Patterns & Frameworks for Asynchronous Event Handling: Part 1

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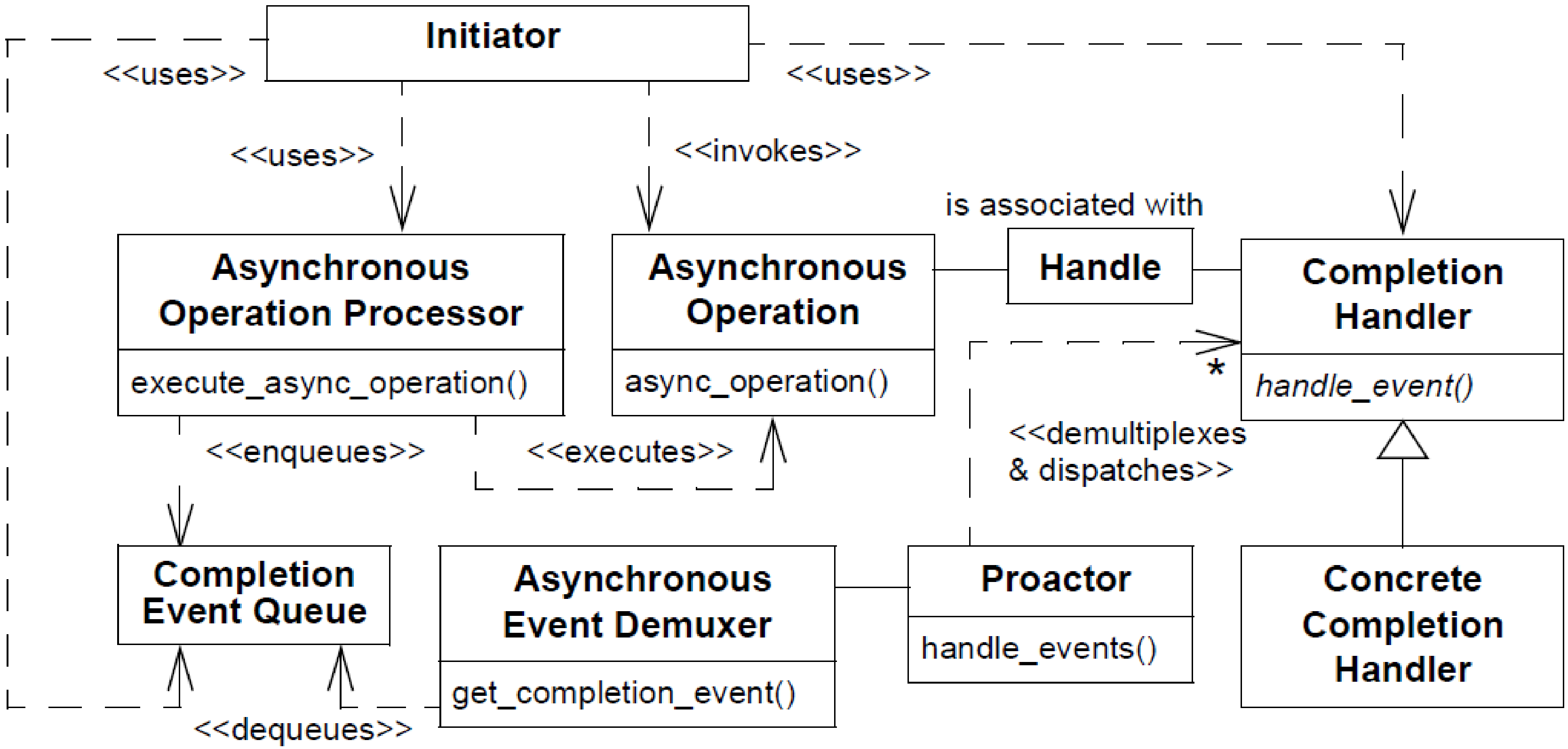
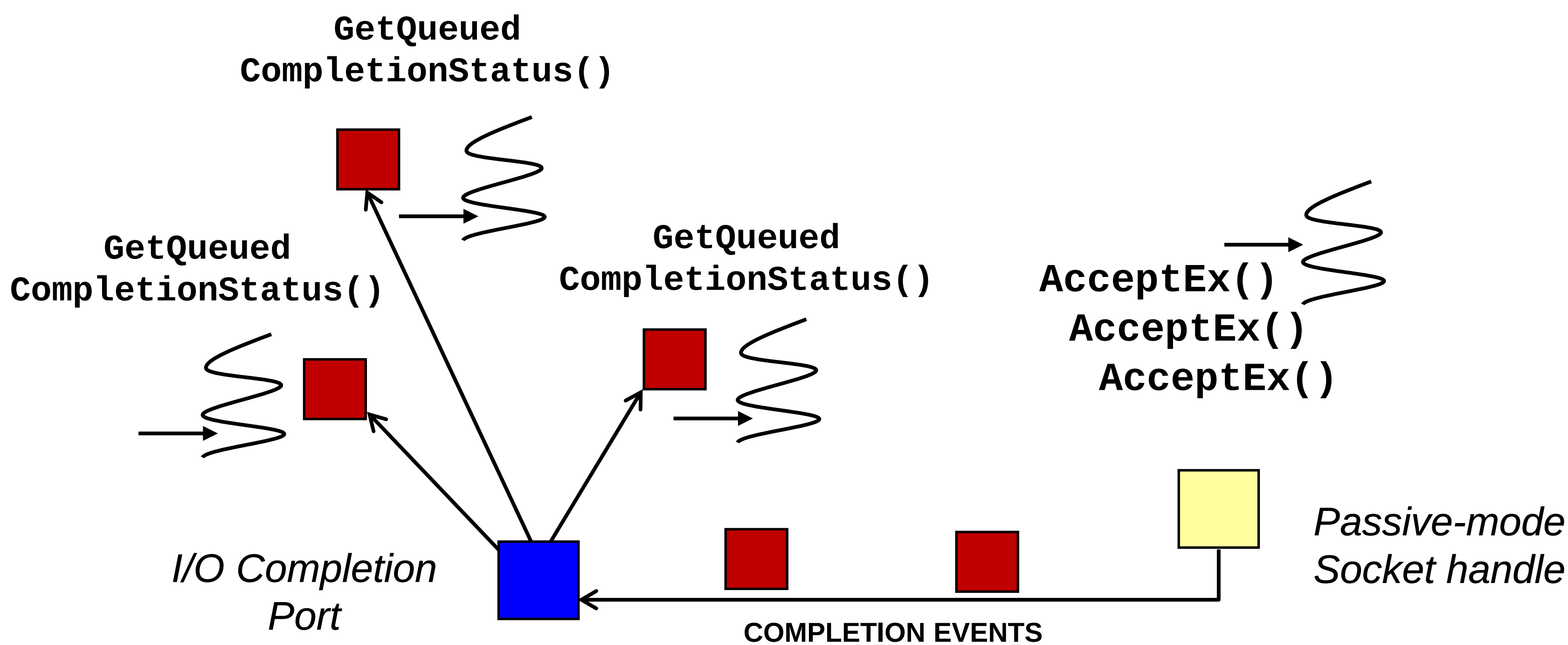
Topics Covered in this Part of the Module

- Describe the *Proactor* pattern



Using Asynchronous I/O Effectively

Context	Problem
• Synchronous event handling & multi-threading may not achieve most scalable web server when OS supports async I/O	• Leveraging efficiency & scalability of async I/O is hard due to time/space separation of async operation invocations & their subsequent completion events



See en.wikipedia.org/wiki/Input/output_completion_port for more info

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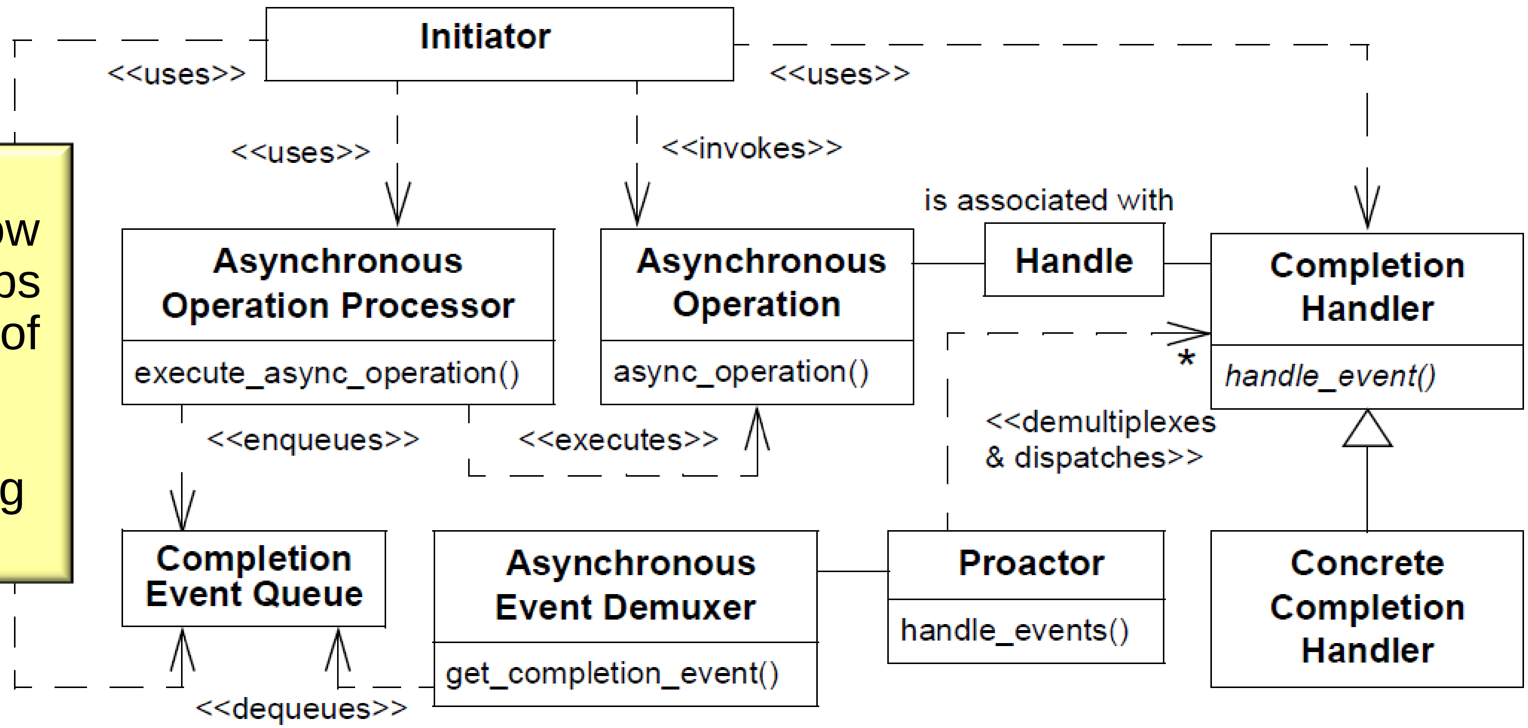
Structure

Proactor uses async I/O to allow event-driven apps to gain benefits of concurrency performance without incurring its liabilities



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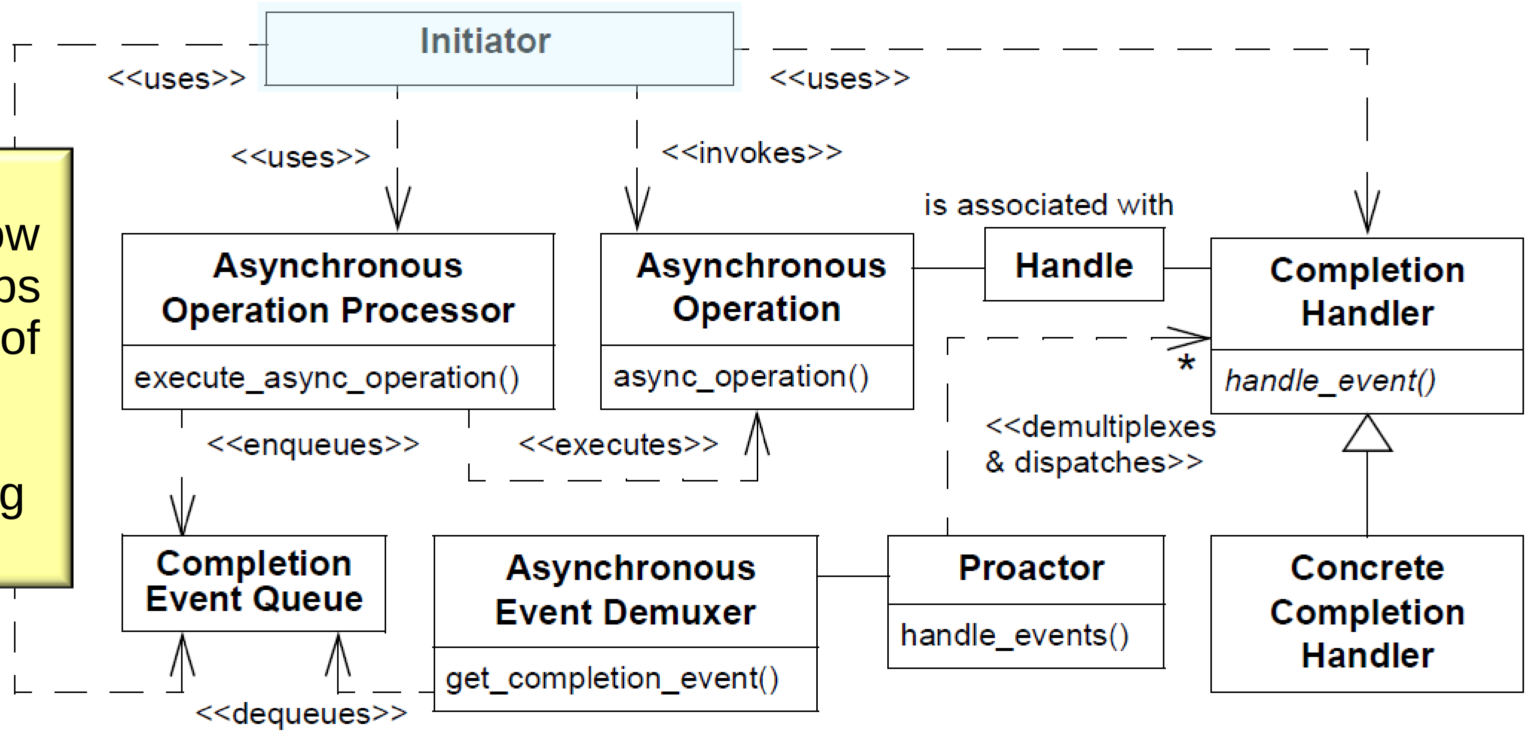

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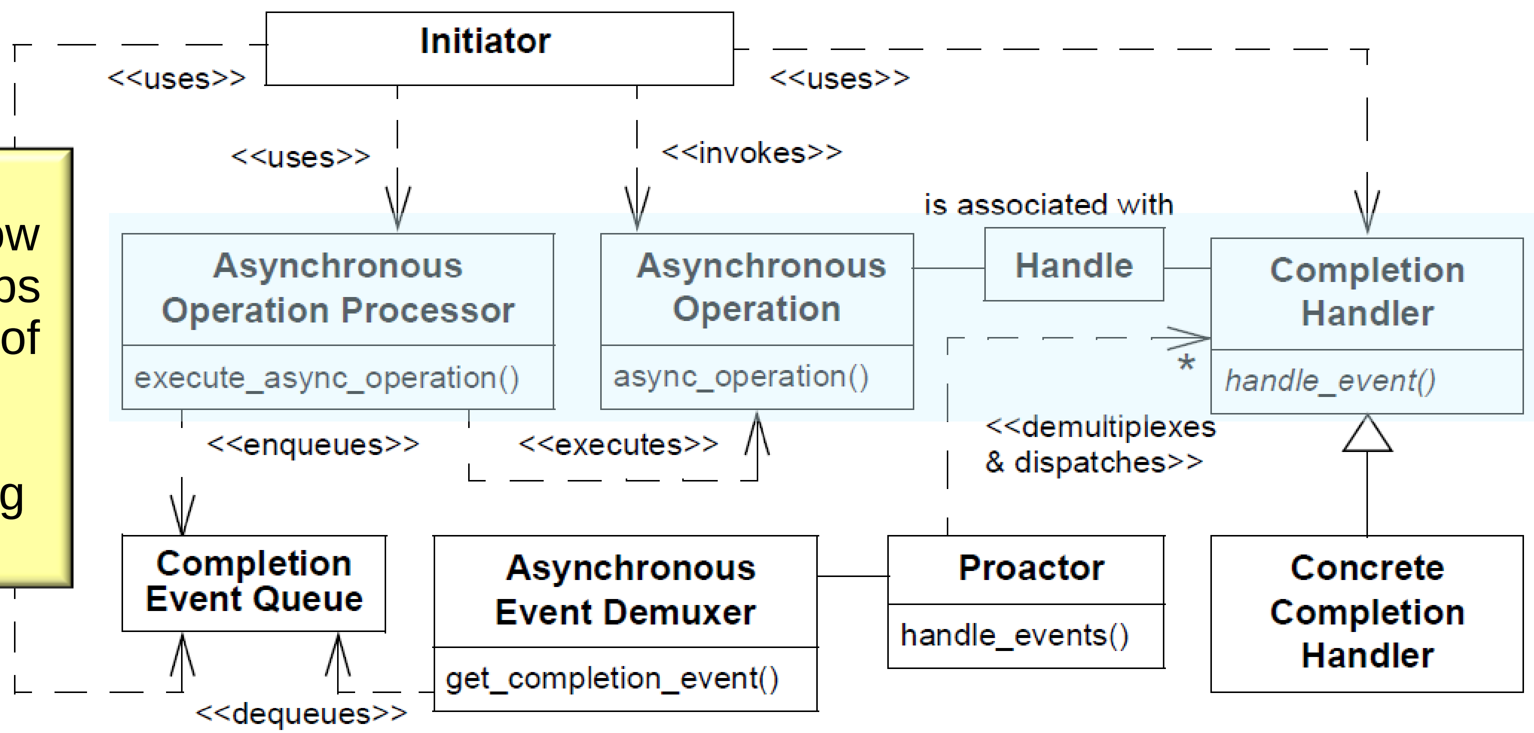

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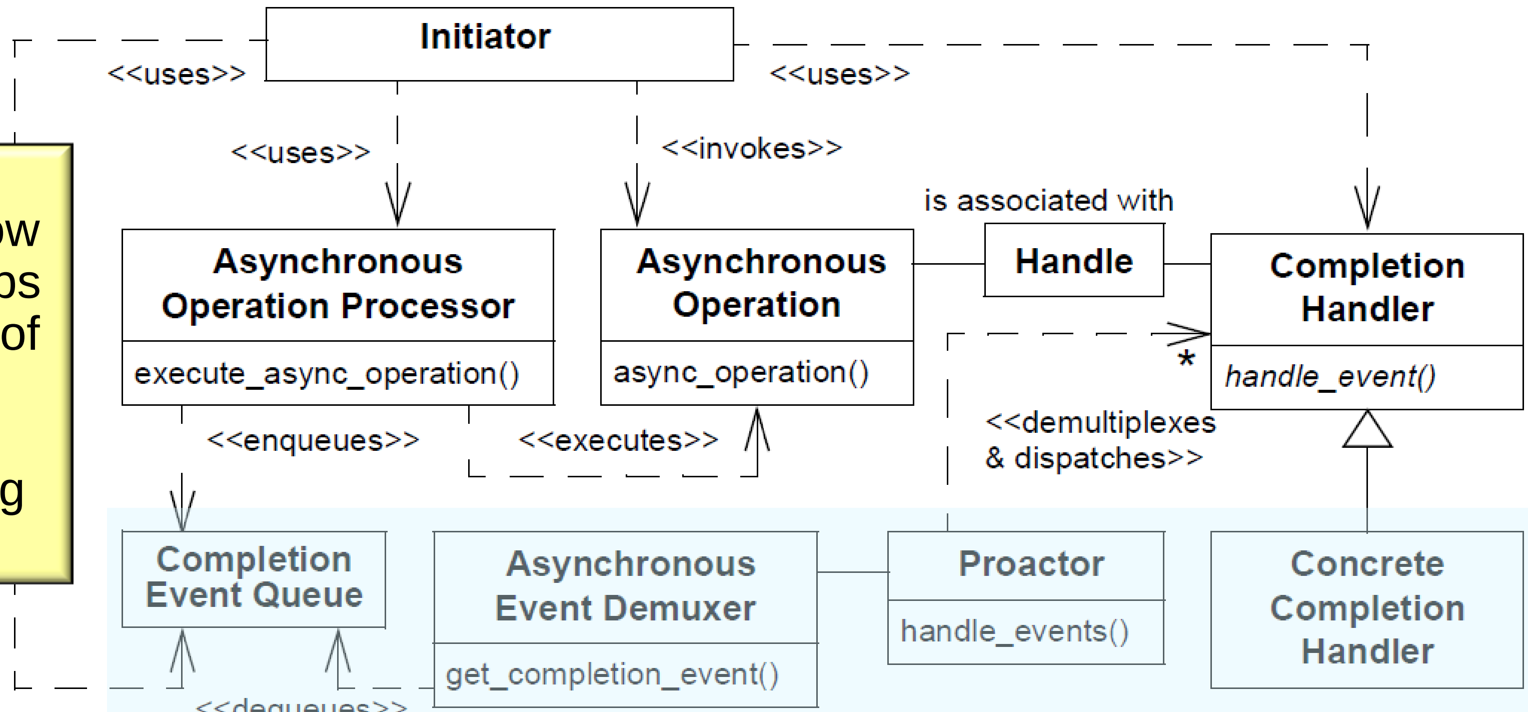

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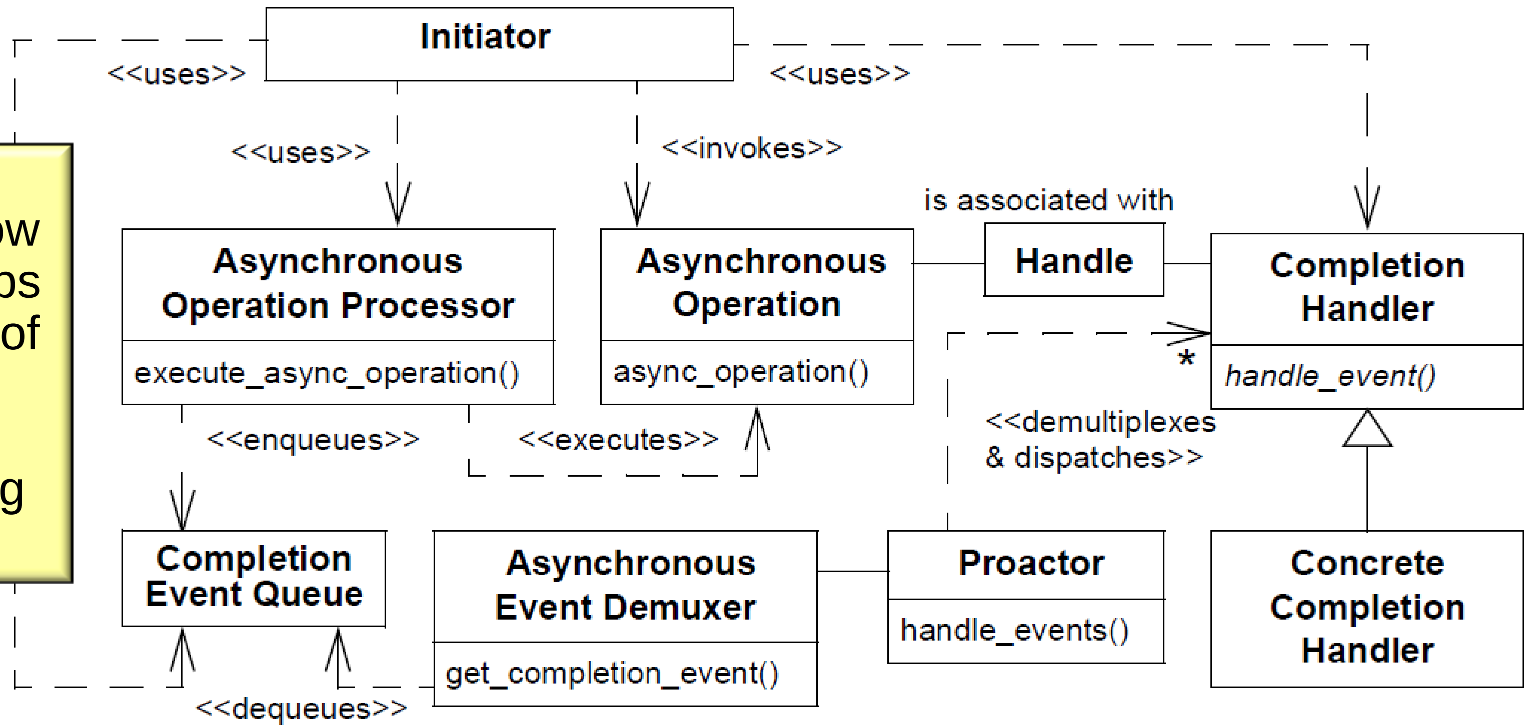

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See www.dre.vanderbilt.edu/~schmidt/PDF/proactor.pdf for more info

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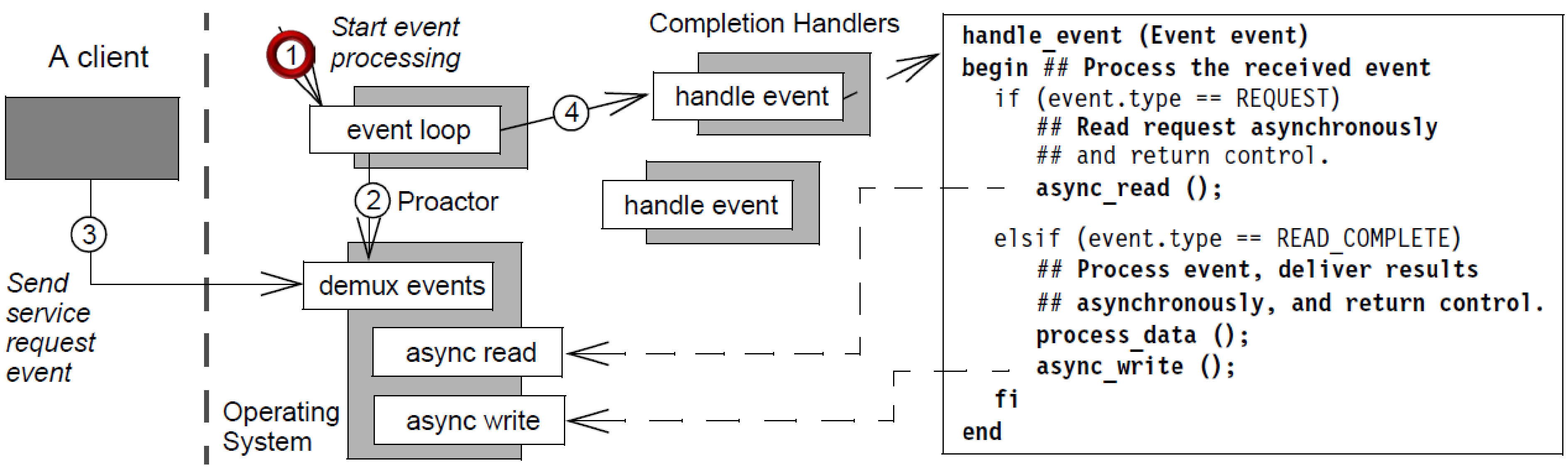

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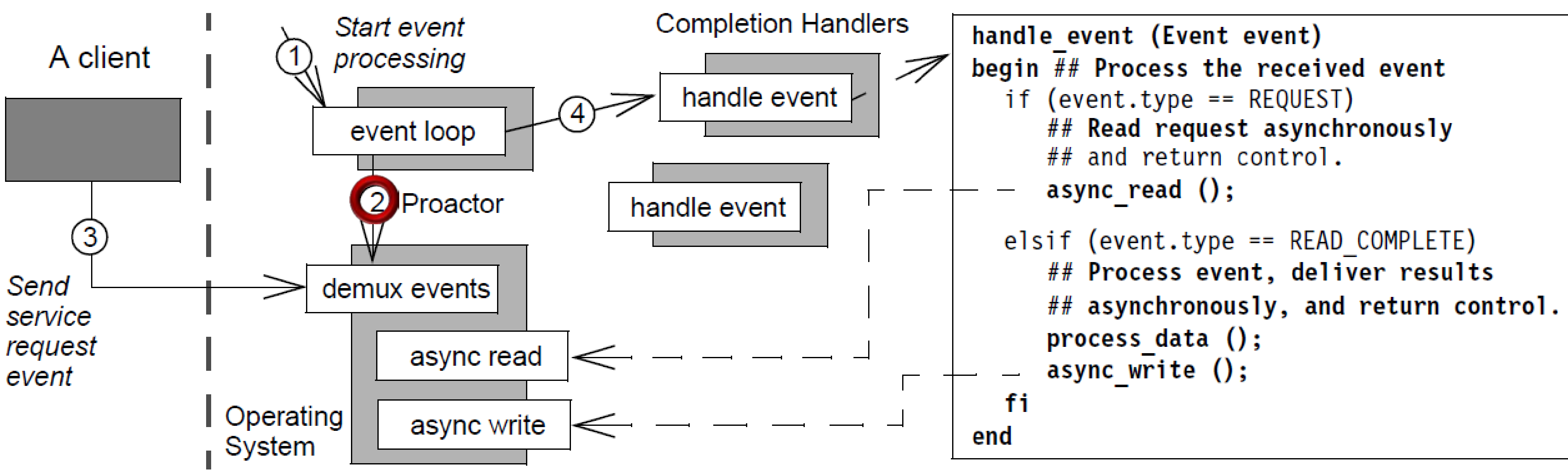

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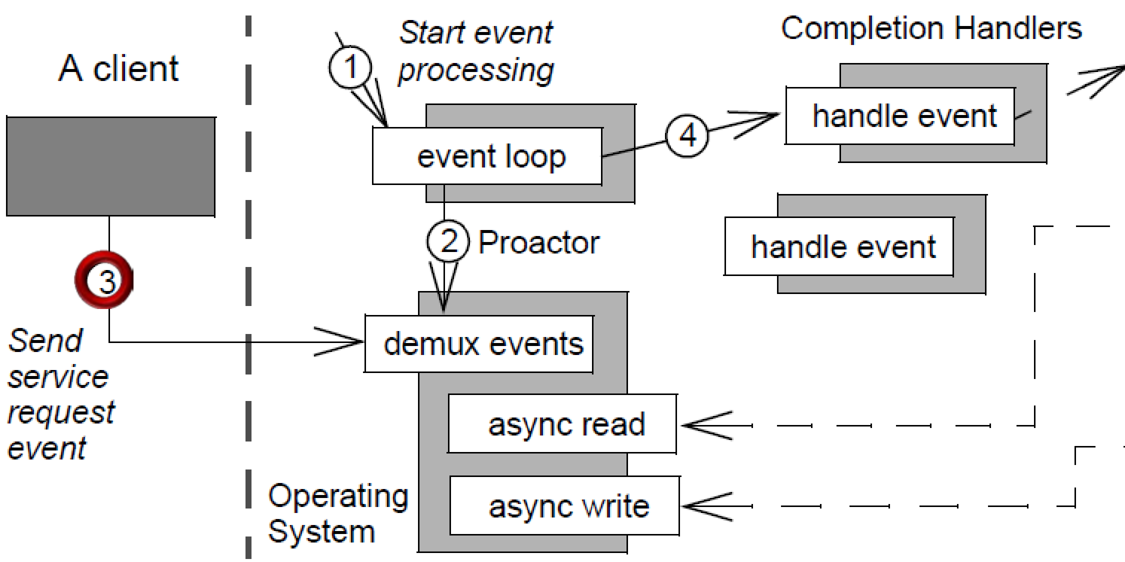


```
handle_event (Event event)
begin ## Process the received event
   if (event.type == REQUEST)
      ## Read request asynchronously
      ## and return control.
      async_read ();
   elsif (event.type == READ_COMPLETE)
      ## Process event, deliver results
      ## asynchronously, and return control.
      process_data ();
      async_write ();
   fi
end
```

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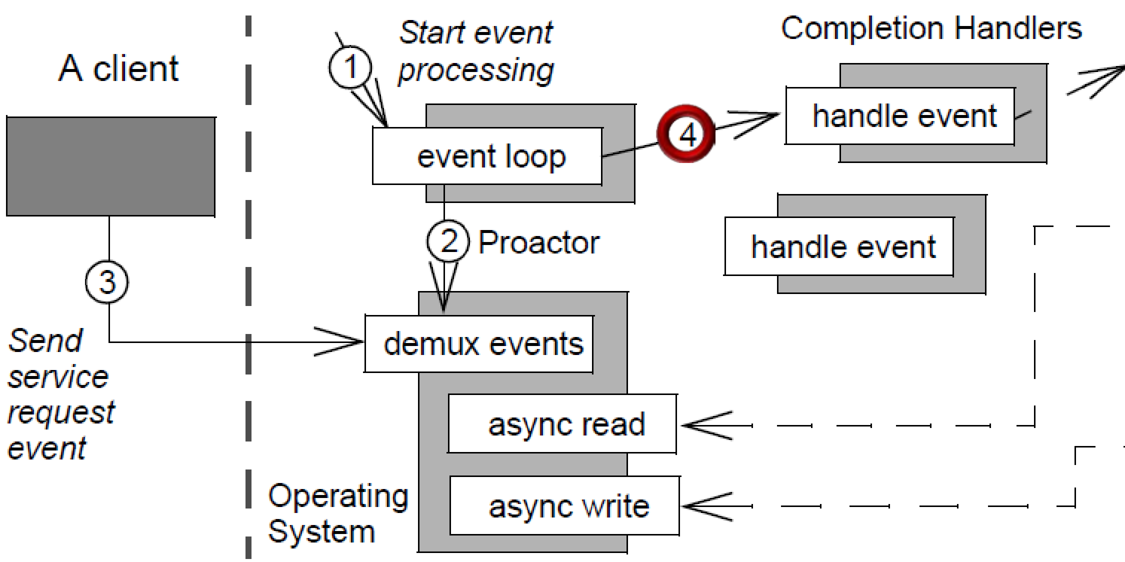


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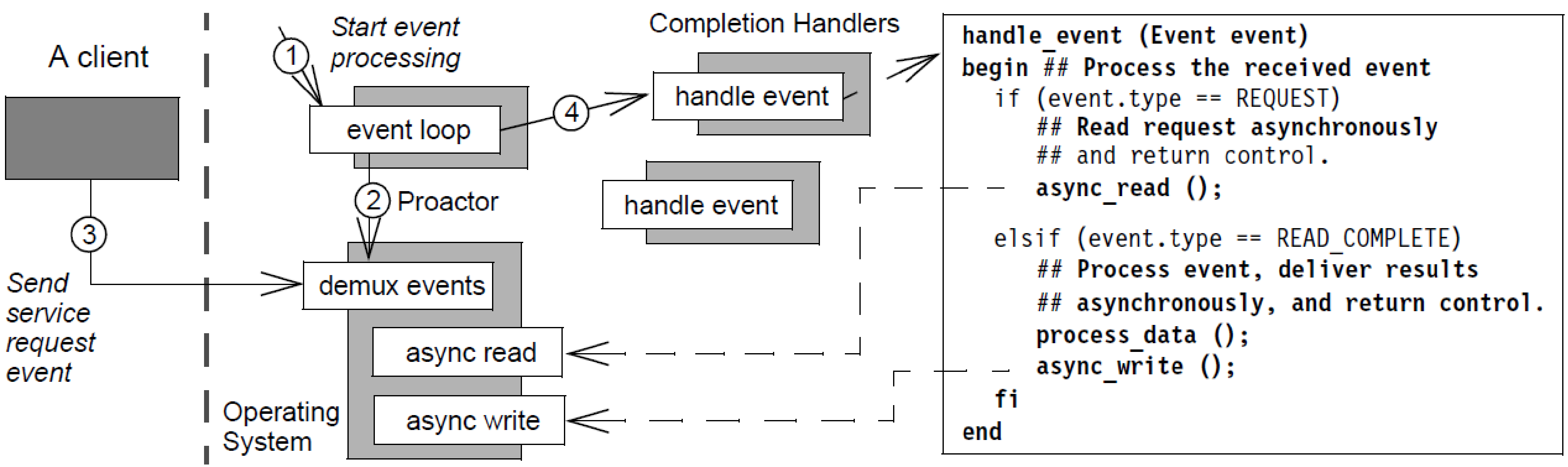
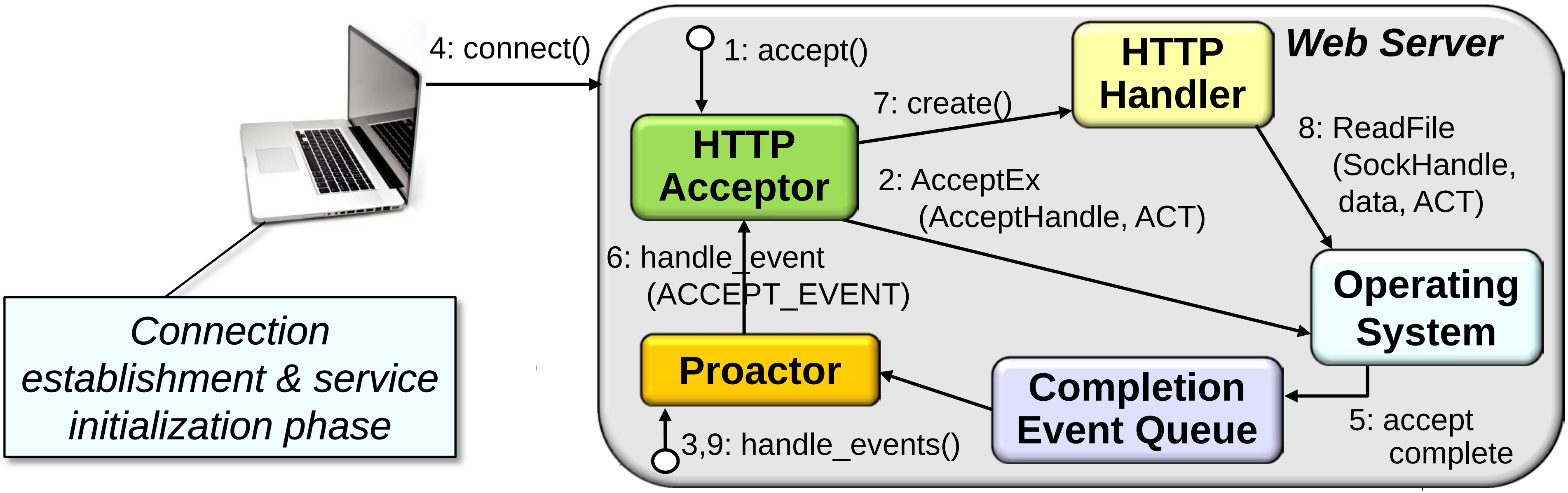
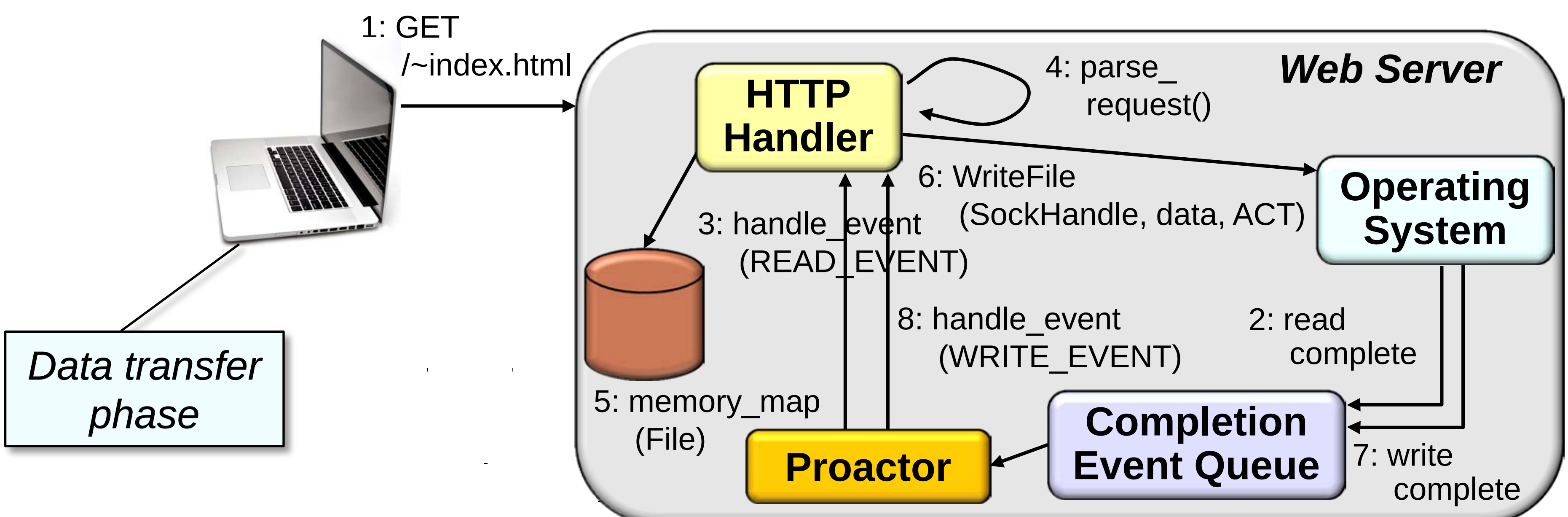


Note *similarities & differences* with the *Reactor* pattern

Applying the Proactor Pattern to JAWS

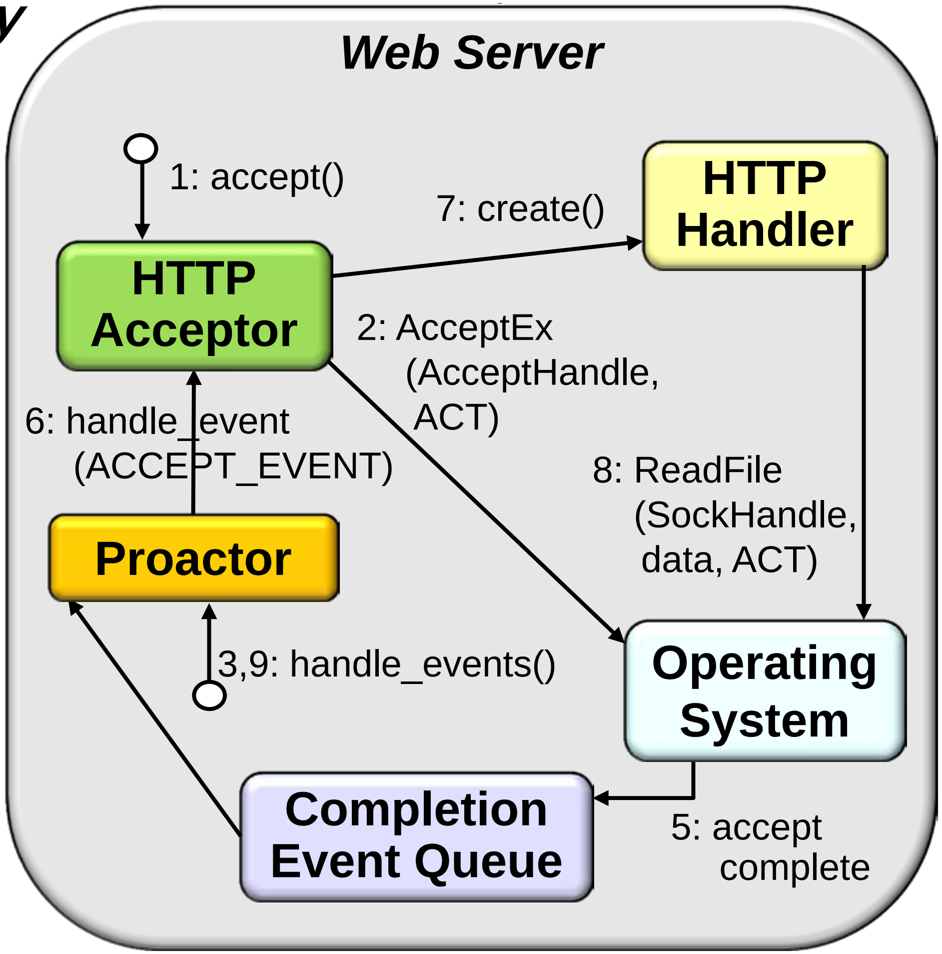




Benefits of Proactor Pattern

Separation of concerns & portability

- Decouples app-independent & app-specific async operations



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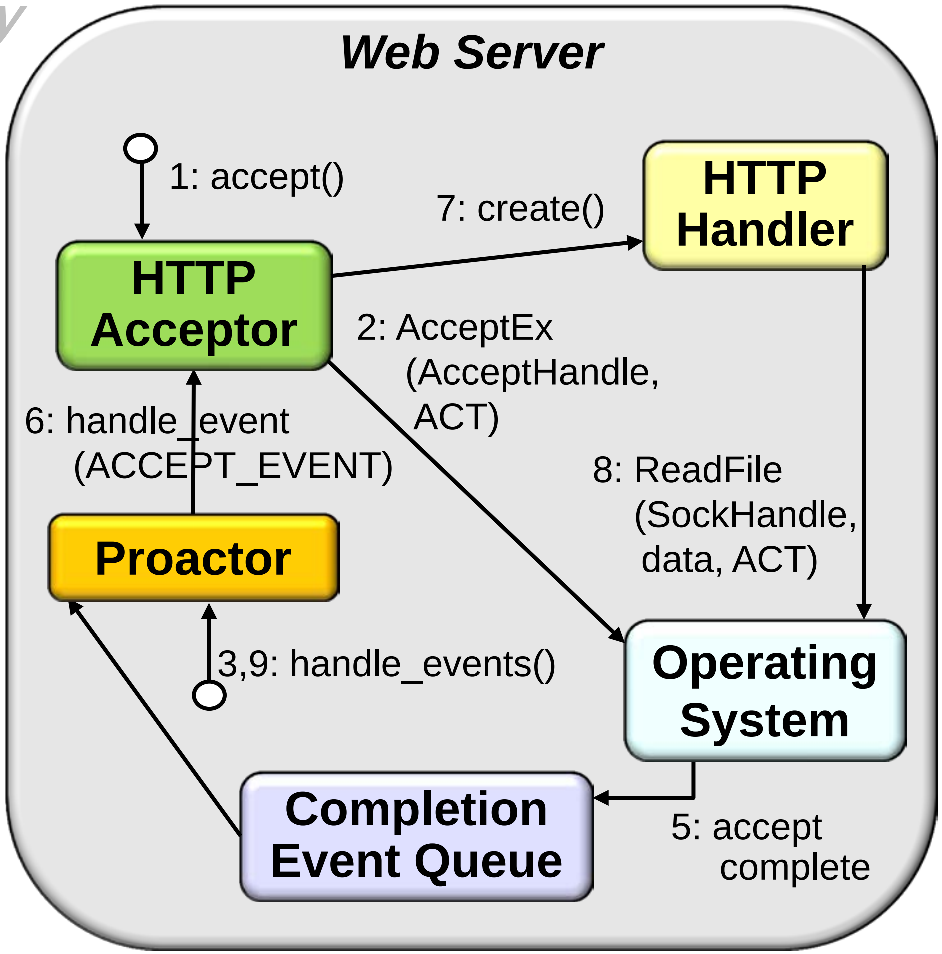
Decoupling of threading from concurrency

- Async operation processor executes long-duration operations so apps can spawn fewer threads



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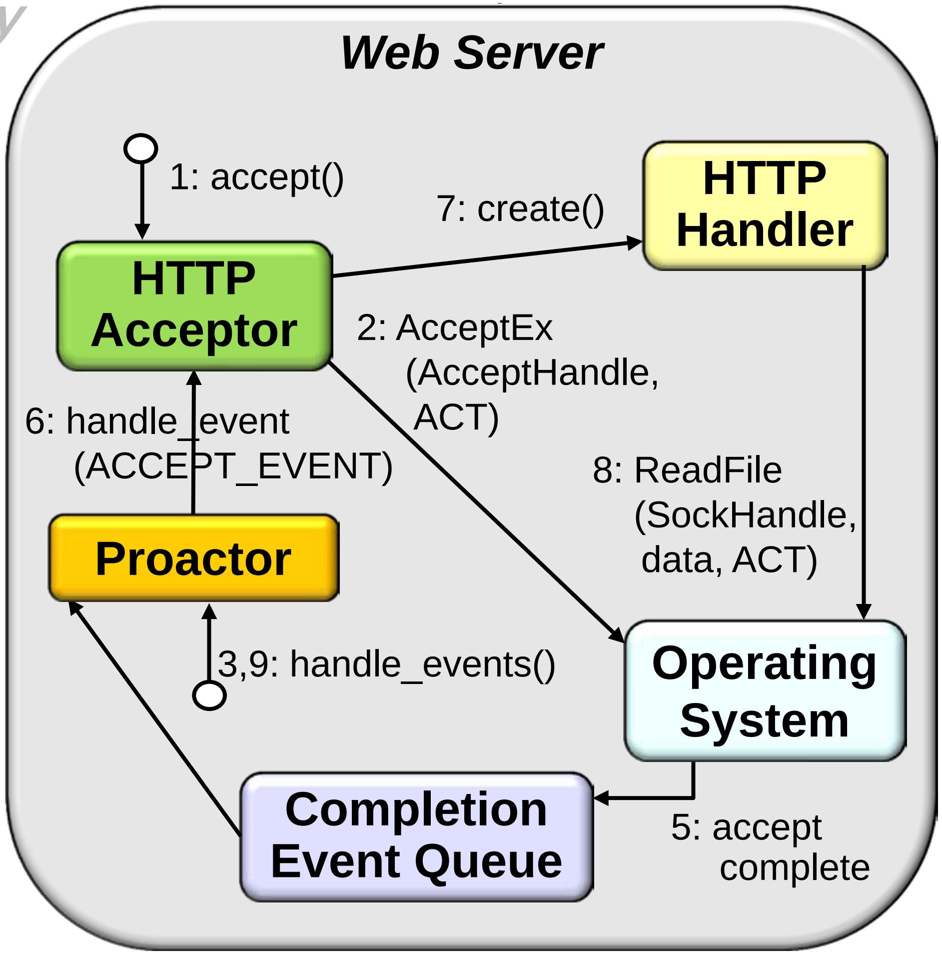

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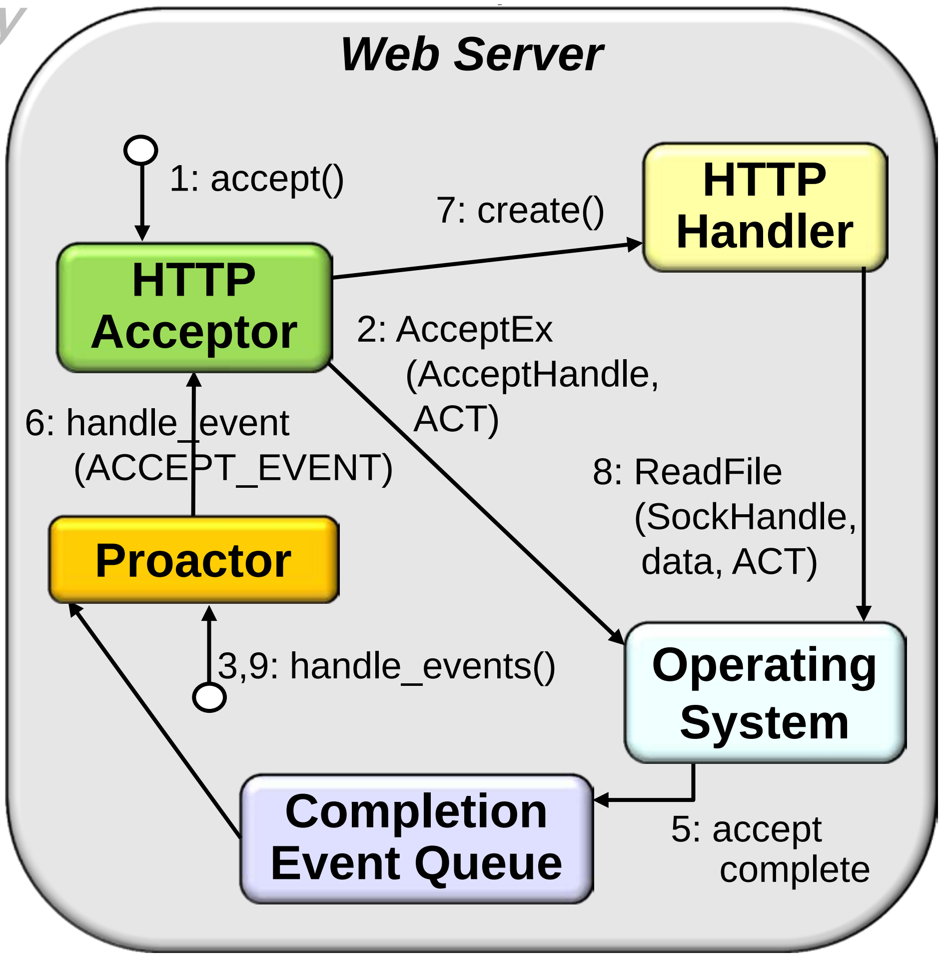
Simplification of app synchronization

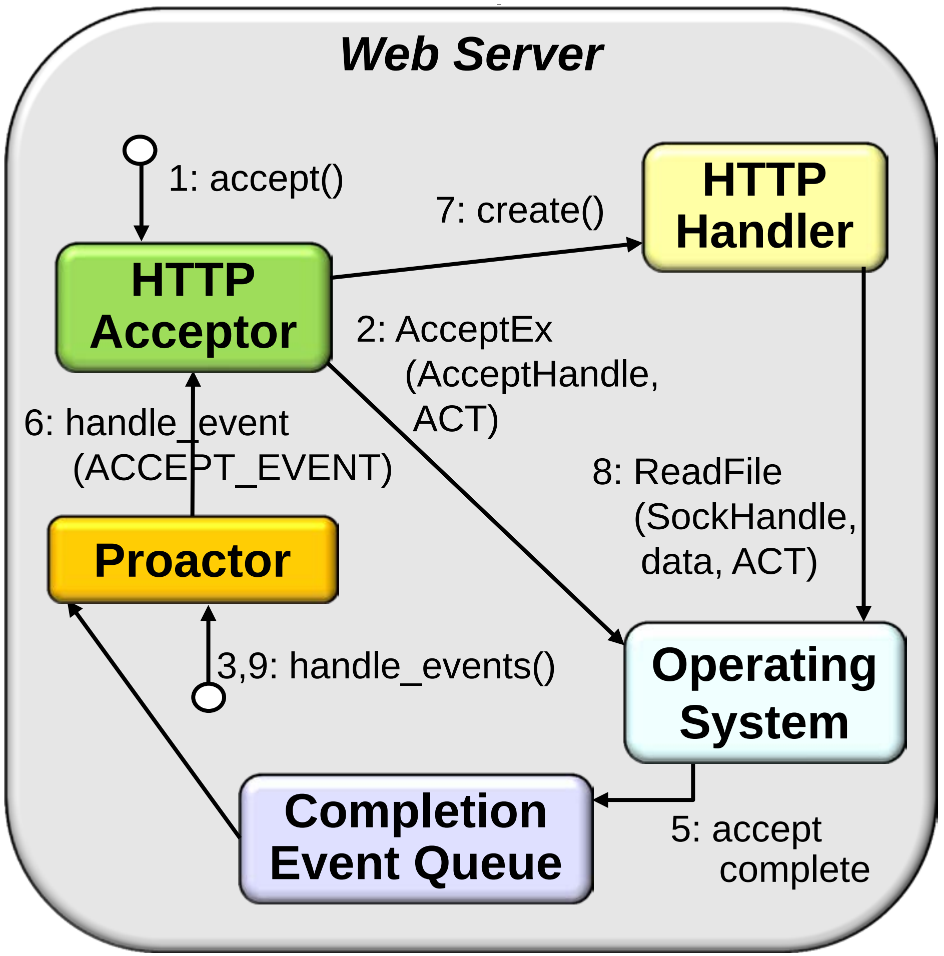
- If completion handlers spawn no threads, apps can be written without synchronization concerns



Limitations of Proactor Pattern

Restricted applicability

- Requires native OS support for asynchronous operations



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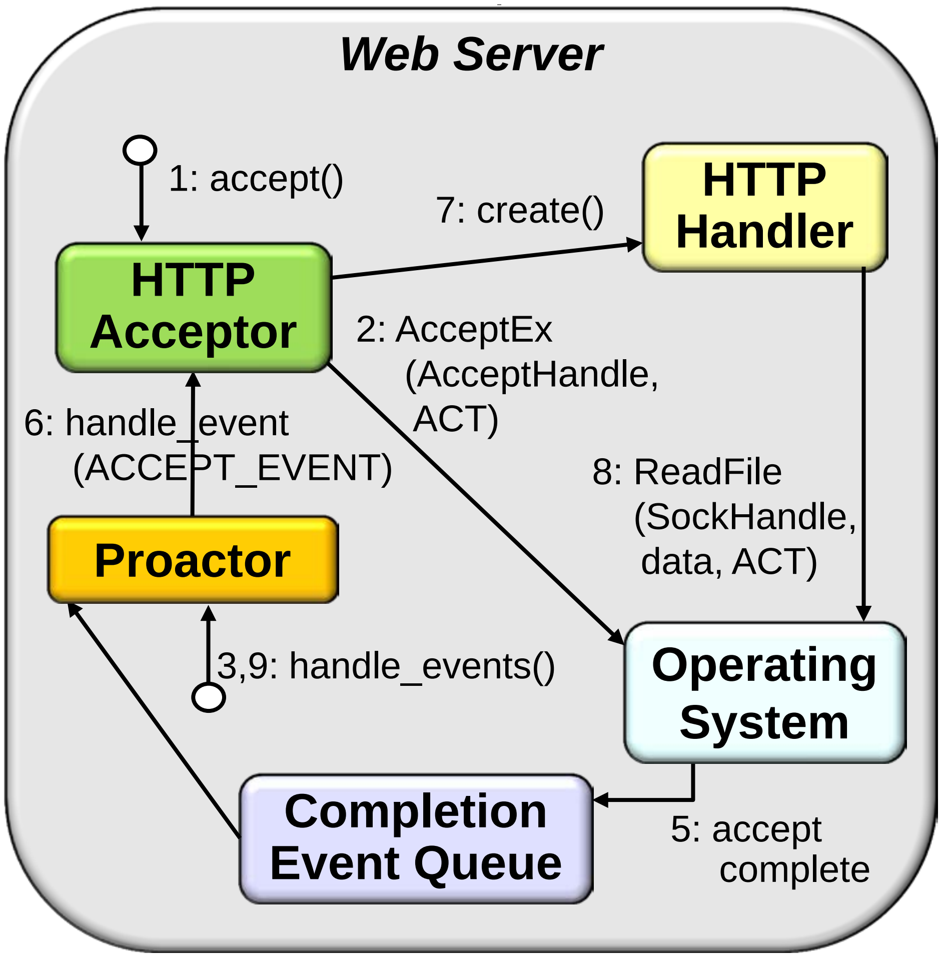
Complexity of programming, debugging, & testing

- It is hard to program apps & services using asynchrony due to separation in time & space between operation invocation & completion



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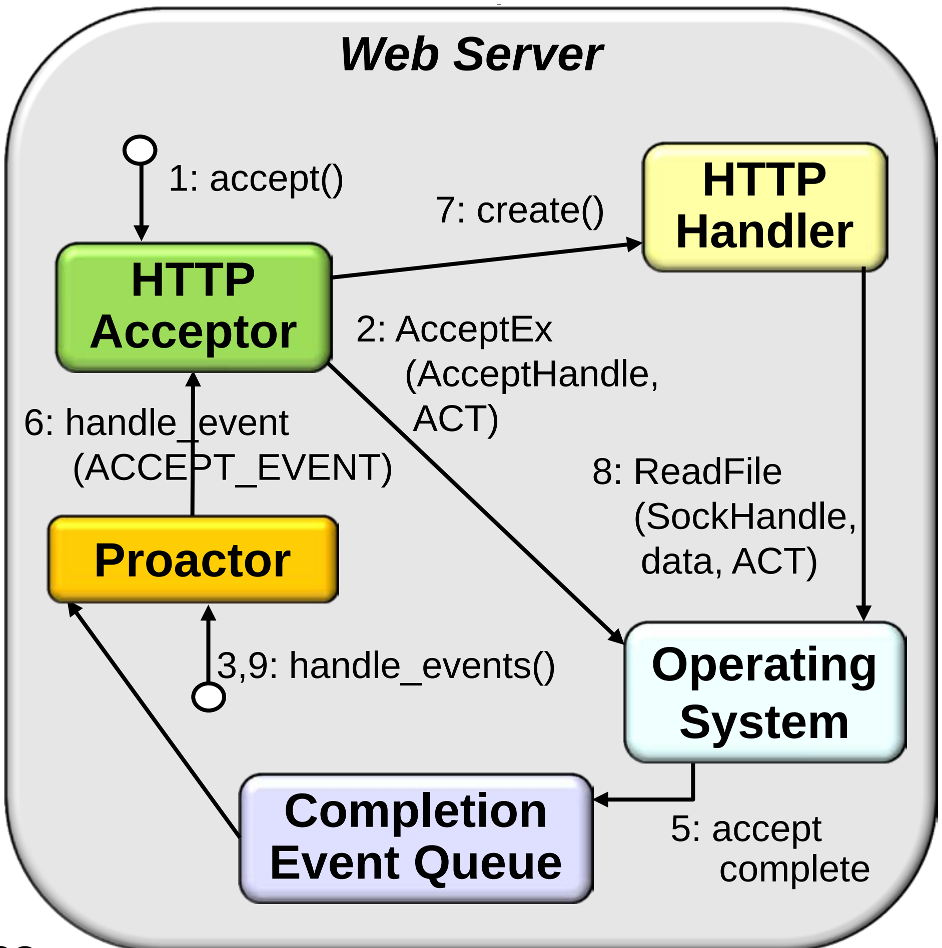
Scheduling, controlling, & canceling asynchronously running operations

- Initiators may not be able to control order in which asynchronous operations are executed by asynchronous operation processor
- May also not be able to cancel operations



Patterns & Frameworks for Asynchronous Event Handling: Part 2

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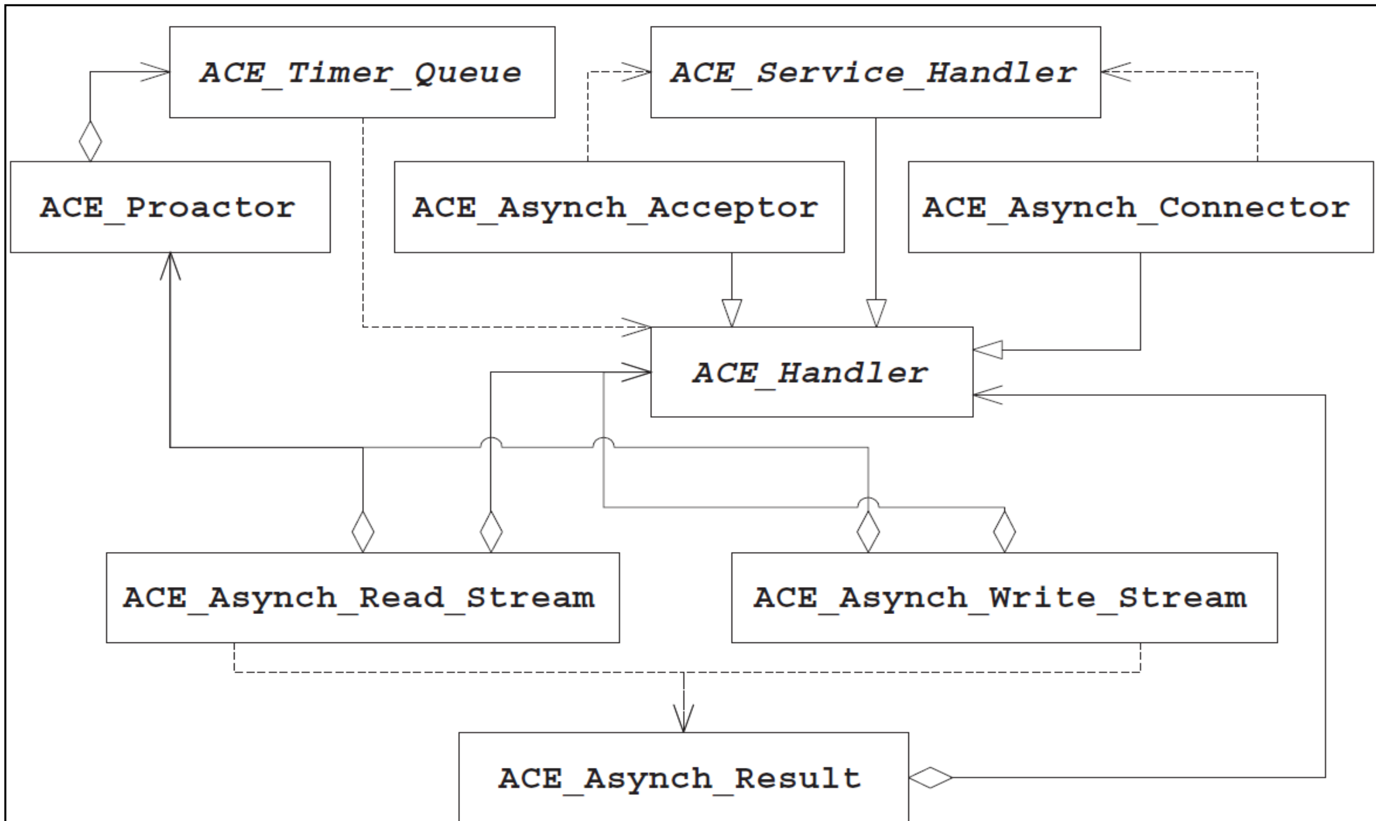
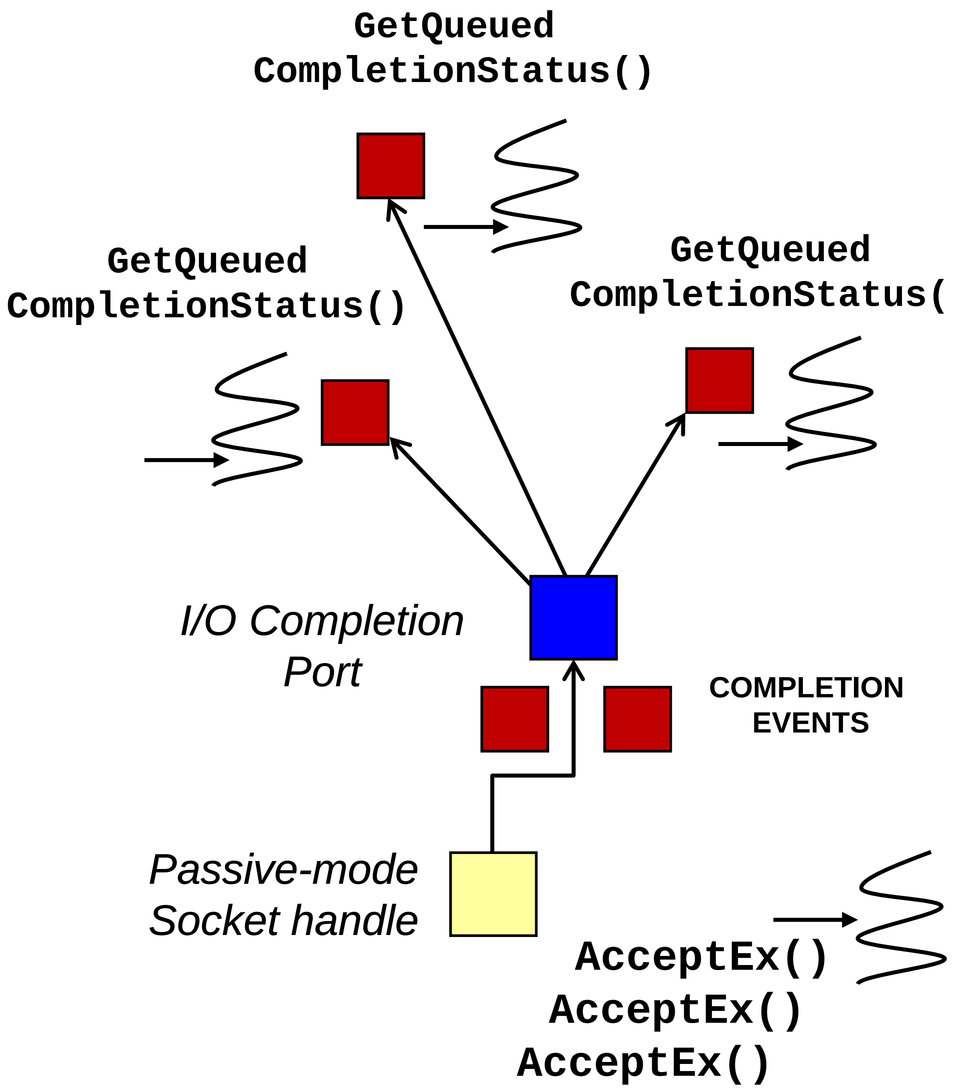
- Describe the *Proactor* pattern
- Describe the ACE *Proactor* framework



The *Proactor* is the most complicated ACE framework

Motivation for the ACE Proactor Framework

- OS support for asynchronous operations has several limitations
  - Tedious & error-prone to program
  - Non-portable and/or inefficient



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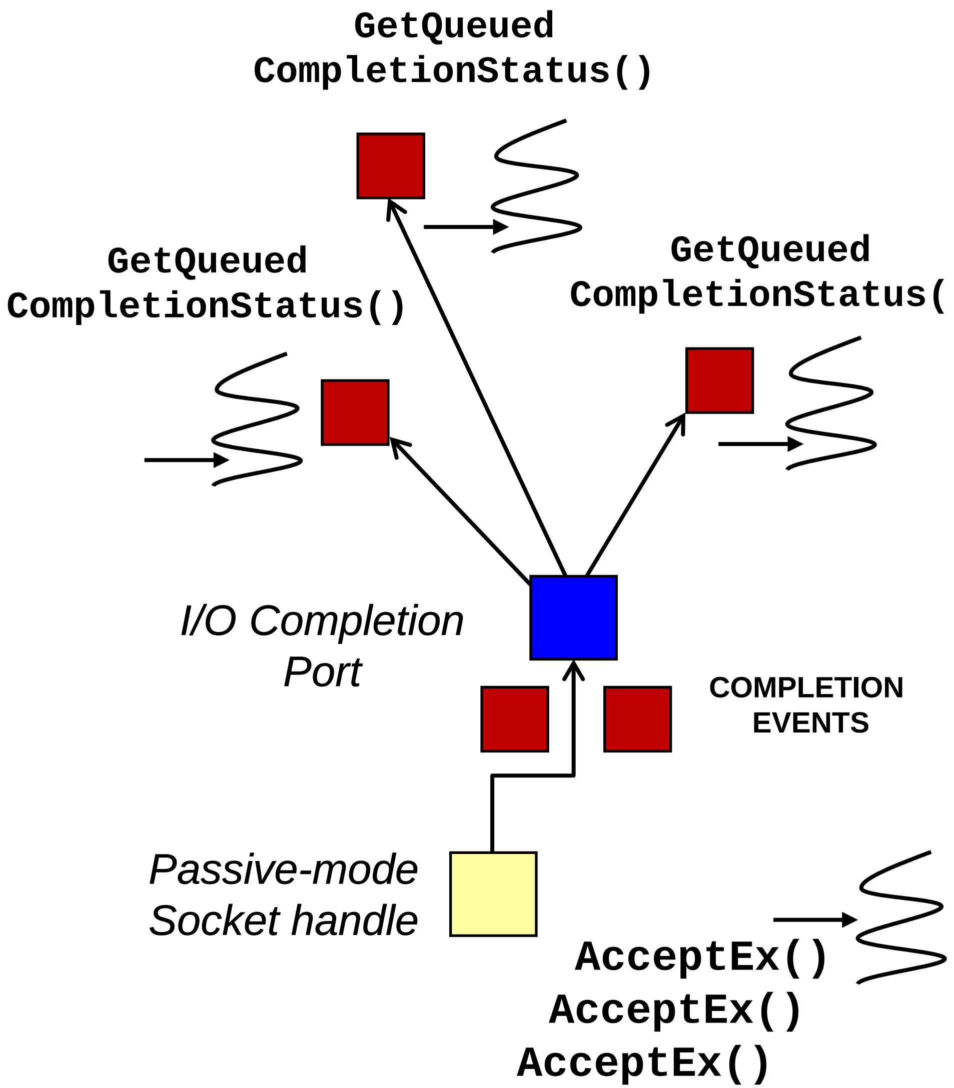
- Modern Windows platforms support both overlapped I/O & I/O completion ports
  - These mechanisms are effcient, but tricky to program



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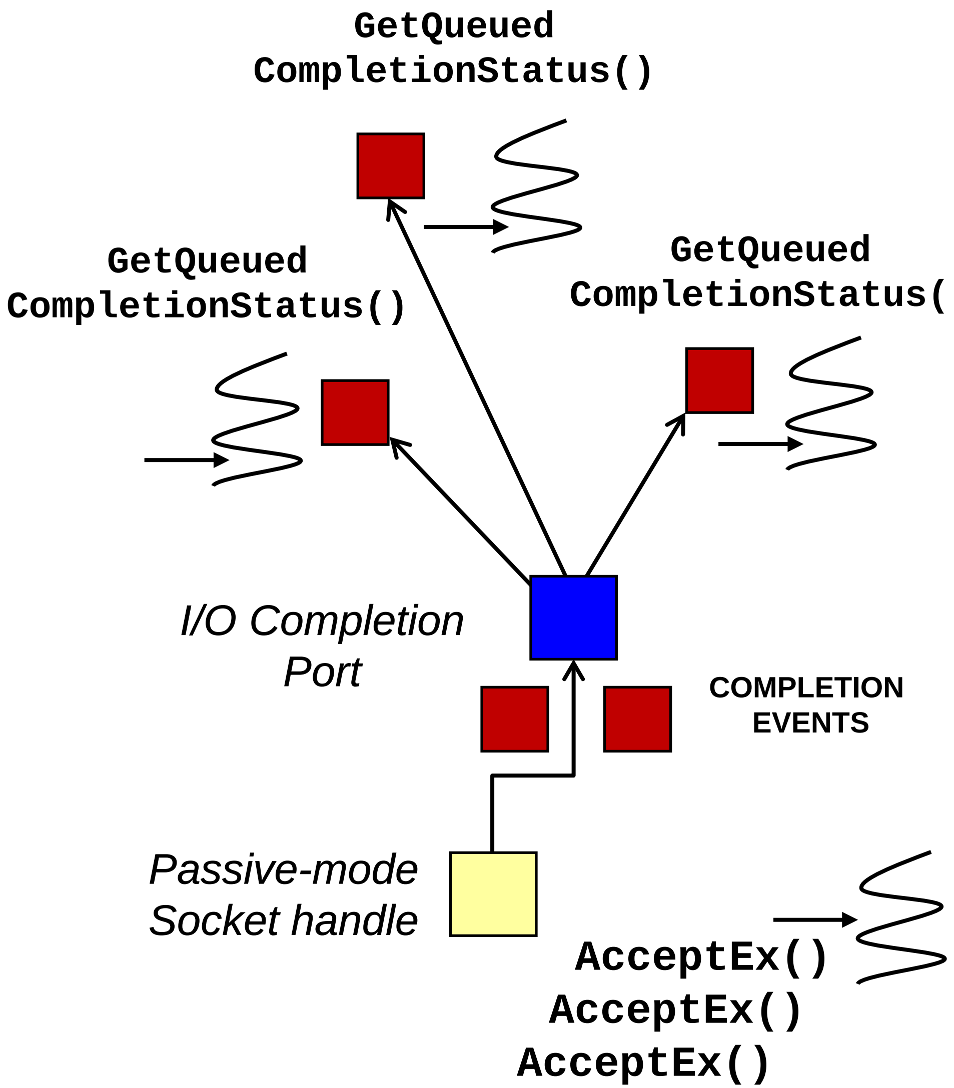
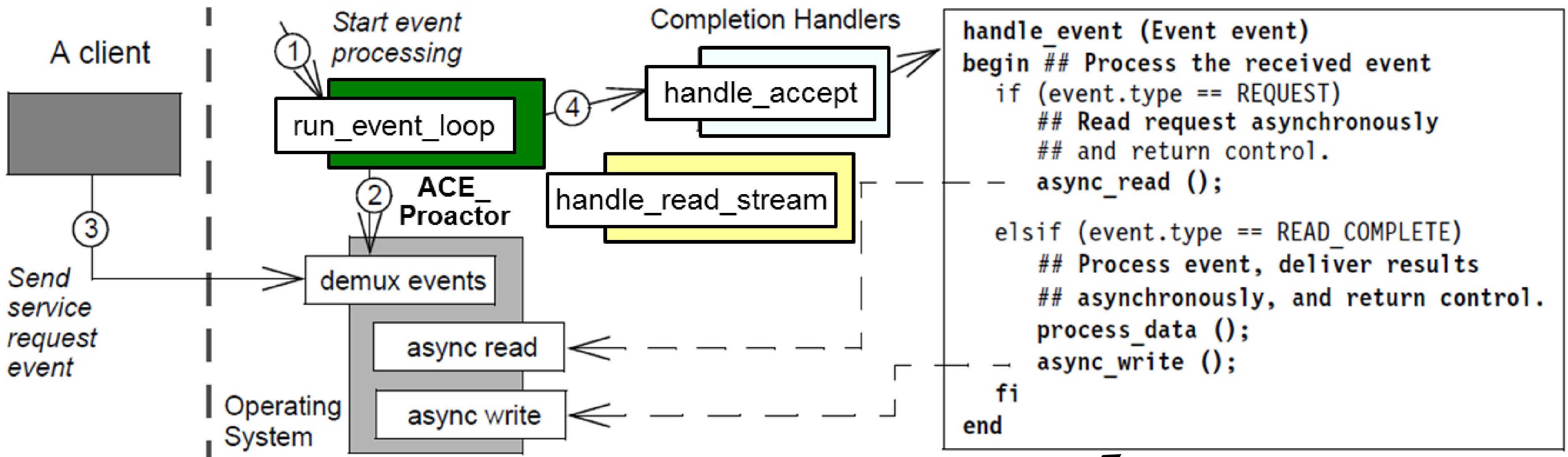
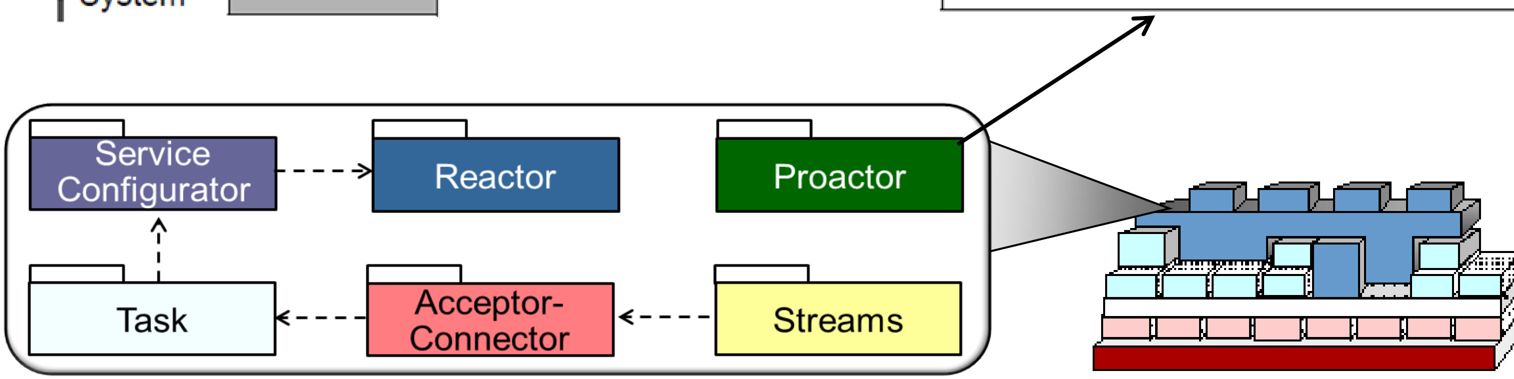
- Modern Windows platforms support both overlapped I/O & I/O completion ports
  - These mechanisms are efficient, but tricky to program
- Some operating systems implement the POSIX.4 AIO specification
  - The spec focuses on disk I/O & implementations are often buggy & inefficient



Overview of the ACE Proactor Framework

- Classes in this framework allow event-driven apps to process completion events for operations invoked asynchronously





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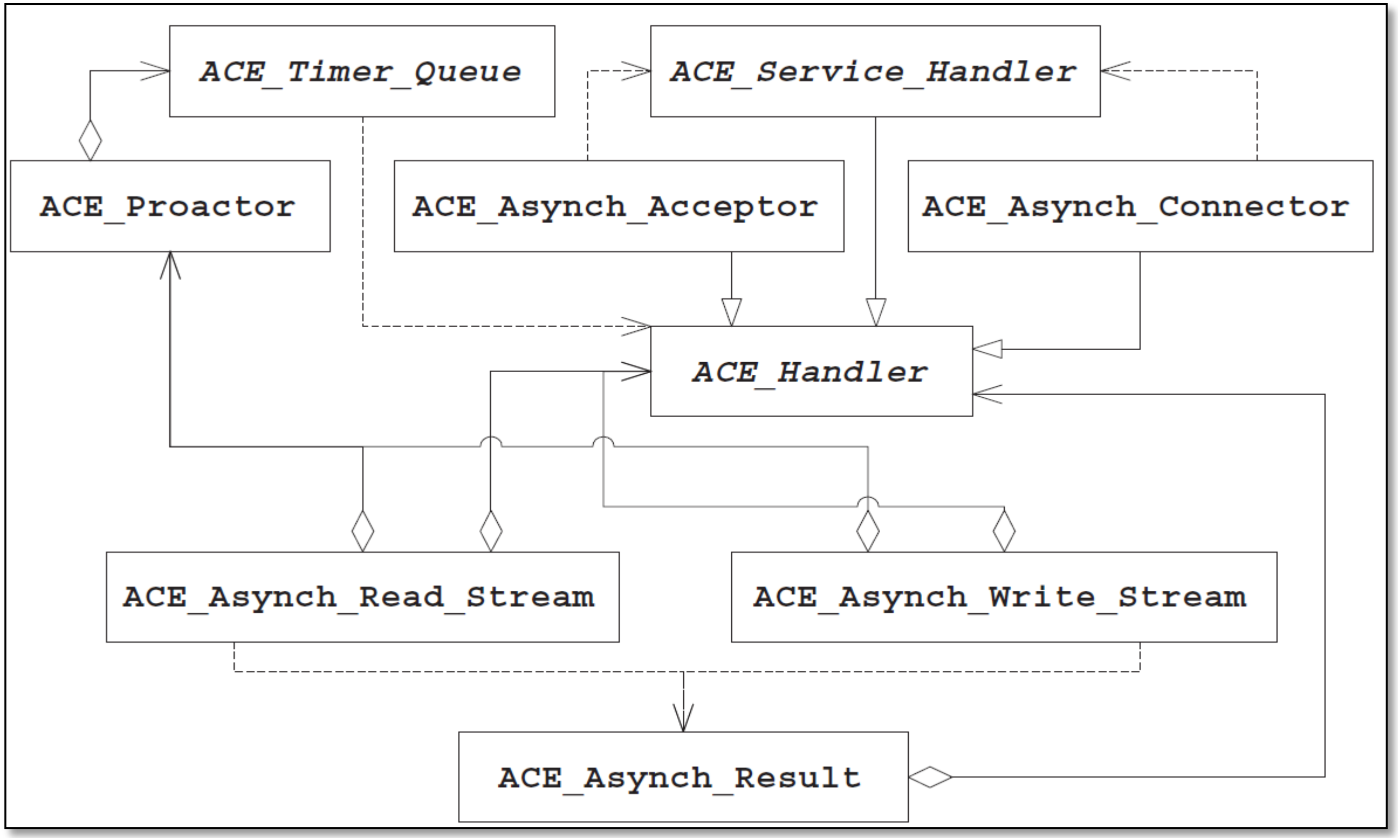
- Apps inherit from **`ACE_Service_Handler`** & override its hook methods, which ACE *Proactor* framework then dispatches to process completion events



These classes are designed in accordance with the *Proactor* pattern

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ACE Class	Description
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ACE_Asynch_Acceptor **ACE_Asynch_Connector**	Implementation of *Acceptor-Connector* pattern that establishes new TCP/IP connections asynchronously
ACE_Service_Handler	Defines the target of the **ACE_Asynch_Acceptor** & **ACE_Asynch_Connector** connection factories & provides the hook methods to initialize a TCP/IP connected service
ACE_Proactor	Manages timers & asynchronous I/O completion event demultiplexing

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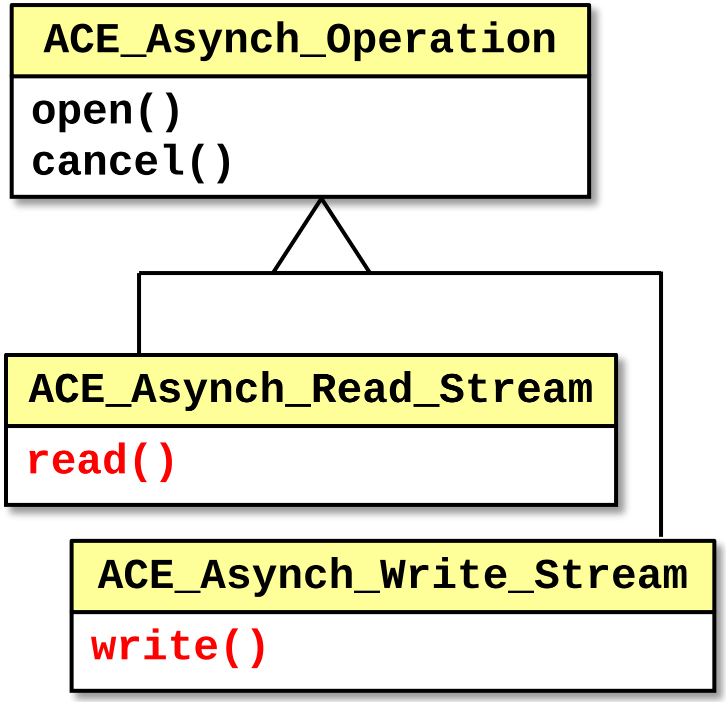
The ACE_Asynch_[Read|Write]_Stream Classes

These factory classes enable applications to initiate portable asynchronous **`read()`** & **`write()`** operations that provide the following capabilities:

- They can initiate asynchronous I/O operations on a stream-oriented IPC mechanism, such as a TCP socket



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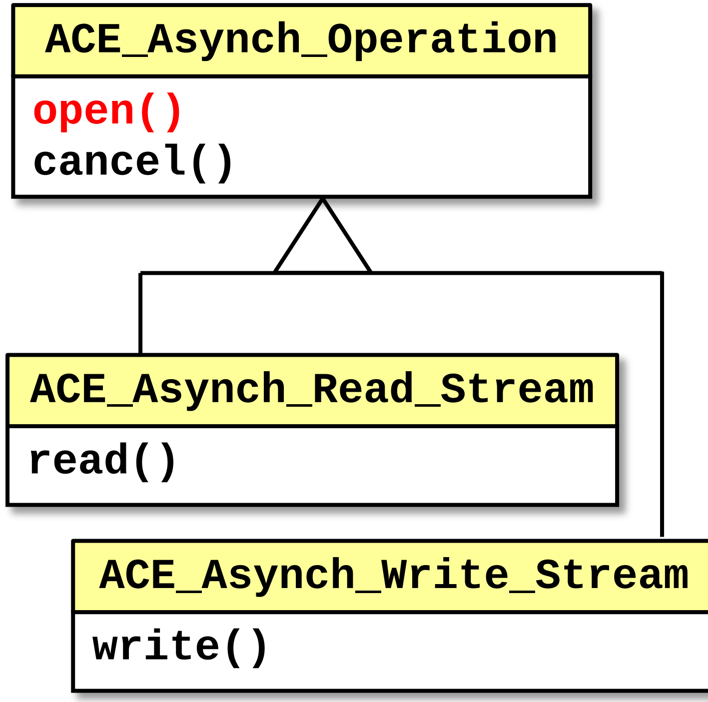

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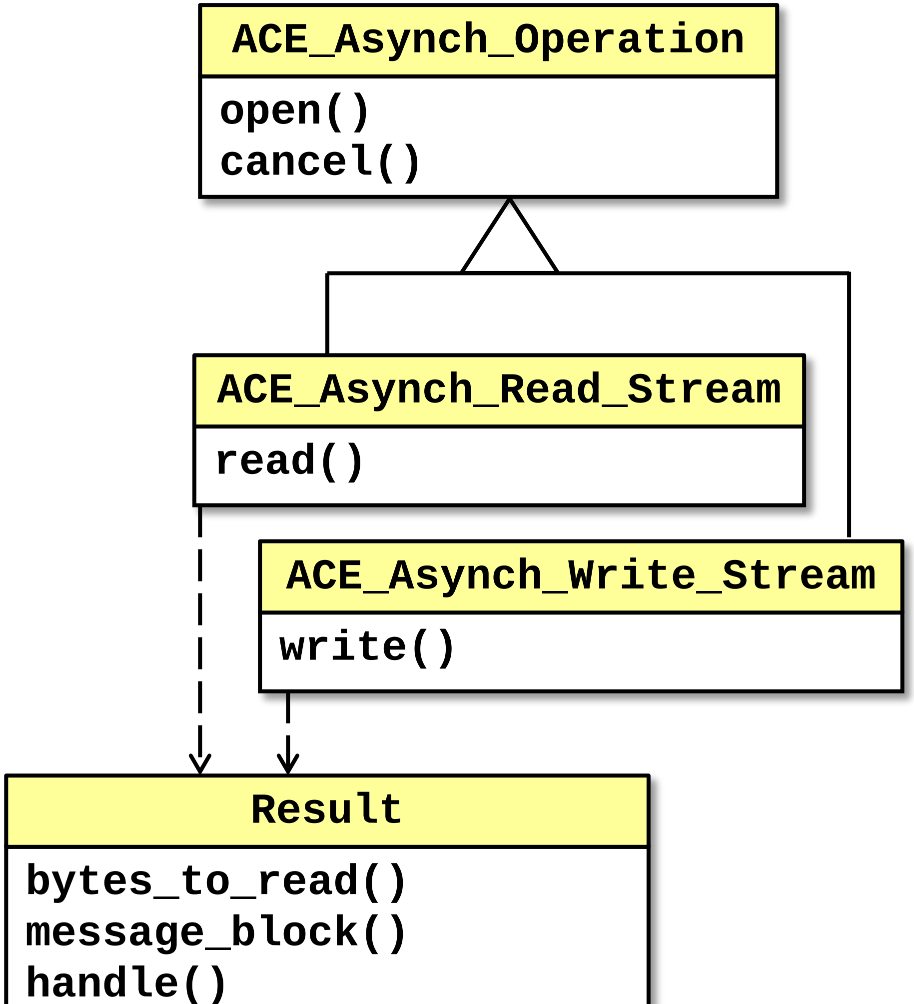

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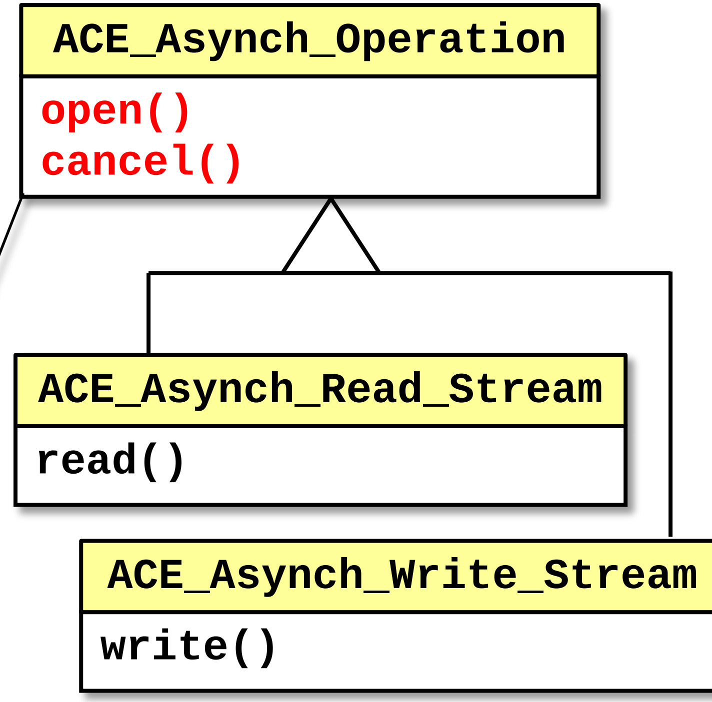

*They derive from **`ACE_Asynch_Operation`**, which provides the interface to initialize the object & cancel outstanding I/O operations*

Handles *variability* of asynchronous I/O operations via a *common* API

The ACE_Handler Class

The base class of all asynchronous completion handlers in the ACE *Proactor* framework

- It provides hook methods to handle completion of all asynchronous I/O operations defined in ACE
  - Including connection establishment & I/O operations on files & IPC streams

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handle_connect()
handle_read_stream
handle_write_stream()
handle_transmit_file()
handle_read_file()
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Handles *variability* of asynchronous event completion via a *common* API

The ACE_Service_Handler Class

This class defines the interface for the **`ACE_Asynch_Acceptor`** & **`ACE_Asynch_Connector`** to activate when a new TCP connection is accepted

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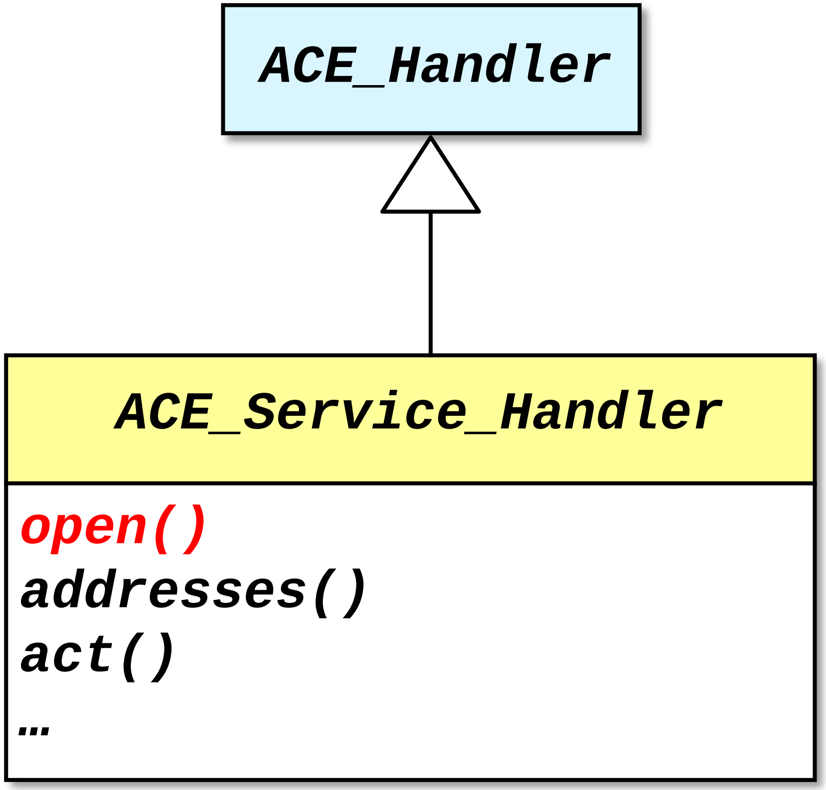

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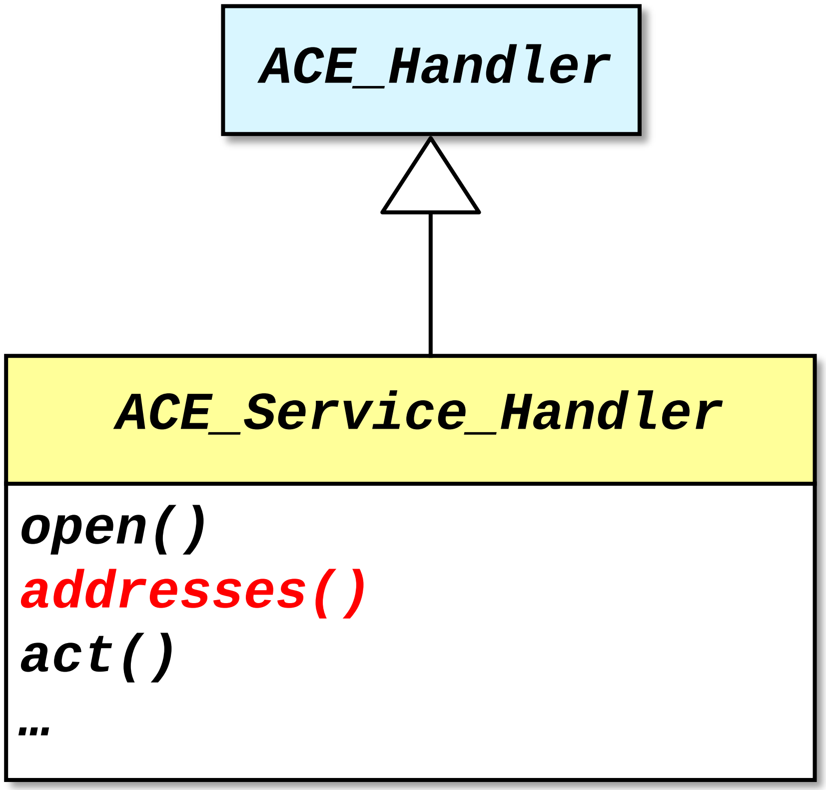

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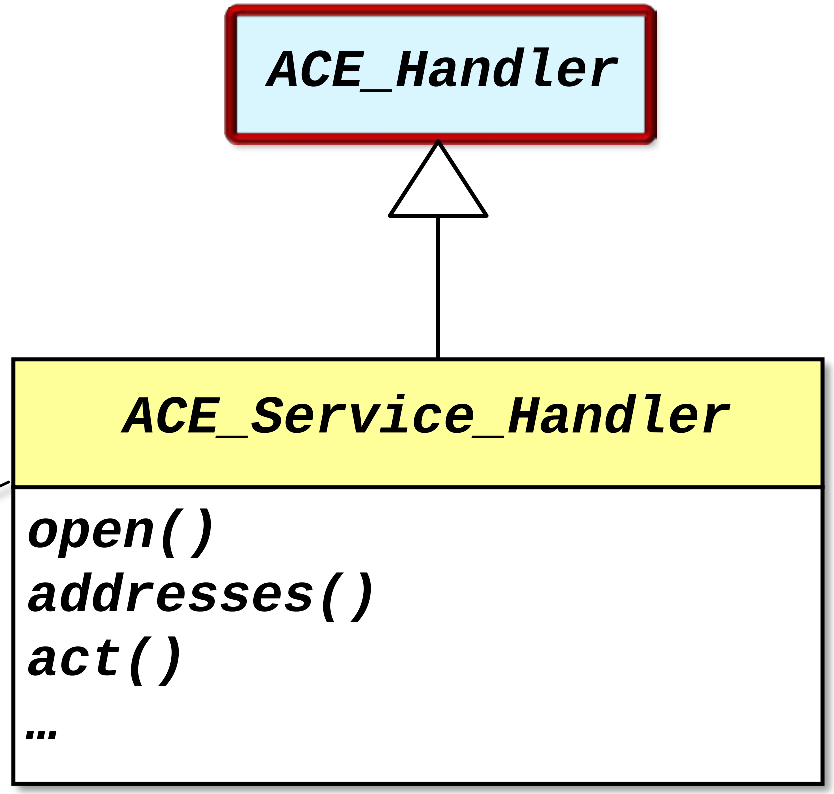

It inherits the ability to handle asynchronous I/O completion events since it derives from ***`ACE_Handler`***

Handles *variability* of asynchronous network I/O via a *common* API

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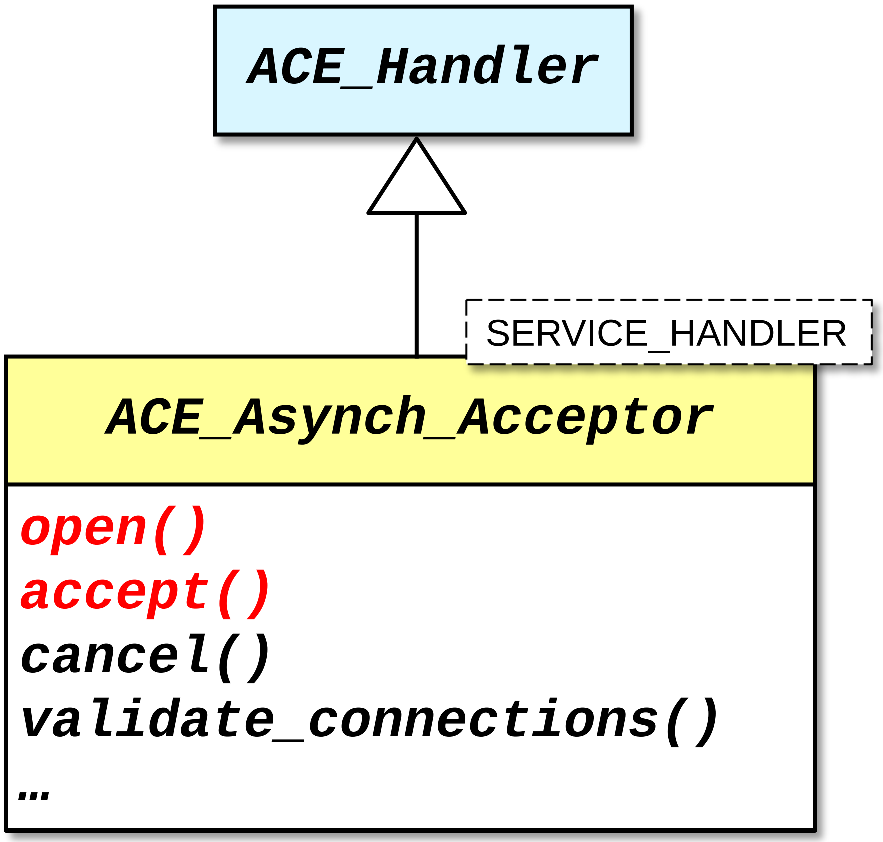
This class provides an implementation of asynchronous *Acceptor* capability in the *Acceptor-Connector* pattern:

- It initiates asynchronous passive connection establishment



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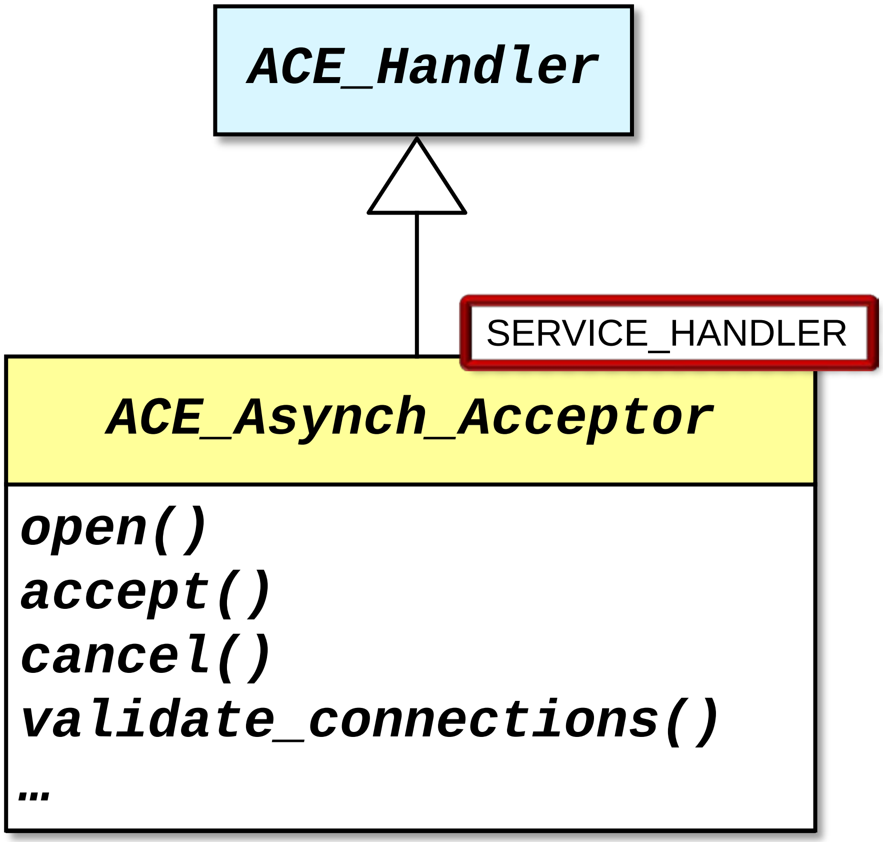

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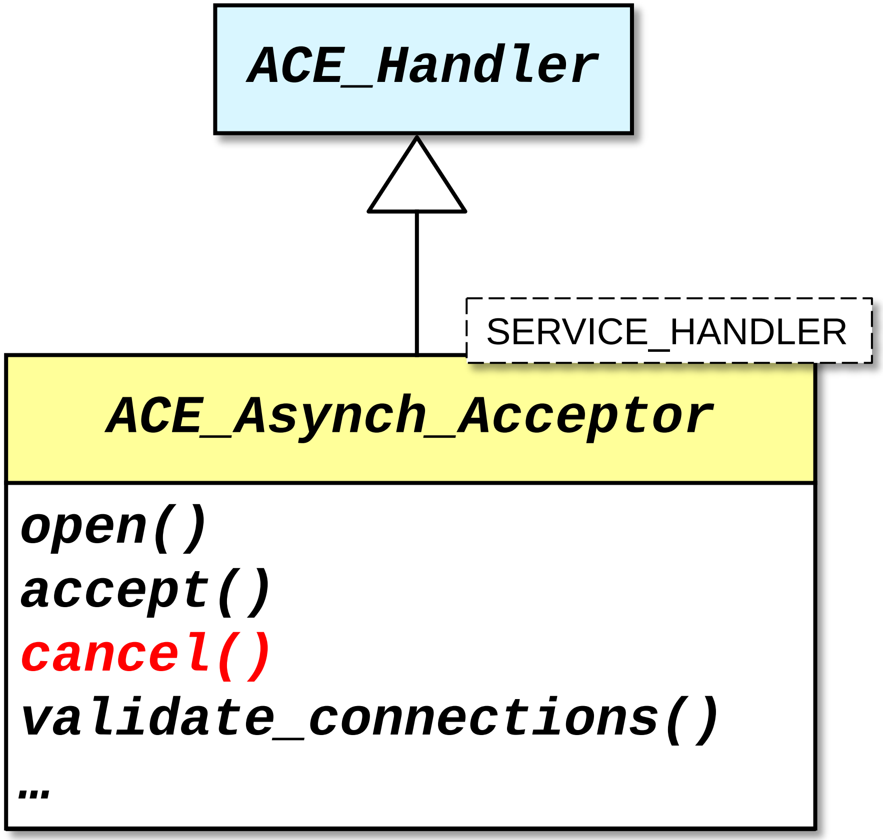

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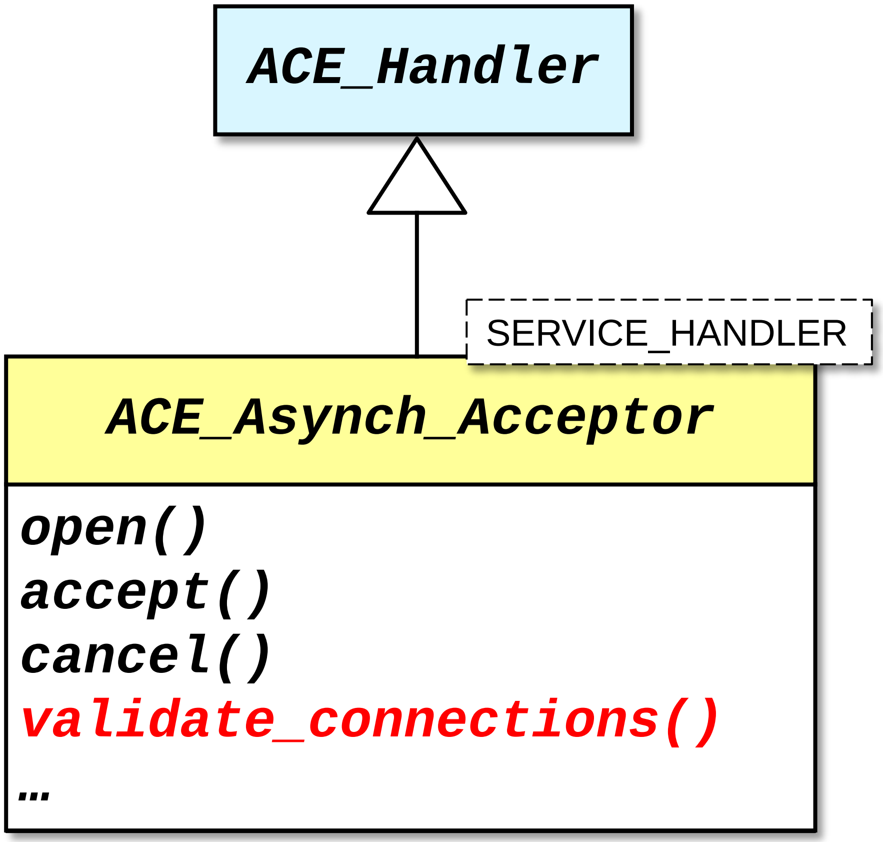

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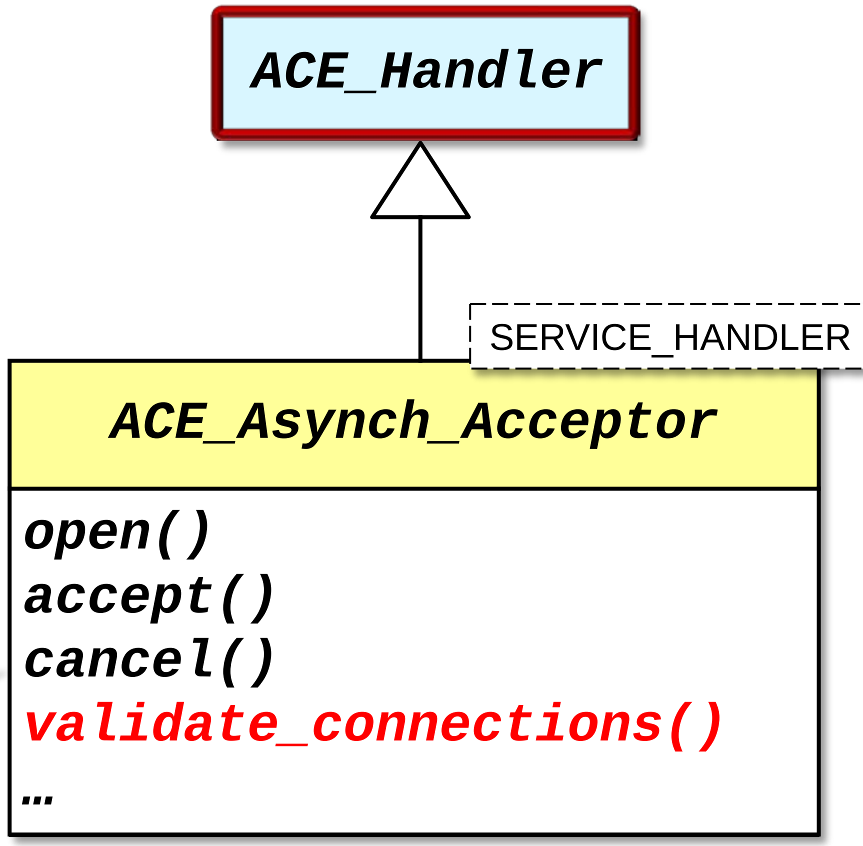
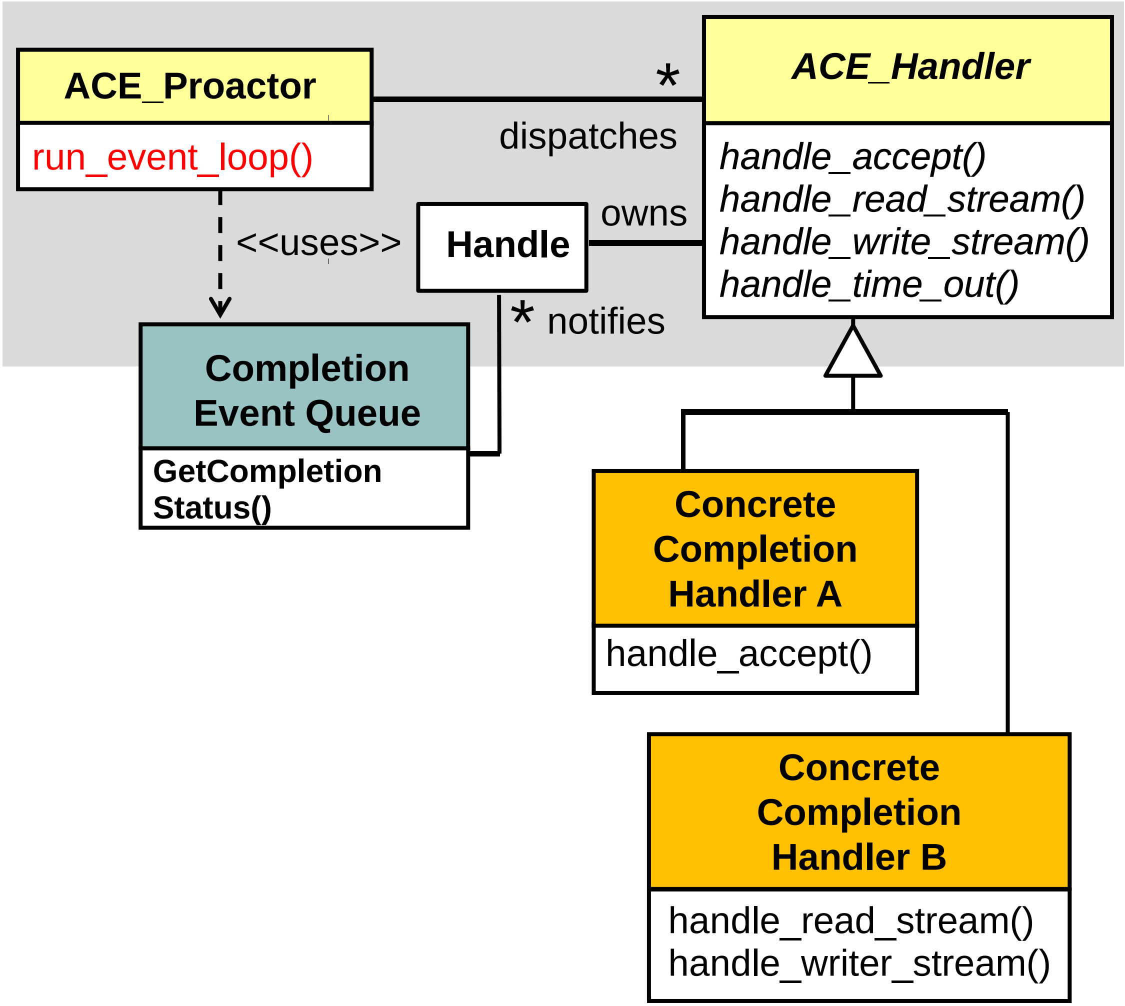


*Inherits from **`ACE_Handler`** to handle asynchronous accept completion events*

The ACE_Proactor Class

Defines an interface for ACE *Proactor* framework capabilities:

- Centralize event loop processing



The ACE_Proactor Class

Defines an interface for ACE *Proactor* framework capabilities:

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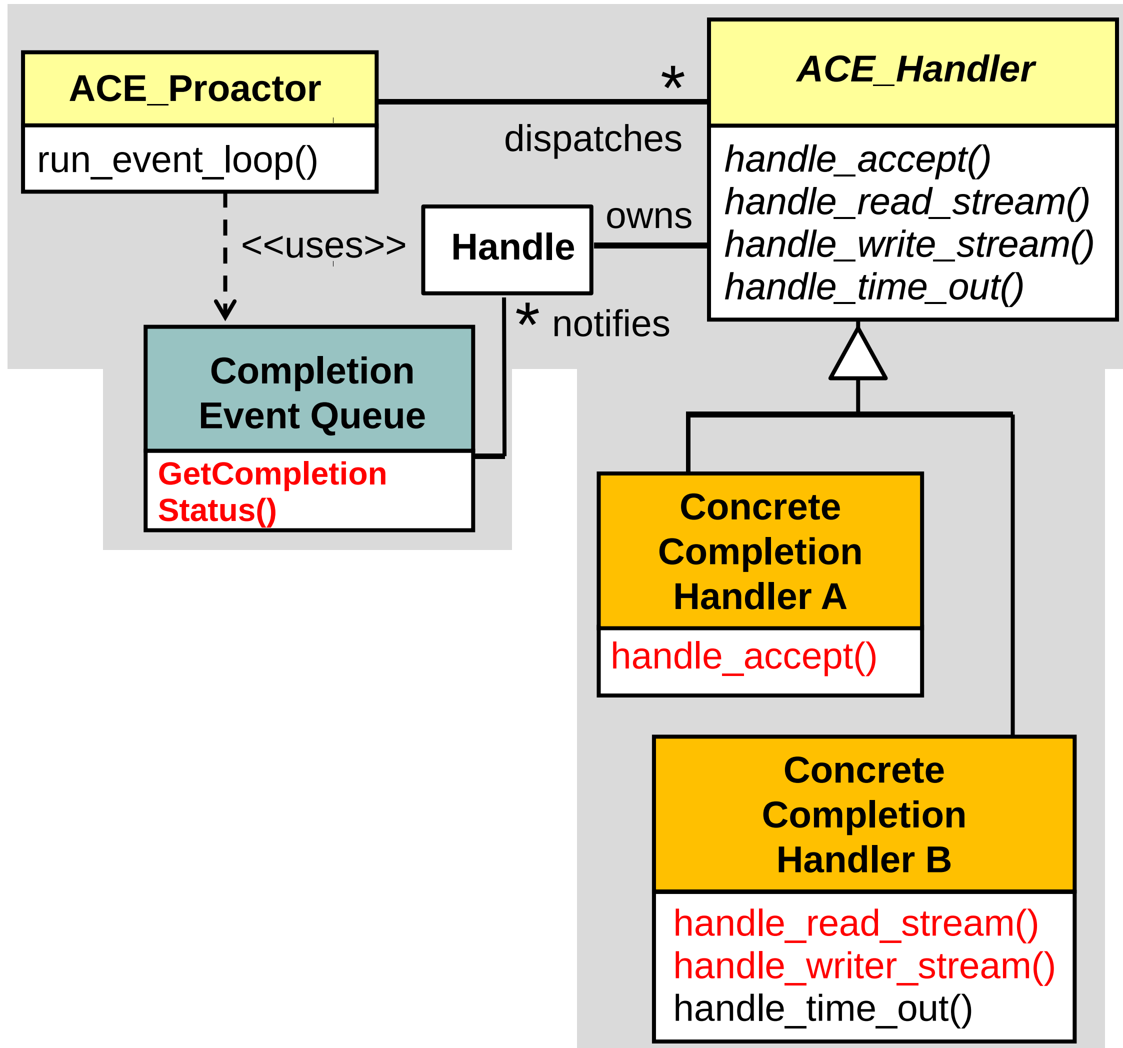

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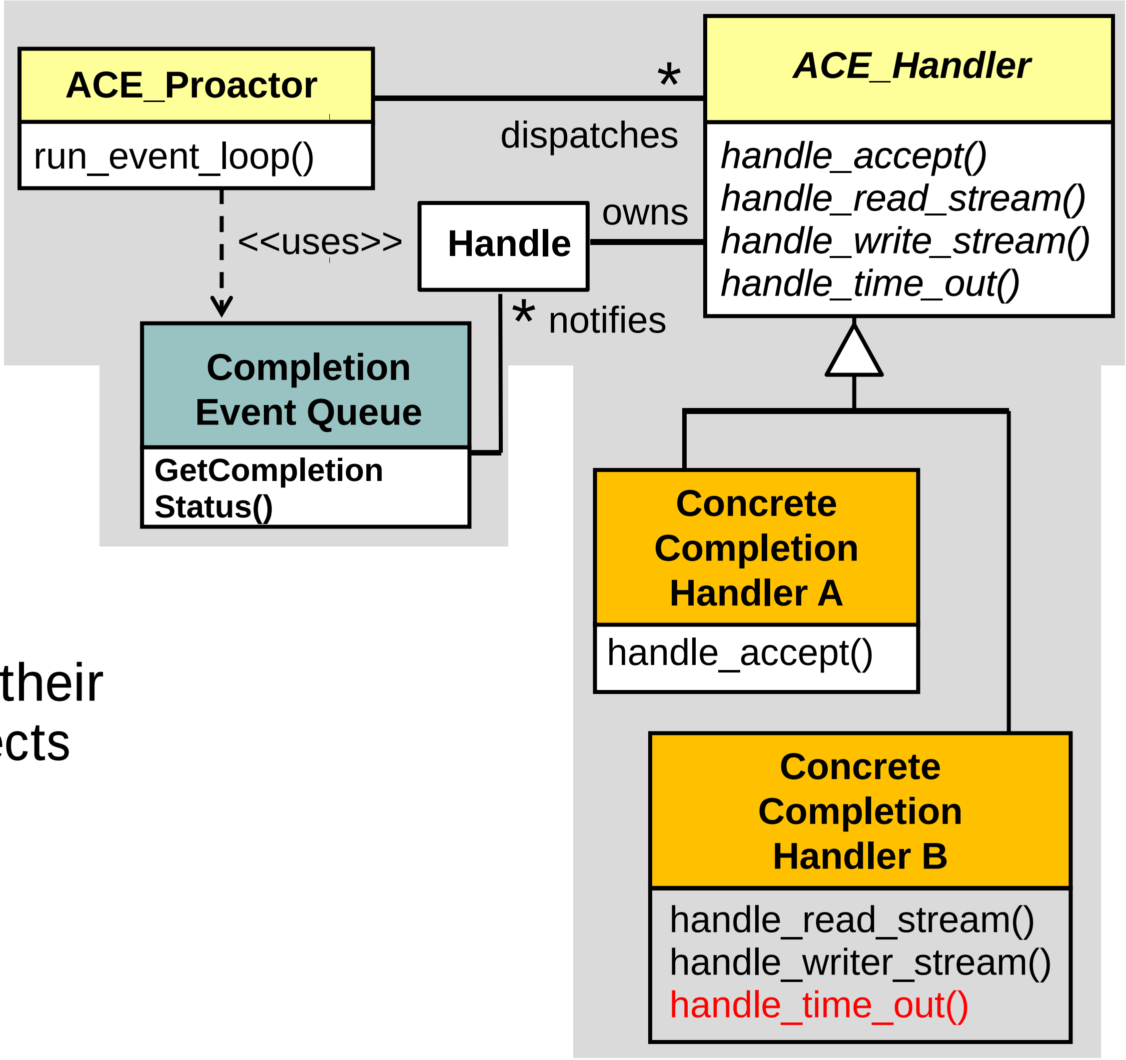

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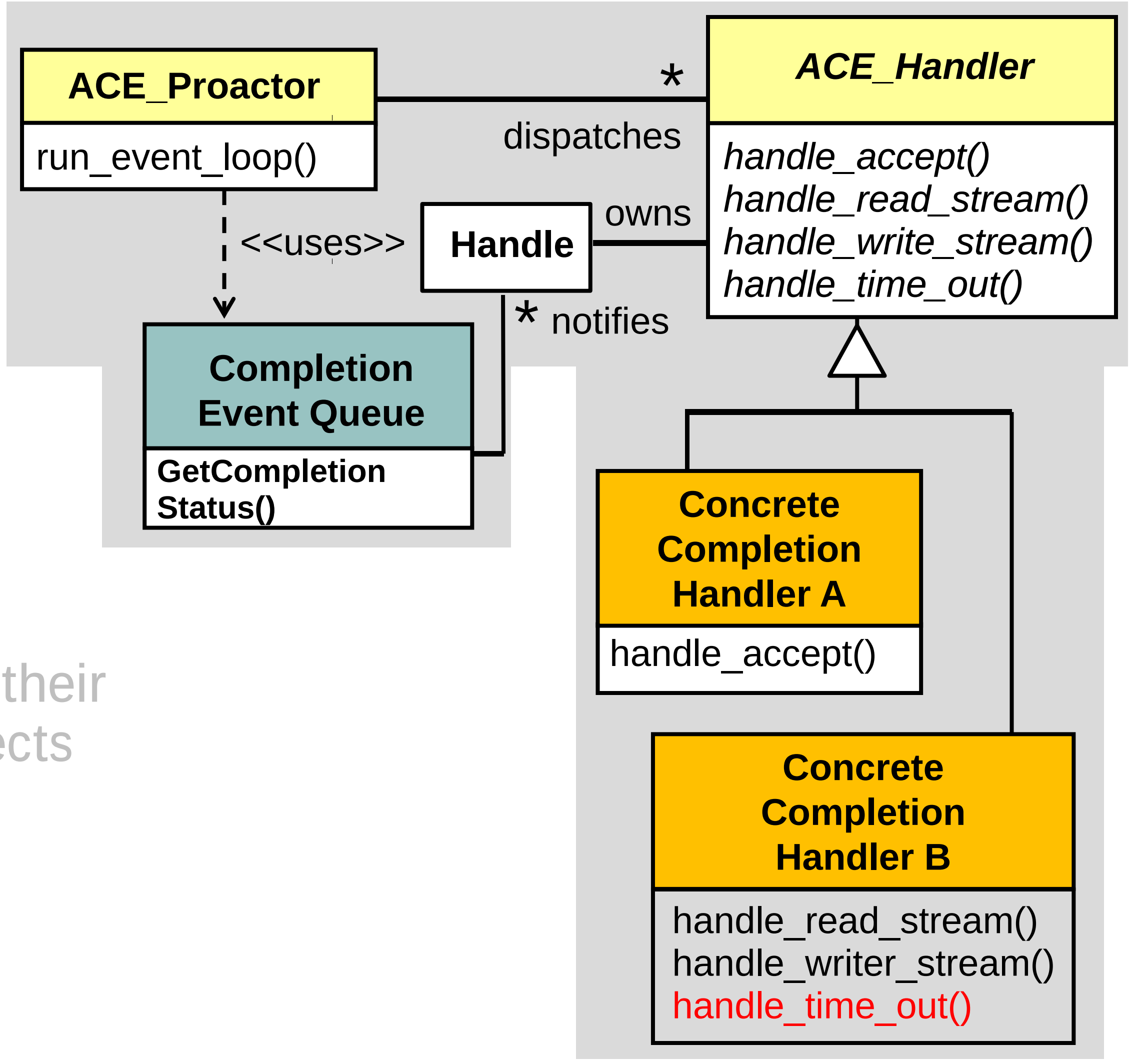
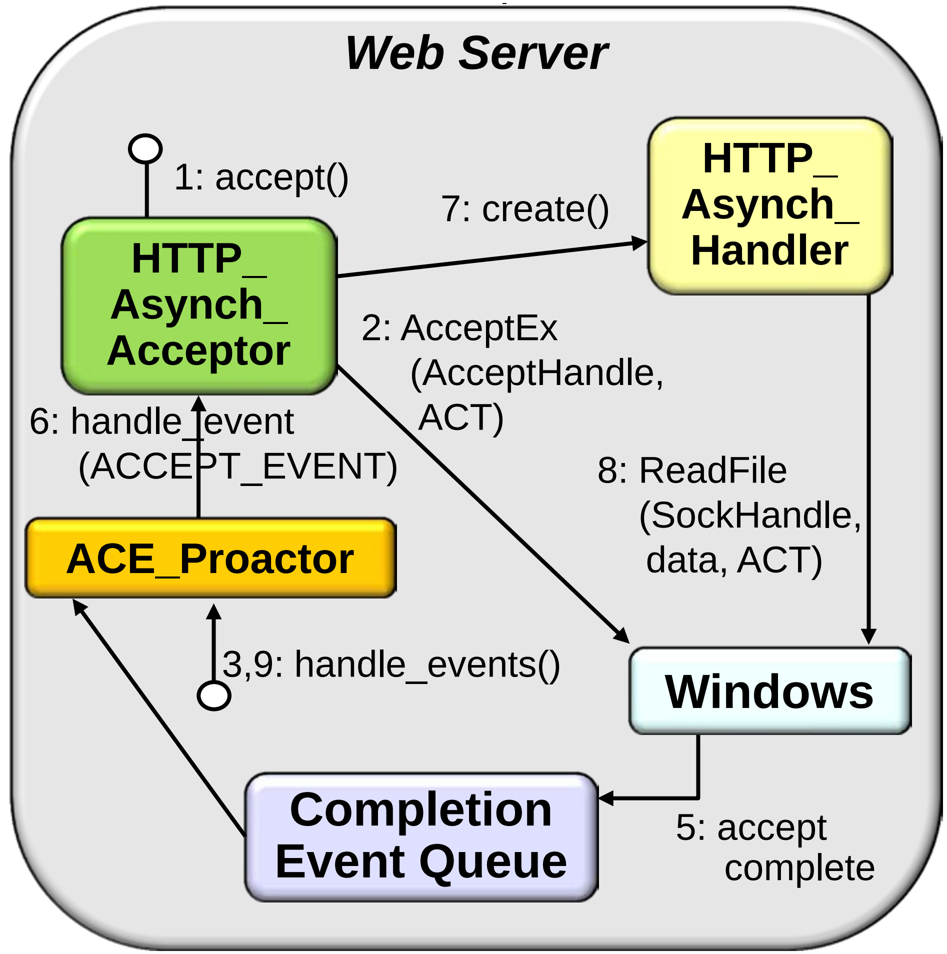


Handles *variability* of asynchronous event handling via a *common* API

Summary

- A proactive I/O model is harder to program than reactive & synchronous I/O models for several reasons
  - There's a time/space separation between asynchronous invocation & completion handling that requires tricky state management
    - e.g., bookkeeping details & data fragments must be managed explicitly, rather than handled implicitly on the run-time stack



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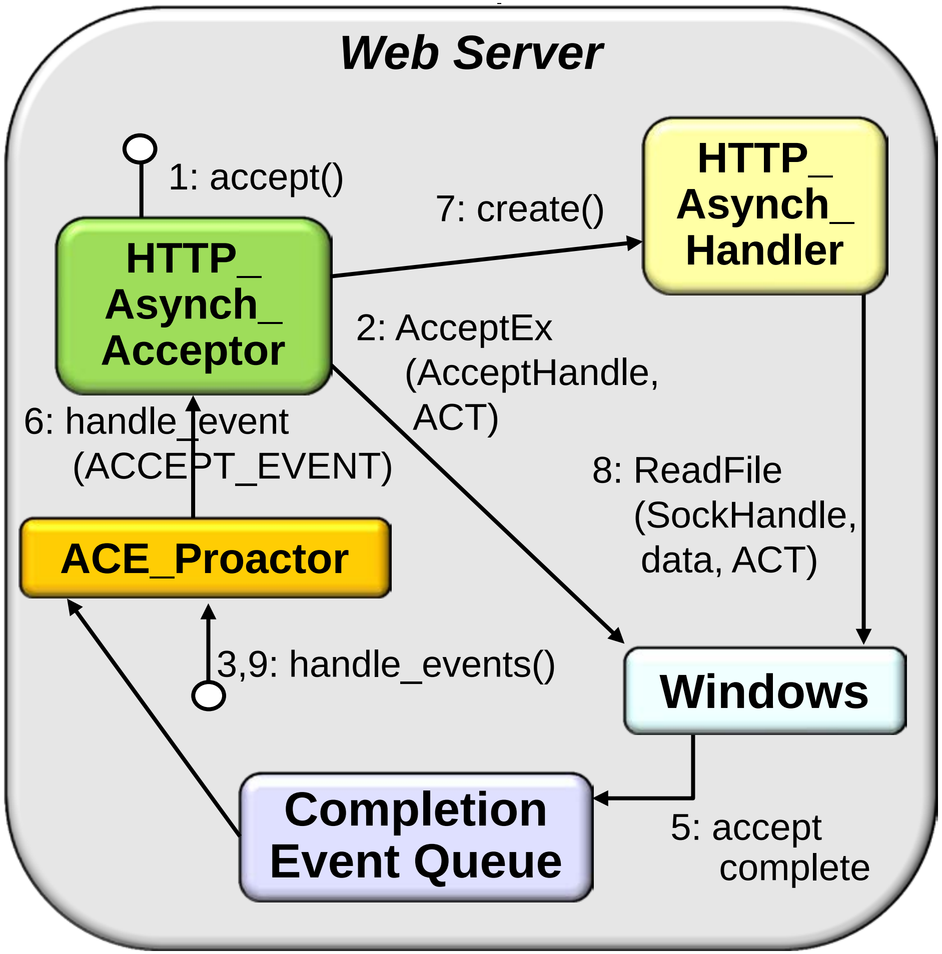

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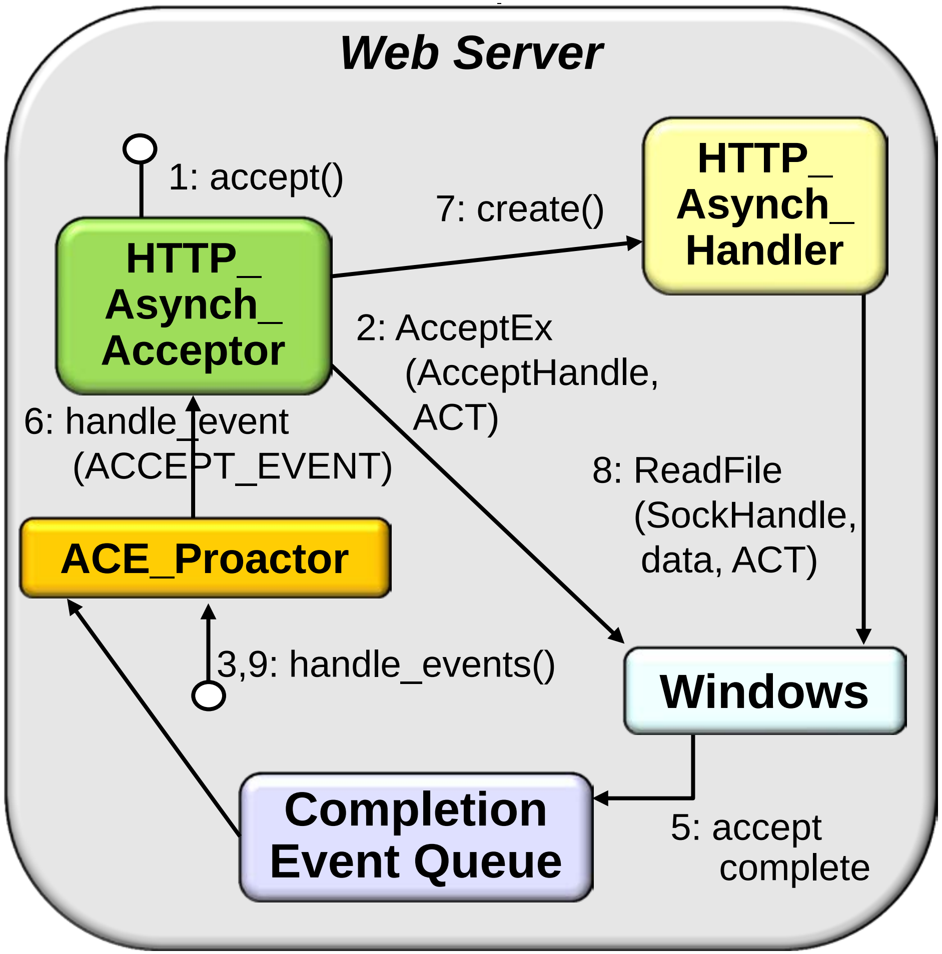

- The ACE *Proactor* framework helps to alleviate many of these complexities

Patterns & Frameworks for Asynchronous Event Handling: Part 3

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Topics Covered in this Part of the Module

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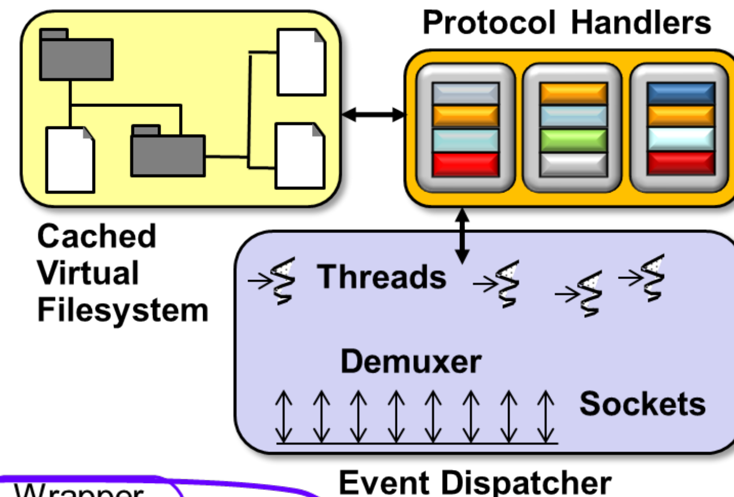
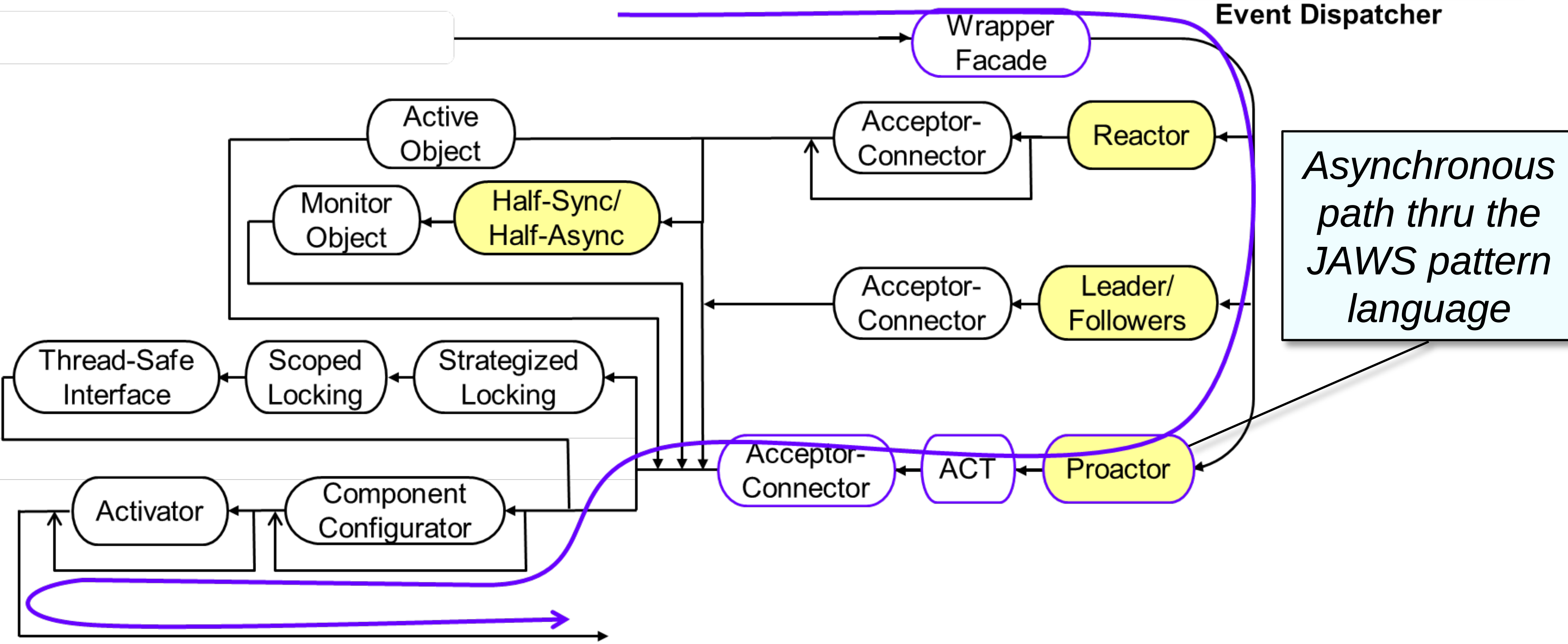
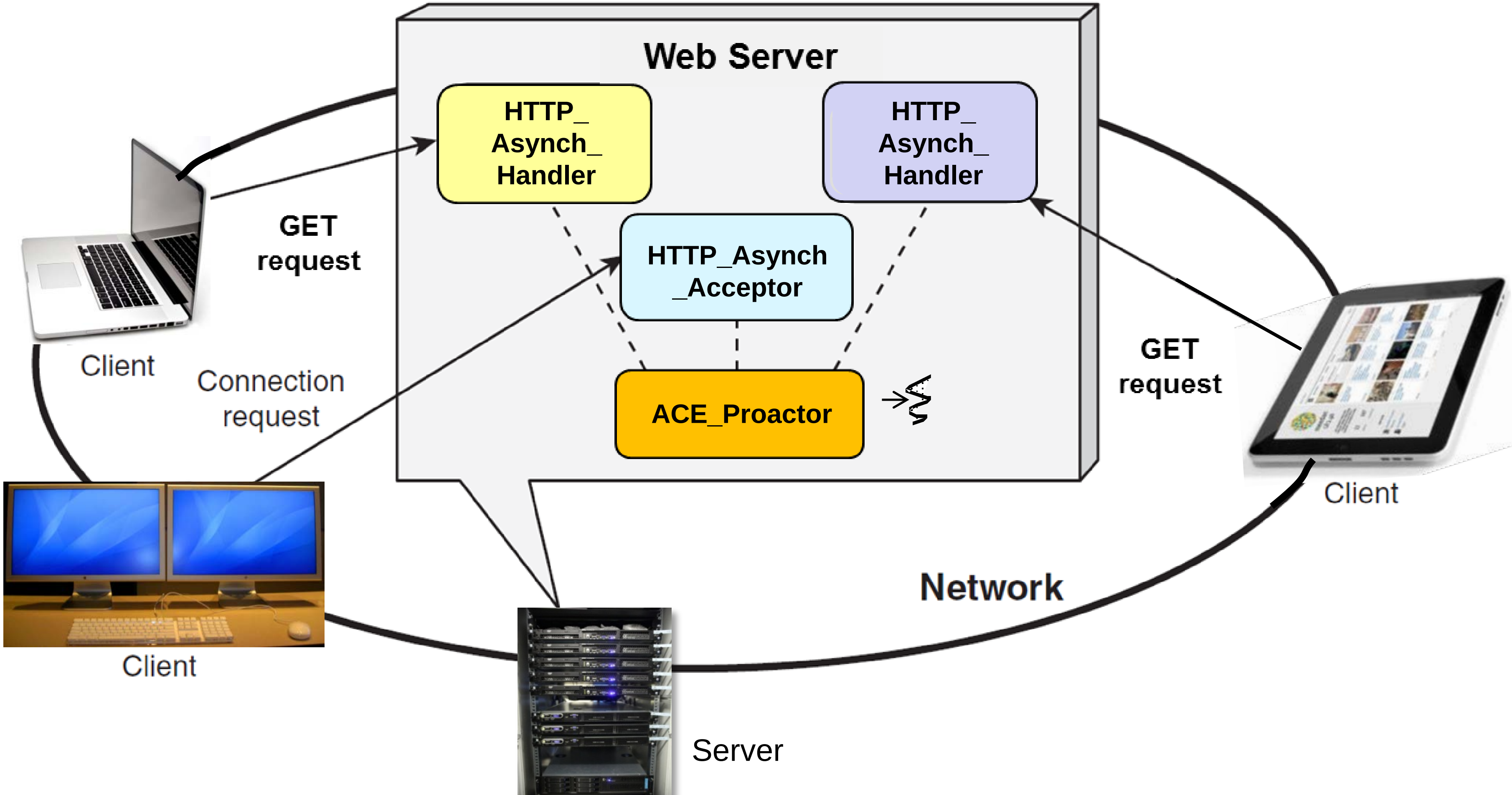
- Describe the ACE *Proactor* framework
- Apply the ACE *Proactor* framework to JAWS





Proactive Processing w/ACE Proactor Framework

Use **`ACE_Service_Handler`** & **`ACE_Asynch_Acceptor`** to implement a JAWS web server based on the *Proactor* pattern



This implementation only uses a single thread, but is still scalable on Windows

Proactive Processing with ACE_Service_Handler

Implements HTTP using asynchronous operations

```
class HTTP_Asynch_Handler : public ACE_Service_Handler {
private:
  ACE_Proactor *proactor_; // Cached Proactor.
  ACE_Mem_Map file_; // Memory-mapped file
  ACE_HANDLE handle_; // Socket endpoint

  HTTP_Request request_;

  ACE_Asynch_Read_Stream read_stream_;
  ACE_Asynch_Write_Stream write_stream_;

public:
  HTTP_Asynch_Handler (ACE_Proactor *proactor)
                                        : proactor_ (proactor) {}
// ... Continued below
```

Hold HTTP request while it's being processed

Read/write asynchronous socket I/O

Proactive Processing with ACE_Service_Handler

Hook method invoked by `HTTP_Asynch_Acceptor`

```
virtual void open (ACE_HANDLE new_handle,
                   ACE_Message_Block &mb) {
  request_.state_ = INCOMPLETE; // Initialize state for request
  io_handle_ = new_handle; // Store handle to the open socket


  read_stream_.open
    (*this,
     io_handle_,
     0, proactor_);
```

Initialize `ACE_Async_Read_Stream`, with `*this` as completion handler

Start asynchronous read operation on connected socket

```
  read_stream_.read
    (request_.message (), request_.size ());
}
```

Proactive Processing with ACE_Service_Handler

Completion event handling method dispatched by ACE *Proactor* framework

```
virtual void handle_read_stream
          (const ACE_Asynch_Read_Stream::Result &result) {

  if (request_complete (result))
    handle_request ();
```

Got the entire read request, so handle it

```
  else
    read_stream_.read (request_.message (),
                       request_.size ());
}
  // ...
}
```

Didn't get entire request, so initiate a new asynchronous `read()` operation to try & get the remainder

Proactive Processing with ACE_Service_Handler

Handle processing of a completed request

Switch on the HTTP command type

Memory map the requested content & invoke an asynchronous write operation to transmit it to the client

```
void handle_request () {

  switch (request_.command ()) {

  case HTTP_Request::GET: // Request to download a file

    file_.map (request_.filename ());
    write_stream_.write (file_.addr (),
                         file_.size ());
    break;

  case HTTP_Request::PUT: // Request to upload a file
  ...
```

We could also use **transmit_file()** here

Proactive Processing with ACE_Asynch_Acceptor

Implements HTTP using asynchronous operations

```
class HTTP_Asynch_Acceptor
 : public ACE_Asynch_Acceptor<HTTP_Asynch_Handler> {
public:
  HTTP_Asynch_Acceptor (ACE_INET_Addr addr,
                        ACE_Proactor *proactor) {

    open (addr, 0, false, ACE_DEFAULT_ASYNCH_BACKLOG, 1,
          proactor);
 }
```

Starts multiple asynchronous accept requests on addr

Applying the ACE Proactor framework to JAWS

```
const u_short PORT = 80;

int main (int argc, char *argv[]) {
  ACE_INET_Addr addr (argc == 1 ? PORT : atoi (argv[1]));
```

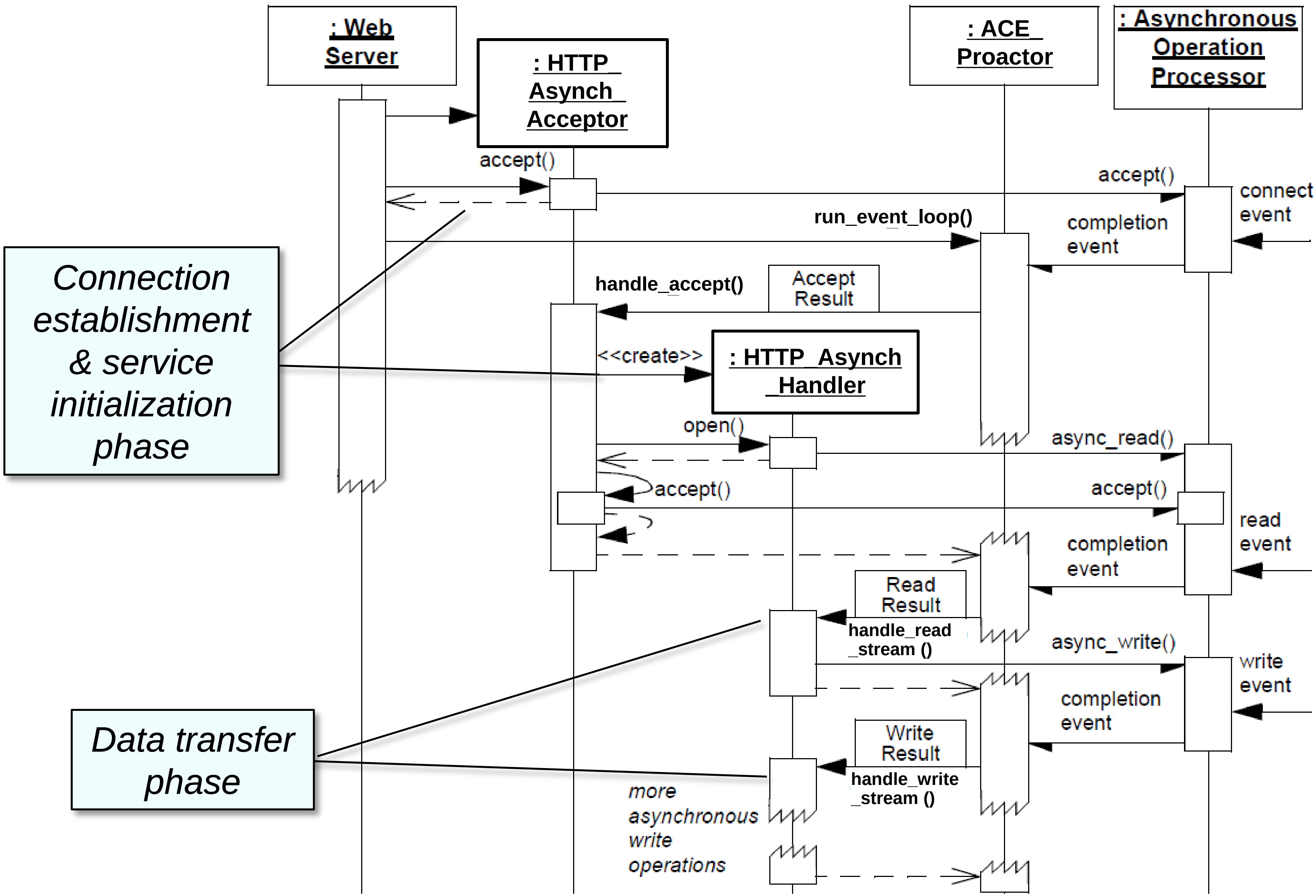
Associate the `HTTP_Asynch_Acceptor`'s passive-mode socket handle with the `ACE_Proactor` singleton's completion port & invoke multiple asynchronous accept operations to initiative proactive web serve processing

```
  HTTP_Asynch_Acceptor acceptor (addr,
                                 ACE_Proactor::instance ());
```

Event loop processes client connection requests & HTTP requests proactively

```
  for (;;)
    ACE_Proactor::instance ()->run_proactor_event_loop ();
  ...
```

Sequence Diagram of ACE Proactor Web Server



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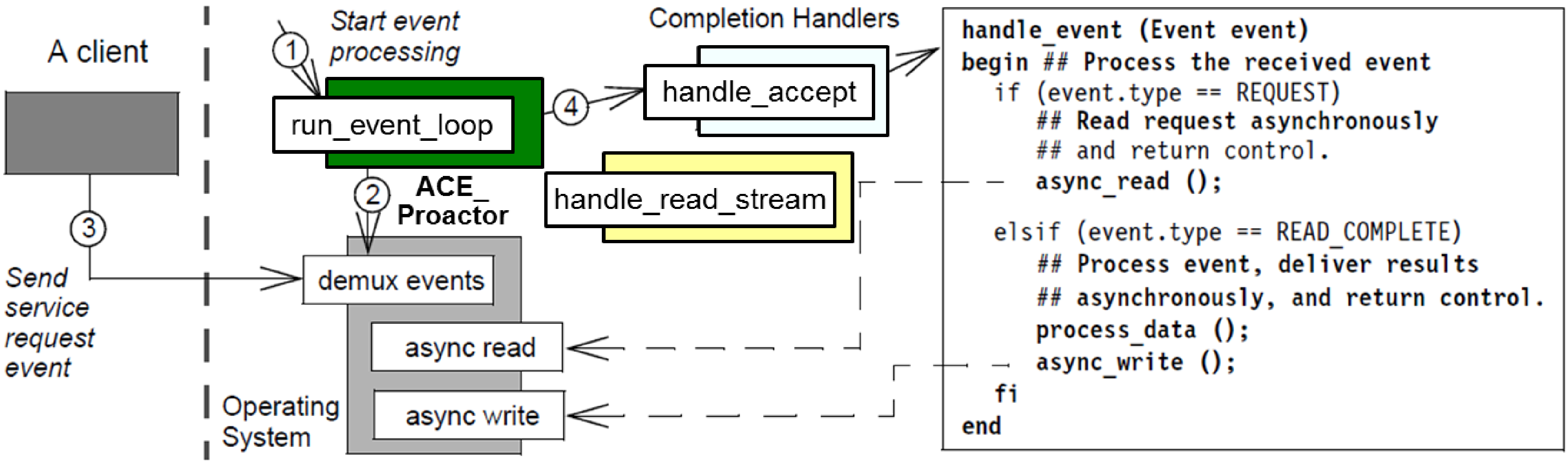

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- The ACE *Proactor* framework alleviates reactive I/O bottlenecks without introducing the complexity & overhead of synchronous I/O & multi-threading
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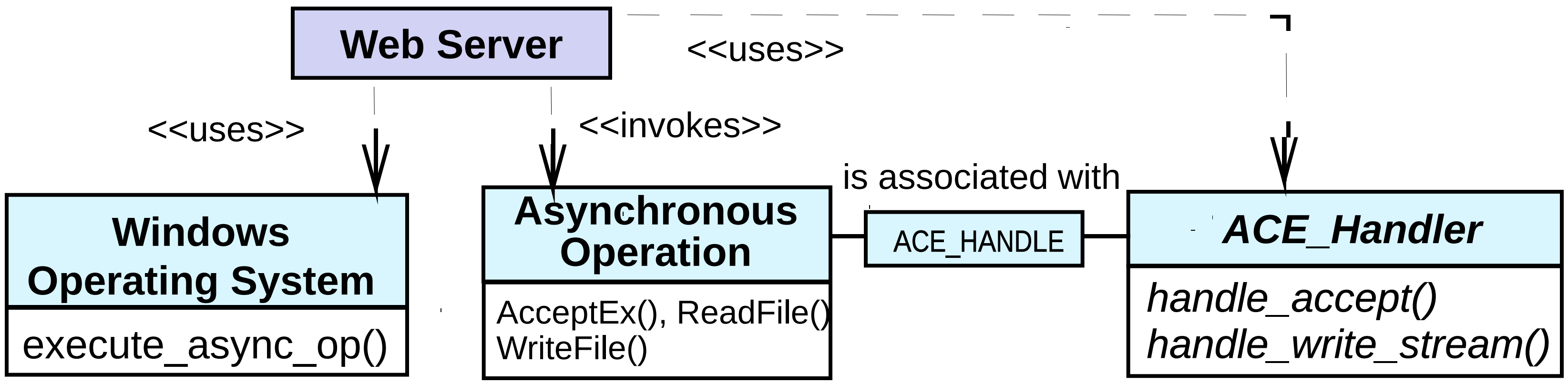
1. An app can initiate one or more asynchronous I/O operations on multiple I/O handles in parallel without having to wait until they complete



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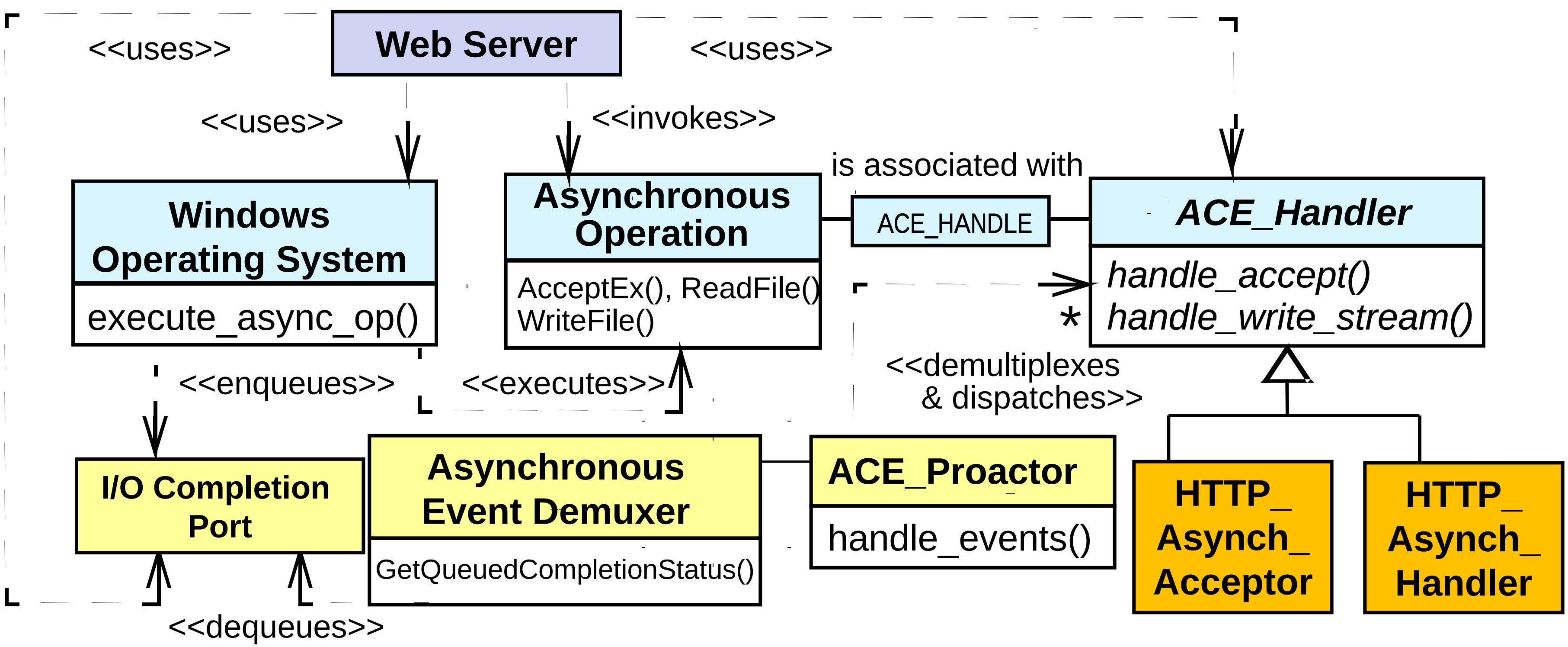

2. As each operation completes, the OS notifies an app-defined completion handler that then processes the results from the completed I/O operation

Patterns & Frameworks for Asynchronous Event Handling: Part 4

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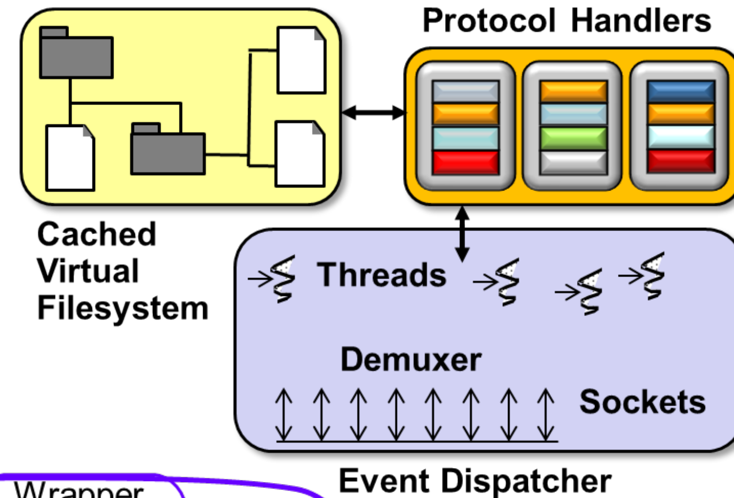
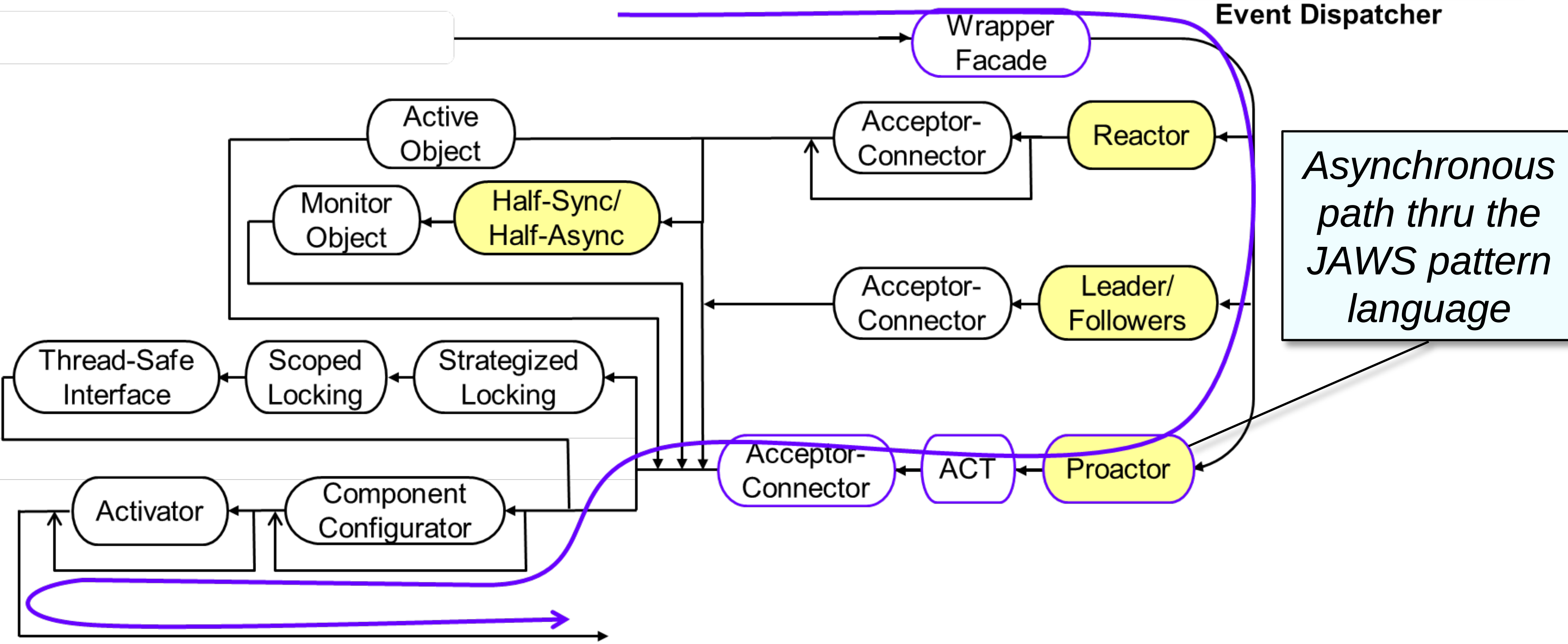
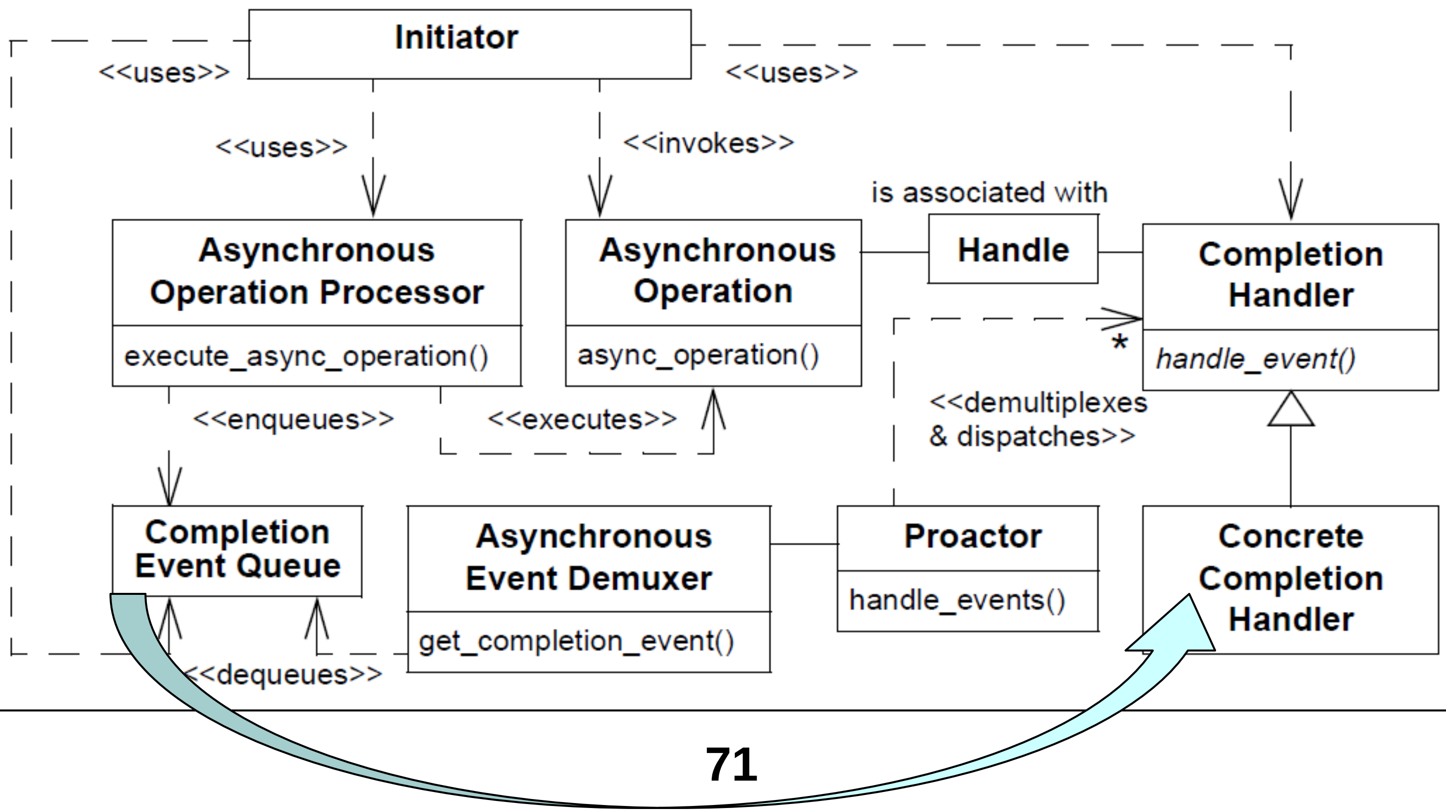
- Describe the *Asynchronous Completion Token* pattern & apply it to JAWS





Efficiently Demuxing Asynch Event Completions

Context	Problem
• In a proactive web server async I/O operations will yield I/O completion event responses that must be processed efficiently	• Need to minimize time/ space used to demux completion events to their associated completion handler



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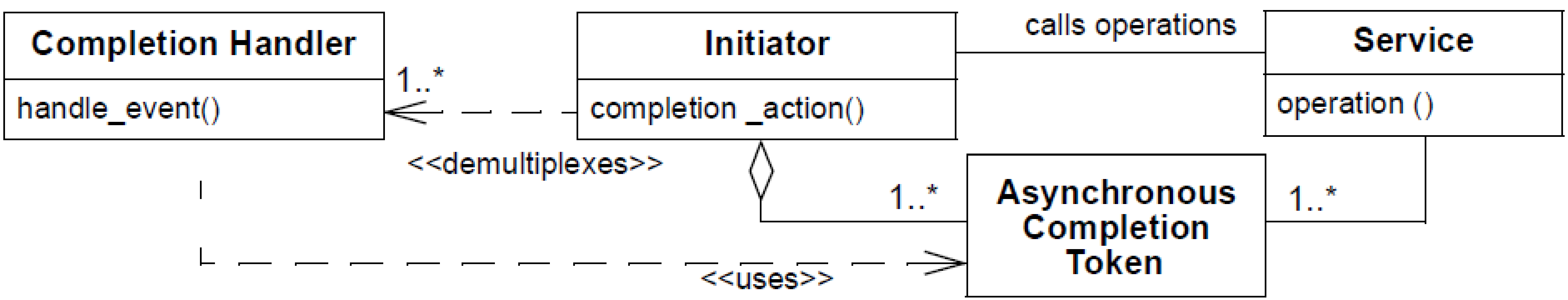
Asynchronous Completion Token allows an app to efficiently demux & process the responses of asynchronous operations it invokes on services



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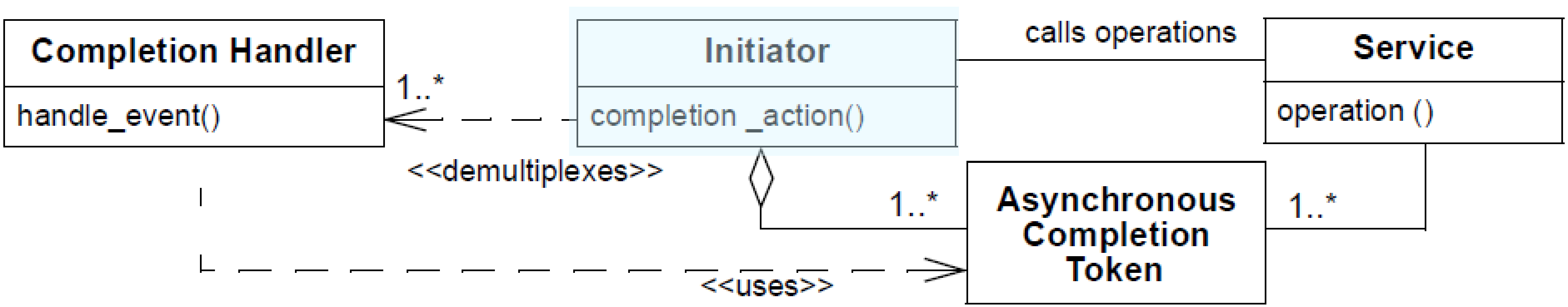

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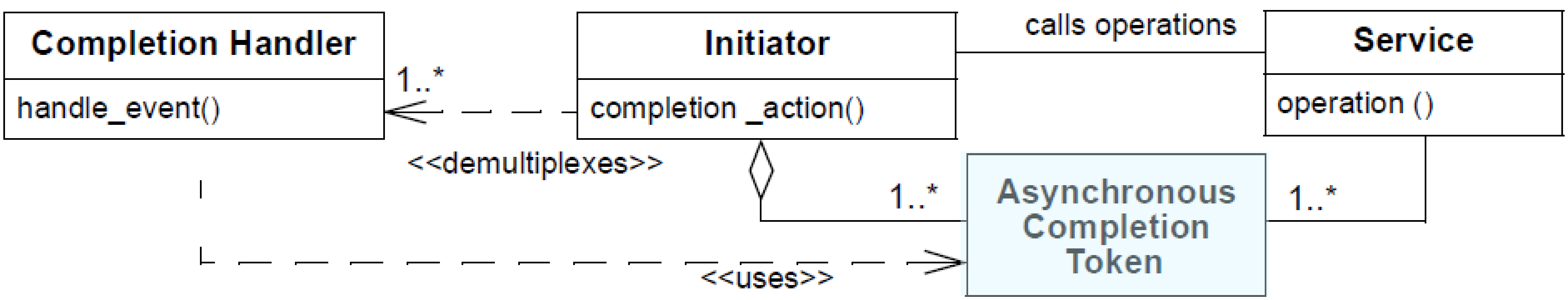

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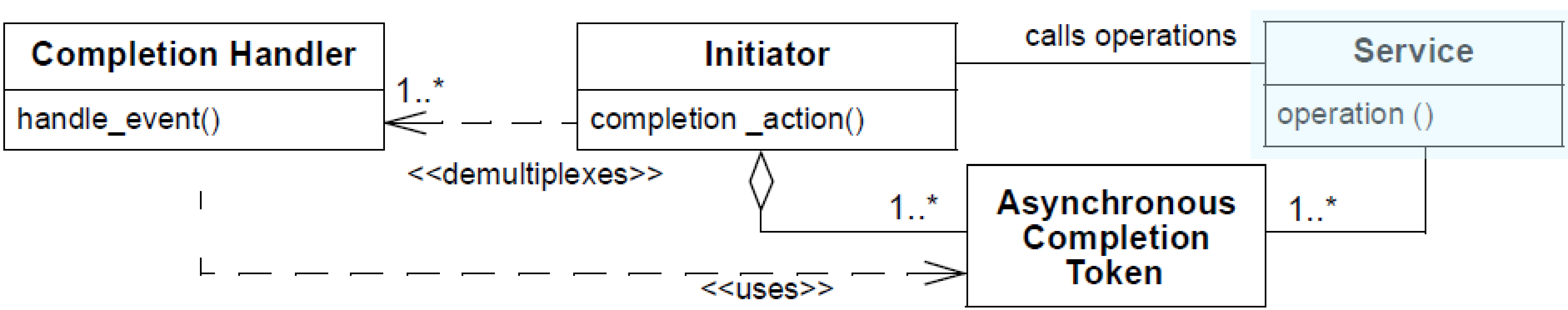

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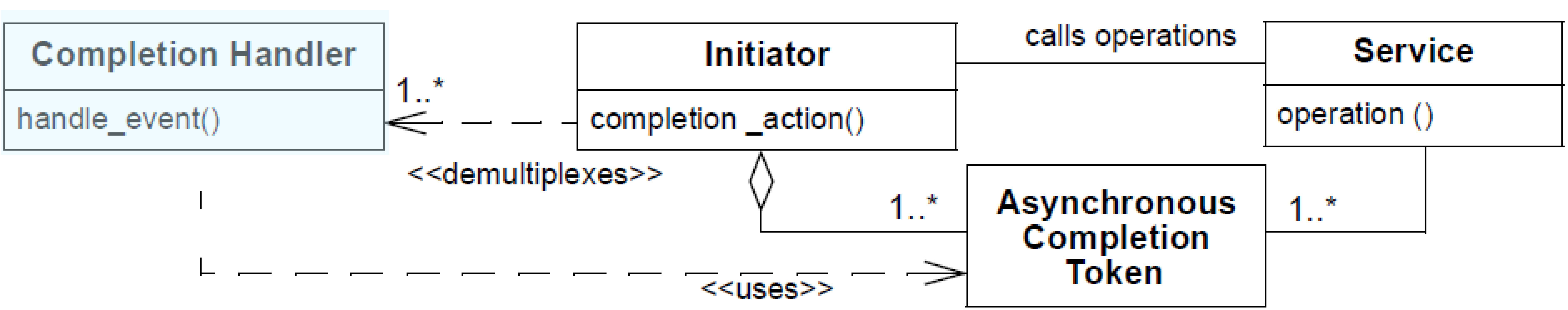

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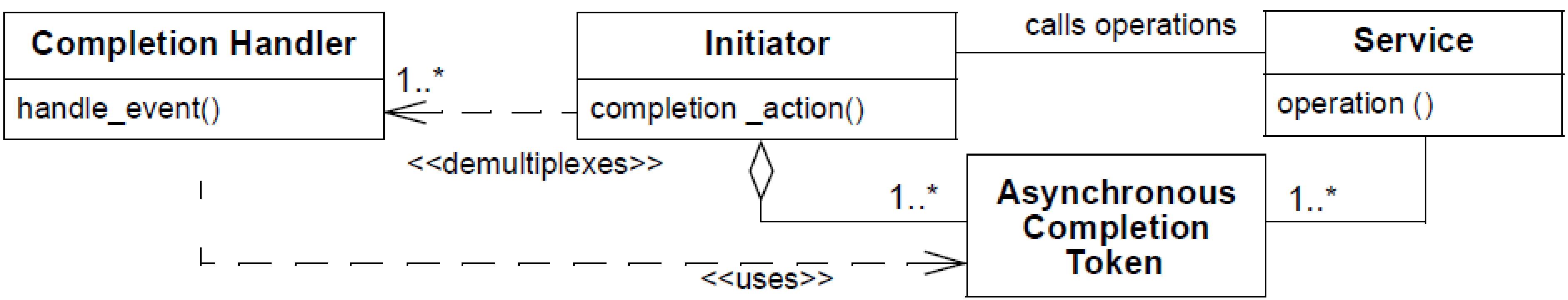

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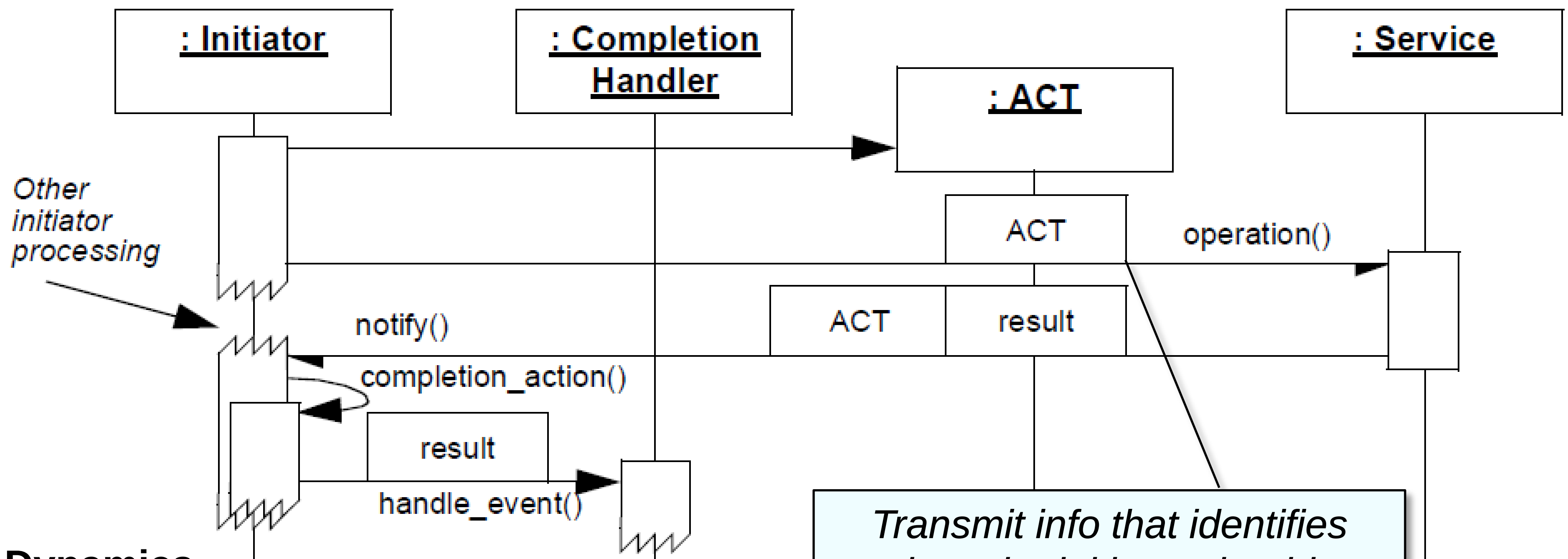

Dynamics

Transmit info that identifies how the initiator should process the service's response

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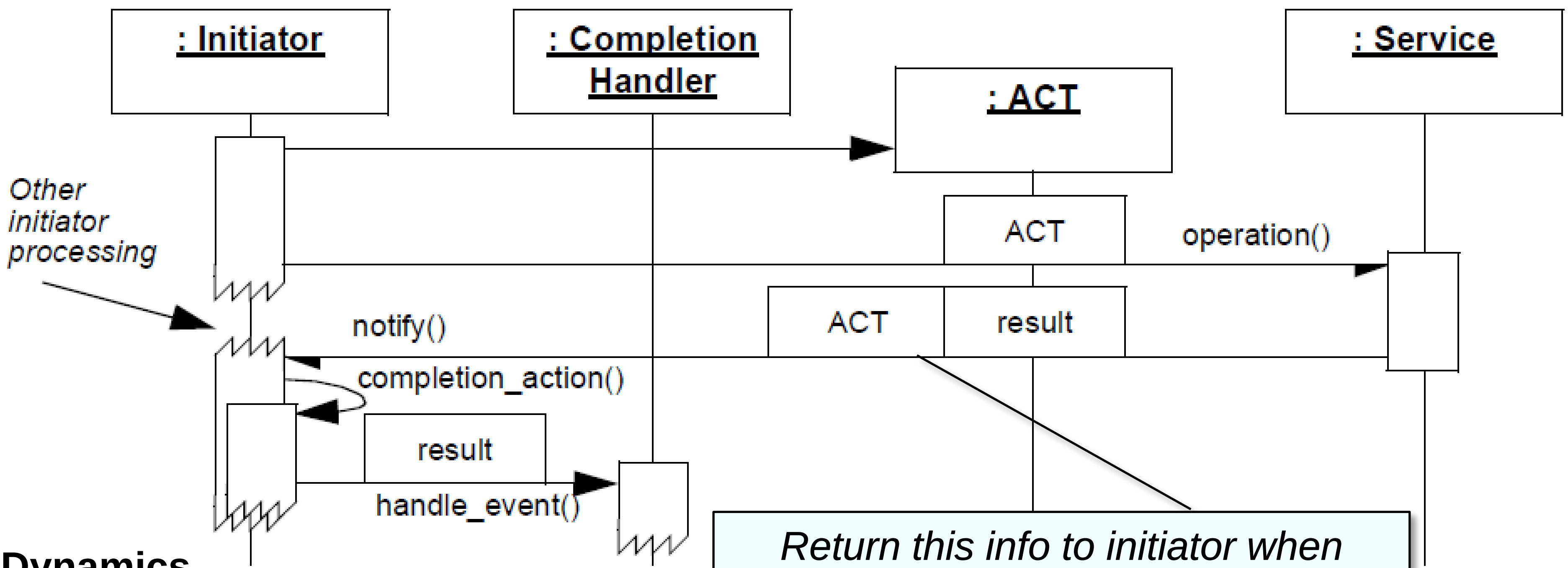


Return this info to initiator when operation finishes, so it can be used to demux the response efficiently

Dynamics

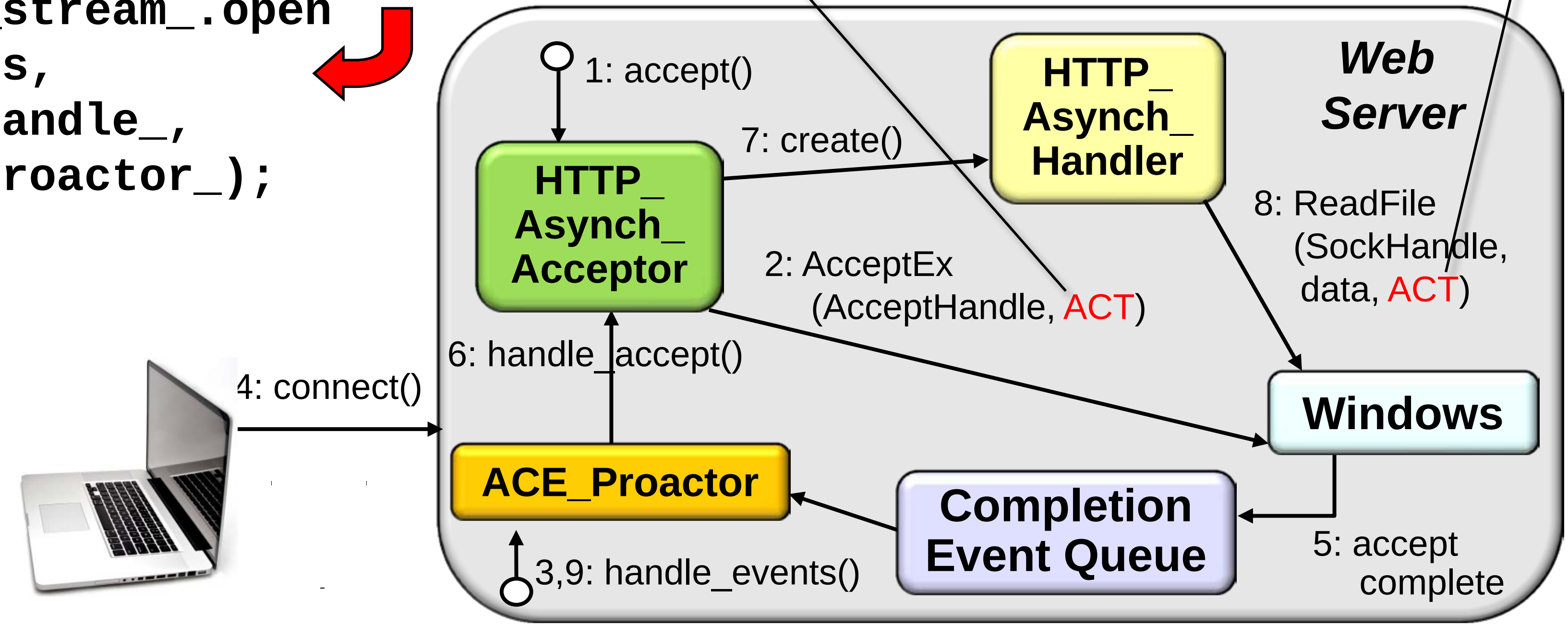
Applying the Asynchronous Completion Token Pattern in JAWS

```
class HTTP_Asynch_Handler :
     public ACE_Service_Handler {

  virtual void open (.....) {
    ...
```

Pass this as ACT

```
    read_stream_.open
    (*this,
     io_handle_,
     0, proactor_);

    ...
```

Asynchronous completion tokens (ACTs) are passed to all asynchronous operations to efficiently indicate completion handlers



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Completion event handling method dispatched by ACE *Proactor* framework

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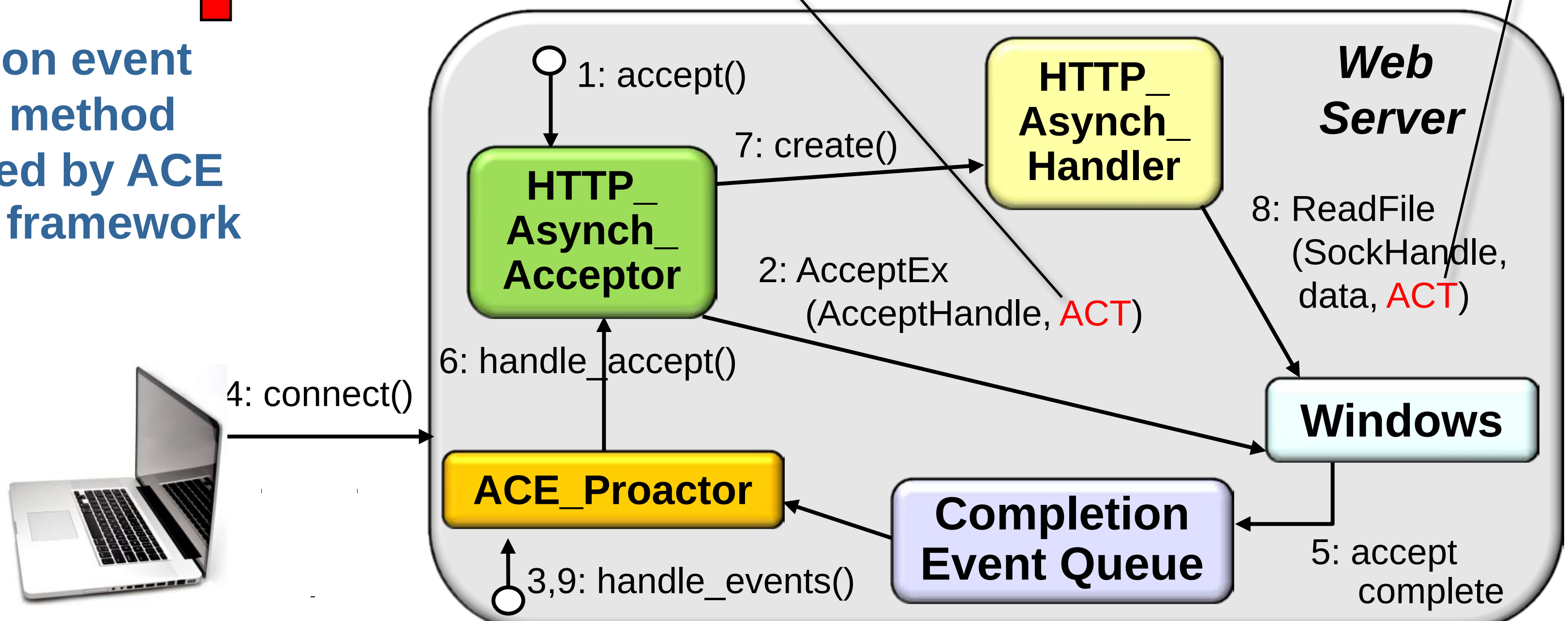
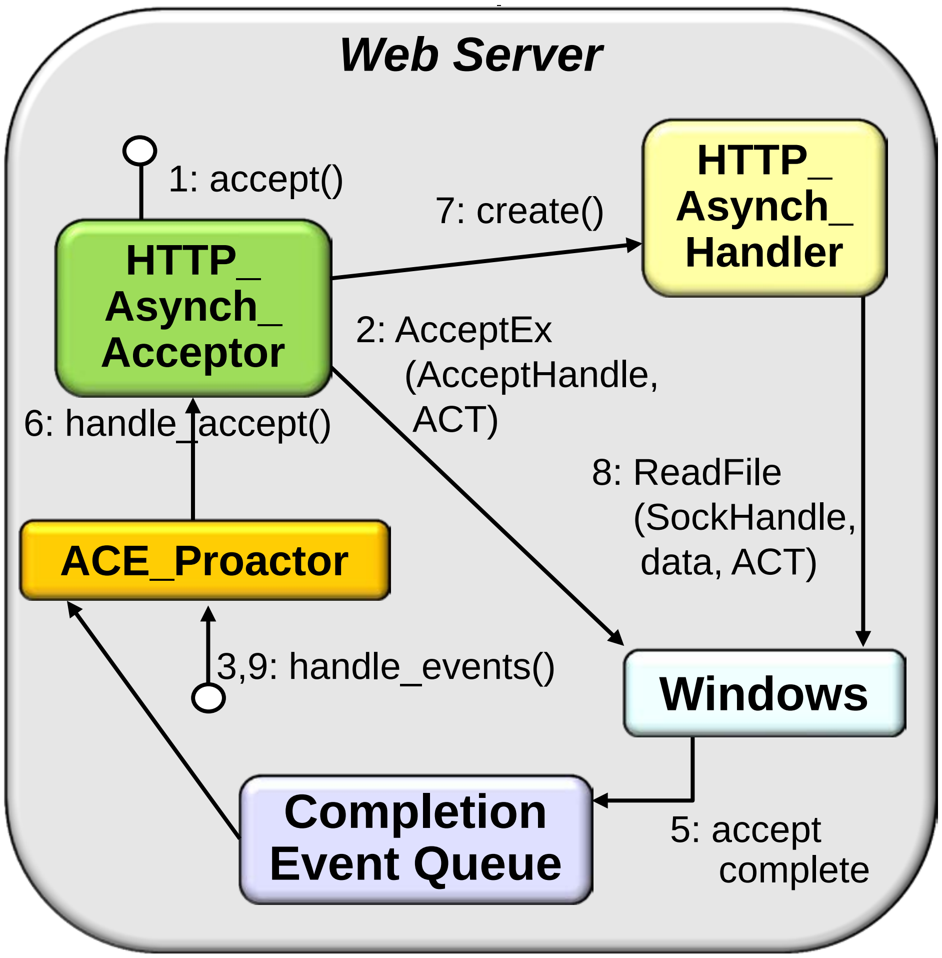


Benefits of Asynchronous Completion Token

Simplified initiator data structures

- Initiators need not maintain complex data structures to associate responses with completion handlers



Benefits of Asynchronous Completion Token

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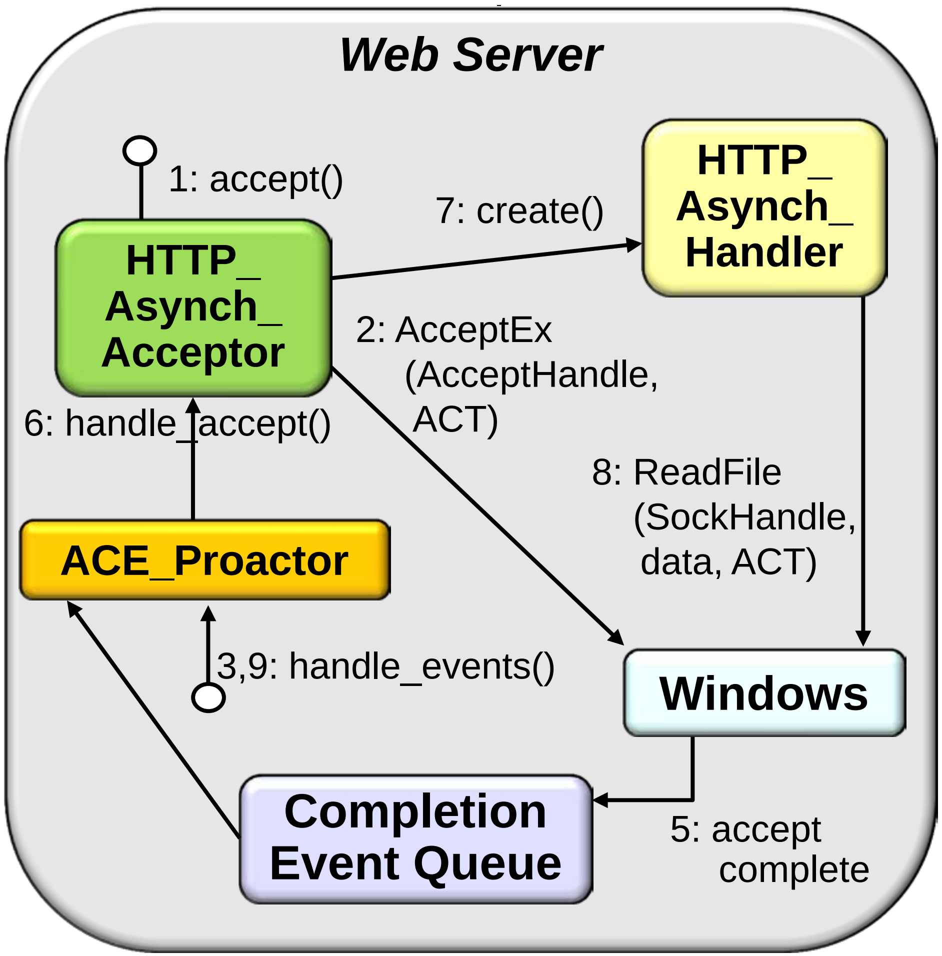
Efficient state acquisition

- ACTs are time efficient because they need not require complex parsing of data returned with service response



Benefits of Asynchronous Completion Token

Simplified initiator data structures

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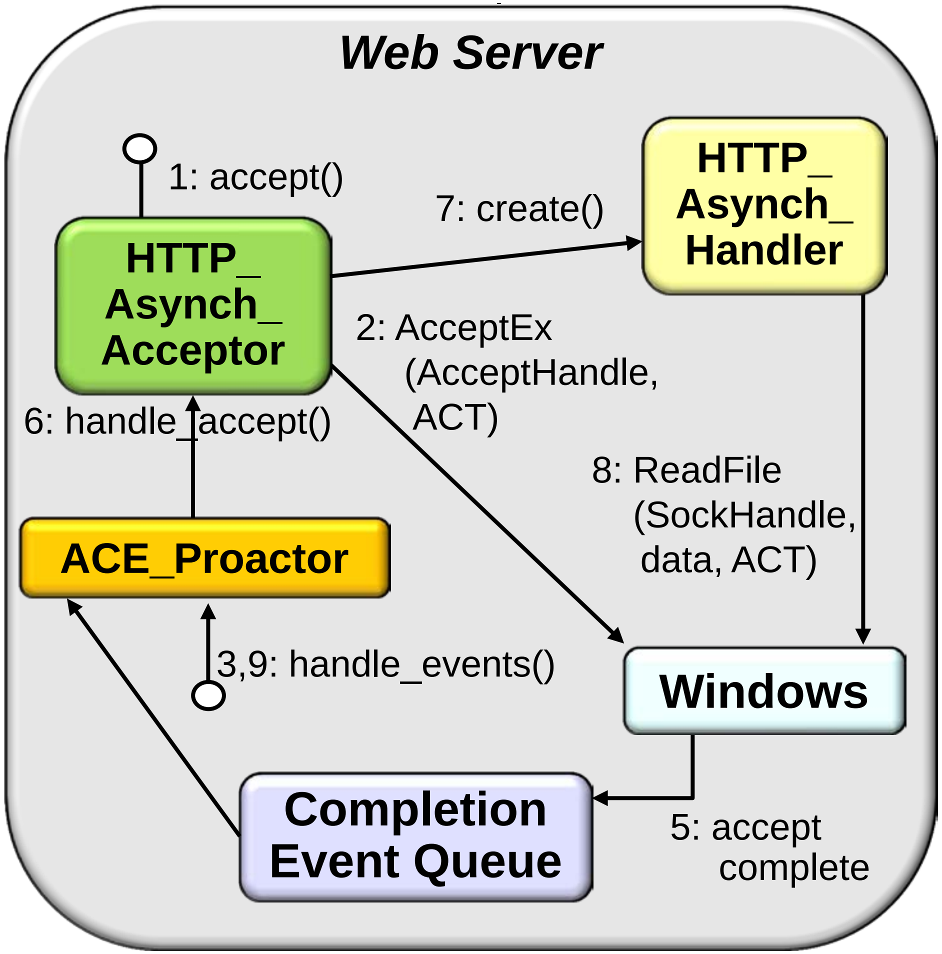

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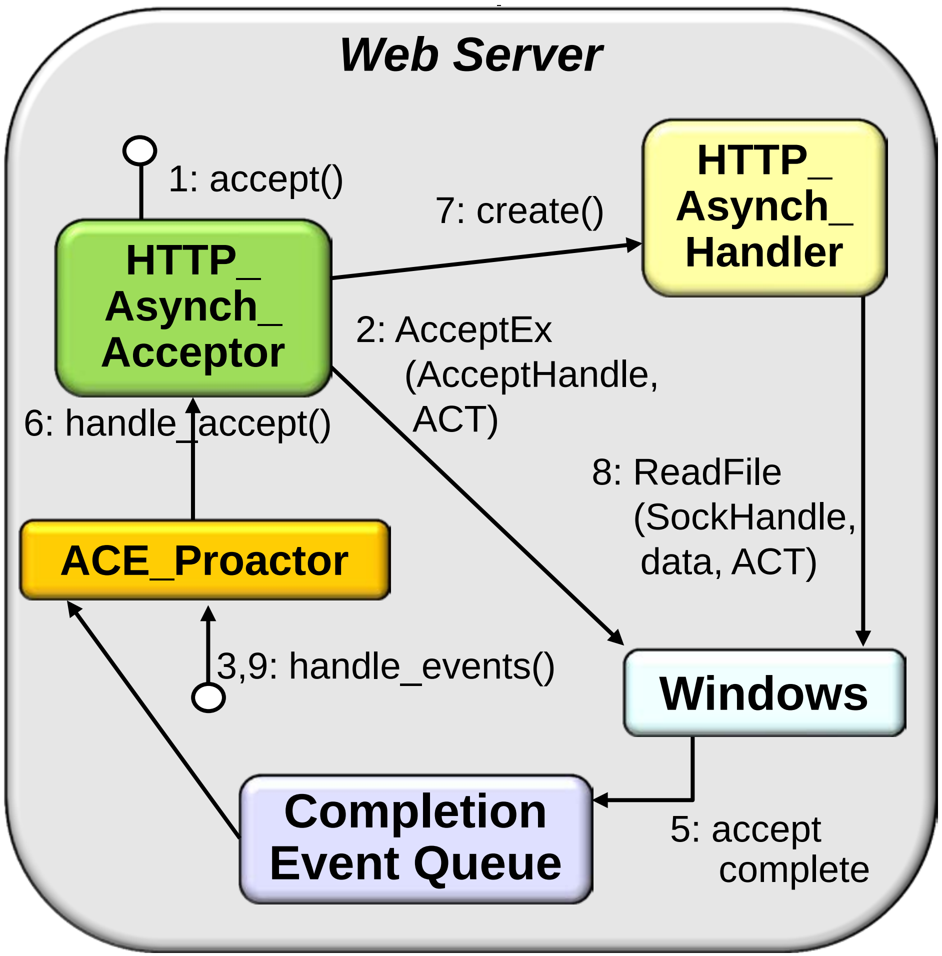
Flexibility

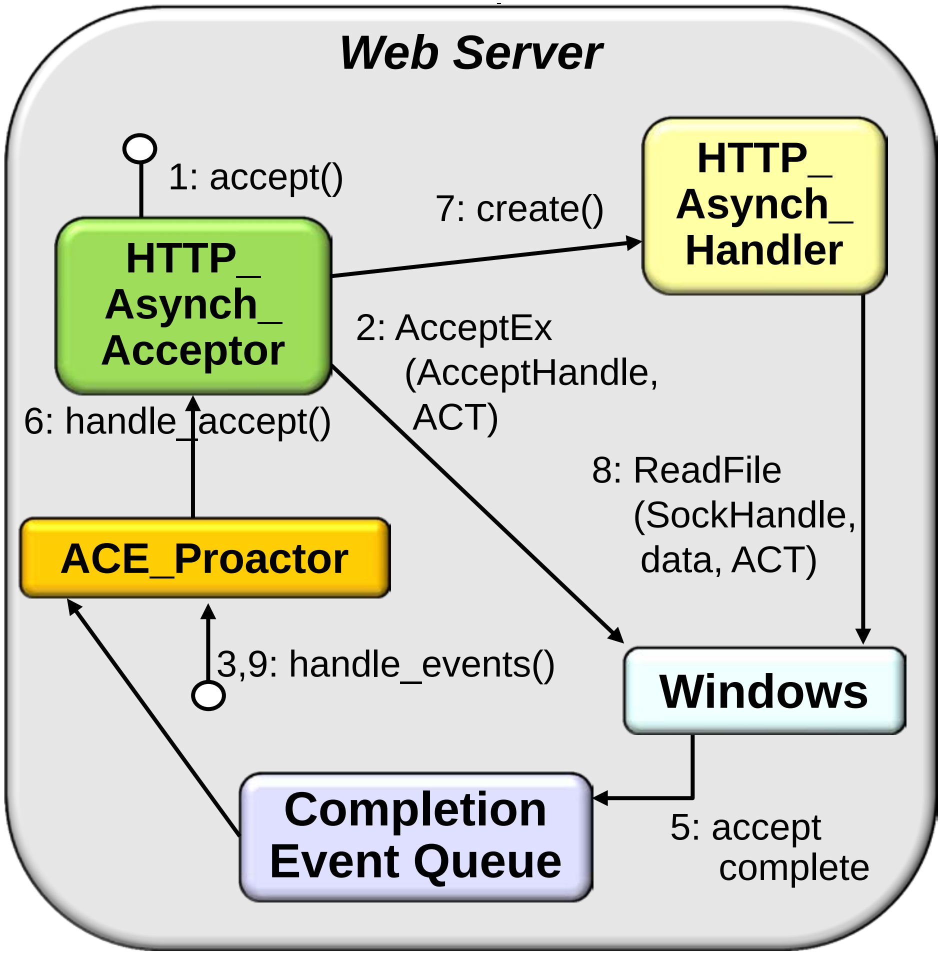
- User-defined ACTs are not forced to inherit from an interface to use the service's ACTs



Limitations of Asynchronous Completion Token

Memory leaks

- Memory leaks can result if initiators use ACTs as pointers to dynamically allocated memory & services fail to return the ACTs



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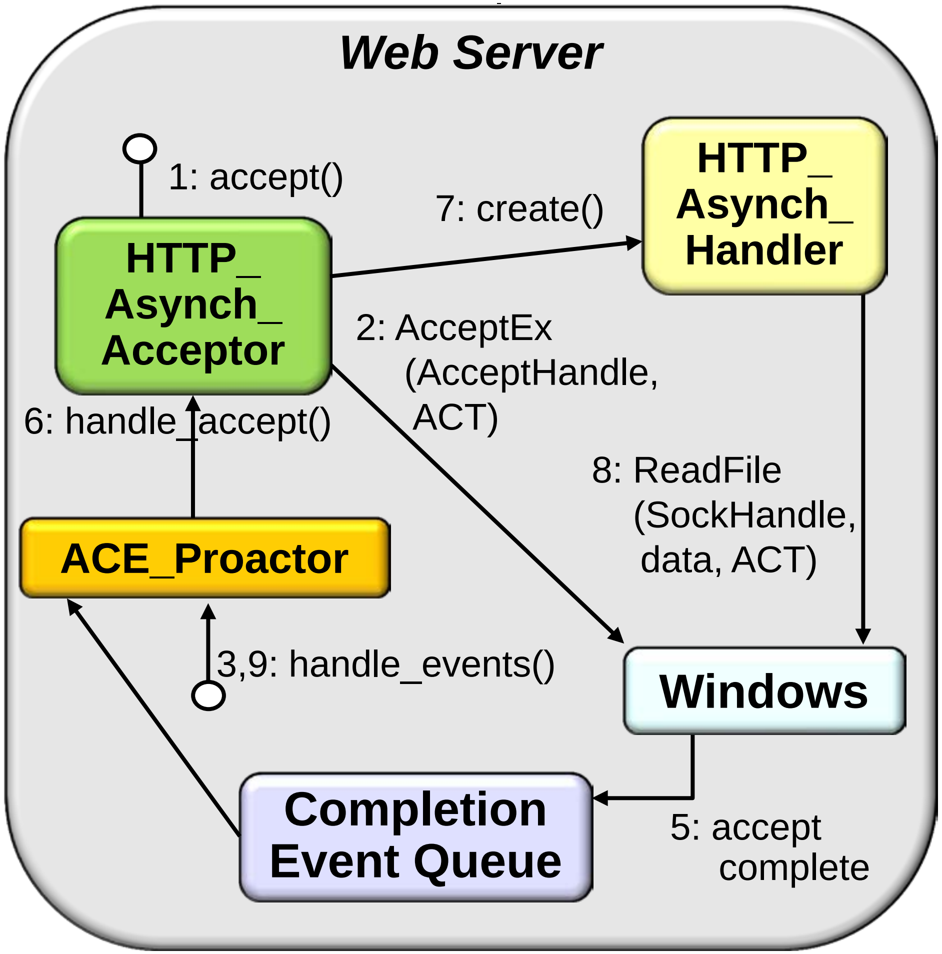

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Application re-mapping

- If ACTs are used as direct pointers to memory, errors can occur if part of the application is re-mapped in virtual memory