Design Patterns in C++

Concurrency Patterns

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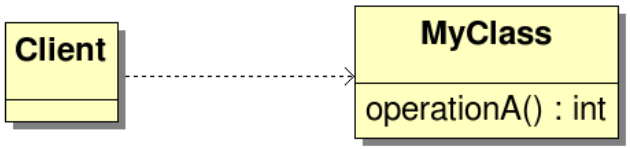
Outline

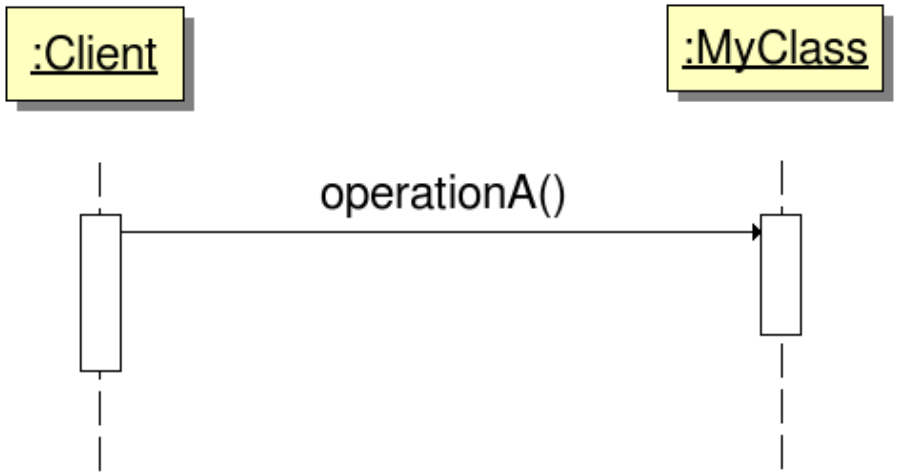
Problem

- Suppose we want to design a simple server
  - Clients send processing requests to the server gateway
  - The requests are processed according to their type
  - While the server processes, clients should not be blocked
- In other words, we want to implement an asynchronous method call:
  - The client “sends” a request to the server and then continues its processing
  - The server starts processing the request concurrently with the clients
  - when the server completes the request, the result is stored so that it can be read later by the client

Synchronous method call

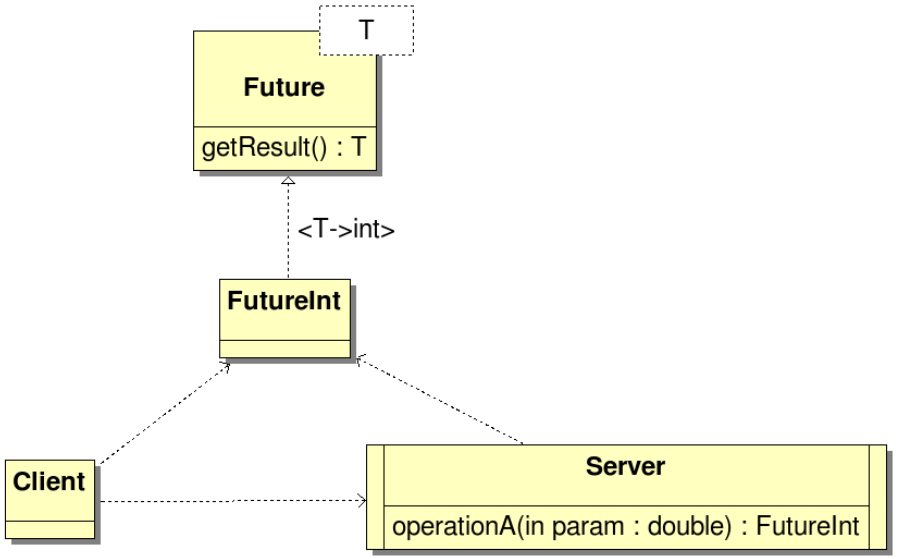
- In a synchronous method call, there is only one thread of flow control: the client one
- the client code can continue only when the function call returns

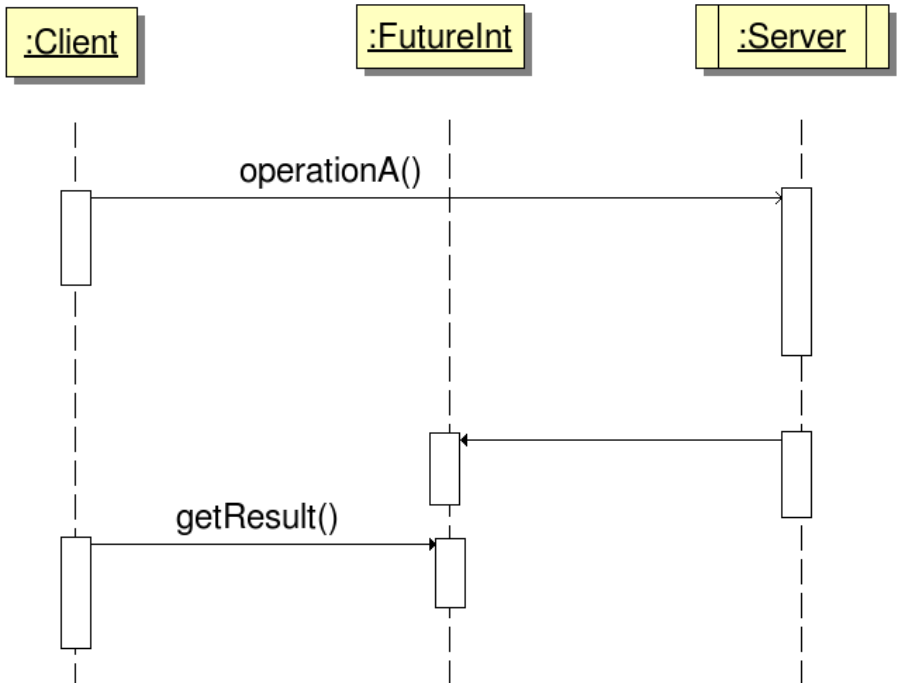




Asynchronous method call

- in an asynchronous method call, both the client and the object have their own thread of flow control
- when a client calls a method on the object, it is actually sending a message, and after that it can continue its execution
- when it wants to get the result, it synchronises on the `Future` that contains the result





Active Object

The Active Object design pattern decouples method execution from method invocation for an object

- Method invocation should occur in the client's thread of control
- Method execution occurs in the Active Object's thread of control
- Design should make this transparent: it should appear as the client is invoking and ordinary synchronous method

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- Design should make this transparent: it should appear as the client is invoking and ordinary synchronous method
- To solve the latter problem, we must apply the "proxy" pattern

Pattern Components

- **A proxy**
  - Provides an interface to the client, with regular methods
- **A method request**
  - A hierarchy of classes that models client requests
  - We need one for each public method in the proxy
- **An activation list**
  - Contains the method requests object
- **A scheduler**
  - Decides with request must be processed next
- **A servant**
  - Processes the requests
- **A future**
  - Contains the response

Proxy

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Proxy

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- it is an ordinary object
- however, it does not processes requests, but transforms each request (method call) into an appropriate “method request” object, which is then inserted into the “activation list”
- it also prepares a *future*, that is an object that will contain the method return value (once the processing is complete)
- the *future* is initially empty, and it is returned back to the client

Method requests

- A hierarchy of classes, each one models one request
- A method request encodes the method parameters, and contains a reference to a future (for the response)
- it may also contain other specific fields (e.g. priority, preconditions, etc.)
- The proxy creates method requests, and insert them into the activation list, according to some policy

Scheduler and Activation List

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  - It will be shared between the client's thread and the scheduler's thread
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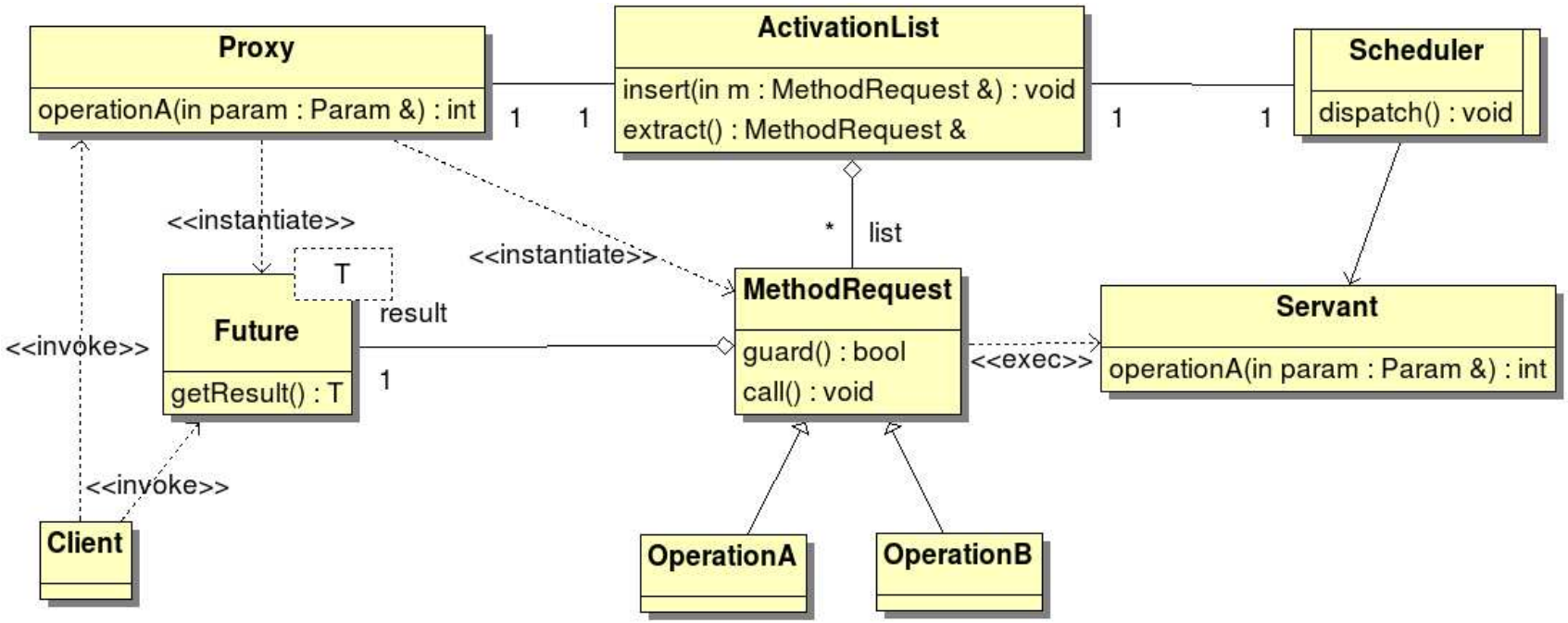
  - It can be implemented using the *Monitor pattern*
- the Scheduler is a thread that extracts requests from the activation list and executes them by calling the servant's methods
- The processing order can be customised
  - For example, according to a FIFO order, or based on priority
  - The scheduler also checks the *guards* on the request (i.e. conditions that must be true before a method can be executed)
  - It is useful to define a specific separate class for defining the order, according to the *strategy pattern*
  - In this way, the list can be easily customized with a user-defined scheduling policy

The Servant

- It has the same interface of the Proxy, and it implements the actual methods
- It can also implement *guard methods* that are used by the method request object to understand if they can actually be processed

Class diagram



Dynamics

- A Client invokes a method on the Proxy
  - the proxy creates a concrete method request,
  - binds the method's parameters to it
  - if necessary, creates a future and binds it to the request
  - inserts the request into the activation list
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Dynamics

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  - inserts the request into the activation list
  - if necessary, returns the reference to the future
- The scheduler monitors the activation list
  - it calls extract() in a loop, and it blocks if the queue is empty
  - when the extract returns a request object, it first checks the conditions, by calling the `guard()` method
    - this is resolved by calling the preconditions methods on the servant
  - if the response is `true`, the scheduler runs it by calling method `call()`
    - this is resolved into a method call to the servant object, the result is stored in the future
  - if the response is negative, the request is enqueued again in the list
  - when no other request is *runnable*, the scheduler suspends itself

Implementation

- It is convenient to start implementing and testing the Servant object
  - In this way we can test the functionality separately
  - There is no need to implement synchronisation in the Servant, because its methods will be automatically serialised by the Scheduler
  - In other words, all its methods are called by a single thread, the Scheduler
  - However, we have to export part of the state through appropriate *getter* methods, so that we can implement the “guards” in the request objects
  - these are equivalent to the blocking conditions in a monitor
  - also, they are “equivalent” to guards in the Rendez-vous interactions of Ada

Implementing the method requests

- Method requests are similar to the *Command pattern*
  - they encode commands with their parameters and results
  - they also implement *guards*
  - they contain a reference to the Servant
- A base class `MethodRequest` implements the basic methods for checking the guards and executing the request
  - they are declared as pure virtual functions, and will be implemented in the concrete classes
  - the concrete classes also are in charging of storing the parameters and the future
- Notice that requests are created by the Proxy, but will be destructed by the Scheduler
  - For safety, it may be the case to wrap them inside smart pointers (e.g. `shared_ptr<>`), to avoid memory leaks or memory corruption due to exceptions and border cases

Proxy

- It simply creates the method requests
- It may use a factory pattern (for example, factory method, or abstract factory) for the purpose
- if it can be called by several concurrent clients, it may need to be synchronised (especially if it uses a single factory)
  - a simple mutex is sufficient
  - to generalize, we can use a *strategized locking* pattern, so that the Proxy can be configured with a regular mutex, or with a null mutex (when used by only one client), thus reducing overhead
- after creating the request, it inserts it into the Activation List

Activation List

- The Activation List is a queue of requests
  - It needs to be synchronised because there are at least two threads using it: the client and the scheduler's thread
  - usually implemented using the *monitor pattern*
- when the list is full we can:
  - Block the client (with or without timeout)
  - return an error
  - raise an exception (will be caught in the client's thread)
- The scheduler may need to go through the list to find the first *runnable* request
  - Therefore, we should let it iterate through the list and invoke the `guard()` method on every request until it finds a "good" one

Future

- The future needs to implement a *rendez-vous* policy
  - The client that calls the `getResult()` method too soon will be blocked waiting for the result to become ready
  - it will be unblocked when the result has been computed by the servant
  - it's the request object responsibility to fill the result and unblock the client
- in practice, a future is a single-buffer synchronized queue that is used once
  - however, we must be careful with its lifetime
  - the future is created by the proxy as an "empty" buffer and returned to the client
  - the client becomes the "owner" of the future (the one responsible for its deallocation)
  - however, the pointer to the future is also used by the request object to store the result
  - to deal with corner-cases (exceptions, errors, etc.) without memory corruption and memory leaks, we should use a smart pointer

Outline

Implementation of Active Object

- The Active Object pattern requires the implementation of many classes
  - In particular, for every operation on the Servant (and on the Proxy), a Message Request class must be prepared
  - every such class must encode all the parameters of the operation and maintain a future, and call the appropriate Servant operation
- this is a lot of code, that must be written and tested
- It is also “boring code”, that could be made automatic
- it is a candidate for “code generation tools”
  - Even code generators like Rapsody require the programmer to “draw” classes, operations and attributes
- another way of generating code it through C++ templates

How to implement the request classes

- If we want to automatize the production of request classes, we could take advantage of type lists
  - We can use type lists to specify a certain number of parameters for the constructor of the request class
  - We can also use templates for generating calls to the Servant object