Pregel: A System for Large-Scale Graph Processing

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Agenda

- Motivation
- Related Work
- Model of Computation
- Execution Architecture
- Experiments
- Final Remarks
Motivation

- Graph algorithms don’t lend themselves to scalability and efficiency
  - Poor locality of memory access
  - Changing degree of parallelism over course of execution
- No scalable system for arbitrary graph algorithms
- Need for scalable general-purpose system for executing graph algorithms in large-scale distributed environment
Related/Prior Work

● Existing distributed systems:
  ○ ie: MapReduce
  ○ Sub-optimal performance and usability

● Single-computer graph algorithm libraries
  ○ BGL, LEDA, NetworkX, JDSL, GraphBase, FGL
  ○ Not scalable

● Existing parallel graph systems
  ○ Parallel BGL, CGMgraph
  ○ No fault tolerance

● Valiant’s Bulk Synchronous Parallel Model
Model of Computation

- Input:
  - Directed graph, each vertex labeled with a string identifier
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    - Vertex computations
    - Message passing between vertices
    - Topology mutations
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  - Vertex halting
    - No associated computations or messages
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  - All vertices have halted
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- **Output:**
  - Set of vertex output values
Message Passing

- Vertices can send any number of messages to any other number of vertices in the graph
  - Send message at superstep $S$
  - Messages received at superstep $S+1$
Message Passing

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  - Send message at superstep $S$
  - Messages received at superstep $S+1$
- User-defined handlers:
  - Specify behavior if message receiver does not exist in graph
Message Passing

- Combiners
  - Function to combine result of all messages sent to a certain vertex
  - Use by subclassing pre-defined Combiner class
Message Passing

- **Combiners**
  - Function to combine result of all messages sent to a certain vertex
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- **Aggregators**
  - Result made available to all vertices
  - Use by subclassing of pre-defined Aggregator class
Topology Mutations

- Removals and additions
  - Add/remove edges
  - Add nodes
  - Remove nodes and outgoing edges
Topology Mutations

- **Removals and additions**
  - Add/remove edges
  - Add nodes
  - Remove nodes and outgoing edges

- **Partial ordering**
  - Removals before additions
  - Edge removals, vertex removals, vertex additions, edge additions

- **Handlers**
Maximum Value Calculation using Pregel
Maximum Value Calculation using Pregel
Maximum Value Calculation using Pregel
Maximum Value Calculation using Pregel
Applications

- PageRank
- Shortest Paths
- Bipartite Matching
- Semi-clustering
Example: Shortest Paths

- Implemented for single-source shortest path
- All vertices initialized to INF
- Superstep 0:
  - Source vertex updates value to 0, broadcasts to neighbors
- Subsequent supersteps:
  - Broadcast new minimum values
- Terminates when no remaining updates
Basic Architecture

- Graph partitioned into sets:
  - Each set contains a group of vertices + outgoing edges from vertices
- Worker and master machine separation
Basic Architecture

- Graph partitioned into sets:
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- Worker and master machine separation
- Execution Steps:
  - Many copies of the input graph run
  - Master determines number of partitions
  - Master assigns partitions to workers
  - Master orchestrates superstep start
Worker and Master Implementations

- **Worker:**
  - Loops through all vertices, performs `Compute()` step
  - Runs two threads:
    - Thread to process vertices
    - Thread to receive messages

- **Master:**
  - Coordinating worker activities
  - Barrier Synchronization
Fault Tolerance

- Checkpointing
  - Worker state saved
  - Frequency selected based on mean time to failure model
- “Ping” messages for failure detection
- Confined recovery
Experiments

Figure 7: SSSP—1 billion vertex binary tree: varying number of worker tasks scheduled on 300 multicore machines

Figure 8: SSSP—binary trees: varying graph sizes on 800 worker tasks scheduled on 300 multicore machines
Experiments

Figure 9: SSSP—log-normal random graphs, mean out-degree 127.1 (thus over 127 billion edges in the largest case): varying graph sizes on 800 worker tasks scheduled on 300 multicore machines
Final Remarks

- Fault tolerant, scalable implementation of model
- “Think like a vertex” vs “Think like a graph”
  - Improved locality
  - Improved linear scalability
- Model for many other graph processing algorithms (i.e., Apache Giraph)