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Life + CS15 after Brown

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- CS Concentrator
- CS15 HTA
- CS15, CS16, CS195Y UTA

Now...

Software Engineer @
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Responsible CS (1/2)

Cloudflare's Response to Internet Extremists

- Christ Church and El Paso shootings linked to 8chan, online free-speech platform
- Shooters post anti-Muslim and anti-Semitic content, actions praised by 8chan users
- Cloudflare protects 8chan against cyber attacks
- 8chan will re-emerge one way or another, as forums like this have inn the past

CLOUDFLARE®

Sources:
https://www.nytimes.com/2019/08/05/technology/8chan-cloudflare-el-paso.html
https://newrepublic.com/article/154714/no-law-can-ban-white-supremacy-internet

Responsible CS (2/2)

"*Banning 8chan would make our lives a lot easier, but it would make the job of law enforcement and controlling hate groups online harder."* - Matthew Prince, Cloudflare's Chief Executive

- Hosting 8chan on a public server allows cooperation with law enforcement
- Banning 8chan sets a dangerous precedent for the companies future (repressive country theory).
- Cloudflare has a moral obligation to ban 8chan, a site that breeds perpetrators of violent crime.

Whose responsibility should it be to moderate violent content, the government or the individual companies?

Lecture 4

Working with Objects:
Variables, Containment, and Association

This Lecture:

- Storing values in variables
- Methods that take in objects as parameters
- Containment and association relationships (how objects know about other objects in the same program)

Review: Methods

- **Call methods**: give commands to an object

```
samBot.turnRight();
```

- **Define methods**: give a class specific capabilities

```
public void turnLeft() {
    // code to turn Robot left goes here
}
```

Review: Constructors and Instances

- Declare a **constructor** (a method called whenever an object is “born”)

```
public Calculator() {
    // code for setting up Calculator
}
```

- Create an **instance** of a class with the `new` keyword

```
new Calculator();
```

Review: Parameters and Arguments

- **Define** methods that take in **parameters** (input) and have **return** values (output), e.g., this `Calculator`'s method:

```
public int add(int x, int y) {
    // x, y are dummy (symbolic) variables
    return (x + y);
}
```

- **Call** such methods on instances of a class by providing **arguments** (actual values for symbolic parameters)

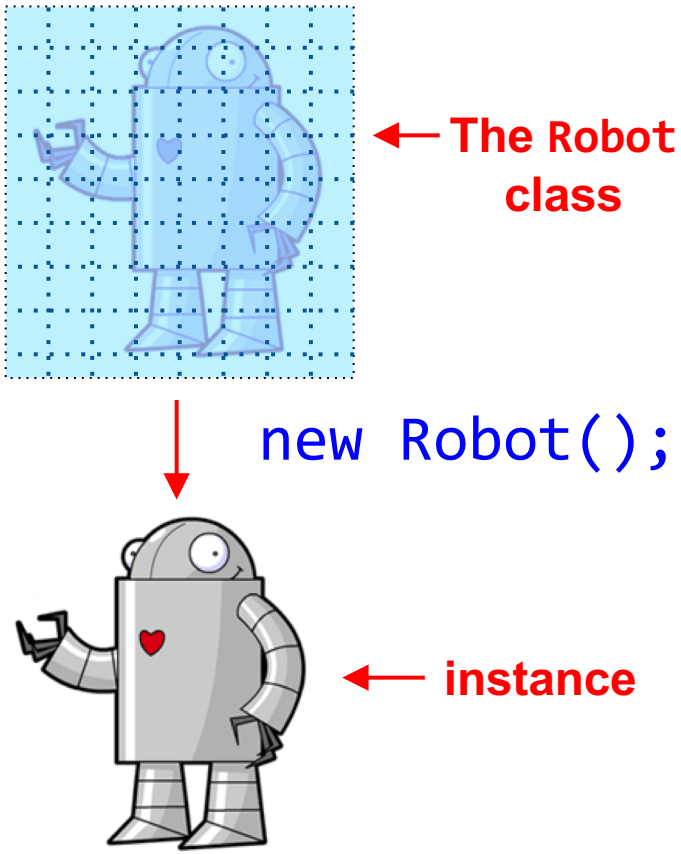
```
myCalculator.add(5, 8);
```

Review: Classes

- Recall that classes are just blueprints
- A class gives a basic definition of an **object** we want to model (one or more instances of that class)
- It tells the **properties** and **capabilities** of that **object**
- You can create any class you want and invent any methods and properties you choose for it!

Review: Instantiation

- **Instantiation** means building an instance from its class
  - A class can be considered a "blueprint," where the properties of the instantiated object are defined through the class's methods
- Ex: `new Robot();` creates an instance of Robot by calling the `Robot` class' **constructor** (see next slide)



Review: Constructors (1/2)

- A **constructor** is a method that is called to create a new object
- Let's define one for the Dog class
- Let's also add methods for actions all Dogs know how to do like bark, eat, and wag their tails

```
public class Dog {
  public Dog() {
    // this is the constructor!
  }

  public void bark(int numTimes) {
    // code for barking goes here
  }

  public void eat() {
    // code for eating goes here
  }

  public void wagTail() {
    // code for wagging tail goes here
  }
}
```

Review: Constructors (2/2)

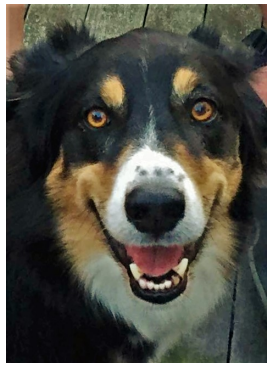
- Note constructors do not specify a return type
- Name of constructor must exactly match name of class
- Now we can instantiate a Dog in some method:

```
new Dog();
```

```
public class Dog {
  public Dog() {
    // this is the constructor!
  }

  public void bark(int numTimes) {
    // code for barking goes here
  }

  public void eat() {
    // code for eating goes here
  }

  public void wagTail() {
    // code for wagging tail goes here
  }
}
```

Variables

- Once we create a `Dog` instance, we want to be able to give it commands by calling methods on it!
- To do this, we need to name our `Dog`
- Can name an object by storing it in a **variable**



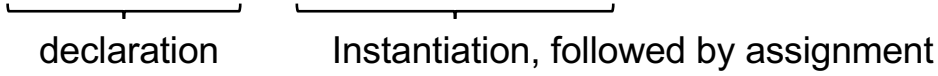
```
Dog django = new Dog();
```

```
/* named after Django Reinhardt – see https://www.youtube.com/watch?v=plpSfvdCH0Q */
```

- In this case, `django` is the variable, and it stores a newly created instance of `Dog`
  - the variable name `django` is also known as an “identifier”
- Now we can call methods on `django`, a specific instance of `Dog`
  - i.e. `django.bark();`

Syntax: Variable Declaration and Assignment

- To **declare** and **assign** a variable, thereby initializing it, in a single statement is: `Dog django = new Dog();`




```
<type> <name> = <value>;
```

- The "=" operator **assigns** the instance of `Dog` that we created to the variable `django`. We say "`django` **gets** a new `Dog`"

- Note: type of `value` must match declared `type` on left

- We can reassign as many times as we like (example soon)

Assignment vs. Equality

In Java:

```
price = price + 10;
```

- Means “add 10 to the current value of price and assign that to price.” We shorthand this to “increment price by 10”

In Algebra:

- price = price + 10 is a logical contradiction

Values vs. References

- A variable stores information as either:
  - a **value** of a **primitive** (aka **base**) **type** (like `int` or `float`)
  - a **reference** to an instance (like an instance of `Dog`) of an arbitrary type stored elsewhere in memory
    - we symbolize a reference with an arrow

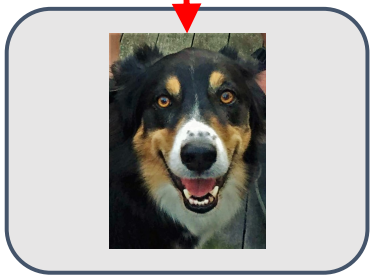
```
int favNumber = 9;
```

favNumber

9

```
Dog django = new Dog();
```

django



(somewhere else in memory)

- Think of the variable like a box; storing a value or reference is like putting something into the box
- Primitives have a predictable memory size, while arbitrary objects vary in size. Thus, Java simplifies its memory management by having a fixed size reference to an instance elsewhere in memory
  - "one level of indirection"

TopHat Question

Given this code, fill in the blanks:

```
int x = 5;
Calculator myCalc = new Calculator();
```

Variable `x` stores a _____, and `myCalc` stores a _____.

A. value, value
B. value, reference
C. reference, value
D. reference, reference

Example: Instantiation (1/2)

```
public class PetShop {

  /*constructor of trivial PetShop! */
  public PetShop() {
    this.testDjango();
  }

  public void testDjango() {
     Dog django = new Dog();
     django.bark(5);
     django.eat();
     django.wagTail();
  }
}
```

- Let's define a new class `PetShop` which has a `testDjango()` method.
  - don't worry if the example seems a bit contrived…
- Whenever someone instantiates a `PetShop`, its constructor is called, which calls `testDjango()`, which in turn instantiates a `Dog`
- Then `testDjango()` tells the `Dog` to bark, eat, and wag its tail (see definition of `Dog`)

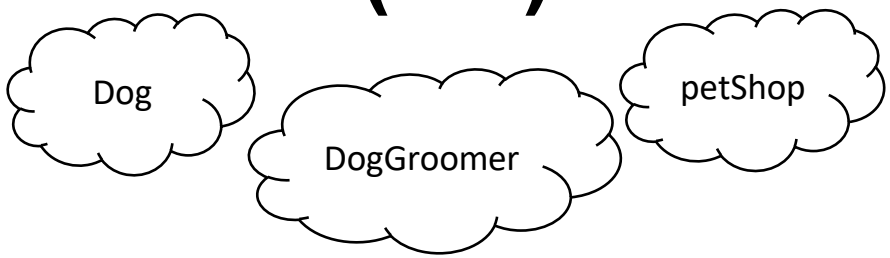
Another Example: Instantiation (2/2)

```
public class MathStudent {

  /* constructor elided */

  public void performCalculation() {
    Calculator myCalc = new Calculator();
    int answer = myCalc.add(2, 6);
    System.out.println(answer);
  }

  /* add() method elided */
          ...
}
```

- *Another example:* can instantiate a a `MathStudent` and then call that instance to perform a simple, fixed, calculation
- First, create new `Calculator` and store its reference in variable named `myCalc`
- Next, tell `myCalc` to add 2 to 6 and store result in variable named `answer`
- Finally, use `System.out.println` to print value of `answer` to the console!

Instances as Parameters (1/3)

- Methods can take in not just numbers but also instances as parameters
- The `DogGroomer` class has a method `groom`
- `groom` method needs to know which `Dog` to groom
- Method calling `groom` will have to supply a specific instance of a `Dog`




```
public class DogGroomer {

  public DogGroomer() {
    // this is the constructor!
  }

  public void groom(Dog shaggyDog) {
    // code that grooms shaggyDog
  }
}
```

type/class

name of specific instance

- Analogous to `void moveForward(int numberOfSteps);`

Instances as Parameters (2/3)

- Where to call the `DogGroomer`'s `groom` method?
- Do this in the `PetShop` method `testGroomer()`
- `PetShop`'s call to `testGroomer()` instantiates a `Dog` and a `DogGroomer`, then calls the `DogGroomer` to groom the `Dog`
- First two lines could be in either order


```
public class PetShop {

  public PetShop() {
    this.testGroomer();
  }

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
  }

}
```

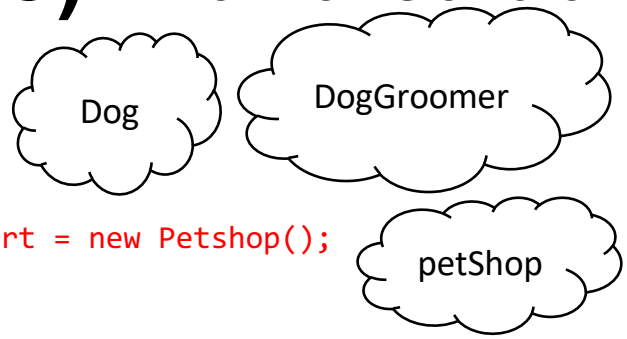
Instances as Parameters (3/3): Flow of Control

0. In `App`'s constructor, a `PetShop` is instantiated (thereby calling `PetShop`'s constructor). Then:

1. The `PetShop` in turn calls the `testGroomer()` helper method, which instantiates a `Dog` and stores a reference to it in the variable `django`

2. Next, it instantiates a `DogGroomer` and stores a reference to it in the variable `groomer`

3. The `groom` method is called on `groomer`, passing in `django` as an argument; the `groomer` will think of it as `shaggyDog`, a synonym




```
public class App {
   public App() {
 0.  Petshop petSmart = new Petshop();
   }
}

public class PetShop {
   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
  1.  Dog django = new Dog();
  2.  DogGroomer groomer = new DogGroomer();
  3.  groomer.groom(django);
   //exit method, django and groomer disappear
   }
}
```

Code from Slide 21

What is Memory?

- Memory ("system memory" aka RAM, not disk or other peripheral devices) is the hardware in which computers store information during computation
- Think of memory as a list of slots; each slot holds information (e.g., an `int` variable, or a reference to an instance of a class)
- Here, two references are stored in memory: one to a `Dog` instance, and one to a `DogGroomer` instance


```
//Elsewhere in the program
Petshop petSmart = new Petshop();

public class PetShop {

  public PetShop() {
    this.testGroomer();
  }

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
  }

}
```

Instances as Parameters: Under the Hood (1/6)

```
public class PetShop {

   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
     Dog django = new Dog();
     DogGroomer groomer = new DogGroomer();
     groomer.groom(django);
   }
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     // code that grooms shaggyDog goes here!
   }
}
```

Somewhere in memory...

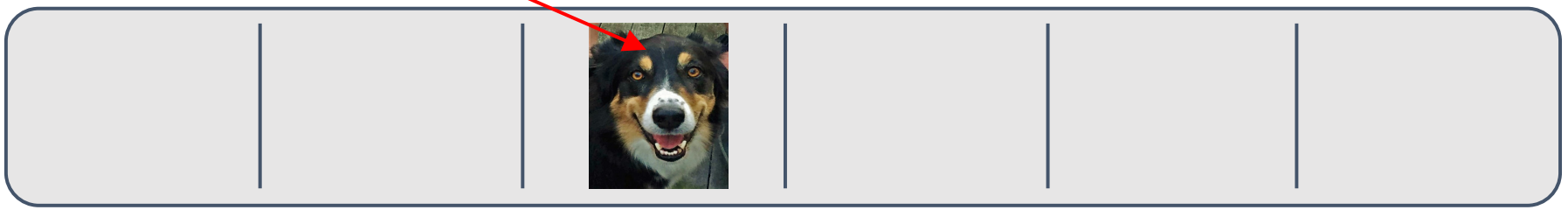
Note: Recall that in Java, each class is stored in its own file. Thus, when creating a program with multiple classes, the program will work as long as all classes are written before the program is run. Order doesn't matter.

Instances as Parameters: Under the Hood (2/6)

```
public class PetShop {

   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
     Dog django = new Dog();
     DogGroomer groomer = new DogGroomer();
     groomer.groom(django);
   }
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     // code that grooms shaggyDog goes here!
   }
}
```

Somewhere in memory...



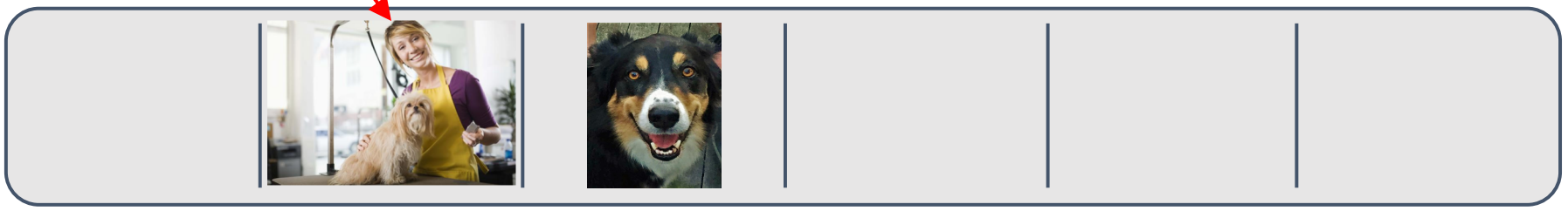
When we instantiate a `Dog`, he's stored somewhere in memory. Our `PetShop` will use the name `django` to refer to this particular `Dog`, at this particular location in memory.

Instances as Parameters: Under the Hood (3/6)

```
public class PetShop {

   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
     Dog django = new Dog();
     DogGroomer groomer = new DogGroomer();
     groomer.groom(django);
   }
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     // code that grooms shaggyDog goes here!
   }
}
```

Somewhere in memory...



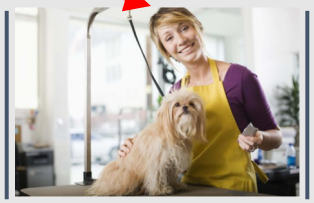
Same goes for the `DogGroomer`—we store a particular `DogGroomer` somewhere in memory.
Our `PetShop` knows this `DogGroomer` by the name `groomer`.

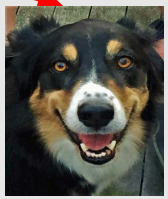
Instances as Parameters: Under the Hood (4/6)

```
public class PetShop {

   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
     Dog django = new Dog();
     DogGroomer groomer = new DogGroomer();
     groomer.groom(django);
   }
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     // code that grooms shaggyDog goes here!
   }
}
```

Somewhere in memory...





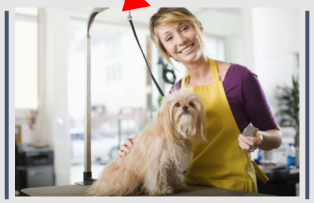
We call the `groom` method on our `DogGroomer`, `groomer`. We need to tell her which `Dog` to groom (since the `groom` method takes in a parameter of type `Dog`). We tell her to groom `django`.

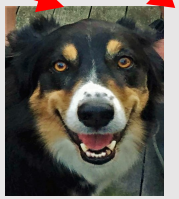
Instances as Parameters: Under the Hood (5/6)

```
public class PetShop {

   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
     Dog django = new Dog();
     DogGroomer groomer = new DogGroomer();
     groomer.groom(django);
   }
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     // code that grooms shaggyDog goes here!
   }
}
```

Somewhere in memory...





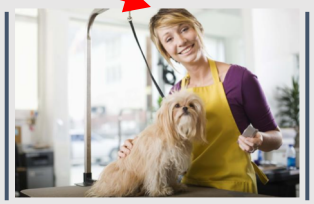
When we pass in `django` as an argument to the `groom` method, we're telling the `groom` method about him. When `groom` executes, it sees that it has been passed that particular `Dog`.

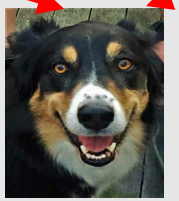
Instances as Parameters: Under the Hood (6/6)

```
public class PetShop {

   public PetShop() {
     this.testGroomer();
   }

   public void testGroomer() {
     Dog django = new Dog();
     DogGroomer groomer = new DogGroomer();
     groomer.groom(django);
   }
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     // code that grooms shaggyDog goes here!
   }
}
```

Somewhere in memory...





The `groom` method doesn't really care which `Dog` it's told to groom—no matter what another object's name for the `Dog` is, `groom` is going to know it by the name `shaggyDog`.

Variable Reassignment (1/3)

- After giving a variable an initial value or reference, we can **reassign** it (make it refer to a different instance)
- What if we wanted our `DogGroomer` to `groom` two different `Dog`s when the `PetShop` opened?
- Could create another variable, or re-use the variable `django` to first point to one `Dog`, then another!

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
  }

}
```

Variable Reassignment (2/3)

- First, instantiate another `Dog`, and **reassign** variable `django` to point to it
- Now `django` no longer refers to the first `Dog` instance we created, which was already groomed
- Then tell `groomer` to `groom` the newer `Dog.` It will also be known as `shaggyDog` inside the `groom` method

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog(); // reassign django
    groomer.groom(django);
  }
}
```

Variable Reassignment (3/3)

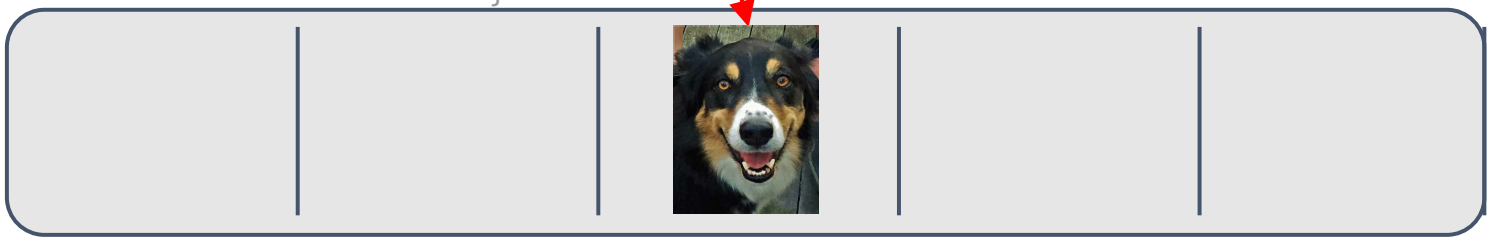
- When we **reassign** a variable, we do not declare its type again, Java remembers from first time
- Can **reassign** to a brand new instance (like in `PetShop`) or to an already existing instance by using its variable

```
Dog django = new Dog();
Dog scooby = new Dog();
django = scooby;
```

- Now `django` and `scooby` refer to the same `Dog`, specifically the one that was originally `scooby`

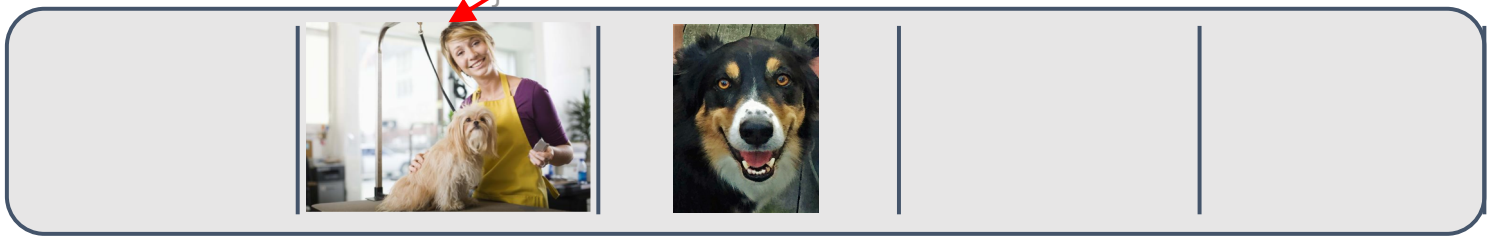
Variable Reassignment: Under the Hood (1/5)

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog();
    groomer.groom(django);
  }
```



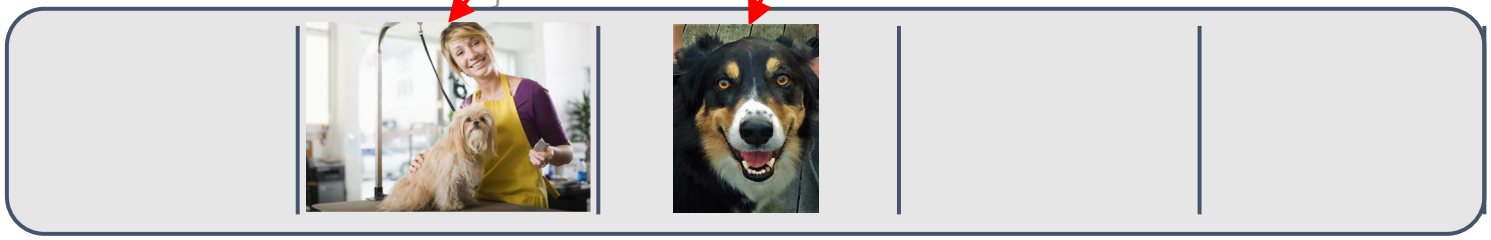
Variable Reassignment: Under the Hood (2/5)

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog();
    groomer.groom(django);
  }
```



Variable Reassignment: Under the Hood (3/5)

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog();
    groomer.groom(django);
  }
```



Variable Reassignment: Under the Hood (4/5)

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog(); //old ref garbage collected – stay tuned!
    groomer.groom(django);
  }
```

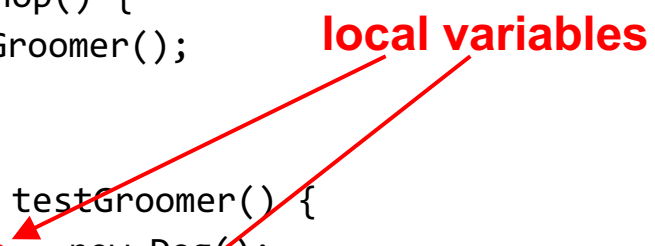
Variable Reassignment: Under the Hood (5/5)

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog(); //old ref garbage collected – stay tuned!
    groomer.groom(django);
  }
```

Local Variables (1/2)

- All variables we've seen so far have been **local variables**: variables declared **inside a method**
- Problem: the **scope** of a local variable (where it is known and can be accessed) is limited to its own method—it cannot be accessed from anywhere else
  - same is true of method's parameters

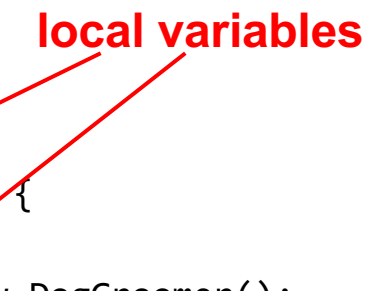
```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog();
    groomer.groom(django);
  }

}
```



Local Variables (2/2)

- We created `groomer` and `django` in our `PetShop`'s helper method, but as far as the rest of the class is concerned, they don't exist
- Once the method is executed, they're gone :(
  - This is known as "Garbage Collection"

```
public class PetShop {

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

  public void testGroomer() {
    Dog django = new Dog();
    DogGroomer groomer = new DogGroomer();
    groomer.groom(django);
    django = new Dog();
    groomer.groom(django);
  }

}
```



“Garbage Collection”

- If an instance referred to by a variable goes out of scope, we can no longer access it. Because we can’t access the instance, it gets garbage collected
  - in garbage collection, the space that the instance took up in memory is freed and the instance no longer exists
- Lose access to an instance when:
  - local variables go out of scope at the end of method execution
  - variables lose their reference to an instance during variable reassignment (`django`, slide 37)

Accessing Local Variables

- If you try to access a local variable outside of its method, you'll receive a "cannot find symbol" compilation error.

scope of groomer

```
public class PetShop {

   /* This is the constructor! */
   public PetShop() {
     DogGroomer groomer = new DogGroomer();
     this.cleanShop();
   }

   public void cleanShop() {
     //assume we've added a sweep method
     //to DogGroomer
     groomer.sweep();
     //other methods to empty trash, etc.
   }
}
```

In Terminal:

```
Petshop.java:13: error: cannot find symbol
  groomer.sweep();
     ^
  symbol: variable groomer
  location: class PetShop
```

Introducing… Instance Variables!

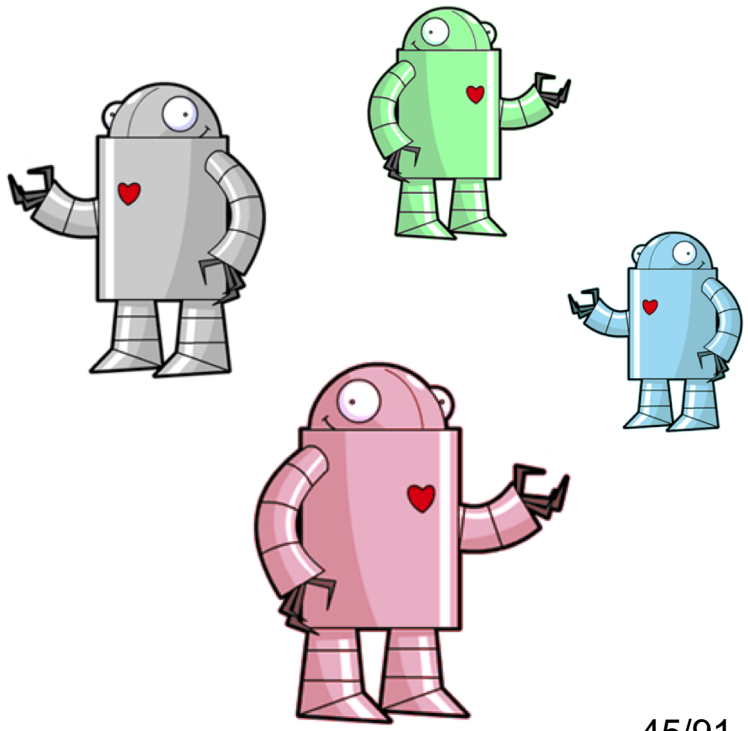
- Local variables aren't always what we want. We'd like every `PetShop` to come with a `DogGroomer` who exists for as long as the `PetShop` exists
- That way, as long as the `PetShop` is in business, we'll have our `DogGroomer` on hand
- We accomplish this by storing the `DogGroomer` in an **instance variable**
- It may seem unnatural to have a PetShop contain a DogGroomer, but it works in the kind of modeling that OOP makes possible – stay tuned

What's an Instance Variable?

- An **instance variable** models a property that all instances of a class have
  - its ***value*** can differ from instance to instance
- Instance variables are declared within a class, not within a single method, and are accessible from anywhere within the class – their **scope** is the entire class
- Instance variables and local variables are identical in terms of what they can store—either can store a base type (like an `int`) or a reference to an object (instance of some other class)

Modeling Properties with Instance Variables (1/2)

- Methods model **capabilities** of a class (e.g., move, dance)
- All instances of same class have exact same methods (capabilities) **and the same properties**
- BUT: the potentially differing values of those **properties** can differentiate a given instance from other instances of the same class
- We use instance variables to model these properties and their values (e.g., the robot's size, position, orientation, color, …)



Modeling Properties with Instance Variables (1/2)

- All instances of a class have same set of properties, but ***values*** of these properties will differ
- E.g. `CS15Students` might have property "height"
  - for one student, the value of "height" is 5'2". For another, it's 6'4"
- `CS15Student` class would have an **instance variable** to represent height
  - value stored in this instance variable would differ from instance to instance

When should I define an instance variable?

- In general, variables that fall into one of these three categories should be instance variables of the class rather than local variables within a method:
  - **attributes**: simple descriptors of an instance, e.g., color, height, age, ...; the next two categories encode relationships between objects:
  - **components**: "parts" that make up an instance. If you are modeling a car, the car's engine and doors will be used in multiple methods, so they should be instance variables; ditto `PetShop` and its `DogGroomer`
  - **associations**: a relationship between two instances in which one instance knows about the other, but they are not necessarily part of each other. For example, the instructor needs to know about TAs (more on this soon), but the instructor is not a part of the TA class – they are peers.
- All methods in a class can access all its properties, to use them and/or change them

Instance Variables (1/4)

- We've modified `PetShop` example to make our `DogGroomer` an **instance variable** for the benefit of multiple methods – yes, `DogGroomer` here is considered a component (part) of the `PetShop`
- Split up declaration and assignment of instance variable:
  - **declare** instance variable at the top of the class, to notify Java compiler
  - **initialize** the instance variable by **assigning** a value to it in the constructor
  - primary purpose of constructor is to initialize all instance variables so the instance has a valid initial "state" at its "birth"; it typically should do no other work
  - **state** is the set of all values for all properties—local variables don't hold properties - they are "temporaries"

```
public class PetShop {

  private DogGroomer _groomer;

  /* This is the constructor! */
  public PetShop() {
    _groomer = new DogGroomer();
    this.testGroomer();
  }

  public void testGroomer() {
    Dog django = new Dog();//local var
    _groomer.groom(django);
  }

}
```

declaration

initialization

Instance Variables (2/4)

- Note we include the keyword `private` in declaration of our instance variable
- `private` is an **access modifier**, just like `public`, which we've been using in our method declarations

Instance Variables (3/4)

- If declared as `private`, the method or instance variable can only be accessed inside the class – their **scope** is the entire class
- If declared as `public`, can be accessed from anywhere – their **scope** can include multiple classes
- **In CS15, you'll declare instance variables as `private`, with rare exception!**
- Note that local variables don't have access modifiers-- they always have the same scope (their own method)

Instance Variables (4/4)

- CS15 instance variable rules:
  - start instance variable names with an **underscore** to easily distinguish them from local variables
  - make all instance variables `private` so they can only be accessed from within their own class!
  - **encapsulation** for safety…your properties are your private business. We will also show you safe ways of allowing other classes to have selective access to designated properties… stay tuned.

```
public class PetShop {

  private DogGroomer _groomer;

  /* This is the constructor! */
  public PetShop() {
    _groomer = new DogGroomer();
    this.testGroomer();
  }

  public void testGroomer() {
    Dog django = new Dog();//local var
    _groomer.groom(django);
  }

}
```

Always Remember to Initialize!

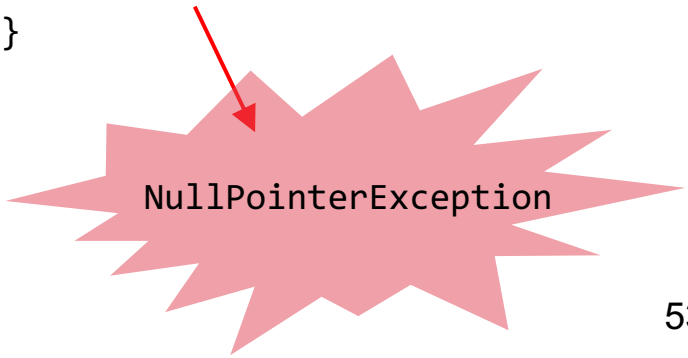
- What if you declare an instance variable, but forget to initialize it? What if you don't supply a constructor and your instance variables are not initialized?
- The instance variable will assume a "default value"
  - if it's an `int`, it will be 0
  - if it's an instance, it will be `null`— a special value that means your variable is not referencing any instance at the moment

```
public class PetShop {

  private DogGroomer _groomer;

  /* This is the constructor! */
  public PetShop() {
    //oops! Forgot to initialize _groomer
    this.testGroomer();
  }

  public void testGroomer() {
    Dog django = new Dog();//local var
    _groomer.groom(django);
  }

}
```

NullPointerExceptions

- If a variable's value is null and you try to give it a command, you'll be rewarded with a ***runtime error***—you can't call a method on "nothing"!
- `_groomer`'s default value is `null` so this particular error yields a `NullPointerException`
- When you run into one of these (we promise, you will), make sure all variables have been explicitly initialized, preferably in the constructor, and none are initialized as null

```
public class PetShop {

   private DogGroomer _groomer;

   public PetShop() {
       //oops! Forgot to initialize _groomer
       this.testGroomer();
   }

   public void testGroomer() {
       Dog django = new Dog(); //local var
       _groomer.groom(django);
   }

}
```



Instance Variables Example (1/2)

- Let's add an instance variable to the `Dog` class
- `_hairLength` stores an `int` that keeps track of the length of a `Dog`'s hair
- `_hairLength` is assigned a default value of 3 in the constructor

```
public class Dog {

    private int _hairLength;

    public Dog() {
        _hairLength = 3;
    }

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

Instance Variables Example (2/2)

- `_hairLength` is a **private** instance variable— only accessible within `Dog` class
- What if another object needs to know or change the value of `_hairLength`?
- When a `DogGroomer` grooms a `Dog`, it needs to update `_hairLength`

```
public class Dog {

    private int _hairLength;

    public Dog() {
        _hairLength = 3; /* all dogs have
        same hairlength initially */
    }


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

Accessors / Mutators (1/3)

- A class may make the value of an instance variable publicly available via an **accessor method** that **returns** the value when called
- `getHairLength` is an accessor method for `_hairLength`
- Can call `getHairLength` on an instance of `Dog` to **return** its current `_hairLength` value
- Remember: return type specified and value returned must match!

```
public class Dog {

  private int _hairLength;

  public Dog() {
    _hairLength = 3;
  }

  public int getHairLength() {
    return _hairLength;
  }

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

return type is `int`

value returned, type `int`

Accessors / Mutators (2/3)

- Similarly, a class may define a **mutator method** which allows another class to change the value of some instance variable
- `setHairLength` is a mutator method for `_hairLength`
- Another instance can call `setHairLength` on a `Dog` to change the value stored in `_hairLength`

```
public class Dog {

  private int _hairLength;

  public Dog() {
    _hairLength = 3;
  }

  public int getHairLength() {
    return _hairLength;
  }

  public void setHairLength(int length) {
    _hairLength = length;
  }
    /* bark, eat, and wagTail elided */
}
```

Accessors / Mutators (3/3)

- We filled in `DogGroomer`'s `groom` method to modify hair length of the `Dog` it grooms
- When a `DogGroomer` grooms a dog, it calls the **mutator** `setHairLength` on the `Dog` and passes in 1 as an argument

```
public class DogGroomer {

  public DogGroomer() {
    // this is the constructor!
  }

  public void groom(Dog shaggyDog) {
    shaggyDog.setHairLength(1);
  }
}
```

Example: Accessors (1/2)

Check that the `groom` method works by printing out the `Dog`'s hair length before and after we send it to the groomer

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     System.out.println(django.getHairLength());
     _groomer.groom(django);
     System.out.println(django.getHairLength());
   }
}
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     shaggyDog.setHairLength(1);
   }
}
```

We use the **accessor** `getHairLength` to retrieve the value `django` stores in its `_hairLength` instance variable

Example: Accessors (2/2)

- What values print out to the console?

Code from previous slide!

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     System.out.println(django.getHairLength());
     _groomer.groom(django);
     System.out.println(django.getHairLength());
   }
}
```

```
public class DogGroomer {

   public DogGroomer() {
     // this is the constructor!
   }

   public void groom(Dog shaggyDog) {
     shaggyDog.setHairLength(1);
   }
}
```

  - first, 3 is printed because 3 is the initial value we assigned to `_hairLength` in the `Dog` constructor (slide 54)
  - next, 1 prints out because `groomer` just set `django`'s hair length to 1

Example: Mutators

- What if we don't always want to cut the dog's hair to a length of 1?
- When we tell `groomer` to groom, let's also tell `groomer` how short to cut the hair

```
public class PetShop {

  // Constructor elided

  public void testGroomer() {
    Dog django = new Dog();
    _groomer.groom(django, 2);
  }
}
```

```
public class DogGroomer {
  /* Constructor and other code elided */

  public void groom(Dog shaggyDog, int hairLength) {
    shaggyDog.setHairLength(hairLength);
  }
}
```

The groomer will cut the dog's hair to a length of 2!

- `groom` will take in a second parameter, and set dog's hair length to the passed-in value of `hairLength` (note `Dog` doesn't error check to make sure that `hairLength` passed in is less than current value of `hairLength`)
- Now pass in two parameters when calling `groom` so `_groomer` knows how long `hairLength` should be after trimming

Summary of Accessors/Mutators

- Instance variables should always be declared `private` for safety, and should be declared at the top of class definition
  - but classes may want to offer useful functionality that allows access to selective properties (instance variables).

- If we made such instance variables `public`, any method could change them, i.e., with the caller in control of the inquiry or change – this is totally 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.

Containment and Association

- **Key to OOP:** how are different classes related to each other so they can communicate to collaborate?
- Relationships established via **containment** or **association**
- Object A **contains** Object B when B is a component of A (A creates B). Thus A knows about B and can call methods on it. Note this is **not symmetrical**: B can't call methods on A!
  - thus a `car` can call methods of a contained `engine` but the `engine` can't call methods on the `car`
- Object C and Object D are **associated** if C "knows about" D, but D is not a component of C; this is also non-symmetric, D doesn't automatically know about C
  - can make association symmetric by separately telling C to be associated with D

Example: Containment

- PetShop **contains** a DogGroomer
- Containment relationship because PetShop itself instantiates a DogGroomer with
  "new DogGroomer();"
- Since PetShop created a DogGroomer and stored it in an instance variable, all PetShop's methods "know" about the _groomer and can access it

```
public class PetShop {

  private DogGroomer _groomer;

  public PetShop() {//constructor
    _groomer = new DogGroomer();
    this.testGroomer();
  }

  public void testGroomer() {
    Dog django = new Dog();//local var
    _groomer.groom(django);
  }

}
```

Association (1/8)

- We haven't seen an association relationship yet—let's set one up!
- **Association** means one object knows about another "peer" object that is not one of its components

```
public class DogGroomer {



  public DogGroomer() {
    // this is the constructor!
  }

  public void groom(Dog shaggyDog) {
    shaggyDog.setHairLength(1);
  }
}
```

Prior DogGroomer code

Motivation for Association (2/8)

- As noted, `PetShop` contains a `DogGroomer`, so it can send messages to the `DogGroomer`
- But what if the `DogGroomer` needs to send messages to the `PetShop` she works in?
  - the `DogGroomer` probably needs to know several things about her `PetShop`: for example, operating hours, grooming supplies in stock, customers currently in the shop...

```
public class DogGroomer {

  public DogGroomer() {
    // this is the constructor!
  }

  public void groom(Dog shaggyDog) {
    shaggyDog.setHairLength(1);
  }
}
```

Prior DogGroomer code

Association (3/8)

- The PetShop keeps track of such information in its properties (not shown here)
- We can set up an **association** so DogGroomer can send her PetShop messages to retrieve information from it as needed

```
public class DogGroomer {



  public DogGroomer() {
    // this is the constructor!
  }

  public void groom(Dog shaggyDog) {
    shaggyDog.setHairLength(1);
  }
}
```

Prior DogGroomer code

Example: Setting up the Association (4/8)

- To set up the association, we must modify `DogGroomer` to store the knowledge of the `_petShop`
- To set it up, declare an instance variable named `_petShop` in the `DogGroomer`
- But how to initialize this instance variable? Such initialization should be done in `DogGroomer`'s constructor

```
public class DogGroomer {

  private PetShop _petShop;

  public DogGroomer(PetShop myPetShop) {
    _petShop = myPetShop;//store the assoc.
  }

  public void groom(Dog shaggyDog) {
    shaggyDog.setHairLength(1);
  }
}
```

Example: Setting up the Association (5/8)

- We modify `DogGroomer`'s constructor to take in a parameter of type `PetShop`
- Constructor will refer to it by the name `myPetShop`. To "remember" the passed argument, the constructor stores it in the `_PetShop` instance variable

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
      _petShop =  myPetShop; // store the assoc.
   }
   //groom method elided
}
```

```
public class PetShop {
   private DogGroomer _groomer;

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

   //testGroomer() elided
}
```

Code from previous slides

Example: Setting up the Association (6/8)

- What argument should DogGroomer's constructor store in _petShop?
  - The PetShop instance that created the DogGroomer
- How?
  - By passing this as the argument

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
      _petShop =  myPetShop; // store the assoc.
   }
   //groom method elided
}
```

```
public class PetShop {
   private DogGroomer _groomer;

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

   //testGroomer() elided
}
```

Code from previous slides

Example: Setting up the Association (7/8)

- Now, the instance variable, `_petShop`, records the instance of `PetShop`, called `myPetShop`, that the `DogGroomer` belongs to
- `_petShop` now points to same `PetShop` instance passed to its constructor
- After constructor has been executed and can no longer reference `myPetShop`, any `DogGroomer` method can still access same `PetShop` instance by the name `_petShop`

```
public class DogGroomer {

  private PetShop _petShop;

  public DogGroomer(PetShop myPetShop) {
    _petShop = myPetShop; // store the assoc.
  }

  public void groom(Dog shaggyDog) {
    shaggyDog.setHairLength(1);
  }
}
```

Example: Using the Association (8/8)

- Let's say we've written an **accessor** method and a **mutator** method in the `PetShop` class: `getClosingTime()` and `setNumCustomers(int customers)`
- If the `DogGroomer` ever needs to know the closing time, or needs to update the number of customers, she can do so by calling
  - `getClosingTime()`
  - `setNumCustomers(int customers)`

```
public class DogGroomer {

   private PetShop _petShop;
   private Time _closingTime;

   public DogGroomer(PetShop myPetShop) {
     _petShop = myPetShop; // store assoc.
     _closingTime = _petShop.getClosingTime();
     _petShop.setNumCustomers(10);
   }
}
```

Association: Under the Hood (1/5)

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     _groomer.groom(django);
   }
}
```

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
     _petShop = myPetShop;
   }

   /* groom and other methods elided for this
   example */
}
```

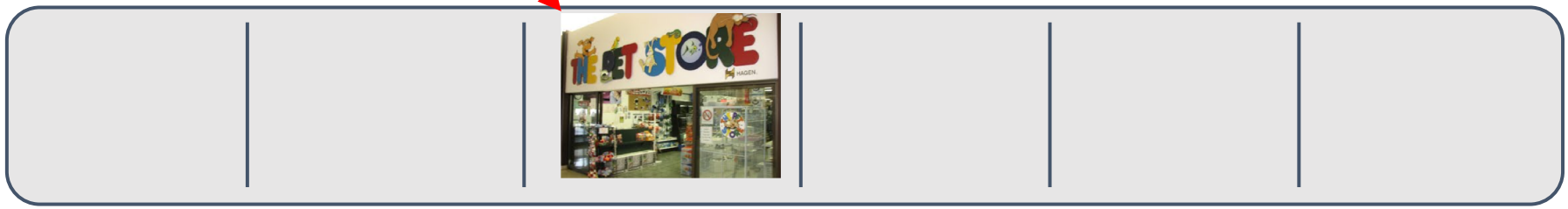
Somewhere in memory...

Association: Under the Hood (2/5)

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     _groomer.groom(django);
   }
}
```

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
     _petShop = myPetShop;
   }

   /* groom and other methods elided for this
   example */
}
```

Somewhere in memory...



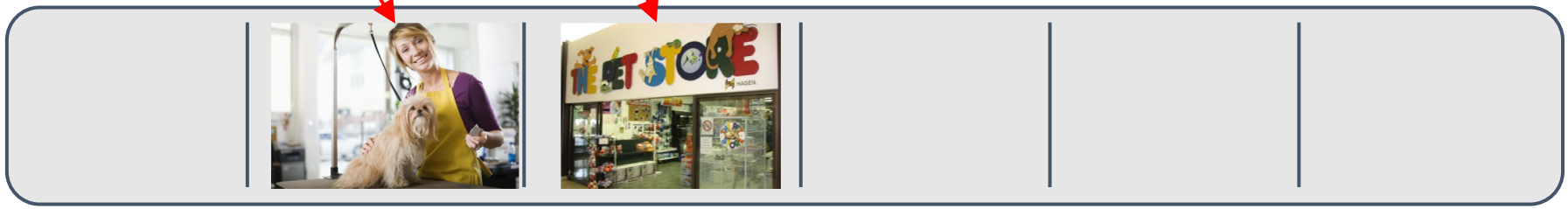
Somewhere else in our code, someone calls `new PetShop()`. An instance of `PetShop` is created somewhere in memory and `PetShop`'s constructor initializes all its instance variables (just a `DogGroomer` here)

Association: Under the Hood (3/5)

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     _groomer.groom(django);
   }
}
```

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
     _petShop = myPetShop;
   }

   /* groom and other methods elided for this
   example */
}
```

Somewhere in memory...



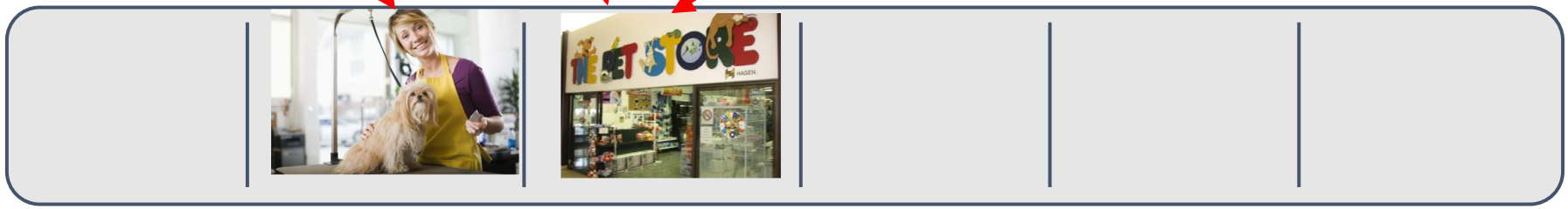
The `PetShop` instantiates a new `DogGroomer`, passing itself in as an argument to the `DogGroomer`'s constructor (remember the `this` keyword?)

Association: Under the Hood (4/5)

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     _groomer.groom(django);
   }
}
```

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
     _petShop = myPetShop;
   }

   /* groom and other methods elided for this
   example */
}
```

Somewhere in memory...



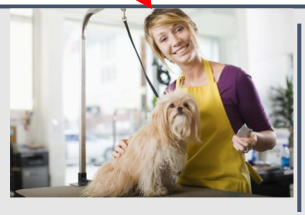
When the DogGroomer's constructor is called, its parameter, myPetShop, points to the same PetShop that was passed in as an argument by the caller, i.e., the PetShop itself

Association: Under the Hood (5/5)

```
public class PetShop {
   private DogGroomer _groomer;

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

   public void testGroomer() {
     Dog django = new Dog();
     _groomer.groom(django);
   }
}
```

```
public class DogGroomer {
   private PetShop _petShop;

   public DogGroomer(PetShop myPetShop) {
     _petShop = myPetShop;
   }

   /* groom and other methods elided for this
   example */
}
```

Somewhere in memory...



The `DogGroomer` sets its `_petShop` instance variable to point to the same `PetShop` it received as an argument. Now it "knows about" the `PetShop` that instantiated it, and so do all its methods (see slide 69!)

TopHat Question

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() {
      _teacher = new Teacher(this);
  }
  //additional methods, some using
  //_teacher
}
```

```
public class Teacher {
  private School _school;

  public Teacher(School school) {
      _school = school;
  }
  //additional methods, some using
  // _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() {
      _teacher = new Teacher(this);
  }
  //additional methods, some using
  //_teacher
}
```

```
public class Teacher{
  private School _school;

  public Teacher(School school) {
      _school = school;
  }
  //additional methods, some using
  // _school

}
```

- Does `School` contain `Teacher`?
  - yes! `School` instantiated `Teacher`, therefore `School` contains a `Teacher`. `Teacher` is a component of `School`
- Can `School` send messages to `Teacher`?
  - Yes! `School` can send messages to all its components that it created
- Does `Teacher` contain `School`?
  - no! `Teacher` knows about `School` that created it, but does not contain it
  - but can send messages to `School` because it "knows about" `School`

Another Example: Association (1/6)

- Here we have the class `CS15Professor`
- We want `CS15Professor` to know about his Head TAs—he didn't create them or vice versa, hence no containment – they are peer objects
- And we also want Head TAs to know about `CS15Professor`
- Let's set up associations!

```
public class CS15Professor {

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

   public CS15Professor(/* parameters */) {


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

   /* additional methods elided */
}
```

Another Example: Association (2/6)

- The `CS15Professor` needs to know about 5 Head TAs, all of whom will be instances of the class `HeadTA`
- Once he knows about them, he can call methods of the class `HeadTA` on them: `remindHeadTA`, `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 */
}
```

Another Example: Association (3/6)

- Here's our solution!
- Remember, you can choose your own names for the instance variables and parameters
- The `CS15Professor` can now send a message to one of his `HeadTA`s like this:

```
_hta2.setUpLecture();
```

```
public class CS15Professor {

  private HeadTA _hta1;
  private HeadTA _hta2;
  private HeadTA _hta3;
  private HeadTA _hta4;
  private HeadTA _hta5;

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

    _hta1 = firstTA;
    _hta2 = secondTA;
    _hta3 = thirdTA;
    _hta4 = fourthTA;
    _hta5 = fifthTA;
  }

  /* additional methods elided */
}
```

Another Example: Association (4/6)

- We've got the `CS15Professor` class down
- Now let's create a professor and head TAs from a class that contains all of them: `CS15App`
- Try and fill in this class!
  - you can assume that the `HeadTA` class takes no parameters in its constructor

```
public class CS15App {

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

  public CS15App() {
    // instantiate the professor!
    // …
    // …
    // instantiate the five HeadTAs
  }
}
```

Another Example: Association (5/6)

- We declare `_andy`, `_julie`, `_angel`, `_noah`, `_taylor` and `_lucy` as instance variables
- In the constructor, we instantiate them
- Since the constructor of `CS15Professor` takes in 5 `HeadTA`s, we pass in `_julie`, `_angel`, `_noah`, `_taylor` and `_lucy`

```
public class CS15App {

  private CS15Professor _andy;
  private HeadTA _julie;
  private HeadTA _angel;
  private HeadTA _noah;
  private HeadTA _taylor;
  private HeadTA _lucy;

  public CS15App() {
    _julie = new HeadTA();
    _angel = new HeadTA();
    _noah = new HeadTA();
    _taylor = new HeadTA();
    _lucy = new HeadTA();
    _andy = new CS15Professor(_julie,
              _angel, _noah, _taylor,
             _lucy);
  }
}
```

Another Example: Association (6/6)

```
public class CS15Professor {

   private HeadTA _hta1;
   private HeadTA _hta2;
   private HeadTA _hta3;
   private HeadTA _hta4;
   private HeadTA _hta5;

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

     _hta1 = firstTA;
     _hta2 = secondTA;
     _hta3 = thirdTA;
     _hta4 = fourthTA;
     _hta5 = fifthTA;
   }

   /* additional methods elided */
}
```

```
public class CS15App {

   private CS15Professor _andy;
   private HeadTA _julie;
   private HeadTA _angel;
   private HeadTA _noah;
   private HeadTA _taylor;
   private HeadTA _lucy;

   public CS15App() {
     _julie = new HeadTA();
     _angel = new HeadTA();
     _noah = new HeadTA();
     _taylor = new HeadTA();
     _lucy = new HeadTA();
     _andy = new CS15Professor(_julie,
                _angel, _noah, _taylor,
                _lucy);
   }
}
```

More Associations (1/5)

- Now the CS15Professor can call on the HeadTAs but can the HeadTAs call on the CS15Professor too?
- NO: Need to set up another association
- Can we just do the same thing and pass _andy as a parameter into each HeadTAs constructor?

```
public class CS15App {

  private CS15Professor _andy;
  private HeadTA _julie;
  private HeadTA _angel;
  private HeadTA _noah;
  private HeadTA _taylor;
  private HeadTA _lucy;

  public CS15App() {
    _julie = new HeadTA();
    _angel = new HeadTA();
    _noah = new HeadTA();
    _taylor = new HeadTA();
    _lucy = new HeadTA();
    _andy = new CS15Professor(_julie,
              _angel, _noah, _taylor,
              _lucy);
  }
}
```

Code from previous slide

More Associations (2/5)

- When we instantiate `_julie`, `_angel`, `_noah`, `_taylor`, and `_lucy`, we would like to use a modified `HeadTA` constructor that takes an argument, `_andy`
- But `_andy` hasn't been instantiated yet (will get a `NullPointerException`)! And we can't initialize `_andy` first because the `HeadTA`s haven't been created yet…
- How to break this deadlock?

```
public class CS15App {

  private CS15Professor _andy;
  private HeadTA _julie;
  private HeadTA _angel;
  private HeadTA _noah;
  private HeadTA _taylor;
  private HeadTA _lucy;

  public CS15App() {
    _julie = new HeadTA();
    _angel = new HeadTA();
    _noah = new HeadTA();
    _taylor = new HeadTA();
    _lucy = new HeadTA();
    _andy = new CS15Professor(_julie,
              _angel, _noah, _taylor,
              _lucy);
  }
}
```

Code from previous slide

More Associations (3/5)

- Instantiate `_julie`, `_angel`, `_noah`, `_taylor`, and `_lucy` **before** we instantiate `_andy`
- Use a new method (mutator), `setProf`, and pass `_andy` to each `HeadTA`

```
public class CS15App {

   private CS15Professor _andy;
   private HeadTA _julie;
   private HeadTA _angel;
   private HeadTA _noah;
   private HeadTA _taylor;
   private HeadTA _lucy;

   public CS15App() {
     _julie = new HeadTA();
     _angel = new HeadTA();
     _noah = new HeadTA();
     _taylor = new HeadTA();
     _lucy = new HeadTA();
     _andy = new CS15Professor(_julie,
                 _angel, _noah, _taylor,
           _lucy);

     _julie.setProf(_andy);
     _angel.setProf(_andy);
     _noah.setProf(_andy);
     _taylor.setProf(_andy);
     _lucy.setProf(_andy);
   }
}
```

More Associations (4/5)

```
public class HeadTA {

   private CS15Professor _professor;

   public HeadTA() {

     //Other code elided

   }

   public void setProf(CS15Professor prof) {
     _professor = prof;
   }
}
```

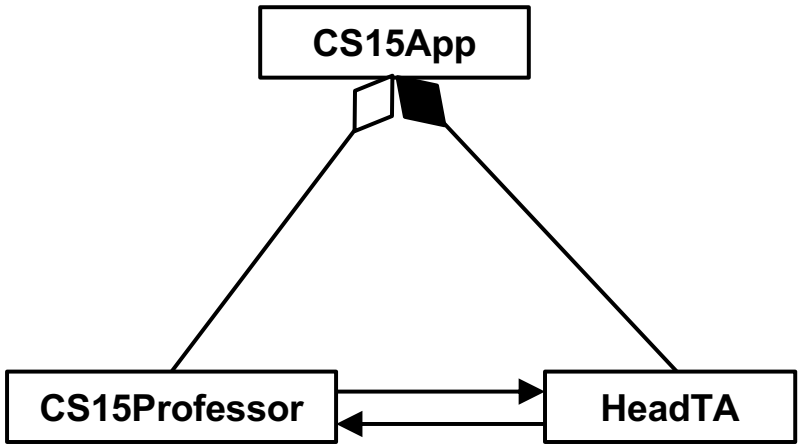
- Now each HeadTA will know about _andy!

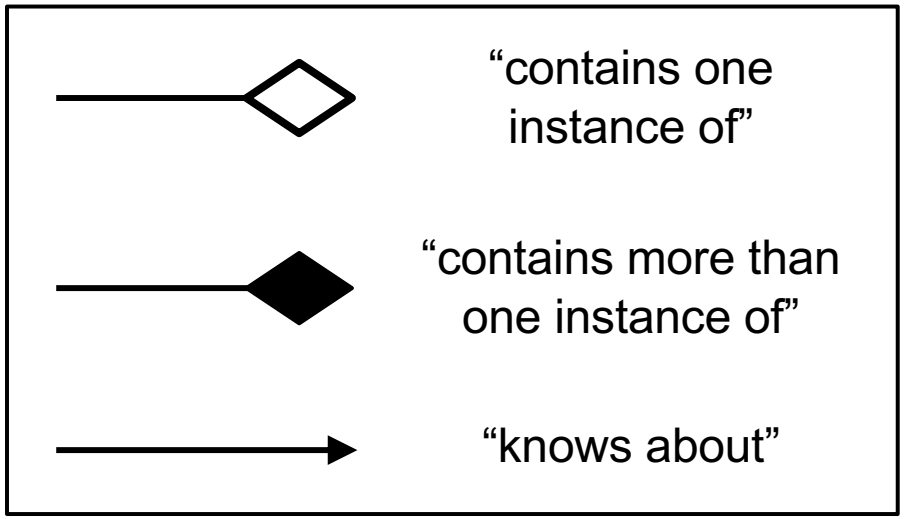
```
public class CS15App {

   private CS15Professor _andy;
   private HeadTA _julie;
   private HeadTA _angel;
   private HeadTA _noah;
   private HeadTA _taylor;
   private HeadTA _lucy;

   public CS15App() {
     _julie = new HeadTA();
     _angel = new HeadTA();
     _noah = new HeadTA();
     _taylor = new HeadTA();
     _lucy = new HeadTA();
     _andy = new CS15Professor(_julie,
                 _angel, _noah, _taylor,
           _lucy);

     _julie.setProf(_andy);
     _angel.setProf(_andy);
     _noah.setProf(_andy);
     _taylor.setProf(_andy);
     _lucy.setProf(_andy);
   }
}
```

More Associations (5/5)

- But what happens if `setProf` is never called?
- Will the Head TAs be able to call methods on the `CS15Professor`?
- No! We would get a `NullPointerException`!
- So this is not a completely satisfactory solution, but we will learn more tools soon that will allow us to develop a more complete solution

Visualizing Containment and Association





Summary

Important concepts:

- Using **local variables**, whose scope is limited to a method
- Using **instance variables**, which store the properties of instances of a class for use by multiple methods—use them only for that purpose
- A variable that "goes out of scope" is **garbage collected**
  - for a local variable when the method ends
  - for an instance when the last reference to it is deleted
- **Containment**: when one object is a component of another so the container can therefore send the component it created messages
- **Association**: when one object knows about another object that is not one of its components—has to be set up explicitly

Announcements

- Lab 1 is out now! Go to the Sunlab for this week's section!
- AndyBot is due this Thursday at 11:59PM
- Remember to sign up for Piazza! This is a very good portal to ask questions!
- Mentorship form due Thursday! More information in last week's e-mail and course website!