

Raw Outputs

September 9, 2023

1 Raw data and graphs

This pdf contains the raw data and graphs used to test the performance of the code.

1.1 Setup 1

- Threads all increment one variable **without a mutex**

code

```
// Ziad Arafat
// Created: Aug 31 2023
// Figure 1.7 in the textbook

/**
 * @brief This program will create an array of a specified size and fill it
 * with random numbers between 1 and 3 inclusive. It will then try to count
 * the number of threes in the array using a serial method and a parallel method
 * it will return the counts for each attempt as well as the running times.
 *
 * This version will use a single variable shared by all the threads without
 * using a mutex. We expect it to return incorrect results
 *
 */

/**
Changelog
08/31
- added argument handling
- Added handling to create an array of a certain size.
- added random number generator to fill array
- Created serial program to count 3s in array

09/07
- tested thread creation using pthread
- created function to generate threads to handle different sections of array

09/09
- corrected my thread code because it wasnt being joined so output was shown
```

```

- before thread was closed.
- added timing code.
- fixed timing code.
- added free() calls to clean up the memory when done
- fixed the way the array is split for the threads

*/

#define DEBUG 0 // flag to print debug values

#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <pthread.h>

int *A; // Pointer to our array in heap
int COUNT = 0; // The count of threes we found for the parallel code
int SEGSIZE; // the size of each chunk per tread
int NUMOFTHREADS; // the number of threads to spawn
int SIZE; // The size of the input array

/**
 * @brief Iterates through a chunk of the A array and counts the number of
 * threes by updating the COUNT variable
 *
 *
 *
 * @param index The index of the array chunks re are working with
 * @return void* returns a void pointer to work with pthread
 *
 * @pre The global A variable must be a pointer to an array in heap containing numbers between
 * 1 and 3. index must be a number referring to the index of the chunk we want
 * to work through starting at 0. The global COUNT variable must contain the
 * number of threes we have already counted
 *
 * @post When done the COUNT variable must be updated to have the number of
 * threes found in our chunk of the array
 */
void *count3s(void *idx)
{
    // if (DEBUG)
    //     printf("I ran once %d\n", index);

    int *index = (int *)idx; // cast the void star input to an int ptr
    int mystart = *index * SEGSIZE; // set the starting point for the thread
    int myend = mystart + SEGSIZE; // set the end point for the thread

    if (DEBUG) {
        printf("start is %d\n", mystart);
    }
}

```

```

        printf("end is   %d\n", myend);
    }

    // iterate through our section of the array and count the threes
    for (int i = mystart; i < myend; i++) {
        if (A[i] == 3) {
            if (DEBUG)
                printf("Found a three\n");
            COUNT++;
        }
    }

    // When we reach the final index we will calculate the remaining values in the array
    // So that we can add them to the result.
    // This can become quite high once you go past the 50% mark of the array size
    // but our tests will never go that far so this is a pretty good solution.
    if ((myend < SIZE) && (*index == NUMOFTHREADS - 1)) {
        if (DEBUG) {
            int remain = SIZE - myend;
            printf("Remainder: %d \n", remain);
        }

        // printf("ACTIVE \n");

        // iterate through the remainder of the array and count the 3s
        for (int i = myend; i < SIZE; i++) {
            if (A[i] == 3) {
                COUNT++; // increment count
            }
        }

        if (DEBUG) {
            printf("The count is now %d threads %d index %d SIZE %d end %d \n",
                COUNT, NUMOFTHREADS, *index, SIZE, myend);
        }
    }

    return (void *)0;
}

/**
 * @brief This function is used to spawn the appropriate number of threads as
 * well as keep track of their progress.
 *
 *
 * @return int containing the time it took
 *
 *
 * @pre The global COUNT variable is 0. NUMOFTHREADS is greater than 0.
 * SEGSIZE is the size of the array divided by NUMOFTHREADS. the A variable

```

```

* points to an array in heap.
*
* @post The global COUNT contains the correct three count
*
*/
int count3s_parallel()
{
    // initialize the timer for the parallel work
    struct timespec starttime, endtime;
    int j, k;

    // get the start time
    clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

    // Created an array allocated at runtime to hold the identifiers for
    // our threads
    pthread_t *t_idents;
    int *t_indices;

    // Allocates the space needed for the thread IDs
    t_idents = (pthread_t *) (malloc(sizeof(pthread_t) * NUMOFTHREADS));

    // in order to fix the "integer to pointer conversion" warning
    // i made an array to store the indices for each thread that way
    // i can pass it as a pointer in the for loop
    t_indices = (int *) (malloc(sizeof(int) * NUMOFTHREADS));

    // Create the threads
    for (int i = 0; i < NUMOFTHREADS; i++) {
        t_indices[i] = i;
        pthread_create(&t_idents[i], NULL, count3s,
                      (void *)&t_indices[i]);
    }

    // wait for all the threads to finish.
    for (int i = 0; i < NUMOFTHREADS; i++) {
        pthread_join(t_idents[i], NULL);
    }

    // free the ids and indexes in memory so we dont leak
    free(t_idents);
    free(t_indices);

    // get the end time
    clock_gettime(CLOCK_REALTIME, &endtime);

    // calculate duration
    j = endtime.tv_sec - starttime.tv_sec;

```

```

    k = endtime.tv_nsec - starttime.tv_nsec;
    j = j * 1000000000 + k;

    // return the duration
    return j;
}

int main(int argc, char const *argv[])
{
    // this variable stores the time for generating the random numbers.
    time_t t;

    // initialize the random number with the time as the seed
    srand((unsigned)time(&t));

    // check if the correct arguments are used
    if (argc != 3) {
        // if they are wrong barf and exit
        printf("Not correct arguments \n");
        printf("Usage %s <size of array> <number of threads> \n",
            argv[0]);
        exit(1);
    }

    // Convert the user input to integers
    SIZE = atoi(argv[1]);
    NUMOFTHREADS = atoi(argv[2]);

    // Set the size of the array chunks to process to the size over the
    // number of threads
    SEGSIZE = SIZE / NUMOFTHREADS;

    if (DEBUG) {
        printf("number is %s \n", argv[1]);
        printf("number is %d \n", SIZE);
        printf("NumThr is %d \n", NUMOFTHREADS);
        printf("Seg Size is %d \n", SEGSIZE);
    }

    // Allocate the array based on the input size
    A = (int *) (malloc(sizeof(int) * SIZE));

    // if the array is null barf
    if (A == NULL) {
        printf("Austin, we have a problem");
        exit(1);
    }
}

```

```

// generate random numbers and fill them in the array
// the numbers are between 1 and 3 inclusive
for (int i = 0; i < SIZE; i++) {
    A[i] = rand() % 4;
    // printf("E%d \n", A[i]);
}

// Count the threes in parallel
int parallel_time = count3s_parallel();

// initialize the count for the serial code
int local_count = 0;

// initialize the timer for the parallel work
struct timespec starttime, endtime;
int j, k;

clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

// Count the threes in serial
for (int i = 0; i < SIZE; i++) {
    if (A[i] == 3) {
        local_count++;
    }
}

// get end time
clock_gettime(CLOCK_REALTIME, &endtime);

// calculate duration
j = endtime.tv_sec - starttime.tv_sec;
k = endtime.tv_nsec - starttime.tv_nsec;
j = j * 1000000000 + k;

// free the array
free(A);

// print the times and counts
printf("Time parallel: %d \n", parallel_time);
printf("Time serial:   %d \n", j);

printf("parallel count is %d\n", COUNT);
printf("serial count is   %d\n", local_count);

return 0;
}

```

Raw console outputs

- All runs are done with an array of size 10,000,000

1 Thread

```
doge@godemperordoge1998 ~/D/parallel-programming (main)> cd figure1_7/
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> make
gcc -O0 -Wall -Werror -Wextra -pedantic -pthread -o figure1_7 figure1_7.c
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 1
Time parallel: 41548092
Time serial: 40781794
parallel count is 2499294
serial count is 2499294
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 1
Time parallel: 41616537
Time serial: 40523451
parallel count is 2499311
serial count is 2499311
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 1
Time parallel: 41686727
Time serial: 40876149
parallel count is 2498476
serial count is 2498476
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 1
Time parallel: 40781165
Time serial: 40663692
parallel count is 2501086
serial count is 2501086
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 1
Time parallel: 42017216
Time serial: 40238289
parallel count is 2499818
serial count is 2499818
doge@godemperordoge1998 ~/D/p/figure1_7 (main)>
```

2 Threads

- Since the output was not the same for parallel likely due to the race condition caused by line 85 we will stop testing this code

```
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 2
Time parallel: 62501107
Time serial: 39678580
parallel count is 2186343
serial count is 2499866
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 2
Time parallel: 61941468
Time serial: 40740028
```

```

parallel count is 2185462
serial count is 2498949
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 2
Time parallel: 41536079
Time serial: 41486353
parallel count is 2300733
serial count is 2499709
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 2
Time parallel: 62254078
Time serial: 40387819
parallel count is 2180401
serial count is 2499807
doge@godemperordoge1998 ~/D/p/figure1_7 (main)> ./figure1_7 10000000 2
Time parallel: 62037290
Time serial: 40656079
parallel count is 2184139
serial count is 2499412
doge@godemperordoge1998 ~/D/p/figure1_7 (main)>

```

1.2 Setup 2

- Threads all increment one variable **with a mutex**

```

[1]: import matplotlib.pyplot as plt
import pandas
ser = [84013074, 81465166.2, 85934827.4, 80388688.8, 80466492]
par = [120240643.2, 308139976, 629666501.2, 712601966.2, 651475517.6]

val_dict = {}

for k, v in enumerate(par):
    val_dict[str(2**k)]={
        "serial": ser[k],
        "parall": par[k]
    }

df1 = pandas.DataFrame.from_dict(val_dict, orient='index')

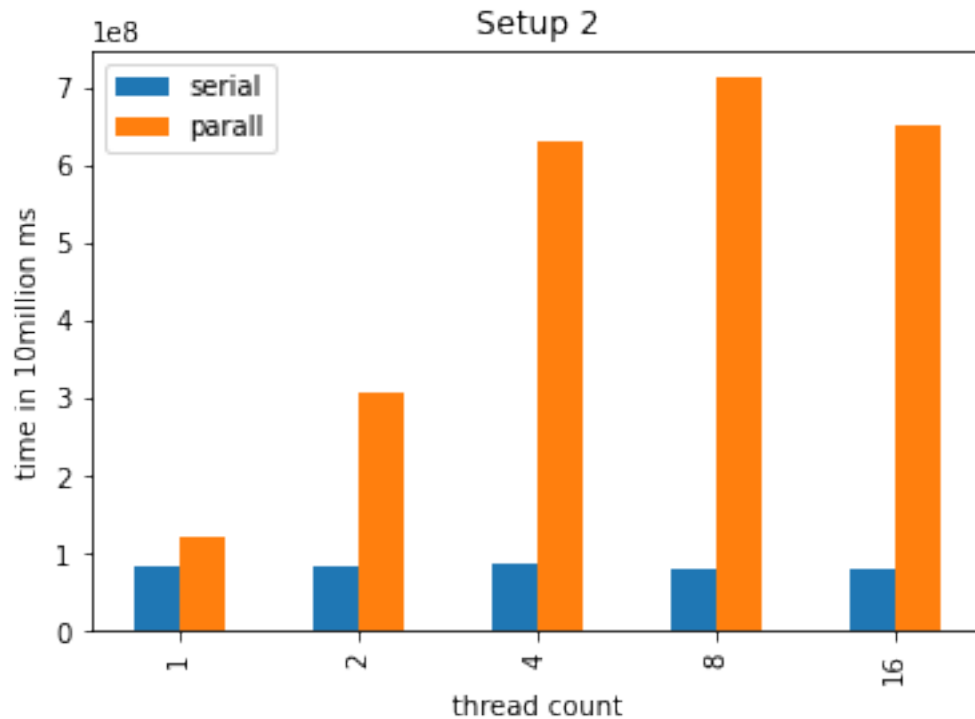
df1.plot.bar(title='Setup 2')
plt.xlabel("thread count")
plt.ylabel("time in 10million ms")

```

```

[1]: Text(0, 0.5, 'time in 10million ms')

```

code

```
// Ziad Arafat
// Created: Sep 09 2023
// Figure 1.9 in the textbook

/**
 * @brief This program will create an array of a specified size and fill it
 * with random numbers between 1 and 3 inclusive. It will then try to count
 * the number of threes in the array using a serial method and a parallel method
 * it will return the counts for each attempt as well as the running times.
 *
 *
 * This version adds a mutex to prevent the race condition. We expect the
 * the outputs to be correct but the performance will be very bad because
 * the threads will all be waiting on each other and locking/unlocking the
 * mutex causing an overhead with the OS.
 */

/**
Changelog

09/09
- Copied code from the figure1_7.c
```

```

- added mutex initializer
- added lock and unlock to the thread function
- added free() calls to clean up the memory when done
- fixed the way the array is split for the threads

*/

#define DEBUG 0 // flag to print debug values

#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <pthread.h>

int *A; // Pointer to our array in heap
int COUNT = 0; // The count of threes we found for the parallel code
int SEGSIZE; // the size of each chunk per tread
int NUMOFTHREADS; // the number of threads to spawn
int SIZE; // The size of the input array

pthread_mutex_t mtx = PTHREAD_MUTEX_INITIALIZER; // this is our mutex variable

/**
 * @brief Iterates through a chunk of the A array and counts the number of
 * threes by updating the COUNT variable
 *
 *
 * @param index The index of the array chunks we are working with
 * @return void* returns a void pointer to work with pthread
 *
 * @pre The global A variable must be a pointer to an array in heap containing numbers between
 * 1 and 3. index must be a number referring to the index of the chunk we want
 * to work through starting at 0. The global COUNT variable must contain the
 * number of threes we have already counted
 *
 * @post When done the COUNT variable must be updated to have the number of
 * threes found in our chunk of the array
 */
void *count3s(void *idx)
{
    // if (DEBUG)
    //     printf("I ran once %d\n", index);

    int *index = (int *)idx; // cast the void star input to an int ptr
    int mystart = *index * SEGSIZE; // set the starting point for the thread
    int myend = mystart + SEGSIZE; // set the end point for the thread

```

```

if (DEBUG) {
    printf("start is %d\n", mystart);
    printf("end is   %d\n", myend);
}

// iterate through our section of the array and count the threes
for (int i = mystart; i < myend; i++) {
    if (A[i] == 3) {
        if (DEBUG) {
            printf("Found a three\n");
        }

        // lock the mutex thereby waiting until other threads
        // are done with this section of the code before
        // locking it.
        pthread_mutex_lock(&mtx); // lock the mutex

        COUNT++; // increment count

        // unlock the mutex to let the OS know we are done
        // with this section of code.
        pthread_mutex_unlock(&mtx);
    }
}

// When we reach the final index we will calculate the remaining values in the array
// So that we can add them to the result.
// This can become quite high once you go past the 50% mark of the array size
// but our tests will never go that far so this is a pretty good solution.
if ((myend < SIZE) && (*index == NUMOFTHREADS - 1)) {
    if (DEBUG) {
        int remain = SIZE - myend;
        printf("Remainder: %d \n", remain);
    }

    // iterate through the remainder of the array and count the 3s
    for (int i = myend; i < SIZE; i++) {
        // if its a three in the array
        if (A[i] == 3) {
            // lock the mutex thereby waiting until other threads
            // are done with this section of the code before
            // locking it.
            pthread_mutex_lock(&mtx); // lock the mutex

            COUNT++; // increment count

            // unlock the mutex to let the OS know we are done
            // with this section of code.

```

```

        pthread_mutex_unlock(&mtx);
    }
}

    if (DEBUG) {
        printf("The count is now %d threads %d index %d SIZE %d end %d \n",
            COUNT, NUMOFTHREADS, *index, SIZE, myend);
    }
}

return (void *)0;
}

/**
 * @brief This function is used to spawn the appropriate number of threads
 *
 * @return int containing the time it took
 *
 * @pre The global COUNT variable is 0. NUMOFTHREADS is greater than 0.
 * SEGSIZE is the size of the array divided by NUMOFTHREADS. the A variable
 * points to an array in heap.
 *
 * @post The global COUNT contains the correct three count
 */
int count3s_parallel()
{
    // initialize the timer for the parallel work
    struct timespec starttime, endtime;
    int j, k;

    // get the start time
    clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

    // Created an array allocated at runtime to hold the identifiers for
    // our threads
    pthread_t *t_idents;
    int *t_indices;

    // Allocates the space needed for the thread IDs
    t_idents = (pthread_t *) (malloc(sizeof(pthread_t) * NUMOFTHREADS));

    // in order to fix the "integer to pointer conversion" warning
    // i made an array to store the indices for each thread that way
    // i can pass it as a pointer in the for loop
    t_indices = (int *) (malloc(sizeof(int) * NUMOFTHREADS));

    // Create the threads

```

```

    for (int i = 0; i < NUMOFTHREADS; i++) {
        t_indices[i] = i;
        pthread_create(&t_idents[i], NULL, count3s,
                      (void *)&t_indices[i]);
    }

    // wait for all the treads to finish.
    for (int i = 0; i < NUMOFTHREADS; i++) {
        pthread_join(t_idents[i], NULL);
    }

    // free the ids and indexes in memory so we dont leak
    free(t_idents);
    free(t_indices);

    // get the end time
    clock_gettime(CLOCK_REALTIME, &endtime);

    // calculate duration
    j = endtime.tv_sec - starttime.tv_sec;
    k = endtime.tv_nsec - starttime.tv_nsec;
    j = j * 1000000000 + k;

    // return the duration
    return j;
}

int main(int argc, char const *argv[])
{
    // this variable stores the time for generating the random numbers.
    time_t t;

    // intitilize the random number with the time as the seed
    srand((unsigned)time(&t));

    // check the user arguments
    if (argc != 3) {
        // if they are wrong count barf
        printf("Not correct arguments \n");
        printf("Usage %s <size of array> <numbe>r of threads> \n",
              argv[0]);
        exit(1);
    }

    // Convert the user input to integers
    SIZE = atoi(argv[1]);
    NUMOFTHREADS = atoi(argv[2]);

```

```

// Set the size of the array chunks to process to the size over the
// number of threads
SEGSIZE = SIZE / NUMOFTHREADS;

if (DEBUG) {
    printf("number is %s \n", argv[1]);
    printf("number is %d \n", SIZE);
    printf("NumThr is %d \n", NUMOFTHREADS);
    printf("Seg Size is %d \n", SEGSIZE);
}

// Allocate the array based on the input size
A = (int *) (malloc(sizeof(int) * SIZE));

// if the array is null barf
if (A == NULL) {
    perror("Austin, we have a problem");
    // printf("Austin, we have a problem");
    exit(1);
}

// generate random numbers and fill them in the array
// the numbers are between 1 and 3 inclusive
for (int i = 0; i < SIZE; i++) {
    A[i] = rand() % 4;

    // printf("E%d \n", A[i]);
}

// Count the threes in parallel
int parallel_time = count3s_parallel();

// since the COUNT for the parallel is defined before starting the
// timer i choose to define this one before timer as well.
int local_count = 0;

// initialize the timer for the parallel work
struct timespec starttime, endtime;
int j, k;
clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

// Count the threes in serial
for (int i = 0; i < SIZE; i++) {
    if (A[i] == 3) {
        local_count++;
    }
}

```

```

    // get end time
    clock_gettime(CLOCK_REALTIME, &endtime);

    // calculate duration
    j = endtime.tv_sec - starttime.tv_sec;
    k = endtime.tv_nsec - starttime.tv_nsec;
    j = j * 1000000000 + k;

    // free the array
    free(A);

    // print the times and counts
    printf("Time parallel: %d \n", parallel_time);
    printf("Time serial:   %d \n", j);

    printf("parallel count is %d\n", COUNT);
    printf("serial count is   %d\n", local_count);

    return 0;
}

```

Raw console outputs

1 Thread

```

doge@godemperordoge1998 ~/D/p/withmutex (main)> make
gcc -O0 -Wall -Werror -Wextra -pedantic -pthread -lpthread -o withmutex withmutex.c
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 1
Time parallel: 120021411
Time serial:   78854234
parallel count is 2501472
serial count is  2501472
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 1
Time parallel: 120497170
Time serial:   81333878
parallel count is 2499989
serial count is  2499989
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 1
Time parallel: 120347221
Time serial:   87031321
parallel count is 2501315
serial count is  2501315
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 1
Time parallel: 120116256
Time serial:   78876653
parallel count is 2501360

```

```
serial count is 2501360
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 1
Time parallel: 120221158
Time serial: 93969284
parallel count is 2501360
serial count is 2501360
doge@godemperordoge1998 ~/D/p/withmutex (main)>
```

2 Threads

```
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 2
Time parallel: 278855092
Time serial: 81221853
parallel count is 2499954
serial count is 2499954
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 2
Time parallel: 315544116
Time serial: 89160223
parallel count is 2501195
serial count is 2501195
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 2
Time parallel: 309496769
Time serial: 79645116
parallel count is 2499936
serial count is 2499936
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 2
Time parallel: 310133511
Time serial: 78546513
parallel count is 2499456
serial count is 2499456
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 2
Time parallel: 326670392
Time serial: 78752126
parallel count is 2500418
serial count is 2500418
doge@godemperordoge1998 ~/D/p/withmutex (main)>
```

4 threads

```
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 4
Time parallel: 621104281
Time serial: 78621872
parallel count is 2500078
serial count is 2500078
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 4
Time parallel: 628150499
Time serial: 92534186
parallel count is 2499876
```



```
serial count is 2499876
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 4
Time parallel: 612589789
Time serial: 88590668
parallel count is 2498990
serial count is 2498990
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 4
Time parallel: 631838048
Time serial: 78806044
parallel count is 2501489
serial count is 2501489
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 4
Time parallel: 654649889
Time serial: 91121367
parallel count is 2499659
serial count is 2499659
doge@godemperordoge1998 ~/D/p/withmutex (main)>
```

8 threads

```
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 8
Time parallel: 735814192
Time serial: 78948171
parallel count is 2500200
serial count is 2500200
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 8
Time parallel: 637441065
Time serial: 83372267
parallel count is 2500024
serial count is 2500024
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 8
Time parallel: 733727894
Time serial: 78821827
parallel count is 2502801
serial count is 2502801
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 8
Time parallel: 715607851
Time serial: 79105103
parallel count is 2501713
serial count is 2501713
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 8
Time parallel: 740418829
Time serial: 81696076
parallel count is 2500349
serial count is 2500349
doge@godemperordoge1998 ~/D/p/withmutex (main)>
```

16 threads

```

doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 16
Time parallel: 670948609
Time serial: 78550634
parallel count is 2497839
serial count is 2497839
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 16
Time parallel: 669674494
Time serial: 78881891
parallel count is 2500331
serial count is 2500331
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 16
Time parallel: 606297090
Time serial: 82304114
parallel count is 2501547
serial count is 2501547
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 16
Time parallel: 677565931
Time serial: 83745498
parallel count is 2499270
serial count is 2499270
doge@godemperordoge1998 ~/D/p/withmutex (main)> ./withmutex 10000000 16
Time parallel: 632891464
Time serial: 78850323
parallel count is 2502719
serial count is 2502719
doge@godemperordoge1998 ~/D/p/withmutex (main)>

```

1.3 Setup 3

- Each thread increments it's own count variable in an array **without padding**

```

[2]: ser = [77342337.6, 76163542.4, 75757667, 76600539.4, 76741758.4, 76538017.4, 76620890.8, 77830947.6, 76217962.6, 76562336.2]
par = [80784200.2, 118902330.6, 115032536.8, 75653505.8, 51827737.4, 41478460.2, 26468548.4, 25685669.4, 31348666.2, 46536505.8]

val_dict = {}

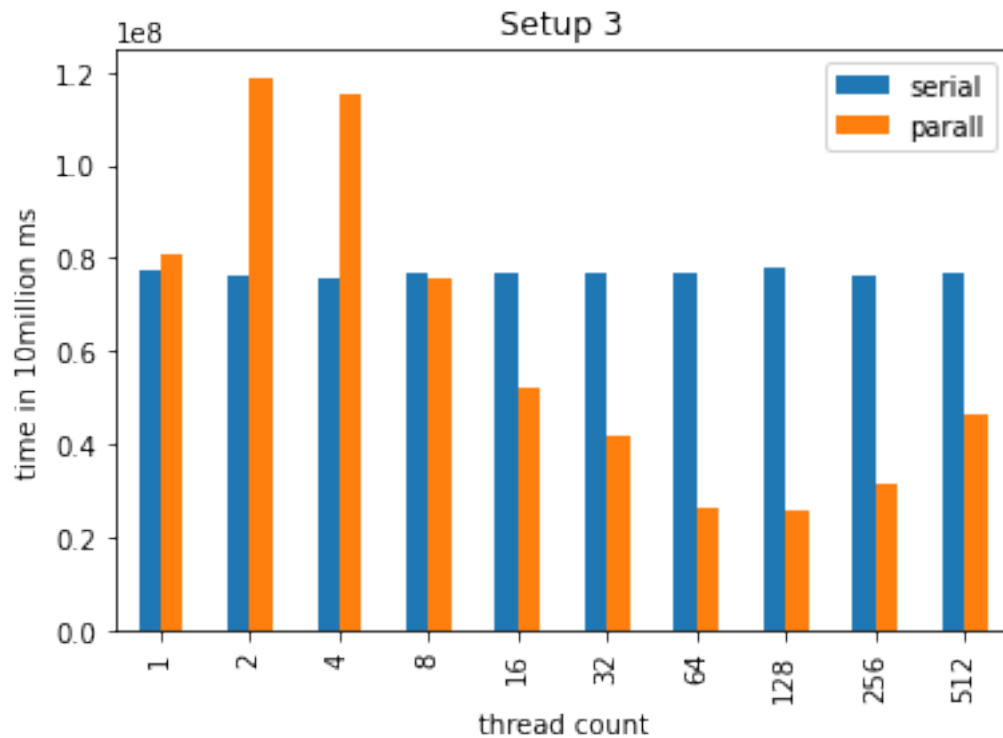
for k, v in enumerate(par):
    val_dict[str(2**k)]={
        "serial": ser[k],
        "parall": par[k]
    }

df1 = pandas.DataFrame.from_dict(val_dict, orient='index')

```

```
df1.plot.bar(title='Setup 3')
plt.xlabel("thread count")
plt.ylabel("time in 10million ms")
```

```
[2]: Text(0, 0.5, 'time in 10million ms')
```



code

```
// Ziad Arafat
// Created: Sep 09 2023
// Figure 1.10 in the textbook

/**
 * @brief This program will create an array of a specified size and fill it
 * with random numbers between 1 and 3 inclusive. It will then try to count
 * the number of threes in the array using a serial method and a parallel method
 * it will return the counts for each attempt as well as the running times.
 *
 */

/**
Changelog
09/09
```

- Copied code from the withmutex.c code
- added dynamic array allocation for the results of the threads
- removed the mutex lock and unlock
- modified the thread to increment the corresponding item in the array instead of global count
- added free() calls to clean up the memory when done
- fixed the way the array is split for the threads

```
*/
```

```
#define DEBUG 0 // flag to print debug values
```

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <pthread.h>
```

```
int *A; // Pointer to our array in heap
int COUNT = 0; // The count of threes we found for the parallel code
int SEGSIZE; // the size of each chunk per tread
int NUMOFTHREADS; // the number of threads to spawn
int *t_results; // an array to store the results from each thread
int SIZE; // The size of the array
```

```
pthread_mutex_t mtex = PTHREAD_MUTEX_INITIALIZER; // this is our mutex variable
```

```
/**
```

```
 * @brief Iterates through a chunk of the A array and counts the number of
 * threes by updating an item in a results array corresponding to the thread.
```

```
 *
```

```
 *
```

```
 * @param index The index of the array chunks we are working with
```

```
 * @return void* returns a void pointer to work with pthread
```

```
 *
```

```
 * @pre The global A variable must be a pointer to an array in heap containing numbers between
 * 1 and 3. index must be a number referring to the index of the chunk we want
 * to work through starting at 0. The global t_results array must be 0 at the
 * corresponding index
```

```
 *
```

```
 * @post When done the array element corresponding to the thread must have the
 * number of threes we found in our chunk of the array
```

```
 */
```

```
void *count3s(void *idx)
```

```
{
```

```
    int *index = (int *)idx; // cast the void star input to an int ptr
    int mystart = *index * SEGSIZE; // set the starting point for the thread
    int myend = mystart + SEGSIZE; // set the end point for the thread
```

```

    if (DEBUG) {
        printf("I ran once %d\n", *index);
    }

    if (DEBUG) {
        printf("start is %d\n", mystart);
        printf("end is   %d\n", myend);
    }

    // iterate through our chunk and increment our array element when a
    // three is found
    for (int i = mystart; i < myend; i++) {
        if (A[i] == 3) {
            t_results[*index]++; // increment result
        }
    }

    // printf("Threads %d index %d size %d END %d \n", NUMOFTHREADS, *index, SIZE, myend);

    // When we reach the final index we will calculate the remaining values in the array
    // So that we can add them to the result.
    // This can become quite high once you go past the 50% mark of the array size
    // but our tests will never go that far so this is a pretty good solution.
    if ((myend < SIZE) && (*index == NUMOFTHREADS - 1)) {
        if (DEBUG) {
            int remain = SIZE - myend;
            printf("Remainder: %d \n", remain);
        }

        // iterate through the remainder of the array and count the 3s
        for (int i = myend; i < SIZE; i++) {
            if (A[i] == 3) {
                t_results[*index]++;
            }
        }
    }

    return (void *)0;
}

/**
 * @brief This function is used to spawn the appropriate number of threads and
 * also gathers the results of each thread and sums them.
 *
 * @return int containing the time it took
 *
 * @pre Global COUNT is 0. NUMOFTHREADS is greater than 0.
 * SEGSIZE is the size of the array divided by NUMOFTHREADS. the A variable

```

```

* points to an array in heap.
*
* @post The global COUNT contains the correct three count
*
*/
int count3s_parallel()
{
    // initialize the timer for the parallel work
    struct timespec starttime, endtime;
    int j, k;

    // get the start time
    clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

    // Created an array allocated at runtime to hold the identifiers for
    // our threads
    pthread_t *t_idents;
    int *t_indices;

    // Allocates the space needed for the thread IDs
    t_idents = (pthread_t *) (malloc(sizeof(pthread_t) * NUMOFTHREADS));

    // in order to fix the "integer to pointer conversion" warning
    // i made an array to store the indices for each thread that way
    // i can pass it as a pointer in the for loop
    t_indices = (int *) (malloc(sizeof(int) * NUMOFTHREADS));

    // allocate an array of ints to store the results.
    t_results = (int *) (calloc(NUMOFTHREADS, sizeof(int) * NUMOFTHREADS));

    // Create the threads
    for (int i = 0; i < NUMOFTHREADS; i++) {
        t_indices[i] = i;
        pthread_create(&t_idents[i], NULL, count3s,
                      (void *)&t_indices[i]);
    }

    // wait for all the threads to finish.
    for (int i = 0; i < NUMOFTHREADS; i++) {
        pthread_join(t_idents[i], NULL);
        COUNT += t_results[i];
    }

    // free the three arrays we made so we dont leak.
    free(t_idents);
    free(t_indices);
    free(t_results);
}

```

```

    // get the end time
    clock_gettime(CLOCK_REALTIME, &endtime);

    // calculate duration
    j = endtime.tv_sec - starttime.tv_sec;
    k = endtime.tv_nsec - starttime.tv_nsec;
    j = j * 1000000000 + k;

    // return the duration
    return j;
}

int main(int argc, char const *argv[])
{
    // this variable stores the time for generating the random numbers.
    time_t t;

    // initialize the random number with the time as the seed
    srand((unsigned)time(&t));

    // check the user arguments
    if (argc != 3) {
        // if they are wrong count barf
        printf("Not correct arguments \n");
        printf("Usage %s <size of array> <number of threads> \n",
            argv[0]);
        exit(1);
    }

    // Convert the user input to integers
    SIZE = atoi(argv[1]);
    NUMOFTHREADS = atoi(argv[2]);

    // Set the size of the array chunks to process to the size over the
    // number of threads
    SEGSIZE = SIZE / NUMOFTHREADS;

    if (DEBUG) {
        printf("number is %s \n", argv[1]);
        printf("number is %d \n", SIZE);
        printf("NumThr is %d \n", NUMOFTHREADS);
        printf("Seg Size is %d \n", SEGSIZE);
    }

    // Allocate the array based on the input size
    A = (int *) (malloc(sizeof(int) * SIZE));

    // if the array is null barf

```

```

if (A == NULL) {
    // printf("Austin, we have a problem");
    perror("Austin, we have a problem");
    exit(1);
}

// generate random numbers and fill them in the array
// the numbers are between 1 and 3 inclusive
for (int i = 0; i < SIZE; i++) {
    // if we are debugging lets make them all threes.
    // that way we can tell if something isnt
    // being counted.
    if (DEBUG) {
        A[i] = 3;
    } else {
        A[i] = rand() % 4;
    }
}

// Count the threes in parallel
int parallel_time = count3s_parallel();

// since the COUNT for the parallel is defined before starting the
// timer i choose to define this one before timer as well.
int local_count = 0;

// initialize the timer for the parallel work
struct timespec starttime, endtime;
int j, k;
clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

// Count the threes in serial
for (int i = 0; i < SIZE; i++) {
    if (A[i] == 3) {
        local_count++;
    }
}

// get end time
clock_gettime(CLOCK_REALTIME, &endtime);

// calculate duration
j = endtime.tv_sec - starttime.tv_sec;
k = endtime.tv_nsec - starttime.tv_nsec;
j = j * 1000000000 + k;

// free the array
free(A);

```



```

        // print the times and counts
        printf("Time parallel: %d \n", parallel_time);
        printf("Time serial:   %d \n", j);

        printf("parallel count is %d\n", COUNT);
        printf("serial count is   %d\n", local_count);

        if (DEBUG) {
            printf("SEGSIZE %d \n", SEGSIZE);
        }

        return 0;
}
a

```

Raw console outputs

1 Thread

```

doge@godemperordoge1998 ~/D/p/witharray (main)> make
gcc -O0 -Wall -Werror -Wextra -pedantic -pthread -lpthread -o witharray witharray.c
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 1
Time parallel: 81863555
Time serial:   75568341
parallel count is 2500620
serial count is  2500620
SEGSIZE 10000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 1
Time parallel: 79677104
Time serial:   75715147
parallel count is 2499935
serial count is  2499935
SEGSIZE 10000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 1
Time parallel: 80084768
Time serial:   76378151
parallel count is 2498190
serial count is  2498190
SEGSIZE 10000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 1
Time parallel: 83075721
Time serial:   78784952
parallel count is 2499420
serial count is  2499420
SEGSIZE 10000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 1
Time parallel: 79219853

```

```
Time serial: 80265097
parallel count is 2503792
serial count is 2503792
SEGSIZE 10000000
doge@godemperordoge1998 ~/D/p/witharray (main)>
```

2 Threads

```
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 2
^[[ATime parallel: 117217005
Time serial: 76232392
parallel count is 2500931
serial count is 2500931
SEGSIZE 5000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 2
Time parallel: 117227900
Time serial: 75723948
parallel count is 2499572
serial count is 2499572
SEGSIZE 5000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 2
Time parallel: 125809927
Time serial: 76198239
parallel count is 2499572
serial count is 2499572
SEGSIZE 5000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 2
^[[A
Time parallel: 117415982
Time serial: 76056322
parallel count is 2497775
serial count is 2497775
SEGSIZE 5000000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 2
Time parallel: 116840839
Time serial: 76606811
parallel count is 2497775
serial count is 2497775
SEGSIZE 5000000
doge@godemperordoge1998 ~/D/p/witharray (main)>
```

4 Threads

```
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 4
Time parallel: 119560039
Time serial: 75835135
parallel count is 2498552
serial count is 2498552
```

```

SEGSIZE 2500000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 4
Time parallel: 110999175
Time serial: 75637135
parallel count is 2502155
serial count is 2502155
SEGSIZE 2500000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 4
Time parallel: 120659063
Time serial: 75797630
parallel count is 2502155
serial count is 2502155
SEGSIZE 2500000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 4
Time parallel: 105918640
Time serial: 75691681
parallel count is 2500763
serial count is 2500763
SEGSIZE 2500000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 4
Time parallel: 118025767
Time serial: 75826754
parallel count is 2501575
serial count is 2501575
SEGSIZE 2500000
doge@godemperordoge1998 ~/D/p/witharray (main)>

```

8 Threads

```

doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 8
Time parallel: 75531675
Time serial: 76051224
parallel count is 2500300
serial count is 2500300
SEGSIZE 1250000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 8
Time parallel: 75182817
Time serial: 75753420
parallel count is 2499436
serial count is 2499436
SEGSIZE 1250000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 8
Time parallel: 76046405
Time serial: 76348748
parallel count is 2501044
serial count is 2501044
SEGSIZE 1250000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 8

```

```
Time parallel: 75545853
Time serial: 76008551
parallel count is 2499779
serial count is 2499779
SEGSIZE 1250000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 8
Time parallel: 75960779
Time serial: 78840754
parallel count is 2499779
serial count is 2499779
SEGSIZE 1250000
doge@godemperordoge1998 ~/D/p/witharray (main)>
```

16 threads

```
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 16
Time parallel: 51618507
Time serial: 79680457
parallel count is 2500182
serial count is 2500182
SEGSIZE 625000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 16
Time parallel: 52043701
Time serial: 75934658
parallel count is 2502307
serial count is 2502307
SEGSIZE 625000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 16
Time parallel: 51582748
Time serial: 75689934
parallel count is 2499453
serial count is 2499453
SEGSIZE 625000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 16
Time parallel: 52321250
Time serial: 76262634
parallel count is 2499453
serial count is 2499453
SEGSIZE 625000
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 16
Time parallel: 51572481
Time serial: 76141109
parallel count is 2498729
serial count is 2498729
SEGSIZE 625000
doge@godemperordoge1998 ~/D/p/witharray (main)>
```

32 threads

```

doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 32
Time parallel: 52033155
Time serial: 75630360
parallel count is 2502265
serial count is 2502265
SEGSIZE 312500
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 32
Time parallel: 40560746
Time serial: 75752932
parallel count is 2496956
serial count is 2496956
SEGSIZE 312500
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 32
Time parallel: 33518090
Time serial: 79269021
parallel count is 2499218
serial count is 2499218
SEGSIZE 312500
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 32
Time parallel: 42830797
Time serial: 75999611
parallel count is 2499218
serial count is 2499218
SEGSIZE 312500
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 32
Time parallel: 38449513
Time serial: 76038163
parallel count is 2498024
serial count is 2498024
SEGSIZE 312500
doge@godemperordoge1998 ~/D/p/witharray (main)>

```

64 threads

```

doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 64
Time parallel: 23108945
Time serial: 76429135
parallel count is 2501086
serial count is 2501086
SEGSIZE 156250
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 64
Time parallel: 32038014
Time serial: 78676976
parallel count is 2501086
serial count is 2501086
SEGSIZE 156250
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 64
Time parallel: 29387118

```

```

Time serial: 75795394
parallel count is 2499983
serial count is 2499983
SEGSIZE 156250
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 64
Time parallel: 21765129
Time serial: 75698106
parallel count is 2499590
serial count is 2499590
SEGSIZE 156250
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 64
Time parallel: 26043536
Time serial: 76504843
parallel count is 2499590
serial count is 2499590
SEGSIZE 156250
doge@godemperordoge1998 ~/D/p/witharray (main)>

```

128 threads

```

doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 128
Time parallel: 27093181
Time serial: 75747694
parallel count is 2499556
serial count is 2499556
SEGSIZE 78125
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 128
Time parallel: 23288786
Time serial: 76220100
parallel count is 2501938
serial count is 2501938
SEGSIZE 78125
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 128
Time parallel: 28004540
Time serial: 84610064
parallel count is 2498595
serial count is 2498595
SEGSIZE 78125
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 128
Time parallel: 24022050
Time serial: 76480189
parallel count is 2498595
serial count is 2498595
SEGSIZE 78125
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 128
Time parallel: 26019790
Time serial: 76096691
parallel count is 2500116

```

```
serial count is 2500116
SEGSIZE 78125
doge@godemperordoge1998 ~/D/p/witharray (main)>
```

256 threads

```
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 256
Time parallel: 30797702
Time serial: 76585020
parallel count is 2500664
serial count is 2500664
SEGSIZE 39062
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 256
Time parallel: 30520153
Time serial: 76308938
parallel count is 2502137
serial count is 2502137
SEGSIZE 39062
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 256
Time parallel: 29454864
Time serial: 76265916
parallel count is 2501344
serial count is 2501344
SEGSIZE 39062
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 256
Time parallel: 32954541
Time serial: 76108284
parallel count is 2498982
serial count is 2498982
SEGSIZE 39062
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 256
Time parallel: 33016071
Time serial: 75821655
parallel count is 2498982
serial count is 2498982
SEGSIZE 39062
doge@godemperordoge1998 ~/D/p/witharray (main)>
```

512 Threads

```
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 512
^[[ATime parallel: 48074062
Time serial: 76889948
parallel count is 2503817
serial count is 2503817
SEGSIZE 19531
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 512
Time parallel: 44829655
```

```

Time serial: 76344138
parallel count is 2500075
serial count is 2500075
SEGSIZE 19531
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 512
Time parallel: 45507953
Time serial: 75874944
parallel count is 2500075
serial count is 2500075
SEGSIZE 19531
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 512
Time parallel: 49365148
Time serial: 76632722
parallel count is 2499084
serial count is 2499084
SEGSIZE 19531
doge@godemperordoge1998 ~/D/p/witharray (main)> ./witharray 10000000 512
Time parallel: 44905711
Time serial: 77069929
parallel count is 2499084
serial count is 2499084
SEGSIZE 19531
doge@godemperordoge1998 ~/D/p/witharray (main)>

```

1.4 Setup 4

- Each thread increments it's own count variable in an array **with padding**

Raw Data Processing and Graphing

```

[3]: # Data Processing

ser = [76142799.4, 77717943.8, 76086493.6, 76067440.6, 76296925.4, 76344599.4,
      ↪76862234.8, 76255383.8]
par = [78454322.4, 40209206.6, 20134348.6, 10790813.6, 12481699.4, 12199778.2,
      ↪13109907.8, 15661670.6]

val_dict = {}

for k, v in enumerate(par):
    val_dict[str(2**k)]={
        "serial": ser[k],
        "parall": par[k]
    }

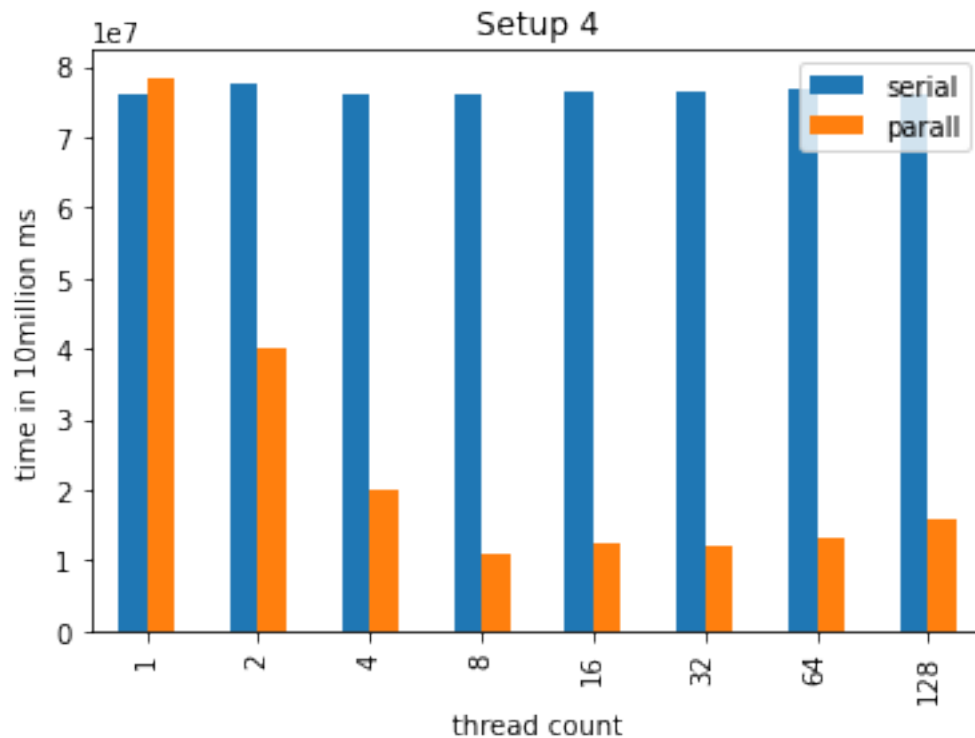
df1 = pandas.DataFrame.from_dict(val_dict, orient='index')

```



```
df1.plot.bar(title='Setup 4')
plt.xlabel("thread count")
plt.ylabel("time in 10million ms")
```

```
[3]: Text(0, 0.5, 'time in 10million ms')
```



code

```
// Ziad Arafat
// Created: Sep 09 2023
// Figure 1.11 in the textbook

/**
 * @brief This program will create an array of a specified size and fill it
 * with random numbers between 1 and 3 inclusive. It will then try to count
 * the number of threes in the array using a serial method and a parallel method
 * it will return the counts for each attempt as well as the running times.
 *
 * In this version we will create a struct called padded_int which will contain
 * the count as well as a padding of chars set to fill up the chache line of
 * the maching we run it on.
```

```

*/

/**
Changelog

09/09
- copied code from witharray.c
- created the struct padded_int with the appropriate char padding
- modified the results array to be an array of our padded_int
- modified the thread to correctly access and increment the padded_ints
- added free() calls to clean up the memory when done
- fixed the way the array is split for the threads by making the size global

BUGFIX: The way the array was being split was incorrect because unless the array
size was a multiple of the thread count there would be a remaining chunk of
the array. In fact if the thread count is more than half the array size this
chunk could be massive. The fix involved adding an extra loop that gathered the
remaining array elements on the last run. I feel like there is a more elegant
solution but this seems to work well for the purpose of this program?

*/

#define DEBUG 0 // flag to print debug values

#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <pthread.h>

int *A; // Pointer to our array in heap
int COUNT = 0; // The count of threes we found for the parallel code
int SEGSIZE; // the size of each chunk per tread
int NUMOFTHREADS; // the number of threads to spawn
int SIZE; // size of the array

// This is a struct that will hold our data in the array for padding.
struct padded_int {
    // We need 64B of padding. Because our processor has 64B cache lines
    int value; // an int is 4 bytes
    char padding[60]; // now we need 64-4 more bytes so we make 60 chars
};

struct padded_int *t_results; // an array to store the results from each thread

pthread_mutex_t mtex = PTHREAD_MUTEX_INITIALIZER; // this is our mutex variable

/**
* @brief Iterates through a chunk of the A array and counts the number of

```

```

* threes by updating the COUNT variable
*
*
* @param index The index of the array chunks re are working with
* @return void* returns a void pointer to work with pthread
*
* @pre The global A variable must be a pointer to an array in heap containing numbers between
* 1 and 3. index must be a number referring to the index of the chunk we want
* to work through starting at 0. The global COUNT variable must contain the
* number of threes we have already counted
*
* @post When done the value attribute of the padded int in the array element
* corresponding to the thread must have the correct number of threes we found
* in our chunk of the array
*/
void *count3s(void *idx)
{
    int *index = (int *)idx; // cast the void star input to an int ptr
    int mystart = *index * SEGSIZE; // set the starting point for the thread
    int myend = mystart + SEGSIZE; // set the end point for the thread

    if (DEBUG) {
        printf("I ran once %d\n", *index);
    }

    // this temporary variable is here because i am scared of pointers and
    // structs so this just makes sure i dont break things.
    int valueforthread = 0;

    if (DEBUG) {
        printf("start is %d\n", mystart);
        printf("end is   %d\n", myend);
    }

    for (int i = mystart; i < myend; i++) {
        if (A[i] == 3) {
            valueforthread++; // increment result
        }
    }

    // When we reach the final index we will calculate the remaining values in the array
    // So that we can add them to the result.
    // This can become quite high once you go past the 50% mark of the array size
    // but our tests will never go that far so this is a pretty good solution.
    if ((myend < SIZE) && (*index == NUMOFTHEADS - 1)) {
        // int remain = SIZE - myend;
        // printf("Remainder: %d \n", remain);
        // printf("ACTIVE \n");
    }
}

```

```

        for (int i = myend; i < SIZE; i++) {
            if (A[i] == 3) {
                valueforthread++;
            }
        }

    }

    if (DEBUG) {
        printf("value counted: %d \n", valueforthread);
    }

    // I am once again scared of pointers so i manually set it to 0
    // and add on the value.
    t_results[*index].value = 0;
    t_results[*index].value += valueforthread;

    return (void *)0;
}

/**
 * @brief This function is used to spawn the appropriate number of threads and
 * also gathers the results of each thread and sums them.
 *
 * @return int containing the time it took
 *
 * @pre The global COUNT variable is 0. NUMOFTHREADS is greater than 0.
 * SEGSIZE is the size of the array divided by NUMOFTHREADS. the A variable
 * points to an array in heap.
 *
 * @post The global COUNT contains the correct three count
 *
 */
int count3s_parallel()
{
    // initialize the timer for the parallel work
    struct timespec starttime, endtime;
    int j, k;

    // get the start time
    clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

    // Created an array allocated at runtime to hold the identifiers for
    // our threads
    pthread_t *t_ids;
    int *t_indices;

    // Allocates the space needed for the thread IDs
    t_ids = (pthread_t *) (malloc(sizeof(pthread_t) * NUMOFTHREADS));

```

```

// in order to fix the "integer to pointer conversion" warning
// i made an array to store the indices for each thread that way
// i can pass it as a pointer in the for loop
t_indices = (int *) (malloc(sizeof(int) * NUMOFTHREADS));

// We will initialize the padded ints manually in the thread because
// I dont know how calloc will behave with a struct.
t_results = (struct padded_int *) (malloc(sizeof(struct padded_int) *
                                         NUMOFTHREADS));

// Create the threads
for (int i = 0; i < NUMOFTHREADS; i++) {
    t_indices[i] = i;
    pthread_create(&t_idents[i], NULL, count3s,
                  (void *)&t_indices[i]);
}
COUNT = 0;
// wait for all the treads to finish.
for (int i = 0; i < NUMOFTHREADS; i++) {
    pthread_join(t_idents[i], NULL);
    COUNT += t_results[i].value;
}

// free the three arrays we made so we dont leak.
free(t_idents);
free(t_indices);
free(t_results);

// get the end time
clock_gettime(CLOCK_REALTIME, &endtime);

// calculate duration
j = endtime.tv_sec - starttime.tv_sec;
k = endtime.tv_nsec - starttime.tv_nsec;
j = j * 1000000000 + k;

// return the duration
return j;
}

int main(int argc, char const *argv[])
{
    // this variable stores the time for generating the random numbers.
    time_t t;

    // intitilize the random number with the time as the seed
    srand((unsigned)time(&t));

```

```

if (argc != 3) {
    printf("Not correct arguments \n");
    printf("Usage %s <size of array> <number of threads> \n",
        argv[0]);
    exit(1);
}

// Convert the user input to integers
SIZE = atoi(argv[1]);
NUMOFTHREADS = atoi(argv[2]);

// Set the size of the array chunks to process to the size over the
// number of threads
SEGSIZE = SIZE / NUMOFTHREADS;

if (DEBUG) {
    printf("number is %s \n", argv[1]);
    printf("number is %d \n", SIZE);
    printf("NumThr is %d \n", NUMOFTHREADS);
    printf("Seg Size is %d \n", SEGSIZE);
}

// Allocate the array based on the input size
A = (int *) (malloc(sizeof(int) * SIZE));

// if the array is null barf
if (A == NULL) {
    // printf("Austin, we have a problem");
    perror("Austin, we have a problem");
    exit(1);
}

// generate random numbers and fill them in the array
// the numbers are between 1 and 3 inclusive
for (int i = 0; i < SIZE; i++) {
    // if we are debugging lets make them all threes.
    // that way we can tell if something isnt
    // being counted.
    if (DEBUG) {
        A[i] = 3;
    } else {
        A[i] = rand() % 4;
    }
}

// Count the threes in parallel
int parallel_time = count3s_parallel();

```

```

// since the COUNT for the parallel is defined before starting the
// timer i choose to define this one before timer as well.
int local_count = 0;

// initialize the timer for the parallel work
struct timespec starttime, endtime;
int j, k;
clock_gettime(CLOCK_REALTIME, &starttime); // start the timer

// Count the threes in serial
for (int i = 0; i < SIZE; i++) {
    if (A[i] == 3) {
        local_count++;
    }
}

// get end time
clock_gettime(CLOCK_REALTIME, &endtime);

// calculate duration
j = endtime.tv_sec - starttime.tv_sec;
k = endtime.tv_nsec - starttime.tv_nsec;
j = j * 1000000000 + k;

// free the array
free(A);

// print the times and counts
printf("Time parallel: %d \n", parallel_time);
printf("Time serial:   %d \n", j);

printf("parallel count is %d\n", COUNT);
printf("serial count is   %d\n", local_count);

return 0;
}

```

Raw console outputs

1 Thread

```

doge@godemperordoge1998 ~/D/p/padded (main)> make
gcc -O0 -Wall -Werror -Wextra -pedantic -pthread -lpthread -o padded padded.c
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 1
Time parallel: 79589173
Time serial:   76582925
parallel count is 2499295

```

```

serial count is 2499295
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 1
Time parallel: 77817021
Time serial: 76191186
parallel count is 2501600
serial count is 2501600
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 1
Time parallel: 78369396
Time serial: 76075458
parallel count is 2501212
serial count is 2501212
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 1
Time parallel: 77878131
Time serial: 75789878
parallel count is 2497788
serial count is 2497788
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 1
Time parallel: 78617891
Time serial: 76074550
parallel count is 2499979
serial count is 2499979
doge@godemperordoge1998 ~/D/p/padded (main)>

```

2 Threads

```

doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 2
Time parallel: 39898720
Time serial: 76881427
parallel count is 2498665
serial count is 2498665
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 2
Time parallel: 38993717
Time serial: 75975306
parallel count is 2498665
serial count is 2498665
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 2
Time parallel: 43756962
Time serial: 75922017
parallel count is 2499470
serial count is 2499470
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 2
Time parallel: 39628155
Time serial: 75874106
parallel count is 2499470
serial count is 2499470
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 2
Time parallel: 38768479
Time serial: 83936863

```



```
parallel count is 2499249
serial count is 2499249
doge@godemperordoge1998 ~/D/p/padded (main)>
```

4 Threads

```
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 4
Time parallel: 20135731
Time serial: 76379757
parallel count is 2500818
serial count is 2500818
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 4
Time parallel: 20184131
Time serial: 76066309
parallel count is 2500619
serial count is 2500619
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 4
Time parallel: 20012671
Time serial: 76159618
parallel count is 2500619
serial count is 2500619
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 4
Time parallel: 20407135
Time serial: 76091592
parallel count is 2501896
serial count is 2501896
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 4
Time parallel: 19932075
Time serial: 75735192
parallel count is 2501896
serial count is 2501896
doge@godemperordoge1998 ~/D/p/padded (main)>
```

8 Threads

```
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 8
Time parallel: 10802910
Time serial: 76379477
parallel count is 2499488
serial count is 2499488
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 8
Time parallel: 10938262
Time serial: 75819630
parallel count is 2499488
serial count is 2499488
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 8
Time parallel: 10780422
```

```
Time serial: 75986271
parallel count is 2499970
serial count is 2499970
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 8
Time parallel: 10738028
Time serial: 75738055
parallel count is 2499970
serial count is 2499970
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 8
Time parallel: 10694446
Time serial: 76413770
parallel count is 2498866
serial count is 2498866
doge@godemperordoge1998 ~/D/p/padded (main)>
```

16 Threads

```
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 16
Time parallel: 15428848
Time serial: 76461611
parallel count is 2499356
serial count is 2499356
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 16
Time parallel: 10718332
Time serial: 76038093
parallel count is 2497083
serial count is 2497083
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 16
Time parallel: 11129069
Time serial: 76266824
parallel count is 2497083
serial count is 2497083
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 16
Time parallel: 12962264
Time serial: 76701516
parallel count is 2500337
serial count is 2500337
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 16
Time parallel: 12169984
Time serial: 76016583
parallel count is 2500337
serial count is 2500337
doge@godemperordoge1998 ~/D/p/padded (main)>
```

32 Threads

```
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 32
Time parallel: 13191343
```

```
Time serial: 76977528
parallel count is 2501573
serial count is 2501573
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 32
Time parallel: 11433019
Time serial: 75182119
parallel count is 2499230
serial count is 2499230
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 32
Time parallel: 11259742
Time serial: 76361110
parallel count is 2499230
serial count is 2499230
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 32
Time parallel: 13108860
Time serial: 76463636
parallel count is 2497643
serial count is 2497643
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 32
Time parallel: 12005927
Time serial: 76738602
parallel count is 2500608
serial count is 2500608
doge@godemperordoge1998 ~/D/p/padded (main)>
```

64 Threads

```
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 64
Time parallel: 13443889
Time serial: 75998703
parallel count is 2501406
serial count is 2501406
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 64
Time parallel: 13066536
Time serial: 80285631
parallel count is 2498365
serial count is 2498365
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 64
Time parallel: 12961145
Time serial: 76057230
parallel count is 2497858
serial count is 2497858
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 64
Time parallel: 13297153
Time serial: 76248665
parallel count is 2497858
```

```

serial count is 2497858
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 64
Time parallel: 12780816
Time serial: 75720945
parallel count is 2500354
serial count is 2500354
doge@godemperordoge1998 ~/D/p/padded (main)>

```

128 Threads

```

doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 128
Time parallel: 14702009
Time serial: 75864468
parallel count is 2497320
serial count is 2497320
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 128
Time parallel: 15708353
Time serial: 76406018
parallel count is 2497320
serial count is 2497320
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 128
Time parallel: 14599762
Time serial: 76125185
parallel count is 2499108
serial count is 2499108
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 128
Time parallel: 18146093
Time serial: 76192373
parallel count is 2496782
serial count is 2496782
doge@godemperordoge1998 ~/D/p/padded (main)> ./padded 10000000 128
Time parallel: 15152136
Time serial: 76688875
parallel count is 2496782
serial count is 2496782
doge@godemperordoge1998 ~/D/p/padded (main)>

```

```

[4]: ser = [76142799.4, 77717943.8, 76086493.6, 76067440.6, 76296925.4, 76344599.1,
↪76862234.8, 76255383.8]
par = [78454322.4, 40209206.6, 20134348.6, 10790813.6, 12481699.4, 12199778.2, 13109907.8, 15661670.6]

val_dict = {}

for k, v in enumerate(par):
    val_dict[str(2**k)]={
        "serial": ser[k],
        "parall": par[k]

```

```

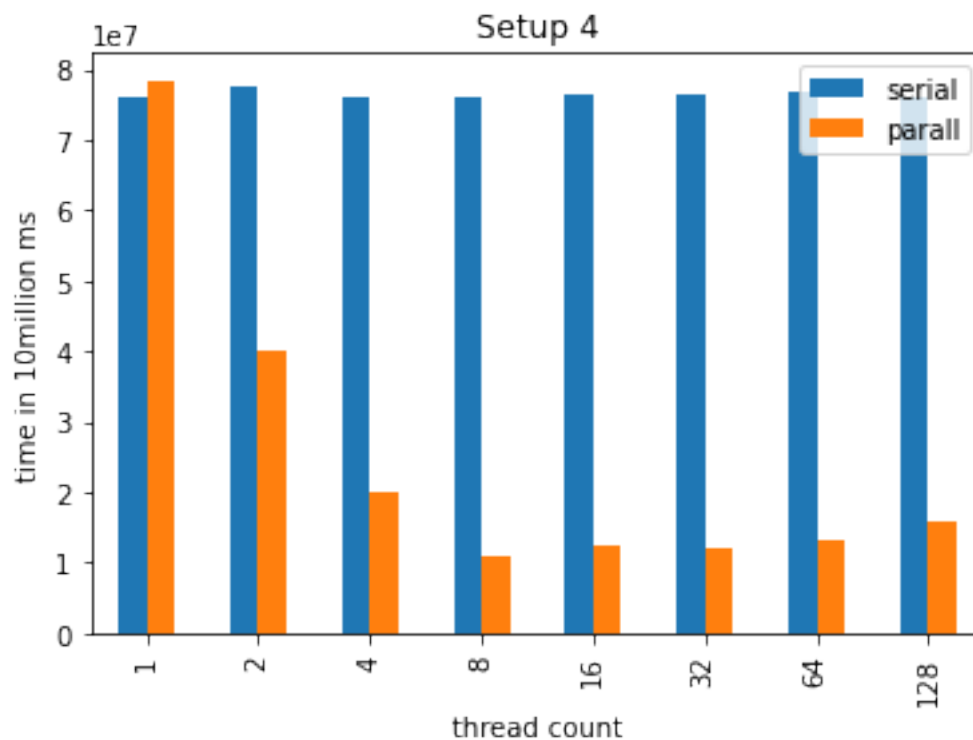
    }

df1 = pandas.DataFrame.from_dict(val_dict, orient='index')

df1.plot.bar(title='Setup 4')
plt.xlabel("thread count")
plt.ylabel("time in 10million ms")

```

```
[4]: Text(0, 0.5, 'time in 10million ms')
```



Python Code For more data processing To quickly calculate average values for each thread count i wrote this python program that parses the console output and prints out the averages in sequence.

```

from statistics import mean
par = []
ser = []

avgp = []
avgs = []

```

```

threads = 0
vals = 0

with open('./outs.txt') as reader:
    lines = reader.readlines()

    for line in lines:
        if vals == 5:
            avgp.append(mean(par))
            avgs.append(mean(ser))
            par=[]
            ser=[]
            vals = 0
            threads += 1
        word = line.split(' ')
        if 'parallel:' in word:
            par.append(int(word[2]))
        if 'serial:' in word:
            ser.append(int(word[4]))
            vals += 1

print("ser: ", avgs, "par: ", avgp, threads)

```

[]: