Synchronisation: Reader-Writer Problem

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I. The Reader-Writer Problem

We consider a situation in which a shared resource is concurrently accessed by two types of entities: the readers and the writers. The readers access the resource without modifying it. The writers, can alter the resource. To keep the resource is in a consistent state, multiple readers may access it concurrently but writers should access it exclusively. In other terms, when a writer is using a resource, no reader or writer can access this ressource.

The reader-writer problem is a classical synchronization problem. This access scheme is typically used when working with files or memory.

In the following we will consider the following functions:

- `init(reader_writer_t)` is the initialization function
- `begin_read(reader_writer_t)` and `end_read(reader_writer_t)` are the functions used by each reader before and after reading
- `begin_write(reader_writer_t)` et `end_write(reader_writer_t)` are the funstions used by a writer before and after writing.

The structure `reader_writer_t` is to be defined. It must contain all the variables used by the synchronization primitives.

II. Implementing a thread-safe linked list

Your are asked to implement a **thread-safe linked list**. A **non** thread-safe linked list implementation is included in the archive[1] (`linked_list.c, linked_list.h`).

In the linked list the `list_insert()` and `list_remove()` are concidered to be *writings*, since it alter the linked list. `list_exists()` is concidered to be *reading*.

The provided implementation includes correct calls to the `begin_read(), end_read(), begin_write()` and `end_write()` primitives. Your work consists in implementing theses primitives so the linked list behave correctly when accessed by multiple threads.

[1] `http://membres-lig.imag.fr/negrevergne/ens/assignment_two.tar.gz`

```
Thread nmbr 0, won.
Thread nmbr 1, won.
THREAD 0 TIME: +0s 0.046ms, TYPE : BEGIN WRITE
THREAD 0 TIME: +0s 0.047ms, TYPE : END WRITE
THREAD 0 TIME: +0s 0.047ms, TYPE : BEGIN READ
THREAD 0 TIME: +0s 0.047ms, TYPE : END READ
THREAD 1 TIME: +0s 0.062ms, TYPE : BEGIN WRITE
THREAD 1 TIME: +0s 0.065ms, TYPE : END WRITE
THREAD 1 TIME: +0s 0.065ms, TYPE : BEGIN READ
THREAD 1 TIME: +0s 0.066ms, TYPE : END READ
THREAD 1 TIME: +0s 0.066ms, TYPE : BEGIN WRITE
THREAD 1 TIME: +0s 0.066ms, TYPE : END WRITE
THREAD 1 TIME: +0s 0.066ms, TYPE : BEGIN READ
THREAD 1 TIME: +0s 0.066ms, TYPE : END READ
THREAD 1 TIME: +0s 0.067ms, TYPE : BEGIN WRITE
THREAD 1 TIME: +0s 0.067ms, TYPE : END WRITE
THREAD 1 TIME: +0s 0.067ms, TYPE : BEGIN READ
THREAD 1 TIME: +0s 0.067ms, TYPE : END READ
THREAD 1 TIME: +0s 0.067ms, TYPE : BEGIN WRITE
THREAD 1 TIME: +0s 0.068ms, TYPE : END WRITE
THREAD 1 TIME: +0s 0.068ms, TYPE : BEGIN READ
THREAD 1 TIME: +0s 0.068ms, TYPE : END READ
```

Figure 1: output of : linked_list_simple_test

The archive also contains a simple test file `linked_list_simple_test.c`. Read it carefully. Any successful test must return `EXIT_SUCCESS`.

Question II.1: *Considering that no synchronization has been implemented yet, what result could you expect from this test. If you run the test, it won't actually fail, why ? What do you conclude on the validity of this test ?*

The code of `begin_read()`, `end_read()`, `begin_write()` and `end_write()` contains calls to the tracing module (`reader_writer_tracing.h`, `reader_writer_tracing.c`). This module allow one to record events and to prints them afterward.

Question II.2: *Fig. 1 is a possible output of* `./linked_list_simple_test 2`. *Using this output, how can you verify the consistency of the calls to* `begin_read()`, `end_read()`, `begin_write()` *and* `end_write()`.

Question II.3: *Write a naÔve implementation of* `begin_read()`, `end_read()`, `begin_write()` *and* `end_write()` *in a new file named* `reader_writer_1.c` *using only mutexes*[2].

Question II.4: *Write a test program using the tracing module to check the consistency of the calls to* `begin_read()`, `end_read()`, `begin_write()` *and* `end_write()`.

[2] You must uncomment the corresponding line in the `Makefile`

Question II.5: *What could be the definition of efficiency in this particular problem ? In synchronization problems in general ? How would you evaluate the efficiency of this solution according to your previous definition ?*

III. Improving concurrency

The previous solution does not meet the requirements in terms of concurrency since two readers cannot read the list simultaneously.

Question III.1: *Implement new* `begin_read()`, `end_read()`, `begin_write()` *and* `end_write()` *functions in* `reader_writer_2.c` *to improve the concurrent capabilities of your thread-safe list. You may use conditions.*

Question III.2: *Write a test program that verify that readers can access the list concurrently. Note that this test will fail with your first implementation and pass with your second implementation.*

IV. Improving fairness

Question IV.1: *Introducing the events* `WAITS TO READ` *and* `WAITS TO WRITE` *for threads waiting in the functions* `begin_read()` *and* `begin_write()`. *Spot the fairness issue in Fig. 2.*

Question IV.2: *Discuss about the* **fairness** *of your previous solution.*

Question IV.3: *Build a fair solution for the reader writer problem in* `reader_writer_3.c`. *Write a corresponding test.*
Hint : You must not mix the readers which arrived before a writer with the ones arriving after.

```
THREAD 0 TIME: +0s 0.068ms, TYPE : BEGIN READ
THREAD 1 TIME: +0s 0.069ms, TYPE : WAITS TO WRITE
THREAD 2 TIME: +0s 0.070ms, TYPE : BEGIN READ
THREAD 0 TIME: +0s 0.071ms, TYPE : END READ

THREAD 0 TIME: +0s 0.083ms, TYPE : BEGIN READ
THREAD 2 TIME: +0s 0.085ms, TYPE : END READ

THREAD 2 TIME: +0s 0.123ms, TYPE : BEGIN READ
THREAD 0 TIME: +0s 0.127ms, TYPE : END READ

THREAD 0 TIME: +0s 0.143ms, TYPE : BEGIN READ
THREAD 2 TIME: +0s 0.145ms, TYPE : END READ

THREAD 2 TIME: +0s 0.161ms, TYPE : BEGIN READ
THREAD 0 TIME: +0s 0.168ms, TYPE : END READ
...
THREAD 2 TIME: +0s 0.183ms, TYPE : END READ
THREAD 1 TIME: +0s 0.184ms, TYPE : BEGIN WRITE
THREAD 1 TIME: +0s 0.187ms, TYPE : END WRITE
```

Figure 2: problematic behavior