Second Workshop on Software Challenges to Exascale Computing
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Overcoming MPI Communication Overhead for Distributed Community Detection

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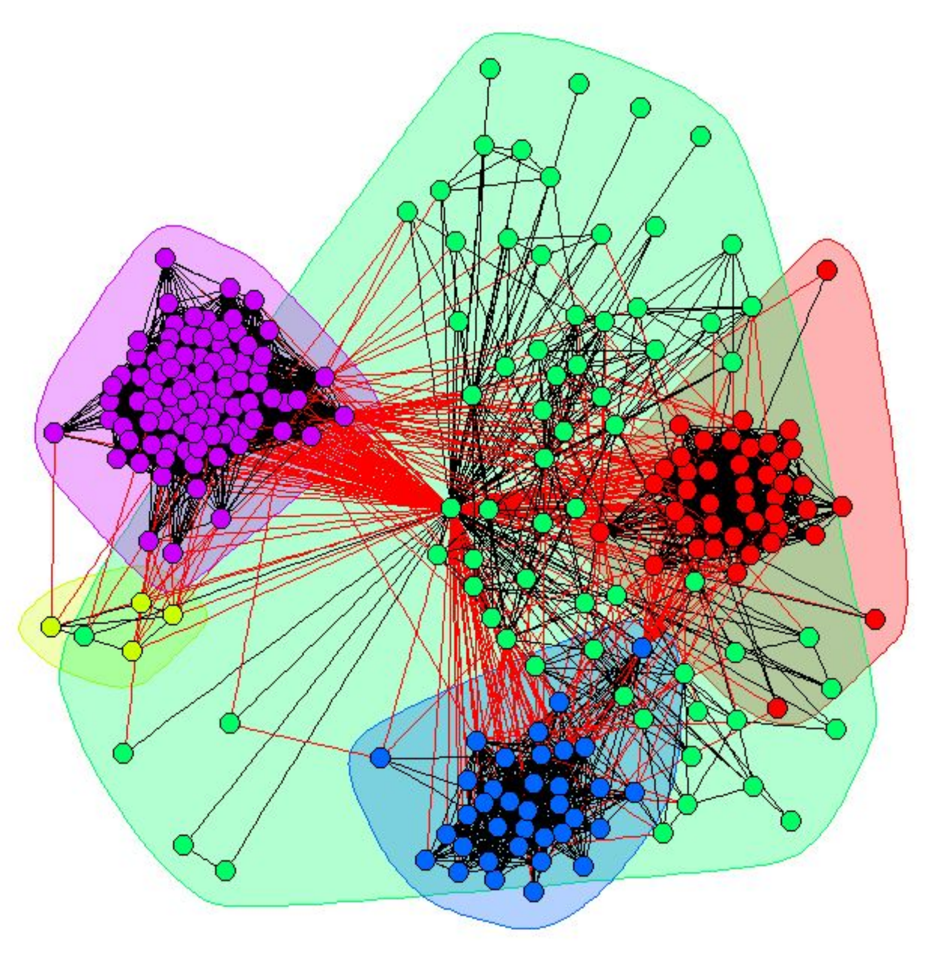
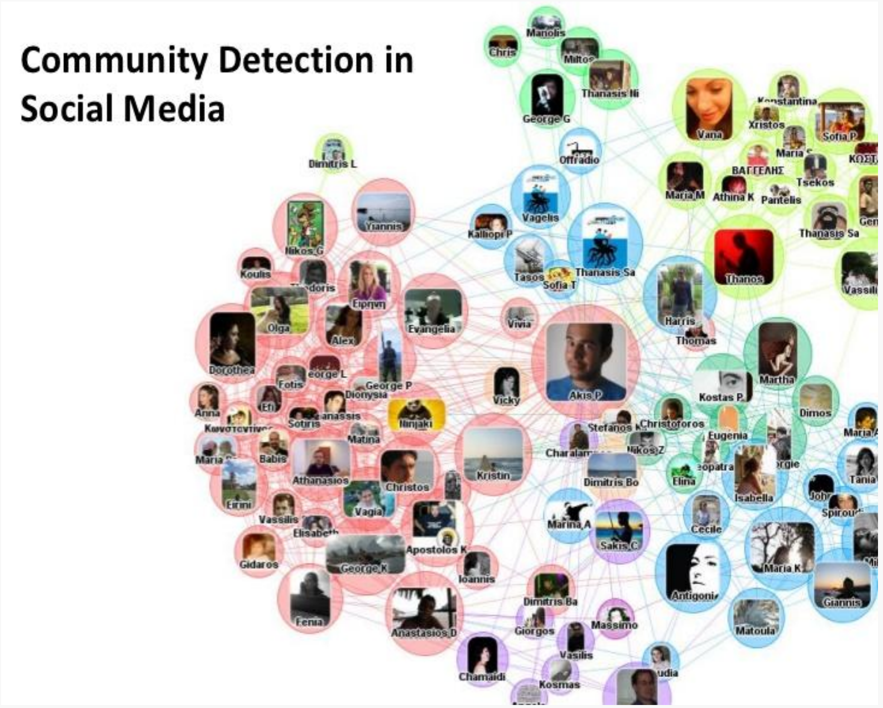
Introduction

- Louvain algorithm
  - A well-known and efficient method for detecting communities
- Community
  - a subset of nodes having more inside connections than outside



Motivation

- Community Detection Challenges
  - Large networks emerging from online social media
    - Facebook
    - Twitter
  - Other scientific disciplines
    - Sociology
    - Biology
    - Information & technology
- Load balancing
  - Minimize communication overhead
  - Reduce idle times of processors leading to increased speedup



Parallelization Challenges

Shared Memory

- Merits
  - Conventional multi-core processors
- Demerits
  - Scalability limited by moderate no. of available cores
  - Physical cores limited for the scalable chip size restriction
  - Shared global address space size limited for memory constraint

Distributed Memory

- Merits
  - utilize a large number of processing nodes
  - freedom of communication among processing nodes through passing messages
- Demerits
  - An efficient communication scheme required

Louvain Algorithm

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- Detects community based on modularity optimization
- Better than other community detection algorithms in terms of
    - Computation time and
    - Quality of the detected communities

❑ Modularity Calculation

$$Q = \frac{1}{2m} \sum_{ij} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i c_j)$$

Here,

Q = Modularity

A_{ij} = Link weight between nodes i and j

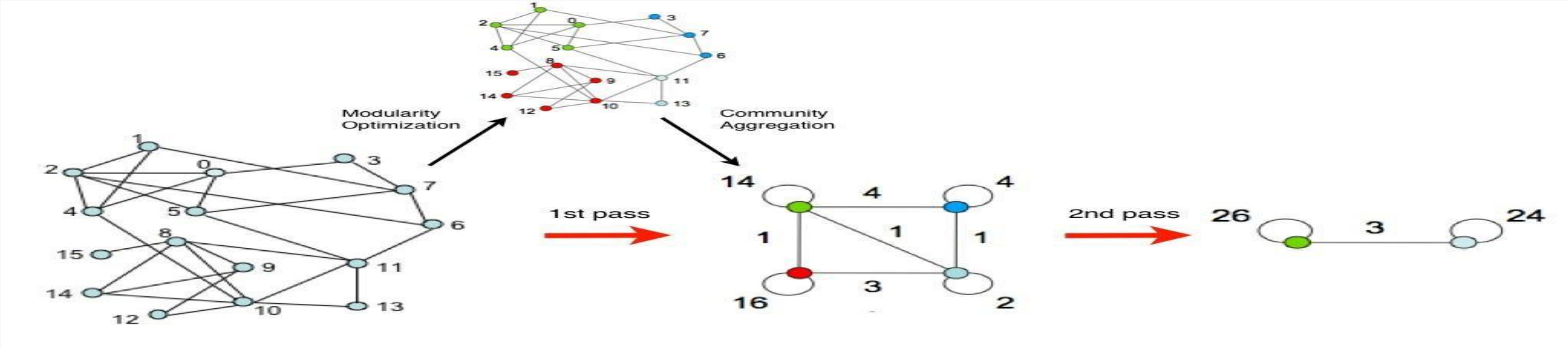
m = Total link weight in the network

k_i = Sum of the link weights attached to node i

c_i = Community to which node i is assigned

$\delta(c_i c_j)$ = Kronecker delta. Value is 1 when nodes i and j are assigned to the same community. Otherwise, the value is 0

Louvain Algorithm



- 2 Phases
  - Modularity Optimization- looking for "small" communities by local optimization of modularity
  - Community Aggregation- aggregating nodes of the same community a new network is built with the communities as nodes

Shared Memory Parallel Algorithm

- Parallelize computational task-wise
  - iterate over the full network
  - the neighbors of a node
- Work done by multiple threads
  - minimize the workload
  - do the computation faster

Distributed Memory Parallel Algorithm

Algorithm 1: Our Parallel Louvain using MPI

```
Data: Input Graph G(V,E)
Result: (Vertex, Community) Pair
while increase in modularity do
    G (V, E) is divided into p processes;
    Each graph_i.bin contains ⌈n/p⌉ vertices and
     corresponding edges in adjacency list format;
    for Each processor P_i (executing in parallel) do
        Gather_Neighbour_Info();
        Compute_Community();
        Exchange_Updated_Community();
        Resolve_Community _Duality();
        Exchange_Duality _Resolved _Community();
        Find_Unique_Communities();
        Compute_Modularity();
        Generate_NextLevel_Graph();
        if number_of_communities < i then
            i ← number_of_communities / 2;
        end
    end
end
```

Hybrid
Parallel Algorithm

- Both MPI and OpenMP together
- Flexibility to balance between both shared and distributed memory system

❑ Challenge

  ➢ Demerits of Distributed Memory Overweigh the performance

DPLAL- Distributed Parallel Louvain Algorithm with Load-balancing

- Similar approach as Distributed Memory Parallel Algorithm
- Load balancing of Input Graph using Graph-partitioner METIS
- Re-computation required for each function being calculated from Input Graph

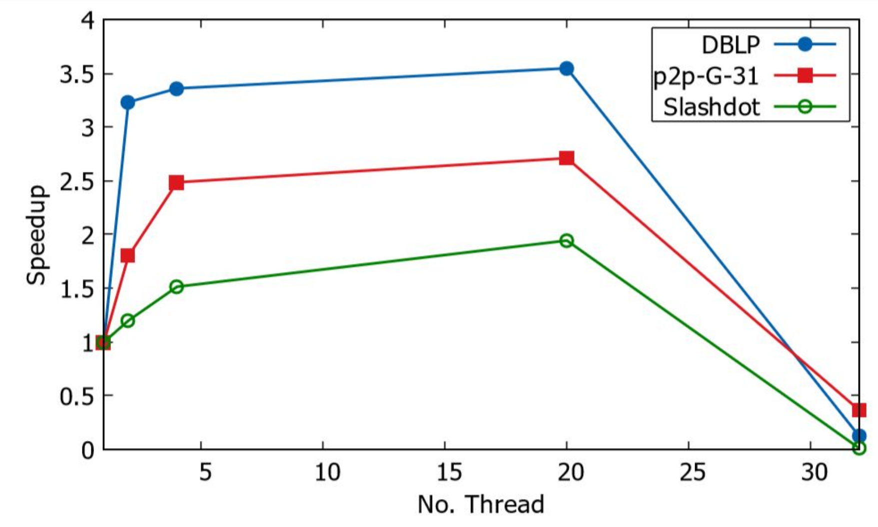
Experimental Setup

- Language
  - C++
- Libraries
  - Open Multi-Processing (OpenMP)
  - Message Passing Interface (MPI)
  - METIS
- Environment
  - Louisiana Optical Network Infrastructure (LONI) QB2 compute cluster
    - 1.5 Petaflop peak performance
    - 504 compute nodes
    - over 10,000 Intel Xeon processing cores of 2.8 GHz

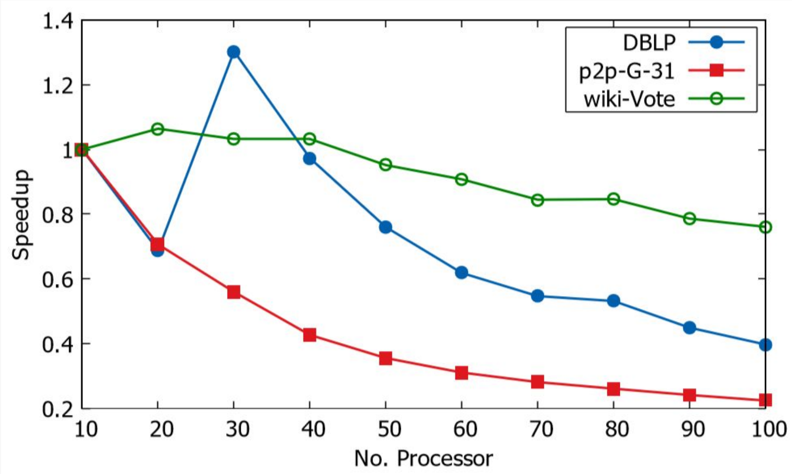
Dataset

Network	Vertices	Edges	Description
email-Eu-core	1,005	25,571	Email network from a large European research institution
ego-Facebook	4,039	88,234	Social circles ('friends lists') from Facebook
wiki-Vote	7,115	1,03,689	Wikipedia who-votes-on-whom network
p2p-Gnutella08, 09, 04, 25, 30, 31	6,301 - 62,586	20,777 - 1,47,892	A sequence of snapshots of the Gnutella peer-to-peer file sharing network for different dates of August 2002
soc-Slashdot0922	82,168	9,48,464	Slashdot social network from February 2009
com-DBLP	3,17,080	10,49,866	DBLP collaboration(co-authorship) network
roadNet-PA	1,088,092	1,541,898	Pennsylvania road network

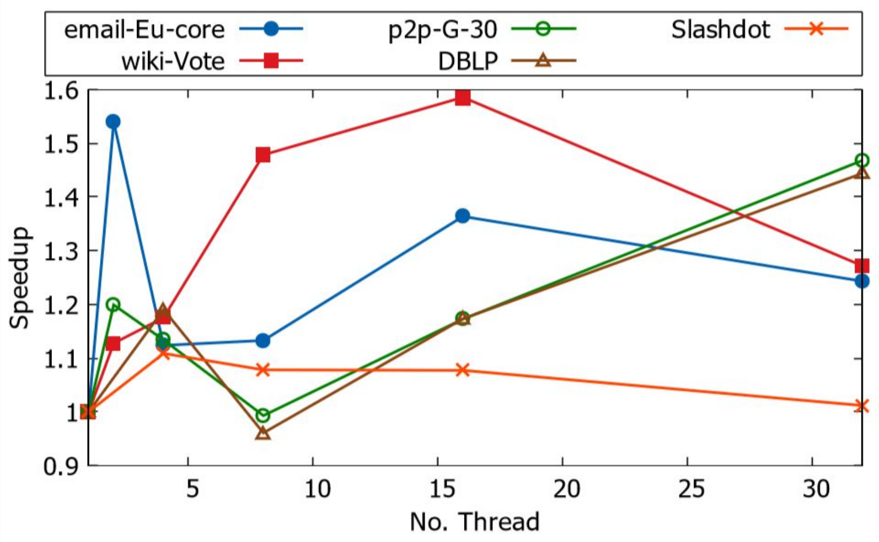
Speedup Factors of Parallel Louvain Algorithms



(a) Shared Memory Algorithm

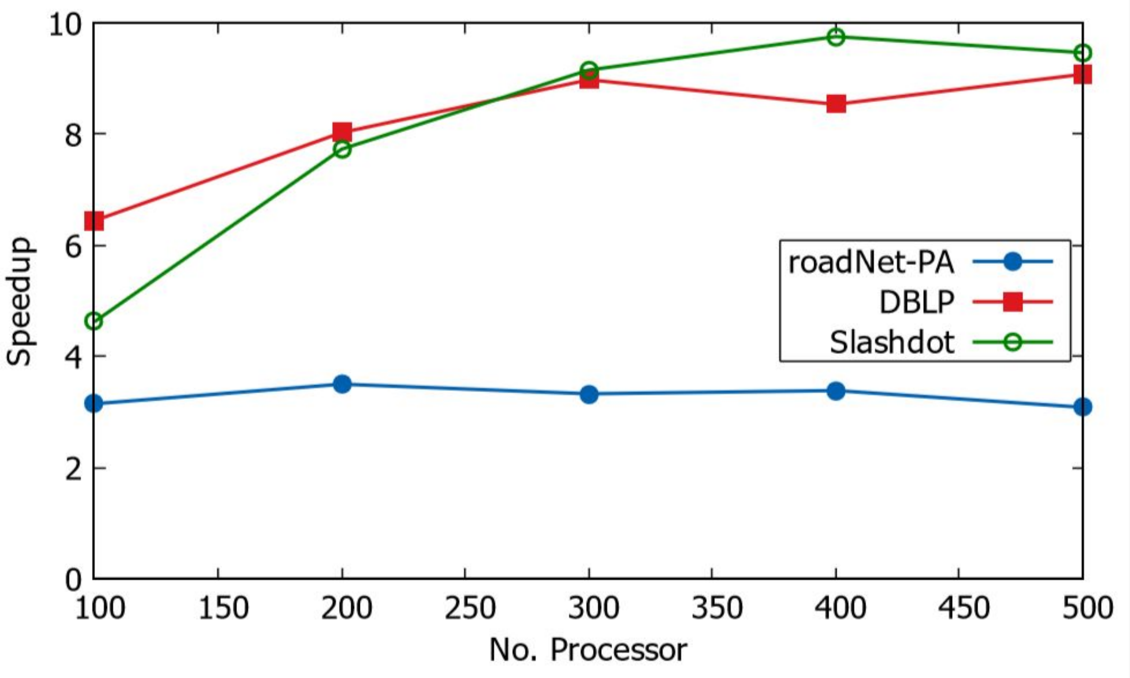


(b) Distributed Memory Algorithm

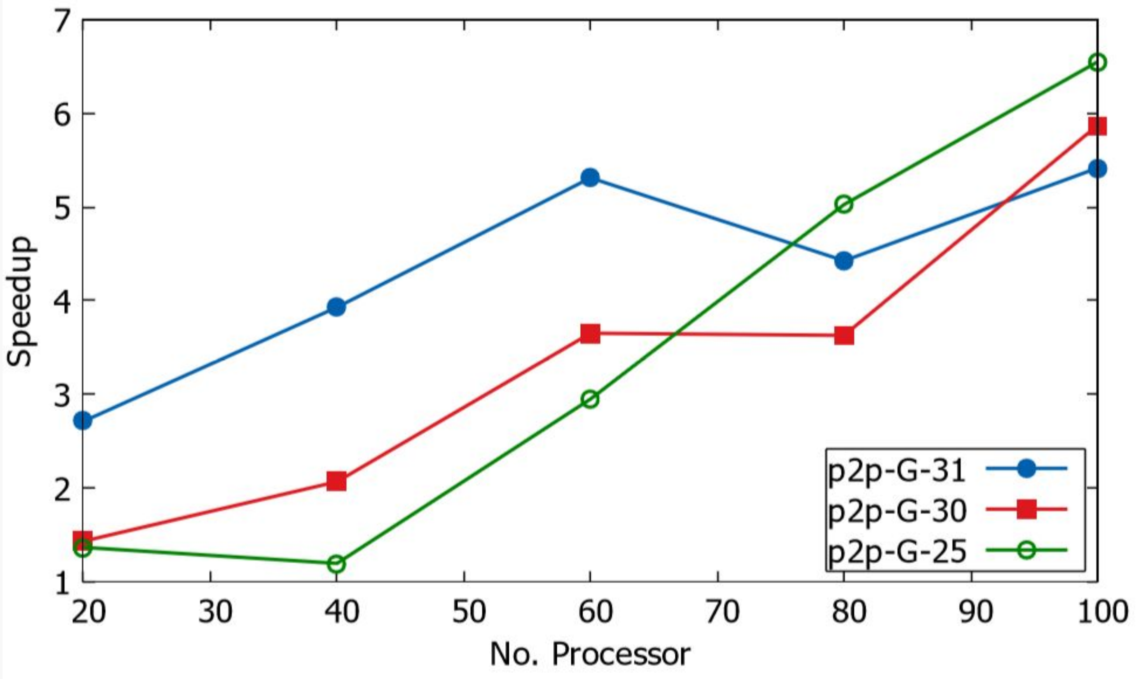


(c) Hybrid Algorithm

Speedup Factor of DPLAL-Distributed Parallel Louvain Algorithm with Load Balancing

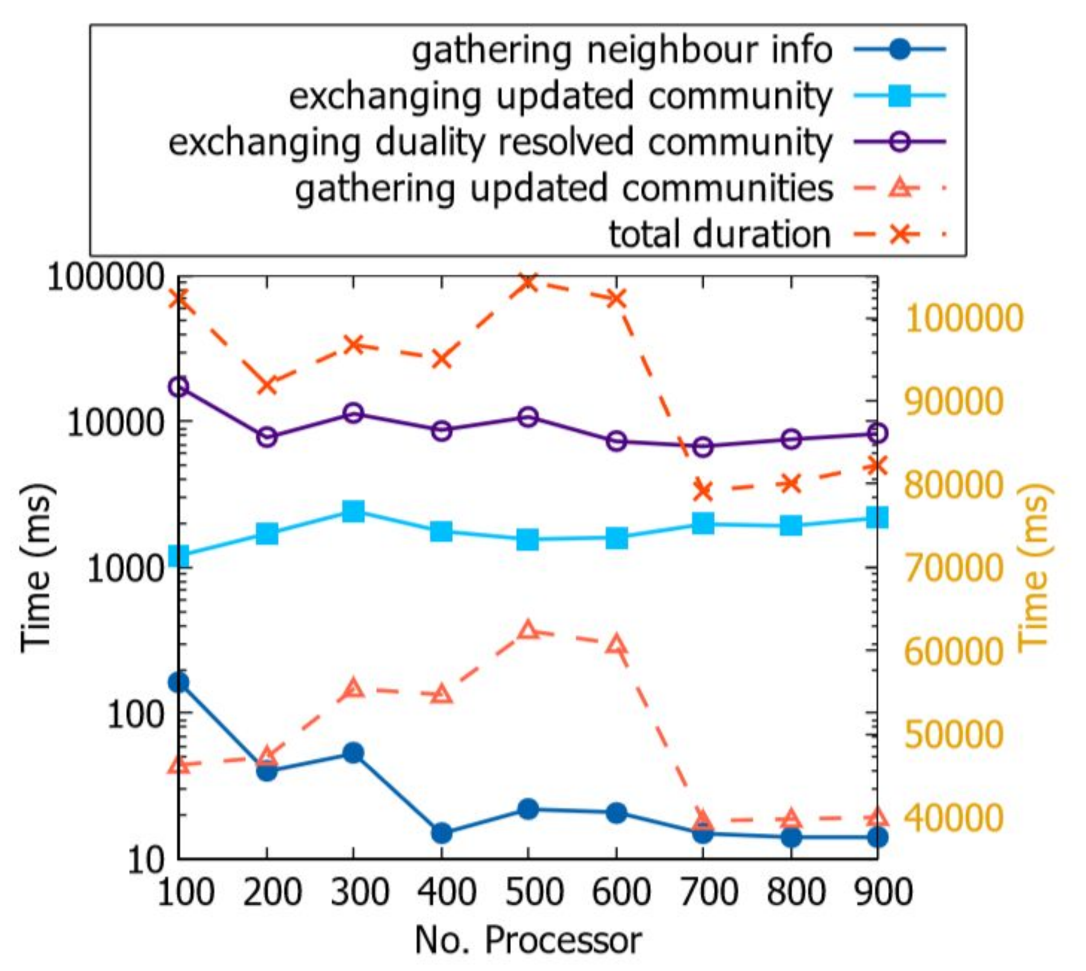


(a) Speedup results for large graphs

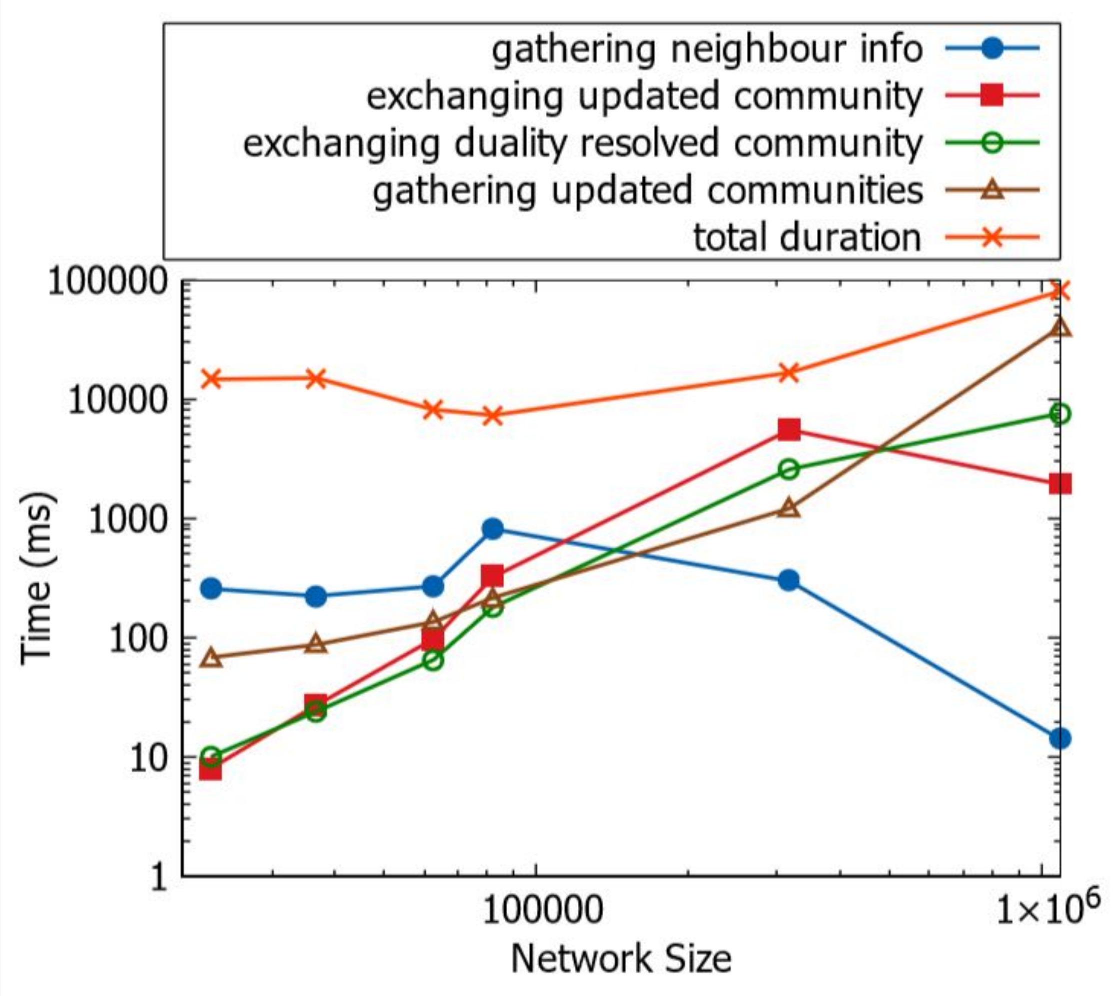


(b) Speedup results for relatively small graphs

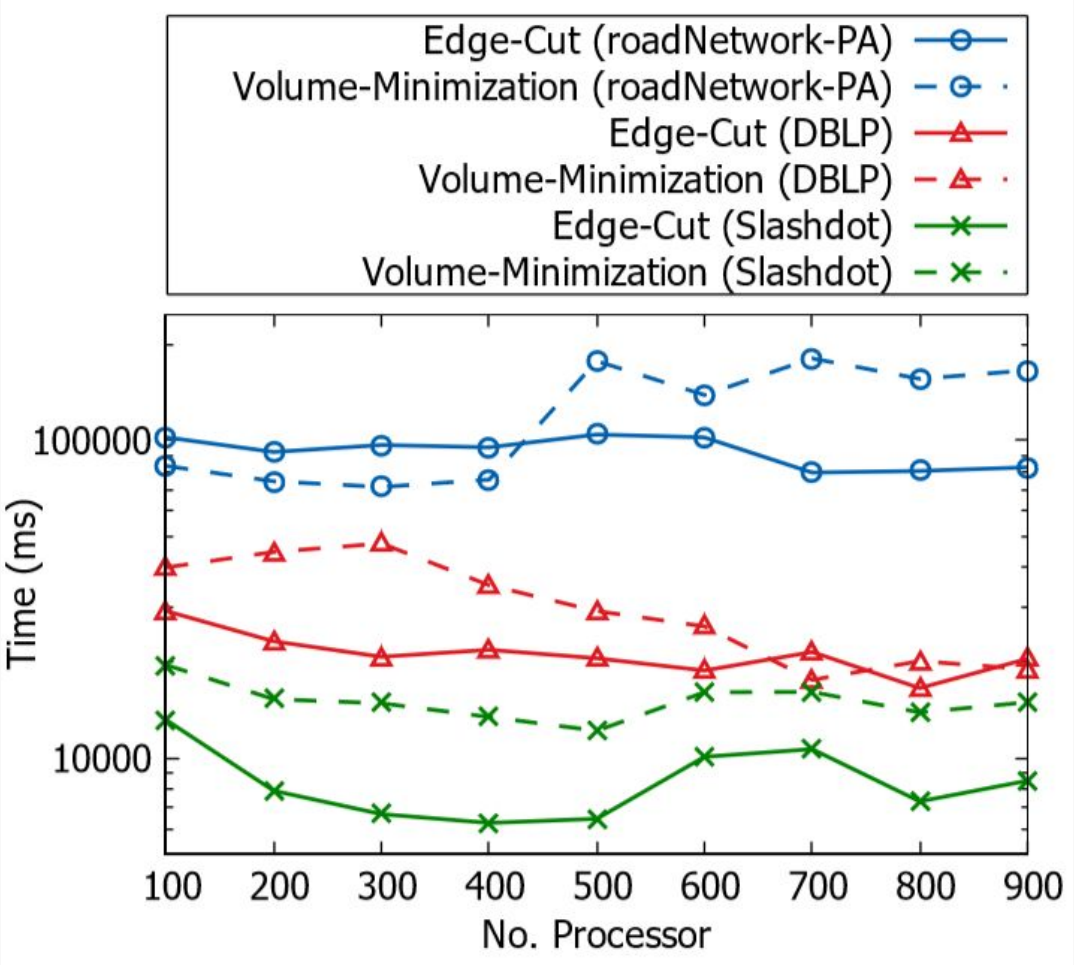
Runtime Analysis of RoadNet-PA Graph with DPLAL algorithm



Runtime of DPLAL Algorithm with Increasing Network Sizes



Comparison of METIS Partitioning Approaches



Performance Analysis

Sequential Algorithm

Algorithm	Network			
	com-DBLP		wiki-Vote	
	Comm. No.	Dev. (%)	Comm. No.	Dev. (%)
Sequential	109,104	-	1,213	-
Shared	109,102	.0006	1,213	0
Distributed	109,441	0.106	1,216	0.042
Hybrid	104,668	1.39	1,163	0.71
DPLAL	109,063	0.0129	1,210	0.042

Another MPI based Parallel Algorithm

	DPLAL	**Charith *et.al***
Network (node) size – Speedup	317,080 – 12, almost double	500,000 - 6
Speedup for the largest network	4 (1M nodes), same	4 (8M nodes)
Scalability for Processors	Upto 1000	Upto 16

Conclusion

- Our parallel algorithms for Louvain method demonstrating good speedup on several types of real-world graphs
- Implementation of Hybrid Parallel Algorithm to tune between shared and distributed memory depending on available resources
- Identification of the problems for the parallel implementations
- An optimized implementation DPLAL
  - DBLP network 12-fold speedup.
  - Our largest network, roadNetwork-PA 4-fold speedup for same number of processors

Future Works

- Improve the scalability of our algorithm for large scale graphs with billions of vertices and edges
  - other load balancing schemes to find an efficient load balancing
- Eliminate the effect of small communities hindering the detection of meaningful medium sized communities
- Investigate the effect of node ordering on the performance
  - degree based ordering
  - kcores
  - clustering coefficients

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