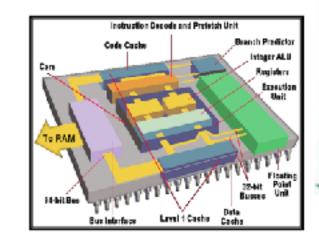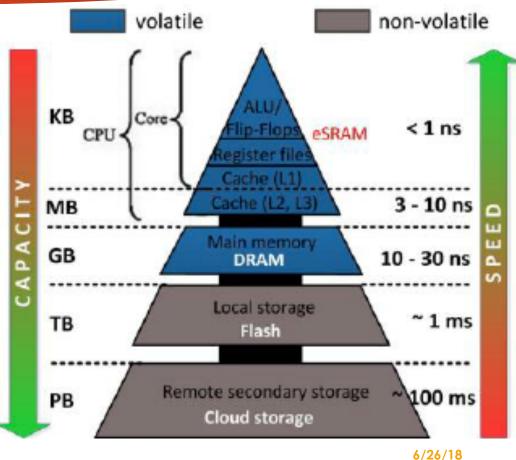# Introduction to Data Science

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Big Data & Computing

Memory Hierarchy in Computers

- ▶ Actual computation happens on a CPU
  - ❑ Fastest when the operands are in registers
- ▶ Data and programs are in main memory
  - ❑ Frequent items can be found in cache
- ▶ Beyond MM are 2° and 3° storage
  - ❑ Disk
  - ❑ Flash
  - ❑ Magnetic tapes
  - ❑ cloud

High-Performance Computing

▶ Multi-core Multi-processor machines

▶ Multi-thread vs Multi-process

▶ GPU machines

▶ Clusters

▶ Clouds

▶ Supercomputers

The "Map-Reduce" Framework

MapReduce

▶ Sometimes a single computer cannot process data or takes too long

❑ Processor constraints

❑ Storage constraints

❑ Memory Constraints

▶ But when resources are pooled, it may be possible

▶ **MapReduce**: a programming paradigm to process large data sets

Map-Reduce

▶ **Ranking (e.g., PageRank) requires iterated matrix-vector multiplication with matrix containing millions of rows and columns**

▶ **Computing with social networks involves graphs with hundreds of millions of nodes and billions of edges**

▶ **Map-Reduce** **is a parallel programming paradigm, a software-stack that will help to address big data processing**

  ❑ **Distributed file system** **with** **redundancy** **(e.g., Google FS, Hadoop DFS, CloudStore)**

  ❑ **Network of racks of processors forming a** **cluster**
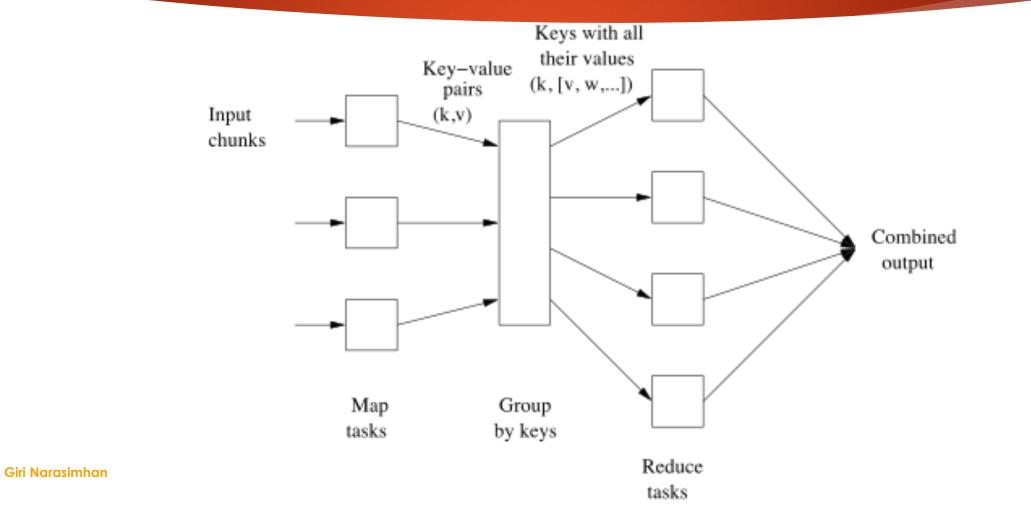
MapReduce

- **Framework used by writing 2 procedures – Map and Reduce**
- **Map**
  - **Input is broken into chunks and each Map task is given one or more chunks**
  - **Output of Map task: (key, value) pairs. Master controller sorts by keys**
  - **Reduce task works on all pairs with same key and combines values as defined**

MapReduce Schematic

MapReduce Example

▶ **Input**: repository of documents

▶ **Output**: word Frequencies (want freq of word in a collection of docs)

▶ **Input element**: one document

▶ **Map task**: For each document, for each of its words, output pair (w,1)

▶ **Master Controller** groups pairs by keys into a list, then merges into a file

▶ **Reduce task**: "Combines" items related to a word getting frequency of single word

❑ If Combine is associative & commutative, can move work between map/reduce
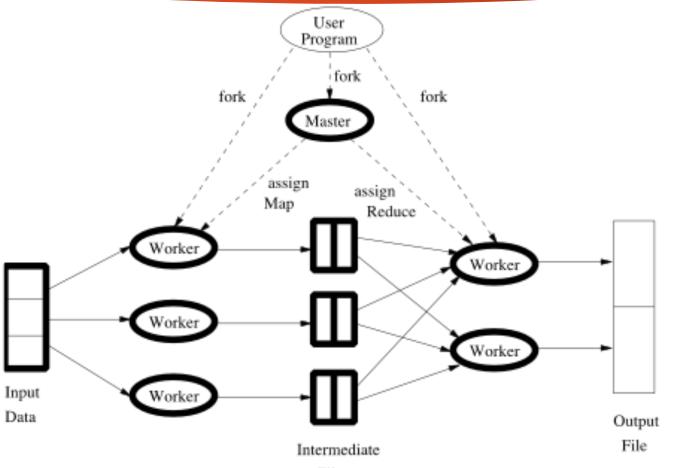
MapReduce Subtleties

▶ **One document assigned to one Map task (many docs to same Map)**

▶ **Tradeoff between Map-Reduce**: Map could do part of combine and decrease work for Reduce, i.e., it could return (w.m) count of number of occurrences of word w in one document

▶ **Master Controller uses a hash function** to distribute work into r tasks, since it knows # of Reduce nodes. One bucket → one file for Reduce. This helps to distribute work randomly among Reduce tasks/nodes.

▶ **One word assigned to one Reduce task (many words to same Reduce)**

Skew

- **Imbalance in workload to different tasks and their compute nodes**
  - ❑ **More tasks means more overhead of creating tasks**
  - ❑ **More tasks means greater ability to balance out load**
  - ❑ **More documents and words than nodes**
  - ❑ **Number of documents and their sizes may be known beforehand**

MapReduce Execution

Node Failures

- **Compute node failure: Restart**

- **Map node failure: Master node monitors, reassigns, and restarts task; all Reduce tasks informed of new task/location and to discard old task/ location**

- **Reduce node failure: Master node monitors, reassigns and restarts task**
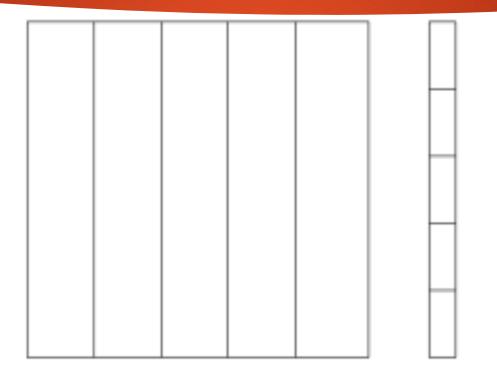
Matrix-Vector Multiplication

- Same vector in MM of every node

- Matrix M: n X n

- Vector v: length n

- Map step: focus on one element of M

- Output contribution by one element:

- Reduce step: Sum up all entries for key i to get result x_i

$$x_i = \sum_{j=1}^{n} m_{ij} v_j$$

$$(i, m_{ij} v_j)$$

What if vector is too large for MM

Figure 2.4: Division of a matrix and vector into five stripes

Matrix Multiplication: 2 MapReduce steps

▶ Matrix M can be thought of as a relation with tuples (i, j, m_{ij})

▶ Matrix N can be thought of as a relation with tuples (j, k, n_{jk})

▶ Map operation creates these tuples

▶ Map: Join of M and N brings us closer to M X N by creating:

- ❑ Relation $(i, j, k, m_{ij}, n_{jk})$ or the relation $(i, j, k, m_{ij} X n_{jk})$

▶ Grouping and aggregation produces M X N

- ❑ Map operation: identity operation producing tuple $(i, k, m_{ij} X n_{jk})$
- ❑ Reduce operation: aggregates all tuples with (i, k, Z) and stores in cell (i,k)

Matrix Multiplication: 1 MapReduce step

▶ Map:

- ❑ Produce tuples $((i, k), (M, j, m_{ij}))$ from M
- ❑ Produce tuples $((i, k), (M, j, m_{ij}))$ from M

▶ Reduce:

- ❑ Produce one entry of M X N

Relational DB operations using MapReduce

- Selection
- Projection
- Union, Intersection & Difference
- Natural Join
- Grouping and aggregation

Example: Paths of length 2 in network

▶ If we want to know if there is a path of length 2 in a directed network from vertex A to B, then we need to find a vertex C such that (A,C) and (C,B) are directed edges in the network.

▶ This can be written as a join of 2 relations. **How**?

▶ This can also be written as a matrix multiplication of 2 adjacency matrices of a network/graph. **How**?

❑ Now we can implement using a MapReduce framework

More complex example: Arbitrage

▶ Assume currency exchange rates as follows:

- ❑ EUR/CAD: 0.664 (1 CAD buys you .0.664 EUR)

- ❑ USD/EUR: 1.234

- ❑ CAD/USD: 1.398

▶ If you start with 10,000 CAD, then use it to buy

- ❑ 6,640 EUR

- ❑ 6,640 * 1.234 USD

- ❑ 6,640 * 1.234 * 1.398 CAD = 11,454.87 CAD

▶ **Profit** of 1,454.87 CAD or 14.5%. Not bad!

Triangular Arbitrage

Arbitrage using MapReduce

▶ Process currency market quotes

▶ Look for uncompleted offers to make the 3 currency exchanges

❑ Find all offers to BUY EUR with CAD, BUY USD with EUR, and BUY CAD with USD

▶ Find a triple that makes you a profit

▶ Now read this blog article that explains how to do it in Python/Hadoop

❑ https://medium.com/@rrfd/your-first-map-reduce-using-hadoop-with-python-and-osx-ca3b6f3dfe78

Running MapReduce

▶ Need **Map** code

▶ Need **Reduce** code

▶ Need **Hadoop** set up

   ❑ Hadoop Distributed File System (HDFS)

   ❑ Parallel Processing environment

▶ Blog tells you in detail how to set it up and run the MapReduce code

   ❑ https://medium.com/@rrfd/your-first-map-reduce-using-hadoop-with-python-and-osx-ca3b6f3dfe78

   ❑

Many more examples …

- https://datascienceguide.github.io/map-reduce