# COLA: Optimizing Stream Processing Applications Via Graph Partitioning

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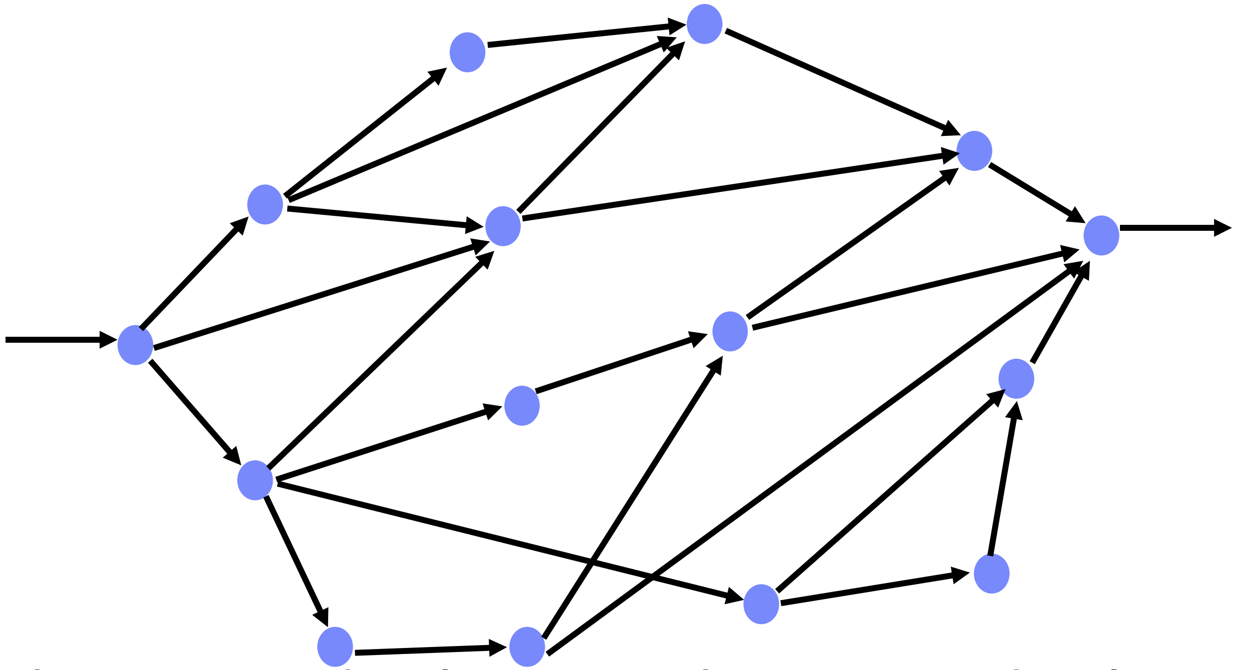
# Streaming application in SPADE

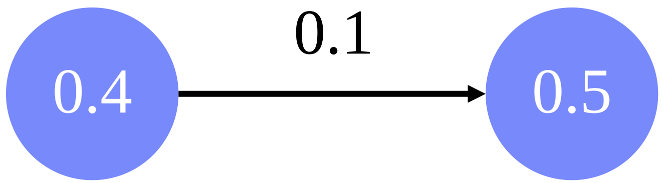


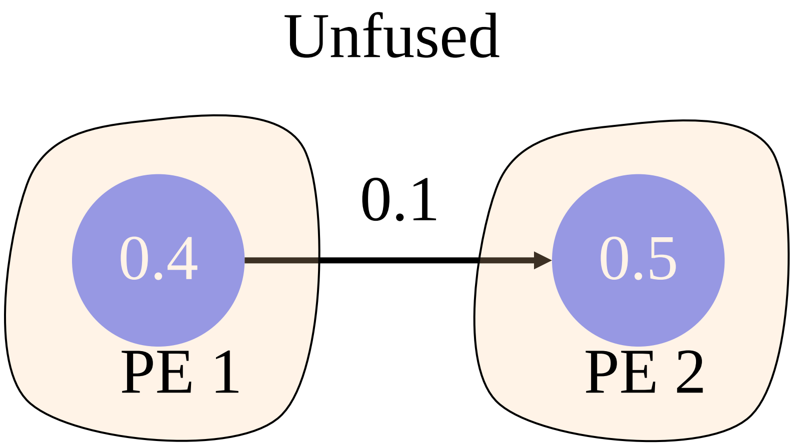
- Input is a stream of tuples, output is a stream of tuples
- May be distributed over many hosts
- Operators perform transformations on the data
- Many operators are quite simple, eg:
  - Drop tuple if $temp_c < 37$
  - $temp_c \rightarrow temp_f = 9/5\ temp_c + 32$

# Simple operators mean high communication cost

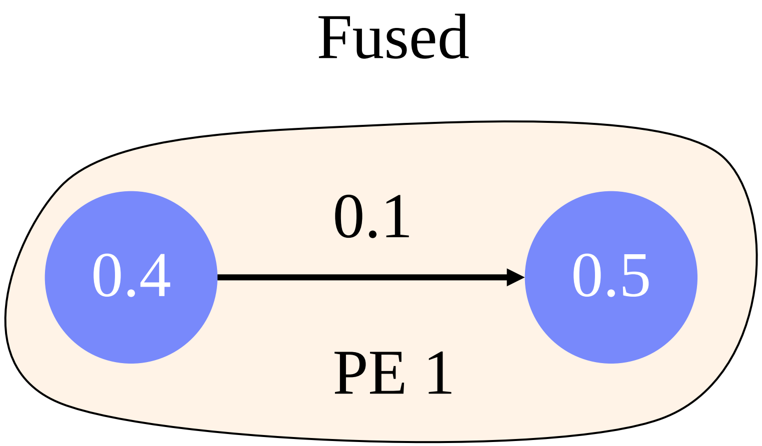
- **Problem: The cost of unpackaging and packaging a tuple can be high relative to the cost of a simple operation**
  - Receiving $temp_c$ and sending $temp_f$ may be greater than computing $temp_f$ from $temp_c$.
  - This is obviously wasteful, and paid many times over can limit the data rate the application can process.
- **Solution: SPADE provides a way to fuse operators into PEs.**
  - The code for them is compiled together, and the operators form a single process.
  - Passing a tuple within a PE is a function call
- **Caveat: Fusing too many operators together means that the resulting PEs runs out of CPU cycles on the node.**

# Fusion example




PE1 has size 0.5
PE2 has size 0.6
Total size: 1.1




Single PE has size 0.9
Total size: 0.9

# Fusing operators: Competing Goals

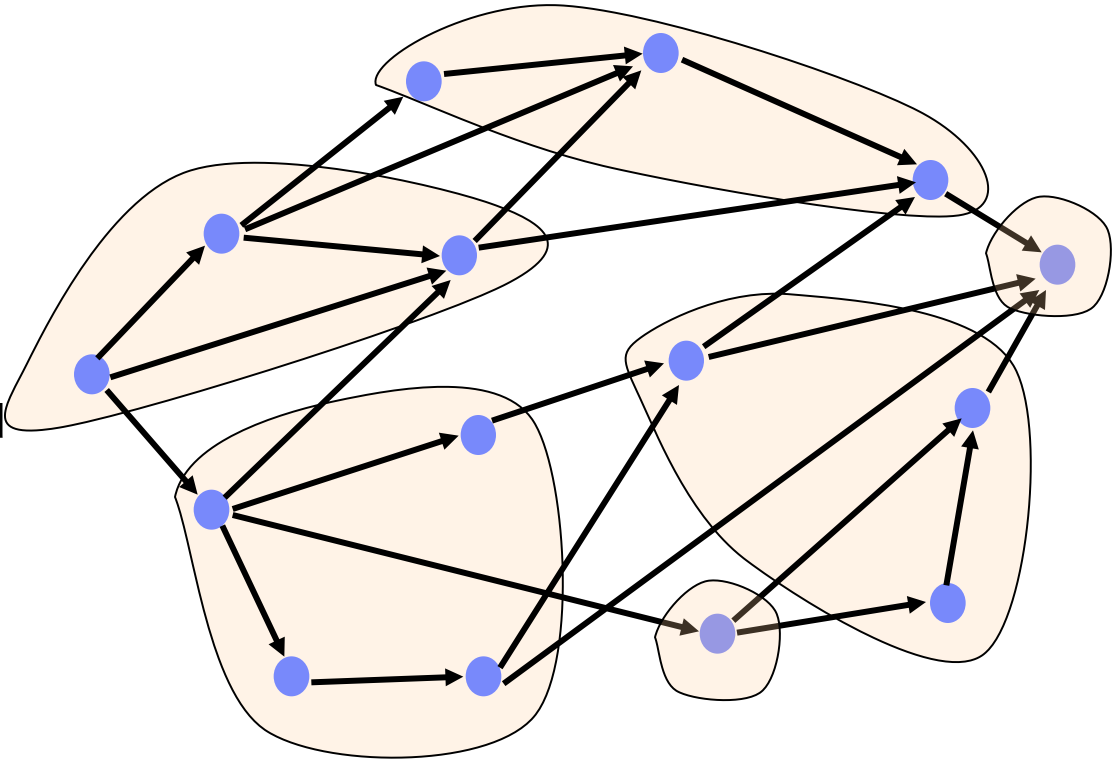
- **Lower communication cost**
  - Best: Fuse all operators together.
  - Worst: One operator per PE.
- **Ensure that no piece is too large (and provide scheduler flexibility)**
  - Best: One operator per PE.
  - Worst: Fuse all operators together.
- **Our algorithm: Fuses operators to lower communication cost while keeping the pieces small enough to allow for good scheduling.**

# Outline

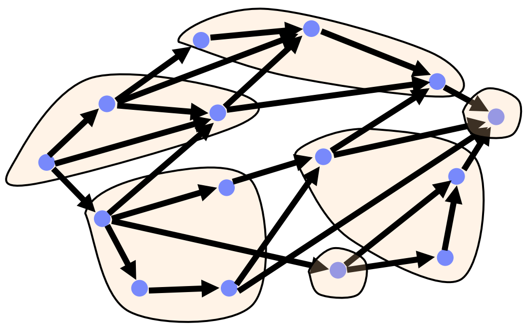
- Our algorithmic approach
  - **Graph Partitioner**
  - **Oracle**
- Additional fusion constraints handled
- Experimental results
- NOTE: Talk presents simplified algorithm, please see paper for more detailed scheme

# The SPADE fusion problem, mathematically

- **Input:**
  - Directed graph
  - Vertices: operators
    - Weights = CPU fractions
  - Arcs: streams
    - Weights = CPU fraction needed for packaging and unpackaging tuples (communication cost)
- **Output:** A fusion of operators into clusters (PEs).

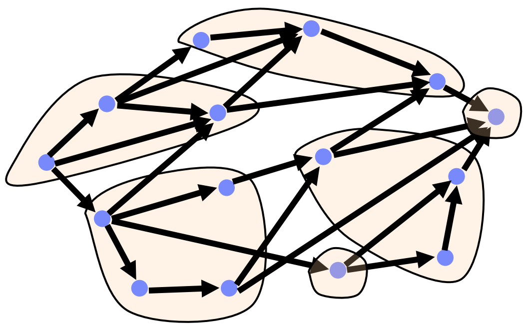


# The SPADE fusion problem



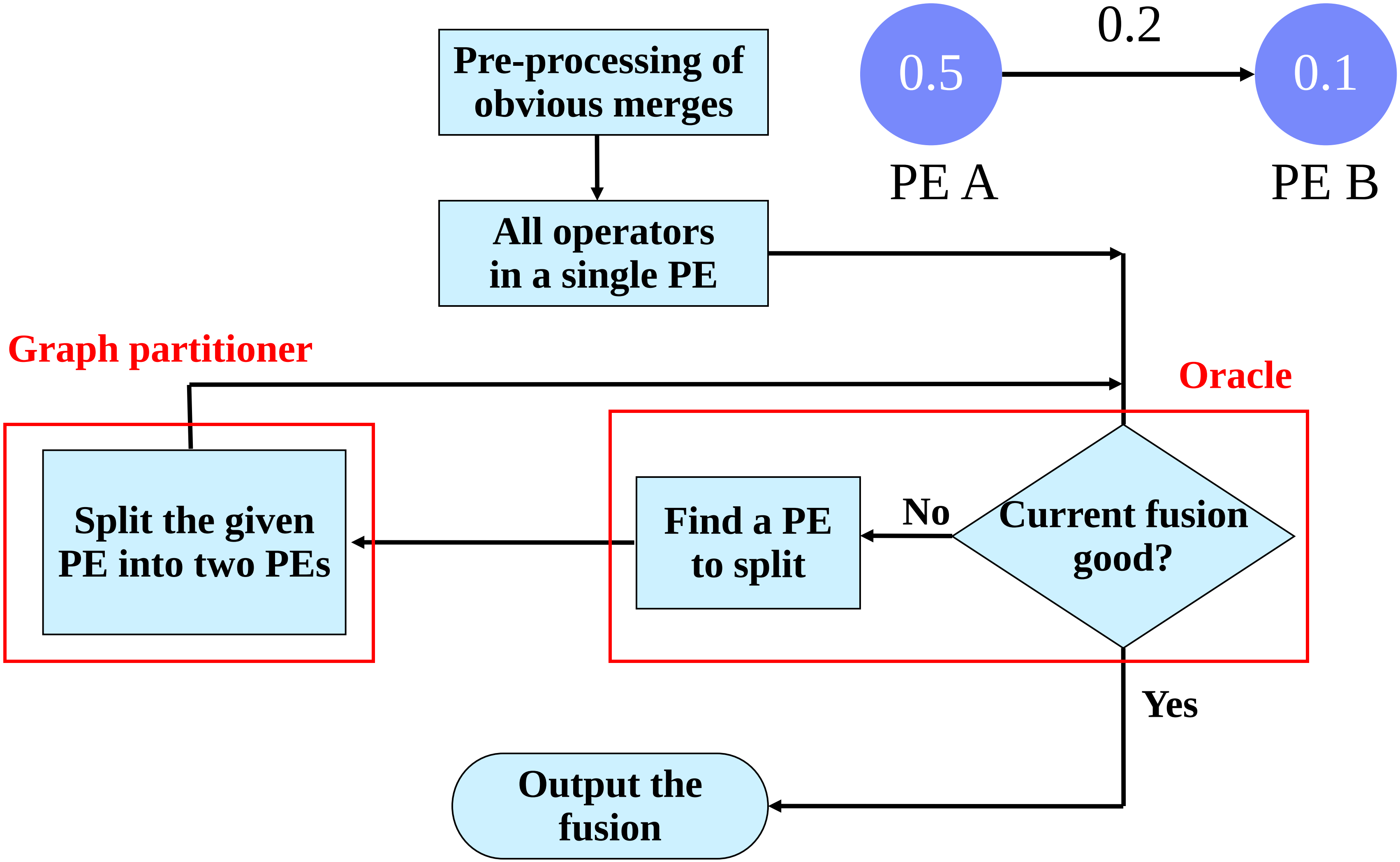
- **Objective**
  – Maximize the throughput when deployed
- **Surrogate objective**
  – Minimize the communication cost between PEs
- **Constraints**
  – Size of any PE (= total operator cost inside + total communication cost at the boundary) is bounded
  – The PEs fit well onto hosts
  – Several other constraints (later)

# The SPADE fusion problem

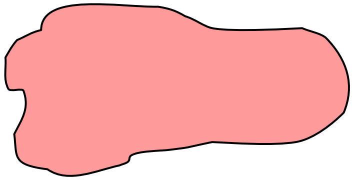


- It is unlikely that efficient algorithms exists to solve the problem optimally (NP-hard)
- Use approximation algorithms or heuristics to find near-optimal solutions quickly

# Our approach: Outline



# Binary Tree



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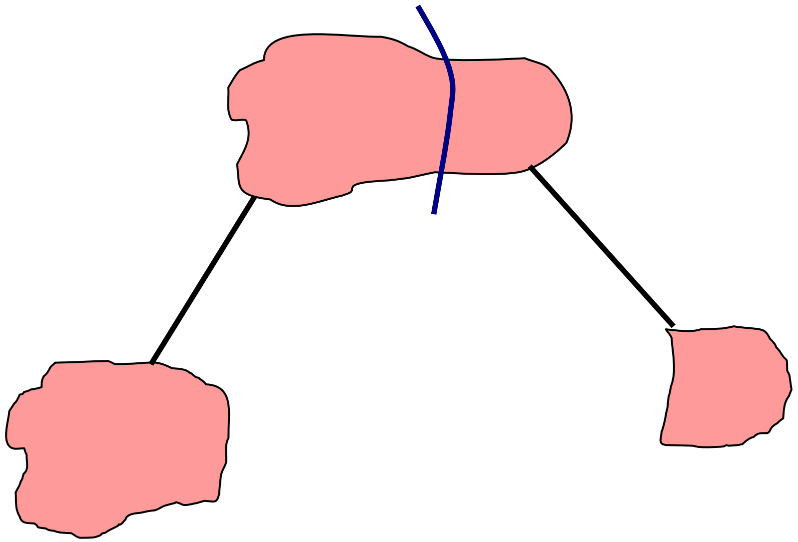

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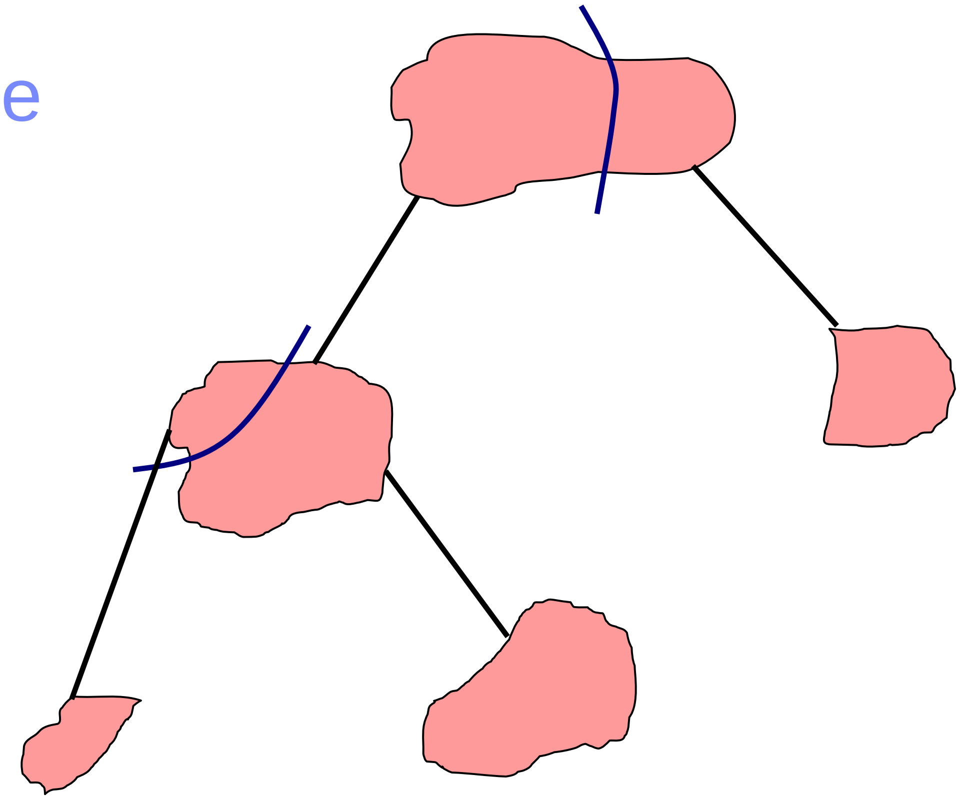

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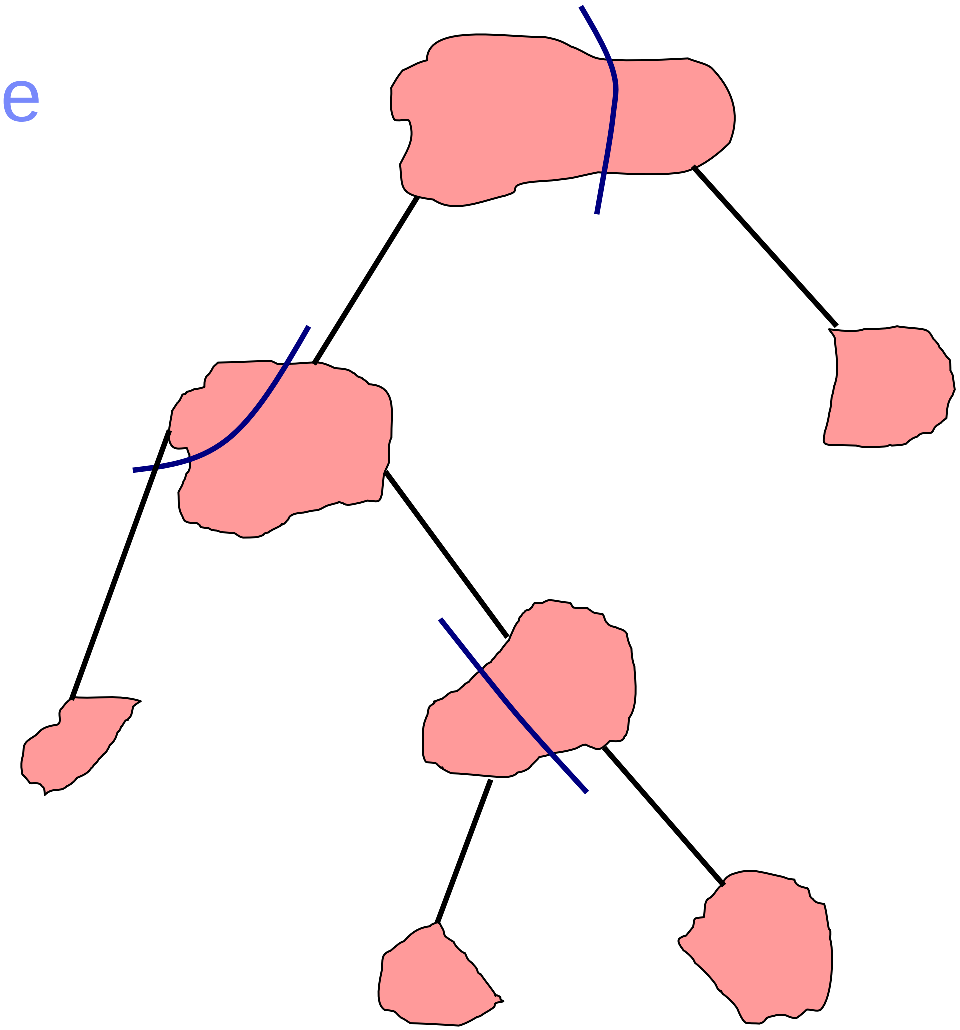

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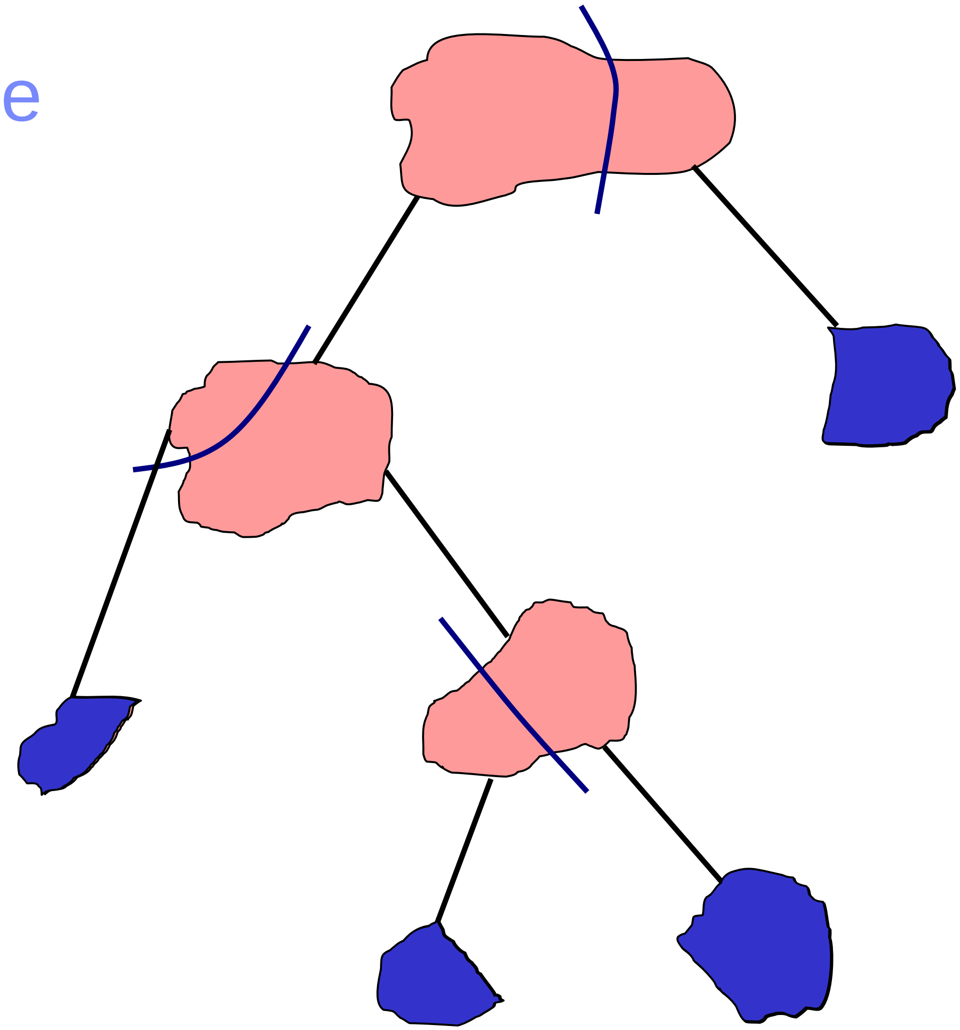
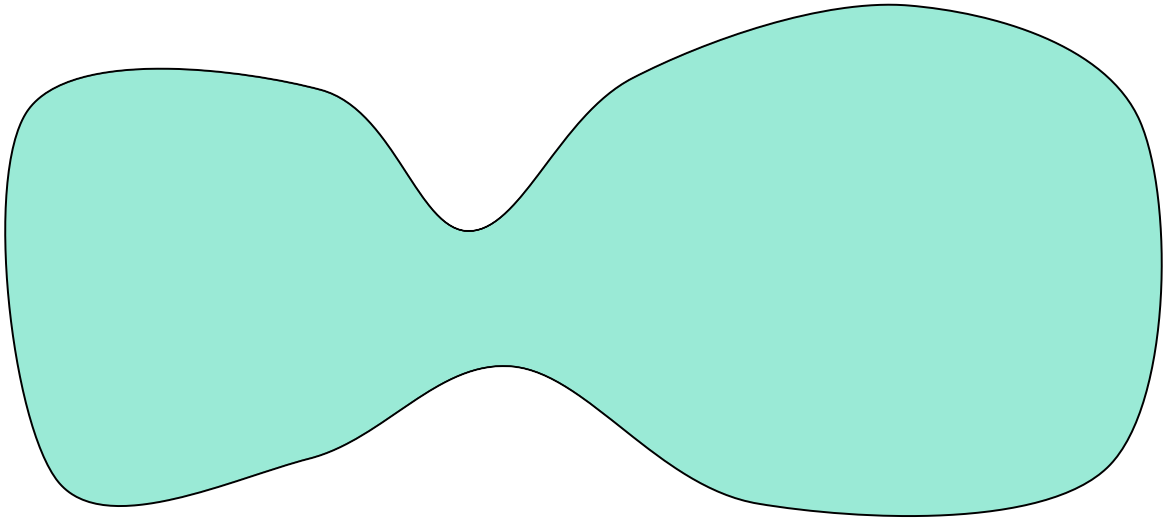


A fusion corresponds to a frontier in this binary tree.

# Graph Partitioner: The intuition



- Think of the operator graph as a system of pipes (arcs) capable of carrying a flow between operators.
- An LP Leighton and Rao [1988] sends a unit flow between every pair of operators.
- The congested arcs (full pipes) correspond to a bottleneck that sends a lot of flow from one side to the other.

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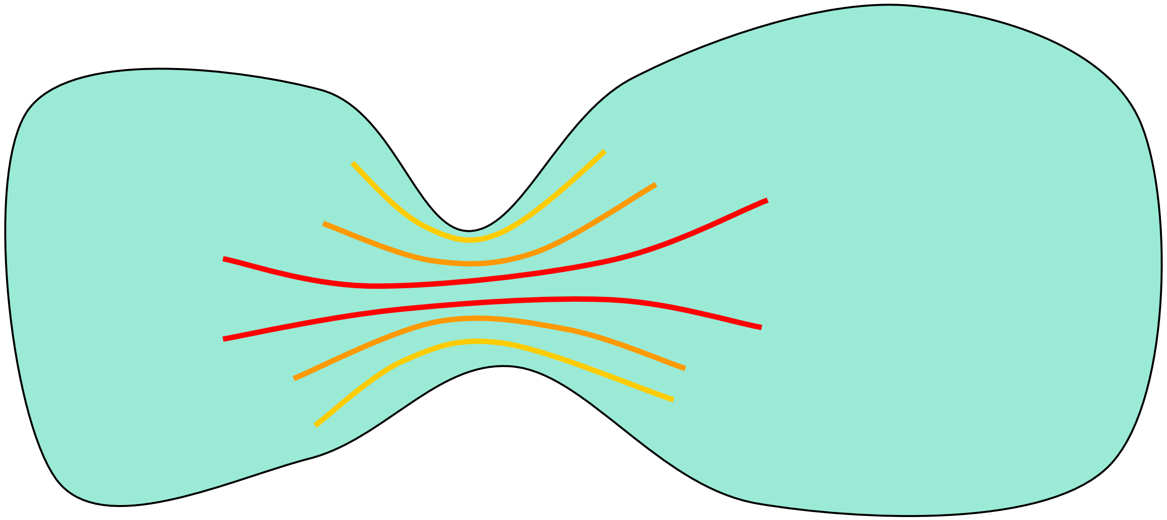

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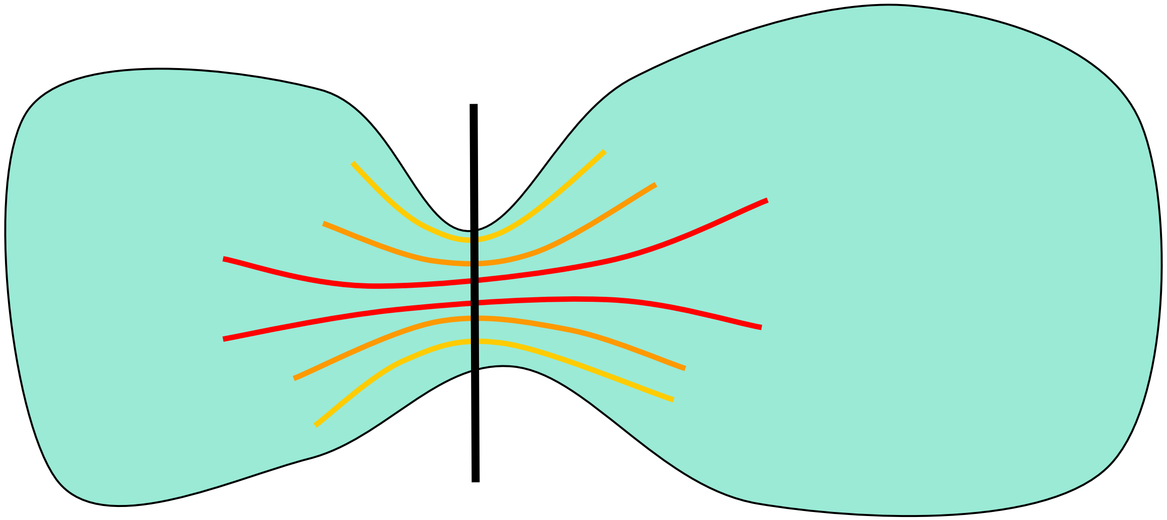

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# Graph Partitioner

- Problem: Leighton-Rao uses a linear program with $n^2$ variables and constraints.
  - **Even with n = 1000, the LP has 1 million variables/constraints. This is too large for CPLEX (state-of-the-art LP solver) to handle.**
- Solution: We implement an approximation algorithm due to [Garg and Könemann 98] to solve this LP.
  - **An LP with a million variables can be solved in less than a second.**

# COLA Oracle

- Role Given a fusion, determine if it is good enough. If not, find a PE to split next.
- Objectives
  - Keep the processor loads balanced, and
  - Keep the communication cost low
- Simplest version
  - Use “Longest Processing Time” (LPT) scheme to simulate a scheduler (assign PEs to processors).
  - If the PEs do not fit well, return the largest-size PE to split.
  - Oracle understands that hosts are multicore.
  - (Size of PE is computation cost of operators plus communication cost of incoming and outgoing edges)

# Why simulate a scheduler?

- **Even if all PEs fit individually, they could not fit collectively.**
- **Example:**
  - Consider the case of four PEs taking up 51% of the node
    - Requires four hosts
    - Split one of those PEs, only three hosts are required even if there is an increase in total size
      - More PEs $\rightarrow$ more communication cost $\rightarrow$ total CPU requirement increases
- **For that reason, oracle tries to assign PEs to host, and doesn't just measure their size.**

# COLA Features and Constraints

- **Heterogeneous processors**
- **Resource matching constraints: An operator has a limited set of hosts on which it is permitted**
- **Partition colocation constraints: Two operators must be in same partition**
- **Host colocation constraints: Two operators must be assignable by scheduler to the same host**
- **Partition exlocation constraints: Two operators must be in separate partitions**
- **Host exlocation constraints: Two operators must be assignable by scheduler to separate hosts**
- **High Availability constraints: Ensure that replicated pieces are placed on separate hosts**

# Experimental Results

- **Experimental application is VWAP, a stock market data processing application**
  - Two different versions
  - Varied number of available hosts
- **Compare our strategy (COLA) to**
  - NONE: no fusion
  - FINT: built-in SPADE fusion optimizer
- **Compare two competing objectives (communication cost and PE size)**
- **Measure throughput**

# Competing objectives: Results

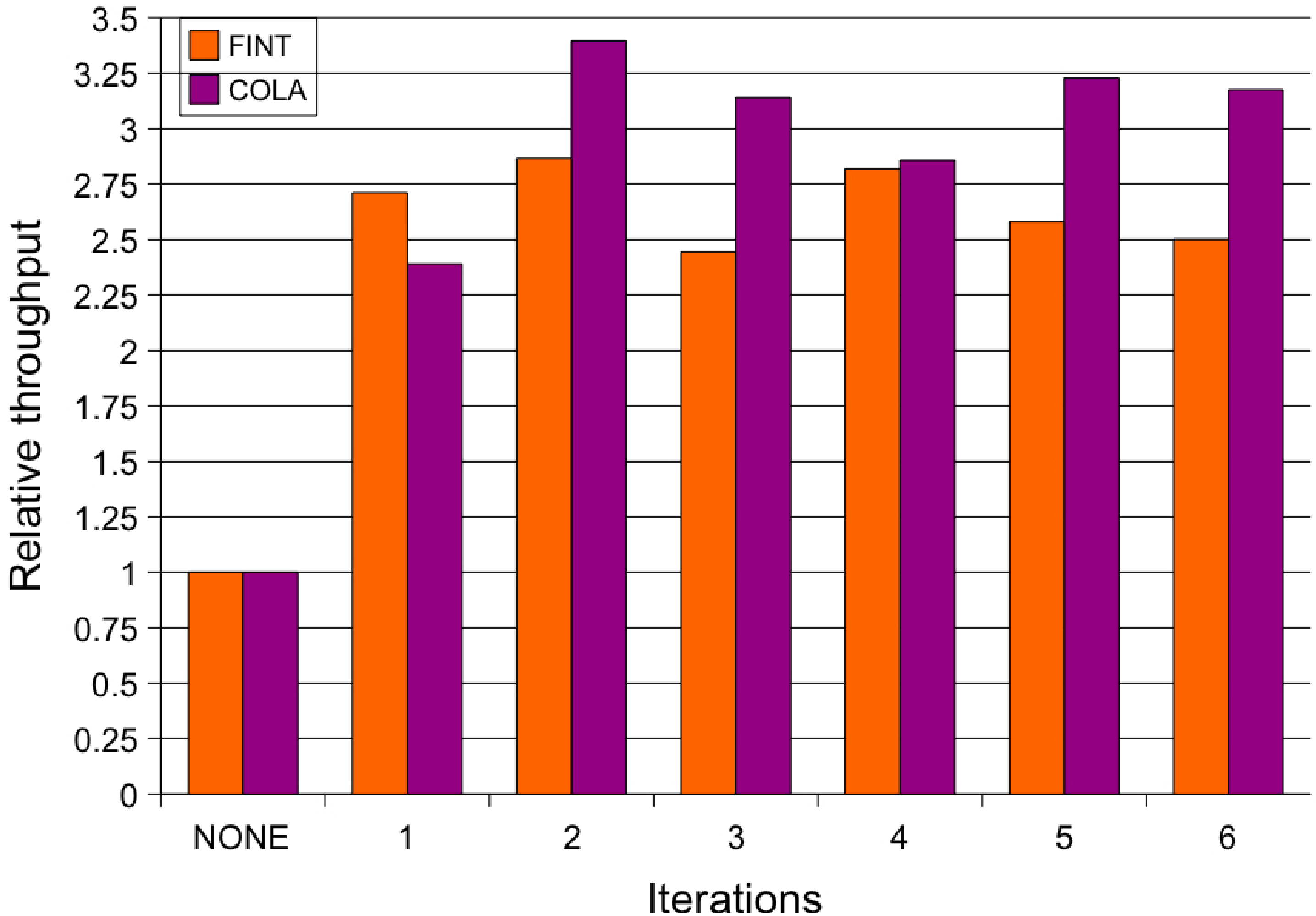
| | NONE | | FINT | | COLA | |
|---|---|---|---|---|---|---|
| Hosts | Comm cost | max PE size | Comm cost | max PE size | Comm cost | max PE size |
| 4 | 0.3792 | 0.3218 | 0.0661 | 0.5353 | 0.0332 | 0.4990 |
| 5 | 0.3703 | 0.2980 | 0.0441 | 0.5476 | 0.0587 | 0.4676 |
| 6 | 0.7236 | 0.8169 | 0.2698 | 0.8169 | 0.1998 | 0.7560 |
| 7 | 0.6833 | 0.6697 | 0.2492 | 0.6697 | 0.1860 | 0.6666 |

- COLA does better than FINT on cut size without larger PEs
  - In a few cases, the maximum PE size is actually **smaller** than the no fusion case!

# Throughput

- At different throughput rates, the operator-costs and communication-costs do not scale linearly
  - **Initial run with a poorly-performing fusion results in low estimates of operator sizes, and we cannot just “scale up” to see how big operators can get.**
  - **Use an iterative scheme**
    - Use NONE to gather initial metrics
    - Have COLA find a fusion based on these metrics
    - Gather metrics with this new fusion
    - Use these new metrics as input to COLA and repeat

# Iterating to fight inaccurate data



# Results: Throughput

| | NONE | FINT | | | COLA | | |
|---|---|---|---|---|---|---|---|
| Hosts | | 1st | 1st-local | Max | 1st | 1st-local | Max |
| 4 | 99.4 (1) | 273 (2.75) | 295 (2.96) | 295 (2.96) | 284 (2.86) | 286 (2.88) | 303 (3.05) |
| 5 | 97.2 (1) | 263 (2.71) | 279 (2.87) | 279 (2.87) | 232 (2.39) | 330 (3.40) | 330 (3.40) |
| 6 | 189 (1) | 286 (1.51) | 286 (1.51) | 293 (1.55) | 280 (1.48) | 379 (2.00) | 391 (2.06) |
| 7 | 179 (1) | 268 (1.50) | 322 (1.80) | 336 (1.88) | 267 (1.50) | 349 (1.95) | 363 (2.03) |

- First row shows that COLA usually outperforms FINT
- Notice that as the number of hosts increases, the gain from the fusion strategy goes down

# Conclusion

- **Graph partitioning is an effective way of determining which small operators to fuse together into PEs**
- **Future work**
  - Better characterization of a good-throughput fusion
  - Thread aware: PE size limits do not take into account whether the PE is single or multithreaded
  - Fast constraint checking
    - NP hard problem, but “difficult” instances likely to be rare