C++ Programming II

STL - Concurrent Programming I

C++ Programming II
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Agenda

- Intro

Intro

STL Threads

Data Races and Mutex

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- ▶ **Intro**
- ▶ **STL Threads**

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- STL Threads
- Data Races and Mutex

Intro

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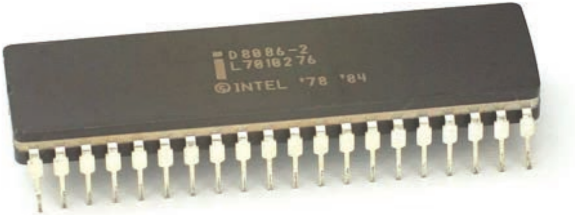
STL Threads

Data Races and Mutex

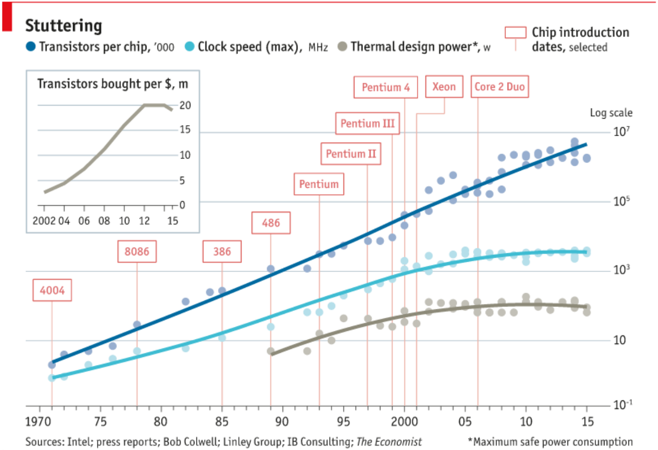
Intro
History & Moore's Law



- 1978: Intel 8086, 16-bit, 10MHz
- 2017: Intel Core i7-7700K, 64-bit, 4.2 GHz (4 cores (8 threads))

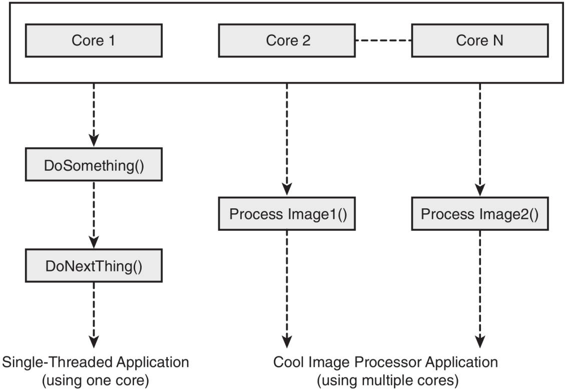
Intro

History & Moore's Law



- Moore's Law: Double clock speed each 2 years
- But clock speed stabilized around 2000 (heat dissipation)
- Number of Cores did not!

Intro
Single vs. Multi Core



- Single Core: Sequential Program Flow
- Multi Core: Parallel Program Flow
- Since C++ 11, STL provides a clean and simple way to start and stop threads without using external libraries

STL Threads

Intro

STL Threads

Data Races and Mutex

Enable Threads in CMake

`find_package` and `target_link_libraries`

- In order to use STL threads we have to:
  1. locate them with `find_package` and
  2. link the OS specific thread libraries with `target_link_libraries`

Enable Threads in CMake

`find_package` and `target_link_libraries`

- In order to use STL threads we have to:
  1. locate them with `find_package` and
  2. link the OS specific thread libraries with `target_link_libraries`
- Fortunately, `CMake` is doing that for us:

```
...
...
find_package(Threads)
...
...
...
target_link_libraries (${PROJECT_NAME} ${CMAKE_THREAD_LIBS_INIT})
```

STL Thread

Using and Creating Threads

```
#include <iostream>

using namespace std;

void counting()
{
    for (size_t i = 0; i < 1000; ++i)
        cout << i << endl;
}

int main()
{
    counting();
    return 0;
}
```

- Single threaded program which counts to 1000

STL Thread

Using and Creating Threads

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

using namespace std;

void counting()
{
    for (size_t i = 0; i < 1000; ++i)
        cout << i << endl;
}

int main()
{
    thread t(counting);
    t.join();

    return 0;
}
```

- In the main thread we start a second thread doing the work.
- The main thread waits for the “worker-thread” to finish by calling the `join()` function! Otherwise the application might crash.
- Either the function `join()` or `detach()` have to be used.
- `join()`: blocks the main thread until the “worker-thread” is finished!
- `detach()`: detaches the “worker-thread” from the main thread, no longer external control over the thread

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Intro
STL Threads
Data Races and Mutex

STL Thread

Using and Creating Threads

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

using namespace std;

void counting(size_t count)
{
    for (size_t i = 0; i < count; ++i)
        cout << i << endl;
}

int main()
{
    thread t(counting, 1000);
    t.join();

    return 0;
}
```

- We can also provide function parameters to the thread constructor

Thread Synchronisation

An Example

```
#include <iostream>
#include <thread>
using namespace std;
using namespace chrono_literals;

void threadWithParam(int threadNbr)
{
    this_thread::sleep_for(1ms * threadNbr);
    cout << "Hello from thread " << threadNbr << '\n';

    this_thread::sleep_for(1s * threadNbr);
    cout << "Bye from thread " << threadNbr << '\n';
}
```

- Simple function taking an argument as thread ID to identify the thread output later
- The threads wait a different amount of time to not write to `cout` at the same time

Thread Synchronisation

An Example

```
int main()
{
    cout << thread::hardware_concurrency()
         << " concurrent threads are supported.\n";
    thread t1 {threadWithParam, 1};
    thread t2 {threadWithParam, 2};
    thread t3 {threadWithParam, 3};

    t1.join();
    t2.join();
    t3.detach();

    cout << "Threads joined.\n";
}
```

- In the main function we can print how many threads can be run at the same time using `hardware_concurrency()`
- We start 3 threads with different thread ID. `Thread t{f, x}` leads to a call of `f(x)`
- Since these threads are freely running, we need to stop them again when they are done with their work (`join()`, `detach()`)

Intro

STL Threads

Data Races and Mutex

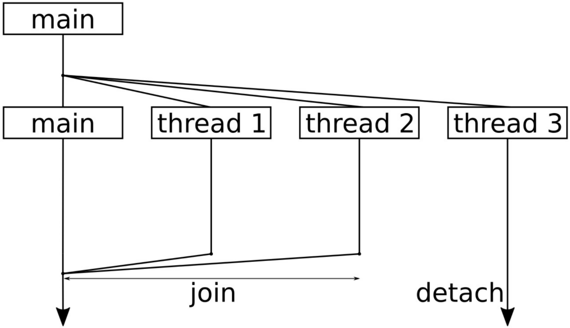
Thread Synchronisation
An Example

- The output of the program can look like this:

```
8 concurrent threads are supported.
Hello from thread 1
Hello from thread 2
Hello from thread 3
Bye from thread 1
Bye from thread 2
Threads joined.
```

Thread Synchronisation

`join()` and `detach()`



- Reading the diagram from top to the bottom, it shows one point in time where we split the program workflow to four threads in total
- After starting the threads, the main thread executing the main function remained without work
- The main thread waits for thread 1 and thread 2, but not for detached thread 3

Thread Parameters

Passing Value by Reference using `std::ref`

- By default, parameters are passed by copy
- To pass by reference use `std::ref`

```
#include <iostream>
#include <thread>
using namespace std;

void addToVal(int& val, int addent)
{
    val +=addent;
}

int main()
{
    int val = 23;
    // Pass paramter by refernce
    thread t{addToVal, std::ref(val), 19};
    // Main and child thread share memory!

    if(t.joinable())
        t.join();

    cout << " Result is: " << val << endl; // 42
    return 0;
}
```

Data Races and Mutex

Intro

STL Threads

Data Races and Mutex

Data Race Example

Two Threads try to set the same variable `x`

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

using namespace std;

void setX(int& x, int value)
{
    x = value;
}

int main()
{
    int x = 1;
    thread setX1{setX, ref(x), 100};
    thread setX2{setX, ref(x), 200};

    setX1.join();
    setX2.join();

    cout << x << " ";
    return 0;
}
```

- What is the output?
- Demo...

Data Race Example

Two Threads try to set the same variable `x`

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

using namespace std;

void setX(int& x, int value)
{
    x = value;
}

int main()
{
    int x = 1;
    thread setX1{setX, ref(x), 100};
    thread setX2{setX, ref(x), 200};

    setX1.join();
    setX2.join();

    cout << x << " ";
    return 0;
}
```

- What is the output?
- Demo...
- The two threads are racing for the same resource

Data Race Example 2

Two Threads race for the common resource `cout`

```
#include <iostream>
#include <string>
#include <thread>

using namespace std;

void print()
{
    for (int i = 0; i > -100; --i)
        cout << "From child: " << i << endl;
}

int main()
{
    thread t{print};

    for (int i = 0; i < 100; ++i)
        cout << "From main: " << i << endl;

    t.join();

    return 0;
}
```

- The output is cluttered!
- We have to synchronise the access of the common resource `cout`!

Data Race Example 2

Two Threads race for the common resource `cout`

```
From child: -29
From child: -30
From child: -31
From child: -32
From main: From child: -33
28From child: -34
From child: -35

From main: 29
From main: 30
From main: 31
From main: 32
From child: From main: -36
From child: -37
From child: -38
From child: -39
33From child: -40
From child: -41
```

Data Race Example 2

Synchronise the access of the common resource with `std::mutex`

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

using namespace std;

mutex mu;

void sharedPrint(string msg, int value)
{
    mu.lock(); // only one thread can enter!
    cout << msg << value << endl;
    mu.unlock();
}
```

- We can restrict access to one thread using `std::mutex`
- `lock` locks the mutex
- `unlock` frees the mutex

Data Race Example 2

Synchronise the access of the common resource with `std::mutex`

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

using namespace std;

mutex mu;

void sharedPrint(string msg, int value)
{
    mu.lock(); // only one thread can enter!
    cout << msg << value << endl;
    mu.unlock();
}

void print()
{
    for (int i = 0; i > -100; --i)
        sharedPrint("From child: " , i);
}

int main()
{
    thread t{print};

    for (int i = 0; i < 100; ++i)
        sharedPrint("From main: ", i);

    t.join();

    return 0;
}
```

- Do you see a problem? What happens if the code between the lock fails, *i.e.* throws an exception
- Mutex `mu` is locked for ever

Data Race Example 2

Synchronise the access of the common resource with `std::mutex`

```
#include <iostream>
#include <string>
#include <thread>
#include <mutex>

using namespace std;

mutex mu;

void sharedPrint(string msg, int value)
{
    lock_guard<mutex> guard(mu); // RAII
    cout << msg << value << endl;
}
```

- Therefore don't use `lock` and `unlock` directly
- Use RAII technique: `std::lock_guard`
- Mutex is freed automatically when going out of scope

Thank You

Questions

???

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Intro

STL Threads

Data Races and Mutex