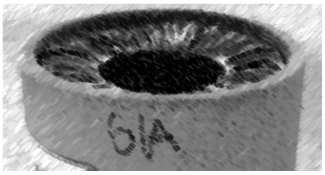

CS61A Lecture 42

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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

Announcements

- HW13 due Wednesday
- Scheme project due tonight!!!
- Scheme contest deadline extended to Friday

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

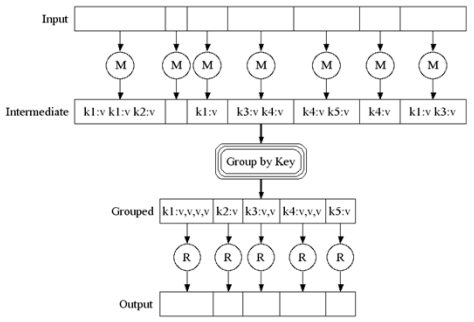
```
#!/usr/bin/env python3

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

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

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

MapReduce Execution Model



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

Parallel Computation Patterns

Not all problems can be solved efficiently using functional programming

The Berkeley View project has identified 13 common computational patterns in engineering and science:

1. Dense Linear Algebra
2. Sparse Linear Algebra
3. Spectral Methods
4. N-Body Methods
5. Sructured Grids
6. Unstructured Grids
7. MapReduce
8. Combinational Logic
9. Graph Traversal
10. Dynamic Programming
11. Backtrack and Branch-and-Bound
12. Graphical Models
13. Finite State Machines

MapReduce is only one of these patterns

The rest require shared mutable state

http://view.eecs.berkeley.edu/wiki/Dwarf_Mine

Parallelism in Python

Python provides two mechanisms for parallelism:

Threads execute in the same interpreter, sharing all data

- However, the CPython interpreter executes only one thread at a time, switching between them rapidly at (mostly) arbitrary points
- Operations external to the interpreter, such as file and network I/O, may execute concurrently

Processes execute in separate interpreters, generally not sharing data

- Shared state can be communicated explicitly between processes
- Since processes run in separate interpreters, they can be executed in parallel as the underlying hardware and software allow

The concepts of threads and processes exist in other systems as well

Threads

The **`threading`** module contains classes that enable threads to be created and synchronized

Here is a "hello world" example with two threads:

```
from threading import Thread, current_thread

def thread_hello():
    other = Thread(target=thread_say_hello, args=())
    other.start()
    thread_say_hello()

def thread_say_hello():
    print('hello from', current_thread().name)
```

Function that the new thread should run

Start the other thread

Arguments to that function

```
>>> thread_hello()
hello from Thread-1
hello from MainThread
```

Print output is not synchronized, so can appear in any order

Processes

The **`multiprocessing`** module contains classes that enable processes to be created and synchronized

Here is a "hello world" example with two processes:

```
from multiprocessing import Process, current_process

def process_hello():
    other = Process(target=process_say_hello, args=())
    other.start()
    process_say_hello()

def process_say_hello():
    print('hello from', current_process().name)
```

Function that the new process should run

Start the other process

Arguments to that function

```
>>> process_hello()
hello from MainProcess
>>> hello from Process-1
```

Print output is not synchronized, so can appear in any order

The Problem with Shared State

Shared state that is mutated and accessed concurrently by multiple threads can cause subtle bugs

Here is an example with two threads that concurrently update a counter:

```
from threading import Thread

counter = [0]

def increment():
    counter[0] = counter[0] + 1

other = Thread(target=increment, args=())
other.start()
increment()
other.join()
print('count is now', counter[0])
```

Wait until other thread completes

What is the value of **`counter[0]`** at the end?

The Problem with Shared State

```
from threading import Thread

counter = [0]

def increment():
    counter[0] = counter[0] + 1

other = Thread(target=increment, args=())
other.start()
increment()
other.join()
print('count is now', counter[0])
```

What is the value of **`counter[0]`** at the end?

Only the most basic operations in CPython are *atomic*, meaning that they have the effect of occurring instantaneously

The counter increment is three basic operations: read the old value, add 1 to it, write the new value

The Problem with Shared State

We can see what happens if a switch occurs at the wrong time by trying to force one in CPython:

```
from threading import Thread
from time import sleep

counter = [0]

def increment():
    count = counter[0]
    sleep(0)
    counter[0] = count + 1

other = Thread(target=increment, args=())
other.start()
increment()
other.join()
print('count is now', counter[0])
```

May cause the interpreter to switch threads

The Problem with Shared State

```
def increment():
    count = counter[0]
    sleep(0)
    counter[0] = count + 1
```

May cause the interpreter to switch threads

Given a switch at the `sleep` call, here is a possible sequence of operations on each thread:

```
Thread 0                    Thread 1
read counter[0]: 0
                            read counter[0]: 0
calculate 0 + 1: 1
write 1 -> counter[0]
                            calculate 0 + 1: 1
                            write 1 -> counter[0]
```

The counter ends up with a value of 1, even though it was incremented twice!

Race Conditions

A situation where multiple threads concurrently access the same data, and at least one thread mutates it, is called a *race condition*

Race conditions are difficult to debug, since they may only occur very rarely

Access to shared data in the presence of mutation must be *synchronized* in order to prevent access by other threads while a thread is mutating the data

Managing shared state is a key challenge in parallel computing

- Under-synchronization doesn't protect against race conditions and other parallel bugs
- Over-synchronization prevents non-conflicting accesses from occurring in parallel, reducing a program's efficiency
- Incorrect synchronization may result in *deadlock*, where different threads indefinitely wait for each other in a circular dependency

We will see some basic tools for managing shared state

Synchronized Data Structures

Some data structures guarantee synchronization, so that their operations are atomic

```
from queue import Queue
queue = Queue()
def increment():
    count = queue.get()
    sleep(0)
    queue.put(count + 1)
other = Thread(target=increment, args=())
other.start()
queue.put(0)
increment()
other.join()
print('count is now', queue.get())
```

Synchronized FIFO queue

Waits until an item is available

Add initial value of 0