Empowering Fast Incremental Computation Over Large Scale Dynamic Graphs

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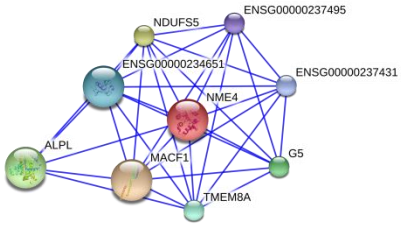
Large-Scale Graph Data

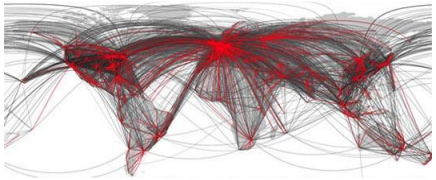
Online social networks

Protein interactions

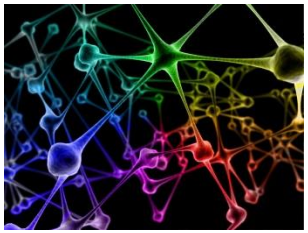


WWW

Air traffic network



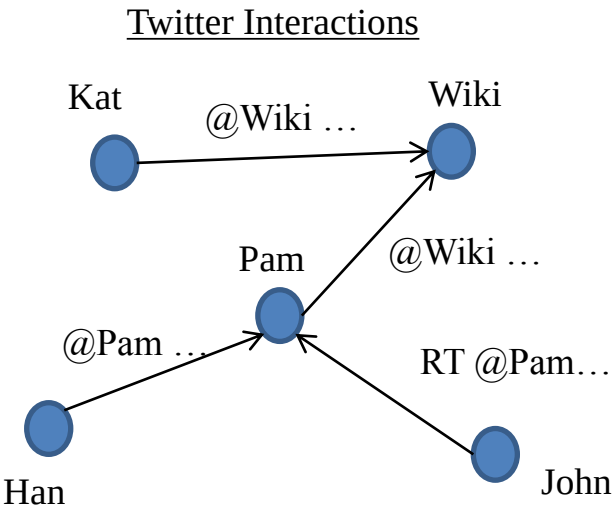
Citation networks

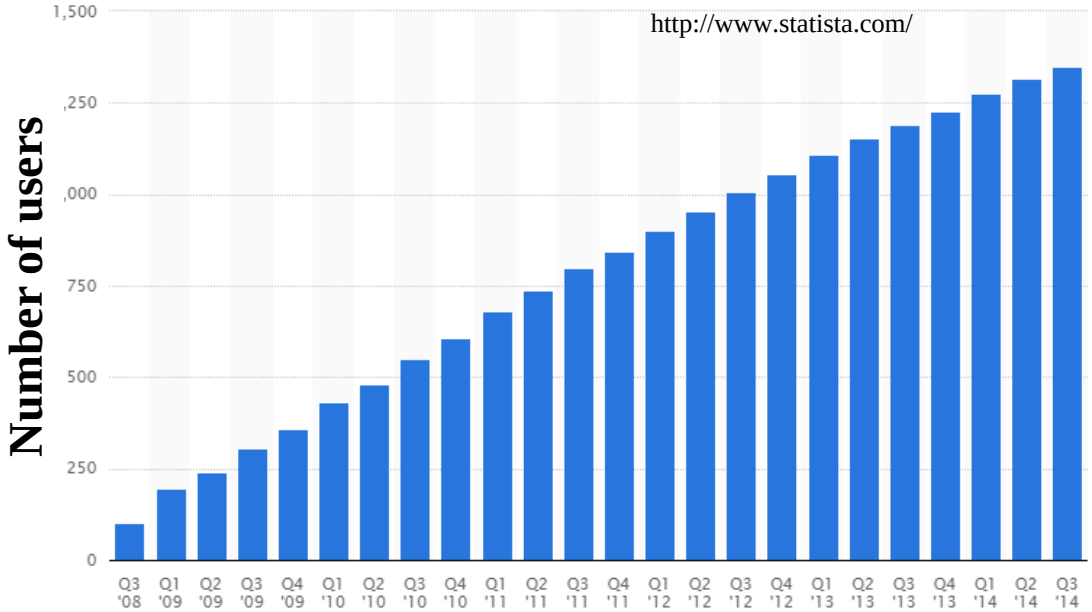


Neural network

Large-Scale Graph Data are "Evolving"

- **Large volume**
  - > 2 B internet users[1]
  - > 1 B active Facebook users[1]
  - > 2.5 M daily active Twitter users[2]





- **High velocity**
  - >7.5 K Tweets/second[1]
  - >1.5 K Skype calls/second[1]
  - >2000k emails/second[1]

[1]http://www.internetlivestats.com
[2]http://www.statista.com/

Vertex-Centric Model(1)

- Program written thinking as a vertex
- Computation performed at vertex level
- Communication using message passing between vertices
- Computation happens in iterations
  - Super-steps
- Bulk synchronous parallel model

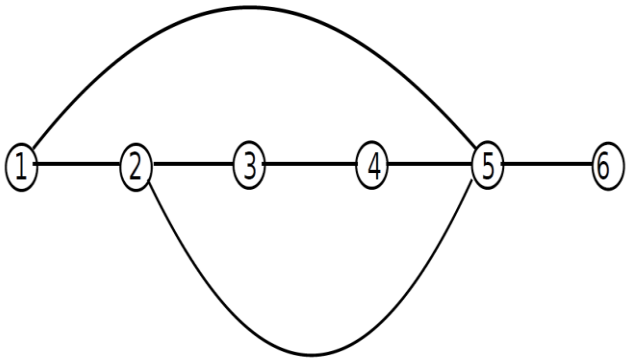
Example: Single source shortest path

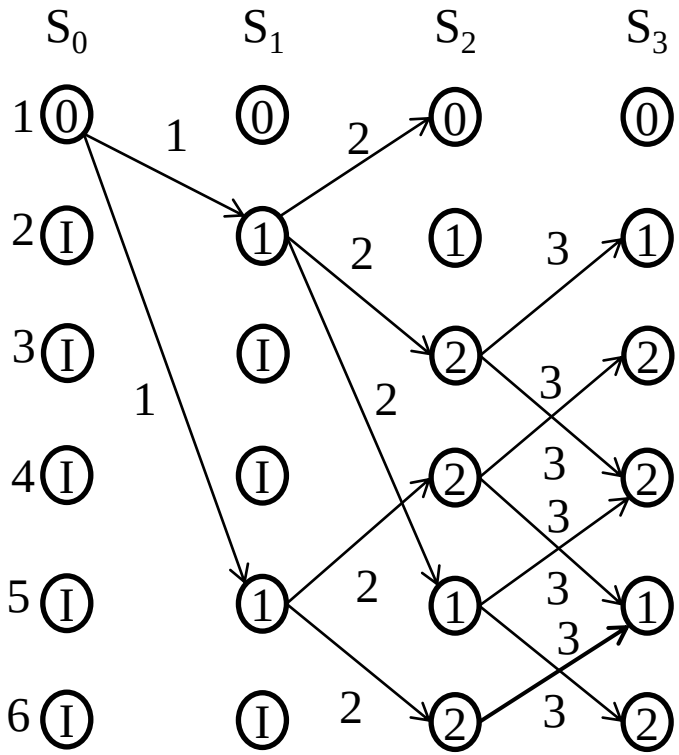
```
Compute(Messages  msgs) {
 int  distance=IsSource(vertex_id()) ? 0 : INF;
 for each  m in msgs {
   distance = (distance, m->value())
 }
 if( distance < getValue()) {
  setValue(disance)
  for each e in getOutEdges() {
    sendMessage(e.sink(),  distance  +  e.value()
  }
  voteToHalt()
 }
}
```

Malewicz, Grzegorz, et al. "Pregel: a system for large-scale graph processing."*Proceedings of the 2010 ACM SIGMOD International Conference on Management of data*. ACM, 2010.

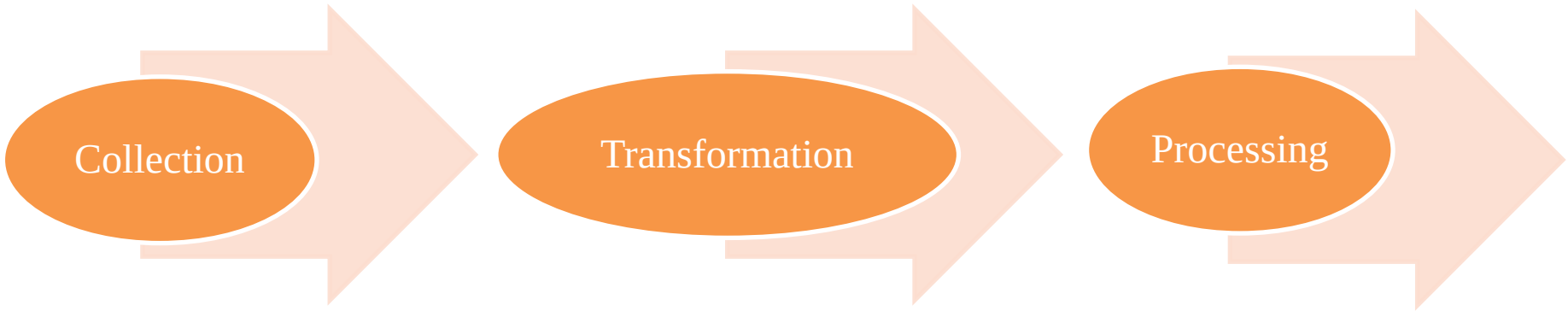
Vertex-Centric Model(2)

Example: Single source shortest path



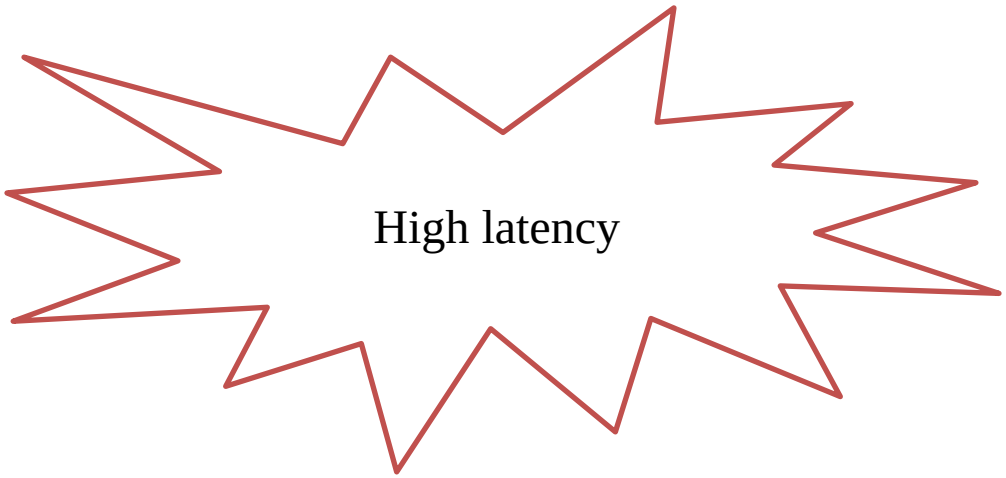


Vertex-Centric Model(3)



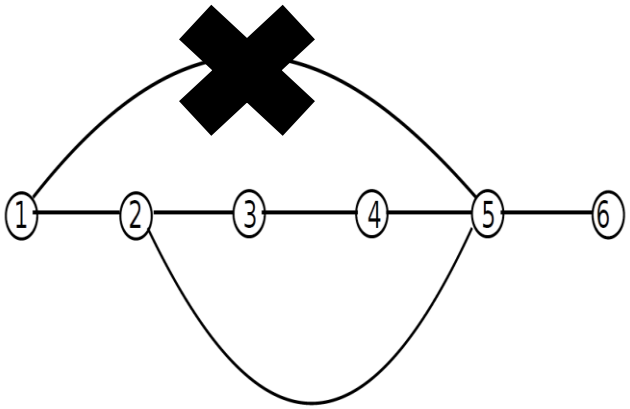
Existing Systems

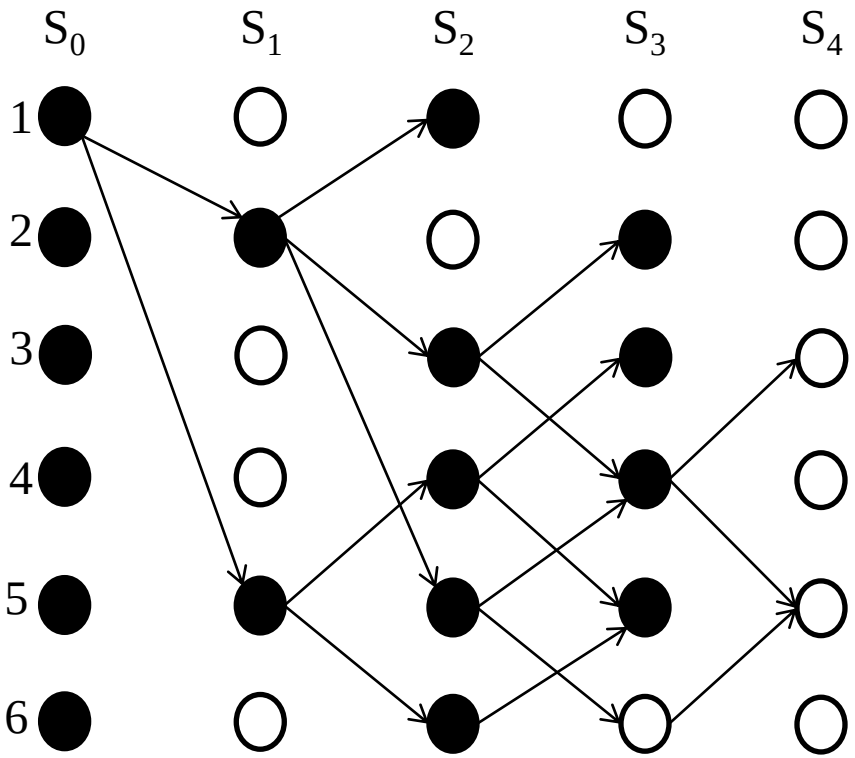
- Google Pregel
- Apache Giraph
- Graph Lab



Incremental Computation On Large-Scale Graphs

- **Key idea:**
  - Minimize number of re-computations





Approach(1)

Memorization

- Assumptions
  - Deterministic graph algorithm
  - Vertex state at end of any super-step depends only on
    - State at end of previous super-step
    - Incoming messages
- Memorize incoming messages and state at each super-step
- Avoid re-computation on updated graph by comparing with the memorized state

Cai, Zhuhua, Dionysios Logothetis, and Georgos Siganos. "Facilitating real-time graph mining." *Proceedings of the fourth international workshop on Cloud data management*. ACM, 2012.

Approach(2)

1. Mark affected vertices after graph update

Type of change	Affected vertices
Vertex property change	Only the specific vertex
Vertex addition	The specific vertex and any vertices it points to
Vertex deletion	All neighbors of the vertex, connected with either incoming or outgoing edges
Edge addition/deletion	**Directed**: only the source vertex **Undirected**: both ends of the edge
Edge property change	**Directed**: only the source vertex **Undirected**: both ends of the edge

Cai, Zhuhua, Dionysios Logothetis, and Georgos Siganos. "Facilitating real-time graph mining." *Proceedings of the fourth international workshop on Cloud data management*. ACM, 2012.

Approach(3)

2. Re-execute the vertex if any of following are true
   - Any of the in-coming messages are different from memorized messages at that super-step
   - State is different from memorized state at that super-step
   - Affected vertex
- Advantages
   - Framework takes care of incremental execution

Cai, Zhuhua, Dionysios Logothetis, and Georgos Siganos. "Facilitating real-time graph mining." *Proceedings of the fourth international workshop on Cloud data management*. ACM, 2012.

Challenges

- Vertex centric programming model
  - Little computation per vertex
  - Large number of global synchronization steps
    - High communication/computation ratio
- Vertex centric memorization
  - Per-vertex comparisons
    - High comparison cost/compute cost

Our Approach(1)

- **Approach**
  - Multilevel memorization to prune computation
    - Partition level: coarse grain pruning of re-computations
    - Vertex level: fine grain pruning of re-computations
  - Partition centric hierarchical BSP
    - Partition the graph
    - Local barrier synchronization within each partition
    - Global barrier synchronization across partitions
  - Resource allocation
    - 1 node → 1 partition
    - 1 core → subset of vertices

Our Approach(2)

- Programming model
  - Vertex centric
    - Very similar to Pregel model
  - Two levels of iterations
    - Sub-super-steps: intra partition
    - Super-step: inter partition
  - Messaging
    - Intra partition messages sent within sub-super-steps
    - Inter partition messages are aggregated and send at start of each new super-step
  - Reduce operation to limit communication
    - Enable users to minimize communication between partitions

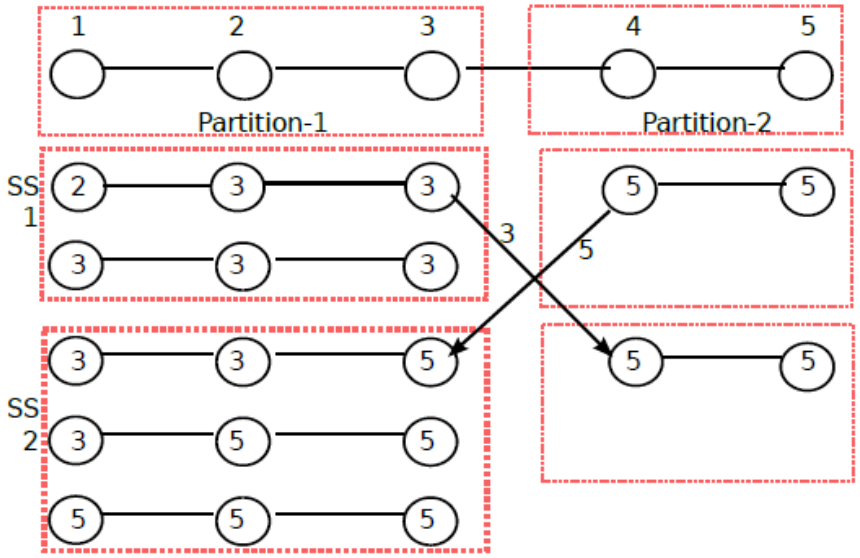
Our Approach(3)

- Advantages
  - Framework takes care of incremental execution
  - Less global barrier synchronization overhead
  - Partition/Sub-graph level pruning of re-computations
    - Less comparison cost / computation cost

Example(1)

Algorithm 1 Max Vertex Using HBSP

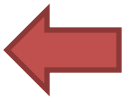
```
1: procedure COMPUTE(Vertex v, Iterator<Messages> msgs)
2:     if super-step == 0 and sub-super-step == 0 then
3:         BROADCASTGREATESTNEIGHBOR(v)        ▷ Find the greatest vertex id m from the neighborhood set (including self), set m as the current value, and sent it to all neighbors
4:         return
5:     end if
6:     changed ← false
7:     maxId ← v.value
8:     while msgs.hasNext do
9:         m = msgs.next
10:        if maxId < m.value then
11:            maxId ← m.value
12:            change ← true
13:        end if
14:    end while
15:    if changed then
16:        v.value ← maxId
17:        BROADCASTUPDATE(v)    ▷ Send the vertex value to all neighbors of v
18:    end if
19: end procedure
```



Example(2)

- Reduce Operation
  - Max vertex id

```
reduce(I neighborId,  List<Messages> msgs)  {
   int max = 0
   for each  msg in msgs {
     max = max(max, msg.value)
   }
  sendMessage(neighbour, new Message(max));
}
```



Per each remote vertex with outgoing messages

Implementation

- Implemented vertex centric and hierarchical BSP model on Apache Giraph (1.1.0)
- Local barriers using in-memory data structures. (Semaphores)
- Communication within partition each using in-memory data structures.
- Number of threads = number of cores
- Work stealing to reduce imbalance computation within each worker.
- Vertex to partition mapping is provided by user
- Memorized state was stored at partition level in local memory

Experimental Setup(1)

- Cluster of 15 nodes
  - 8-Core Intel Xeon CPU
  - 16GB RAM
- Workers
  - Number of workers: 12
  - Memory per worker: 14GB
- Datasets

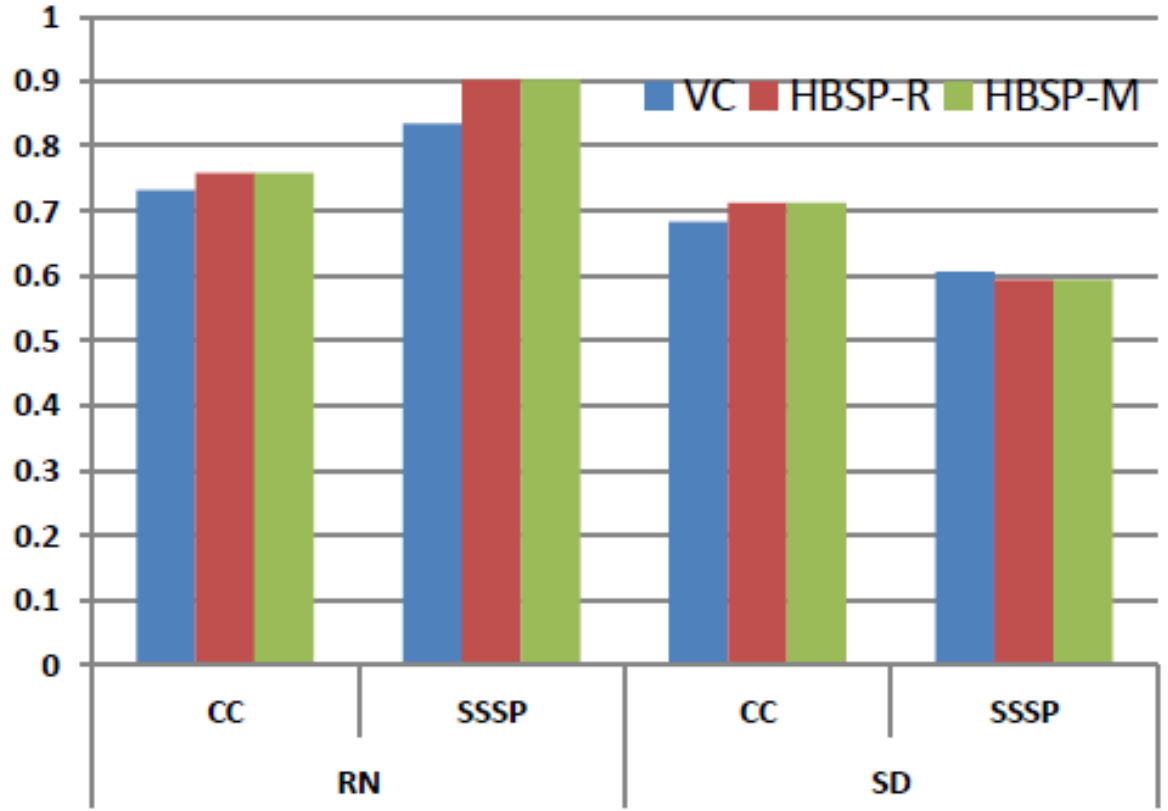
Dataset	# Vertices	# Edges
SlashDot (SD)	82,168	948,464
Road Network - CA (RN)	1,965,206	2,766,607

https://snap.stanford.edu/data/

Experimental Setup(2)

- Algorithms
  - Connected component (CC)
  - Single source shortest path (SSSP)
- Generating random graphs for each dataset
  - 100 new edges added randomly
  - 30 random edges deleted
- Partitioning algorithms
  - Random
  - Metis
- Fraction of computations saved
  - Logged number vertices executed
    - Without memorization (r_e)
    - With memorization (m_e)
  - $(r_e-m_e)/(r_e)$

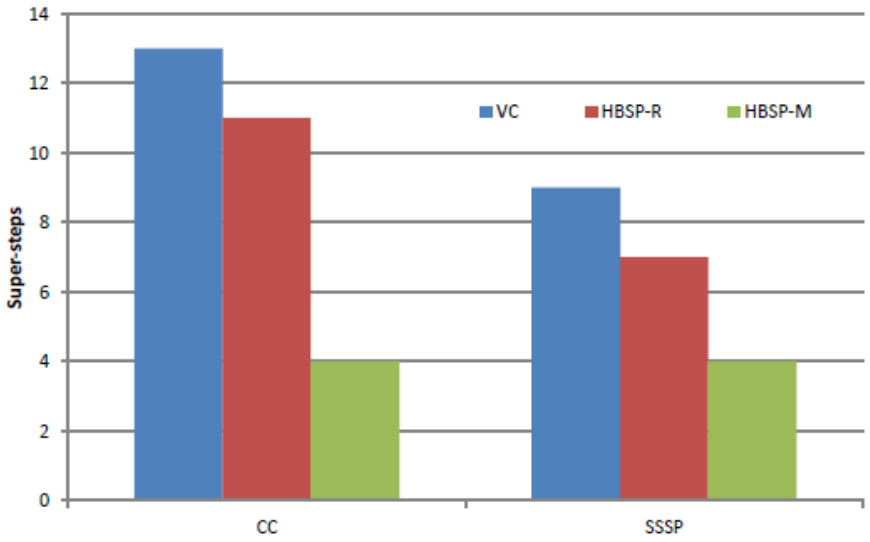
Fraction of Computations Saved



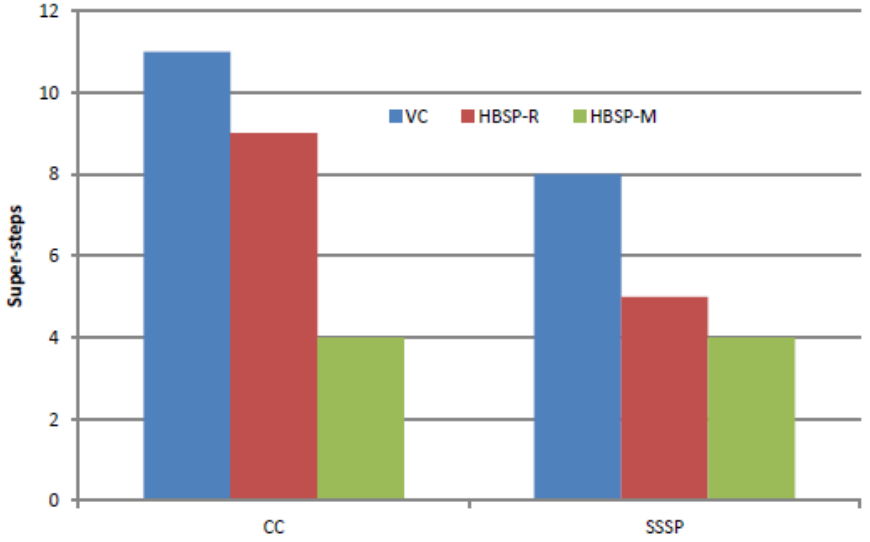
RN: Road network
SD: SlashDot

Reduction in Super-Steps(1)

- SlashDot dataset



On static graphs

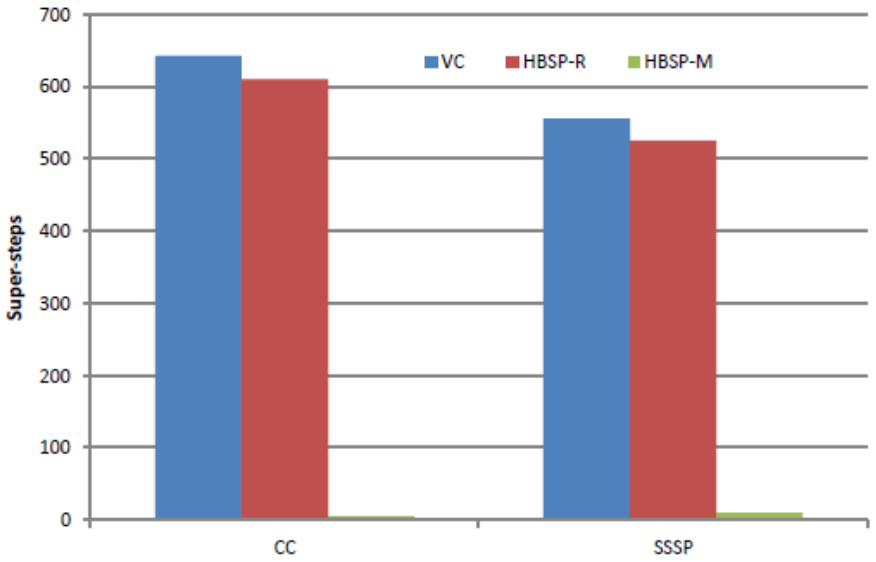


On updated graphs using memorization

Reduction in Super-Steps(2)

- Road network dataset

On static graphs



On updated graphs using memorization

Conclusion

- Hierarchical BSP Model
  - Huge reduction on number of super-steps for sparse graphs
  - Simple programming abstraction
- Memorization with HBSP
  - No/Minimal impact on number of saved computations
  - Takes the burden of developing incremental graph algorithms
- Future Work
  - Reduce memorization overhead
    - Memory
    - Computation (Due to comparisons)
  - Combine with existing distributed time series graph processing models
    - Ex: Simmhan, Yogesh, et al. "Scalable analytics over distributed time-series graphs using goffish." *arXiv preprint arXiv:1406.5975* (2014).

Questions

http://www.infertility.org/wp-content/uploads/2013/10/5-Questions-to-Ask-Before-1st-Round-of-IVF.jpg