[CoolName++]: A Graph Processing Framework for Charm++

Hassan Eslami, Erin Molloy, August Shi, Prakalp Srivastava
Laxmikant V. Kale

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University of Illinois at Urbana-Champaign

{eslami2,emolloy2,awshi2,psrivas2,kale}@illinois.edu

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A graph is a set of vertices and a set of edges, which describe relationships between pairs of vertices. Data analysts wish to gain insights into characteristics of increasingly large networks, such as

- roads
- utility grids
- internet
- social networks
- protein-protein interaction networks
- gene regulatory processes

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Why large-scale graph processing?

Large social networks\(^2\)

- 1 billion vertices, 100 billion edges
- 111 PB adjacency matrix
- 2.92 TB adjacency list
- 2.92 TB edge list

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Why large-scale graph processing?

Large web graphs\(^3\)
- 50 billion vertices, 1 trillion edges
- 271 PB adjacency matrix
- 29.5 TB adjacency list
- 29.1 TB edge list

Why large-scale graph processing?

Large brain networks\(^4\)
- 100 billion vertices, 100 trillion edges
- \(2.08 \, mN_A \cdot \text{bytes}^2\) (molar bytes) adjacency matrix
- 2.84 PB adjacency list
- 2.84 PB edge list

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Many graph algorithms result in\(^5\)...

- ...a large volume of fine grain messages.
- ...little computation per vertex.
- ...irregular data access.
- ...load imbalances due to highly connected communities and high degree vertices.

Vertex-centric graph computation

- Introduced in Google’s graph processing framework, Pregel\(^6\)
- Based on the Bulk Synchronous Parallel (BSP) model
- A series of global supersteps are performed, where each **active** vertex in the graph
  1. processes incoming messages from the previous superstep
  2. does some computation
  3. sends messages to other vertices
- Algorithm terminates when all vertices are **inactive** (i.e., they vote to halt the computation) and there are no messages in transit.
- Note that supersteps are synchronized via a global barrier
  - Costly
  - Simple and versatile

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Our contributions

- Implement and optimize a vertex-centric graph processing framework on top of Charm++
- Evaluate performance for several graph applications
  - Single Source Shortest Path
  - Approximate Graph Diameter
  - Vertex Betweenness Centrality
- Compare our framework to GraphLab\textsuperscript{7}

CoolName++ framework overview

- Vertices are divided amongst parallel objects (Chares), called Shards.
- Shards handle the receiving and sending of messages between vertices.
- Main Chare coordinates the flow of computation by initiating supersteps.
Implementation of graph algorithms requires the formation of a
- vertex class
- compute member function

In addition, users may also define functions for
- graph I/O
- mapping vertices to Shards
- combining messages being sent to and received by the same vertex
Algorithm 1 Constructor for SSSP

1: if vertex is the source vertex then
2:     setActive()
3:     distance = 0
4: else
5:     distance = ∞
6: end if
Algorithm 2 Compute function for SSSP

1: min_dist = isSource() ? 0 : \infty
2: for each of your messages do
3:   if message.getValue() < min_dist then
4:     min_dist = message.getValue()
5:   end if
6: end for
7: if min_dist < distance then
8:   distance = min_dist
9:   sendMessageToNeighbors(distance + 1)
10: end if
11: voteToHalt()
mainchar Main {
    entry Main(CkArgMsg* m);
    entry [reduction target] void start();
    entry [reduction target] void checkin(int n, int counts[n]);
};

group ShardCommManager {
    entry ShardCommManager();
}

array [1D] Shard {
    entry Shard(void);
    entry void processMessage(int superstepId, int length,
                               std::pair<uint32_t, MessageType> msg[length]);
    entry void run(int mcount);
};
void Shard::run(int messageCount) {
    // Start a new superstep
    superstep = commManagerProxy.ckLocalBranch() -> getSuperstep();
    ...
    if (messageCount == expectedNumberOfMessages) {
        startCompute();
    } else {
        // Continue to wait for messages in transit
    }
}

void Shard::startCompute() {
    for (vertex in activeVertices) {
        vertex.compute(messages[vertex]);
    }
    for (vertex in inactiveVertices with incoming messages) {
        vertex.compute(messages[vertex]);
    }
    managerProxy.ckLocalBranch() -> done();
}
Optimizations

Messages between vertices tend to be small but still incur overhead.

- Shards buffer messages
- User-defined message combine function (send/receive)
Algorithm 3 Combine function for SSSP

1: if message1.getValue() < message2.getValue() then
2:   return message1
3: else
4:   return message2
5: end if
We consider three applications for the preliminary evaluation of our framework.

- **Single Source Shortest Path (SSSP)**
- **Graph Diameter**
  - Longest shortest path between any two vertices
  - We implement the *approximate* diameter with Flajolet-Martin (FM) bitmasks\(^8\).
- **Betweenness Centrality of a Vertex**
  - Number of shortest paths between every two vertices that pass through a vertex divided by the total number of shortest paths between every two vertices
  - We implement Brandes’ algorithm\(^9\).

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We want to tune parameters, specifically

- Number of Shards per PE
- Size of message buffer (i.e., the number of messages in the buffer)
Approximate diameter on a graph of sheet metal forming (0.5M vertices, 8.5M edges).

All subsequent experiments use one shard per PE.
Varying message buffer size on a graph of sheet metal forming (0.5M vertices, 8.5M edges).

In the following experiments, we use a buffer size of 64 for SSSP, 128 for Approximate Diameter, and 32 for Betweenness Centrality.
Preliminary data for strong scalability

We examine three undirected graphs from the Stanford Large Network Dataset Collection (SNAP)\textsuperscript{10}.

- “as-skitter”
  - Internet topology graph from trace-routes run daily in 2005
  - 1.7M vertices and 11M edges

- “roadNet-PA”
  - Road network of Pennsylvania
  - 1.1M vertices and 1.5M edges

- “com-Youtube”
  - Youtube online social network
  - 1.1M vertices and 3M edges

We compare our framework to GraphLab\textsuperscript{11}, a state-of-the-art graph processing framework originally developed at CMU.


Strong scalability of single source shortest path (SSSP)

![Graphs showing runtime vs. number of cores for as-skitter, roadNet-PA, and com-youtube datasets with different algorithms and implementations.](image-url)
Strong scalability of approximate diameter

![Graphs showing runtime (s) vs. number of cores for different datasets and libraries: as-skitter, roadNet-PA, com-youtube.](image)

- **as-skitter**: Red dots represent CoolName++, and blue dots represent GraphLab. The runtime decreases as the number of cores increases, indicating strong scalability.
- **roadNet-PA**: Similar trend observed with CoolName++ and GraphLab, showing strong scalability.
- **com-youtube**: Again, strong scalability is observed with CoolName++ and GraphLab as the runtime decreases with an increase in the number of cores.
Strong scalability of betweenness centrality

![Graphs showing the Strong scalability of betweenness centrality for different datasets (as-skitter, roadNet-PA, com-youtube).](image-url)
Conclusions

We ...

- implemented a scalable vertex-centric framework on Charm++.
- implemented three applications using our framework.
- get promising preliminary results in comparison to GraphLab.
- hope to test on larger graphs and a greater number of compute cores.
Future work

- Parallel I/O
- Vectorization of compute function
- Aggregators (e.g., global variables computed across vertices)
- Graph mutability
  - Vertex addition/deletion
  - Edge addition/deletion
  - Edge contraction (message redirection)