Generic Synchronization Policies in C++

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Introduction

- Most people know that writing synchronization code is:
  - Difficult: APIs are low-level
  - Non-portable: many threading APIs: POSIX, Windows, Solaris, DCE, …
- In practice, most synchronization code implement a small number of high-level “usage patterns”:
  - Let’s call these *generic synchronization policies* (GSPs)
  - The most common GSPs can be implemented as a C++ library
- Using GSPs in applications:
  - Is much easier than using low-level APIs
  - Encapsulates the underlying threading package → provides portability

1. Scoped Locks

Critical section

- The following (pseudocode) function uses a critical section:

```
void foo()
{
    getLock(mutex);
    ...
    releaseLock(mutex);
}
```

- The above code is very simple. However…
- Complexity increases if the function has several exit points:
  - Because `releaseLock()` must be called at each exit point
  - Examples of extra exit points:
    - Conditional `return` statements
    - Conditionally throwing an exception

Critical section with multiple exit points

```
void foo()
{
    getLock(mutex);
    ...
    if (...) {
        releaseLock(mutex);
        return;
    }
    if (...) {
        releaseLock(mutex);
        throw anException;
    }
    ...
    releaseLock(mutex);
}
```

Have to call `releaseLock()` at every exit point from the function

Critique

- Needing to call `releaseLock()` at every exit point:
  - Clutters up the "business logic" code with synchronization code
  - This clutter makes code harder to read and maintain
- Forgetting to call `releaseLock()` at an exit point is a common source of bugs
- There is a better way…

Solution: `ScopedMutex` class

- Define a class called, say, `ScopedMutex`:
  - This class has no operations! Just a constructor and destructor
  - Constructor calls `getLock()`
  - Destructor calls `releaseLock()`
- Declare a `ScopedMutex` variable local to a function
  - At entry to function → constructor is called → calls `getLock()`
  - At exit from function → destructor is called → calls `releaseLock()`
- The following two slides show:
  - Pseudocode implementation of `ScopedMutex` class
  - Use of `ScopedMutex` in a function

The `ScopedMutex` class

```
class ScopedMutex {
public:
    ScopedMutex(Mutex & mutex)
        : m_mutex(mutex)
    { getLock(m_mutex); }

    ~ScopedMutex()
    { releaseLock(m_mutex); }
private:
    Mutex & m_mutex;
};
```

Use of `ScopedMutex`

```
void foo()
{
    ScopedMutex    scopedLock(mutex);
    ...
    if (...) { return; }
    if (...) { throw anException; }
    ...
}
```

No need to call `releaseLock()` at every exit point from the function!

Comments on `ScopedMutex`

- This technique is *partially* well known in the C++ community:
  - 50% of developers the author worked with already knew this technique
  - They considered it to be a “basic” C++ coding idiom
  - Other 50% of developers had not seen the technique before
- Of the developers who already knew this technique:
  - They all used it for mutex locks
  - Only a few knew it could be used for readers-writer locks too
  - Nobody knew it could be used for almost any type of synchronization code
- Contribution of this presentation:
  - Generalize the technique so it can be used much more widely
- To explain how to do this, I need to take a slight detour:
  - Have to introduce the concept of *generic synchronization policies*

2. The Concept of Generic Synchronization Policies

Genericity for types

- C++ provides template types
- Example of a template type definition:

```
template<t> class List { ... };
```

- Examples of template type instantiation:

```
List<int>    myIntList;
List<double> myDoubleList;
List<Widget> myWidgetList;
```

- Some other languages provide a similar capability, often with different terminology and syntax
  - Perhaps called *generic types* instead of *template types*
  - Perhaps surround type parameters with `[]` instead of `<>`

Genericity for synchronization policies

- Using a pseudocode notation, here are declarations of mutual exclusion and readers-writer policies

```
Mutex[Op]
RW[ReadOp, WriteOp]
```

- In above examples, each parameter is a set of operations
- Example instantiations on operations `Op1`, `Op2` and `Op3`

```
Mutex[{Op1, Op2, Op3}]
RW[{Op1, Op2}, {Op3}]
```

Producer-consumer policy

- Useful when:
  - A buffer is used to transfer data between threads
  - A producer thread *puts* items into the buffer
  - A consumer thread *gets* items from the buffer
  - If the buffer is empty when the consumer tries to get an item then the consumer thread blocks
  - The buffer might have *other* operations that examine the state of the buffer

- In pseudocode notation, the policy declaration is:

```
ProdCons[PutOp, GetOp, OtherOp]
```

- Example instantiations:

```
ProdCons[{insert}, {remove}, {count}]
ProdCons[{insert}, {remove}, {}]
```

Bounded producer-consumer policy

- Variation of the producer-consumer policy:
  - Buffer has a fixed size
  - If the buffer is full when the producer tries to put in an item then the producer thread blocks

- In pseudocode notation, policy is:

```
BoundedProdCons(int size)[PutOp, GetOp, OtherOp]
```

- Typically, the `size` parameter is instantiated on a parameter to the constructor of the buffer class
  - An example instantiation will be shown later

3. Generic Synchronization Policies in C++

Mapping Mutex[Op] into C++

```
class GSP_Mutex {
public:
  GSP_Mutex()  { /* initialize m_mutex */ }
  ~GSP_Mutex() { /* destroy m_mutex */ }
  class Op {
  public:
    Op(GSP_Mutex & data) : m_data(data)
    { getLock(m_data.m_mutex); }
    ~Op()
    { releaseLock(m_data.m_mutex); }
  private:
    GSP_Mutex & m_data;
  };
private:
    friend class ::GSP_Mutex::Op;
    OS-specific-type m_mutex;
};
```

- Class name = "GSP_" + name of policy
- Constructor & destructor of outer class initialize and destroy locks
- A nested class for each policy parameter
- Constructor & destructor of nested class *get* and *release* locks stored in the outer class

Mapping RW[ReadOp, WriteOp] into C++

```
class GSP_RW {
public:
  GSP_RW();
  ~GSP_RW();

  class ReadOp {
  public:
    ReadOp(GSP_RW & data);
    ~ReadOp();
  };

  class WriteOp {
  public:
    WriteOp(GSP_RW & data);
    ~WriteOp();
  };
};
```

This policy has two parameters so there are two nested classes

Mapping BoundedProdCons into C++

- This is the mapping for

```
BoundedProdCons(int size)[PutOp, GetOp, OtherOp]
```

```
class GSP_BoundedProdCons {
public:
  GSP_BoundedProdCons(int size);
  ~ GSP_BoundedProdCons();
  class PutOp   {...};
  class GetOp   {...};
  class OtherOp {...};
 };
```

The size parameter to the policy maps into a parameter to the constructor of the class

This policy has three parameters so there are three nested classes

Instantiating GSP_RW[ReadOp, WriteOp]

```
#include "gsp_rw.h"

class Foo {
private:
  GSP_RW    m_sync;
public:

  void op1(...) {
    GSP_RW::ReadOp    scopedLock(m_sync);
    ...
  }

  void op2(...) {
    GSP_RW::WriteOp    scopedLock(m_sync);
    ...
  }
};
```

`#include` header file (name of class written in lowercase)

Add instance variable whose type is name of policy's outer class

Synchronize an operation by adding a local variable whose type is a nested class of the policy

Instantiating GSP_BoundedProdCons

```
#include "gsp_boundedprodcons.h"

class Buffer {
private:
  GSP_BoundedProdCons  m_sync;
public:
  Buffer(int size) : m_sync(size) { ... }

  void insert(...) {
    GSP_BoundedProdCons::PutOp    scopedLock(m_sync);
    ...
  }

  void remove(...) {
    GSP_BoundedProdCons::GetOp    scopedLock(m_sync);
    ...
  }
};
```

The `size` parameter of the policy is initialized with value of a parameter to the constructor

4. Critique

Strengths of GSPs

- Only one person needs to know how to implement GSPs
  - Trivial for everyone else to instantiate GSPs
- Separates synchronization code from “business logic” code
  - Improve readability and maintainability of both types of code
- Removes a common source of bugs:
  - Locks are released even if an operation throws an exception
- Improves portability:
  - API of GSPs does *not* expose OS-specific details of synchronization
- Efficiency:
  - GSPs can be implemented with inline code

Potential criticisms fo GSPs

- "Can they handle *all* my synchronization needs?"
  - 80/20 principle: *most* synchronization needs can be handled by just a small library of GSPs
  - You are not restricted to a library of pre-written GSPs. Instead…
  - You can write new GSPs if the need arises
- "GSPs are just a `ScopedMutex` with a new name"
  - The "just" part is inaccurate
  - GSPs generalize the `ScopedMutex` concept so it can be used for a much wider set of synchronization policies

Issues not addressed

- GSPs do not address:
  - POSIX thread cancellation
  - Timeouts
  - Lock hierarchies
- In the author's work, these issues arise infrequently so he did not bother to support them
  - GSPs could probably be extended to support the above issues

5. Ready-to-run GSPs

Ready-to-run GSPs

- A library of ready-to-use GSPs is available:
  - Download from `www.CiaranMcHale.com/download`
  - Documentation provided in multiple formats:
    - Manual: LaTeX (source), PDF & HTML
    - Slides: PowerPoint, PDF and N-up PDF
- Library contains all GSPs discussed in this paper:
  - Mutex[Op]
  - RW[ReadOp, WriteOp]
  - ProdCons[PutOp, GetOp, OtherOp]
  - BoundedProdCons(int size)[PutOp, GetOp, OtherOp]
- GSPs are implemented for multiple thread packages:
  - POSIX, Solaris, Windows, DCE
  - Dummy (for non-threaded applications)

Using GSP classes

- Define one of the following preprocessor symbols before you `#include` a GSP header file
  - P_USE_POSIX_THREADS
  - P_USE_SOLARIS_THREADS
  - P_USE_WIN32_THREADS
  - P_USE_DCE_THREADS
  - P_USE_NO_THREADS
- Typically done with `-D<symbol>` command-line option to compiler

Summary

- GSPs are a generalization of the `ScopedMutex` class:
  - Out-of-the-box support for mutual-exclusion, readers-writer and (bounded) producer-consumer policies
  - You can write new GSPs if the need arises
- Benefits:
  - Makes it trivial to add synchronization to a C++ class
  - Makes code easier to read and maintain
  - Portability across multiple thread packages
  - Minimal performance overhead due to `inline` implementation
- All software and documentation is available:
  - MIT-style license (open-source, non-viral)
  - Download from `www.CiaranMcHale.com/download`