Lecture 5

Working with Objects: Part 2

Review Topics at the end of the deck

Please make sure you understand what we have covered so far

- Variables
- Local vs. Instance Variables
- Variable Reassignment
- Instances as Parameters
- Delegation Pattern
- NullPointer Exceptions
- Encapsulation

Outline

Accessors

- All instances of a class have the same instance variables (properties) but their own values
- Instance variables hold the instance's `private` properties: encapsulation
- But a class may choose to allow other classes to have selective access to designated properties without making them `public`
    - e.g., `Dog` can allow `DogGroomer` to access its `furLength` property
- To do this, the class can make the value of an instance variable publicly available via an **accessor method**
- These **accessor** methods typically have the name convention **get<Property>** and have a non-`void` return type
- The return type specified and the type of the value returned must also match!
- Let's see an example…

Accessors: Example

- Let's make `Dog`'s `furLength` a private property but allow controlled access
- `getFurLength` is an **accessor** method for `furLength`
- Can call `getFurLength` on an instance of `Dog` to **return** its current `furLength` value
- `DogGroomer` can now access this value. We will see why this is useful in a few slides

```java
public class Dog {

   private int furLength;

   public Dog() {
         this.furLength = 3;
   }

   public int getFurLength() {
         return this.furLength;
   }

   /* bark, eat, and wagtail elided */
}
```

Mutators

- A class can give other classes even greater permission by allowing them to change the value of its properties/instance variables
  - e.g., `Dog` can allow `DogGroomer` to change the value of its `furLength` property
- To do this, the class can define a **mutator method** which modifies the value of an instance variable
- These methods typically have the name convention **set<Property>** and have `void` return types
- They also take in a parameter that is used to modify the value of the instance variable

Mutators: Example

- Let's define a mutator method, setFurLength, in Dog that sets furLength to the value passed in
- DogGroomer can call setFurLength on an instance of Dog to change its furLength value
- In fact, DogGroomer can use both getFurLength and setFurLength to modify furLength based on its previous value. Stay tuned for an example

```
public class Dog {

   private int furLength;

   public Dog() {
       this.furLength = 3;
   }

   public int getFurLength() {
        return this.furLength;
  }

   public void setFurLength(int myFurLength) {
        this.furLength = myFurLength;
    }
    /* bark, eat, and wagTail elided */
}
```

Accessors and Mutators: Example (1/5)

- Fill in `DogGroomer`'s `trimFur` method to modify the `furLength` of the `Dog` whose fur is being trimmed
- When a `DogGroomer` trims the fur of a dog, it calls the **mutator** `setFurLength` on the `Dog` and passes in `1` as an argument. This will be the new value of `furLength`

```java
public class DogGroomer {

  public DogGroomer() {
        // Constructor body elided
  }

  public void trimFur(Dog shaggyDog) {
        shaggyDog.setFurLength(1);
        //note trimFur could do other
        //things to shaggyDog as well
  }
}
```

Accessors and Mutators: Example (2/5)

Check that `trimFur` works by printing out the `Dog`'s `furLength` before and after we send it to the `groomer`

```
public class PetShop {
   private DogGroomer groomer;

   public PetShop() {
      this.groomer = new DogGroomer();
      this.testGrooming();
   }

   public void testGrooming() {
      Dog effie = new Dog();
      System.out.println(effie.getFurLength());
      this.groomer.trimFur(effie);
      System.out.println(effie.getFurLength());
   }
}
```

```
public class DogGroomer {

   public DogGroomer() {
      // Constructor body elided
   }

   public void trimFur(Dog shaggyDog) {
      shaggyDog.setFurLength(1);
   }
}
```

accessor `getFurLength` retrieves value `effie` stores in `furLength` instance variable; **mutator** `setFurLength` used in `trimFur` updates it

Accessors and Mutators: Example (3/5)

- What values print out to the console?

```
public class PetShop {
    private DogGroomer groomer;

    public PetShop() {
        this.groomer = new DogGroomer();
        this.testGrooming();
    }

    public void testGrooming() {
        Dog effie = new Dog();
        System.out.println(effie.getFurLength());
        this.groomer.trimFur(effie);
        System.out.println(effie.getFurLength());
    }
}
```

```
public class DogGroomer {

    public DogGroomer() {
        // Constructor body elided
    }

    public void trimFur(Dog shaggyDog) {
        shaggyDog.setFurLength(1);
    }
}
```

Code from previous slide!

- first, 3 is printed - the initial value assigned to `furLength` in the `Dog` constructor (slide 10)
- next, 1 prints out because `groomer` just set `effie`'s `furLength` to 1

Accessors and Mutators: Example (4/5)

- What if we don't always want to trim a `Dog`'s fur to a value of 1?
- When we tell `groomer` to `trimFur`, let's also tell `groomer` the length to trim the `Dog`'s fur

```
public class PetShop {
   // Constructor elided
   public void testGroomer() {
      Dog effie = new Dog();
      this.groomer.trimFur(effie,2);
   }
}
```

```
public class DogGroomer {
   /* Constructor and other code elided */
   public void trimFur(Dog shaggyDog, int furLength) {
         shaggyDog.setFurLength(furLength);
   }
}
```

The `groomer` will trim the fur to a `furLength` of 2!

- `trimFur` will take in a second parameter, and set `Dog`'s fur length to the passed-in value of `furLength` (for simplicity, `Dog` doesn't error check to make sure that `furLength` passed in is less than current value of `furLength`)
- Now pass in two arguments when calling `trimFur` so `groomer` knows what `furLength` should be after trimming fur

Accessors and Mutators: Example (5/5)

- What if we wanted to make sure the value of furLength after trimming is always less than the value before?
- When we tell `groomer` the length to trim the `Dog`'s fur, let's specify a length less than the current value of `furLength` (but no error checking for negative result)

```
public class PetShop {
   // Constructor elided
   public void testGroomer() {
      Dog effie = new Dog();
      int newLen = effie.getFurLength() - 2;
      this.groomer.trimFur(effie, newLen);
   }
}
```

```
public class DogGroomer {
    /* Constructor and other code elided */
   public void trimFur(Dog shaggyDog, int furLength) {
         shaggyDog.setFurLength(furLength);
   }
}
```

decrease `furLength` by 2

- We could eliminate the local variable `newLen` by nesting a call to `getFurLength` as the second parameter:

```
this.groomer.trimFur(effie, effie.getFurLength() - 2);
```

Accessors and Mutators: Summary

- Instance variables should always be declared `private` for safety reasons
- If we made these instance variables `public`, any method could change them, i.e., with the caller in control of the inquiry or change – this is unsafe
- Instead, the class can provide accessors/mutators (often in pairs, but not always) which give the class control over how the variable is queried or altered. For example, a mutator could do error checking on the new value to make sure it is in range
- Also, an accessor needn't be as simple as returning the value of a stored instance variable – it is just a method and can do arbitrary computation on one or more variables
- Use them sparingly – only when other classes need them

TopHat Question   Join Code: 316062

Which of the following method declaration and definition is correct for an accessor method in Farm?

```java
public class Farm {
    private House farmHouse;

    // Farm constructor
    public Farm() {
      this.farmHouse = new House();
      //other methods
    }
}
```

A
```java
public void getFarmHouse() {
   return this.farmHouse;
}
```

B
```java
public House getFarmHouse() {
   return this.farmHouse;
}
```

C
```java
public House getFarmHouse(FarmHouse myFarmHouse) {
  this.farmHouse = myFarmHouse;
}
```

D
```java
public House getFarmHouse(FarmHouse myFarmHouse) {
   return this.myFarmHouse;
}
```

Outline

- Accessors and Mutators
- Association
    - Component-Container Association
    - “Many-to-One” Association
    - Two-way Association

Last Time: Instance Variables

- **Instance variables**: store the properties of instances of a class for use by multiple methods—use them only for that purpose

- **Attributes** are descriptors of objects
  - models “described by” relationship
    - `Humans` are described by `age`, `height`, `weight`, etc.
  - attributes typically described by primitives (i.e., `int`)

- **Components** are structural parts of composite objects
  - models “composed of” relationship
    - `Humans` are composed of a `Head`, `Torso`, `Legs`, etc.
    - can have hierarchal relationships - `Head` is further composed of `Eyes`, `Ears`, etc.
  - composite objects are exceedingly common
  - our classes are typically composed of other classes in our program

Today: Peer Objects & Association

- An instance variable can also represent a reference to a **peer object**

- **Peer objects** are classes that a class can send messages to – they aren't attributes or components
  - models "knows about" relationship
    - `Human`s know about `Computer`s, `Pet`s, `Bed`s, etc.

- How can we create this relationship in our code?

- Use a design pattern we call **association**
  - Several different ways to accomplish this – you will see a few through this lecture

Association

- We've seen how an instance can call methods on instances of its components; however this relationship is not symmetric: the component instance cannot communicate with its container!
    - Consider an example where we have an `Orchestra` composed of instrumentalists and a `Conductor`
    - `Orchestra` creates **new** instances of instrumentalists and a **new** instance of a `Conductor`
    - The `Conductor` instance is a *component* of the `Orchestra`
    - The `Orchestra` can now call methods on the `Conductor` instance – it "knows about" the `Conductor`
    - But what if the `Conductor` needs to communicate with/"know about" the `Orchestra?`
    - We need additional code to allow this symmetry
- We will tell the `Conductor` instance about the instance that created it, in this case, an `Orchestra` instance. We want to **associate** the `Conductor` with the `Orchestra`
    - The easiest way is to pass the `Orchestra` instance as a parameter to the `Conductor`'s constructor
    - How?!?

Example: Setting up Association (1/4)

- Let's write a program that models the orchestra
  - define an `Orchestra` class that is composed of different instrumentalists and the conductor
- Its `play` method will be used to start and direct the musical performance
- The `Orchestra` will delegate to its `Conductor` that has the capabilities to do this, so we instantiate an instance of `Conductor` in `Orchestra`. We say `Conductor` is a component of `Orchestra`
- The `Orchestra` can tell the `Conductor` to start performance because it created it as a component; `play` doesn't need a parameter because it has access to the `conductor`
- Separated `play` so it can be invoked multiple times, not just in constructor

```java
public class Orchestra {

   private Conductor conductor;
   //other instance variables for players

   public Orchestra() {
      this.conductor = new Conductor();
      this.play();
   }

   public void play() {
      this.conductor.startPerformance();
   }

}
```

Example: Motivation for Association (2/4)

- But what if the `Conductor` needs to call methods on the `Orchestra`?
  - the conductor probably needs to know several things about the orchestra. E.g., how many instrumentalists are there? Which ones are present? When is the next rehearsal?...
- We can set up an association so the `Conductor` can communicate with the `Orchestra`
- We modify the `Conductor`'s constructor to take an `Orchestra` parameter
  - and record it as a “knows about” in an instance variable
  - but where do we get this Orchestra?

```
public class Conductor {

    private Orchestra myOrchestra;
    // other instance variables elided

    public Conductor(Orchestra myOrchestra) {
          this.orchestra = myOrchestra;
    }

    public void startPerformance() {
        // code elided
    }

    // other methods elided
}
```

Example: Using the Association (3/4)

- Back in the `Orchestra` class, what argument should `Conductor`'s constructor now be passed?
  - the `Orchestra` instance that created the `Conductor`
- How?
  - by passing `this` as the argument
    - i.e., the `Orchestra` tells the `Conductor` about itself

```
public class Orchestra {
   private Conductor conductor;
   // other instance variables elided

   public Orchestra() {
      //this is the constructor
      this.conductor = new Conductor(this);
   }

   public void play() {
      this.conductor.startPerformance();
   }

   // other methods elided
}
```

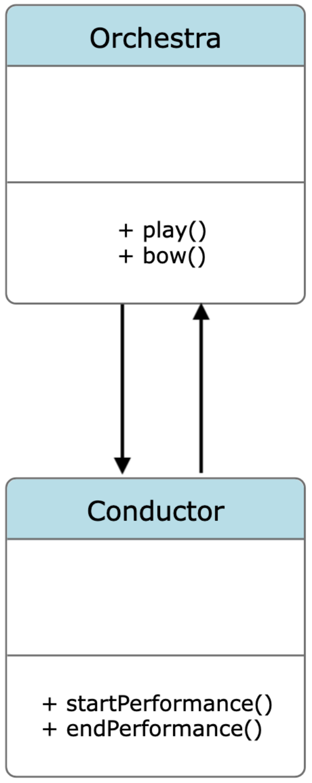
Example: Using the Association (4/4)

- The instance variable, `orchestra`, stores a reference to the instance of `Orchestra`, of which the `Conductor` is a component
  - Third type of instance variable relationship: one class stores a reference to another, peer class – the `Conductor` "knows about" its peer class `Orchestra`.
  - Note: peer class relationship is not necessarily bidirectional. The `Conductor` is a component of the `Orchestra`, while the `Orchestra` is a peer class of the `Conductor`.
  - We will see an example of this relationship being bidirectional later in this lecture!
- After constructor has been executed and can no longer reference **parameter** `myOrchestra`, any `Conductor` method can still access same `Orchestra` instance by the name `orchestra`
  - e.g., can call `bow()` on `orchestra` in `endPerformance()`

```
public class Conductor {
   private Orchestra orchestra;

   public Conductor(Orchestra myOrchestra){
        this.orchestra = myOrchestra;
   }

   public void startPerformace() {
       // code elided
   }

   public void endPerformance() {
        this.orchestra.bow();
   }

}
```

Class Diagram

- Here is the class diagram for our program, a subset of UML (Unified Modeling Language)
  - the top box contains class name
  - middle box lists attributes (none in this program)
  - bottom box lists methods
    - + signifies public, - signifies private (exception to rule)
- Arrow is drawn to show an association between classes
  - classes 'know about' their components, so we draw arrow (`Orchestra` → `Conductor`)
    - Important: the "is a component of" relationship discussed in lecture is also a form of association -- an instance knows about its components!
  - peer class relationship also gets arrow (`Conductor` → `Orchestra`)



TopHat Question Join Code: 316062

Which of the following statements is correct, given the code below that establishes an association from `Teacher` to `School`?

```
public class School {
  private Teacher teacher;

  public School() {
      this.teacher = new Teacher(this);
  }
  //additional methods, some using
  //this.teacher
}
```

```
public class Teacher {
  private School school;

  public Teacher(School mySchool) {
      this.school = mySchool;
  }
  //additional methods, some using
  //this.school
}
```

A. `School` can send messages to `Teacher`, but `Teacher` cannot send messages to `School`
B. `Teacher` can send messages to `School`, but `School` cannot send messages to `Teacher`
C. `School` can send messages to `Teacher`, and `Teacher` can send messages to `School`
D. Neither `School` nor `Teacher` can send messages to each other

TopHat Question Review

```
public class School{
  private Teacher teacher;

  public School() {
      this.teacher = new Teacher(this);
  }
  //additional methods, some using
  //this.teacher
}
```

```
public class Teacher{
  private School school;

  public Teacher(School mySchool) {
      this.school = mySchool;
  }
  //additional methods, some using
  //this.school
}
```

- Is `Teacher` a component of `School`?
  - yes! `Teacher` is a structural part of the `School`
- Can `School` send messages to `Teacher`?
  - yes! `School` can send messages to all of its components
- Is `School` a component of `Teacher`?
  - no! `Teacher` knows about School, but `School` is not a component of `Teacher` – this is a different that comes from the modeling choices in your program
  - still can send messages to `School` because it "knows about" `School` – instance variable indicates a reference to a peer class

Outline

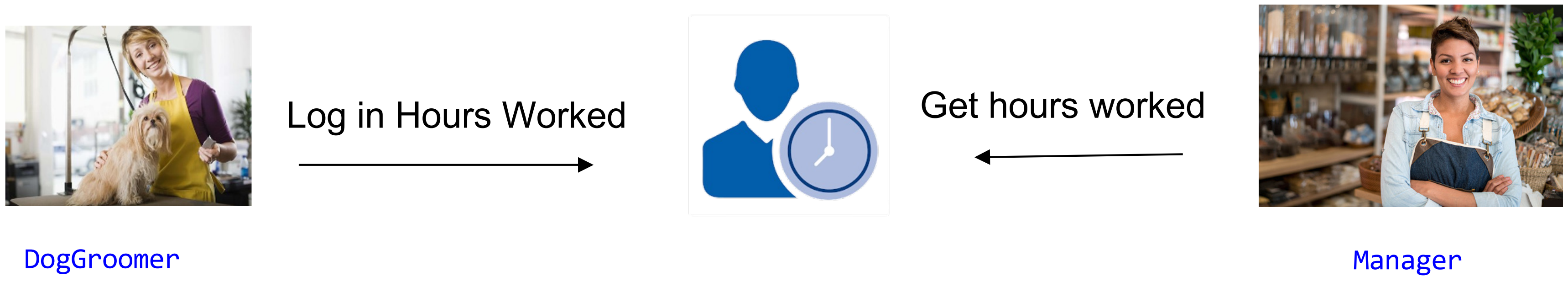
- Accessors and Mutators
- Association
  - Component-Container Association
  - “Many-to-One” Association
  - Two-way Association

“Many-to-One” Association

- Multiple classes, say `A` and `B`, may need to communicate with the same instance of another class, say `C`, to accomplish a task. Let’s consider an extension of our `PetShop` example
- Want to set up a system that allows `PetShop` employees, in this case `DogGroomer`, to log hours worked, and the `Manager` to approve worked hours and make necessary payment
- `Manager` could keep track of the `DogGroomer`’s worked hours in its class as a new functionality, in addition to all of the `Manager`’s other functionalities
- Alternatively, the `Manager` can **delegate** these tasks to another class
  - doesn’t need to know how employee’s working hours are tracked as long as they are tracked
- `DogGroomer` and `Manager` would need to “know about” this class in order to send messages to its instance
- Adding complexity to our design by adding another class, but making the `Manager` less complex – like many things in life, it is a *tradeoff*!

“Many-to-One” Association

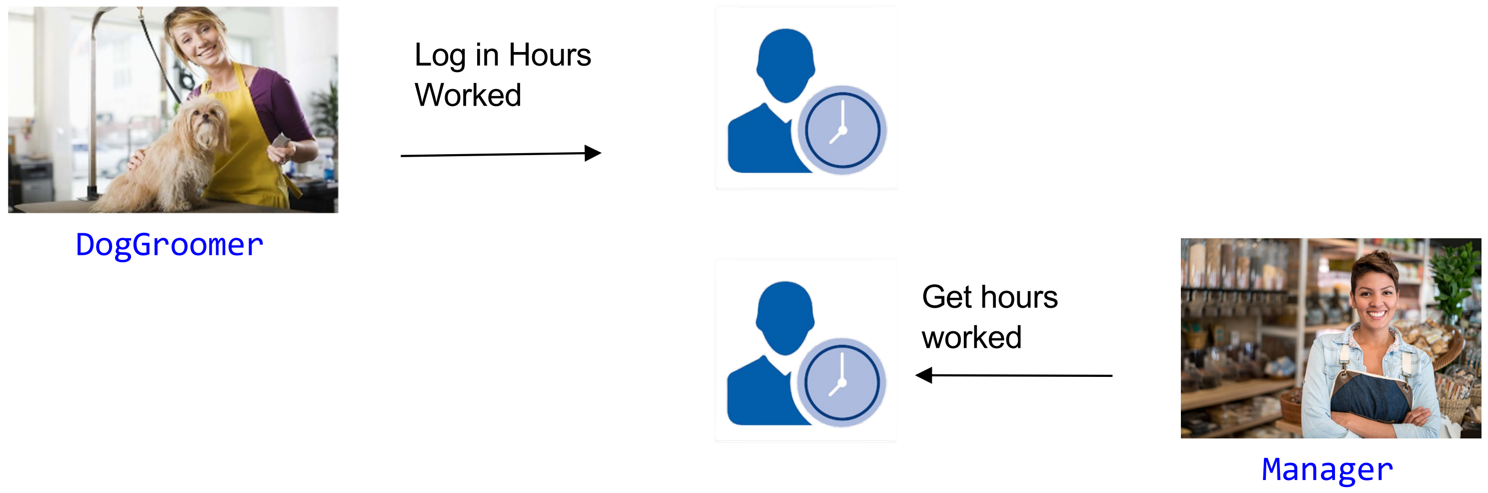
- If we define a `TimeKeeper` class as this third, peer class, both the `DogGroomer` and `DogGroomer` need to be **associated** with the same instance of `TimeKeeper`



- What would happen if `DogGroomer` and `DogGroomer` weren’t associated with the same instance of `TimeKeeper`?

Example: Motivation for Association (1/9)

- If `DogGroomer` and `Manager` were associated with different instances, our communication would fail!



- Still abstract? Let’s see how this looks like with code!

Example: Motivation for Association (2/9)

- Create a simple `TimeKeeper` class and define some of its properties and capabilities
- `setStartTime` and `setEndTime` record the start and end times of a working period
- `computeHoursWorked` calculates amount of hours worked

```java
public class TimeKeeper {
   private Time start;
   private Time end;

   public TimeKeeper() {
      //initialize start and end to 0
   }

   public void setStartTime(Time time) {
      this.start = time;
   }

   public void setEndTime(Time time) {
      this.end = time;
   }

   public Time computeHoursWorked() {
      return this.end - this.start;
   }

}
```

Example: Motivation for Association (3/9)

- DogGroomer needs to send messages to an instance of TimeKeeper in order to keep track of their worked hours
- Thus, set up an **association** between DogGroomer and TimeKeeper, using our pattern
- Modify DogGroomer's constructor to take in a parameter of type TimeKeeper. The constructor will refer to it by the name myKeeper
- DogGroomer now needs to track time spent trimming fur so call TimeKeeper's setStartTime and setEndTime methods inside trimFur, that takes in just a Dog as before
- Given that DogGroomer was passed an instance of TimeKeeper in its constructor, how can DogGroomer's other methods access this instance?

```
public class DogGroomer {

   public DogGroomer(TimeKeeper myKeeper){
      // code for modified constructor
   }

}  public void trimFur(Dog shaggyDog) {
      // code to call setStartTime
      shaggyDog.setFurLength(1);
      // code to call setEndTime
   }
}
```

Example: Motivation for Association (4/9)

- As with the Conductor example, want to have `DogGroomer` store its knowledge of `TimeKeeper` in an instance variable
- Declare an instance variable `keeper` in `DogGroomer` and have constructor initialize it to the passed parameter
- `keeper` now records the `myKeeper` instance passed to `DogGroomer`'s constructor, for use by its other methods
- Inside `trimFur`, can now tell `this.keeper` to record start and end time
  - we use Java's built-in method `Instant.Now();`

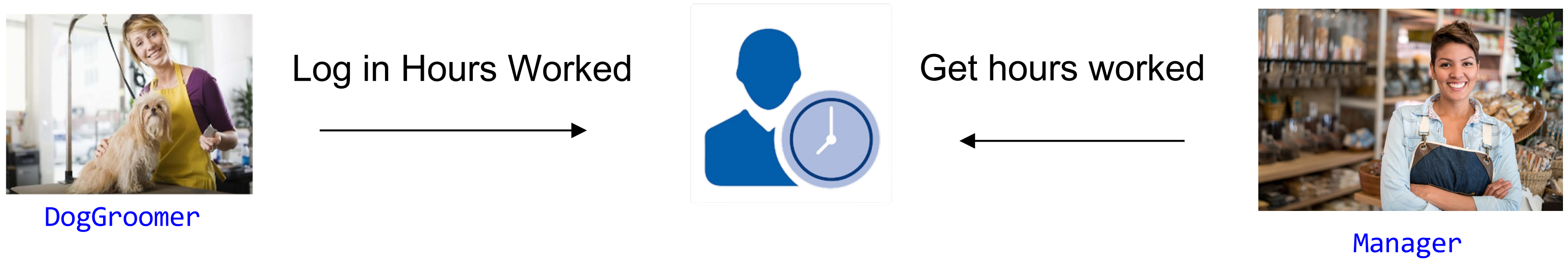
```
public class DogGroomer {
    private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
        this.keeper = myKeeper;
    }

    public void trimFur(Dog shaggyDog) {
      this.keeper.setStartTime(Instant.Now());
      shaggyDog.setFurLength(1);
      this.keeper.setEndTime(Instant.Now());
    }
}
```

Example: Motivation for Association (5/9)

- Back in our `PetShop` class, we need to modify how we instantiate the `DogGroomer`
- What argument should we pass in to the constructor of `DogGroomer`?
    - a new instance of `TimeKeeper`

```
public class DogGroomer {
    private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
       this.keeper = myKeeper; // store the assoc.
    }
}

public class PetShop {
    private DogGroomer groomer;

    public PetShop() {
       this.groomer = new DogGroomer(new TimeKeeper());
       this.testGroomer();
    }

    public void testGroomer() {
       Dog effie = new Dog(); // local var
       this.groomer.trimFur(effie);
    }
}
```

Example Cont.: Setting up Association (6/9)



- The `Manager`, who deals with payments, and the `DogGroomer` use the `TimeKeeper` as an intermediary
- The `Manager`'s `makePayment(int rate)` needs to know the hours worked by the `DogGroomer`
  - the `TimeKeeper` keeps track of such information with its properties (See slide 31)

```
public class Manager {

   public Manager() {
           // fill in code
   }

   public void makePayment(int rate) {
           // fill in code
    }


}
```

Example Cont.: Setting up Association (7/9)

- We can set up a second association so the `Manager` can retrieve information from the `TimeKeeper` as needed
- Following the same pattern as with `DogGroomer`, modify the `Manager`’s constructor to take in an instance of the `TimeKeeper` class and record it in an instance variable

```
public class Manager {
  private TimeKeeper keeper;

   public Manager(TimeKeeper myKeeper){
      this.keeper = myKeeper;
   }

   public void makePayment(int rate) {
      // fill in code
    }
}
```

Example Cont.: Setting up Association (8/9)

- Call `TimeKeeper`’s `computeHoursWorked` method inside `makePayment` to compute the total number of hours worked by an employee and use that to calculate their total wages

```
public class Manager {

  private TimeKeeper keeper;
  public Manager(TimeKeeper myKeeper) {
      this.keeper = myKeeper
   }

  public int makePayment(int rate) {
      int hrs = this.keeper.computeHoursWorked();
      int wages = hrs * rate;
      return wages;
  }
}
```

Example Cont.: Using the Association (9/9)

- Back in `PetShop` class, add a new instance of `Manager` and associate it with `TimeKeeper`
- `Manager` makes payment after `groomer` trims fur
- Note: `groomer` and `manager` refer to the same `TimeKeeper` instance created by `PetShop`
    - Neither `DogGroomer` nor `Manager` create the instance of `TimeKeeper` – it is instantiated in the top level logic class

```
public class PetShop {
   private DogGroomer groomer;
   private Manager manager;


   public PetShop() {
      TimeKeeper keeper = new TimeKeeper();
      this.groomer = new DogGroomer(keeper);
      this.manager = new Manager(keeper);
      this.testGroomer();
      manager.makePayment(<groomer’s pay rate>);
   }

   public void testGroomer() {
      Dog effie = new Dog();//local var
      this.groomer.trimFur(effie);
   }
}
```

Association: Under the Hood (1/5)

```
public class PetShop {
    private DogGroomer groomer;
    private Manager manager;
    public PetShop() {
        TimeKeeper keeper = new TimeKeeper();
        this.manager = new Manager(keeper);
        this.groomer = new DogGroomer(keeper);
        this.testGroomer();
        this.manager.makePayment(<groomer’s pay rate>);
    }
    // testGroomer elided

}
```

PetShop's naming local variable keeper is completely arbitrary and independent of formal parameter names myKeeper in Manager and DogGroomer - pure coincidence!

```
public class Manager {
  private TimeKeeper keeper;

    public Manager(TimeKeeper myKeeper) {
       this.keeper = myKeeper;
    }
}
```

```
public class DogGroomer {
  private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
       // this is the constructor!
       this.keeper = myKeeper;
    }
}
```

Somewhere in memory...

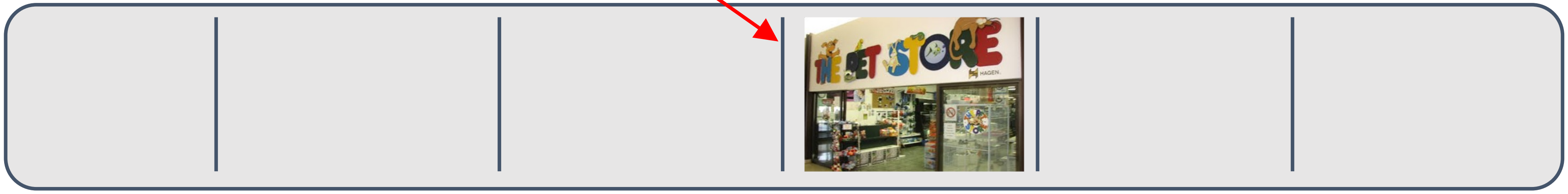
Association: Under the Hood (2/5)

```
public class PetShop {
    private DogGroomer groomer;
    private Manager manager;

    public PetShop() {
        TimeKeeper keeper = new TimeKeeper();
        this.manager = new Manager(keeper);
        this.groomer = new DogGroomer(keeper);
        this.testGroomer();
        this.manager.makePayment(<groomer’s pay rate>);
    }
    // testGroomer elided

}
```

```
public class Manager {
  private TimeKeeper keeper;

    public Manager(TimeKeeper myKeeper) {
       this.keeper = myKeeper;
    }
}
```

```
public class DogGroomer {
  private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
       // this is the constructor!
       this.keeper = myKeeper;
    }
}
```

Somewhere in memory...



Somewhere else in our code, someone calls `new PetShop()`. An instance of `PetShop` is created somewhere in memory and `PetShop`’s constructor initializes all its instance and local variables

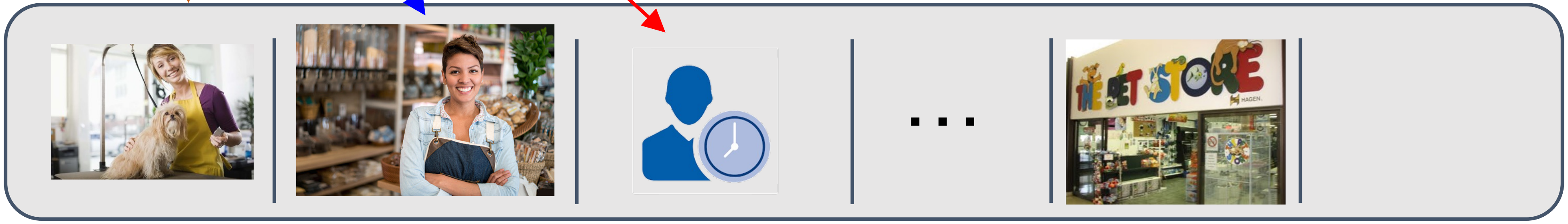
Association: Under the Hood (3/5)

```
public class PetShop {
    private DogGroomer groomer;
    private Manager manager;

    public PetShop() {
        TimeKeeper keeper = new TimeKeeper();
        this.manager = new Manager(keeper);
        this.groomer = new DogGroomer(keeper);
        this.testGroomer();
        this.manager.makePayment(<groomer's pay rate>);
    }
    // testGroomer elided

}
```

```
public class Manager {
  private TimeKeeper keeper;

    public Manager(TimeKeeper myKeeper) {
       this.keeper = myKeeper;
    }
}
```

```
public class DogGroomer {
  private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
       // this is the constructor!
       this.keeper = myKeeper;
    }
}
```

Somewhere in memory...



The PetShop instantiates a new TimeKeeper, Manager and DogGroomer, passing the same TimeKeeper instance in as an argument to the Manager's and DogGroomer's constructors

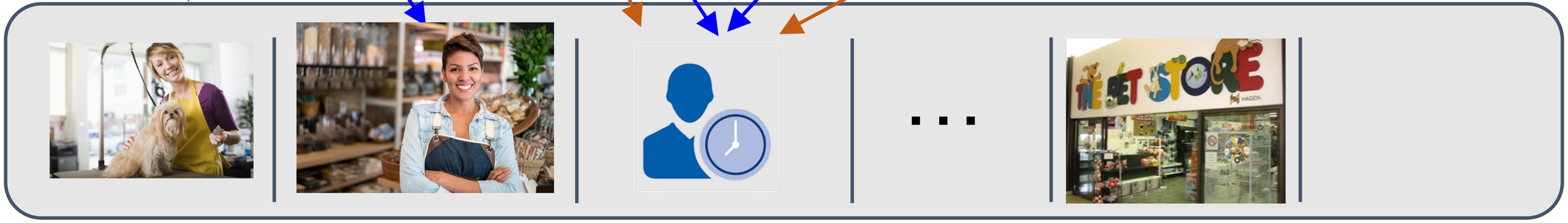
Association: Under the Hood (4/5)

```java
public class PetShop {
   private DogGroomer groomer;
   private Manager manager;

   public PetShop() {
      TimeKeeper keeper = new TimeKeeper();
      this.manager = new Manager(keeper);
      this.groomer = new DogGroomer(keeper);
      this.testGroomer();
      this.manager.makePayment(<groomer’s pay rate>);
   }
   // testGroomer elided

}
```

```java
public class Manager {
   private TimeKeeper keeper;

    public Manager(TimeKeeper myKeeper) {
       this.keeper = myKeeper;
    }
}
```

```java
public class DogGroomer {
   private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
       this.keeper = myKeeper;
    }
}
```

Somewhere in memory...



When the DogGroomer’s and Manager’s constructors are called, their parameter, myKeeper, points to the same TimeKeeper that was passed in as an argument by the caller, i.e., the PetShop

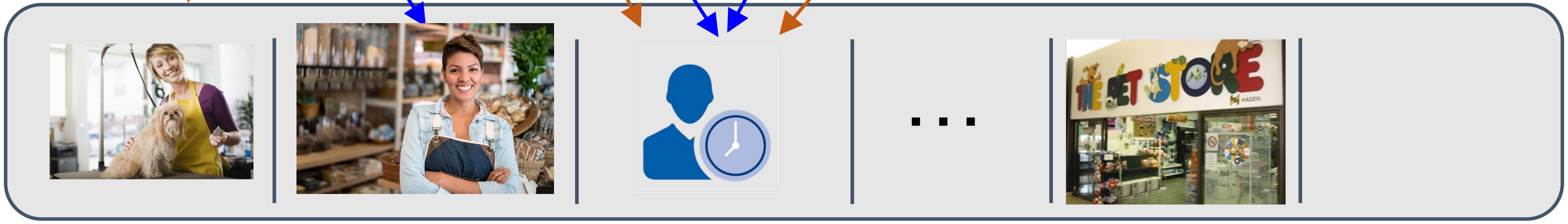
Association: Under the Hood (5/5)

```
public class PetShop {
    private DogGroomer groomer;
    private Manager manager;

    public PetShop() {
        TimeKeeper keeper = new TimeKeeper();
        this.manager = new Manager(keeper);
        this.groomer = new DogGroomer(keeper);
        this.testGroomer();
        this.manager.makePayment(<groomer's pay rate>);
    }
    // testGroomer elided

}
```

```
public class Manager {
    private TimeKeeper keeper;

    public Manager(TimeKeeper myKeeper) {
        this.keeper = myKeeper;
    }
}
```

```
public class DogGroomer {
    private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
        this.keeper = myKeeper;
    }
}
```

Somewhere in memory...



DogGroomer and Manager set their keeper instance variable to point to the same TimeKeeper they received as an argument. Now they "know about" the same TimeKeeper and share the same properties.

Wrong Association

- If different instances of `TimeKeeper` are passed to the constructors of `Manager` and `DogGroomer`, the `DogGroomer` will still log their hours, but the `Manager` will not see any hours worked when `computeHoursWorked` is called
- This is because `Manager` and `DogGroomer` would be sending messages to different `TimeKeeper`s
- And each of those `TimeKeeper`s could have different hours
- Let’s see what this looks like under the hood

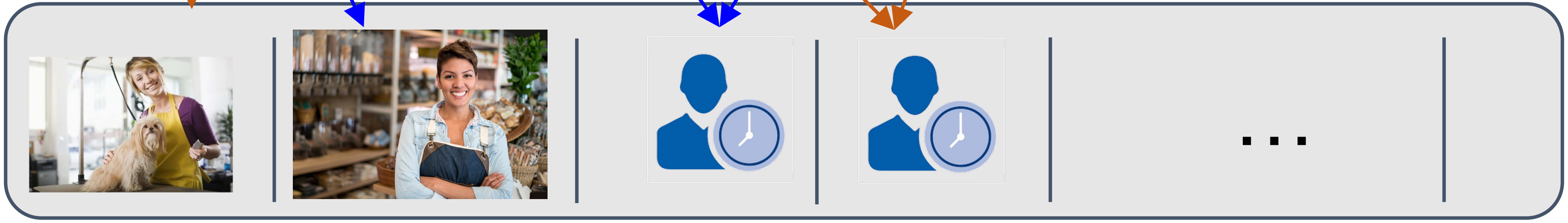
Wrong Association: Under the Hood

```java
public class PetShop {
    private DogGroomer groomer;
    private Manager manager;


    public PetShop() {
        this.manager = new Manager(new TimeKeeper());
        this.groomer = new DogGroomer(new TimeKeeper());
        this.testGroomer();
        this.manager.makePayment(<groomer's pay rate>);
    }
    // testGroomer elided
}
```

```java
public class Manager {
  private TimeKeeper keeper;

    public Manager(TimeKeeper myKeeper) {
       this.keeper = myKeeper;
    }
}
```

```java
public class DogGroomer {
   private TimeKeeper keeper;

    public DogGroomer(TimeKeeper myKeeper) {
       this.keeper = myKeeper;

    }
}
```

Somewhere in memory...

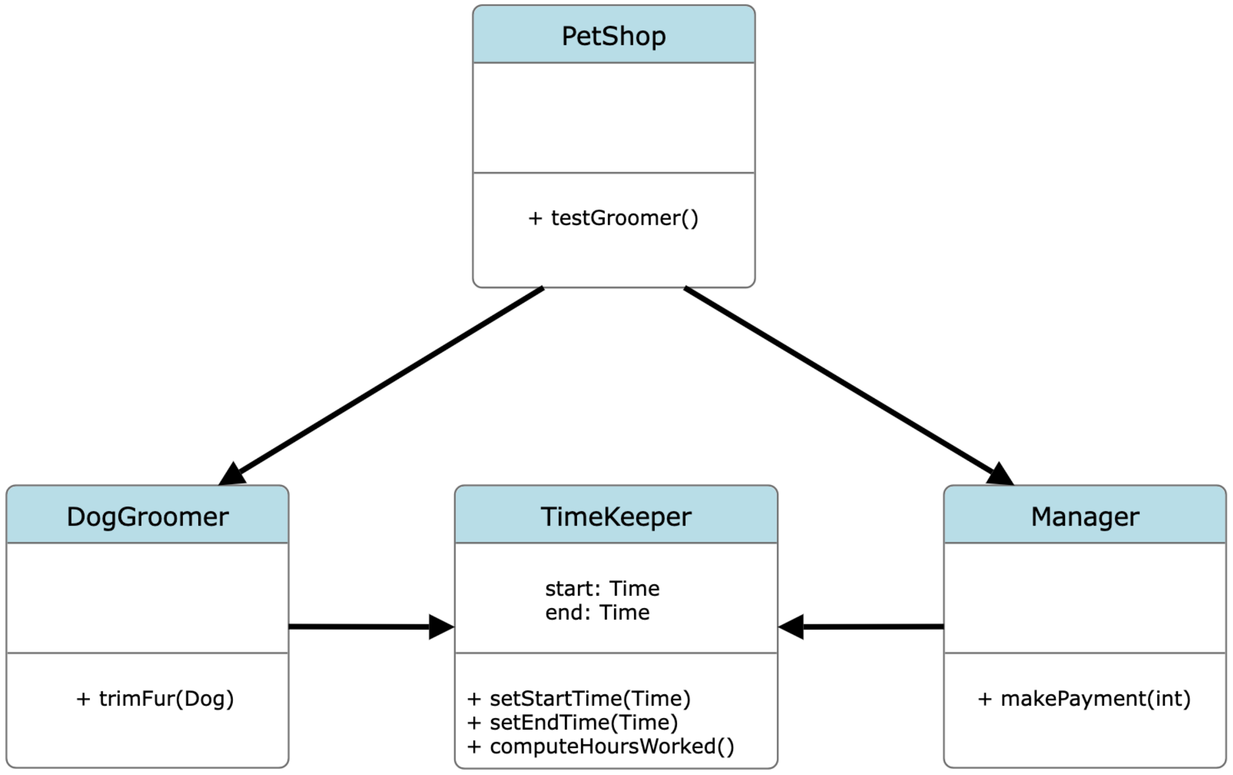


DogGroomer and Manager set their keeper instance variable to point to different instances of TimeKeeper. A change in one instance (e.g., when an instance variable changes) is not reflected in the other instance.

Visualizing Association

- Note that because `TimeKeeper` is not an instance variable in `PetShop`, we do not create a reference arrow pointing from `PetShop` to `TimeKeeper`.

- We can see that `DogGroomer` and `Manager` ‘know about’ `TimeKeeper`, but the relationship is not symmetrical



Association as a Design Choice

- How we associate classes in our program is a design choice
  - if we had multiple employees in the `PetShop`, it would not make sense to pass the same instance of `TimeKeeper` to all employees. Why?
    - they would all modify the same `start` and `end` instance variables
    - the `Manager` would need to know which employee they are paying
  - in such a case, we may choose to associate the `Manager` with the employees (each employee instance would have its own `start` and `end` variables that they can modify)
- In later assignments, you will have to justify your design choices and how you decide to associate your classes, if at all, would be one of them

TopHat Question

Which of the following lines of code would **NOT** produce a compiler error, assuming it’s written in the **App class**?

A `Farmer farmer = new Farmer(this);`

B `Farmer farmer = new Farmer();`

C `Distributor dist = new Distributor(new Farmer());`

D `Farmer farmer = new Farmer(new Distributor());`

```
public class Farmer {
    private Distributor dist;

    public Farmer(Distributor myDist){
      this.dist = myDist;
    }
     //other methods
}

public class Distributor {

    public Distributor() {

    }
     //other methods
 }
```

Outline

- Accessors and Mutators
- Association
    - Association with intermediary
    - Component-Container Association
    - Two-way Association

Two-way Association

- In the previous example, we showed how two classes can communicate with each other
  - `Orchestra` is composed of `Conductor`, thus can send messages to it
  - `Conductor` knows about its container `Orchestra`, thus can send messages to it too
- Also shown how two classes can communicate with a third class with no component-container relationships
  - Both `Manager` and `DogGroomer` can send messages to the same instance of `TimeKeeper`, but the association isn't bidirectional
- Sometimes, want to model peer classes, say, `A` and `B`, where neither is a component of the other and we want the communication to be bidirectional without an intermediate class
- We can set up a **two-way association** where class `A` knows about `B` and vice versa
- Let's see an example

Example: Motivation for Association (1/10)

- Here we have the class `CS15Professor`
- We want `CS15Professor` to know about his Head TAs — he didn't create them or vice versa, so neither is a component of the other
- And we also want Head TAs to know about `CS15Professor`
- Let's set up associations!

```java
public class CS15Professor {

   // declare instance variables here
   // and here…
   // and here…
   // and here!

   public CS15Professor(/* parameters */) {

      // initialize instance variables!
      // …
      // …
      // …
   }

   /* additional methods elided */
}
```

Example: Motivation for Association (2/10)

- The `CS15Professor` needs to know about 5 Head TAs, all of whom will be instances of the class `HTA`
- Once he knows about them, he can call methods of the class `HTA` on them: `remindHTA`, `setUpLecture`, etc.
- Take a minute and try to fill in this class

```
public class CS15Professor {

    // declare instance variables here
    // and here…
    // and here…
    // and here!

    public CS15Professor(/* parameters */) {

        // initialize instance variables!
        // …
        // …
        // …
    }

    /* additional methods elided */
}
```

Example: Setting up Association (3/10)

- Our solution: we record passed-in `HTAs` created by whatever object creates `CS15Professor` and `HTA`s, e.g., `CS15_2024`
- Remember, you can choose your own names for the instance variables and parameters
- The `CS15Professor` can now send a message to one of his `HTA`s like this:

  ```
  this.hta2.setUpLecture();
  ```

```
public class CS15Professor {

  private HTA hta1;
  private HTA hta2;
  private HTA hta3;
  private HTA hta4;
  private HTA hta5;

  public CS15Professor(HTA firstTA,
        HTA secondTA, HTA thirdTA,
        HTA fourthTA, HTA fifthTA) {

        this.hta1 = firstTA;
        this.hta2 = secondTA;
        this.hta3 = thirdTA;
        this.hta4 = fourthTA;
        this.hta5 = fifthTA;
  }

  /* additional methods elided */
}
```

Example: Using the Association (4/10)

- We’ve got the CS15Professor class down
- Now let’s create a Professor and Head TAs from a class that is composed of all of them: CS15_2024
    - The constructor will be called by the App class
- Try and fill in this class!
    - you can assume that the HTA class takes no parameters in its constructor

```
public class CS15_2024 {

   // declare CS15Professor instance var
   // declare five HTA instance vars
   // …
   // …
   // …

   public CS15_2024() {
      // instantiate the professor!
      // …
      // …
      // instantiate the five HTAs
   }
}
```

Example: Using the Association (5/10)

- We declare chloe, grace, ilan, karim, and sarah as instance variables - they are peers
- In the constructor, we instantiate them
- Since the constructor of CS15Professor takes in 5 HTAs, we pass in chloe, grace, ilan, karim, and sarah

```
public class CS15_2024 {
   private CS15Professor andy;
   private HTA chloe;
   private HTA grace;
   private HTA ilan;
   private HTA karim;
   private HTA sarah;

   public CS15_2024() {
       this.chloe = new HTA();
       this.grace = new HTA();
       this.ilan = new HTA();
       this.karim = new HTA();
       this.sarah = new HTA();
       this.andy = new
          CS15Professor(this.chloe,
          this.grace, this.ilan,
          this.karim, this.sarah);
   }
}
```

Example: Using the Association (6/10)

```
public class CS15Professor {

   private HTA hta1;
   private HTA hta2;
   private HTA hta3;
   private HTA hta4;
   private HTA hta5;

   public CS15Professor(HTA firstTA,
          HTA secondTA, HTA thirdTA
          HTA fourthTA, HTA fifthTA) {

        this.hta1 = firstTA;
        this.hta2 = secondTA;
        this.hta3 = thirdTA;
        this.hta4 = fourthTA;
        this.hta5 = fifthTA;
   }

   /* additional methods elided */
}
```

```
public class CS15_2024 {

   private CS15Professor andy;
   private HTA chloe;
   private HTA grace;
   private HTA ilan;
   private HTA karim;
   private HTA sarah;

   public CS15_2024() {
       this.chloe = new HTA();
       this.grace = new HTA();
       this.ilan = new HTA();
       this.karim = new HTA();
       this.sarah = new HTA();
       this.andy = new
          CS15Professor(this.chloe,
          this.grace, this.ilan,
          this.karim, this.sarah);
   }
}
```

More Associations (7/10)

- Now the `CS15Professor` can call on the `HTA`s but can the `HTA`s call on the `CS15Professor` too?
- No! Need to set up another association
- Can we just do the same thing and pass `this.andy` as a parameter into each `HTA`s constructor?

```
public class CS15_2024 {

  private CS15Professor andy;
  private HTA chloe;
  private HTA grace;
  private HTA ilan;
  private HTA karim;
  private HTA sarah;

  public CS15_2024() {
      this.chloe = new HTA();
      this.grace = new HTA();
      this.ilan = new HTA();
      this.karim = new HTA();
      this.sarah = new HTA();
      this.andy = new
         CS15Professor(this.chloe,
         this.grace, this.ilan,
         this.karim, this.sarah);
   }
}
```

Code from previous slide

More Associations (8/10)

- When we instantiate `chloe`, `grace`, `ilan`, `karim`, and `sarah`, we would like to use a modified `HTA` constructor that takes an argument, `this.andy`
- But `this.andy` hasn't been instantiated yet (will get a `NullPointerException`)! And we can't initialize `andy` first because the `HTA`s haven't been created yet…
- How to break this deadlock?

```
public class CS15_2024 {

  private CS15Professor andy;
  private HTA chloe;
  private HTA grace;
  private HTA ilan;
  private HTA karim;
  private HTA sarah;

  public CS15_2024() {
      this.chloe = new HTA();
      this.grace = new HTA();
      this.ilan = new HTA();
      this.karim = new HTA();
      this.sarah = new HTA();
      this.andy = new
         CS15Professor(this.chloe,
         this.grace, this.ilan,
         this.karim, this.sarah);
   }
}
```

$\Big\}$ Code from previous slide

More Associations (9/10)

- To break this deadlock, we need to have a new mutator
- First, instantiate `chloe`, `grace`, `ilan`, `karim`, and `sarah`, then instantiate `andy`
- Use a new mutator, `setProf`, in the HTA body and pass `andy` to each `HeadTA` to record the association

```
public class CS15_2024 {

   private CS15Professor andy;
   private HTA chloe;
   private HTA grace;
   private HTA ilan;
   private HTA karim;
   private HTA sarah;

   public CS15_2024() {
      this.chloe = new HTA();
      this.grace = new HTA();
      this.ilan = new HTA();
      this.karim = new HTA();
      this.sarah = new HTA();
      this.andy = new CS15Professor(this.chloe,
           this.grace, this.ilan, this.karim,
           this.sarah);

      this.chloe.setProf(this.andy);
      this.grace.setProf(this.andy);
      this.ilan.setProf(this.andy);
      this.karim.setProf(this.andy);
      this.sarah.setProf(this.andy);
   }
}
```

More Associations (10/10)

```
public class HTA {

   private CS15Professor professor;

   public HTA() {
      //other code elided
   }
   public void setProf(CS15Professor myProf)
   {
      this.professor = myProf;
   }
}
```

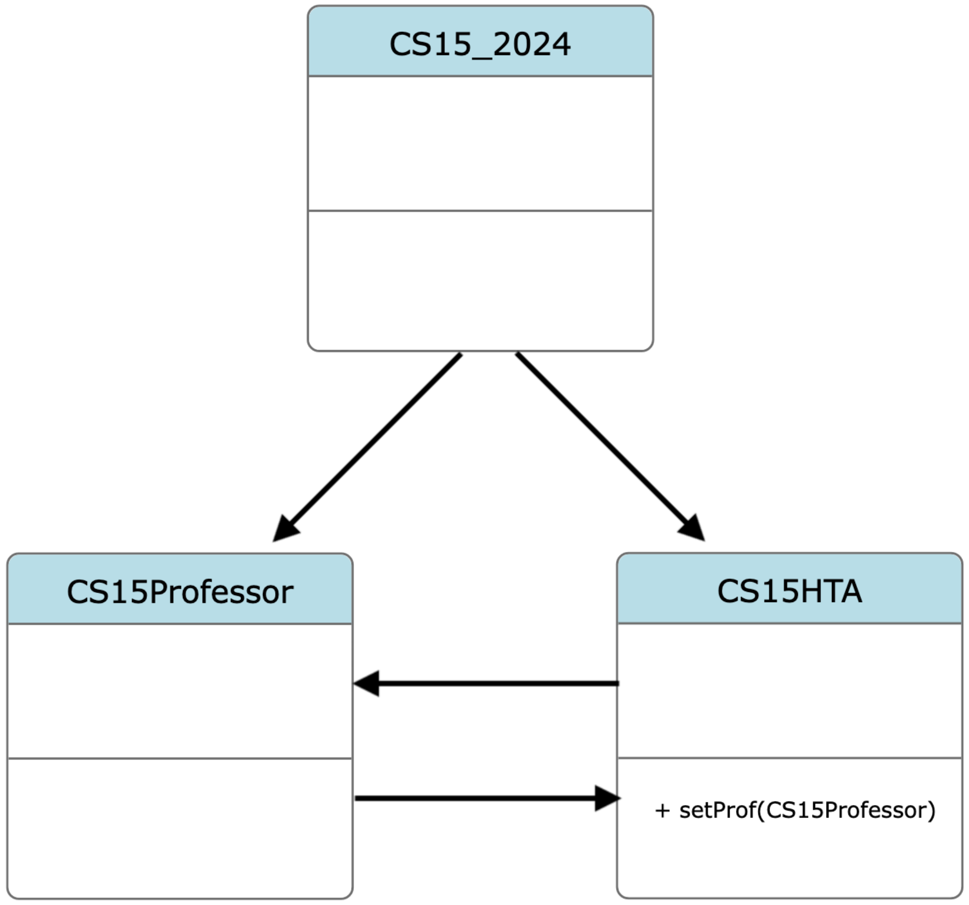
- Now each HTA will know about andy!

```
public class CS15_2024 {

   private CS15Professor andy;
   private HTA chloe;
   private HTA grace;
   private HTA ilan;
   private HTA karim;
   private HTA sarah;

   public CS15_2024() {
      this.chloe = new HTA();
      this.grace = new HTA();
      this.ilan = new HTA();
      this.karim = new HTA();
      this.sarah = new HTA();
      this.andy = new CS15Professor(this.chloe,
           this.grace, this.ilan, this.karim,
           this.sarah);

      this.chloe.setProf(this.andy);
      this.grace.setProf(this.andy);
      this.ilan.setProf(this.andy);
      this.karim.setProf(this.andy);
      this.sarah.setProf(this.andy);
   }
}
```

More Associations

- But what happens if `setProf` is never called?
- Will the HTAs be able to call methods on the `CS15Professor`?
- No! We would get a `NullPointerException`!
  - remember: `NullPointerExceptions` occur at **runtime** when a variable's value is null, and you try to give it a command

Class Diagram



Summary

Important Concepts:

- In OOP, it's necessary for classes to interact with each other to accomplish specific tasks
- Delegation allows us to have multiple classes and specify how their instances can relate with each other. Today, we learned an important way to to establish these relationships:
    - **association**, where one class knows about an instance of another class and call methods on it
        - Notice that classes are considered to be "associated with" instance variables that represent their components.
- Delegation and association are some of the many "design pattern" we will learn about in CS15. Stay tuned for more design patterns and discussion about design in later lectures.

Announcements

- Pong comes out today!
  - Due Monday 9/23 at 11:59 PM EST
  - No early or late hand in!
- HTA Hours
  - Fridays 3:00 – 4:00 PM at CIT 209
  - Not for project help – logistical questions only
- Movie night tonight!
  - Metcalf Auditorium @ 7:30pm
  - Fritz Lang's 1927 *Metropolis*
- Section Swaps
  - Deadline to make permanent swaps Friday 09/20 (tomorrow)
- CS15 Mentorship!
  - If you have not gotten an assignment email and wanted to participate in the mentorship program, email the HTAs

Writing Classes Code-along!

Helpful for Pong + Tic Tac Toe

- ➔ How to write a class
- ➔ Understand constructors (and how to create one)
- ➔ How to use and create instance variables
- ➔ Getter/setter methods
- ➔ How to create instances of a class and call its public methods
- ➔ Where to logically create instances of classes

Thurs 9/19 →Friedman 208 7:00pm-8:30pm
Sat 9/21 → CIT 165 3:00pm-4:30pm

WRITING CLASSES CODE-ALONG

Mom: Did you sleep well?
Me:
you when you don't go to the codealong and can't finish your cs15 hw

9/19 – 7:00PM–8:30PM – FRIEDMAN 208
9/21 – 3:00PM–4:30PM – CIT 165

Review: Variables

- Store information either as a value of a primitive or as a reference to an instance

```
int favNumber = 9;

Dog effie = new Dog();
```

$$\underbrace{\texttt{<type> <name>}}_{\text{declaration}}\ \underbrace{\texttt{= <value>;}}_{\text{initialization}}$$

Review: Local vs. Instance Variables (1/2)

- Local variables are declared inside a method and cannot be accessed from any other method
- Once the method has finished executing, they are garbage collected

```
public class PetShop {

   // This is the constructor!
   public PetShop() {
         this.testGroomer();
   }

   public void testGroomer() {
         Dog effie = new Dog();
         DogGroomer groomer = new DogGroomer();
         groomer.trimFur(effie);
         effie = new Dog();
         groomer.trimFur(effie);
   }

}
```

Local Variables

Review: Local vs. Instance Variables (2/2)

- Instance variables model properties that all instances of a class have – attributes, components, and references to other classes

- Instance variables are accessible from anywhere within the class — their scope is the entire class

- The purpose of a constructor is to initialize all instance variables

declaration

initialization

```
public class PetShop {
   private DogGroomer groomer;

   public PetShop() {
         this.groomer = new DogGroomer();
         this.testGroomer();
   }
   // testGroomer elided
}
```

Review: Variable Reassignment

- After giving a variable an initial value or reference, we can reassign it (make it store a different instance)
- When reassigning a variable, we do not declare its type again, Java remembers it from the first assignment

```java
Dog effie = new Dog();
Dog appa = new Dog();

effie = appa; // reassign effie
```

- `effie` now stores a different dog (another instance of Dog), specifically the one that was `appa`. The initial dog stored by `effie` is garbage collected

Review: Instances as Parameters

- Methods can take in class instances as parameters

```
public void trimFur(Dog shaggyDog) {
// code that trims the fur of shaggyDog
}
```

- When calling the method above, every dog passed as an argument, e.g., `effie`, will be thought of as `shaggyDog`, a synonym, in the method

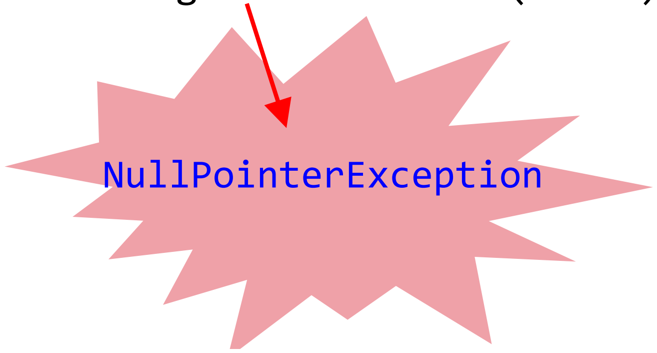
Review: Delegation Pattern

- Delegation allows us to separate different sets of functionalities and assign them to other classes
- With delegation, we'll use multiple classes to accomplish one task. A side effect of this is we need to set up relationships between classes for their instances to communicate
- Association is an important design pattern used to establish these class relationships. We'll learn about it today. Stay tuned!

Review: NullPointer Exceptions

- What happens if you fail to initialize an instance variable in the constructor?
  - instance variable `groomer` never initialized so default value is `null`
  - when a method is called on `groomer` we get a `NullPointerException`

```
public class PetShop {

  private DogGroomer groomer;

  public PetShop() {
      //oops! Forgot to initialize groomer
      this.testGrooming();
  }
  public void testGrooming() {
      Dog effie = new Dog(); //local var
      this.groomer.trimFur(effie);
  }
}
```



Review: Encapsulation

- In CS15, instance variables should be declared as `private`
- Why? **Encapsulation** for safety purposes
    - your properties are your private business
- If public, instance variables would be accessible from **any class**. There would be no way to restrict other classes from modifying them
- Private instance variables also allow for a chain of abstraction, so classes don't need to worry about the inner workings of their components
- We'll learn safe ways of allowing external classes to access instance variables