- Previous lecture:
  - Array of objects
  - Methods that handle a variable number of arguments
  - Using a class in another
- Today's lecture:
  - Why use OOP?
  - Attributes (`private`, `public`) for properties and methods
  - Inheritance: extending a class
- Announcement:
  - Project 5 due tonight
  - Test 2B released Tue, May 5
    - Review session Sunday, 2pm EDT
  - Project 6, part A to be released Fri; due May 12

OOP ideas

- *Aggregate* variables/methods into an abstraction (a class) that makes their relationship to one another explicit
- Object properties (data) need not be passed to instance methods—only the object handle (reference) is passed. Useful for large data sets!

OOP ideas

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- Objects (instances of a class) are *self-governing* (protect and manage themselves)
  - Hide details from clients while exposing the services they need
  - Don’t allow clients to invalidate data and break those services

Engineering software ≠ software engineering

Engineering software

- Solve a technical problem or provide insight into data
- Be confident that answers are correct – clear, documented code; testing
- Used mostly by yourself or your team

Software engineering

- Build large, reliable systems that operate continuously
- Used mostly by other people
- Make components easy to (re)use correctly, hard to use incorrectly

The *design* of code becomes at least as important as its output

Best of both worlds: a well-engineered engineering application

Restricting access to properties and methods

- Hide implementation details from "outside parties" who do not need to know how things work—depend on behavior, not representation
- E.g., we decide that users of Interval class cannot directly change `left` and `right` once the object has been created. Force users to use the provided methods—`scale()`, `shift()`, etc.—to cause changes in the object data
- Protect data from unanticipated user action—keep properties self-consistent
- Information hiding is very important in large projects
  - Helps avoid brittle code

```
classdef  Interval < handle

   properties
      left
      right
    end

   methods
      function scale(self,  f)
         . . .
      end

      function Inter = overlap(self,  other)
         . . .
      end
      . . .

   end

end
```

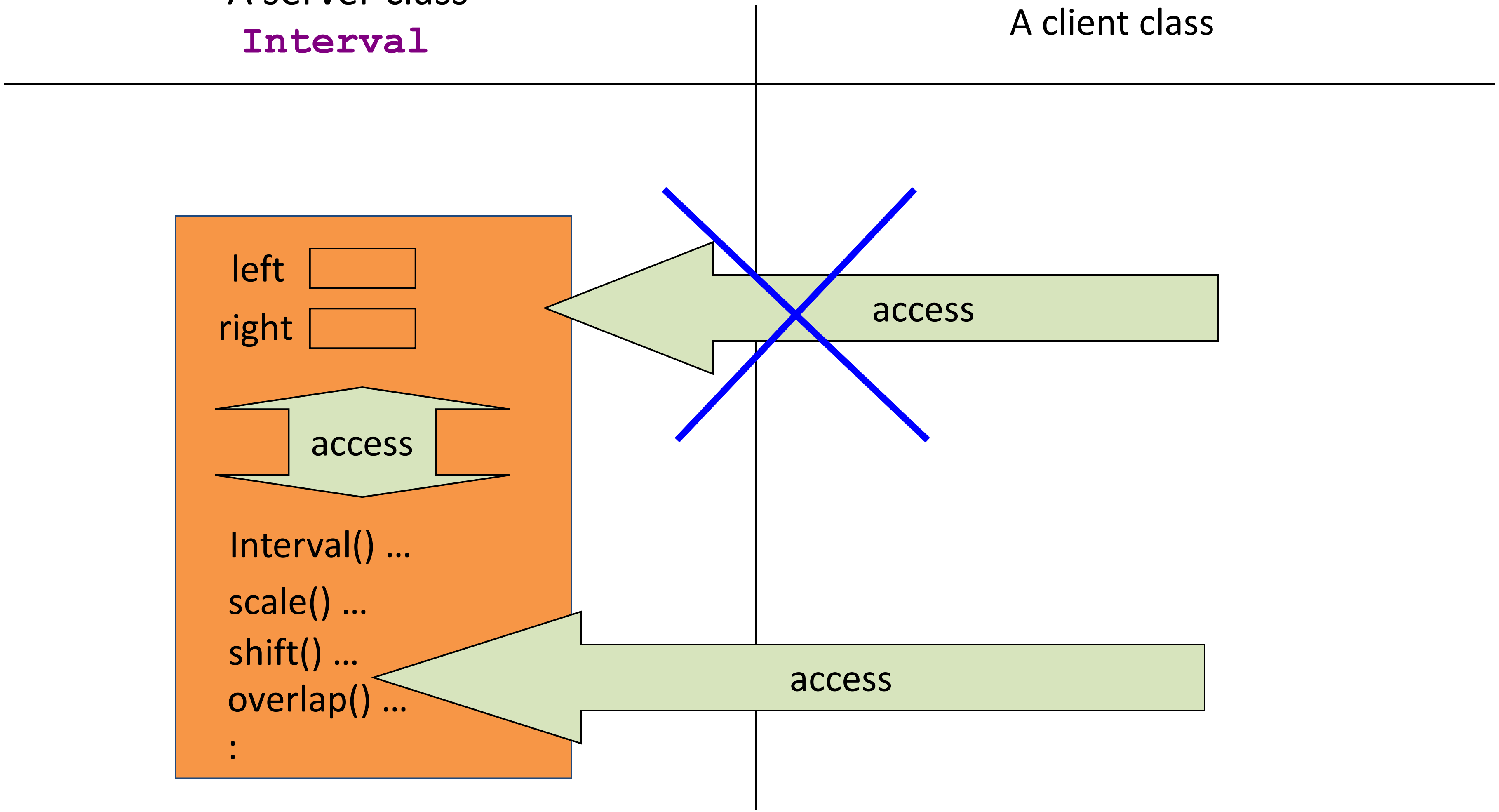
Server

```
% Interval experiments
for k=1:5
    fprintf('Trial %d\n', k)
    a= Interval(3, 3+rand*5);
    b= Interval(6, 6+rand*3);
    disp(a)
    disp(b)
    c= a.overlap(b);
    if ~isempty(c)
        fprintf('Overlap is ')
        disp(c)
    else
        disp('No overlap')
    end
    pause
end
```

Example client code

A server class
`Interval`

A client class



Data that the client does not need to access should be protected: **`private`**
Provide a set of methods for **`public`** access.

The “client-server model”

Preserving relationships between properties

```
classdef  Interval < handle
   properties
      left = 0;
      right = 0;  % Invariant: right >= left
   end

   methods
      function  Inter = Interval(lt, rt)
         if nargin == 2

               Inter.left= lt;
               Inter.right= rt;



         end
      end
      . . .
   end
end
```

Don't neglect the default constructor (if any); either pick a sensible default state, or make it so that nothing works.

Constructor can be written to do error checking!

```
classdef  Interval < handle
   properties
      left = 0;
      right = 0;  % Invariant: right >= left
   end

   methods
      function  Inter = Interval(lt, rt)
         if nargin == 2
            if  lt <= rt
               Inter.left= lt;
               Inter.right= rt;
            else
               error('Error at instantiation: left>right')
            end
         end
      end
      . . .
   end
end
```

Should force users (clients) to use code provided in the class to create an Interval or to change its property values once the Interval has been created.

E.g., if users cannot directly set the properties left and right, then they cannot accidentally "mess up" an Interval.

Attributes for properties and methods

- **public**
  - Client has access
  - Default
- **private**
  - Client cannot access

```
% Client code
r= Interval(4,6);
r.scale(5); %OK
r= Interval(4,14); % OK
r.right=14; %error
disp(r.right) %error
```

```
classdef  Interval < handle
% An Interval has a left end and a right end

 properties (Access=private)
     left
     right
 end

 methods
      function Inter = Interval(lt, rt)
      % Constructor:  construct an Interval obj
          Inter.left= lt;
          Inter.right= rt;
      end

      function scale(self, f)
      % Scale the interval by a factor f
          w= self.right - self.left;
          self.right= self.left + w*f;
      end
      :
 end
end
```

Both GetAccess and SetAccess are private

Within the class, there is always access to the properties, even if private

Public “getter” method

- Provides client the ability to get a property value

```
% Client code
r= Interval(4,6);
disp(r.left) % error
disp(r.getLeft()) % OK
```

```
classdef  Interval < handle
% An Interval has a left end and a right end

 properties (Access=private)
    left
    right
 end

 methods
     function Inter = Interval(lt, rt)
        Inter.left= lt;
        Inter.right= rt;
     end

     function lt = getLeft(self)
     % lt is the interval’s left end
        lt= self.left;
     end
     function rt = getRight(self)
     % rt is the interval’s right end
        rt= self.right;
     end
     :
 end
end
```

Public “setter” method

- Provides client the ability to set a property value
- Don’t do it unless really necessary! If you implement public setters, include error checking (not shown here).

```
% Client code
r= Interval(4,6);
r.right= 9; % error
r.setRight(9) % OK
```

```
classdef Interval < handle
% An Interval has a left end and a right end

 properties (Access=private)
    left
    right
 end

 methods
     function Inter = Interval(lt, rt)
        Inter.left= lt;
        Inter.right= rt;
     end

     function setLeft(self, lt)
     % the interval’s left end gets lt
        self.left= lt;
     end
     function setRight(self, rt)
     % the interval’s right end gets rt
        self.right= rt;
     end
     :
 end
end
```

Prefer to use available methods, even when within same class

```
classdef  Interval < handle
  properties (Access=private)
    left; right
  end
  methods
    function  Inter = Interval(lt, rt)
      …
    end
    function lt = getLeft(self)
        lt = self.left;
    end
    function rt = getRight(self)
        rt = self.right;
    end
    function w = getWidth(self)
        w= self.getRight() – self.getLeft() ;
    end
    …
  end
end
```

In here… code that always uses the getters & setters

New Interval implementation

```
classdef  Interval < handle
  properties (Access=private)
    left; width
  end
  methods
    function  Inter = Interval(lt, rt)
      …
    end
    function lt = getLeft(self)
        lt = self.left;
    end
    function rt = getRight(self)
        rt = self.getLeft() + self.getWidth();
    end
    function w = getWidth(self)
        w= self.width ;
    end
    …
  end
end
```

Rewrite old getters/setters; add new getters/setters. BUT everything else stays the same! Cool! Happy clients!

Getters and setters: what have we achieved?

- Getters let us change properties without changing interface
- Setters (or lack thereof) let us control how properties can change
  - Read-only
  - Methods that keep them "in sync" (e.g. `shift(), scale(), …`)
  - Error checking on attempts to write
- Both allow interactions to be "intercepted"
  - Track how many times they are changed?
  - Break points when debugging

Quiz: access control

Which of these lines are legal?

- A: None
- B: 1
- C: 1 & 2
- D: 1-3
- E: All

```
classdef Square < handle
   properties (Access=private)
      s = 1  % side length
   end
   methods (Access=public)
      function obj = Square(side)
         if nargin == 1
       1 obj.s = side;
         end
      end
      function a = area(self)
      2 a = self.s*self.s;
      end
   end
end
```

```
  shape = Square(2);
  a1= shape.area();
3 a2= shape.s*shape.s;

4 shape.s= 1;
```

OOP ideas → Great for managing large projects

- *Aggregate* variables/methods into an abstraction (a class) that makes their relationship to one another explicit
- Object properties (data) need not be passed to instance methods—only the object handle (reference) is passed. Important for large data sets!
- Objects (instances of a class) are *self-governing* (protect and manage themselves)
  - Hide details from clients while exposing the services they need
  - Don't allow clients to invalidate data and break those services
- Maximize code reuse

A fair die is…

```
classdef Die < handle
 properties (Access=private)
  sides=6;
  top
 end
 methods
  function D = Die(…)  …
  function roll(…)  …
  function disp(…)  …
  function s = getSides(…)  …
  function t = getTop(…)  …
 end
 methods (Access=private)
  function setTop(…)  …
 end
end
```

What about a trick die?

Separate classes—each has its own members

```
classdef Die < handle
 properties (Access=private)
  sides=6;
  top
 end
 methods
  function D = Die(…)  …
  function roll(…)  …
  function disp(…)  …
  function s = getSides(…)  …
  function t = getTop(…)  …
 end
 methods (Access=private)
  function setTop(…)  …
 end
end
```

```
classdef TrickDie < handle
 properties (Access=private)
  sides=6;
  top
  favoredFace
  weight=1;
 end
 methods
  function D = TrickDie(…)  …
  function roll(…)  …
  function disp(…)  …
  function s = getSides(…)  …
  function t = getTop(…)  …
  function f = getFavoredFace(…) …
  function w = getWeight(…)  …
 end
 methods (Access=private)
  function setTop(…)
 end
end
```

Separate classes—each has its own members

```
classdef Die < handle
 properties (Access=private)
  sides=6;
  top
 end
 methods
  function D = Die(…)   …
  function roll(…)   …
  function disp(…)   …
  function s = getSides(…)   …
  function t = getTop(…)   …
 end
 methods (Access=private)
  function setTop(…)   …
 end
end
```

```
classdef TrickDie < handle
 properties (Access=private)
  sides=6;
  top
  favoredFace
  weight=1;
 end
 methods
  function D = TrickDie(…)   …
  function roll(…)   …
  function disp(…)   …
  function s = getSides(…)   …
  function t = getTop(…)   …
  function f = getFavoredFace(…) …
  function w = getWeight(…)   …
 end
 methods (Access=private)
  function setTop(…)
 end
end
```

Can we get all the functionality of Die in TrickDie without re-writing all the Die code in class TrickDie?

```
classdef Die < handle
 properties (Access=private)
  sides=6;
  top
 end
 methods
  function D = Die(…)   …
  function roll(…)   …
  function disp(…)   …
  function s = getSides(…)   …
  function t = getTop(…)   …
 end
 methods (Access=private)
  function setTop(…)   …
 end
end
```

```
classdef TrickDie < handle
```

“Inherit” the components of class Die

```
 properties (Access=private)
  favoredFace
  weight=1;
 end
 methods
  function D = TrickDie(…)   …
  function f =getFavoredFace(…) …
  function w = getWeight(…)   …
 end
end
```

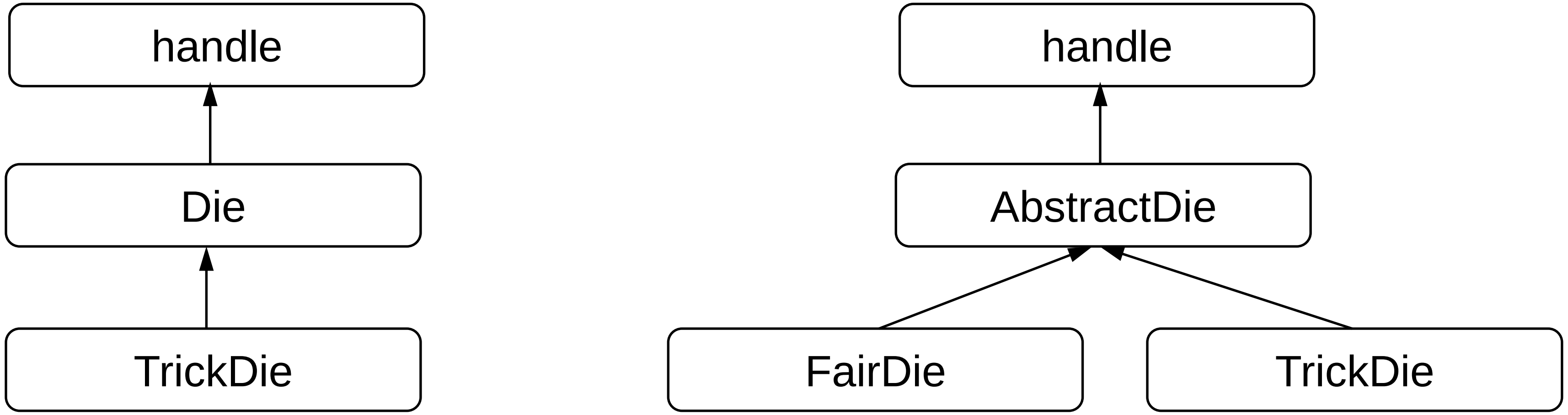
Yes! Make TrickDie a **subclass** of Die

```
classdef Die < handle
 properties (Access=private)
  sides=6;
  top
 end
 methods
  function D = Die(…)  …
  function roll(…)  …
  function disp(…)  …
  function s = getSides(…)  …
  function t = getTop(…)  …
 end
 methods (Access=protected)
  function setTop(…)  …
 end
end
```

```
classdef TrickDie < Die

 properties (Access=private)
  favoredFace
  weight=1;
 end

 methods
  function D = TrickDie(…)  …
  function f=getFavoredFace(…)…
  function w = getWeight(…)  …
 end

end
```

Inheritance

Inheritance relationships are shown in a *class diagram*, with the arrow pointing to the parent class



An ***is-a*** relationship: the child ***is a*** more specific version of the parent. Eg., a trick die *is a* die.

Multiple inheritance: can have multiple (direct) parents ← e.g., Matlab

Single inheritance: can have one (direct) parent only ← e.g., Java

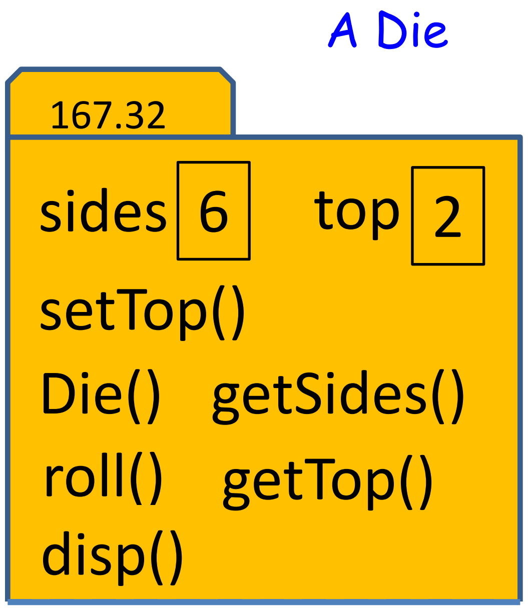
If relationship is "has a" or "can do", prefer *composition* to inheritance

Inheritance vocabulary

- Allows programmer to *derive* a class from an existing one
- Existing class is called the *parent class*, or *superclass*
- Derived class is called the *child class* or *subclass*
- The child class *inherits* the (public and protected) members defined for the parent class
- Inherited trait can be *accessed as though it was **locally** defined*

Which components get "inherited"?

- public components get inherited
- private components exist in object of child class, but cannot be directly accessed in child class ⇒ we say they are not inherited
- Note the difference between inheritance and existence!



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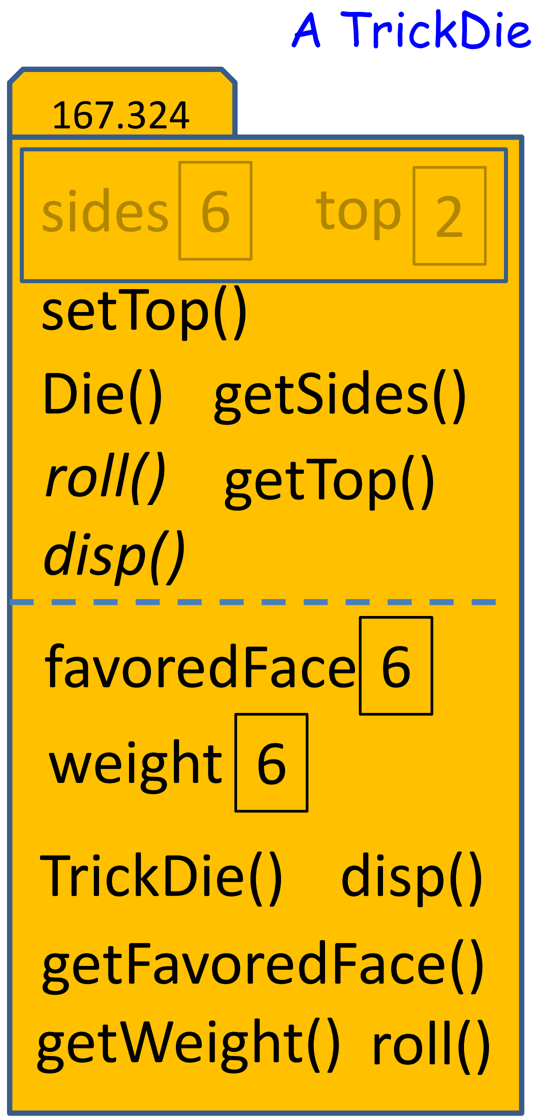

`protected` attribute

- Attributes dictate which members get inherited

- **`private`**
  - Not inherited, can be *accessed* by local class only
- **`public`**
  - Inherited, can be *accessed* by all classes
- **`protected`**
  - Inherited, can be *accessed* by subclasses

- *Access*: access as though defined locally
- All members from a superclass *exist* in the subclass, but the **`private`** ones cannot be *accessed* directly—can be accessed through inherited (public or protected) methods

```
>> d = Die(6);
>> td = TrickDie(2, 10, 6);
>> %… more code in Command Window …
```

A `d.setTop(3)` *and* `td.setTop(3)` *both work*

B *Neither* `d.setTop(3)` *nor* `td.setTop(3)` *works*

C `d.setTop(3)` *works but* `td.setTop(3)` *doesn't*

```
classdef Die < handle
 properties (Access=private)
  sides=6;
  top
 end
 methods
  function D = Die(…)   …
  function roll(…)   …
  function disp(…)   …
  function s = getSides(…)   …
  function t = getTop(…)   …
 end
 methods (Access=protected)
  function setTop(…)   …
 end
end
```

Overriding methods

- Subclass can *override* definition of inherited method
- New method in subclass has the same name (but has different method body)
- Which method gets used??

  The ***object*** *that is used to invoke a method determines which version is used*
- Since a TrickDie object is calling method **`roll`**, the TrickDie's version of **`roll`** is executed
- In other words, the method most specific to the type (class) of the object is used

(Cell) Array of objects

- A cell array can reference objects of different classes

```
A{1}= Die();
A{2}= TrickDie(2,10);   % OK
```

- A simple array can reference objects of only one single class

```
B(1)= Die();
B(2)= TrickDie(2,10);   % ERROR
```

OOP in computing culture