Differential Dataflow

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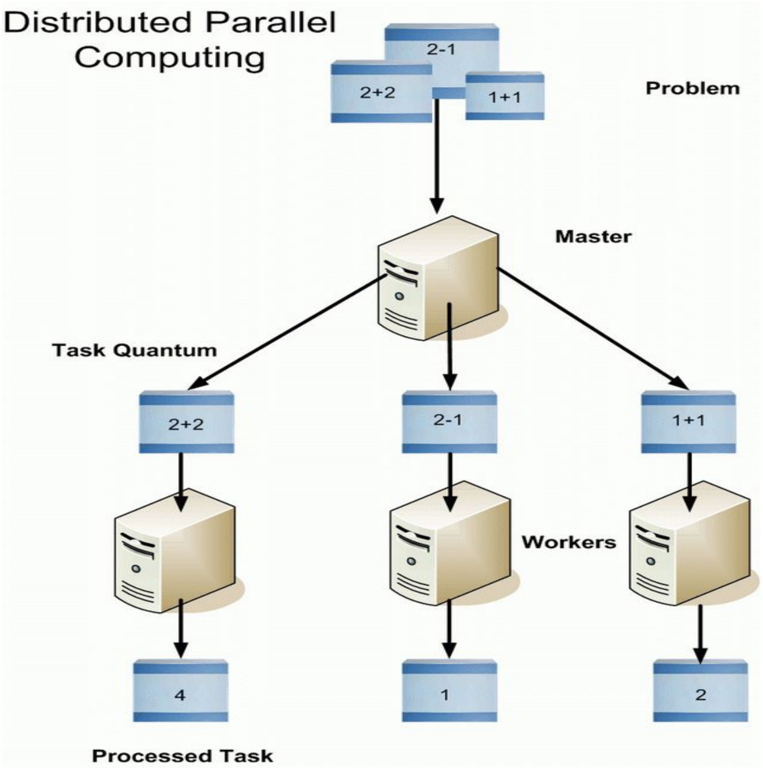
Outline

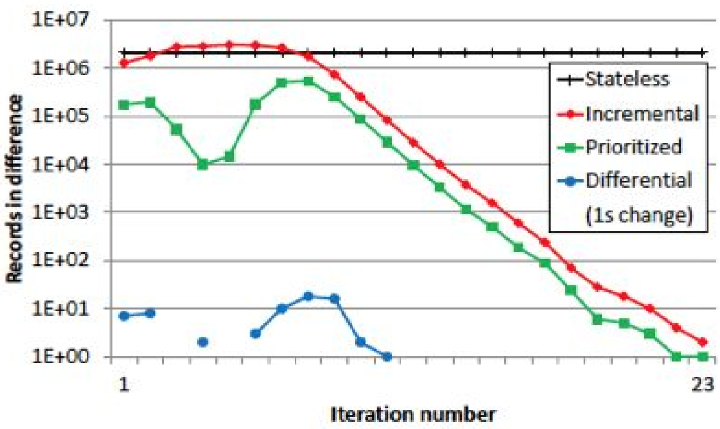
- Motivation for Differential Dataflow
- Key Concepts
- Differential Dataflow in practice
- Discussion

Motivation

Traditional data parallel processing



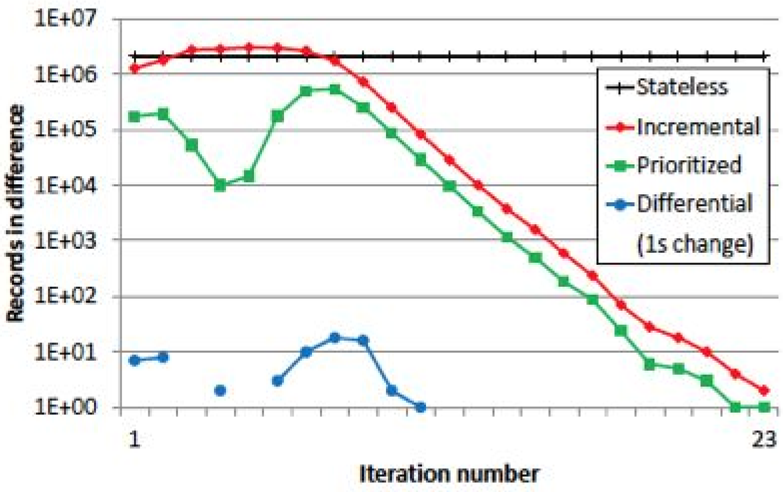
- Take input data in batches.
- Process and output.
- Highly evolved - Hadoop, Spark.
- Mostly stateless.



Interactive - Twitter Mention Graph

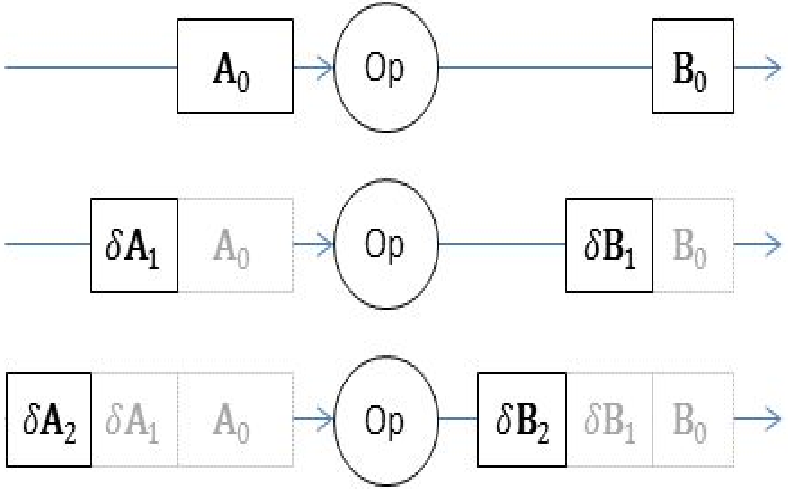
- Used to find trending #hashtags.
- Billions of vertices and edges.
- Millions of updates per second (storm).
- Needs low latency of streaming and throughput of spark.
- Similar issue with interactive analytics

Loop Processing



- Some algorithms require iterations
  - Pagerank
  - Connected components
- Usually requires transferring entire state between iterations
- Spark, Hadoop etc execution times ~ stateless

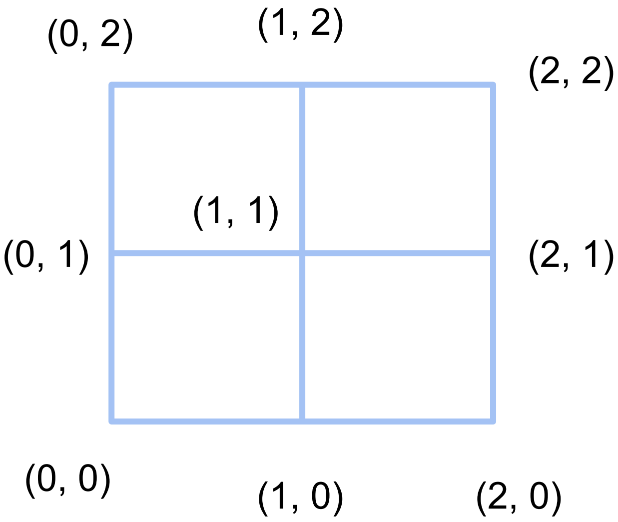
Incremental Dataflow



- Stateful.
- Get the differences of collections.
- Only calculate changes.
- Example
  - Wordcount in Hadoop Online.
- Can deal with changes due to,
  - Loops
  - New Data
- But NOT both!!

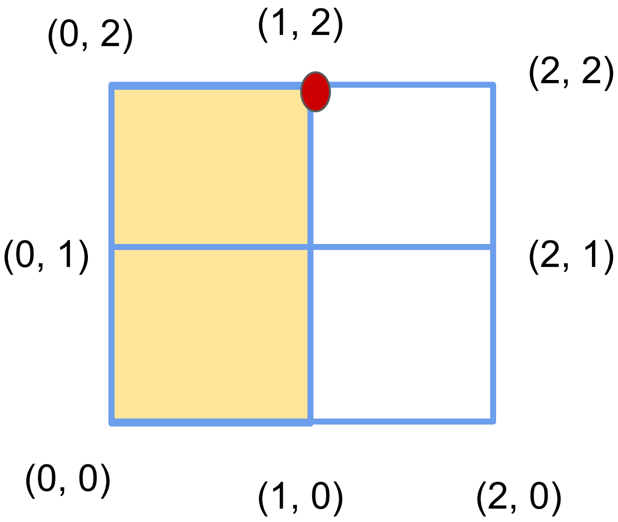
Concepts

Total vs Partial Ordering



- Traditional dataflow systems expect total ordering
    - Multiple variables are a problem
- A partial ordering uses a time vector for ordering
    - Deals well with multiple variables
- Partial because ordering by variable x gives only a partial ordering

Total vs Partial Ordering



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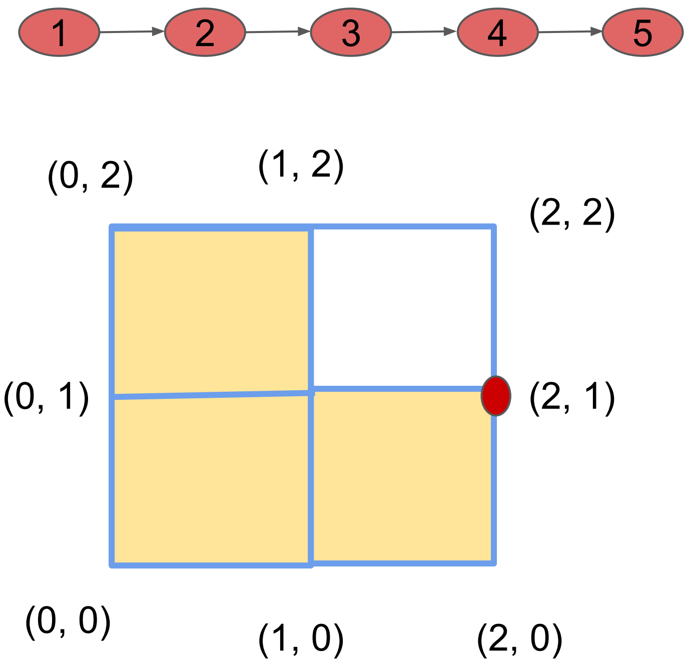

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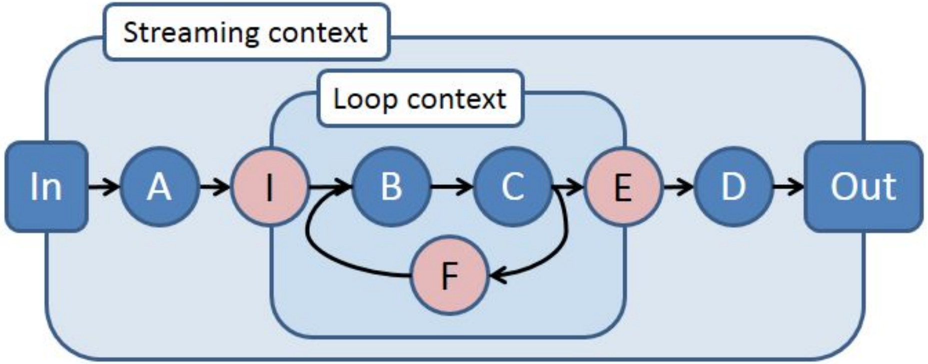
Differential Dataflow

- Computational Model
  - Defines how to process partially ordered data.
  - Defines state between iterations

- Goals
  - Do less calculation per change
  - Converge quicker per iteration

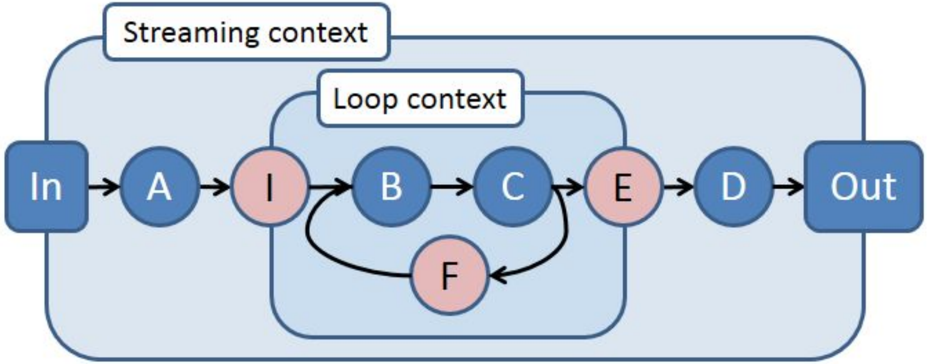
Timely Dataflow



- Performs Iterative Calculations
- Computational model with directed graph
- Vertices exchange messages
- Logical Timestamps for messages

$$: (\overbrace{e \in \mathbb{N}}^{\text{epoch}}, \overbrace{\langle c_1, \ldots, c_k \rangle \in \mathbb{N}^k}^{\text{loop counters}})$$

Timely Dataflow

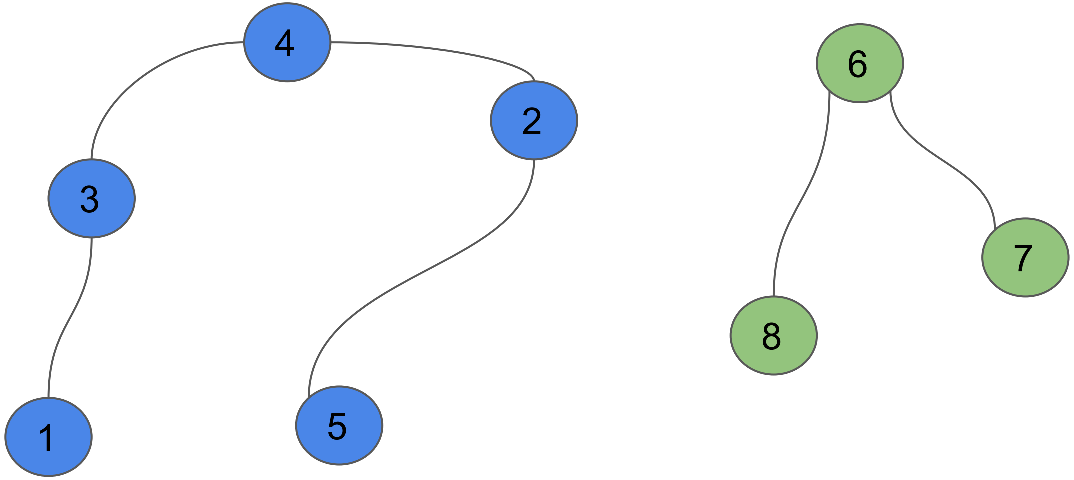


- Loops denoted by,
  - Ingress - adds a counter
  - Feedback - increments a counter
  - Egress - removes a counter
- Pointstamps - events at location and time

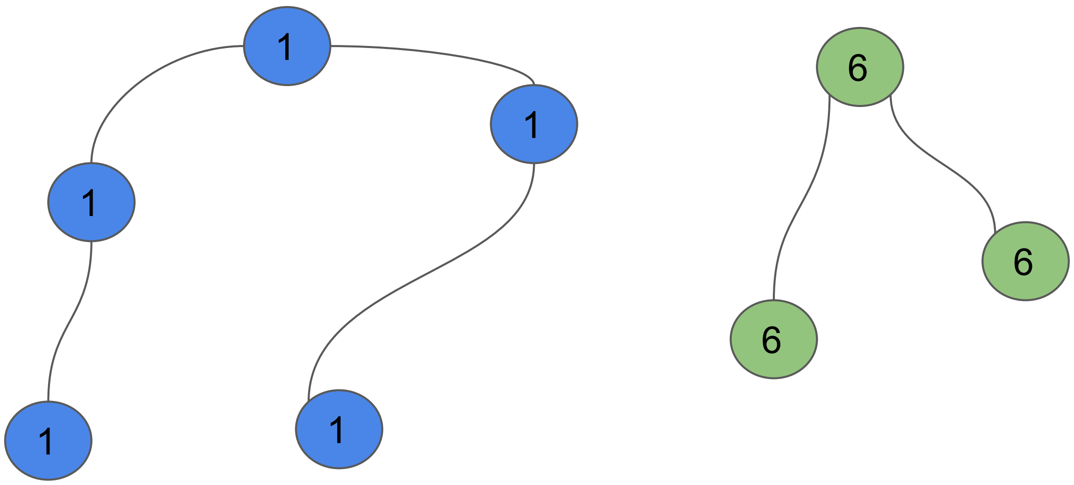
$$(t \in \text{Timestamp}, \overbrace{l \in \text{Edge} \cup \text{Vertex}}^{\text{location}})$$

Differential Dataflow in practise

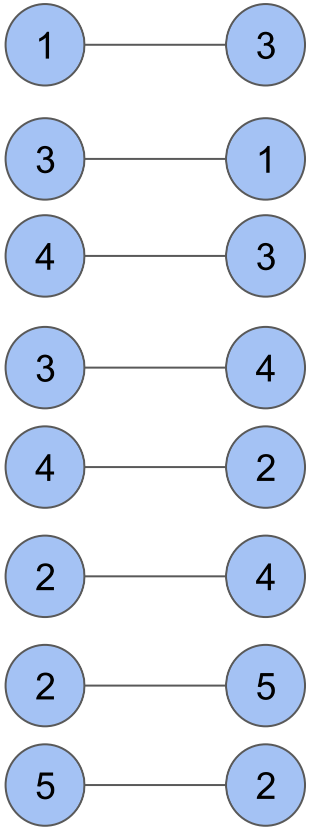
The Connected Graph Problem

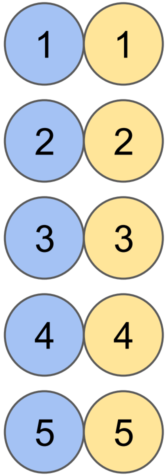


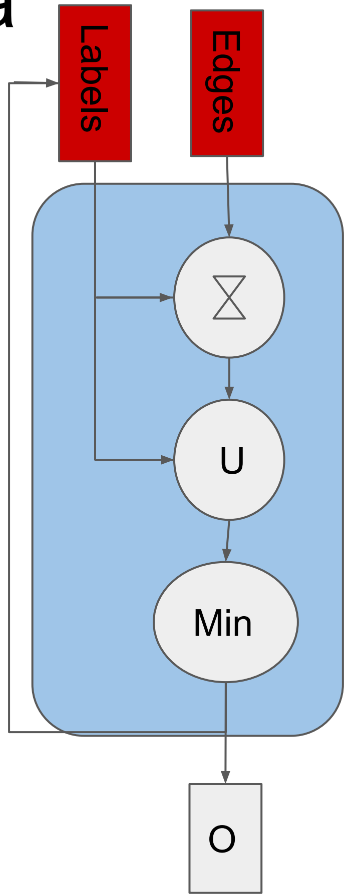
The Connected Graph Problem



Connected Graph with Relational Algebra







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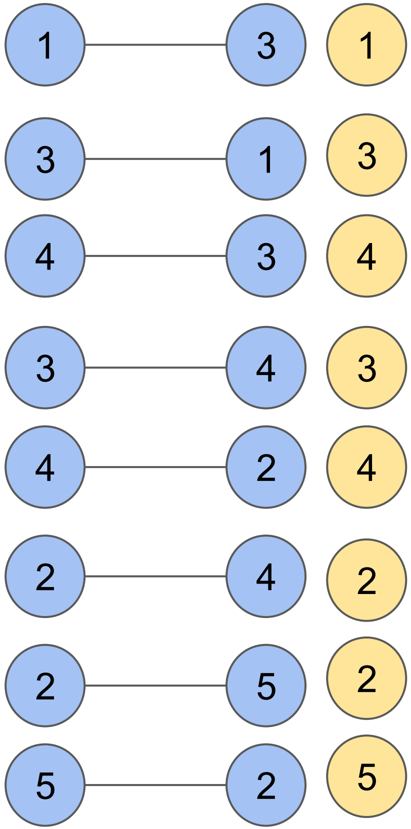

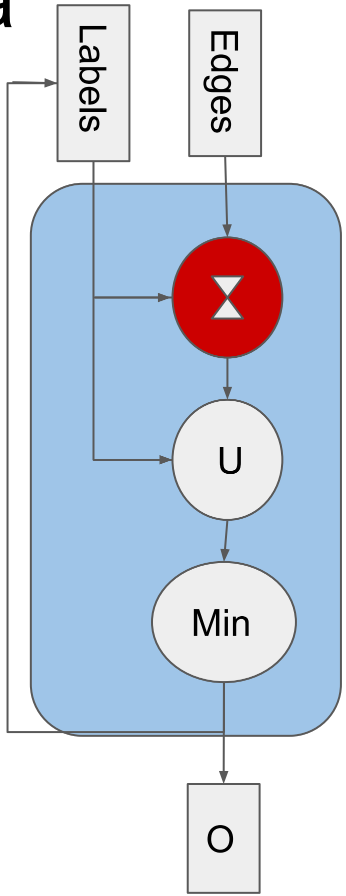

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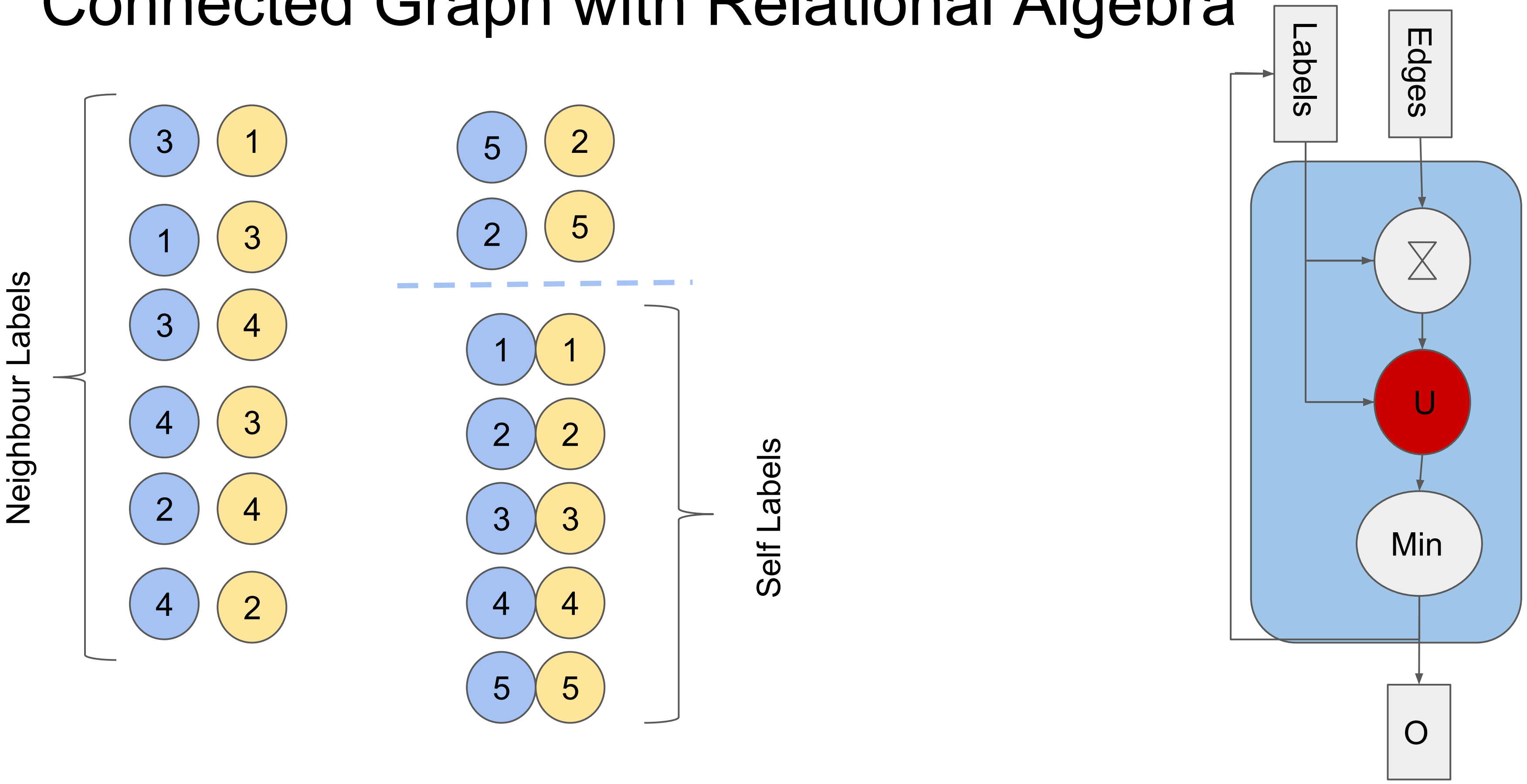

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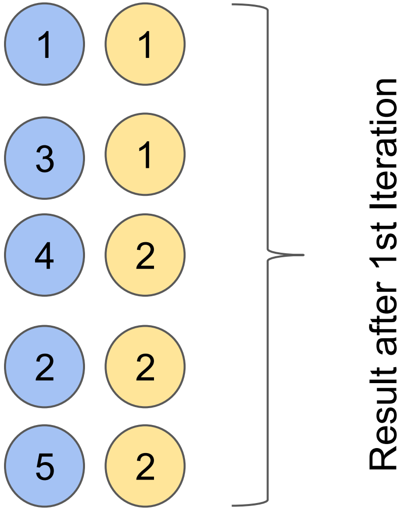
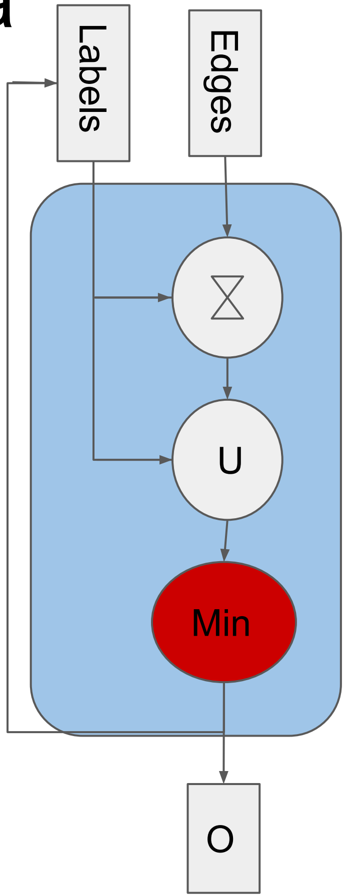
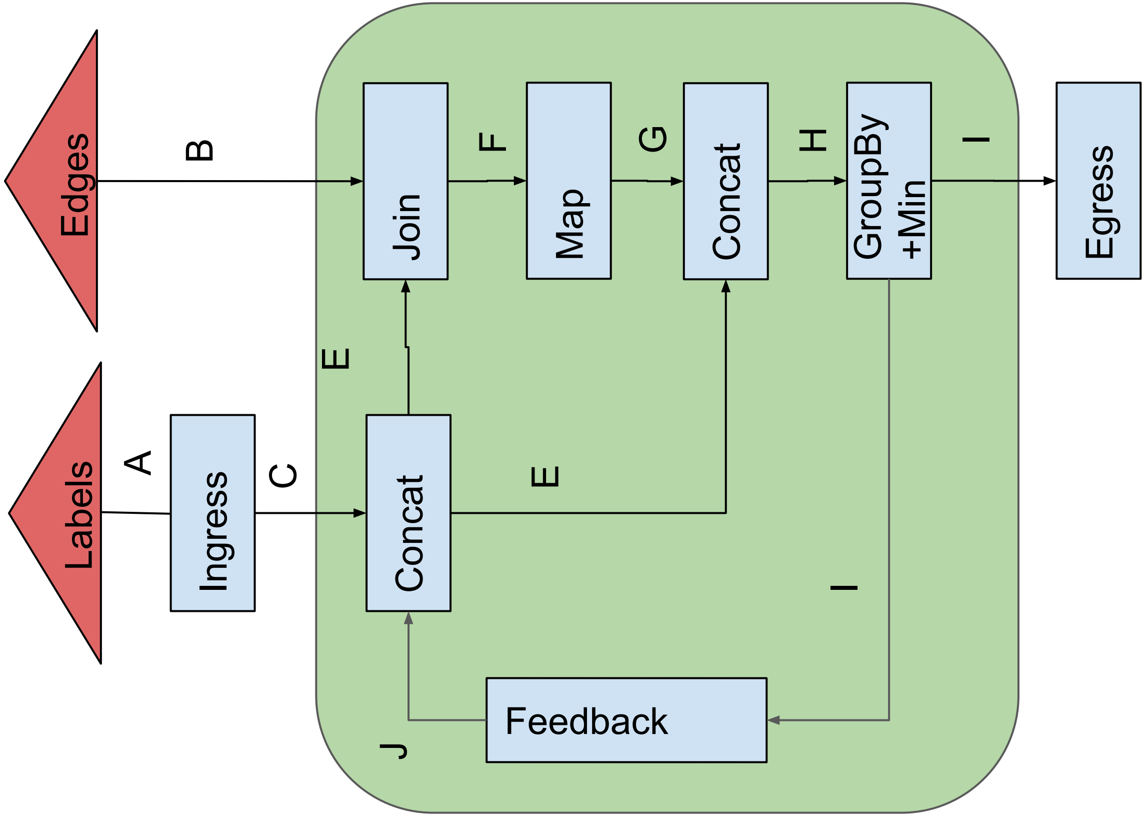




Connected Graph in Timely



- Edges are available constantly
- Add counter at Ingress
- Remove Counter at egress
- Increment counter at feedback
- Map converts joined tuples into node/label tuples
- Concat performs the union

Maintaining State in Differential Dataflow

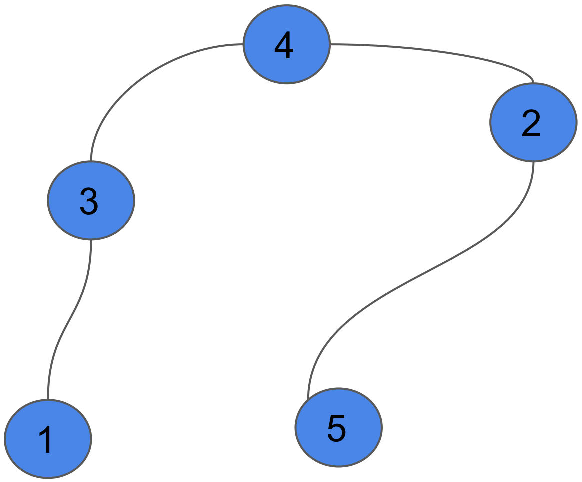
$$\delta\mathbf{B}_t = \mathrm{Op}\left(\sum_{s \leq t} \delta\mathbf{A}_s\right) - \sum_{s<t} \delta\mathbf{B}_s$$

Change in state at node *b* at *t*

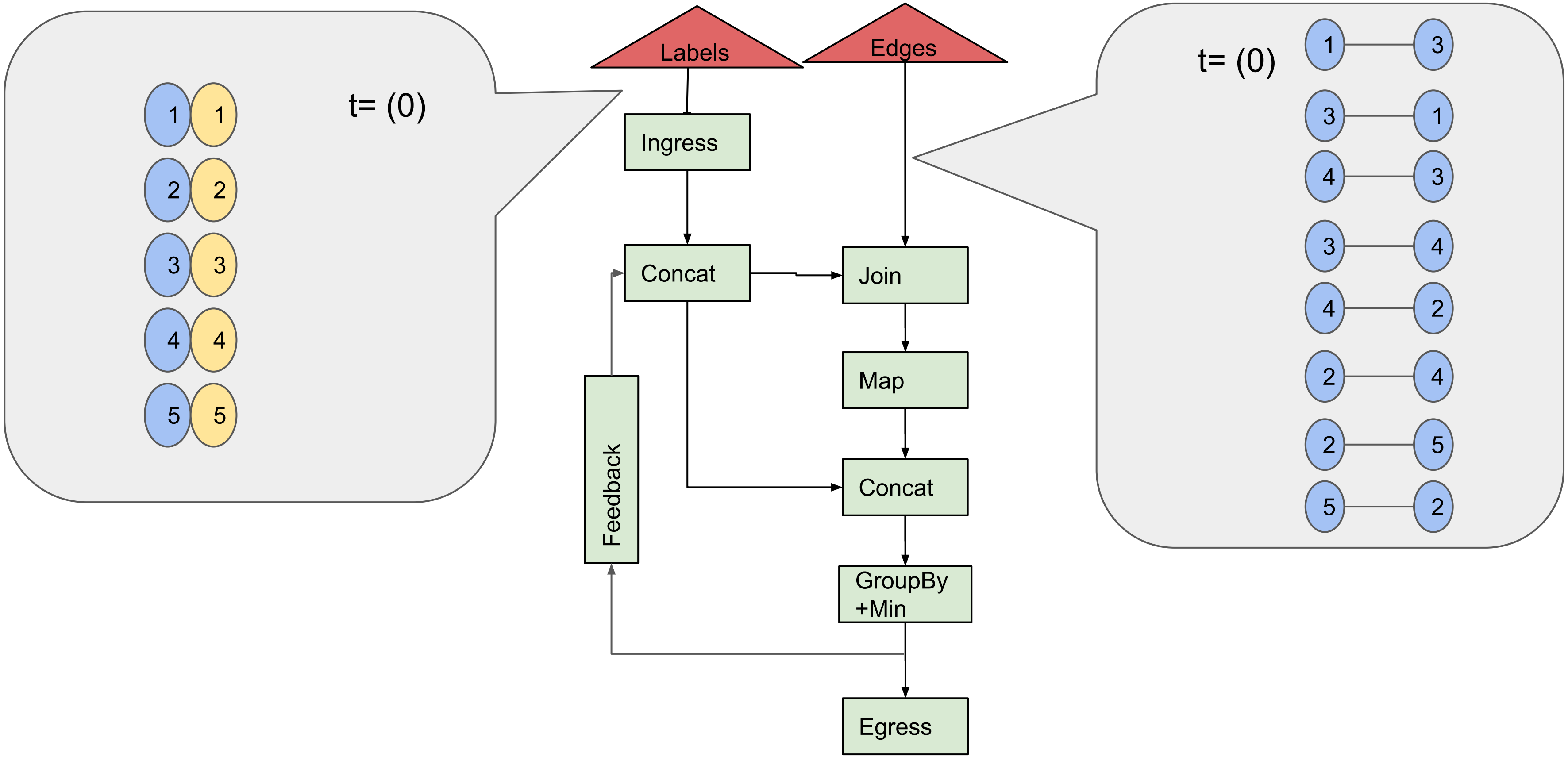
Cumulative state at *b* upto *t*

Sum of all states at *b* before *t*

Connected Graph



Connected Graph in Differential



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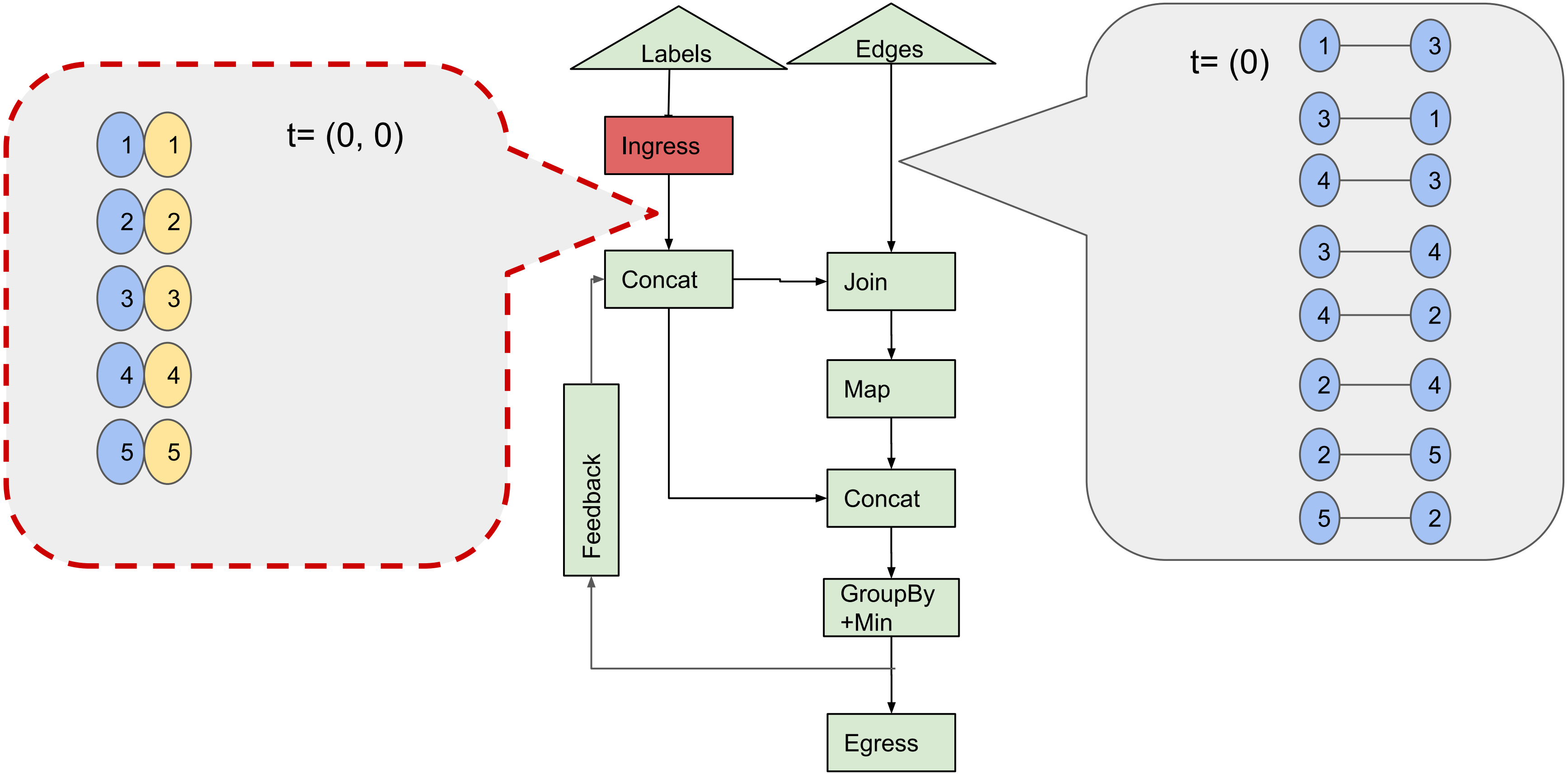

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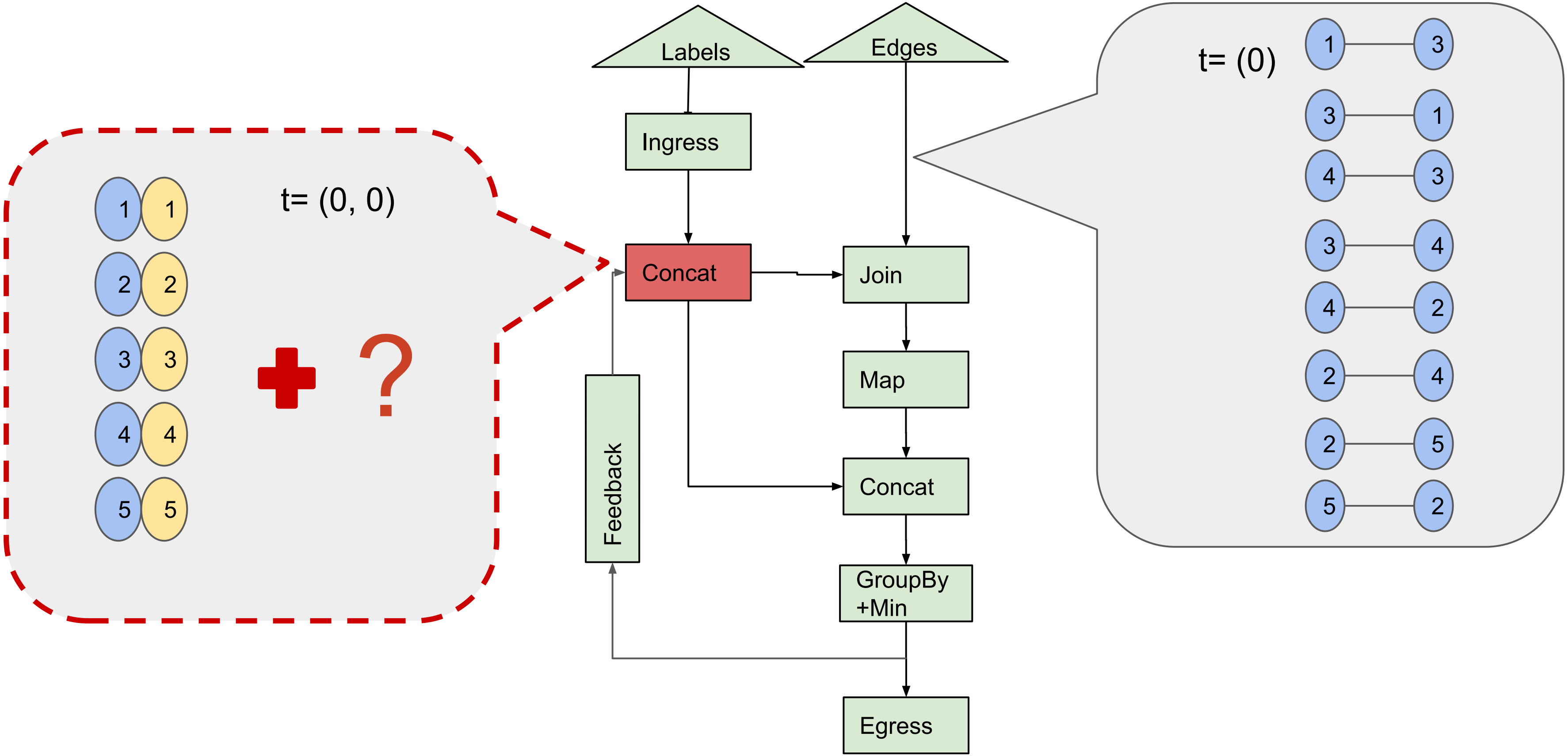

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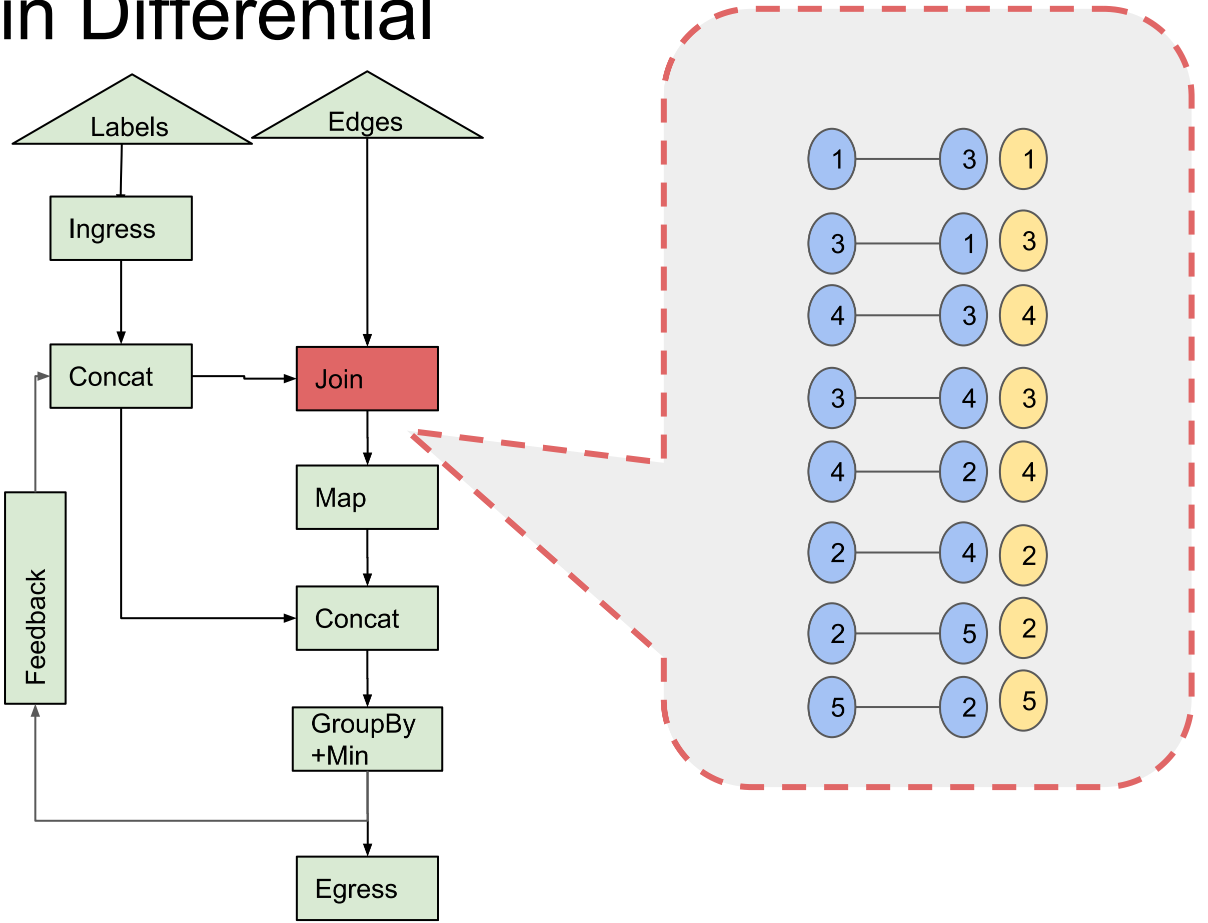

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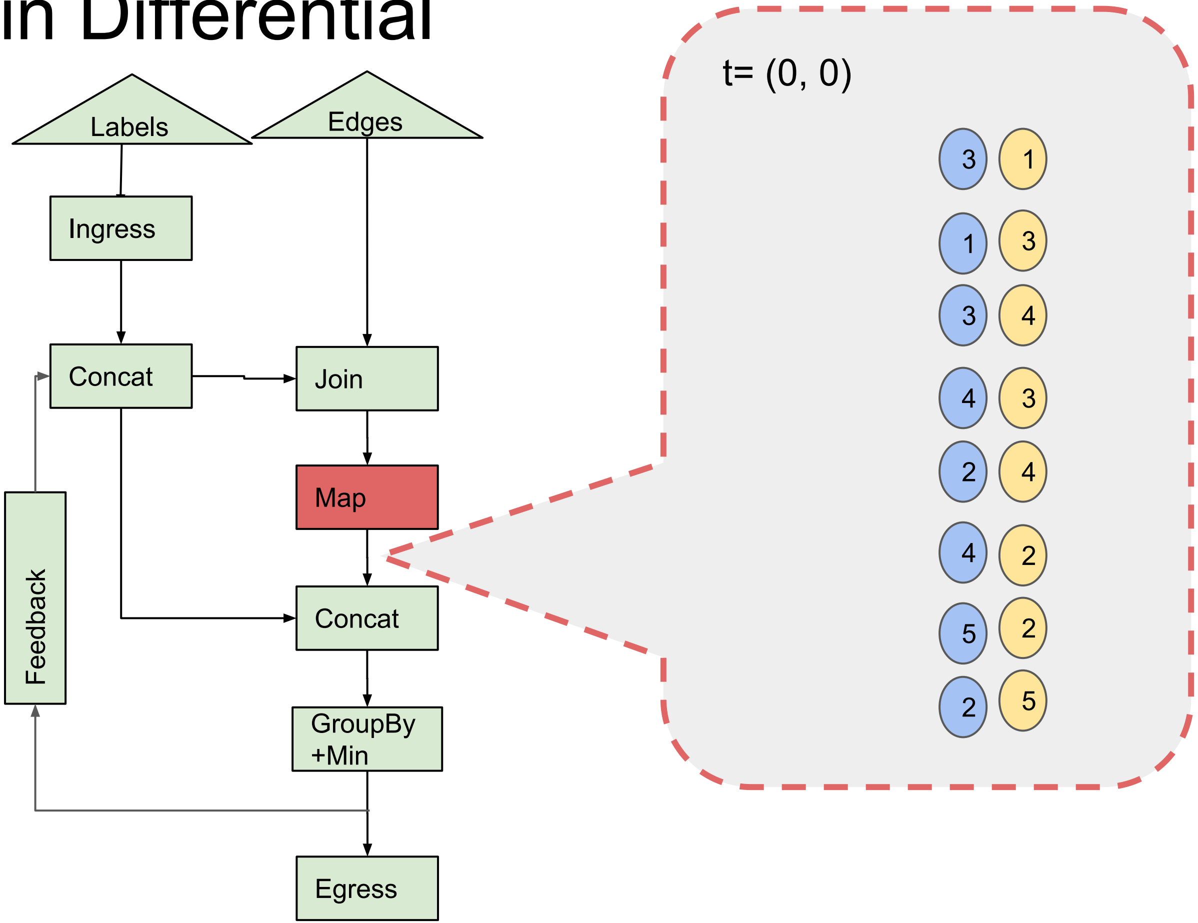

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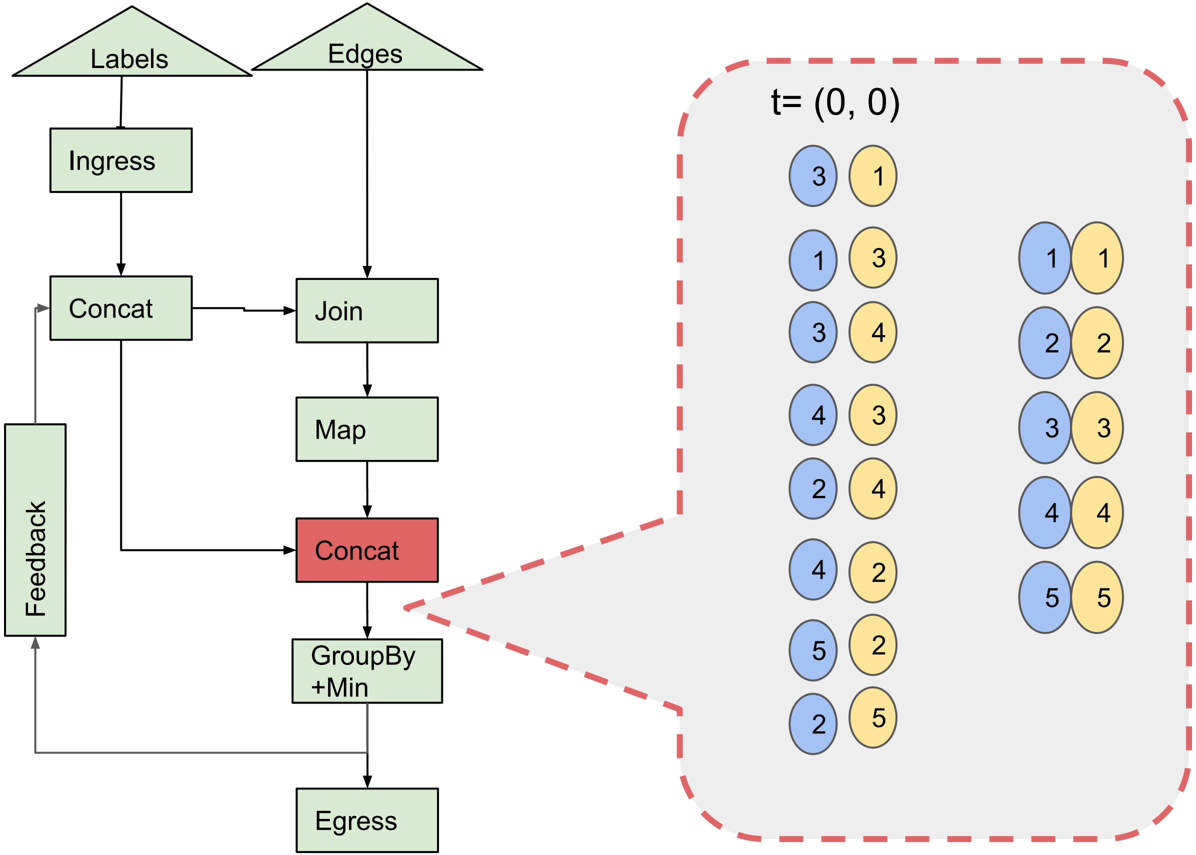

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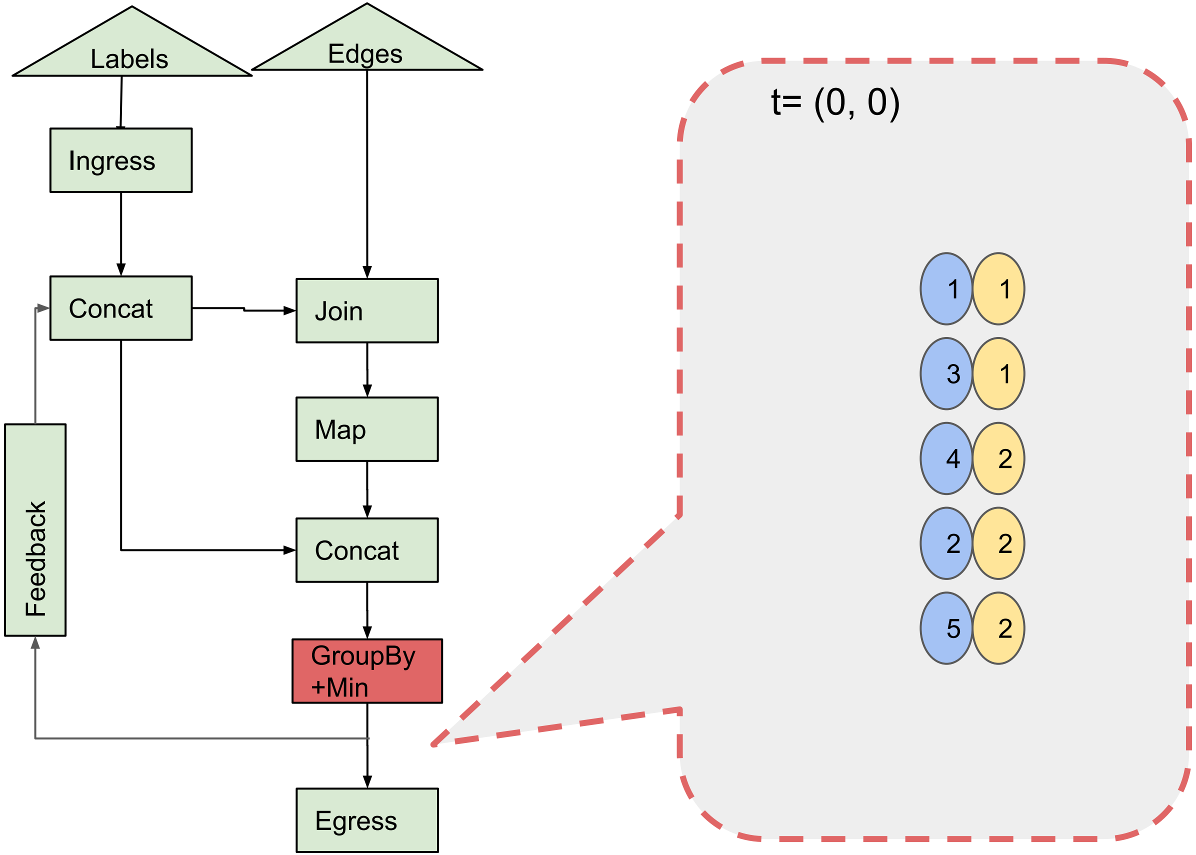

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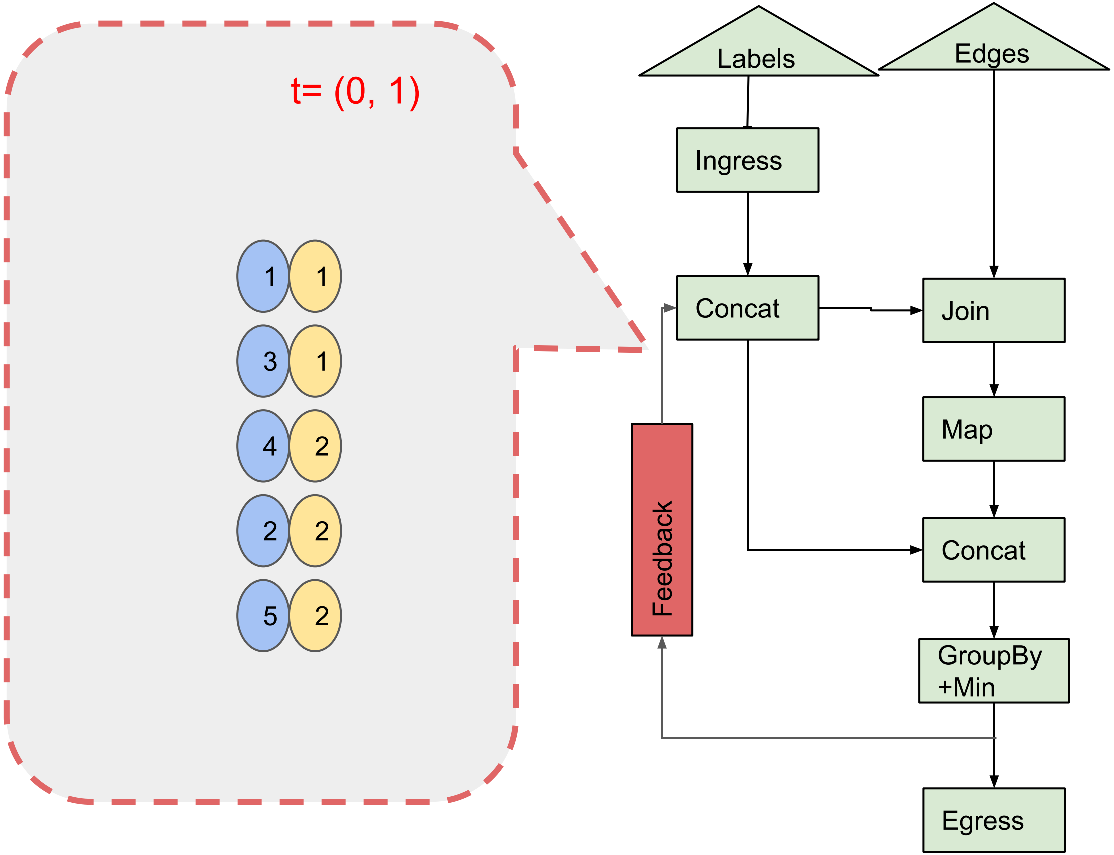

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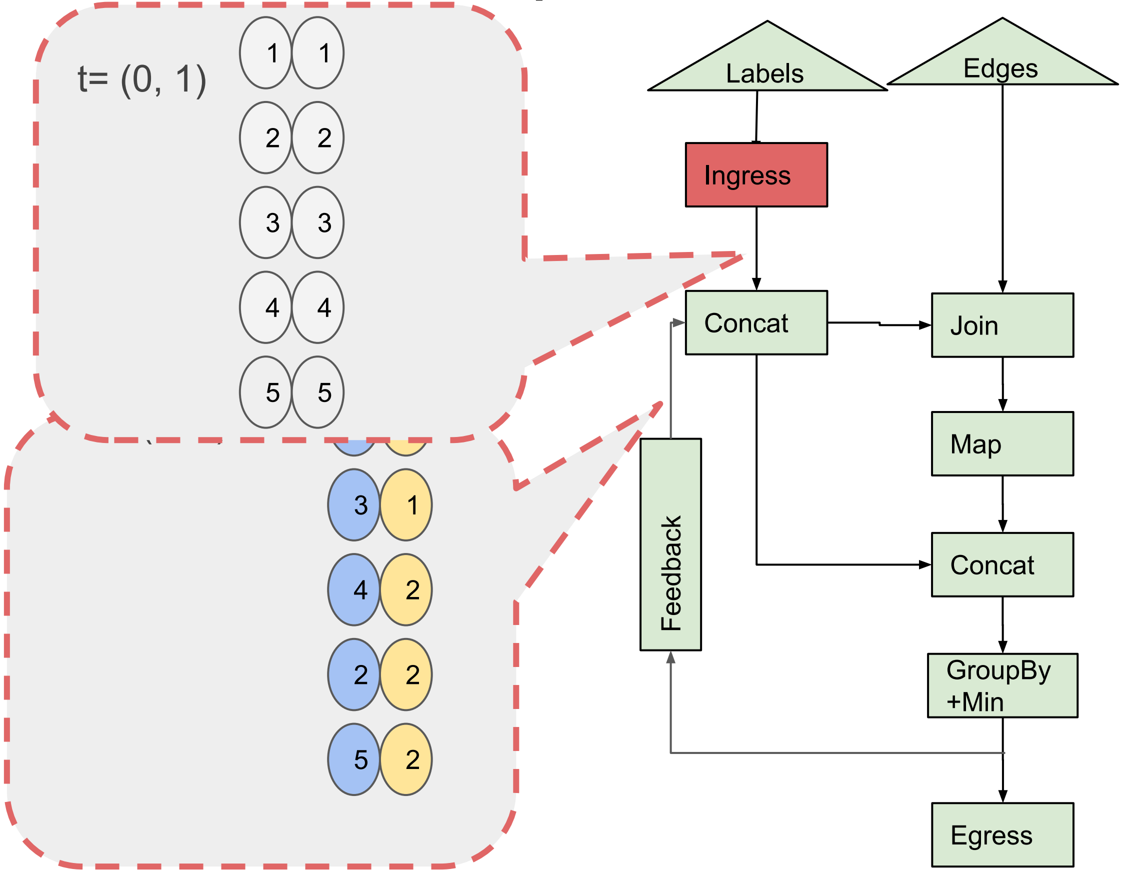

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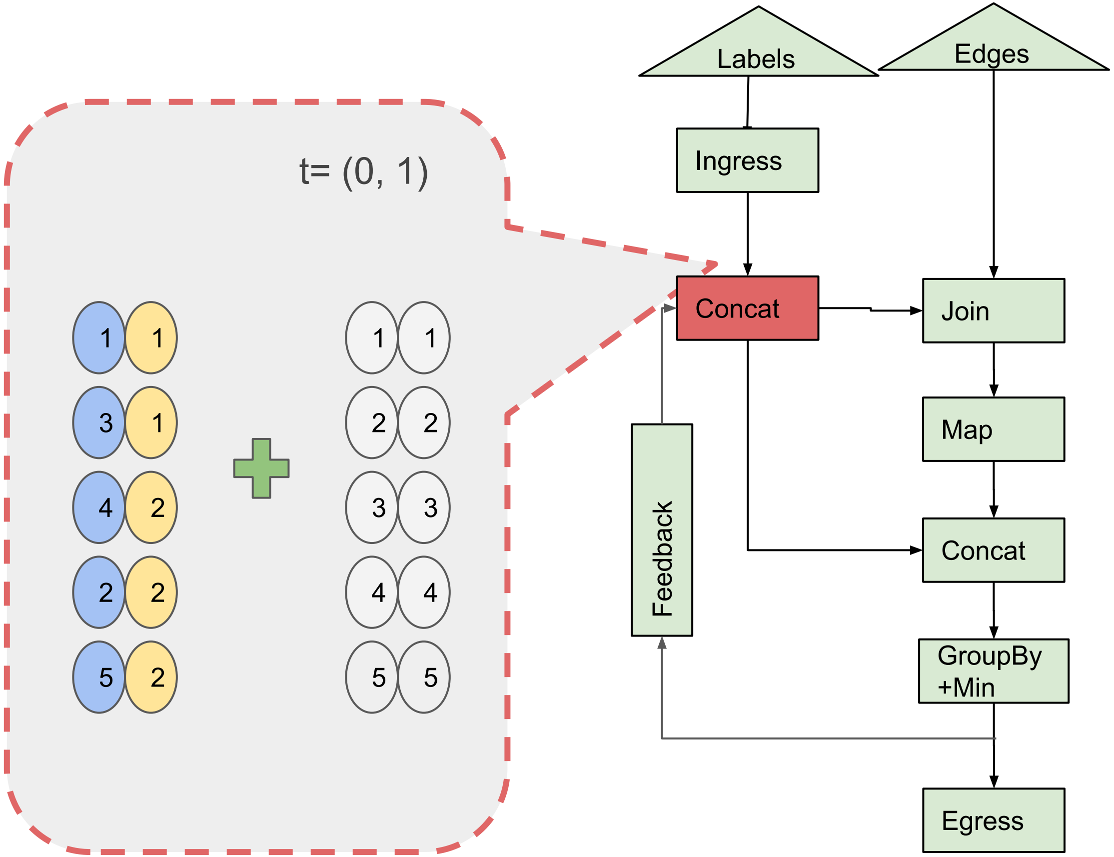

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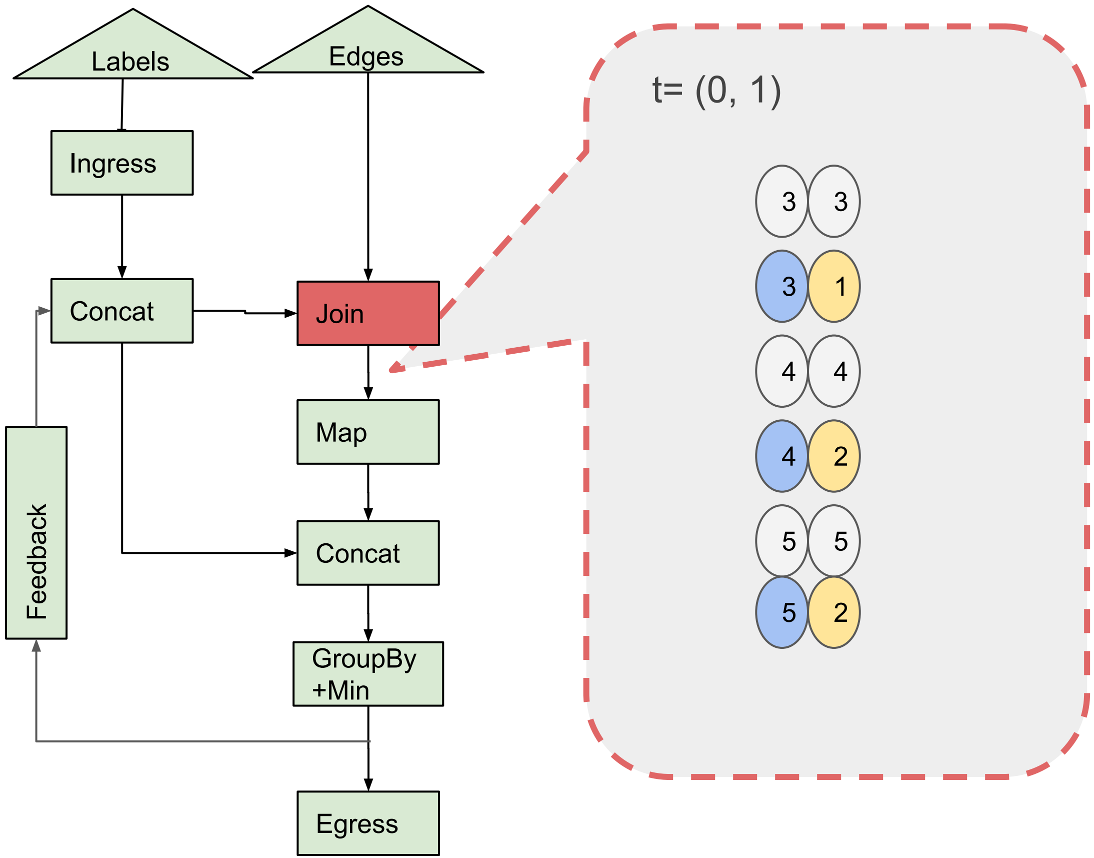

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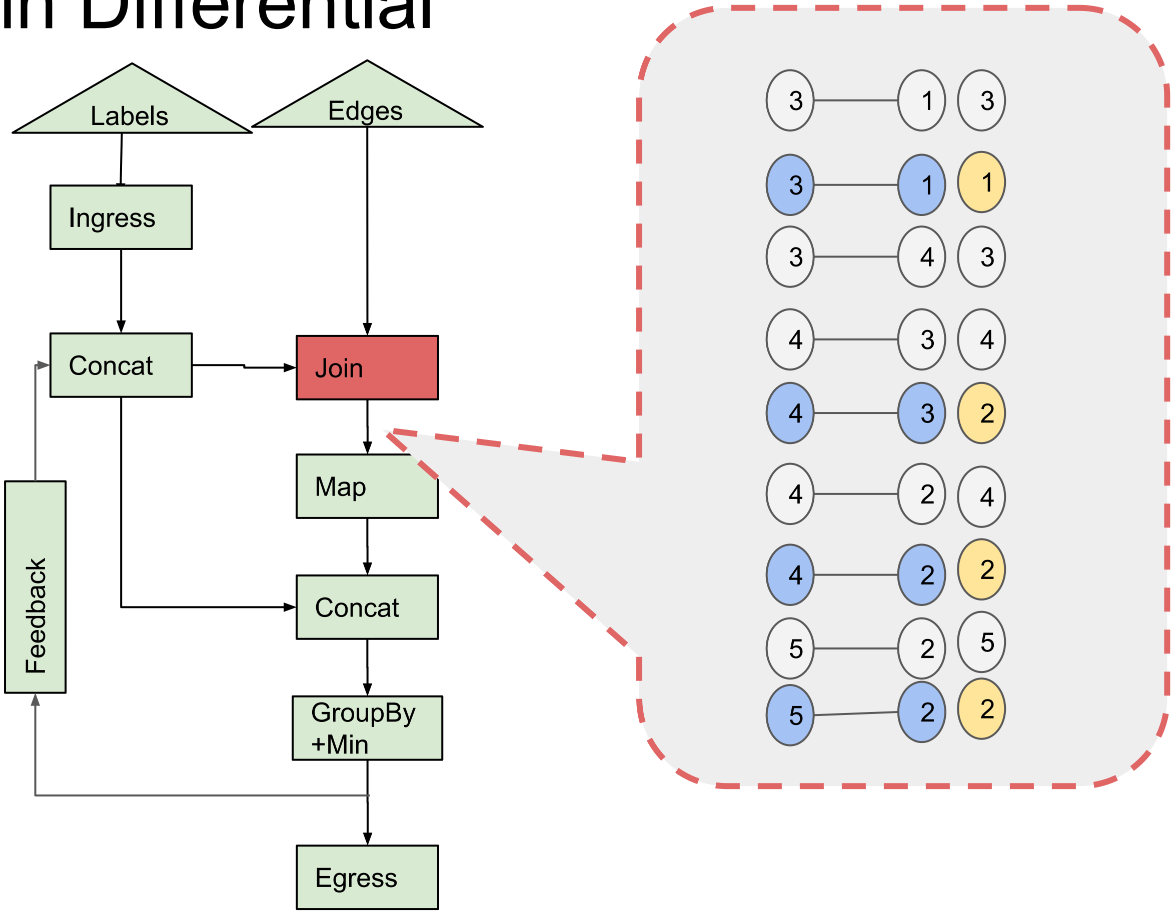

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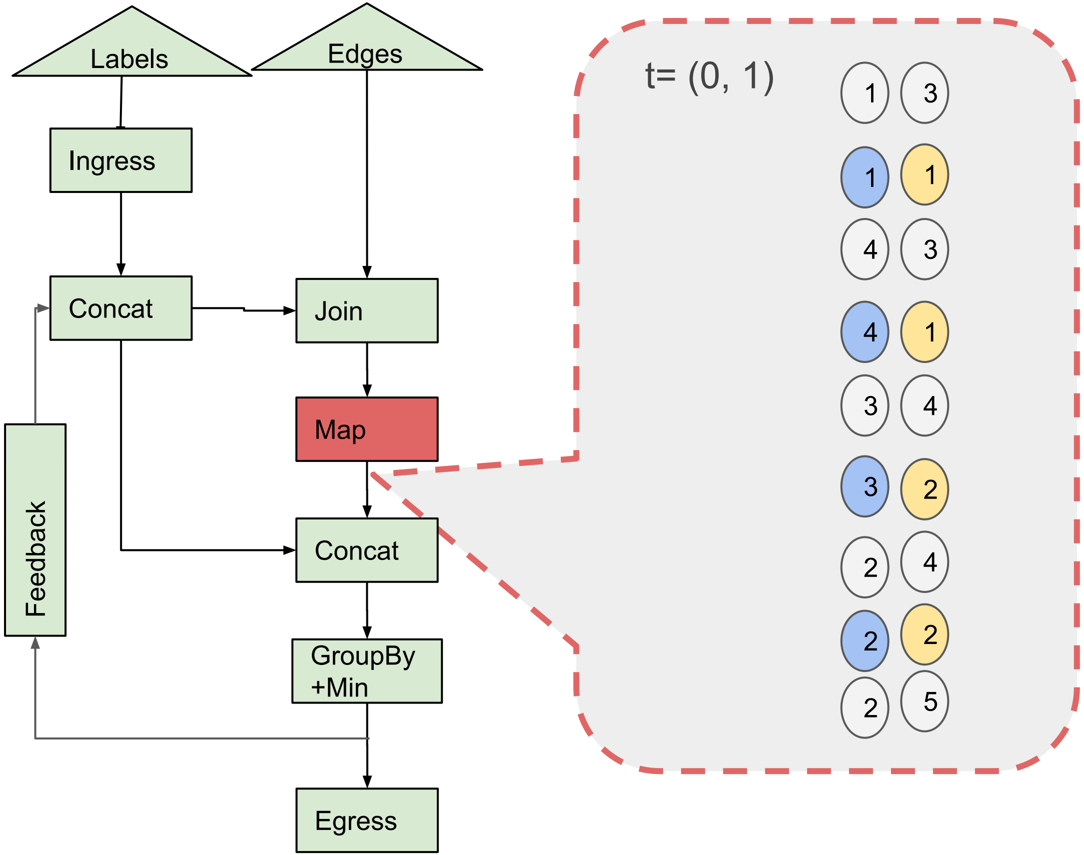

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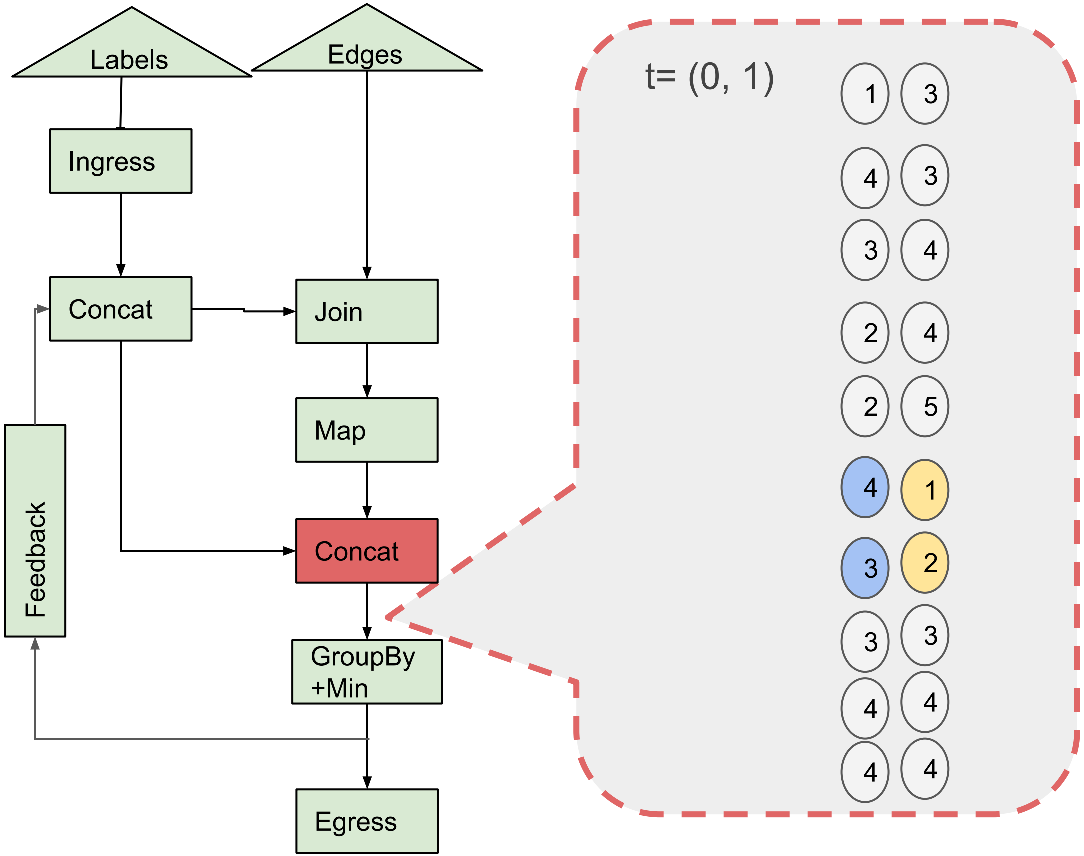

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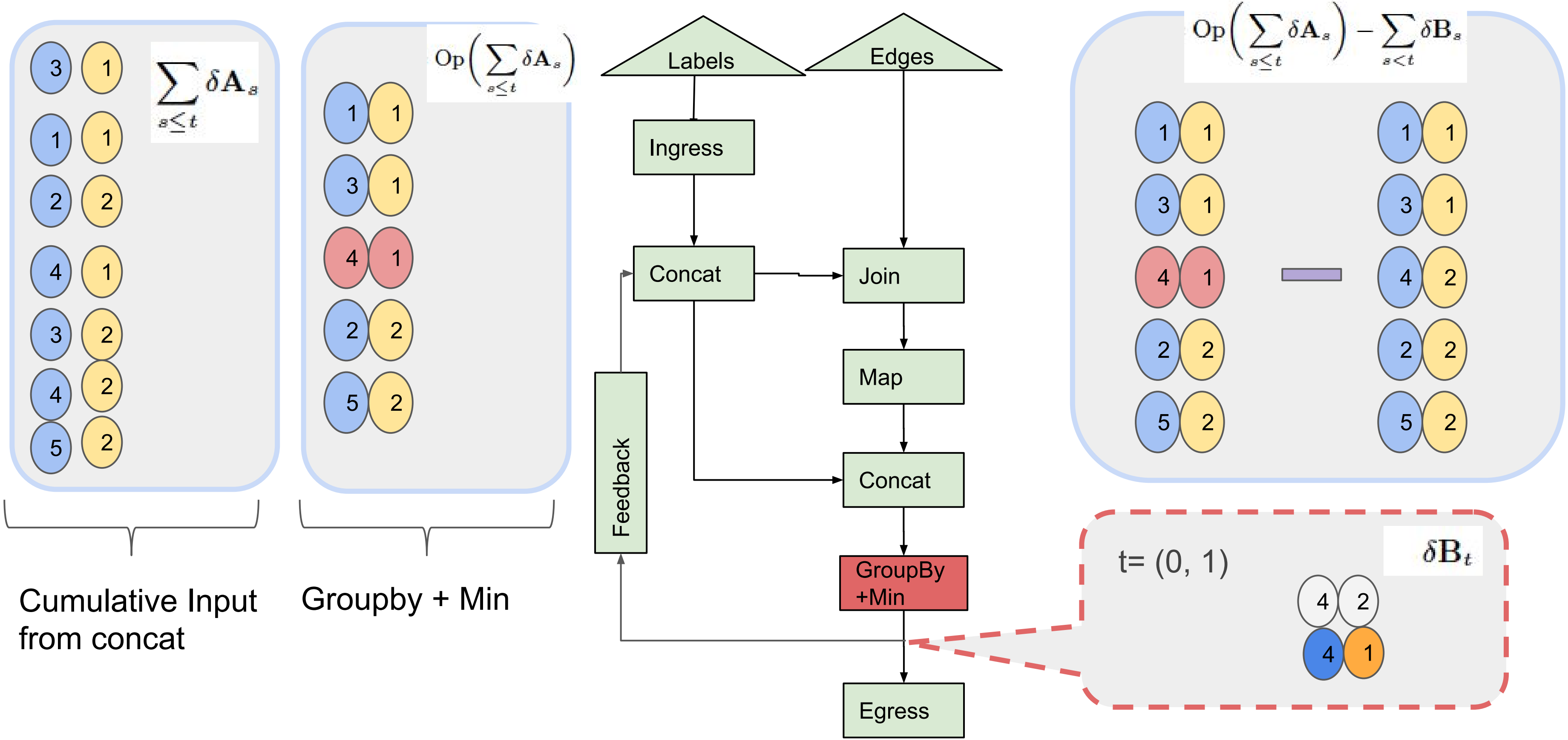

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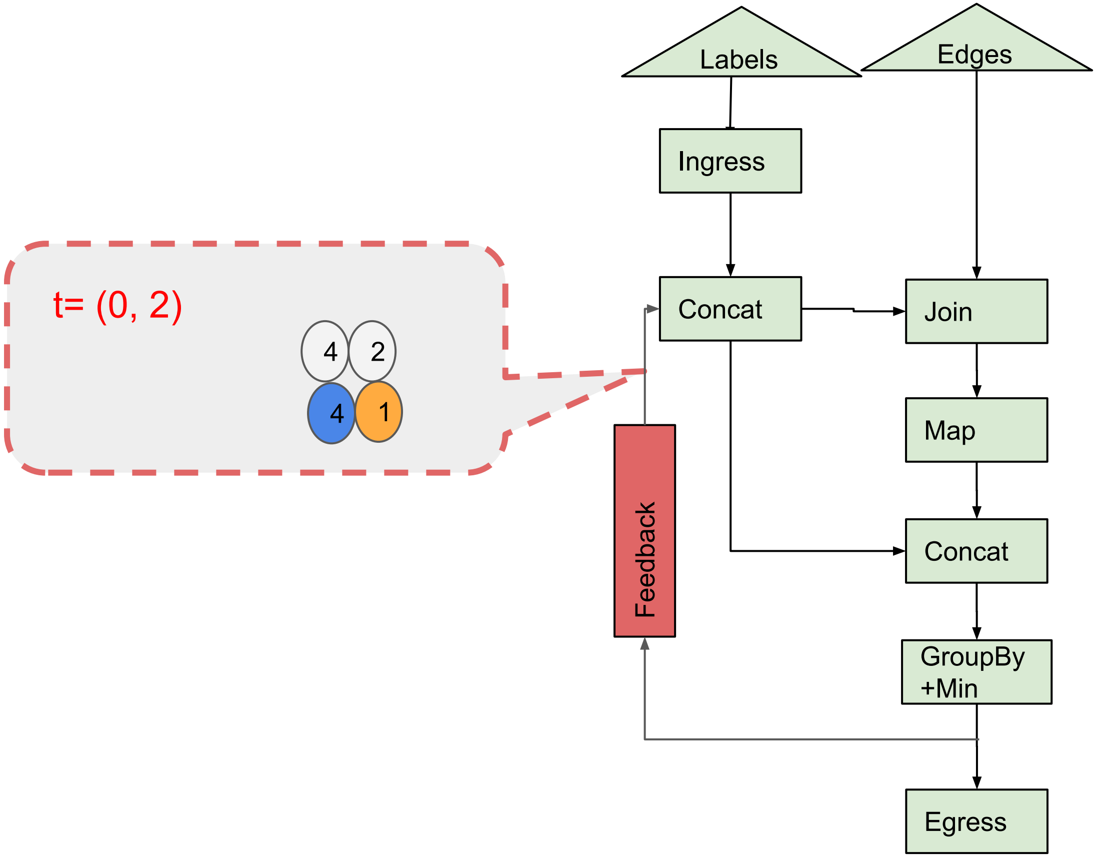

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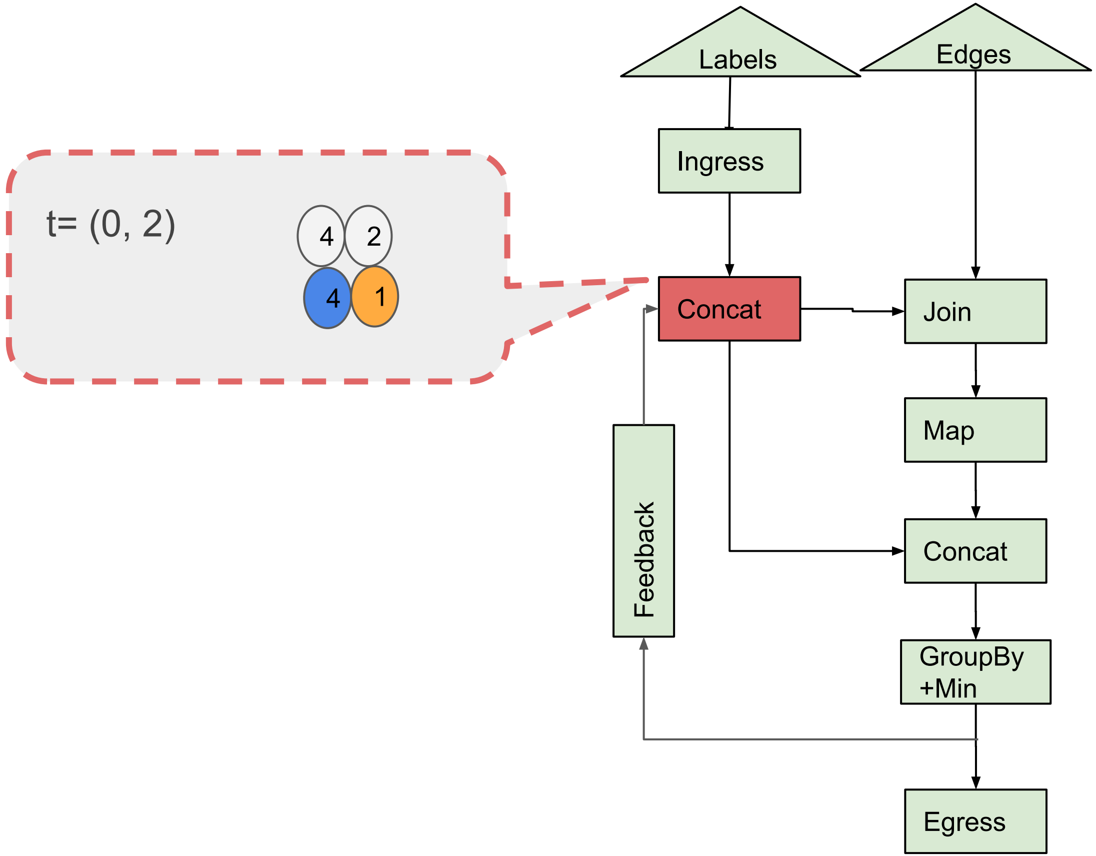

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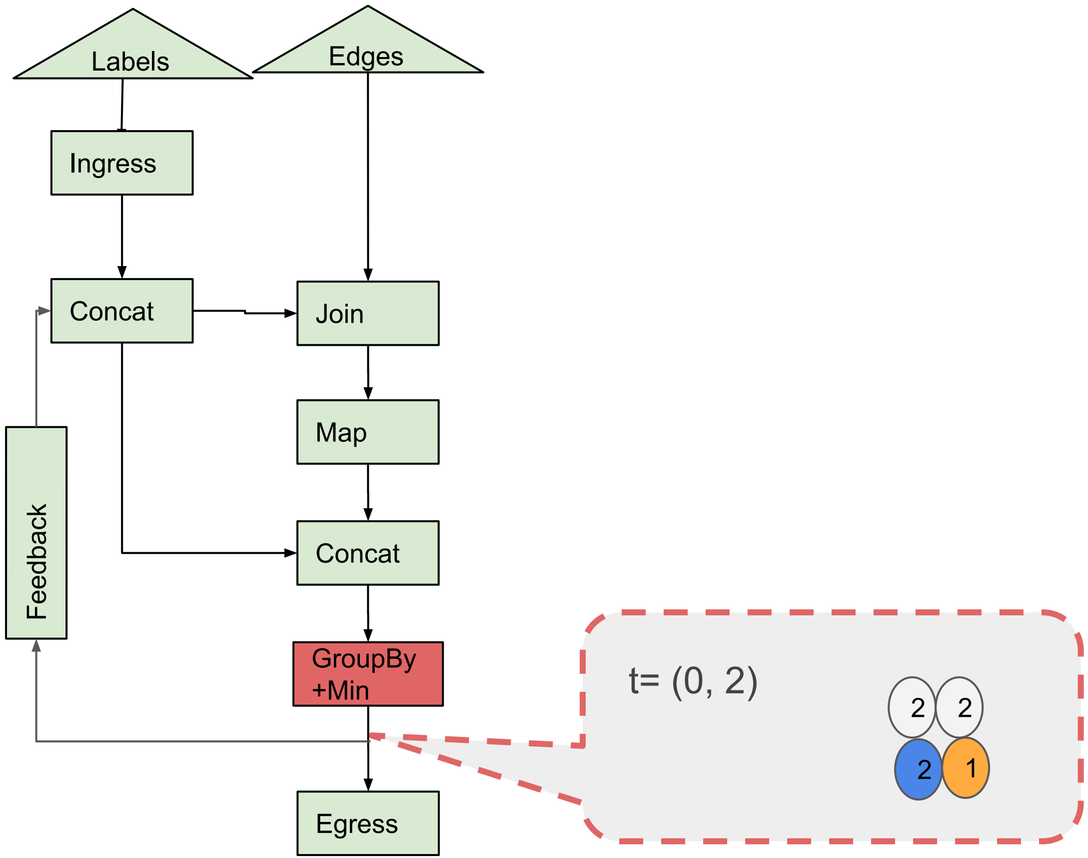

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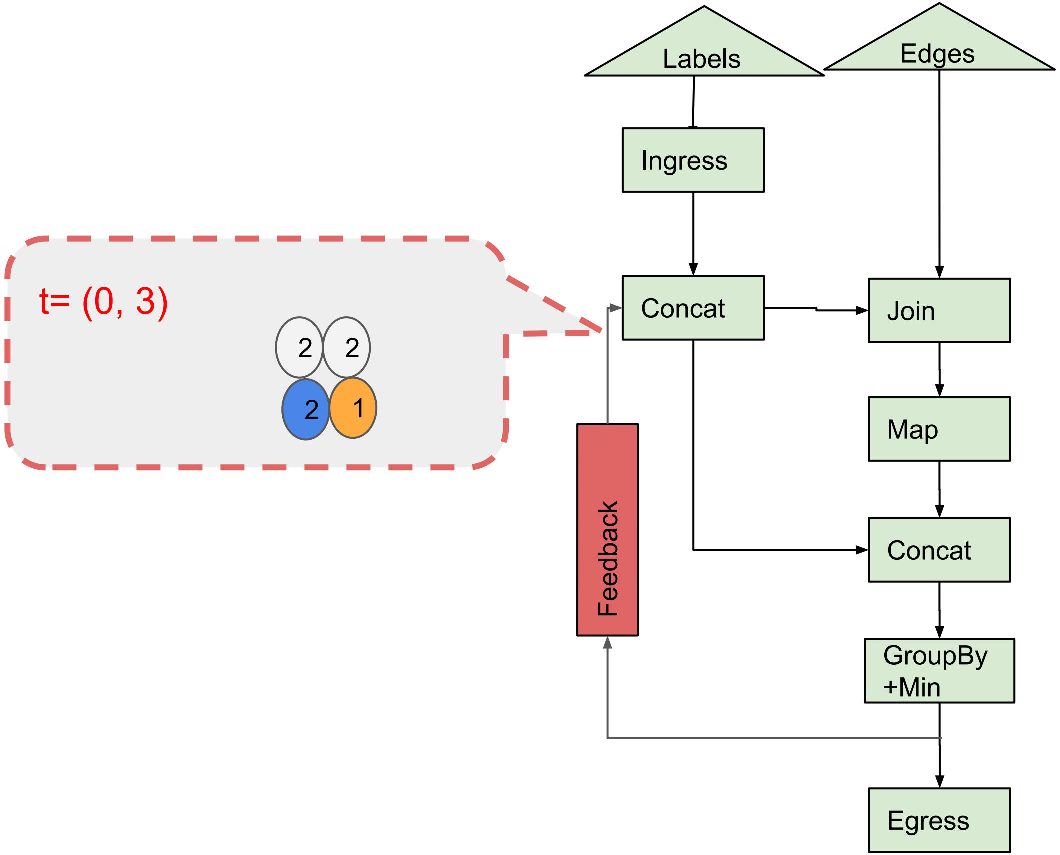

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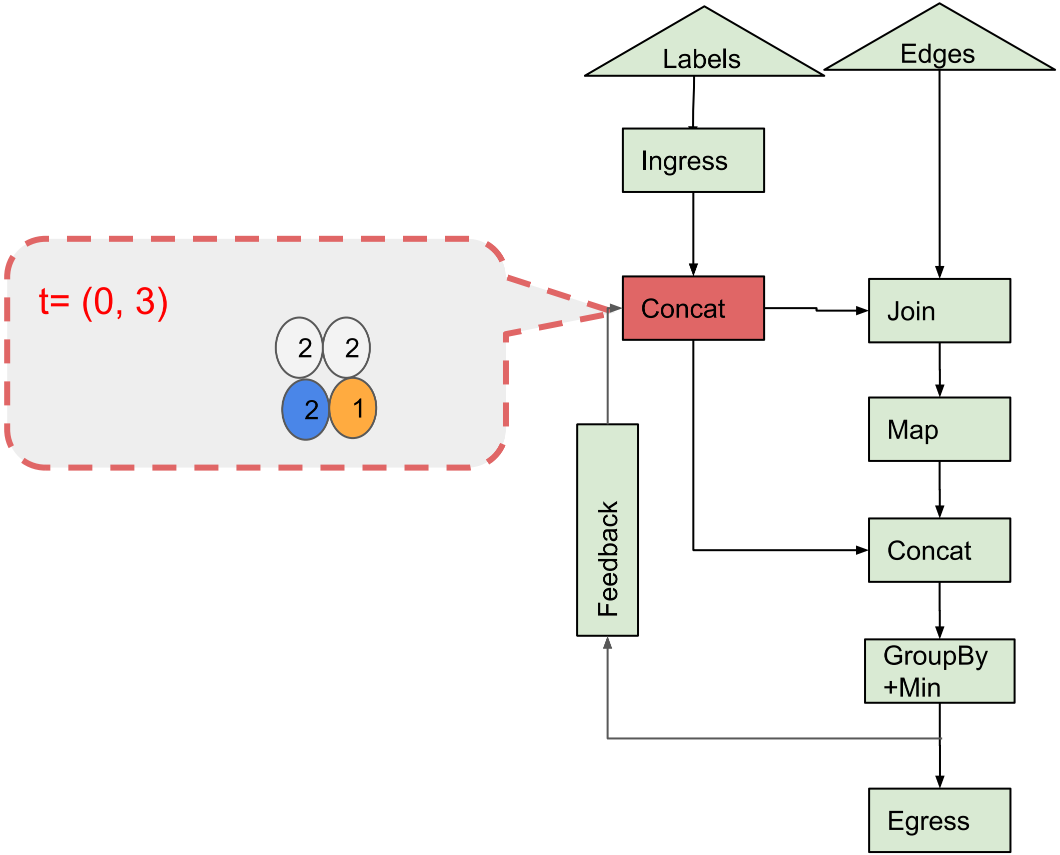

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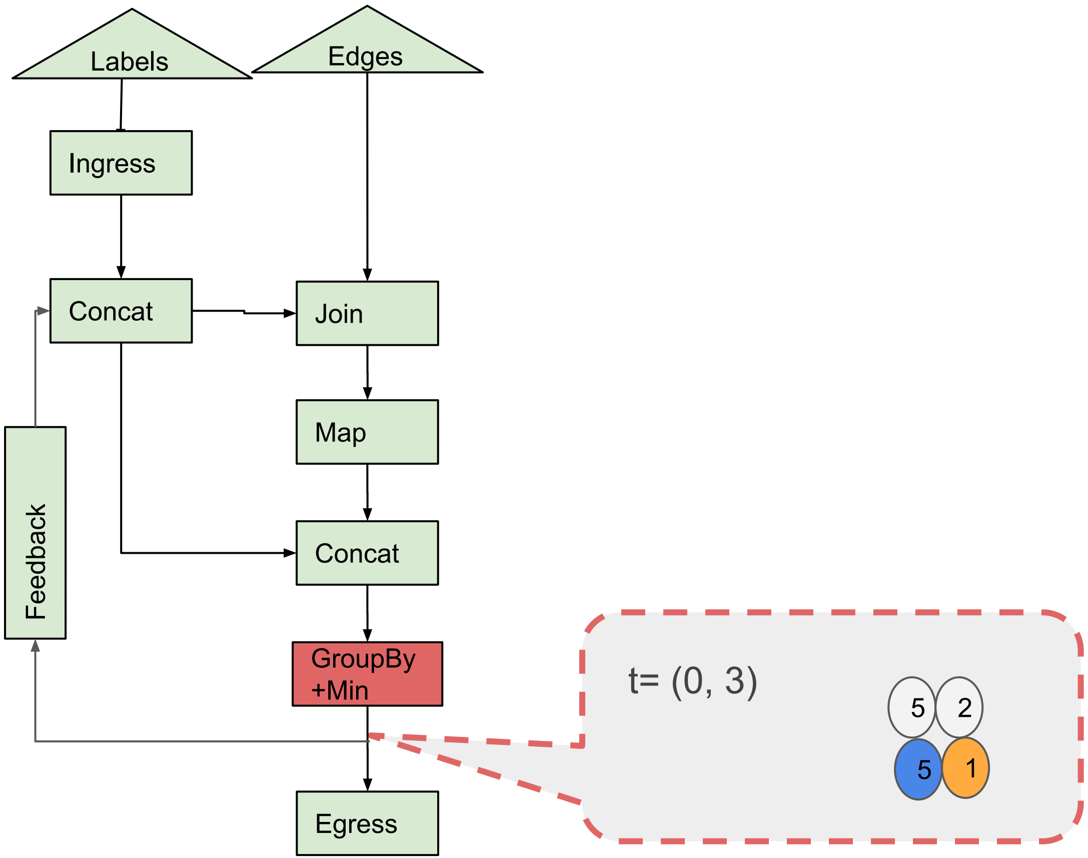

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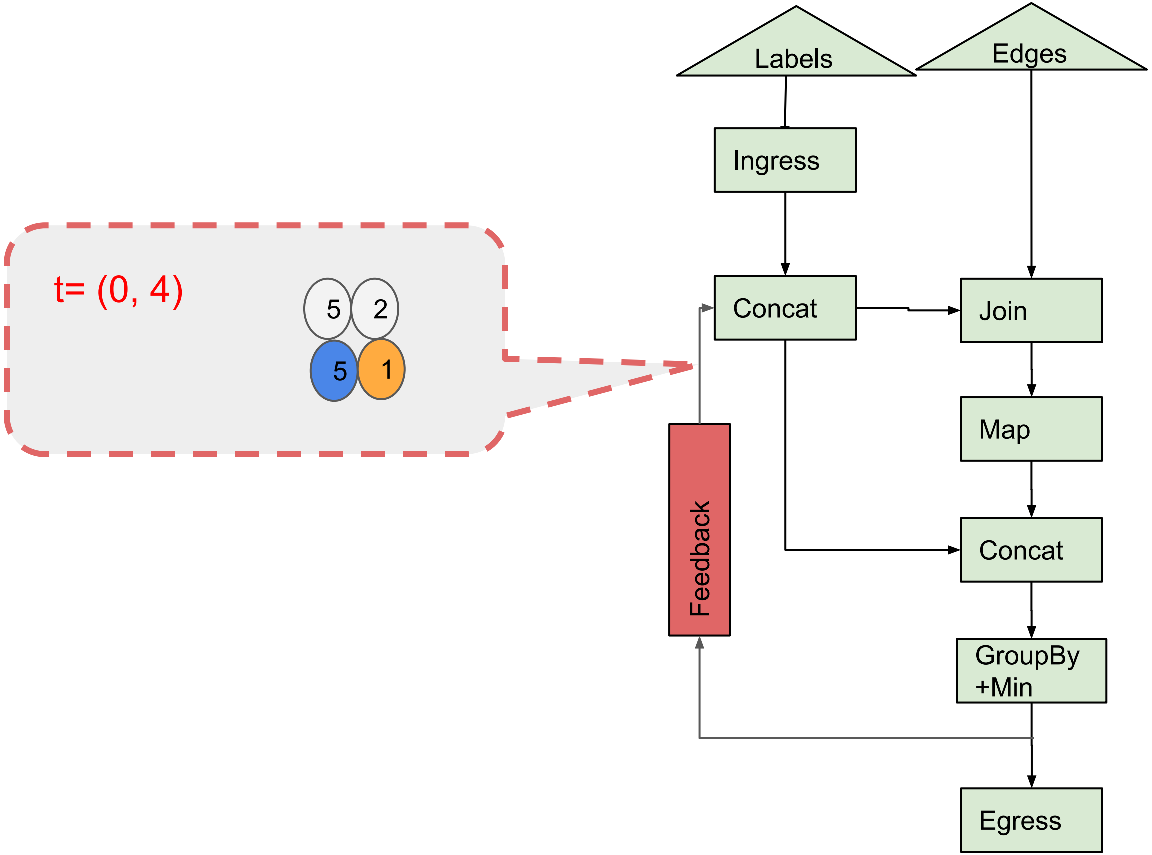

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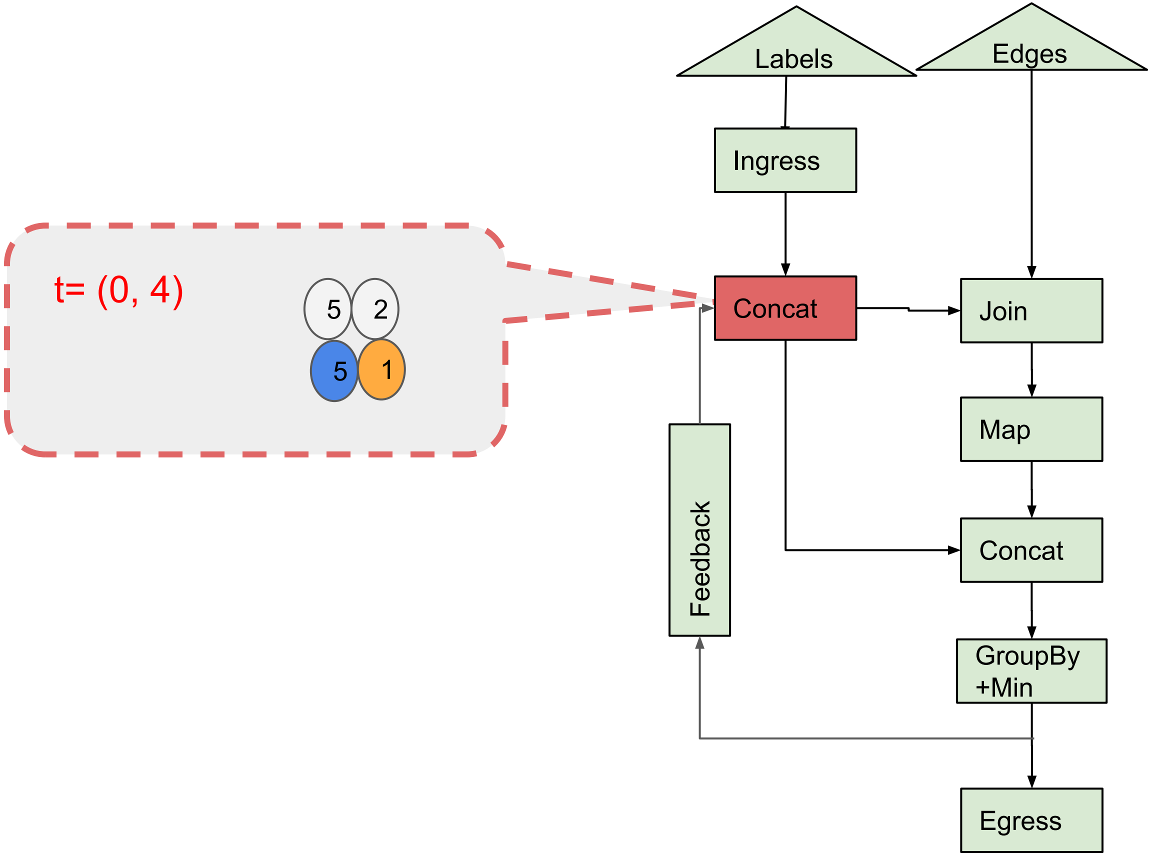

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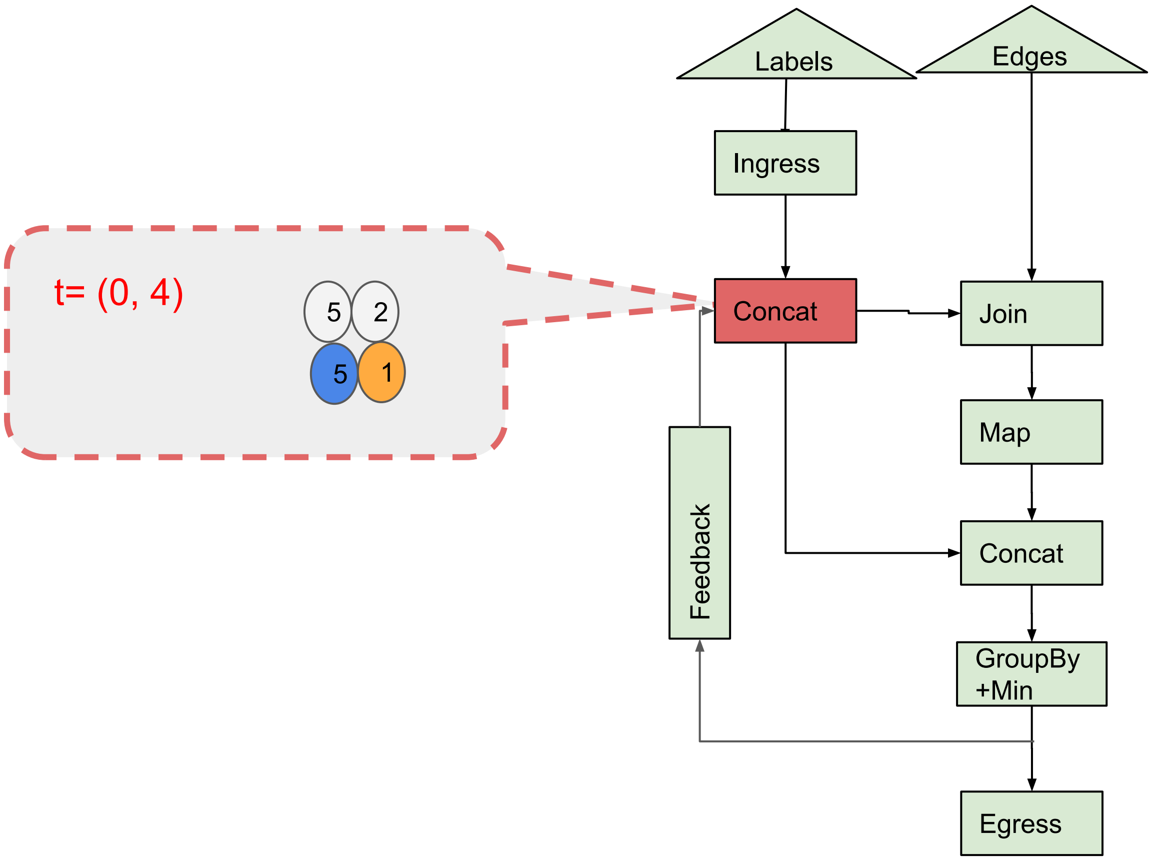

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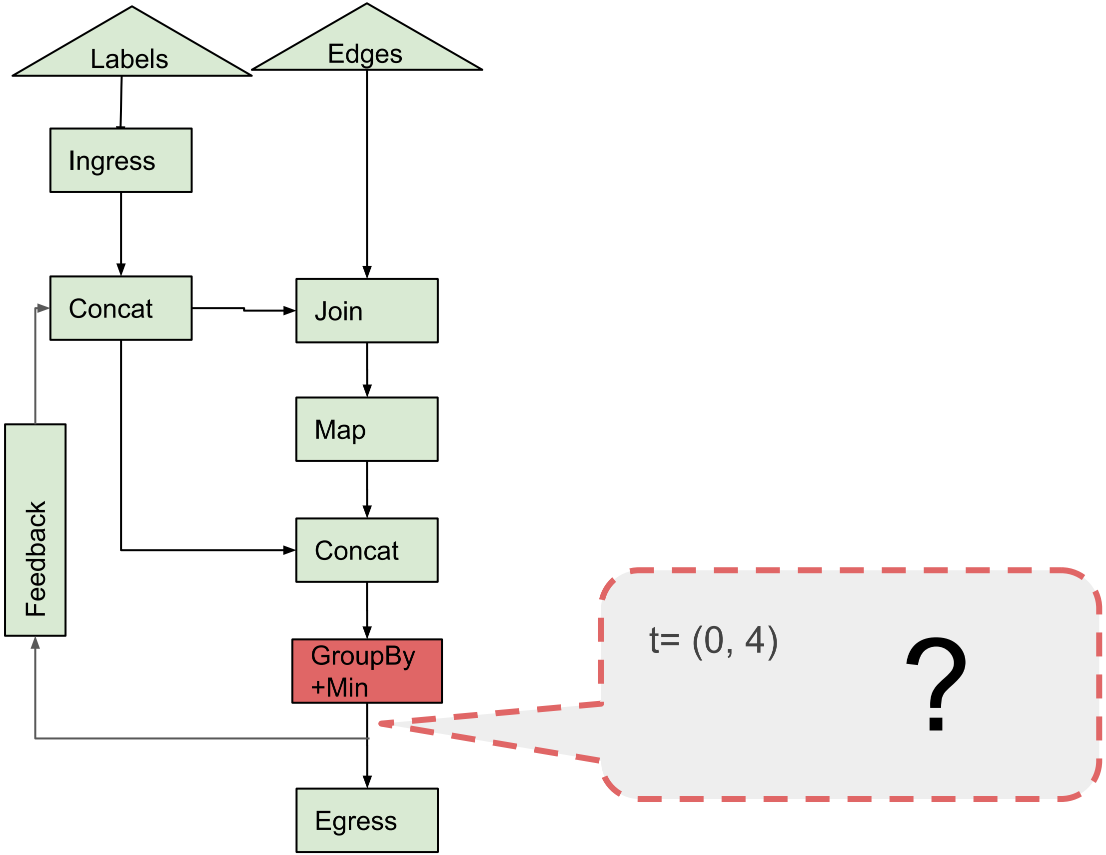

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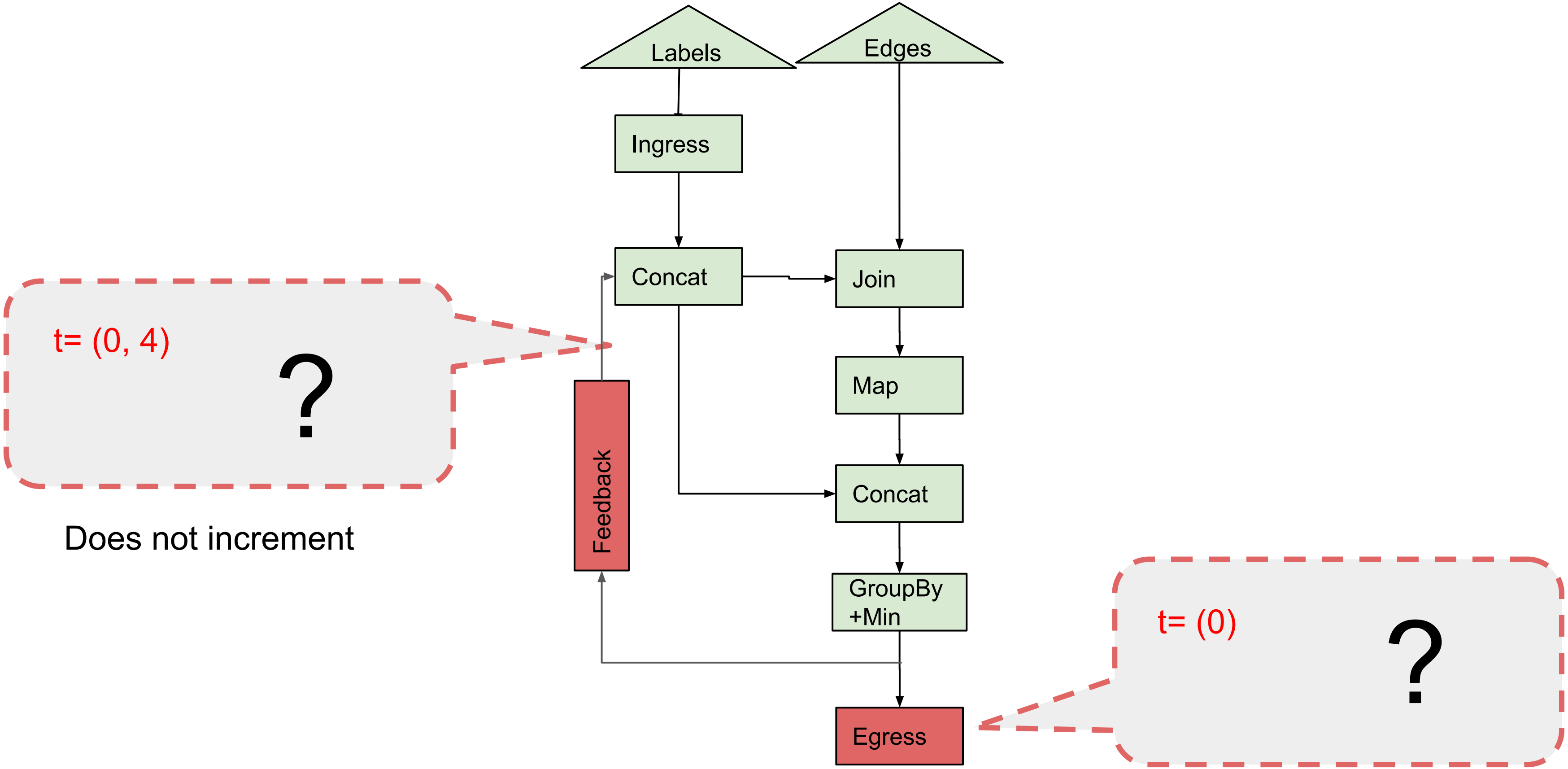
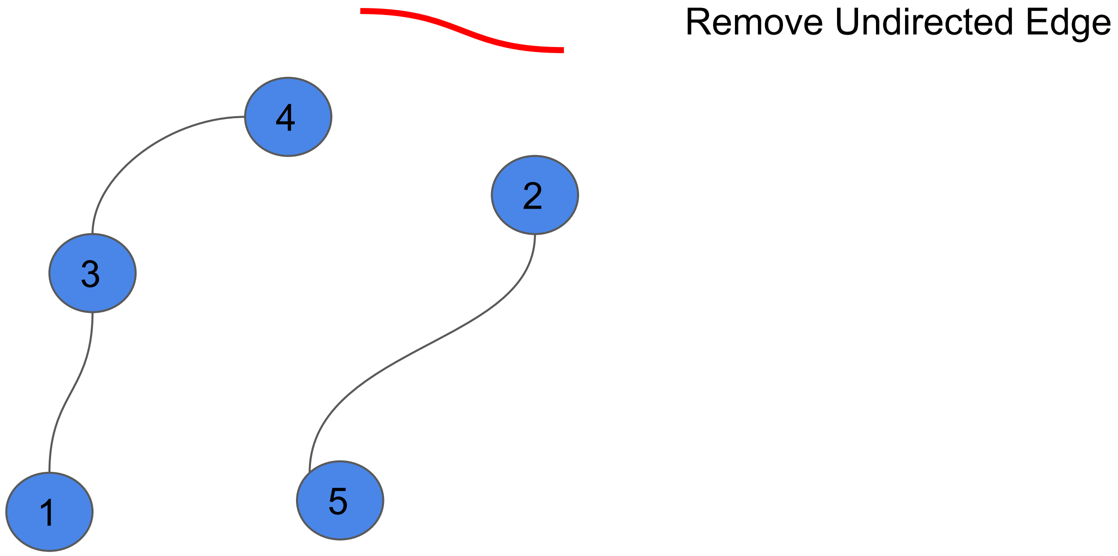


Does not increment

Changes to Connected Graph - I



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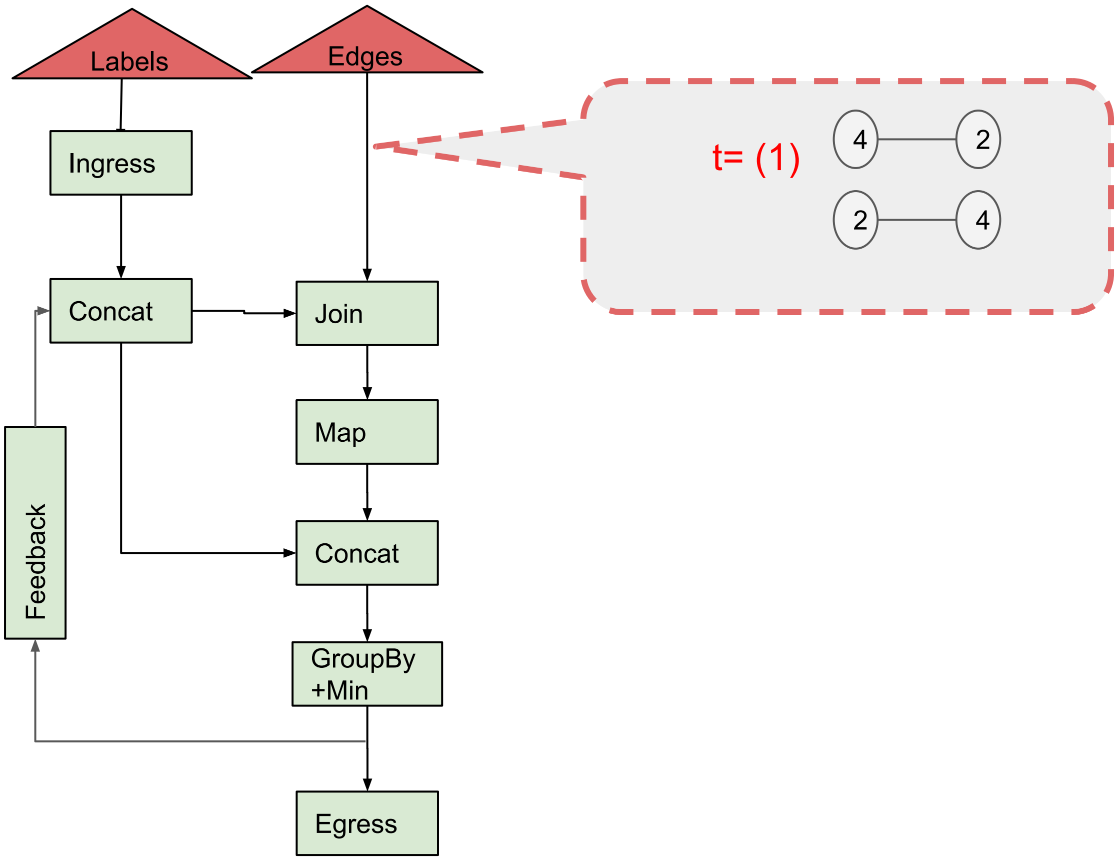

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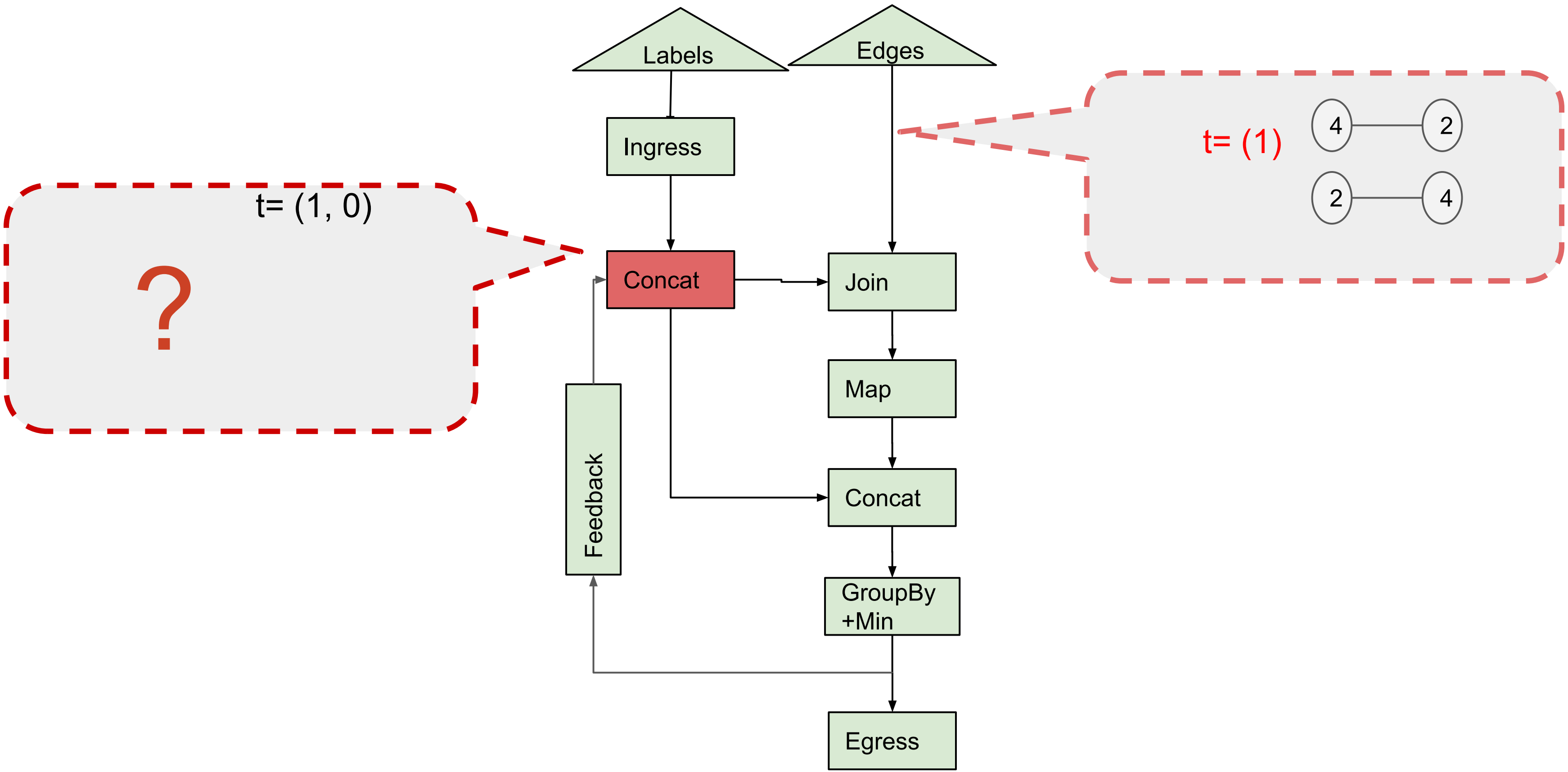

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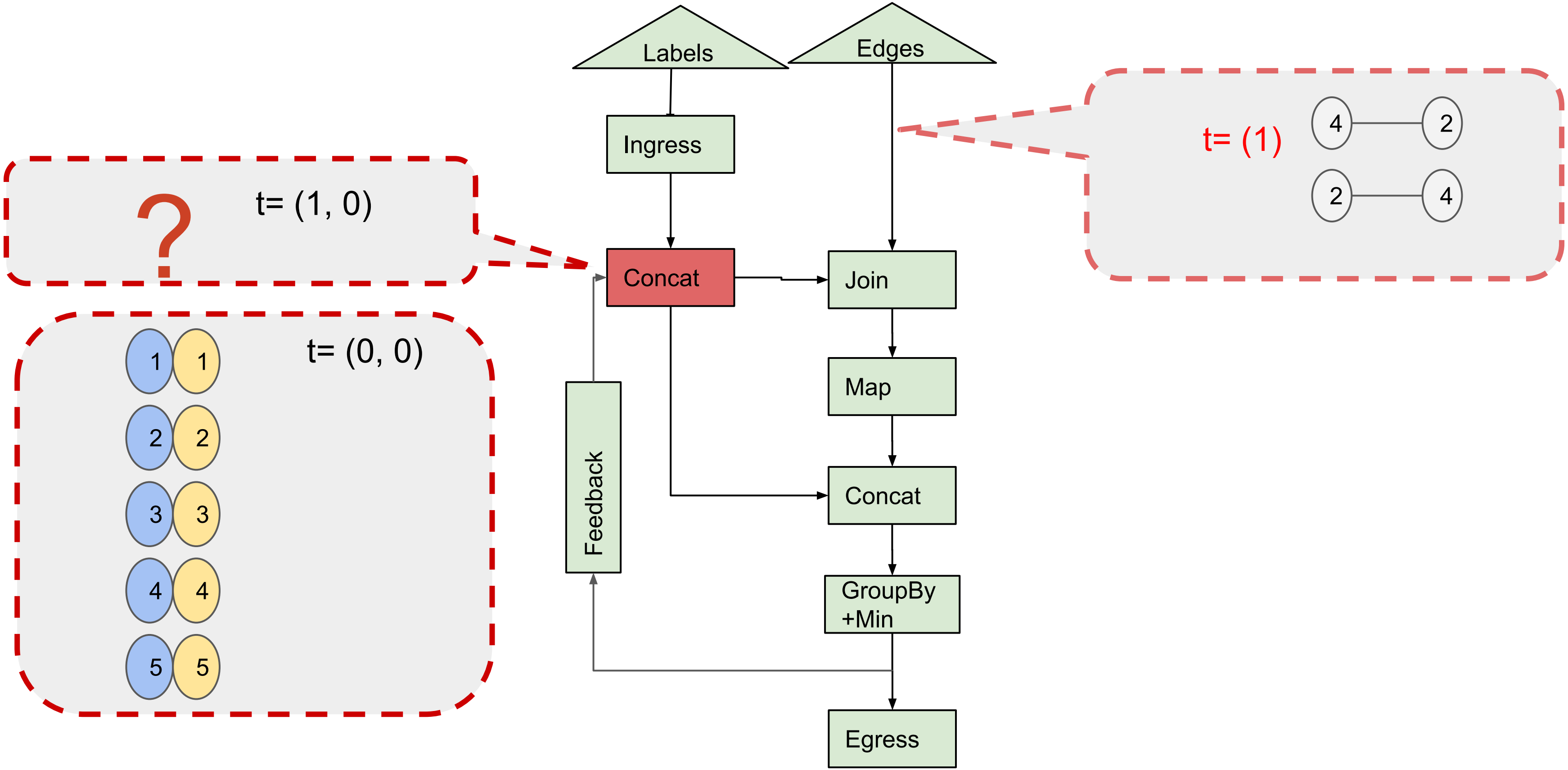

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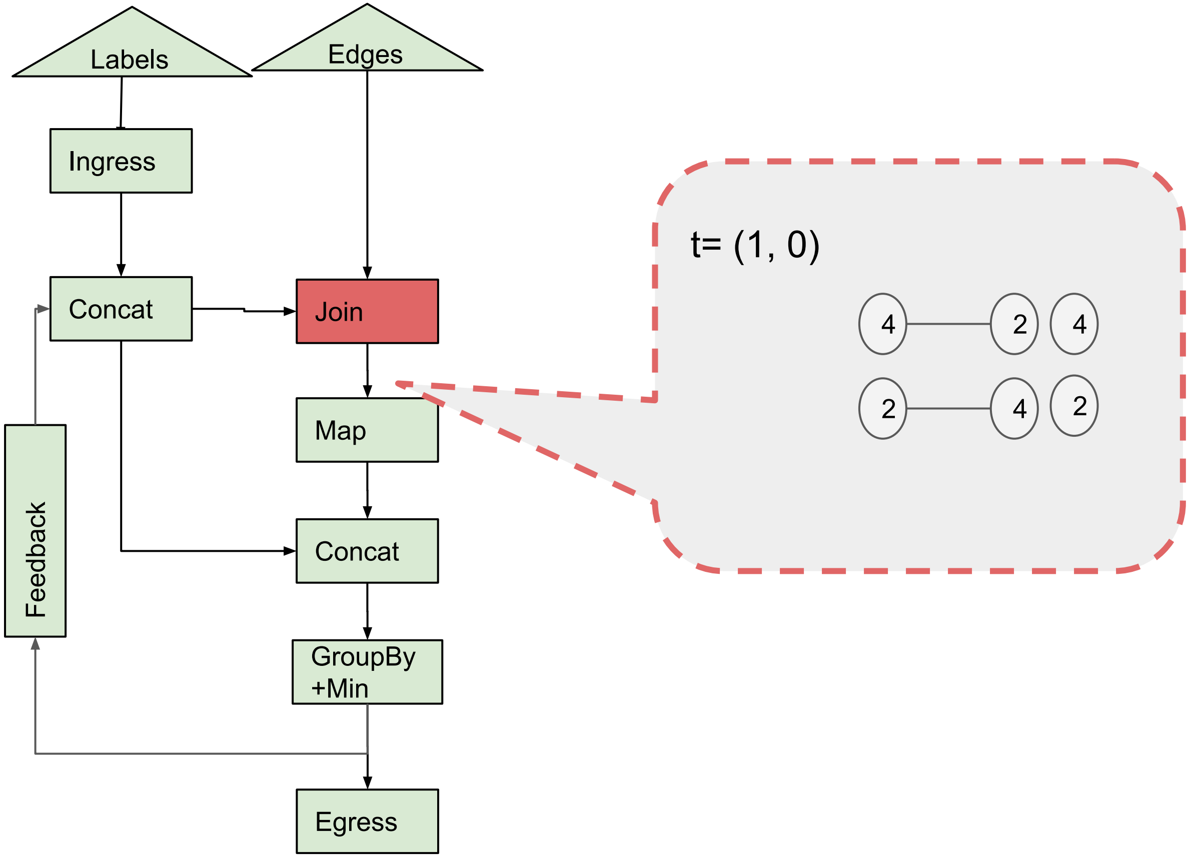

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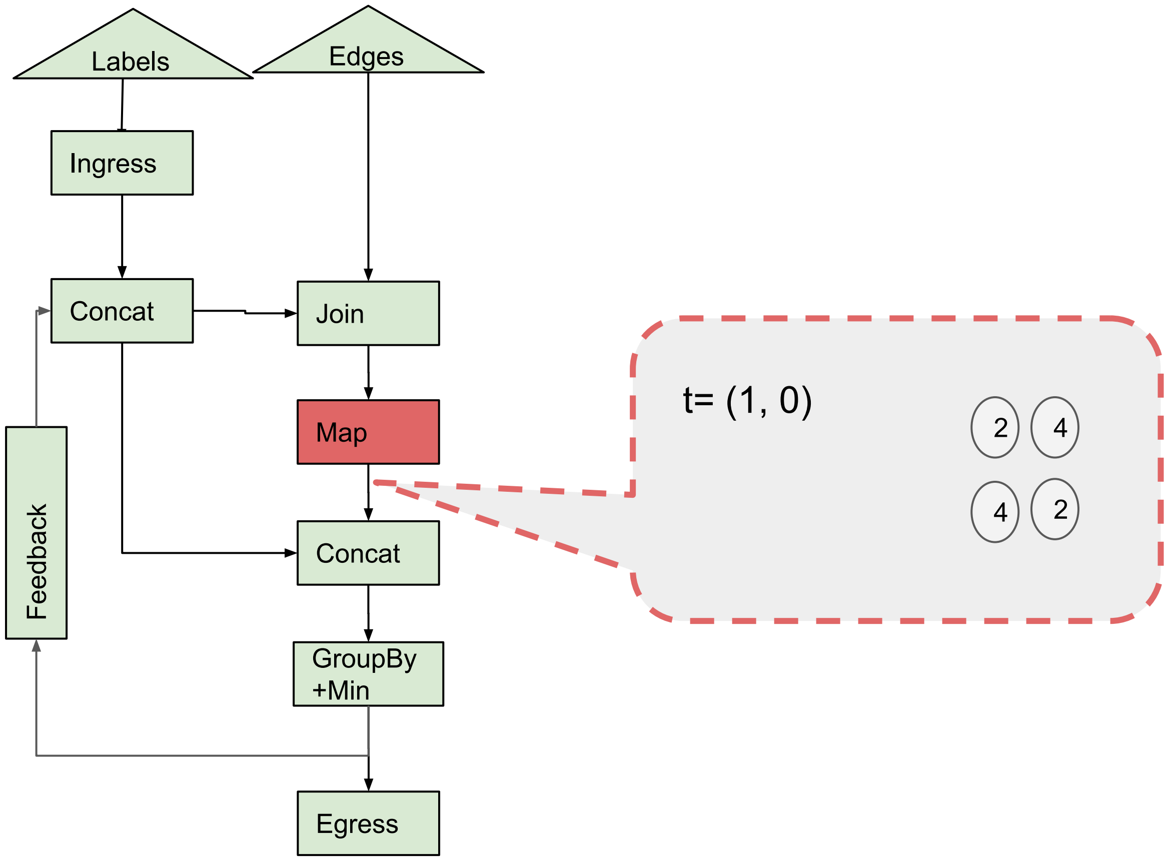

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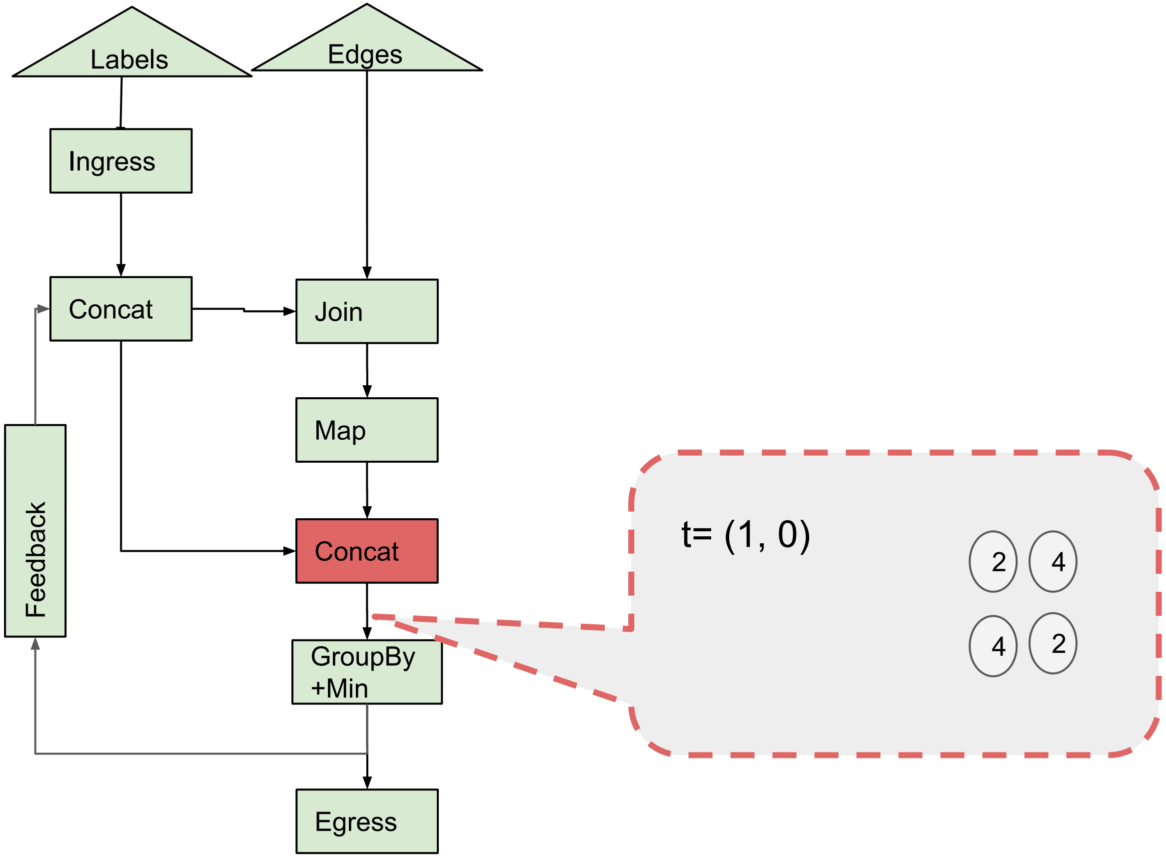

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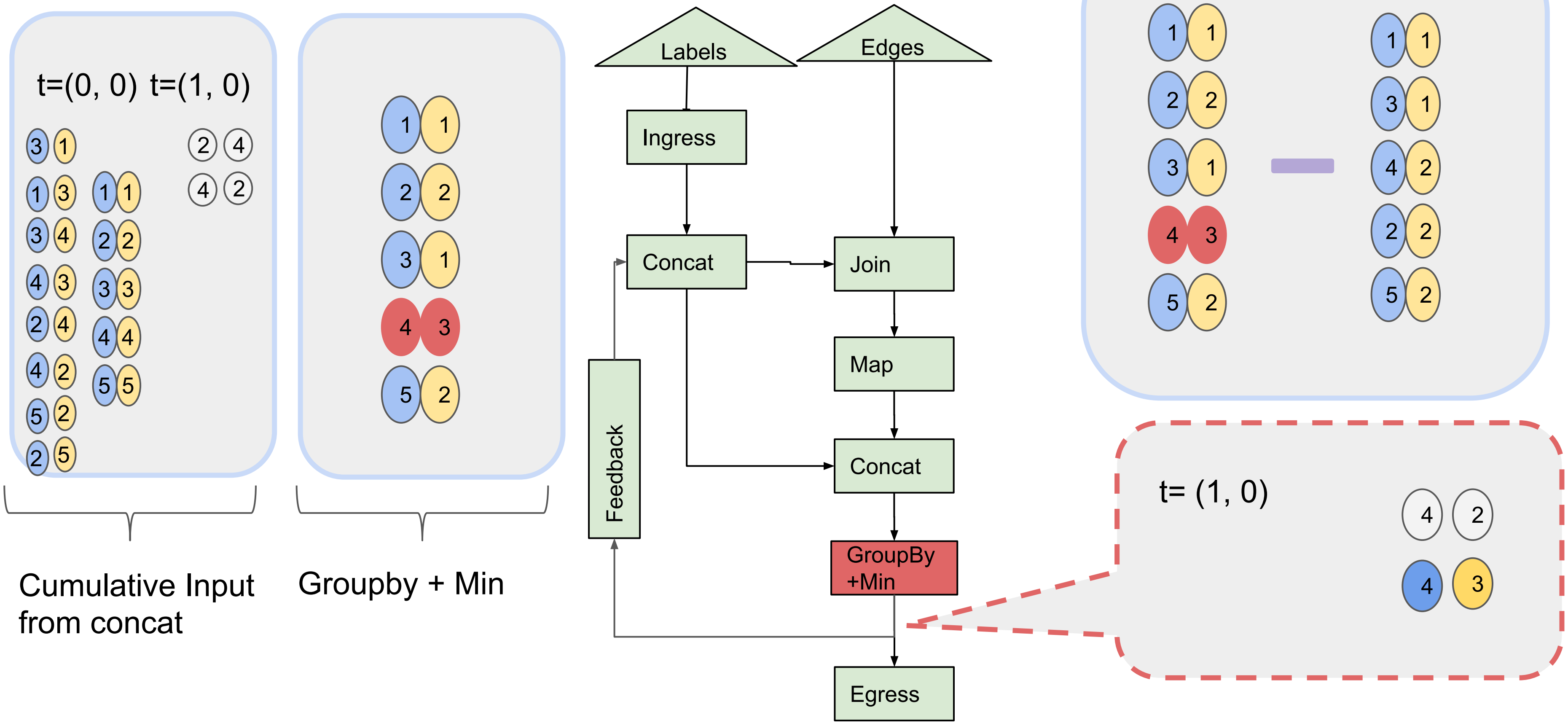

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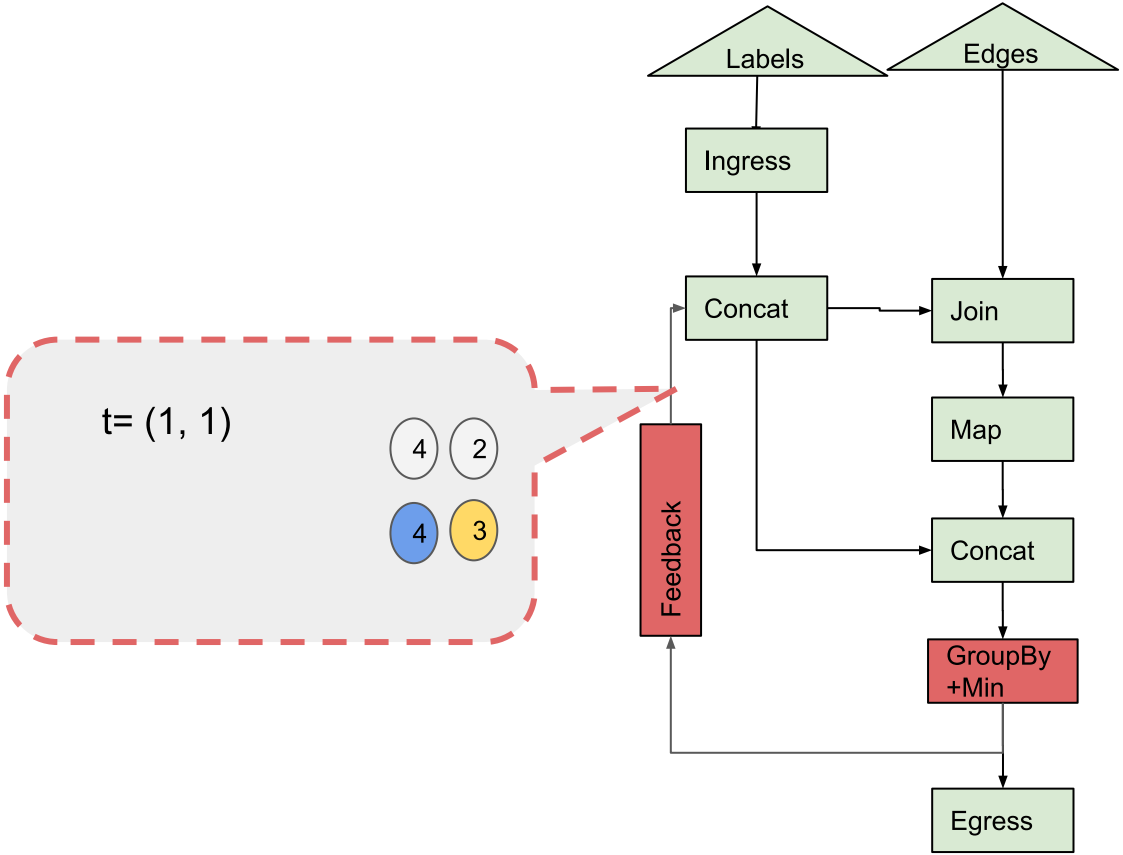

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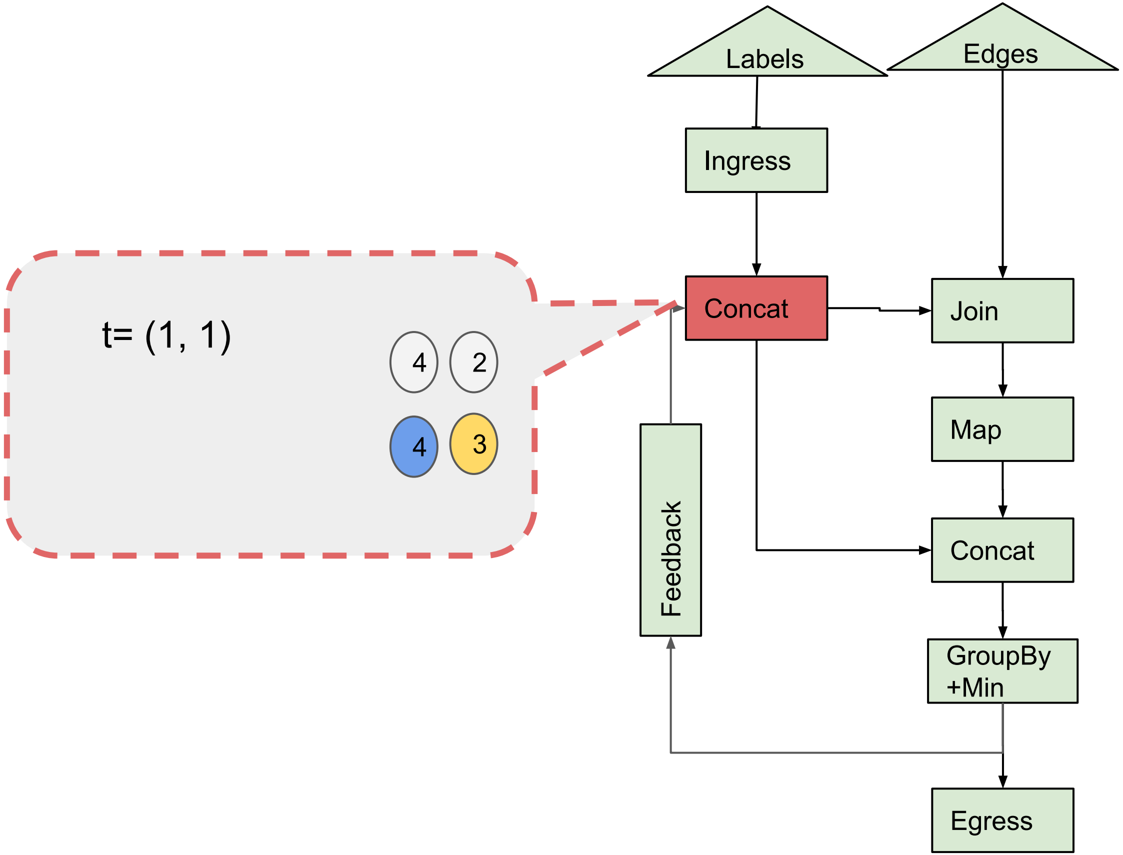

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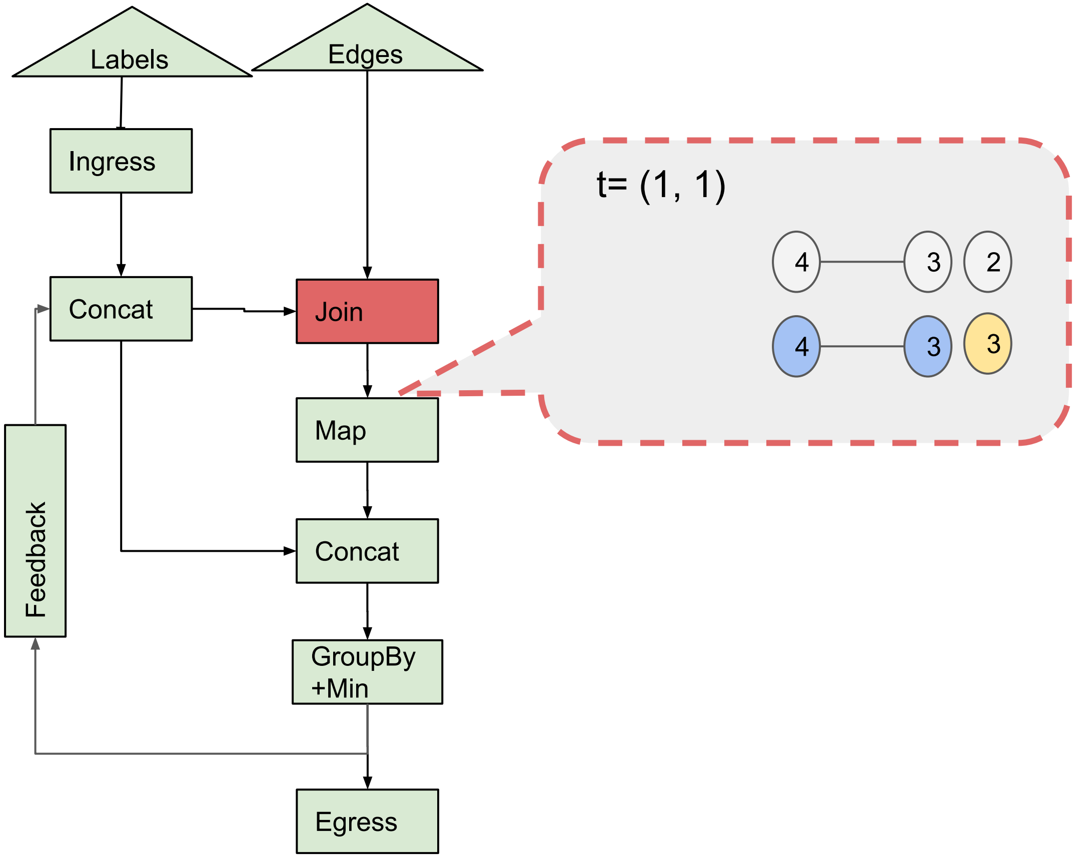

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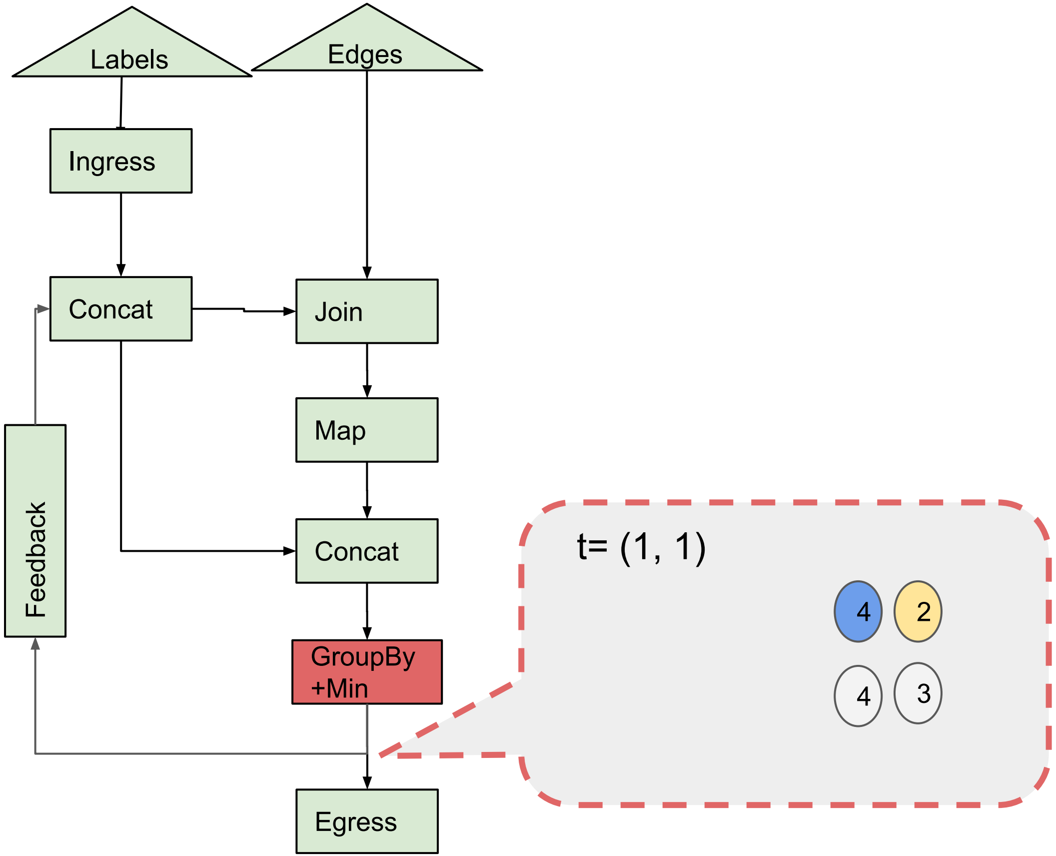

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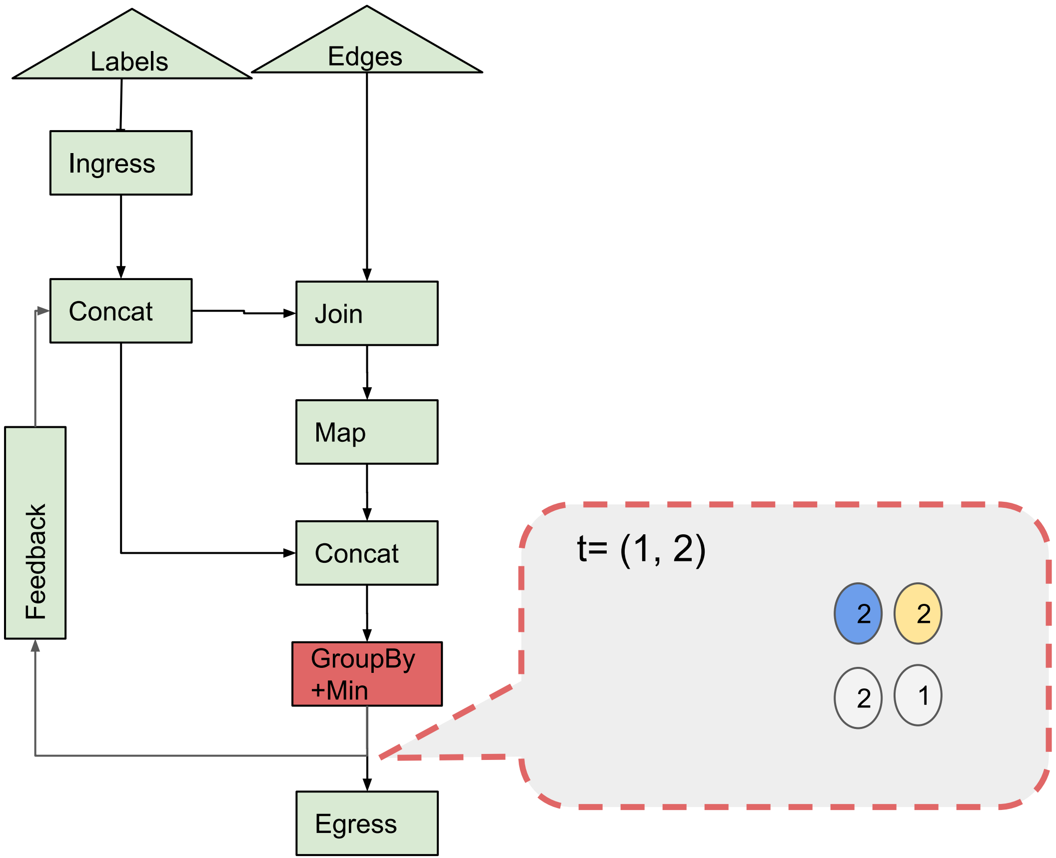
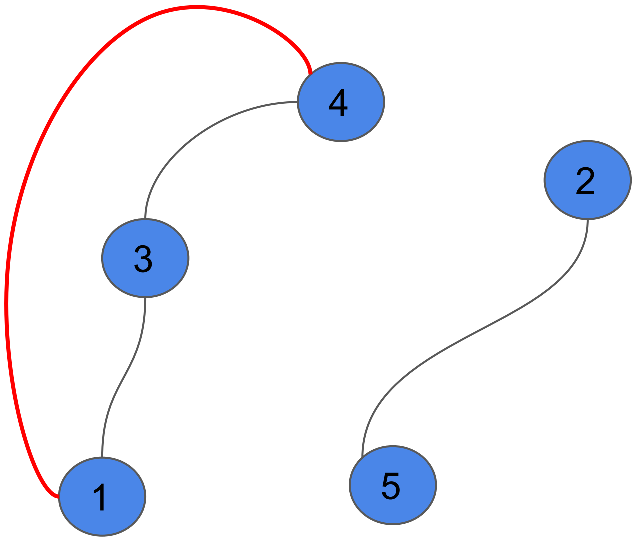


Changes to Connected Graph - II

Add Undirected Edge



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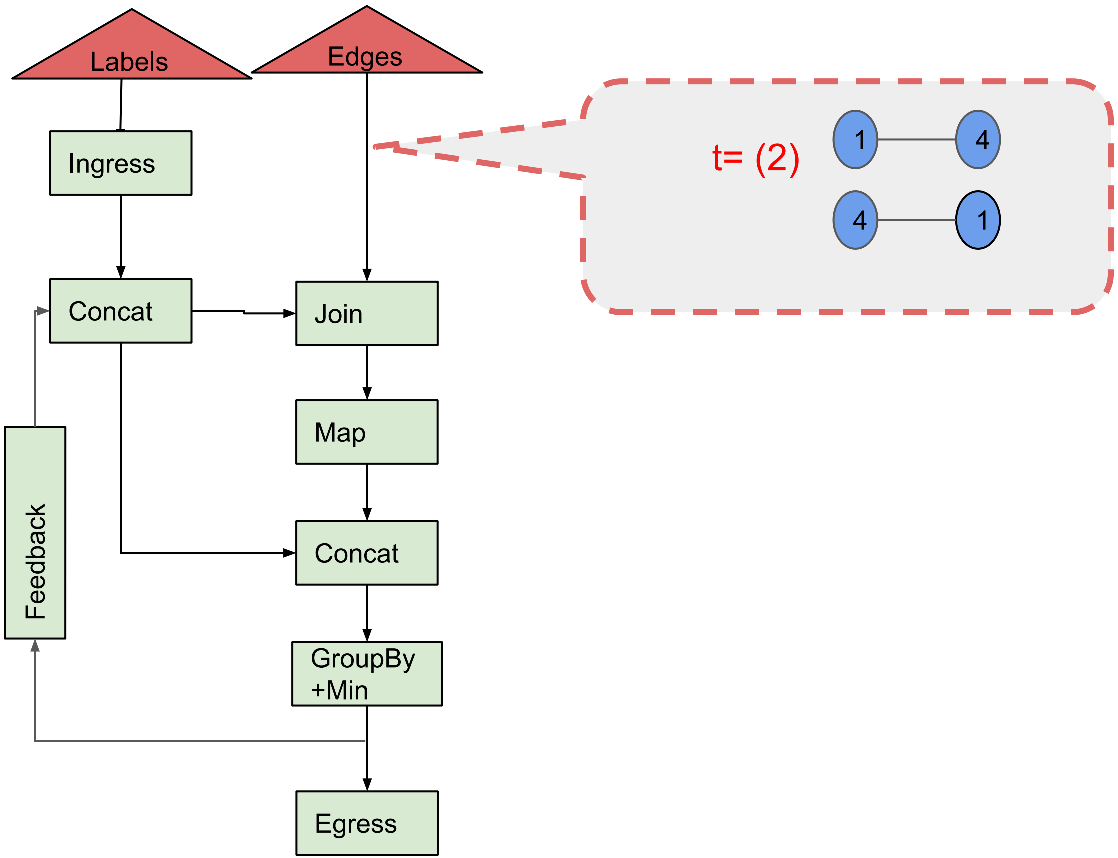

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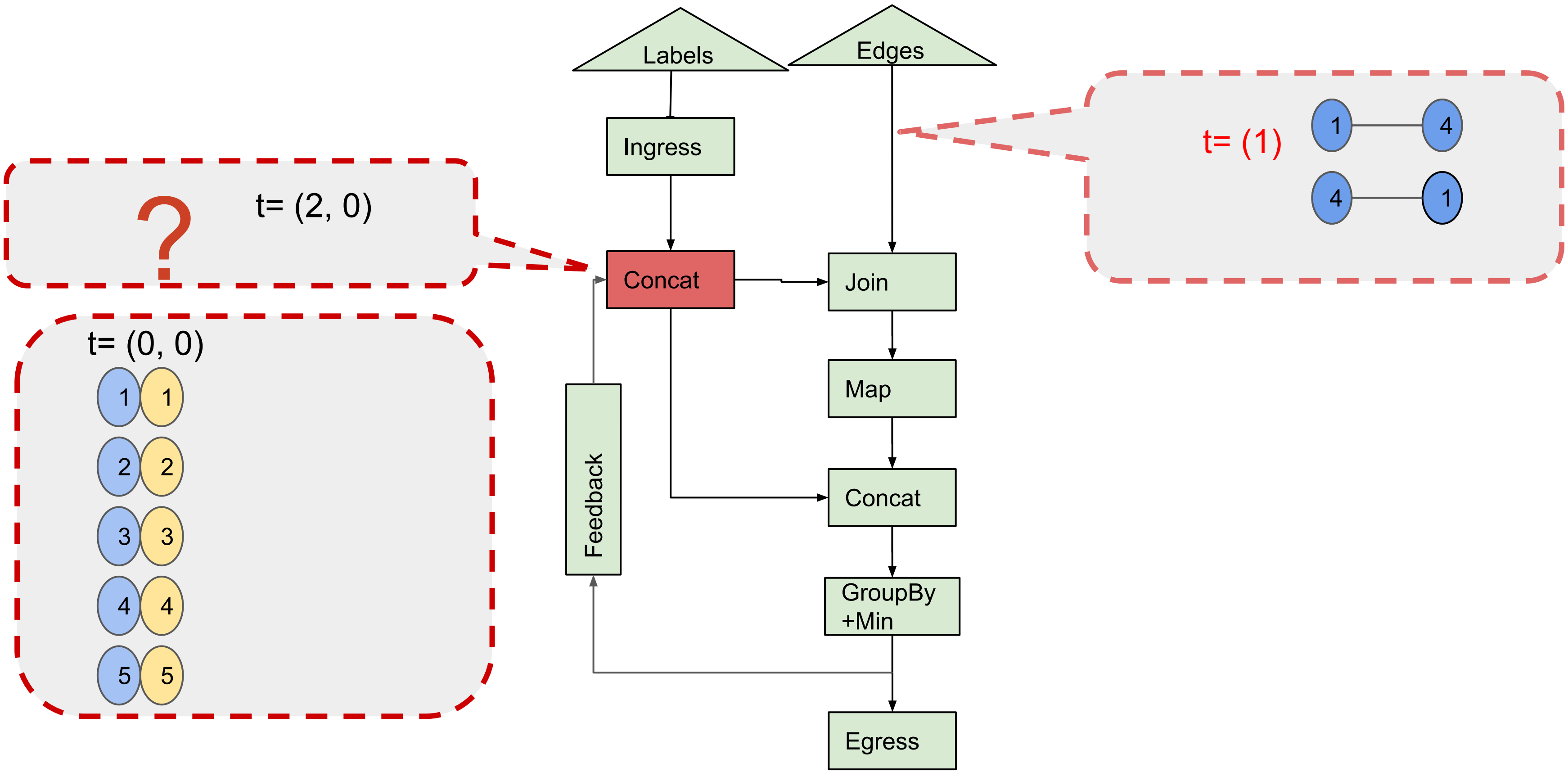

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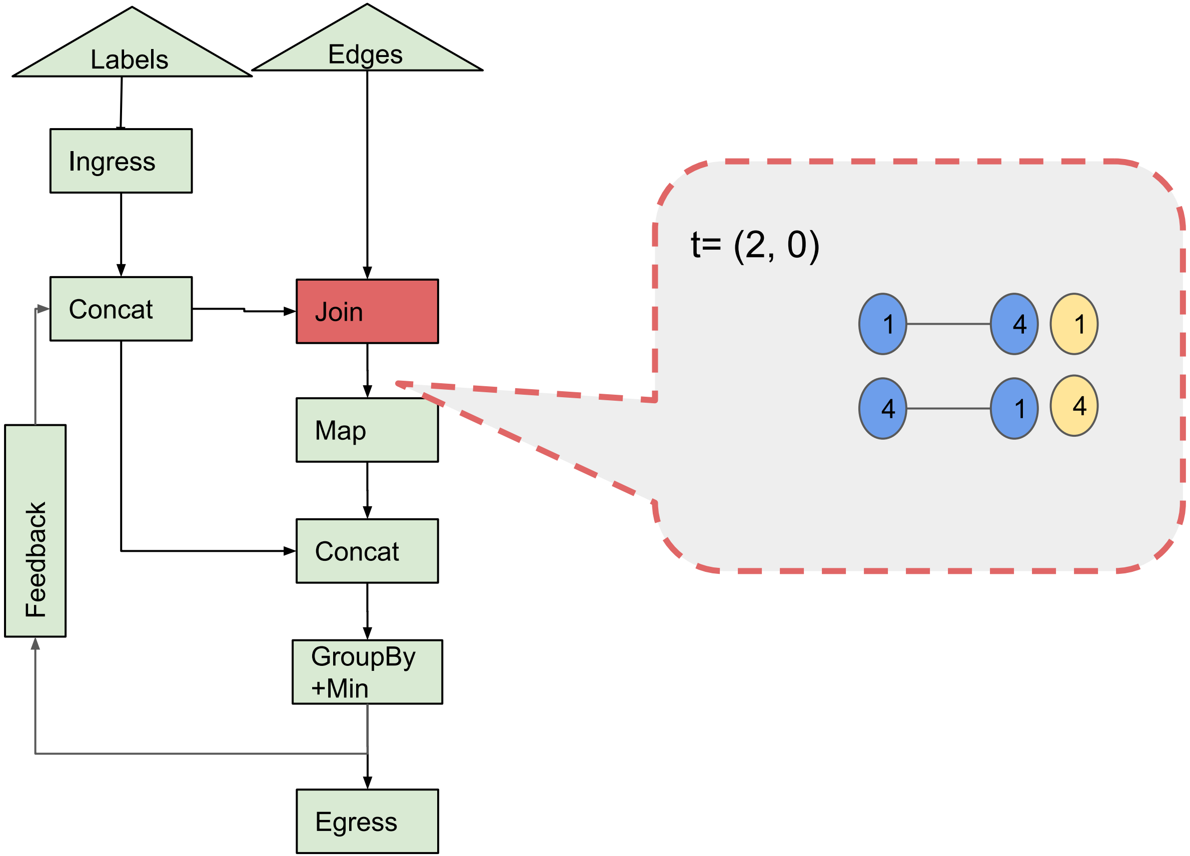

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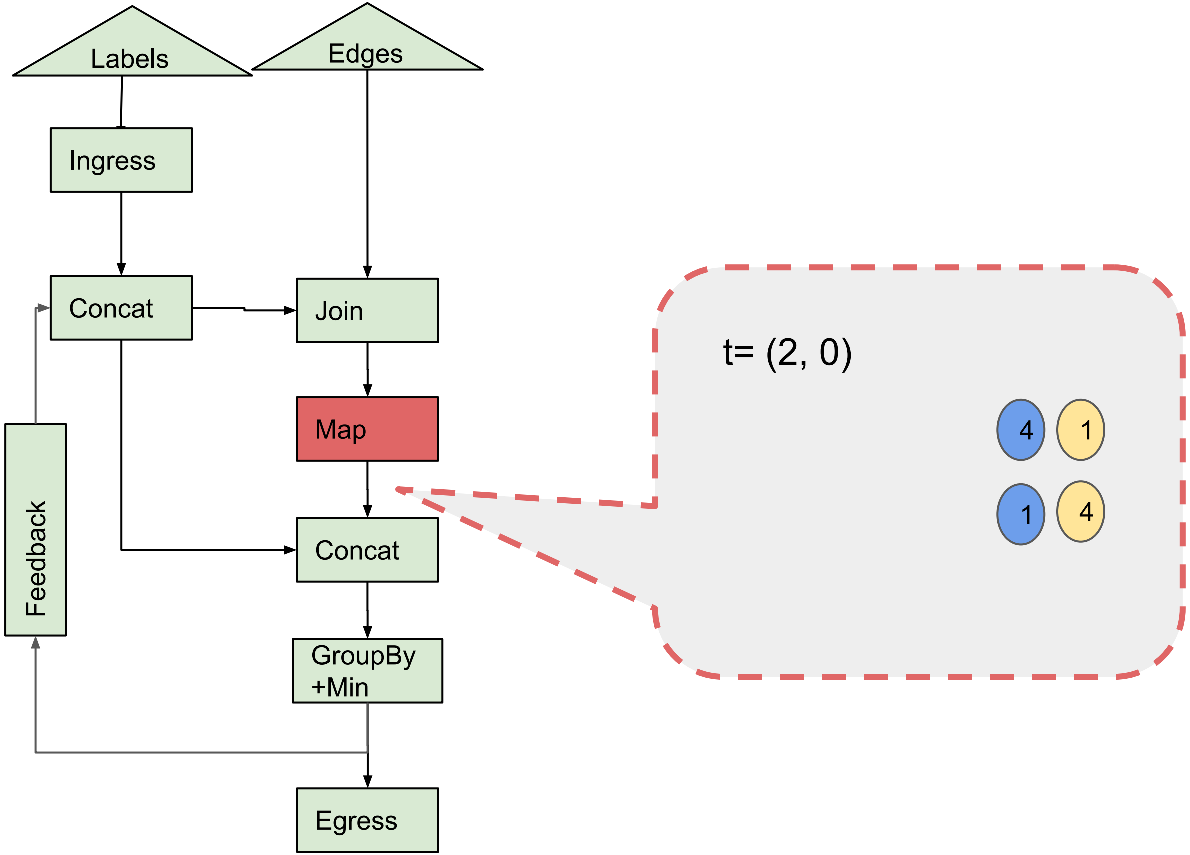
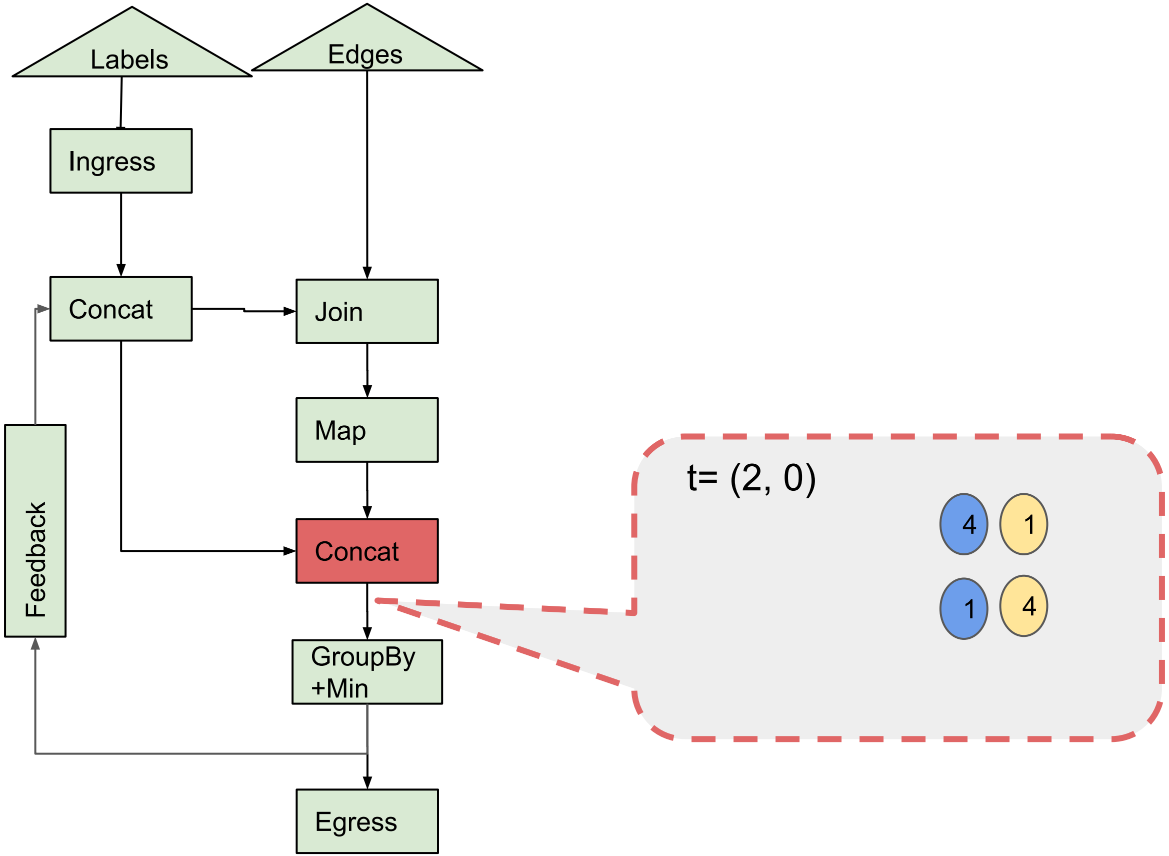


Changes to Connected Graph - II



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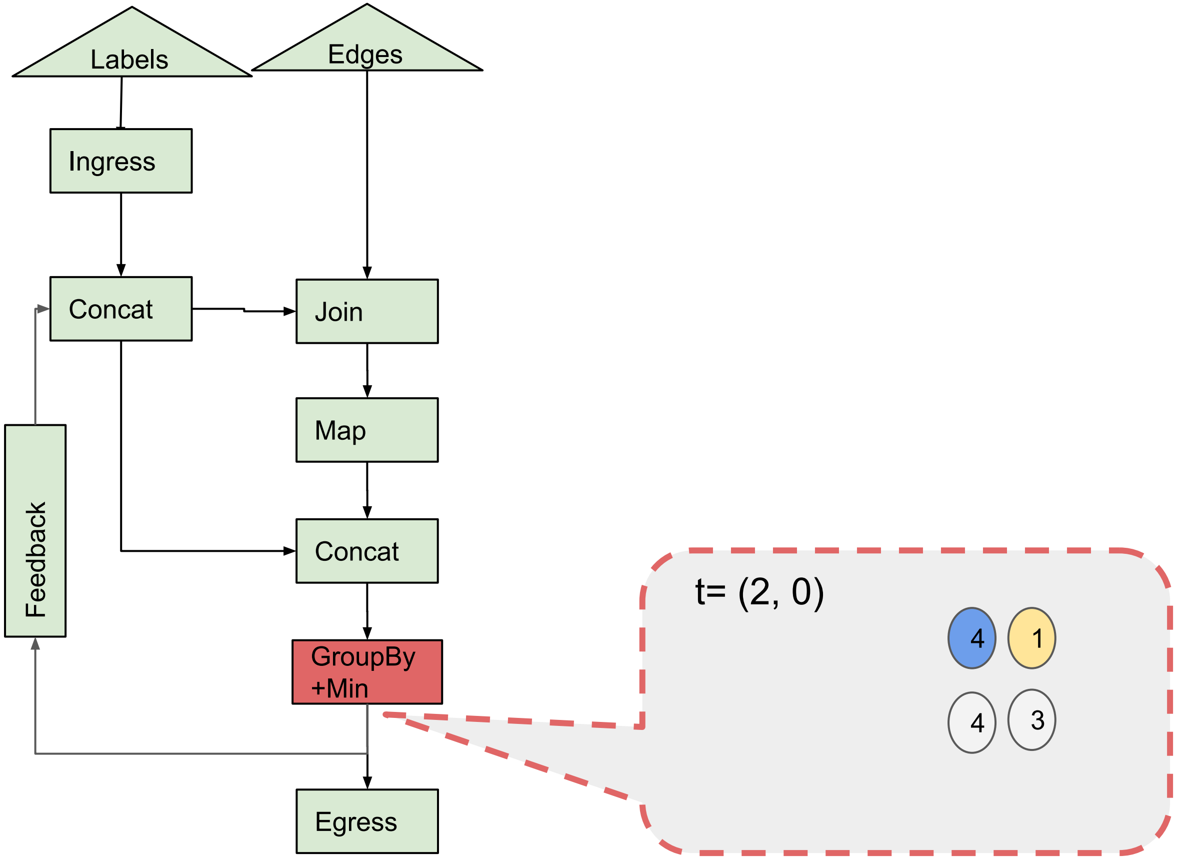

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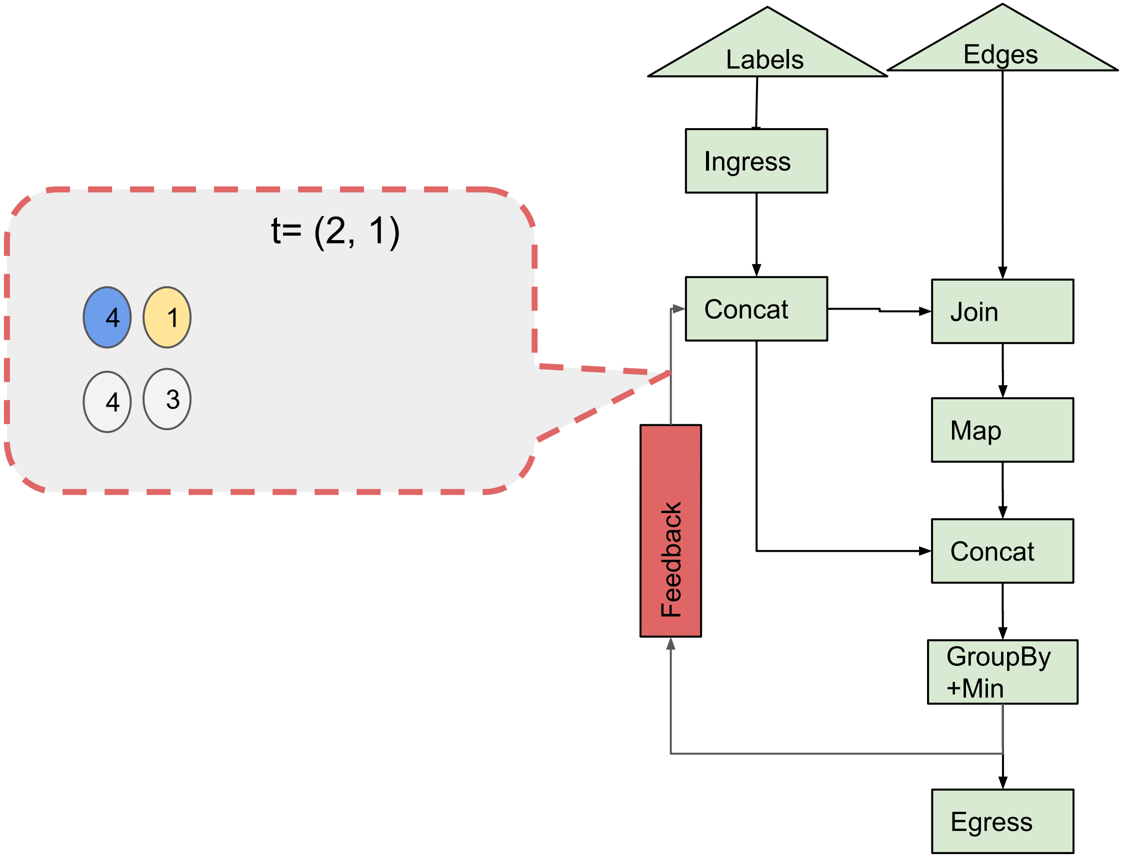

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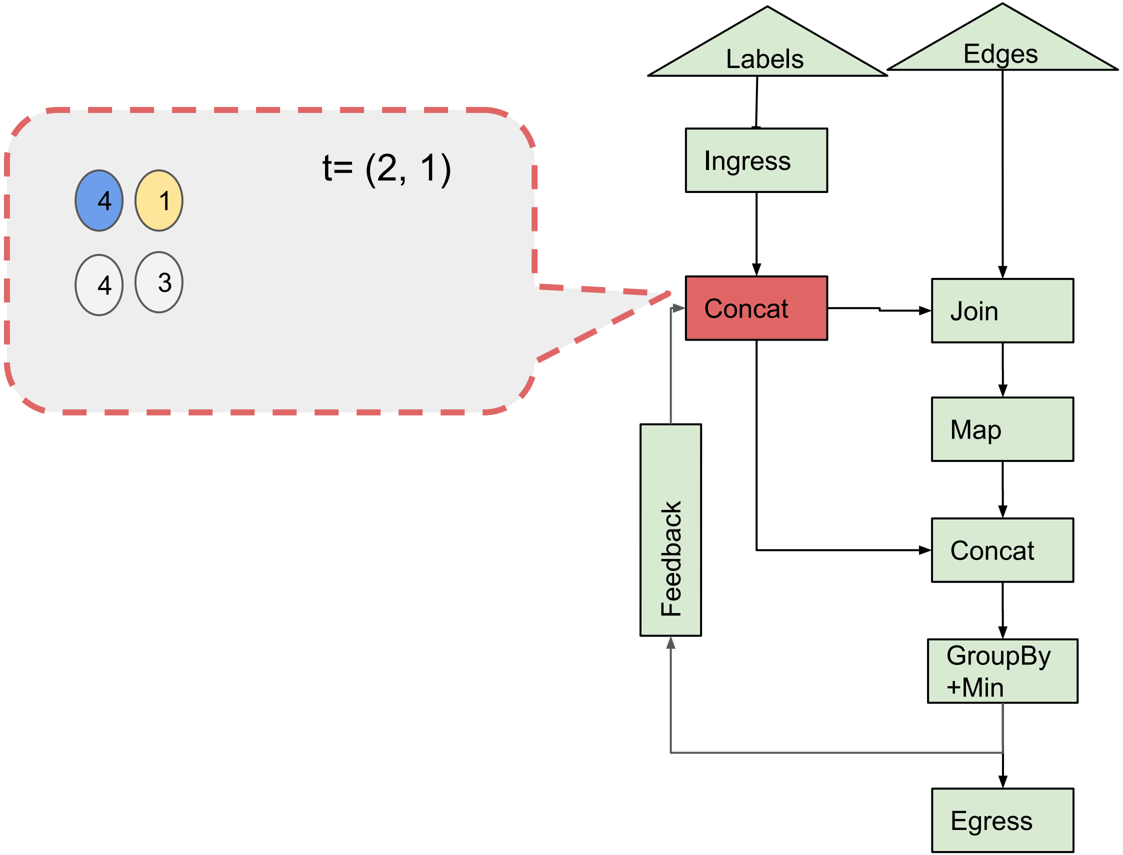

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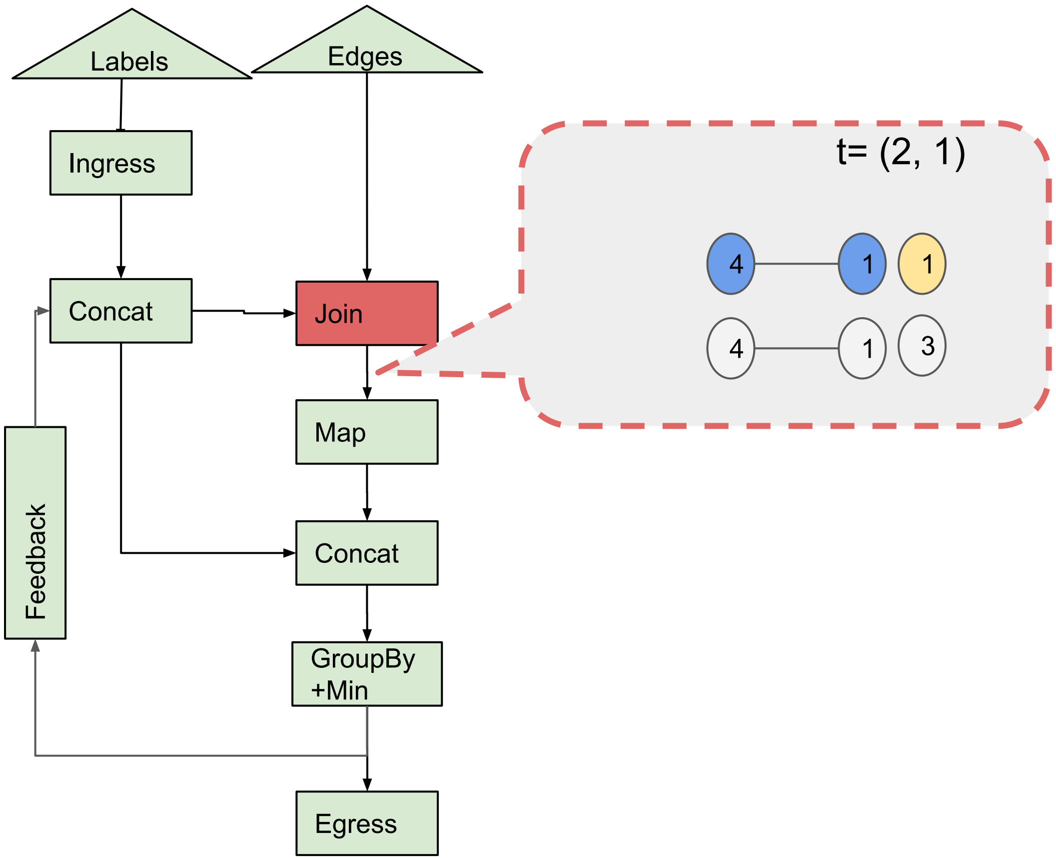

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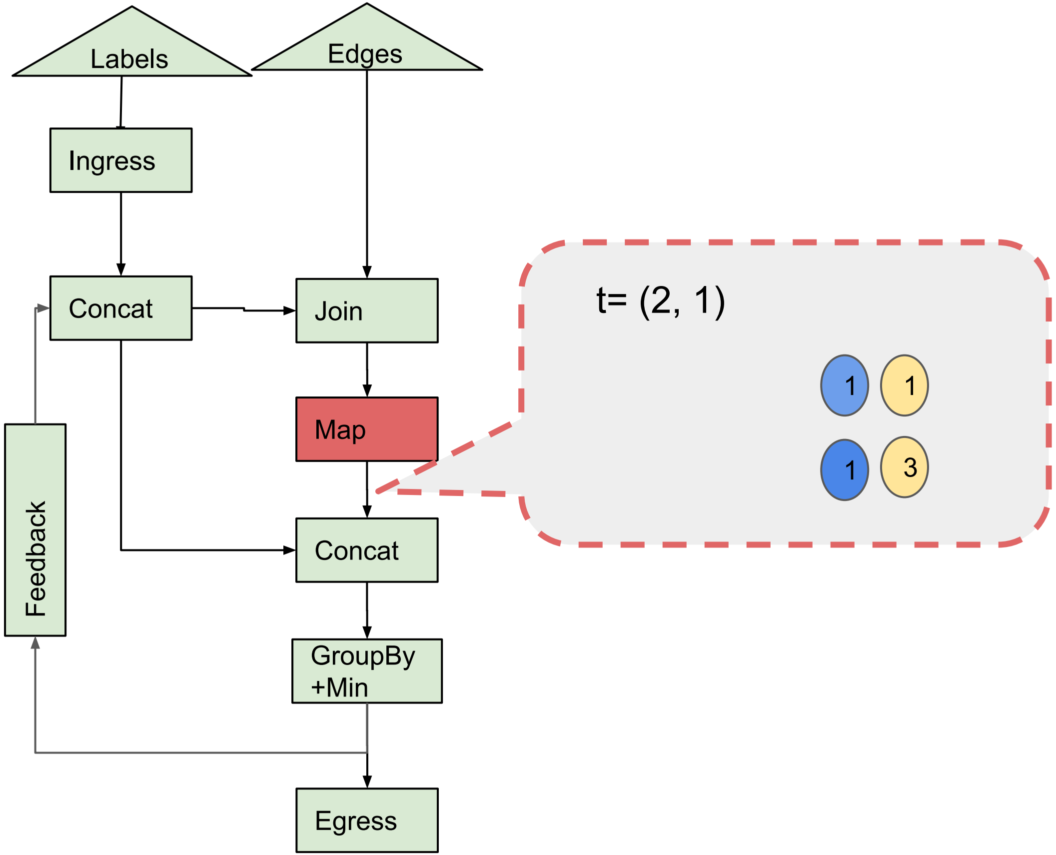
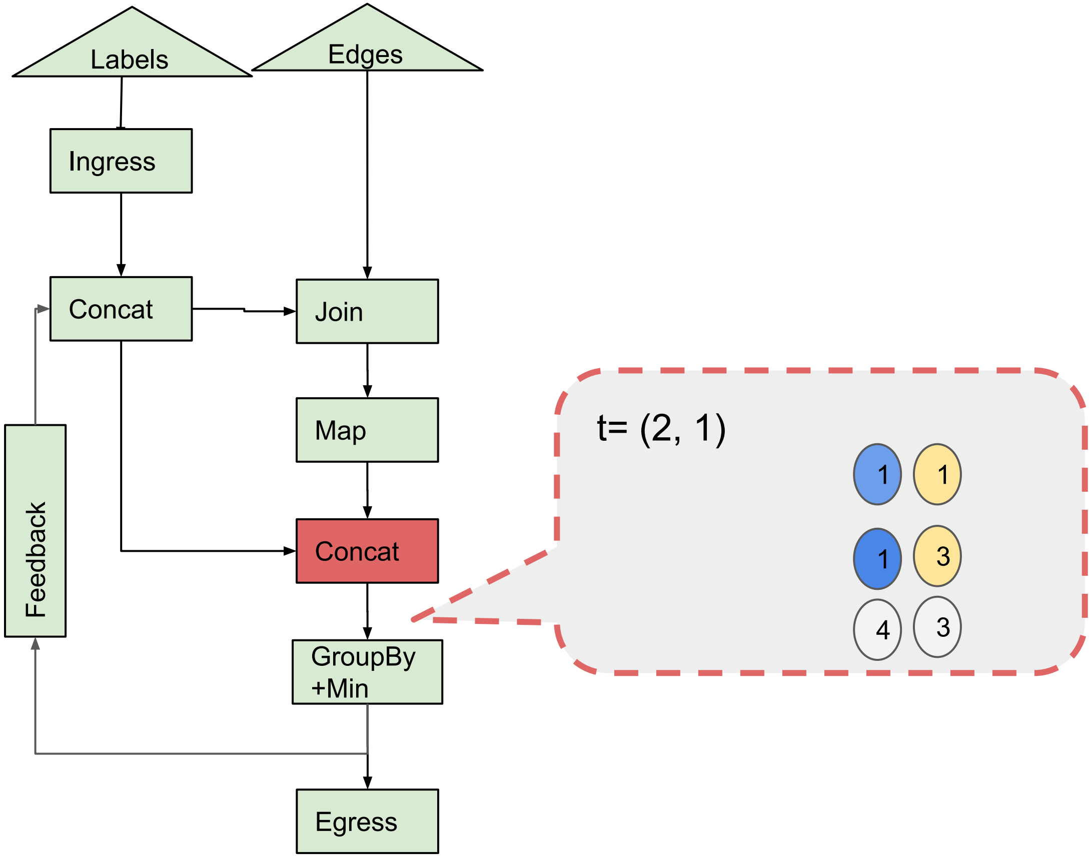
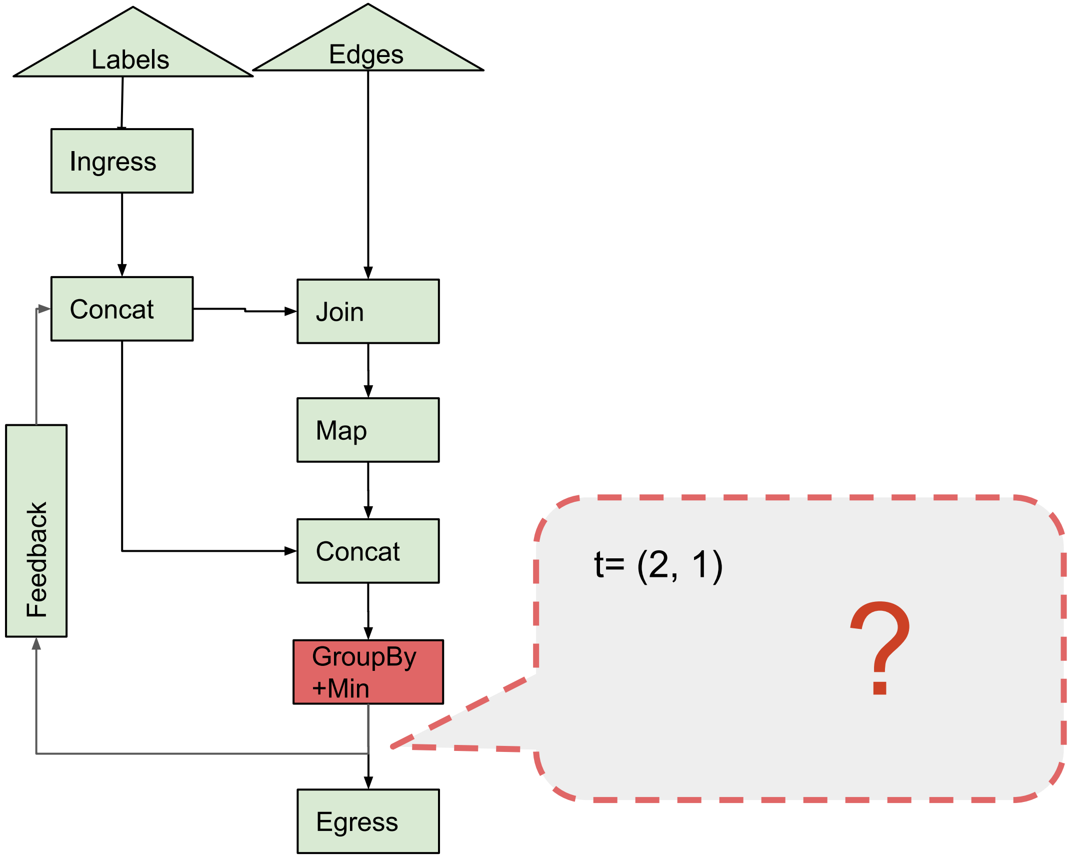


Changes to Connected Graph - II



Changes to Connected Graph - II



Discussion

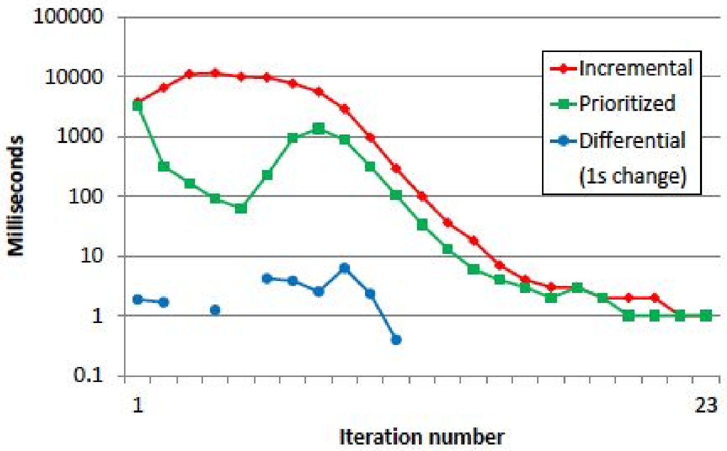
Tradeoffs in Iterative Systems

How do you deal with new data when you are iterating with old data?

- How much state to keep (Memory)
  - Do you keep all data in memory
  - What about intermediate calculations
  - Incremental View Maintenance
- How much work to do
  - Do everything from the beginning
  - Do work only in the nodes where new data came in

Iterative vs Differential Dataflow

- The flexibility of partial Ordering.
  - Iterative Ordering - $(i_1, j_1) \leq (i_2, j_2)$ iff $i_1 \leq i_2$ and $j_1 \leq j_2$.
  - Lexicographic Ordering - $(i_1, j_1) \leq (i_2, j_2)$ if $i_1 < i_2$ or $i_1 = i_2$ and $j_1 \leq j_2$.
  - Programmer can choose the partial ordering.
- Communication via Diffs
  - Only the diffs are sent around as messages
  - Nodes on both sides know the previous calculations



Discussion

- Is the memory for performance tradeoff justified?

Thank You