Concurrency in the Real World

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- Problems with multithreaded code
- Solutions to some of the problems
- Adding concurrency to an application

Problems with multithreaded code

The biggest problem with multithreaded code is

incorrect synchronization

Too much synchronization

Too little synchronization

Data Races

```
unsigned i=0;
void func()
{
    for(unsigned c=0;c<2000000;++c)
        ++i;
    for(unsigned c=0;c<2000000;++c)
        --i;
}
std::thread t1(func),t2(func);
```

Data Races

```
Final i=0
Final i=4294345393
Final i=169708
```

A mutex doesn't save us from race conditions

```
template<typename Data>
class racy_queue
{
    std::mutex the_mutex;
    std::queue<Data> the_queue;
public:
    void push(Data const& data);
    void pop();
    bool empty();
    Data front();
};
```

Our racy queue

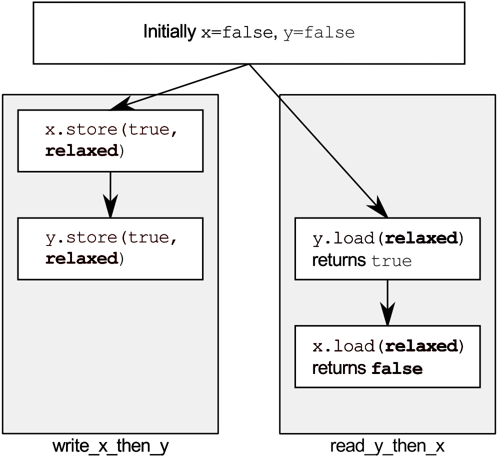
Consider a queue with one element ...

Thread A	Thread B
`if(q.empty()) return;`	
	`if(q.empty()) return;`
`Data local=q.front();`	
	`Data local=q.front();`
`q.pop();`	
	`q.pop();`

We're not used to thinking "concurrently"

Things can happen out of order

Out of order visibility

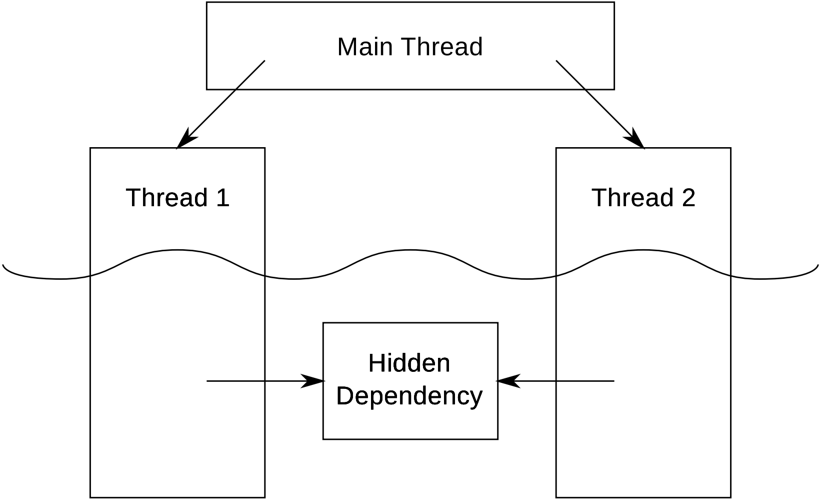


Why we get concurrency wrong

- We work in imperative languages — do this, **then** do that
- True concurrency is hard to reason about
- Single core systems interleave threads

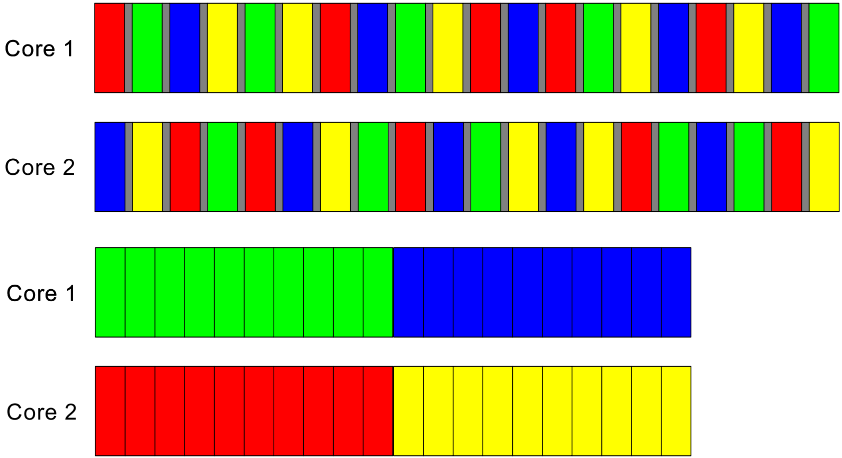
Problems with multithreaded code

Hidden dependencies are evil


Main Thread
Thread 1
Thread 2
Hidden Dependency

Too many ~~notes~~ threads (oversubscription)

Task switching and oversubscription



How can we avoid these problem?

Avoiding the Pitfalls

- Share less mutable data
- Use carefully chosen mechanisms for sharing
- Scale the number of threads with the hardware

Sharing less mutable data

No globals

Sharing less mutable data

No singletons either!

Copy data and merge changes later

Communication Mechanisms

SynchronizedValue

```
template<typename T>
class SynchronizedValue {
    T data;
    std::mutex m;
public:
    struct Updater {
        T* operator->();
        T& operator*();
    };
    Updater operator->();
    Updater get();
    T operator*();
    void set(T const&);
};
```

SynchronizedValue usage

```
void foo(SynchronizedValue<std::string>& s) {
    std::string local=*s;
    s->append("foo");
    auto locked=s.get();
    unsigned pos=locked->find("f");
    if(pos==std::string::npos)
        *locked = "bar";
    else
        (*locked)[pos] = 'b';
}
```

DataFlowValue

```
template<typename T>
struct DataFlowValue {
    template<typename F>
    void task(F);              // compute value
    void operator=(T value); // set value
    T const& get();            // blocking wait
};
```

DataFlowValue usage

```
void test_sum() {
    DataFlow<int> x,y,z;
    z.task([&]{return x.get()+y.get();});
    y=99;
    x=123;
    assert(z.get()==222);
}
```

Use futures for synchronization

- Futures are a one-way, one-time channel
- Good for passing computation results and “done” flags
- `std::async` makes it easy to get started.

Use std::async for “divide and conquer” algorithms

```
template<typename Iter,typename Func>
void parallel_for_each(Iter first,Iter last,Func f) {
    ptrdiff_t const range_length=last-first;
    if(!range_length) return;
    if(range_length==1) {
        f(*first); return;
    }
    Iter const mid=first+(range_length/2);
    std::future<void> bgtask=std::async(
        &parallel_for_each<Iter,Func>,first,mid,f);
    parallel_for_each(mid,last,f);
    bgtask.get();
}
```

Scaling threads to the hardware

- `std::async()` automatically scales number of threads to the hardware
- Use `std::hardware_concurrency()` when scaling manually

Use message queues for communication between threads

MS Windows example GUI thread

```
void gui_thread(msg_queue& messages) {
  HANDLE handles[]={messages.event(),...};
  for(;;) {
    MsgWaitForMultipleObjects(arraySize(handles),
      &handles,false,INFINITE,QS_ALLINPUT);
    for(bool do_loop=true;do_loop;) {
      do_loop=false;
      if(message_type local_message=messages.try_pop()) {
        process(local_message); do_loop=true; }
      MSG winMsg={0};
      if(PeekMessage(&winMsg,NULL,0,0,PM_REMOVE)) {
        processWindowsMessage(&winMsg); do_loop=true;}
} } }
```

Message types

There are two ways to pass messages:

- As data, like Windows messages, or
- As tasks, like the Command pattern

Typed messages

```
struct HandlerBase {
    virtual ~HandlerBase() {}
};
template<typename MessageType>
struct MessageHandler: public virtual HandlerBase {
    virtual void handle(MessageType const&)=0;
};
struct MessageBase {
    virtual ~MessageBase() {}
    virtual void dispatch(HandlerBase* handler) const=0;
};
threadsafe_queue<std::shared_ptr<MessageBase>> queue;
```

Typed messages (2)

```
struct Msg1: MessageBase {
    void dispatch(HandlerBase* handler) const {
        MessageHandler<Msg1>* my_handler=
            dynamic_cast<MessageHandler<Msg1>*>(handler);
        if(my_handler) my_handler->handle(*this);
    }
};
struct Msg2: MessageBase {
    void dispatch(HandlerBase* handler) const;
};
struct MyHandler:
    MessageHandler<Msg1>,
    MessageHandler<Msg2>,
    MessageHandler<Msg3> { /* ... */ };
```

Task messages

Post tasks rather than messages for

- GUI thread — simpler than multiple custom message types
- Worker threads (e.g. in a thread pool)

Task messages (2)

```
threadsafe_queue<std::packaged_task<void()>> queue;

template<typename Func>
std::future<void> post_task_on_queue(Func f) {
    std::packaged_task<void()> task(f);
    std::future<void> res=task.get_future();
    queue.push_back(std::move(task));
    return res;
}
```

Why add concurrency?

More concurrency $\Rightarrow$ Faster execution?

How much faster?

Amdahl's Law:

$$\gamma = \frac{T_{serial}}{T_{total}}$$

$$S(P) = \frac{1}{\gamma + \frac{1-\gamma}{P}}$$

More concurrency $\Rightarrow$ Process more data?

How much more data?

Fixed execution time $\Rightarrow$

$$T(n_2, P) = \frac{T(n_2, 1)}{S(P)} = T(n_1, 1)$$

How much more can we process in the same time?

$$O(n) \Rightarrow n_2 \simeq n_1.S(P)$$

$$O(n^2) \Rightarrow n_2 \simeq n_1.\sqrt{S(P)}$$

$$O(\lg n) \Rightarrow n_2 \simeq {n_1}^{S(P)}$$

More concurrency $\Rightarrow$ Do extra stuff?

What extra stuff?

- Background spell checking
- Incremental search
- Autosuggest
- Background compilation
- Background testing

Background processing must be interruptible

More concurrency $\Rightarrow$ Greater responsiveness?

Get "work" off the GUI thread

A progress bar (with a cancel button) is better than a "frozen" application.

Don't move existing GUI elements in the background

The future

- Newer CPUs have more cores rather than faster clock speeds
- New approaches to concurrency will make things easier

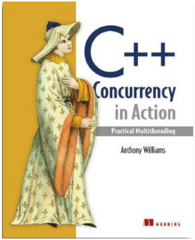
just::thread

`just::thread` provides a complete implementation of the C++0x thread library for MSVC 2008, MSVC 2010, g++ 4.3 and g++ 4.4.

For a 50% discount go to:

`http://www.stdthread.co.uk/accu2010`

My book



C++ Concurrency in Action: Practical Multithreading with the new C++ Standard, currently available under the Manning Early Access Program at

http://www.stdthread.co.uk/book/

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