iShuffle: Improving Hadoop Performance with Shuffle-on-Write

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MapReduce

A framework for processing parallelizable problems across huge data sets using a large number of machines

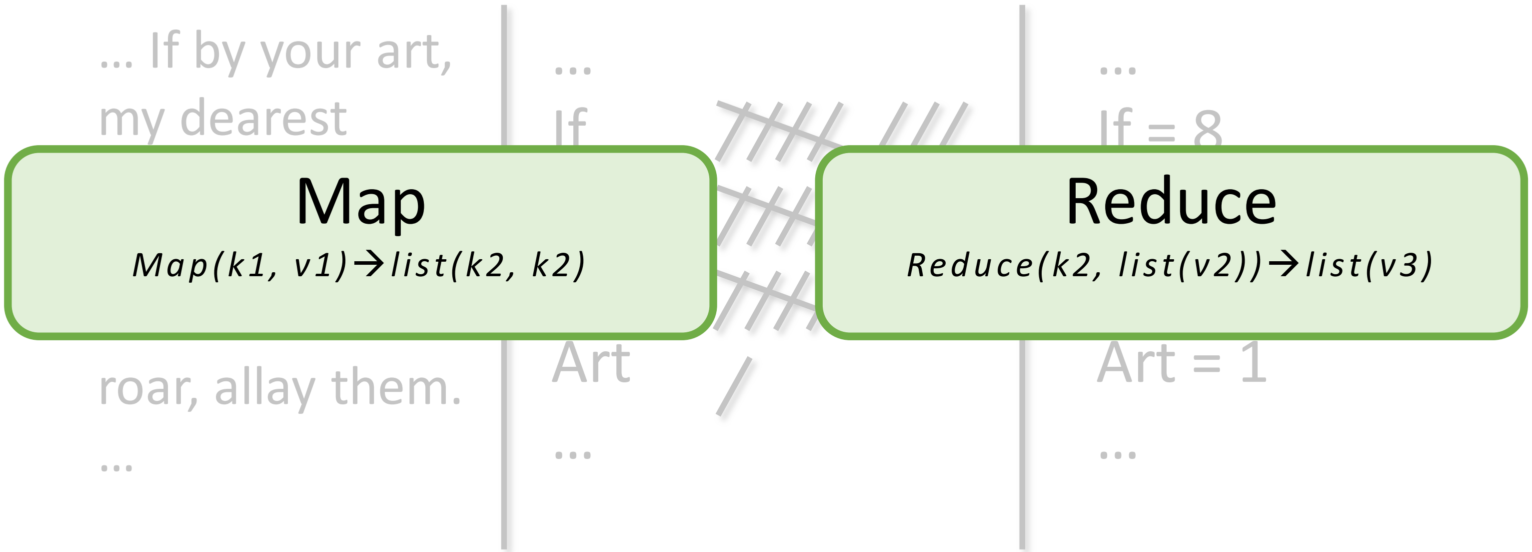
- Invented and used by Google [OSDI'04]
- Many implementations
  - Apache Hadoop, Dryad
- From interactive query to massive/batch computation
  - Nutch, Hive, HBase

MapReduce Model

Apply a common function to the problem's input

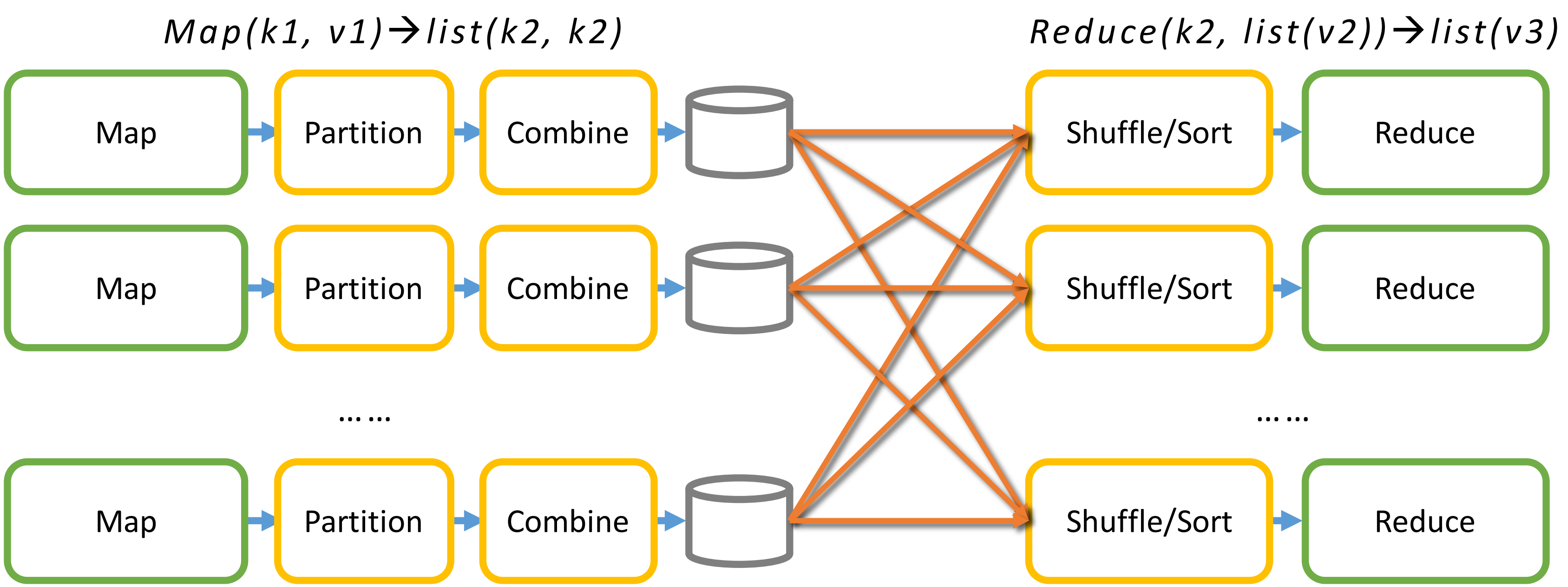
Generate intermediate data

Process intermediate data for answer



MapReduce

Programming and Execution Model

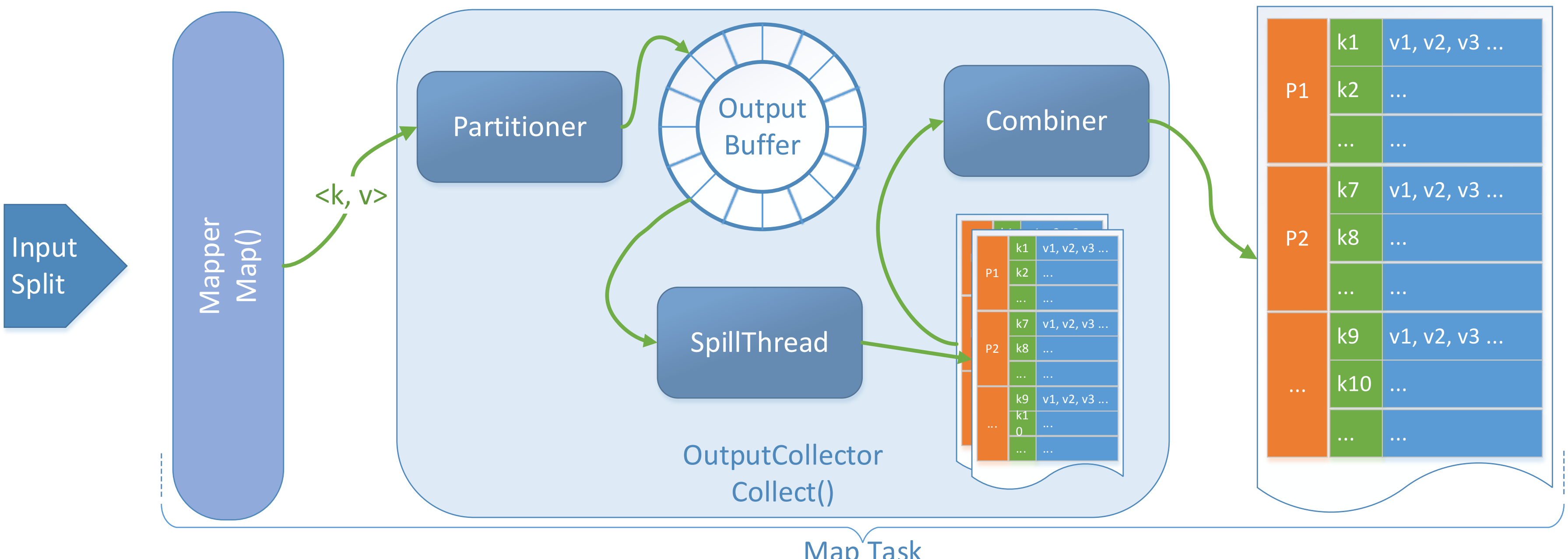


Hadoop Implementation

Map

- Buffered output
- Spill to disk

Reduce



Hadoop Key Designs

Shuffle

- All-to-all input data fetching phase in a reduce task
- The reduce function will not be performed until its completion
- Disk I/O and network intensive

Overlapping shuffle with map tasks

- Hadoop allows an early start of the shuffle phase as soon as part of the reduce input is available
- By default, shuffle is started when 5% of map tasks finished

Fair sharing

- Hadoop enforces fairness among users/jobs
- Fair share of map and reduce slots

Issues

Input data skew among reduce tasks

- Non-uniform key distribution → Different partition size
- Lead to disparity in reduce completion time

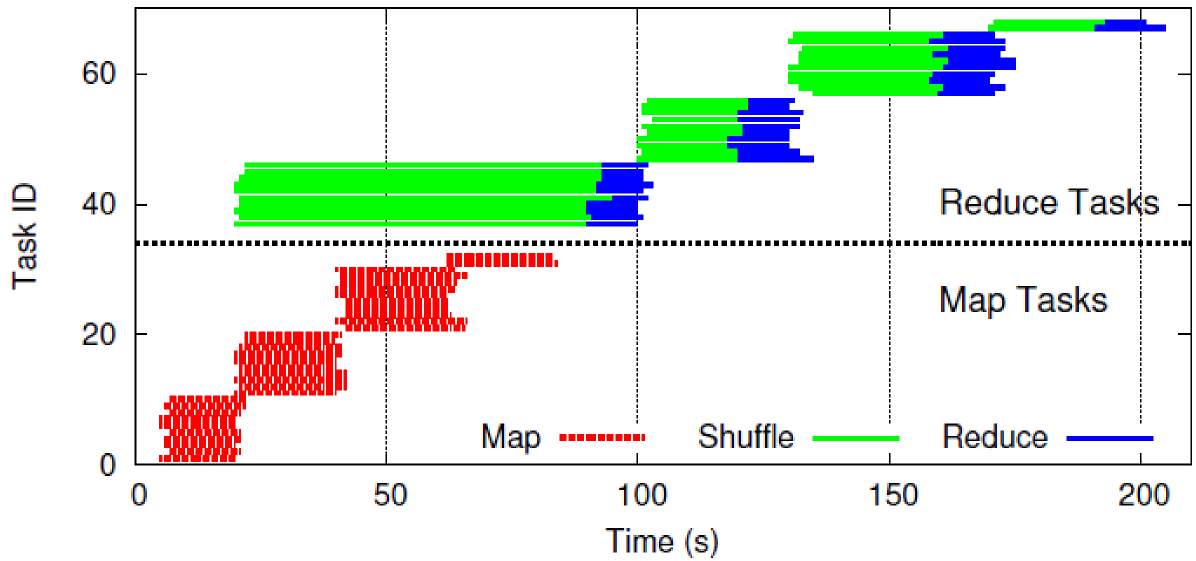
Inflexible Scheduling of Reduce Tasks

- Reduce tasks are created during job initialization
- Tasks are scheduled in ascending order of their ID
- Reduce tasks can not start even if all their input partitions are available

Tight coupling of shuffle and reduce

- Shuffle starts only when the corresponding reduce is scheduled
- Leaving parallelism within and between jobs unexploited

A Motivating Example



Workload: tera-sort with 4GB dataset
Platform: 10-node Hadoop cluster
1 map and 1 reduce slots per node

Related Work

Map Scheduling in Hadoop

- Accelerating straggler Task: [OSDI'08]
- Enforcing Fairness: [Middleware'10], [EuroSys'10]

Not applicable to reduce tasks

Improving reduce performance

- Push-based shuffling: [NSDI'10]
- RDMA-based acceleration: [SC'11]
- Specially designed partitioner: [TPDS'12]

Requiring hardware support or not effective in multiple wave execution

Our Approach

Decouple shuffle phase from reduce tasks

- Shuffle as a platform service provided by Hadoop
- Pro-actively and deterministically push map output to different slave nodes

Balancing the partition placement

- Predict partition sizes during task execution
- Determine which node should a partition been shuffled to
- Mitigate data skew

Flexible reduce task scheduling

- Assign partitions to reduce tasks only when scheduled

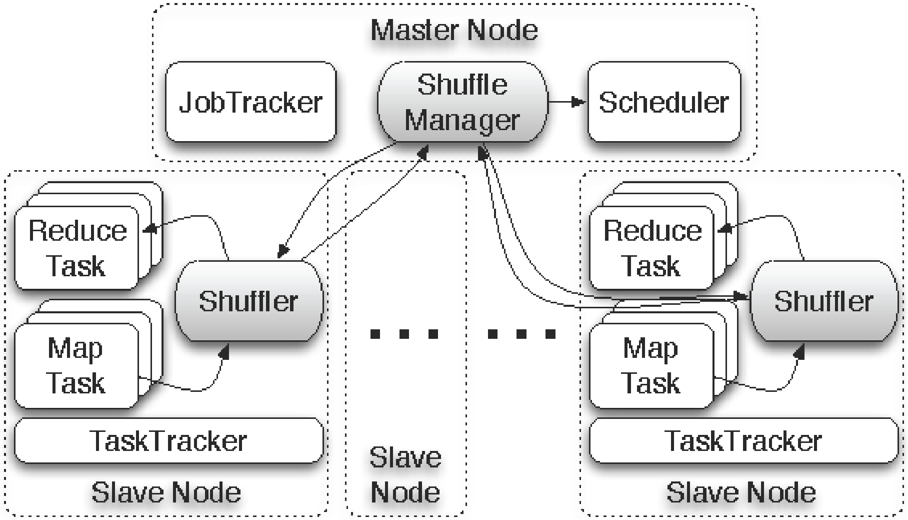
iShuffle Design

iShuffle

- Shuffler
- Shuffle Manager
- Task Scheduler

Features

- User-Transparent Shuffle Service
- Shuffle-on-Write
- Automated Map Output Placement
- Flexible Reduce Task Scheduling



Shuffle-on-Write

“shuffle” when Hadoop stores intermediate results

Map output collection

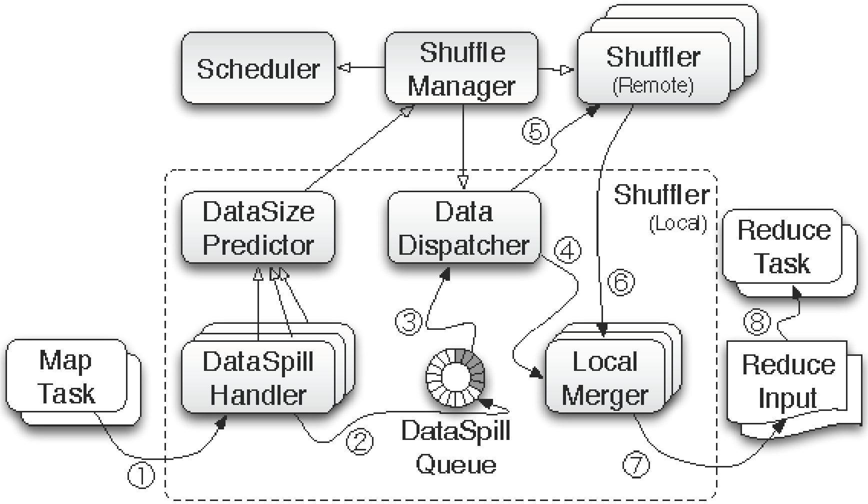
- MapOutputCollector
- DataSpillHandler

Data shuffling

- Queuing and Dispatching
- Data Size Predictor
- Shuffle Manager

Map output merging

- Merger
- Priority-Queue merge sort



Partition Placement

Prediction of Partition Sizes

- Task characteristics: input data size, map selectivity
- Linear model between partition size and input data size
- Metrics measured during the task execution

$$p_{i,j} = a_j + b_j D_i$$

Partition Placement Problem

- Minimizes the difference of total partition size on different nodes
  - $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\mu - \sum_{j \in s_i} p_j\right)}$

Heuristic Placement Algorithm

Largest Partition First (LPF)

- Pick the largest partition first
- Place it to node with the least total partition size

Data: p: list of partition
Data: S: list of nodes, has the size of all allocated partitions
Result: Balanced partition placement

```
sort list p in descending order of partition sizes;
for i ← 1 to m do
    min_node ← S[1];
    for j ← 1 to n do
        if S[j].size < min_node.size then
            min_node ← S[j];
        end
    end
    min_node.place(p[i]);
end
```

Flexible Reduce Scheduling

Assign Partitions to Reduce Tasks at Runtime

- Override the partition assignment at job initialization
- Allow tasks to run on any node

Multiple Job Scheduling

- Fair scheduling for map tasks
- Disabled fair share for reduce tasks
- Prevent wasted cluster cycles for waiting unfinished maps

Experiments

32-node Hadoop Cluster

- 1 namenode, 1 jobtracker, 30 slave nodes
- 4 map slots and 2 reduce slots per slave
- HDFS Block size = 64 MB
- Hadoop version 1.1.1

Hardware

- Intel Xeon E5530, 4-core, 2.4 GHz
- 4 GB Memory
- 1 Gbps Ethernet

Benchmark

Purdue MapReduce Benchmark Suite (PUMA)

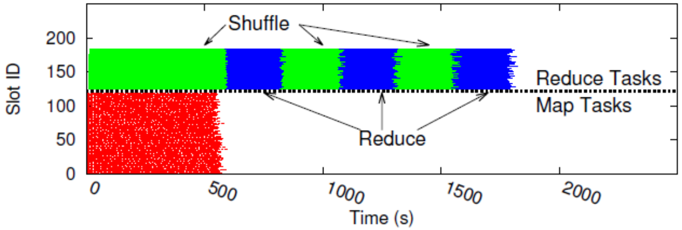
- Real data set from Wikipedia, Netflix
- Shuffle-heavy and shuffle-light

	Job	Input Size (GB)	# Map	# Reduce	Shuffle Vol (GB)
Shuffle-heavy	Self-join	250	4000	180	246
	Tera-sort	300	4800	180	300
	Ranked-inverted-index	220	3520	180	235
	K-means	30	480	6	43
	Inverted-index	250	4000	180	57
	Term-vector	250	4000	180	59
	wordcount	250	4000	180	49
Shuffle-light	Histogram-movies	200	3200	180	0.002
	Histogram-ratings	200	3200	180	0.0012
	Grep	250	4000	180	0.0013

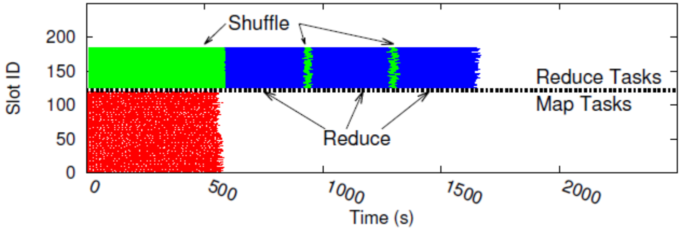
iShuffle Performance

Execution Trace

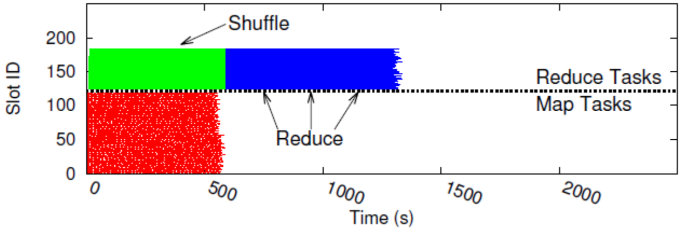
- Slow start of Hadoop does not eliminate shuffle delay for multiple reduce wave
- Overhead of remote disk access of Hadoop-A [SC'11]
- iShuffle has almost no shuffle delay



(a) Hadoop.



(b) Hadoop-A.



(c) iShuffle.

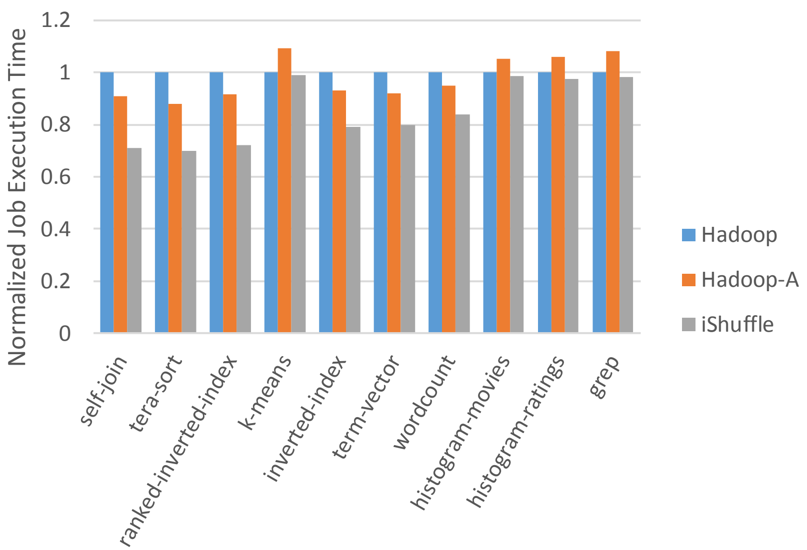
iShuffle Performance (cont'd)

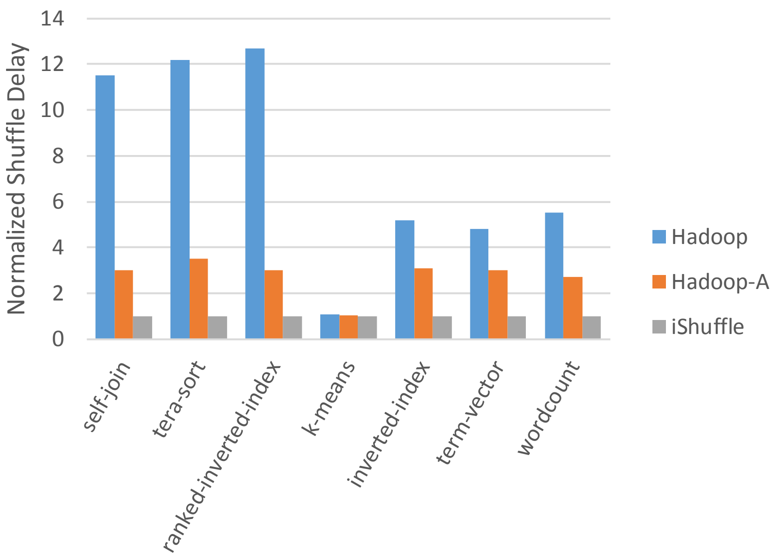
Reducing Job Completion Time

- **30%** and **21%** less than vanilla Hadoop and Hadoop-A

Reducing Shuffle Delay

- **10x** less than vanilla Hadoop in job's with large shuffle volume
- **2x** to **3x** less than Hadoop-A

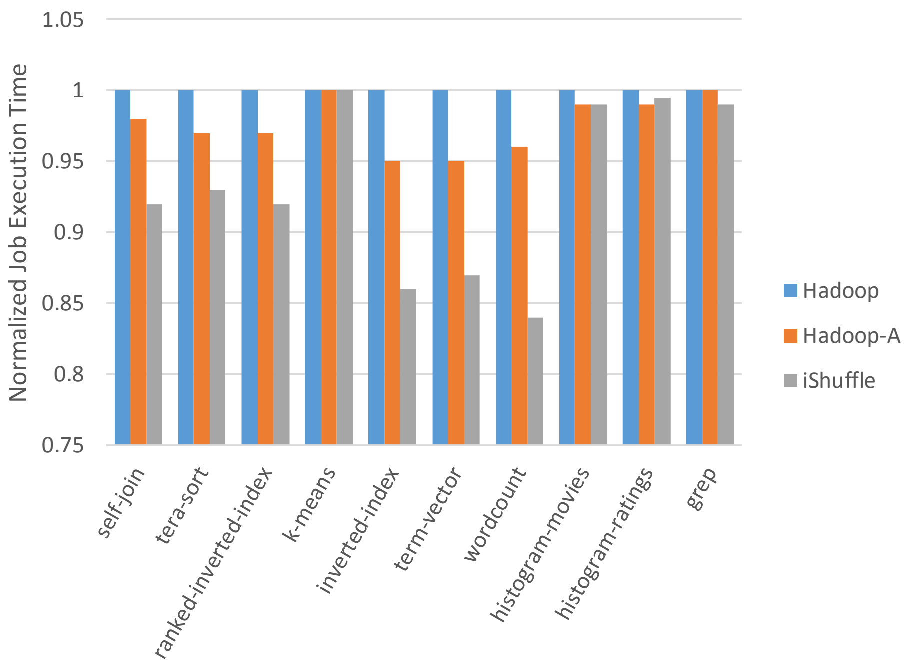




Balanced Partition Placement

Performance improvement by a Balanced Partition Placement

- **8-12%** shorter job completion time



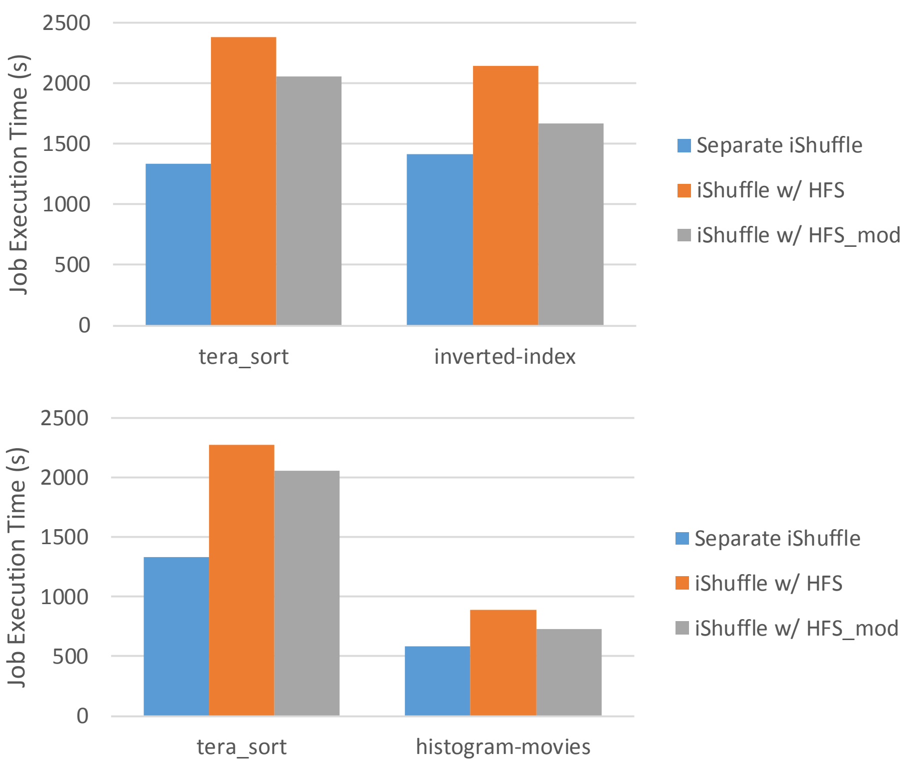
Multiple Job Performance

Shuffle-heavy + Shuffle-heavy

- **8%** and **23%** improvement on tera_sort and inverted-index

Shuffle-heavy + Shuffle-light

- **16%** and **25%** improvement on tera_sort and histogram-movies



Conclusions

Motivations

- Tight coupling of shuffle of reduce
- Inefficient reduce scheduling
- Parallelism unexploited

iShuffle

- Proactively push shuffle data
- Balancing map output to mitigate data skew
- Flexible reduce scheduling

Results

- Significantly reducing completion time for shuffle-heavy jobs

Questions?

Backup Slides

iShuffle v.s. Random Placement

iShuffle outperforms randomization -based placement algorithms