INTRO TO DATA SCIENCE MAP-REDUCE

I. BIG DATA
II. PROGRAMMING MODEL
III. IMPLEMENTATION DETAILS
IV. WORD COUNT EXAMPLE

EXERCISE:

V. MAP-REDUCE USING PYTHON

INTRO TO DATA SCIENCE

I. BIG DATA

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A: Scalability; in particular, storing & processing web-scale (multi-terabyte) datasets...

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But this is only half of the story...how would you do this?

One approach would be to get a huge supercomputer.

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But this has some obvious drawbacks:

- expensive
- difficult to maintain
- scalability is bounded

Instead of one huge machine, what if we got a bunch of regular (commodity) machines?

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This has obvious benefits!

- cheaper
- easier to maintain
- scalability is unbounded (just add more nodes to the *cluster*)

Now we can give a complete answer to our earlier question.

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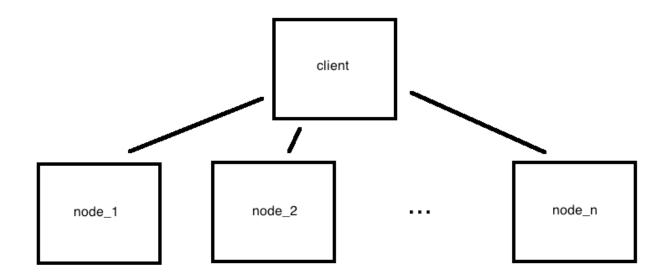
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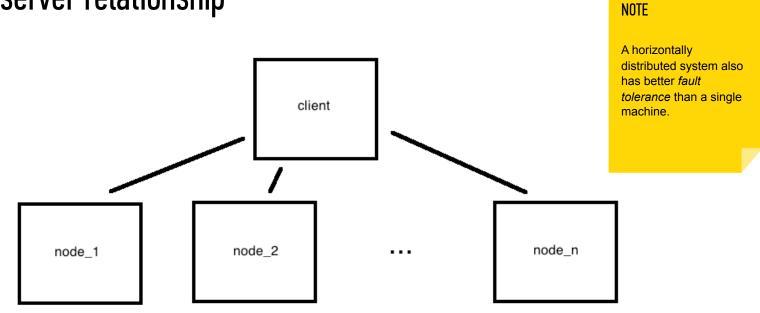
A: Scalability; in particular, storing & processing web-scale (multi-terabyte) datasets using clusters of multiple computing nodes.

"Scale out vs scale up!"

We can visualize this *horizontal* cluster architecture as a single client-multiple server relationship



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There are two ways to process data in a distributed architecture:

1) move data to cores (& code)

2) move code to data (& cores)

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- 1) move data to cores (& code)
 - SETI@home

- 2) move code to data (& cores)
 - map-reduce → less overhead (network traffic, disk I/0)

"Computing nodes are the same as storage nodes."

Divide and conquer is a fundamental algorithmic technique for solving a given task, whose steps include:

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- 1) split task into subtasks
- 2) solve these subtasks *independently*
- 3) recombine the subtask results into a final result

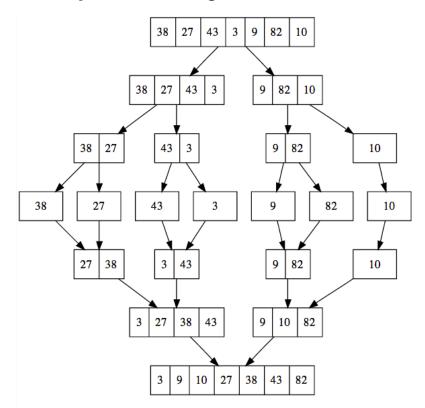
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- 2) solve these subtasks *independently*
- 3) recombine the subtask results into a final result

This is how recursive algorithms work, for example.

One famous example of divide and conquer is *merge sort*.





Map-reduce leverages the divide and conquer approach by splitting a large dataset into several smaller datasets and performing a computation on each of these in parallel.

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In fact, running a map-reduce job with identity (eg, do-nothing) mappers and reducers is similar to merge sort!

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In fact, running a map-reduce job with identity (eg, do-nothing) mappers and reducers is similar to merge sort!

(The similarity is approximate, because results are output in multiple sets, and data is not broken down to single-element subsets.)

The defining characteristic of a problem that is suitable for the divide and conquer approach is that it can be broken down into *independent* subtasks.

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Tasks that can be *parallelized* in this way include:

- count, sum, average
- grep, sort, inverted index
- graph traversals, some ML algorithms

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- graph traversals, some ML algorithms

NOTE

Parallelizing an ML algorithm can be a non-trivial exercise!

II. PROGRAMMING MODEL

As we've discussed, the map-reduce approach involves splitting a problem into subtasks and processing these subtasks in parallel.

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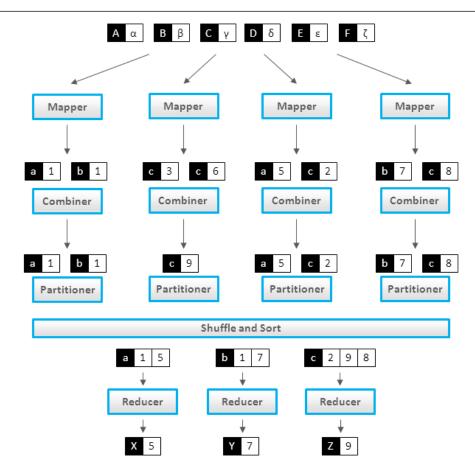
This takes place in two phases:

- 1) the **mapper** phase
- 2) the **reducer** phase

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This takes place in (*approximately*) two phases:

- 1) the **mapper** phase
- 1.5) shuffle/sort
- 2) the **reducer** phase



Map-reduce uses a *functional programming* paradigm. The data processing *primitives* are mappers and reducers, as we've seen.

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MAP-REDUCE

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The functional paradigm is good at describing how to solve a problem, but not very good at describing data manipulations (eg, relational joins).

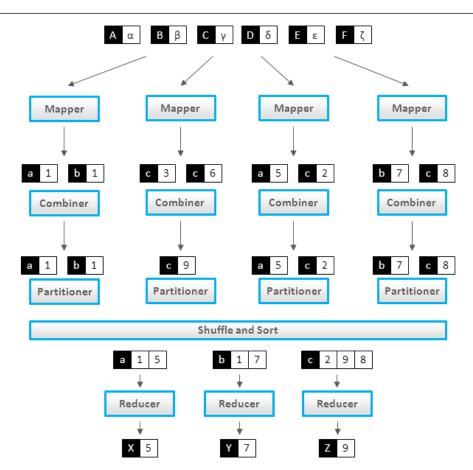
MAP-REDUCE

As our earlier diagram suggests, there are additional intermediate steps in a map-reduce workflow.

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MAP-REDUCE



It's possible to overlay the map-reduce framework with an additional declarative syntax.

This makes operations like select & join easier to implement and less error prone.

Popular examples include Pig and Hive.

Why Pig?

Because I bet you can read the following script.

A Real Pig Script

```
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  users = load 'users.csv' as (username: chararray, age: int); -
  users 1825 = filter users by age >= 18 and age <= 25;
  pages = load 'pages.csv' as (username: chararray, url: chararray); -
  joined = join users 1825 by username, pages by username;
  grouped = group joined by url; -
  summed = foreach grouped generate group as url, COUNT(joined) AS views; -
  sorted = order summed by views desc;
  top 5 = limit sorted 5;
      e top_5 into 'top_5_sites.csv';
```

Now, just for fun... the same calculation in vanilla Hadoop MapReduce.

No, seriously.

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III. IMPLEMENTATION DETAILS

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The map-reduce framework handles a lot of messy details for you:

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- parallelization & distribution (eg, input splitting)
- partitioning (shuffle/sort/redirect)
- fault-tolerance (fact: tasks/nodes will fail!)
- I/O scheduling
- status and monitoring

IMPLEMENTATION DETAILS

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- I/O scheduling
- status and monitoring

This (along with the functional semantics) allows you to focus on solving the problem instead of accounting & housekeeping details.

HADOOP

Hadoop is a popular open-source Java-based implementation of the map-reduce framework (including file storage for input/output).

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Hadoop is written in Java, but the *Hadoop Streaming* utility allows client code to be supplied as executables (eg, written in any language).

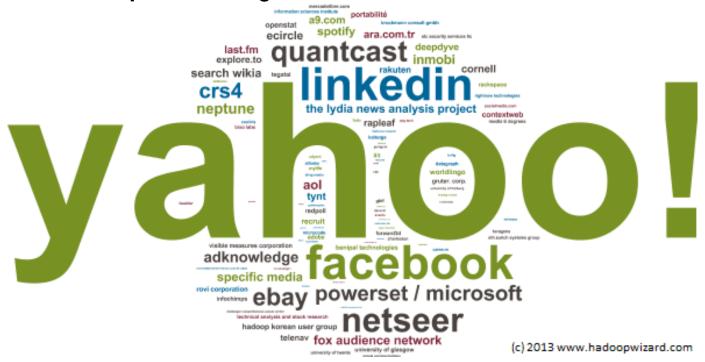
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HADOOP

Frequently when people say "map-reduce" they're referring to Hadoop, but there are some exceptions:

- many NoSQL databases support native map-reduce queries
- commercial distributions (Cloudera, MapR, etc)
- Google's internal implementation

That said, Hadoop has a large user base.



Data is replicated in the (distributed) file system across several nodes.

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This permits locality optimization (and fault tolerance) by allowing the mapper tasks to run on the same nodes where the data resides.

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So we move code to data (instead of data to code), thus avoiding a lot of network traffic and disk I/O.

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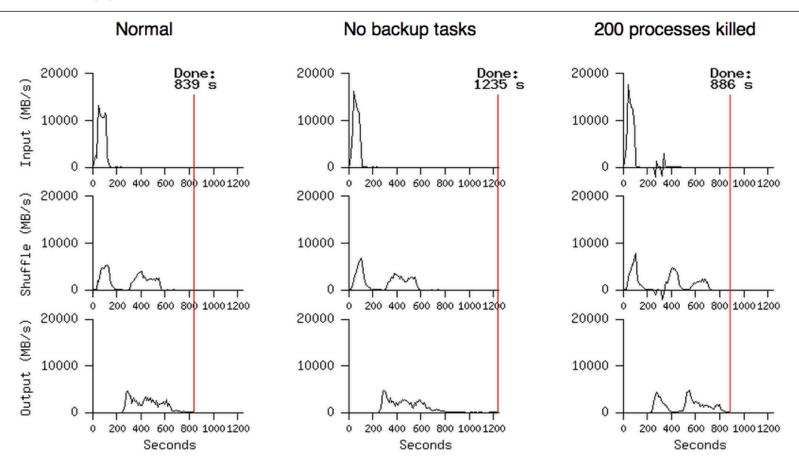
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If you use Amazon EMR, you can use Amazon S3.



IV. WORD COUNT EXAMPLE

Map-reduce processes data in terms of *key-value pairs*:

```
input <k1, v1> mapper <k1, v1> \rightarrow <k2, v2> (partitioner) <k2, v2> \rightarrow <k2, [all k2 values]> reducer <k2, [all k2 values]> \rightarrow <k3, v3>
```

MAP-REDUCE EXAMPLE

Using the following input, we can implement the "Hello World" of map-reduce: a word count.

MAP-REDUCE EXAMPLE: MAPPER INPUT

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```
where in where in the where in the world where in the world is where in the world is carmen where in the world is carmen sandiego
```

MAP-REDUCE EXAMPLE: MAPPER

The first processing primitive is the mapper, which filters & transforms the input data, and *emits* transformed key-value pairs.

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```
mapper(k1, v1):
// k1 = line number
// v1 = line contents (eg, space-delimited string)

words = tokenize(v1) // split string into words
for word in words:
    emit (word, 1)
```

MAP-REDUCE EXAMPLE: MAPPER OUTPUT

The mapper emits key-value pairs for each word encountered in the input data.

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```
where 1 where 1 where 1 in 1 the 1
```

MAP-REDUCE EXAMPLE: PARTITIONER

The partitioner is internal to the map-reduce framework, so we don't have to write this ourselves. It shuffles & sorts the mapper output, and redirects all intermediate results for a given key to a *single* reducer.

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```
where
    [1, 1, 1, 1, 1, 1, 1]
in
    [1, 1, 1, 1, 1, 1]
the
    [1, 1, 1, 1, 1]
world
is
    [1, 1, 1, 1]
carmen
    [1, 1]
sandiego
[1]
```

MAP-REDUCE EXAMPLE: REDUCER

Finally, the reducer receives all values for a given key and aggregates (in this case, sums) the results.

MAP-REDUCE EXAMPLE: REDUCER

Finally, the reducer receives all values for a given key and aggregates (in this case, sums) the results.

```
reducer(k2, k2_vals):
// k2 = word
// k2_vals = word counts
   emit k2, sum(k2_vals)
```

MAP-REDUCE EXAMPLE: REDUCER OUTPUT

Reducer output is aggregated...

```
where
in 6
the 5
world 4
is 3
carmen 2
sandiego 1
```

MAP-REDUCE EXAMPLE: REDUCER OUTPUT

Reducer output is aggregated & sorted by key.

```
carmen 2
is 3
in 6
the 5
sandiego 1
where 7
world 4
```

V. EXERCISE