Alternative Techniques for Designing Concurrent Server Daemons

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Motivation

- Network applications (particularly servers) often handle different types of events *simultaneously*, *e.g.*,
  1. *I/O events*
     - *e.g.*, input, output, exceptions corresponding to interactions with clients
  2. *Time-related events*
     - *e.g.*, handle timeouts and retransmissions
- Connection-oriented servers often identified clients internally via distinct I/O *handles*
  - Handles are *internal IDs* that correspond to *external IDs* of network resources
    - ▷ Handles are typically implemented via integers or pointers

Common Traps and Pitfalls

- Blocking on a single I/O handle in `read` or `accept`
  - In general, a "concurrent daemon" should not service one I/O handle at the exclusion of the other handles
    - ▷ This will result in starvation for other services
- Polling via "busy waiting"
  - This will result in wasted CPU time
- Excessive process or thread creation
  - It is wasteful to dedicate OS resources while waiting for communication activity to occur

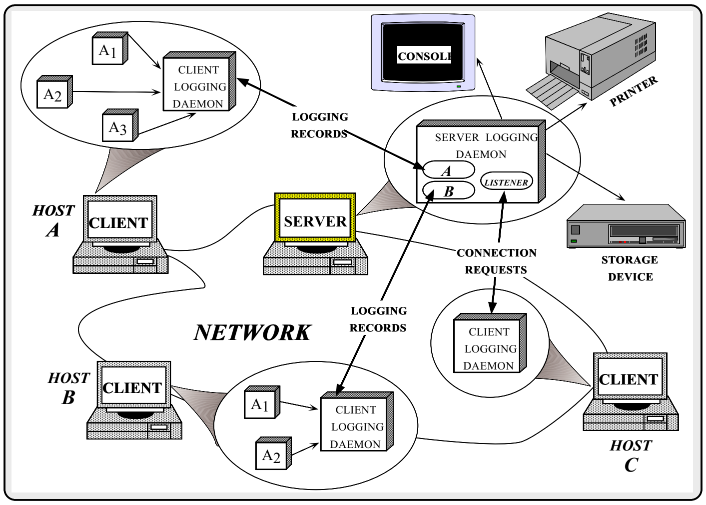
Distributed Logger

- This lecture describes an extended example of a distributed logging facility
- This example illustrates the applicability of various ACE components and covers:
  1. The application-level logging API
  2. The client logging daemon IPC mechanisms
  3. Several alternative concurrent server logging daemon designs and implementations
- The examples illustrate how OO and C++ simplify development and improve several key software quality factors

Distributed Logger (cont'd)

- The distributed logging facility was originally written in C and used `select` and/or `poll` directly
- The original version was part of a commercial distributed on-line transaction-processing product that was ported from BSD to System V
- This was later ported to C++ and is now in ACE

Distributed Logger Architecture



- *Server logging daemon* collects, formats, and outputs logging records forwarded from multiple *client logging daemons* residing throughout a network or internetwork

Distributed Logger Architecture (cont'd)

- Note the two levels of I/O multiplexing in the distributed logger architecture:
  1. *One or more application processes multiplex their logging records to a single client logging daemon located on each local host*
  2. *One or more client logging daemons multiplex their accumulated messages to a single server logging daemon running on a designated host in a network/internetwork*
- Different IPC mechanisms may be used for each component, but the general architectures are the same
  - Note that ACE reflects these similarities in the design and implementation

Distributed Logger Architecture (cont'd)

- The distributed logger provides services that:
  1. *Identify processes via their program name, process ID (PID), and host name*
  2. *Time-stamp records to facilitate chronological tracing*
  3. *Prioritize record delivery at a client logging daemon*
- *e.g.*,

```
ACE_ERROR ((LM_ERROR, "unable to fork in function spawn"));
ACE_DEBUG ((LM_DEBUG, "sending to server %s", server_host));

Feb 30 14:50:13 1997@tango.cs.wustl.edu@22766@7@client-test
 ::unable to fork in function spawn
Feb 30 14:50:28 1997@tango.ics.uci.edu@18352@2@drwho
 ::sending to server mambo
```

Application Logging API

- Provides applications with a thread-safe "variadic" logging interface similar to printf, *e.g.*,

```
ACE_DEBUG ((LM_DEBUG, "server is %s\n", hostname);
ACE_ERROR ((LM_ERROR, "usage: %n filename\n");
```

- In addition to interpreting and expanding the variadic arguments, the API library code also:

1. *Creates a logging record and copies the expanded data into it*
2. *Time-stamps the logging record*
3. *Adds the PID and program name to the record*
4. *Sends the record to the client logging daemon running on the local host* via a local IPC channel
   - *e.g.*, named pipes or STREAM pipes

Application Logging API (cont'd)

- Applications can specify different levels of logging priority (similar to UNIX `syslogd`), *e.g.*,

```
enum Log_Priority
{
  LM_SHUTDOWN = 1, /* Shutdown the logger */
  LM_DEBUG = 2,    /* Messages with debugging info */
  LM_INFO = 3,     /* Informational messages */
  LM_NOTICE = 4,   /* Conditions that are not errors
                      but require special handling */
  LM_WARNING = 5,  /* Warning messages */
  LM_STARTUP = 6,  /* Initialize the logger */
  LM_ERROR = 7,    /* Errors */
  LM_CRIT = 8,     /* Critical conditions, such as
                      hard device errors */
  LM_ALERT = 9,    /* A condition that must corrected,
                      such as a corrupted database */
  LM_EMERG = 10,   /* A panic condition  This is normally
                      broadcast to all users */
  LM_MAX = 11      /* Maximum value + 1 */
};
```


Client Logging Daemon

- Runs on the local host, reads from the named pipe being written to by different instances of the application logging API (which is linked into different user processes and/or threads)
- When logging records arrive, the client logging daemon behaves as follows:

1. *Reads the records in priority order*
2. *Performs network-byte order conversions on multi-byte header fields*
3. *Transmits the records to the server logging daemon across the network using TCP*
   - However, TCP does not maintain logging record priorities...
   - Note, the client logging daemon may also run as a stand-alone process on a local host

Client Logging Daemon (cont'd)

- The following logging record PDU format is exchanged between the client and server logging daemons:

```
class Log_Record {
public:
  enum   {
    MAXLOGMSGLEN = BUFSIZ, /* Maximum logging message. */
    ALIGN_WORDB  = 8,    /* Most restrictive alignment. */
  };

  Log_Record (void);
  Log_Record (Log_Priority lp, long time_stamp, pid_t pid);
  int  print (const char host_name[], FILE *fp = stderr);
  void encode (void);
  void decode (void);
  int  length (void);
  void length (int len);

private:
  long type;        /* Type of logging record */
  long length;      /* length of the logging record */
  long time_stamp;  /* Time logging record generated */
  long pid;         /* Process Id generating the record */
  char msg_data[MAXLOGMSGLEN]; /* Logging record data */
};
```

Concurrent Daemon Designs

- To motivate the utility of OO network programming techniques, the following slides examine several alternative designs for handling multiple sources of input and output in the distributed logger, *e.g.*,
  - *Non-blocking I/O concurrent daemon*
    - ▷ *i.e.*, "polling"
    - ▷ Daemon process continuously sweeps across all open handles, performing non-blocking I/O on each
  - *Multiple-process or multi-threaded concurrent daemon*
    - ▷ *i.e.*, `fork` or thread facilities (*e.g.*, POSIX/Solaris)
    - ▷ Allows each separate *slave* daemon process or thread to block while reading from a single I/O handle

Concurrent Daemon Designs (cont'd)

- Alternative designs (cont'd)
  - *Single-threaded concurrent daemon*
    - ▷ *i.e.*, based upon I/O demultiplexing with `select` and `poll`
      - · `select` and `poll` allow blocking, non-blocking, and/or timed-wait on multiple I/O handles simultaneously
    - ▷ In certain cases, this approach may be easier to design, more portable, and potentially more efficient than alternative designs
  - Note, hybrid designs are also possible

The handle_logging_record Function

- The following function is used in each alternative daemon design to handle the reception of logging records sent from the client logging daemon to the server logging daemon

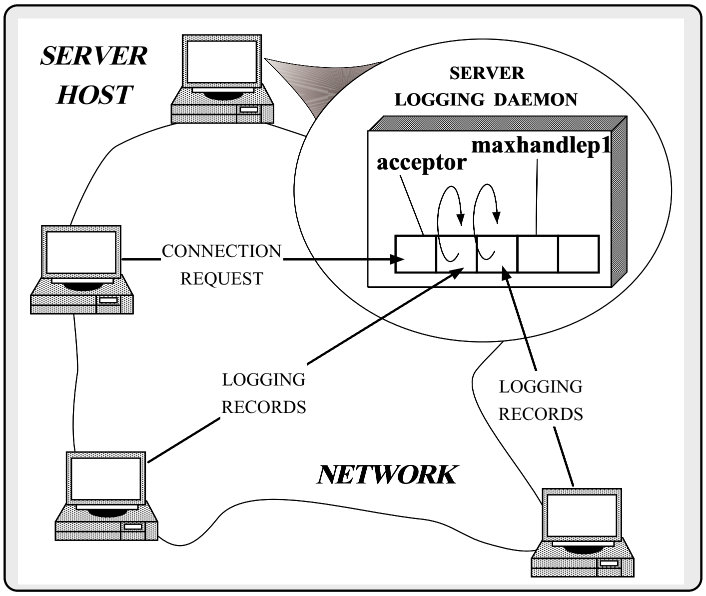
```
// Perform two recv's to simulate a record service
// via the underlying bytestream-oriented TCP connection.
// Note that the sender must follow this protocol also...

template <class MUTEX = Null_Mutex>
int handle_logging_record (int handle)
{
  MUTEX lock;
  long m_len;
  Log_Record log_record;

  // The first recv reads the length (stored as a
  // fixed-size integer) of the adjacent logging record.

  size_t n = ACE_OS::recv (handle, &m_len, sizeof m_len);
  if (n != sizeof m_len)
```



```
      return n;
    else {
      // Convert byte-ordering
      m_len = ntohl (m_len);

      // The second recv then reads "length" bytes to
      // obtain the actual record.

      n = ACE_OS::recv (handle, (char *) &log_record, m_len);
      if (n != m_len) return -1;

      log_record.decode ();

      if (log_record.length () == n) {
        // Automatically obtain lock for MT designs.
        ACE_Guard<MUTEX> monitor (lock);

        log_record.print (output_device);
        // Automatically release lock here for
        // MT designs.
      }
      return n;
    }
  }
```

- Note, fault tolerant applications may require more sophisticated message-oriented data transfer techniques

Polling via Non-blocking I/O



Polling via Non-blocking I/O (cont'd)

- Pseudo-code for sample non-blocking server logging daemon

```
initialize acceptor endpoint in non-blocking mode
loop
    foreach open client handle loop
        if data available from client then
            call handle_logging_record
        else if client has shutdown connection then
            duplicate highest handle
                to maintain contiguity
        else
            continue
        end if
    end loop
    while connection requests pending loop
        accept next request and set new client
            handle to non-blocking mode
    end loop
end loop
```


Polling via Non-blocking I/O (cont'd)

- C++ code for sample non-blocking server logging daemon

```
int main (void)
{
  // Create a server end-point
  ACE_SOCK_Acceptor acceptor ((ACE_INET_Addr) PORT_NUM);
  ACE_SOCK_Stream new_stream;

  // Extract handle
  int s_handle = acceptor.get_handle ();
  int maxhandlep1 = s_handle + 1;

  // Set acceptor in non-blocking mode
  acceptor.enable (ACE_NONBLOCK);

  // Loop forever performing logger server processing

  for (;;) {

    // Poll each handle to see if logging
    // records are immediately available on
    // active network connections
```



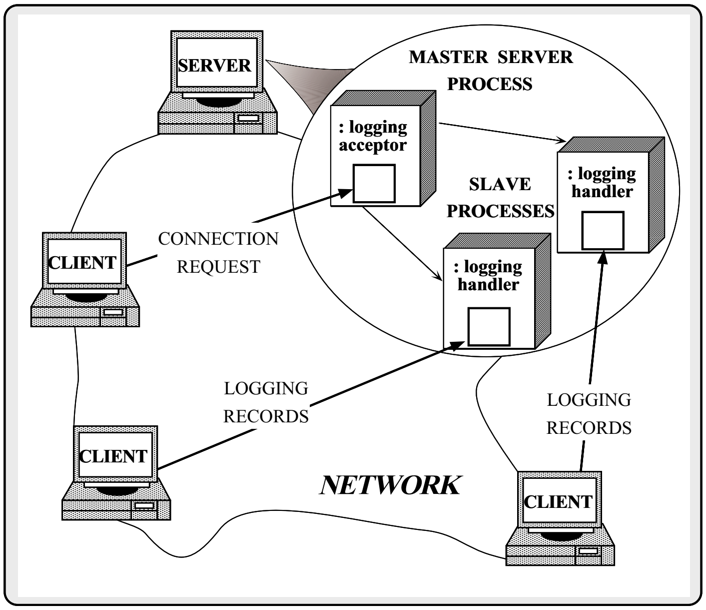
```
    for (int handle = s_handle + 1;
         handle < maxhandlep1;
         handle++) {
      ssize_t n = handle_logging_record (handle);
      if (n == -1) {
        // No input pending
        if (errno == EWOULDBLOCK)
          continue;
      }
      else if (n == 0) {
        // Keep handles contiguous...
        ACE_OS::dup2 (handle, --maxhandlep1);
        ACE_OS::close (maxhandlep1);
      }
    }

    // Handle all pending connections

    while (acceptor.accept (new_stream) != -1) {
      // Make new connection non-blocking
      new_stream.enable (ACE_NONBLOCK);
      handle = new_stream.get_handle ();
      assert (handle + 1 == maxhandlep1);
      maxhandlep1++;
    }
    if (errno != EWOULDBLOCK)
      ACE_OS::perror ("accept failed");
  }
  /* NOTREACHED */
}
```

Polling via Non-blocking I/O (cont'd)

- *Advantages*
  - Relatively portable across UNIX and many PC platforms

- *Disadvantages*
  1. Inefficient
     - Wasteful of CPU resources due to "busy waiting"
  2. Non-extensible
     - Difficult to extend server to handle other types of I/O events and services without writing additional special code and modifying existing code
     - Note, this is a general drawback with all the functionally-designed approaches illustrated here

Multiple Process Creation



Multiple Process Creation (cont'd)

- Pseudo-code for sample multi-process master server logging daemon

initialize acceptor endpoint
loop
    foreach *connection request pending* **loop**
        accept request
        fork a child process to handle request
    end loop
end loop

- Pseudo-code for sample multi-process slave server logging daemon

loop
    foreach *incoming data message from client* **loop**
        call handle_logging_record
    end loop
    exit process
end loop

- Note, handling the SIGCHLD signal complicates this basic logic somewhat...

Multiple Process Creation (cont'd)

- Sample C++ multi-process server logging daemon

```
// Handle all logging records from a particular
// client (run in the slave process)
void logging_handler (int handle)
{
  // Perform a "blocking" receive and process
  // client logging records until client shuts down
  // the connection
  for (int n;;) {
    n = handle_logging_record <ACE_Process_Mutex> (handle);
    if (n <= 0)
      break;
  }
}
```

```
// Reap zombie'd children (run in the
// master process)
void child_reaper (int)
{
  for (int res;
      (res = ACE_OS::waitpid (-1, 0, WNOHANG)) > 0
       || (res == -1 && errno == EINTR); )
    continue;
}

// Master process
int main (void)
{
  // Register the SIGCHLD signal handler.
  ACE_Sig_Action sa (ACE_SignalHandler (child_reaper),
                     SIGCHLD, 0, SA_RESTART);

  logging_acceptor ();
}
```



```
static void
logging_acceptor (void)
{
  // Create a server end-point
  ACE_SOCK_Acceptor acceptor ((ACE_INET_Addr) PORT_NUM);
  ACE_SOCK_Stream new_stream;

  // Loop forever performing logging server processing
  for (;;) {
    // Wait for client connection request and create
    // new ACE_SOCK_Stream endpoint (accept is
    // automatically restarted after interrupts)
    acceptor.accept (new_stream);

    // Create a new process to handle client request
    switch (ACE_OS::fork ()) {
    case -1: ACE_OS::perror ("fork failed"); break;
    case 0: // In child
      acceptor.close ();
      logging_handler (new_stream.get_handle ());
      /* NOTREACHED */
    default: // In parent
      new_stream.close (); break;
    }
  }
  /* NOTREACHED */
}
```


Multiple Process Creation (cont'd)

- *Advantages*

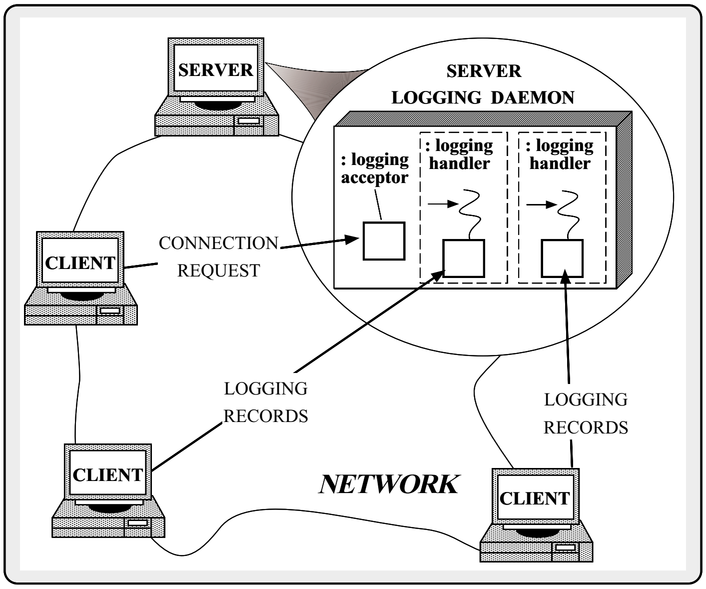
1. `fork` is portable (on UNIX)
   - Win32 is more problematic...
2. In general, this design is efficient for certain types of daemons, *e.g.*,
   - *I/O bound*
   - *Longer-duration/variable-length services*
     - *e.g.*, file transfer and rlogin
   - *Services that set ownership and permissions based upon userid*
3. Also, transparently take advantage of multiple CPUs

Multiple Process Creation (cont'd)

- *Disadvantages*

1. Often wasteful of OS resources
   - *e.g.*, process table slots, virtual memory
2. Incurs additional overhead to schedule and context switch between the multiple processes
3. May require additional synchronization and/or mutual exclusion primitives to serialize access to shared output devices
   - *e.g.*, in `Logging_Handler`
4. SIGCHLD signal handling is subtle and non-portable

Multiple Thread Creation



Multiple Thread Creation (cont'd)

- Pseudo-code for sample multi-threaded master server logging daemon

initialize acceptor endpoint
loop
    foreach *connection request pending* **loop**
        accept request
        spawn a thread to handle request
    end loop
end loop

- Pseudo-code for sample multi-thread slave server logging daemon

loop
    foreach *incoming data message from client* **loop**
        call handle_logging_record
    end loop
    exit thread
end loop

Multiple Thread Creation (cont'd)

- Sample C++ multi-threaded server logging daemon

```
// Handle all logging records from a particulur
// client (run in each slave thread)
void
logging_handler (int handle)
{
  // Perform a "blocking" receive and process
  // client logging records until client shuts
  // down the connection
  for (ssize_t n;;) {
    n = handle_logging_record <ACE_Thread_Mutex> (handle);
    if (n <= 0)
      break;
  }

  ACE_OS::close (handle);
  ACE_Thread::exit ();
  /* NOTREACHED */
}
```



```
static void
logging_acceptor (void)
{
  // Create a server end-point
  ACE_SOCK_Acceptor acceptor ((ACE_INET_Addr) PORT_NUM);
  ACE_SOCK_Stream new_stream;

  // Loop forever performing logging server processing

  for (;;) {

    // Wait for client connection request and create
    // a new ACE_SOCK_Stream endpoint (automatically
    // restarted upon interrupts)

    acceptor.accept (new_stream);

    // Create a new thread to handle client request

    ACE_Thread::spawn
      (ACE_THR_FUNC (logging_handler),
      (void *) new_stream.get_handle (),
      THR_DETACHED | THR_NEW_LWP);
  }
  /* NOTREACHED */
}

// Master server
int main (void)
{
  logging_acceptor ();
}
```

Multiple Thread Creation (cont'd)

- *Advantages*
  - Somewhat easier to program than `fork`
    - ▷ *e.g.*, no subtle signal handling semantics
  - Potentially more efficient
    - ▷ Modulo the thread library and OS implementation...
- *Disadvantages*
  - Not portable
  - Many threads libraries are incapable of providing adequate performance and functionality
    - ▷ *e.g.*, lack of support for sockets in Solaris <= 2.2!
    - ▷ Only allow one system call at a time...

Synopsis of select and poll

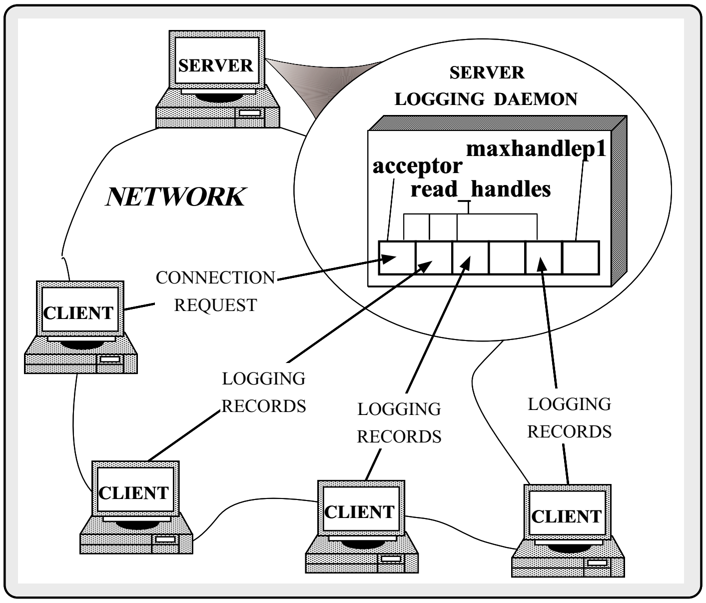
- `select` and `poll` are both I/O multiplexing mechanisms that perform "timed-waits" for input, output, or exception events to occur
  - The `select` API

```
int select
(
  int maxhandlep1, // Maximum handle plus 1
  fd_set *readhandles, // bit-mask of "read" handles
  fd_set *writehandles, // bit-mask of "write" handles
  fd_set *excepthandles, // bit-mask of "exception" handles
  struct timeval *tv // Amount of time to wait for events
);
```

  - The `poll` API

```
int poll
(
  struct pollfd *fds, // Handles of interest
  unsigned long nfds, // Number of handles to check
  int timeout // Length of time to wait (in milliseconds)
);

struct pollfd {
  int fd; // file handle to poll
  short events; // events of interest on fd
  short revents; // events that occurred on fd
};
```


Single-Threaded Concurrent Daemon (select-based)



Single-Threaded Concurrent Daemon (select-based) (cont'd)

- Pseudo-code for sample single-threaded, concurrent server logging daemon

initialize acceptor endpoint
initialize select handle sets
loop
    select on active handles
    foreach *active client handle* **loop**
        call handle_logging_record
    end loop

    while *connection requests pending* **loop**
        accept the client connection and
            update handle set
    end loop
end loop

Single-Threaded Concurrent Daemon (select-based) (cont'd)

- Sample C++ single-threaded, concurrent server logging daemon using I/O multiplexing
  - Note the serialization at the transport layer interface...

```
int
main (void)
{
  // Create a server end-point
  ACE_SOCK_Acceptor acceptor ((ACE_INET_Addr) PORT_NUM);
  ACE_SOCK_Stream new_stream;

  int s_handle = acceptor.get_handle ();
  int maxhandlep1 = s_handle + 1;

  fd_set temp_handles;
  fd_set read_handles;

  FD_ZERO (&temp_handles);
  FD_ZERO (&read_handles);
  FD_SET (s_handle, &read_handles);

  // Loop forever performing logging server processing

  for (;;) {
    temp_handles = read_handles; // structure assignment
```



```
    // Wait for client I/O events.
    ACE_OS::select (maxhandlep1, &temp_handles, 0, 0, 0);

    // Handle pending logging records first (s_handle + 1)
    // is guaranteed to be lowest client handle)

    for (int handle = s_handle + 1;
         handle < maxhandlep1;
         handle++)
      if (FD_ISSET (handle, &temp_handles)) {
        // Guaranteed not to block in this case!
        ssize_t n = handle_logging_record (handle);

        if (n == -1)
          ACE_OS::perror ("logging failed");
        else if (n == 0) {
          // Handle client connection shutdown

          FD_CLR (handle, &read_handles);
          ACE_OS::close (handle);
          if (handle + 1 == maxhandlep1) {
            // Decrement past unused handles

            while (!FD_ISSET (--handle, &read_handles))
              continue;

            maxhandlep1 = handle + 1;
          }
        }
      }
```

```
    // Check whether any connection requests arrived

    if (FD_ISSET (s_handle, &temp_handles)) {
      // Handle all pending connection request
      // (note use of "polling" feature)

      while (ACE_OS::select (s_handle + 1, &temp_handles,
                     0, 0, ACE_Time_Value::zero) > 0)
        if (acceptor.accept (new_stream) == -1)
          ACE_OS::perror ("accept");
        else {
          handle = new_stream.get_handle ();
          FD_SET (handle, &read_handles);
          if (handle >= maxhandlep1)
            maxhandlep1 = handle + 1;
        }
    }
  }
  /* NOTREACHED */
}
```

Single-Threaded Concurrent Daemon (select-based) (cont'd)

- *Advantages*
  - May be more efficient than multi-threading and multi-processing for certain applications
    - ▷ *e.g.*, no need to serialize logging record handling since output is single-threaded within a daemon process
    - ▷ Does not consume excessive OS resources by creating multiple processes or threads
    - ▷ Less context switching and scheduling overhead
  - Does not consume excessive CPU time by performing "busy-waiting"

Single-Threaded Concurrent Daemon (select-based) (cont'd)

- *Disadvantages*
  - Complicated and error-prone low-level interfaces
    - ▷ Requires developers to handle *many* details manually, *e.g.*,
      - · Value/result parameter passing of handle sets requires copying
      - · Handle set parsing
      - · Multiple bitmasks, interrupts, etc.
    - ▷ Updating `maxhandlep1` is tricky on `close`
    - ▷ There is a per-process limit on the number of handles available
  - Does not scale up to take advantage of multi-processor platforms
    - ▷ *i.e.*, serialization is at transport interface within a single process...

Single-Threaded Concurrent Daemon (poll-based)

- Sample single-threaded, concurrent server logging daemon

```
// Maximum per-process open I/O handles
const int MAX_HANDLES = 200;

int main (void)
{
  // Create a server end-point
  ACE_SOCK_Acceptor acceptor ((ACE_INET_Addr) PORT_NUM);
  ACE_SOCK_Stream new_stream;
  int s_handle = acceptor.get_handle ();
  struct pollfd poll_array[MAX_HANDLES];

  for (int i = 0; i < MAX_HANDLES; i++) {
    poll_array[i].fd = -1;
    poll_array[i].events = POLLIN;
  }

  poll_array[0].fd = s_handle;

  for (int nhandles = 1;;) {
    // Wait for client I/O events.
    ACE_OS::poll (poll_array, nhandles);
```



```
    // Handle pending logging messages first
    // (poll_array[i = 1].fd is guaranteed to be
    // lowest client handle)

    for (int i = 1; i < nhandles; i++) {
      if (poll_array[i].revents & POLLIN) {
        char buf[BUFSIZ];
        // Guaranteed not to block in this case!
        ssize_t n =
          handle_logging_record (poll_array[i].fd);

        if (n == 0) {
          // Handle client connection shutdown
          ACE_OS::close (poll_array[i].fd);n
          poll_array[i].fd = poll_array[--nhandles].fd;
        }
      }
    }
    if (poll_array[0].revents & POLLIN) {
      // Handle all pending connection request
      // (note use of "polling" feature)
      while (ACE_OS::poll (poll_array, 1,
                           ACE_Time_Value::zero) > 0)
        acceptor.accept (new_stream, &client);
        poll_array[nhandles++].fd =
          new_stream.get_handle ();
    }
  }
  /* NOTREACHED */
}
```

Single-Threaded Concurrent Daemon (poll-based) (cont'd)

- *Advantages*
  - The same basic advantages as the `select-based` approach
  - However, compared to `select`, `poll` facilitates easier "packing" of handles in the `poll_fd` array
  - `poll` also detects a wider range of events than `select`
    - ▷ *e.g.*, priority-band events
- *Disadvantages* (cont'd)
  - Same as `select-based`

Limitations with Preceding Concurrent Daemon Designs

- *Non-portable*
  - Both *within* and *across* UNIX platforms
    - ▷ *e.g.*, `select`, `poll`, and threads are not standard across platforms

- *Difficult to extend/enhance services*
  - Generally based upon functional design
    - ▷ Though certain components are OO
      - · *e.g.*, SOCK_SAP
  - Lack of policy/mechanism separation
    - ▷ *i.e.*, changing functionality often requires modifying, recompiling, relinking existing code
  - Moreover, the implementation is tightly coupled with SOCK_SAP network API

Overview of the Reactor

- The Reactor encapsulates the `select` and `poll` I/O multiplexing facilities
  - It is a portable interface to an OO library of extensible, reusable, and type-secure C++ classes
  - The Reactor addresses many limitations with the existing UNIX I/O demultiplexing facilities, while preserving the benefits they offer

- The Reactor helps simplify network programming by integrating mechanisms that support multiplexing of:
  1. Synchronous I/O-based events
  2. Timer-based events

- When these events occur, the Reactor automatically dispatches previously-registered "call-back" member functions that perform application-specific services

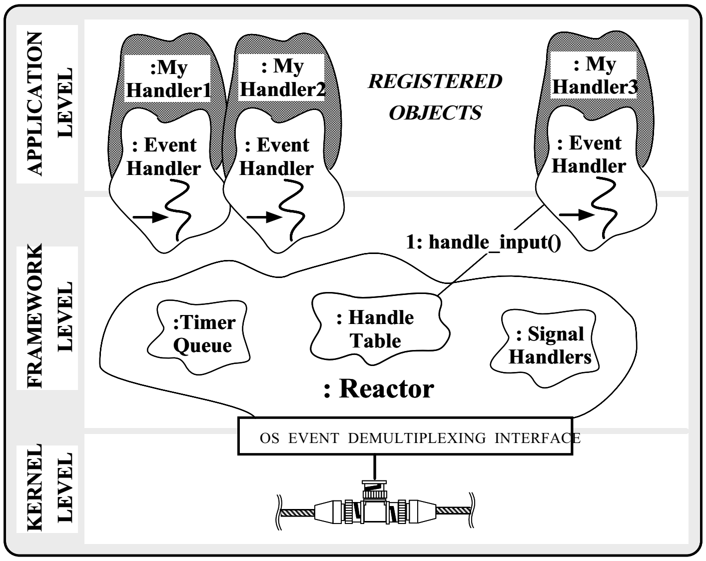
Overview of the Reactor (cont'd)

- The Reactor's object-oriented design is based upon domain analysis of typical client/server I/O multiplexing structures and functionality

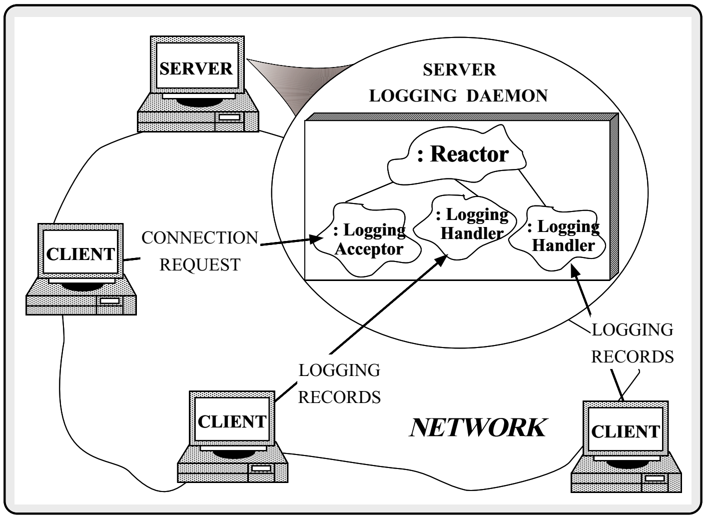
- A primary design goal is to decouple
  1. **mechanisms** for *sensing*, *demultiplexing*, and *dispatching* the I/O-based and timer-based events from
  2. **policies** of the application-specific services

- The Reactor forms the basis for more comprehensive OO daemon configuration, port multiplexing, and service dispatching frameworks
  - *e.g.*, the Service Configurator framework in ACE

Overview of the Reactor (cont'd)



Single-threaded Concurrent Daemon (Reactor-based)



Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

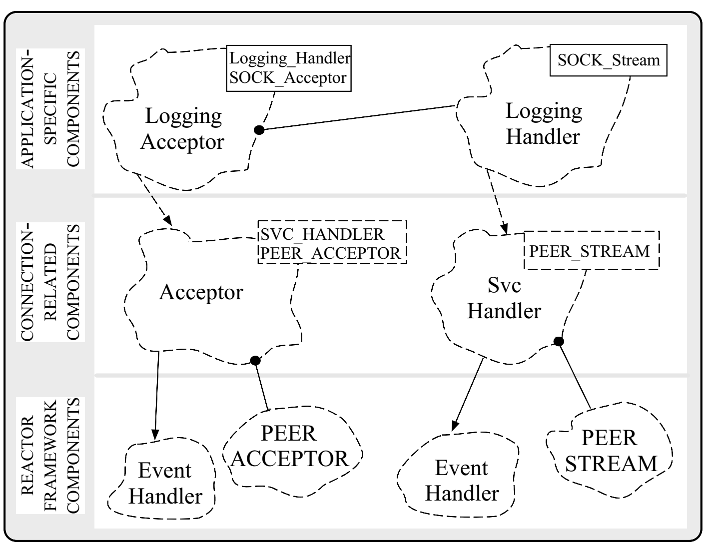
- Pseudo-code for sample Reactor-based single-threaded, concurrent server logging daemon

initialize acceptor endpoint
initialize Reactor object with acceptor object
loop
    call Reactor event loop function
end loop

- Pseudo-code for Reactor event dispatcher function

wait for set of client handles to become active
foreach *active client handle* **loop**
    invoke appropriate service call-back routine
end loop

Single-threaded Concurrent Daemon (Reactor-based) (cont'd)



- Class relationships via Booch notation

Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- The server logging daemon is decoupled into several modular components that perform different tasks
  - *Application-specific components*
    - ▷ Process logging records
  - *Connection-related components*
    1. *Acceptor*
       - ▷ Accepts connection requests from clients
       - ▷ Dynamically creates a `Svc_Handler` object per-client and registers it with the `Reactor`
    2. *Svc_Handler*
       - ▷ Performs I/O with clients
  - *ACE framework components*
    - ▷ Perform IPC, event demultiplexing, dynamic linking, etc.

Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- C++ interface for registrating and dispatching event objects

```
class ACE_Event_Handler
{
public:
    // Returns the I/O handle associated.
  virtual int get_handle (void) const = 0;

    // Called when object is removed from the ACE_Reactor
  virtual int handle_close (int handle);
    // Called when input becomes available on HANDLE
  virtual int handle_input (int handle);
    // Called when output is possible on HANDLE
  virtual int handle_output (int handle);
    // Called when urgent data is available on HANDLE
  virtual int handle_exception (int handle);

    // Called when timer expires (TV stores the
    // current time and ARG is the argument given
    // when the handler was originally scheduled)
  virtual int handle_timeout (const Time_Value &tv,
                              const void *arg = 0);
};
```


Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- Template class interface for accepting connection requests from remote client daemons

```
template <class SVC_HANDLER,
          class PEER_ACCEPTOR>
class Acceptor : public ACE_Event_Handler
{
public:
  Acceptor (void);
  Acceptor (ACE_Reactor *r, const ADDR &a);
  ~Acceptor (void);

  int open (ACE_Reactor *r, const ADDR &a);

  // Dynamic linking hooks
  virtual int init (int argc, char *argv[]);
  virtual int info (char **info_string,
                    int length) const;
```



```
private:
  virtual int get_handle (void) const;
  virtual int handle_input (int);
  virtual int handle_close (int = -1);

  PEER_ACCEPTOR acceptor_; // Accept connections
  ACE_Reactor *reactor_; // Demultiplex events.
};
```


Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- `Acceptor` implementation

```
// Shorthand names
#define SH SVC_HANDLER
#define PA PEER_ACCEPTOR

template <class SH, class PA> int
Acceptor<SH, PA>::open (const PA::PEER_ADDR &addr)
{
  acceptor_.open (addr);
}

template <class SH, class PA>
Acceptor<SH, PA>::Acceptor (const PA::PEER_ADDR &addr)
{
  open (addr);
}
```

```
template <class SH, class PA>
Acceptor<SH, PA>::init (int argc, char *argv[])
{
  PA::PEER_ADDR addr;
  Get_Opt getopt (argc, argv, "p:");

  for (int c; (c = getopt ()) != -1; )
    switch (c) {
      case 'p':
        addr.set (ACE_OS::atoi (getopt.optarg));
        break;
      default:
        break;
   }
  return open (addr);
}

template <class SH, class PA>
Acceptor<SH, PA>::info (char **strp, int length) const
{
  char buf[BUFSIZ];
  PA::PEER_ADDR addr;
  acceptor_.get_local_addr (addr);
  ACE_OS::sprintf (buf, "%s\t %d/%s %s",
           "Logger", addr.get_port_number (), "tcp",
           "# distributed client facility\n");

  if (*strp == 0 && (*strp = ACE_OS::strdup (buf)) == 0)
    return -1;
  else ACE_OS::strncpy (*strp, buf, length);
  return ACE_OS::strlen (buf);
}
```



```
template <class SH, class PA> int
Acceptor<SH, PA>::handle_close (int)
{
  return acceptor_.close ();
}

template <class SH, class PA> int
Acceptor<SH, PA>::get_handle (void) const
{
  return acceptor.get_handle ();
}

template <class SH, class PA> int
Acceptor<SH, PA>::handle_input (int)
{
  // Create a new service handler.
  SH *svc_handler = new SH;

  // Accept connections from client client daemons.
  acceptor_.accept (*svc_handler);

  // Activate the service handler.
  svc_handler->open ();
  return 0;
}
```

Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- Template class that performs I/O with remote clients

```
template <class PEER_STREAM>
class Svc_Handler : public ACE_Event_Handler
{
public:
  Svc_Handler (ACE_Reactor *);

  // = Must be filled in by subclass.
  virtual int open (void) = 0;
  virtual int svc (void) = 0;

  operator PEER_STREAM &();
  virtual int get_handle (void) const;
```



```
protected:
  // = Demultiplexing hook.
  virtual int handle_input (int);
  virtual int handle_close (int);
  // Ensure dynamic allocation
  virtual ~Svc_Handler (void);

  char host_name_[MAXHOSTNAMELEN + 1];

  // Communicates with connected peer.
  PEER_STREAM peer_stream_;

  ACE_Reactor *reactor_;
};
```

Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- `Handler` implementation

```
#define CS PEER_STREAM

template <class CS>
Svc_Handler<CS>::Svc_Handler (ACE_Reactor *r)
  : reactor_ (r) {}

// Extract the underlying CS (e.g., for
// purposes of accept()).

template <class CS>
Svc_Handler<CS>::operator CS &() { return peer_stream_; }

// Initiate the virtual function call-back.

template <class CS> int
Svc_Handler<CS>::handle_input (int)
{
  // Hook method.
  return svc ();
}
```



```
template <class CS> int
Svc_Handler<CS>::get_handle (void) const
{
  return peer_stream_.get_handle ();
}

template <class CS> int
Svc_Handler<CS>::handle_close (int)
{
  peer_stream_.close ();
  // Must be allocated dynamically!
  delete this;
  return 0;
}
```


Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- Define the classes that perform server logging daemon functionality

```
class Logging_Handler :
  public Svc_Handler<ACE_SOCK_Stream>
{
public:
  Logging_Handler (ACE_Reactor *);
  virtual int open (void);
  virtual int svc (void);
};

typedef Acceptor<Logging_Handler,
                 ACE_SOCK_Acceptor>
        Logging_Acceptor;
```


Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- Implementing the application-specific functions

```
// Constructor.

Logging_Handler::Logging_Handler (ACE_Reactor *reactor)
  : Svc_Handler<ACE_SOCK_Stream> (reactor)
{
}

// Open hook (register with ACE_Reactor).

int
Logging_Handler::open (void)
{
  reactor_.register_handler
    (this, ACE_Event_Handler::READ_MASK);
}
```

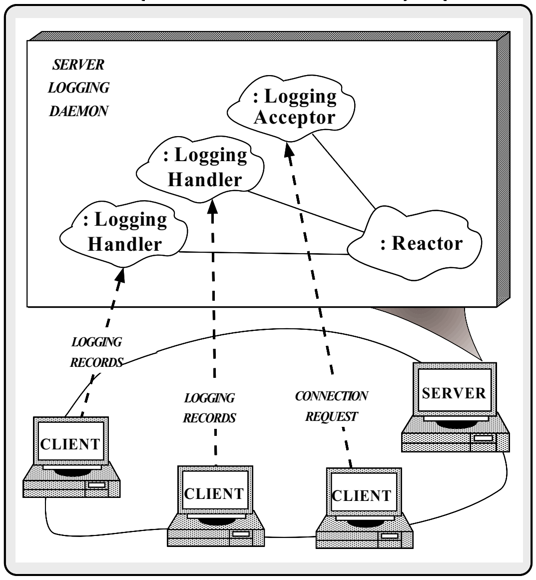
```
// Callback routine for handling the
// reception of remote logging transmissions.

int
Logging_Handler::svc (void)
{
  ssize_t n = peer_stream_.recv (&len, sizeof len);
  int len;

  switch (n) {
    default:
    case -1: return -1; /* NOTREACHED */
    case 0: return 0; /* NOTREACHED */
    case sizeof (int): {
      Log_Record lp;

      len = ntohl (len);
      n = peer_stream_.recv_n ((void *) &lp,
                               len);

      lp.decode ();

      if (lp.len == n)
        lp.print (host_name_, 0, stderr);
      break;
    }

  return 0;
}
```


Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- Main event-loop for the server logging daemon

```
int
main (int argc, char *argv[])
{
  // Event demultiplexor.
  ACE_Reactor reactor;

  // Create the Acceptor.
  Logging_Acceptor acceptor ((ACE_INET_Addr) port);

  // Register handler.
  reactor.register_handler
    (&acceptor, ACE_Event_Handler::READ_MASK);

  // Performs event loop.

  for (;;)
    reactor.handle_events ();
}
```


Single-threaded Concurrent Daemon (Reactor-based) (cont'd)



Single-threaded Concurrent Daemon (Reactor-based) (cont'd)

- *Advantages*
  - OO design decouples the low-level I/O-based event multiplexing mechanisms from the application-specific service policies
    - ▷ This improves extensibility, portability, and reuse significantly
  - The use of parameterized types decouples the reliance on a particular network IPC interface
    - ▷ *e.g.*, both socket-based and TLI-based C++ wrappers may be used
- *Disadvantages*
  - The flow of control for the Reactor's event-driven service dispatching is somewhat difficult to follow at first
  - Parameterized types tend to be slow to compile!

Summary

- There are a wide variety of alternative designs for structuring concurrent network server daemons
- Object-oriented techniques are useful for devising highly decoupled software architectures that are modular, reusable, extensible, and efficient
- C++ features such as inline functions, parameterized types, inheritance, and dynamic binding facilitate the implementation and design of such architectures