CS 4530: Fundamentals of Software Engineering

Module 5: Interaction-Level Design Patterns

Adeel Bhutta, Joydeep Mitra, and Mitch Wand

Khoury College of Computer Sciences

Learning Goals for this Lesson

- By the end of this lesson, you should be able to
  - Explain how patterns capture common solutions and tradeoffs for recurring problems.
  - Explain and give an example of each of the following:
    - The Demand-Pull pattern
    - The Data-Push (aka Listener or Observer) pattern
    - The Callback or Handler pattern
    - The Typed-Emitter pattern

What is a Pattern?

- A Pattern is a summary of a standard solution (or solutions) to a specific class of problems.
- A pattern should contain
  - A statement of the problem being solved
  - A solution of the problem
  - Alternative solutions
  - A discussion of tradeoffs among the solutions.
- For maximum usefulness, a pattern should have a name.
  - So you can say "here I'm using pattern P" and people will know what you had in mind.

Patterns help communicate intent

- If your code uses a well-known pattern, then the reader has a head start in understanding your code.

Patterns are intended to be flexible

- We will not engage in discussion about whether a particular piece of code is or is not a “correct” instance of a particular pattern.

This week we will talk about the interaction scale

The Structural Scale

- key questions: what are the pieces? how do they fit together to form a coherent whole?

The Interaction Scale

- key questions: how do the pieces interact? how are they related?

The Code Scale

- key question: how can I make the actual code easy to test, understand, and modify?

src/clockWithPull/simpleClock.interface.ts

Example: Interface for a simple clock

```
export default interface ISimpleClock {

    /** sets the time to 0 */
    reset():void

    /** increments the time */
    tick():void

    /** returns the current time */
    getTime():number
}
```

Tests for the clock and the client describe their desired behavior

```
import { SimpleClock, ClockClient } from "./simpleClock"

test("test of SimpleClock", () => {
    const clock1 = new SimpleClock
    expect(clock1.time).toBe(0)
    clock1.tick()
    clock1.tick()
    expect(clock1.time).toBe(2)
    clock1.reset()
    expect(clock1.time).toBe(0)
})
```

```
test("test of ClockClient", () => {
    const clock1 = new SimpleClock
    expect(clock1.time).toBe(0)
    const client1 = new ClockClient(clock1)
    expect(clock1.time).toBe(0)
    expect(client1.getTimeFromClock()).toBe(0)
    clock1.tick()
    clock1.tick()
    expect(client1.getTimeFromClock()).toBe(2)
})
```

src/clockWithPull/simpleClock.test.ts

PullingClock/simpleClockUsingPull.ts

simpleClockUsingPull.ts

```
import IClock from "./IPullingClock";

export class SimpleClock implements IClock {
    private time = 0
    public reset () : void {this.time = 0}
    public tick () : void { this.time++ }
    public get time(): number { return this.time }
}

export class ClockClient {
    constructor (private theclock:IClock) {}
    getTimeFromClock ():number {
       return this.theclock.time
    }
}
```

SimpleClock is the Producer

ClockClient is the Consumer

The code is simple…

src/clockWithPull/simpleClock.ts

```
import IClock from "./simpleClock.interface";

export class SimpleClock implements IClock {
    private time = 0

    public reset () : void {this.time = 0}

    public tick () : void { this.time++ }

    public getTime(): number { return this.time }
}

export class ClockClient {
    constructor (private theclock:IClock) {}

    getTimeFromClock ():number {return this.theclock.getTime()}
}
```

We call this the "demand-pull" pattern

- because the when the client needs som data, it *pulls* the data it needs from the server.
- Alternative names: you could call these the consumer and the producer.

But there's a potential problem here.

- What if the clock ticks once per second, but there are dozens of clients, each asking for the time every 10 msec?
- Our clock might be overwhelmed!
- Can we do better for the situation where the clock updates rarely, but the clients need the values often?

The 'data-push' pattern

- We'd like to arrange it so that the server *pushes* the data to the consumer only when it changes
- To accomplish that, the consumer needs to advertise an 'update' method that the producer can call.

This is called the Listener or Observer Pattern

- Also called "publish-subscribe pattern"
- The object being observed (the “subject”) keeps a list of the objects who need to be notified when something changes.
  - subject = producer = publisher
- When a new object (i.e., the “consumer”) wants to be notified when the subject changes, it registers with ("subscribes to") the subject/producer/publisher
  - observer = consumer = subscriber = listener

src/PushingClock/pushingClock.interface.ts

Interface for a clock using the Push pattern

```
export interface IPushingClock {

    /** resets the time to 0 */
    reset():void

    /**
     * increments the time and sends a .nofify message with the
     * current time to all the consumers
     */
    tick():void

    /** adds another consumer and initializes it with the current time */
    addListener(listener:IPushingClockClient):number
}
```

src/pushingClock/pushingClock.interface.ts

Interface for a clock listener

```
interface IPushingClockClient {
    /**
     *   * @param t - the current time, as reported by the clock
     */
    notify(t:number):void
}
```

Tests

src/pushingClock/pushingClock.test.ts

```
test("single observer", () => {
        const clock1 = new PushingClock()
        const observer1
          = new PushingClockClient(clock1)
        expect(observer1.time).toBe(0)
        clock1.tick()
        clock1.tick()
        expect(observer1.time).toBe(2)
    })
```

```
test("Multiple Observers", () => {
    const clock1 = new PushingClock()
    const observer1
      = new PushingClockClient(clock1)
    const observer2
      = new PushingClockClient(clock1)
    const observer3
      = new PushingClockClient(clock1)
    clock1.tick()
    clock1.tick()
    expect(observer1.time).toBe(2)
    expect(observer2.time).toBe(2)
    expect(observer3.time).toBe(2)
})
```

src/pushingClock/pushingClock.ts

A PushingClock class

```
export class PushingClock implements IPushingClock {
    private observers: IPushingClockClient[] = []
    public addListener(obs:IPushingClockClient): number {
        this.observers.push(obs);
        return this.time
    }
    private notifyAll() : void {
            this.observers.forEach(obs => obs.notify(this.time))
        }
    private time = 0
    reset() : void { this.time = 0; this.notifyAll() }
    tick() : void { this.time++; this.notifyAll() }

}
```

src/pushingClock/pushingClockClients.ts

A Client

```
export class PushingClockClient implements IPushingClockClient
{
    private time:number
    constructor (theclock:IPushingClock) {
        this.time = theclock.addListener(this)
    }

    notify (t:number) : void {this.time = t}
    getTime () : number {return this.time}
}
```

The observer can do whatever it likes with the notification

```
export class DifferentClockClient implements IPushingClockClient {

    /** TWICE the current time, as reported by the clock */
    private twiceTime:number

    constructor (theclock:IPushingClock) {
        this.twiceTime = theclock.addListener(this) * 2
    }

    /** list of all the notifications received */
    public readonly notifications : number[] = [] // just for fun

    notify(t: number) : void {
        this.notifications.push(t)
        this.twiceTime =  t * 2 }

    time : number { return (this.twiceTime / 2) }
}
```

src/pushingClock/pushingClockClients.ts

Better test this, too

src/pushingClock/pushingClock.test.ts

```
test("test of DifferentClockClient", () => {
        const clock1 = new PushingClock()
        const observer1 = new DifferentClockClient(clock1)
        expect(observer1.time).toBe(0)
        clock1.tick()
        expect(observer1.time).toBe(1)
        clock1.tick()
        expect(observer1.time).toBe(2)
    })
```

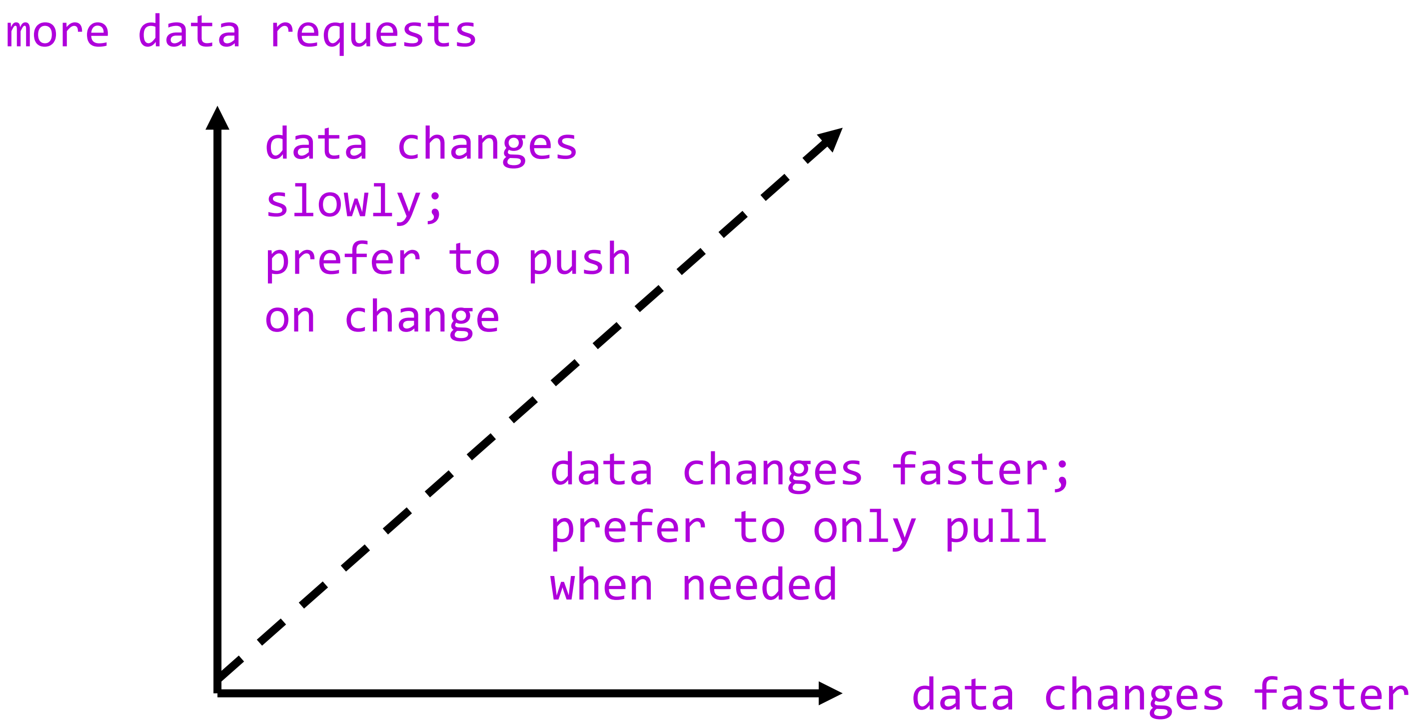
Tests for .notifications method

```
test("DifferentClockClient accumulates the times correctly", ()
=> {
        const clock1 = new PushingClock()
        clock1.tick()
        const differentClient = new DifferentClockClient(clock1)
        expect(differentClient.time).toBe(1)
        expect(differentClient.notifications).toEqual([])
        clock1.tick()
        clock1.tick()
        clock1.tick()
        expect(differentClient.time).toBe(4)
        expect(differentClient.notifications).toEqual([2, 3, 4])
    })
```

src/pushingClock/pushingClock.test.ts

There are more tests in here; you should look at them.

Push or Pull?


more data requests
data changes
slowly;
prefer to push
on change
data changes faster;
prefer to only pull
when needed
data changes faster

Maybe the server doesn't want to give the client access to all of its methods

```
export class DifferentClockClient implements IPushingClockClient {

    /** TWICE the current time, as reported by the clock */
    private twiceTime:number

    constructor (theclock:IPushingClock) {
        this.twiceTime = theclock.addListener(this) * 2
    }

    /** list of all the notifications received */
    public readonly notifications : number[] = [] // just for fun

    notify(t: number) : void {
        this.notifications.push(t)
        this.twiceTime =  t * 2 }

    time : number { return (this.twiceTime / 2) }
}
```

DANGER!!

src/pushingClock/pushingClockClients.ts

Pattern #3: The callback or handler pattern

- Maybe the server doesn't want to give the client access to all of the server's methods.
- the server constructs the client and gives it a *function* to call instead.
- Typically, this will be a function inside the server
- We call this function the *callback* or *handler* for the client's action.
- This pattern is used all the time in REACT.

src/callBacksFunctional/callBacks.interface.ts

The interface

```
export interface ICallBackServer {

    // returns a new client that satisfies the ICallBackClient interface
    newClient(clientName: string): ICallBackClient;

    // returns the log of all push messages received
    log(): string[];
}

export interface ICallBackClient {
     // sends a push message to the server,
    sendPush: () => void
    // asks the server for list of all push messages received
    // from all clients.
    getLog: () => string[];

}
```

src/callBacksFunctional/callBacks.test.ts

Example: Expected Behavior

```
it('works', () => {

    const server = new Server()
    const client1 = server.newClient("A")
    const client2 = server.newClient("B")


    client1.sendPush()
    expect(client1.getLog()).toEqual(["A"])
    client2.sendPush()
    expect(client1.getLog()).toEqual(["A", "B"])
    expect(client2.getLog()).toEqual(["A", "B"])
    // now client1 pushes again
    client1.sendPush()
    // now the clients can see all the pushes
    expect(client1.getLog()).toEqual(["A", "B", "A"])
    expect(client2.getLog()).toEqual(["A", "B", "A"])

})
```

CallBacks/callBackExample.ts

The Server

```
export class Server implements ICallBackServer {

    // the log of all push messages received
    private _log: string[] = []

    // using arrow function to bind 'this' correctly
    private pushHandler = (clientName: string) => () => {this._log.push(clientName)}
    private logHandler = () : string[] => { return this._log }

    public log(): string[] { return this._log }
    public newClient(clientName:string): ICallBackClient {
        return new Client(this.pushHandler(clientName), this.logHandler)
    }
}
```

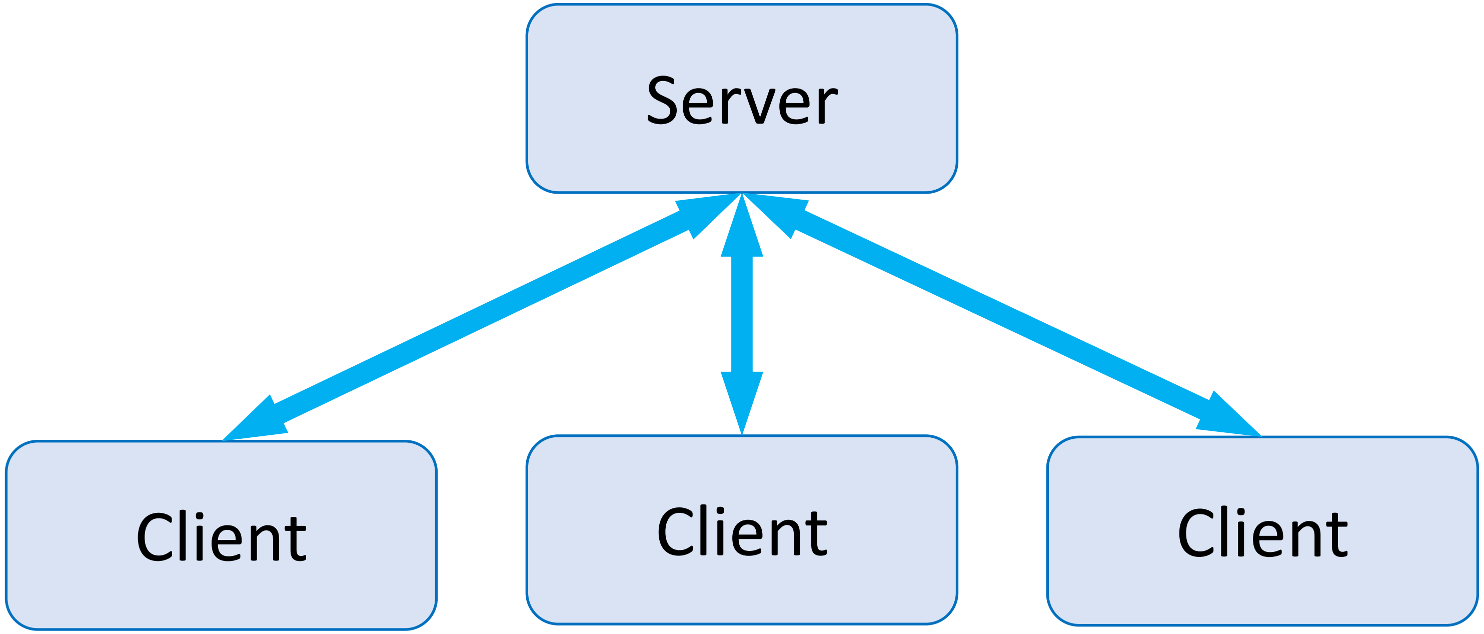
The Client

```
export class Client implements ICallBackClient {

    // the client doesn't get to see the server directly; the server
    // creates it with two callbacks.

    constructor(
        _pushHandler: () => void,
        _logHandler: () => string[],
    ) { this.pushHandler = _pushHandler; this.logHandler = _logHandler; }

    private pushHandler: () => void
    private logHandler: () => string[]

    // the public methods just call the callbacks
    public sendPush() { this.pushHandler(); }
    public getLog(): string[] { return this.logHandler(); }

}
```

Pattern #4: The Typed-Emitter Pattern

- What if the data source wants to notify its listeners with several different kinds of messages?
- Maybe with different data payloads?
- And what if we want to take advantage of type-checking?

Emitters use a server/client model



- Client can send a message to its server
- Server can send a message to an individual client
- …or to some or all its clients

Typed Emitters use types to specify messages that servers and clients can exchange

```
// a simple ping-pong protocol for testing WebSocket connections.

// server starts with (ping 0)
// client replies to server 'ping n' with 'pong n' (n <= 5)
// server replies to client 'pong n' with 'ping n+1'

export interface ServerToClientEvents {
    'ping': (count:number) => void;
}

export interface ClientToServerEvents {
    'pong': (clientName: string, count:number) => void;
    'goodbye': (clientName: string) => void;
}
```

Note: this is the interface for the socket-io implementation of emitters. Other implementations use somewhat different interfaces.

Emitters typically provide many methods

```
export interface EventEmitter {

    /** The event callbacks are called with the passed arguments */
    emit(type, ... args);
    /** Run callback every time event is emitted */
    on(event, callback);
    /** Run callback when event is emitted just for the first time */
    once(event, callback);
    /** Removes the callback for event */
    off(event, callback);
    /** Removes all callbacks for event */
    off(event);
    /** Removes all callbacks for all events */
    off();
}
```

This pattern can be used across multiple machines using websockets.

- Websockets is a standard, but low-level protocol for sending messages between machines.
- Socket.io provides a typed-emitter-style programming model for webSockets.
- It also provides automatic reconnection, broadcast rooms, and other goodies

src/webSocketsSimple/server.ts

Using an emitter: at the Server end

```
function startClientHandlers(
    socket: Socket<ServerToClientEvents, ClientToServerEvents>,
    clientName: string
) {

    // system starts by sending 'connect'
    socket.on('connect', () => {
        console.log(`${clientName} connected to server on ${clientURL}`);
    });

    socket.on('ping', (n: number) => {
        console.log(`${clientName} received ping with count ${n}`);
        if (n <= 5) {
            socket.emit('pong', clientName, n); // reply with pong
        } else {// invariant violated! disconnect if count exceeds 5
            console.log(`${clientName} received ping with count ${n} > 5`)
            socket.disconnect();
        }
    });
```

Look at the file if you want to see where the socket comes from.

src/webSocketsSimple/client.ts

Using an emitter: at the Client end

```
function startClientHandlers(socket:
    Socket<ServerToClientEvents, ClientToServerEvents>) {

    // system starts by sending 'connect'
    socket.on('connect', () => {
        console.log(`${this.clientName} connected to server on ${clientURL}`);
    });

    socket.on('ping', (n: number) => {
        console.log(`${this.clientName} received ping with count ${n}`);
        if (n < 5) {
            this.socket.emit('pong', this.clientName, n); // reply with pong
        } else {
            this.socket.emit('goodbye', this.clientName);
            this.socket.disconnect(); // disconnect after 5 pings
            process.exit(0); // exit the process
        }
    });
}
```

Look at the file if you want to see where the socket comes from.

Choreographies and Projections

Choreography

```
// a simple ping-pong protocol for testing WebSocket connect:

// server starts with (ping 0)
// client replies to server 'ping n' with 'pong n' (n <= 5)
// server replies to client 'pong n' with 'ping n+1'

export interface ServerToClientEvents {
    'ping': (count:number) => void;
}

export interface ClientToServerEvents {
    'pong': (clientName: string, count:number) => void;
    'goodbye': (clientName: string) => void;
}
```

```
function startClientHandlers(
    socket: Socket<ServerToClientEvents, ClientToServerEvents>,
    clientName: string
) {

    // system starts by sending 'connect'
    socket.on('connect', () => {
        console.log(`${clientName} connected to server on ${clientURL}
    });

    socket.on('ping', (n: number) => {
        console.log(`${clientName} received ping with count ${n}`);
        if (n <= 5) {
            socket.emit('pong', clientName, n); // reply with pong
        } else {// invariant violated! disconnect if count exceeds 5
            console.log(`${clientName} received ping with count ${n} >
            socket.disconnect();
        }
    });
```

```
function startClientHandlers(socket:
    Socket<ServerToClientEvents, ClientToServerEvents>) {

    // system starts by sending 'connect'
    socket.on('connect', () => {
        console.log(`${this.clientName} connected to server on ${clientURL}`);
    });

    socket.on('ping', (n: number) => {
        console.log(`${this.clientName} received ping with count ${n}`);
        if (n < 5) {
            this.socket.emit('pong', this.clientName, n); // reply with pong
        } else {
            this.socket.emit('goodbye', this.clientName);
            this.socket.disconnect(); // disconnect after 5 pings
            process.exit(0); // exit the process
        }
    });
```

Look at the file if you want to see where the socket comes from.

Projections

Review: Learning Goals for this Lesson

- You should now be able to:
  - Explain how patterns capture common solutions and tradeoffs for recurring problems.
  - Explain and give an example of each of the following:
    - The Demand-Pull pattern
    - The Data-Push (aka Listener or Observer) pattern
    - The Callback or Handler pattern
    - The Typed-Emitter pattern