IOGP

an **I**ncremental **O**nline **G**raph **P**artitioning algorithm for distributed graph databases

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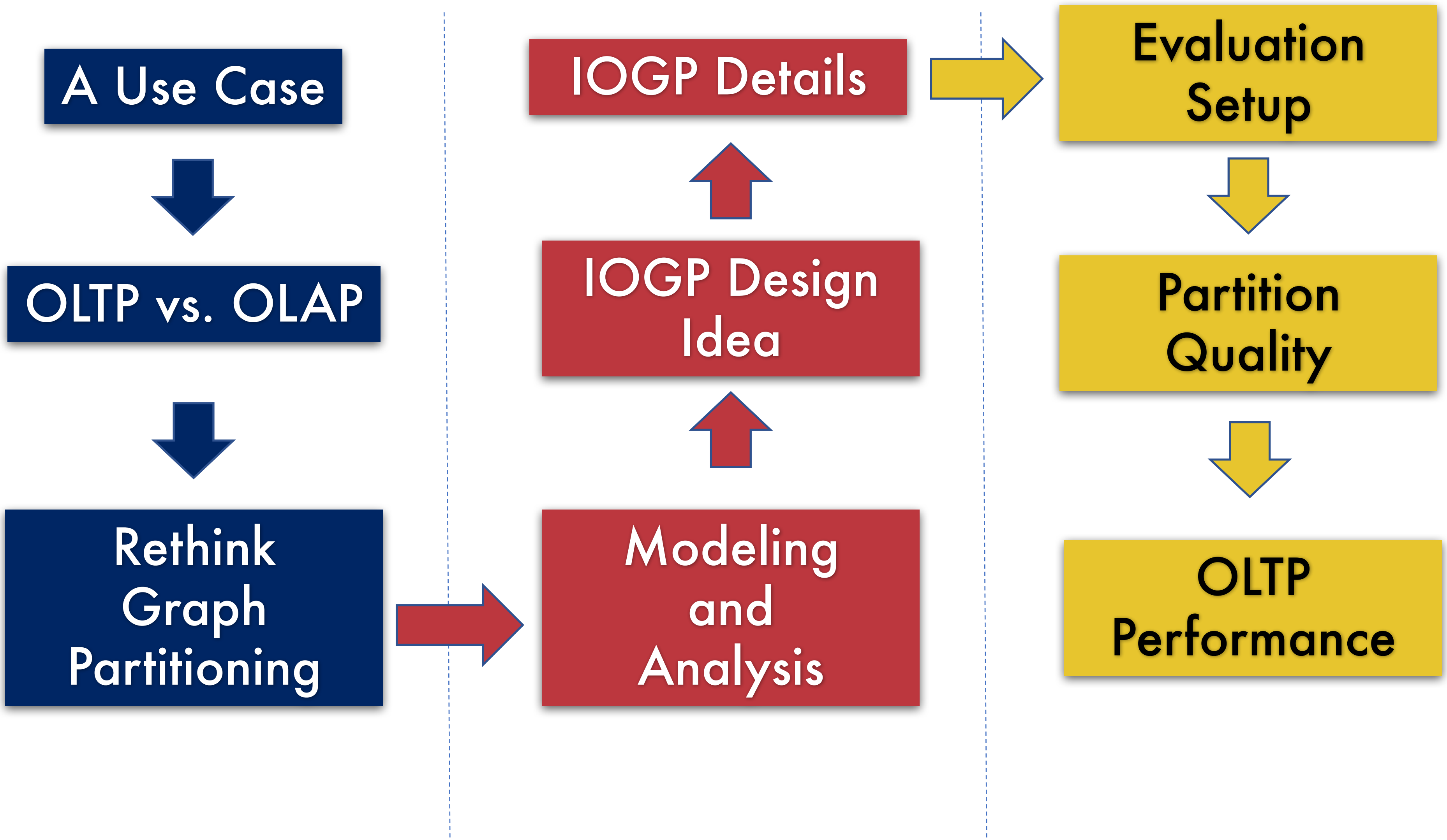
Workflow of The Presentation



A Use Case

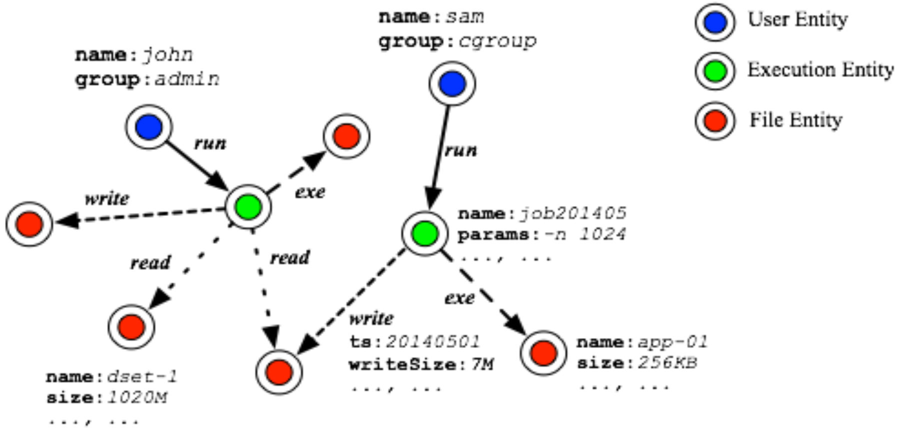
- Meet Daniel from “All-About-HPC” LLC
  - He wants to build a provenance system for HPC
    - He traces all provenance-relevant events
    - He models and stores them into a provenance graph
    - He offers users graph interfaces to query provenance

New events inserted continuously

Build large graphs with properties

Thousands of clients query it

Typical OLTP Workloads



OLTP vs. OLAP

- We have two sets of tools to handle graphs
- Graph Databases → **OLTP**
  - short, finish in milliseconds
  - touch a small part of the graph
  - measured by time cost of each transaction
- Graph Processing Engines → **OLAP**
  - longer, finish in seconds, minutes
  - touch a large part of or the whole graph
  - measured by system throughput

Daniel needs **distributed graph databases** for his OLTP ops

But, how **he partitions the graphs?**

Rethink the Graph Partitioning

- Many graph partitioning algorithms
  - Multi-level scheme
    - METIS, Chaco, PMRSB, Scotch, ParMetis, Pt-Scotch, etc.
  - Heuristic single-pass methods
    - LDG, Fennel, 2D-Grid, Vertex-Cut, etc.
  - Online partitioning algorithms
    - Hashing, Leopard, etc.

Not Designed for OLTP Workloads

Rethink the Graph Partitioning

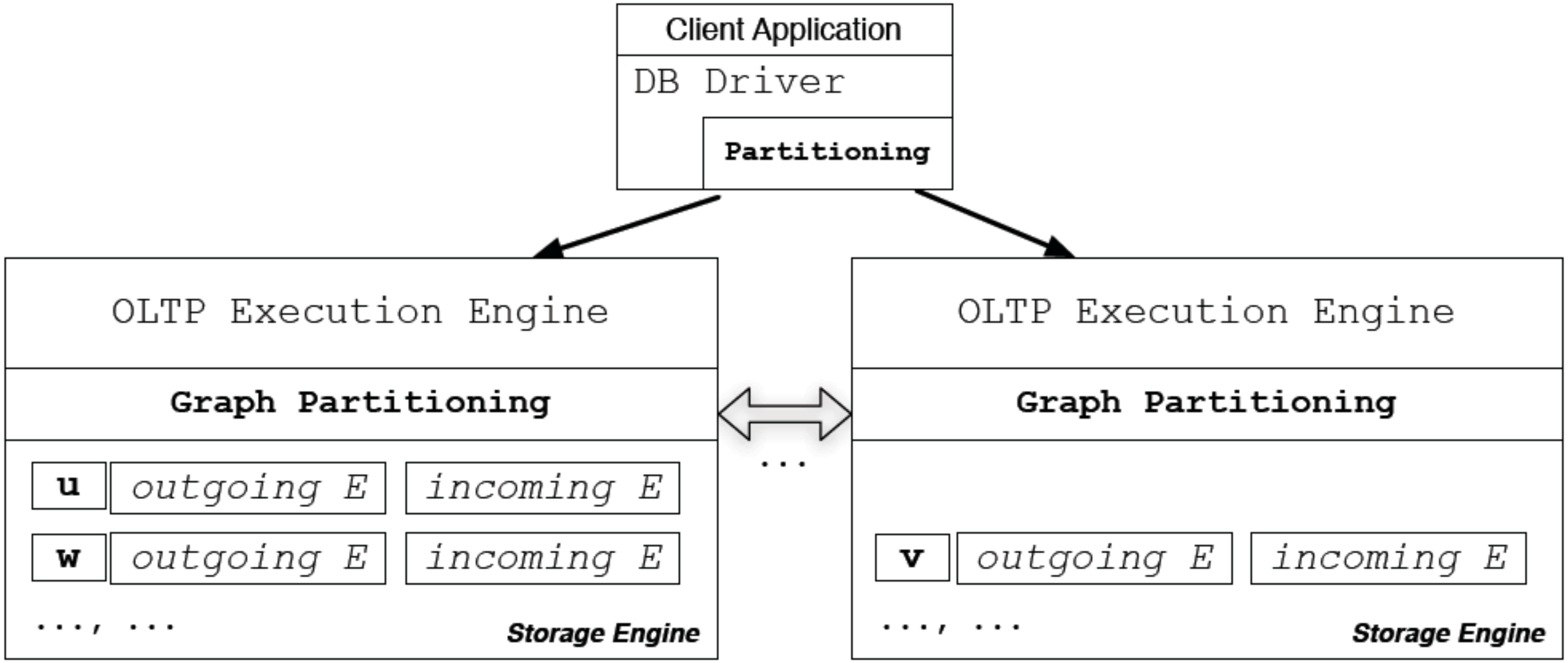
- What does OLTP need?
- Response quickly when insertion happens
  - It needs to finish fast (in *ms*)
  - No time to wait for multi-level schemes or even re-partiti
- R

graph partitioning for OLTP workloads

- Me ment of a good partitioning
  - OLTP cares response time of each operation
  - Only minimizing edge-cuts/maximizing the balance is not enough
  - Think about a graph with *n* equal-size subgraphs

Modeling and Analysis

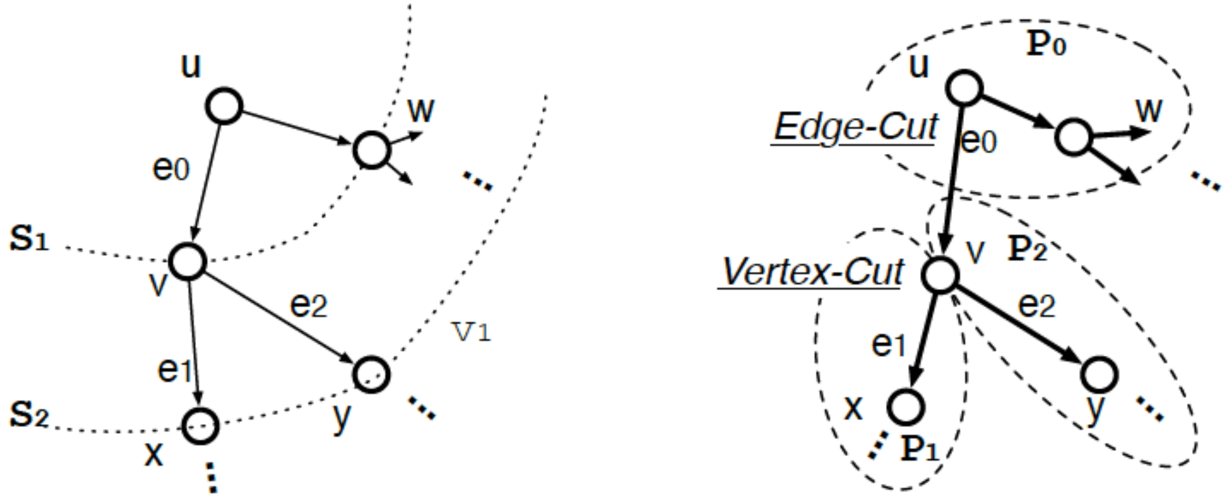
- Generic distributed graph database model
  - directed/undirected graphs
  - bi-direction accesses on the graphs
  - queryable properties on vertices and edges



Factors of OLTP Performance

- Single-Point Access Performance
  - One-hop: if clients know the location of queried data
  - It saves time for querying location information

- Traversal Performance (Edge-Cut and Vertex-Cut)



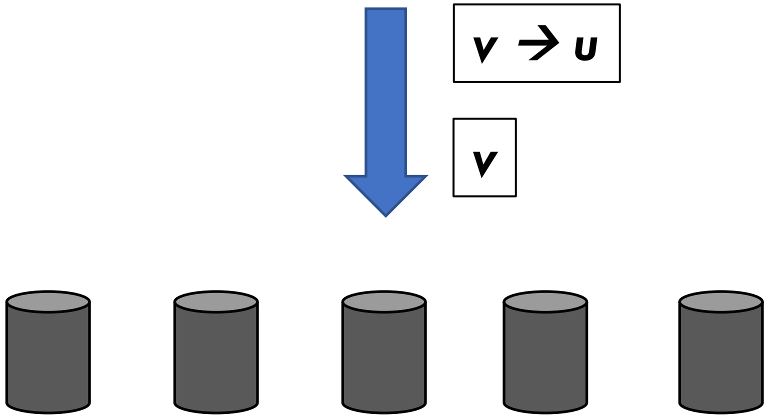
a) Graph travel example from *u*　　b) Graph with 3 partitions (P0,P1,P2)

IOGP Core Idea

- Leverage deterministic hashing to place new vertices
  - fast and easy to calculate
  - enable one-hop access
  - need **no** info to conduct partitioning
- Incrementally reassign vertices to better location
  - continuously get better locality with increasing knowledge
- For vertex is too large, change from edge-cut to vertex-cut
  - increase the parallelism
  - improve OLTP response time

IOGP - Quiet Stage

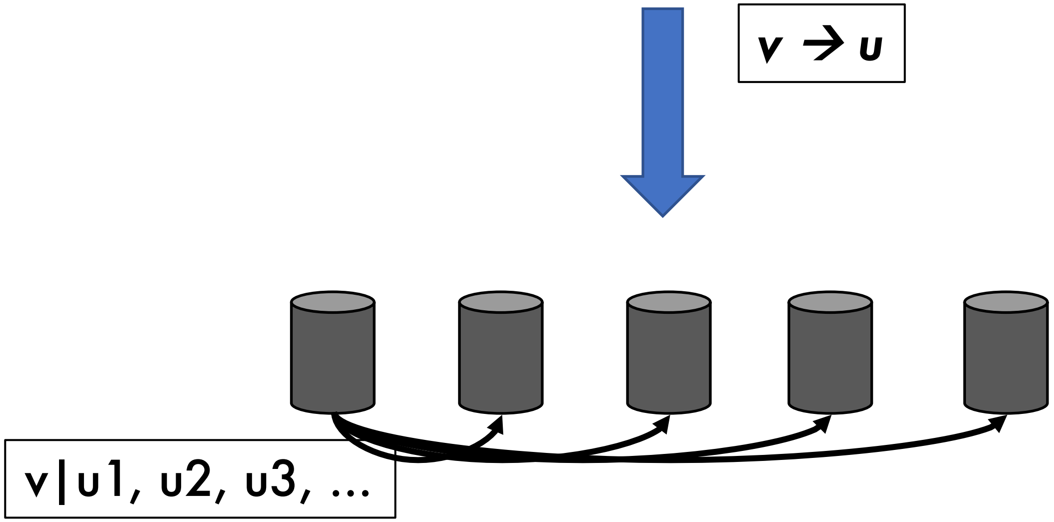
- Quiet Stage is the default stage
  - a vertex *v* is inserted, it will be placed based on Hashing
  - an edge *u->v* is inserted, it will be placed together with its connected vertices



Vertex Reassign Stage

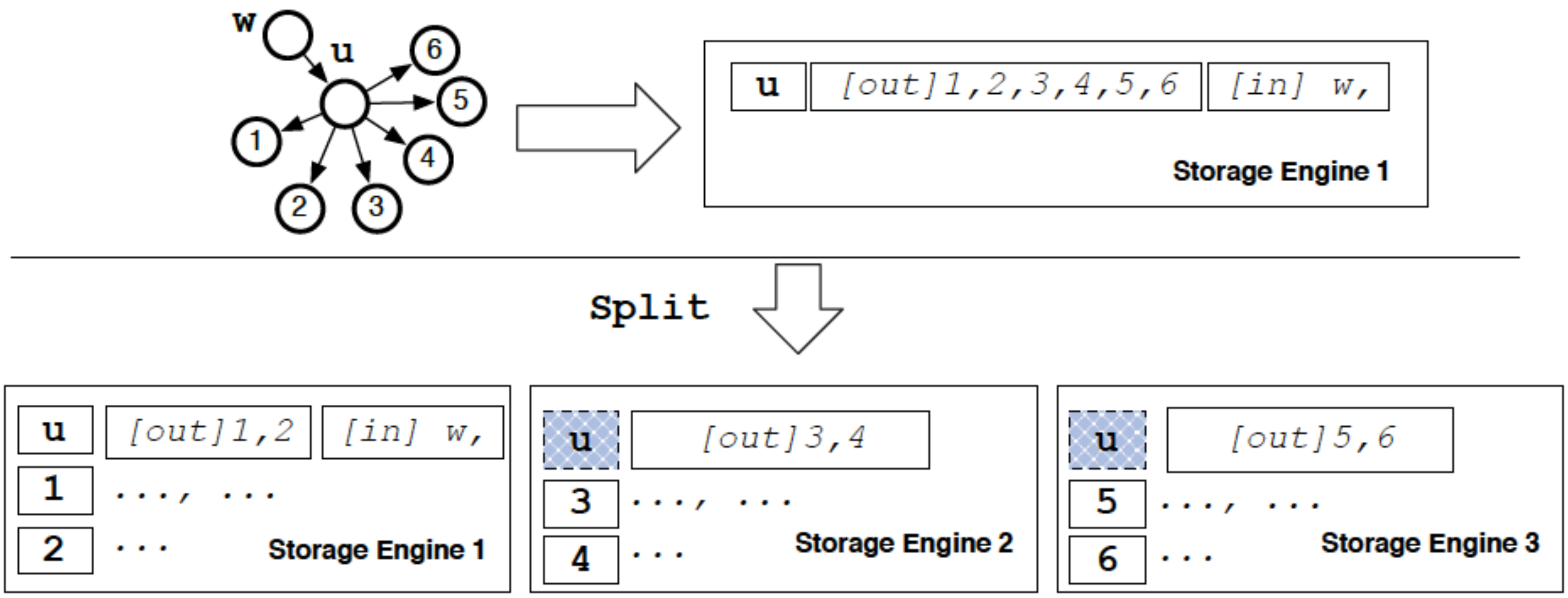
- When we knew enough connectivity of a vertex *v*
  - move it to the partition that stores the most of its neighbors
  - A heuristic function (derived from Fennel)

$$max\{|N(v) \cap P_i| - \alpha\frac{\gamma}{2}(|P_i|)^{\gamma-1}\}$$



Edge Splitting Stage

- When a vertex becomes extremely large
  - Edge-cut leads to significant performance degradation
  - Split all edges to increase the parallelism of data accesses

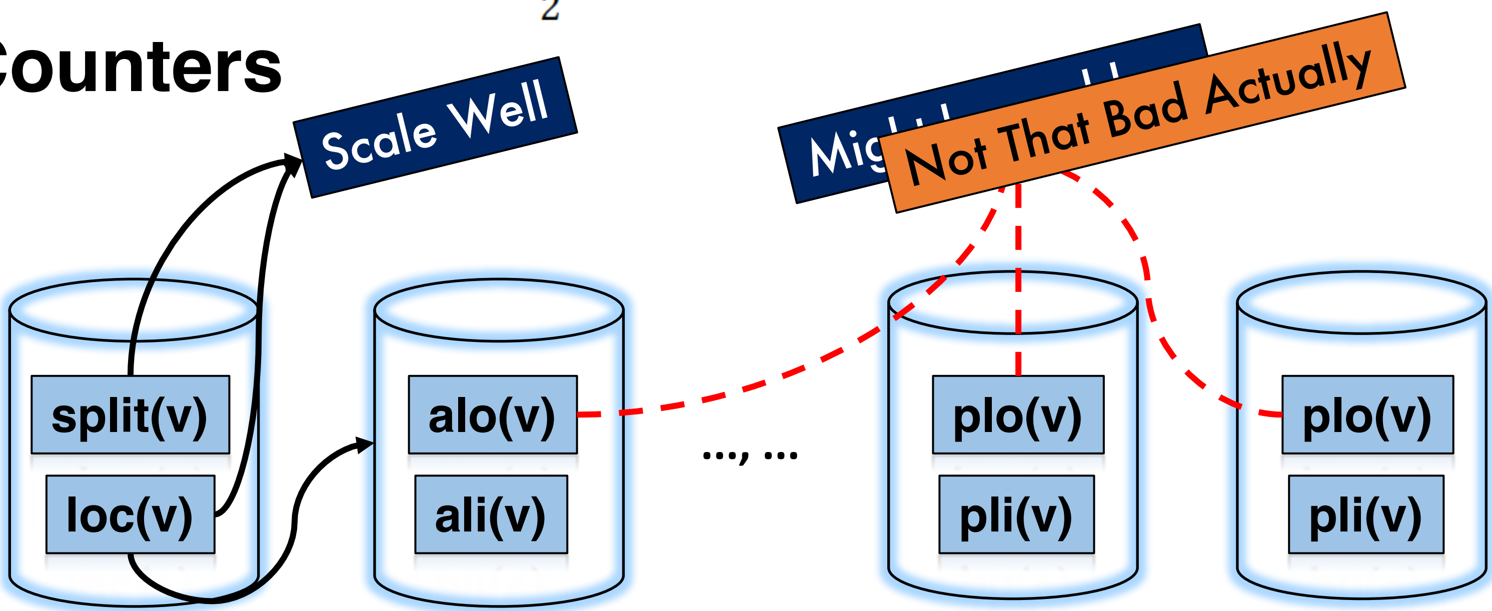


IOGP Details

- We need per-vertex metadata
  - To record vertex location loc(v)
  - To know vertex degree or it has been split split(v)
  - To efficiently calculate counters(v)

$$max\{|N(v) \cap P_i| - \alpha\frac{\gamma}{2}(|P_i|)^{\gamma-1}\}$$

- **Counters**



Original Location

Update Counters after Reassignment

1. Update *loc(v)* in the original server

2. In server S_u (v is moving out of it)
   - v's actual locality turns into potential locality
   - v's local neighbors
     - reduce actual locality by 1 because v is not local anymore

3. In server S_k (v is moving into it)
   - v's potential locality turns into actual locality
   - v's local neighbors
     - increase their actual locality by 1 because v is local to them now

Optimization: Timing of Vertex Reassignment

- Vertex reassignment is time-consuming
- Observation
  - more edges, more stable connectivity;
  - less reassignment is needed
- Design
  - deferring vertex reassignment until its connectivity stabilizes
  - reducing vertex reassignment frequency with more edges
- Implementation
  - Start reassignment until its degree is higher than *k*
  - Check for reassignment when its degree reaches [$2*k$, $4*k$, ..., 2^l*k...]

Optimization: Asynchronous Data Movement

- Vertex reassignment and edge splitting
  - sync data movement may stale OLTP operations
  - optimization: asynchronous data movement
- Edge splitting example
  - Update in-memory counters
  - add vertex in pending movement queue
  - Server starts to reject new edges
- Data may in different locations during movement
  - original server, new server, and maybe both
  - clients need to read multiple copies and aggregate them
    - Prefer the one from "new server"

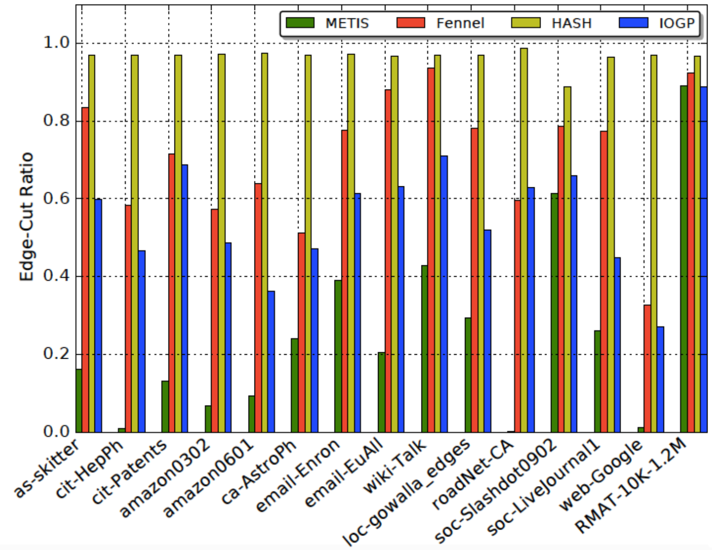
Evaluation Setup

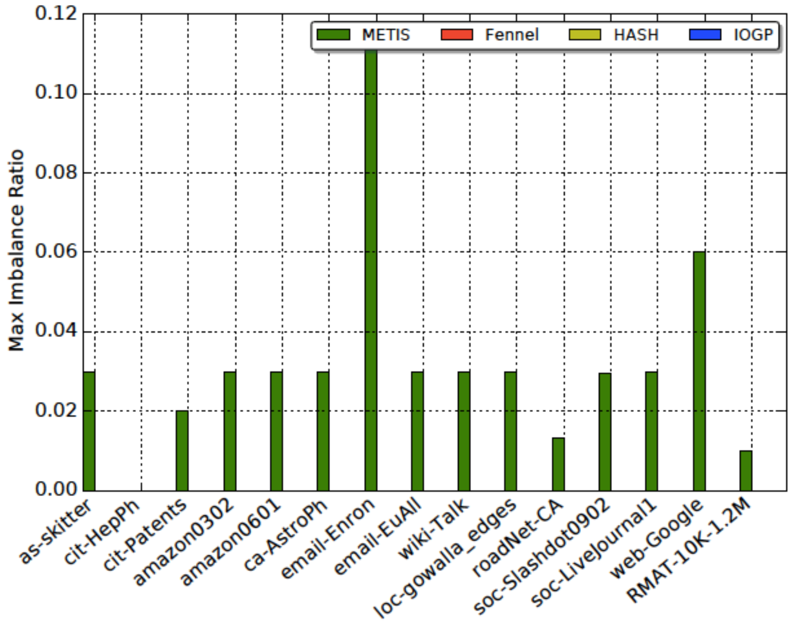
- All evaluations were conducted on the CloudLab cluster
  - 32 servers for back-end storage
- We chose various datasets from SNAP for evaluations
  - scales from 200K edges to over 100M edges
  - from various domains, forming different shapes
- We evaluated IOGP on a distributed graph database prototype, namely SimpleGDB (https://github.com/daidong/simplegdb-Java)
  - A prototype system has been used in several research projects
  - For fair comparison and controllable optimizations

Partitioning Quality

- METIS runs directly on the final graph
- Fennel runs in random order

METIS is still the best
IOGP achieves very well



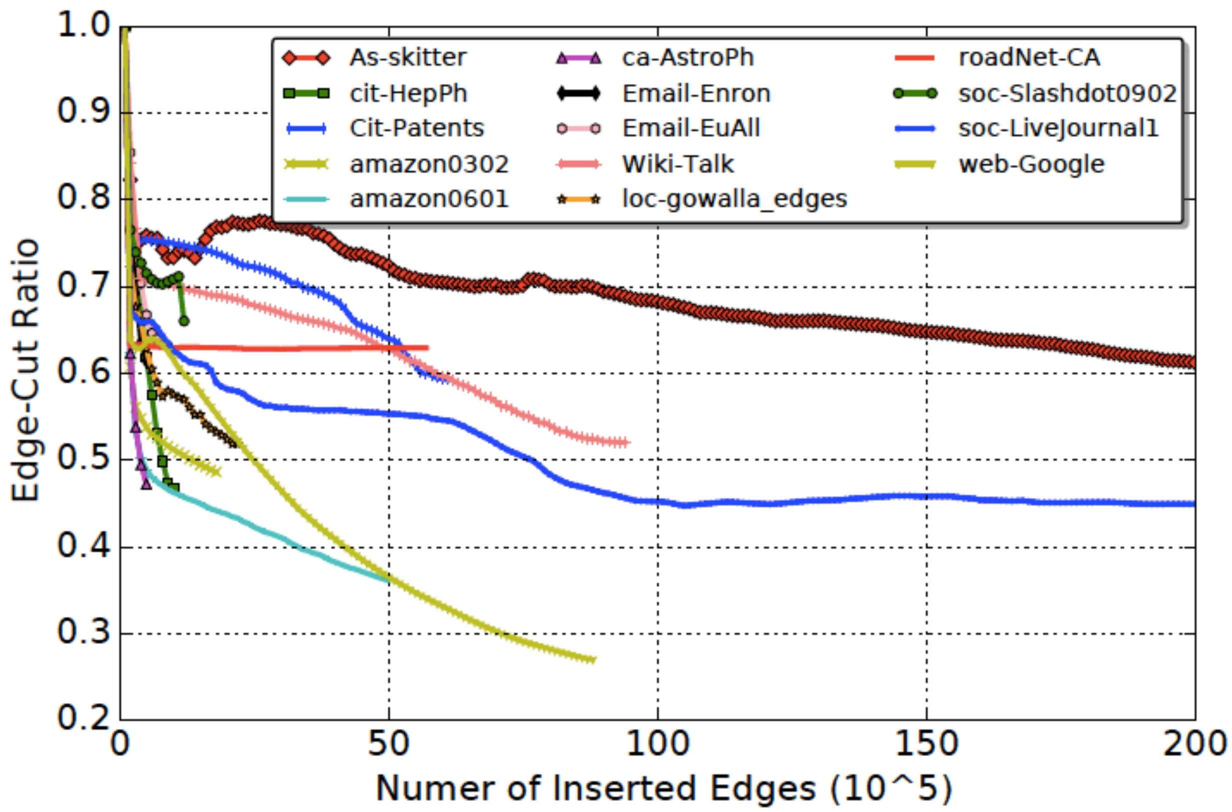


METIS is not always balanced

Others (including IOGP) are well balanced

Continuous Refinement of IOGP

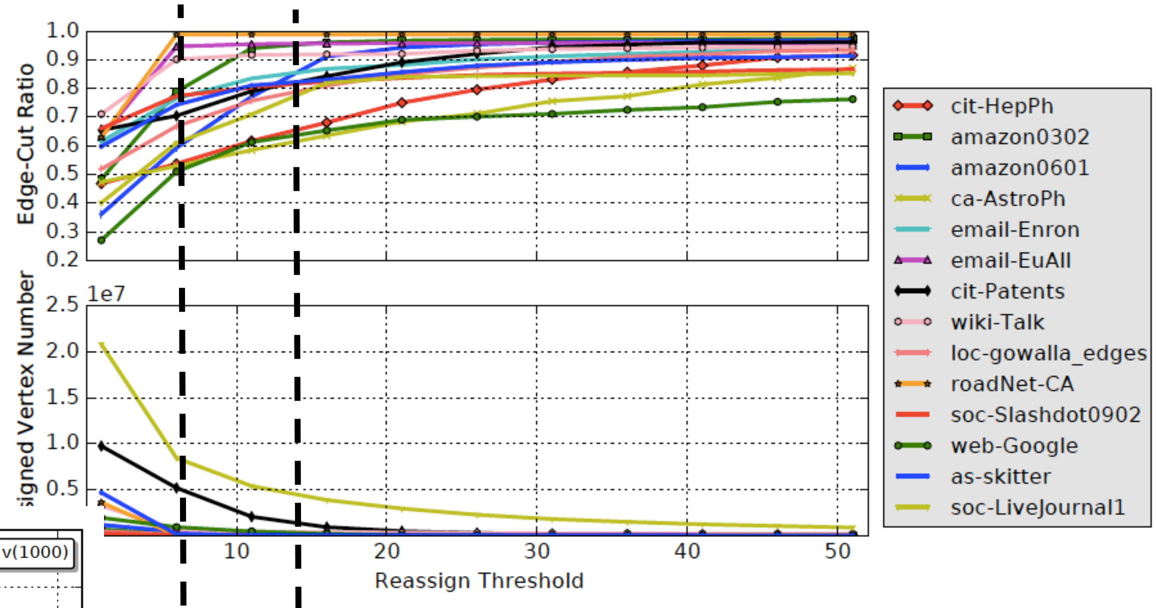
- Using similar heuristic, IOGP performs better than Fennel due to continuous refinement

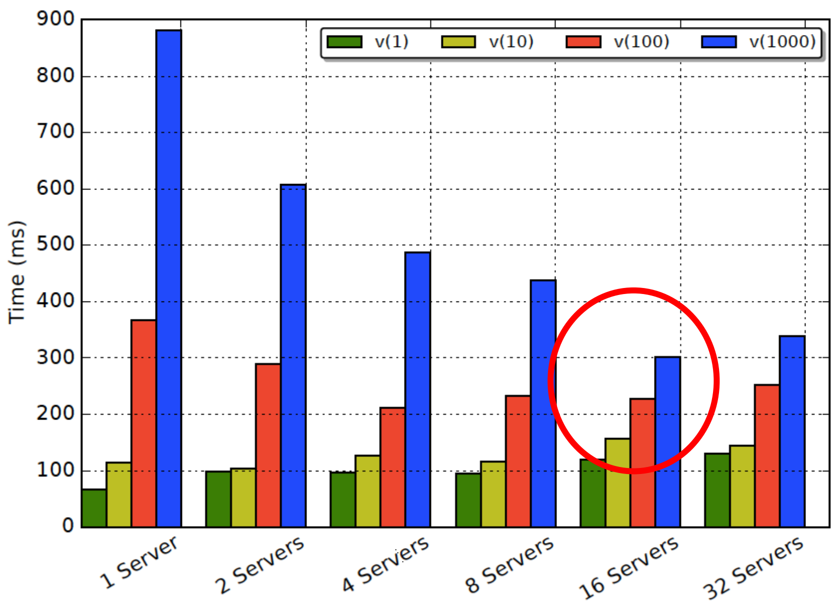


Key Tunable Parameters

Reassignment Threshold

somewhere around average degree of the graph



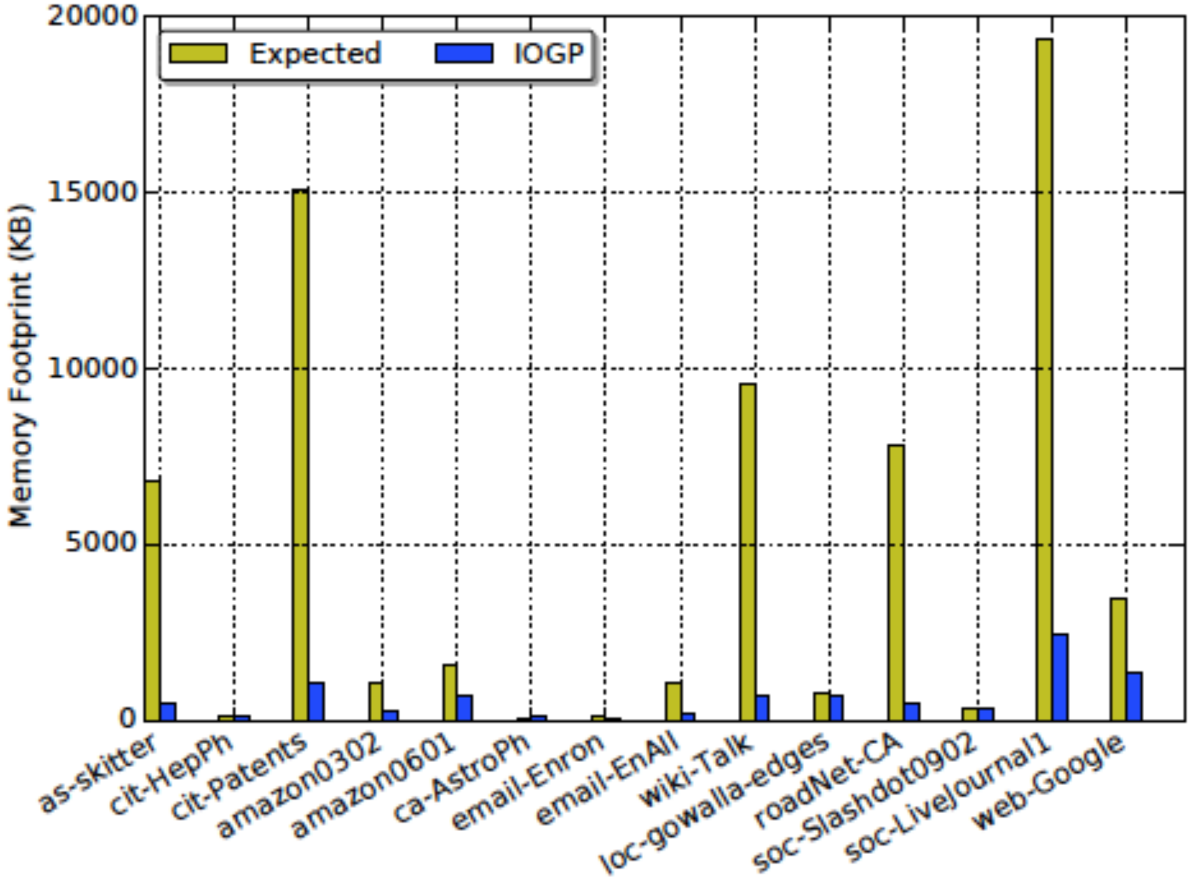


Split Threshold

Relevant with
1) hardware;
2) scale of the database cluster;
3) vertex degree and property size

Memory Footprint

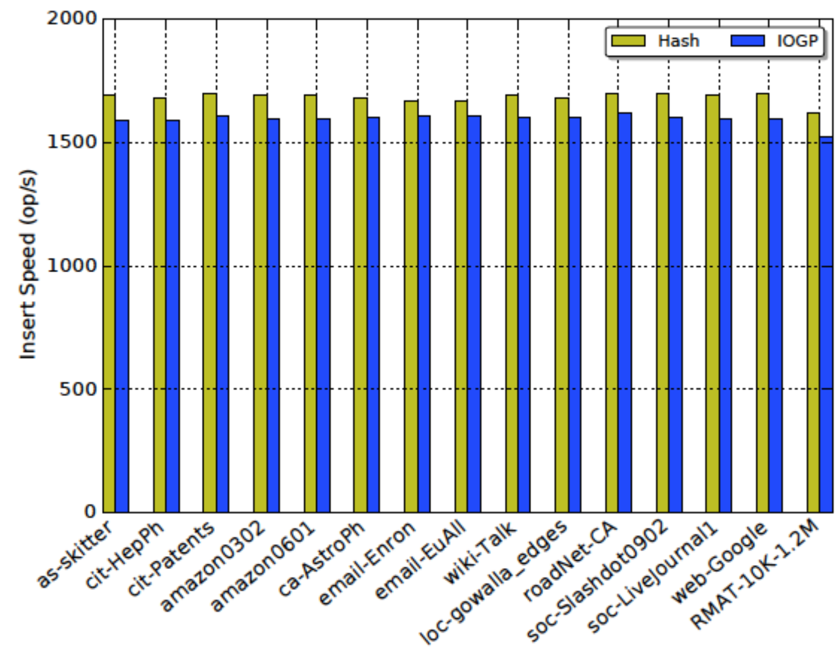
- How many memory is used in IOGP to keep the in-memory counters?

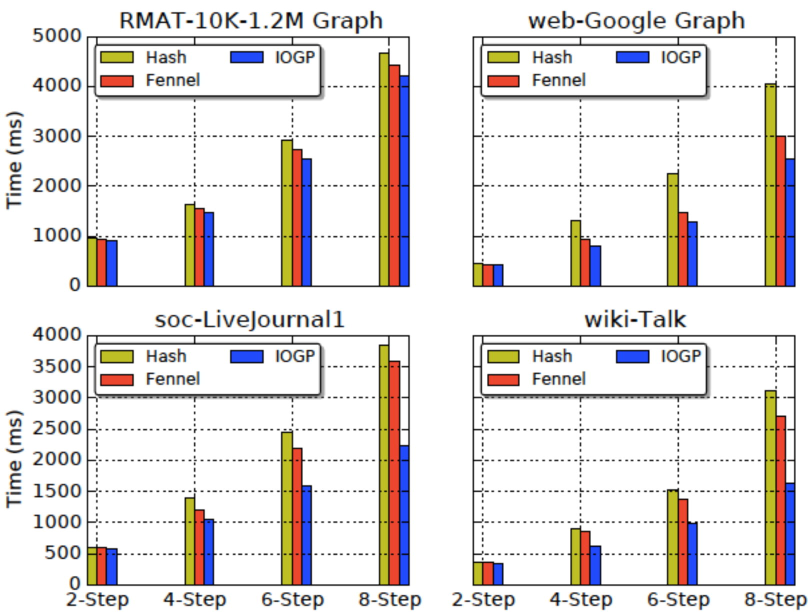


OLTP Performance

Graph Insertion

less than 10% overhead





Graph Travel

As much as 2x benefits

Conclusion & Future Work

- OLTP workloads of distributed graph databases require new set of graph partitioning algorithms.
- IOGP achieves less than 10% overheads on insertion, and as much as 2x performance improvement on queries.
- There are still lots of things can be done
  - Reduce the overheads of vertex reassignments
  - Partitioning the graphs based on the exact workload patterns
  - …

Thanks and Questions