

CSE 437

REAL TIME SYSTEM ARCHITECTURES

Homework 1

**A Thread-safe Set
Project Report**

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Content:

ABSTRACT

0. REQUIREMENTS.....	
1. INTRODUCTION.....	
2. PROJECT DESIGN & IMPLEMENTATION.....	
3. CLASS DIAGRAMS.....	

ABSTRACT

We are implementing a thread-safe set data structure. There are various way of implementing a set data structure. It can be use Tree set, Hash linked set, List set etc. and also there are various way of avoiding race conditions using some tools. Some of them are supported by operating system (OS) like conditions variables, semaphores, atomic operations etc to avoid race conditions and undefined behavior.

In this project I implemented a Thread Safe Lock-free Tree Set Data Structure. Using c++20 new features and gcc 12.1.0 version.

REQUIREMENTS

Add compile parameter -std=c++2a standard.

Use g++ 12.1.0 compiler (updated version current date).

INTRODUCTION

Set is a data structure that stores unique elements of the same type. In the implementation I use the tree structure. Because of the tree structure design the comparison is easy to other list approach If the value is smaller than the current value go left if the value is greater than go right. If the comparison is equal then the item already in the list.

So the class template argument must be comparable object. For the comparison operator< and operator== is added to the class. If the class not implement these operators Thread-safe set returning an assert fault. Telling the user you need to implement these operators.

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24     ThreadSafeSet(){
25         static_assert(has_less_than<T>, "T must have operator<");
26         static_assert(has_equal_to<T>, "T must have operator==");
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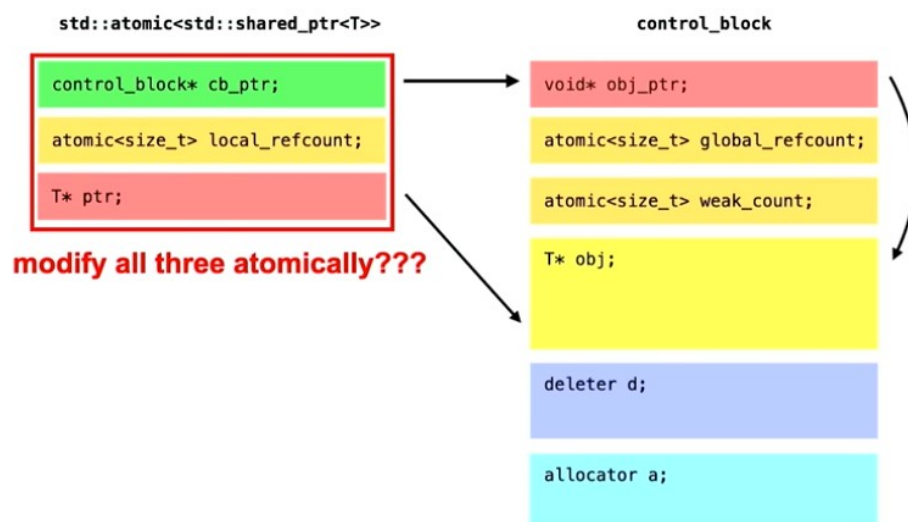
```

The tree uses the shared pointers to go to the other nodes.

```
100, 8 nodes ago; 1 node; 100;
struct Node
{
    T value;
    std::atomic<std::shared_ptr<Node>> left;
    std::atomic<std::shared_ptr<Node>> right;

    Node(const T& value) : value(value), left(nullptr), right(nullptr) {}
};
```

Until c++20 there is no direct exchange operation for the shared pointer. We are passing as an argument and we are hoping the exchange process will be atomic. Because of the shared pointer structure. The shared pointer has a lot of operation in the copying.



[A Lock-Free Atomic Shared Pointer in Modern Cpp - Timur Doumler - CppCon 2022]

For the lock-free approach a new features comes with the c++20 we can directly declare shared pointers in the atomic.

```
bool compare_exchange_weak(std::shared_ptr<T>& expected, std::shared_ptr<T> desired)
{
    //c++11
    // return std::atomic_compare_exchange_weak(&ptr, &expected, desired);

    //c++20`
    return ptr.compare_exchange_weak(expected, desired);
}
```

There is open source and commercial implementation for the atomic shared pointer on the internet.

https://github.com/vtyulb/AtomicSharedPtr/blob/master/src/atomic_shared_ptr.h

<https://github.com/facebook/folly/blob/main/folly/concurrency/AtomicSharedPtr.h>

https://github.com/anthonywilliams/atomic_shared_ptr

These makes the operations are being atomic for the lock-free set.

For more detail watch the Timur Doumler - CppCon 2022 YouTube video please.

PROJECT DESIGN & IMPLEMENTATION

PART 1:

For the part 1 we have 1 writer and 1 reader. Even the operations are being an atomic. The operations are not executed at the same time. One before one after executing. So if the one writer is in the tree set actually there is not problem for the reader because it is not change the structure it just reading. The time reader is read if the object is exist it is exists return true if the object does not exist it is not exist return false. In that case no need protection for the reader. And there is 1 writer. Because of the just exist 1 writer also there is no need concurrency protection between writers. Because there is no other writer exist. It can iterate over as it wanted. Insertion and removing operations are making by its. The wrapper function just take an T argument and creating a local copy of the root node shared pointer. So we can iterate the other function. (Atomic objects not copyable in c++20) so we are sending a shared pointer to function.

```
std::atomic<std::shared_ptr<Node>> local;
local.store(root.load());

bool added = false;
while (true)
{
    std::shared_ptr<Node> v = local.load();
    std::shared_ptr<Node> result;

    COMPARE_EXCHANGE_WEAK(local, v, result);
    result = insert(v, value, added);

    if(result != nullptr){
        root.store(result);
        break;
    }
}
```

The function is started and proceeding as a normal tree set addition algorithm.

Insert:

```
std::shared_ptr<Node> insert(std::shared_ptr<Node> _local, T value, bool& added){

    std::atomic<std::shared_ptr<Node>> local;
    local.store(_local);

    if(local.load() == nullptr){
        added = true;
        return std::make_shared<Node>(value);
    }else{

        if(value < local.load()->value){

            std::shared_ptr<Node> v = local.load()->left;
            COMPARE_EXCHANGE_WEAK(local.load()->left, v, insert(v, value, added));
        }

        if(!(value < local.load()->value) && !(value == local.load()->value)){
            std::shared_ptr<Node> v = local.load()->right;
            COMPARE_EXCHANGE_WEAK(local.load()->right, v, insert(v, value, added));
        }
    }

    return local.load();
}
```

The exchanged operations are made in a while loop. There is no need a protection for the critical region. Removing, searching and size operations are same as adding operations for the normal binary search tree algorithm.

Remove:

```
std::atomic<std::shared_ptr<Node>> local;
local.store(_local);

if(local.load() == nullptr){
    return local;
}
if(value < local.load()->value){
    std::shared_ptr<Node> v = local.load()->left;
    COMPARE_EXCHANGE_WEAK(local.load()->left, v, remove(v, value, removed));
}else if(!(value < local.load()->value) && !(value == local.load()->value)){
    std::shared_ptr<Node> v = local.load()->right;
    COMPARE_EXCHANGE_WEAK(local.load()->right, v, remove(v, value, removed));
}else{
    removed = true;
    if(local.load()->left.load() == nullptr && local.load()->right.load() == nullptr){
        std::shared_ptr<Node> v = local;
        COMPARE_EXCHANGE_WEAK(local, v, nullptr);
    }else if(local.load()->left.load() == nullptr){
        std::shared_ptr<Node> v = local;
        COMPARE_EXCHANGE_WEAK(local, v, local.load()->right);
    }else if(local.load()->right.load() == nullptr){
        std::shared_ptr<Node> v = local;
        COMPARE_EXCHANGE_WEAK(local, v, local.load()->left);
    }else{
        T max = findMax(local.load()->left);
        local.load()->value = max;
        std::shared_ptr<Node> v = local.load()->left;
        COMPARE_EXCHANGE_WEAK(local.load()->left, v, remove(v, max, removed));
        local.load()->right.store(remove(local.load()->right, local.load()->value, removed));
    }
}

return local;
```

Search:

```
bool search(std::shared_ptr<Node> _local, T value) const {

    std::atomic<std::shared_ptr<Node>> local;
    local.store(_local);

    if(local.load() == nullptr){
        return false;
    }
    if(value < local.load()->value){
        return search(local.load()->left, value);
    }else if(!(value < local.load()->value) && !(value == local.load()->value)){
        return search(local.load()->right, value);
    }else{
        return true;
    }
}
```

Size & Iterate:

```
int size(std::shared_ptr<Node> local) const {
    if(local == nullptr)
        return 0;
    else
        return 1 + size(local->left) + size(local->right);
}

void iterate(std::shared_ptr<Node> local, const std::function<void(const T& obj)>& func) const {
    if(local != nullptr){
        iterate(local->left, func);
        func(local->value);
        iterate(local->right, func);
    }
}
```

For the making test you can change the sleep settings to see much more different result.

PART 1 TEST RESULT:

```
199499, 199502, 199505, 199512, 199513, 199514, 199515, 199521, 19952
583, 199591, 199601, 199603, 199605, 199616, 199622, 199624, 199630,
, 199694, 199696, 199702, 199710, 199713, 199724, 199728, 199736, 199
99802, 199805, 199810, 199814, 199819, 199821, 199822, 199823, 199825
80, 199882, 199885, 199895, 199898, 199902, 199909, 199914, 199918, 1
199990, 199993, 199998,
Insertion time: 1405 ms
Size: 50000
Added: 100000
Removed: 50000
Contains: 3846
Removed + Size: 100000

Does set contains 188284: 1
Remove call result: 1
Add call result: 1
Does set contains 48334: 0
Remove call result: 0
Add call result: 1
Does set contains 99019: 1
Remove call result: 1
Add call result: 1
Does set contains 184963: 0
Remove call result: 0
Add call result: 1
Does set contains 36398: 0
Remove call result: 0
Add call result: 1

Does set contains 42296: 0
Add call result: 1
Remove call result: 1
Does set contains 62337: 1
Add call result: 0
Remove call result: 1
Does set contains 180136: 1
Add call result: 0
Remove call result: 1
Does set contains 73680: 1
Add call result: 0
Remove call result: 1
Does set contains 113287: 1
Add call result: 0
Remove call result: 1
Cleaning...
Size: 0
Done!
```

```
4, 19447, 19450, 19455, 19458, 19462, 19467, 19468, 19480,
9, 19563, 19574, 19584, 19590, 19595, 19596, 19600, 19602,
7, 19718, 19727, 19730, 19733, 19735, 19739, 19740, 19741,
5, 19817, 19821, 19822, 19827, 19832, 19834, 19835, 19846,
7, 19939, 19942, 19945, 19948, 19949, 19950, 19953, 19979,
Insertion time: 136 ms
Size: 5000
Added: 10000
Removed: 5000
Contains: 1223
Removed + Size: 10000

Does set contains 5610: 0
Remove call result: 0
Add call result: 1
Does set contains 661: 0
Remove call result: 0
Add call result: 1
Does set contains 19440: 0
Remove call result: 0
Add call result: 1
Does set contains 12852: 1
Remove call result: 1
Add call result: 1
Does set contains 5485: 0
Remove call result: 0
Add call result: 1

Does set contains 4768: 0
Add call result: 1
Remove call result: 1
Does set contains 19735: 0
Add call result: 1
Remove call result: 1
Does set contains 2203: 0
Add call result: 1
Remove call result: 1
Does set contains 3760: 0
Add call result: 1
Remove call result: 1
Does set contains 4521: 1
Add call result: 0
Remove call result: 1
Cleaning...
Size: 0
Done!
```

```
Insertion time: 1412 ms
Size: 50000
Added: 100000
Removed: 50000
Contains: 3785
Removed + Size: 100000
```

```
Does set contains 21664: 0
Remove call result: 0
Add call result: 1
Does set contains 153133: 1
Remove call result: 1
Add call result: 1
Does set contains 125098: 1
Remove call result: 1
Add call result: 1
Does set contains 157464: 0
Remove call result: 0
Add call result: 1
Does set contains 29280: 0
Remove call result: 0
Add call result: 1
```

```
Does set contains 61924: 0
Add call result: 1
Remove call result: 1
Does set contains 130950: 1
Add call result: 0
Remove call result: 1
Does set contains 60511: 0
Add call result: 1
Remove call result: 1
Does set contains 124484: 0
Add call result: 1
Remove call result: 1
Does set contains 56070: 1
Add call result: 0
Remove call result: 1
Cleaning...
Size: 0
Done!
```

```
Insertion time: 129 ms
Size: 5000
Added: 100000
Removed: 5000
Contains: 3333
Removed + Size: 10000
```

```
Does set contains 8546: 0
Remove call result: 0
Add call result: 1
Does set contains 5253: 1
Remove call result: 1
Add call result: 1
Does set contains 3836: 0
Remove call result: 0
Add call result: 1
Does set contains 18578: 0
Remove call result: 0
Add call result: 1
Does set contains 7342: 0
Remove call result: 0
Add call result: 1
```

```
Does set contains 6911: 0
Add call result: 1
Remove call result: 1
Does set contains 7552: 0
Add call result: 1
Remove call result: 1
Does set contains 5001: 1
Add call result: 0
Remove call result: 1
Does set contains 4327: 1
Add call result: 0
Remove call result: 1
Does set contains 2462: 1
Add call result: 0
Remove call result: 1
Cleaning...
Size: 0
Done!
```

```
Insertion time: 1563 ms
Size: 50000
Added: 100000
Removed: 50000
Contains: 30986
Removed + Size: 100000
```

```
Does set contains 147945: 1
Remove call result: 1
Add call result: 1
Does set contains 171039: 1
Remove call result: 1
Add call result: 1
Does set contains 192234: 1
Remove call result: 1
Add call result: 1
Does set contains 38571: 0
Remove call result: 0
Add call result: 1
Does set contains 103443: 0
Remove call result: 0
Add call result: 1
```

```
Does set contains 128170: 0
Add call result: 1
Remove call result: 1
Does set contains 167604: 0
Add call result: 1
Remove call result: 1
Does set contains 72618: 0
Add call result: 1
Remove call result: 1
Does set contains 37680: 1
Add call result: 0
Remove call result: 1
Does set contains 43224: 0
Add call result: 1
Remove call result: 1
Cleaning...
Size: 0
Done!
```


PART 2:

In this part we are going to implement thread-safe tree set for multiple reader and multiple writer. There are various ways for the implementation some of them are working perfect but take more time according to the other some of them are missing %3-%5 percent (Because of the tree structure there are a lot of unrelated branch not effecting each other) but it is %70 - %80 percent faster according to the other. Even if we don't put a lock mechanism It just missing %5-%7 percent if the size of data is not important for you the more important thing is the fast you can check it out.

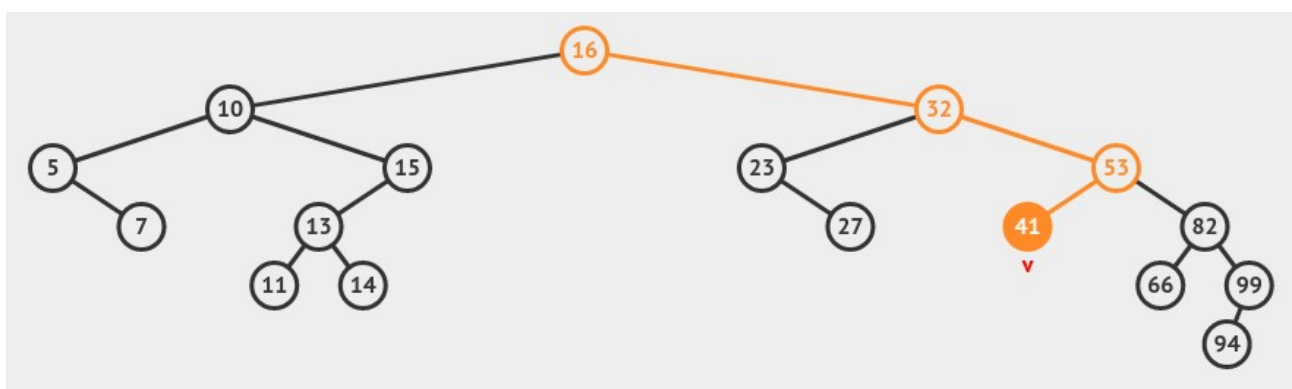
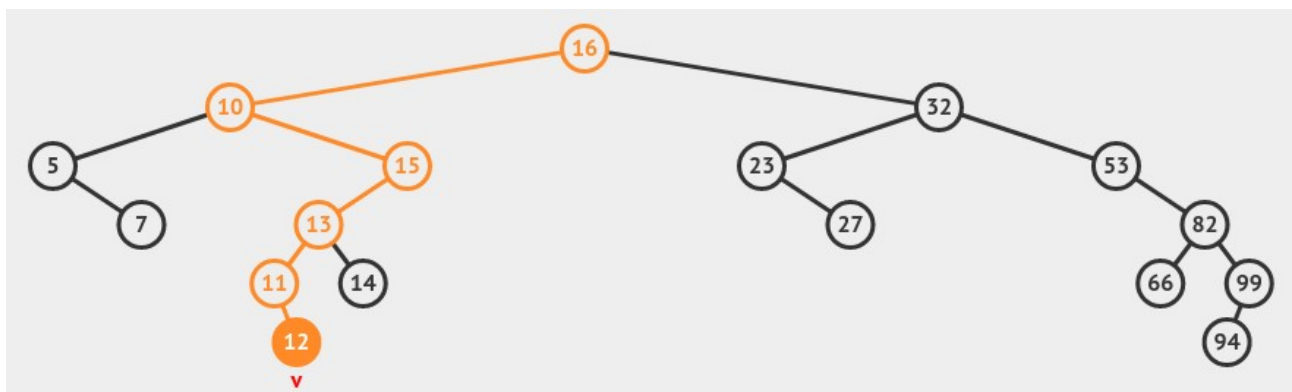
I will explain two different implementation first one is more complex according to the other one but it would has a much more speed according to the second implementation. I implement the second one because of the simplicity.

First Implementation:

There are a lot of list not depend on each other. for example one adding operation add new node left branch, other adding operation add new node right branch these are totally different rote. This allows us the multiple writer can access at the same time without waiting other. But how can we achieve this addition? For that each node need a marked boolean value if the node marked as doing an operation on it. The operation request waiting on a `std::atomic_flag` variable and wait until the `atomic_flag` is become true. But how we can make it true. As a result each node path start from the root variable. We need to make the flags true in some where. For this purpose we are sending the parent and grand parent address to the child. If the current check is on a node we are remark the grand parent node's flag. So the other node can pass the grand parent node.

For example:

We want to add 12, and 41 at the same time;

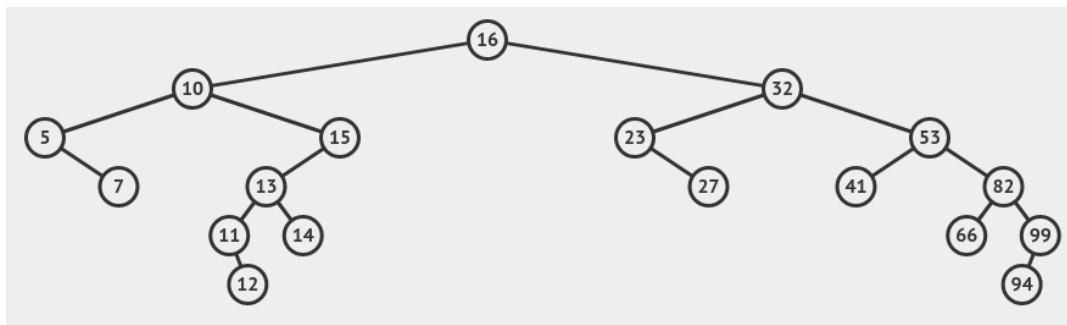


first 12 take the root and start to continue with std::atomic_flag locking.

Locked 16
Locked 10
Locked 15 and Unlock 16
Locked 13 and Unlock 10
Locked 11 and Unlock 15
Create new node 12
Assign left of 11
Come back with unlocking

41 start adding operations
Locked 16
Locked 32
Locked 53 and Unlock 16
Create new node 41
Assign left of 53
come back with unlocking

As a result:



Ps: I try to implement this method but time because of the time constraint I could not finish the implementation, but in the theory it seems work. I did not implement and test it.

```
std::shared_ptr<Node> add(std::shared_ptr<Node> _local, T value, std::shared_ptr<Node> parent, std::shared_ptr<Node> grand_parent,
    std::atomic<std::shared_ptr<Node>> local;
    local.store(_local);

    // if(local.load() != nullptr)
    //     local.load()->mark();

    // if(grand_parent != nullptr && grand_parent->is_marked())
    //     grand_parent->un_mark();

    // if(local.load() != nullptr && local.load()->is_marked())
    //     local.load()->wait_unlock();

    if(local.load() == nullptr){
        added = true;
        return std::make_shared<Node>(value);
    }else{
        // local.load()->wait_left_unlock();
        if(value < local.load()->value){
            while(true){
                std::shared_ptr<Node> v = local.load()->left;
                if(local.load()->left.compare_exchange_weak(v, add(v, value, local.load(), parent, added))){
                    break;
                }
            }
            // local.load()->left = add(local.load()->left, value, local.load(), added);
        }
        // local.load()->un_mark_left();

        // You, 11 hours ago * kajdladsaldjksd _
        // local.load()->wait_right_unlock();
        if(!(value < local.load()->value) && !(value == local.load()->value)){
            while(true){
                std::shared_ptr<Node> v = local.load()->right;
                if(local.load()->right.compare_exchange_weak(v, add(v, value, local.load(), parent, added))){
                    break;
                }
            }
            // local.load()->right = add(local.load()->right, value, local.load(), added);
        }
        // local.load()->un_mark_right();

        // if(local.load()->is_marked()){
        //     local.load()->un_mark();
        // }

        return local.load();
    }
}
```

Code in
comment.

SonarLint is unable to analyze C and C++ files
there is no configured compilation database.

Second Implementation:

In the second implementation I used the `std::atomic_flag` variable for entrance to operate over the tree. Use of the `atomic_flag` mention that OS-2 lecture page 9.

```
atomic_flag disable_inputs = ATOMIC_FLAG_INIT;

void consumer() {
    MyData localBuffer;
    for (;;) {
        if (!atomic_test_and_set(&disable_inputs) {
```

This way just one request making an operation others are waiting for the finish of the current instruction. But it is still thread-safe, slow but thread-safe. Wrapper method entrance make the flag true and others are wait in a while loop. If the loop number bigger than a specific number the thread calling `std::thread_yield()` method. To give the its order to some other thread.

```
22
23 #define ATOMIC_FLAG_LOCK(lock) \
24     int c = 0;\
25     while(lock.test_and_set(std::memory_order_acquire)){\
26         if(c++ >= 58){\
27             std::this_thread::yield();\
28         }\
29     }\
30
31 #define ATOMIC_FLAG_UNLOCK(lock) \
32     lock.clear(std::memory_order_release);\
33
```

We are making an lock in wrapper class and sending copy of the root to make an iteration over the tree.

```
ATOMIC_FLAG_LOCK(flag);
std::atomic<std::shared_ptr<Node>> local;
local.store(root.load());
bool added = false;
while (true)
{
    std::shared_ptr<Node> v = local.load();
    std::shared_ptr<Node> result;
    COMPARE_EXCHANGE_WEAK(local, v, result);
    result = add(v, value, added);

    if(result != nullptr){
        root.store(result);
        break;
    }
}
ATOMIC_FLAG_UNLOCK(flag);
```

Insertion:

```
// std::shared_ptr<Node> add(std::shared_ptr<Node> _local, T value, std::shared_ptr<Node> parent,
std::shared_ptr<Node> add(std::shared_ptr<Node> _local, T value, bool& added){

    std::atomic<std::shared_ptr<Node>> local;
    local.store(_local);

    // if(gParent != nullptr){
    //     ATOMIC_FLAG_UNLOCK(gParent->marked);
    // }
    // if(local.load() != nullptr){
    //     ATOMIC_FLAG_LOCK(local.load()->marked);
    // }

    if(local.load() == nullptr){
        added = true;
        return std::make_shared<Node>(value);
    }else{
        if(value < local.load()->value){
            std::shared_ptr<Node> v = local.load()->left;
            COMPARE_EXCHANGE_WEAK(local.load()->left, v, add(v, value, added));
            // local.load()->left = add(local.load()->left, value, local.load(), added);
        }

        if(!(value < local.load()->value) && !(value == local.load()->value)){
            std::shared_ptr<Node> v = local.load()->right;
            COMPARE_EXCHANGE_WEAK(local.load()->right, v, add(v, value, added));
            // local.load()->right = add(local.load()->right, value, local.load(), added);
        }
    }

    // ATOMIC_FLAG_UNLOCK(local.load()->marked);
    return local.load();
}
```

Remove:

```
std::shared_ptr<Node> remove(std::shared_ptr<Node> _local, T value, bool& removed){

    std::atomic<std::shared_ptr<Node>> local;
    local.store(_local);

    if(local.load() == nullptr){
        return local;
    }
    if(value < local.load()->value){
        std::shared_ptr<Node> v = local.load()->left;
        COMPARE_EXCHANGE_WEAK(local.load()->left, v, remove(v, value, removed));
    }else if(!(value < local.load()->value) && !(value == local.load()->value)){
        std::shared_ptr<Node> v = local.load()->right;
        COMPARE_EXCHANGE_WEAK(local.load()->right, v, remove(v, value, removed));
    }else{
        removed = true;
        if(local.load()->left.load() == nullptr && local.load()->right.load() == nullptr){
            std::shared_ptr<Node> v = local;
            COMPARE_EXCHANGE_WEAK(local, v, nullptr);
        }else if(local.load()->left.load() == nullptr){
            std::shared_ptr<Node> v = local;
            COMPARE_EXCHANGE_WEAK(local, v, local.load()->right);
        }else if(local.load()->right.load() == nullptr){
            std::shared_ptr<Node> v = local;
            COMPARE_EXCHANGE_WEAK(local, v, local.load()->left);
        }else{
            T max = findMax(local.load()->left);
            local.load()->value = max;
            std::shared_ptr<Node> v = local.load()->left;
            COMPARE_EXCHANGE_WEAK(local.load()->left, v, remove(v, max, removed));
            local.load()->right.store(remove(local.load()->right, local.load()->value, removed));
        }
    }

    return local;
}
```

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there is no con

Search:

```
bool search(std::shared_ptr<Node> _local, T value) const {  
  
    std::atomic<std::shared_ptr<Node>> local;  
    local.store(_local);  
  
    if(local.load() == nullptr){  
        return false;  
    }  
    if(value < local.load()->value){  
        return search(local.load()->left, value);  
    }else if(!(value < local.load()->value) && !(value == local.load()->value)){  
        return search(local.load()->right, value);  
    }else{  
        return true;  
    }  
}
```

Size & Iterator:

```
int size(std::shared_ptr<Node> local) const {  
    if(local == nullptr)  
        return 0;  
    else  
        return 1 + size(local->left) + size(local->right);  
}  
  
void iterate(std::shared_ptr<Node> local, std::function<void(T)> f) const {  
    if(local != nullptr){  
        iterate(local->left, f);  
        f(local->value);  
        iterate(local->right, f);  
    }  
}
```

I used local copy for the search, size and iterator functions to make it independence. If the node exist do operation if not den return. This make reader function more flexible.

PART 2 TEST RESULT:

```
57, 99758, 99759, 99761, 99763, 99765, 99769, 99771, 99773, 99776, 99778  
40, 99843, 99845, 99847, 99853, 99854, 99855, 99859, 99861, 99862, 99865  
21, 99926, 99928, 99929, 99931, 99932, 99933, 99936, 99938, 99939, 99946  
  
Insertion time: 1070 ms  
Size: 33561  
Added: 50000  
Removed: 16439  
Contains: 950  
Removed + Size: 50000  
  
Does set contains 66398: 1  
Remove call result: 1  
Add call result: 1  
Does set contains 67537: 0  
Remove call result: 0  
Add call result: 1  
Does set contains 29153: 0  
Remove call result: 0  
Add call result: 1  
Does set contains 52641: 0  
Remove call result: 0  
Add call result: 1  
Does set contains 54230: 0  
Remove call result: 0  
Add call result: 1  
  
Does set contains 62910: 0  
Add call result: 1  
Remove call result: 1  
Does set contains 95927: 1  
Add call result: 0  
Remove call result: 1  
Does set contains 75935: 1  
Add call result: 0  
Remove call result: 1  
Does set contains 24521: 0  
Add call result: 1  
Remove call result: 1  
Does set contains 57631: 1  
Add call result: 0  
Remove call result: 1  
Cleaning...  
Size: 0  
Done!  
mbulucay@mbulucay:~/Desktop/RealTime0s/hw1/1901042697_multis
```

```
5, 199776, 199777, 199779, 199780, 199784, 199788, 199789, 199790, 19979  
199834, 199838, 199841, 199842, 199848, 199851, 199852, 199855, 199859,  
910, 199913, 199914, 199918, 199919, 199922, 199923, 199924, 199926, 199  
199977, 199978, 199980, 199989, 199990, 199992, 199993, 199996, 199998  
  
Insertion time: 2266 ms  
Size: 76671  
Added: 100000  
Removed: 23329  
Contains: 392  
Removed + Size: 100000  
  
Does set contains 111752: 1  
Remove call result: 1  
Add call result: 1  
Does set contains 195886: 1  
Remove call result: 1  
Add call result: 1  
Does set contains 145297: 0  
Remove call result: 0  
Add call result: 1  
Does set contains 159352: 0  
Remove call result: 0  
Add call result: 1  
Does set contains 77697: 0  
Remove call result: 0  
Add call result: 1  
  
Does set contains 94032: 0  
Add call result: 1  
Remove call result: 1  
Does set contains 121071: 1  
Add call result: 0  
Remove call result: 1  
Does set contains 46054: 1  
Add call result: 0  
Remove call result: 1  
Does set contains 149264: 1  
Add call result: 0  
Remove call result: 1  
Does set contains 152450: 0  
Add call result: 1  
Remove call result: 1  
Cleaning...  
Size: 0  
Done!  
mbulucay@mbulucay:~/Desktop/RealTime0s/hw1/1901042697_multis
```

```
mbulucav@mbulucav:~/Desktop/RealTimeOs/hw1/1901042697 multis$
```

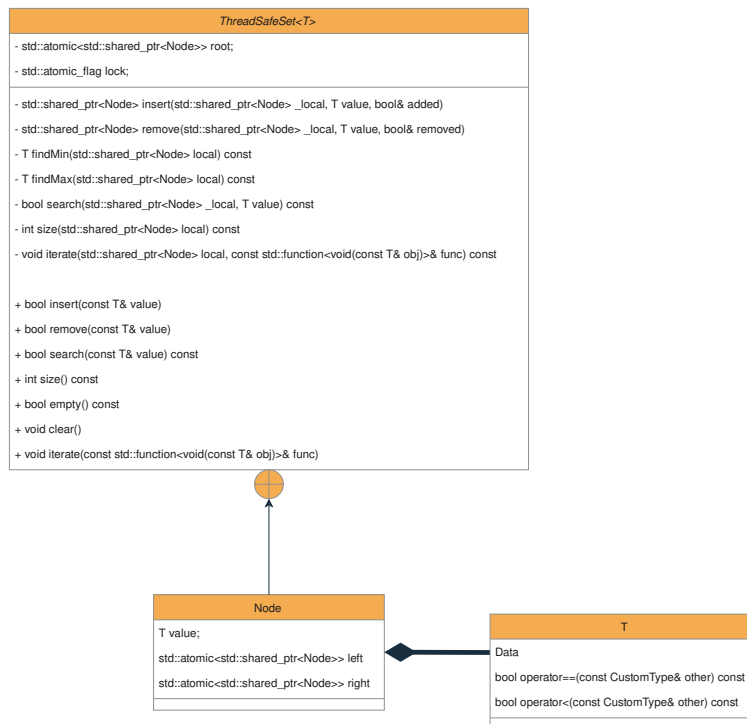


```
mbulucay@mbulucay:~/Desktop/Re
```

```
mbulucay@mbulucay:~/Desktop/Re
```

```
mbulucay@mbulucay:~/Desktop/Re
```

CLASS DIAGRAMS:



Bonus Implementation:

I try to implement classic classic reader writer implementation with atomic operations in c++20. But it did not worked at some point it entrance the deadlock.

```
std::atomic_flag read_flag = ATOMIC_FLAG_INIT;
std::atomic_flag write_flag = ATOMIC_FLAG_INIT;

std::atomic_flag lock_flag = ATOMIC_FLAG_INIT;
std::atomic<bool> lock_ = false;

std::atomic<int> active_read_count = 0;
std::atomic<int> active_write_count = 0;
std::atomic<int> waiting_read_count = 0;
std::atomic<int> waiting_write_count = 0;
```

```
// std::atomic<bool> lock;
void lock(){
    while(lock_.exchange(true)){
        // Wait until lock_ assign false
    }
}

void unlock(){
    lock_.store(false);
}
```

```
// WRITER ENTRY LOCK
lock();
while( active_write_count + active_read_count > 0){
    waiting_write_count++;
    unlock();
    do{
        write_flag.wait(false);
    }while(active_read_count || active_write_count);
    lock();
    waiting_write_count--;
}
active_write_count = 1;
unlock();

wait_add_lock();
std::atomic<std::shared_ptr<Node>> local;
local.store(root.load());
bool added = false;
while (true)
{
    std::shared_ptr<Node> v = local.load();
    std::shared_ptr<Node> result;
    while(!local.compare_exchange_weak(v, result)){
        // Wait for compare_exchange_weak to succeed
    }
    result = add(v, value, nullptr, nullptr, added);

    if(result != nullptr){
        root.store(result);
        break;
    }
}
add_unlock();

// WRITER EXIT LOCK
lock();
active_write_count = 0;
if(waiting_write_count > 0){
    write_flag.notify_one();
}else if(waiting_read_count > 0){
    read_flag.notify_all();
}
unlock();
```