61A LECTURE 28 – MAPREDUCE

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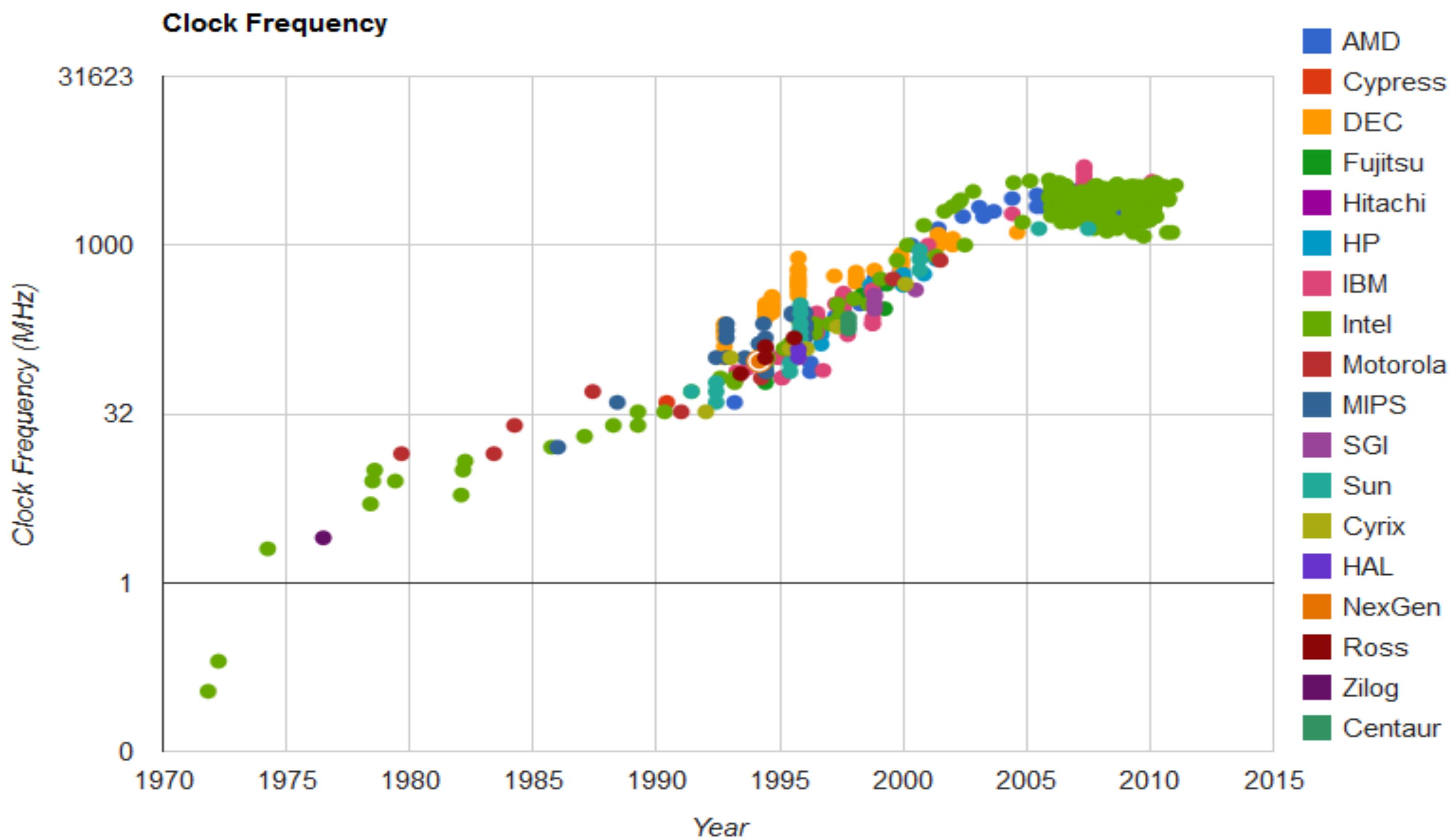
Announcements

- Project 4 Recursive Art Contest – due tonight (8/12) at 11:59!
  - `submit proj4contest`
- HW13 – due Tuesday (8/13) at 11:59pm.
- Project 4 – due Tuesday (8/13) at 11:59pm.
- Final Exam – Thursday (8/15) at 7pm.
- Extra Office Hours up on the website!

CPU Performance

Performance of individual CPU cores has largely stagnated in recent years

Graph of CPU clock frequency, an important component in CPU performance:



http://cpudb.stanford.edu

Parallelism

Applications must be *parallelized* in order run faster

- Waiting for a faster CPU core is no longer an option

Parallelism is easy in functional programming:

- When a program contains only pure functions, call expressions can be evaluated in any order, lazily, and in parallel
- Referential transparency: a call expression can be replaced by its value (or *vice versa*) without changing the program

But not all problems can be solved efficiently using functional programming

Today: the easy case of parallelism, using only pure functions

- Specifically, we will look at *MapReduce*, a framework for such computations

MapReduce

MapReduce is a *framework* for batch processing of Big Data

What does that mean?

- **Framework**: A system used by programmers to build applications
- **Batch processing**: All the data is available at the outset, and results aren't used until processing completes
- **Big Data**: A buzzword used to describe data sets so large that they reveal facts about the world via statistical analysis

The MapReduce idea:

- Data sets are too big to be analyzed by one machine
- When using multiple machines, systems issues abound
- Pure functions enable an abstraction barrier between data processing logic and distributed system administration

Systems

Systems research enables the development of applications by defining and implementing abstractions:

- **Operating systems** provide a stable, consistent interface to unreliable, inconsistent hardware
- **Networks** provide a simple, robust data transfer interface to constantly evolving communications infrastructure
- **Databases** provide a declarative interface to software that stores and retrieves information efficiently
- **Distributed systems** provide a single-entity-level interface to a cluster of multiple machines

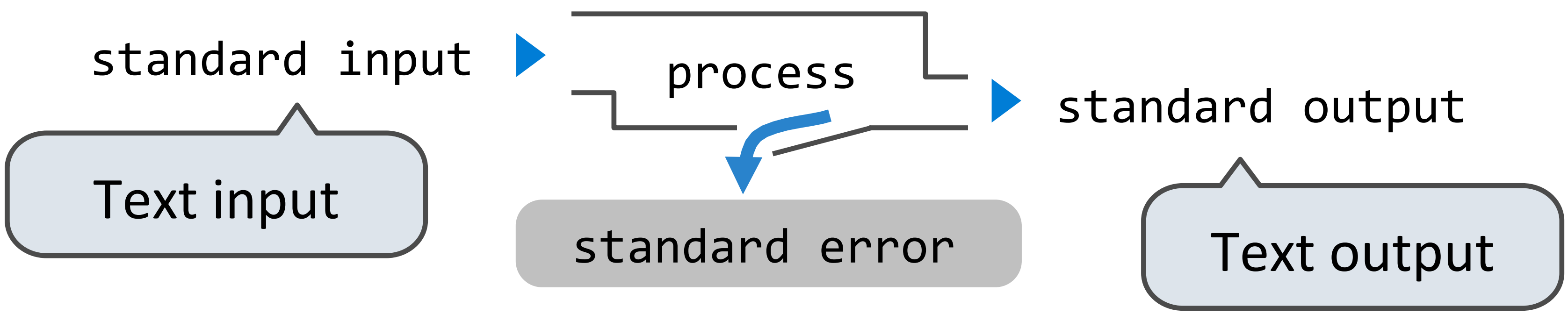
A unifying property of effective systems:

Hide *complexity*, but retain *flexibility*

The Unix Operating System

Essential features of the Unix operating system (and variants):

- **Portability**: The same operating system on different hardware
- **Multi-Tasking**: Many processes run concurrently on a machine
- **Plain Text**: Data is stored and shared in text format
- **Modularity**: Small tools are composed flexibly via pipes



The ***standard streams*** in a Unix-like operating system are conceptually similar to Python iterators

Python Programs in a Unix Environment

The built-in `input` function reads a line from *standard input*

The built-in `print` function writes a line to *standard output*

Demo

The values `sys.stdin` and `sys.stdout` also provide access to the Unix *standard streams* as "files"

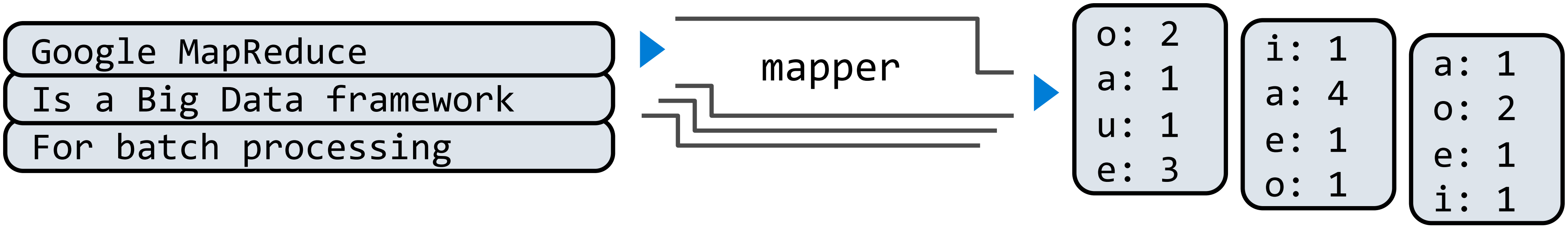
A Python "file" is an interface that supports iteration, read, and write methods

Using these "files" takes advantage of the operating system *standard stream* abstraction

MapReduce Evaluation Model

Map phase: Apply a *mapper* function to inputs, emitting a set of intermediate key-value pairs

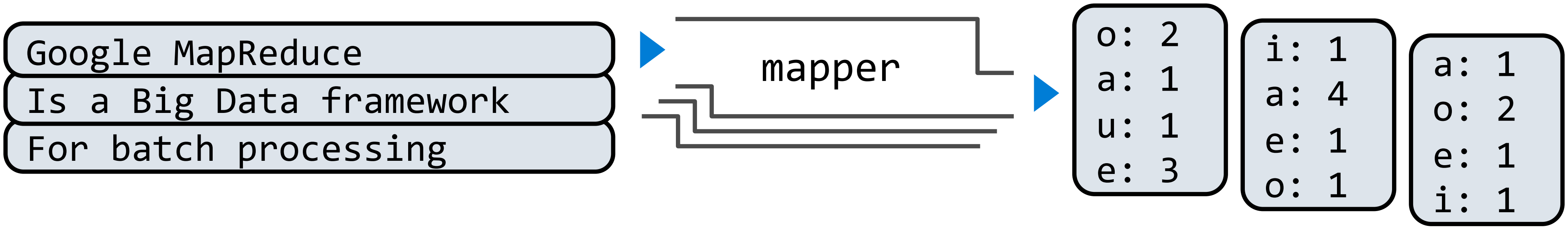
- The *mapper* takes an iterator over inputs, such as text lines
- The *mapper* yields zero or more key-value pairs per input



Reduce phase: For each intermediate key, apply a *reducer* function to accumulate all values associated with that key

- The *reducer* takes an iterator over key-value pairs
- All pairs with a given key are consecutive
- The *reducer* yields 0 or more values, each associated with that intermediate key

MapReduce Evaluation Model



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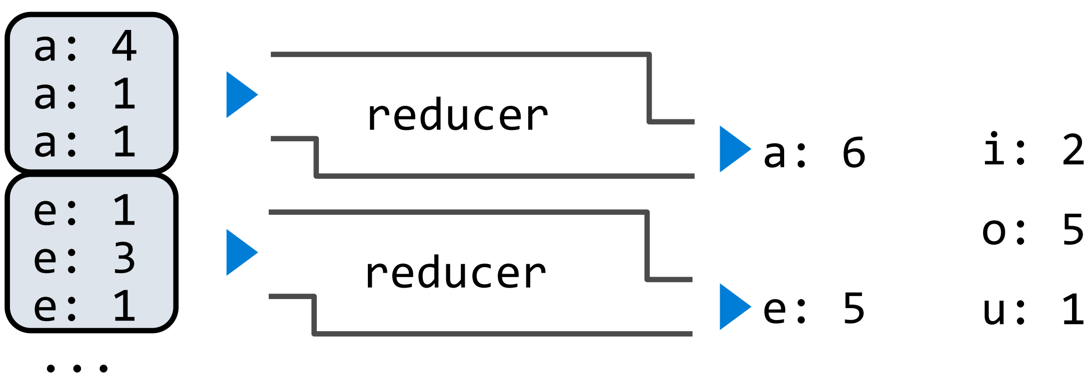
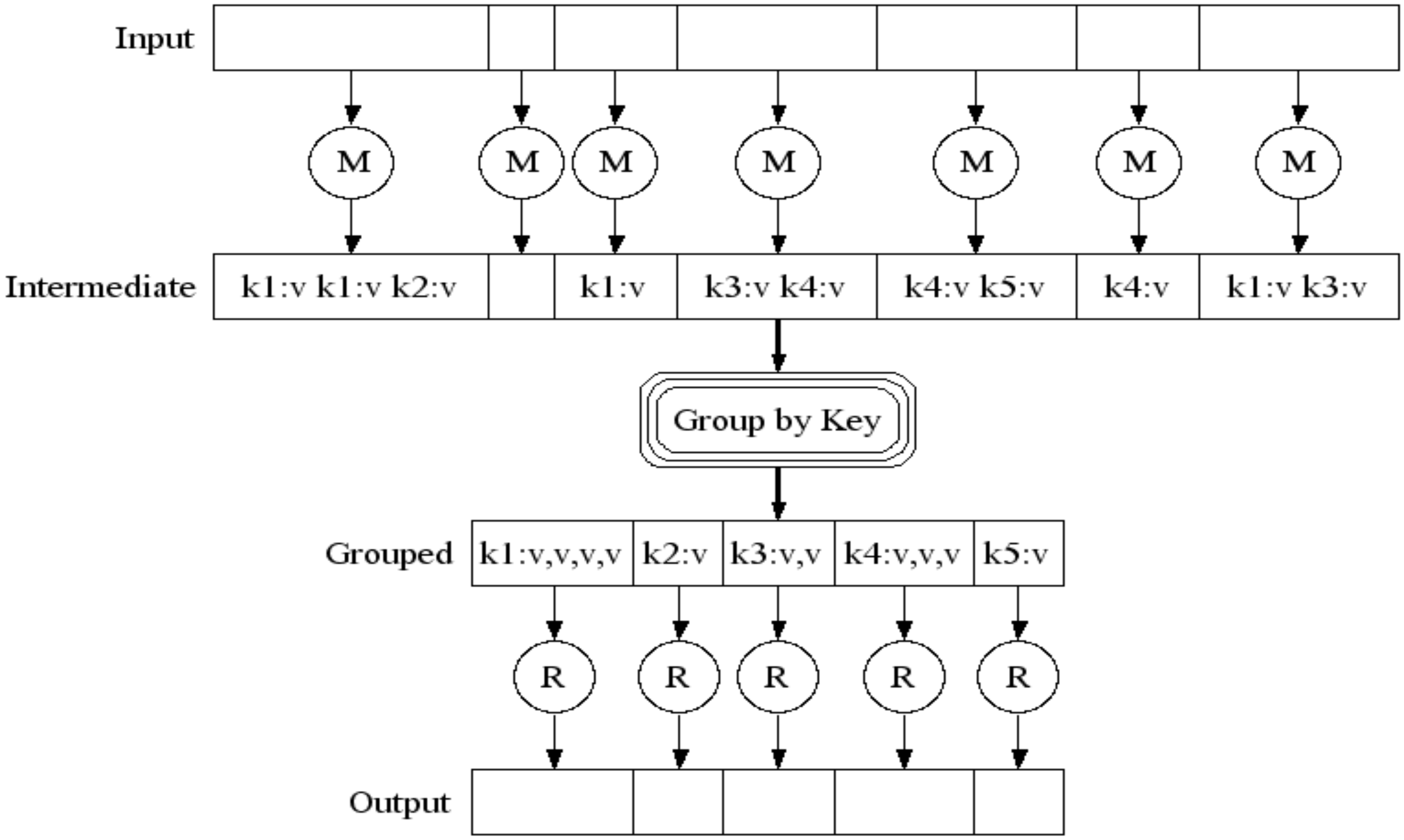
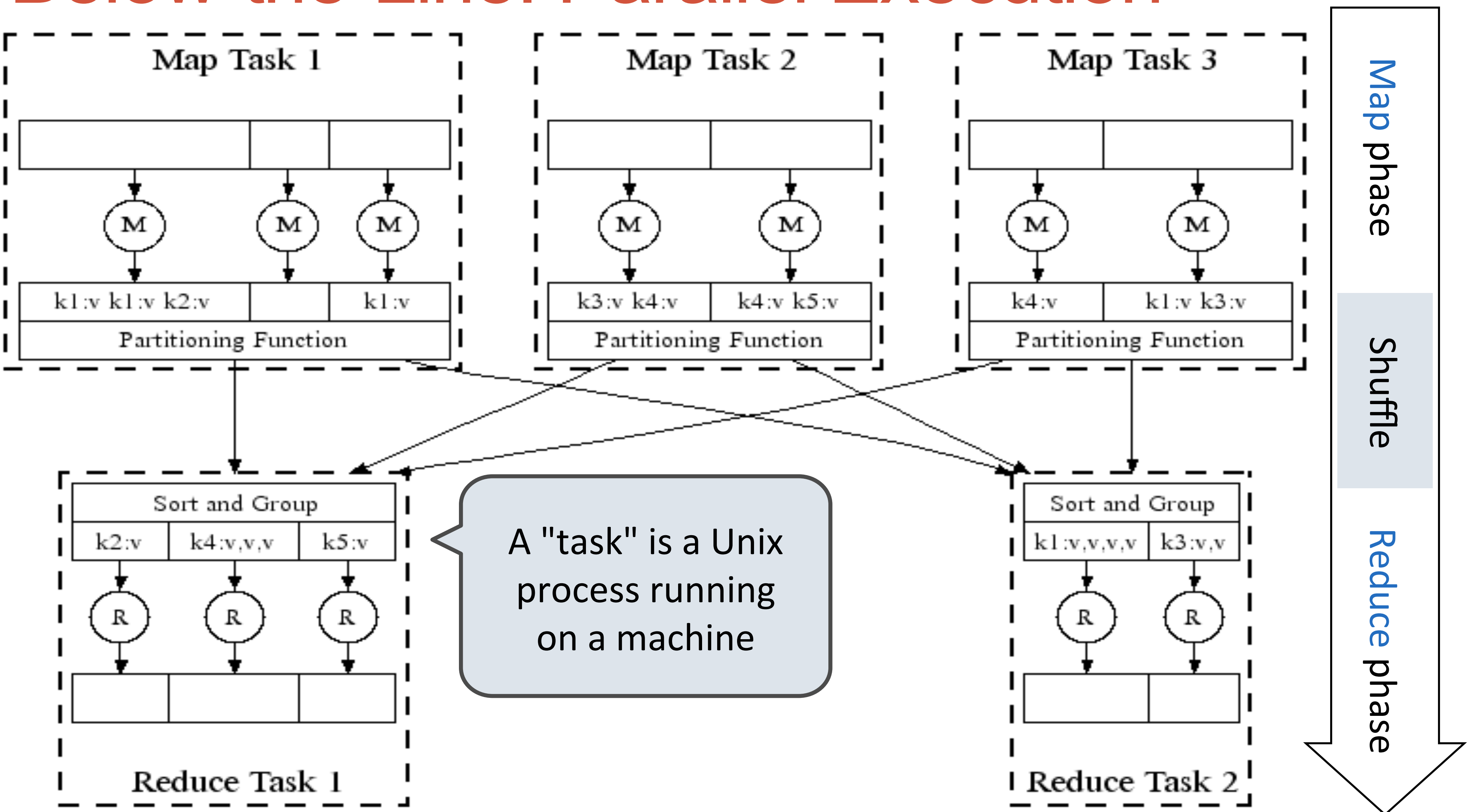


Above-the-Line: Execution Model



http://research.google.com/archive/mapreduce-osdi04-slides/index-auto-0007.html

Below-the-Line: Parallel Execution



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MapReduce Assumptions

Constraints on the *mapper* and reducer:

- The *mapper* must be equivalent to applying a deterministic pure function to each input independently
- The *reducer* must be equivalent to applying a deterministic pure function to the sequence of values for each key

Benefits of functional programming:

- When a program contains only pure functions, call expressions can be evaluated in any order, lazily, and in parallel
- Referential transparency: a call expression can be replaced by its value (or *vice versa*) without changing the program

In MapReduce, these functional programming ideas allow:

- Consistent results, however computation is partitioned
- Re-computation and caching of results, as needed

Python Example of a MapReduce Application

The *mapper* and *reducer* are both self-contained Python programs

- Read from *standard input* and write to *standard output*!

Mapper

```
#!/usr/bin/env python3

import sys
from ucb import main
from mapreduce import emit

def emit_vowels(line):
    for vowel in 'aeiou':
        count = line.count(vowel)
        if count > 0:
            emit(vowel, count)

for line in sys.stdin:
    emit_vowels(line)
```

Tell Unix: this is Python

The **`emit`** function outputs a key and value as a line of text to standard output

Mapper inputs are lines of text provided to standard input

Python Example of a MapReduce Application

The *mapper* and *reducer* are both self-contained Python programs

- Read from *standard input* and write to *standard output*!

Reducer

```
#!/usr/bin/env python3

import sys
from ucb import main
from mapreduce import emit, group_values_by_key
```

Takes and returns iterators

Input: lines of text representing key-value pairs, grouped by key

Output: Iterator over (key, value_iterator) pairs that give all values for each key

```
for key, value_iterator in group_values_by_key(sys.stdin):
    emit(key, sum(value_iterator))
```

What the MapReduce Framework Provides

Fault tolerance: A machine or hard drive might crash

- The MapReduce framework automatically re-runs failed tasks

Speed: Some machine might be slow because it's overloaded

- The framework can run multiple copies of a task and keep the result of the one that finishes first

Network locality: Data transfer is expensive

- The framework tries to schedule map tasks on the machines that hold the data to be processed

Monitoring: Will my job finish before dinner?!?

- The framework provides a web-based interface describing jobs