

Module.4

4. Race Conditions in Multithreaded Code Description:

Reverse debugging is used to analyze nondeterministic bugs caused by race conditions.

Debugging Tasks:

1. Compile with threads

2. Use GDB:

Run the program and observe output.

Use record to enable reverse debugging.

Reverse-step through thread execution (reverse-next and reverse-step) to locate simultaneous access to counter.

3. Fix the issue using a mutex and retest.

bug_raceconditions_multithread.c

```
#include <stdio.h>
```

```
#include <pthread.h>
```

```
int shared_counter = 0; // Shared variable
```

```
void *increment(void *arg) {
```

```
    for (int i = 0; i < 10; i++) {
```

```
        shared_counter++; // Increment the shared variable
```

```
        printf("Incrementing: Counter = %d\n", shared_counter);
```

```
    }
```

```
    return NULL;
```

```
}
```

```
void *decrement(void *arg) {
```

```
    for (int i = 0; i < 10; i++) {
```

```
        shared_counter--; // Decrement the shared variable
```

```
        printf("Decrementing: Counter = %d\n", shared_counter);
```

```

    }

    return NULL;
}

int main() {
    pthread_t thread1, thread2;

    // Create two threads: one for incrementing and one for decrementing
    pthread_create(&thread1, NULL, increment, NULL);
    pthread_create(&thread2, NULL, decrement, NULL);

    // Wait for both threads to finish
    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);

    printf("Final Counter Value: %d\n", shared_counter);
    return 0;
}

```

Step to find bug_raceconditions_multithread by debugging using gdb.

Steps to Debug Race Condition

```
gcc -g -pthread -o bug_raceconditions_multithread bug_raceconditions_multithread.c
```

```
gdb ./bug_raceconditions_multithread
```

```
break increment
```

```
break decrement
```

```
run
```

```
record
```

```
next
```

```
print shared_counter
```

```
reverse-next
```

```
reverse-step
```

```
info threads
```

thread <thread-number>

forward or backward shared_counter

delete record

```
Activities Terminal Jan 25 16:59
rps@rps-Standard-PC-Q35-ICH9-2009: ~/manish/ManishDTA/capstone_project/project2_day1/module4
rps@rps-Standard-PC-Q35-ICH9-2009:~/manish/ManishDTA/capstone_project/project2_day1/module4$ gcc -g -pthread -o bug_raceconditions_multithread bug_raceconditions_multithread.c
rps@rps-Standard-PC-Q35-ICH9-2009:~/manish/ManishDTA/capstone_project/project2_day1/module4$ gdb ./bug_raceconditions_multithread
GNU gdb (Ubuntu 12.1-0ubuntu1~22.04.2) 12.1
Copyright (C) 2022 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from ./bug_raceconditions_multithread...
(gdb) break increment
Breakpoint 1 at 0x110b: file bug_raceconditions_multithread.c, line 7.
(gdb) break decrement
Breakpoint 2 at 0x120e: file bug_raceconditions_multithread.c, line 15.
(gdb) run
Starting program: /home/rps/manish/ManishDTA/capstone_project/project2_day1/module4/bug_raceconditions_multithread
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
[New Thread 0x7ffff7a00640 (LWP 68362)]
[New Thread 0x7ffff7000640 (LWP 68363)]
[Switching to Thread 0x7ffff7a00640 (LWP 68362)]

Thread 2 "bug_raceconditi" hit Breakpoint 1, increment (arg=0x0) at bug_raceconditions_multithread.c:7
7      for (int i = 0; i < 10; i++) {
(gdb) target record-full
(gdb) record
The process is already being recorded. Use "record stop" to stop recording first.
(gdb) next
[Switching to Thread 0x7ffff7000640 (LWP 68363)]
(gdb) next
[Switching to Thread 0x7ffff7000640 (LWP 68403)]

Thread 3 "bug_raceconditi" hit Breakpoint 2, decrement (arg=0x0) at bug_raceconditions_multithread.c:15
15     for (int i = 0; i < 10; i++) {
(gdb) print shared_counter
$1 = 0
(gdb) next
Incrementing: Counter = 1
Incrementing: Counter = 2
Incrementing: Counter = 3
Incrementing: Counter = 4
Incrementing: Counter = 5
Incrementing: Counter = 6
Incrementing: Counter = 7
Incrementing: Counter = 8
Incrementing: Counter = 9
Incrementing: Counter = 10
[Thread 0x7ffff7a00640 (LWP 68402) exited]
16     shared_counter--; // Decrement the shared variable
(gdb) next
17     printf("Decrementing: Counter = %d\n", shared_counter);
(gdb) print shared_counter
$2 = 9
(gdb) next
Decrementing: Counter = 9
15     for (int i = 0; i < 10; i++) {
(gdb) next
16     shared_counter--; // Decrement the shared variable
(gdb) next
17     printf("Decrementing: Counter = %d\n", shared_counter);
(gdb) print shared_counter
$3 = 8
(gdb) info threads
Id      Target Id      Frame
1      Thread 0x7ffff7a8740 (LWP 68399) "bug_raceconditi" __futex_abstined_wait_common64 (private=128, cancel=true, abstime=0x0, op=265, expected=68403, futex_word=0x7ffff7000910) at ./nptl/futex-internal.c:57
* 3      Thread 0x7ffff7000640 (LWP 68403) "bug_raceconditi" decrement (arg=0x0) at bug_raceconditions_multithread.c:17
# 3      Thread 0x7ffff7000640 (LWP 68403) "bug_raceconditi" decrement (arg=0x0) at bug_raceconditions_multithread.c:17
(gdb) thread 1
[Switching to thread 1 (Thread 0x7ffff7a8740 (LWP 68399))]
#0 __futex_abstined_wait_common64 (private=128, cancel=true, abstime=0x0, op=265, expected=68403, futex_word=0x7ffff7000910)
at ./nptl/futex-internal.c:57
57 ./nptl/futex-internal.c: No such file or directory.
(gdb) thread 3
[Switching to thread 3 (Thread 0x7ffff7000640 (LWP 68403))]
#0 decrement (arg=0x0) at bug_raceconditions_multithread.c:17
17     printf("Decrementing: Counter = %d\n", shared_counter);
(gdb) print shared_counter
$4 = 8
(gdb) quit
A debugging session is active.

Inferior 1 [process 68399] will be killed.

Quit anyway? (y or n) y
rps@rps-Standard-PC-Q35-ICH9-2009:~/manish/ManishDTA/capstone_project/project2_day1/module4$
```

Fix the issue using a mutex support the multi threads and retest using gdb:-

fix_bug_raceconditions_multithread.c

```
#include <stdio.h>
```

```
#include <pthread.h>
```

```
int shared_counter = 0; // Shared variable
```

```
pthread_mutex_t lock; // Mutex lock
```

```
void *increment(void *arg) {
```

```
    for (int i = 0; i < 10; i++) {
```

```
        pthread_mutex_lock(&lock);
```

```
        shared_counter++; // Safely increment
```

```
        printf("Incrementing: Counter = %d\n", shared_counter);
```

```
        pthread_mutex_unlock(&lock);
```

```
    }
```

```
    return NULL;
```

```
}
```

```
void *decrement(void *arg) {
```

```
    for (int i = 0; i < 10; i++) {
```

```
        pthread_mutex_lock(&lock);
```

```
        shared_counter--; // Safely decrement
```

```
        printf("Decrementing: Counter = %d\n", shared_counter);
```

```
        pthread_mutex_unlock(&lock);
```

```
    }
```

```
    return NULL;
```

```
}
```

```
int main() {
```

```
    pthread_t thread1, thread2;
```

```

pthread_mutex_init(&lock, NULL); // Initialize the mutex

// Create threads
pthread_create(&thread1, NULL, increment, NULL);
pthread_create(&thread2, NULL, decrement, NULL);

// Wait for threads to finish
pthread_join(thread1, NULL);
pthread_join(thread2, NULL);

pthread_mutex_destroy(&lock); // Destroy the mutex

printf("Final Counter Value: %d\n", shared_counter);
return 0;
}

```

Steps to Verify if the Bug is Fixed or not using debugging with gdb

```

gcc -g -pthread -o fix_bug_raceconditions_multithread fix_bug_raceconditions_multithread.c
gdb ./fix_bug_raceconditions_multithread
break increment
break decrement
run
record
next
print shared_counter
info threads
thread <thread-number>
reverse-next
reverse-step
delete record

```

```
Activities Terminal Jan 25 17:33
rps@rps-Standard-PC-Q35-ICH9-2009: ~/manish/ManishDTA/capstone_project/project2_day1/module4
rps@rps-Standard-PC-Q35-ICH9-2009:~/manish/ManishDTA/capstone_project/project2_day1/module4$ gcc -g -pthread -o fix_bug_raceconditions_multithread fix_bug_raceconditions_multithread.c
rps@rps-Standard-PC-Q35-ICH9-2009:~/manish/ManishDTA/capstone_project/project2_day1/module4$ gdb ./fix_bug_raceconditions_multithread
GNU gdb (Ubuntu 12.1-0ubuntu1-22.04.2) 12.1
Copyright (C) 2022 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from ./fix_bug_raceconditions_multithread...
(gdb) break increment
Breakpoint 1 at 0x1239: file fix_bug_raceconditions_multithread.c, line 8.
(gdb) break decrement
Breakpoint 2 at 0x12ac: file fix_bug_raceconditions_multithread.c, line 18.
(gdb) run
Starting program: /home/rps/manish/ManishDTA/capstone_project/project2_day1/module4/fix_bug_raceconditions_multithread
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
[New Thread 0x7ffff7a00640 (LWP 68622)]
[New Thread 0x7ffff7000640 (LWP 68623)]
[Switching to Thread 0x7ffff7a00640 (LWP 68622)]

Thread 2 "fix_bug_racecon" hit Breakpoint 1, increment (arg=0x0) at fix_bug_raceconditions_multithread.c:8
8      for (int i = 0; i < 10; i++) {
(gdb) print shared_counter
$1 = 0
(gdb) print i
$2 = 0
(gdb) next
[Switching to Thread 0x7ffff7000640 (LWP 68623)]

Thread 3 "fix_bug_racecon" hit Breakpoint 2, decrement (arg=0x0) at fix_bug_raceconditions_multithread.c:18
18     for (int i = 0; i < 10; i++) {
(gdb) print shared_counter
$3 = 0
(gdb) next
Incrementing: Counter = 1
Incrementing: Counter = 2
Incrementing: Counter = 3
Incrementing: Counter = 4
Incrementing: Counter = 5
Incrementing: Counter = 6
Incrementing: Counter = 7
Incrementing: Counter = 8
Incrementing: Counter = 9
Incrementing: Counter = 10
[Thread 0x7ffff7a00640 (LWP 68622) exited]
19     pthread_mutex_lock(&lock);
(gdb) print shared_counter
$4 = 10
(gdb) next
20     shared_counter--; // Safely decrement
(gdb) next
21     printf("Decrementing: Counter = %d\n", shared_counter);
(gdb) print shared_counter
$5 = 9
(gdb) next
Decrementing: Counter = 9
22     pthread_mutex_unlock(&lock);
(gdb) print shared_counter
$6 = 9
(gdb) next
18     for (int i = 0; i < 10; i++) {
(gdb) next
19     pthread_mutex_lock(&lock);
(gdb) next
20     shared_counter--; // Safely decrement
(gdb) next
21     printf("Decrementing: Counter = %d\n", shared_counter);
(gdb) print shared_counter
$7 = 8
(gdb) info threads
Id Target Id Frame
1 Thread 0x7ffff7fa8740 (LWP 68619) "fix_bug_racecon" __futex_abstined_wait_common64 (private=128, cancel=true, abstime=0x0, op=265, expected=68623, futex_word=0x7ffff7000910) at ./nptl/futex-internal.c:57
* 3 Thread 0x7ffff7000640 (LWP 68623) "fix_bug_racecon" decrement (arg=0x0) at fix_bug_raceconditions_multithread.c:21
(gdb) thread 1
[Switching to thread 1 (Thread 0x7ffff7fa8740 (LWP 68619))]
#0 __futex_abstined_wait_common64 (private=128, cancel=true, abstime=0x0, op=265, expected=68623, futex_word=0x7ffff7000910)
at ./nptl/futex-internal.c:57
57 ./nptl/futex-internal.c: No such file or directory.
(gdb) thread 3
[Switching to thread 3 (Thread 0x7ffff7000640 (LWP 68623))]
#0 decrement (arg=0x0) at fix_bug_raceconditions_multithread.c:21
21     printf("Decrementing: Counter = %d\n", shared_counter);
(gdb) quit
A debugging session is active.

Inferior 1 [process 68619] will be killed.

Quit anyway? (y or n) y
rps@rps-Standard-PC-Q35-ICH9-2009:~/manish/ManishDTA/capstone_project/project2_day1/module4$
```

