Cloud Computing
MapReduce to Spark

Minchen Yu
SDS@CUHK-SZ
Fall 2024

香港中文大學（深圳）
The Chinese University of Hong Kong, Shenzhen

SCHOOL OF
DATA SCIENCE
數據科學學院

Hadoop is great, but it’s really waaaaay too low level! (circa 2007)

What’s the solution?

Design a higher-level language
Write a compiler

Hadoop is great, but it's really waaaay too low level!

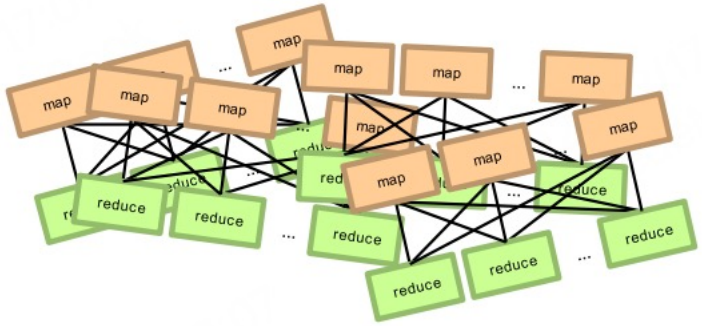
What we really need is SQL

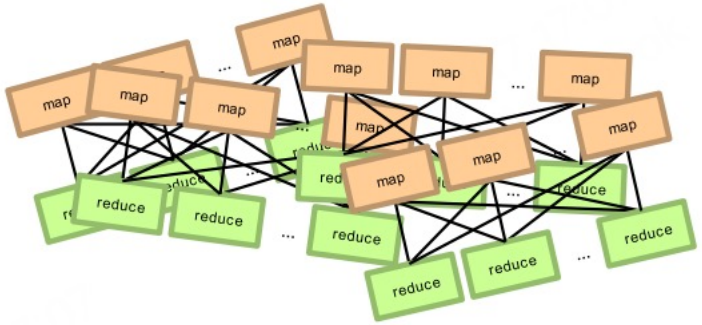
What we really need is scripting language

SQL

Why not just use a database?

Pig Scripts





Jeff Hammerbacher, Information Platforms and the Rise of the Data Scientist. In Beautiful Data, O'Reilly, 2009.

> "On the first day of logging the Facebook clickstream, more than 400 gigabytes of data was collected. The load, index, and aggregation processes for this data set really taxed the Oracle data warehouse. Even after significant tuning, we were unable to aggregate a day of clickstream data in less than 24 hours."

Story for another day…

Pig: Example

Find the top 10 most visited pages in each category

Visits

User	Url	Time
Amy	cnn.com	8:00
Amy	bbc.com	10:00
Amy	flickr.com	10:05
Fred	cnn.com	12:00

URL Info

User	Category	PageRank
cnn.com	News	0.9
bbc.com	News	0.8
flickr.com	Photos	0.7
espn.com	Sports	0.9

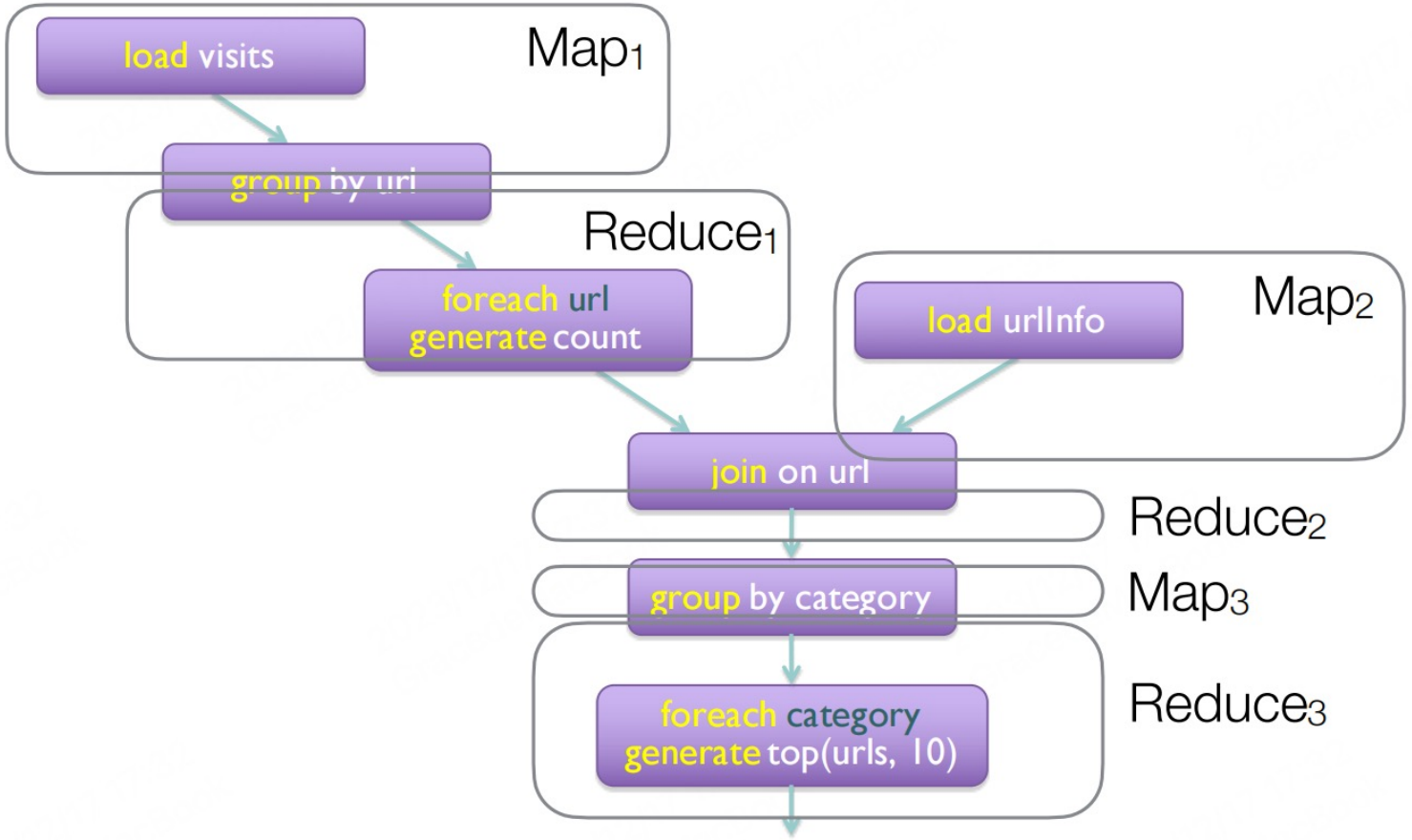
Pig slides adapted from Olston et al. (SIGMOD'08)

Pig: Example

```
visits = load '/data/visits' as (user, url, time);
gVisits = group visits by url;
visitCounts = foreach gVisits generate url, count(visits);
urlInfo = load '/data/urlInfo' as (url, category, pRank);
visitCounts = join visitCounts by url, urlInfo by url;
gCategories = group visitCounts by category;
topUrls = foreach gCategories generate top(visitCounts,10);

store topUrls into '/data/topUrls';
```

Pig slides adapted from Olston et al. (SIGMOD'08)

Pig query plan



Pig slides adapted from Olston et al. (SIGMOD'08)

```
visits = load '/data/visits' as (user, url, time);
gVisits = group visits by url;
visitCounts = foreach gVisits generate url, count(visits);
urlInfo = load '/data/urlInfo' as (url, category, pRank);
visitCounts = join visitCounts by url, urlInfo by url;
gCategories = group visitCounts by category;
topUrls = foreach gCategories generate top(visitCounts,10);
```

Or this?

```
import java.io.IOException;
import java.util.ArrayList;
import java.util.Iterator;
import java.util.List;

import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.io.Writable;
i mport org.apache.hadoop.io.WritableComparable;
import org.apache.hadoop.mapred.FileInputFormat;
import org.apache.hadoop.mapred.FileOutputFormat;
import org.apache.hadoop.mapred.JobConf;
import org.apache.hadoop.mapred.KeyValueTextInputFormat;
import org.a     pache.hadoop.mapred.Mapper;
import org.apache.hadoop.mapred.MapReduceBase;
import org.apache.hadoop.mapred.OutputCollector;
import org.apache.hadoop.mapred.RecordReader;
import org.apache.hadoop.mapred.Reducer;
import org.apache.hadoop.mapred.Reporter;
imp ort org.apache.hadoop.mapred.SequenceFileInputFormat;
import org.apache.hadoop.mapred.SequenceFileOutputFormat;
import org.apache.hadoop.mapred.TextInputFormat;
import org.apache.hadoop.mapred.jobcontrol.Job;
import org.apache.hadoop.mapred.jobcontrol.JobC                ontrol;
import org.apache.hadoop.mapred.lib.IdentityMapper;

public class MRExample {
    public static class LoadPages extends MapReduceBase
        implements Mapper<LongWritable, Text, Text, Text> {

        public void map(LongWritable k, Text val,
                        OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // Pull the key out
            String line = val.toString();
            int firstComma = line.indexOf(',');
            String key = line.sub          string(0, firstComma);
            String value = line.substring(firstComma + 1);
            Text outKey = new Text(key);
            // Prepend an index to the value so we know which file
            // it came from.
            Text outVal = new Text("1              " + value);
            oc.collect(outKey, outVal);
        }
    }
    public static class LoadAndFilterUsers extends MapReduceBase
        implements Mapper<LongWritable, Text, Text, Text> {

        public void map(LongWritable k, Text val,
                        OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // Pull the key out
            String line = val.toString();
            int firstComma = line.indexOf(',');
            String value = line.substring(                  firstComma + 1);
            int age = Integer.parseInt(value);
            if (age < 18 || age > 25) return;
            String key = line.substring(0, firstComma);
            Text outKey = new Text(key);
            // Prepend an index to the value so w                  e know which file
            // it came from.
            Text outVal = new Text("2" + value);
            oc.collect(outKey, outVal);
        }
    }
    public static class Join extends MapReduceBase
        implements Reducer<Text, Text, Text, Text> {

        public void reduce(Text key,
                Iterator<Text> iter,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // For each value, figure out which file it's from and
store it
            // accordingly.
            List<String> first = new ArrayList<String>();
            List<String> second = new ArrayList<String>();

            while (iter.hasNext()) {
                Text t = iter.next();
                String value = t.to            String();
                if (value.charAt(0) == '1')
first.add(value.substring(1));
                else second.add(value.substring(1));
```

```
                reporter.setStatus("OK");
            }

            // Do the cross product and collect the values
            for (String s1 : first) {
                for (String s2 : second) {
                    String outval = key + "," + s1 + "," + s2;
                    oc.collect(null, new Text(outval));
                    reporter.setStatus("OK");
                     )

                }
            }
        }
    public static class LoadJoined extends MapReduceBase
        implements Mapper<Text, Text, Text, LongWritable> {

        public void map(
                Text k,
                Text val,
                OutputColle          ctor<Text, LongWritable> oc,
                Reporter reporter) throws IOException {
            // Find the url
            String line = val.toString();
            int firstComma = line.indexOf(',');
            int secondComma = line.indexOf(',', first                    Comma);
            String key = line.substring(firstComma, secondComma);
            // drop the rest of the record, I don't need it anymore,
            // just pass a 1 for the combiner/reducer to sum instead.
            Text outKey = new Text(key);
             oc.collect(outKey, new LongWritable(1L));
        }
    }
    public static class ReduceUrls extends MapReduceBase
        implements Reducer<Text, LongWritable, WritableComparable,
Writable> {

        public void reduce(
                Text ke          y,
                Iterator<LongWritable> iter,
                OutputCollector<WritableComparable, Writable> oc,
                Reporter reporter) throws IOException {
            // Add up all the values we see

            long sum = 0;
            wh          ile (iter.hasNext()) {
                sum += iter.next().get();
                reporter.setStatus("OK");
            }

            oc.collect(key, new LongWritable(sum));
        }
    }
    public static class LoadClicks extends MapReduceBase
        i   mplements Mapper<WritableComparable, Writable, LongWritable,
Text> {

        public void map(
                WritableComparable key,
                Writable val,
                OutputCollector<LongWritable, Text> oc,
                Reporter reporter)          throws IOException {
            oc.collect((LongWritable)val, (Text)key);
        }
    }
    public static class LimitClicks extends MapReduceBase
        implements Reducer<LongWritable, Text, LongWritable, Text> {

        int count = 0;
        public      void reduce(
            LongWritable key,
            Iterator<Text> iter,
            OutputCollector<LongWritable, Text> oc,
            Reporter reporter) throws IOException {

            // Only output the first 100 records
            while (count          < 100 && iter.hasNext()) {
                oc.collect(key, iter.next());
                count++;
            }
        }
    }
    public static void main(String[] args) throws IOException {
        JobConf lp = new JobConf(MRExample.class);
        lp.se     tJobName("Load Pages");
        lp.setInputFormat(TextInputFormat.class);
```

This?

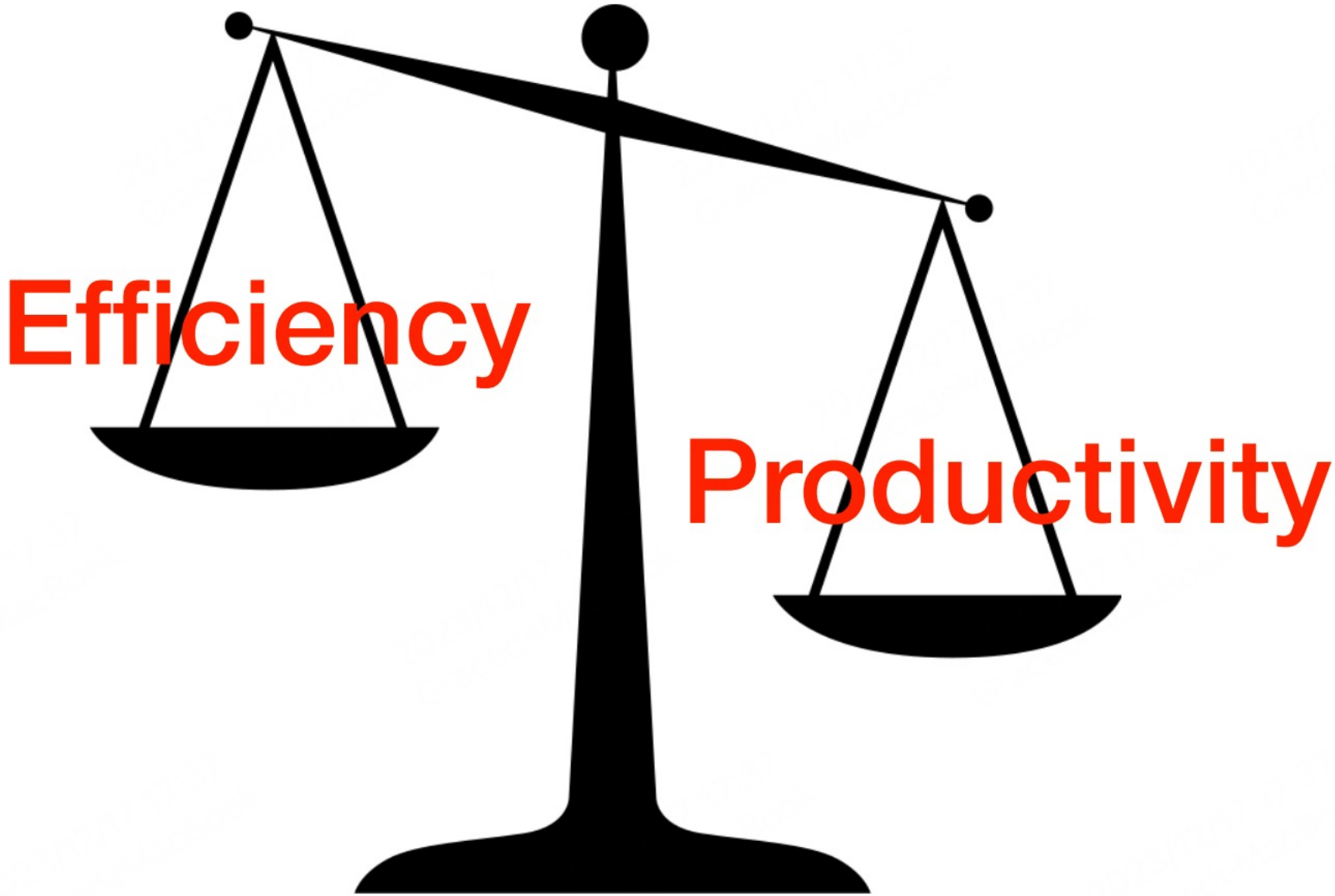
```
        lp.setOutputKeyClass(Text.class);
        lp.setOutputValueClass(Text.class);
        lp.setMapperClass(LoadPages.class);
        FileInputFormat.addInputPath(lp, new
Path("/   user/gates/pages"));
        FileOutputFormat.setOutputPath(lp,
            new Path("/user/gates/tmp/indexed_pages"));
        lp.setNumReduceTasks(0);
        Job loadPages = new Job(lp);

        JobConf lfu = new JobConf(MRExample.class);
        lfu.s     etJobName("Load and Filter Users");
        lfu.setInputFormat(TextInputFormat.class);
        lfu.setOutputKeyClass(Text.class);
        lfu.setOutputValueClass(Text.class);
        lfu.setMapperClass(LoadAndFilterUsers.class);
        FileInputFormat.add              InputPath(lfu, new
Path("/user/gates/users"));
        FileOutputFormat.setOutputPath(lfu,
            new Path("/user/gates/tmp/filtered_users"));
        lfu.setNumReduceTasks(0);
        Job loadUsers = new Job(lfu);

        JobConf join = new JobConf(             MRExample.class);
        join.setJobName("Join Users and Pages");
        join.setInputFormat(KeyValueTextInputFormat.class);
        join.setOutputKeyClass(Text.class);
        join.setOutputValueClass(Text.class);
        join.setMapperClass(IdentityMap                 per.class);
        join.setReducerClass(Join.class);
        FileInputFormat.addInputPath(join, new
Path("/user/gates/tmp/indexed_pages"));
         FileInputFormat.addInputPath(join, new
Path("/user/gates/tmp/filtered_users"));
        FileOutputFormat.se          tOutputPath(join, new
Path("/user/gates/tmp/joined"));
        join.setNumReduceTasks(50);
        Job joinJob = new Job(join);
        joinJob.addDependingJob(loadPages);
        joinJob.addDependingJob(loadUsers);

        JobConf group = new JobConf(MRE              xample.class);
        group.setJobName("Group URLs");
        group.setInputFormat(KeyValueTextInputFormat.class);
        group.setOutputKeyClass(Text.class);
        group.setOutputValueClass(LongWritable.class);
        group.setOutputFormat(SequenceFi                 leOutputFormat.class);
        group.setMapperClass(LoadJoined.class);
        group.setCombinerClass(ReduceUrls.class);
        group.setReducerClass(ReduceUrls.class);
        FileInputFormat.addInputPath(group, new
Path("/user/gates/tmp/joined"));
        FileOutputFormat.setOutputPath(group, new
Path("/user/gates/tmp/grouped"));
        group.setNumReduceTasks(50);
        Job groupJob = new Job(group);
        groupJob.addDependingJob(joinJob);

        JobConf top100 = new JobConf(MRExample.class);
         top100.setJobName("Top 100 sites");
        top100.setInputFormat(SequenceFileInputFormat.class);
        top100.setOutputKeyClass(LongWritable.class);
        top100.setOutputValueClass(Text.class);
        top100.setOutputFormat(SequenceFileOutputF                  ormat.class);
        top100.setMapperClass(LoadClicks.class);
        top100.setCombinerClass(LimitClicks.class);
        top100.setReducerClass(LimitClicks.class);
        FileInputFormat.addInputPath(top100, new
Path("/user/gates/tmp/grouped"));
            FileOutputFormat.setOutputPath(top100, new
Path("/user/gates/top100sitesforusers18to25"));
        top100.setNumReduceTasks(1);
        Job limit = new Job(top100);
        limit.addDependingJob(groupJob);

        JobControl jc = new JobControl("Find top                  100 sites for users
18 to 25");
        jc.addJob(loadPages);
        jc.addJob(loadUsers);
        jc.addJob(joinJob);
        jc.addJob(groupJob);
        jc.addJob(limit);
        jc.run();
    }
}
```

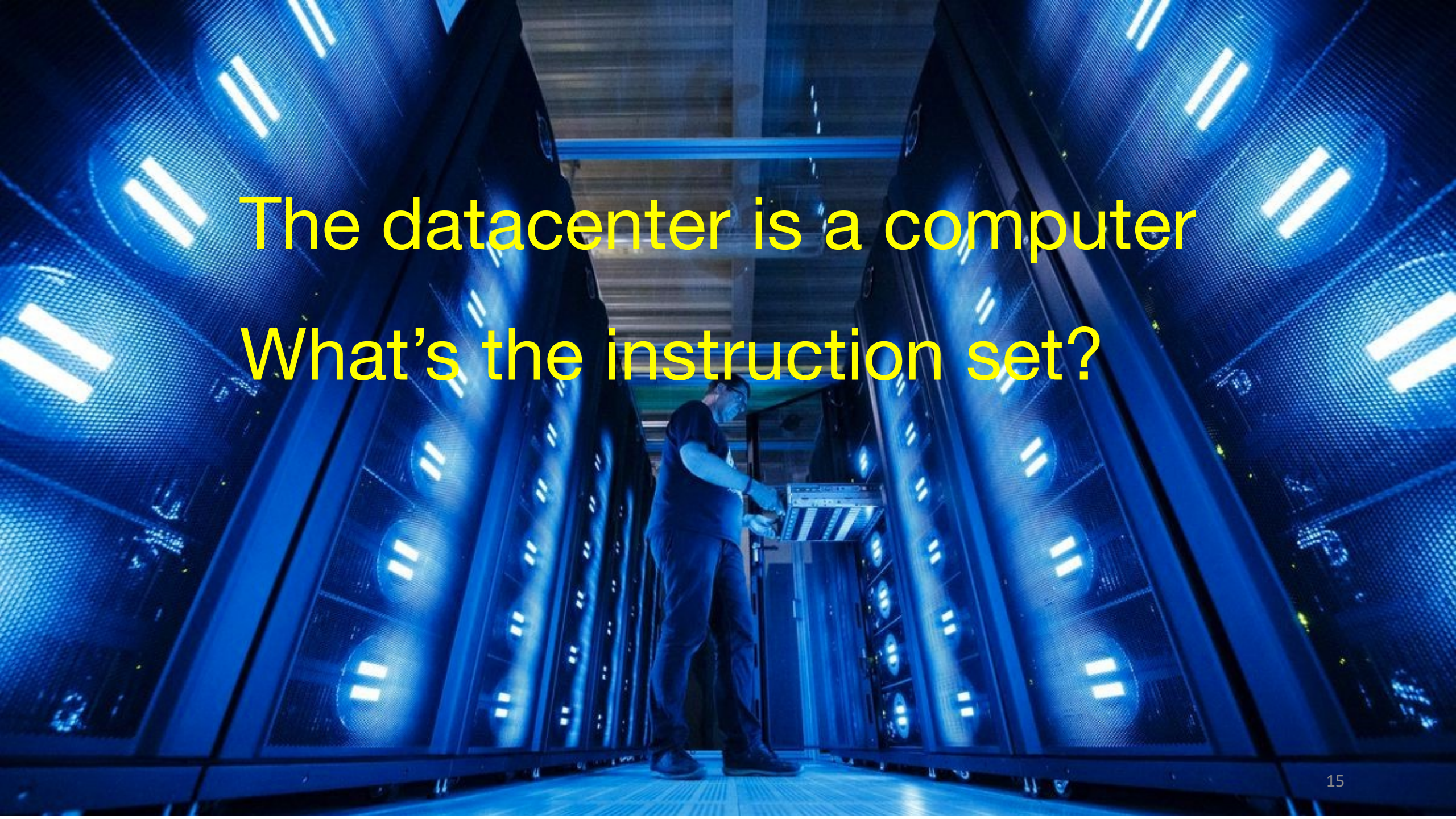
Programming at a high level

Specify “what”, and let the system figure out “how”

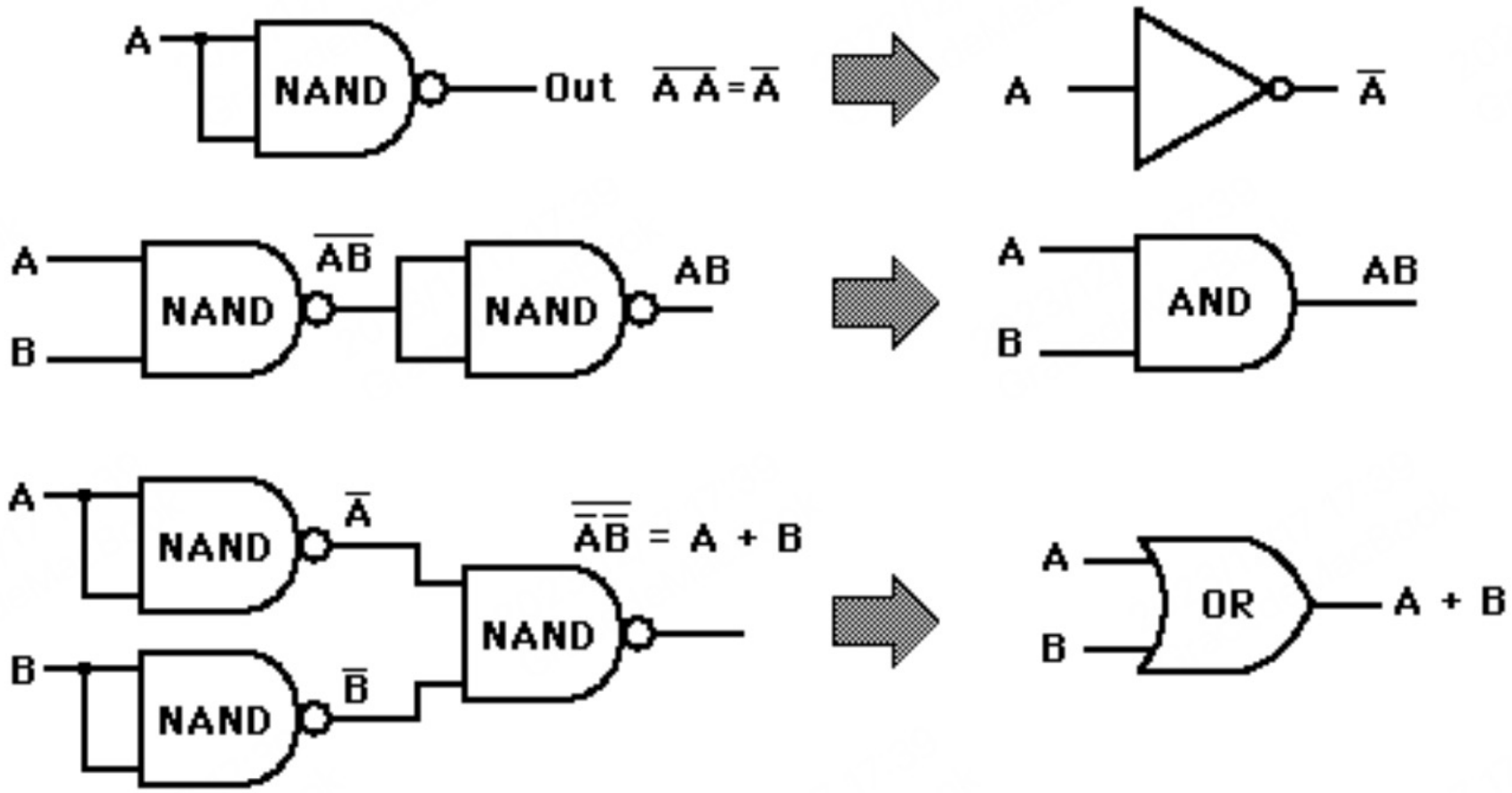
But isn’t Pig slower?

Sure, but C can be slower than assembly too…


Efficiency
Productivity


The datacenter is a computer
What's the instruction set?

Analogy: NAND Gates are universal



Let’s design a data processing language “from scratch”!

Why is MapReduce the way it is?

Data-parallel dataflow languages

We have a collection of records

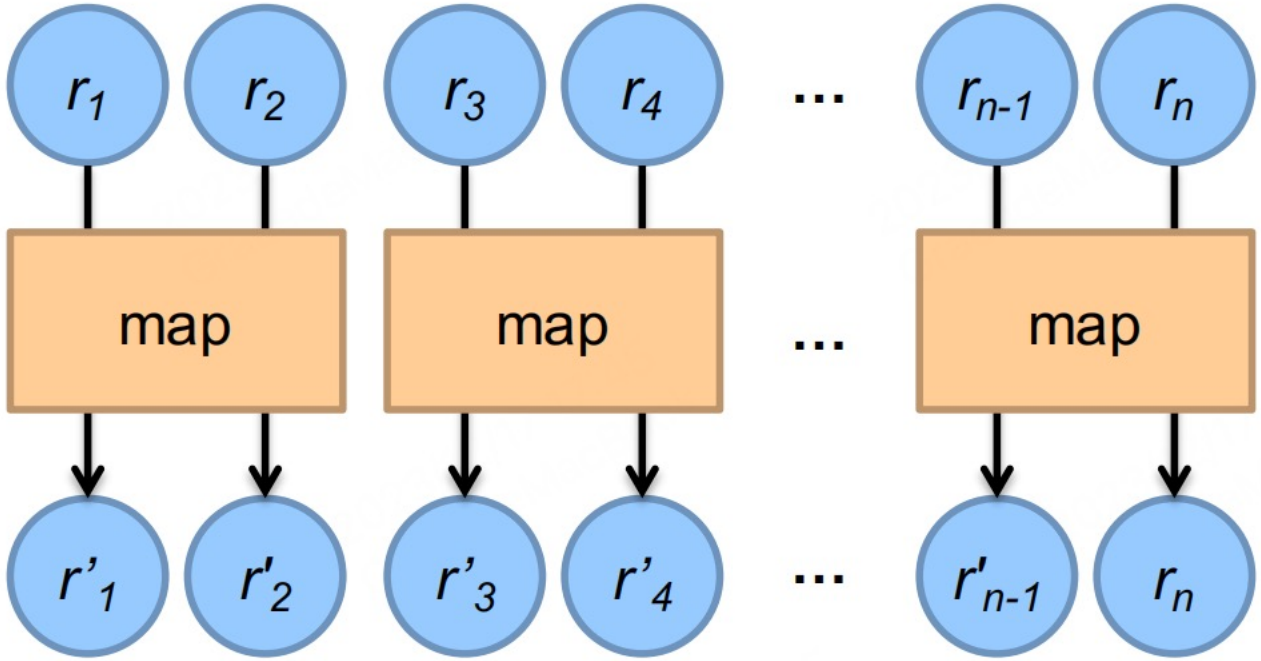
- want to apply a bunch of transformations to compute some results

Assumptions

- static collection records (not necessarily key-value pairs)

We need per-record processing

(note: not necessarily key-value pairs)



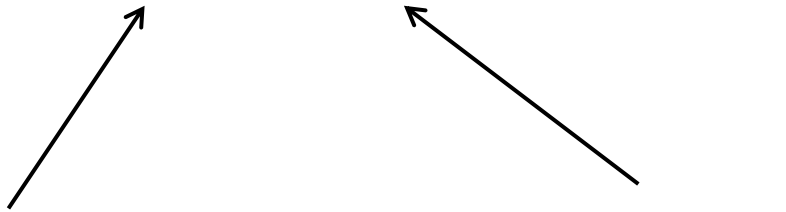
Easy to parallelize maps

Record to “mapper” assignment is an implementation detail

Map alone isn't enough

We need a way to group partial results

- intermediate **(key, value)** pairs

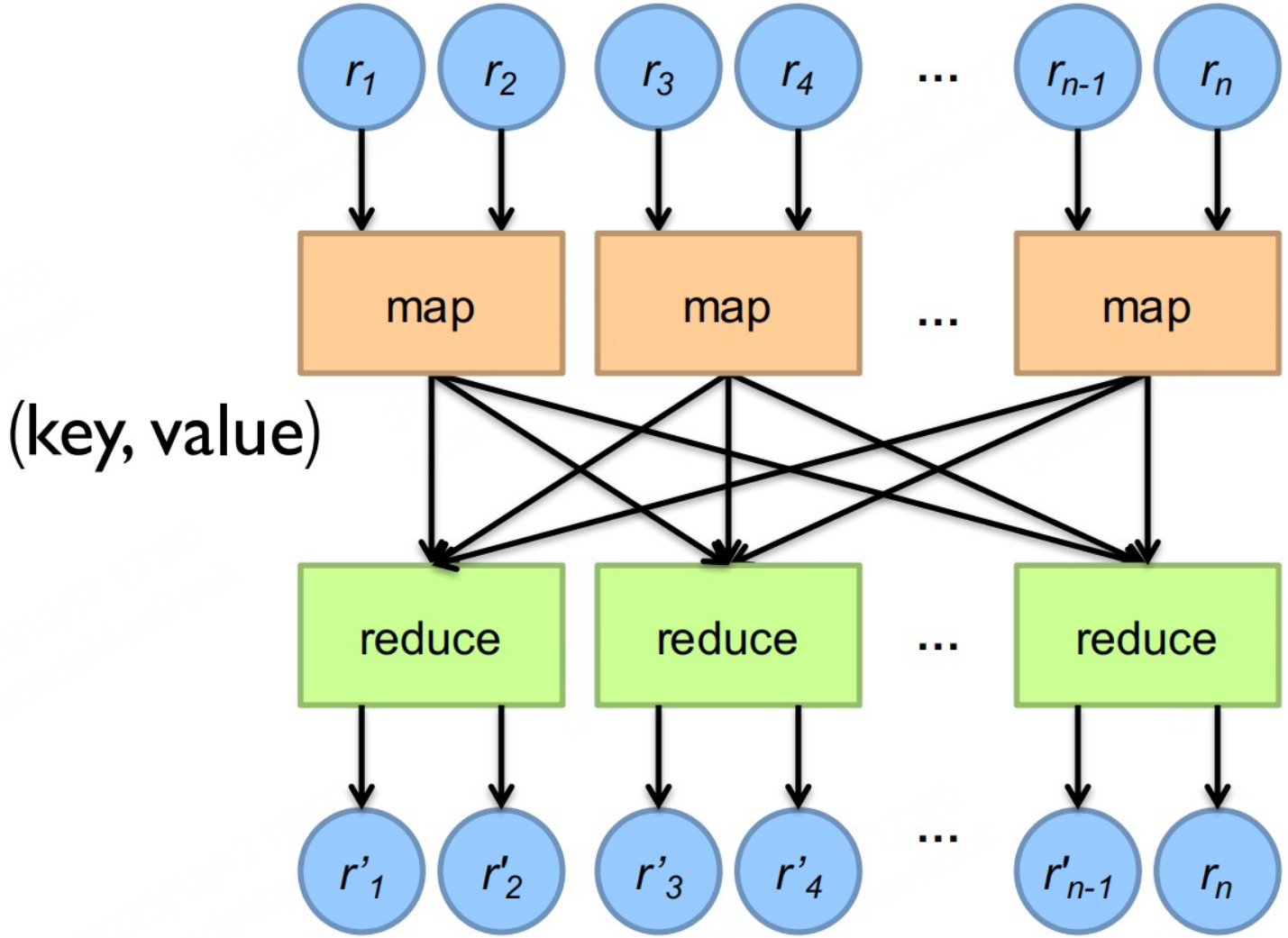


grouping key partial result

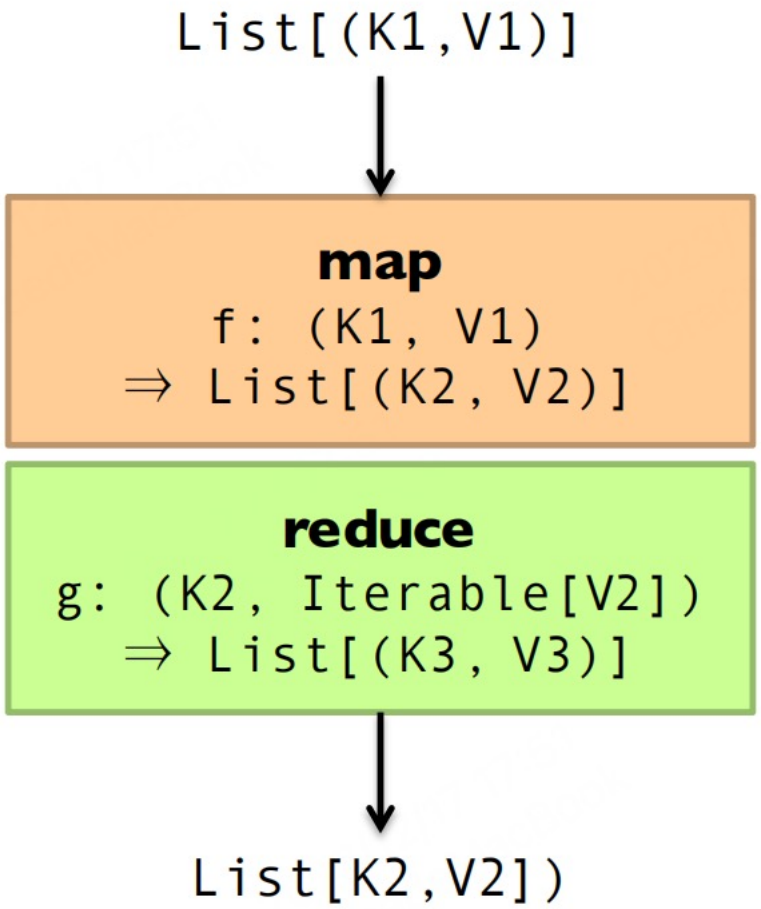
For each key, we can apply some computation

- e.g., aggregation, counting

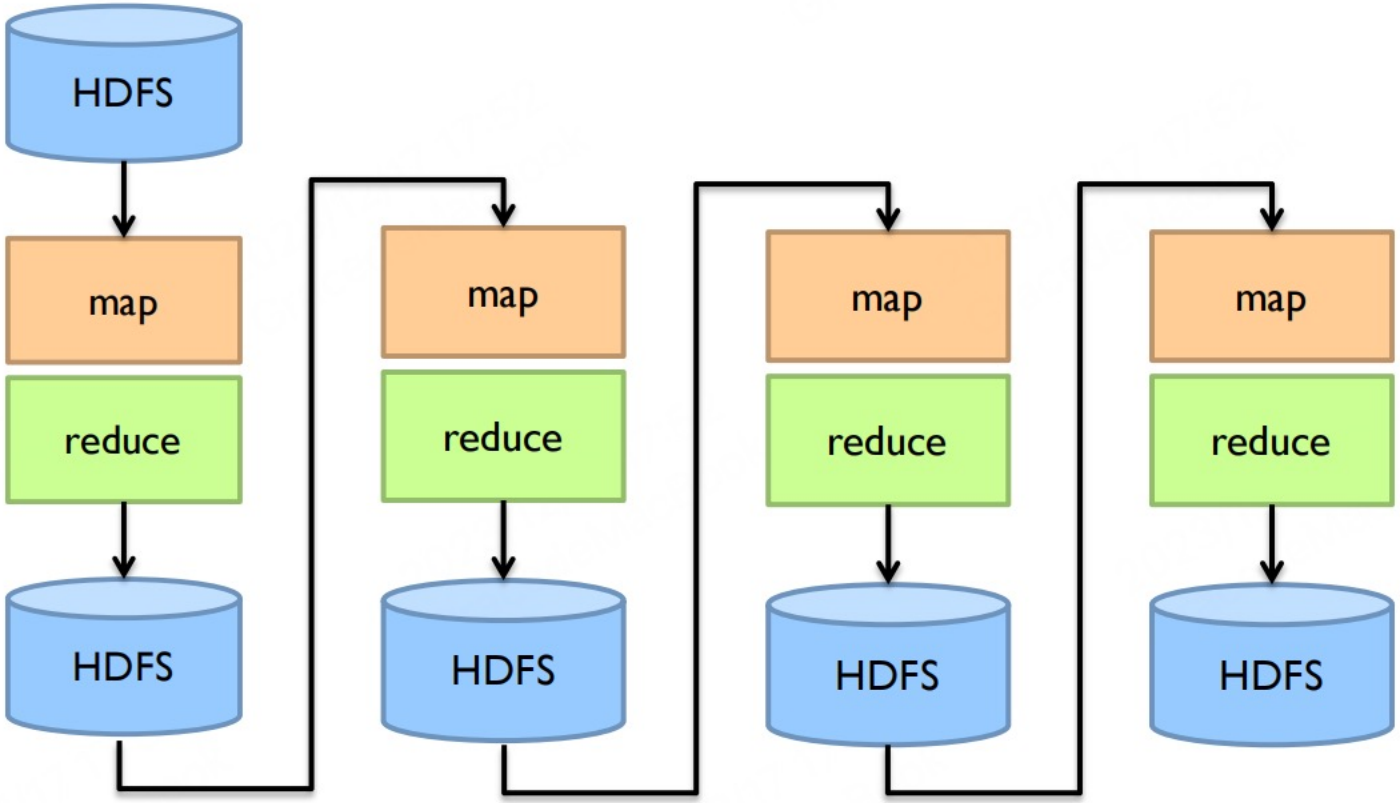
MapReduce


r1
r2
r3
r4
...
rn-1
rn
map
map
...
map
(key, value)
reduce
reduce
...
reduce
r'1
r'2
r'3
r'4
...
r'n-1
rn

MapReduce

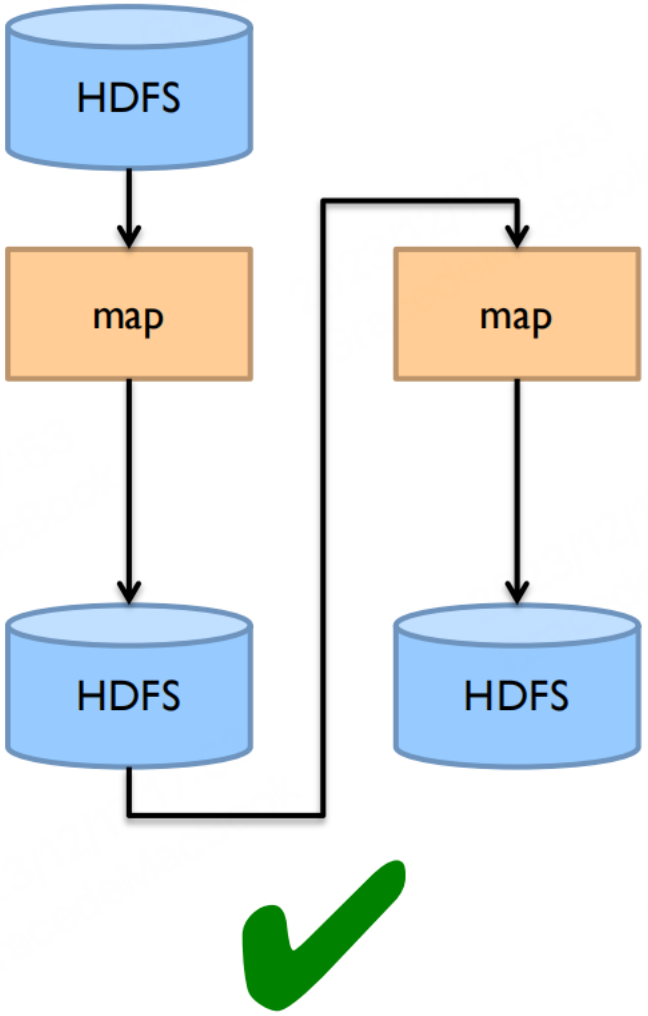

List[(K1,V1)]
map
f: (K1, V1)
⇒ List[(K2, V2)]
reduce
g: (K2, Iterable[V2])
⇒ List[(K3, V3)]
List[K2,V2])

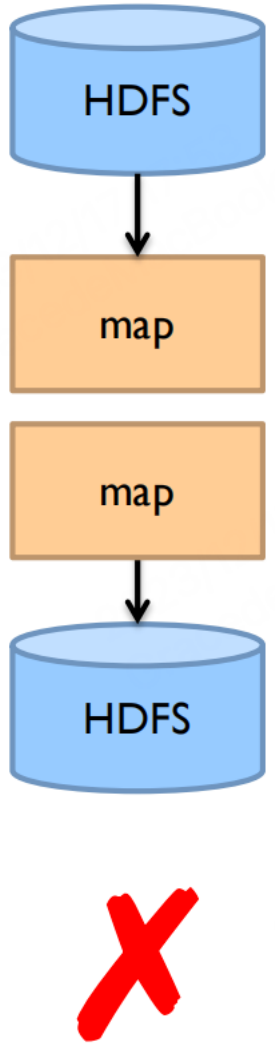
MapReduce workflows



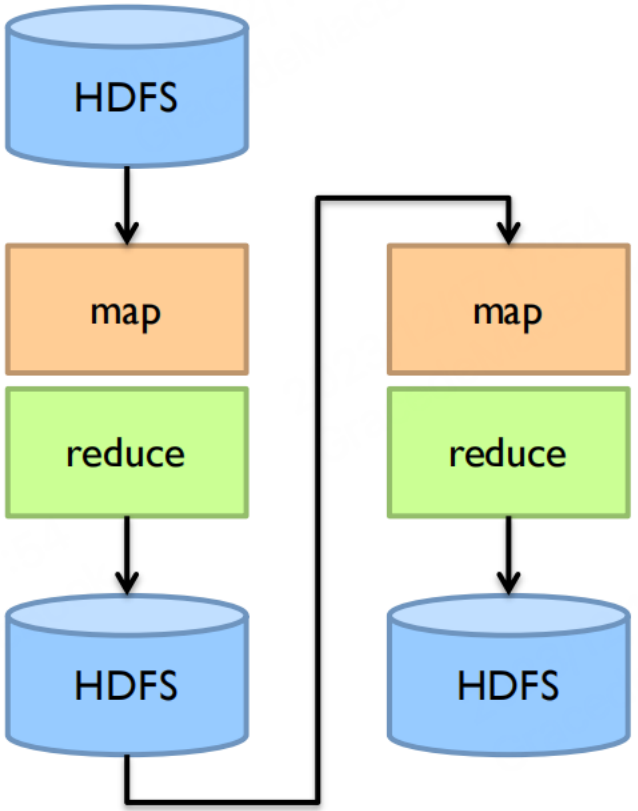
What's wrong?

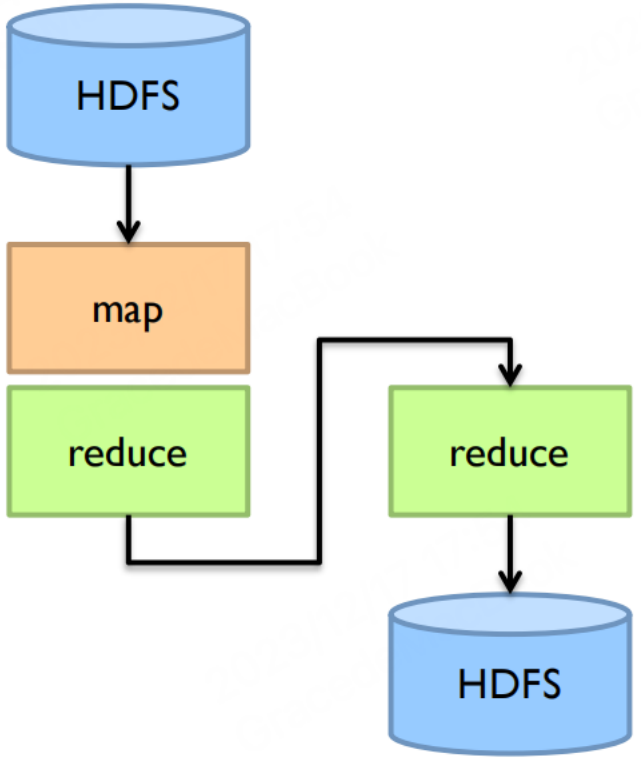
Want MM?





Want MRR?


HDFS
map
reduce
HDFS
map
reduce
HDFS


HDFS
map
reduce
reduce
HDFS

In MapReduce, the only way to share data across jobs is stable storage

Disk I/O is waaaaaaay too slow!

Data-parallel dataflow languages

We have a collection of records

- want to apply a bunch of transformations to compute some results

What are the operators?

- MapReduce?

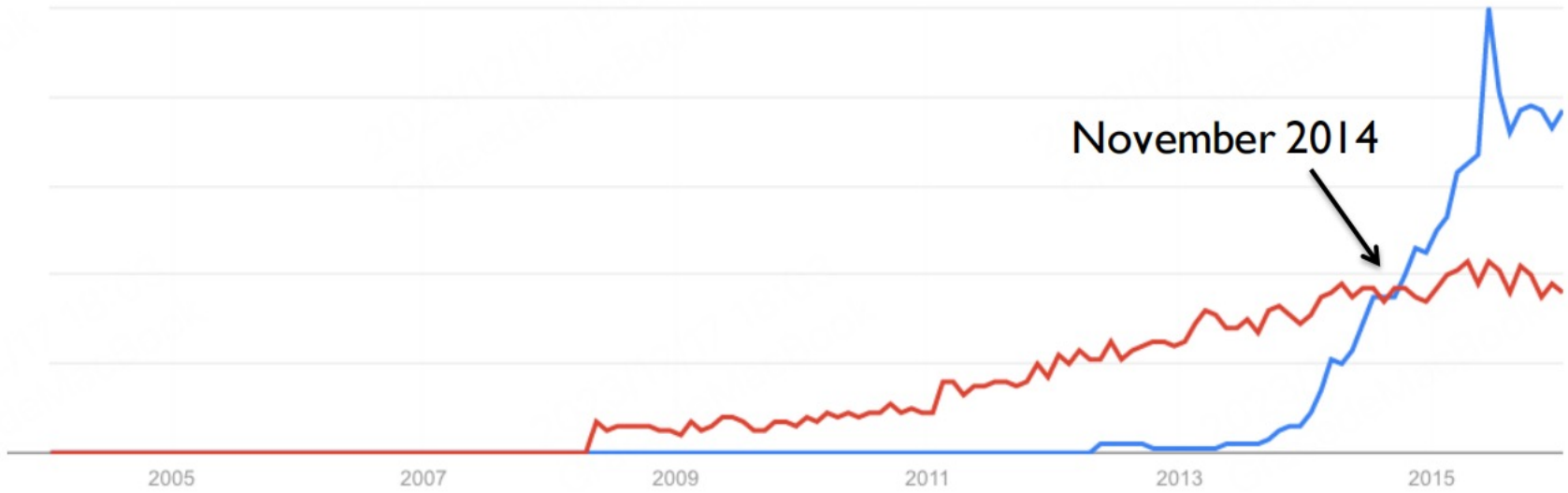
Where the hype is!

- answer to “What’s beyond MapReduce?”

Brief history:

- developed at UC Berkeley AMPLab in 2009
- open-sourced in 2010
- became top-level Apache project in Feb 2014
- commercial support provided by Databricks

Spark vs. hadoop



Google Trends

Source: Datanami (2014): http://www.datanami.com/2014/11/21/spark-just-passed-hadoop-popularity-web-heres/

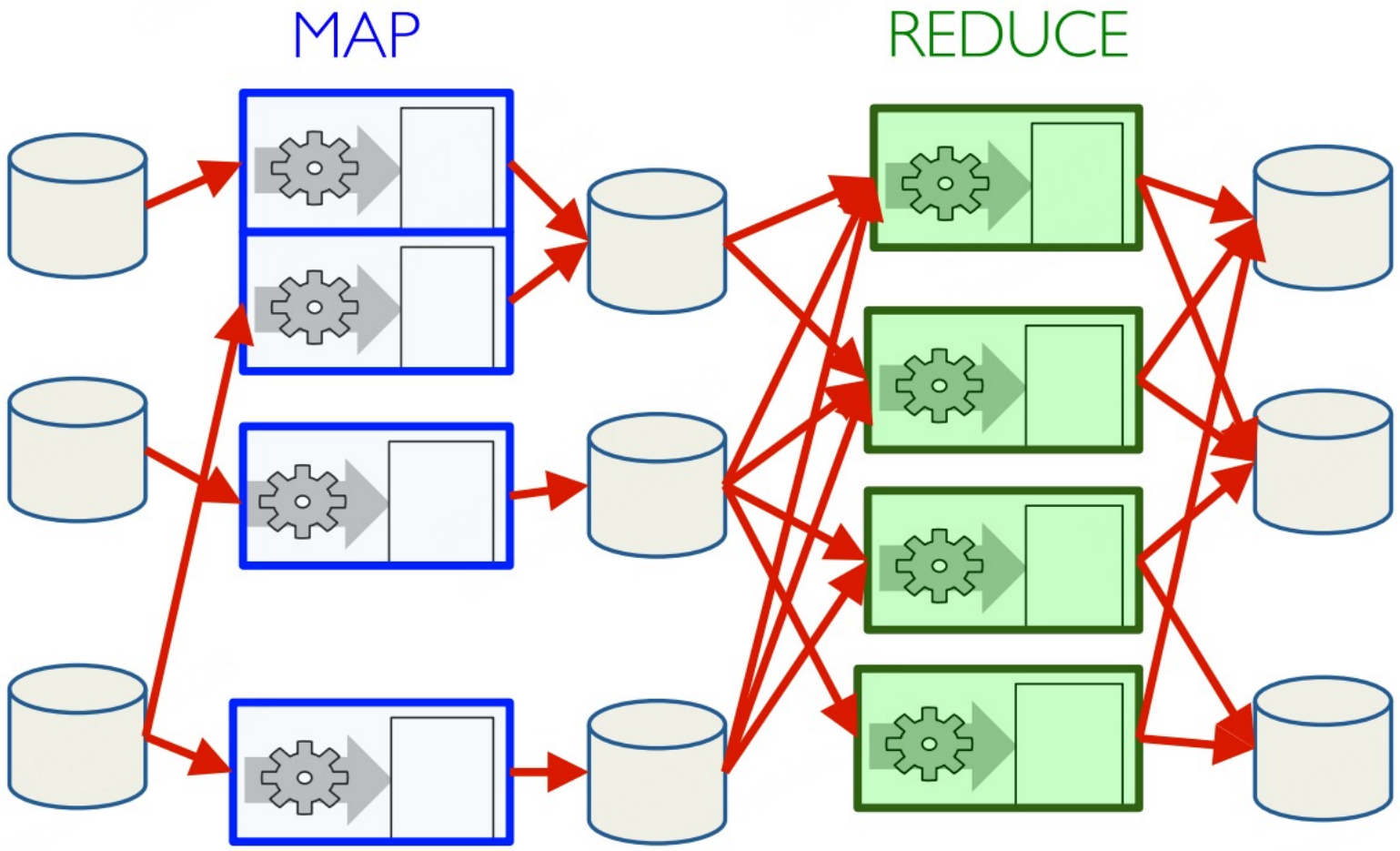
Motivation

MapReduce is a restrictive programming model for batch processing jobs

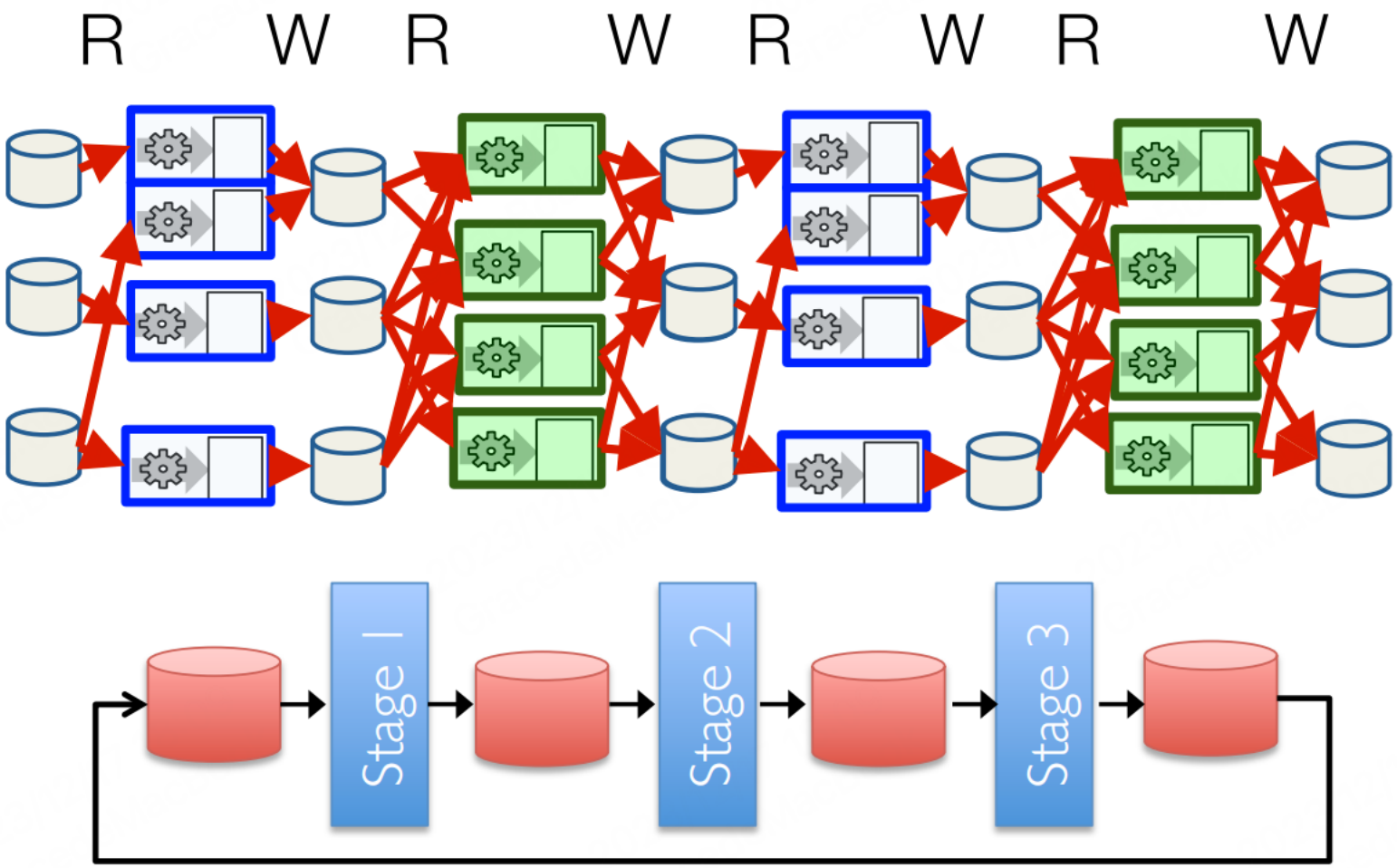
But we want more…

- More complex, multi-stage data processing, e.g., iterative machine learning
- Low latency, interactive ad-hoc data analytics, e.g., streaming processing

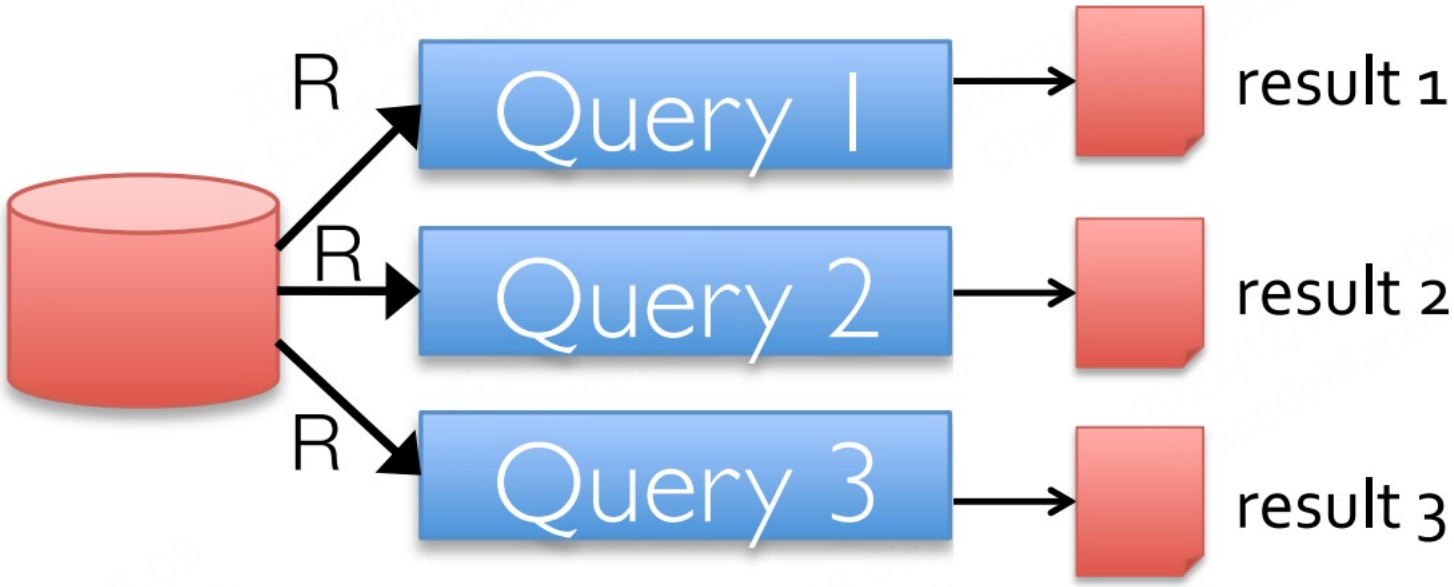
Each stage passes through the stable storage!



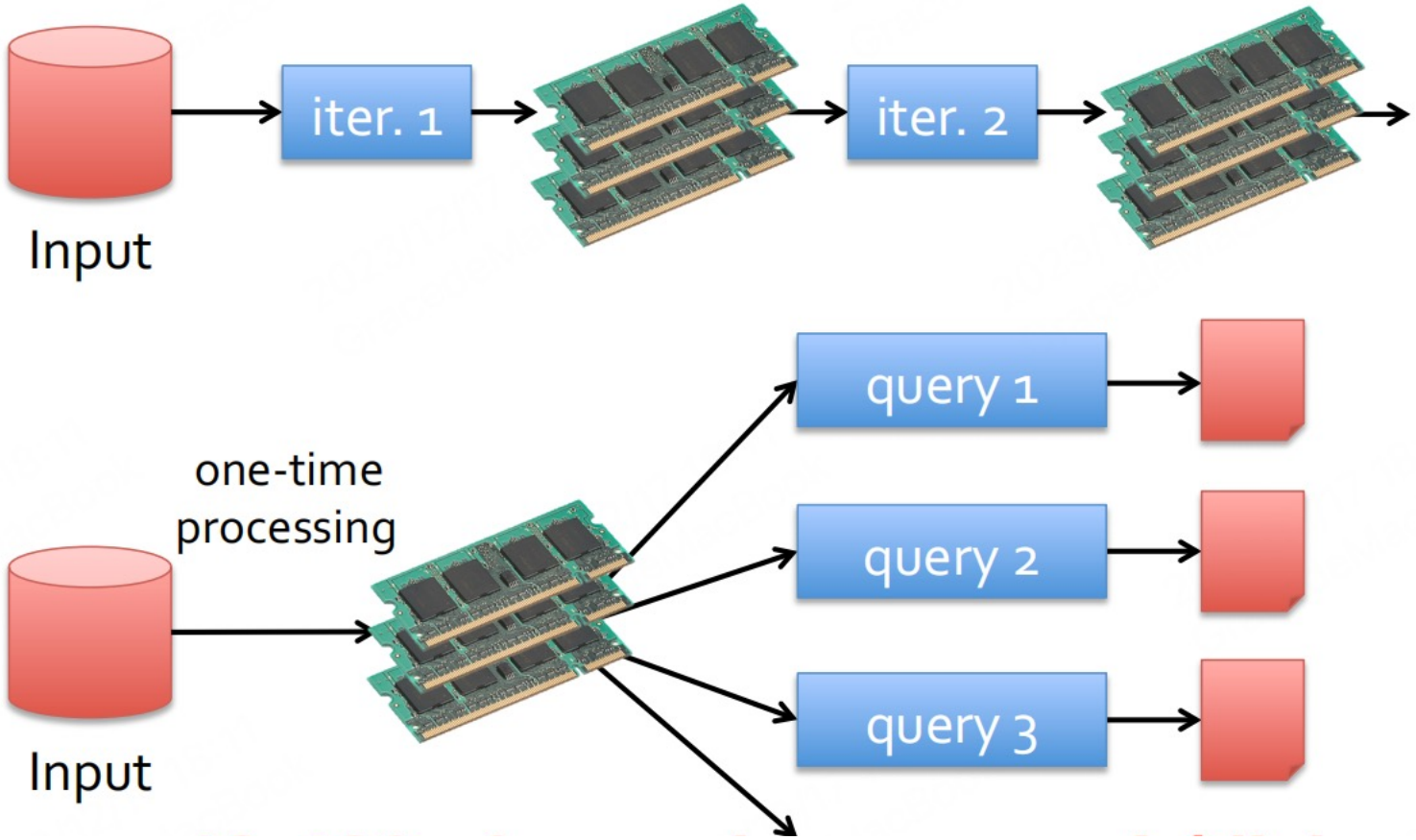
Iterative computations



Iterative queries



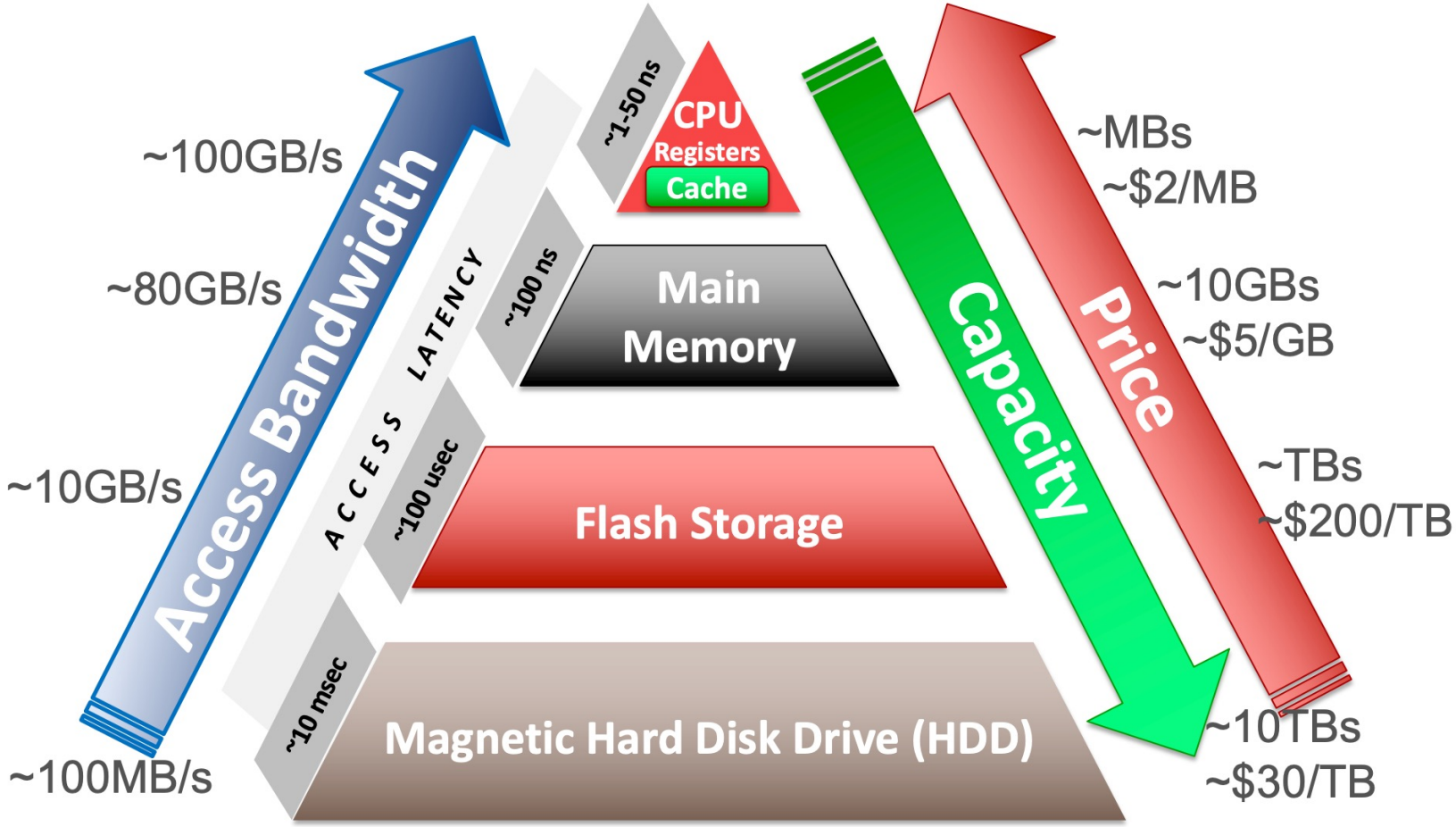
Intuition: In-memory data sharing



10-100x faster than network/disk

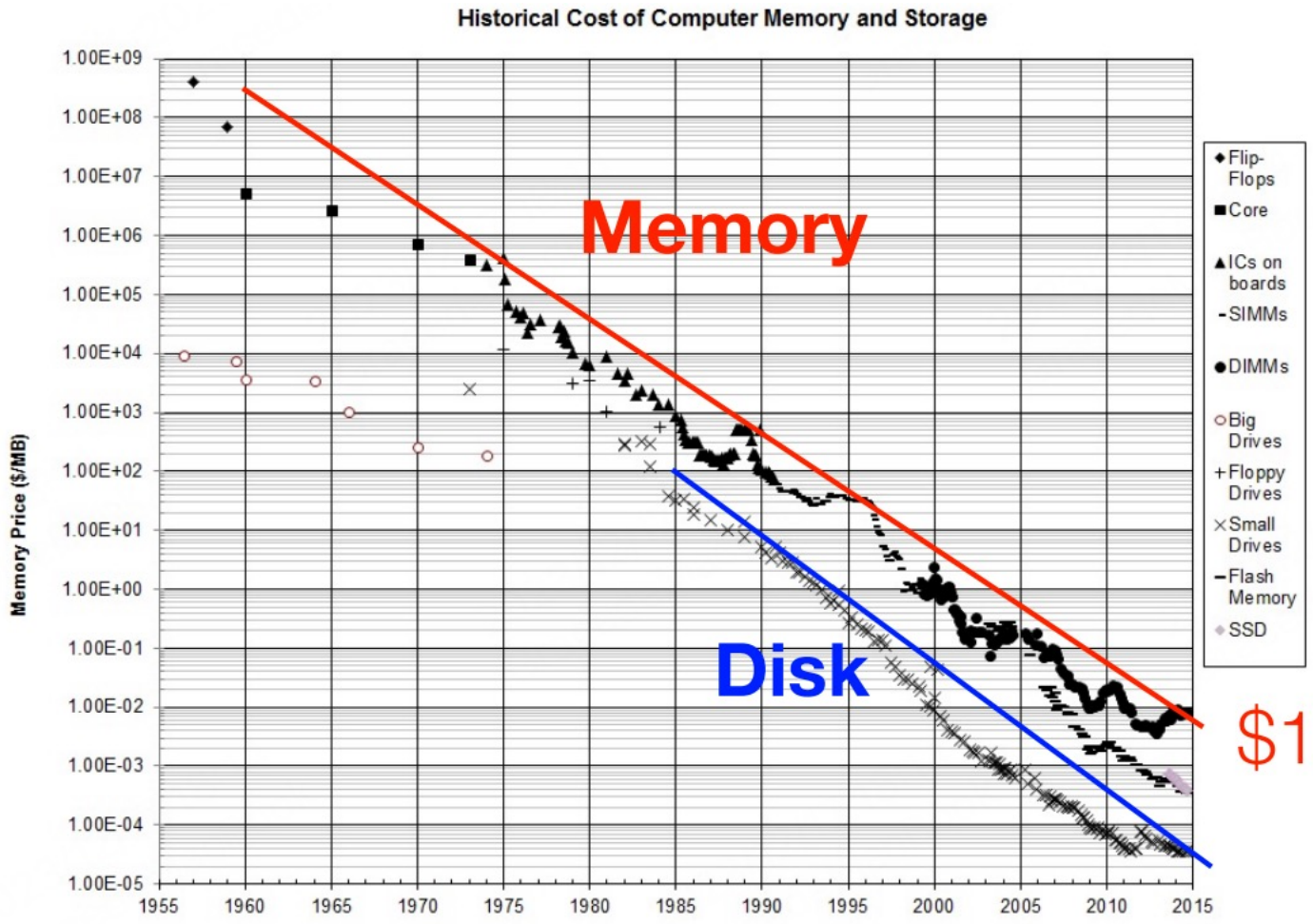
Zaharia, "Resilient Distributed Datasets: A Fault-Tolerant Abstraction for In-Memory Cluster Computing," Talk in NSDI 2012.

Memory-storage hierarchy



Source: UCSD DSC 102 - Systems for scalable analysis. Arun Kumar

Cost of Memory



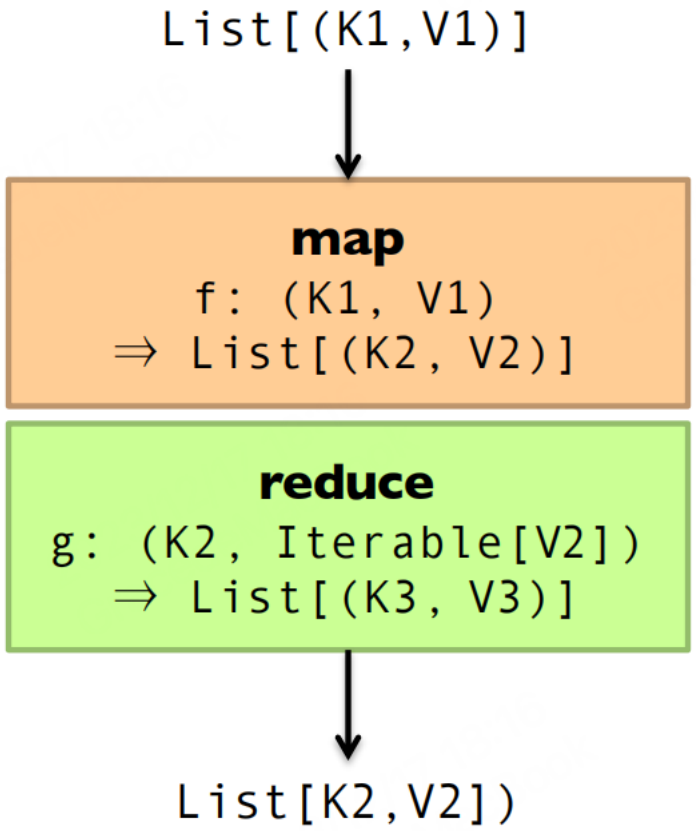
$1 cent/MB

http://www.jcmit.com/mem2014.htm

Intermediate results are stored in-memory as **Resilient Distributed Datasets** (RDDs)

Much more next lecture…

MapReduce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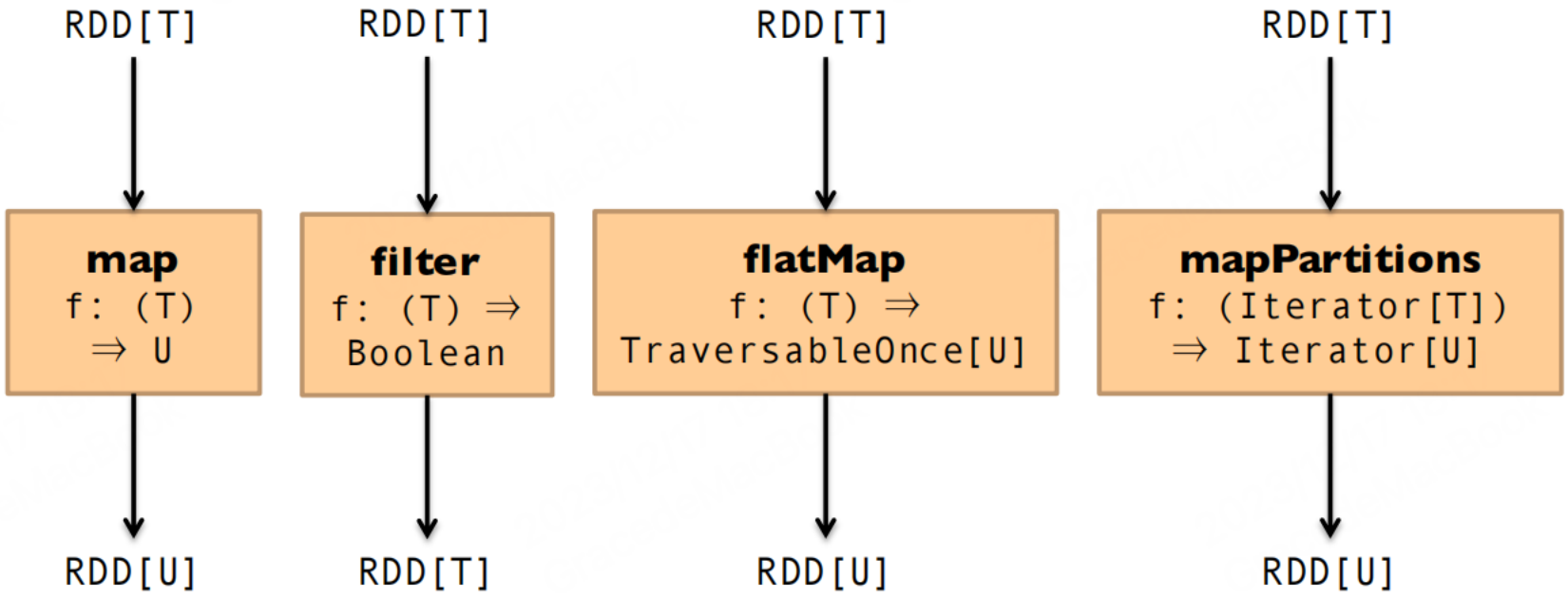
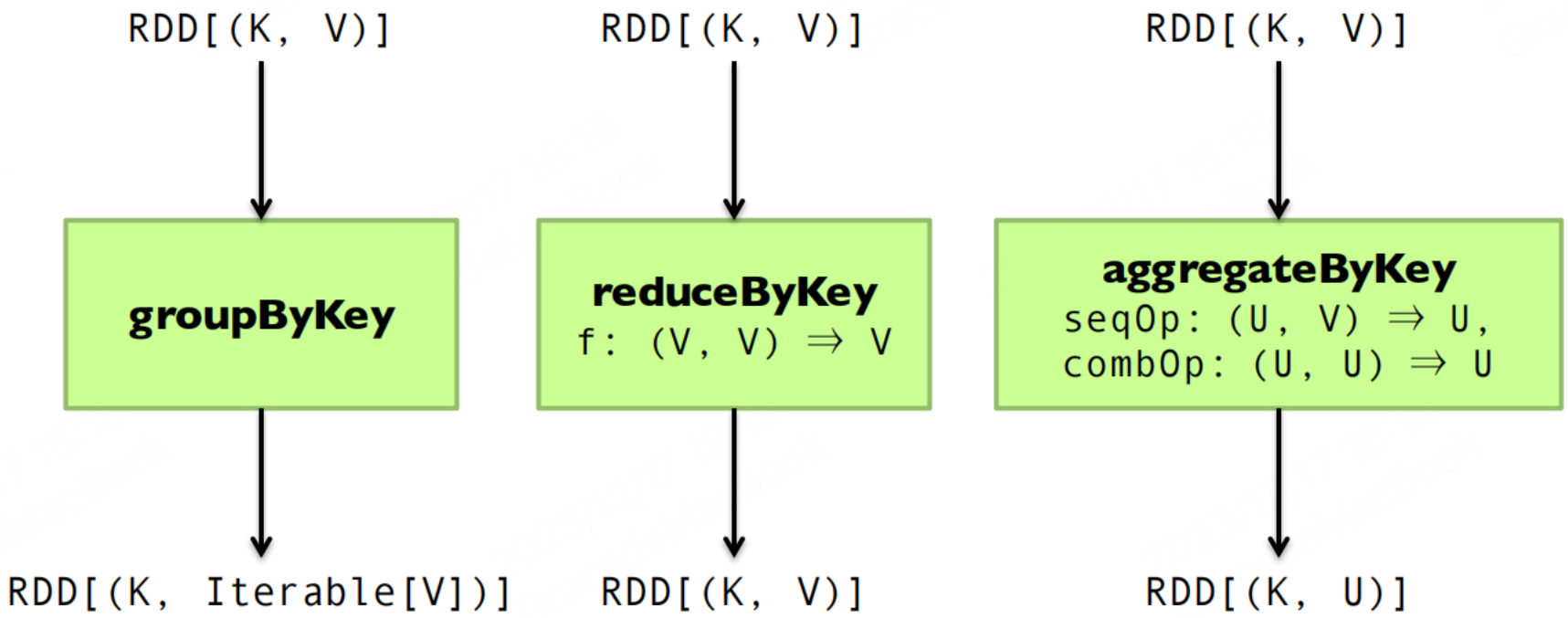
map
f: (K1, V1)
⇒ List[(K2, V2)]
reduce
g: (K2, Iterable[V2])
⇒ List[(K3, V3)]
List[K2,V2])

Map-like operations



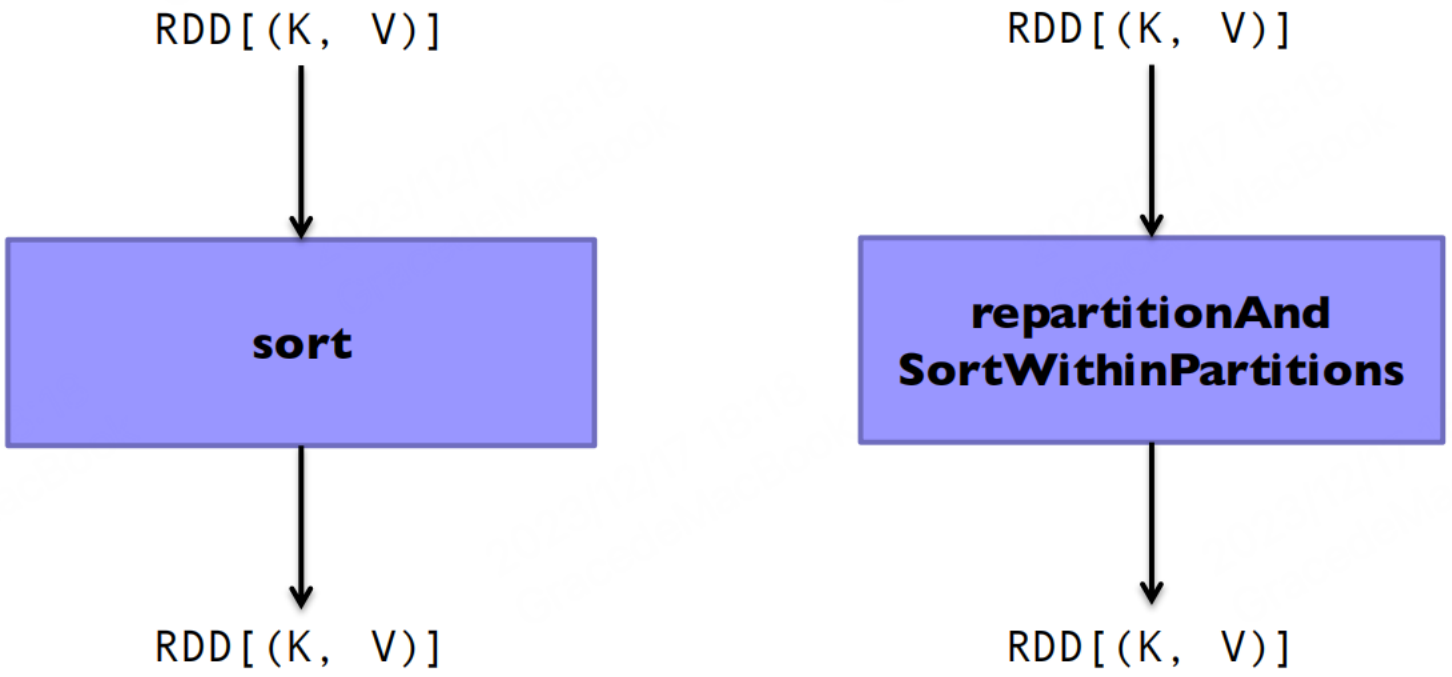
Not meant to be exhaustive

Reduce-like operations



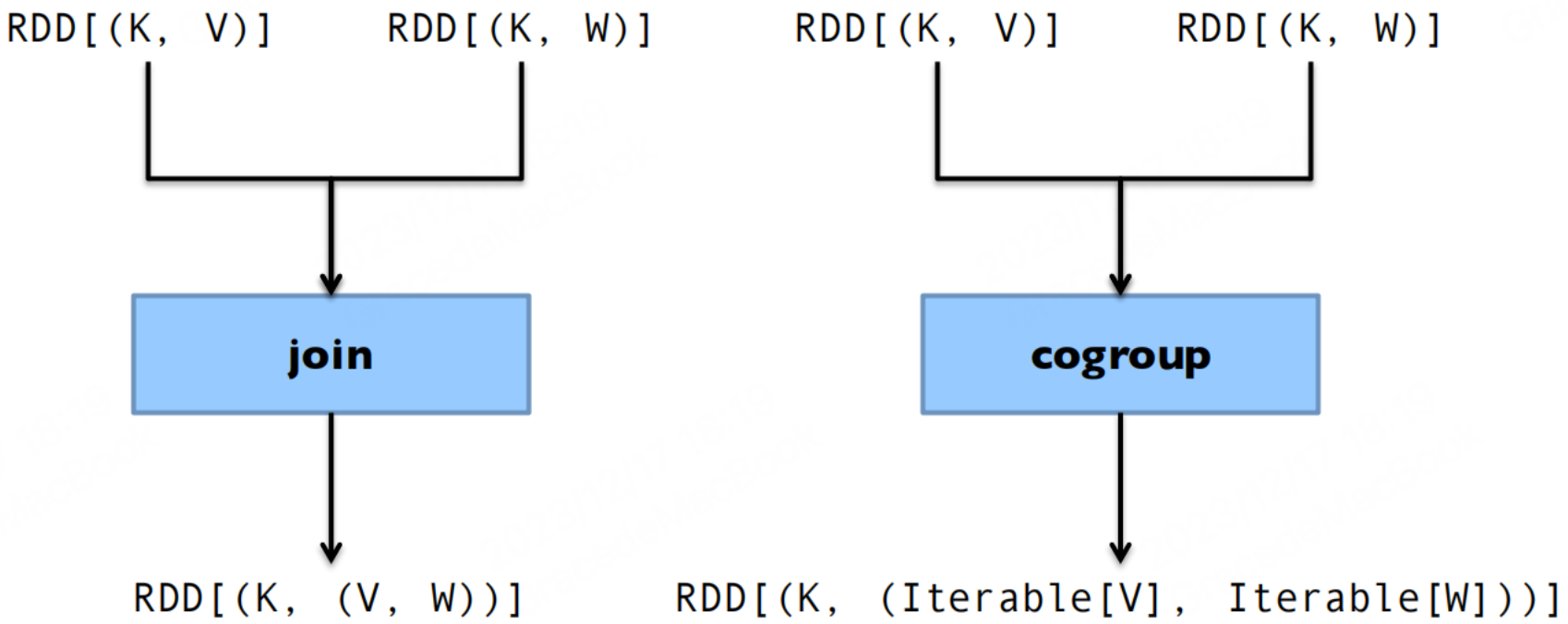
Not meant to be exhaustive

Sort operations



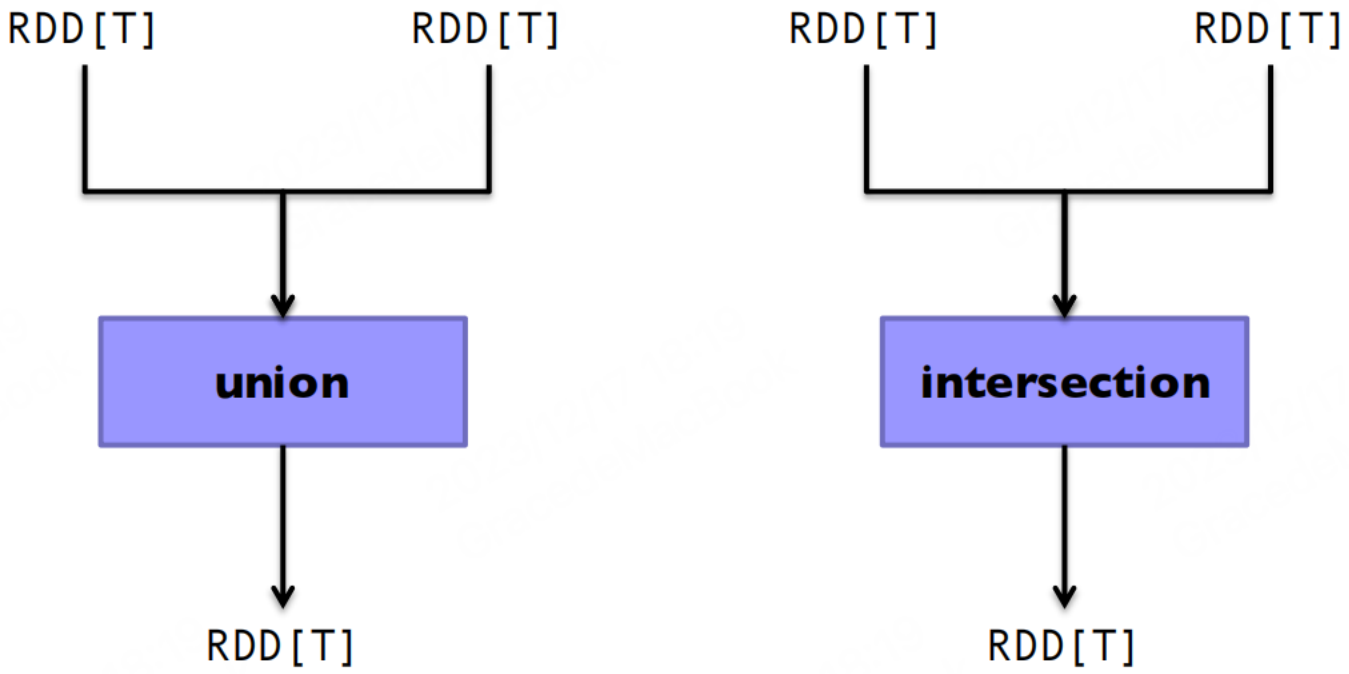
Not meant to be exhaustive

Join-like operations



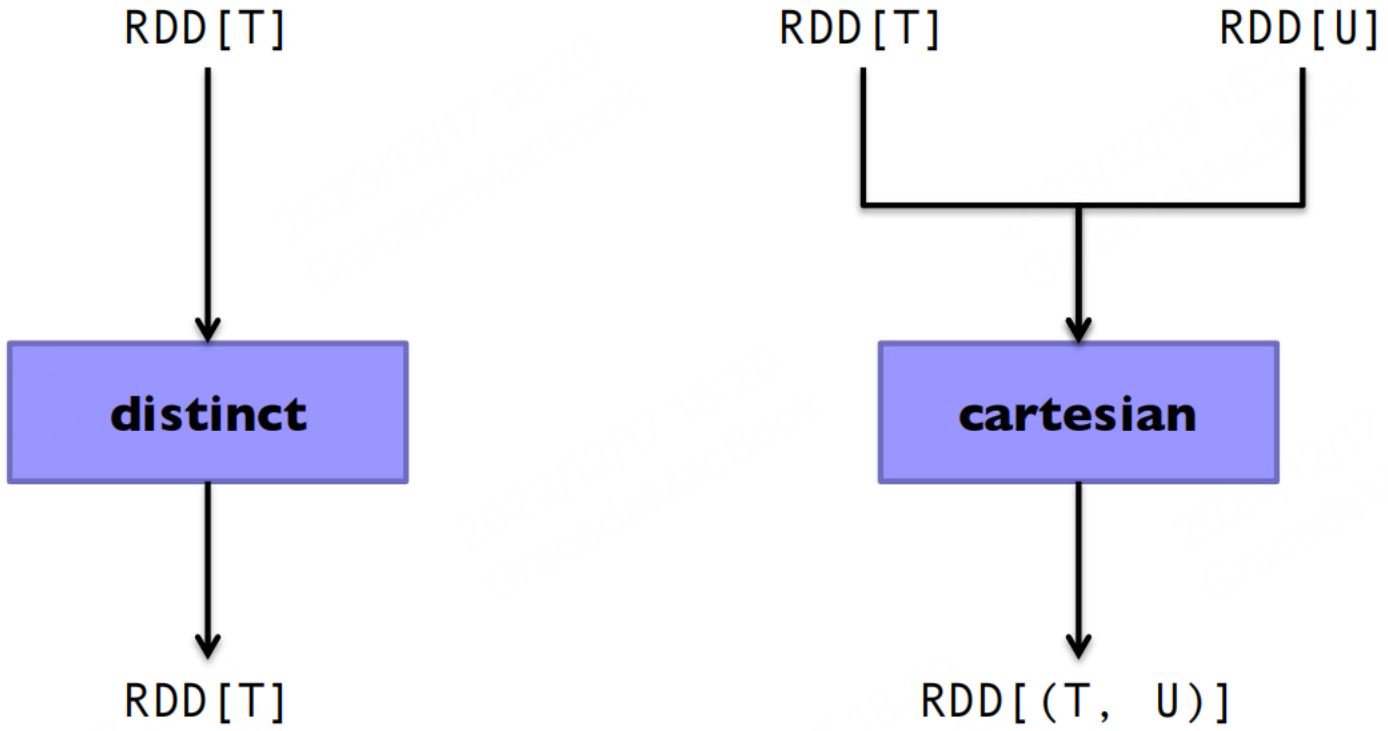
Not meant to be exhaustive

Set-ish operations



Not meant to be exhaustive

Set-ish operations



Not meant to be exhaustive

Spark WordCount: 3-liner

```
text_file = sc.textFile("hdfs://...")
counts = text_file.flatMap(lambda line: line.split(" ")) \
                  .map(lambda word: (word, 1)) \
                  .reduceByKey(lambda a, b: a + b)
counts.saveAsTextFile("hdfs://...")
```

This?

```
private static class MyMapper
     extends Mapper<LongWritable, Text, Text, IntWritable> {

    private final static IntWritable ONE = new IntWritable(1);
    private final static Text WORD = new Text();

    @Override
    public void map(LongWritable key, Text value, Context context)
        throws IOException, InterruptedException {
      String line = ((Text) value).toString();
      String[] words = line.trim().split("\\s+");
      for (String w: words) {
        WORD.set(w);
        context.write(WORD, ONE);
      }
    }
  }
```

```
private static class MyReducer
    extends Reducer<Text, IntWritable, Text, IntWritable> {

   private final static IntWritable SUM = new IntWritable();

   @Override
   public void reduce(Text key, Iterable<IntWritable> values,
       Context context) throws IOException, InterruptedException {
     int sum = 0;
     for (IntWritable v: values) {
                    sum += v.get();
     }
     SUM.set(sum);
     context.write(key, SUM);
   }
 }
```

```
Configuration conf = getConf();
Job job = Job.getInstance(conf);
job.setJobName("Word Count");
job.setJarByClass(WordCount.class);
job.setNumReduceTasks(reduceTasks);
FileInputFormat.setInputPaths(job, new Path(inputPath));
FileOutputFormat.setOutputPath(job, new Path(outputPath));
job.setOutputKeyClass(Text.class);
job.setOutputValueClass(IntWritable.class);
job.setMapperClass(WordCountMapper.class);
job.setCombinerClass(WordCountReducer.class);
job.setReducerClass(WordCountReducer.class);
System.exit(job.waitForCompletion(true) ? 0: 1);
```

Or this?

Credits

- Some slides are adapted from course slides of COMP 4651 in HKUST
- Some slides adapted from course slides of DS5110 in UVA