TEGRA: Efficient Ad-Hoc Analytics on Evolving Graphs

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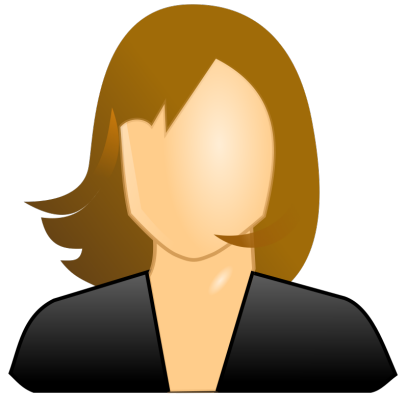
[*]Microsoft Research [▲]UC Berkeley [◆]Google [■]Two Sigma

USENIX NSDI, April 2021

Microsoft Research

riselab UC Berkeley

Meet **Carol**



Network Administrator
ACME Cellular Company

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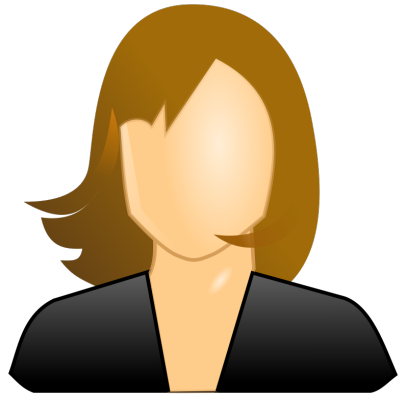

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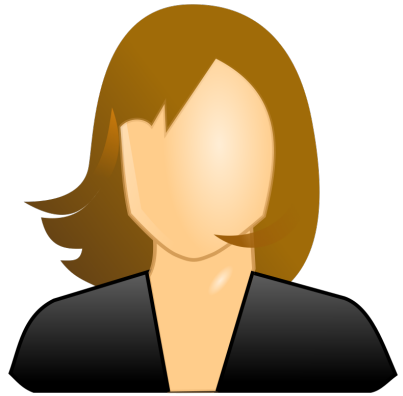

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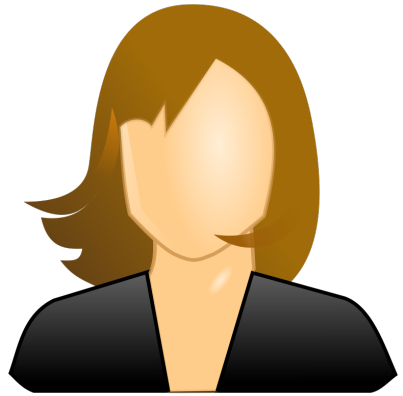

Network Administrator
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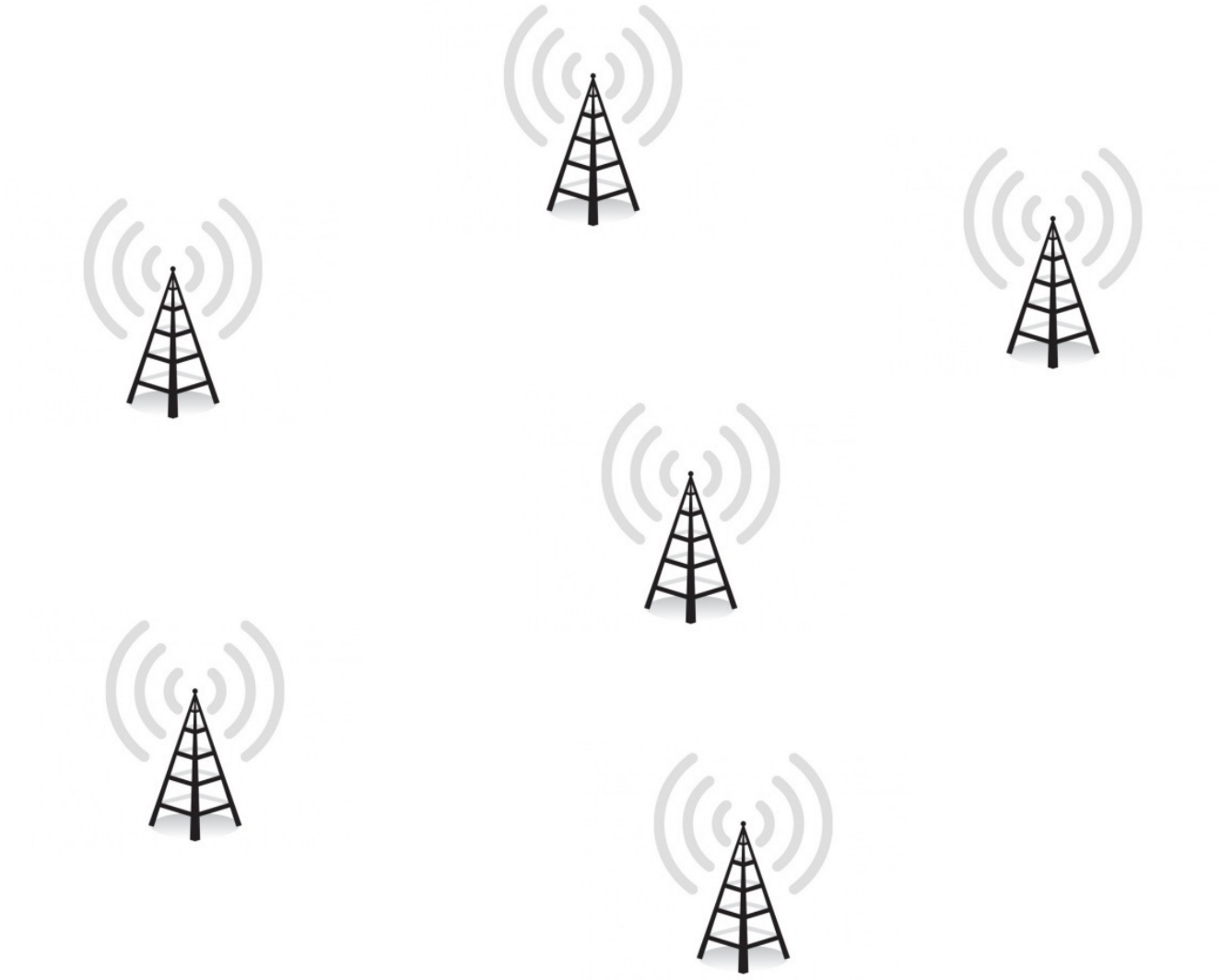
What is the **reason** for poor download speeds for many users at 9am?

How **Carol** does this



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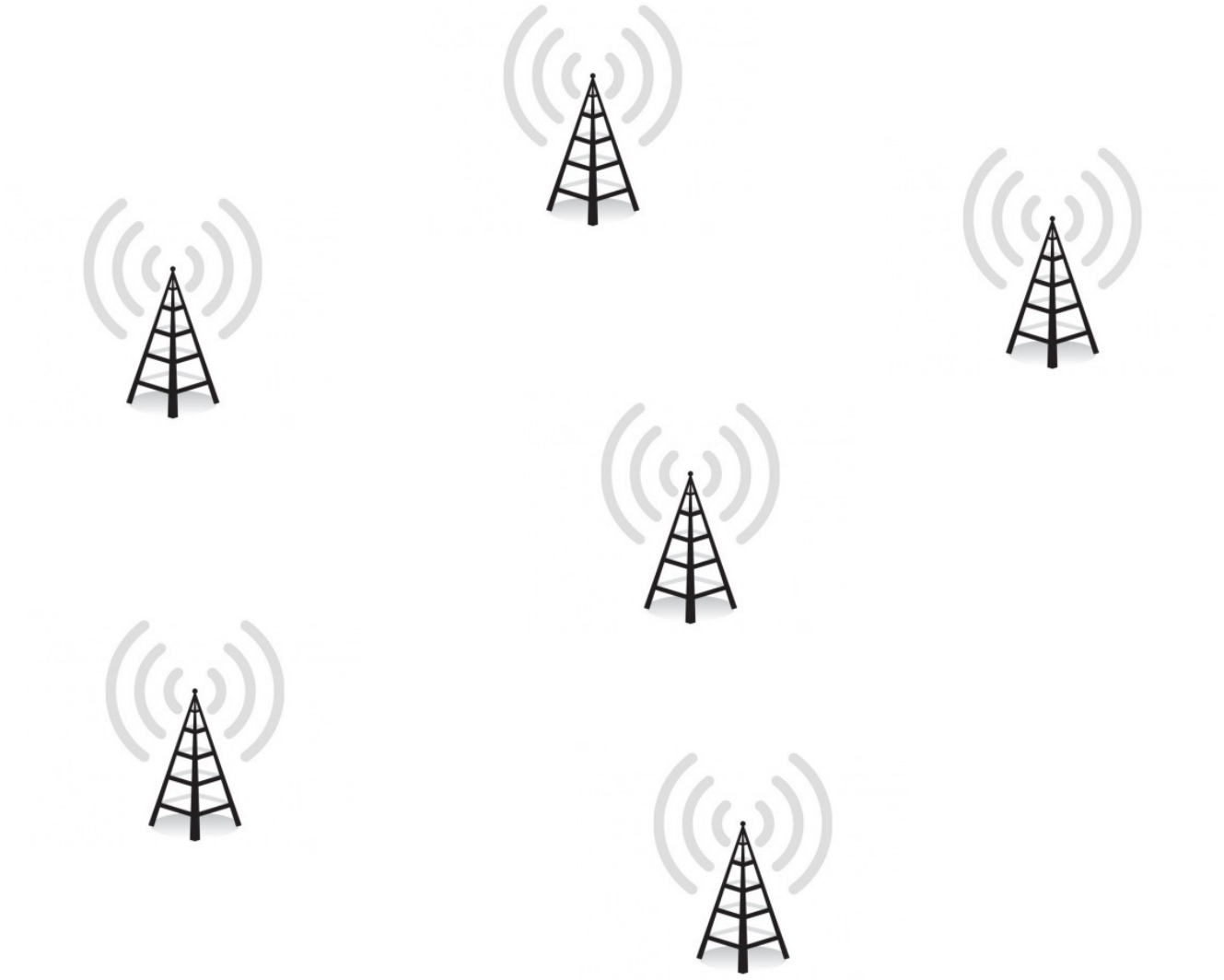

What did the network look like at 9am?

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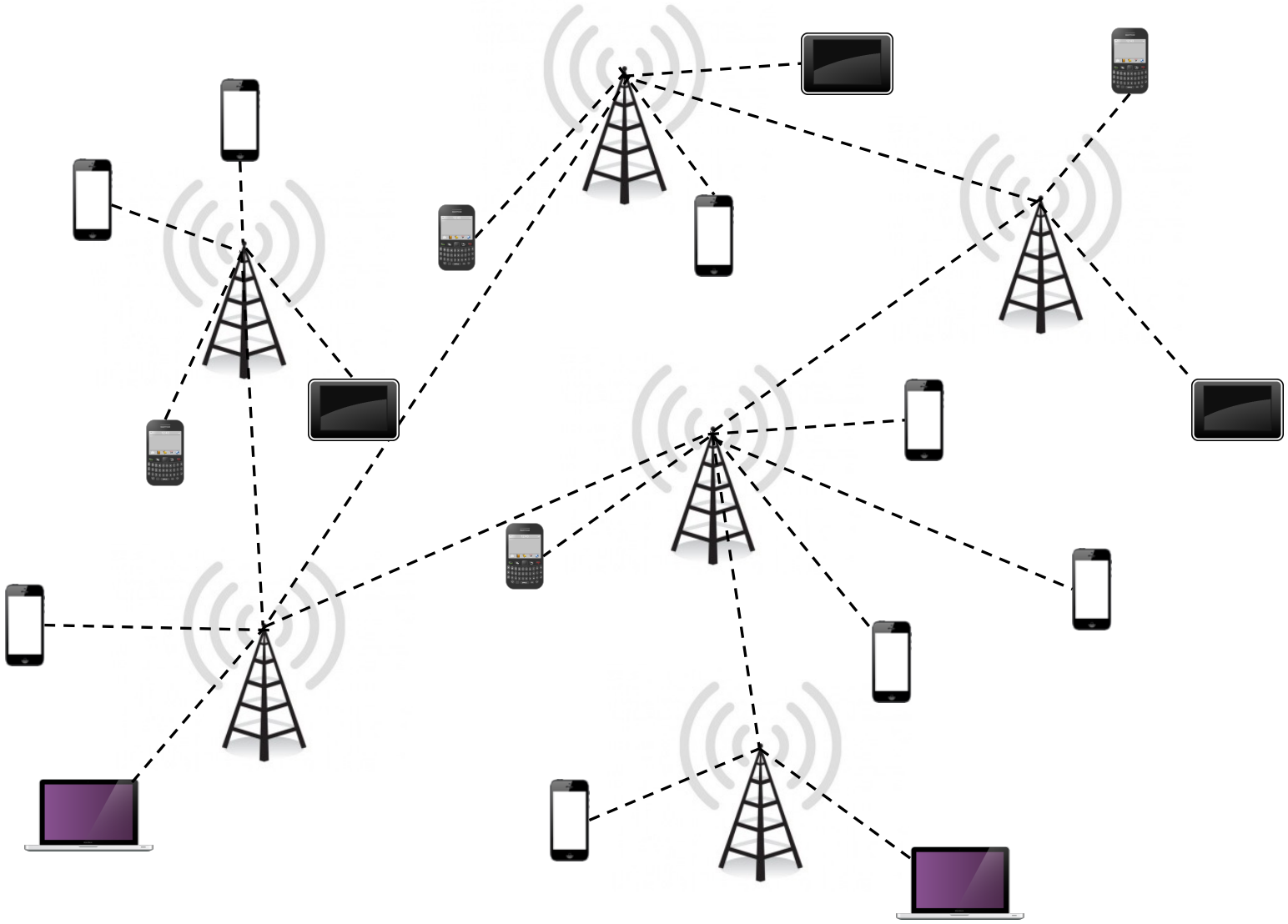

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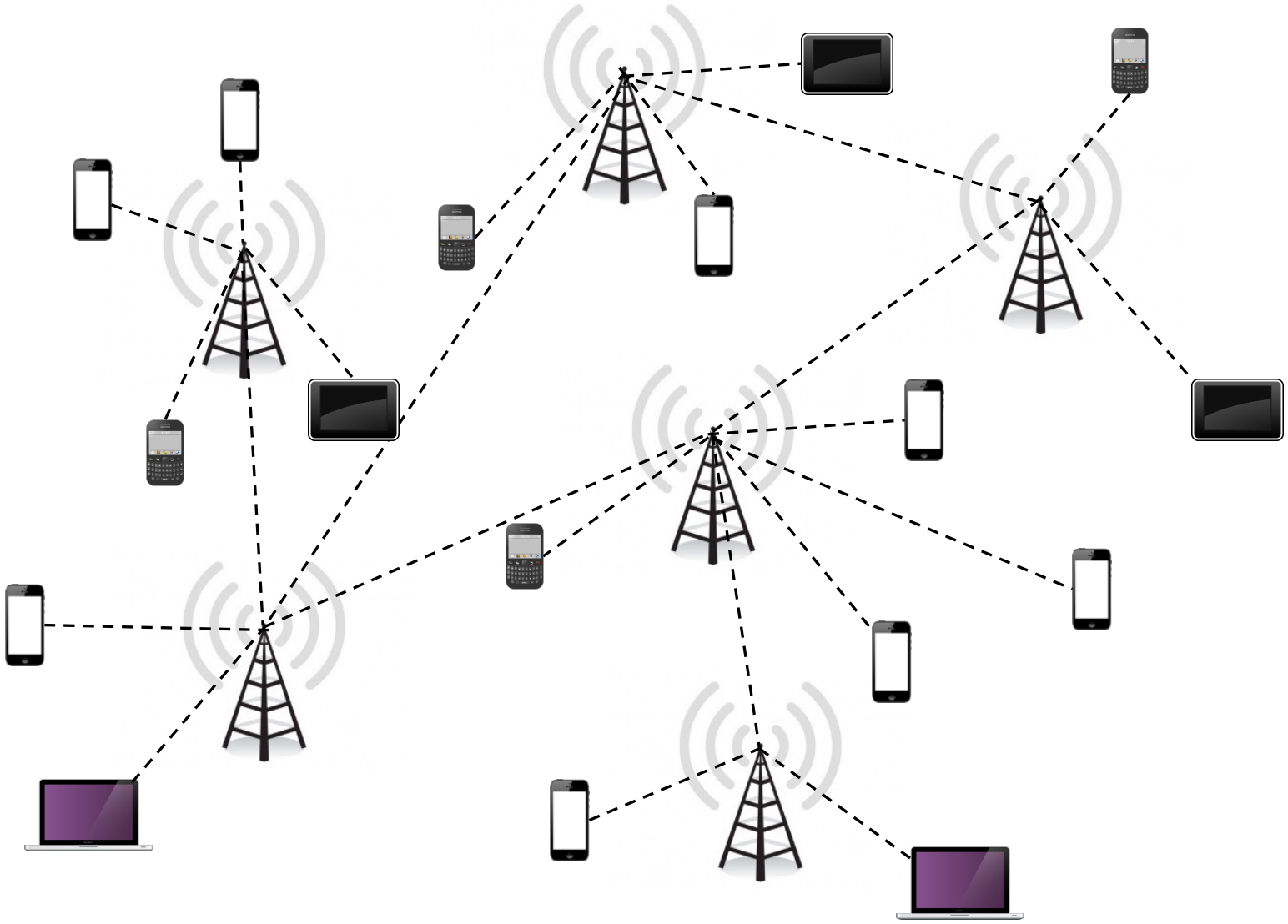

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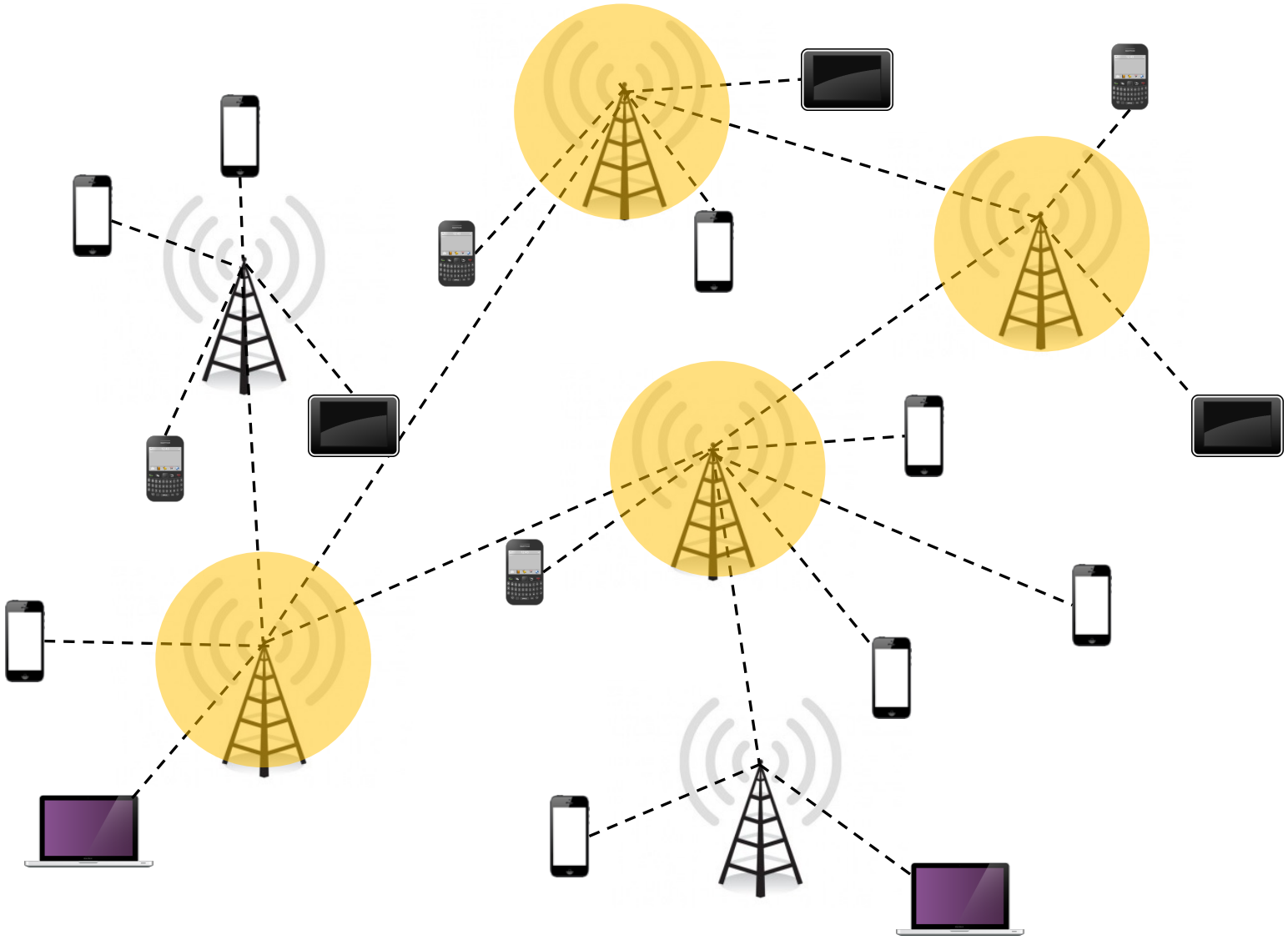

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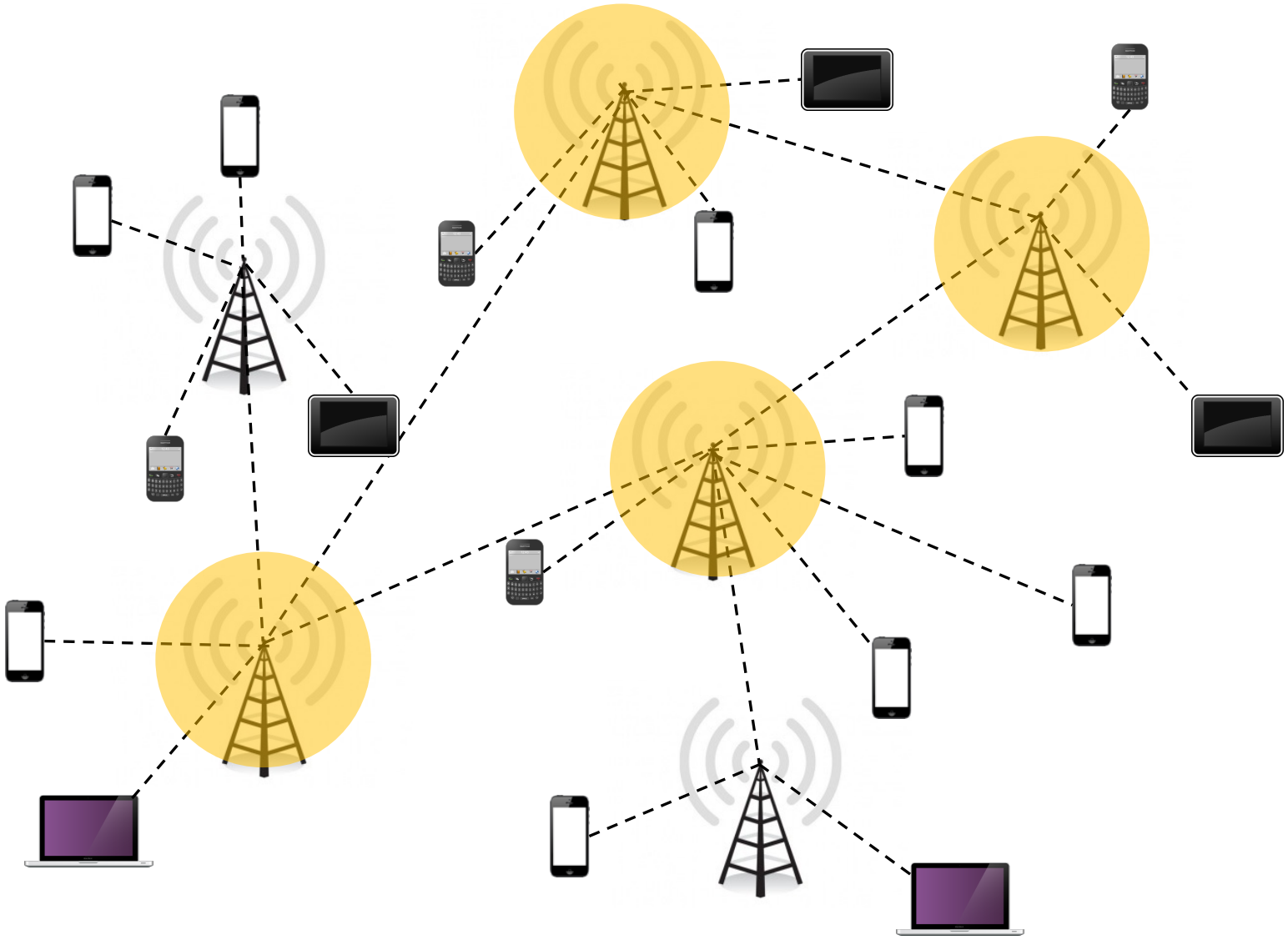

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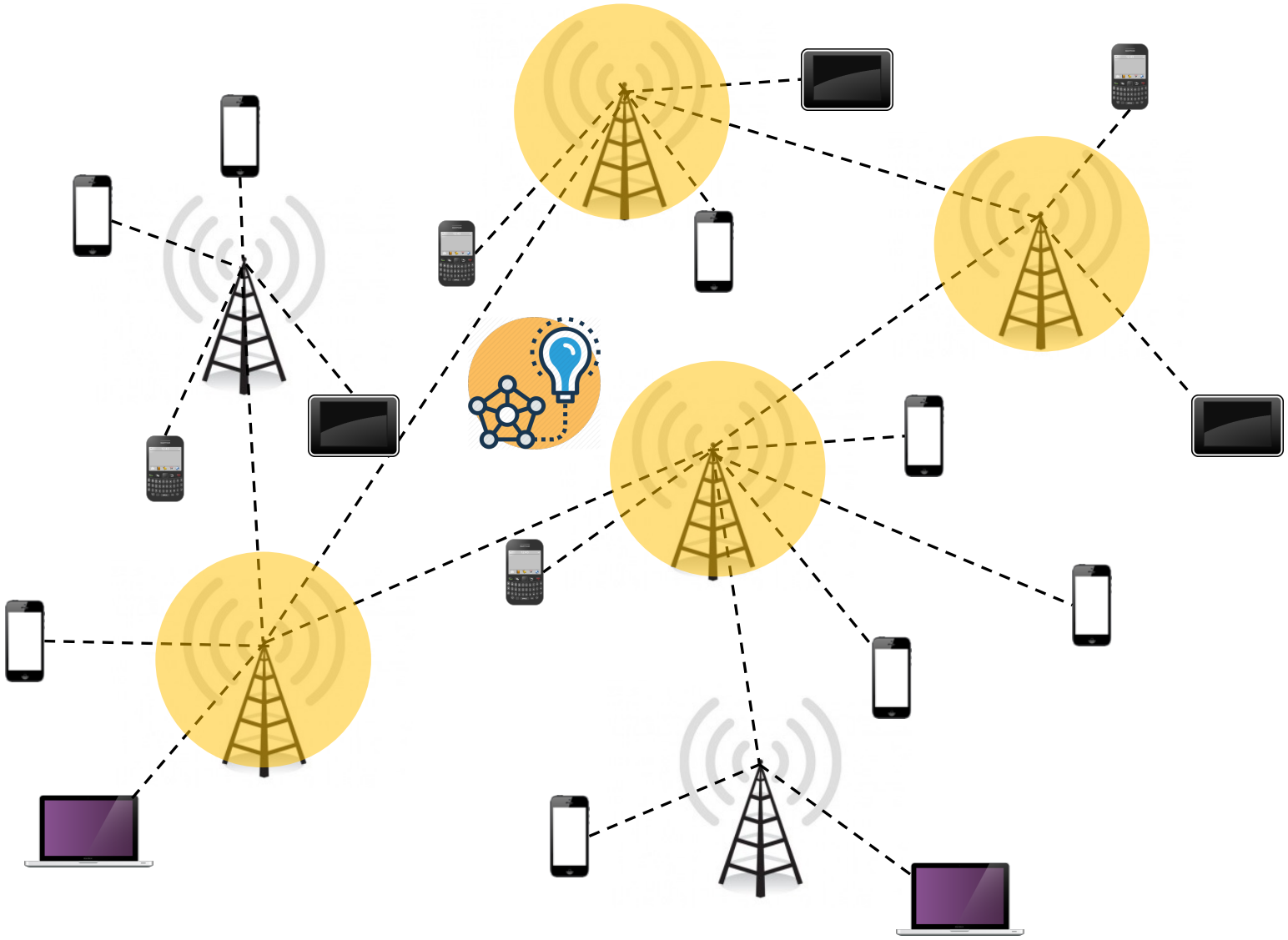

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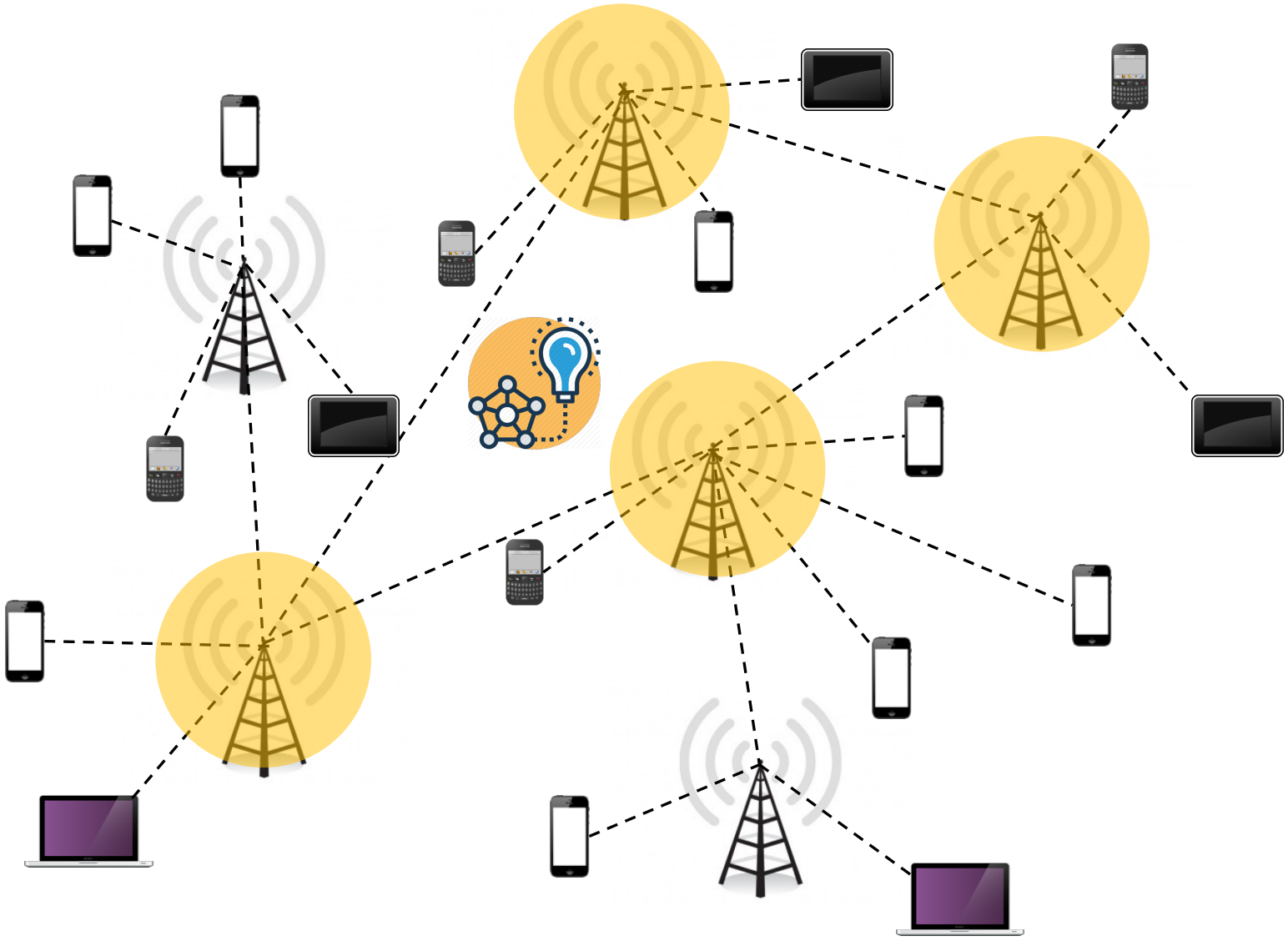

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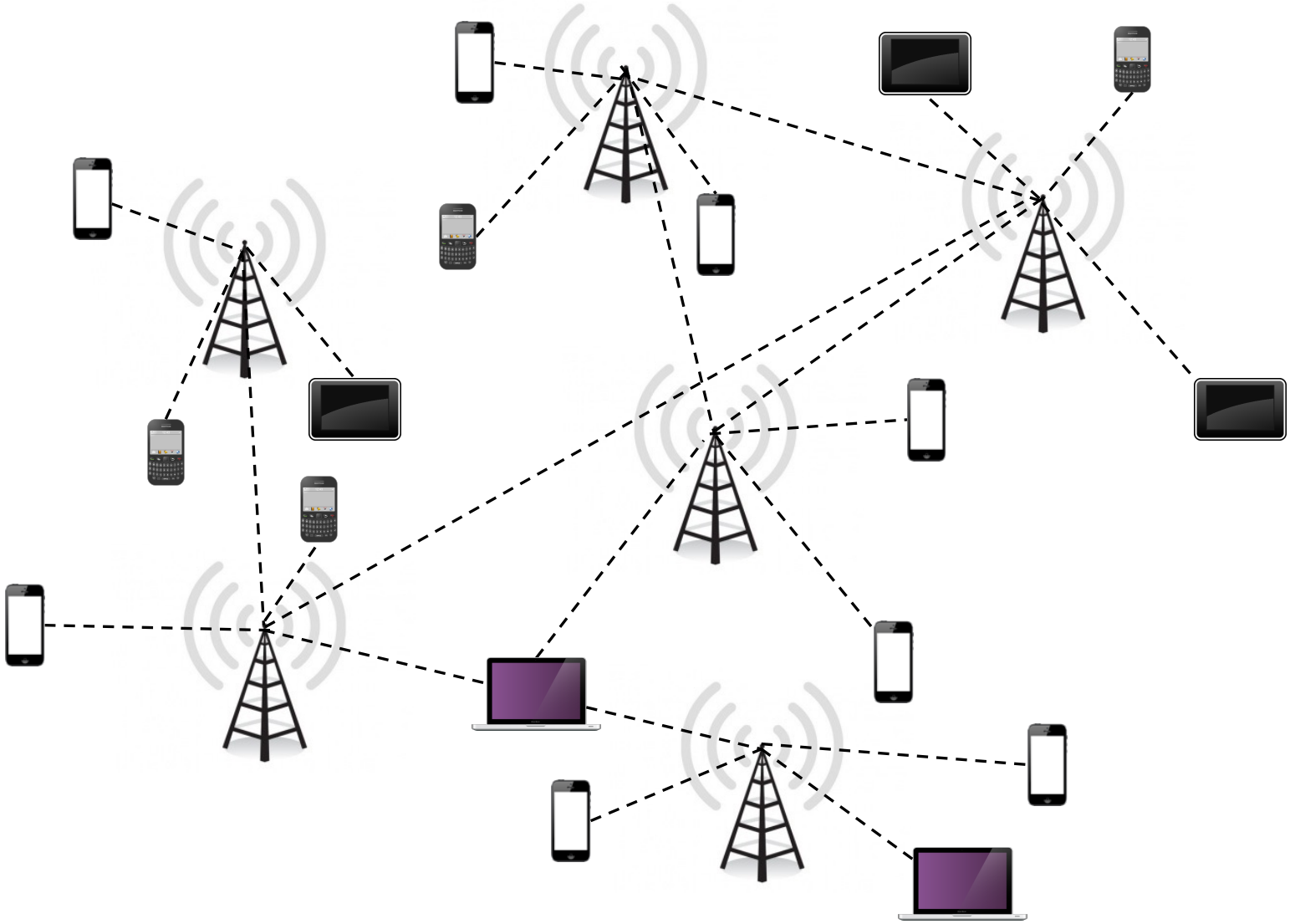

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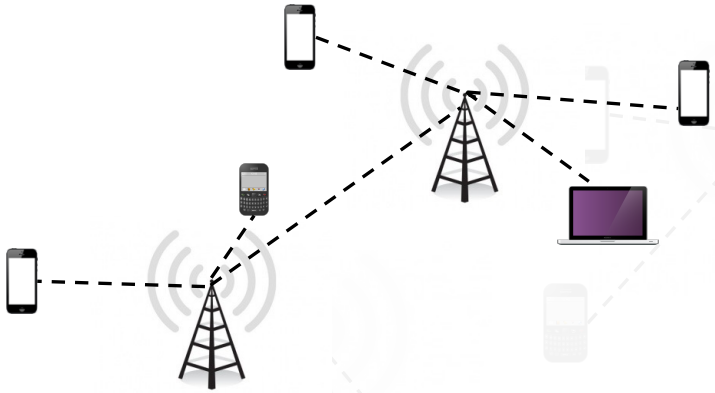

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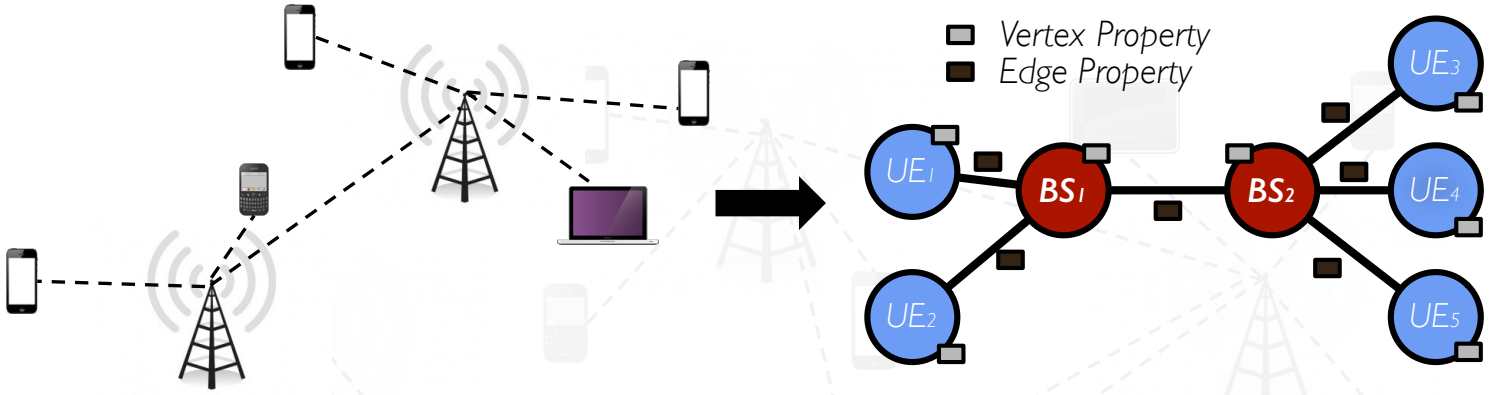

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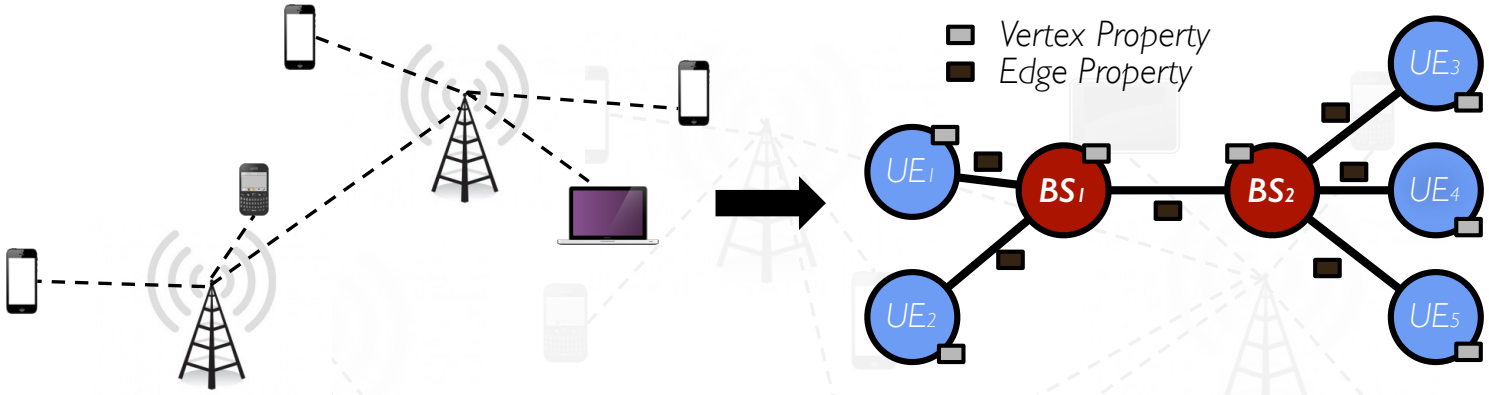

Interactive ad-hoc analysis on **evolving** graphs

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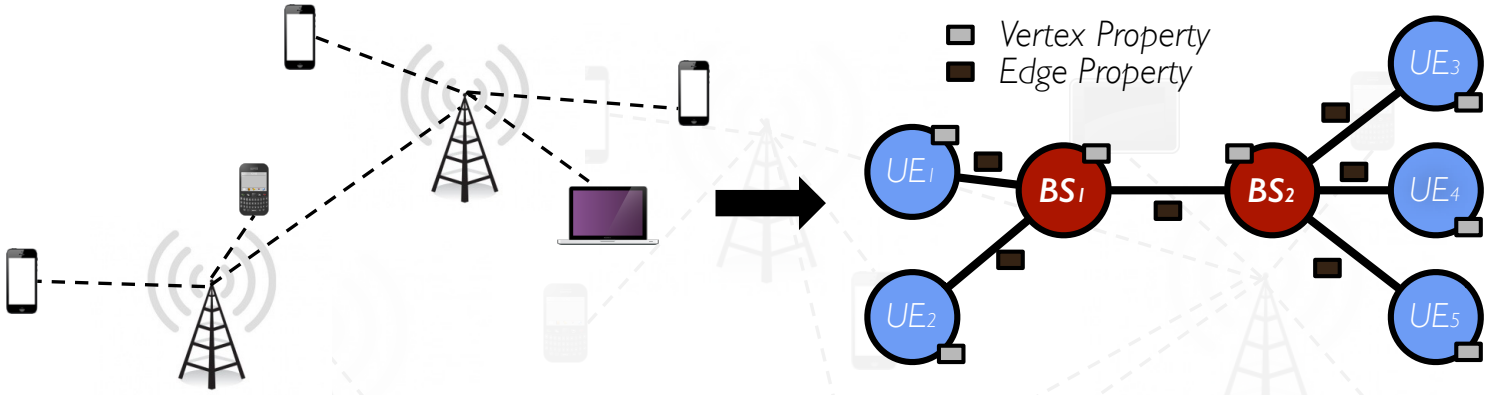

Interactive ad-hoc analysis on **evolving** graphs

Current systems focus on **streaming** or **temporal** analysis

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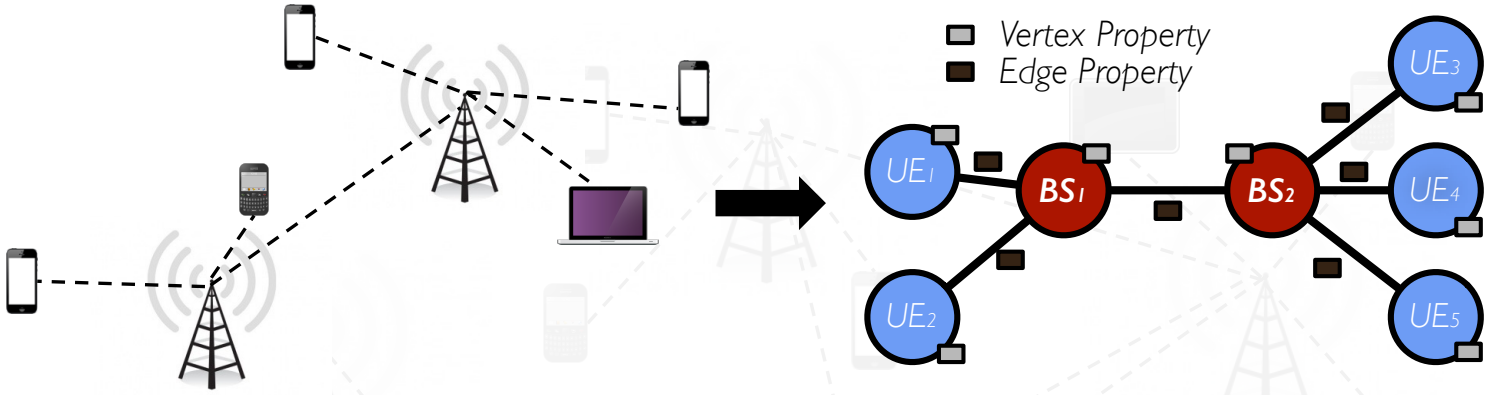

Interactive ad-hoc analysis on **evolving** graphs

Current systems focus on **streaming** or **temporal** analysis

Can benefit significantly from *efficient* ad-hoc analytics

What did the network look like at 9am?

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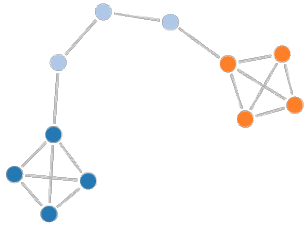
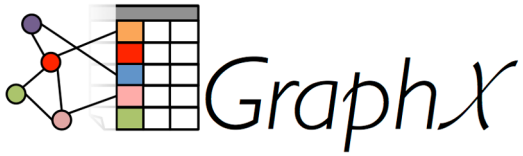
Challenges

Programming
Storage
Performance

How do we enable ad-hoc queries on dynamic graphs in a **natural** and **intuitive** way?



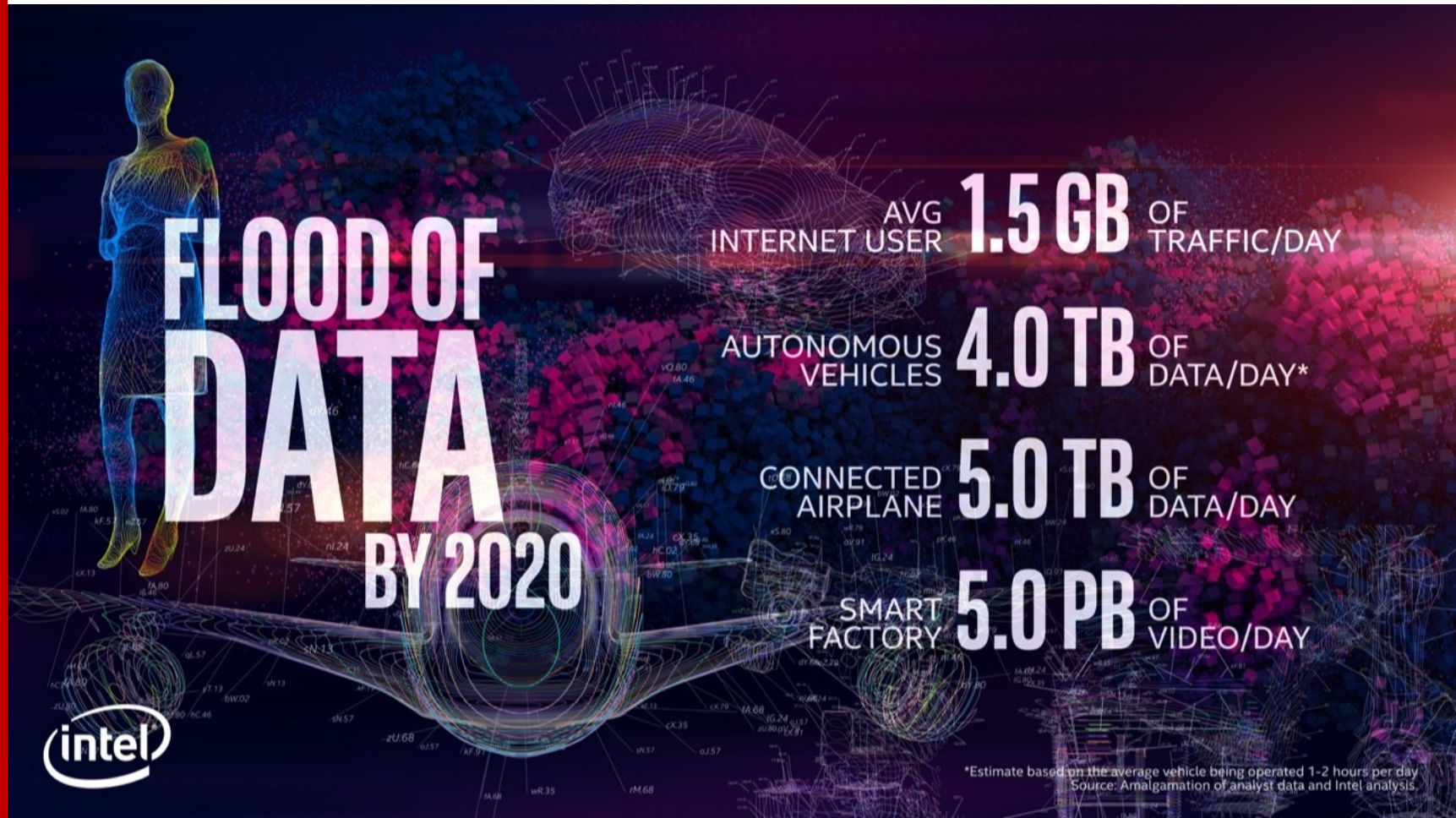
NetworkX



Challenges

Programming
Storage
Performance

Ad-hoc queries are
data intensive



Challenges

Programming
Storage
Performance

Ad-hoc queries are both
interactive and **exploratory**

Changes to the graph are **relatively small *during*** ad-hoc analysis

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Queries are frequently applied to **multiple windows *close-by*** in time

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Queries are frequently applied to **multiple windows *close-by*** in time

TEGRA accelerates ad-hoc analytics by **sharing storage and computation** across queries and windows

Challenges

Programming

Timelapse abstraction with simple API

Storage

Incremental storage for efficient access

Computation

Incremental computation model for interactivity & efficiency

Timelapse Abstraction

Key idea: Illusion of a **series** of static graph snapshots

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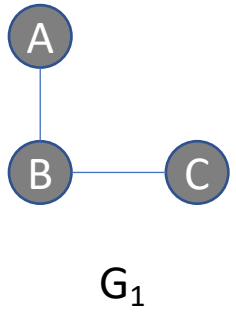
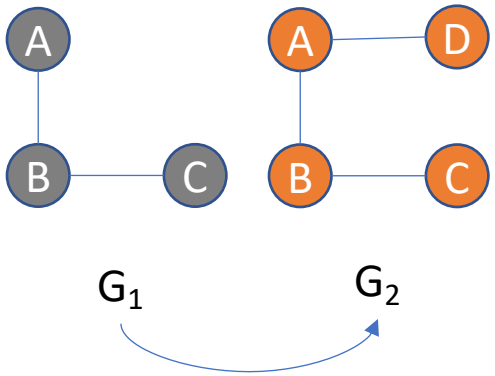


G_1

Timelapse Abstraction

Key idea: Illusion of a **series** of static graph snapshots



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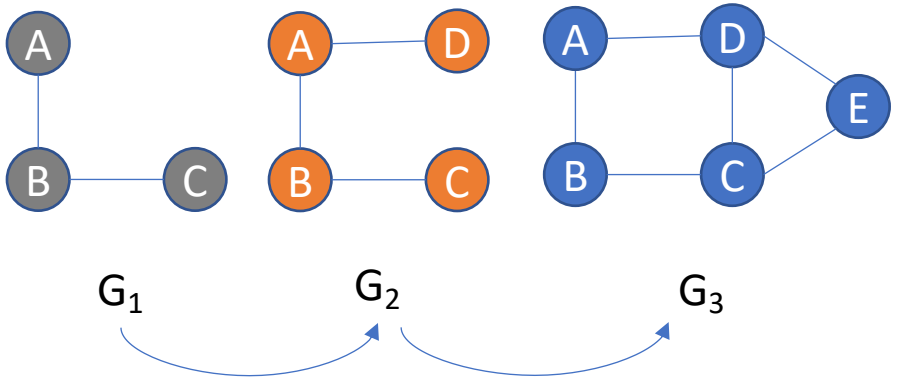

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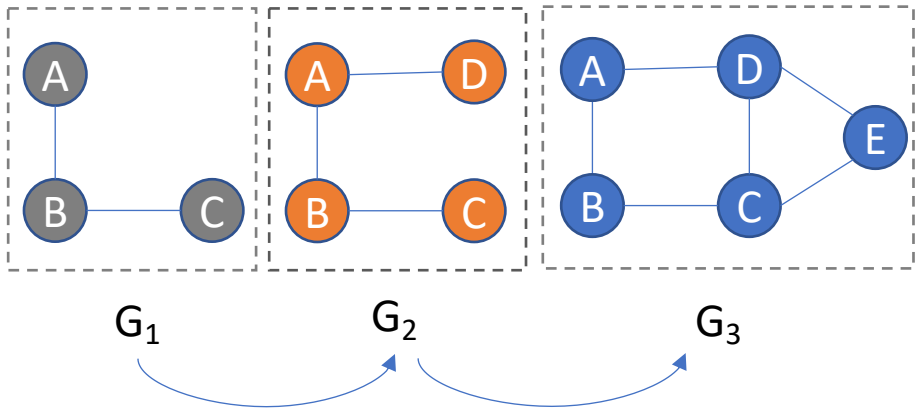

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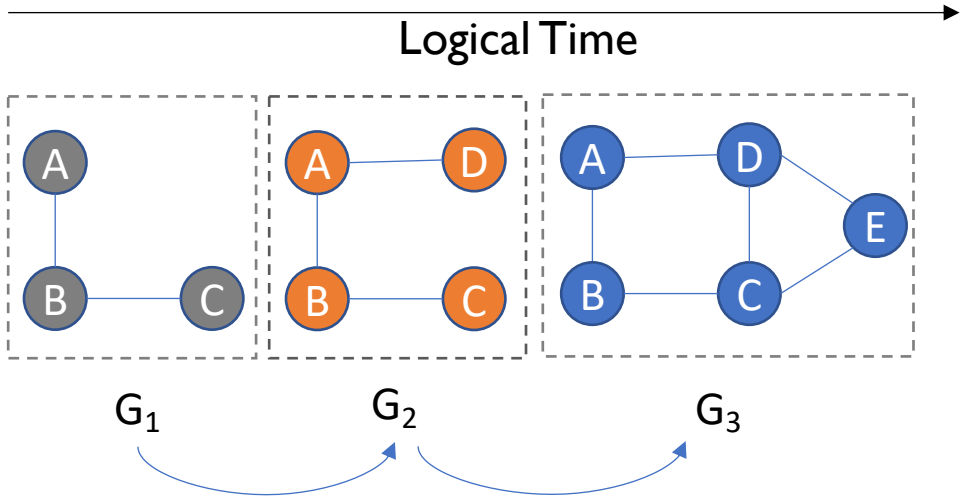

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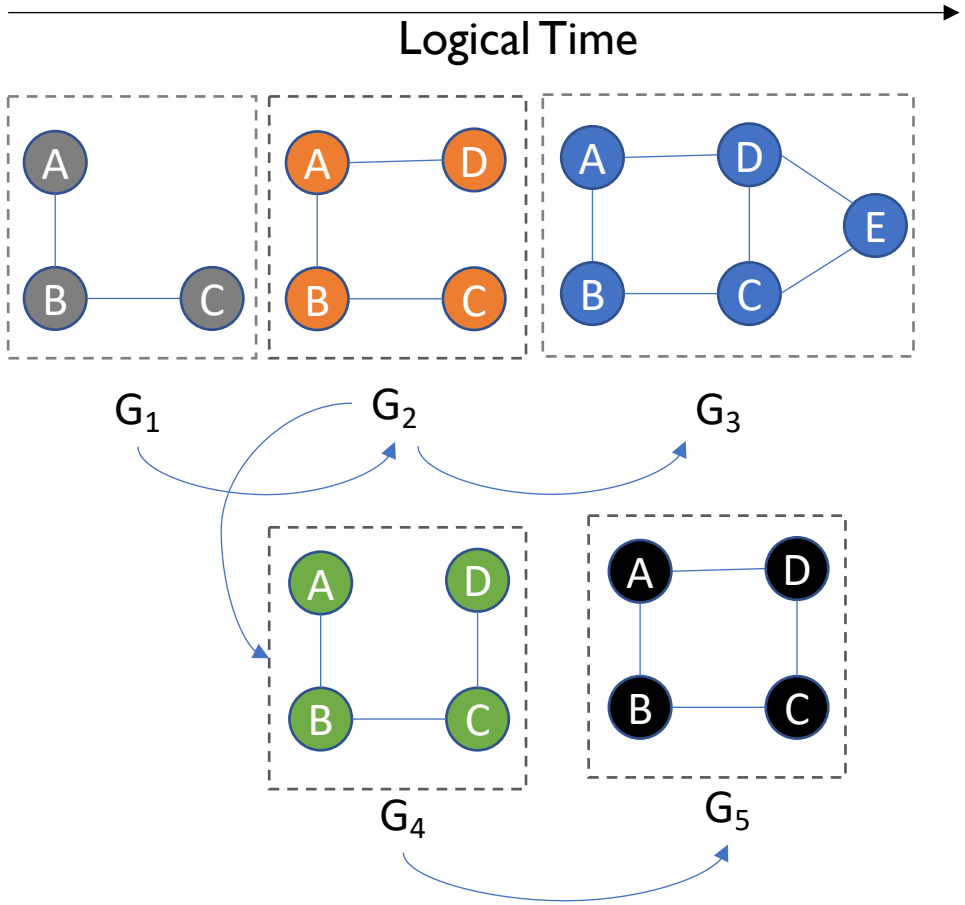

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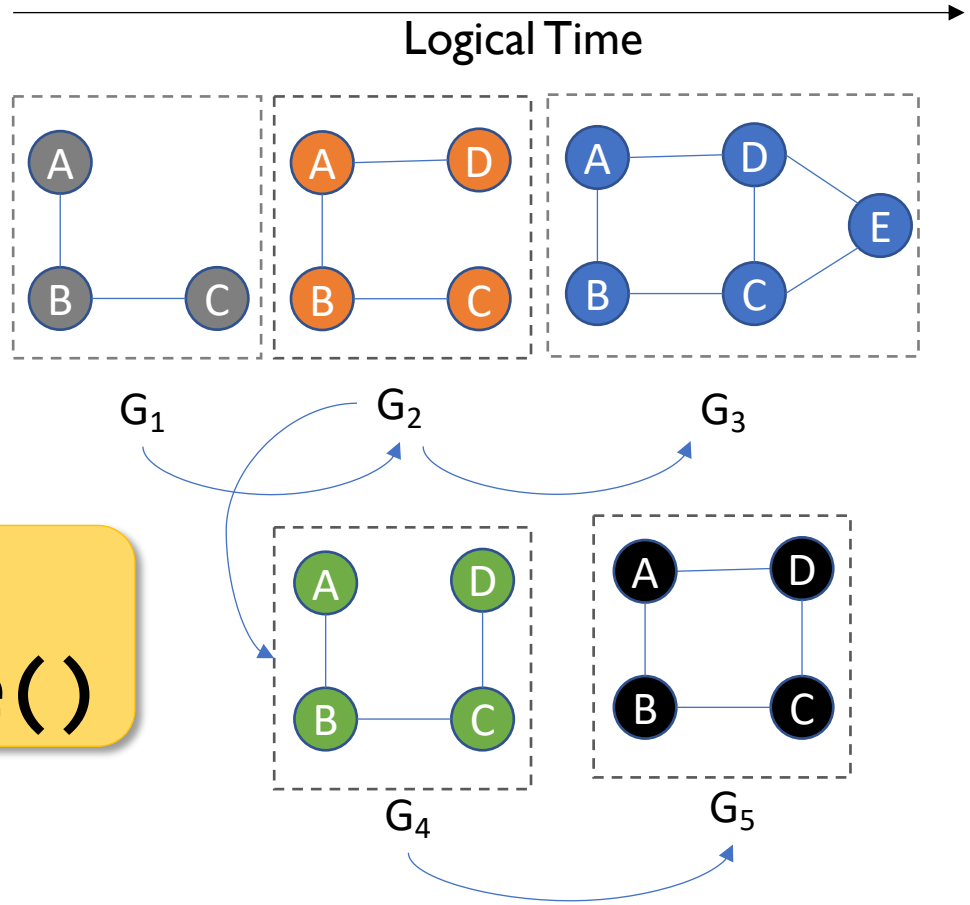


```
save()
retrieve()
```

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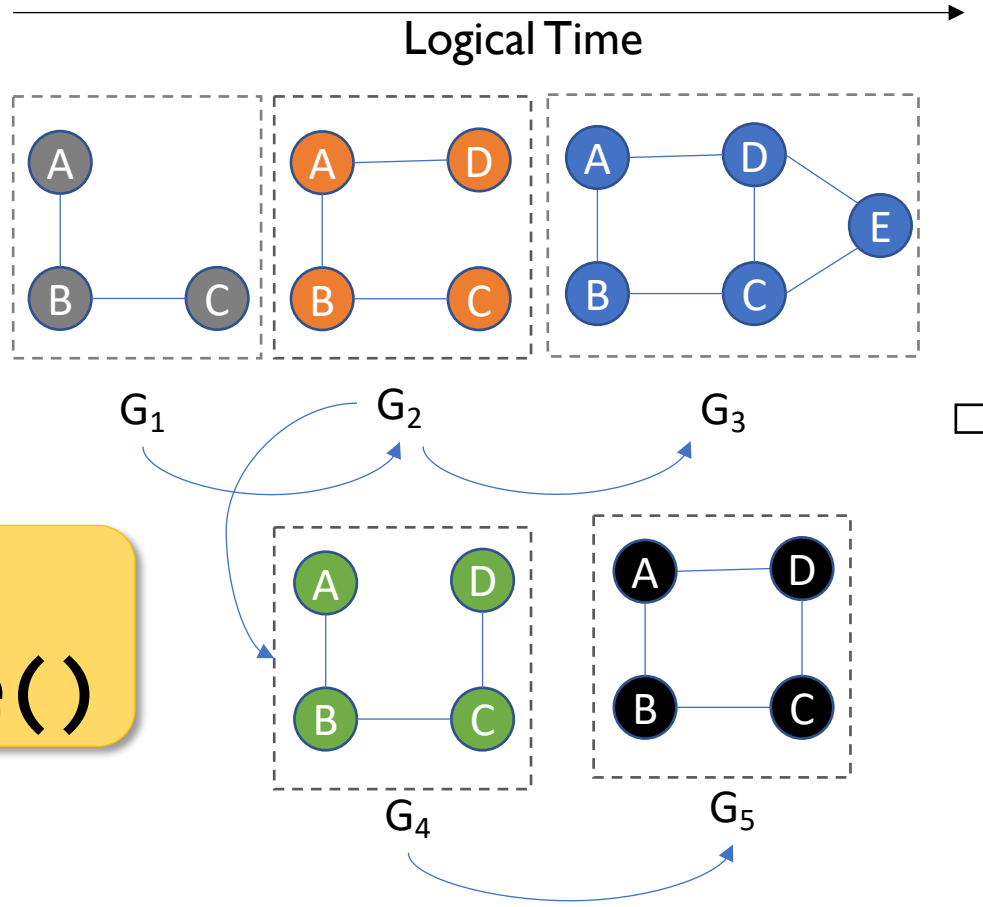

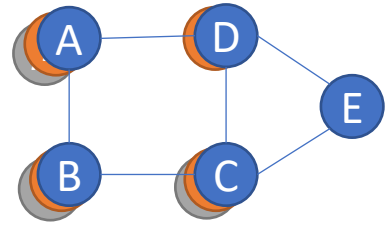

`save()`
`retrieve()`

`diff()`
`merge()`
`expand()`

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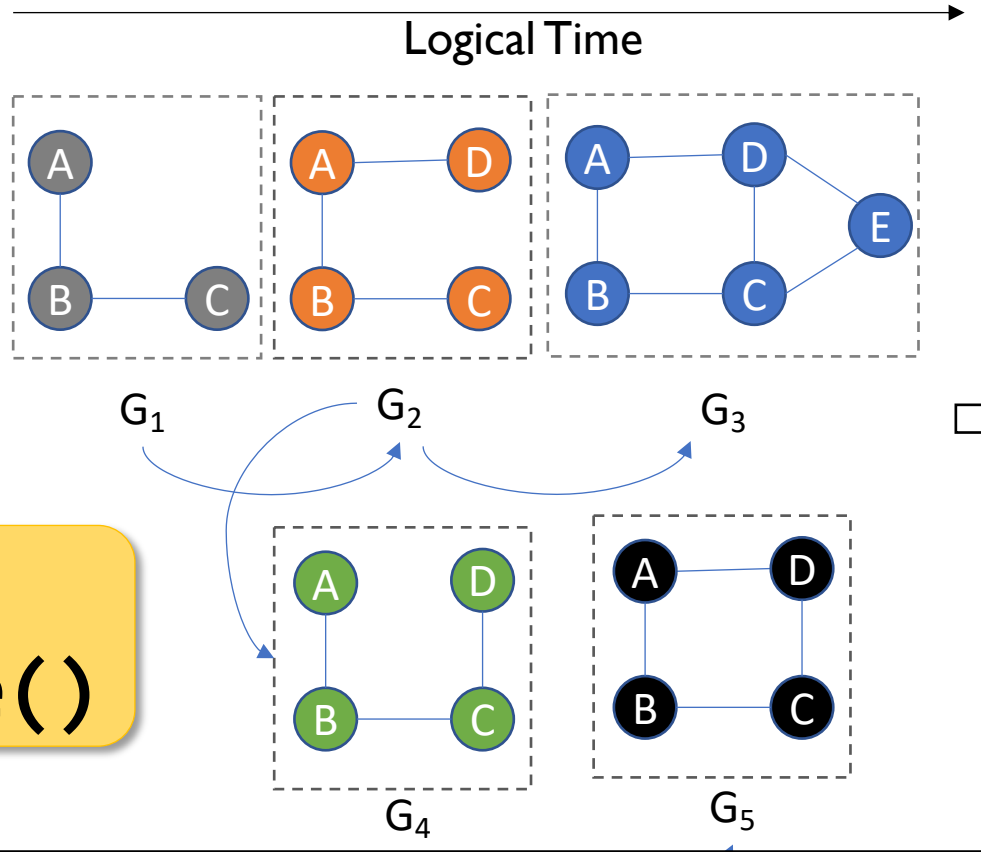

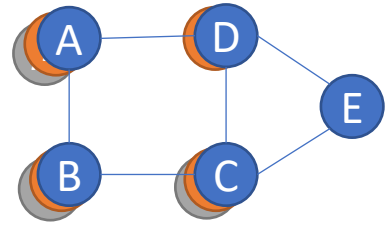

`save()`
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`diff()`
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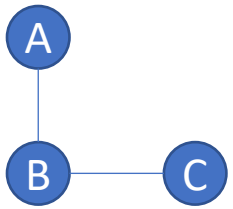
Enable system to **efficiently store & operate** on them

Snapshot **Storage**

Store entire snapshots



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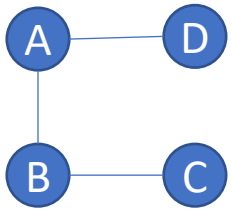

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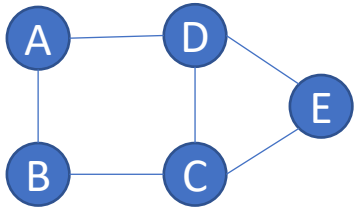

G_3

Snapshot **Storage**

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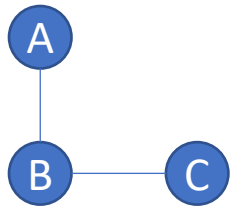

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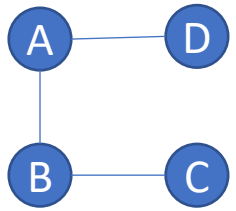

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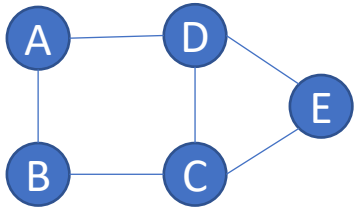

G_3

+ Efficient retrieval
- Storage overhead

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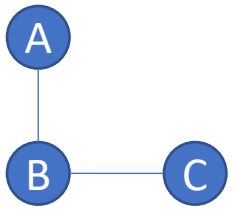

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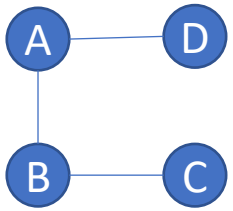

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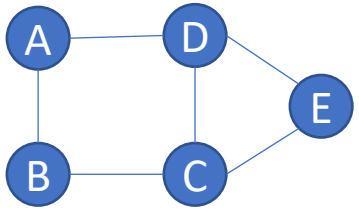
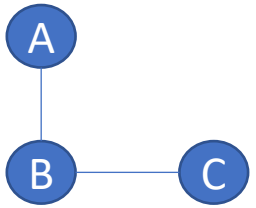


G_3

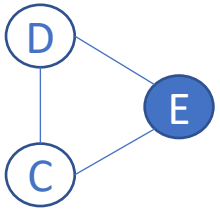
+ Efficient retrieval
- Storage overhead

Store only differences



δg_1

δg_2



δg_3

Snapshot **Storage**

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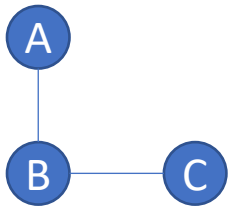

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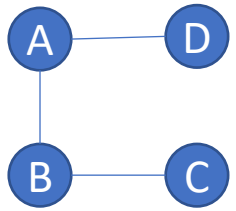

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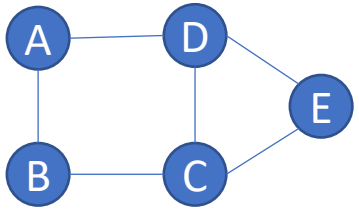

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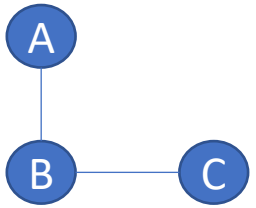
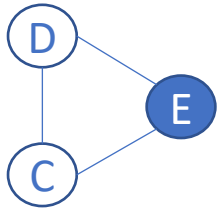


δg_1

δg_2



δg_3

+ Efficient storage
- Retrieval overhead

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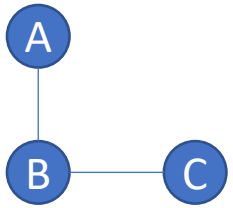

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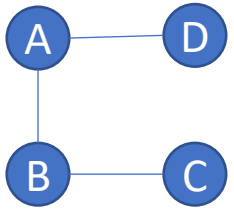
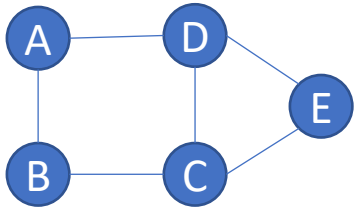


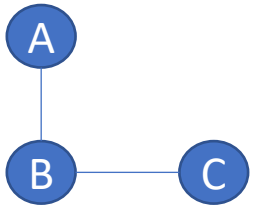
G_2



G_3

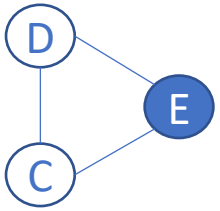
+ Efficient retrieval
- Storage overhead

Store only differences



δg_1

δg_2



δg_3

+ Efficient storage
- Retrieval overhead

Fundamental trade-off between storage **overhead** and retrieval **efficiency**

Challenges

Programming

Timelapse abstraction with simple API

Storage

Incremental storage for efficient access

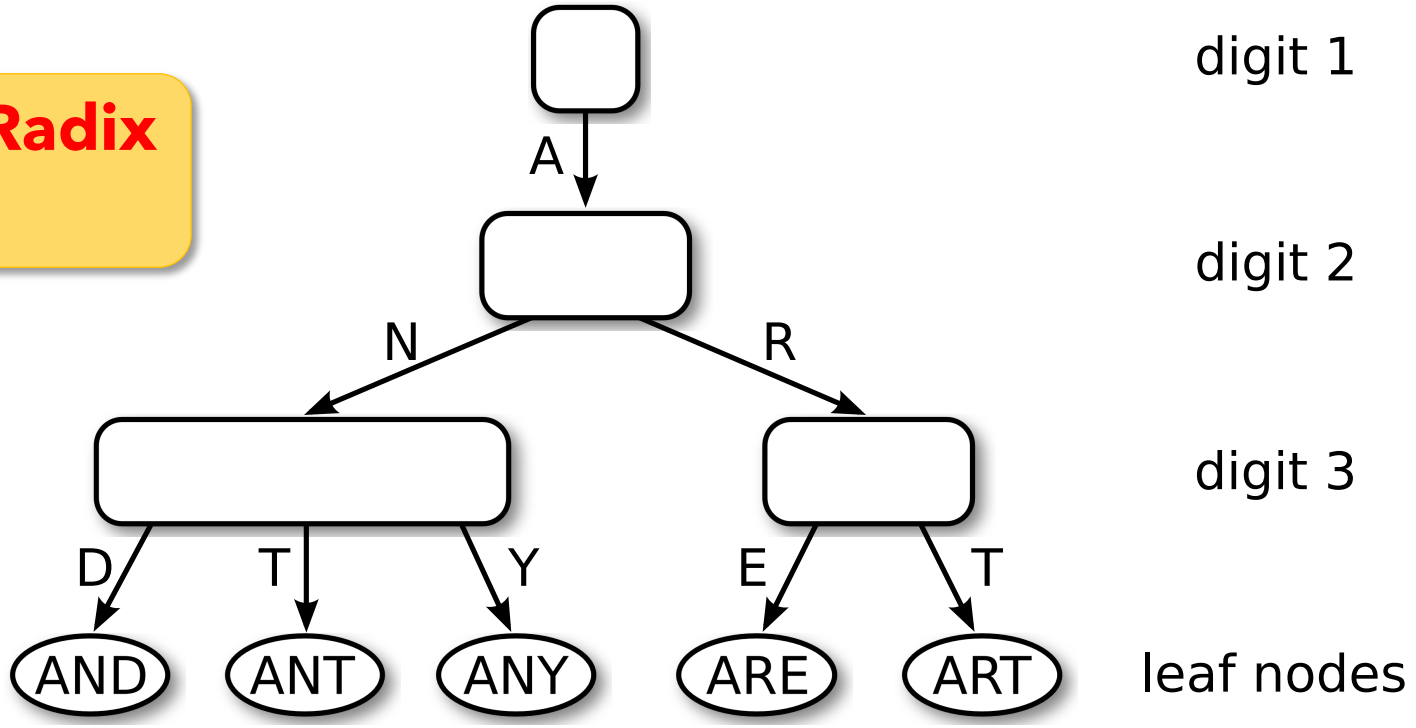
Computation

Incremental computation model for interactivity & efficiency

Optimizing **Storage**

Key idea: Leverage persistent data structures

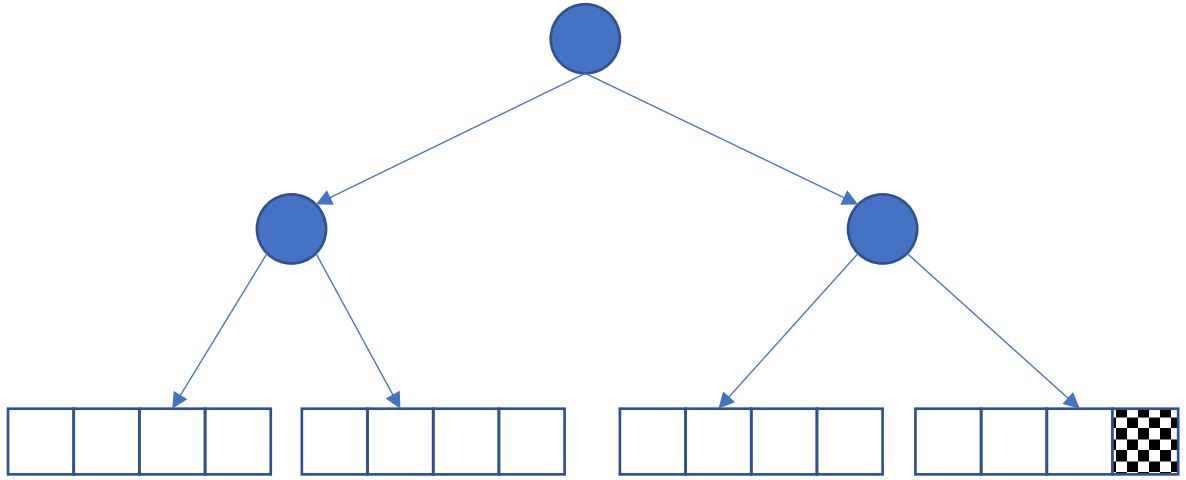
Adaptive Radix Tree



"The adaptive radix tree: ARTful indexing for main-memory databases", Leis et. al., ICDE 2013

Optimizing **Storage**

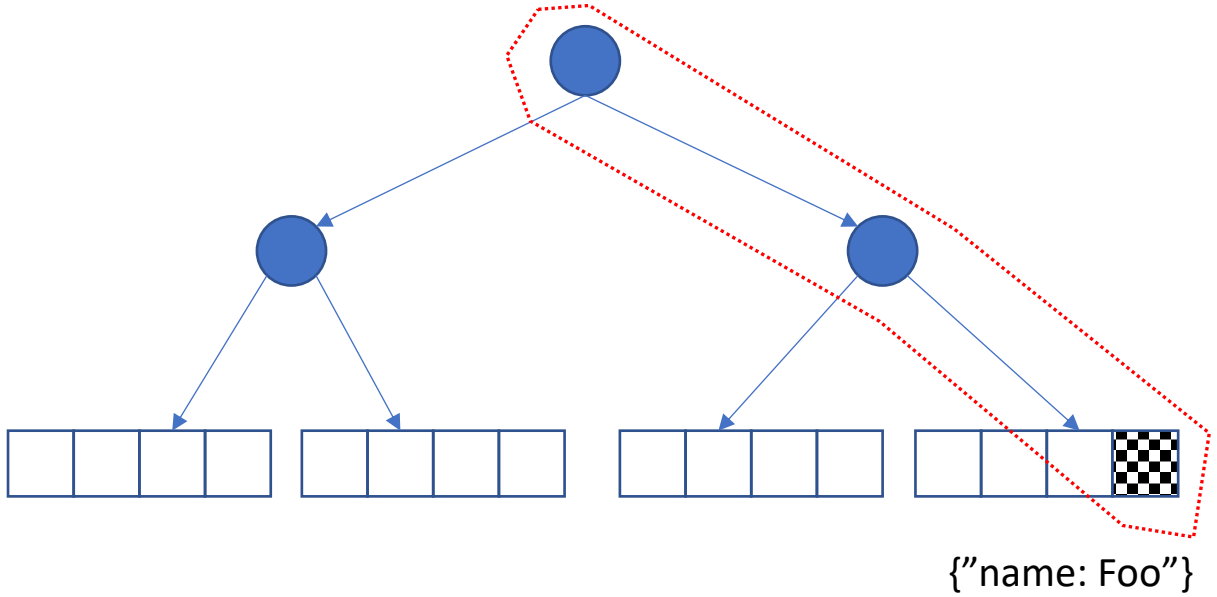
Key idea: Build a persistent data structure based distributed dynamic graph store



Vertex ➡ Property

Optimizing **Storage**

Key idea: Build a persistent data structure based distributed dynamic graph store



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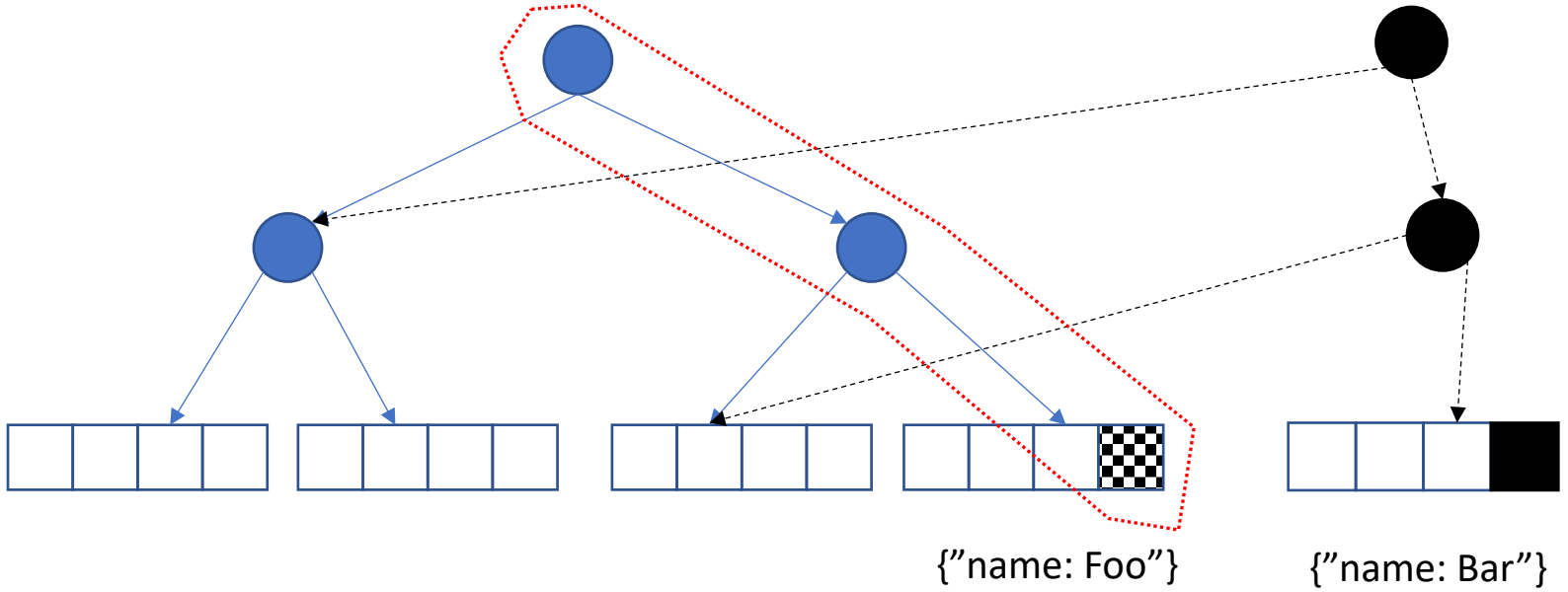

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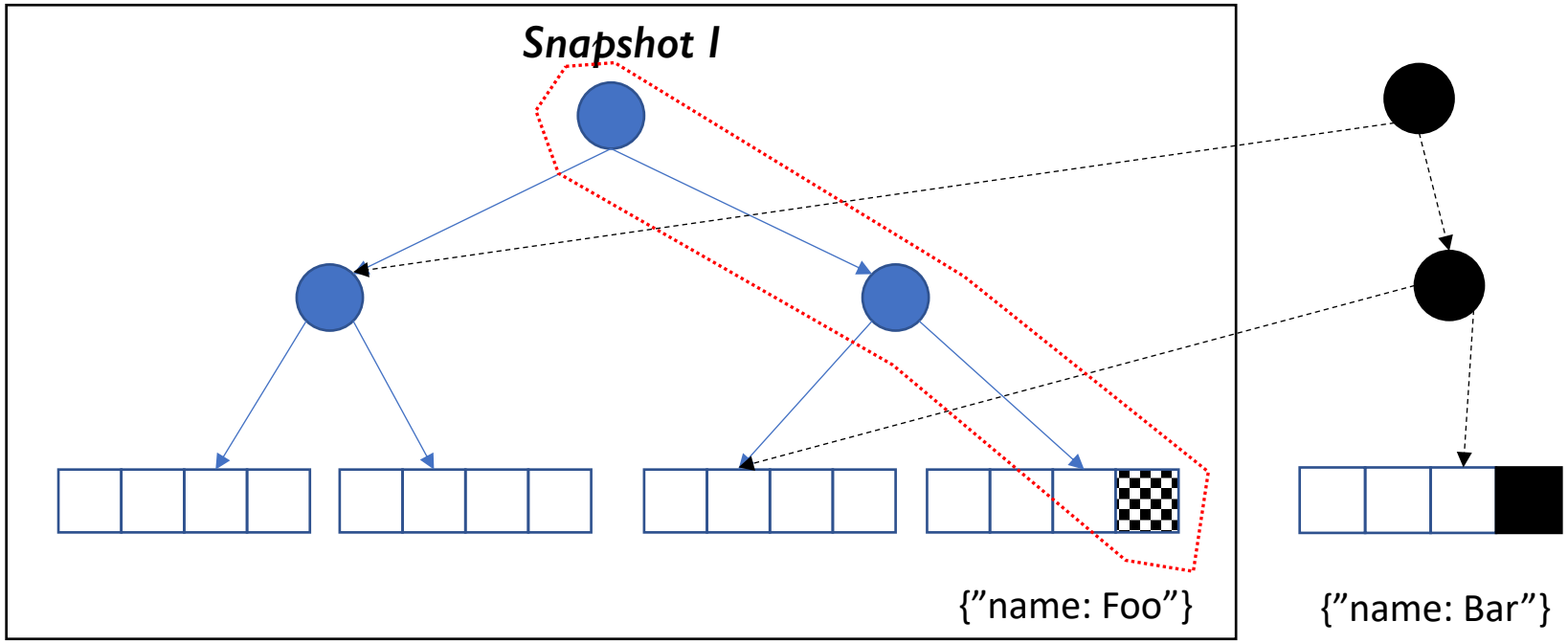

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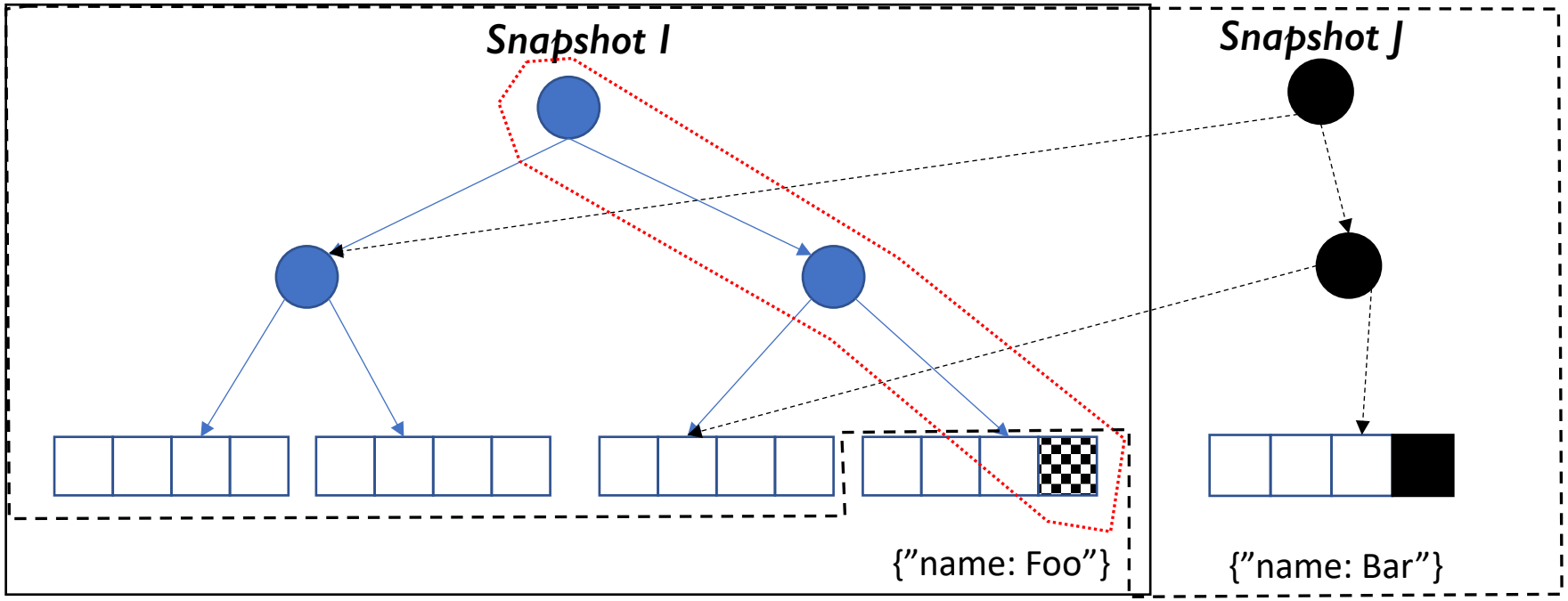

Vertex ➡ Property

Distributed Graph Snapshot Index (DGSI)

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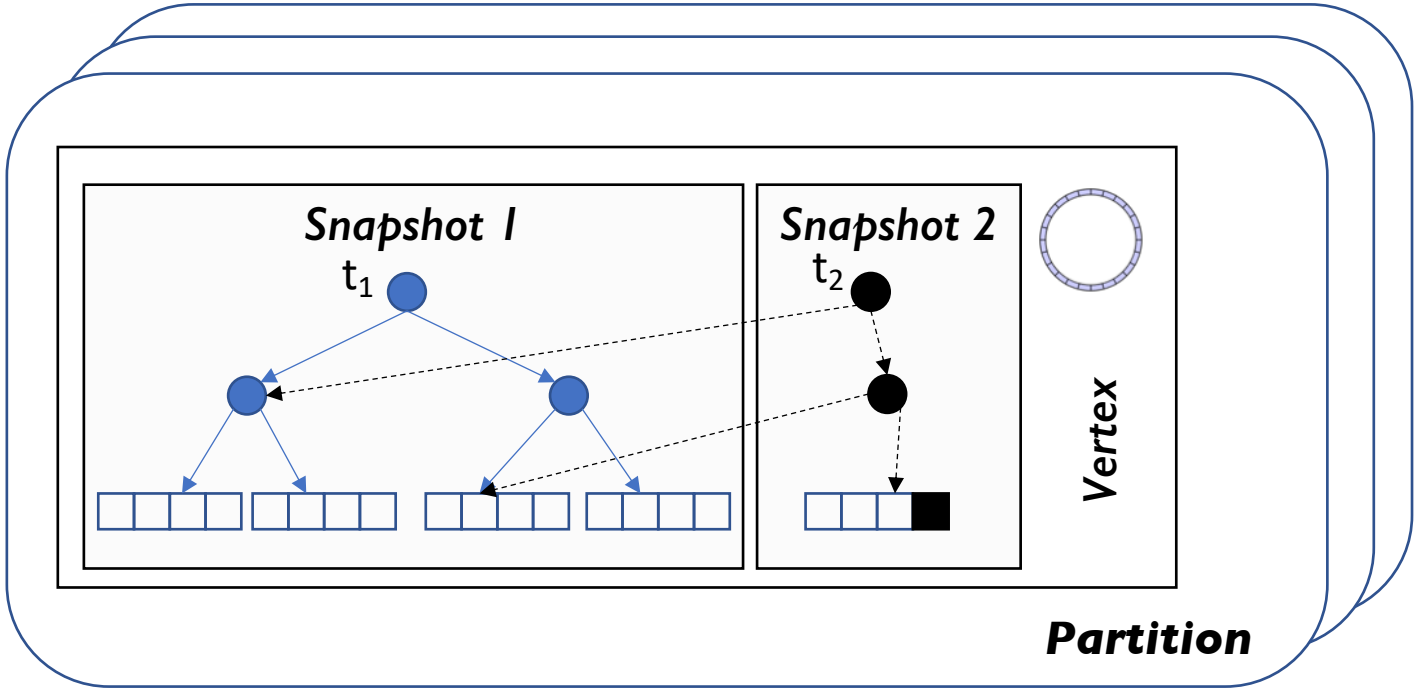
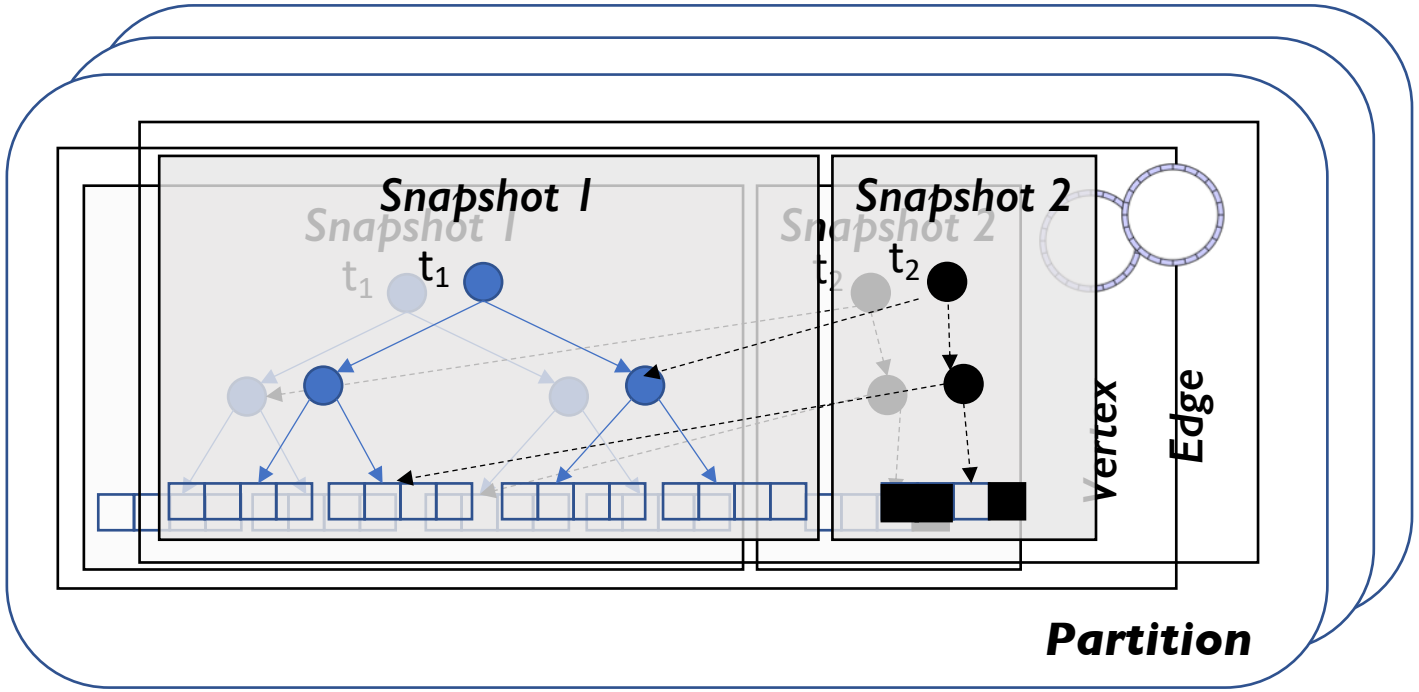
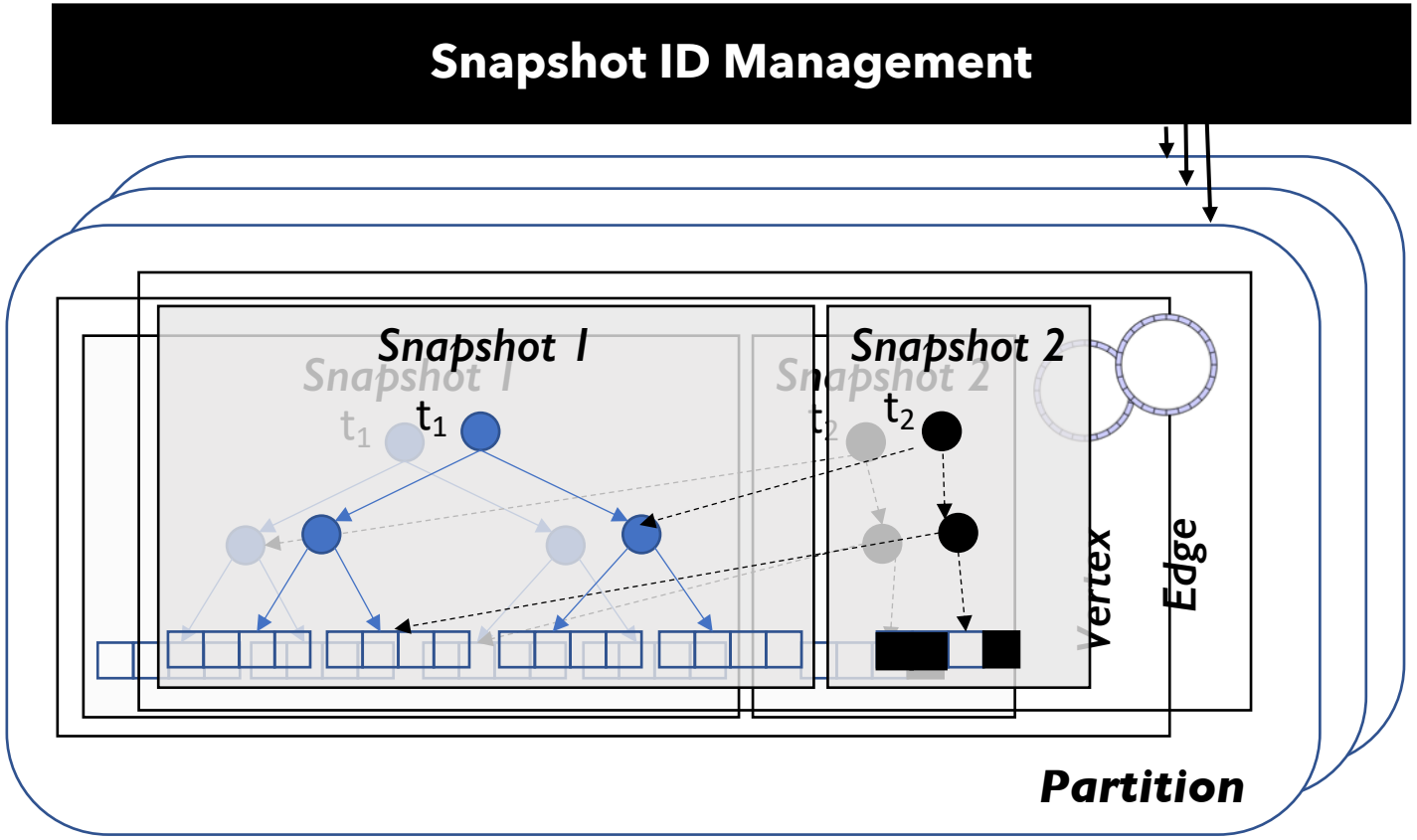


Distributed Graph Snapshot Index (DGSI)



Distributed Graph Snapshot Index (DGSI)



Memory Management

Enables management of storage at the **leaf** level

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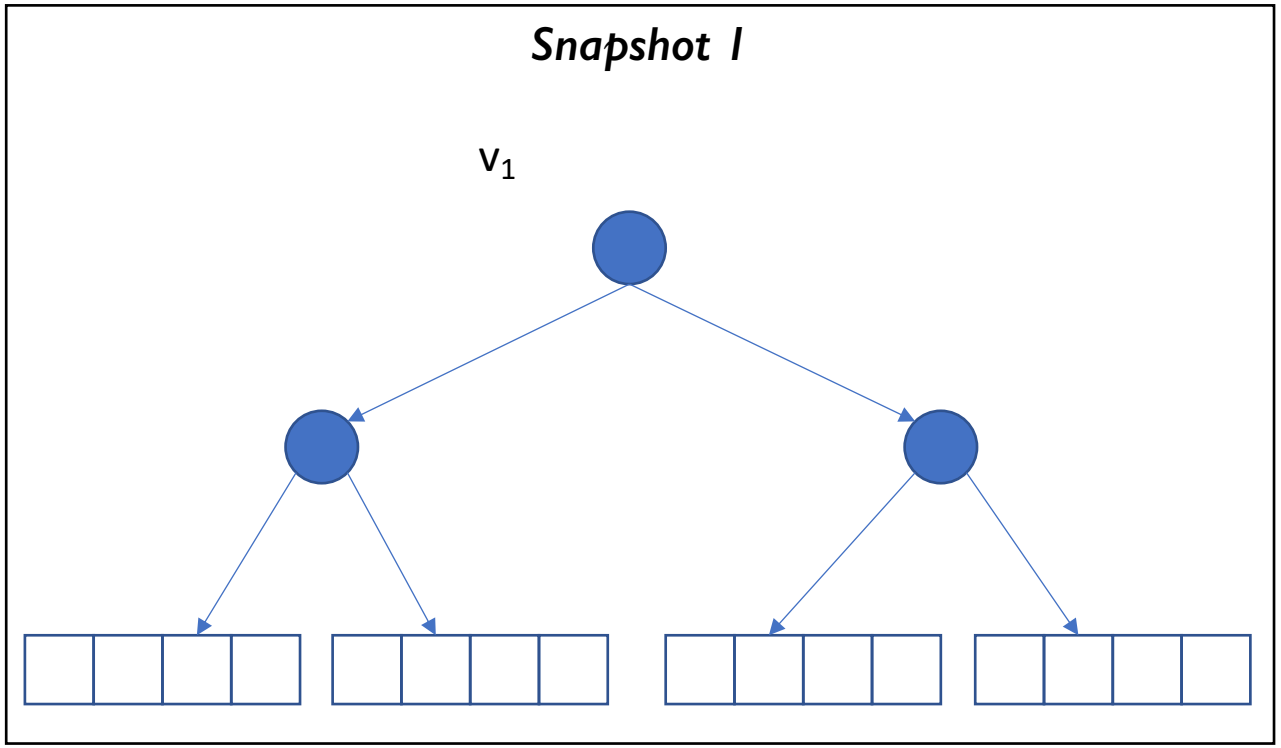

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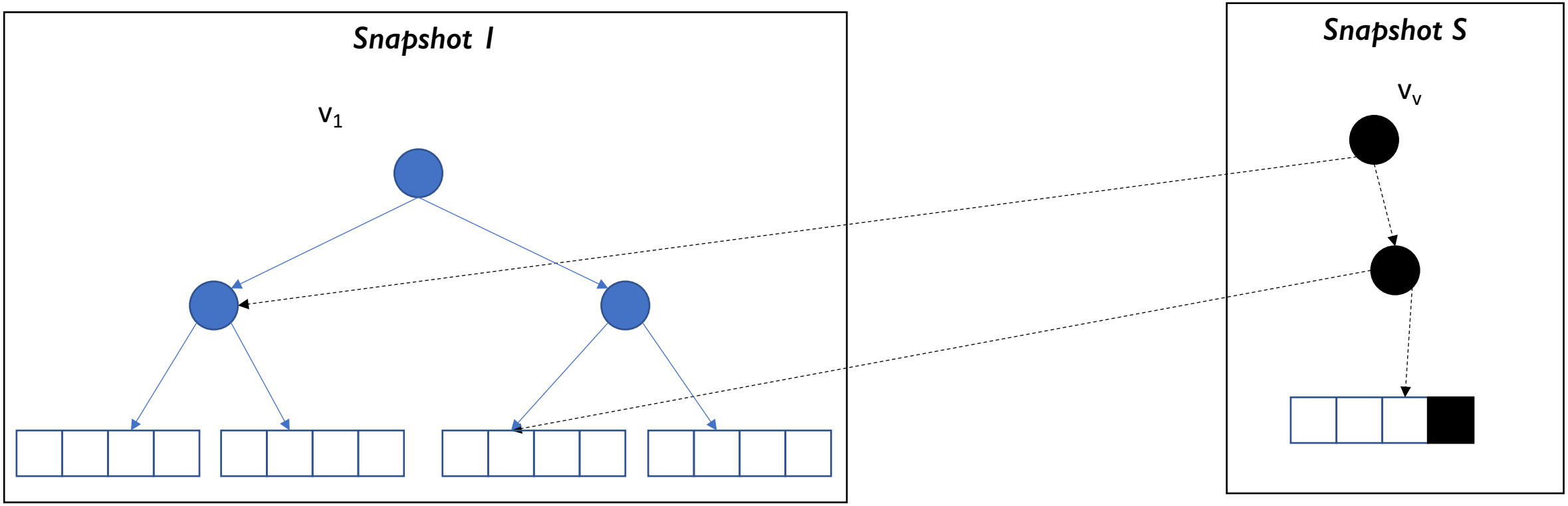

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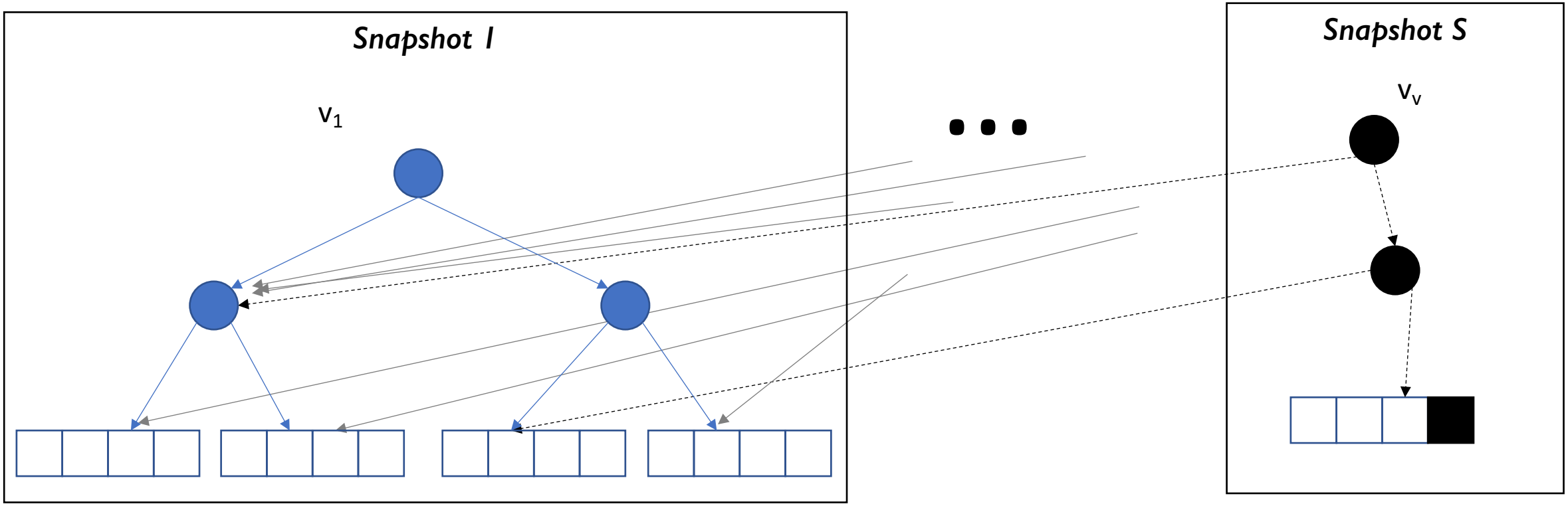

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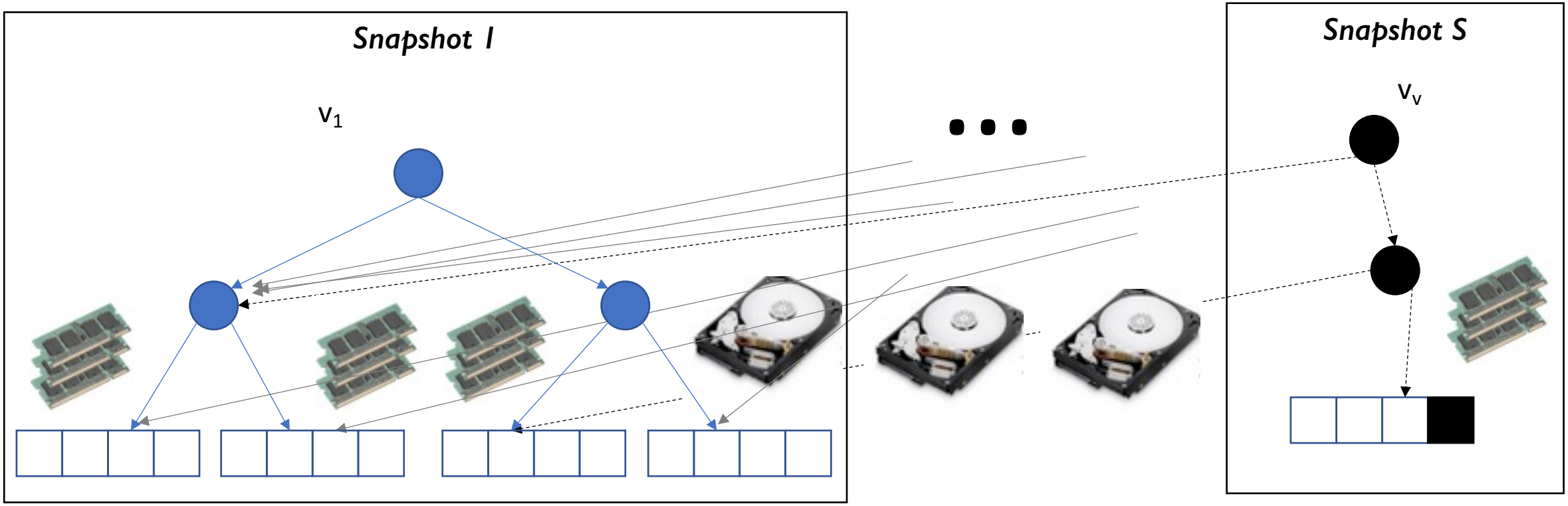

Challenges

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Storage

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Computation

Incremental computation model for interactivity & efficiency

Computation Model

Leverages the characteristics of graph-parallel execution model

Computation Model

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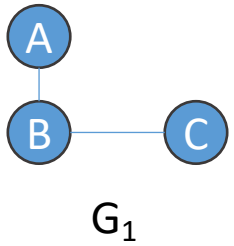
Graph

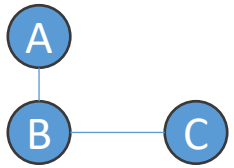


G_1

Computation Model

Leverages the characteristics of graph-parallel execution model

Graph



G_1

Computation

Computation Model

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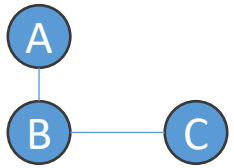
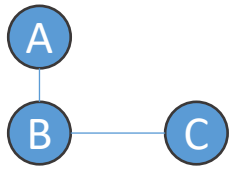
Graph



G_1

Computation



G_1^0

Computation Model

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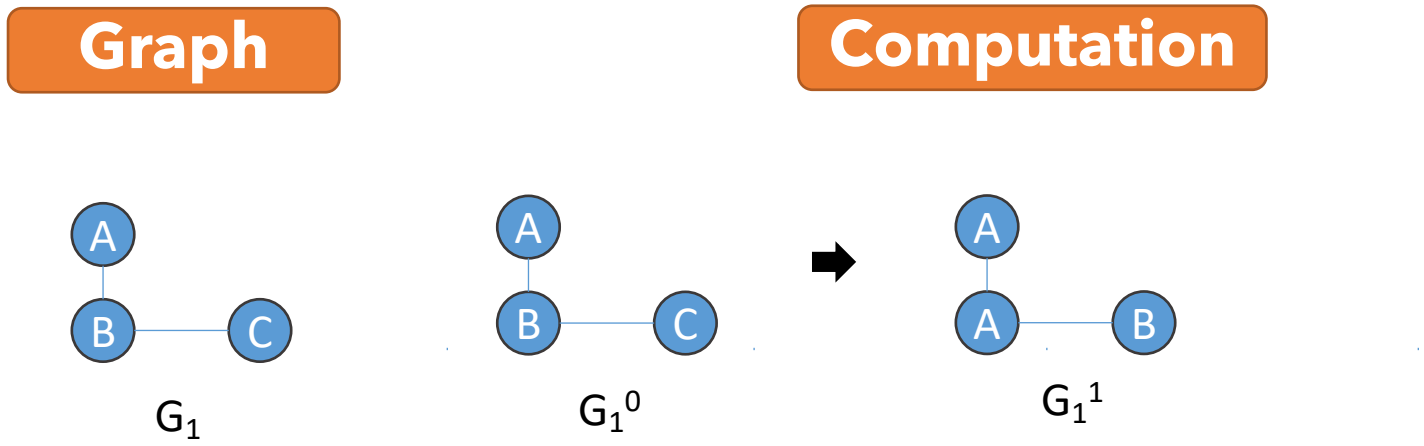

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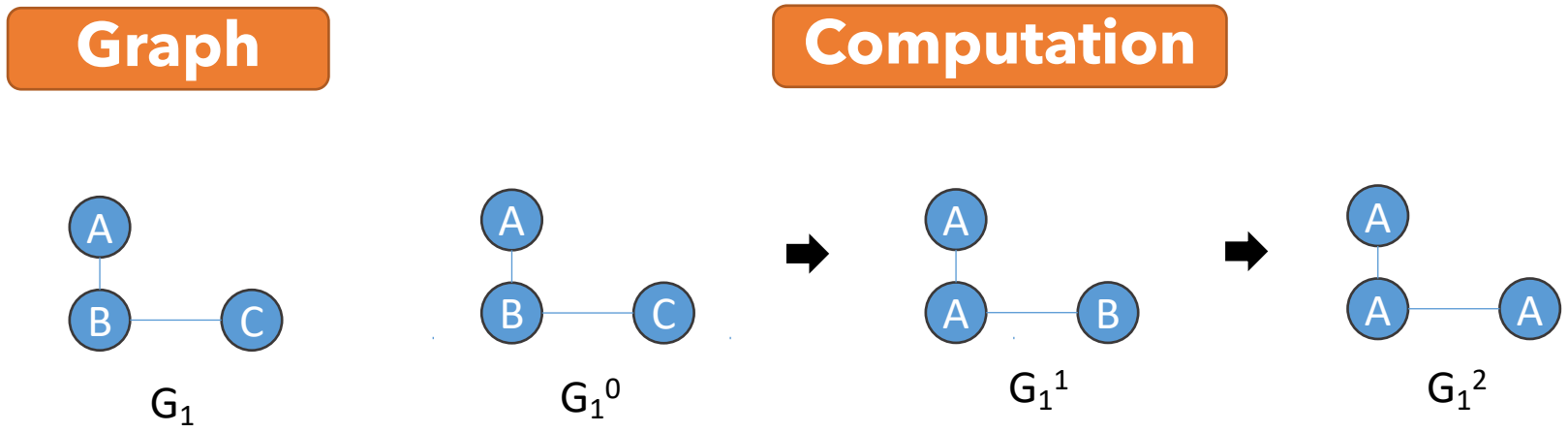

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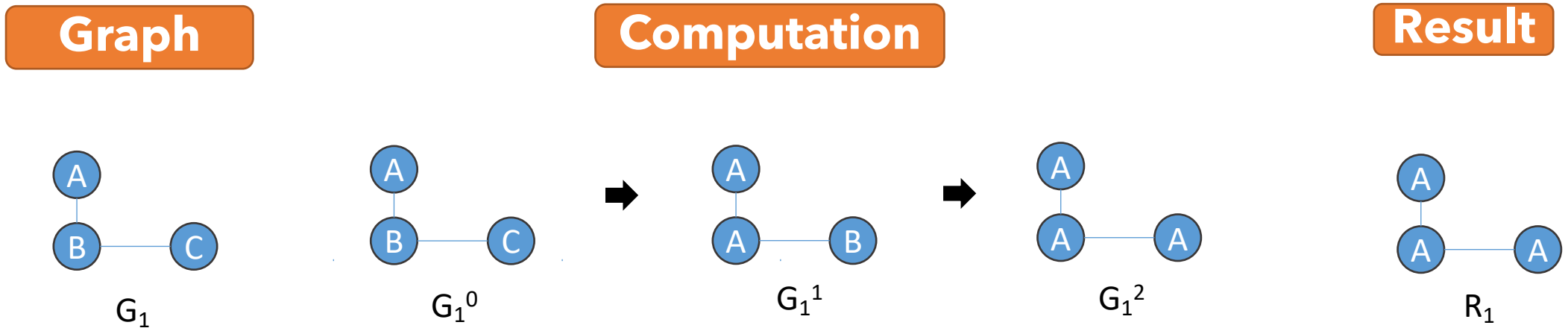

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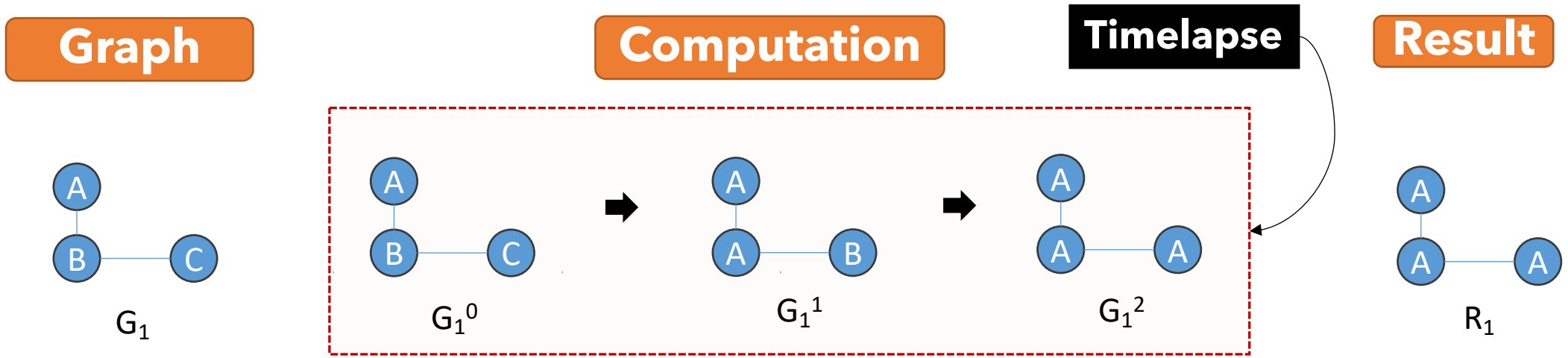

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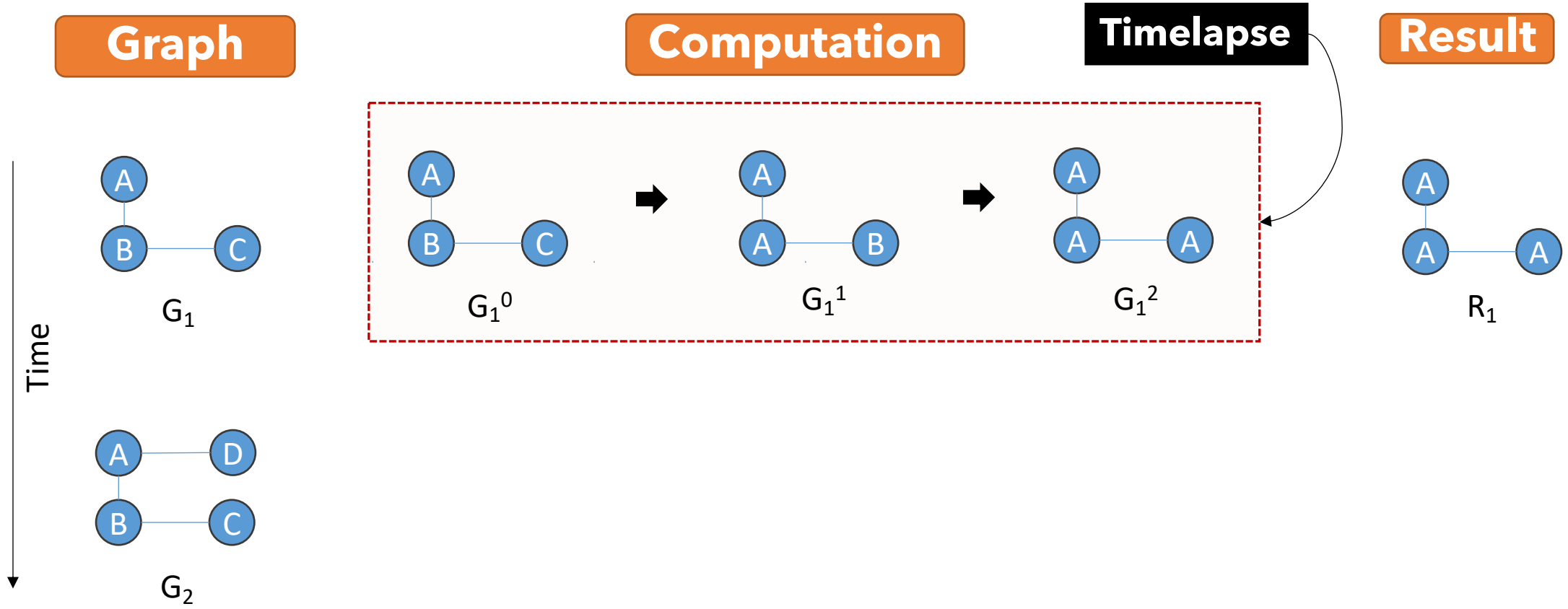

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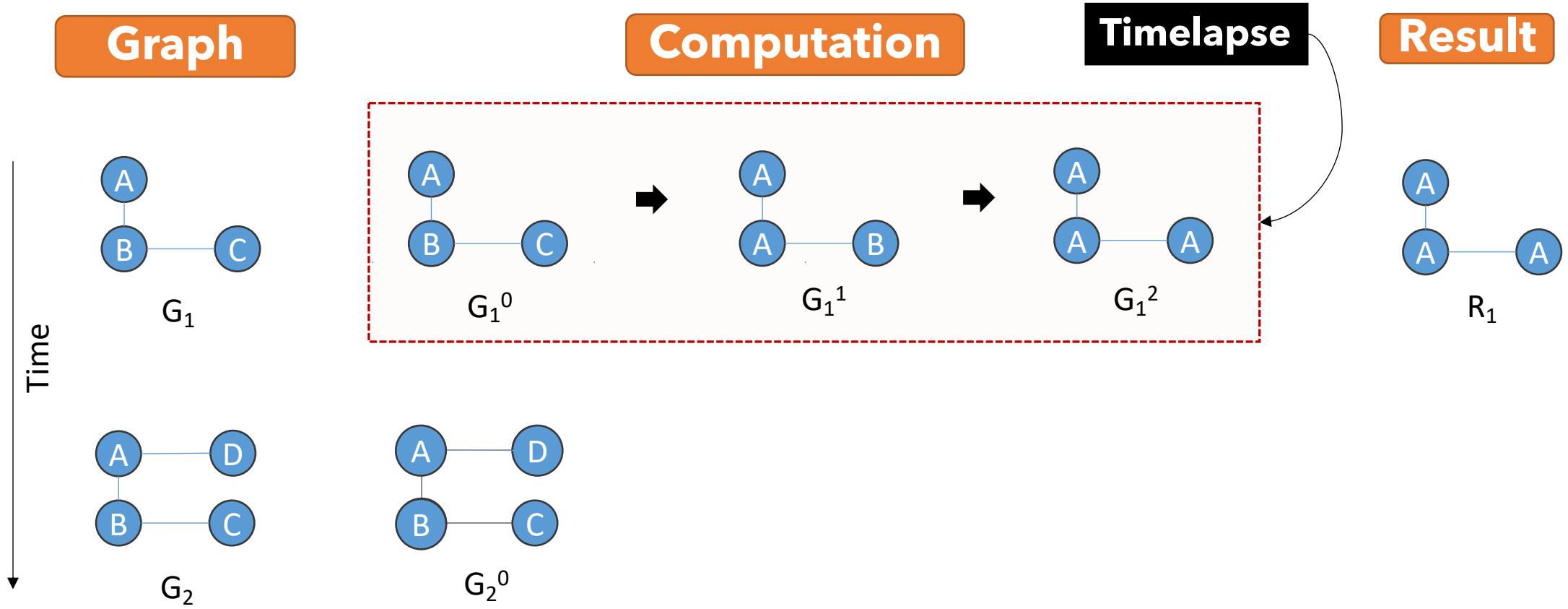

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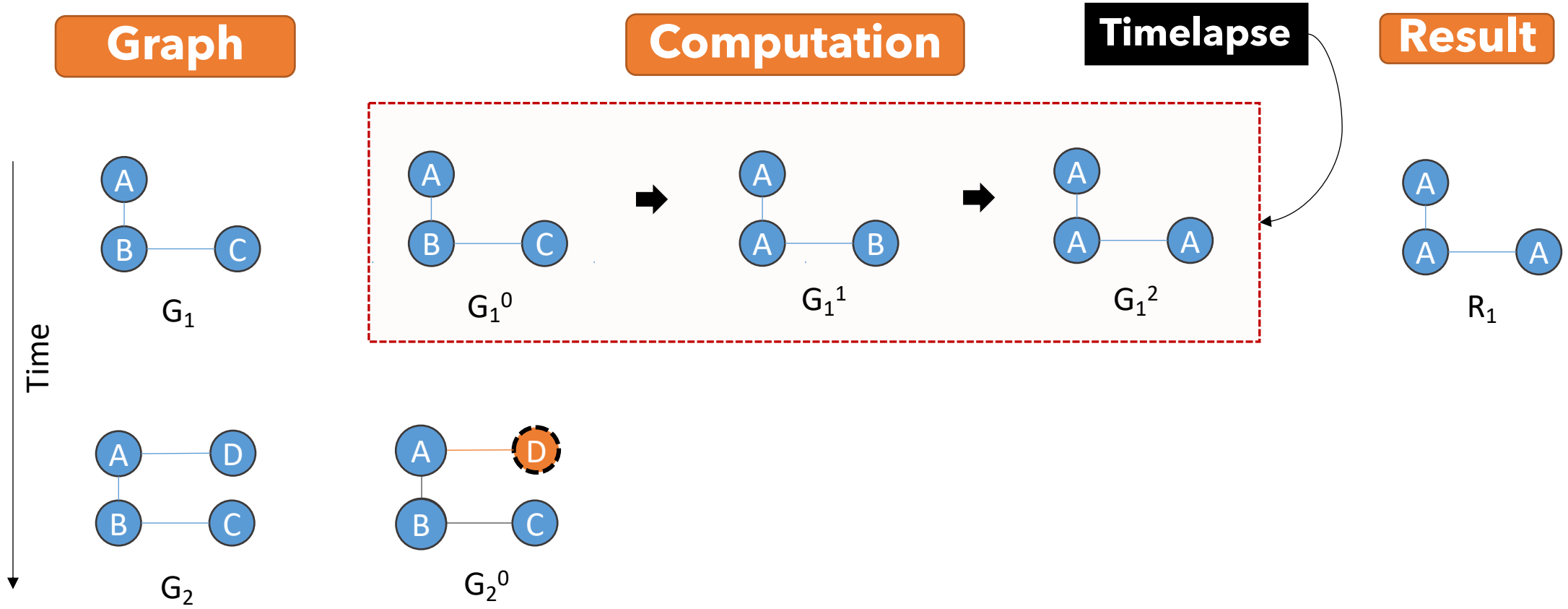

Computation Model

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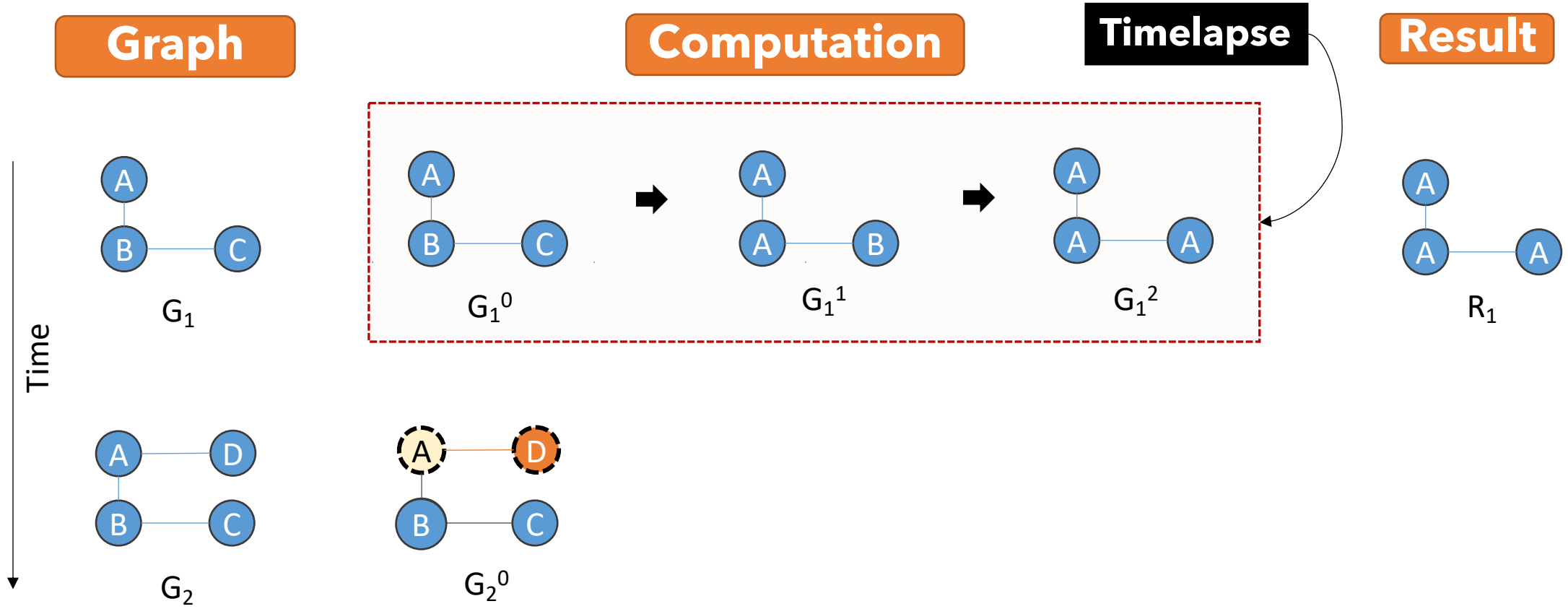

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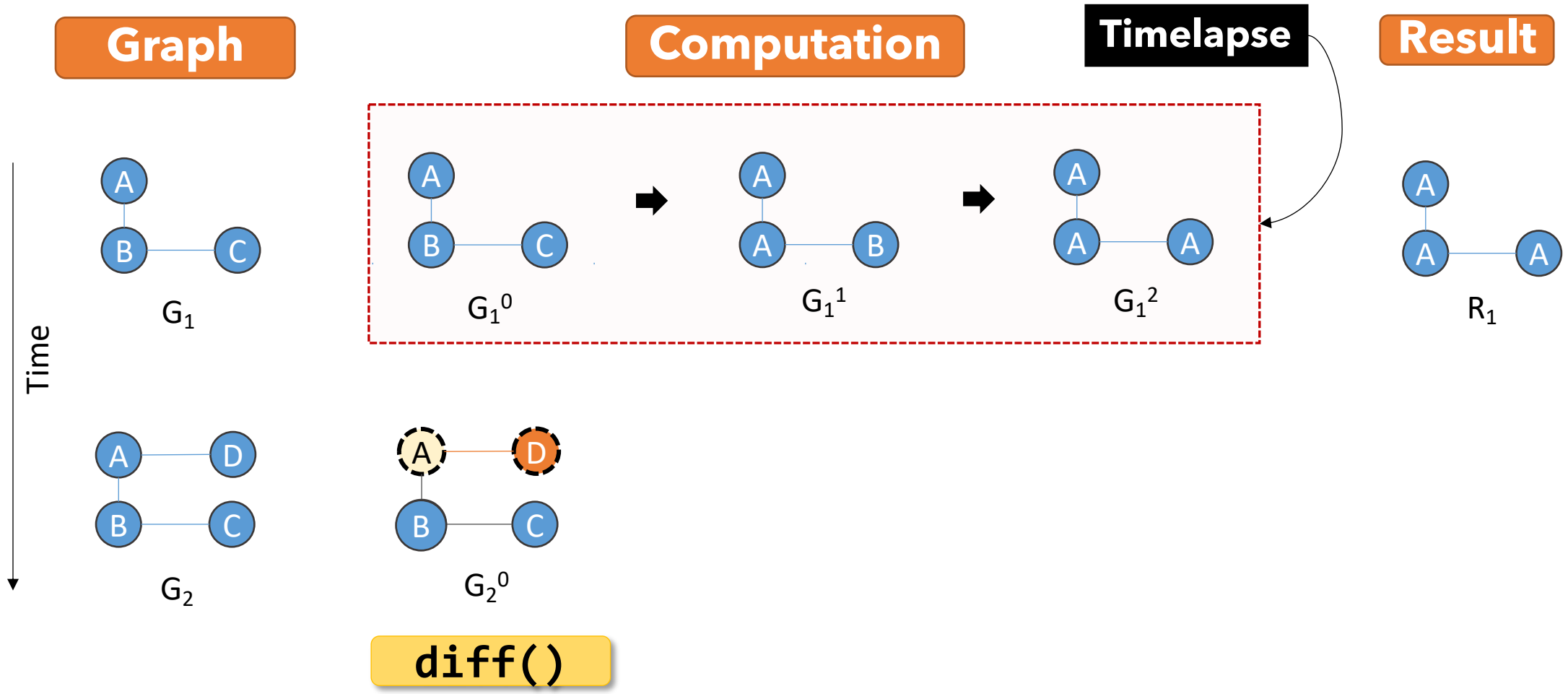

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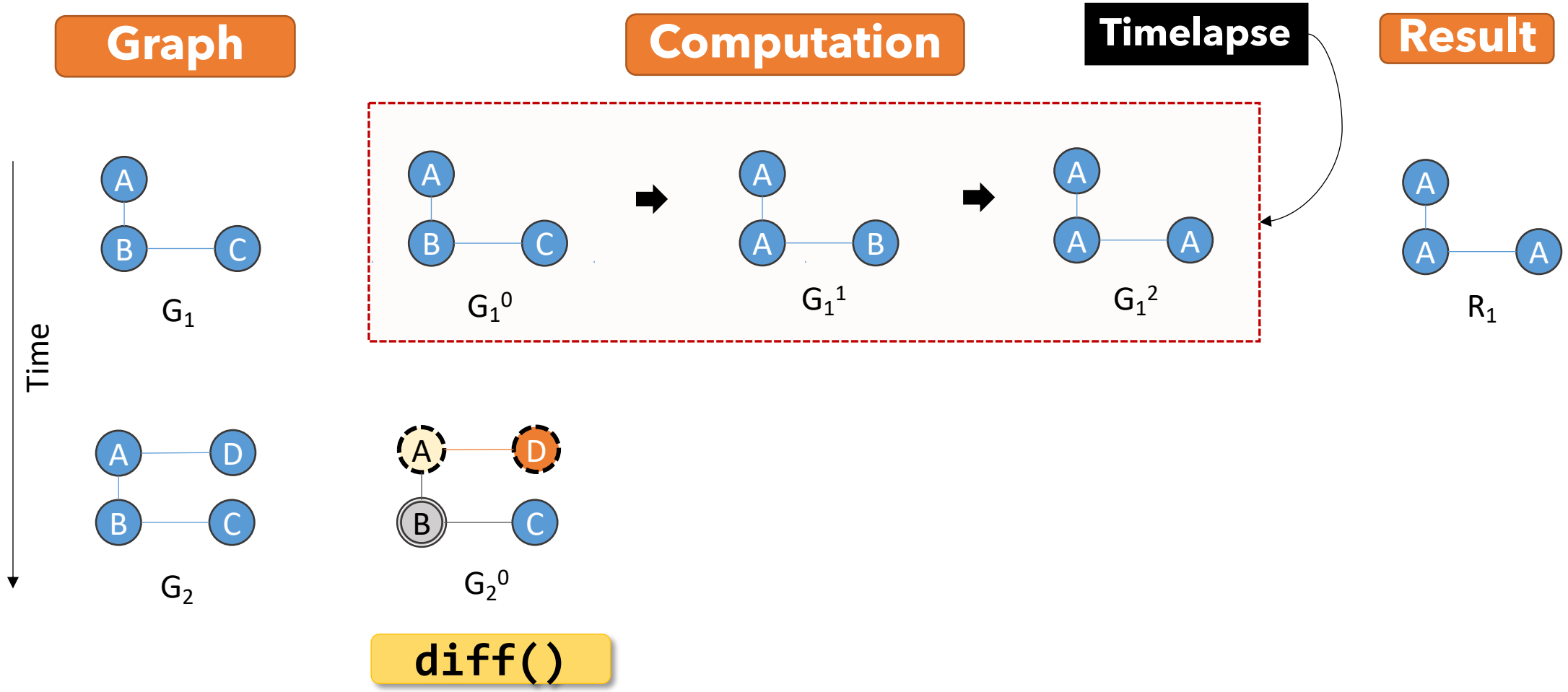

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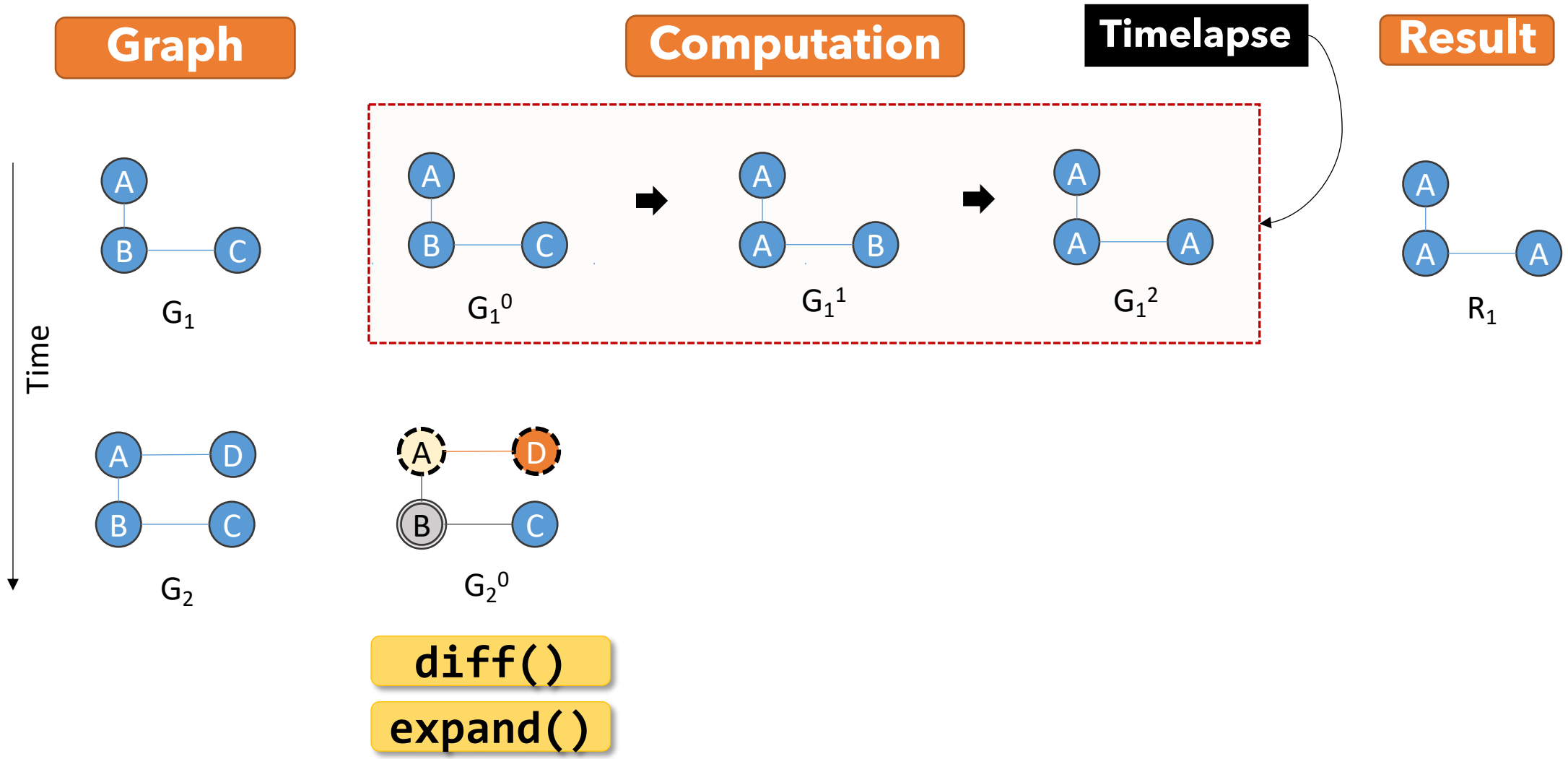

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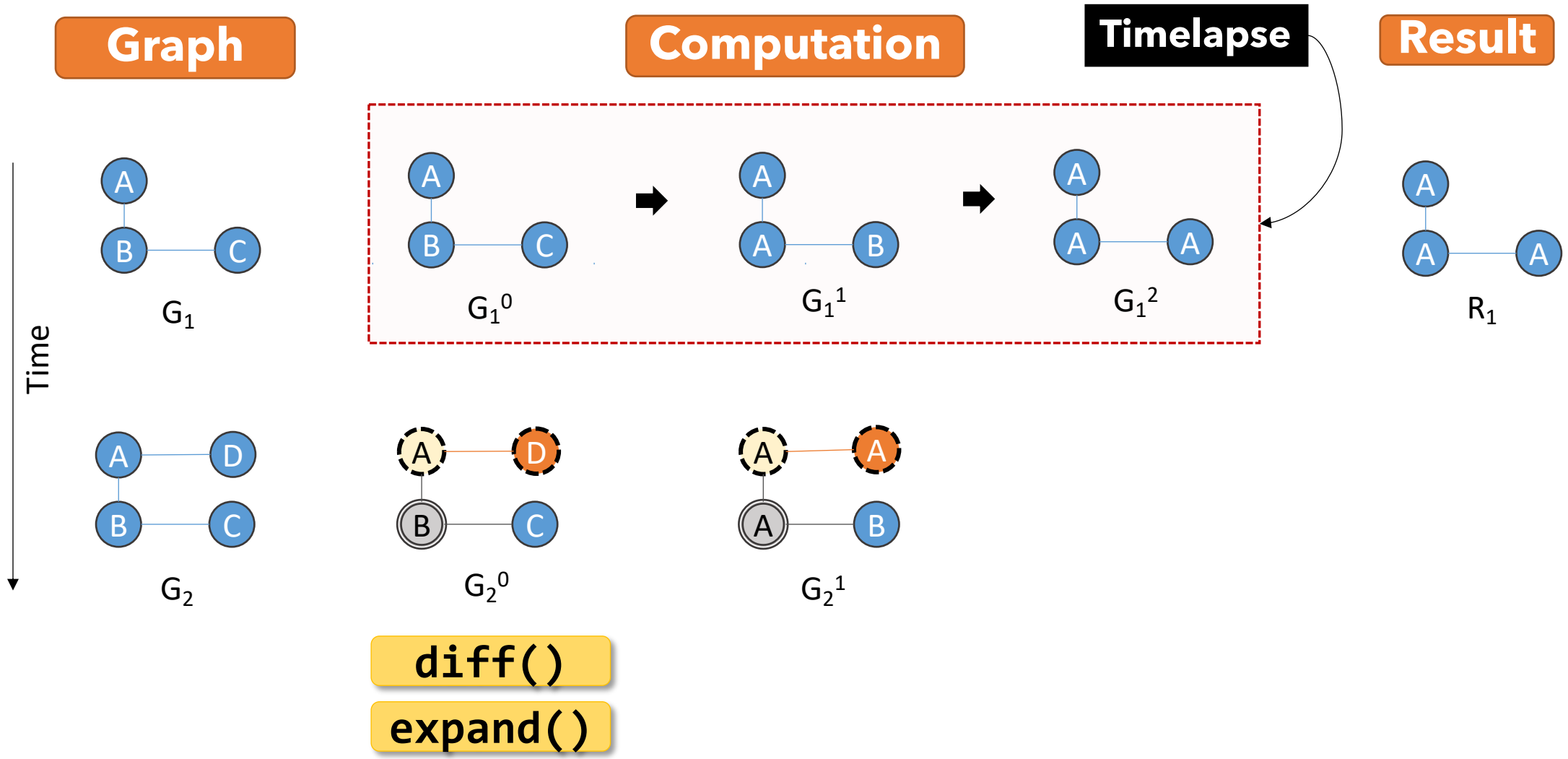

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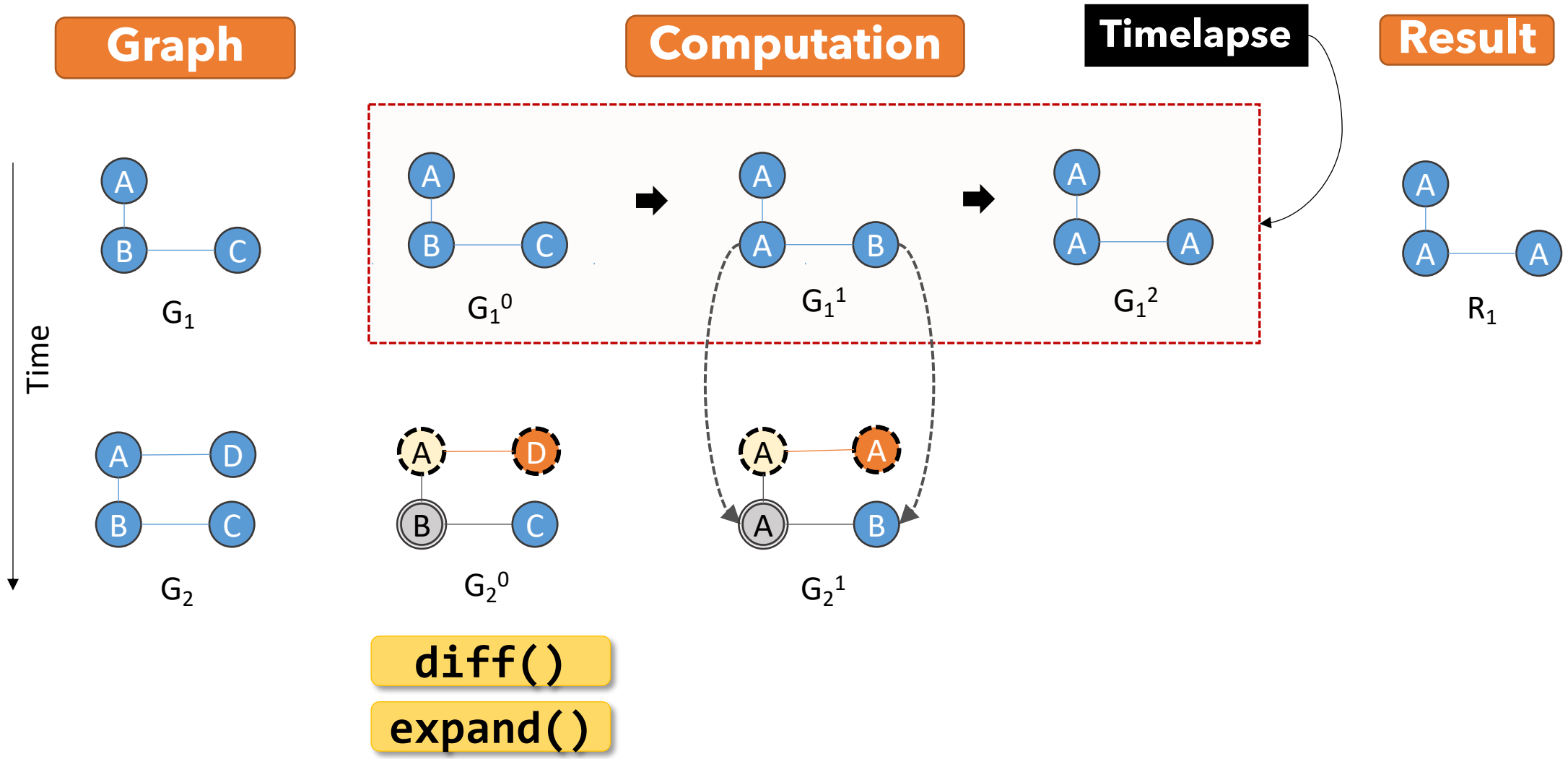

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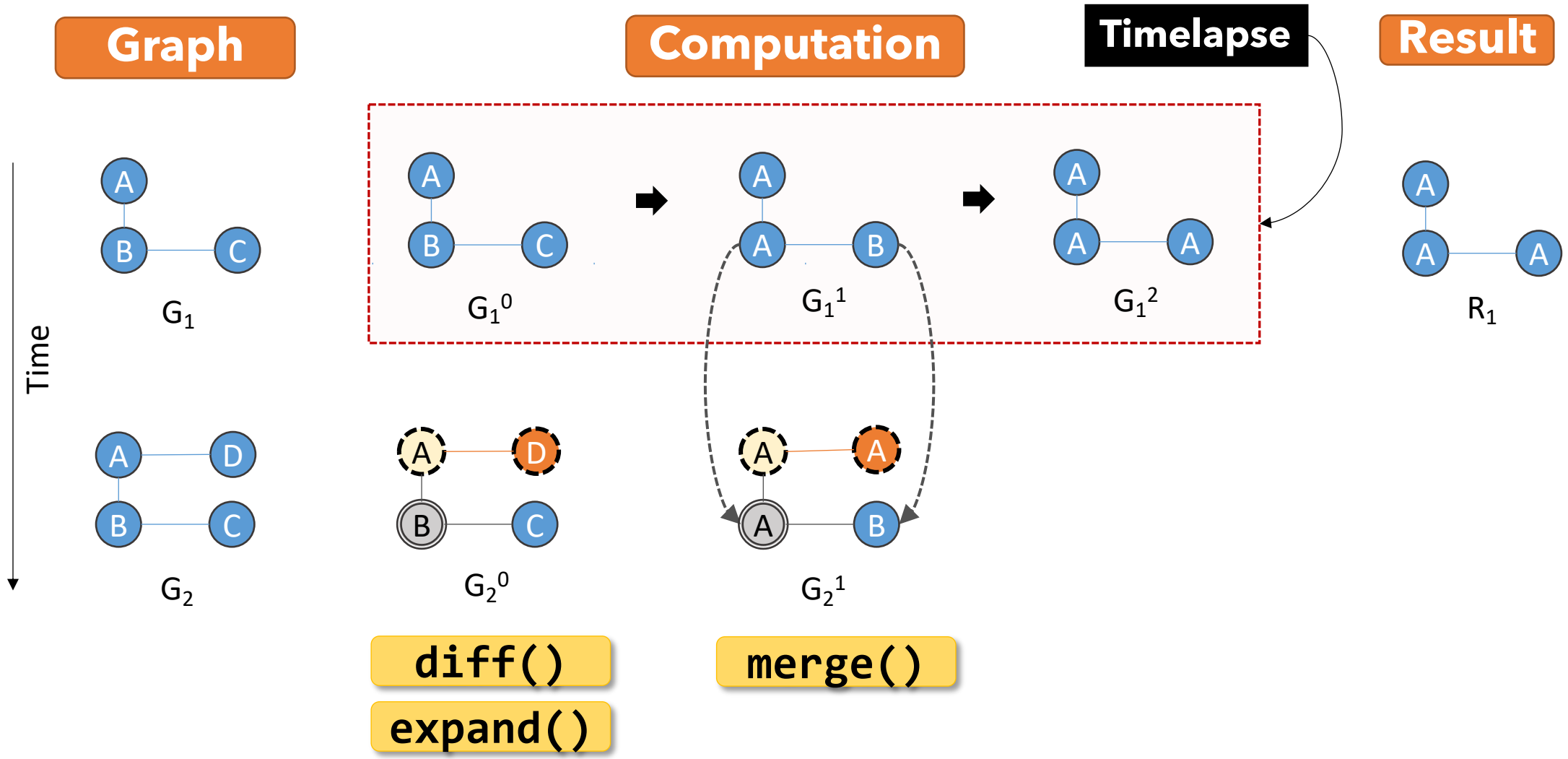

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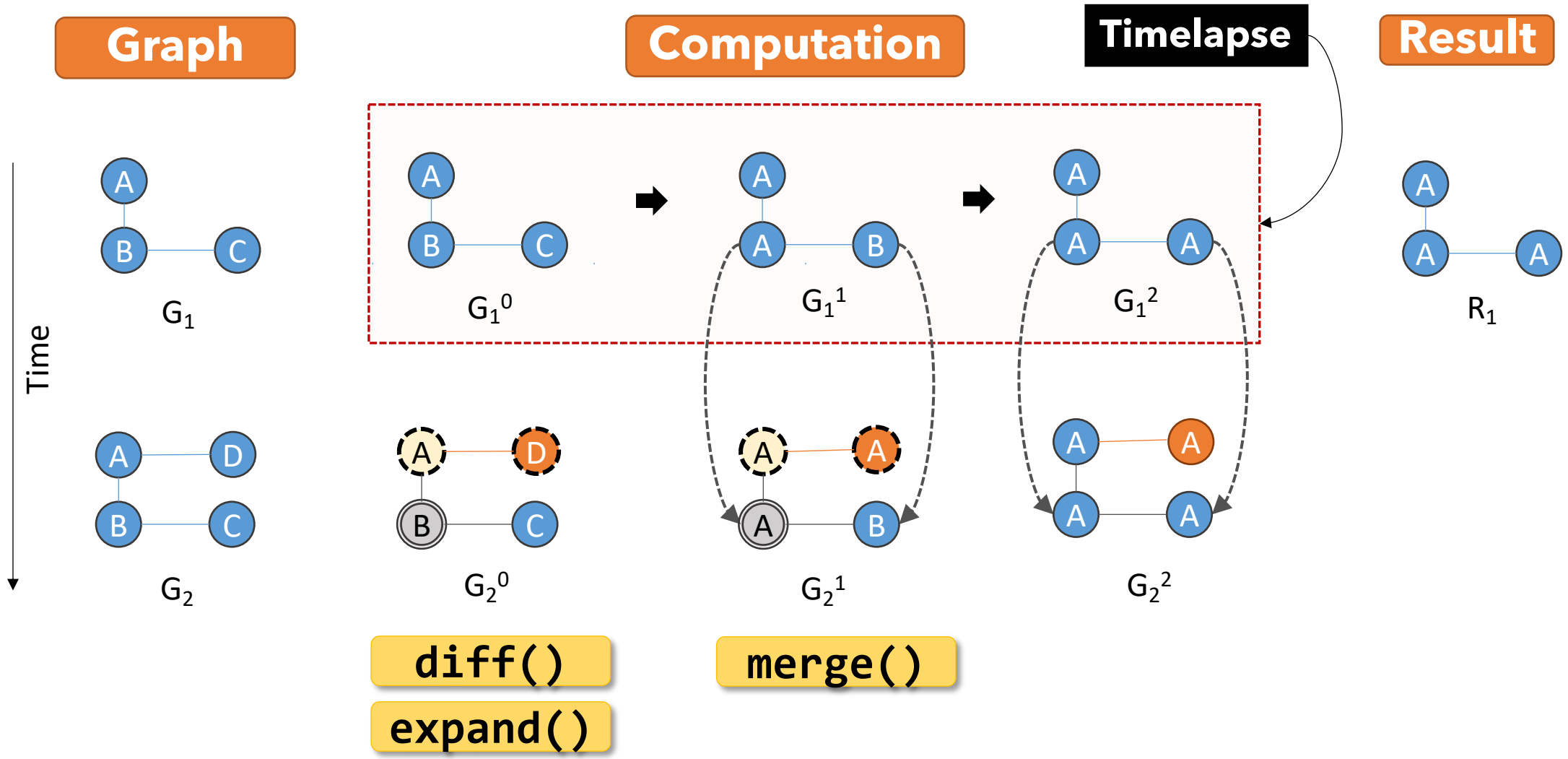

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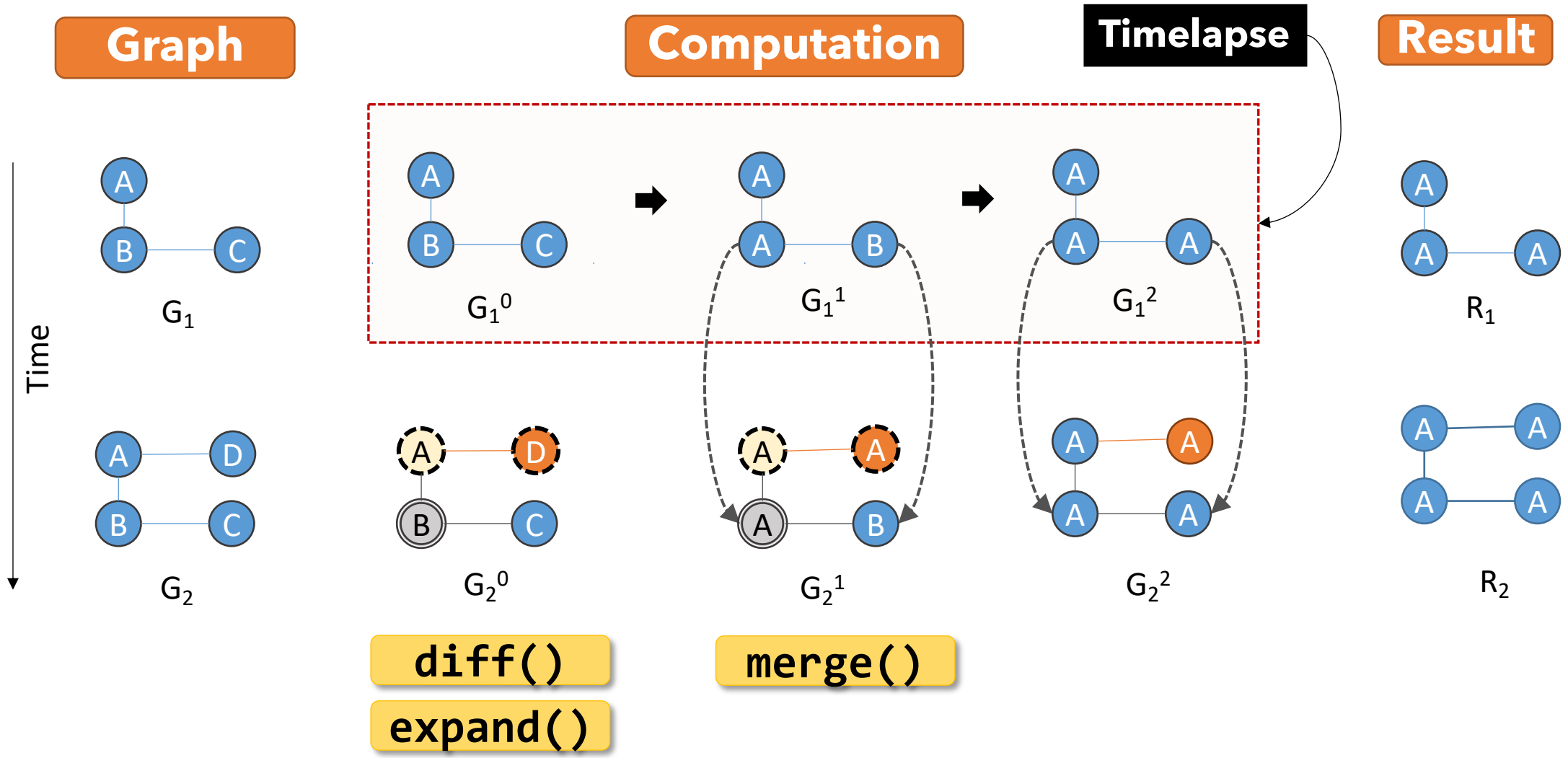


Computation Model

- Generates the **same** **intermediate state** for all entities at every iteration as compared to full re-execution
  - Correctness is preserved for any algorithm
- Computation **decoupled** **from state**
  - Can use any state, not just the previous
  - Can share state across queries
- Incremental computations **not** **always useful**
  - Can switch between incremental and full execution at any iteration
  - Uses random forest based model to do so

Details in the paper!

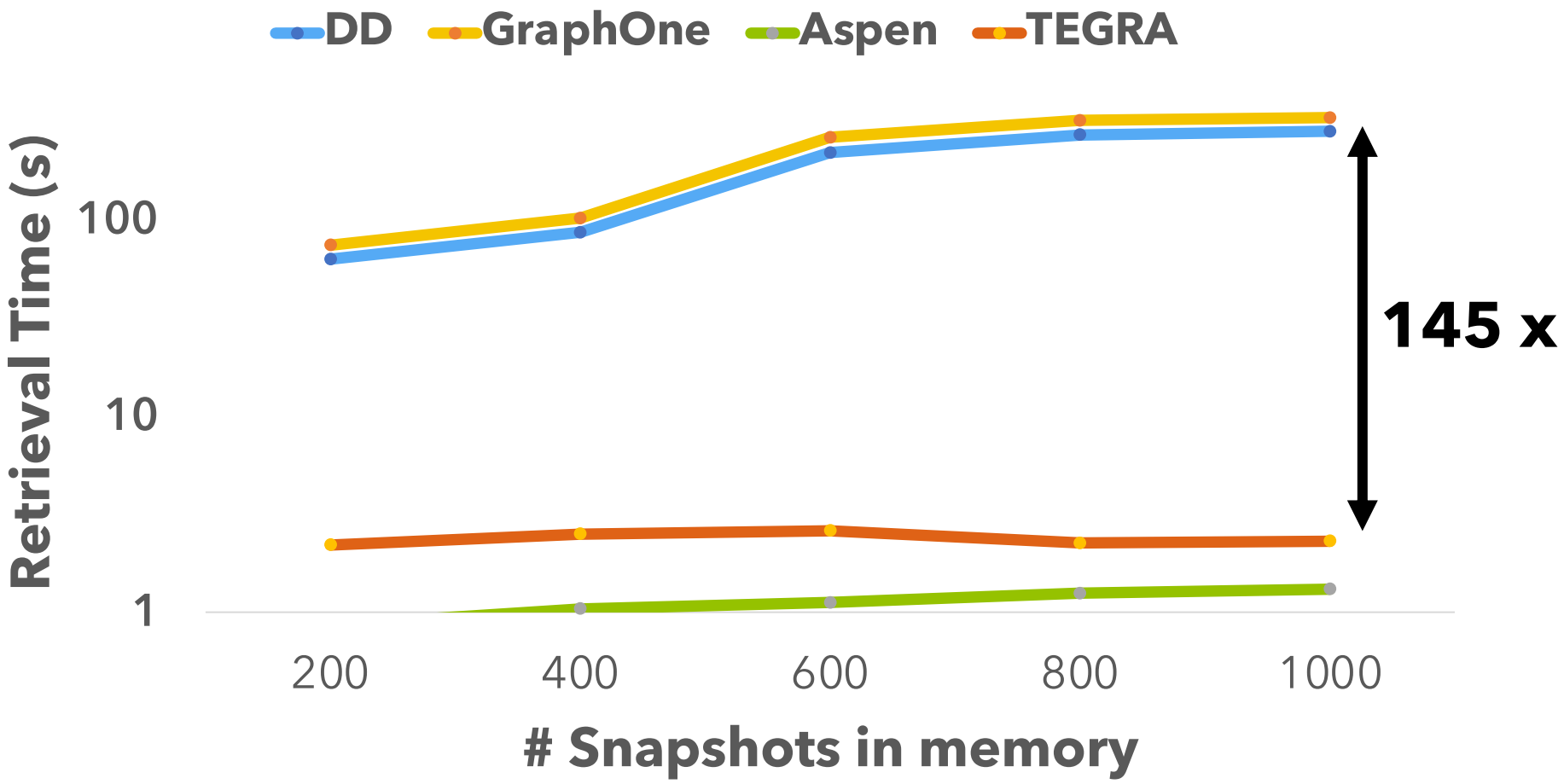
Implementation & **Evaluation**

- Implemented on Apache Spark
  - Drop-in replacement for GraphX
- Evaluated in a 16 node cluster
  - **Twitter:** 1.47B edges
  - **UK:** 3.73B edges
  - **Facebook:** 5B, 10B, 50B edges
- Comparisons & Algorithms
  - Differential dataflow [SOSP'13], GraphBolt [Eurosys '19], Chlonos [Chronos, Eurosys '14], Aspen [PLDI '19], GraphOne [FAST '19]
  - Connected components, Page rank, Belief propagation, and others.

More evaluation in the paper

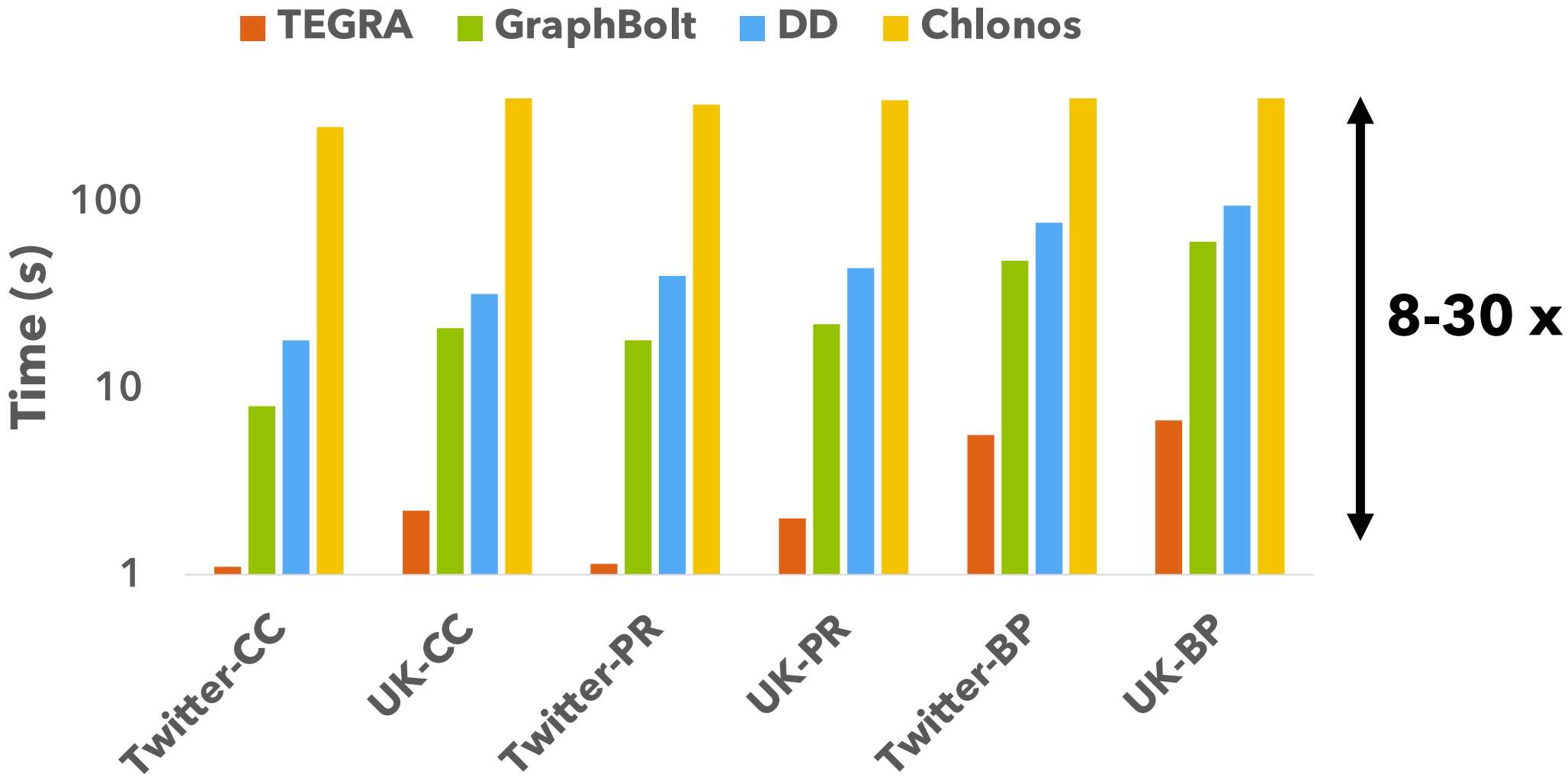
Ad-hoc **Retrieval**

Retrieval latency with varying amount of state in memory



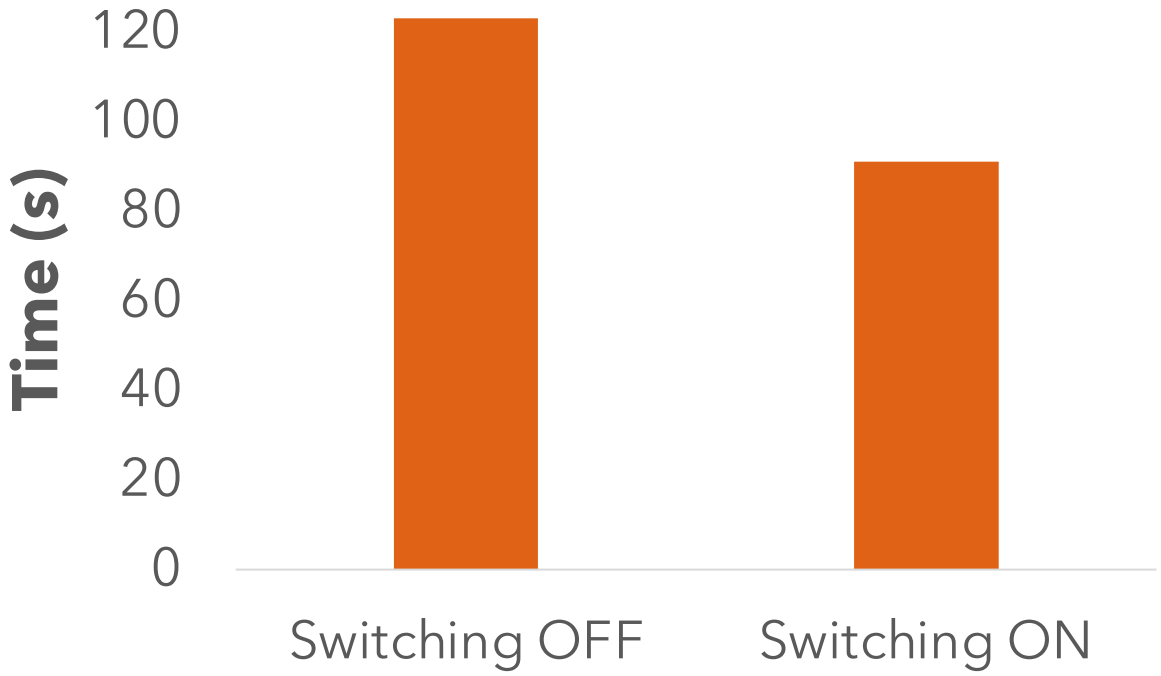
Ad-hoc **Analytics**

Random snapshot, use previous state if available

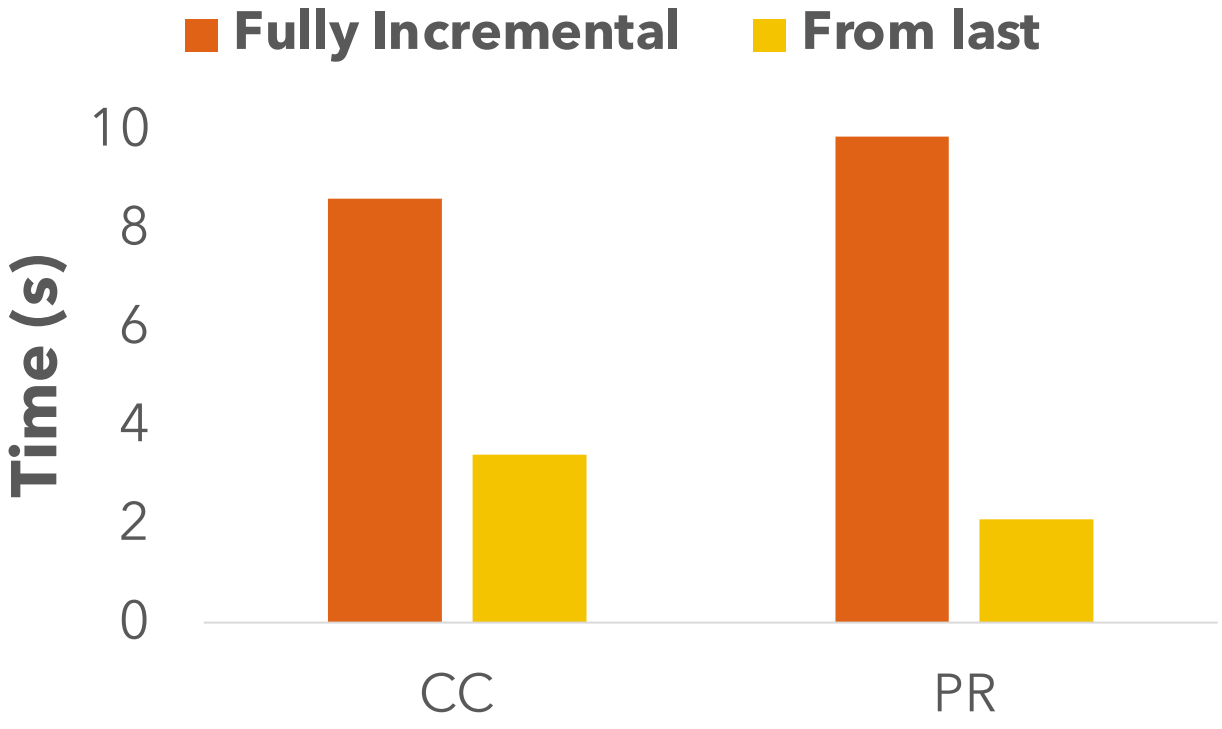


Computation Model Benchmarks

Switch to full re-execution



Flexibility in state reuse



Summary

- Ad-hoc analytics important emerging graph workload
- TEGRA enables efficient ad-hoc analytics on evolving graphs
  - Simple abstraction
  - Compact representation of state
  - Share storage and computation
- TEGRA outperforms state-of-the-art solutions

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