On the Performance of MapReduce: A Stochastic Approach

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Agenda

- Introduction
- Background
- Disk I/O
- Merge Overhead
- Runtime

Introduction

- MapReduce is a popular programming model for cluster computing, big data processing
- Resource constraints and data properties dictate MapReduce performance
  - Specifically, RAM size and distribution of key frequency impact both the run-time and volume of disk I/O
- Existing literature is missing an accurate performance model for external-memory sorting/merging
- Common to assume a linear relationship between input size and processing overhead
  - This includes disk spill, number of comparison in sort/merge

Introduction (2)

- Open questions:
  - Is this dependency indeed linear with some constant factor converting input size to various metrics of interest?
  - Does the constant stay the same in the full design space?
  - Is the constant easy to obtain/estimate?
- Our objective: analyze a shared-memory MapReduce system with a single host for all computation
  - Multiple CPU cores provide parallelism
  - Data distribution is only through disks, not network
- Due to limited space, we analyze only the *external merge-sort* as the underlying algorithm

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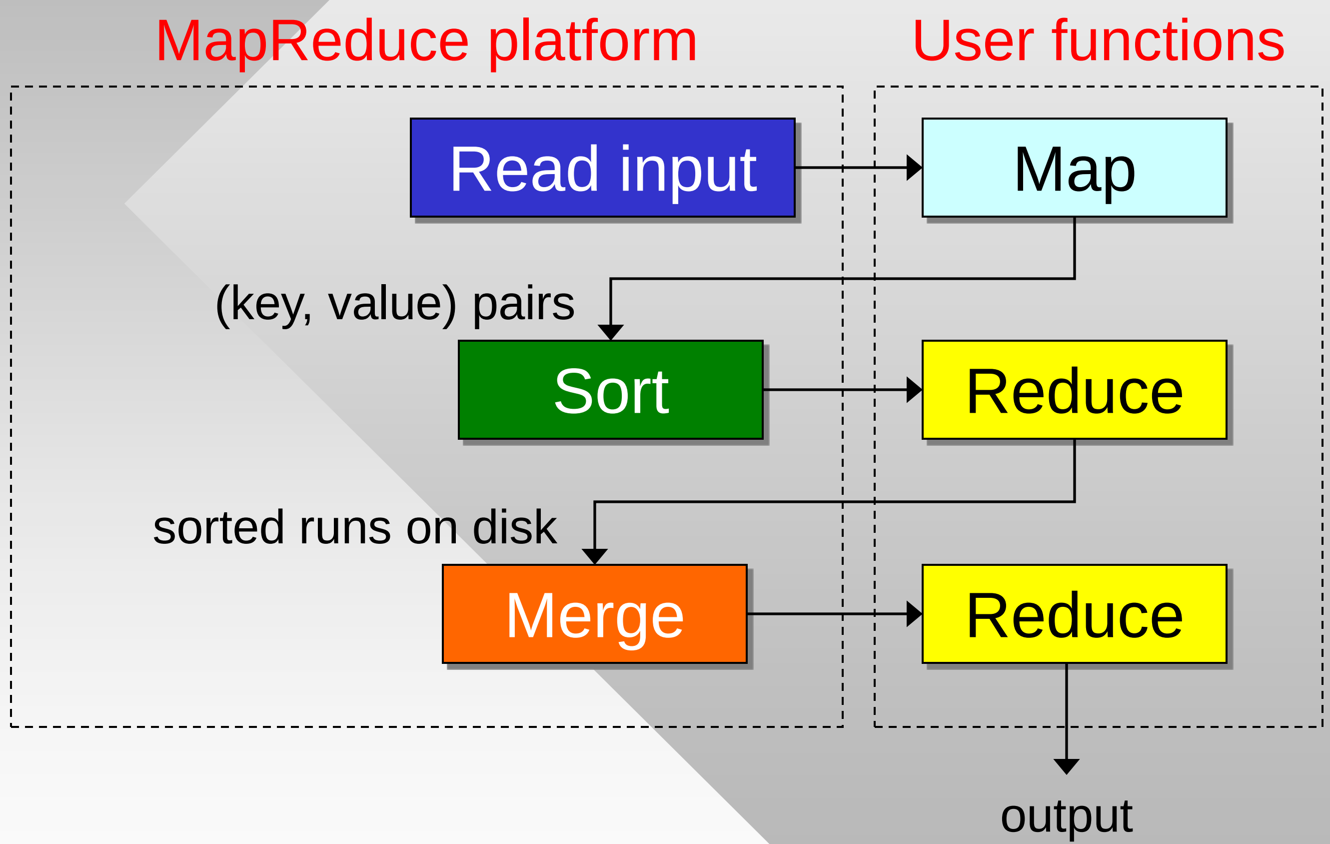
Background



MapReduce platform
User functions
Read input
Map
(key, value) pairs
Sort
Reduce
sorted runs on disk
Merge
Reduce
output

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MapReduce Disk I/O

- Input is a stream of length T
  - Entries are key-value pairs, each $K{+}D$ bytes
  - At time step t, one pair is processed by MapReduce
  - Keys belong to a finite set V of size n
  - Each key v is repeated $\mathcal{I}(v)$ times
- Disk I/O consists of:
  - Input with T pairs (some duplicate)
  - Output with n unique pairs
  - Sorted runs of size L
- Total disk overhead is $W = (K{+}D)(T + n + 2L)$
  - Our first goal is to derive L

MapReduce Disk I/O (2)

- Suppose RAM can hold m key-value pairs
- Let S_t denote the seen set at time t and $\epsilon_t = t/T$ be the fraction of input processed by t
  - Then, $k = \lceil T/m \rceil$ is the number of sorted runs, where each contains $E[|S_m|]$ pairs on average
- Theorem 1: The expected size of the seen set at t is:

$$E[|S_t|] = n - nE[(1-\epsilon_t)^{\mathcal{I}}]$$

- Theorem 2: Disk spill L of a merge-sort MapReduce is:

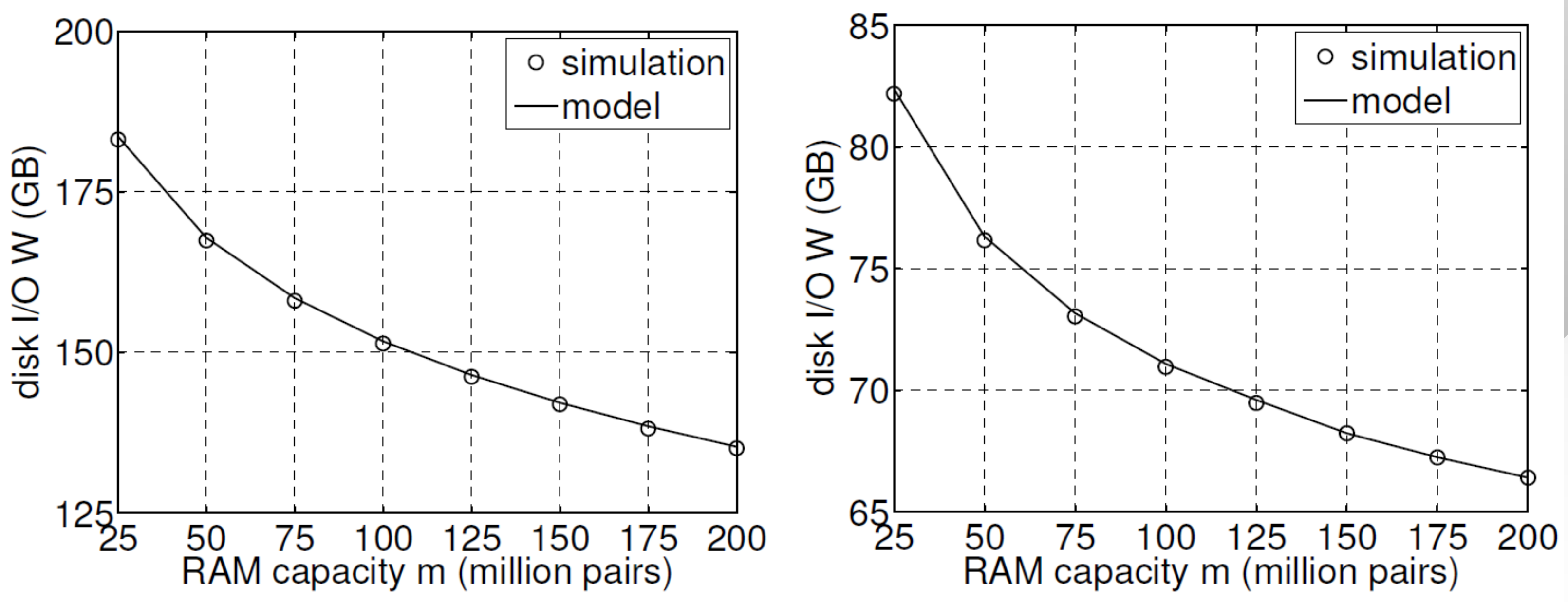
$$L = nk(K+D)\left(1 - E\left[(1-\epsilon_m)^{\mathcal{I}}\right]\right)$$

- Total I/O overhead is thus:

$$W = n(K+D)\left\{E[\mathcal{I}] + 1 + 2k\left(1 - E\left[(1-\epsilon_m)^{\mathcal{I}}\right]\right)\right\}$$

MapReduce Disk I/O (3)

- Quite a complex function of m and $\mathcal{I}$
- Verification on real graphs
  - IRLbot host graph (640M nodes, 6.8B edges, 55 GB)
  - WebBase web graph (667M nodes, 4.2B edges, 33 GB)



(c) IRLbot host graph (d) WebBase web graph

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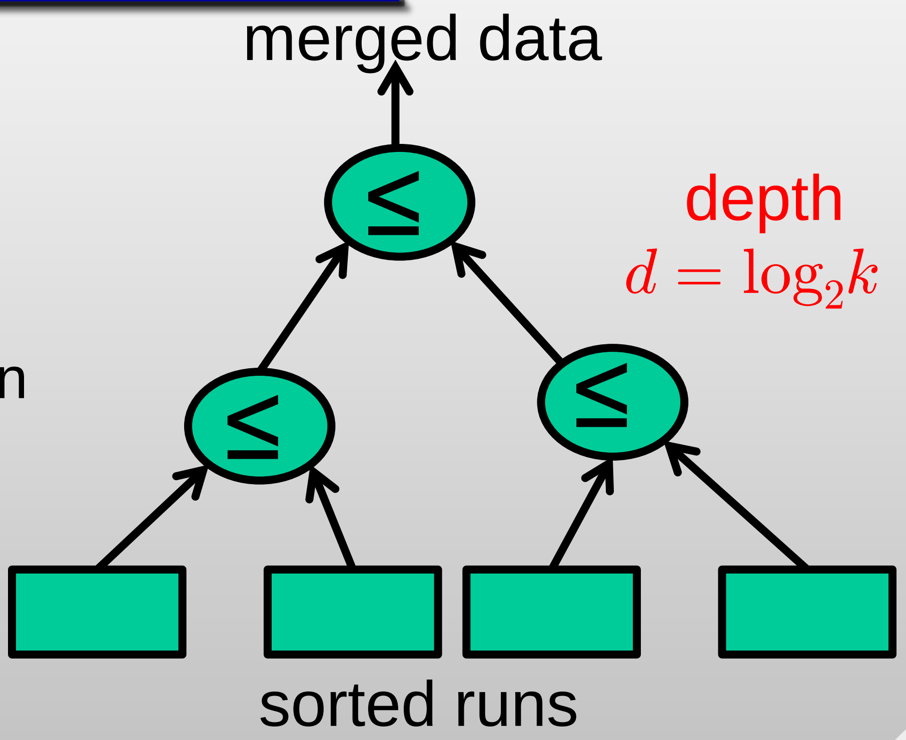
MapReduce Merge Overhead



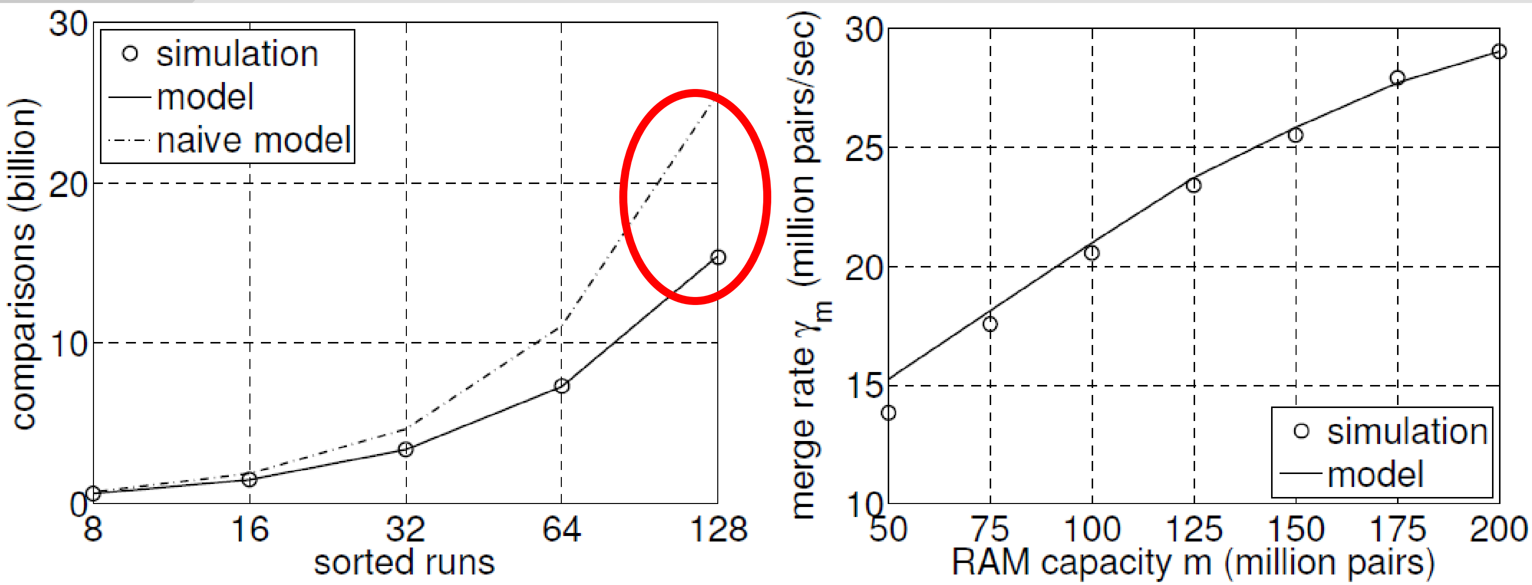
- Selection tree for merging sorted runs, where each internal node
  - Executes binary comparison
  - Applies reduce operation
- De-duplication makes upper nodes perform less work than lower
- Theorem 3**:** The number of comparisons in a binary selection tree with k leaf nodes is:

$$C_k = nk \sum_{i=1}^{d} \frac{1}{2^{i-1}} \left(1 - E\left[(1-\epsilon_{im})^{\mathcal{I}}\right]\right)$$

Merge Rate Evaluation

- Comparison with naïve model (no de-duplication):

$$\widehat{C}_k = n \log_2 k \cdot \left(1 - E[(1-\epsilon_m)^{\mathcal{I}}]\right)$$



(a) merge comparisons (b) merge speed γ_m

- Comparison overhead and merge rate γ_m dictated by k
  - Higher k implies more de-duplication

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MapReduce Runtime

- Total runtime is:

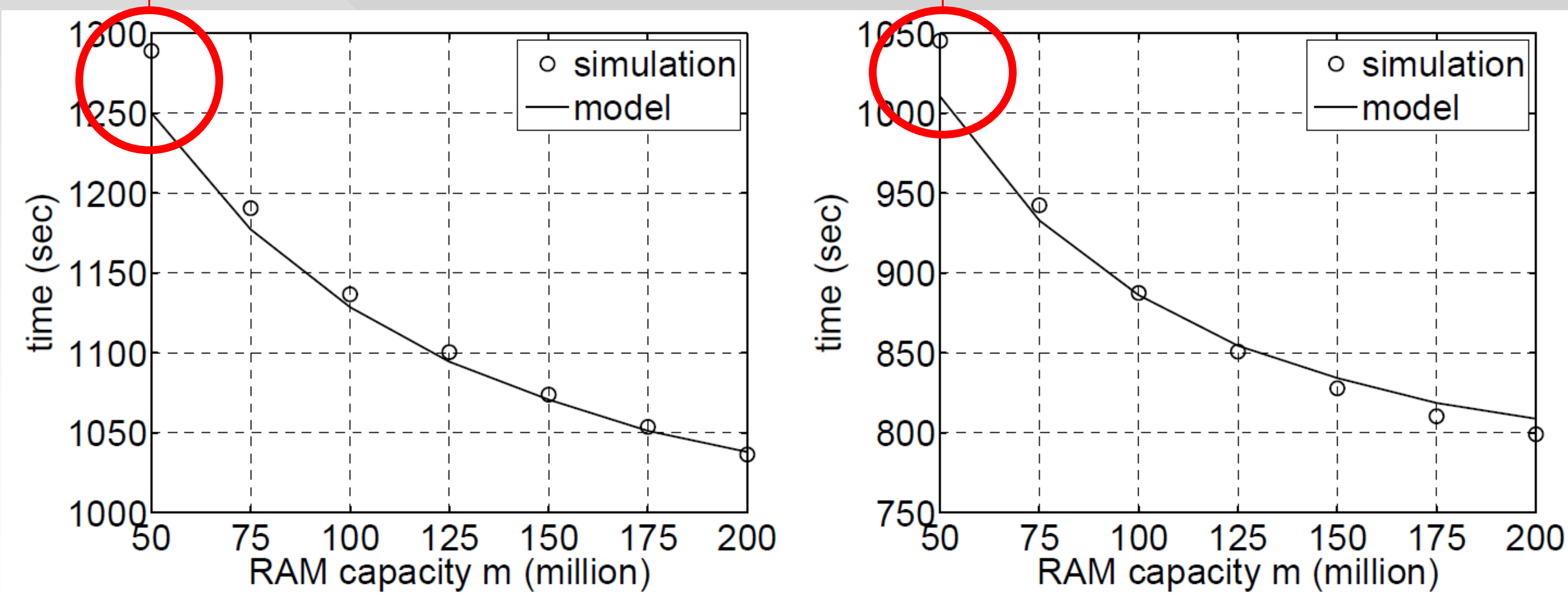
$$\mathcal{M} = \frac{W}{\rho} + \frac{T}{\delta} + \frac{L}{\gamma m},$$

disk speed

sort rate

merge rate

slight discrepancy due to disk seeking during merge



(a) 500 MB/s disk

(b) 2500 MB/s disk

Computer Science, Texas A&M University

Thank you!
Questions?