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CECS 327

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Starvation-Free Dining Philosophers

Summary:

A solution to the dining philosophers problem, a classic concurrency problem in Computer Science, was presented to us for modification. In the unmodified version of the solution, philosophers that wish to eat were subject to starvation: when one philosopher finished eating and signaled the next philosopher to eat it would do so with no regard to how long (in seconds or turns elapsed) since that philosopher had last eaten. In our implementation, we have attempted to use turns elapsed since a philosopher has last eaten in order to determine which philosopher to signal.

We utilize a global counter that is incremented every time a philosopher eats. We then record the value of that counter to an array where indices correspond to each philosopher and update it every time the philosopher eats again. When each philosopher attempts to take the sticks to eat, it will ensure that its priority is higher than both of its neighbors before testing to see if it can eat and then ultimately eating or waiting. If the philosopher is made to wait, it will attempt to regain the lock and take the sticks again. When the philosopher has finished eating and puts the sticks down, it will then signal its neighbor should that neighbor be capable of eating at the moment. This signal may or may not be dropped as it depends on whether or not the signaled philosopher has sent the *await* message to that condition object. With this framework in place, the remainder of this paper will explore a starvation-free implementation for accessing the critical section of this classic problem.

Experiment 1: (5 philosophers, 20 turns)

For this portion of the project the runtime environment contained 5 philosophers each executing 20 turns. Each turn guarantees a philosopher will eat, although the ordering of the eat assignments are dependent upon the *takeSticks* implementation used for the program execution. Below is a table outlining the relative performance of the fair *takeSticks* implementation involving 5 philosophers. In summary, the relative execution durations for both implementations were largely equivalent in their average over the 10 trials used to collect the samples for this experiment.

Environment	Average Max Wait (turns)	Runtime (ms)		Aggregate Metrics	
Fair (5)	5	2631			
	5	2638			
	5	2611			
	5	2620			
	5	2623		Average of Average Max Waits	5
	5	2607		Average Runtime	2619.5
	5	2597			
	5	2621			
	5	2631			
	5	2616			

Collected metrics for the fair takeSticks implementation involving 5 philosophers

Though not shown the unfair *takeSticks* implementation performed only slightly better in its runtime, registering an average runtime of 2573.7 ms approximately 59 ms faster in the average case. However, the fair *implementation* performed better in terms of its fairness and predictability for the anticipated maximum wait for a potential philosopher. As can be seen in the table above, the maximum wait was never over 5 for any execution of the fair *takeSticks* implementation. In the unfair implementation average max waits varied between 6.0 and 6.6 turns. This trend of lower waits and longer runtimes will begin to manifest itself more prevalently in the subsequent experiments where the runtimes for the unfair implementation will experience constant rate growth as compared to the linear growth of the fair implementation runtimes. However in contrast, the fair implementation will always provide a upper limit for exactly how long a thread will wait to eat, equal exactly to number of philosophers in the environment.

Experiment 2: (25 philosophers, 20 turns)

Moving the number of executing philosopher to 25, while maintaining the same number of turns for each philosopher, began to expose the differences between the two implementations of *takeSticks*. Most notably was the relatively unchanging execution duration for the unfair implementation. That is, although the number of philosophers increased by a factor of 5, the program completed execution in approximately the same amount of time. This is likely due to the fact that although the environment became more populated with the increase in philosophers, the effect upon which philosopher would be eating had no relation to whether that philosopher should be eating. Concretely, any philosopher who could eat at the time they wanted to eat would therefore eat, reducing the under-utilization of the critical section. It is this mechanism which contributes to both the small execution time, along with the starvation potential for the unfair *takeSticks* implementation. As can be seen in the table below, when allowing anyone who can eat, to eat, there is potential that some philosopher ready to eat must wait a disproportionate number of turns before they are signaled. This is likely caused by the influence of locality in assigning the sticks to waiting philosophers. If there exist a set of philosopher who repeatedly release and acquire the sticks more consistently due to lack of an assignment policy, then those who continuously fail to acquire the lock will experience starvation in the form of large number of turns between their eat turns, which in the fairest case would see a max wait of exactly 25 since the longest a philosopher is guaranteed to wait is exactly equal to the number of philosophers eating.

Environment	Average Max Wait (turns)	Runtime (ms)		Aggregate Metrics	
Unfair (25)	33.36	2585			
	33.68	2601			
	32.2	2581			
	34.08	2588			
	33.68	2580		Average of Average Max Waits	33.268
	32.72	2575		Average Runtime	2584.2
	33.72	2582			
	33.36	2583			
	33.12	2580			
	32.76	2587			

Collected metrics for the unfair takeSticks implementation involving 25 philosophers

Experiment 3: (100 philosophers, 20 turns)

Following the trends of the two previous experiments the strengths and weaknesses of each implementation are highlighted most here. More precisely the fair *takeSticks* implementation reveals its strength as a strictly fair algorithm (FCFS critical section access). In providing this fairness however, the execution times have grown linearly with the number of executing philosophers as is displayed in the concluding graphs below. In comparison, the unfair *takeSticks* implementation has not deviated far from its execution duration of ≈2600 ms while the average max wait times among all philosophers now vary between ≈25-35 turns longer than that that of the fair implementation. With these three experiments in place, we can begin to forecast how exactly these two implementations fare in terms of the two primary metrics under consideration in this report. As it appears, the cost of guaranteed fairness and predictability is a large performance hit in terms of the programs relative throughput. That is, it will take far longer to pipe N philosophers through their respective turns if fairness is required. Also at the cost of fairness is the large resulting number of idle (busy-wait/polling) philosophers who continuously loop until the state of the system is such that they may eat. This can be observed in the code below, but at the high level this is due to the need for a philosopher to constrain itself when its neighbors appear hungrier than itself. Prohibiting this progression is ultimately the reason we see linear growth in the program runtimes for the fair implementation. Specifically, as in the 100 philosopher case here, philosophers must eat in such a manner that requires all other philosophers to eat before one philosopher may eat another time, adding a degree of rigidity that serves as a large bottleneck in the overall system's progression.

Environment	Average Max Wait (turns)	Runtime (ms)		Aggregate Metrics	
Fair (100)	100	134498			
	100	137805			
	100	136698			
	100	135218			
	100	137971		Average of Average Max Waits	100
	100	141861		Average Runtime	138063.5
	100	139906			
	100	141446			
	100	142002			
	100	133230			

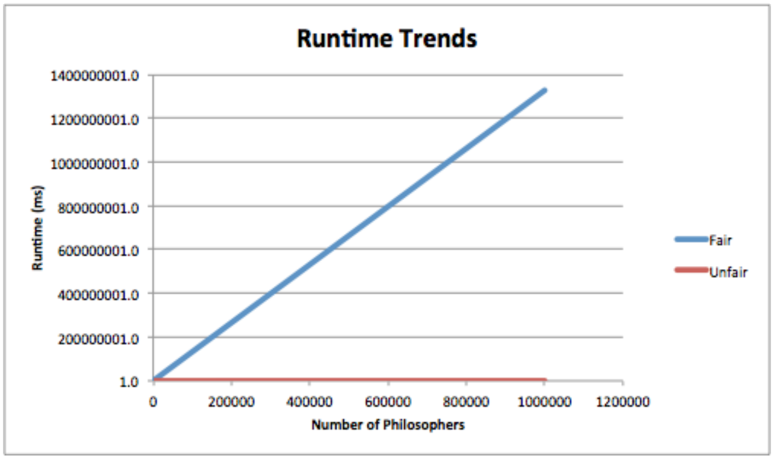
Collected metrics for the fair takeSticks implementation involving 100 philosophers

Environment	Average Max Wait (turns)	Runtime (ms)		Aggregate Metrics	
Unfair (100)	125.41	2585			
	126.39	2598			
	124.87	2586			
	131.84	2595			
	124.75	2577		Average of Average Max Waits	127.99
	133.07	2577		Average Runtime	2593.1
	131.77	2595			
	126.78	2616			
	126.67	2609			
	128.35	2593			

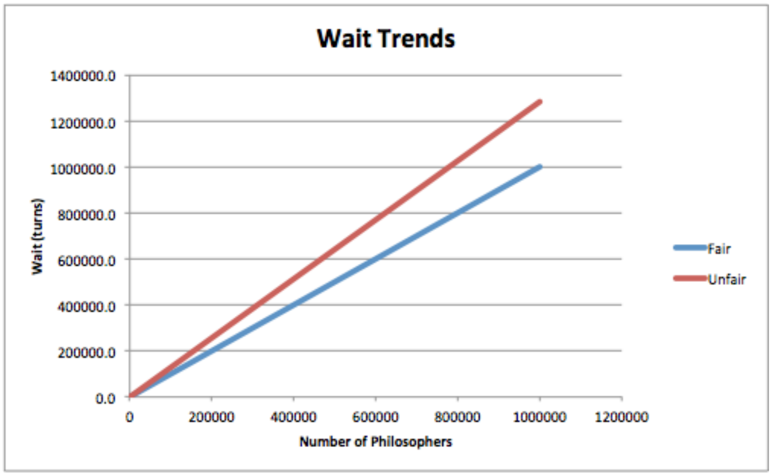
Collected metrics for the unfair takeSticks implementation involving 100 philosophers

Conclusion:

To sum up the above results, the cost of fairness in the suggested implementation here is a significant bottleneck resulting in much longer program runtimes. Alternatively, the unfair implementation here presents greater starvation risk as the environment becomes more populated. While further optimizations were not explored in this general solution, intuitively it seems as though the trending growth in wait times may be subject to some improvement, however the fact of coordination and FCFS eat assignments means that any fair implementation will likely experience some lower bound resulting from the waits required to guarantee linearization of the eating philosophers. The diagrams below highlight the trends for each of the implementations in terms of waits and runtimes, extrapolating these values out to a million philosophers in the environment. As can be seen the decision in which algorithm is applicable within a given context will largely be determined by the demands of the environment as both implementations have exactly opposite strengths and weaknesses.



Fair implementation runtime grows linearly compared to constant unfair implementation growth



Unfair implementation experiences larger rate of change in average max wait compared to ideal (fair)

Source:

```
import java.util.ArrayList;
import java.util.Collections;
import java.util.concurrent.atomic.AtomicInteger;
import java.util.concurrent.locks.*;

public class Philosopher extends Thread {

        public static int WAITING = 0, EATING = 1, THINKING = 2;
        public static final int TURNS = 20;

        public Philosopher
                (Lock l, Condition p[], int st[], int num,
                        int ID, AtomicInteger cnt, int[] apps, double[] max) {

                // default implementation
                lock = l;
                phil = p;
                states = st;
                NUM_PHILS = num;
                id = ID;

                // starvation free implementation
                this.counter = cnt; // reference to timestamp allocator
                this.appetites = apps; // reference to all others appetites
                this.max = max; // shared array for writing this philosophers max wait
                waits = new ArrayList<Integer>(); // reference to this philosophers waits
                appetites[id] = lastAte = counter.incrementAndGet(); // assign timestamp
        }


        public void run() {
                for (int k = 0; k < TURNS; k++) {

                        try { Thread.sleep(100); }
                        catch (Exception ex) {}

                        takeSticksFairly(id);

                        try { Thread.sleep(20); }
                        catch (Exception ex) {}

                        putSticks(id);
                }

                // write max wait for this philosopher
                max[id] = Collections.max(waits);
        }
```

```
public void takeSticks(int id) {
        lock.lock();
        states[id] = WAITING;
        try {
                if (!canEat(this.id)) {
                        phil[id].await();
                }
                else {
                        // go eat
                }

                eat();

        } catch (InterruptedException e) {
                System.exit(-1);
        } finally {
                lock.unlock();
        }
}


public void takeSticksFairly(int id) {
        while (true) {
                states[id] = WAITING;
                boolean hungrierThanRight =
                        (appetites[rightof(this.id)] >= appetites[this.id]);
                boolean hungrierThanLeft =
                        (appetites[leftof(this.id)] >= appetites[this.id]);
                if (hungrierThanLeft && hungrierThanRight) {
                        lock.lock();
                        try {
                                if (canEat(this.id)) {
                                        // go eat
                                }
                                else {
                                        phil[this.id].await();
                                }

                                eat();

                                break; // from while

                        } catch (InterruptedException e) {
                                System.exit(-1);
                        } finally {
                                lock.unlock();
                        }
                }
                else {
                        continue; // trying to eat
                }
        }
}
```

```
        private void putSticks(int id) {
                lock.lock();
                try {
                        states[id] = THINKING;

                        if (states[leftof(id)] == WAITING
                                && states[leftof(leftof(id))] != EATING) {
                                phil[leftof(id)].signal();
                        }
                        if (states[rightof(id)] == WAITING
                                && states[rightof(rightof(id))] != EATING) {
                                phil[rightof(id)].signal();
                        }
                } finally {
                        lock.unlock();
                }
        }


        private boolean canEat(int id) {
                return (states[id] == WAITING
                                && states[leftof(id)] != EATING
                                && states[rightof(id)] != EATING);
        }

        private void eat() {
                System.out.printf("Philosopher %3d is eating\n", id);
                int count = counter.incrementAndGet();
                waits.add(count - lastAte);
                lastAte = count;
                appetites[id] = lastAte;
                states[id] = EATING;
        }

        private int leftof(int id) { // clockwise
                int retval = id - 1;
                if (retval < 0) // not valid id
                        retval = NUM_PHILS - 1;
                return retval;
        }

        private int rightof(int id) {
                int retval = id + 1;
                if (retval == NUM_PHILS) // not valid id
                        retval = 0;
                return retval;
        }

        private Lock lock;
        private Condition phil[];
        private int states[];
        private int[] appetites;
        private int NUM_PHILS;
        private int id;
        private AtomicInteger counter;
        private int lastAte;
        private ArrayList<Integer> waits;
        private double[] max;

} // end class Philosopher
```

```java
import java.util.concurrent.atomic.AtomicInteger;
import java.util.concurrent.locks.*;

public class PhilTest {

        public static int WAITING = 0, EATING = 1, THINKING = 2;
        public static final int NUM_PHILS = 5;


        public static void main(String a[]) {
                init();
                long start = System.currentTimeMillis();
                execute();
                long end = System.currentTimeMillis();
                System.out.printf("\nMax Wait (Avg): %.2f turns\nRuntime: %d ms",
                        getAverage(max), (end - start));
        }

        public static void init() {

                // construct private data structures
                phil = new Condition[NUM_PHILS];
                states = new int[NUM_PHILS];
                appetites = new int[NUM_PHILS];
                max = new double[NUM_PHILS];

                // initialize environment threads
                for (int k = 0; k < NUM_PHILS; k++) {
                        phil[k] = lock.newCondition();
                        states[k] = THINKING;
                }
        }


        private static void execute() {
                Philosopher p[] = new Philosopher[NUM_PHILS];
                // begin
                for (int k = 0; k < p.length; k++) {
                        p[k] = new Philosopher(lock, phil, states,
                                        NUM_PHILS, k, counter, appetites, max);
                        p[k].start();
                }

                // synchronize
                for (Thread t : p) {
                        try { t.join(); }
                        catch (InterruptedException ex) { ex.printStackTrace(); }
                }
        }


        private static double getAverage(double[] arr) {
                double avg = 0.0;
                for (int i = 0; i < arr.length; i++) {
                        avg += arr[i];
                }
                return avg / arr.length;
        }
        private static Lock lock = new ReentrantLock();
        private static Condition[] phil;
        private static int[] states;
        private static AtomicInteger counter = new AtomicInteger(0);
        private static int[] appetites;
        private static double[] max;

} // end class PhilTest
```