30. Parallel Programming IV

Futures, Read-Modify-Write Instructions, Atomic Variables, Idea of lock-free programming

Futures: Motivation

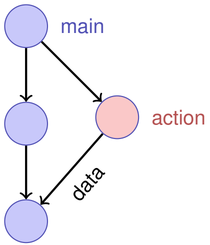
Up to this point, threads have been functions without a result:

```
void action(some parameters){
  ...
}

std::thread t(action, parameters);
...
t.join();
// potentially read result written via ref−parameters
```

Futures: Motivation

Now we would like to have the following

```
T action(some parameters){
  ...
  return value;
}

std::thread t(action, parameters);
...
value = get_value_from_thread();
```



We can do this already!

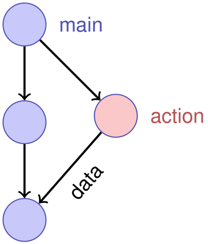
- We make use of the producer/consumer pattern, implemented with condition variables
- Start the thread with reference to a buffer
- We get the result from the buffer.
- Synchronisation is already implemented

Reminder

```
template <typename T>
class Buffer {
  std::queue<T> buf;
  std::mutex m;
  std::condition_variable cond;
public:
  void put(T x){ std::unique_lock<std::mutex> g(m);
    buf.push(x);
    cond.notify_one();
  }
  T get(){ std::unique_lock<std::mutex> g(m);
    cond.wait(g, [&]{return (!buf.empty());});
    T x = buf.front(); buf.pop(); return x;
  }
};
```

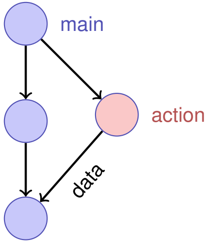
Application

```
void action(Buffer<int>& c){
  // some long lasting operation ...
  c.put(42);
}

int main(){
  Buffer<int> c;
  std::thread t(action, std::ref(c));
  t.detach(); // no join required for free running thread
  // can do some more work here in parallel
  int val = c.get();
  // use result
  return 0;
}
```



With features of C++11

```
int action(){
  // some long lasting operation
  return 42;
}

int main(){
  std::future<int> f = std::async(action);
  // can do some work here in parallel
  int val = f.get();
  // use result
  return 0;
}
```



30.2 Read-Modify-Write

Example: Atomic Operations in Hardware

CMPXCHG **Compare and Exchange**

Compares the value in the AL, AX, EAX, or RAX register with the value in a register or a memory location (first operand). If the two values are equal, the instruction copies the value in the second operand to the first operand and sets the ZF flag in the rFLAGS register to 1. Otherwise, it copies the value in the first operand to the AL, AX, EAX, or RAX register and clears the ZF flag to 0.

The OF, SF, AF, PF and CF flags are set to reflect the results of the compare.

When the first ... modify-write on the memory opera... he same value to the memory opera...

The forms of th... K prefix. For details about the LOC...

Mnemonic		
CMPXCHG reg...		...egister or memory ...perand to the first ...perand to AL.
CMPXCHG reg...		...egister or memory ...perand to the first ...perand to AX.
CMPXCHG reg...		...register or memory ...perand to the first ...perand to EAX.
CMPXCHG *reg/mem64, reg64*	0F B1 /r	... register or mem... location. If equal, copy the second operand to the fi... operand. Otherwise, copy the first operand to RAX.

Related Instructions

CMPXCHG8B, CMPXCHG16B

CMPXCHG mem, reg
«compares the value in Register A with the value in a memory location If the two values are equal, the instruction copies the value in the second operand to the first operand and sets the ZF flag in the flag regsiters to 1. Otherwise it copies the value in the first operand to A register and clears ZF flag to 0»

1.2.5 Lock Prefix

The LOCK prefix causes certain kinds of memory read-modify-write instructions to occur atomically. The mechanism for doing so is implementation-dependent (for example, the mechanism may involve

8 *...struction Formats*

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bus signaling or packet messaging between the processor and a memory controller). The prefix is intended to give the processor exclusive use of shared memory in a multiprocessor system.

The LOCK prefix can only be used with forms of the following instructions that write a memory operand: ADC, ADD, AND, BTC, BTR, BTS, CMPXCHG, CMPXCHG8B, CMPXCHG16B, DEC, INC, NEG, NOT, OR, SBB, SUB, XADD, XCHG, and XOR. An invalid-opcode exception occurs if the LOCK prefix is used with any other instruction.

«The lock prefix causes certain kinds of memory read-modify-write instructions to occur atomically»

AMD64 Architecture Programmer’s Manual

Read-Modify-Write

Concept of Read-Modify-Write: Read, modify and write back at one point in time (atomic).

Example: Test-And-Set

atomic

```
bool TAS(bool& variable){
  bool old = variable;
  variable = true;
  return old;
}
```

Application example TAS in C++11

```
class SpinLock{
std::atomic_flag taken {false};
public:
  void lock(){
    while (taken.test_and_set());
  }

  void unlock(){
    taken.clear();
  }
};
```

30.3 Lock-Free Programming

Compare-And-Swap

atomic

```
bool CAS(int& variable, int& expected, int desired){
  if (variable == expected){
    variable = desired;
    return true;
  }
  else{
    expected = variable;
    return false;
  }
}
```

Lock-free programming

Data structure is called

- *lock-free*: at least one thread always makes progress in bounded time even if other algorithms run concurrently. Implies system-wide progress but not freedom from starvation.
- *wait-free*: all threads eventually make progress in bounded time. Implies freedom from starvation.

Progress Conditions

	Non-Blocking	Blocking
Everyone makes progress	Wait-free	Starvation-free
Someone makes progress	Lock-free	Deadlock-free

Implication

- Programming with locks: each thread can block other threads indefinitely.
- Lock-free: failure or suspension of one thread cannot cause failure or suspension of another thread !

Lock-free programming: how?

Beobachtung:

- RMW-operations are implemented *wait-free* by hardware.
- Every thread sees his result of a CAS or TAS in bounded time.

Idea of lock-free programming: read the state of a data sructure and change the data structure *atomically* if and only if the previously read state remained unchanged meanwhile.

Example: lock-free stack

Simplified variant of a stack in the following

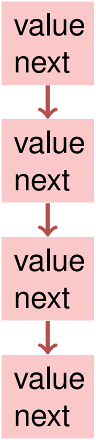
- pop prüft nicht, ob der Stack leer ist
- pop gibt nichts zurück

(Node)

Nodes:

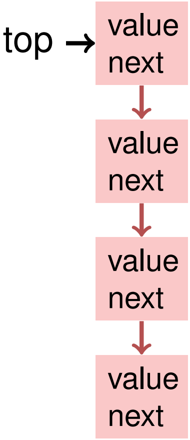
```
struct Node {
  T value;

  Node<T>* next;
  Node(T v, Node<T>* nxt): value(v), next(nxt) {}
};
```



(Blocking Version)

```
template <typename T>
class Stack {
    Node<T> *top=nullptr;
    std::mutex m;
public:
    void push(T val){ guard g(m);
        top = new Node<T>(val, top);
    }
    void pop(){ guard g(m);
        Node<T>* old_top = top;
        top = top->next;
        delete old_top;
    }
};
```



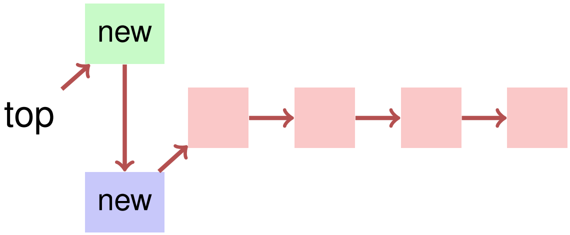
Lock-Free

```
template <typename T>
class Stack {
  std::atomic<Node<T>*> top {nullptr};
public:
  void push(T val){
    Node<T>* new_node = new Node<T> (val, top);
    while (!top.compare_exchange_weak(new_node->next, new_node));
  }
  void pop(){
    Node<T>* old_top = top;
    while (!top.compare_exchange_weak(old_top, old_top->next));
    delete old_top;
  }
};
```

Push

```
void push(T val){
  Node<T>* new_node = new Node<T> (val, top);
  while (!top.compare_exchange_weak(new_node->next, new_node));
}
```

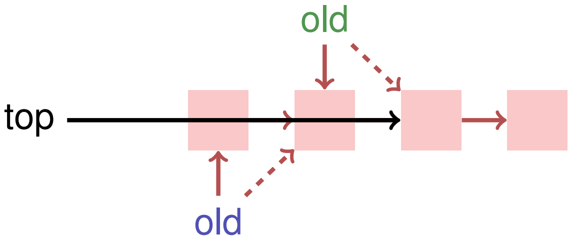
2 Threads:



Pop

```
void pop(){
  Node<T>* old_top = top;
  while (!top.compare_exchange_weak(old_top, old_top->next));
  delete old_top;
}
```

2 Threads:



Lock-Free Programming – Limits

- Lock-Free Programming is complicated.
- If more than one value has to be changed in an algorithm (example: queue), it is becoming even more complicated: threads have to “help each other” in order to make an algorithm lock-free.
- The *ABA problem* can occur if memory is reused in an algorithm.