C++ Programming II

C++ Programming II
STL - Concurrent Programming III

BME – HS2023

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Agenda

- Async
- Future and Promise
- Parallel STL
- Exercise
- Exam

Async

STL-Thread

Running a thread with no return value

- So far, we can easily start a thread to execute a function in an other thread

```cpp
#include <iostream>
#include <thread>

using namespace std;

// For threads to return values:
void factorial(int N)
{
    int res = 1;
    for (int i=N; i>1; i--)
        res *= i;

    cout << "Factorial of " << N << " is " << res << endl;
}

int main()
{
    thread t{factorial,4};
    t.join();
    return 0;
}
// Output:
```

STL-Thread

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}

int main()
{
    thread t{factorial,4};
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    return 0;
}
// Output:
```

- But how can we get a return value from a thread? `std::ref`?

STL-Thread

Passing the return value by `std::ref`

```
void factorial(int N, int& result)
{
    int res = 1;
    for (int i=N; i>1; i--)
        res *= i;

    result = res;
    cout << "Child - Result is: " << res << endl;
}

int main()
{
    int result{0};
    thread t{factorial, 4, ref(result)};
    t.join();
    cout << "Main - Result is: " << result << endl;
    return 0;
}
// Output:
// Child - Result is: 24
// Main - Result is: 24
```

STL-Thread

Passing the return value by `std::ref`

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void factorial(int N, int& result)
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    int res = 1;
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- Is this code safe?

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- Is this code safe?
- First, we have to protect the *shared resources* by a **mutex**

STL-Thread

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- Is this code safe?
- First, we have to protect the *shared resources* by a **mutex**
- Second, we want to make sure, that the child thread sets the **`result`** first and then the parent thread continuous and fetches the variable!

STL-Thread

Passing the return value by `std::ref`

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void factorial(int N, int& result)
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// Output:
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- First, we have to protect the *shared resources* by a **mutex**
- Second, we want to make sure, that the child thread sets the **`result`** first and then the parent thread continuous and fetches the variable!
- We need a **condition variable**

STL-Thread

Passing the return value by `std::ref`

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// Output:
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- Is this code safe?
- First, we have to protect the *shared resources* by a **mutex**
- Second, we want to make sure, that the child thread sets the **`result`** first and then the parent thread continuous and fetches the variable!
- We need a **condition variable** $\rightarrow$ **The code gets blown up**

STL-Async Function

STL provides an easy solution for that kind of job: `std::async`

```cpp
#include <thread>
#include <future>

using namespace std;

int factorial(int N)
{
    int res = 1;
    for (int i=N; i>1; i--)
        res *= i;

    return res;
}

int main()
{
    future<int> fu = async(factorial, 4);
    // Do something else
    this_thread::sleep_for(chrono::seconds(2));
    cout << "Got from child thread: " << fu.get() << endl;
//    fu.get();  // crash!
    return 0;
}
// Output:
// Got from child thread: 24
```

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    cout << "Got from child thread: " << fu.get() << endl;
//    fu.get();  // crash!
    return 0;
}
// Output:
// Got from child thread: 24
```

- **`std::async`** returns a **`std::future`**
- Call **`get`** on the future object **`fu`** to obtain the result
- The factorial function doesn't need a second parameter, but a return value (int).

STL-Async Launch Policy

Control Method of Execution

```
future<int> fu = async(factorial, 4);

future<int> fu = async(launch::deferred, factorial, 4);

future<int> fu = async(launch::async, factorial, 4);

future<int> fu = async(launch::async | launch::deferred,
                       factorial, 4); // Same as first line
```

STL-Async Launch Policy

Control Method of Execution

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future<int> fu = async(factorial, 4);

future<int> fu = async(launch::deferred, factorial, 4);

future<int> fu = async(launch::async, factorial, 4);

future<int> fu = async(launch::async | launch::deferred,
                       factorial, 4); // Same as first line
```

- **`std::launch::deferred`**: The function is executed by the same thread, but later (lazy evaluation). Execution then happens when **`get`** or **`wait`** is called on the future. If none of both happens, the function is not called at all
- **`std::launch::async`**: The function is guaranteed to be executed by another thread.
- **`std::launch::async | std::launch::deferred`**: Default value, chooses policy automatically, depends on the system and library implementation

STL-Async

Example of blocking call

```
int main()
{
    // Record start time
    auto start = std::chrono::high_resolution_clock::now();

    // Blocking call!
    async(factorial,4);
    async(factorial,5);

    // Record end time
    auto finish = std::chrono::high_resolution_clock::now();
    cout << "Elapsed time: " << (finish-start).count()*1e-9 << endl;

    return 0;
}
// Output:
// Elapsed time: 4.00082
```

STL-Async

Example of blocking call

```
int main()
{
    // Record start time
    auto start = std::chrono::high_resolution_clock::now();

    // Blocking call!
    async(factorial,4);
    async(factorial,5);

    // Record end time
    auto finish = std::chrono::high_resolution_clock::now();
    cout << "Elapsed time: " << (finish-start).count()*1e-9 << endl;

    return 0;
}
// Output:
// Elapsed time: 4.00082
```

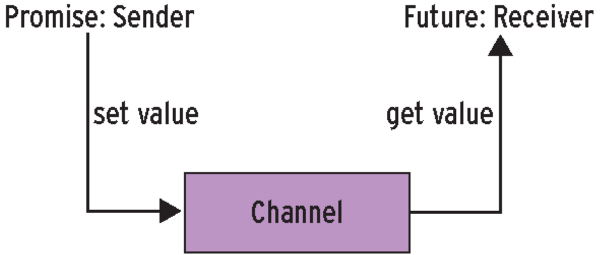
- The lifetime of the futures ends in the same line!
- This means that both the async calls from this short example are blocking
- Fix this by capturing their return values in variables with a longer lifetime

Future and Promise

Future / Promise

Channels between threads

- **`std::future`** and **`std::promise`** are a kind of communication channel between the parent and child thread where we can get the result from the child thread.
- We can get a value from the parent thread
- We can also pass a value from the parent thread in the child thread
- This can be done at some time point in the future!
- Therefore, we need a so called **`std::promise`**



Future / Promise

Set and get values between threads

- We create a **promise** and another **future**:

```
promise<int> p;
future<int> f = p.get_future();
```

Future / Promise

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promise<int> p;
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```

- We pass the **future** by reference to the **async** function

```
future<int> fu = async(launch::async, factorial, ref(f));
```

Future / Promise

Set and get values between threads

- We create a **promise** and another **future**:

```
promise<int> p;
future<int> f = p.get_future();
```

- We pass the **future** by reference to the **async** function

```
future<int> fu = async(launch::async, factorial, ref(f));
```

- We set the promised value in parent thread:

```
p.set_value(4);
```

Future / Promise

Set and get values between threads

- We create a **promise** and another **future**:

```
promise<int> p;
future<int> f = p.get_future();
```

- We pass the **future** by reference to the **async** function

```
future<int> fu = async(launch::async, factorial, ref(f));
```

- We set the promised value in parent thread:

```
p.set_value(4);
```

- Finally we adapt the **factorial** function:

```
int factorial(future<int>& f)
{
    // do something else
    cout << "waiting for promised data...\n";
    this_thread::sleep_for(chrono::seconds(2));

    int N = f.get();
    cout << "Got from main thread: " << N << endl;
    int res = 1;
    for (int i=N; i>1; i--)
        res *= i;

    return res;
}
```

Parallel STL

Parallel STL

Parallelizing Code that uses Standard Algorithms

- C++17 came with one really major extension for parallelism: **execution policies for standard algorithms**!
- **69 algorithms** were extended to accept execution policies in order to run parallel on multiple cores, and even with enabled vectorization (SIMD).
- If we already use STL algorithms everywhere, we get a nice parallelization bonus for free.
- Simply add a single execution policy argument to our existing STL algorithm calls!

Parallel STL

Execution Policy

- **`sequenced_policy`**: Sequential execution form, similar to the original algorithm without an execution policy.
- **`parallel_policy`**: The algorithm may be executed with multiple threads.
- **`parallel_unsequenced_policy`**: The algorithm may be executed with multiple threads sharing the work. In addition to that, it is permissible to vectorize the code.

Parallel STL

Execution Policy

- **`sequenced_policy`**: Sequential execution form, similar to the original algorithm without an execution policy.
- **`parallel_policy`**: The algorithm may be executed with multiple threads.
- **`parallel_unsequenced_policy`**: The algorithm may be executed with multiple threads sharing the work. In addition to that, it is permissible to vectorize the code.

The only specific constraints are:

- All element access functions used by the parallelized algorithm must not cause *deadlocks* or data *races*
- In the case of parallelism and vectorization, all the access functions must not use any kind of blocking synchronization

> As long as we comply with these rules, we should be free from bugs introduced by using the parallel versions of the STL algorithms.

Parallel STL

Example

```
#include <iostream>
#include <vector>
#include <random>
#include <algorithm>

using namespace std;

bool odd(int n) { return n % 2; }

int main()
{
    vector<int> d(50000000);
    mt19937 gen;
    uniform_int_distribution<int> dis(0, 100000);
    auto randNum ([=] () mutable { return dis(gen); });
    generate(begin(d), end(d), randNum);

    sort(begin(d), end(d));
    reverse(begin(d), end(d));

    auto odds(count_if(begin(d), end(d), odd));
    cout << 100.0*odds/d.size() << "% of the numbers are odd.\n";
    // --> 50.4% of the numbers are odd.
}
```

Parallel STL

Example

```
#include <iostream>
#include <vector>
#include <random>
#include <algorithm>
#include <execution>
using namespace std;

bool odd(int n) { return n % 2; }

int main()
{
    vector<int> d(50000000);
    mt19937 gen;
    uniform_int_distribution<int> dis(0, 100000);
    auto randNum ([=] () mutable { return dis(gen); });
    generate(execution::par, begin(d), end(d), randNum);

    sort(execution::par, begin(d), end(d));
    reverse(execution::par, begin(d), end(d));

    auto odds(count_if(execution::par, begin(d), end(d), odd));
    cout << 100.0*odds/d.size() << "% of the numbers are odd.\n";
    // --> 50.4% of the numbers are odd.
}
```

Exercise

In Class Exercise

- Copy the function **calcStats** which generates **nbrElements** random samples between 1 **&** 1000 and returns the number of elements > 500

```
int calcStats(int nbrElelements)
{
    vector<int> d(nbrElelements);
    random_device r;
    mt19937 gen{r()};
    uniform_int_distribution<int> dis(1, nbrElelements);
    auto rand_num ([=] () mutable { return dis(gen); });
    generate(begin(d), end(d), rand_num);
    return count_if(begin(d), end(d), [&nbrElelements](int val){return val > nbrElelements/2;});
}
```

- In the **main**-function launch **calcStats** with **async** on all available thread and collect the the futures in a vector.
- In a second for-loop **get** and print the the results to **cout**.

In Class Exercise

- Vary the execution policy, **nbrElements** and measure the execution time.

```
int main()
{
    // Record start time
    auto start = std::chrono::high_resolution_clock::now();

    int nbrElements = 50000000;
    int nbrThreads = thread::hardware_concurrency();
```

- Your code:

```
    // Record end time
    auto finish = std::chrono::high_resolution_clock::now();
    cout << "Elapsed time: " << (finish-start).count()*1e-9 << endl;
}
```

- Possible output:

```
// Run 0: 49.9905% of the numbers are larger than 25000000.
// Run 1: 49.9973% of the numbers are larger than 25000000.
// .
// .
// Run 6: 50.0071% of the numbers are larger than 25000000.
// Run 7: 50.0045% of the numbers are larger than 25000000.
// Elapsed time: 5.30622
```

Exam

Exam

Contents, Style & Material

Content:

1. STL Containers, Algorithms & Iterators
   - Lambda Functions
   - Knowing STL
   - Write faster, better and more readable code
2. STL Concurrent Programming
   - `mutex, lock & lock_guard`
   - `condition_variable`
   - `thread & asynch`
   - `future & promise`

Style:

- 90 minutes
- Hand written exam (paper & pen)
- Write code, interpret code and fix code
- Skill questions

Material:

- C++ Reference Card
- STL-Quick Reference

Thank You

Questions

???