61FIT3JSD
Fall 2023

Lecture 11

Networked Application Development

Lecture outline

- TCP/IP review
- Client/server application
- Application protocol
- Design & implementation
  - single-threaded application
  - multi-threaded application

TCP/IP review

- TCP/IP protocol stack
- TCP
- UDP

TCP/IP protocol stack

- Defines layers of protocols that enable data communications between Internet hosts

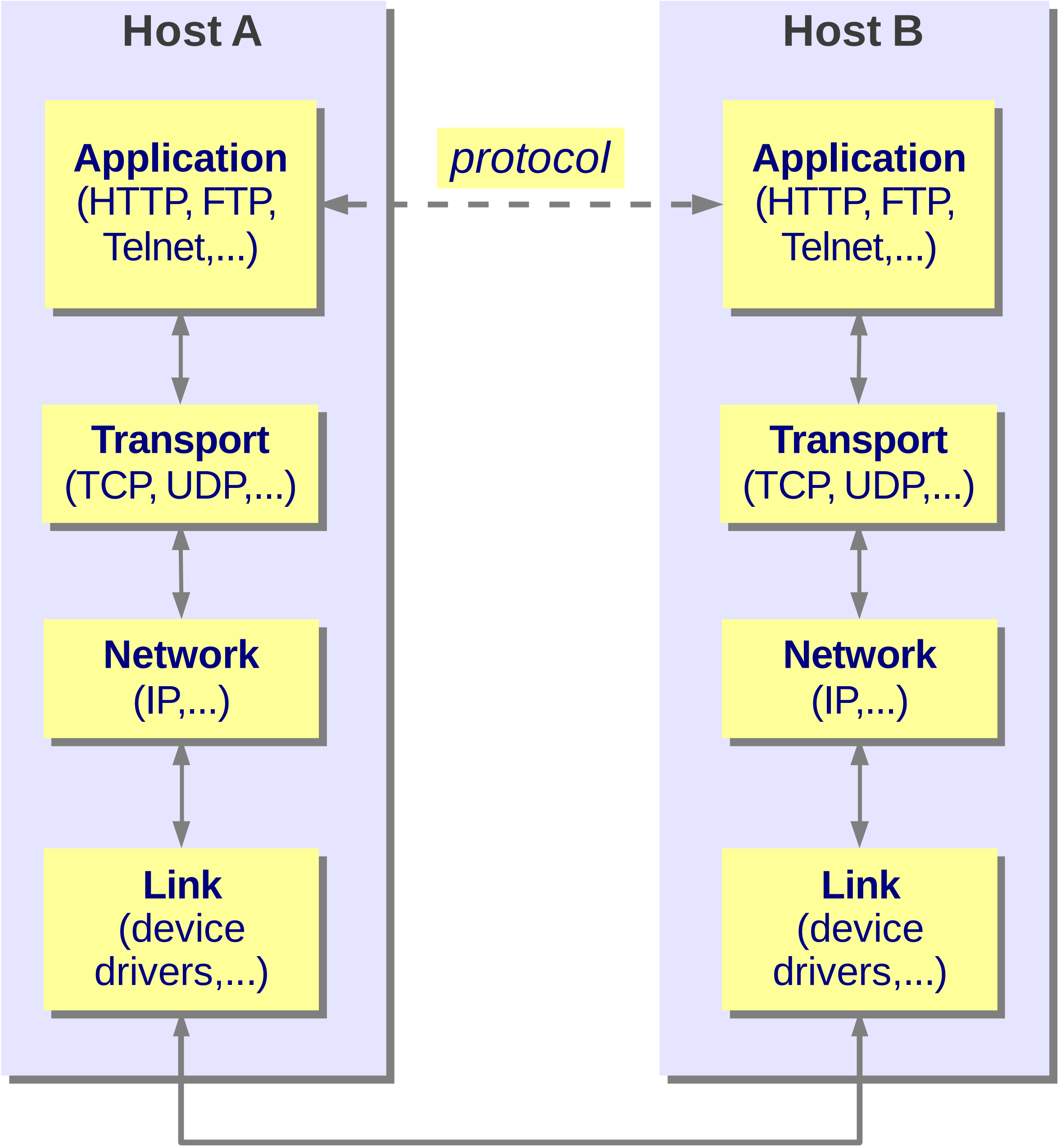
Application
(HTTP, FTP, Telnet,...)

Transport
(TCP, UDP,...)

Network
(IP,...)

Link
(device drivers,...)

TCP/IP hosts



Host A
Host B
Application
(HTTP, FTP,
Telnet,...)
protocol
Application
(HTTP, FTP,
Telnet,...)
Transport
(TCP, UDP,...)
Transport
(TCP, UDP,...)
Network
(IP,...)
Network
(IP,...)
Link
(device
drivers,...)
Link
(device
drivers,...)

TCP

- Transmission Control Protocol
- Transport layer
- Connection-based
- Reliable transmission:
  - guarantee of data arrival
  - guarantee of consistency between sent and received data

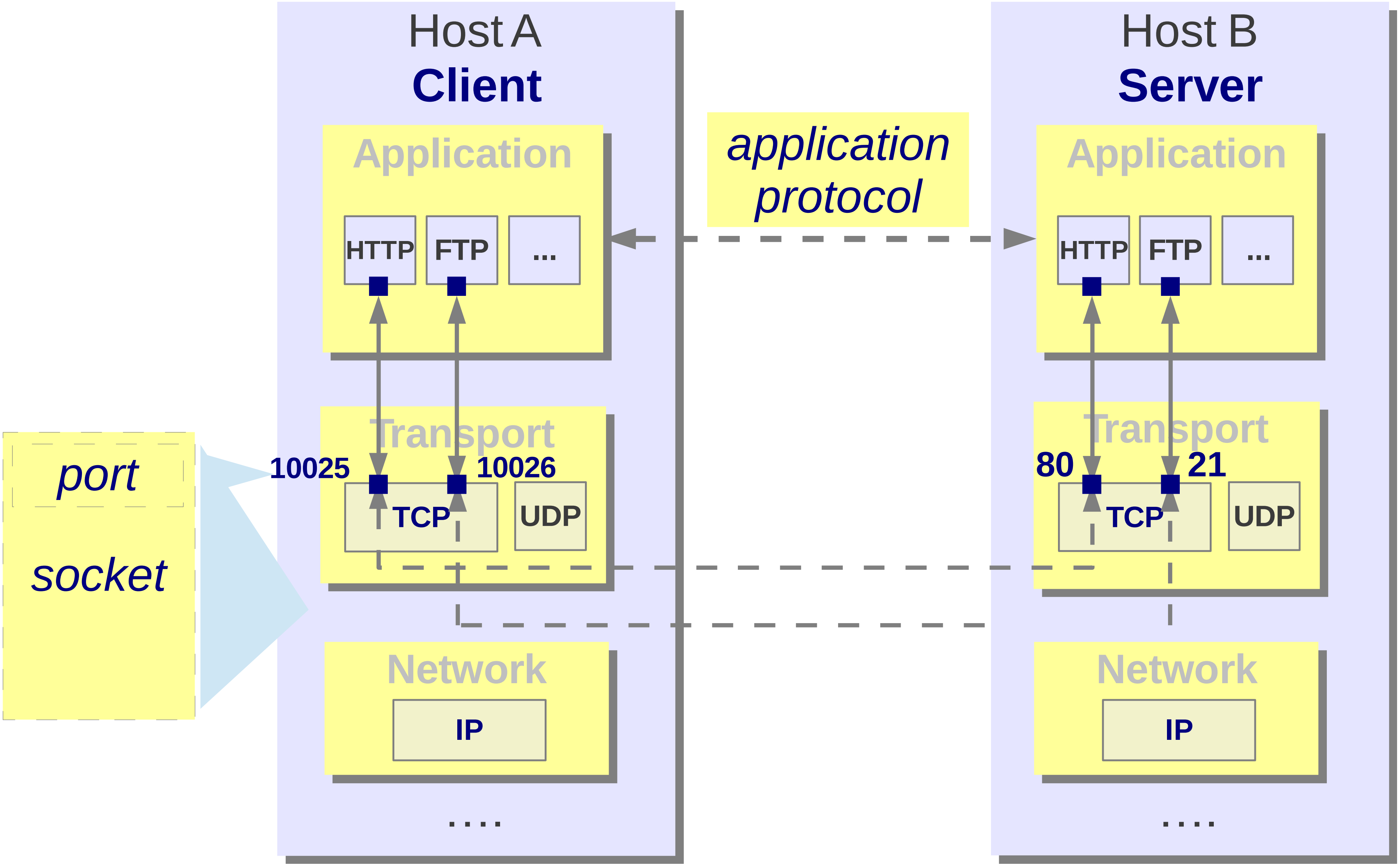
UDP

- User Datagram Protocol
- Transport layer
- Connectionless
- Unreliable transmission
  - no guarantee of data arrival

Client-server application

- Applications reside at the top layer of the TCP/IP stack
- Uses a transport layer protocol to send/receive data
- Follows a client/server architecture:
  - client application: sends requests to a server application
  - server application: processes each client's request to send a suitable response

Client/server application concepts



Client

- An application process that makes requests
- Knows the host and port of the server
- A **local port** is assigned to the client to receive responses from the server
- Local ports are automatically assigned from a range different from the well-known ports

Server

- The application process that handles the requests
- Performs domain-specific tasks (e.g. web functions, file management, etc.) that are shared among many clients
- Listens on a well-known port for connection requests from clients
- A new socket is created for each client to send/receive data

Port and socket

- **Port**: a unique number assigned to each application:
  - well-known port numbers: 80 (HTTP), 21 (FTP)
- **Socket**: a combination of IP address and port number that uniquely identifies an application on the network:
  - e.g.: HTTP on host 1.1.1.1 is different from HTTP on host 1.1.1.2

Application protocol

- Manage connections
- Manage data exchange between client(s) and server

Example: Knock-knock game

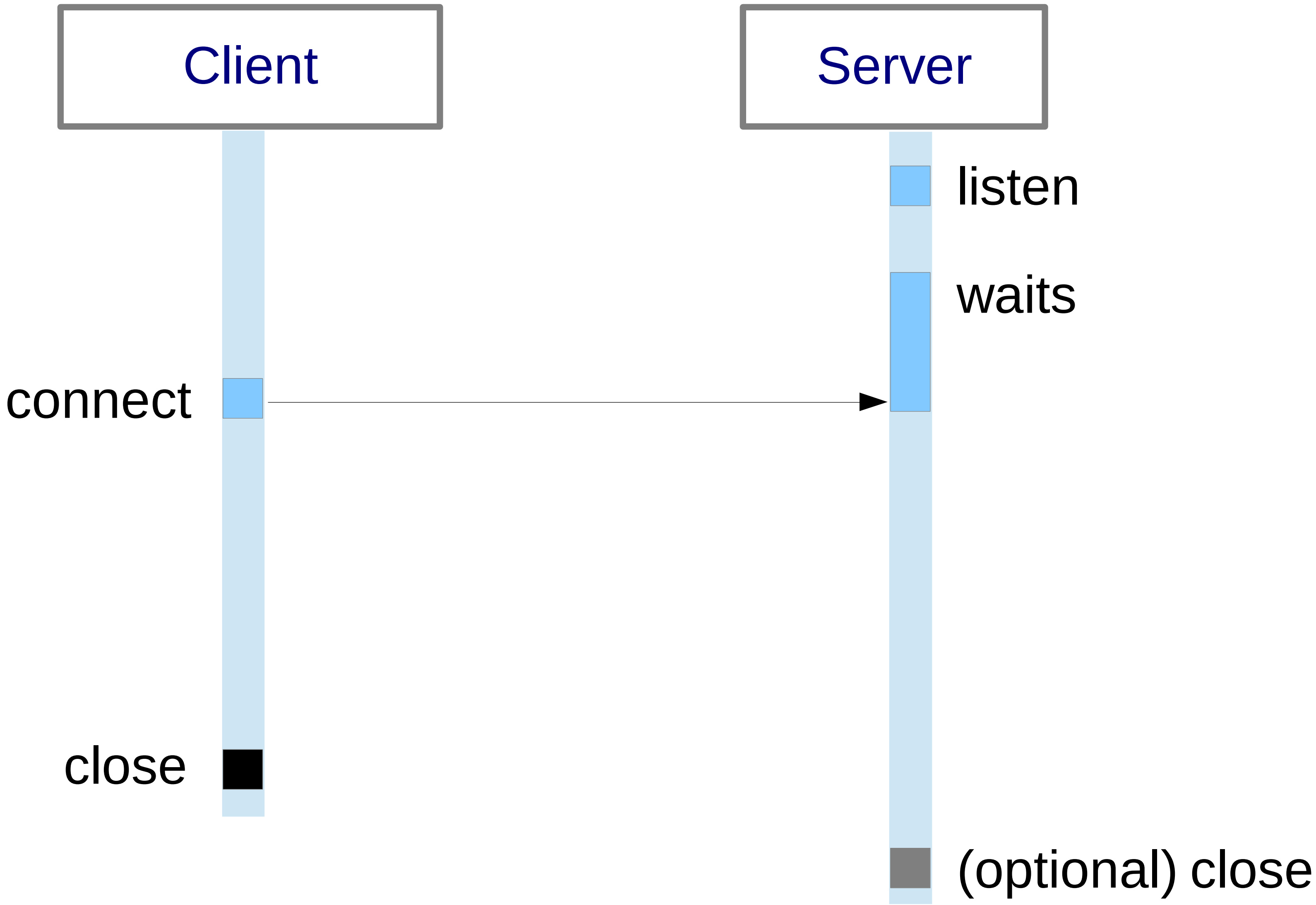
- Sample data exchange:

Client	**Server**
	Knock! Knock!
Who is there?	
	Turnip
Turnip who?	
	Turnip the heat, it's cold in here!
	Want another? (y/n)
y	

Manage connections

- **Connection** set-up and shut-down
- Server:
  - open the server socket
  - wait for client connections
  - (optional) close when finished
- Client:
  - connect to the server socket
  - close when finished

Example



Data exchange

- Application:
  - what **data** to send?
- Presentation:
  - what **format** under which the data is represented?
- Session:
  - **when** to send the data?

Message format

- Depend on the application
- Types:
  - unstructured text: format-free
  - structured text: CSV, XML, etc.
  - binary: e.g. Java object, JPEG, MPEG4, etc.

Example: unstructured text

Knock! Knock!

Who is there?

Turnip

Turnip who?

Turnip the heat, it's cold in here! Want another? (y/n)

y

KnockKnock application

DEMO

- Package `lect11.knockknocksimple`
  - `KnockKnockClient`
  - `KnockKnockProtocol`
  - `KnockKnockServer`

(Source: *Java Tutorial/Custom networking*)

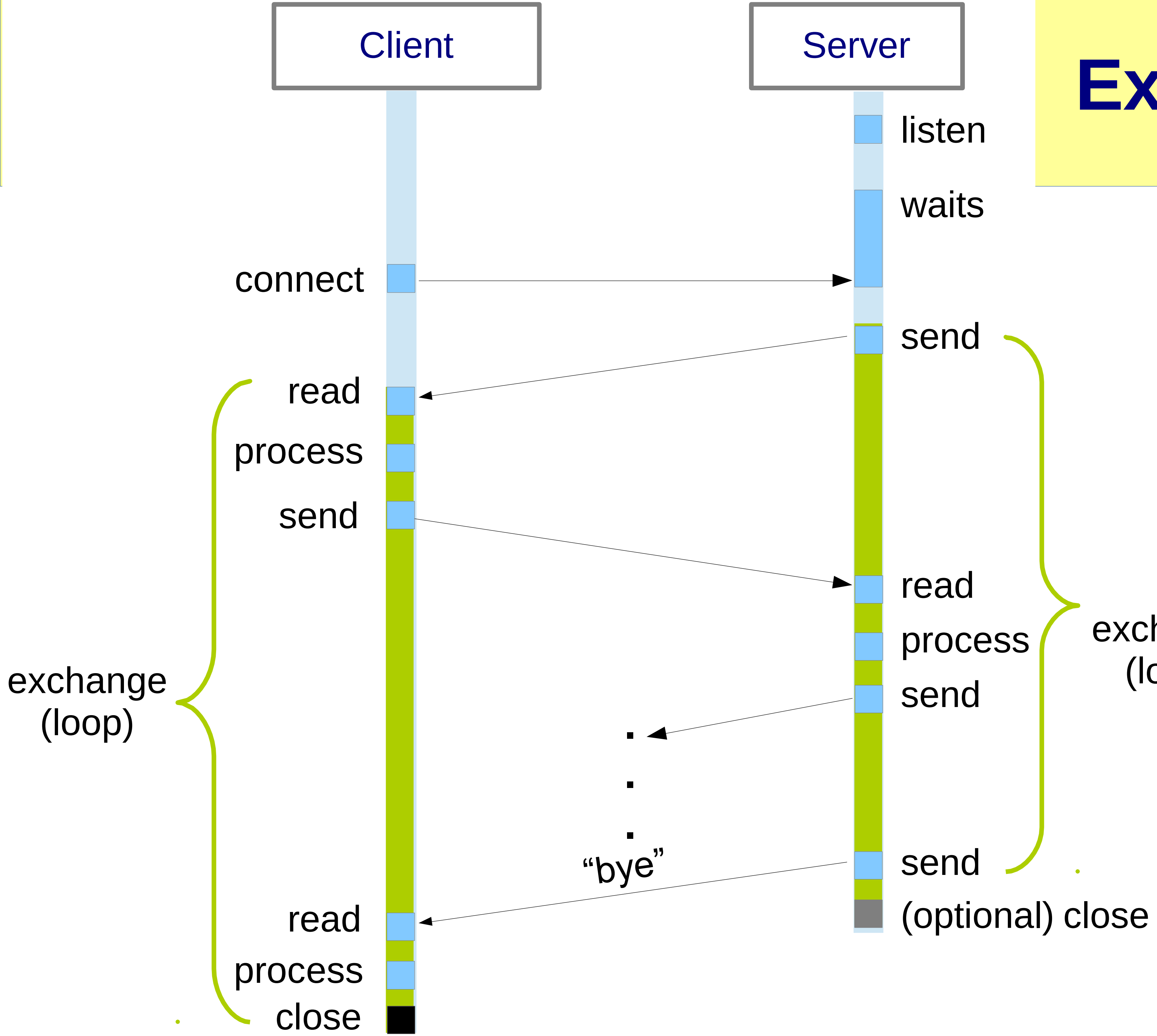
Limitations of `knockknocksimple`

- Ad-hoc design:
  - specific for the need at hand
- Protocol is only used for server
- Design:
  - does not make clear all the protocol functions
  - single-threaded

Data exchange session

- Consists of a finite sequence of 3-step blocks:
  1. read next message from peer (client or server)
  2. process message and prepare a response
  3. send the response to peer
- Steps 1,3 are common for both client and server
- Step 2 differs between client and server
- Raises an end-of-program exception to end normally

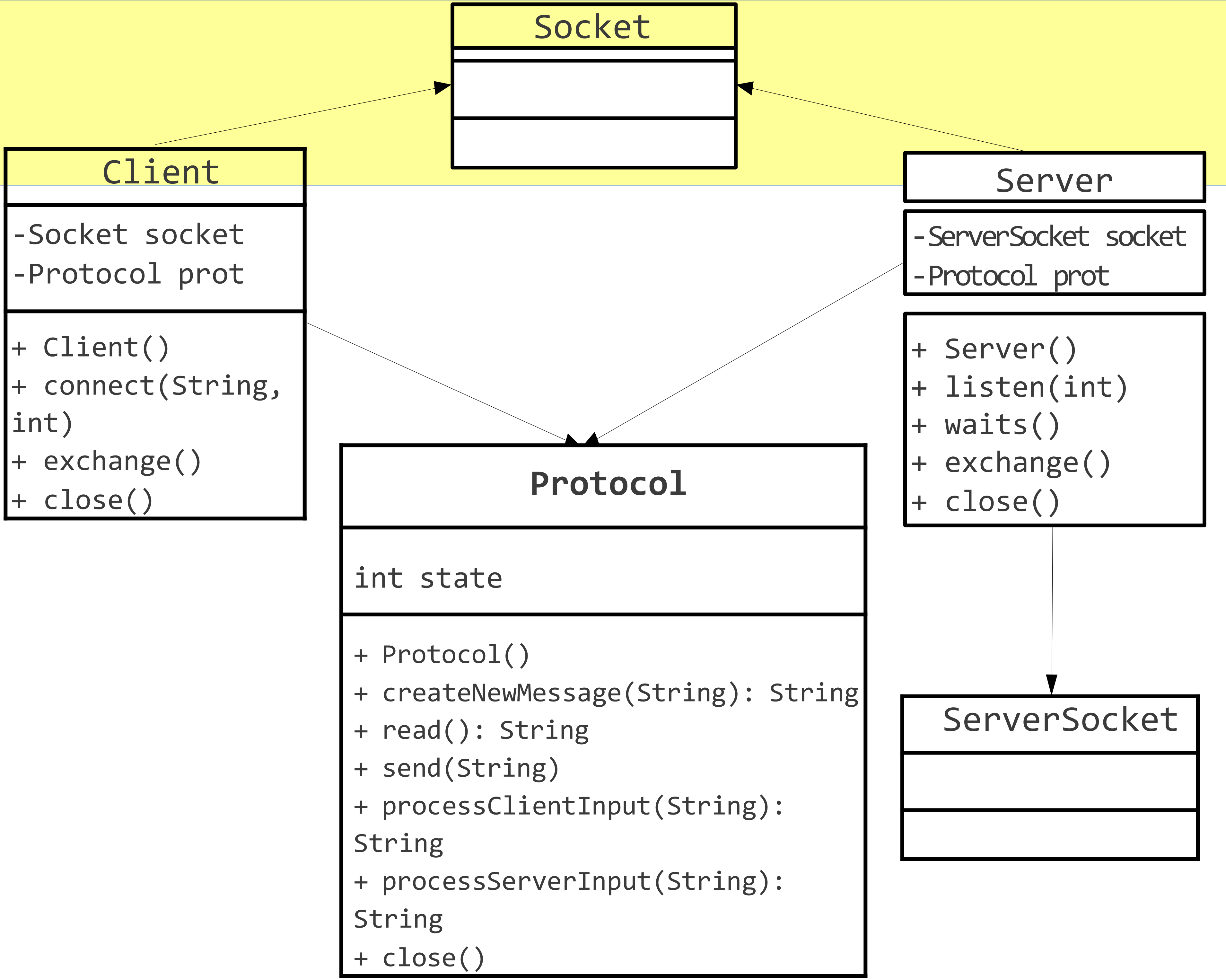
Example


Client
Server
listen
waits
connect
send
read
process
send
read
process
send
exchange
(loop)
exchange
(loop)
. . .
"bye"
send
(optional) close
read
process
close

Design

- **Assumption**: single threaded
  - one client connection at a time
- Two design solutions:
  - single-class design
  - multi-class design

Single-class protocol design



Design note (1)

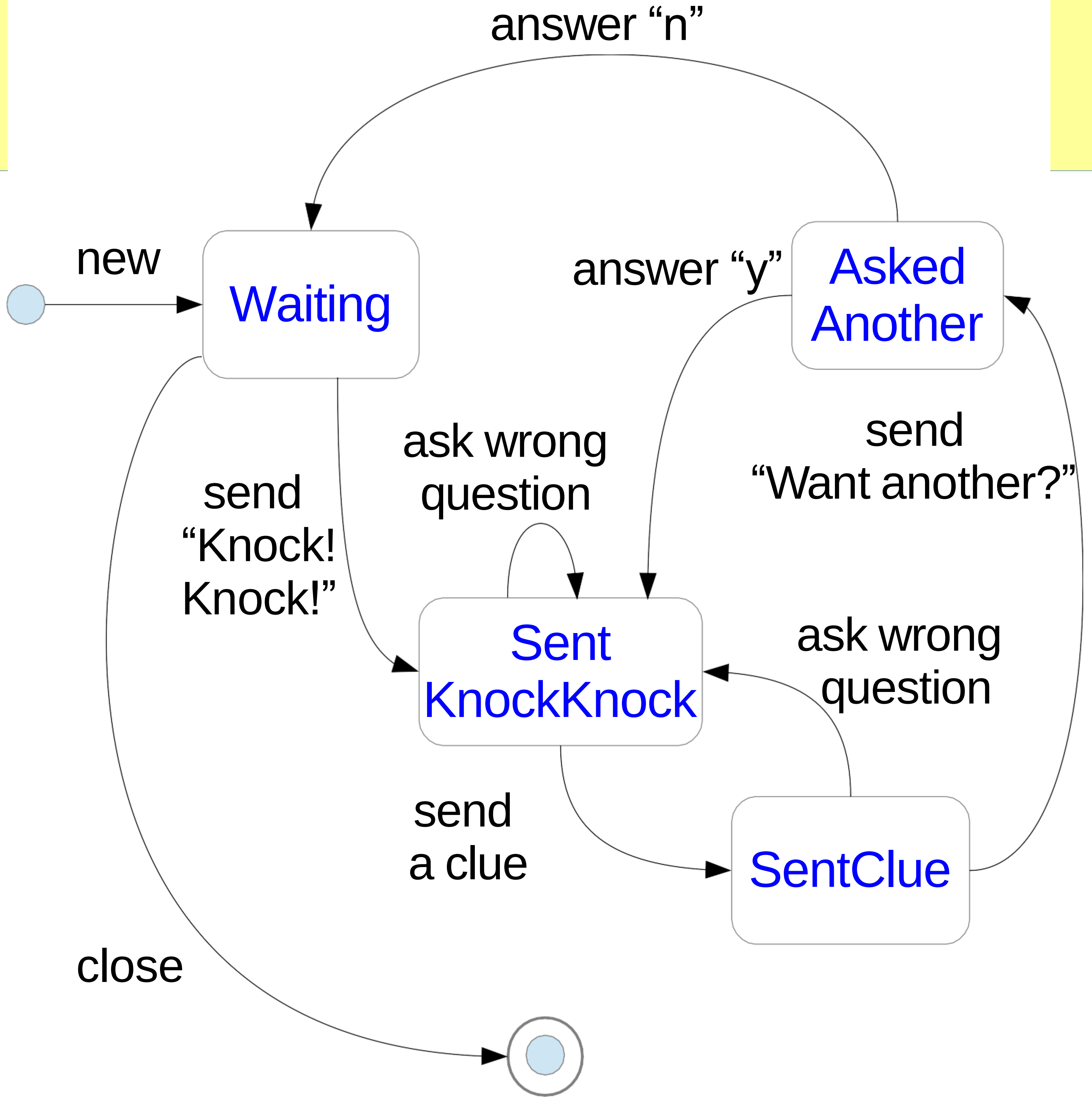
- `Client:`
  - `connect`: set up the connection
- `Server:`
  - `listens`: start the server socket
  - `waits`: waits for the next client connection
- `Client & Server:`
  - `exchange`: performs the data exchange

Design note (2)

- `Protocol`: defines state, message format, and common behaviours:
  - `state`: the current state of the exchange
  - Message format: `String`
  - `processClientInput`: process messages from client
  - `processServerInput`: process message from server

Example

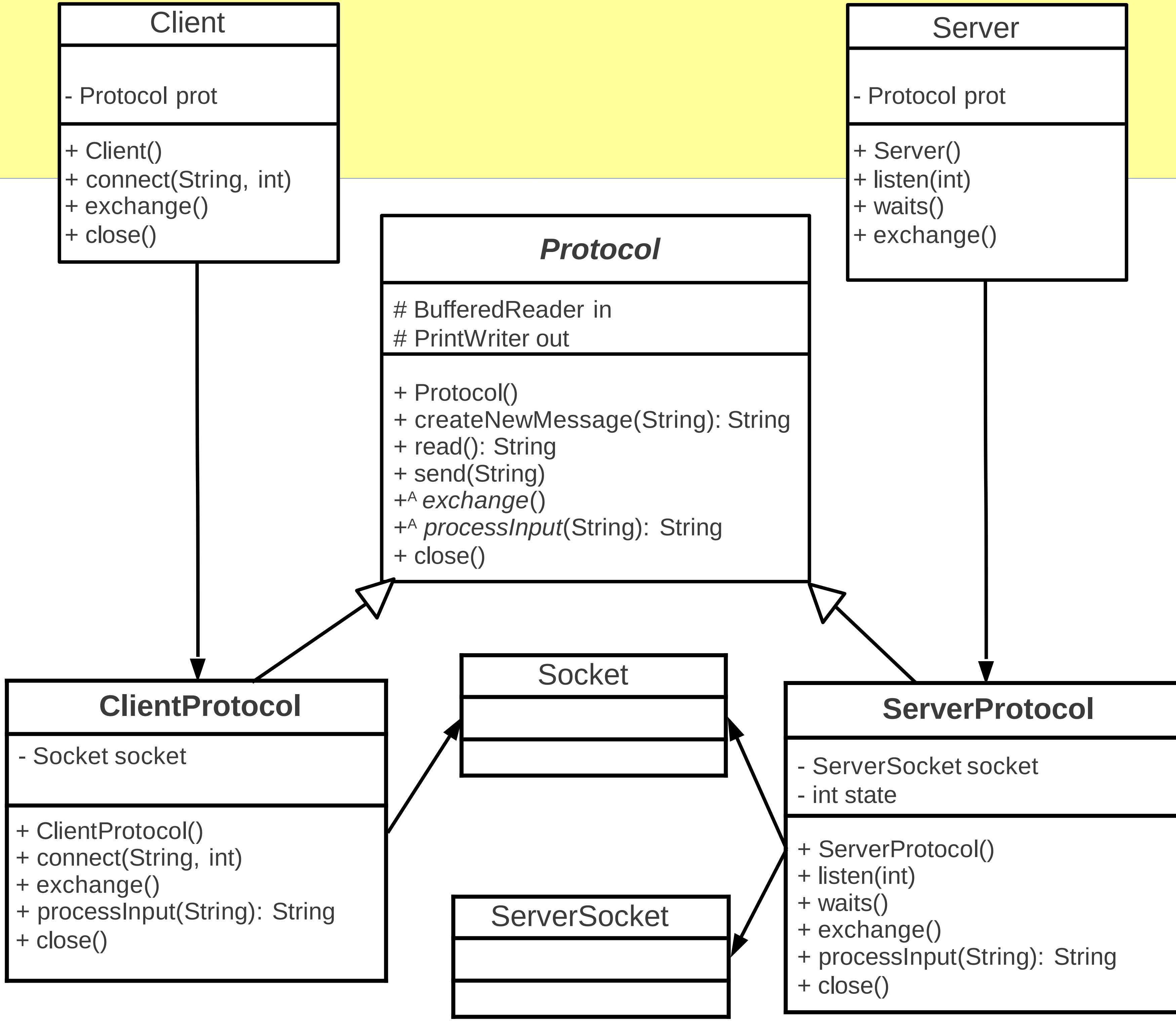
knock-knock states



Features

- One protocol class for both client and server
- Benefits:
  - simple to code and understand
  - easy to update protocol logic (e.g. exchange rules)
- Drawbacks:
  - no listening and connection management in protocol class
  - security concern: server-side logic is visible to client

Multi-class protocol design



Features

- Protocol becomes an abstract super-class
  - defines common data and behaviours
  - abstract methods are common behaviours that have different implementations
- Two protocol classes: one for client and one for server
  - different client and server behaviours are defined in the sub-classes
- Client & server methods are simply the interface for the protocol methods
- Overcome the drawbacks of solution (1)

DEMO

KnockKnock

- `knockknockmulti.Server`
- `knockknockmulti.Client`

Implementation

- Client & server sockets
- Protocol
- ClientProtocol
- ServerProtocol

Socket

- Class: `java.io.Socket`
- Java's implementation of socket
- Provides methods to:
    - connect to a server
    - obtain input and output streams of the connection
- To use with data streams to send and receive data
    - e.g `BufferedReader` and `PrintWriter`

Server socket

- Class: `java.io.ServerSocket`
- Java's implementation of the server-side socket
- Provides methods for:
  - listening on a (server) port
  - accepting clients connections
- An accepted client connection is a `Socket` object

Protocol

```
public abstract class Protocol {
  protected PrintWriter out;
  protected BufferedReader in;

  public Protocol() {
    //
  }
```

createNewMessage()

```
public String createNewMessage(String mesg) {
  return mesg;
}
```

read()

```
public String read() {
  try {
    return in.readLine();
  } catch (IOException e) {
    // prints e
  }
  return null;
}
```

send()

```
public void send(String mesg) {
  out.println(mesg);
}
```

(A) exchange()

```
public abstract void exchange();
```

(A) processInput

```
public abstract String processInput(String
    theInput) throws EOPException;
```

close()

```
    public void close() {
        try {
            out.close();
            in.close();
        } catch (Exception e) {
             // ignore
        }
    }
} // end Protocol
```

ClientProtocol

```
public class ClientProtocol
             extends Protocol {
  protected Socket socket;
  private BufferedReader stdIn;
  public ClientProtocol() {
    super();
    stdIn = new BufferedReader(
             new InputStreamReader(
                 System.in));
  }
```

connect()

```
public void connect(final String host,
  final int port) throws
  UnknownHostException, IOException {
  socket = new Socket(host, port);
  out = new PrintWriter(socket.getOutputStream(),
                                  true);
  in = new BufferedReader(new InputStreamReader(
                  socket.getInputStream()));
}
```

exchange()

```
@Override
public void exchange() {
  String inputLine;
  String outputLine;

  // start the exchange
  try {
    while (true) {
      // read next input
      inputLine = read();

      System.out.println("Server: " + inputLine);

      if (inputLine != null) {
        // process input
        outputLine = processInput(inputLine);
```

...

```
        if (outputLine != null) {
          // next response
          outputLine = createNewMessage(outputLine);

          System.out.println("Client: " + outputLine);
          // send response
          send(outputLine);
        }
      } // end if
    } // end while
  } catch (EOPException e) {
    // end-of-grame print Bye.
    System.out.println(e.getMessage());
  }
}
```

processInput()

```
public String processInput(String fromServer)
                        throws EOPException {
  String fromUser = null;

  // application specific processing
  if (fromServer.equals("Bye."))
    throw new EOPException("Bye.");

  try {
    fromUser = stdIn.readLine();
  } catch (IOException e) {
    // print error
  }
  return fromUser;
}
```

close()

```
  public void close() {
    super.close();
    try {
      socket.close();
      stdIn.close();
    } catch (Exception e) {
      // ignore
    }
  }
} // end ClientProtocol
```

ServerProtocol

```
public class ServerProtocol
                        extends Protocol {

  private ServerSocket socket;

  // application-specific attributes
  // ...
```

listen()

```
public void listen(int port)
 throws UnknownHostException,
        IOException {
  socket = new ServerSocket(port);
}
```

waits()

```
public void waits()
               throws IOException {
  Socket clientSocket = socket.accept();

  out = new PrintWriter(clientSocket.
              getOutputStream(), true);
  in = new BufferedReader(new
        InputStreamReader(clientSocket.
              getInputStream()));
}
```

exchange()

```
@Override
public void exchange()  {
  String inputLine, outputLine;
  try {
    // sends the initial message
    outputLine =
    processInput(null);
    outputLine =
    createNewMessage(outputLine);
    send(outputLine);

    // proceed until end-of-game
    while (true) {
      // read next input
      inputLine = read();
```

...

```
    // process input
    if (inputLine != null) {
      outputLine = processInput(inputLine);
      if (outputLine != null) {
        // new response
        outputLine = createNewMessage(outputLine);

        // send response
        send(outputLine);
      }
    }
  }
} catch (EOPException e) {
  // end-of-game, send Bye
  send(createNewMessage(e.getMessage()));
}
```

processInput()

```
public void processInput(String mesg)
                    throws IOException {
   // application-specific handling
   // ...
}
```

close()

```
public void close() {
    super.close();
    try {
        socket.close();
    } catch (Exception e) {
        //
    }
}
```

Server

```java
// creates a protocol object
Server server = new Server();

// start the socket
try {
  server.listen(port);
} catch (Exception e) {
  e.printStackTrace();
  System.exit(1);
}
```

...

```
// waits for client connections
server.waits();

// data exchange sequence
server.exchange();

// close
server.close();
```

Client

```
// creates a client
Client client = new Client();

// connect
try {
  client.connect(host, port);
} catch (Exception e) {
  e.printStackTrace();
  System.exit(1);
}
```

...

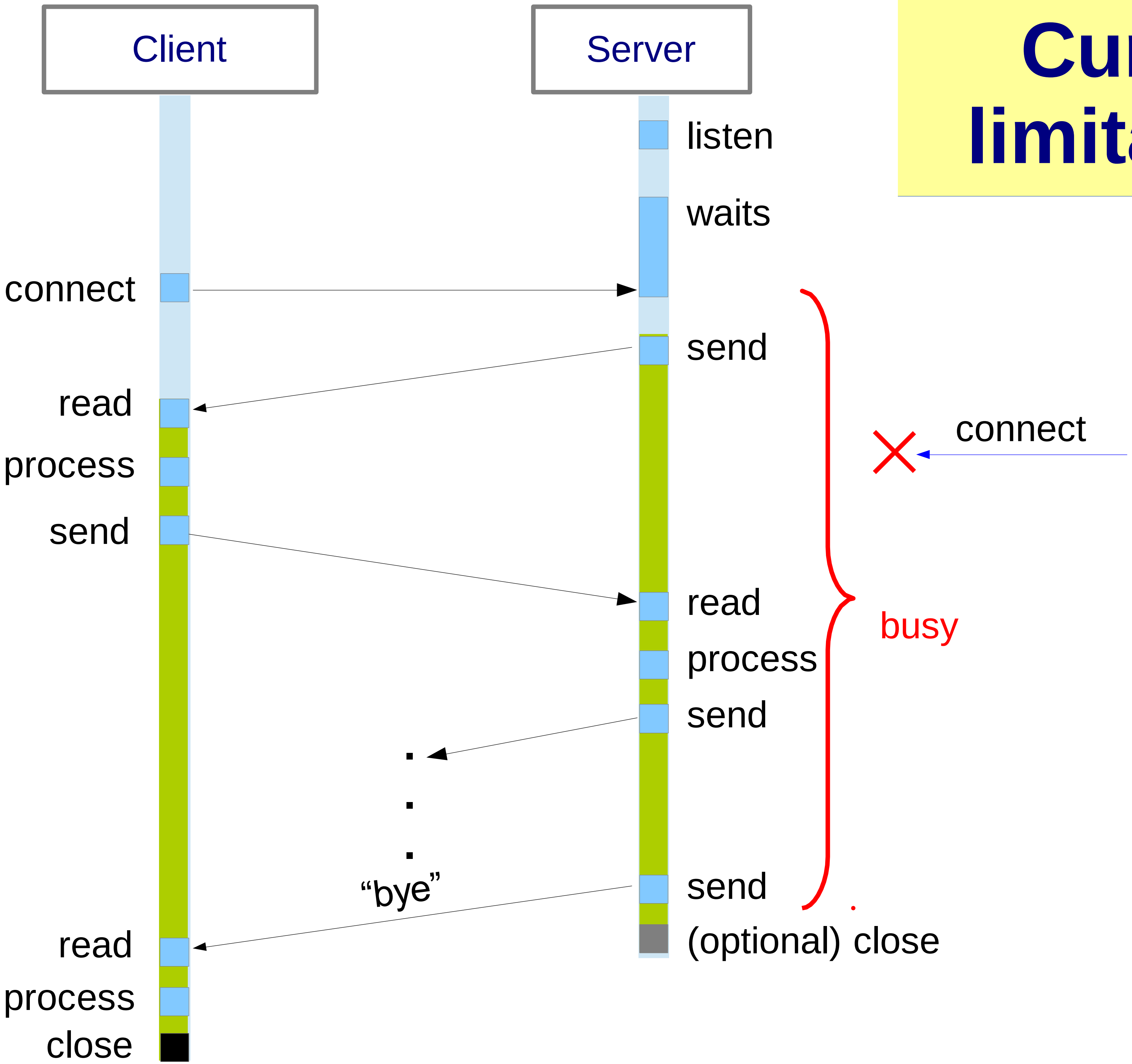
```
// data exchange sequence
client.exchange();

// disconnect and close
client.close();
```

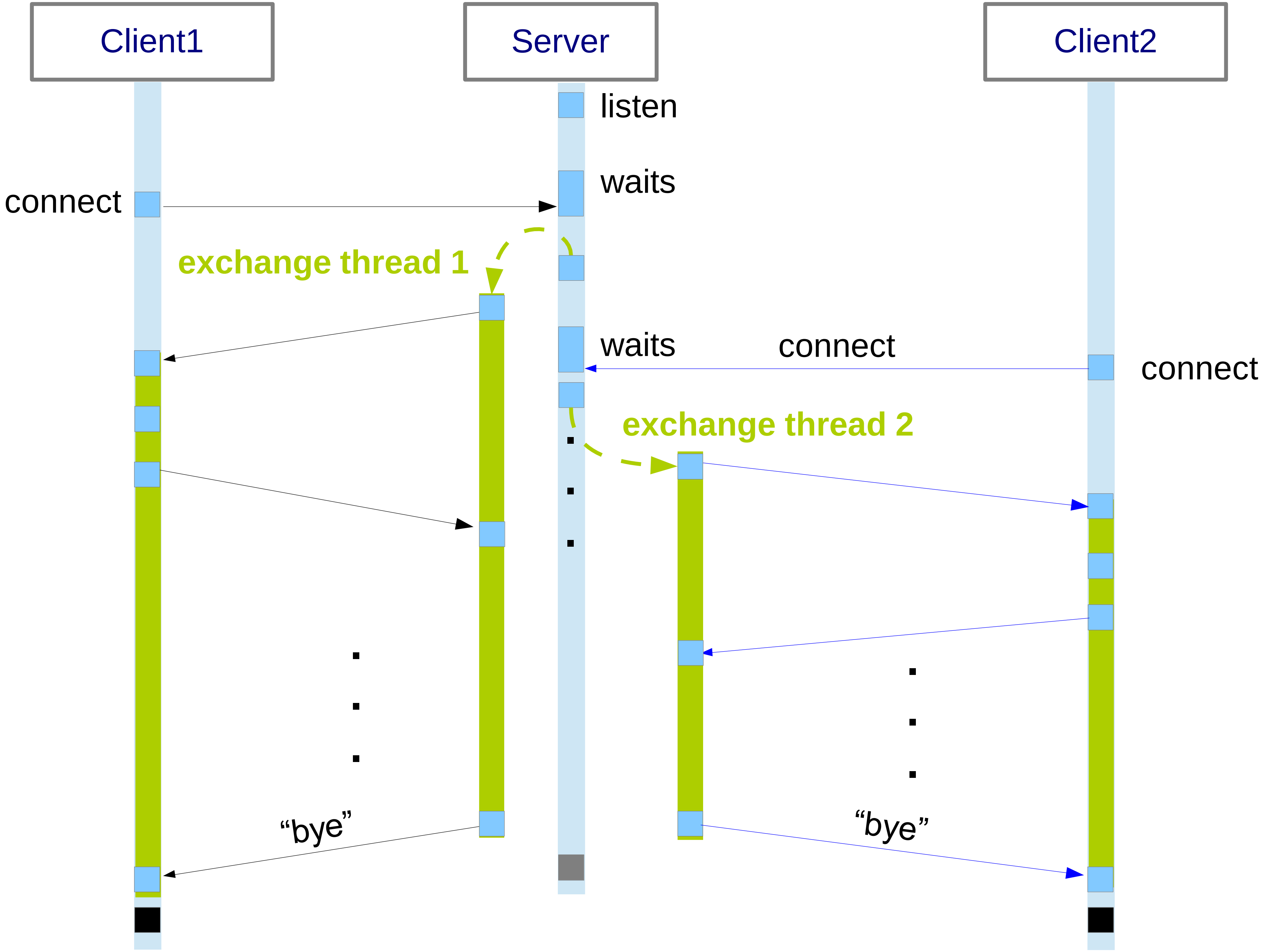
Multi-threaded design

- How to handle concurrent client connections?
- Limitations of the current design:
  - server is busy during the entire exchange session
  - a new client has to wait for the current exchange to finish
- Solution:
  - minimise the busy window of the server,
  - place the exchange session in a thread

Current limitations



A multi-threaded protocol



DEMO

Multi-threaded knockknock

- `knockknock.Server`
- `knockknock.Client`

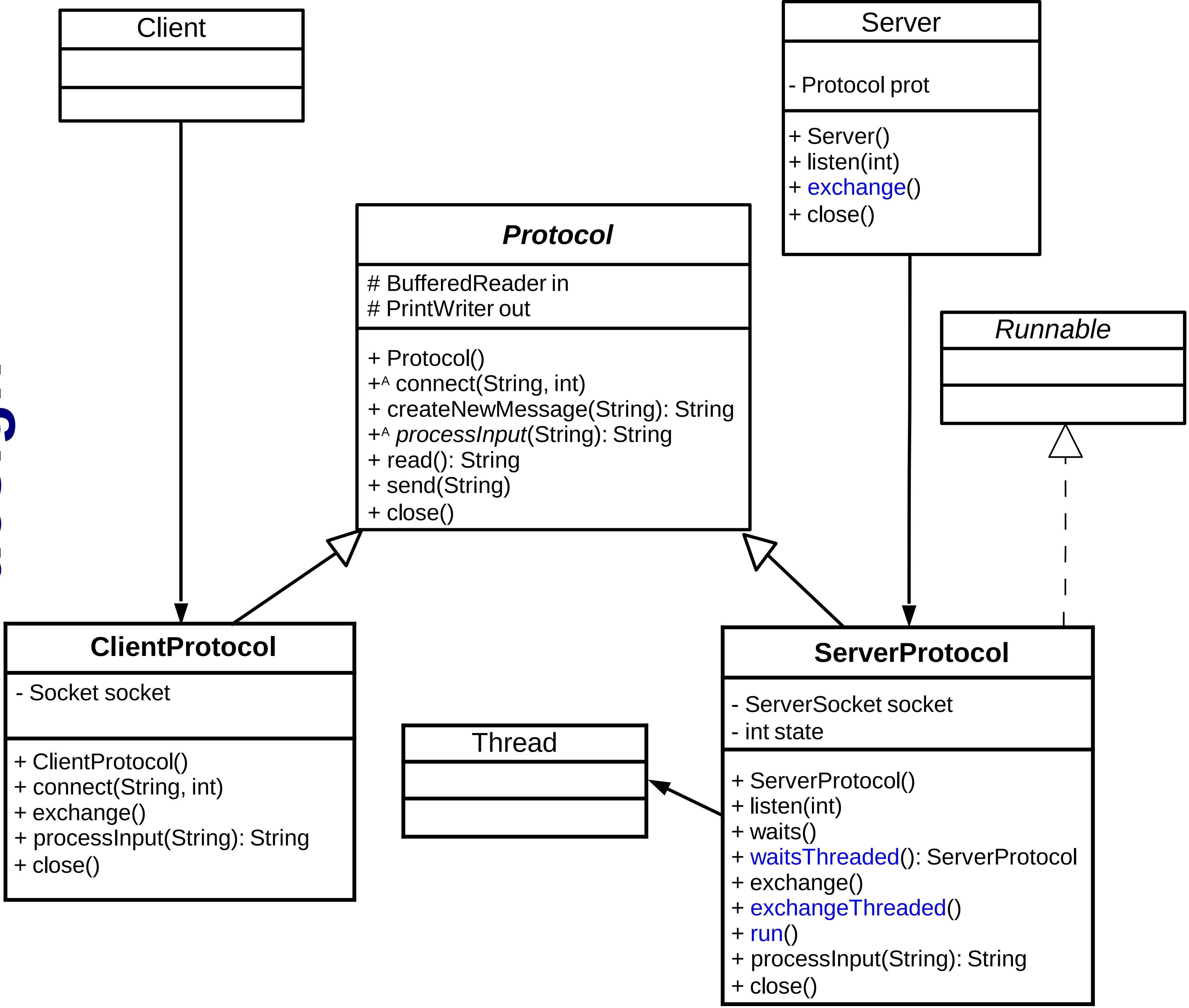
Design changes (1)

- `ServerProtocol`:
  - implements `Runnable`
  - three new methods:
    - `exchangeThreaded, waitsThreaded, run`
- `waitsThreaded`:
  - return a new `ServerProtocol` instance
- `exchangeThreaded`:
  - invoke `waitsThreaded` to obtain a new protocol object
  - create a new `Thread` to run the object

Design changes (2)

- `Server.exchange()`:
    - invokes `prot.exchangeThreaded()`

Multi-threaded protocol design



Implementation

- `ServerProtocol`:
  - `waitsThreaded`
  - `exchangeTheaded`
  - `run`

exchangeThreaded()

```
public void exchangeThreaded() {
  while (true) {
    try {
      // waits
      ServerProtocol protocol = waitsThreaded();

      // creates a new exchange thread
      Thread t = new Thread(protocol);
      t.start();
      System.out.println("Started thread " +
      t.getName());
    } catch (Exception e) {
      e.printStackTrace();
    }
  }
}
```

waitsThreaded()

```java
// creates a rotocol instance to handle each new
// client connection
public ServerProtocol waitsThreaded() throws
                                       IOException {
  Socket clientSocket = socket.accept();
  PrintWriter out = new PrintWriter(
          clientSocket.getOutputStream(), true);
  BufferedReader in = new BufferedReader(new
   InputStreamReader(clientSocket.getInputStream()
                                                 ));
  ServerProtocol kks = new ServerProtocol();
  kks.in = in;
  kks.out = out;
  return kks;
}
```

run()

```
// implements Runnable
public void run() {
  exchange();
}
```

Server.exchange()

```
// exchange data with clients
public void exchange() {
  // use threads
  prot.exchangeThreaded();
}
```

Summary

- Networked applications use the TCP/IP protocol stack for data exchange
- Servers listen on well-known ports and handle clients requests
- Client/server applications are implemented using the `Socket` and `ServerSocket` class in `java.io` package
- Two design solutions: single- and multi-class
- Multi-class design can easily support multiple client connections using threads

References

Oracle, The Java Tutorial, Oracle, http://docs.oracle.com/javase/tutorial

- Trail: Custom networking