State Diagram

C++ Object Oriented Programming
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Introduction

- **State Diagram** is used to described the dynamic behavior of an object.
- What is the state of an object?
  - All objects have internal states.
  - The response of an object to a message depends on its state

  Ex.
  - I can answer the phone, but whether I answer or not depends on I am **busy or not** when the phone rings.
  - A television set usually has a couple of control buttons, e.g. volume up/down, channel up/down, setup, power etc. However, not every button is responding at any moment, e.g. volume up/down do not function when **power is off**. Most of the buttons have a different set of functions when entering **setup mode**.

Introduction (cont'd)

- A turnstile has two states: **locked** or **unlocked** (coin deposited)
- When using an ifstream object for file input, a read operation of an integer might fail if the **current file pointer points to a non-numeric character** or if the file pointer points to the **end of file**.
- We can push a value into a Stack object, only when the stack is **not ful**l. We can pop a value out only when the stack is **not empty**.
- An editor has two input modes: **insert** or **overwrite**. In the insert mode, the input characters from the keyboard are inserted right before the cursor. In the overwrite move, the input characters overwrite the characters at the cursor.
- An editor has two document modes: documents **modified** or **not modified**.
- An editor has two UI modes: document **specified** or **not specified**.
- …

Introduction (cont'd)

Note: 1. A very simple object might have a fixed state such that its behavior is all the way consistent.

2. The timing of messages to an object with various internal states is important and determines how an object responds.

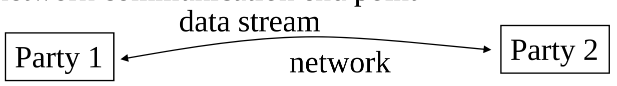
3. Usually the states of an object cannot be observed directly from outside. The messages an object received up to now affect its current state and therefore its future behaviors.

Object Interface vs. Object State

- ✧ The object interface depends also on its current state.
- ✧ Object interface (the usage of an object)
  - ✶ Public operations (member functions)
  - ✶ The sequence (order) of the operations being executed
- ✧ "Some operations are required to follow other operations" indicates the existence of object's internal state.
- ✧ If a client program does not follow the pre-specified order to use the interface, the object could possibly refuse to respond and enter a special error state.

Ex.

A network communication end point



Object with States

```
class NetCommStream {
public:
    void open();
    void connect();
    void read();
    void write();
    void disconnect();
    void close();
private:
    ...
};
```

Correct usage:

```
NetCommStream obj;
obj.open();
obj.connect();
obj.read();
obj.disconnect();
obj.close();
```

- ✧ **Usage description:**

  A stream can only be opened (for setting up its own communication interface) when it is not currently opened. A stream can only be connected (for building up the connection with a remote machine) when it is opened but not connected. A stream object can be read / write / disconnected only when it is connected properly.

Incorrect usage:

```
NetCommStream obj;
obj.open();
obj.read();
```

Intuitive Implementation

- ✧ Using *bool* variables to keep various kinds of states

```
void open() {
   if (!m_fOpen) {
      m_fOpen = true;
      do_open();
   }
}
void connect() {
   if ((m_fOpen)&&(!m_fConnected)) {
      m_fConnected = true;
      do_connect();
   }
}
void read() {
   if (m_fConnected)
      do_read();
}
```

```
void disconnect() {
   if (m_fConnected) {
      m_fConnected = false;
      do_disconnect();
   }
}
void close() {
   if ((m_fOpen)&&(!m_fConnected)) {
      m_fOpen = false;
      do_close();
   }
}
void write() {
   if (m_fConnected)
      do_write();
}
```

implicit and vague

Two flags are used in the above implementation. **4 different states**?

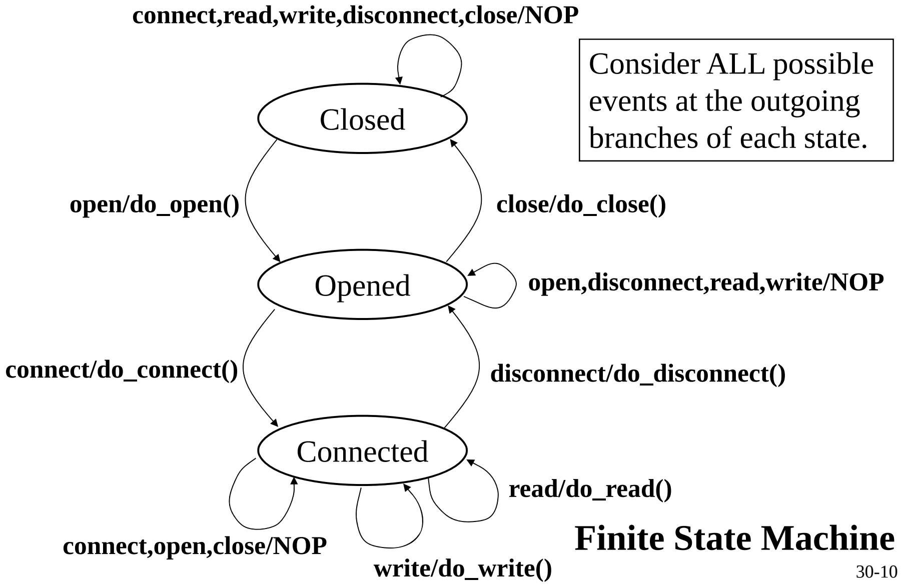
Explicit State

- Two *bool* variables m_fOpen and m_fConnected define 4 legal states; but only 3 of them are meaningful to this application

m_fOpen	m_fConnected	State
false	false	**Closed**
false	true	╳
true	false	**Opened**
true	true	**Connected**

- There are six possible events (messages) to this object
  - **open**
  - **connect**
  - **read**
  - **write**
  - **disconnect**
  - **close**

State Diagram



Consider ALL possible events at the outgoing branches of each state.

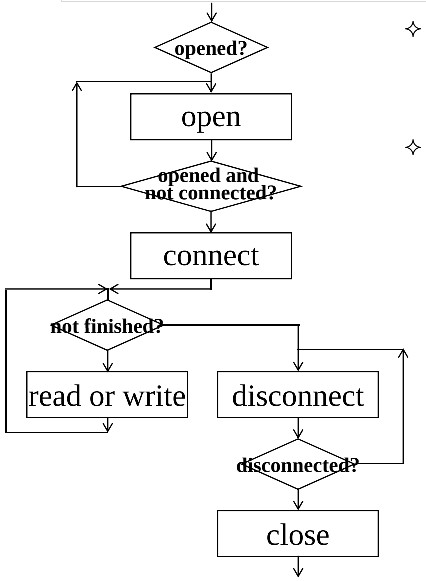
Finite State Machine

State Diagram (cont'd)

- Advantages:
  - Show only valid states in the diagram
  - Label each state with meaningful words
  - Allow programmer to consider the full set of events at each state
  - Simplify the considerations of server program logics. A state diagram for the server object shows a lot more design information than a control flow diagram for the server. (The server control flow diagram is incomplete and fragmented without the client control flow diagram.)
- A control flow diagram of the client simply does not show all possible ways of usages.

See the following example…

Control Flow Diagram of A Client



- This is the control flow for the TYPICAL / CORRECT usage of this NetCommStream object.
- Problems:
  - What if the client does not follow this advised procedure?
    Eg. Not opened but do the connect at the first step? Not connected but do the read/write at the second step?
  - What if there are other possible usage patterns?
    e.g. Opened but find no peer to connect and then close immediately.
    Disconnected but find some other peer to connect.

Implementation of an FSM

- ✧ Use a single *enum* type of variable to represent the state of the system

  enum InternalStates {***Closed***, ***Opened***, ***Connected***};
  InternalStates **m_state**;

- ✧ In an OO system, objects communicate with each other through events. Take the event open and its handler open() as example:
  1. For each open message of each state in the diagram
  2. Implement the response in open()

```
void open() {
   if (m_state == Closed) {
      do_open();
      m_state = Opened;
   }
   else if (m_state == Opened) ;
   else if (m_state == Connected) ;
}
```

A systematic way of implementation for a state diagram

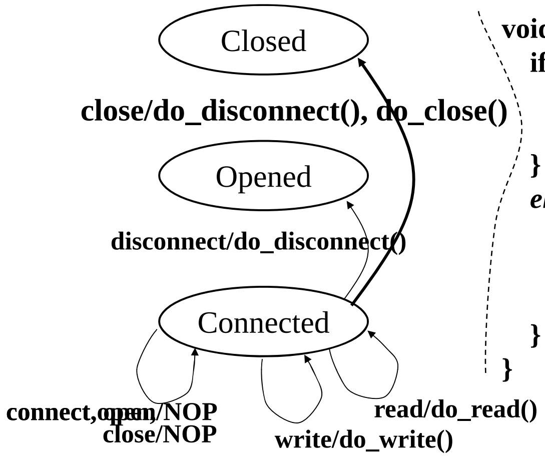
Implementation (cont’d)

```
void close() {
   if (m_state == Opened ) {
      do_close();
      m_state = Closed;
   }
}

void connect() {
   if (m_state == Opened ) {
      do_connect();
      m_state = Connected;
   }
}

void disconnect() {
   if (m_state == Connected ) {
      do_disconnect();
      m_state = Opened;
   }
}
```

```
void read() {
   if (m_state == Connected )
      do_read();
}

void write() {
   if (m_state == Connected )
      do_write();
}
```

Modification over State Diagram

- ✧ If the system specification is modified such that it is allowed to close at the Connected state
- ✧ It is a good idea to change the design on the state diagram directly



```
void close() {
   if (m_state == Opened) {
      do_close();
      m_state = Closed;
   }
   else if (m_state == Connected ) {
      do_disconnect();
      do_close();
      m_state = Closed;
   }
}
```

Second Implementation

- ✧ Use two ***enum*** types for the **state** of the system and the **event**

  enum **State** {***Closed***, ***Opened***, ***Connected***};
  enum **Event** {***open***, ***connect***, ***read***, ***write***, ***disconnect***, ***close***};

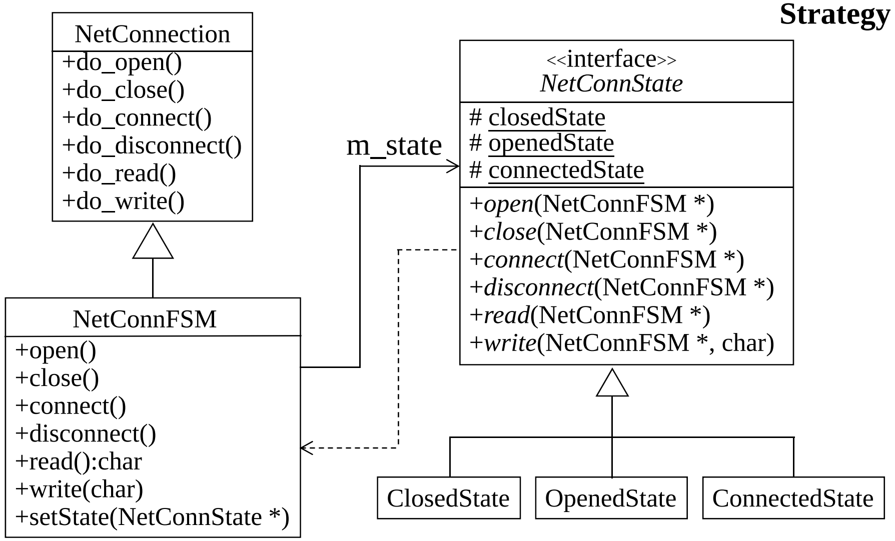
- ✧ Implement all actions as functions

```
void do_open() { … }         void do_close() { … }
void do_connect() { … }      void do_disconnect() { … }
void do_read() { … }         void do_write() { … }
```

- ✧ Use a static **state** variable inside the Transition function

```
void Transition(Event event) {
   static State state = Closed;
   switch (state) {
   case Closed:
      switch (event) {
      case open:
         do_open(); state = Opened;
      } break;
   case Opened:
      switch (event) {
      case connect:
         …
      case close:
         …
      } break;
   case Connected:
      …
   }
}
```

OO Way – the State Pattern



Strategy

NetConnection
+do_open()
+do_close()
+do_connect()
+do_disconnect()
+do_read()
+do_write()

NetConnFSM
+open()
+close()
+connect()
+disconnect()
+read():char
+write(char)
+setState(NetConnState *)

m_state

<<interface>>
NetConnState
# closedState
# openedState
# connectedState
+*open*(NetConnFSM *)
+*close*(NetConnFSM *)
+*connect*(NetConnFSM *)
+*disconnect*(NetConnFSM *)
+*read*(NetConnFSM *)
+*write*(NetConnFSM *, char)

ClosedState
OpenedState
ConnectedState

Implementation (1/4)

- Actual network operations

```
class NetConnection {
public:
   void do_open() { … }            void do_close() { … }
   void do_connect() { … }         void do_disconnect() { … }
   char do_read() { … }            void do_write(char x) { … }
};
```

- Interface for all states

```
class NetConnState {
public:
   virtual void open(NetConnFSM *) = 0;  virtual void close(NetConnFSM *);
   virtual void connect(NetConnFSM *);   virtual void disconnect(NetConnFSM *);
   virtual char read(NetConnFSM *);      virtual void write(NetConnFSM *, char);
protected:
   static ClosedState closedState;
   static OpenedState openedState;
   static ConnectedState connectedState;
};
```

```
ClosedState NetConnState::closedState;
OpenedState NetConnState::openedState;
ConnectedState NetConnState::
                     connectedState;
```

Singleton

Implementation (2/4)

- the Finite State Machine

```
class NetConnFSM: public NetConnection {
public:
   NetConnFSM():m_state(&closedState) {}
   void setState(NetConnState *s) { m_state = s; }
   void open() { m_state->open(this); }
   void close() { m_state->close(this); }
   void connect() { m_state->connect(this); }
   void disconnect() { m_state->disconnect(this); }
   char read() { return m_state->read(this); }
   void write(char x) { m_state->write(this, x); }
private:
   NetConnState *m_state;
};
```

Strategy, delegation of events
Closed for modification

- Usage:

```
void main() {
   NetConnFSM conn_obj;
   conn_obj.open();
   conn_obj.connect();
   int x=conn_obj.read();
      …
   conn_obj.write(x);
      …
   conn_obj.disconnect();
   conn_obj.close();
}
```

real event sequence

Implementation (3/4)

- Actual states

```
class ClosedState: public NetConnState {
public:
   void open(NetConnFSM *fsm) {             void close(NetConnFSM *) {}
      fsm->do_open();
      fsm->setState(&openedState);
   }
   void connect(NetConnFSM *) {}             void disconnect(NetConnFSM *) {}
   char read(NetConnFSM *) { return 0; }     void write(NetConnFSM *, char) {}
};
class OpenedState: public NetConnState {
public:
   void open(NetConnFSM *) {}                void connect(NetConnFSM *fsm) {
   void close(NetConnFSM *fsm) {               fsm->do_connect();
      fsm->do_close();                         fsm->setState(&connectedState);
      fsm->setState(&closedState);           }
   }                                         void disconnect(NetConnFSM *) {}
   char read(NetConnFSM *) { return 0; }
   void write(NetConnFSM *, char) {}
};
```

Implementation (4/4)

```
class ConnectedState: public NetConnState {
public:
   void open(NetConnFSM *) {}
   void close(NetConnFSM *) {}
   void connect(NetConnFSM *) {}
   void disconnect(NetConnFSM *fsm) {
      fsm->do_disconnect();
      fsm->setState(&openedState);
   }
   char read(NetConnFSM *fsm) {
      return fsm->do_read();
   }
   void write(NetConnFSM *fsm, char x) {
      fsm->do_write(x);
   }
};
```

- Implemented through the “Strategy” and “Singleton” patterns
- Object Mentor Finite State Machine Compiler for Java/C++ code http://www.objectmentor.com/resources/bin/smcJava.zip