Sᴍᴏɴ Fʀᴀsᴇʀ Uɴɪᴠᴇʀsɪᴛʏ

CMPT 300: Pʀᴏᴊᴇᴄᴛ II

Design and Implementation of a Monitor Construct.

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1   Introduction

Monitors are a powerful technique for providing mutual exclusion to shared resources in a multiprogramming environment, because of their ability to simplify the programming interface for users of the shared resource. They are, however, a complex construct that must be supported by the compiler for the language that makes use of them. Seeing as the design goals of C/C++ are primarily based on speed and efficiency of the resulting code, Monitors are not supported in these languages.

   In this report we design and implement a software interface that simulates the interface of a Monitor, using the pthreads package to provide the mutual exclusion required. We then use the Monitor construct to provide mutual exclusion to a hard drive simulator, which receives IO requests from multiple users.

2   High-level Design

2.1   Monitor Design

Since the monitor construct has to be implemented as a language feature, we can only hope to simulate the interface of a monitor in C++. The strategy is to use object oriented design and write a Monitor class which has the same interface as a rudimentary monitor, along with some extra helper functions to provide the functionality which would typically be language features.

   Once the Monitor class has been written, a programmer would then be able to write their own monitor as a subclass of the Monitor class, and implement their monitor functions according the documentation provided with the Monitor class. As an example, in this report, we implement a hard drive simulation, and provide mutual exclusion to the shared resources (IO read/write head) by writing a subclass of the Monitor called HDMonitor. Figure 2.1 features a UML class diagram of the intended system.
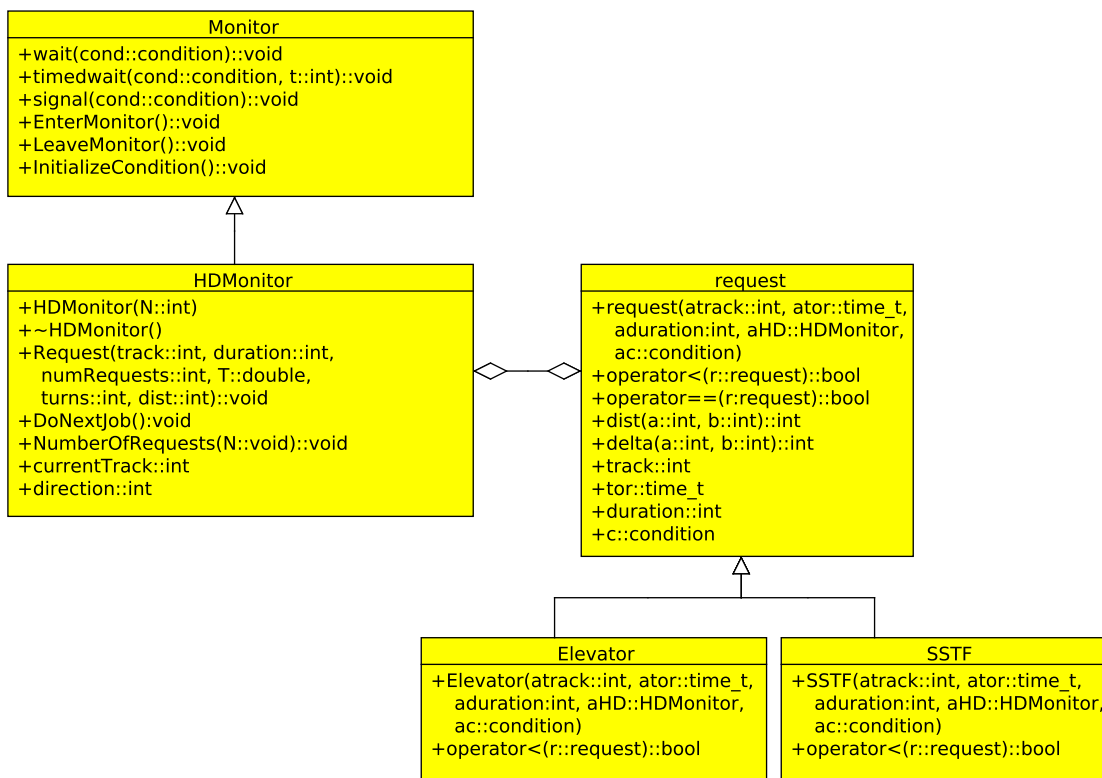
Figure 1: UML diagram from the hard drive simulation.

   As is see in the diagram, the Monitor class has a very basic interface, with only a few function calls, most of which are typical monitor calls like *signal* and *wait*. Two functions which are not standard are

EnterMonitor and *LeaveMonitor*. The monitor construct is supposed to only allow one process to use one of its function calls at a time, and the mutual exclusion is supposed to be provided automatically by the compiler. This is not possible using C++, and so when writing a monitor function as a subclass of the Monitor class, the programmer must ensure that the function calls EnterMonitor before doing anything, and calls LeaveMonitor when the function's work is done. The public interface and implementation in C++ can be found in listings 4.1 and 4.2.

2.2 Hard Drive Simulator Design

To demonstrate both the correctness of the Monitor class and how to implement a monitor as a subclass of Monitor, we implement a hard disk simulation in C++ using the Monitor interface to provide mutual exclusion to the shared resource (the IO read/write head). All of the source code can be found in the Listings section. Multiple threads will be generated to request IO on the tracks of the hard disk (labelled 1 to 15 for our experiments), and the hard disk will be responsible for managing these requests and servicing them according to a scheduling algorithm. The basic picture is illustrated in figure 2.2. In our design, the hard disk simulator will read requests from standard input, which can be generated by any number of threads.
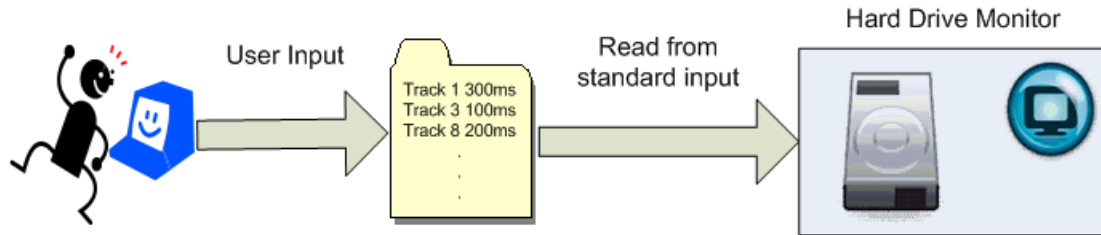

Figure 2: Scheduling environment for the hard drive simulation.

We will also take this opportunity to compare the performance of two popular scheduling algorithms for real hardware, namely the Elevator algorithm and the Shortest Seek-Time First (SSTF) algorithm. In the Elevator algorithm, the IO head moves in one direction, servicing pending requests as it reaches the desired tracks, and only changes direction when it reaches the inner or outer edge. The head will also change direction if there are no more requests for tracks in the direction of travel, but there are requests for tracks in the opposite direction. The SSTF algorithm will move the IO head to whichever desired track is closest to its current position.

To help the simulation decide which request to service next, we define a Request class as was seen in figure 2.1. Not only does the Request object keep a record of all the important request information like the track number and work to be done, but it also defines a weight through the less than operator (¡). The definition of the less-than operator depends on the desired scheduling algorithm. A Request object $\mathcal{A}$ is said to be less than the Request object $\mathcal{B}$ if $\mathcal{A}$ is to be scheduled before $\mathcal{B}$. The simulated hard drive can then maintain a list of Request objects as they are made, and decide the next one to service by finding the smallest Request object. As seen in the UML diagram, the implementation of the less-than operator is found in a separate file from the rest of the Request definition, to make it easy to plug in different definitions to get different scheduling algorithms.
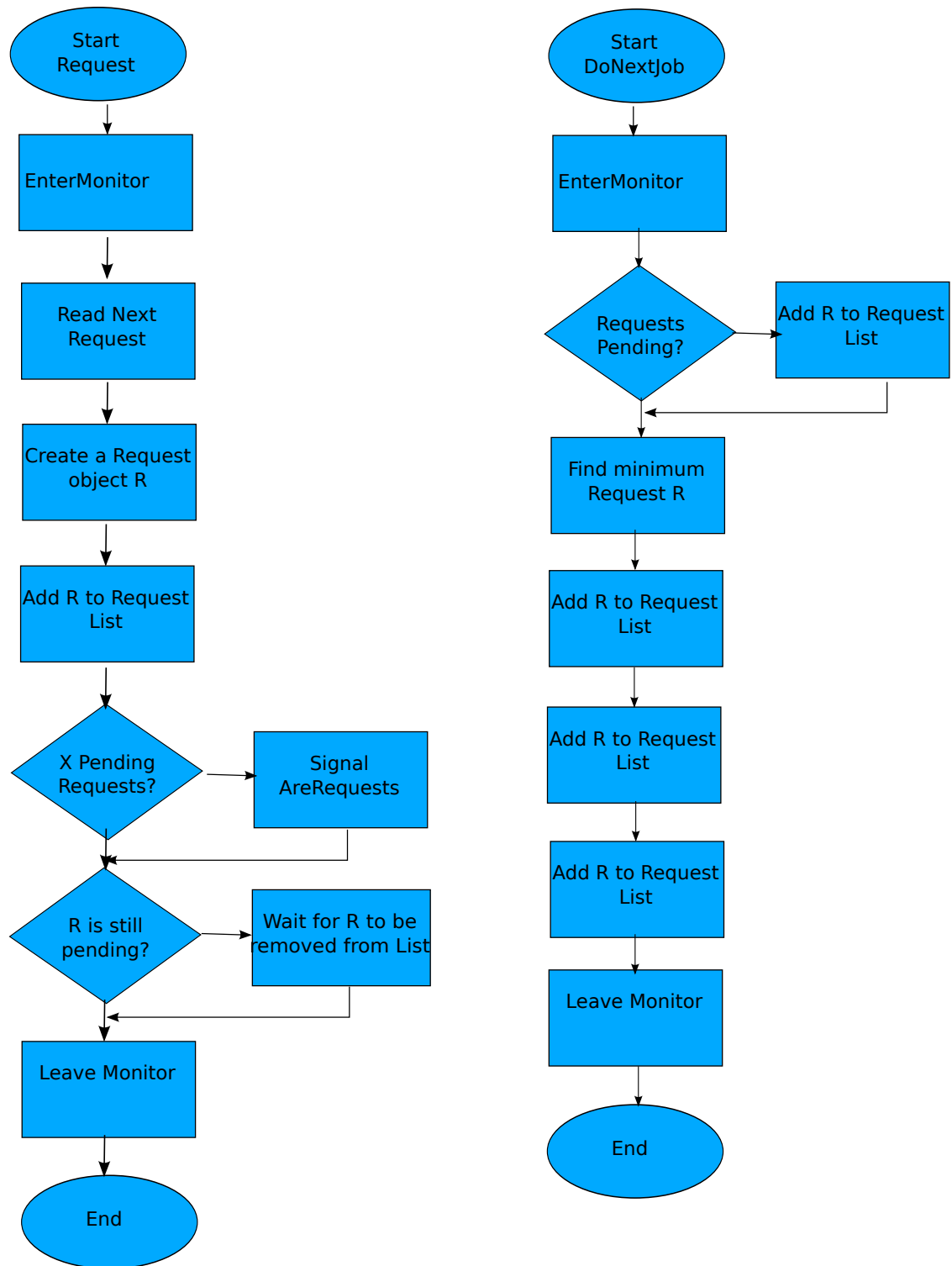
And here's a flow chart

Figure 3: a flow chart

3 Analysis

3.1 Time to Service a Request

One of the most important metrics in analyzing the performance of the hard drive is the time it takes after an IO request is made before it is serviced by the hard drive. This interval is expected to depend on the

number of unserviced requests made to the hard drive thus far, because the servicing thread always has to scan the entire list of requests in order to find the next request according to the scheduling rule. The way we ensure that more requests are pushed into the queue is by increasing the number of requesting threads.

In figures 3.1 and 3.1, this delay interval is shown as a function of the number of request threads for the Elevator and SSTF scheduling algorithms, respectively. This data was gathered from running the simulation multiple times, with increasingly many request threads, and on input data of 1000 requests generated randomly on the disk. IO requests from anywhere on the disk.
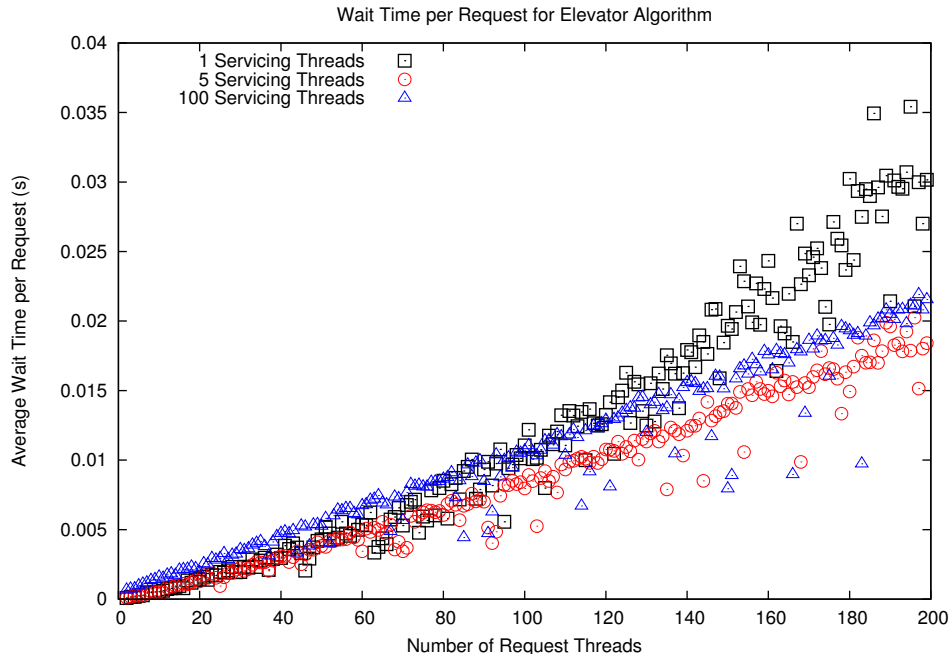

Figure 4: The wait time per request is improved by using more than one servicing thread.

From the graphs, we can make a few observations. Firstly, we can see that the performance of both algorithms are comparable using this metric, on this input data. This happens because the behaviour of the two algorithms are similar when the request queue contains data from everywhere on the disk. In this situation, both algorithms will scan up and down the disk in succession, servicing requests along the way.

Secondly, we can note the change in performance when increasing number of servicing threads are employed. By increasing from one to five threads, there is a clear improvement in performance, especially when there are many request threads. With only one servicing thread, there is a divergence from linear behaviour, but this divergence is delayed when using a large number of servicing threads. However, we can see that when using 100 threads, the performance is reduced from when using 5 threads. This is caused by the overhead of the system having to maintain a large number of threads. Therefore, performance by this metric is optimized by using a small number of servicing threads, but more than one.

There is a test case in which SSTF performs much worse than the Elevator algorithm. The SSTF algorithm can suffer from starvation when most of the IO requests are on one end of the disk (say the outer edge), and then a small number of requests are made for the other end of the disk (inner edge). If requests for the outer edge keep coming in before the servicing thread has the chance to clear the queue of requests, then those requests will never run. The elevator algorithm does not suffer from this problem, of course, since it scans the disk back and forth. Unfortunately (or perhaps fortunately!) it is very difficult to construct a test case that demonstrates this behaviour; the scheduling environment makes it difficult to predict how many requests will be pending at any time, so it is not possible to predict how long the servicing thread will execute before pthreads forces it to yield.
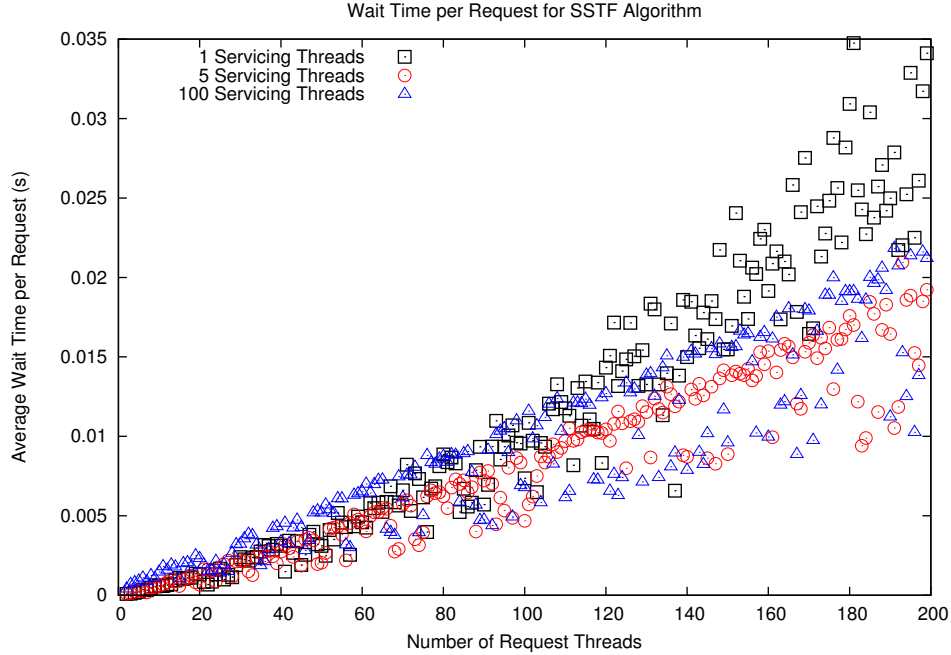
Figure 5: The wait time per request is improved by using more than one servicing thread.

3.2 Distance per Request

In the on the time to service a request, the analysis assumed that all jobs took the same amount of time to execute, and so the time was mostly attributable to the scheduling algorithm, and the relative amount of time spent in requesting threads versus the servicing thread. In real hardware, the IO head will require some time to move to the desired track, and so this might be a useful metric. Specifically, we measure the average number of tracks traversed between the time a request is made, and the same request is serviced. In figures 3.2 and 3.2 we show this quantity with respect to the number of request threads in the simulation, for the Elevator and SSTF algorithms, respectively.
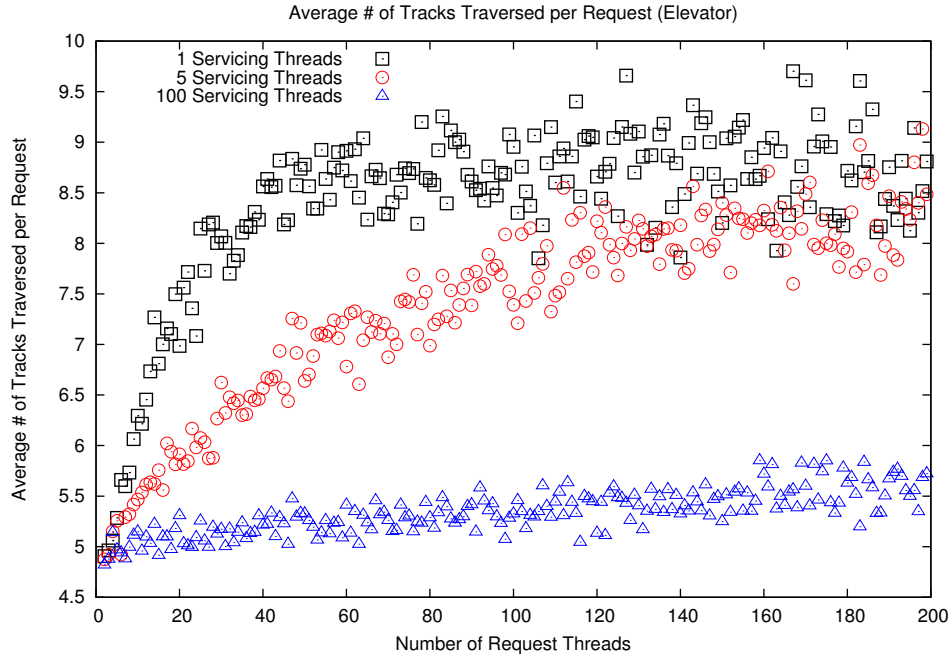
Average # of Tracks Traversed per Request (Elevator)

Figure 6: The average number of tracks traversed by the IO head per request can depend significantly on the number of servicing threads in use.
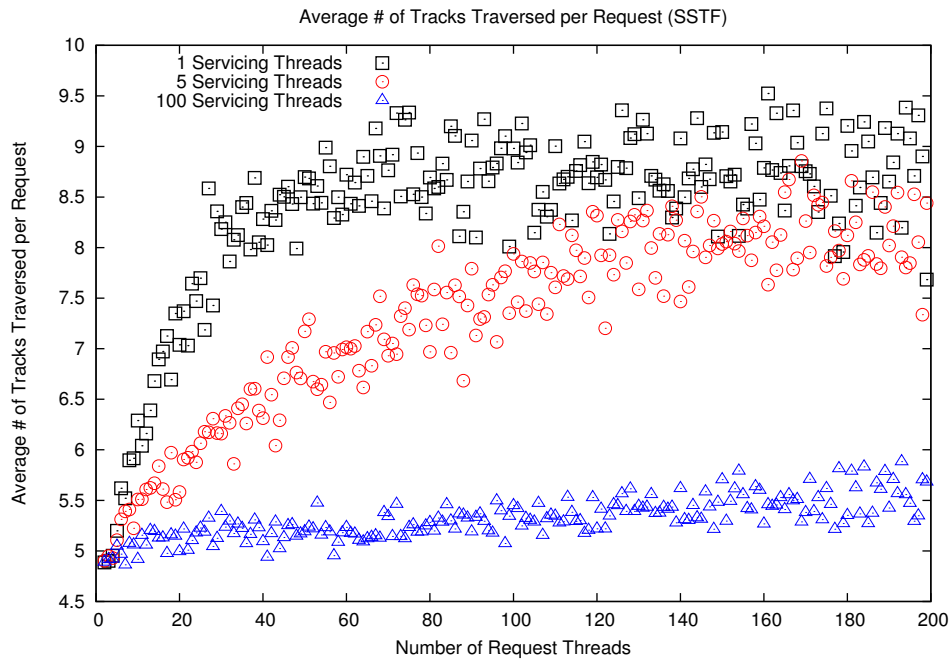
Average # of Tracks Traversed per Request (SSTF)

Figure 7: Performans of SSTF under the distance metric is comparable to Elevator on random input data.

Again, it's clear that the two algorithms have similar performance under this metric. This is again attributable to the behaviour of the two algorithms being similar on the input. Of particular interest, however, is the profile of the data. When the number of request threads is fewer than about twenty, the average distance per request increases linearly. This happens when there are relatively few requests on the queue (the result of fewer request threads), since the IO head will not travel in a straight line to the requested track under SSTF or Elevator, but rather will go back and forth between close requests in SSTF, or in the wrong direction with Elevator. However, when there are many requests, as explained before, both algorithms will scan the entire disk up and down servicing all requests. When multiple servicing queues are used, the average distance levels off at increasingly small values. This happens because having more servicing threads reduces the number of pending requests at any time, and so the average distance travelled does not grow as much.

Note that regardless of the number of servicing threads, the average number of tracks traversed begins at around 5. This is the result of our input data being random, and it can be shown that the expected distance travelled is 5 when using a hard drive of size 15, as we do in our simulations. When there is only 1 request thread, each request is usually serviced immediately because the act of requesting when there are no requests pending signals the servicing thread to do some work. Since the requests are designed to be random, the average distance (D) travelled is the average distance between any two tracks. This is computed below.

$$
\begin{aligned}
\mathrm{E}(D) &= \sum_{i=0}^{N} D \times \mathrm{P}(D), \text{expectation formula} \\
&= \frac{N}{N^2} + \sum_{i=1}^{N} (N - i) \times \frac{2i}{N^2}, N \text{ ways for positions to be identical} \\
&= \frac{1}{N^2} \left[2N \cdot \frac{N \cdot (N+1)}{2} - 2 \cdot \left(\frac{1}{6} \cdot N \cdot (N+1) \cdot (2N+1) \right) + N \right], \text{using summation formulae} \\
&= N + 1 - \frac{(N+1) \cdot (2N+1)}{3N} + \frac{1}{N}.
\end{aligned}
$$

Plugging in $N = 15$ yields $\mathrm{E}(D) = 5.04$, which is close to the observed value.

3.3   Reversals per Request

Another hardware consideration is the number of times the IO head will need to switch directions after a request is made and before it is serviced. Just like the distance metric, in real hardware it is expected that instructing the IO head to reverse direction would take some time, and it may be a desirable quantity to minimize. Figures 3.3 and 3.3 show this quantity with respect to the number of request threads, for the Elevator and SSTF algorithms, respectively. For both algorithms, there is an initial increase in the number of reversals as the number of request threads increase. This again is attributable to a non-empty request queue which is sparse. This initial increase is lost when the number of servicing threads is increased, because the number of pending requests is kept very low.

This is the first metric for which there is a measurable difference in performance. When there is only one request thread, the SSFT algorithm had runs whose *average* number of reversals was greater than one. This means that IO head had to reverse direction on almost every request, and sometimes more than once. This is definitely not very good behaviour if reversals want to be kept to a minimum. In comparison, the number of reversals for the Elevator don't vary as much, and the average number of reversals rarely were more than 0.8.
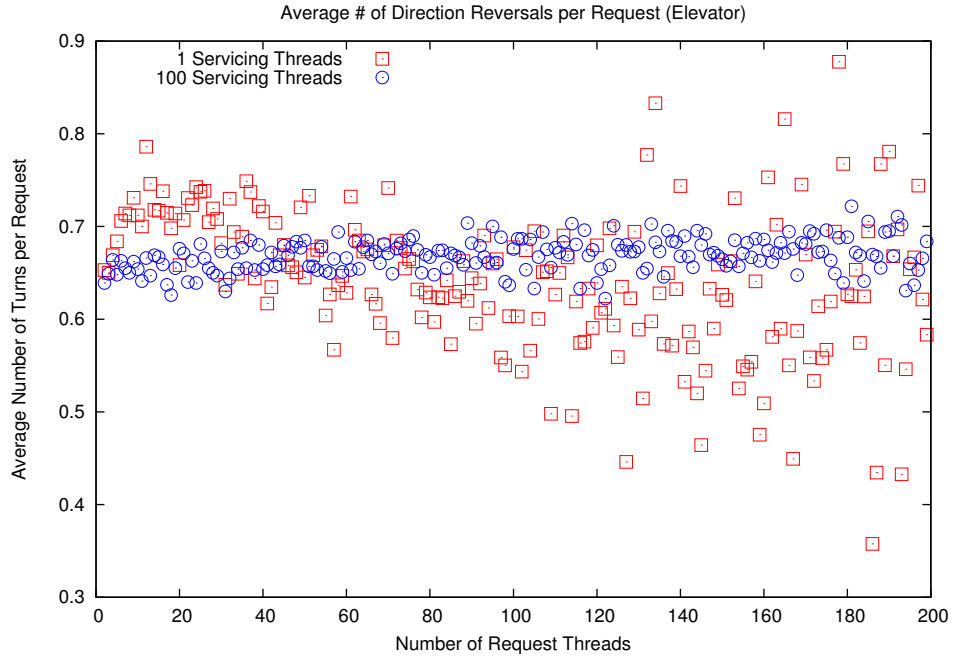
Figure 8: Due to the nature of the Elevator algorithm, the number of turns per request is guaranteed never to be more than one.
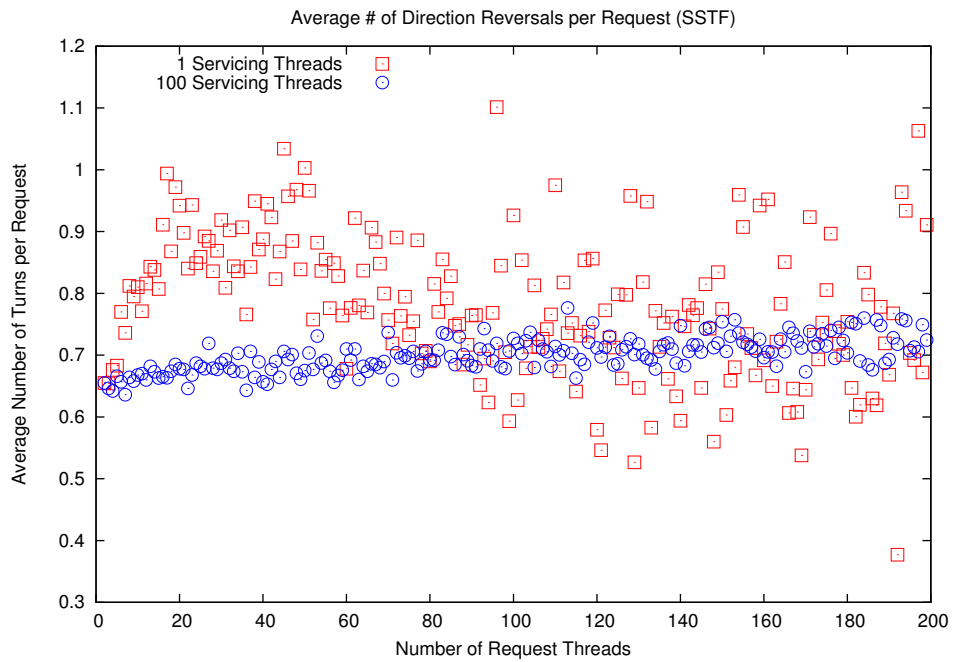

Figure 9: The number of reversals when using SSTF can be more than one per request.

4 Listings

4.1 Monitor Interface

```
1  /*
    *  Monitor.h
3   *  Created  by  Andrew  Inwood  on  11/15/11
    *  Modified  by  Joel  Teichroeb  11/27/11
5   *  for  CMPT  300  Project  2.
    *
7   *  All  rights  reserved.
    *
9   *
    *  Defines  the  interface  for  a  faked  Monitor  construct,  with  synchronization
11  *  of  shared  resources  implemented  using  the  pthreads  library.
    */
13 #ifndef MONITOR_H
   #define MONITOR_H
15 #include <pthread.h>
   #include <map>
17 typedef pthread_cond_t *condition;
   class Monitor{
19     public:
            //Constructor
21          Monitor();
            void wait(condition &cond);
23          void timedwait(condition &cond, int t);
            void signal(condition cond);
25          void EnterMonitor();
            void LeaveMonitor();
27          void InitializeCondition(condition &c);
       private:
29          /*The occupied mutex ensures that only one process is present in the
             *mutex at one time.
31           */
            pthread_mutex_t *occupied;
33 };
   #endif
```

Monitor.h

4.2 Monitor Implementation

```
   /*
2   *  Monitor.cpp
    *
4   *  Created  by  Andrew  Inwood  on  11/15/11
    *  Modified  by  Joel  Teichroeb  11/27/11
6   *  for  CMPT  300  Project  2.
    *
8   *  All  rights  reserved.
    *
10  *  Implementation  of  methods  of  the  Monitor  class  contained  in  Monitor.h
    *
12  */
   #include "Monitor.h"
14 #include <pthread.h>
   #include <ctime>
16 #include <cstdio>
   using namespace std;
18 Monitor::Monitor(){
       occupied = new pthread_mutex_t();
20     pthread_mutex_init(occupied, NULL);
   }
22
```

```cpp
   /*
24  *  InitializeCondition(condition &c).
    *
26  *  Creates and initializes a condition for immidiate use.
    *
28  */void Monitor::InitializeCondition(condition &c){
        c = new pthread_cond_t();
30      pthread_cond_init(c, NULL);
}

32
   /*
34  *  wait(condition cond).
    *
36  *  The executing thread releases the monitor, and is put to sleep until the
    *  condition variable is signalled.
38  *
    */
40 void Monitor::wait(condition &cond){
       int ret;
42     if((ret = pthread_cond_wait(cond, occupied))){
           printf ("wait failed with %d\n", ret);
44     }
}

46
   /*
48  *  timedwait(condition &cond, int t).
    *
50  *  The executing thread releases the monitor, and is put to sleep until the
    *  condition variable is signalled or t nanoseconds pass.
52  *
    */
54 void Monitor::timedwait(condition &cond, int t){
       struct timespec ts;
56     clock_gettime(CLOCK_REALTIME, &ts);
       ts.tv_nsec = ts.tv_nsec + t;
58     pthread_cond_timedwait(cond, occupied, &ts);
}

60
   /*
62  *  signal(condition cond).
    *
64  *  Signals all threads waiting on condition variable cond. The system selects
    *  one thread to execute once the Monitor is released.
66  *
    */
68 void Monitor::signal(condition cond){
       pthread_cond_broadcast(cond);
70 }

72 /*
    *  EnterMonitor().
74  *
    *  When EnterMonitor() completes, the calling thread has control of the Monitor.
76  *  This function must be the first line of all functions defined in the Monitor,
    *  and enables faking the Monitor construct in C++.
78  *
    */
80 void Monitor::EnterMonitor(){
       while(pthread_mutex_lock(occupied));
82 }

84 /*
    *  LeaveMonitor().
86  *
    *  When LeaveMonitor() completes, the Monitor is empty.
88  *
    */
90 void Monitor::LeaveMonitor(){
```

```
       int ret;
92     if((ret = pthread_mutex_unlock(occupied))){
           printf("Mutex unlock returned an error: $d\n", ret);
94     }
}
```

<div align="center">Monitor.cpp</div>

4.3 Hard Disk Monitor Interface

```
1  /*
    * HDMonitor.h
3   *
    * Created by Andrew Inwood on 11/15/11
5   * for CMPT 300 Project 2.
    *
7   * All rights reserved.
    *
9   * The HDMonitor provides the interface to a hard drive simulation, consisting
    * of N tracks and a moveable read/write head. Users of the HDMonitor can
11  * request IO operations on individual tracks, and request that a queued IO
    * operation be performed.
13  *
    * This Monitor schedules the next IO request based on the elevator algorithm.
15  *
    */
17
   #ifndef HD_MONITOR_H
19 #define HD_MONITOR_H
   #include "Monitor.h"
21 #include <list>        //for request list
   #include <ctime>       //for request time
23 #include <map>
   #include "Request.h"
25
   const int WAIT_FOR_X_REQUESTS = 1;
27 const int WAIT_X_NSECONDS = 1000000;
29 class RequestWrap {
     public:
31     request *r;
             virtual bool operator< (const RequestWrap &o) const {
33         return *r < *(o.r);
       }
35     bool operator==(const request *o) const{
         return r == o;
37     }
   };
39
   typedef std::list<RequestWrap> RequestList;
41 /*
    * HDMonitor (Hard Drive Monitor)
43  *
    */
45 class HDMonitor : protected Monitor{
       public:
47         condition areRequests; //Allows the scheduler to wait for requests
           //Constructors
49         HDMonitor(int N);
           ~HDMonitor();
51
           /*
53          * Request(int track, int duration)
            * Creates a new request to the hard drive, and is put on the queue for
55          * scheduling.
            */
```

<div align="center">11</div>

```cpp
57    void Request(int track, int duration, int &numRequests, double &T, int & turns,
         int & dist);
59          /*
             * DoNextJob().
61           * Selects the next job from the list based on the scheduling rule.
             *
63           */
            void DoNextJob();
65          void NumberOfRequests(int &N);
            int currentTrack; //track that read/write head is on [1, N]
67          int direction; //direction of read/write head {-1, 1}
       private:
69          int numWaitingToWork;
            int numTracks; // Equal to N
71          RequestList jobsList;
            std::map<request*, int> NumAtRequestComplete;
73          int numTurns;
            int distance;
75          std::map<request*, int> numTurnsMap;
            std::map<request*, int> distanceMap;
77 };
   #endif
```

HDMonitor.h

4.4   Hard Disk Monitor Implementation

```cpp
   /*
2   * HDMonitor.cpp
    *
4   * Created by Andrew Inwood on 11/15/11
    * for CMPT 300 Project 2.
6   *
    * All rights reserved.
8   *
    * The HDMonitor provides the interface to a hard drive simulation, consisting
10  * of N tracks and a moveable read/write head. Users of the HDMonitor can
    * request IO operations on individual tracks, and request that a queued IO
12  * operation be performed.
    *
14  * This Monitor schedules the next IO request based on the elevator algorithm.
    *
16  */

18 #include "Monitor.h"
   #include "HDMonitor.h"
20 #include <algorithm> //for min_element
   #include <cstdio>    //for output messages
22 #include <list>      //for request list
   #include <ctime>     //for request time
24 #include <unistd.h>

26 #include "SSTF.h"
   #include "Elevator.h"
28
   using namespace std;
30
   /*
32  * HDMonitor (Hard Drive Monitor)
    *
34  */
   HDMonitor::HDMonitor(int N){
36      numWaitingToWork = 0;
        direction = 1;
38      currentTrack = 1;
        numTracks = N;
```

```cpp
40      //InitializeCondition(areRequests);
        areRequests = new pthread_cond_t();
42      pthread_cond_init(areRequests, NULL);
        numTurns = 0;
44      distance = 0;
}
46  HDMonitor::~HDMonitor(){
}
48
    /*
50   * Request(int track, int duration)
     * Creates a new request to the hard drive, and is put on the queue for
52   * scheduling.
     */
54  void HDMonitor::Request(int track, int duration, int &numRequests, double &T, int
    &turns, int &dist){
56      EnterMonitor();
        T = clock()/(double)CLOCKS_PER_SEC;
58      int before = jobsList.size();
        int startTurns = numTurns;
60      int startDistance = distance;
        condition c;
62      InitializeCondition(c);
        request *r = new Elevator(track, time(NULL), duration, this, c);
64
        RequestWrap wrap;
66      wrap.r = r;
        jobsList.push_back(wrap);
68      NumAtRequestComplete.insert(pair<request*,int>(r, 0));
        //printf("The size was %d\n", jobsList->size() +1);
70      printf("Just pushed track %d for %d microseconds\n", track, duration);
        if(numWaitingToWork && jobsList.size() >= WAIT_FOR_X_REQUESTS){
72      //if(jobsList->size() && !before && numWaitingToWork) {
            signal(areRequests);
74      }
        while(find(jobsList.begin(), jobsList.end(), r) !=
76          jobsList.end()){
            timedwait(c, WAIT_X_NSECONDS);
78      }
        T = ( clock()/(double)CLOCKS_PER_SEC) - T;
80      /*
        dist = distance - startDistance;
82      turns = numTurns - startTurns;
        */
84      dist = distanceMap[r] - startDistance;
        turns = numTurnsMap[r] - startTurns;
86      distanceMap.erase(r);
        numTurnsMap.erase(r);
88
        //printf("The size is %d\n", jobsList->size() +1);
90      numRequests = NumAtRequestComplete[r];
        NumAtRequestComplete.erase(r);
92      delete r;
        LeaveMonitor();
94  }
    /*
96   * DoNextJob().
     * Selects the next job from the list based on the scheduling rule.
98   *
     */
100 void HDMonitor::DoNextJob(){
        EnterMonitor();
102     if(!jobsList.size()) { //wait until requests are available
            ++numWaitingToWork;
104         //The loop is necessary, or else pthreads will wake up a thread
            //that has been inactive for some time.
106         while(!jobsList.size()){
                printf("going to wait\n");
```

13

```cpp
108                    //wait(areRequests);
                       timedwait(areRequests, WAIT_X_NSECONDS);
110            }
            --numWaitingToWork;
112        }
        //get next job
114        RequestList::iterator nextRequest = min_element(jobsList.begin(), jobsList.end());
        request *r = nextRequest->r;
116        //change direction if necessary
        if((direction == -1 && r->track > currentTrack) ||
118           (direction == 1  && r->track < currentTrack)) {
              direction *= -1;
120           nextRequest = min_element(jobsList.begin(), jobsList.end());
    r = nextRequest->r;
122        ++numTurns;
        //printf("Have turned %ld times.\n", numTurns);
124        }
        int delta = r->track - currentTrack;
126        if(delta > 15) {
              //printf("Found delta with %d. Next track at $d, current track at $d\n", delta,
128           //r->track, currentTrack);
        }
130        distance += (delta > 0) ? delta : -1*delta;
        currentTrack = r->track;
132        printf("Working on track %d for %d micro seconds\n", r->track, r->duration);
        //printf("Have travelled %ld\n", distance);
134        NumAtRequestComplete[r] = jobsList.size();
        int sleepytime = r->duration;
136        jobsList.erase(nextRequest);
        distanceMap.insert(pair<request*,int>(r, distance));
138        numTurnsMap.insert(pair<request*,int>(r, numTurns));
        signal(r->c);
140        //delete r;
        usleep(1);
142        //usleep(sleepytime); //Do some "work"
        LeaveMonitor();
144 }

146 /*
     * NumberOfRequests()
148  * Returns the number of requests pending
     *
150  */
    void HDMonitor::NumberOfRequests(int & N){
152        EnterMonitor();
        N = jobsList.size();
154        LeaveMonitor();
    }
```

HDMonitor.cpp

4.5   Request Class Definition

```cpp
1 #ifndef REQUEST_H
  #define REQUEST_H
3
  #include <ctime>
5 #include "Monitor.h"

7 class HDMonitor;

9 /*
   * request
11  * The HDMonitor encapsulates an IO request as an instance of the request class,
   * and maintains a list of these objects.
13  *
```

```
    */
15  class request {
        public:
17          int track;
            time_t tor; //Time of Request
19          int duration;
            condition &c;
21          static int dist(int a, int b){ return a < b ? b − a : a − b;}
            static int delta(int a, int b) { return b − a;}
23          request(int atrack, time_t ator, int aduration, HDMonitor *aHD, condition &ac):c (ac
                ){
                track = atrack;
25              tor = ator;
                duration = aduration;
27              H = aHD; //The comparison operator needs the currentTrack from H
            }
29          /*
             * operator<
31           * This is required to find the next request.
             */
33          virtual bool operator< (const request & r) const = 0;
            bool operator==(const request & r) const{
35              return track == r.track && tor == r.tor && duration == r.duration && H
                    == r.H && c == r.c;
37          }
             protected:
39              HDMonitor *H;
    };
41


43  #endif
```

4.6   Scheduling Algorithm Implementations

The scheduling algorithm is implemented by defining an order on the Request objects in the HDMonitor class. The order is defined by implementing the less-than operator($<$), and this is done in separate files for each algorithm and linked at compile time.

Elevator Algorithm

```
    /*
2    * Elevator.cpp
     *
4    * Created by Joel Teichroeb on 11/25/11
     * for CMPT 300 Project 2.
6    *
     * All rights reserved.
8    *
     * The Elevator class as defined in Elevator.h.
10   *
     */
12  #include "Elevator.h"
    #include "HDMonitor.h"
14
    /*
16   * Implement the < operator for requests.
     */
18  bool Elevator::operator< (const request &r) const{
        switch(H−>direction){
20          case 1:
                return ( request::dist(H−>currentTrack, track) < request::dist(H−>currentTrack,
                    r.track) &&
22                      request::delta(H−>currentTrack, track) >= 0 ) ||
```

```
                          ( track == r.track && request::delta(H->currentTrack, track) >= 0 &&
24                          tor < r.tor);
                break;
26          case −1:
                return ( request::dist(H->currentTrack, track) < request::dist(H->currentTrack,
                     r.track) &&
28                      request::delta(H->currentTrack, track) <= 0) ||
                        ( track == r.track && request::delta(H->currentTrack, track) <= 0 &&
30                      tor < r.tor);
         break;
32      default:
                return false;
34              break;
      }
36 }
```

<div align="center">Elevator.cpp</div>

Shortest Seek-Time First Algorithm

```
   /*
2   * SSTF.cpp
    *
4   * Created by Joel Teichroeb on 11/25/11
    * for CMPT 300 Project 2.
6   *
    * All rights reserved.
8   *
    * The SSTF class as defined in SSTF.h.
10  *
    */
12 #include "SSTF.h"
   #include "HDMonitor.h"
14
   /*
16  * Implement the < operator for requests.
    */
18 bool SSTF::operator< (const request &r) const{
     return dist(H->currentTrack, track) < dist(H->currentTrack, r.track);
20 }
```

<div align="center">SSTF.cpp</div>

4.7   Main Program

```
1 #include "HDMonitor.h"
  #include <cstdio>
3 #define NUM_TRACKS 15
  #include <pthread.h>
5 #include <cstdlib>
  #include <ctime>
7 #include <unistd.h>
  #include <map>
9 #define WAIT_TIME 1
  static int NUM_THREADS = 100;
11 static int NUM_WORK_THREADS = 1;
  using namespace std;
13
  // The mutex used so that only one thread calls scanf at a time
15 pthread_mutex_t readmutex;
17 void *Schedule(void* Mon);
  void *DoNext(void* Mon);
19 int main(int argc, char *argv[]){
```

```
        if ( argc > 2) {
21          NUM_THREADS = atoi ( argv [ 1 ] ) ;
            NUM_WORK_THREADS = atoi ( argv [ 2 ] ) ;
23      }
        HDMonitor M(NUM_TRACKS) ;
25      pthread_t threads [NUM_THREADS + NUM_WORK_THREADS] ;
        int rc ;
27      long t ;
        void* status ;
29      pthread_mutex_init(&readmutex , 0 ) ;

31      // Create the worker threads
        for ( t=0; t < NUM_WORK_THREADS ; t++){
33        rc = pthread_create(&threads [ t ] , NULL, DoNext,  &M) ;
          if ( rc ){
35          printf("ERROR; return code from pthread_create() is %d\n", rc ) ;
            exit(-1) ;
37        }
        }
39
        // Create the request threads
41      for ( t=NUM_WORK_THREADS; t<NUM_THREADS + NUM_WORK_THREADS ; t++){
          rc = pthread_create(&threads [ t ] , NULL, Schedule , & M) ;
43        if ( rc ){
            printf("ERROR; return code from pthread_create() is %d\n", rc ) ;
45          exit(-1) ;
          }
47      }

49      if ( rc ){
         printf("ERROR; return code from pthread_create() is %d\n", rc ) ;
51       exit(-1) ;
        }
53
        // Wait for all the request threads to finish before exiting the program
55      for ( t = NUM_WORK_THREADS; t < NUM_THREADS + NUM_WORK_THREADS; ++t ){
            rc = pthread_join(threads [ t ] , &status ) ;
57      }
        return 0 ;
59 }

61
  void* Schedule (void* Mon){
63      int track , duration ;
        FILE* TimingFP = fopen("TimePerRequest.txt", "w") ;
65      fclose(TimingFP) ;
        HDMonitor* M = (HDMonitor*) Mon;
67      while(true){
    pthread_mutex_lock(&readmutex ) ;
69    int ret = scanf("%d %d", &track , &duration ) ;
    pthread_mutex_unlock(&readmutex ) ;
71          if ( ret == 2){
                clock_t start = clock() ;
73              int N;
                double T;
75              int turns , distance ;
                M->Request(track , duration , N, T, turns , distance ) ;
77              TimingFP = fopen("TimePerRequest.txt", "a") ;
                fprintf(TimingFP, "%d %16.14f %d %d\n", N, T, turns , distance ) ;
79
                fclose(TimingFP) ;
81              usleep(rand() % WAIT_TIME) ;
            } else if (ret == EOF) {
83      // if scanf outputs that there is no more data left stop the thread
        break ;
85    }
        }
87 }
```

```
   void* DoNext(void* Mon){
89     HDMonitor* M = (HDMonitor*) Mon;
       while(true){
91         M->DoNextJob();
       }
93 }
```

MonitorDriver.cpp

Contents