

Best Practices

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Best Practices

Allgemein

Multithreading

~~Parallelität~~

Speichermodell

Best Practices

Allgemein

Multithreading

Speichermodell

Code Reviews

```
map<string,int> teleBook{{"Dijkstra", 1972},
                        {"Scott", 1976}, {"Ritchie", 1983}};

shared_timed_mutex teleBookMutex;

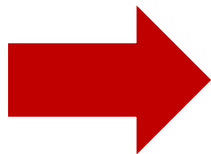
void addToTeleBook(const string& na, int tele){
    lock_guard<shared_timed_mutex> writerLock(teleBookMutex);
    cout << "\nSTARTING UPDATE " << na;
    this_thread::sleep_for(chrono::milliseconds(500));
    teleBook[na]= tele;
    cout << " ... ENDING UPDATE " << na << endl;
}

void printNumber(const string& na){
    shared_lock<shared_timed_mutex> readerLock(teleBookMutex);
    cout << na << ": " << teleBook[na] << endl;
}
```

```
thread reader1([]{ printNumber("Scott"); });
thread reader2([]{ printNumber("Ritchie"); });
thread w1([]{ addToTeleBook("Scott",1968); });
thread reader3([]{ printNumber("Dijkstra"); });
thread reader4([]{ printNumber("Scott"); });
thread w2([]{ addToTeleBook("Bjarne",1965); });
thread reader5([]{ printNumber("Scott"); });
thread reader6([]{ printNumber("Ritchie"); });
thread reader7([]{ printNumber("Scott"); });
thread reader8([]{ printNumber("Bjarne"); });

reader1.join(), reader2.join();
reader3.join(), reader4.join();
reader5.join(), reader6.join();
reader7.join(), reader8.join();
w1.join(), w2.join();

cout << "\nThe new telephone book" << endl;
for (auto teleIt: teleBook){
    cout << teleIt.first << ": " << teleIt.second << endl;
}
```



```
rainer : bash - Konsole <5>
File Edit View Bookmarks Settings Help
rainer@linux:~> readerWriterLock

Scott: 1976Dijkstra: 1972
STARTING UPDATE Scott ... ENDING UPDATE Scott
Ritchie: 1983Scott: 1968
STARTING UPDATE Bjarne ... ENDING UPDATE Bjarne
Ritchie: 1983Scott: 1968Scott: 1968Bjarne: 1965

The new telephone book
Bjarne: 1965
Dijkstra: 1972
Ritchie: 1983
Scott: 1968

rainer@linux:~> █
```

Code Reviews

```
map<string,int> teleBook{{"Dijkstra", 1972},
                        {"Scott", 1976}, {"Ritchie", 1983}};

shared_timed_mutex teleBookMutex;

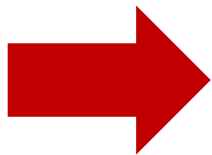
void addToTeleBook(const string& na, int tele){
    lock_guard<shared_timed_mutex> writerLock(teleBookMutex);
    cout << "\nSTARTING UPDATE " << na;
    this_thread::sleep_for(chrono::milliseconds(500));
    teleBook[na]= tele;
    cout << " ... ENDING UPDATE " << na << endl;
}

void printNumber(const string& na){
    shared_lock<shared_timed_mutex> readerLock(teleBookMutex);
    cout << na << ": " << teleBook[na] << endl;
}
```

```
thread reader1([]{ printNumber("Scott"); });
thread reader2([]{ printNumber("Ritchie"); });
thread w1([]{ addToTeleBook("Scott",1968); });
thread reader3([]{ printNumber("Dijkstra"); });
thread reader4([]{ printNumber("Scott"); });
thread w2([]{ addToTeleBook("Bjarne",1965); });
thread reader5([]{ printNumber("Scott"); });
thread reader6([]{ printNumber("Ritchie"); });
thread reader7([]{ printNumber("Scott"); });
thread reader8([]{ printNumber("Bjarne"); });

reader1.join(), reader2.join();
reader3.join(), reader4.join();
reader5.join(), reader6.join();
reader7.join(), reader8.join();
w1.join(), w2.join();

cout << "\nThe new telephone book" << endl;
for (auto teleIt: teleBook){
    cout << teleIt.first << ": " << teleIt.second << endl;
}
```



```
rainer : bash — Konsole
File Edit View Bookmarks Settings Help

rainer@seminar:~$ readerWriterLocks
Bjarne: 0Ritchie: 1983
STARTING UPDATE Scott ... ENDING UPDATE Scott

STARTING UPDATE Bjarne ... ENDING UPDATE Bjarne
Ritchie: 1983Scott: 1968Scott: 1968Scott: 1968Dijkstra: 1972Scott: 1968

The new telephone book
Bjarne: 1965
Dijkstra: 1972
Ritchie: 1983
Scott: 1968

rainer@seminar:~$
```

Code Reviews

```
bool dataReady= false;

std::mutex mutex_;
std::condition_variable condVar1;
std::condition_variable condVar2;

int counter=0;
int COUNTLIMIT=50;

void setTrue(){

    while(counter <= COUNTLIMIT){

        std::unique_lock<std::mutex> lck(mutex_);
        condVar1.wait(lck,[]{return dataReady == false;});
        dataReady= true;
        ++counter;
        std::cout << dataReady << std::endl;
        condVar2.notify_one();

    }
}
```

```
void setFalse(){

    while(counter < COUNTLIMIT){

        std::unique_lock<std::mutex> lck(mutex_);
        condVar2.wait(lck,[]{return dataReady == true;});
        dataReady= false;
        std::cout << dataReady << std::endl;
        condVar1.notify_one();

    }

}

int main(){

    std::cout << std::boolalpha << std::endl;

    std::cout << "Begin: " << dataReady << std::endl;

    std::thread t1(setTrue);
    std::thread t2(setFalse);

    t1.join();
    t2.join();

    dataReady= false;
    std::cout << "End: " << dataReady << std::endl;

    std::cout << std::endl;

}
```

Minimiere Teilen

- Summation eines Vektors mit 100 Millionen Elementen

```
constexpr long long size = 1000000000;

...

// random values
std::vector<int> randValues;
randValues.reserve(size);

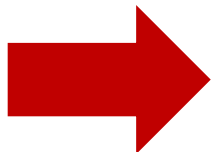
std::random_device seed;
std::mt19937 engine(seed());
std::uniform_int_distribution<> uniformDist(1, 10);
for (long long i = 0 ; i < size ; ++i)
    randValues.push_back(uniformDist(engine));

...
// calculate sum
...
```

Minimiere Teilen

- Single-Threaded in zwei Variationen

```
unsigned long long sum {};  
for (auto n: randValues) sum += n;  
  
const unsigned long long sum = accumulate(randValues.begin(),  
                                           randValues.end(), 0ll);
```



```
File Edit View Bookmarks Settings Help  
rainer@suse:~> calculateWithStd  
  
Time for addition 0.0651712 seconds  
Result: 550030112  
  
rainer@suse:~> █  
rainer: bash
```

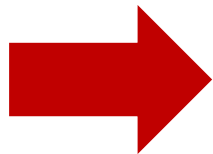

Minimiere Teilen

- Vier Threads mit einer geteilten Summationsvariable

```
void sumUp(unsigned long long& sum, const vector<int>& val,
           unsigned long long beg, unsigned long long end){
    for (auto it = beg; it < end; ++it){
        lock_guard<mutex> myLock(myMutex);
        sum += val[it];
    }
}

...
unsigned long long sum{};

thread t1(sumUp, ref(sum), ref(randValues), 0, fir);
thread t2(sumUp, ref(sum), ref(randValues), fir, sec);
thread t3(sumUp, ref(sum), ref(randValues), sec, thi);
thread t4(sumUp, ref(sum), ref(randValues), thi, fou);
```



```
File Edit View Bookmarks Settings Help
rainer@suse:~> calculateWithLock

Time for addition 3.3389 seconds
Result: 549961505

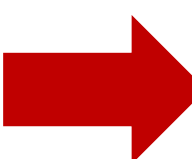
rainer@suse:~> █
```

rainer: bash

Minimiere Teilen

- Vier Threads mit einer einer geteilten, atomaren Summationsvariable

```
void sumUp(atomic<unsigned long long>& sum, const vector<int>& val,  
           unsigned long long beg, unsigned long long end){  
    for (auto it = beg; it < end; ++it){  
        sum += val[it];  
    }  
}  
  
void sumUp(atomic<unsigned long long>& sum, const vector<int>& val,  
           unsigned long long beg, unsigned long long end){  
    for (auto it = beg; it < end; ++it){  
        sum.fetch_add(val[it], memory_order_relaxed);  
    }  
}
```

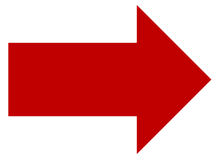


```
File Edit View Bookmarks Settings Help  
rainer@suse:~> calculateWithAtomic  
sum.is_lock_free(): true  
Time for addition 1.33837 seconds  
Result: 549992025  
Time for addition 1.34625 seconds  
Result: 549992025  
rainer@suse:~> █  
rainer: bash
```

Minimiere Teilen

- Vier Threads mit einer lokalen Summationsvariable

```
void sumUp(unsigned long long& sum, const vector<int>& val,  
          unsigned long long beg, unsigned long long end){  
    unsigned long long tmpSum{};  
    for (auto i = beg; i < end; ++i){  
        tmpSum += val[i];  
    }  
    lock_guard<mutex> lockGuard(myMutex);  
    sum += tmpSum;  
}
```



```
File Edit View Bookmarks Settings Help  
rainer@suse:~> localVariable  
  
Time for addition 0.0284271 seconds  
Result: 549996948  
  
rainer@suse:~> █  
  
rainer : bash
```

Minimiere Teilen

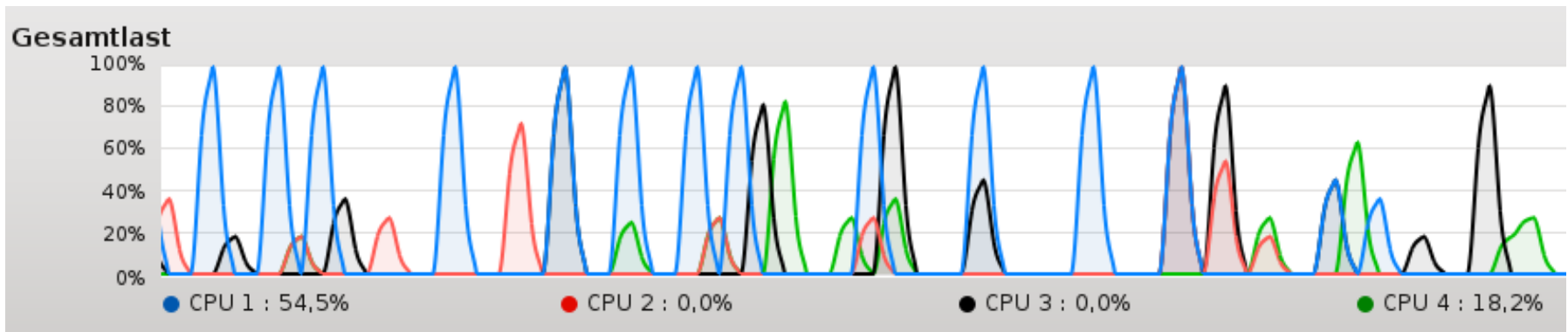
- Die Ergebnisse:

Single-Threaded	4 Threads mit Lock	4 Threads mit atomarer Variable	4 Threads mit lokaler Variable
0.07 sec	3.34 sec	1.34 sec	0.03 sec

Alles gut?

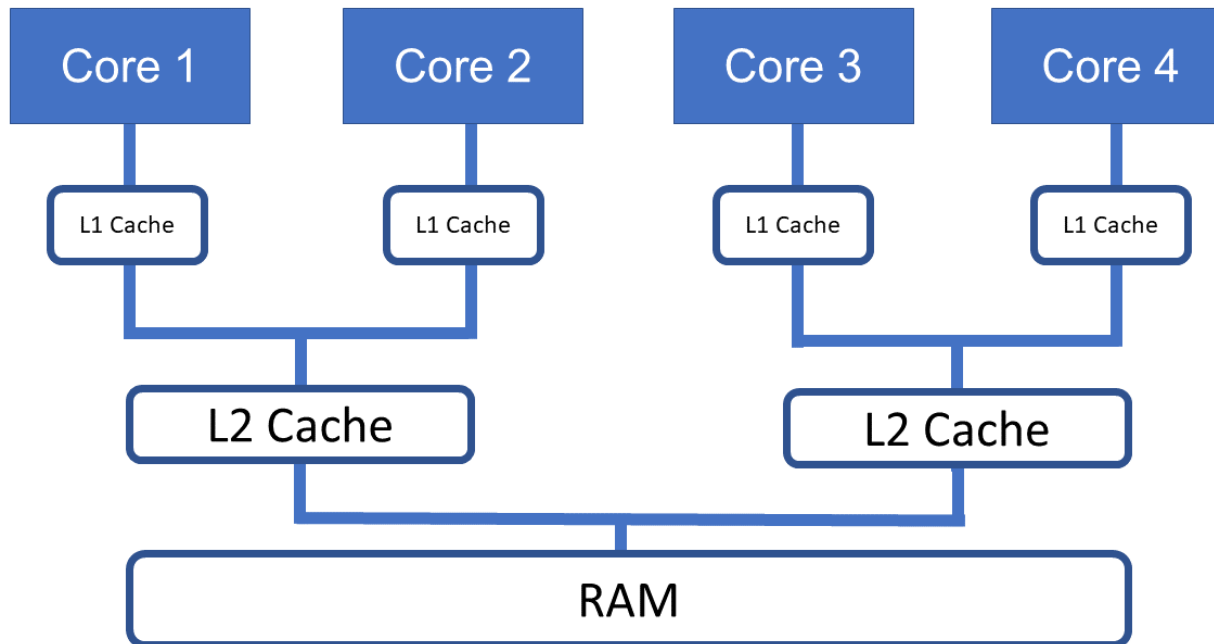
Minimiere Teilen

- Die CPU-Auslastung



Minimiere Teilen

- Die Memory-Wall



Der Speicherzugriff bremst die Applikation aus.

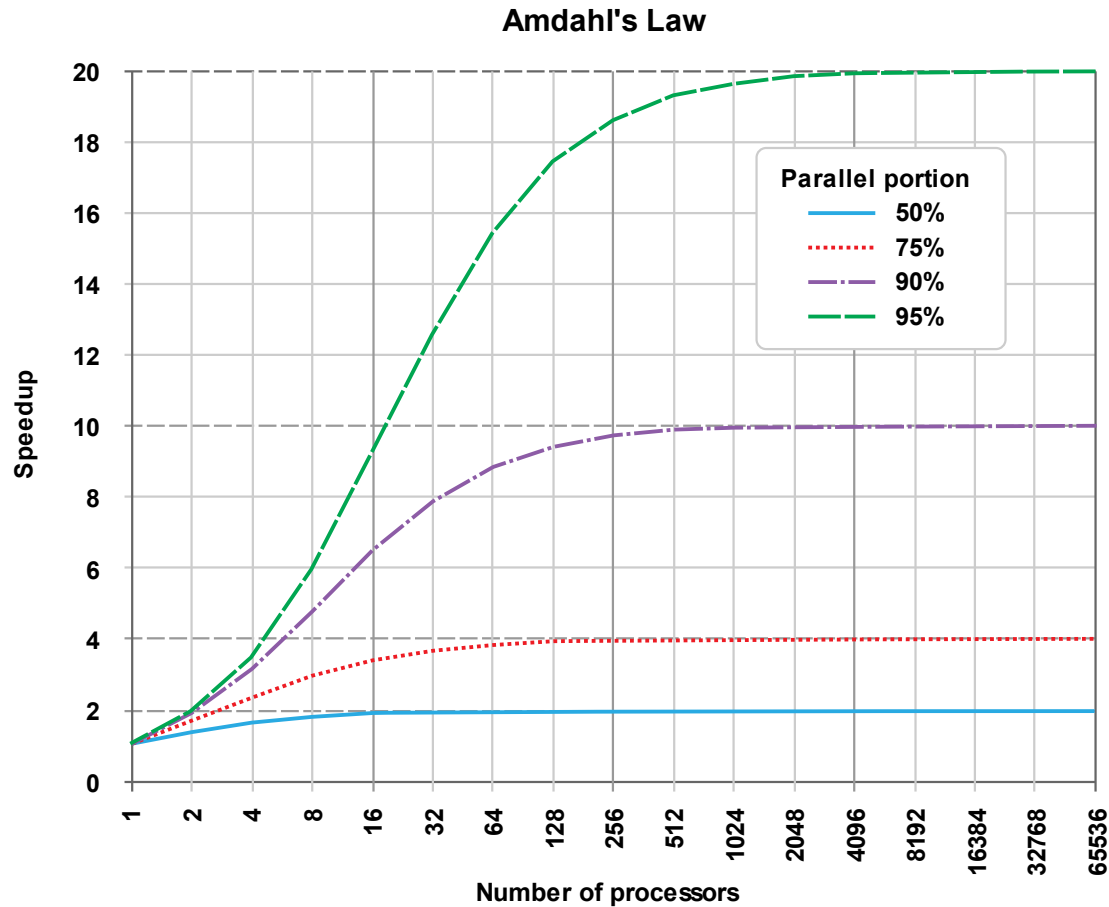
Minimiere Warten (Amdahl's Law)

$$\frac{1}{1 - p}$$

p: Parallele Code

$$p = 0.5 \rightarrow 2$$

Minimiere Warten (Amdahl's Law)



Verwende Codeanalyse Werkzeuge (ThreadSanitizer)

- Findet Data Races
- Speicher- und Performanzoverhead: 10x

```
#include <thread>
```

```
int main() {
```

```
    int globalVar{};
```

```
    std::thread t1([&globalVar]{ ++globalVar; });
```

```
    std::thread t2([&globalVar]{ ++globalVar; });
```

```
    t1.join(), t2.join();
```

```
}
```

Verwende Codeanalyse Werkzeuge (ThreadSanitizer)

```
g++ dataRace.cpp -fsanitize=thread -pthread -g -o dataRace
```

```
File Edit View Bookmarks Settings Help
rainer@suse:~> dataRace
=====
WARNING: ThreadSanitizer: data race (pid=6764)
  Read of size 4 at 0x7fff031ca3bc by thread T2:
    #0 operator() /home/rainer/dataRace.cpp:10 (dataRace+0x000000400f01)
    #1 _M_invoke<> /usr/local/include/c++/6.3.0/functional:1391 (dataRace+0x000000401b3d)
    #2 operator() /usr/local/include/c++/6.3.0/functional:1380 (dataRace+0x000000401a51)
    #3 _M_run /usr/local/include/c++/6.3.0/thread:196 (dataRace+0x0000004019bc)
    #4 execute_native_thread_routine .././.././libstdc++.so.6+0x00000000c11be)

  Previous write of size 4 at 0x7fff031ca3bc by thread T1:
    #0 operator() /home/rainer/dataRace.cpp:9 (dataRace+0x000000400eb9)
    #1 _M_invoke<> /usr/local/include/c++/6.3.0/functional:1391 (dataRace+0x000000401be7)
    #2 operator() /usr/local/include/c++/6.3.0/functional:1380 (dataRace+0x000000401a8b)
    #3 _M_run /usr/local/include/c++/6.3.0/thread:196 (dataRace+0x000000401a06)
    #4 execute_native_thread_routine .././.././libstdc++.so.6+0x00000000c11be)

  Location is stack of main thread.

  Thread T2 (tid=6767, running) created by main thread at:
    #0 pthread_create .././.././libsanitizer/tsan/tsan_interceptors.cc:876 (libtsan.so.0+0x00000002aaed)
    #1 __gthread_create /home/rainer/languages/C++/gcc-6.3.0/x86_64-pc-linux-gnu/libstdc++.so.6+0x0000000c14b4)
    #2 std::thread::_M_start_thread(std::unique_ptr<std::thread::_State, std::default_delete<std::thread::_State> >, void (*)()) .././.././libstdc++.so.6+0x0000000c14b4)
    #3 main /home/rainer/dataRace.cpp:10 (dataRace+0x000000400f97)

  Thread T1 (tid=6766, finished) created by main thread at:
    #0 pthread_create .././.././libsanitizer/tsan/tsan_interceptors.cc:876 (libtsan.so.0+0x00000002aaed)
    #1 __gthread_create /home/rainer/languages/C++/gcc-6.3.0/x86_64-pc-linux-gnu/libstdc++.so.6+0x0000000c14b4)
    #2 std::thread::_M_start_thread(std::unique_ptr<std::thread::_State, std::default_delete<std::thread::_State> >, void (*)()) .././.././libstdc++.so.6+0x0000000c14b4)
    #3 main /home/rainer/dataRace.cpp:9 (dataRace+0x000000400f70)

SUMMARY: ThreadSanitizer: data race /home/rainer/dataRace.cpp:10 in operator()
=====
ThreadSanitizer: reported 1 warnings
rainer@suse:~> █
```

Verwende Codeanalyse Werkzeuge (ThreadSanitizer)

```
bool dataReady= false;

std::mutex mutex_;
std::condition_variable condVar1;
std::condition_variable condVar2;

int counter=0;
int COUNTLIMIT=50;

void setTrue(){

    while(counter <= COUNTLIMIT){

        std::unique_lock<std::mutex> lck(mutex_);
        condVar1.wait(lck,[]{return dataReady == false;});
        dataReady= true;
        ++counter;
        std::cout << dataReady << std::endl;
        condVar2.notify_one();

    }
}
```

```
void setFalse(){

    while(counter < COUNTLIMIT){

        std::unique_lock<std::mutex> lck(mutex_);
        condVar2.wait(lck,[]{return dataReady == true;});
        dataReady= false;
        std::cout << dataReady << std::endl;
        condVar1.notify_one();

    }

}

int main(){

    std::cout << std::boolalpha << std::endl;

    std::cout << "Begin: " << dataReady << std::endl;

    std::thread t1(setTrue);
    std::thread t2(setFalse);

    t1.join();
    t2.join();

    dataReady= false;
    std::cout << "End: " << dataReady << std::endl;

    std::cout << std::endl;

}
```

Verwende Codeanalyse Werkzeuge (ThreadSanitizer)

```
File Edit View Bookmarks Settings Help
rainer@linux:~$ ./conditionVariablePingPong.cpp
Begin: false
true
=====
WARNING: ThreadSanitizer: data race (pid=181251)
Read of size 4 at 0x0000000604350 by thread T2:
#0 setFalse() /home/rainer/conditionVariablePingPong.cpp:30 (conditionVariablePingPong+0x000000401818)
#1 void std::_Bind_simple<void (*)()>::operator()() /usr/include/c++/6/functional:1400
#2 std::_Bind_simple<void (*)()>::operator()() /usr/include/c++/6/functional:1389 (conditionVariablePingPong+0x000000401818)
#3 std::thread::_State_impl<std::_Bind_simple<void (*)()> >::_M_run() /usr/include/c++/6/thread:196 (conditionVariablePingPong+0x000000401818)
#4 <null> <null> (libstdc++.so.6+0x0000000c22de)

Previous write of size 4 at 0x0000000604350 by thread T1 (mutexes: write M11):
#0 setTrue() /home/rainer/conditionVariablePingPong.cpp:21 (conditionVariablePingPong+0x00000040173d)
#1 void std::_Bind_simple<void (*)()>::operator()() /usr/include/c++/6/functional:1400
#2 std::_Bind_simple<void (*)()>::operator()() /usr/include/c++/6/functional:1389 (conditionVariablePingPong+0x00000040173d)
#3 std::thread::_State_impl<std::_Bind_simple<void (*)()> >::_M_run() /usr/include/c++/6/thread:196 (conditionVariablePingPong+0x00000040173d)
#4 <null> <null> (libstdc++.so.6+0x0000000c22de)

Location is global 'counter' of size 4 at 0x0000000604350 (conditionVariablePingPong+0x0000000604350)

Mutex M11 (0x00000006042a0) created at:
#0 pthread_mutex_lock <null> (libtsan.so.0+0x000000003bc0f)
#1 __gthread_mutex_lock /usr/include/c++/6/x86_64-suse-linux/bits/gthr-default.h:748 (conditionVariablePingPong+0x00000006042a0)
#2 std::mutex::lock() /usr/include/c++/6/bits/std_mutex.h:103 (conditionVariablePingPong+0x00000006042a0)
#3 std::unique_lock<std::mutex>::lock() /usr/include/c++/6/bits/std_mutex.h:267 (conditionVariablePingPong+0x00000006042a0)
#4 std::unique_lock<std::mutex>::unique_lock(std::mutex&) /usr/include/c++/6/bits/std_mutex.h:197 (conditionVariablePingPong+0x00000006042a0)
#5 setTrue() /home/rainer/conditionVariablePingPong.cpp:18 (conditionVariablePingPong+0x000000060416f4)
#6 void std::_Bind_simple<void (*)()>::operator()() /usr/include/c++/6/functional:1400
#7 std::_Bind_simple<void (*)()>::operator()() /usr/include/c++/6/functional:1389 (conditionVariablePingPong+0x000000060416f4)
#8 std::thread::_State_impl<std::_Bind_simple<void (*)()> >::_M_run() /usr/include/c++/6/thread:196 (conditionVariablePingPong+0x000000060416f4)
#9 <null> <null> (libstdc++.so.6+0x0000000c22de)

Thread T2 (tid=18140, running) created by main thread at:
#0 pthread_create <null> (libtsan.so.0+0x000000002b740)
#1 std::thread::_M_start_thread(std::unique_ptr<std::thread::_State, std::default_delete<std::thread::_State> >, ...) /usr/include/c++/6/thread:196 (conditionVariablePingPong+0x0000000604197c)
#2 main /home/rainer/conditionVariablePingPong.cpp:49 (conditionVariablePingPong+0x0000000604197c)

Thread T1 (tid=18139, running) created by main thread at:
#0 pthread_create <null> (libtsan.so.0+0x000000002b740)
#1 std::thread::_M_start_thread(std::unique_ptr<std::thread::_State, std::default_delete<std::thread::_State> >, ...) /usr/include/c++/6/thread:196 (conditionVariablePingPong+0x0000000604196b)
#2 main /home/rainer/conditionVariablePingPong.cpp:48 (conditionVariablePingPong+0x0000000604196b)

SUMMARY: ThreadSanitizer: data race /home/rainer/conditionVariablePingPong.cpp:30 in setFalse()
=====
false
true
false
true
false
```

Verwende Codeanalyse Werkzeuge (CppMem)

CppMem: Interactive C/C++ memory model

Model
☐ standard ☒ preferred ☐ release_acquire ☐ tot ☐ relaxed_only

Program
examples/Paper data_race.c

☒ C ☐ Execution

```
// a data race (dr)
int main() {
  int x = 2;
  int y;
  {{{ x = 3;
    ||| y = (x==3);
  }}};
  return 0; }
```

2 reset help 2 executions; 1 consistent, not race free

Execution candidate no. 2 of 2

previous consistent	previous candidate	next candidate	next consistent	2	goto
---------------------	--------------------	----------------	-----------------	---	------

Model Predicates

consistent_race_free_execution = **false**

☒ consistent_execution	= true
☒ assumptions	= true
☒ well_formed_threads	= true
☒ well_formed_rf	= true
☒ locks_only_consistent_locks	= true
☒ locks_only_consistent_lo	= true
☒ consistent_mo	= true
☒ sc_accesses_consistent_sc	= true
☒ sc_fenced_sc_fences_heeded	= true
☒ consistent_hb	= true
☒ consistent_rf	= true
☒ det_read	= true
☒ consistent_non_atomic_rf	= true
☒ consistent_atomic_rf	= true
☒ coherent_memory_use	= true
☒ rmw_atomicity	= true
☒ sc_accesses_sc_reads_restricted	= true
unsequenced_races	are absent
data_races	are present
indeterminate_reads	are absent
locks_only_bad_mutexes	are absent

Computed executions

Display Relations

☒ sb	☐ asw	☐ dd	☐ cd
☒ rf	☒ mo	☒ sc	☒ lo
☐ hb	☐ vse	☐ ithb	☒ sw
☐ rs	☐ hrs	☒ dob	☐ cad
☒ unsequenced_races	☒ data_races		

Display Layout

☐ dot ☐ neato_par ☒ neato_par_init ☐ neato_downwards

☐ tex

edit display options

4

```
graph TD
  a["a:Wna x=2"] -- "sw" --> b["b:Wna x=3"]
  a -- "rf,sw" --> c["c:Rna x=2"]
  b -- "dr" --> c
  c -- "sb" --> d["d:Wna y=0"]
```

Files: out.exc, out.dot, out.dsp, out.tex

Verwende Codeanalyse Werkzeuge (CppMem)

```
int x = 0, std::atomic<int> y{0};
```

```
void writing(){  
    x = 2000;  
    y.store(11, std::memory_order_release);  
}
```

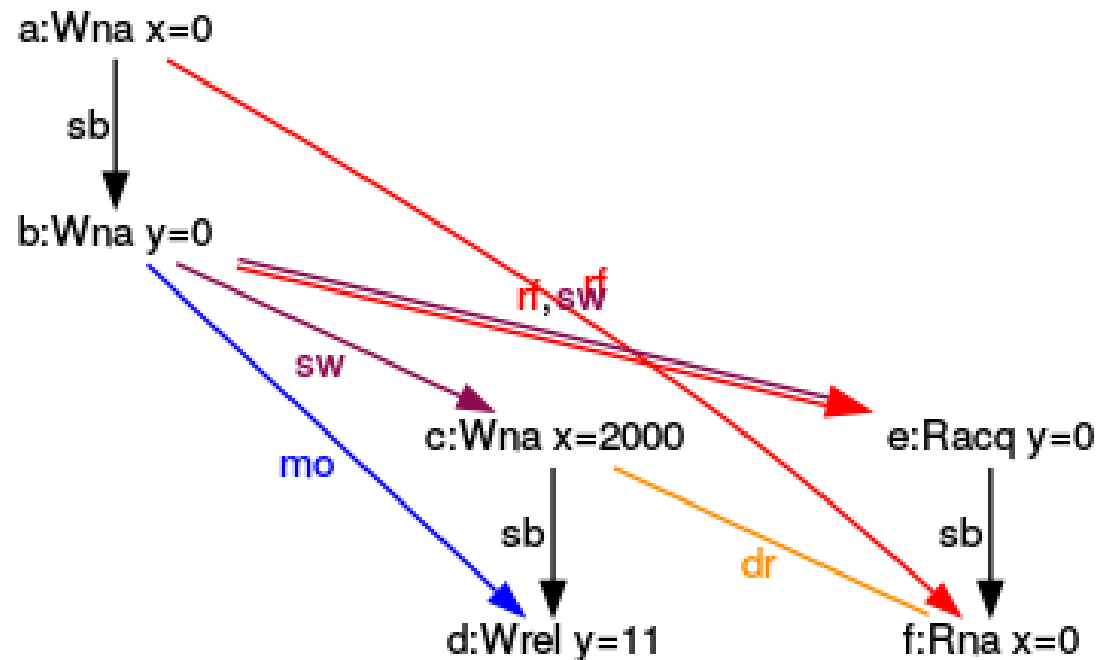
```
void reading(){  
    std::cout << y.load(std::memory_order_acquire) << " ";  
    std::cout << x << std::endl;  
}
```

```
...
```

```
std::thread thread1(writing);  
std::thread thread2(reading);  
thread1.join(), thread2.join();
```

Verwende Codeanalyse Werkzeuge (CppMem)

```
int x = 0, atomic_int y = 0;
{{{ {
    x = 2000;
    y.store(11, memory_order_release);
}
||| {
    y.load(memory_order_acquire);
    x;
}
}}}
```



Verwende unveränderliche Daten

Data Race: Mindestens zwei Threads greifen zu einem Zeitpunkt auf gemeinsame Daten zu. Zumindestens ein Thread versucht diese zu verändern.

Veränderlich?

Geteilt?

	nein	ja
nein	OK	Ok
ja	OK	Data Race

Verwende unveränderliche Daten

Das verbleibende Problem: Die Daten müssen thread-sicher initialisiert werden.

1. Frühzeitiges Initialisieren

```
const int val = 2011;  
thread t1([&val]{ .... });  
thread t2([&val]{ .... });
```

2. Konstante Ausdrücke

```
constexpr auto doub = 5.1;
```

3. `call_once` und `once_flag`

```
void onlyOnceFunc{ .... };  
call_once(onceFlag, onlyOnceFunc);  
thread t3{ onlyOnceFunc() };  
thread t4{ onlyOnceFunc() };
```

4. Statische Variablen mit Blockgültigkeit

```
void func(){  
    .... static int val 2011; ....  
}  
thread t5{ func() };  
thread t6{ func() };
```

Verwende reine Funktionen

Reine Funktionen

Erzeugen immer dasselbe Ergebnis, wenn sie die gleichen Argumente erhalten.

Besitzen keine Seiteneffekte.

Verändern nie den globalen Zustand des Programms.

Vorteile

- Korrektheitsbeweise sind einfacher durchzuführen.
- Refactoring und Tests sind einfacher möglich.
- Ergebnisse von Funktionsaufrufe können gespeichert werden.
- **Die Ausführungsreihenfolge der Funktion kann (automatisch) umgeordnet oder parallelisiert werden.**

Verwende reine Funktionen

- Funktionen

```
int powFunc(int m, int n){  
    if (n == 0) return 1;  
    return m * powFunc(m, n-1);  
}
```

- Metafunktionen

```
template<int m, int n>  
struct PowMeta{  
    static int const value = m * PowMeta<m, n-1>::value;  
};
```

```
template<int m>  
struct PowMeta<m, 0>{  
    static int const value = 1;  
};
```

Verwende reine Funktionen

- `constexpr` Funktionen
 - sind fast reine Funktionen

```
constexpr int powConst(int m, int n){  
    int r = 1;  
    for(int k = 1; k <= n; ++k) r *= m;  
    return r;  
}
```

```
auto res = powConst(2, 10);
```

```
auto constexpr res2 = powConst(2, 10);
```

Best Practices

Allgemein

Multithreading

Speichermodell

Tasks statt Threads

Thread

```
int res;  
thread t([&]{ res = 3 + 4; });  
t.join();  
cout << res << endl;
```

Task

```
auto fut = async([]{ return 3 + 4; });  
cout << fut.get() << endl;
```

Kriterium	Thread	Task
Beteiligten	Erzeuger- und Kinderthread	Promise und Future
Kommunikation	gemeinsame Variable	Kommunikationskanal
Threaderzeugung	verbindlich	optional
Synchronisation	join-Aufruf wartet	get-Aufruf blockiert
Ausnahme im Kinderthread	Kinder- und Erzeugerthread enden	Rückgabewert des get -Aufrufs
Formen der Kommunikation	Werte	Werte, Benachrichtigungen und Ausnahmen

Tasks statt Threads

C++20: Erweiterte Future werden die Komposition unterstützen

- **then**: Führe den Future aus, sobald der vorherige Future fertig ist.
- **when_any**: Führe den Future aus, sobald einer der Futures fertig ist.
- **when_all**: Führe den Future aus, sobald alle Futures fertig sind.

Tasks statt Bedingungsvariablen

Thread 1

```
{  
    lock_guard<mutex> lck(mut);  
    ready = true;  
}  
condVar.notify_one();
```

Thread 2

```
{  
    unique_lock<mutex>lck(mut);  
    condVar.wait(lck, []{ return ready; });  
}
```

```
prom.set_value();
```

```
fut.wait();
```

Kriterium	Bedingungsvariablen	Tasks
Kritischer Bereich	Ja	Nein
Spurious Wakeup	Ja	Nein
Lost Wakeup	Ja	Nein
Mehrmalige Synchronisation möglich	Ja	Nein

Mutexe in Locks verpacken

Keine Freigabe des Mutex

- mutex

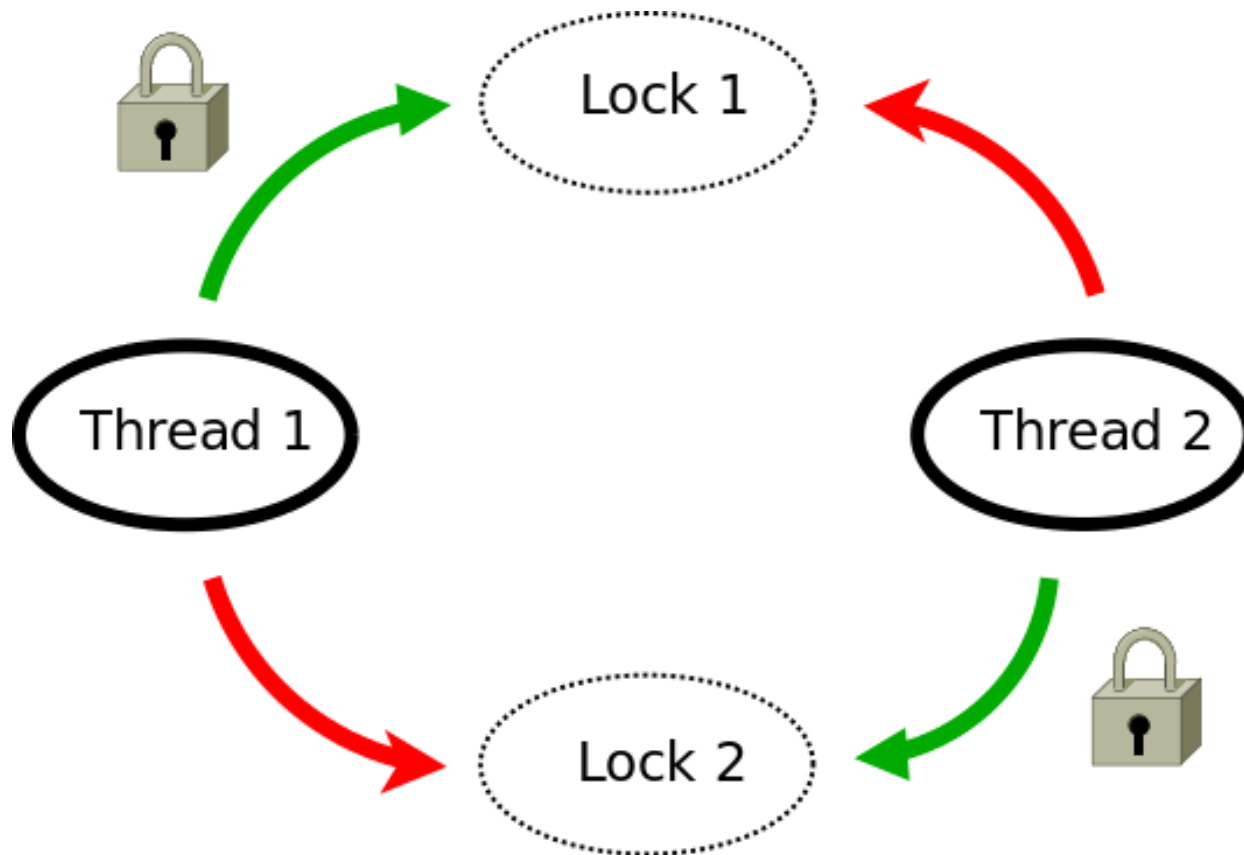
```
mutex m;  
  
{  
    m.lock();  
    shrVar = getVar();  
    m.unlock();  
}
```

- lock_guard

```
mutex m;  
  
{  
    lock_guard<mutex> myLock(m);  
    shaVar = getVar();  
}
```

Mutexe in Locks verpacken

Locken der Mutexe in verschiedener Reihenfolge



Mutexe in Locks verpacken

Atomares Locken der Mutexe

- `unique_lock`

```
{  
  
    unique_lock<mutex> guard1 (mut1, defer_lock) ;  
    unique_lock<mutex> guard2 (mut2, defer_lock) ;  
    lock (guard1, guard2) ;  
  
}
```

- `lock_guard` (C++17)

```
{  
  
    std::scoped_lock (mut1, mut2) ;  
  
}
```

Best Practices

Allgemein

Multithreading

Speichermodell

Programmiere nicht lock-frei

Herb Sutter



Lock-Free Programming

Herb Sutter

Guide to Threaded Coding

1. Forget what you learned in Kindergarten
(ie *stop Sharing*)
2. Use Locks
3. Measure
4. Measure
5. Change your Algorithm
6. GOTO 1

Tony Van Eerd

∞. Lock-free

Lock-free coding is the last thing you want to do.

Safety: off
How not to shoot yourself in the foot with C++ atomics

Anthony Williams



- Writing lock-free programs is hard **Fedor Pikus**
- Writing correct lock-free programs is even harder

The ugly side of weakly ordered atomics

Extreme complexity.

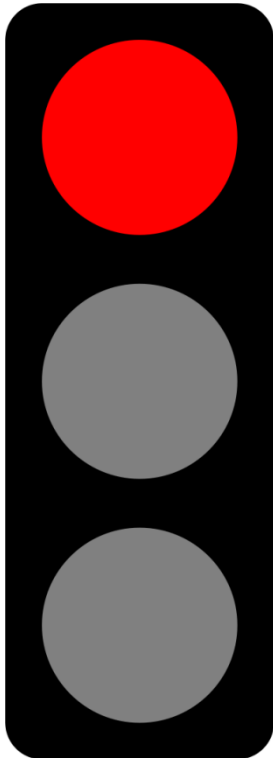
- The rules are not obvious.
- They're often downright surprising.
- And not even well understood.
- The committee still hasn't figured out how to define `memory_order_relaxed`.
... and I'm not even going to talk about `memory_order_consume`.

Hans Böhm

The specification of release-consume ordering is being revised, and the use of `memory_order_consume` is temporarily discouraged. (since C++17)

Programmiere nicht lock-frei: ABA

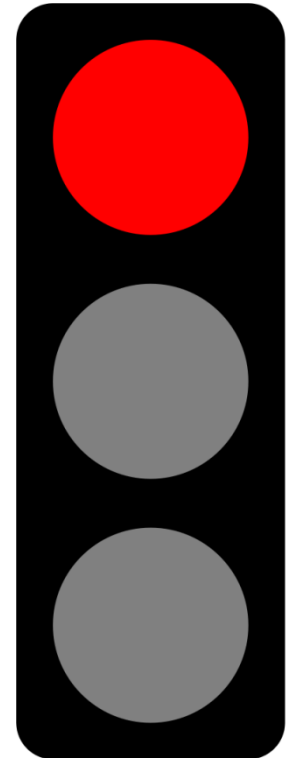
A



B



A



Programmiere nicht lock-frei: ABA

Eine lock-freie, einfach verkettete Liste (Stack)



▪ Thread 1

- möchte A entfernen
- speichert
 - head = A
 - next = B



▪ Thread 2

- entfernt A



- entfernt B und löscht B



- schiebt A auf Liste zurück



- prüft, ob A == head
- macht B zum neuen head
- B wurde bereits durch Thread 2 gelöscht

Programmiere nicht lock-frei: ABA

- Problem der einfache verketteten Liste
 - B wird gelöscht, obwohl es noch verwendet wird
- Lösungen:
 - Tagged State:
 - Jeder Knoten bekommt einen Tag, der anzeigt, wie oft er verändert wurde
 - Verzögertes Löschen:
 - Garbage Collection
 - Hazard Pointers: Garbage Collection auf Thread-Ebene
 - RCU:
 - Modifikation werden nur auf Kopien vollzogen
 - Wenn es keinen Zugriff auf die Daten mehr gibt, werden diese ausgetauscht

Verwende bewährte Muster

Warten mit Sequenzieller Konsistenz

```
std::vector<int> mySharedWork;  
std::atomic<bool> dataReady(false);
```

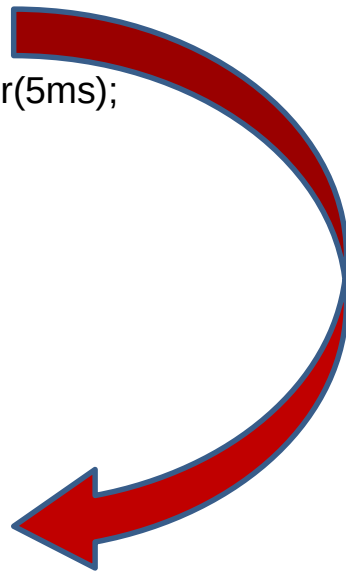
```
void waitingForWork(){  
    while ( !dataReady.load() ){  
        std::this_thread::sleep_for(5ms);  
    }  
    mySharedWork[1] = 2;  
}
```

```
void setDataReady(){  
    mySharedWork = {1, 0, 3};  
    dataReady.store(true);  
}
```

```
int main(){
```

```
    std::thread t1(waitingForWork);  
    std::thread t2(setDataReady);  
    t1.join();  
    t2.join();  
    for (auto v: mySharedWork){  
        std::cout << v << " ";  
        // 1 2 3
```

```
};
```



Verwende bewährte Muster

Warten mit Acquire-Release Semantik

```
std::vector<int> mySharedWork;  
std::atomic<bool> dataReady(false);  
  
void waitingForWork(){  
    while ( !dataReady.load(std::memory_order_acquire) ){  
        std::this_thread::sleep_for(5ms);  
    }  
    mySharedWork[1] = 2;  
}  
  
void setDataReady(){  
    mySharedWork = {1, 0, 3};  
    dataReady.store(true, std::memory_order_release);  
}
```



```
int main(){  
  
    std::thread t1(waitingForWork);  
    std::thread t2(setDataReady);  
    t1.join();  
    t2.join();  
    for (auto v: mySharedWork){  
        std::cout << v << " ";    // 1 2 3  
    }  
};
```

Verwende bewährte Muster

Atomare Zähler

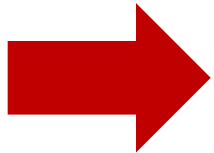
```
#include <vector>
#include <iostream>
#include <thread>
#include<atomic>

std::atomic<int> count{0};

void add(){
    for (int n = 0; n < 1000; ++n){
        count.fetch_add(1, std::memory_order_relaxed);
    }
}

int main(){
    std::vector<std::thread> v;
    for (int n = 0; n < 10; ++n){
        v.emplace_back(add);
    }
    for (auto& t : v) { t.join(); }
    std::cout << count;          // 10000
}
```

Erfinde das Rad nicht neu



[Threading Building Blocks \(TBB\)](#)
[Boost.Lockfree](#)

Erfinde das Rad nicht neu

- Threading Building Blocks (TBB)
 - Queues
 - `concurrent_queue`
 - `concurrent_bounded_queue`
 - `concurrent_priority_queue`
 - Vektor
 - `concurrent_vector`
 - Assoziative Container
 - `concurrent_unordered_map`, `concurrent_unordered_multimap`
 - `concurrent_unordered_set`, `concurrent_unordered_multiset`
 - `concurrent_hash_map`

Erfinde das Rad nicht neu

- Boost.Lockfree
 - Queue
 - eine lock-freie, mehrere Erzeuger-Verbraucher (producer-consumer) Queue
 - Stack
 - eine lock-freie, mehrere Erzeuger-Verbraucher (producer-consumer) Stack
- spsc_queue
 - eine wait-freie, ein Erzeuger-Verbraucher (producer-consumer) Queue (Ringpuffer)

Blogs

www.grimm-jaud.de [De]

www.ModernesCpp.com [En]

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www.ModernesCpp.de