Introduction to Pregel

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What is Pregel?

- Framework for processing and modelling algorithms on large graphs
- Examples of large graphs
  - The Web
  - Transportation networks
- Created by Google Researchers

The Problem

- Running algorithms on large graphs is difficult
  - Distribution over machines leads to issues with machines failing and locality
  - Algorithms are often complex and take many lines of code to write, potentially leading to bugs
  - Current frameworks (such as MapReduce) are ill-suited for graph algorithms

Pregel Basics

- Each vertex is assigned a vertex identifier and associated with a user-defined value
- Pregel computation is defined by a sequence of “supersteps”
- All computation within a superstep is done in parallel
- At each superstep, each vertex performs a user-defined function
- Each vertex can see messages sent to it at the previous superstep and send messages to other vertices for the next superstep

Pregel Basics 2

- Vertices can change the topology of the graph during each superstep
- All vertices are **active** at the beginning
- At any superstep, a vertex can **vote to halt** and then it stops computation for all future supersteps (though it can be reactivated with a message)
- Computation is finished when all vertices vote to halt
- The output is simply the set of values outputted by each of the vertices

C++ API Basics

- Pregel users implement algorithms through the C++ API
- One must create a subclass of the predefined Vertex class
- Compute() -- Executed by each vertex at each superstep
  - GetValue() -- Get the value associated with the vertex
  - MutableValue() -- Modify the value associated with the vertex

Message Passing

- Vertices can pass messages to each other, that can be read at the next superstep
- The order that messages will be delivered is not guaranteed; it is only guaranteed that they will be sent

Combiners

- Sometimes, not all messages individually are important to a vertex. Only the messages in aggregate are important.
  - For example, perhaps a vertex only needs the sum of all incoming message values
- We can make our program more efficient by writing a Combiner that combines messages delivered to a vertex
  - We should only write combiners for associative and commutative operations (because we can’t assume the ordering of messages or how they’re grouped)

Aggregator

- Each vertex provides a value to an aggregator in a superstep, and then the aggregator combines all values together using an operator and provides the result for the next superstep
- Possible use case: Select a “special” vertex by providing all vertex IDs to the aggregator and choosing the maximum one
- Sticky aggregator: Combine values from all previous supersteps rather than just the last one

Topology Mutations

- Multiple vertices can try to change the topology of a graph in a single superstep
- Removals are performed before additions, with edge removal before vertex removal and vertex addition before edge addition
- Other conflicts are handled with user defined handlers

Pregel Architecture

- Each vertex is assigned to one of many partitions
  - The default assignment function is hash(vertexID) (mod N), where N is the number of partitions
- Many copies of the Pregel program are executed on a cluster, with one copy acting as the master
- The master is not assigned a partition like each of the workers are -- rather, the master just coordinates worker activity

Pregel Architecture 2

- The master determines the number of partitions and assigns machines to partitions
  - The user can also control the number of partitions
- The master tells workers when to perform supersteps
- The master can ask workers to save their partitions at the end

Fault Tolerance

- Done through checkpointing
- The master asks workers to save partitions to persistent storage at the beginning of supersteps
- Worker failures detected using ping messages
- Partitions from failed workers are reassigned (a few previous supersteps may need to be repeated depending on when the worker failed)

Worker Implementation

- Worker stores the partition in memory
- Worker stores an incoming message queue and a flag denoting whether the vertex is active (in fact, it stores two copies of these: one for this time-step and one for the next).
- When sending a message to another vertex, if the vertex is on another machine, the message is added to a buffer for delivery
- When the buffer size becomes large enough, it is emptied and all messages are sent to the destination vertex

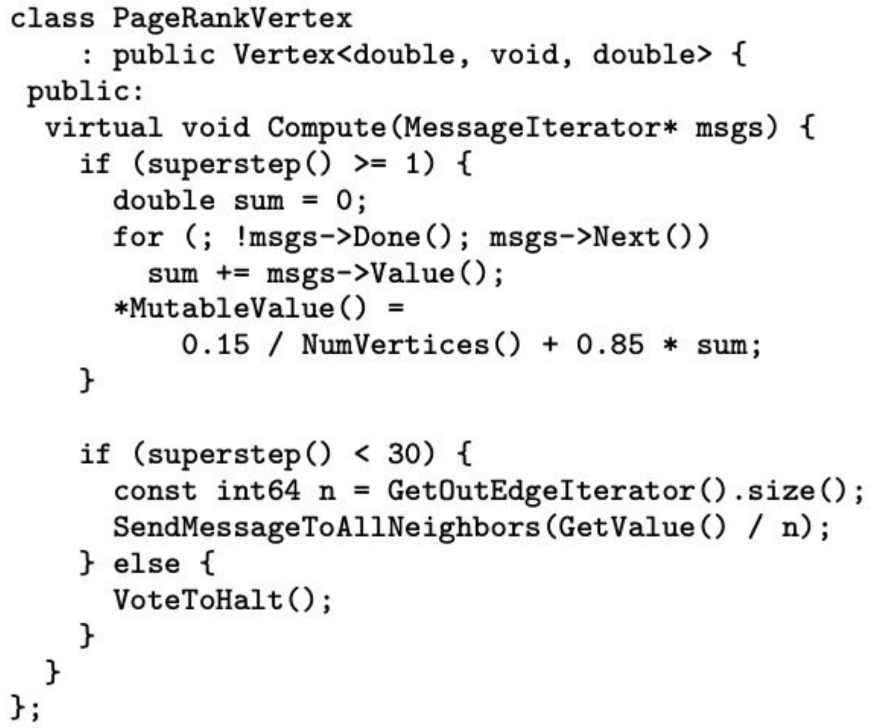
Master Implementation

- The master coordinates the worker’s activities
- The master also maintains various statistics about the graph
  - Size of the graph
  - Number of active vertices
  - Message traffic per superstep

Application: PageRank

- At each superstep, each vertex sends it’s (Current Page Rank) / (Number of outgoing edges)
- Each vertex sums up incoming messages and uses a formula to determine its new PageRank
- This process is repeated 30 times (though in reality page rank should go until convergence)

Application: PageRank



```
class PageRankVertex
    : public Vertex<double, void, double> {
 public:
  virtual void Compute(MessageIterator* msgs) {
    if (superstep() >= 1) {
      double sum = 0;
      for (; !msgs->Done(); msgs->Next())
        sum += msgs->Value();
      *MutableValue() =
          0.15 / NumVertices() + 0.85 * sum;
    }

    if (superstep() < 30) {
      const int64 n = GetOutEdgeIterator().size();
      SendMessageToAllNeighbors(GetValue() / n);
    } else {
      VoteToHalt();
    }
  }
};
```

Application: Shortest Paths

- At each superstep, each vertex receives potential minimum distance updates from its neighbors (from the previous superstep) and updates its value if necessary
- If an update is indeed made, it sends out potential updates to its neighbors
- The algorithm terminates when no updates are made

Experiments

- Experiments were run using a Single Source Shortest Path implementation in Pregel
- Researchers found that runtime scaled well with an increasing number of worker tasks
- Pregel also produced satisfactory (but not optimal) results given the minimal coding effort put in

Experiments

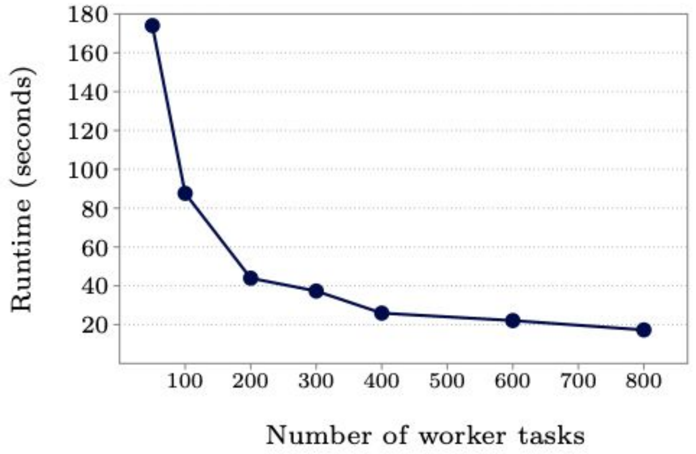


Figure 7: SSSP—1 billion vertex binary tree: varying number of worker tasks scheduled on 300 multicore machines

Strengths and Weaknesses

- Strength: Good results with minimal coding effort, fault tolerant, and flexible
- Primary weakness: Might be slower than optimized implementations

Future Work

- Potentially scaling the framework to even larger graphs
- Assigning vertices to machines to minimize the number of messages sent between different machines

Discussion Questions

- What are some potential attributes of algorithms that would prevent Pregel from being efficient in modelling them?
- Compare Pregel to other similar frameworks, such as Ligra