# Reactor

An Object Behavioral Pattern for
Demultiplexing and Dispatching Handles for Synchronous Events

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## 1 Intent

The Reactor design pattern handles service requests that are delivered concurrently to an application by one or more clients. Each service in an application may consist of serveral methods and is represented by a separate event handler that is responsible for dispatching service-specific requests. Dispatching of event handlers is performed by an initiation dispatcher, which manages the registered event handlers. Demultiplexing of service requests is performed by a synchronous event demultiplexer.

## 2 Also Known As

Dispatcher, Notifier

## 3 Example

To illustrate the Reactor pattern, consider the event-driven server for a distributed logging service shown in Figure 1. Client applications use the logging service to record information about their status in a distributed environment. This status information commonly includes error notifications, debugging traces, and performance reports. Logging records are sent to a central logging server, which can write the records to various output devices, such as a console, a printer, a file, or a network management database.

The logging server shown in Figure 1 handles logging records and connection requests sent by clients. Logging records and connection requests can arrive concurrently on multiple *handles*. A handle identifies network communication resources managed within an OS.

The logging server communicates with clients using a connection-oriented protocol, such as TCP [1]. Clients that want to log data must first send a connection request to the server. The server waits for these connection requests using a *handle factory* that listens on an address known to clients. When a connection request arrives, the handle factory establishes a connection between the client and the server by creating a new handle that represents an endpoint of the connection. This handle is returned to the server, which then waits for client service requests to arrive on the handle. Once clients are connected, they can send logging records concurrently to the server. The server receives these records via the connected socket handles.

Perhaps the most intuitive way to develop a concurrent logging server is to use multiple threads that can process multiple clients concurrently, as shown in Figure 2. This approach synchronously accepts network connections and spawns a "thread-per-connection" to handle client logging records.

However, using multi-threading to implement the processing of logging records in the server fails to resolve the following forces:

- **Efficiency:** Threading may lead to poor performance due to context switching, synchronization, and data movement [2];

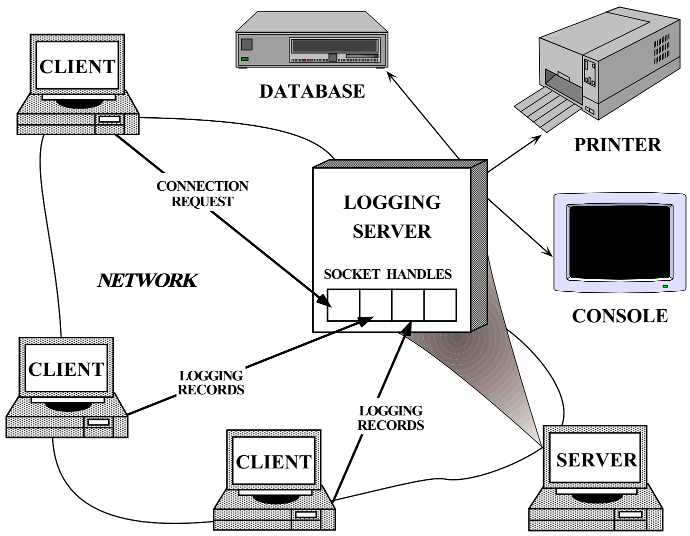



Figure 1: Distributed Logging Service

[1] This work was supported in part by a grant by Siemens.

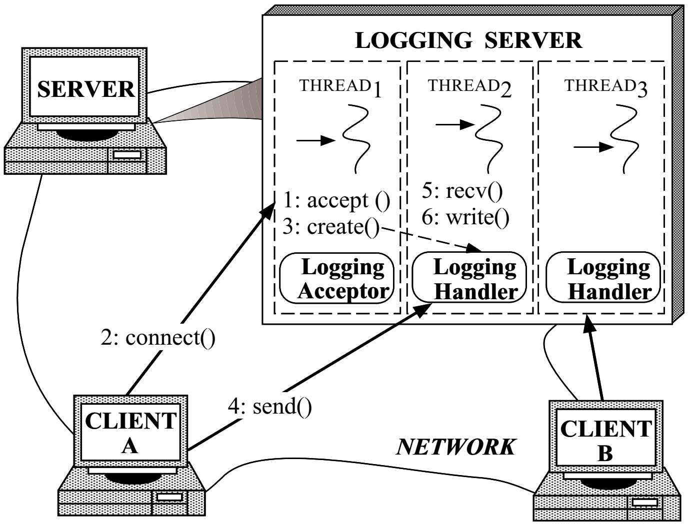



Figure 2: Multi-threaded Logging Server

• **Programming simplicity:** Threading may require complex concurrency control schemes;

• **Portability:** Threading is not available on all OS platforms.

As a result of these drawbacks, multi-threading is often not the most efficient nor the least complex solution to develop a concurrent logging server.

# 4 Context

A server application in a distributed system that receives events from one or more clients concurrently.

# 5 Problem

Server applications in a distributed system must handle multiple clients that send them service requests. Before invoking a specific service, however, the server application must demultiplex and dispatch each incoming request to its corresponding service provider. Developing an effective server mechanisms for demultiplexing and dispatching client requests requires the resolution of the following forces:

• **Availability:** The server must be available to handle incoming requests even if it is waiting for other requests to arrive. In particular, a server must not block indefinitely handling any single source of events at the exclusion of other event sources since this may significantly delay the responseness to other clients.

• **Efficiency:** A server must minimize latency, maximize throughput, and avoid utilizing the CPU(s) unnecessarily.

• **Programming simplicity:** The design of a server should simplify the use of suitable concurrency strategies.

• **Adaptability:** Integrating new or improved services, such as changing message formats or adding server-side caching, should incur minimal modifications and maintenance costs for existing code. For instance, implementing new application services should not require modifications to the generic event demultiplexing and dispatching mechanisms.

• **Portability:** Porting a server to a new OS platform should not require significant effort.

# 6 Solution

Integrate the synchronous demultiplexing of events and the dispatching of their corresponding event handlers that process the events. In addition, decouple the application-specific dispatching and implementation of services from the general-purpose event demultiplexing and dispatching mechanisms.

For each service the application offers, introduce a separate `Event Handler` that processes certain types of events. All `Event Handlers` implement the same interface. `Event Handlers` register with an `Initiation Dispatcher`, which uses a `Synchronous Event Demultiplexer` to wait for events to occur. When events occur, the `Synchronous Event Demultiplexer` notifies the `Initiation Dispatcher`, which synchronously calls back to the `Event Handler` associated with the event. The `Event Handler` then dispatches the event to the method that implements the requested service.

# 7 Structure

The key participants in the Reactor pattern include the following:

**Handles**

- Identify resources that are managed by an OS. These resources commonly include network connections, open files, timers, synchronization objects, etc. `Handles` are used in the logging server to identify socket endpoints so that a `Synchronous Event Demultiplexer` can wait for events to occur on them. The two types of events the logging server is interested in are *connection* events and *read* events, which represent incoming client connections and logging data, respectively. The logging server maintains a separate connection for each client. Every connection is represented in the server by a socket `handle`.

**Synchronous Event Demultiplexer**

- Blocks awaiting events to occur on a set of `Handles`. It returns when it is possible to initiate an operation on a `Handle` without blocking. A common demultiplexer for I/O events is `select` [1], which is an event demultiplexing system call provided by the UNIX and Win32 OS platforms. The `select` call indicates which

Handles can have operations invoked on them synchronously without blocking the application process.

**Initiation Dispatcher**

- Defines an interface for registering, removing, and dispatching Event Handlers. Ultimately, the Synchronous Event Demultiplexer is responsible for waiting until new events occur. When it detects new events, it informs the Initiation Dispatcher to call back application-specific event handlers. Common events include connection acceptance events, data input and output events, and timeout events.

**Event Handler**

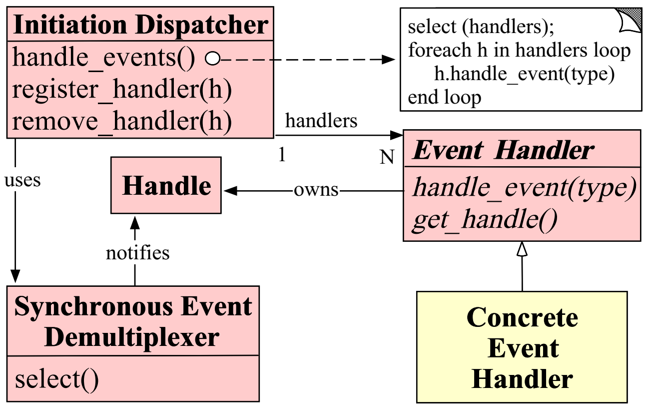
- Specifies an interface consisting of a hook method [3] that abstractly represents the dispatching operation for service-specific events. This method must be implemented by application-specific services.

**Concrete Event Handler**

- Implements the hook method, as well as the methods to process these events in an application-specific manner. Applications register Concrete Event Handlers with the Initiation Dispatcher to process certain types of events. When these events arrive, the Initiation Dispatcher calls back the hook method of the appropriate Concrete Event Handler.

  There are two Concrete Event Handlers in the logging server: Logging Handler and Logging Acceptor. The Logging Handler is responsible for receiving and processing logging records. The Logging Acceptor creates and connects Logging Handlers that process subsequent logging records from clients.

The structure of the participants of the Reactor pattern is illustrated in the following OMT class diagram:




# 8 Dynamics

## 8.1 General Collaborations

The following collaborations occur in the Reactor pattern:

- When an application registers a Concrete Event Handler with the Initiation Dispatcher the application indicates the type of event(s) this Event Handler wants the Initiation Dispatcher to notify it about when the event(s) occur on the associated Handle.

- The Initiation Dispatcher requests each Event Handler to pass back its internal Handle. This Handle identifies the Event Handler to the OS.

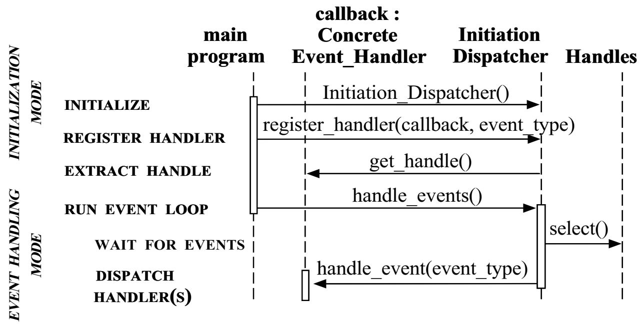
- After all Event Handlers are registered, an application calls handle_events to start the Initiation Dispatcher's event loop. At this point, the Initiation Dispatcher combines the Handle from each registered Event Handler and uses the Synchronous Event Demultiplexer to wait for events to occur on these Handles. For instance, the TCP protocol layer uses the select synchronous event demultiplexing operation to wait for client logging record events to arrive on connected socket Handles.

- The Synchronous Event Demultiplexer notifies the Initiation Dispatcher when a Handle corresponding to an event source becomes "ready," *e.g.*, that a TCP socket is "ready for reading."

- The Initiation Dispatcher triggers Event Handler hook method in response to events on the ready Handles. When events occur, the Initiation Dispatcher uses the Handles activated by the event sources as "keys" to locate and dispatch the appropriate Event Handler's hook method.

- The Initiation Dispatcher calls back to the handle_event hook method of the Event Handler to perform application-specific functionality in response to an event. The type of event that occurred can be passed as a parameter to the method and used internally by this method to perform additional service-specific demultiplexing and dispatching. An alternative dispatching approach is described in Section 9.4.

The following interaction diagram illustrates the collaboration between application code and participants in the Reactor pattern:

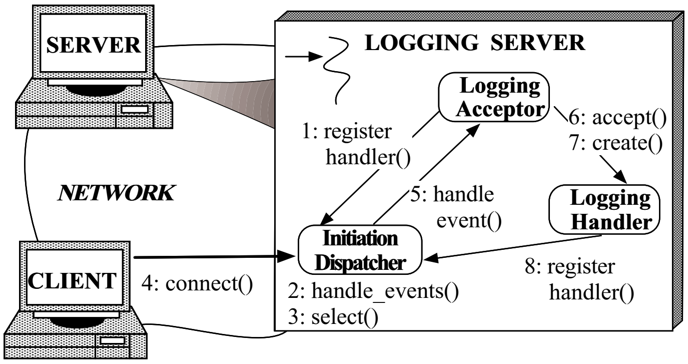



## 8.2 Collaboration Scenarios

The collaborations within the Reactor pattern for the logging server can be illustrated with two scenarios. These scenarios show how a logging server designed using reactive event dispatching handles connection requests and logging data from multiple clients.

### 8.2.1 Client Connects to a Reactive Logging Server

The first scenario shows the steps taken when a client connects to the logging server.

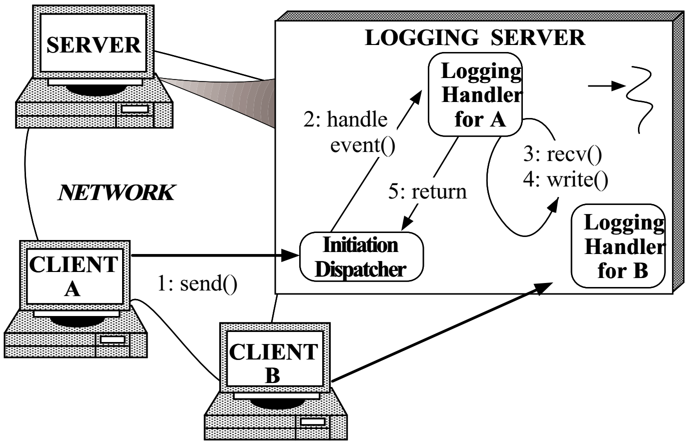



This sequence of steps can be summarized as follows:

1. The logging server (1) registers the `Logging Acceptor` with the `Initiation Dispatcher` to handle connection requests;
2. The logging server invokes the `handle_events` method (2) of the `Initiation Dispatcher`;
3. The `Initiation Dispatcher` invokes the synchronous event demultiplexing `select` (3) operation to wait for connection requests or logging data to arrive;
4. A client connects (4) to the logging server;
5. The `Logging Acceptor` is notified by the `Initiation Dispatcher` (5) of the new connection request;
6. The `Logging Acceptor` accepts (6) the new connection;
7. The `Logging Acceptor` creates (7) a `Logging Handler` to service the new client;
8. `Logging Handler` registers (8) its socket handle with the `Initiation Dispatcher` and instructs the dispatcher to notify it when the socket becomes "ready for reading."

### 8.2.2 Client Sends Logging Record to a Reactive Logging Server

The second scenario shows the sequence of steps that the reactive logging server takes to service a logging record.




This sequence of steps can be summarized as follows:

1. The client sends (1) a logging record;
2. The `Initiation Dispatcher` notifies (2) the associated `Logging Handler` when a client logging record is queued on its socket handle by OS;
3. The record is received (3) in a non-blocking manner (steps 2 and 3 repeat until the logging record has been received completely);
4. The `Logging Handler` processes the logging record and writes (4) it to the standard output.
5. The `Logging Handler` returns (5) control to the `Initiation Dispatcher`'s event loop.

# 9 Implementation

This section describes how to implement the Reactor pattern in C++. The implementation described below is influenced by the reusable components provided in the ACE communication software framework [2].

## 9.1 Select the Synchronous Event Demultiplexer Mechanism

The `Initiation Dispatcher` uses a `Synchronous Event Demultiplexer` to wait synchronously until one or more events occur. This is commonly implemented using an OS event demultiplexing system call like `select`. The `select` call indicates which `Handle`(s) are ready to perform I/O operations without blocking the OS process in which the application-specific service handlers reside. In general, the `Synchronous Event Demultiplexer` is based upon existing OS mechanisms, rather than developed by implementers of the Reactor pattern.

## 9.2 Develop an Initiation Dispatcher

The following are the steps necessary to develop the `Initiation Dispatcher`:

**Implement the Event Handler table:** A `Initiation Dispatcher` maintains a table of `Concrete Event Handlers`. Therefore, the `Initiation Dispatcher` provides methods to register and remove the handlers from this table at run-time. This table can be implemented in various ways, *e.g.*, using hashing, linear search, or direct indexing if handles are represented as a contiguous range of small integral values.

**Implement the event loop entry point:** The entry point into the event loop of the `Initiation Dispatcher` should be provided by a `handle_events` method. This method controls the `Handle` demultiplexing provided by the `Synchronous Event Demultiplexer`, as well as performing `Event Handler` dispatching. Often, the main event loop of the entire application is controlled by this entry point.

When events occur, the `Initiation Dispatcher` returns from the synchronous event demultiplexing call and "reacts" by dispatching the `Event Handler`'s `handle_event` hook method for each handle that is "ready." This hook method executes user-defined code and returns control to the `Initiation Dispatcher` when it completes.

The following C++ class illustrates the core methods on the `Initiation Dispatcher's` public interface:

```
enum Event_Type
  // = TITLE
  //    Types of events handled by the
  //    Initiation_Dispatcher.
  //
  // = DESCRIPTION
  //    These values are powers of two so
  //    their bits can be efficiently ``or'd''
  //    together to form composite values.
{
  ACCEPT_EVENT = 01,
  READ_EVENT = 02,
  WRITE_EVENT = 04,
  TIMEOUT_EVENT = 010,
  SIGNAL_EVENT = 020,
  CLOSE_EVENT = 040
};

class Initiation_Dispatcher
  // = TITLE
  //     Demultiplex and dispatch Event_Handlers
  //     in response to client requests.
{
public:
  // Register an Event_Handler of a particular
  // Event_Type (e.g., READ_EVENT, ACCEPT_EVENT,
  // etc.).
  int register_handler (Event_Handler *eh,
                        Event_Type et);

  // Remove an Event_Handler of a particular
  // Event_Type.
  int remove_handler (Event_Handler *eh,
                      Event_Type et);

  // Entry point into the reactive event loop.
  int handle_events (Time_Value *timeout = 0);
};
```

**Implement the necessary synchronization mechanisms:** If the Reactor pattern is used in an application with only one thread of control it is possible to eliminate all synchronization. In this case, the `Initiation Dispatcher` serializes the `Event Handler` `handle_event` hooks within the application's process.

However, the `Initiation Dispatcher` can also serve as a central event dispatcher in multi-threaded applications. In this case, critical sections within the `Initiation Dispatcher` must be serialized to prevent race conditions when modifying or activating shared state variables (such as the table holding the `Event Handlers`). A common technique for preventing race conditions uses mutual exclusion mechanisms like semaphores or mutex variables.

To prevent self-deadlock, mutual exclusion mechanisms can use *recursive locks* [4]. Recursive locks hold prevent deadlock when locks are held by the same thread across `Event Handler` hook methods within the `Initiation Dispatcher`. A recursive lock may be re-acquired by the thread that owns the lock *without* blocking the thread. This property is important since the Reactor's `handle_events` method calls back on application-specific `Event Handlers`. Application hook method code may subsequently re-enter the `Initiation Dispatcher` via its `register_handler` and `remove_handler` methods.

## 9.3 Determine the Type of the Dispatching Target

Two different types of `Event Handlers` can be associated with a `Handle` to serve as the target of an `Initiation Dispatcher`'s dispatching logic. Implementations of the Reactor pattern can choose either one or both of the following dispatching alternatives:

**Event Handler objects:** A common way to associate an `Event Handler` with a `Handle` is to make the `Event Handler` an object. For instance, the Reactor pattern implementation shown in Section 7 registers `Event Handler` subclass objects with an `Initiation Dispatcher`. Using an object as the dispatching target makes it convenient to subclass `Event Handlers` in order to reuse and extend existing components. In addition, objects integrate the state and methods of a service into a single component.

**Event Handler functions:** Another way to associate an `Event Handler` with a `Handle` is to register a function with the `Initiation Dispatcher`. Using functions as the dispatching target makes it convenient to register callbacks without having to define a new class that inherits from `Event Handler`.

The Adapter pattern [5] be employed to support both objects and functions simultaneously. For instance, an adapter could be defined using an event handler object that holds a pointer to an event handler function. When the `handle_event` method was invoked on the event handler adapter object, it could automatically forward the call to the event handler function that it holds.

## 9.4 Define the Event Handling Interface

Assuming that we use `Event Handler` objects rather than functions, the next step is to define the interface of the `Event Handler`. There are two approaches:

**A single-method interface:** The OMT diagram in Section 7 illustrates an implementation of the `Event Handler` base class interface that contains a single method, called `handle_event`, which is used by the `Initiation Dispatcher` to dispatch events. In this case, the type of the event that has occurred is passed as a parameter to the method.

The following C++ abstract base class illustrates the single-method interface:

```
class Event_Handler
  // = TITLE
  //   Abstract base class that serves as the
  //   target of the Initiation_Dispatcher.
{
public:
  // Hook method that is called back by the
  // Initiation_Dispatcher to handle events.
  virtual int handle_event (Event_Type et) = 0;

  // Hook method that returns the underlying
  // I/O Handle.
  virtual Handle get_handle (void) const = 0;
};
```

The advantage of the single-method interface is that it is possible to add new types of events without changing the interface. However, this approach encourages the use of switch statements in the subclass's `handle_event` method, which limits its extensibility.

**A multi-method interface:** Another way to implement the `Event Handler` interface is to define separate virtual hook methods for each type of event (such as `handle_input`, `handle_output`, or `handle_timeout`).

The following C++ abstract base class illustrates the single-method interface:

```
class Event_Handler
{
public:
  // Hook methods that are called back by
  // the Initiation_Dispatcher to handle
  // particular types of events.
  virtual int handle_accept (void) = 0;
  virtual int handle_input (void) = 0;
  virtual int handle_output (void) = 0;
  virtual int handle_timeout (void) = 0;
  virtual int handle_close (void) = 0;

  // Hook method that returns the underlying
  // I/O Handle.
  virtual Handle get_handle (void) const = 0;
};
```

The benefit of the multi-method interface is that it is easy to selectively override methods in the base class and avoid further demultiplexing, *e.g.,* via `switch` or `if` statements, in the hook method. However, it requires the framework developer to anticipate the set of `Event Handler` methods in advance. For instance, the various `handle_*` methods in the `Event_Handler` interface above are tailored for I/O events available through the UNIX `select` mechanism. However, this interface is not broad enough to encompass all the types of events handled via the Win32 `WaitForMultipleObjects` mechanism [6].

Both approaches described above are examples of the hook method pattern described in [3] and the Factory Callback pattern described in [7]. The intent of these patterns is to provide well-defined hooks that can be specialized by applications and called back by lower-level dispatching code.

## 9.5 Determine the Number of Initiation Dispatchers in an Application

Many applications can be structured using just one instance of the Reactor pattern. In this case, the `Initiation Dispatcher` can be implemented as a Singleton [5]. This design is useful for centralizing event demultiplexing and dispatching into a single location within an application.

However, some operating systems limit the number of `Handles` that can be waited for within a single thread of control. For instance, Win32 allows `select` and `WaitForMultipleObjects` to wait for no more than 64 `Handles` in a single thread. In this case, it may be necessary to create multiple threads, each of which runs its own instance of the Reactor pattern.

Note that `Event Handlers` are only serialized *within* an instance of the Reactor pattern. Therefore, multiple `Event Handlers` in multiple threads can run in parallel. This configuration may necessitate the use of additional synchronization mechanisms if `Event Handlers` in different threads access shared state.

## 9.6 Implement the Concrete Event Handlers

The concrete event handlers are typically created by application developers to perform specific services in response to particular events. The developers must determine what processing to perform when the corresponding hook method is invoked by the initiation dispatcher.

The following code implements the `Concrete Event Handlers` for the logging server described in Section 3. These handlers provide *passive connection establishment* (`Logging Acceptor`) and *data reception* (`Logging Handler`).

**The Logging Acceptor class:** This class is an example of the `Acceptor` component of the Acceptor-Connector pattern [8]. The Acceptor-Connector pattern decouples the task of service initialization from the tasks performed after a service is initialized. This pattern enables the application-specific portion of a service, such as the `Logging Handler`, to vary independently of the mechanism used to establish the connection.

A `Logging Acceptor` passively accepts connections from client applications and creates client-specific `Logging Handler` objects, which receive and process logging records from clients. The key methods and data members in the `Logging Acceptor` class are defined below:

```
class Logging_Acceptor : public Event_Handler
  // = TITLE
  //    Handles client connection requests.
{
public:

  // Initialize the acceptor_ endpoint and
  // register with the Initiation Dispatcher.
  Logging_Acceptor (const INET_Addr &addr);

  // Factory method that accepts a new
  // SOCK_Stream connection and creates a
  // Logging_Handler object to handle logging
  // records sent using the connection.
  virtual void handle_event (Event_Type et);

  // Get the I/O Handle (called by the
  // Initiation Dispatcher when
  // Logging_Acceptor is registered).
  virtual HANDLE get_handle (void) const
  {
    return acceptor_.get_handle ();
  }

private:
  // Socket factory that accepts client
  // connections.
  SOCK_Acceptor acceptor_;
};
```

The `Logging Acceptor` class inherits from the `Event Handler` base class. This enables an application to register the `Logging Acceptor` with an `Initiation Dispatcher`.

The `Logging Acceptor` also contains an instance of `SOCK Acceptor`. This is a concrete factory that enables the `Logging Acceptor` to accept connection requests on a passive mode socket that is listening to a communication port. When a connection arrives from a client, the `SOCK Acceptor` accepts the connection and produces a `SOCK Stream` object. Henceforth, the `SOCK Stream` object is used to transfer data reliably between the client and the logging server.

The `SOCK Acceptor` and `SOCK Stream` classes used to implement the logging server are part of the C++ socket wrapper library provided by ACE [9]. These socket wrappers encapsulate the `SOCK Stream` semantics of the socket interface within a portable and type-secure object-oriented interface. In the Internet domain, `SOCK Stream` sockets are implemented using TCP.

The constructor for the `Logging Acceptor` registers itself with the `Initiation Dispatcher` Singleton [5] for ACCEPT events, as follows:

```
Logging_Acceptor::Logging_Acceptor
  (const INET_Addr &addr)
    : acceptor_ (addr)
{
  // Register acceptor with the Initiation
  // Dispatcher, which "double dispatches"
  // the Logging_Acceptor::get_handle() method
  // to obtain the HANDLE.
  Initiation_Dispatcher::instance ()->
    register_handler (this, ACCEPT_EVENT);
}
```

Henceforth, whenever a client connection arrives, the `Initiation Dispatcher` calls back to the `Logging Acceptor`'s `handle_event` method, as shown below:

```
void
Logging_Acceptor::handle_event (Event_Type et)
{
  // Can only be called for an ACCEPT event.
  assert (et == ACCEPT_EVENT);

  SOCK_Stream new_connection;

  // Accept the connection.
  acceptor_.accept (new_connection);

  // Create a new Logging Handler.
  Logging_Handler *handler =
    new Logging_Handler (new_connection);
}
```

The `handle_event` method invokes the `accept` method of the `SOCK Acceptor` to passively establish a `SOCK Stream`. Once the `SOCK Stream` is connected with the new client, a `Logging Handler` is allocated dynamically to process the logging requests. As shown below, the `Logging Handler` registers itself with the `Initiation Dispatcher`, which will demultiplex all the logging records of its associated client to it.

**The Logging Handler class:** The logging server uses the `Logging Handler` class shown below to receive logging records sent by client applications:

```
class Logging_Handler : public Event_Handler
  // = TITLE
  //    Receive and process logging records
  //    sent by a client application.
{
public:
```

```
  // Initialize the client stream.
  Logging_Handler (SOCK_Stream &cs);

  // Hook method that handles the reception
  // of logging records from clients.
  virtual void handle_event (Event_Type et);

  // Get the I/O Handle (called by the
  // Initiation Dispatcher when
  // Logging_Handler is registered).
  virtual HANDLE get_handle (void) const
  {
    return peer_stream_.get_handle ();
  }

private:
  // Receives logging records from a client.
  SOCK_Stream peer_stream_;
};
```

`Logging Handler` inherits from `Event Handler`, which enables it to be registered with the `Initiation Dispatcher`, as shown below:

```
Logging_Handler::Logging_Handler
  (SOCK_Stream &cs)
    : peer_stream_ (cs)
{
  // Register with the dispatcher for
  // READ events.
  Initiation_Dispatcher::instance ()->
    register_handler (this, READ_EVENT);
}
```

Once it's created, a `Logging Handler` registers itself for READ events with the `Initiation Dispatcher` Singleton. Henceforth, when a logging record arrives, the `Initiation Dispatcher` automatically dispatches the `handle_event` method of the associated `Logging Handler`, as shown below:

```
void
Logging_Handler::handle_event (Event_Type et)
{
  if (et == READ_EVENT) {
    Log_Record log_record;

    peer_stream_.recv ((void *) log_record, sizeof log_record);

    // Write logging record to standard output.
    log_record.write (STDOUT);
  }
  else if (et == CLOSE_EVENT) {
    peer_stream_.close ();
    delete (void *) this;
  }
}
```

When a READ event occurs on a socket `Handle`, the `Initiation Dispatcher` calls back to the `handle_event` method of the `Logging Handler`. This method receives, processes, and writes the logging record to the standard output (STDOUT). Likewise, when the client closes down the connection the `Initiation Dispatcher` passes a CLOSE event, which informs the `Logging Handler` to shut down its `SOCK Stream` and delete itself.

## 9.7 Implement the Server

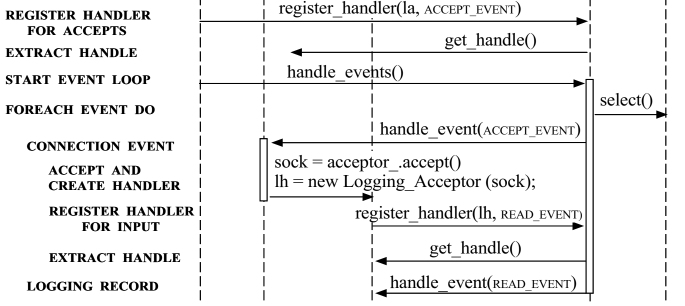
The logging server contains a single `main` function.

**The logging server main function:** This function implements a single-threaded, concurrent logging server that waits in the `Initiation Dispatcher`'s `handle_events` event loop. As requests arrive from clients, the `Initiation Dispatcher` invokes the appropriate `Concrete Event Handler` hook methods, which accept connections and receive and process logging records. The main entry point into the logging server is defined as follows:

```
// Server port number.
const u_short PORT = 10000;

int
main (void)
{
  // Logging server port number.
  INET_Addr server_addr (PORT);

  // Initialize logging server endpoint and
  // register with the Initiation_Dispatcher.
  Logging_Acceptor la (server_addr);

  // Main event loop that handles client
  // logging records and connection requests.
  for (;;)
    Initiation_Dispatcher::instance ()->
      handle_events ();

  /* NOTREACHED */
  return 0;
}
```

The main program creates a `Logging Acceptor`, whose constructor initializes it with the port number of the logging server. The program then enters its main event-loop. Subsequently, the `Initiation Dispatcher` Singleton uses the `select` event demultiplexing system call to synchronously wait for connection requests and logging records to arrive from clients.

The following interaction diagram illustrates the collaboration between the objects participating in the logging server example:



Once the Initiation Dispatcher object is initialized, it becomes the primary focus of the control flow within the logging server. All subsequent activity is triggered by hook methods on the Logging Acceptor and Logging Handler objects registered with, and controlled by, the Initiation Dispatcher.

When a connection request arrives on the network connection, the Initiation Dispatcher calls back the Logging Acceptor, which accepts the network connection and creates a Logging Handler. This Logging Handler then registers with the Initiation Dispatcher for READ events. Thus, when a client sends a logging record, the Initiation Dispatcher calls back to the client's Logging Handler to process the incoming record from that client connection in the logging server's single thread of control.

# 10 Known Uses

The Reactor pattern has been used in many object-oriented frameworks, including the following:

• **InterViews:** The Reactor pattern is implemented by the InterViews [10] window system distribution, where it is known as the Dispatcher. The InterViews Dispatcher is used to define an application's main event loop and to manage connections to one or more physical GUI displays.

• **ACE Framework:** The ACE framework [11] uses the Reactor pattern as its central event demultiplexer and dispatcher.

The Reactor pattern has been used in many commercial projects, including:

• **CORBA ORBs:** The ORB Core layer in many single-threaded implementations of CORBA [12] (such as VisiBroker, Orbix, and TAO [13]) use the Reactor pattern to demultiplex and dispatch ORB requests to servants.

• **Ericsson EOS Call Center Management System:** This system uses the Reactor pattern to manage events routed by Event Servers [14] between PBXs and supervisors in a Call Center Management system.

• **Project Spectrum:** The high-speed medical image transfer subsystem of project Spectrum [15] uses the Reactor pattern in a medical imaging system.

# 11 Consequences

## 11.1 Benefits

The Reactor pattern offers the following benefits:

**Separation of concerns:** The Reactor pattern decouples application-independent demultiplexing and dispatching mechanisms from application-specific hook method functionality. The application-independent mechanisms become reusable components that know how to demultiplex events and dispatch the appropriate hook methods defined by Event Handlers. In contrast, the application-specific functionality in a hook method knows how to perform a particular type of service.

**Improve modularity, reusability, and configurability of event-driven applications:** The pattern decouples application functionality into separate classes. For instance, there are two separate classes in the logging server: one for establishing connections and another for receiving and processing logging records. This decoupling enables the reuse of the connection establishment class for different types of connection-oriented services (such as file transfer, remote login, and video-on-demand). Therefore, modifying or extending the functionality of the logging server only affects the implementation of the logging handler class.

**Improves application portability:** The Initiation Dispatcher's interface can be reused independently of the OS system calls that perform event demultiplexing. These system calls detect and report the occurrence of one or more events that may occur simultaneously on multiple sources of events. Common sources of events may include I/O handles, timers, and synchronization objects. On UNIX platforms, the event demultiplexing system calls are called select and poll [1]. In the Win32 API [16], the WaitForMultipleObjects system call performs event demultiplexing.

**Provides coarse-grained concurrency control:** The Reactor pattern serializes the invocation of event handlers at the level of event demultiplexing and dispatching within a process or thread. Serialization at the Initiation Dispatcher level often eliminates the need for more complicated synchronization or locking within an application process.

## 11.2 Liabilities

The Reactor pattern has the following liabilities:

**Restricted applicability:** The Reactor pattern can only be applied efficiently if the OS supports Handles. It is possible to emulate the semantics of the Reactor pattern using multiple threads within the Initiation Dispatcher, *e.g.* one thread for each Handle. Whenever there are events available on a handle, its associated thread will read the event and place it on a queue that is processed sequentially by the initiation dispatcher. However, this design is typically very inefficient since it serializes all Event Handlers, thereby increasing synchronization and context switching overhead without enhancing parallelism.

**Non-preemptive:** In a single-threaded application process, `Event Handlers` are not preempted while they are executing. This implies that an `Event Handler` should not perform blocking I/O on an individual `Handle` since this will block the entire process and impede the responsiveness for clients connected to other `Handles`. Therefore, for long-duration operations, such as transferring multi-megabyte medical images [15], the Active Object pattern [17] may be more effective. An Active Object uses multi-threading or multi-processing to complete its tasks in parallel with the `Initiation Dispatcher`'s main event-loop.

**Hard to debug:** Applications written with the Reactor pattern can be hard to debug since the inverted flow of control oscillates between the framework infrastructure and the method callbacks on application-specific handlers. This increases the difficulty of "single-stepping" through the run-time behavior of a framework within a debugger since application developers may not understand or have access to the framework code. This is similar to the problems encountered trying to debug a compiler lexical analyzer and parser written with `LEX` and `YACC`. In these applications, debugging is straightforward when the thread of control is within the user-defined action routines. Once the thread of control returns to the generated Deterministic Finite Automata (DFA) skeleton, however, it is hard to follow the program logic.

# 12 See Also

The Reactor pattern is related to the Observer pattern [5], where all dependents are informed when a single subject changes. In the Reactor pattern, a single handler is informed when an event of interest to the handler occurs on a source of events. The Reactor pattern is generally used to demultiplex events from multiple sources to their associated event handlers, whereas an Observer is often associated with only a single source of events.

The Reactor pattern is related to the Chain of Responsibility (CoR) pattern [5], where a request is delegated to the responsible service provider. The Reactor pattern differs from the CoR pattern since the Reactor associates a specific Event Handler with a particular source of events, whereas the CoR pattern searches the chain to locate the first matching Event Handler.

The Reactor pattern can be considered a *synchronous* variant of the asynchronous Proactor pattern [18]. The Proactor supports the demultiplexing and dispatching of multiple event handlers that are triggered by the *completion* of *asynchronous* events. In contrast, the Reactor pattern is responsible for demultiplexing and dispatching of multiple event handlers that are triggered when it is possible to *initiate* an operation *synchronously* without blocking.

The Active Object pattern [17] decouples method execution from method invocation to simplify synchronized access to a shared resource by methods invoked in different threads of control. The Reactor pattern is often used in place of the Active Object pattern when threads are not available or when the overhead and complexity of threading is undesirable.

An implementation of the Reactor pattern provides a Facade [5] for event demultiplexing. A Facade is an interface that shields applications from complex object relationships within a subsystem.

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