Concurrency Patterns

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Definition

"*Each pattern is a three-part rule, which expresses a relation between a certain context, a problem, and a solution.*"

(Christopher Alexander)

Three Types of Patterns

- Architecture pattern
  - Fundamental structure
  - Software system
- Design pattern
  - Interplay of components
  - Focus on a subsystem
- Idiome
  - Implementation of an architecture or design pattern in a programming language.

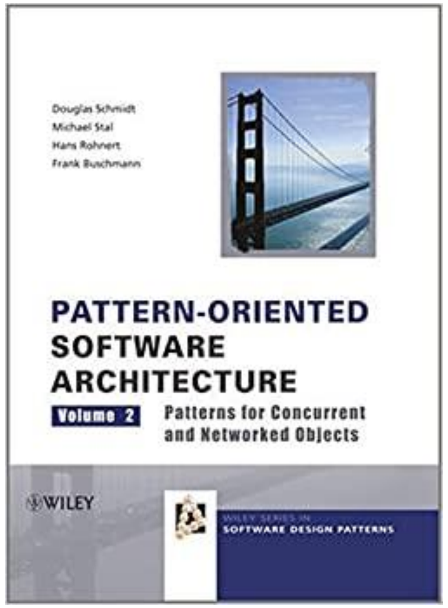
Components of a Pattern

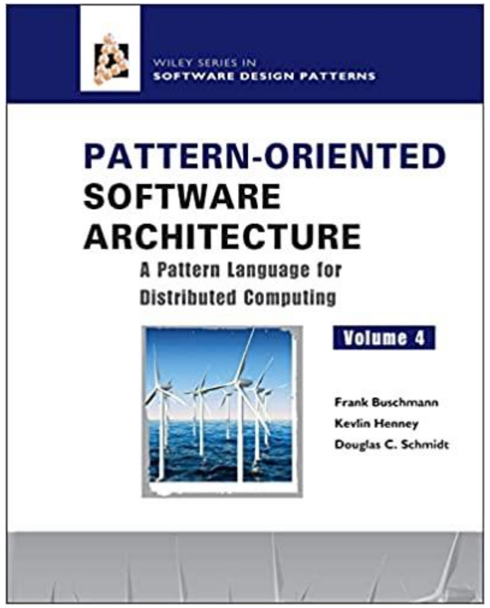
1. Name
2. Also known as
3. Summary
4. Motivation
5. Context
6. Interaction
7. Solution
8. Example
9. Consequenses
10. Related pattern
11. Known usages

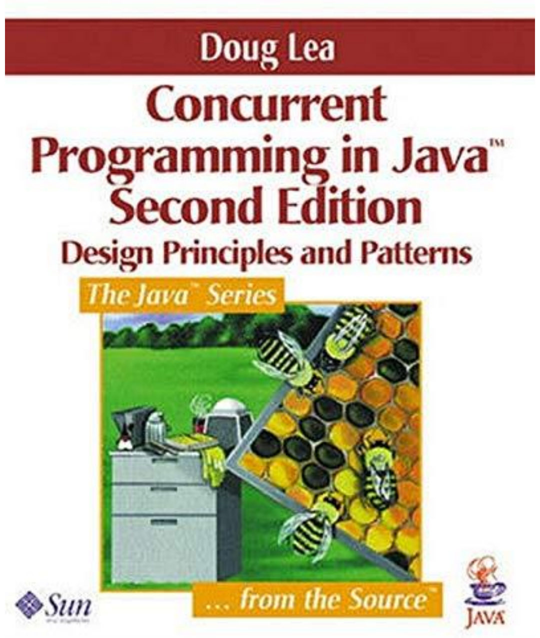
Concurrency Patterns

[Pattern-Oriented Software Architecture (Volume 2 and 4)]

[Concurrent Programming in Java]







Concurrency Patterns

Synchronization Patterns

Dealing with Sharing

- Copied Value
- Thread-Specific Storage
- Future

Dealing with Mutation

- Scoped Locking
- Strategized Locking
- Thread-Safe Interface
- Guarded Suspension

Concurrent Architecture

- Active Object
- Monitor Object

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Copied Value

There is no need to synchronize when a thread takes its arguments by copy and not by reference.

➡ Data races or lifetime issues are not possible.

[copiedValueDataRace.cpp]

Thread-Specific Storage

Thread-specific storage enables global state within a thread.

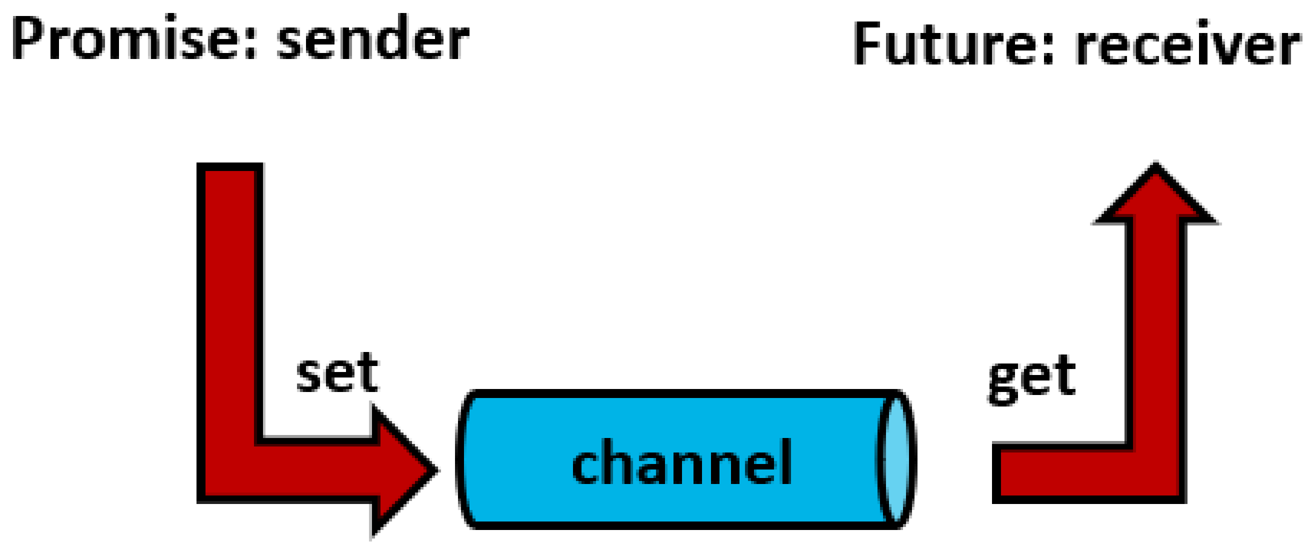
- Typical use-cases
  - Porting a single-thread to multithreaded program
  - Compute thread-local and publish the result
  - Thread-local logger

threadLocalSummation.cpp

Future

A future is a non-mutable placeholder for a value, which is set by a promise.

```
auto future = std::async([]{ return "LazyOrEager"; });
future.get();
```



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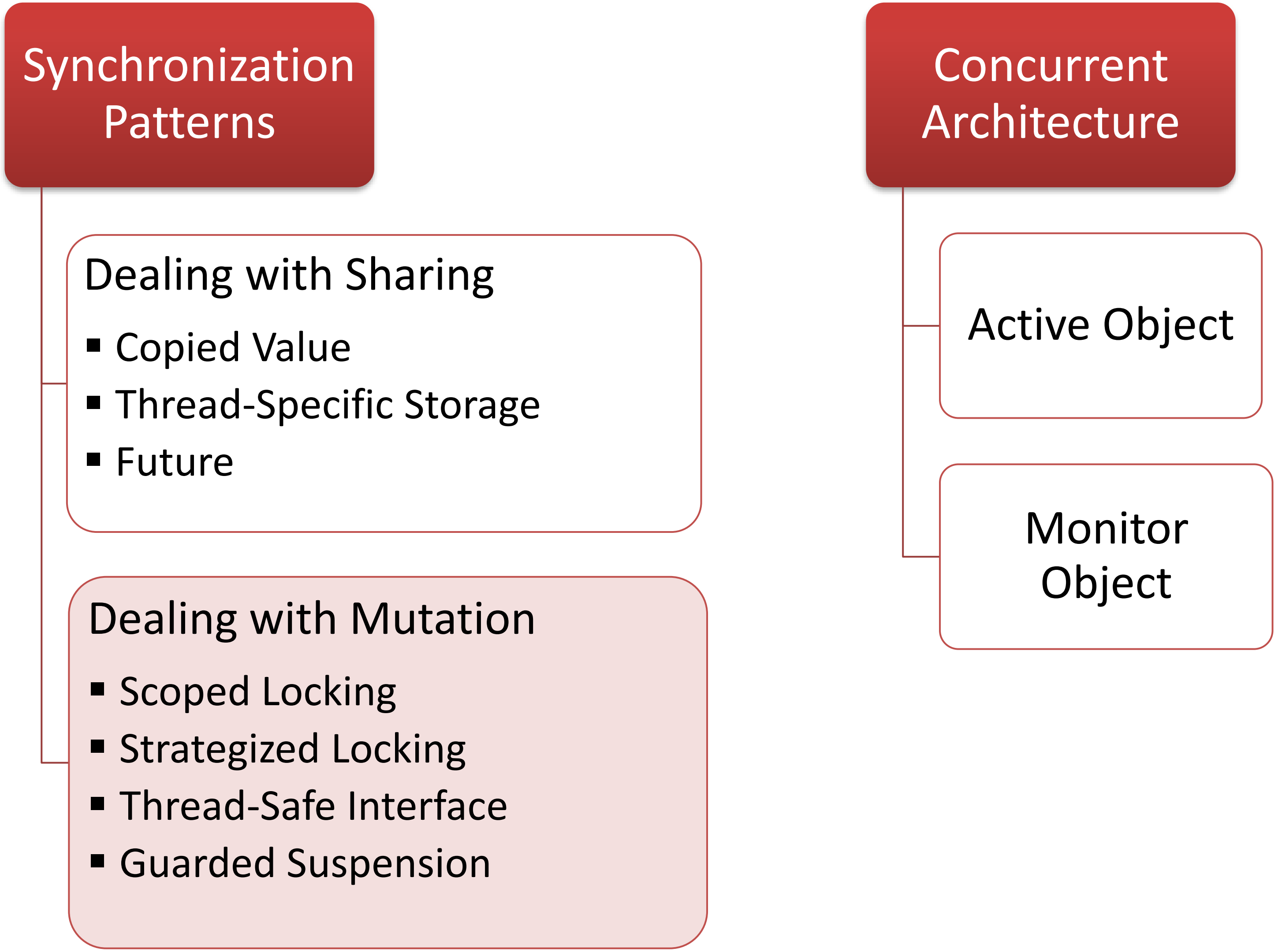

Scoped Locking

Scoped Locking is RAII applied to locking.

- Idea
  - Bind the acquiring (constructor) and the releasing (destructor) of the resource to the lifetime of an object.
  - The lifetime of the object is scoped.
  - The C++ run time is responsible for invoking the destructor and releasing the resource.
- C++ Implementation
  - `std::lock_guard` and `std::scoped_lock`
  - `std::unique_lock` and `std::shared_lock`

scopedLock.cpp

Strategized Locking

Strategized Locking

- Enables it to use various locking strategies as replaceable components.
- Is the application of the strategy pattern to locking.

- Idea
  - You want to use your library in various domains.
  - Depending on the domain, you want to use exclusive locking, shared locking, or no locking.
  - Configure your locking strategy at compile time or run time.

Strategized Locking

Advantages:

- Run-time polymorphism
  - Enables it to change the locking strategy at runtime.
- Compile-time polymorphism
  - No cost at runtime
  - Flatter object hierarchies

Disadvantages:

- Run-time polymorphism
  - Needs a pointer indirection.
- Compile-time polymorphism
  - Produces in the error case a quite challenging to understand error message (when no concepts are used).

strategizedLockingRuntime.cpp
strategizedLockingCompileTimeWithConcepts.cpp

Thread-Save Interface

The thread-save interface extends the critical region to an object.

- Antipattern: Each member function uses a lock internally.
  - The performance of the system goes down.
  - Deadlocks appear when two member functions call each other.

Thread-Save Interface

A deadlock due to entangled calls.

```
struct Critical{
    void method1(){
        std::lock_guard l(mut);
        method2();
        . . .
    }
    void method2(){
        std::lock_guard l(mut);
        . . .
    }
    std::mutex mut;
}
```

```
int main(){
    Critical crit;
    crit.method1();
}
```

Thread-Save Interface

- Solutions:
  - All interface member functions (`public`) use a lock.
  - All implementation member functions (`protected` and `private`) must not use a lock.
  - The interface member functions call only implementation member functions.

[threadSafeInterface.cpp]()

Guarded Suspension

A guarded suspension consists of a lock and a condition. The condition has to be fulfilled by the calling thread.

- The calling thread will put itself to sleep if the condition is not meet.
- The calling thread uses a lock when it checks the condition.
- The lock protects the calling thread from a data race or deadlock.

Guarded Suspension

- Guarded suspension enables thread synchronization. It is available in many variations.
  - The waiting thread is notified about the state change or asks for the state change.
    - Push principle: condition variables, future/promise pairs, atomics, latches and barriers, or semaphores
    - Pull principle: not natively supported in C++
  - The waiting thread waits with or without a time limit.
    - Condition variables, or future/promise pairs
  - The notification is sent to one or all waiting threads.
    - Shared futures, condition variables, atomics, latches and barriers, or semaphores

bossWorkerFuturePromise.cpp
bossWorkerLatch.cpp

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Active Object

The active object pattern separates the method execution from the method invocation.

- Each object owns its own thread.
- Each method invocation is stored in an activation list.
- A scheduler triggers the method execution.

Active Object

Proxy:

- Proxy for the member functions on the active object
- Triggers the construction of a request object which goes to the activation list and returns a future.
- It runs in the client thread.

Method Request

- Includes all context information to be executed later.

Activation List:

- Has the pending requests objects.
- Decouples the client from the Active Object thread.

Scheduler:

- Runs in the thread of the Active Object.
- Decides with request from the Activation List is executes.

Active Object

- Servant:
  - Implements the member functions of the active objects.
  - Supports the interface of the Proxy.

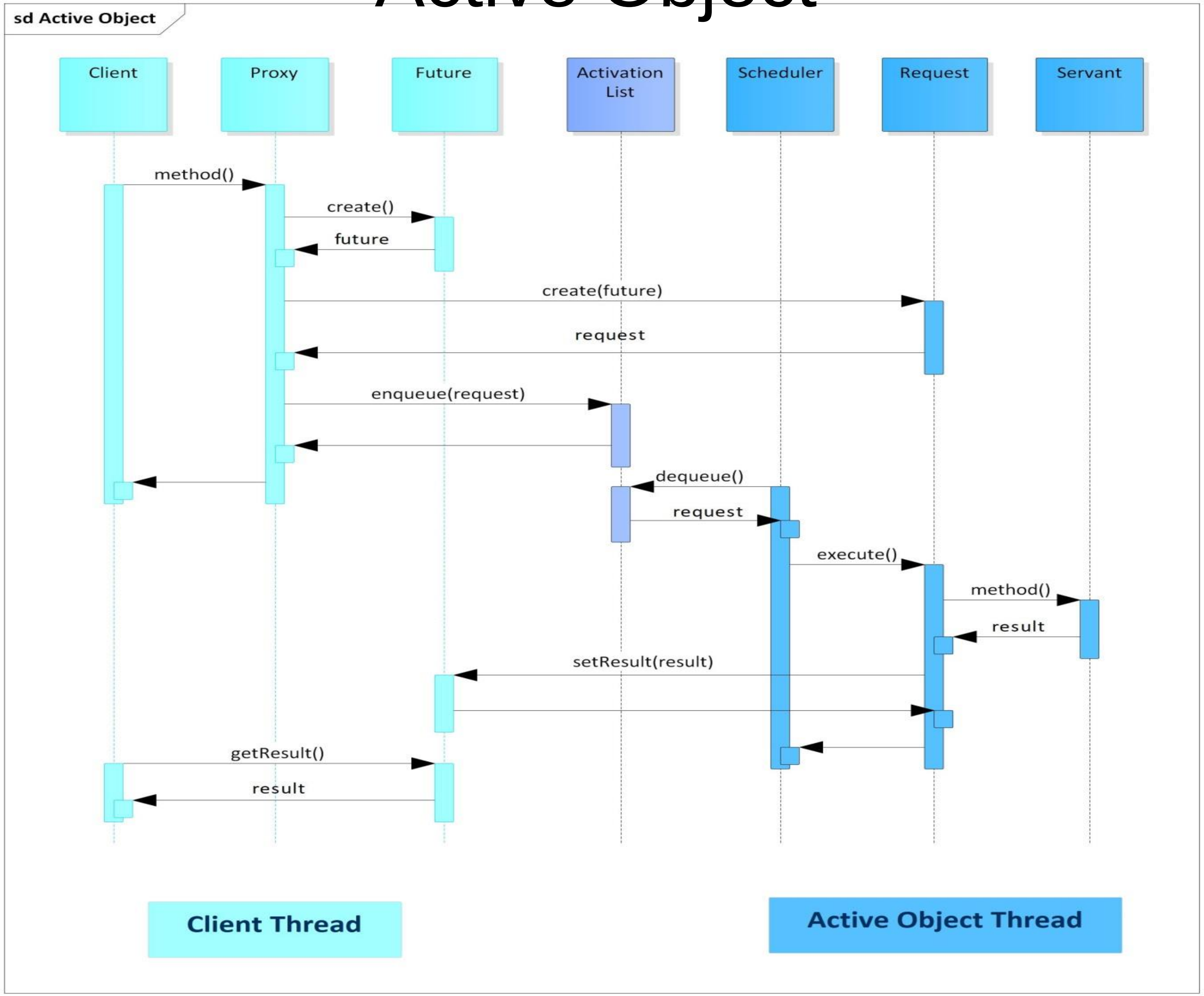
- Future:
  - Is created by the Proxy.
  - Is only necessary if the request objects returns a result.
  - The client uses the future to get the result of the request object.

Active Object

Dynamic Behavior

1. Request construction and scheduling:
   - The client invokes the method on the proxy.
   - The proxy creates a request and passes it to the scheduler.
   - The scheduler enqueues the request on the activation list and returns a future to the client if the request returns something.
2. Member function execution
   - The scheduler determines which request becomes runnable.
   - It removes the request from the activation list and dispatches it to the servant.
3. Completion:
   - Stores eventually the result of the request object in the future.
   - Destructs the request object and the future if the client has the result.

Active Object



Active Object

Advantages:

- Only the access to the activation list has to be synchronized
- Clear separation of client and server
- Improved throughput due to the asynchronous execution
- The scheduler can use various execution policies.

Disadvantages:

- If the member function execution is too fine-grained, the indirection may cause significant overhead.
- The asynchronous member function execution and the various execution strategies make the system quite difficult to debug.

activeObject.cpp

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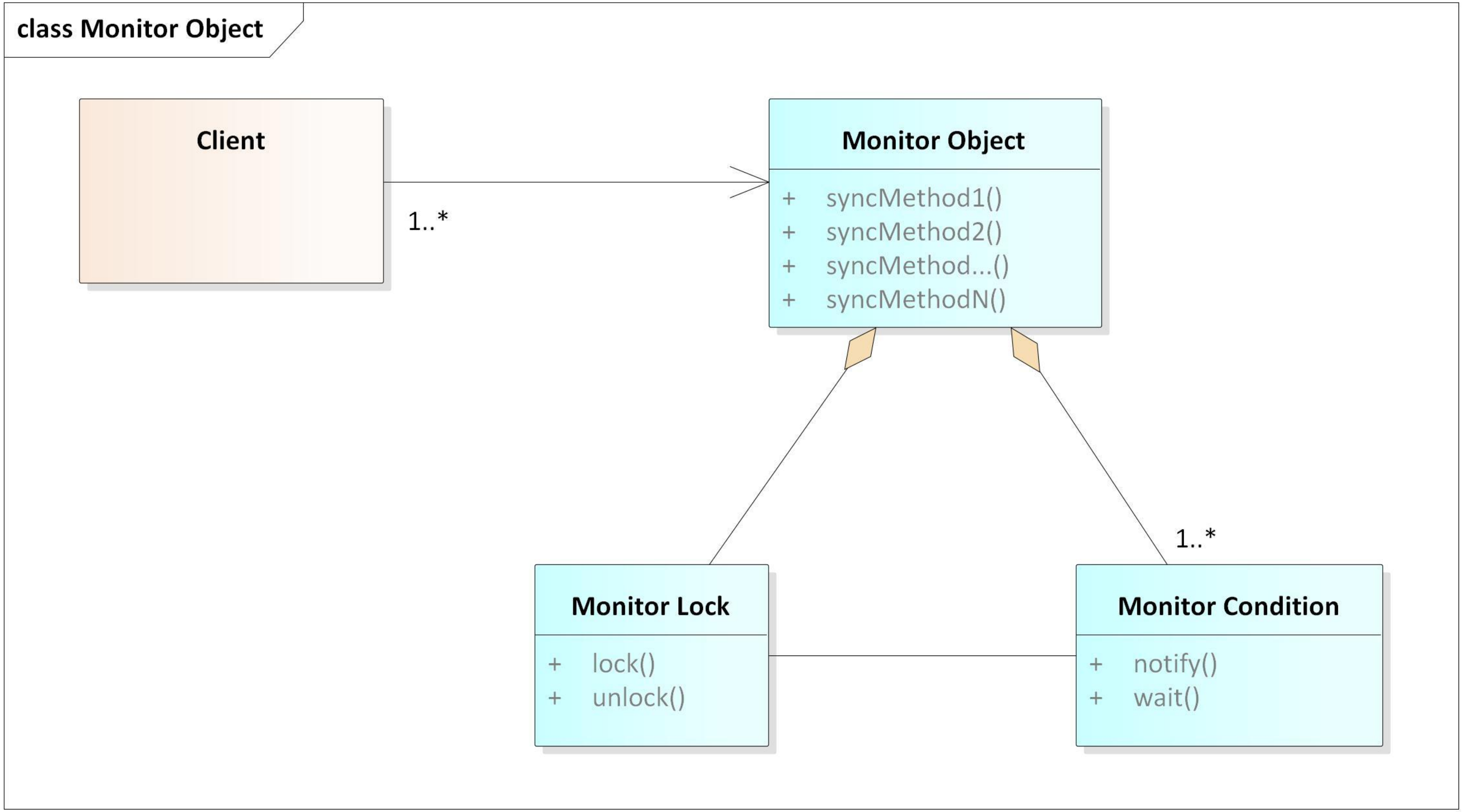
Monitor Object

The monitor object synchronizes the access to an object so that at most one member function can run at any time.

- Each object has a monitor lock and a monitor condition.
- The monitor lock guarantees that only one client can execute a member function of the object.
- The monitor condition notifies the waiting clients.

Monitor Object



Monitor Object

Monitor Object:

- Support member functions, which can run in the thread of the client.

Synchronized Methods:

- Interface member functions of the monitor object.
- At most, one member function can run at any time
- The member functions should apply the thread-safe interface pattern.

Monitor Lock:

- Each monitor object has a monitor lock.
- Guarantees exclusive access to the member functions.

Monitor Condition:

- Allows various threads to store their member function invocation.
- When the current thread is done with its member function execution, the next thread is awoken.

Monitor Object

Advantages:

- The synchronization is encapsulated in the implementation.
- The member function execution is automatically stored and performed.
- The monitor object is a simple scheduler.

Disadvantages:

- The synchronization mechanism and the functionality are strongly coupled and can, therefore, not easily be changed.
- When the synchronized member functions invoke an additional member function of the monitor object, a deadlock may happen.

monitorObject.cpp

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