Developing Efficient and Portable Communication Software with ACE and C++

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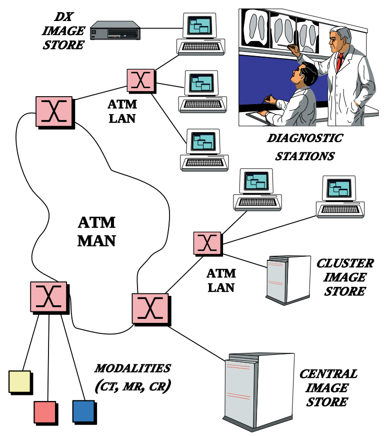
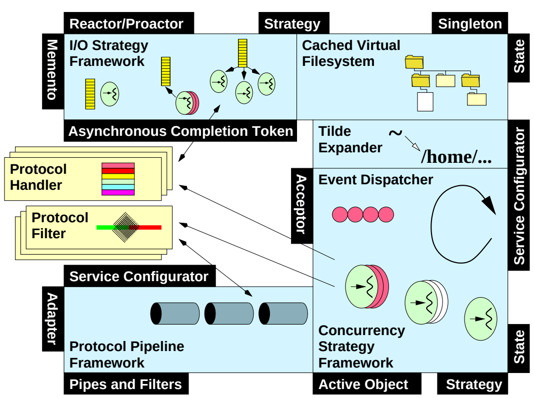
http://www.cs.wustl.edu/~schmidt/ACE-examples4.ps.gz

Problem: Software Evolution



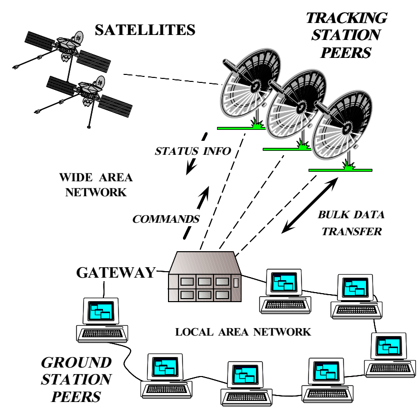
- **Key Challenges**
  - Communication software evolves over time
    - ∗ Requirements change
    - ∗ Platforms change
    - ∗ New design forces emerge
  - It is essential to *plan* for inevitable change

Solution: Plan for Change Using Frameworks and Patterns



- **Solution Approach**
  - Identify sources of *commonality* and *variability*
  - Use patterns to identify reusable design artifacts
  - Use frameworks to "unify" variation in code artifacts

Sources of Variation in Communication Software



- Syntactic Variations
  - Unsupported non-essential APIs
  - Gratuitous differences in API
- Semantic Variations
  - Underlying platform differences
  - Framework must respect these differences
- Complex Variations
  - Unsupported essential portions of API
  - Emulation is necessary

ACE framework: Resolving Syntactic Variations

```
int ACE_OS::fstat (ACE_HANDLE handle,
                   struct stat *stp)
{
#if defined (ACE_PSOS_LACKS_PHILE)
  ACE_UNUSED_ARG (handle);
  ACE_UNUSED_ARG (stp);
  ACE_NOTSUP_RETURN (-1);
#elif defined (ACE_PSOS)
  ACE_OSCALL_RETURN
    (::fstat_f (handle, stp), int, -1);
#else
  ACE_OSCALL_RETURN
    (::fstat (handle, stp), int, -1);
#endif /* ACE_PSOS_LACKS_PHILE */
}
```

- **Examples**
  - *Unsupported*
    - Provide “no-op” definitions
    - Conditional compilation
  - *Syntax*
    - Re-map function parameters

ACE framework: Resolving Semantic Variations

```
int ACE_OS::clock_gettime
  (clockid_t clockid, struct timespec *ts)
{
#if defined (ACE_HAS_CLOCK_GETTIME)
  ACE_OSCALL_RETURN (::clock_gettime
    (clockid, ts), int, -1);
#elif defined (ACE_PSOS)
  ACE_UNUSED_ARG (clockid);
  ACE_PSOS_Time_t pt;
  int result = ACE_PSOS_Time_t::get_system_time (pt);
  *ts = ACE_static_cast (struct timespec, pt);
  return result;
#else
  ACE_UNUSED_ARG (clockid);
  ACE_UNUSED_ARG (ts);
  ACE_NOTSUP_RETURN (-1);
#endif /* ACE_HAS_CLOCK_GETTIME */
}
```

- **Examples**
  - *Underlying differences*
    - Time in clock ticks
    - Ticks-per-second is board-dependent
  - *Framework must respect these differences*
    - Provide a consistent abstraction
    - Intermediate wrappers are useful for small, coherent abstractions

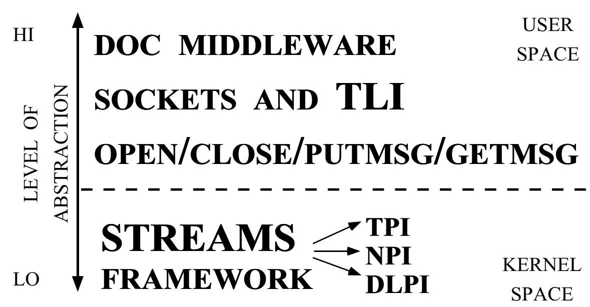
ACE framework: Resolving Complex Variations

```
void *ACE_TSS_Emulation::tss_open
  (void *ts_storage[ACE_TSS_KEYS_MAX])
{
#if defined (ACE_PSOS)
  u_long tss_base;
  tss_base = (u_long) ts_storage;
  t_setreg (0, PSOS_TASK_REG_TSS, tss_base);

  void **tss_base_p = ts_storage;
  for (u_int i = 0;
       i < ACE_TSS_KEYS_MAX;
       ++i, ++tss_base_p)
    *tss_base_p = 0;
  return (void *) tss_base;
#elif defined (...)
// ...
```

- **Examples**
  - *Unsupported but essential portions of the API* (*e.g.*, thread-specific storage)
    - Provided by POSIX, NT
    - Not provided by VxWorks, pSOS
- **Emulation in user space is necessary**
  - Create a TSS emulation class
  - Provide platform-specific method implementations

Network Programming Alternatives



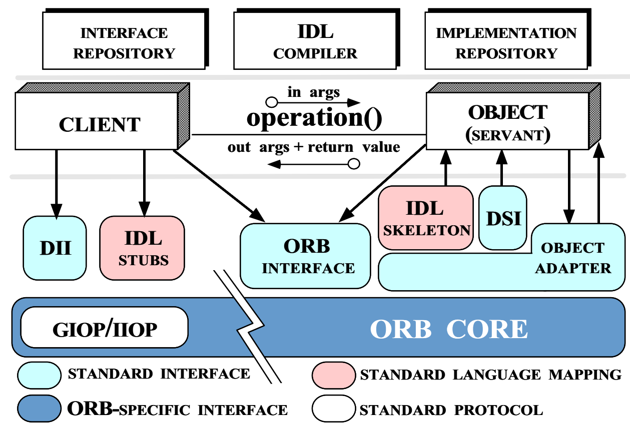
- Communication software can be programmed at several levels of abstraction
- Different levels are appropriate for different tasks

Navigating Through the Design Alternatives

Choosing the appropriate level of abstaction to program involves many factors

- Performance
  - Higher levels may be less efficient
- Functionality
  - Certain features, *e.g.*, multicast, are not available at all levels
- Ease of programming
  - DOC middleware is typically easier to use
- Portability
  - The socket API is generally portable...

Overview of DOC Middleware



www.cs.wustl.edu/~schmidt/corba.html

- Helps simplify many types of applications
- Lets developers work at higher levels of abstraction
- Examples include CORBA, DCOM, Java RMI, DCE, Sun RPC

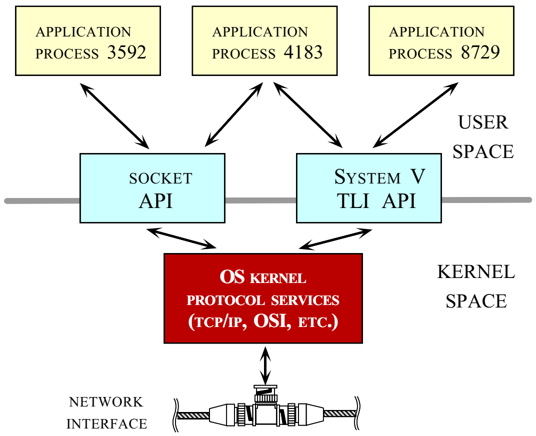
Common DOC Middleware Features

- DOC middleware "stub/skeleton compiler" support
  - Automatically generate code to perform presentation layer conversions
    - *e.g.*, network byte-ordering and parameter marshaling
- DOC middleware runtime support
  - Handle network addressing and remote service identification
  - Perform service registration, port monitoring, and service dispatching
  - Enforce authentication and security
  - Manage transport protocol selection and request delivery
  - Provide reliable operation delivery
  - Demultiplexing and dispatching
  - Concurrency and connection management

DOC Middleware Limitations

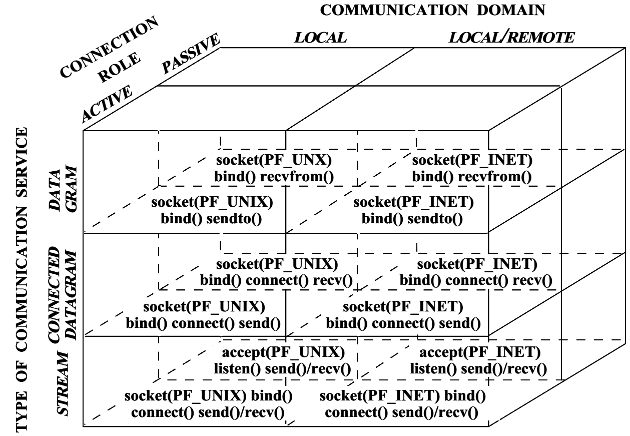
- Some applications may need to access lower-level IPC mechanisms directly to meet certain requirements
  - *e.g.*, performance, functionality, portability, etc.
- Compared with direct use of sockets and TLI, DOC middleware may be less efficient due to
  - Presentation conversion processing and excessive data copying
  - Synchronous client-side and server-side stub behavior
  - Stop-and-wait flow control
  - Non-adaptive retransmission timer schemes
  - Non-optimized demultiplexing and concurrency models

Standard APIs for Network IPC



- Sockets and TLI allow access to lower-level IPC mechanisms, *e.g.*:
  - TCP/IP
  - XNS and Novell IPX NetWare protocols
  - UNIX domain sockets
  - OSI protocols

Socket Taxonomy



- The Socket API can be classified along three dimensions

Problem with Sockets: Lack of Type-safety

```
int buggy_echo_server (u_short port_num)
{ // Error checking omitted.
  sockaddr_in s_addr;
  int s_fd = socket (PF_UNIX, SOCK_DGRAM, 0);
  s_addr.sin_family = AF_INET;
  s_addr.sin_port = port_num;
  s_addr.sin_addr.s_addr = INADDR_ANY;

  bind (s_fd, (sockaddr *) &s_addr,
        sizeof s_addr);
  int n_fd = accept (s_fd, 0, 0);
  for (;;) {
    char buf[BUFSIZ];
    ssize_t n = read (s_fd, buf, sizeof buf);
    if (n <= 0) break;
    write (n_fd, buf, n);
  }
}
```

- I/O handles are not amenable to strong type checking at compile-time
- The adjacent code contains many subtle, common bugs

Problem with Sockets: Steep Learning Curve

Many socket/TLI API functions have complex semantics, *e.g.*:

- Multiple protocol families and address families
  - *e.g.*, TCP, UNIX domain, OSI, XNS, etc.
- Infrequently used features, *e.g.*:
  - Broadcasting/multicasting
  - Passing open file handles
  - Urgent data delivery and reception
  - Asynch I/O, non-blocking I/O, I/O-based and timer-based event multiplexing

Problem with Sockets: Poorly Structured

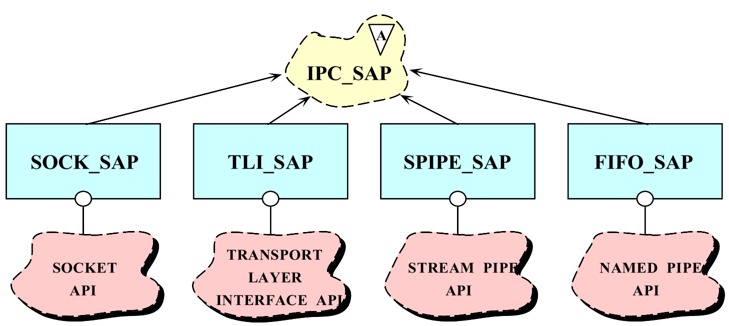
socket()
bind()
connect()
listen()
accept()
read()
write()
readv()
writev()
recv()
send()
recvfrom()
sendto()
recvmsg()
sendmsg()
setsockopt()
getsockopt()
getpeername()
getsockname()
gethostbyname()
getservbyname()

- Note the socket API is *linear* rather than *hierarchical*
  - Thus, it gives no hints on how to use it correctly
- In addition, there is no consistency among names...

Problem with Sockets: Portability

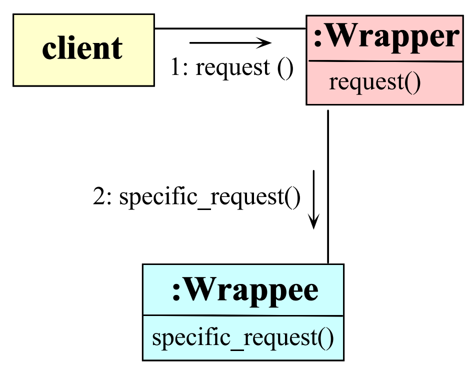
- Having multiple "standards," *i.e.*, sockets and TLI, makes portability difficult, *e.g.*,
  - May require conditional compilation
  - In addition, related functions are not included in POSIX standards
    - *e.g.*, `select`, `WaitForMultipleObjects`, and `poll`
- Portability between UNIX and Win32 Sockets is problematic, *e.g.*:
  - Header files
  - Error numbers
  - Handle vs. descriptor types
  - Shutdown semantics
  - I/O controls and socket options

The ACE C++ IPC Wrapper Solution



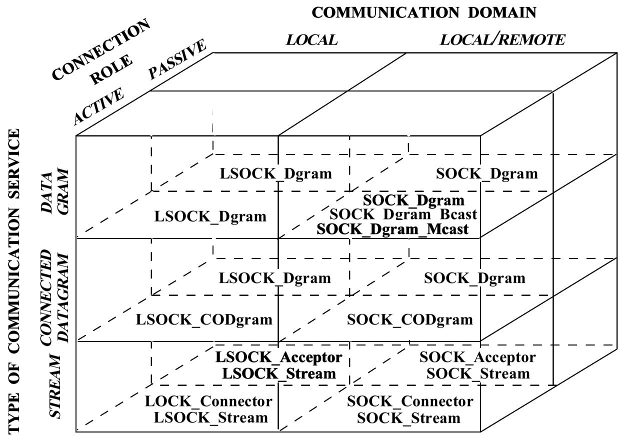
- ACE provides C++ "wrappers" that encapsulate IPC programming interfaces like sockets and TLI
  - This is an example of the *Wrapper Facade Pattern*

Intent and Structure of the Wrapper Facade Pattern



- **Intent**
  - *Encapsulates low-level, stand-alone system mechanisms within type-safe, modular, and portable class interfaces*
- **Forces Resolved**
  - Avoid tedious, error-prone, and non-portable system APIs
  - Create cohesive abstractions

The ACE C++ Socket Wrapper Class Structure



- Note how stand-alone functions are replaced by C++ class components

SOCK_SAP Factory Class Interfaces

```
class SOCK_Connector
{
public:
  // Traits
  typedef INET_Addr PEER_ADDR;
  typedef SOCK_Stream PEER_STREAM;

  int connect
    (SOCK_Stream &new_sap,
     const INET_Addr &raddr,
     Time_Value *timeout,
     const INET_Addr &laddr);
  // ...
};
```

```
class SOCK_Acceptor
  : public SOCK
{
public:
  // Traits
  typedef INET_Addr PEER_ADDR;
  typedef SOCK_Stream PEER_STREAM;

  SOCK_Acceptor
    (const INET_Addr &local_addr);
  int accept
    (SOCK_Stream &new_sap,
     INET_Addr *,
     Time_Value *);
  //...
};
```


SOCK_SAP Stream and Addressing Class Interfaces

```
class SOCK_Stream : public SOCK
{
public:
  // Trait.
  typedef INET_Addr PEER_ADDR;

  ssize_t send (const void *buf,
                int n);
  ssize_t recv (void *buf,
                int n);
  ssize_t send_n (const void *buf,
                  int n);
  ssize_t recv_n (void *buf,
                  int n);
  int close (void);
  // ...
};
```

```
class INET_Addr : public Addr
{
public:
  INET_Addr (u_short port_number,
             const char host[]);
  u_short get_port_number (void);
  int32 get_ip_addr (void);
  // ...
};
```


OO Design Interlude

Q: *Why decouple the* `SOCK_Acceptor` *and the* `SOCK_Connector` *from* `SOCK_Stream`*?*

A: For the same reasons that `Acceptor` and `Connector` are decoupled from `Svc_Handler`, *e.g.*,

- A `SOCK_Stream` is only responsible for data transfer
  - Regardless of whether the connection is established passively or actively
- This ensures that the `SOCK*` components are not used incorrectly...
  - *e.g.*, you can't accidentally `read` or `write` on `SOCK_Connectors` or `SOCK_Acceptors`, etc.

ACE C++ Wrapper `echo_server`

```
int echo_server (u_short port_num)
{
  // Error handling omitted.
  INET_Addr my_addr (port_num);
  SOCK_Acceptor acceptor (my_addr);
  SOCK_Stream new_stream;

  acceptor.accept (new_stream);

  for (;;)
  {
    char buf[BUFSIZ];
    // Error caught at compile time!
    ssize_t n = acceptor.recv (buf, sizeof buf);
    new_stream.send_n (buf, n);
  }
}
```


A Generic Version of the Echo Server

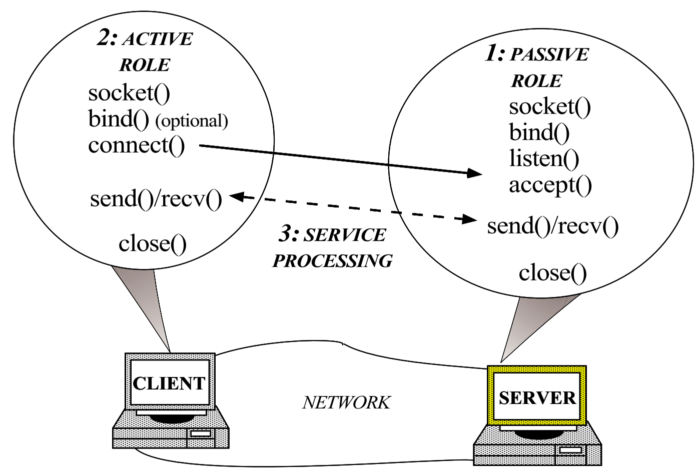
```
template <class ACCEPTOR>
int echo_server (u_short port)
{
  // Local address of server (note use of traits).
  ACCEPTOR::PEER_ADDR my_addr (port);
  // Initialize the passive mode server.
  ACCEPTOR acceptor (my_addr);
  // Data transfer object (note use of traits).
  ACCEPTOR::PEER_STREAM stream;
  // Accept a new connection.
  acceptor.accept (stream);

  for (;;) {
    char buf[BUFSIZ];
    ssize_t n = stream.recv (buf, sizeof buf);
    stream.send_n (buf, n);
  }
}
```

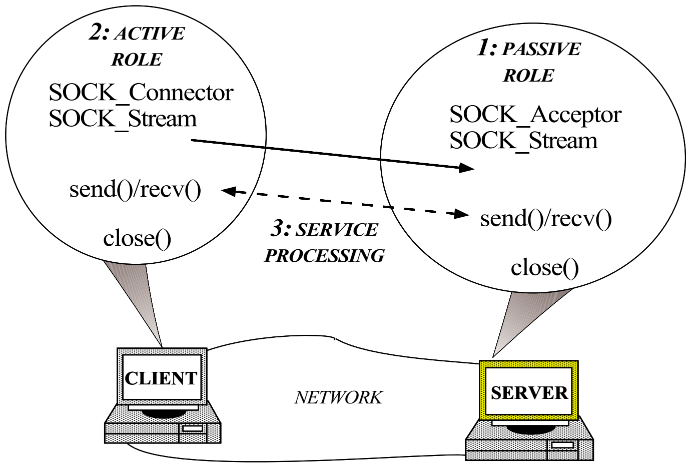

Socket vs. ACE C++ Socket Wrapper Example

- The following slides illustrate differences between using the Socket interface vs. the ACE C++ Socket wrappers
- The example is a simple client/server "network pipe" application that behaves as follows:
  1. Starts an *iterative daemon* at a well-known server port
  2. Client connects to the server and transmits its standard input to the server
  3. The server prints this data to its standard output
- The server portion of the "network pipe" application may actually run either locally or remotely...

Network Pipe with Sockets



Network Pipe with ACE C++ Socket Wrappers



Running the Network Pipe Program

- *e.g.*,

```
% ./server &
% echo "hello world" | ./client localhost
client localhost.cs.wustl.edu%: hello world
```

- Note that the ACE C++ Socket wrapper example:
  - Requires *much* less code (about 1/2 to 2/3 less)
  - Provides greater clarity and less potential for errors
  - Operates at no loss of efficiency
- Complete example available at URL:
  - www.cs.wustl.edu/~schmidt/IPC_SAP-92.ps.gz

Socket Client

```
#define PORT_NUM 10000

int
main (int argc, char *argv[]) {
  struct sockaddr_in saddr;
  struct hostent *hp;
  char *host = argc > 1 ? argv[1] : "tango.cs.wustl.edu";
  u_short port_num = argc > 2
    htons (argc > 2 ? atoi (argv[2]) : PORT_NUM);
  char buf[BUFSIZ];
  int s_fd;
  int w_bytes;
  int r_bytes;
  int n;

  /* Create a local endpoint of communication */
  s_fd = socket (PF_INET, SOCK_STREAM, 0);

  /* Determine IP address of the server */
  hp = gethostbyname (host);
```


Socket Client (cont'd)

```
  /* Set up the address information to
     contact the server */
  memset ((void *) &saddr, 0, sizeof saddr);
  saddr.sin_family = AF_INET;
  saddr.sin_port = port_num;
  memcpy (&saddr.sin_addr, hp->h_addr, hp->h_length);

  /* Establish connection with remote server */
  connect (s_fd, (struct sockaddr *) &saddr,
           sizeof saddr);

  /* Send data to server (correctly handles
     "incomplete writes" due to flow control) */

  while ((r_bytes = read (0, buf, sizeof buf)) > 0)
    for (w_bytes = 0; w_bytes < r_bytes; w_bytes += n)
      n = write (s_fd, buf + w_bytes, r_bytes - w_bytes);

  /* Explicitly close the connection */
  close (s_fd);
  return 0;
}
```

C++ Socket Wrapper Client

```
const u_short PORT_NUM = 10000;
int main (int argc, char *argv[])
{
  char buf[BUFSIZ];
  char *host = argc > 1 ? argv[1] : "ics.uci.edu";
  u_short port_num =
    htons (argc > 2 ? atoi (argv[2]) : PORT_NUM);

  INET_Addr server_addr (port_num, host);
  SOCK_Stream cli_stream;
  SOCK_Connector connector.

  // Establish the connection with server.
  connector.connect (cli_stream, server_addr);
```


C++ Socket Wrapper Client (cont'd)

```
  // Send data to server (correctly handles
  // "incomplete writes").

  for (;;) {
    ssize_t r_bytes = read (0, buf, sizeof buf);
    cli_stream.send_n (buf, r_bytes);
  }

  // Explicitly close the connection.
  cli_stream.close ();
  return 0;
}
```


Socket Server

```
#define PORT_NUM 10000
int
main (int argc, char *argv[])
{
  u_short port_num =
    htons (argc > 1 ? atoi (argv[1]) : PORT_NUM);
  struct sockaddr_in saddr;
  int s_fd, n_fd;

  /* Create a local endpoint of communication */
  s_fd = socket (PF_INET, SOCK_STREAM, 0);

  /* Set up the address information to
     become a server */
  memset ((void *) &saddr, 0, sizeof saddr);
  saddr.sin_family = AF_INET;
  saddr.sin_port = port_num;
  saddr.sin_addr.s_addr = INADDR_ANY;

  /* Associate address with endpoint */
  bind (s_fd, (struct sockaddr *) &saddr,
        sizeof saddr);
  /* Make endpoint listen for service requests */
  listen (s_fd, 5);
```


Socket Server (cont'd)

```
  /* Performs the iterative server activities */
  for (;;) {
    char buf[BUFSIZ];
    struct sockaddr_in cli_addr;
    int r_bytes, cli_addr_len = sizeof cli_addr;
    struct hostent *hp;

    /* Create a new endpoint of communication */
    while ((n_fd = accept (s_fd, (struct sockaddr *)
                           &cli_addr,
                           &cli_addr_len)) == -1
           && errno == EINTR)
      continue;
    if (n_fd == -1)
      continue;
    hp = gethostbyaddr ((char *) &cli_addr.sin_addr,
                        cli_addr_len, AF_INET);
    printf ("client %s: ", hp->h_name), fflush (stdout);
    /* Read data from client (terminate on error) */
    while ((r_bytes = read (n_fd, buf, sizeof buf)) > 0)
      write (1, buf, r_bytes);
    /* Close the new endpoint
       (listening endpoint remains open) */
    close (n_fd);
  }
}
```

C++ Wrapper Socket Server

```
const u_short PORT_NUM = 10000;

// SOCK_SAP Server.

int
main (int argc, char *argv[])
{
  u_short port_num =
    argc == 1 ? PORT_NUM : ::atoi (argv[1]);

  // Create a server.
  SOCK_Acceptor acceptor ((INET_Addr) port_num);
  SOCK_Stream new_stream;
  INET_Addr cli_addr;
```


C++ Wrapper Socket Server (cont'd)

```
  // Performs the iterative server activities.

  for (;;) {
    char buf[BUFSIZ];

    // Create a new SOCK_Stream endpoint (note
    //  automatic restart if errno == EINTR).
    acceptor.accept (new_stream, &cli_addr);

    printf ("client %s: ", cli_addr.get_host_name ());
    fflush (stdout);

    // Read data from client (terminate on error).

    for (;;) {
      ssize_t r_bytes;
      r_bytes = new_stream.recv (buf, sizeof buf);
      if (r_bytes <= 0) break;
      write (1, buf, r_bytes);
    }
    // Close new endpoint (listening
    // endpoint stays open).
    new_stream.close ();
  }
}
```


ACE C++ Wrapper Design Principles

- Enforce typesafety at compile-time
- Allow controlled violations of typesafety
- Simplify for the common case
- Replace one-dimensional interfaces with hierarchical class categories
- Enhance portability with parameterized types
- Inline performance critical methods
- Define auxiliary classes to hide error-prone details

Enforce Typesafety at Compile-Time

Sockets cannot detect certain errors at compile-time, *e.g.*,

```
int s_sd = socket (PF_INET, SOCK_STREAM, 0);
// ...
bind (s_sd, ...); // Bind address.
listen (s_sd); // Make a passive-mode socket.

// Error not detected until run-time.
read (s_sd, buf, sizeof buf);
```

ACE enforces type-safety at compile-time via *factories*, *e.g.*:

```
SOCK_Acceptor acceptor (port);

// Error: recv() not a method of SOCK_Acceptor.
acceptor.recv (buf, sizeof buf);
```

Allow Controlled Violations of Typesafety

Make it easy to use the C++ Socket wrappers correctly, hard to use it incorrectly, but not impossible to use it in ways the class designers did not anticipate

- *e.g.*, it may be necessary to retrieve the underlying socket handle:

```
fd_set rd_sds;

FD_ZERO (&rd_sds);

FD_SET (acceptor.get_handle (), &rd_sds);

select (acceptor.get_handle () + 1, &rd_sds, 0, 0, 0);
```


Supply Default Parameters

```
SOCK_Connector (SOCK_Stream &new_stream,
                const Addr &remote_sap,
                ACE_Time_Value *timeout = 0,
                const Addr &local_sap = Addr::sap_any,
                int protocol_family = PF_INET,
                int protocol = 0);
```

The result is extremely concise for the common case:

```
SOCK_Stream stream;

// Compiler supplies default values.
SOCK_Connector con (stream, INET_Addr (port, host));
```


Define Parsimonious Interfaces

e.g., use LSOCK to pass socket handles:

```
LSOCK_Stream stream;
LSOCK_Acceptor acceptor ("/tmp/foo");

acceptor.accept (stream);
stream.send_handle (stream.get_handle ());
```

versus

```
LSOCK::send_handle (const HANDLE sd) const {
  u_char a[2]; iovec iov; msghdr send_msg;

  a[0] = 0xab, a[1] = 0xcd;
  iov.iov_base = (char *) a; iov.iov_len = sizeof a;
  send_msg.msg_iov = &iov; send_msg.msg_iovlen = 1;
  send_msg.msg_name = (char *) 0;
  send_msg.msg_namelen = 0;
  send_msg.msg_accrights = (char *) &sd;
  send_msg.msg_accrightslen = sizeof sd;
  return sendmsg (this->get_handle (), &send_msg, 0);
```


Combine Multiple Operations into One Operation

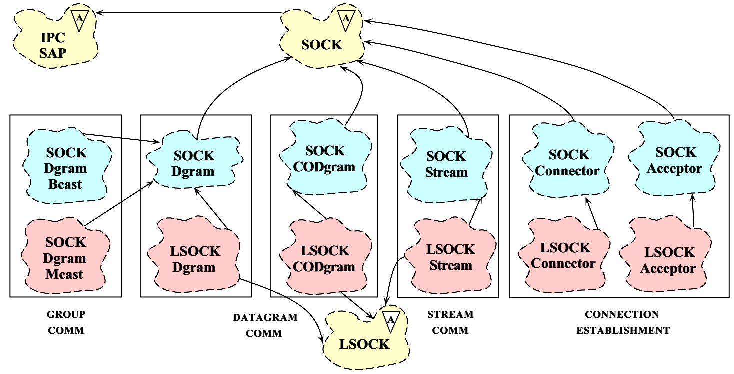
Creating a conventional passive-mode socket requires multiple calls:

```
int s_sd = socket (PF_INET, SOCK_STREAM, 0);
sockaddr_in addr;
memset (&addr, 0, sizeof addr);
addr.sin_family = AF_INET;
addr.sin_port = htons (port);
addr.sin_addr.s_addr = INADDR_ANY;
bind (s_sd, &addr, addr_len);
listen (s_sd);
// ...
```

`SOCK_Acceptor` combines this into a single operation:

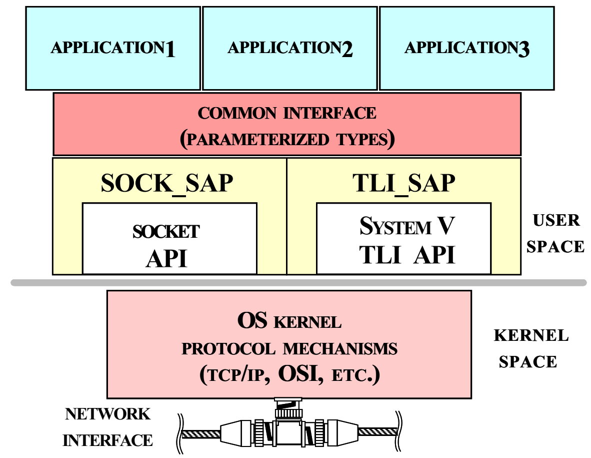
```
SOCK_Acceptor acceptor ((INET_Addr) port);
```

Create Hierarchical Class Categories



- Shared behavior is isolated in base classes
- Derived classes implement different communication services, communication domains, and connection roles

Enhance Portability with Parameterized Types



Enhance Portability with Parameterized Types (cont'd)

Switching wholesale between sockets and TLI simply requires instantiating a different C++ wrapper, *e.g.*,

```
// Conditionally select IPC mechanism.
#if defined (USE_SOCKETS)
typedef SOCK_Acceptor PEER_ACCEPTOR;
#elif defined (USE_TLI)
typedef TLI_Acceptor PEER_ACCEPTOR;
#endif // USE_SOCKETS.

int main (void)
{
  // ...

  // Invoke the echo_server with appropriate
  // network programming interfaces.
  echo_server<PEER_ACCEPTOR> (port);
}
```


Inline Performance Critical Methods

Inlining is time and space efficient since key methods are very short:

```
class SOCK_Stream : public SOCK
{
public:
  ssize_t send (const void *buf, size_t n)
  {
    return ACE_OS::send (this->get_handle (), buf, n);
  }

  ssize_t recv (void *buf, size_t n)
  {
    return ACE_OS::recv (this->get_handle (), buf, n);
  }
};
```

Define Auxiliary Classes to Hide Error-Prone Details

Standard C socket addressing is awkward and error-prone

- *e.g.*, easy to neglect to zero-out a `sockaddr_in` or convert port numbers to network byte-order, etc.

ACE C++ Socket Wrappers define classes to handle these details

```
class INET_Addr : public Addr {
public:
  INET_Addr (u_short port, long ip_addr = 0) {
    memset (&this->inet_addr_, 0, sizeof this->inet_addr_);
    this->inet_addr_.sin_family = AF_INET;
    this->inet_addr_.sin_port = htons (port);
    memcpy (&this->inet_addr_.sin_addr, &ip_addr, sizeof ip_addr);
  }
  // ...
private:
  sockaddr_in inet_addr_;
};
```


Summary of ACE C++ Socket Wrapper Design Principles

- *Domain analysis* identifies and groups related classes of existing API behavior
  - Example *subdomains* include
    - Local context management and options, data transfer, connection/termination handling, etc.
    - Datagrams vs. streams
    - Local vs. remote addressing
    - Active vs. passive connection roles
- These relationships are directly reflected in the ACE C++ Socket wrapper inheritance hierarchy

Summary of ACE C++ Socket Wrapper Design Principles (cont'd)

- The ACE C++ Socket wrappers are designed to maximize reusability and sharing of components
  - Inheritance is used to *factor out* commonality and *decouple* variation *e.g.*,
    - Push common services "upwards" in the inheritance hierarchy
    - Factor out variations in client/server portions of socket API
    - Decouple datagram vs. stream operations, local vs. remote, etc.
  - Inheritance also supports "functional subsetting"
    - *e.g.*, passing open file handles...

Summary of ACE C++ Socket Wrapper Design Principles (cont'd)

- Performance improvements techniques include:
  - Inline functions are used to avoid additional function call penalties
  - Dynamic binding is used sparingly to reduce time/space overhead
    - *i.e.*, it is eliminated for `recv`/`send` path
- Note the difference between the *composition* vs. *decomposition/composition* aspects in design complexity
  - *i.e.*, ACE C++ Socket wrappers are primarily an exercise in *composition* since the basic components already exist
  - More complex OO designs involve both aspects...
    - *e.g.*, the ACE Streams, Service Configurator, and Reactor frameworks, etc.

Concluding Remarks

- Defining C++ wrappers for native OS APIs simplifies the development of correct, portable, and extensible applications
  - C++ `inline` functions ensure that performance isn't sacrificed
- ACE contains many C++ wrappers that encapsulate UNIX, Win32, and RTOS APIs interfaces
  - *e.g.*, sockets, TLI, named pipes, STREAM pipes, etc.
- ACE can be integrated conveniently with CORBA and DCOM provide a flexible high-performance, real-time development framework