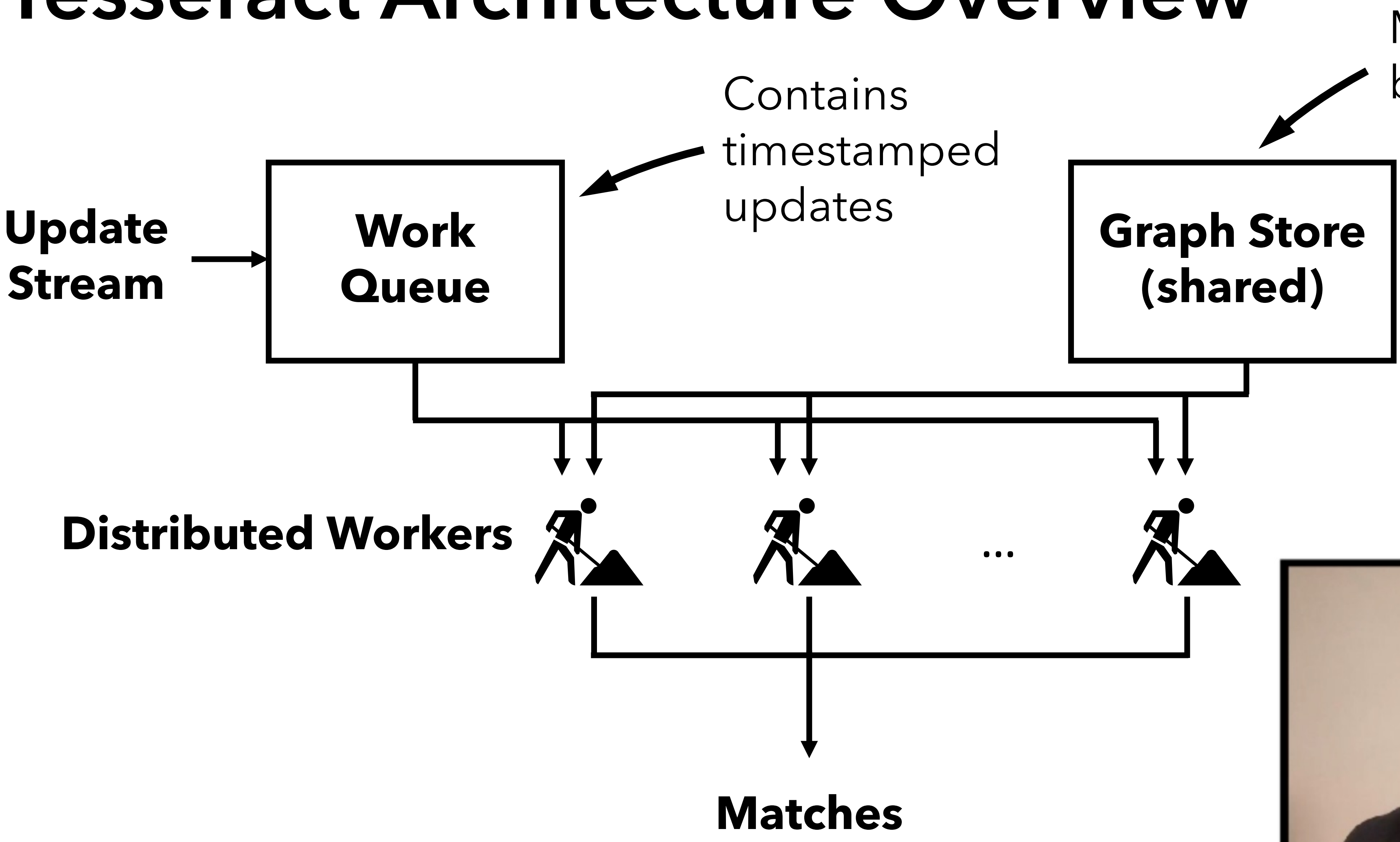
⇒ Each update is completely independent of the others

⇒ Updates can be processed in any order

⇒ Any update can be processed by any worker

(even updates in the same snapshot)

Tesseract Architecture Overview

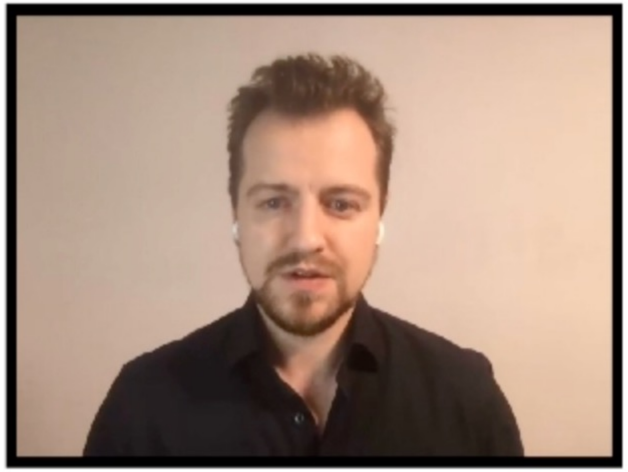


Evaluation

8 16-core machines (one rack)
128GB RAM, 2x500GB SSD, 40GigE switch

4-C: Clique Mining
4-CL: Labeled Clique Mining
4-MC: Motif Counting
5-GKS-3: Graph Keyword Search
4-FSM-2K: Frequent Subgraph Mining

LiveJournal (4M vertices, 68M edges)
UK-2007 (106M vertices, 3.7B edges)
DC-2012 (3.5B vertices, 128B edges)



Summary of Key Results

Tesseract is faster than naive computation from scratch

- 5X to 6000X faster runtime

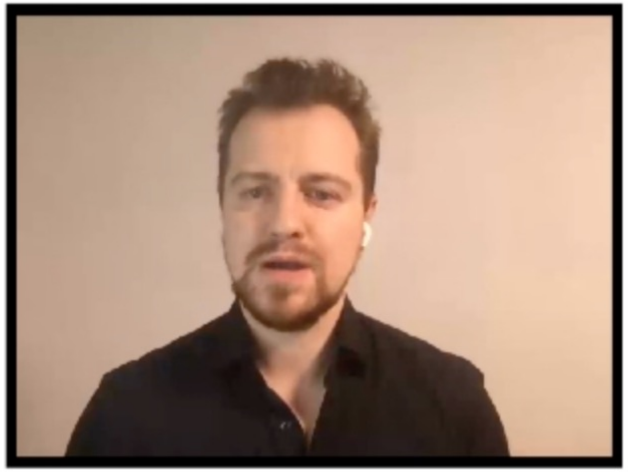
Tesseract outperforms subgraph query systems

- 1.1X to 12.3X faster than Delta-BigJoin

Tesseract is even faster on static graphs!

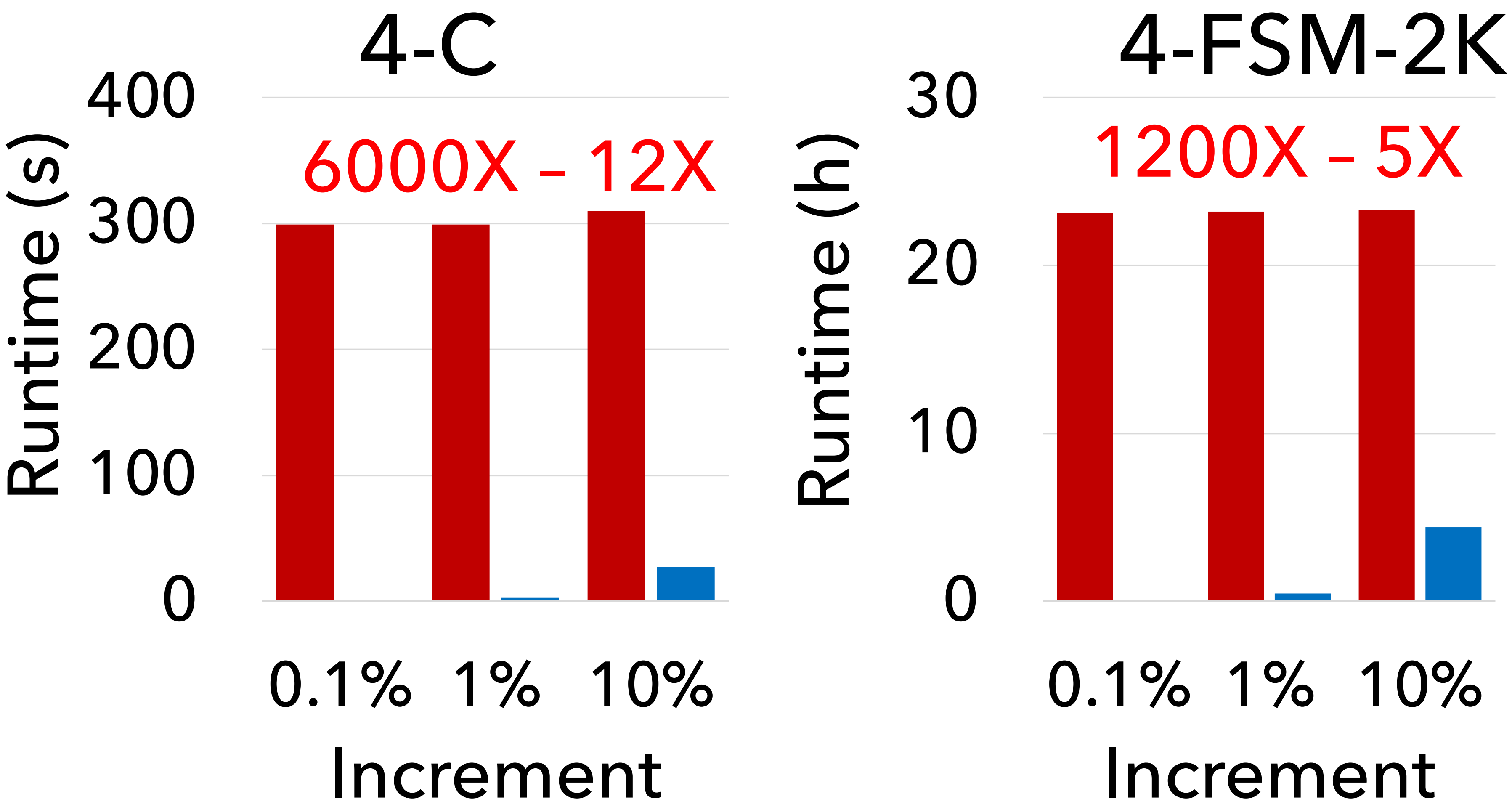
- 2X to 6X faster than static distributed mining systems

Tesseract can maintain matches in large graphs

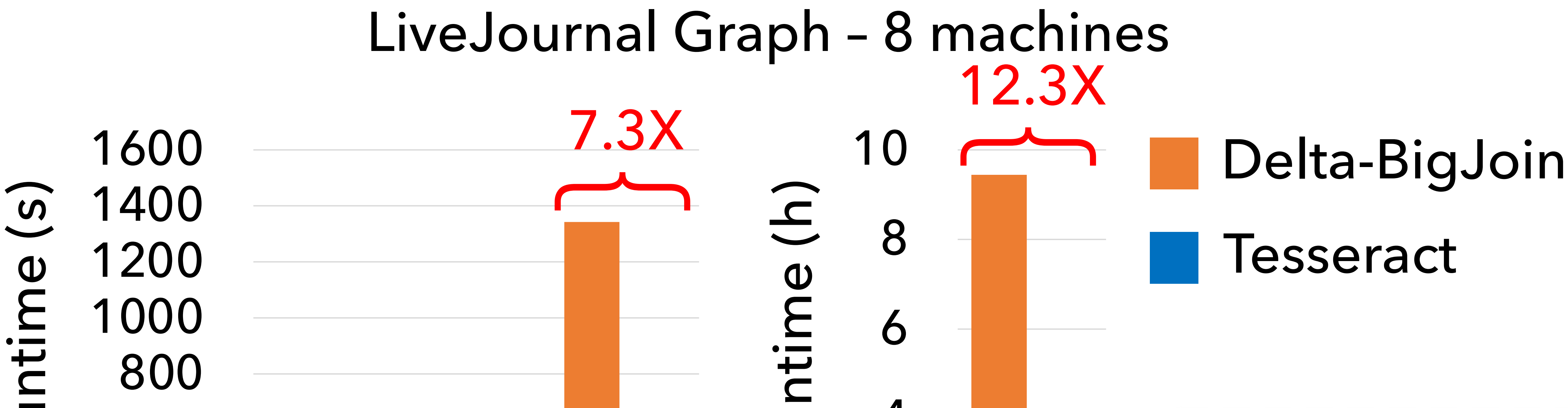


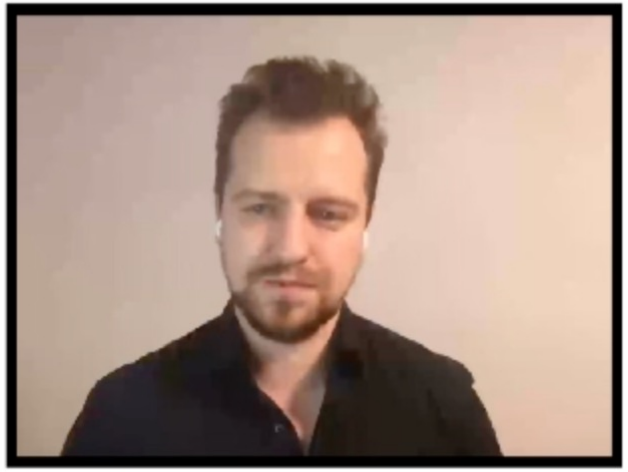
Incremental Computation Benefits

LiveJournal Graph – 8 machines



Comparison with Delta-BigJoin [VLDB'18]

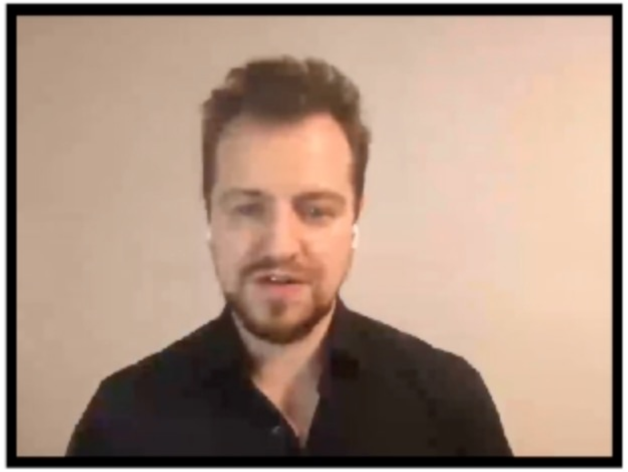




Comparison on Static Graphs

Algorithm	Arabesque [SOSP'15]	Fractal [SIGMOD'19]	Tesseract
4-C	4.9h	310s	147s
4-MC	OOM	12.3h	1.9h
4-FSM-2K	OOM	23.7h	10.3h

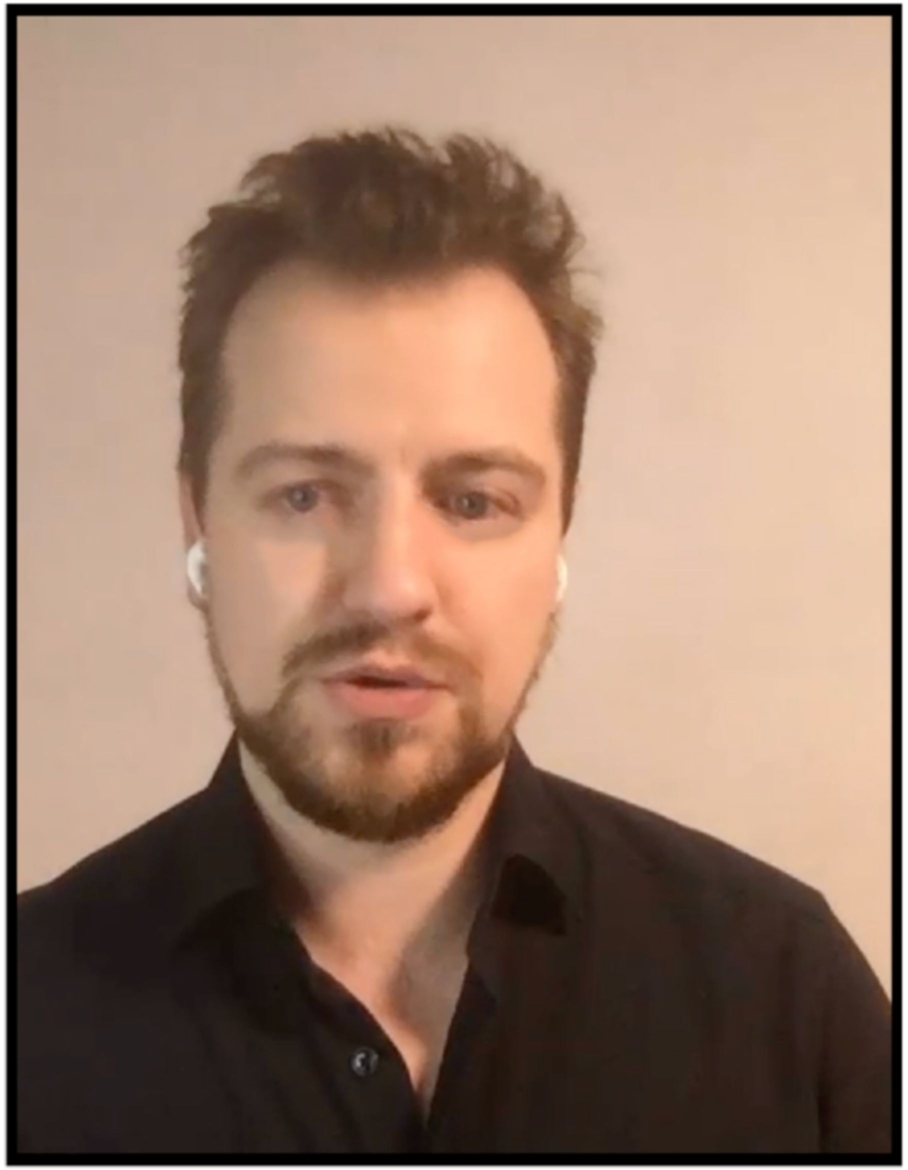
LiveJournal Graph with 8 machines



Incrementally Mining Large Graphs

Metric	UK-2007	DC-2012
Processing Time (1M updates)	372s	1.5h
Output Rate	11.4M/s	7.57M/S

5-GKS-3 algorithm with 8 machines



Additional Results in Paper

- Scalability
- Performance on static graphs
- More large graphs
- Performance breakdown
- Overhead analysis
- Ingest rate performance
- Latency
- Deletions

Conclusions

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Tesseract supports mining evolving graphs

- General-purpose API
- Distributed execution
- Millions of updates per second

Key ideas:

- Update-based task-parallel exploration
- Duplicate elimination

Enables a new class of “interactive” graph mining applications